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The Population of the Non-indigenous Bivalve *Arcuatula senhousia* of the Varano Lagoon (Adriatic Sea, Italy)

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Abstract: A population of the invasive mussel *Arcuatula senhousia* (Benson in Cantor, 1842) was monitored seasonally (May, July and October 2015) in the Varano lagoon, the largest brackish basin of Southern Italy, within the Gargano National Park, Central Adriatic Sea, in order to give information on the abundance, wet weight and frequency classes. The data were collected during a survey carried within the framework of the Regional Project FEP Apulia 2007/2013 "Identificazione di misure per una migliore gestione e conservazione della risorsa vongola nel lago di Varano (FG)". Summer anoxia may have reduced the mussel population, resulting in less abundance, wet weight and average size in October than in July and May. In particular, about length data, two cohorts were observed in May and October 2015, while a modal distribution in July 2015.

Key words: NIS (Non-indigenous Species), *Arcuatula senhousia*, Varano lagoon, Central Adriatic Sea, length-frequency distributions.

1. Introduction

Invasive species are altering the composition of biotic communities worldwide by changing the function of communities and by altering the physical environment [1, 2]. Numerous NIS (Non-Indigenous Species), were recorded in the area of the Adriatic Sea in last decades [3, 4]. In recent years there has been considerable scientific attention in Italy on the threats of invading marine species [5]. *A. senhousia* is one of several invasive mollusc species to become widely established in Northern Adriatic lagoons. The species, together with other recent invaders such as *Crassostrea gigas* [6], *Rapana venosa* [7], *Ruditapes philippinarum* [8], *Anadara inaequivalvis* [9] and *Xenostrobus securis* [10], probably exerts profound modification on the native benthic assemblages.

Bivalves are often successful invaders of marine and freshwater environments [11]. One of these NISs in the Adriatic Sea is Asian mussel, *Arcuatula senhousia* (Benson in Cantor, 1842). It is small mytilid, with thin, oval and elongate shell attaining a maximum length of about 32 mm, but the common size is from 10 to 25 mm in length and up to 12 mm in width [12, 13]. Asian mussel is suspension-feeder that inhabits both, hard and soft substrata, where it lives, attached with its bissus, in intertidal and subtidal to 20 m deep [12, 13].

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 facilitates many small benthic invertebrates such as polychaetes, gastropods and crustaceans [14], while larger organisms are not able to live within or close to these structures, such as clams, can be inhibited [11, 15].

It is an opportunist, short-lived species (maximum life span is approximately 2 years), that grows quickly, suffers high mortality, but it could be very abundant within its native range of distribution or in the areas where it has been introduced [12, 16].

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Its native range of distribution is Asian continent, from Siberian coast to Malay Peninsula, and in the Red Sea [10], but it was introduced in different parts of the world: western coast of North America, Australia, New Zealand, the Atlantic coast of Europe and the Mediterranean Sea [12, 17-22]. In the Mediterranean Sea, the species was first recorded in the eastern part, in Israel [18] and Egypt [19], then in the Southern France [23], in Italy in the area of Ravenna in the Northern Adriatic Sea [10], and Slovenia [24]. Additionally, in the Adriatic Sea, the species was found in the Gulf of Trieste [25], along the northern part of the western coast, in Venice lagoon [26], in the Sacca di Goro lagoon and other areas of the Po River Delta [27-31], in the brackish-water lakes in Gargano National Park [32], and in the coastal waters [33]. *A. senhousia*, was also recorded in the Ionian Sea (Taranto seas) [34], in the Tyrrhenian Sea (Gulf of Olbia) [35] and Ligurian Sea (port of Livorno) [36]. In the Southern Mediterranean lagoons, the species has little been studied. In this paper, the seasonal observations on the abundance, wet weight and frequency classes of non-indigenous bivalve *A. senhousia* (Benson in Cantor, 1842) were presented in the Varano lagoon, Gargano National Park, the biggest lagoon in Southern Italy, during a survey carried within the framework of the Regional Project FEP Apulia 2007/2013.

