

Massive mortality of the Asian clam *Corbicula fluminea* in a highly invaded area

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Introduction

Corbicula fluminea is one of the most widespread invasive species in aquatic ecosystems. Originating from Southeast Asia this clam has been dispersing worldwide over the last decades (Darrigran 2002; McMahon 2002; Sousa et al. 2008b).

Corbicula fluminea was first reported in the Minho estuary in 1989 (Araujo et al. 1993), and is now a major component of the benthic fauna in terms of density and biomass, contributing to more than 95% of the overall biomass (Sousa et al. 2008e). Recently, the *C. fluminea*

population has been undergoing rapid die-offs in the Minho estuary, due to extreme abiotic changes that have been occurring in the summer (e.g. low river flow, high temperature, low dissolved oxygen and lower redox potential). The first documented event occurred in the summer 2005, and was associated with a strong heatwave. The major declines in *C. fluminea* density and biomass occurred in estuarine areas with fine sediments and rich in organic matter content (Sousa et al. 2008a, d). Environmental impacts resulted from the 2005 heatwave and the synergistic effects caused by the great mortalities of *C. fluminea* were responsible for dramatic changes in the macrozoobenthic estuarine community (Sousa et al. 2008c), with the native bivalve populations (e.g. *Pisidium amnicum*, *Unio pictorum*, *Anodonta anatina* and *Psilunio littoralis*) being severely affected. However, *C. fluminea* rapidly recovered from this impact, returning in the subsequent years to the earlier density and biomass (Sousa et al. 2008c).

In September 2009, local fisherman reported massive accumulations of soft putrefying parts of this Asian clam at the water surface, suggesting another massive die-off. Given the ecological importance of this phenomenon, and since a long data set concerning the ecology of *C. fluminea* in this estuary already exists (Sousa et al. 2008a, d), the aims of the present study were to report the first results of the recent massive mortality of *C. fluminea* in the Minho estuary, and also to discuss the ecological changes resulting from this occurrence.

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Materials and methods

This study was conducted in the Minho estuary (NW Iberian Peninsula), which is described in more detail in previous studies (see Sousa et al. 2008a, c, e). *C. fluminea* quantitative sampling was carried out each October from 2004 to 2009. Samples were collected using a Van Veen grab with an area of 500 cm² and a volume of 5,000 cm³ at 16 different sites (for a map with sites location please see Fig. 1 of Sousa et al. 2008a) along the estuarine gradient using the methodology described in Sousa et al. (2008a). Abiotic variables (temperature, conductivity, total dissolved solid, redox potential, salinity, dissolved oxygen, pH, nitrites, nitrates, ammonia, phosphates, hardness, granulometry of the sediment and organic matter content) were measured at each site using the methodology described in Sousa et al. (2008a) and detailed annual data about the abiotic factors for each site are available by request from the corresponding author.

In order to test annual variations in the density of *C. fluminea* statistical tests (Kruskal–Wallis and Mann–Whitney *U*-test) were performed with Statistica 9 Software.

Results and discussion

Asian clam populations can reach high density and biomass, but can undergo rapid die-offs triggered by factors such as increase silt loads during spring floods, high and low temperature extremes, and low dissolved oxygen levels associated with decreased water flow (Sickel 1986; Strayer 1999; Mouthon 2001). Significant differences in the annual mean density of *C. fluminea* were found from 2004 to 2009 ($\chi^2 = 17.92$; $P < 0.05$), with the lowest densities recorded in 2005 (956 ind m⁻²) and 2009 (777 ind m⁻²), corresponding to years when summer heat-waves occurred in the region. The density recorded in 2009 was significantly lower than the corresponding 2008 (1200 ind m⁻²) value ($Z = 3.32$; $P < 0.001$) and similar to the one recorded in 2005 ($Z = 0.51$; $P > 0.05$), when the first mass mortality event occurred in this estuary (Sousa et al. 2008c). In the particular case of the Minho estuary, the river flow seems to have an important role triggering the massive mortalities of *C. fluminea*. Indeed, in

September 2009, when the massive die-off occurred, the lowest monthly river flow value since 1991 was observed. Normally, reductions in river flow are associated with high temperatures and low dissolved oxygen concentrations, with the latter condition being particularly important, since *C. fluminea* is relatively intolerant to hypoxia (Belanger et al. 1991; Johnson and McMahon 1998; Matthews and McMahon 1999). Others studies have also registered *C. fluminea* die-offs under extreme conditions of temperature, river flow and low dissolved oxygen levels (Sickel 1986; Phelps 1994; Mouthon and Daufresne 2006; Werner and Rothhaupt 2008; Vohmann et al. 2009).