2. Material and Methods

2.1 Study Area

The Varano lagoon is a Mediterranean coastal lagoon located along the Northern of the Gargano (Central Adriatic Sea) within the Gargano National Park (41.88° N, 15.75° E) (Fig. 1). The lagoon covers an area of 6,500 ha, with a perimeter of 33 km. It is about 10 km long and 7 km wide. The average depth is 2.5 m, with a maximum value of 6 m in the central area. The catchment area of the Varano lagoon is about 300 km^2; it presents in the eastern part two alluvial plains separated by a karstic hilly area, while the remaining part is constituted by karstic steep cliffs exploited as pasture land for bovine, ovine and pigs.

The alluvial plains are mainly exploited for olive and citrus groves and at a lesser extent for vegetable growing, with no industrial activities; moreover, this area receives urban wastewaters from few small towns (about 20.000 inhabitants [37]). Two artificial outlets (Capojale and Varano) at the east and west extremities of the sandy barrier provide a connection with the Adriatic Sea. Hydrology is influenced by exchanges with the sea through the two tidal channels and by freshwater inputs from the catchment area, mainly situated along its south-east edge; the highest residence time (280 days) is found in the central-southern part of the lagoon, while lower values characterize the area close to the edge and near the connecting channels [38].

The lagoon hydrodynamics affects sediment grain size, mainly represented by mud-silt fractions (> 80%) in the central zone and coarser fractions along the edge of the lagoon [38]. Salinity ranges from a maximum of 37‰ near the tidal channels to a minimum of 18‰ on the south-eastern edge where the freshwater inputs are most abundant [39].

The lagoon and the neighboring coastal marine area are exploited by mussel farming [40]. In the last ten years, spontaneous fishing of clam *R. philippinarum* is also practiced in the lagoon. Fish species are those typical of Mediterranean lagoons: seabass, seabream, eel, grey mullet, etc.. In addition to fish species, it is important to highlight the presence of crustaceans of

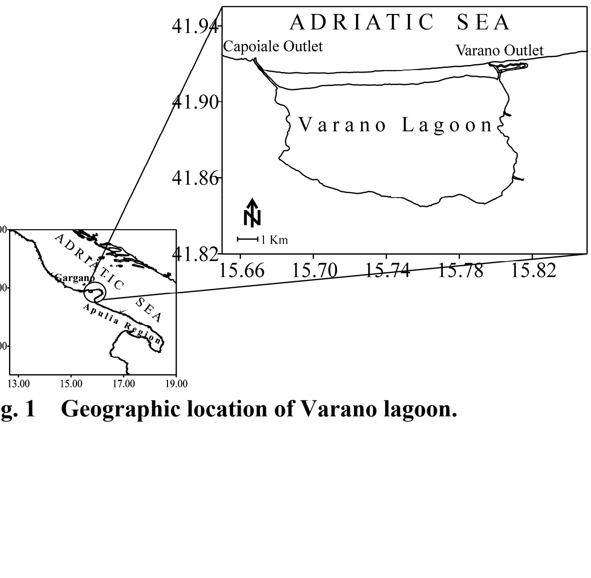

Fig. 1 Geographic location of Varano lagoon.

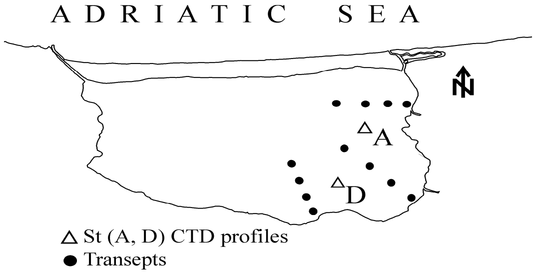

Fig. 2 Location of the sampling stations.

commercial interest such as the *Penaeus kerathurus* and the *Penaeus japonicus* for which sowing was carried out in the years (1985, 2006).

2.2 Sampling and Data Analysis

The samples were collected seasonally (May-July-October) during 2015, in 12 stations arranged along three transepts perpendicular to the coastline in the south-eastern part of the lagoon (Fig. 2), where the spontaneous fishing of clam *R. philippinarum* (Adams & Reeve, 1850) is practiced. The sampling was carried out by professional hydraulic dredge, with an opening of 55 cm and a sack of 7 mm per side on a sampling surface of approximately 5 m^2. The stations were placed on different bathymetries (1, 2, 3, 4 mt), for each station was assessed of the abundance (ind/m^2) and wet biomass (gr/m^2). Collected samples were screened in situ by sieve with mesh of 1 mm. For each transept, random specimens were collected by *A. senhousia* on which the length (mm) and the wet weight (gr) were measured and length-wet weight correlations by the ratio of the minimum squares regression and distribution of length classes were calculated. Spatial and temporal variability of abundance and size classes (length) were evaluated by the ANOSIM test. In addition to biological sampling, in two stations CTD profiles were detected.