Although, in this case the massive die-offs seem to be related to the synergistic effects of high temperatures, low river flow and low dissolved oxygen, we cannot discard the possible interplay of other factors. For example, Vohmann et al. (2009) propose that the high water temperature alone does not seem to be a plausible explanation for the die-off phenomenon in areas where the observed temperature never reaches the upper *C. fluminea* limit of tolerance, which is up to 37°C (McMahon and Williams 1986). Vohmann et al. (2009) attributed the *C. fluminea* mass mortality in the River Rhine to the low food quantity (e.g. algal abundance and concentration of particulate organic matter), that decreases in the summer leading to a starvation period. This condition may be more serious in periods of higher temperature, particularly in nutrient poor habitats. Given the high metabolic rates and food demands of *C. fluminea*, this species can not compensate for the increased metabolic costs in nutrient poor habitats, thus leading to massive die-off events (McMahon 2002; Weitere et al. 2009). Unfortunately, our sampling program did not include data about algal abundance and concentration of particulate organic matter in the water column, and so further discussion on this topic would be speculative. However, it is well established that the Minho estuary is rich in organic matter content, which can also function as a food resource for this species (Sousa et al. 2008d). In addition, the decrease in the river flow could also be responsible for higher tidal influence in upstream areas and consequent increase in salinity. In fact, in the Minho estuary, during the summer, reductions in the density and biomass of *C. fluminea* have already been reported in downstream areas (sites 1 and 2) in response to the higher marine influence that acts as an important environmental

stressor. This increase in salinity clearly reduces the physiological fitness of this invasive species and ultimately can be responsible for higher mortalities in downstream areas during drought periods.

Although the information about the triggering factors responsible for these die-offs is important, possibly the great ecological changes generated by this phenomenon is even more important. The benthic community (mainly other mollusks) resilience to these extreme conditions seems to be low (Cherry et al. 2005; Cooper et al. 2005) and significant changes in the benthic communities have been reported after these massive die-offs (Sousa et al. 2007). Besides, the great biomass released in these events could also impact the higher trophic levels. For example, Mouthon (2001) reported that silurid fish species benefited from the large quantities of dead *C. fluminea* that were available during these events. However, when considering the case observed in the Minho estuary a great proportion of the biomass released is not consumed by higher trophic levels and will go inevitably to the detritus food-web or washed away to downstream areas. This could potentially be responsible for important changes in the biogeochemical cycles (Sousa et al. 2008b). Moreover, another major environmental impact of these events can be related to the release of nutrients, mainly toxic ammonia that could affect the water quality and the overall biota with potential negative effects on benthic species (Cherry et al. 2005; Cooper et al. 2005). Finally, given the spatial distribution of this species in the Minho estuary and further upstream areas, the quantity of empty shells that accumulate after these events are large and may affect local people and tourists that use the river for recreational purposes, and also the local fishing activity since empty shells become trapped in trammel nets making them less efficient.

Given the widespread distribution and the great density and biomass attained by this invasive species in several aquatic ecosystems, allied to the possible increase in the frequency of extreme climatic events, the ecological impacts generated by massive mortalities of *C. fluminea* should be taken into account in future studies.

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References

- Araujo R, Moreno D, Ramos MA (1993) The Asiatic clam *Corbicula fluminea* (Müller, 1774) (Bivalvia: Corbiculidae) in Europe. *Am Malacol Bull* 10:39–49
- Belanger SE, Cherry DS, Farris JL et al (1991) Toxicity of biocides for Asiatic clam control. *J Am Water Works Assoc* 99(2–3):66–73
- Cherry DS, Scheller JL, Cooper NL et al (2005) Potential effects of Asian clam (*Corbicula fluminea*) die-offs on native freshwater mussels (Unionidae) I: water-column ammonia levels and ammonia toxicity. *J N Am Benthol Soc* 24(2):369–380
- Cooper NL, Bidwell JR, Cherry DS (2005) Potential effects of Asian clam (*Corbicula fluminea*) die-offs on native freshwater mussels (Unionidae) II: porewater ammonia. *J N Am Benthol Soc* 24(2):381–394
- Darrigran G (2002) Potential impact of filter-feeding invaders on temperate inland freshwater environments. *Biol Invasions* 4:145–156
- Johnson PD, McMahon RF (1998) Effects of temperature and chronic hypoxia on survivorship of the zebra mussel (*Dreissena polymorpha*) and Asian clam (*Corbicula fluminea*). *Can J Fish Aquat Sci* 55:1564–1572
- Matthews MA, McMahon RF (1999) Effects of temperature and temperature acclimation on survival of zebra mussel (*Dreissena polymorpha*) and Asian clams (*Corbicula fluminea*) under extreme hypoxia. *J Molluscan Stud* 65:317–325
- McMahon RF (2002) Evolutionary and physiological adaptations of aquatic invasive animals: r selection versus resistance. *Can J Fish Aquat Sci* 59:1235–1244
- McMahon RF, Williams CJ (1986) A reassessment of growth rate, life span, life cycles and population dynamics in a natural population and field caged individuals of *Corbicula fluminea* (Müller) (Bivalvia: Corbiculacea). *Am Malacol Bull Special Edition* 2:161–166
- Mouthon J (2001) Life cycle and population dynamics of the Asian clam *Corbicula fluminea* (Bivalvia: Corbiculidae) in the Saone and Rhone rivers (France). *Ann Limnol-Int J Lim* 39(1):15–25
- Mouthon J, Daufresne M (2006) Effects of the 2003 heatwave and climatic warming on mollusc communities of the Saône: a large lowland river and of its two main tributaries (France). *Glob Change Biol* 12:441–449
- Phelps HL (1994) The Asiatic clam (*Corbicula fluminea*) invasion and system-level ecological change in the Potomac River estuaries near Washington, DC. *Estuaries* 17:614–621
- Sickel JB (1986) *Corbicula* population mortalities: factors influencing population control. *Am Malacol Bull Special Edition* 2:89–94
- Sousa R, Antunes C, Guilhermino L (2007) Species composition and monthly variation of the Molluscan fauna in the freshwater subtidal area of the River Minho estuary. *Estuar Coast Shelf S* 75:90–100

- Sousa R, Antunes C, Guilhermino L (2008a) Ecology of the invasive Asian clam *Corbicula fluminea* (Müller, 1774) in aquatic ecosystems: an overview. *Ann Limnol Int J Lim* 44:85–94
- Sousa R, Dias S, Guilhermino L et al (2008b) Minho River tidal freshwater wetlands: threats to faunal biodiversity. *Aquatic Biol* 3:237–250
- Sousa R, Dias S, Freitas V et al (2008c) Subtidal macrozoobenthic assemblages along the River Minho estuarine gradient (north-west Iberian Peninsula). *Aquat Conserv* 18:1063–1077
- Sousa R, Nogueira AJA, Gaspar M et al (2008d) Growth and extremely high production of the non-indigenous invasive species *Corbicula fluminea* (Müller, 1774): possible implications for ecosystem functioning. *Estuar Coast Shelf S* 80:289–295
- Sousa R, Rufino M, Gaspar M et al (2008e) Abiotic impacts on spatial and temporal distribution of *Corbicula fluminea* (Müller, 1774) in the River Minho estuary, Portugal. *Aquat Conserv* 18:98–110
- Strayer DL (1999) Effects of alien species on freshwater mollusks in North America. *J N Am Benthol Soc* 49:19–27
- Vohmann A, Borcharding J, Kureck A et al (2009) Strong body mass decrease of the invasive clam *Corbicula fluminea* during summer. *Biol Invasions* 12:53–64
- Weitere M, Vohmann A, Schulz N et al (2009) Linking environmental warming to the fitness of the invasive *Corbicula fluminea*. *Glob Change Biol* 15:2838–2851
- Werner S, Rothhaupt KO (2008) Mass mortality of the invasive bivalve *Corbicula fluminea* induced by a severe low-water event and associated low water temperatures. *Hydrobiologia* 613:143–150