3. Results

3.1 Environmental Data

Fig. 3 shows the typical seasonal pattern of the environmental parameters (temperature, salinity and dissolved oxygen) in the water column of Varano lagoon in May, July and October 2015. The temperature varied from a minimum of 15.59 ± 0.30 °C (May) to a maximum of 30.05 ± 0.43 °C (July) detected in the St. D. Salinity ranged from a minimum of 19.48 ± 0.69 psu (May) to a maximum of 24.85 ± 0.47 psu (October). Dissolved oxygen (% saturation) showed average values close to saturation. In July, close to the bottom in St. A, low oxygen concentrations (22.46%) were found near hypoxia condition.

3.2 Abundance and Biomass of A. senhousia

The species *A. senhousia* was found in 83% of the sampled sites in the Varano lagoon. Fig. 4 shows the abundance (ind/m^2) and wet-weight (gr/m^2) in the three sampling periods. The average abundance and wet-weight ranged by a minimum (67 ± 146 ind/m^2; 16 ± 44 gr/m^2) in October to a maximum (1.266 ± 1.416 ind/m^2; 411 ± 423 gr/m^2) in July, respectively (Fig. 4).

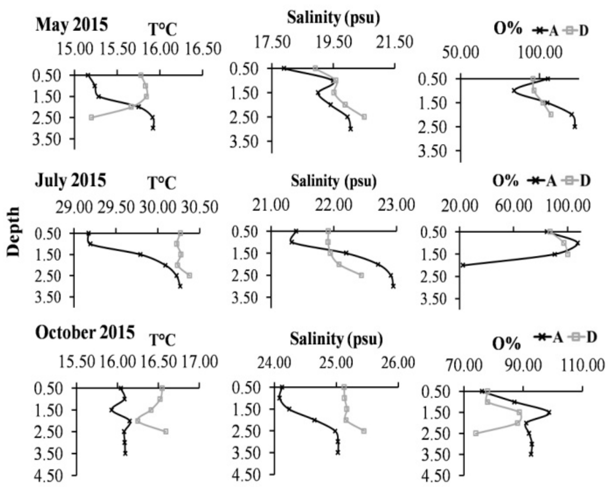

Fig. 3 CTD profiles detected during the three sampling periods.

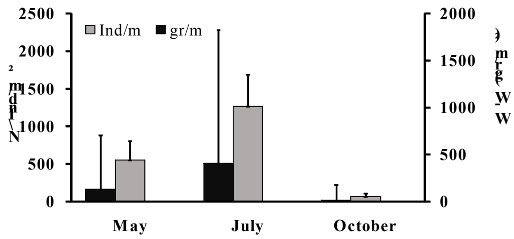

Fig. 4 Abundance (N° ind/m^2) and wet-weight observed in the three sampling periods.

Table 1 Statistical parameters of the length.

Length (mm)			
	May	July	October
N° ind.	600	572	215
Mean	15.74	20.81	12.82
St. dev.	6.19	5.34	5.41
Median	13.67	20.80	13.09
Mode	Multiple	22.33	Multiple
Max.	33.13	33.10	24.50
Min.	5.79	6.77	3.80
Range	27.34	26.33	20.07

Table 1 shows the statistical parameters. The highest average length (20.81 ± 5.34 mm) was found in July, instead the smallest average length (12.82 ± 5.41 mm) in October.

There was a trend of decreasing abundance with time at all sites. In Figs. 5 and 6, the graphs related to absolute abundance and biomass of *A. senhousia* are shown from May to October 2015 at different depths along the three transepts. Average abundance of *A. senhousia* was highest (1.266 ± 1.416 ind/m²) in July, especially along TR-B and TR-C at a depth of 2 and 4 meters, respectively. The minimum value of average abundance was found in October (67 ± 146 ind/m²), especially along TR-A, in particular at 1 m deep. In October, at the depth of 3 and 4 m, no specimens were found. Average biomass ranged by a maximum value of 411 ± 423 gr/m² was measured in July, to a minimum of 16 ± 44 gr/m² in October. In particular, the maximum values were measured along TR-C (4 m deep) in July and the minimum along TR-A (1 m deep) in October.

3.3 Length-Frequency Distributions for A. senhousia

The size distribution of the samples is shown in Fig. 7. The highest average length (20.81 ± 5.34 mm) was found in July, instead the smallest average length (12.82 ± 5.41 mm) in October. The minimum and maximum individual sizes in the population sampled in May 2015 (600 specimens) were 5.79 mm and 33.13 mm, respectively. The sizes showed a bimodal distribution with the modal components being 9-15 mm (63%) and 27-30 mm (8%). The smallest and largest sizes measured in July (572 specimens) were 6.77 mm and 33.10 mm, respectively, and the population showed a modal structure characterized by a single cohort between 18-24 mm (42%). In October only 215 living specimens were found. Their sizes ranged from 3.80 mm to 24.50 mm. A bimodal distribution was observed with the modal classes of 6-9 mm (28%) and 18-21 mm (20%).

3.4 Statistical Analysis

One-way analysis of similarity (ANOSIM) on abundance (R = 0.250; p < 0.001) and length (R = 0.261;

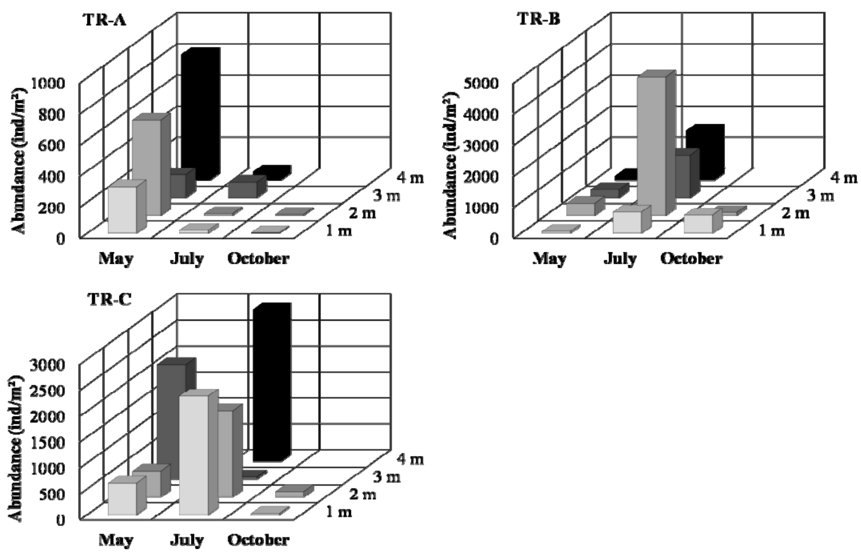

Fig. 5 Abundance of *A. senhousia* sampled at different depths along the three transepts.

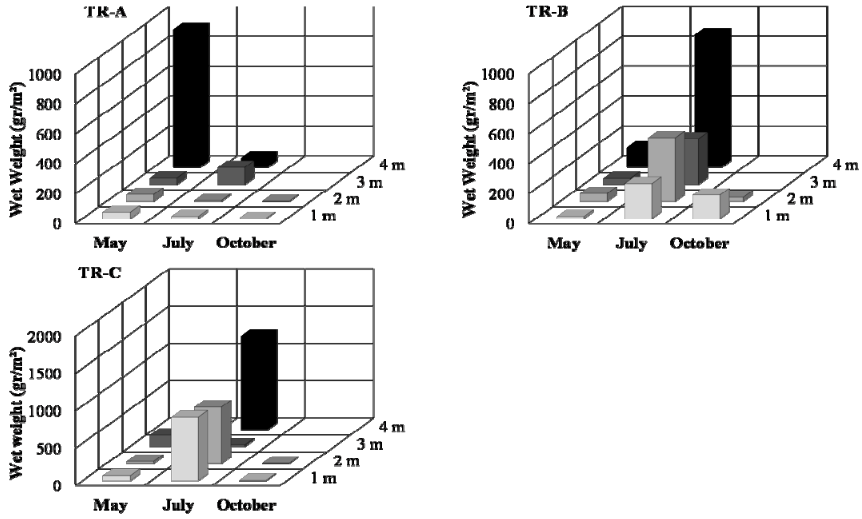

Fig. 6 Biomass of *A. senhousia* sampled at different depths along the three transepts.

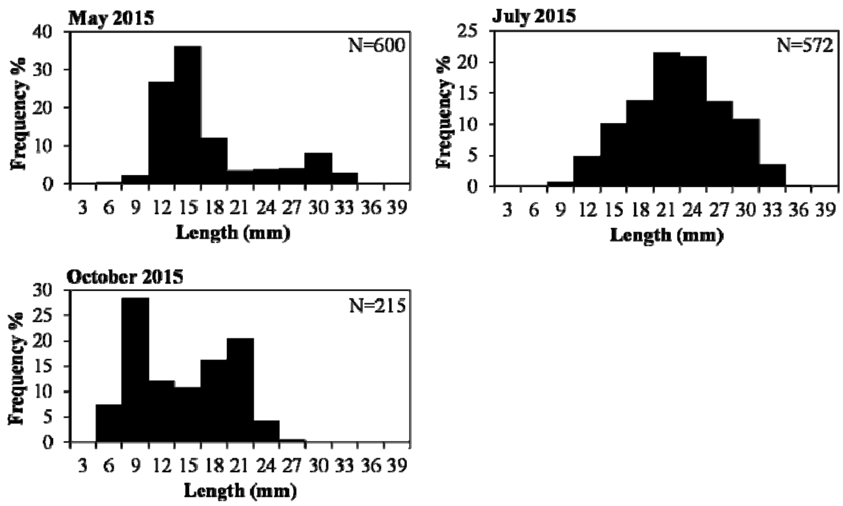

Fig. 7 Length distributions during the three sampling periods.

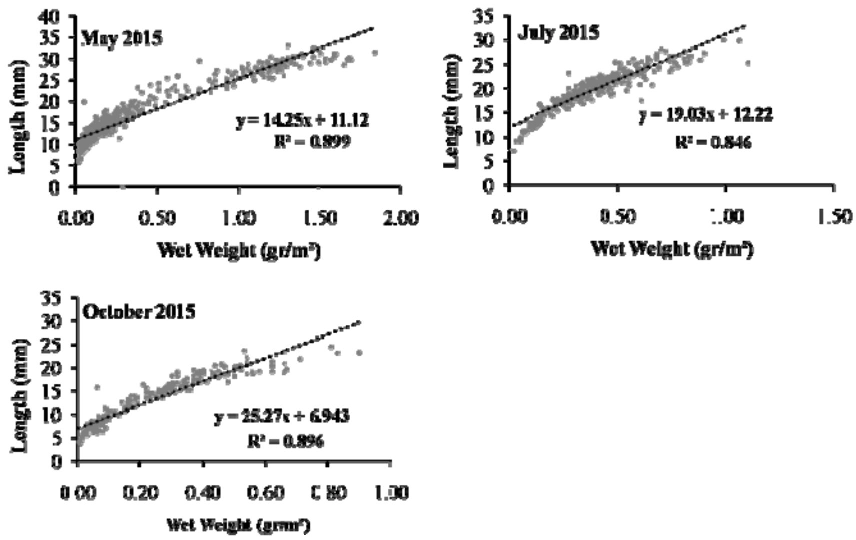

Fig. 8 Regression analyses between wet-weight and length during the three sampling periods.

$p < 0.001$) data highlighted a significant difference between sampling months. The length showed significant differences (ANOSIM) both between transepts ($R = 0.082$; $p < 0.001$) and stations ($R = 0.110$; $p < 0.001$). Regression analyses between wet-weight and length of *A. senhousia* detected in the three samples are represented in Fig. 8. Significantly positive correlations length-wet weight were found for all sampling periods ($R^2 = 0.9087$; $R^2 = 0.8508$; $R^2 = 0.8964$; $p < 0.001$).

4. Discussion

Environmental data (T, °C, Salinity, O%) showed a typical seasonal pattern. The massive decrease in the abundance of the *A. senhousia* detected in October, could be related to different factors like overheating of the water during summer and the low oxygen concentrations (22.46%) near hypoxia condition (July). According to Mistri [29] for Sacca di Goro and Yamamuro [41] for Lake Nakaumi, the species does not tolerate oxygen depletion. In particular, in the Sacca di Goro, the summer dystrophy may be responsible for very high mortality in the *A. senhousia* population [28, 29]. In fact, the temperature and low oxygen concentrations have an important influence on the physiological and biochemical attributes of bivalves [42].

Average abundance data of *A. senhousia* found during this study in the Varano lagoon (Central Adriatic Sea) are comparable with the abundance data found for the same species in the north-eastern Adriatic Sea (Sacca di Goro) [29-31], Tyrrhenian (Gulf of Olbia) [35] and Ionian (Mar Piccolo) [43] coastal areas. The population growth in the Varano lagoon was extremely rapid, in accordance with *r*-selective characteristics of the species, providing yet another example of the explosive potential of Asian date mussel populations in a Mediterranean lagoon. As for the Sacca di Goro [44], also for the Varano lagoon, a vital succession of the *A. senhousia* population could be guessed: in April-May, after the larval recruitment, there are many medium-sized individuals (15.74 ± 6.19 mm), that reach the adult stage (bigger sizes) in July (20.81 ± 5.34 mm); in October, following the hypoxic crisis, the population is decimated but small individuals are present (12.82 ± 5.41 mm), ready to grow.

The distribution and abundance of the mussel in the Varano lagoon reveal the highly erratic nature of *A. senhousia* populations over time. In some station, *A. senhousia* was numerous (up to 4.450 m^2), while in others it was almost absent (11 m^2). This pattern seems to be a distinguishing feature of the species in San Diego Bay [45] and Asia [16, 46, 47]. Such dramatic population fluctuations exhibited by *A. senhousia* are typical of many opportunistic species [48, 49]. The presence in October of the largest cohort is probably due to individuals who survived the effect of the hypoxic crisis from the previous colonization. Instead the pool of the smallest individuals constitutes the new generation ready to recolonize the area. The two separated cohorts detected in May and October are according to Mastrototaro [43], as the consequence of two discrete spawning events. The size distribution pattern in July showed a unimodal trend with a marked symmetry, suggesting that the population is well-structured in that period. Morphometric relationships between length and weight confirm the presence of a stable population of *A. senhousia* and are well-structured and well-adapted to the Varano lagoon environment. Within its native range, densities of *A. senhousia* can exceed several thousand m^2 [16, 47, 50-52]. Juveniles have been reported in very high numbers, ranging from 28.650 m^2 on eelgrass blades [53] to 126.000 m^2 on synthetic filament line [51]. *A. senhousia* is often patchily distributed on the spatial scales examined in this study.

At present, introduction way of the bivalve *A. senhousia* into Varano lagoon is unclear, but it could suppose its presence may be attributable to spontaneous penetration from near Adriatic Sea and introduction of larvae and juveniles brought to lagoon with the seed of *M. galloprovincialis* bought from Northern Adriatic Sea farms. In the near future, if the conditions would be favourable for spreading of the species on the soft bottoms, we can expect very dense populations, as is the case, for example, in the area of the Northern Adriatic lagoon (Sacca di Goro) where the population spread on soft sediments was explosive, and after few years of its first observation, it carpeted thousands of square meters and its densities exceeded 10.000 individuals per square meter [31]. It acts as secondary substratum that enhances environmental complexity, and its beds facilitate the presence of other macrofaunal invertebrates [29, 54].

5. Conclusions

From this study, it emerges that *A. senhousia* seems well adapted to Varano lagoonal habitats, and has all the characteristics of a formidable opportunistic invader. Further investigations about growth and spread of *A. senhousia* throughout the lagoon could be conducted. Information found may be useful for understanding the rapid spread that species have had in Adriatic Sea and, in particular, in transitional water ecosystems. We suggest the realization of a management plan of the mussel farming activity in Varano that controlled presence of shellfish farming to reduce introduction of the new arrivals in our study area. Also, unfavorable environmental conditions (i.e. anoxia) in summer can periodically erode mussel populations of *A. senhousia* from entering an expansion phase, mitigating subsequent ecological impacts on the local infauna and the functioning of the system.

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