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Short communication

Alien species in the Guadiana Estuary (SE-Portugal/SW-Spain): *Blackfordia virginica* (Cnidaria, Hydrozoa) and *Palaemon macrodactylus* (Crustacea, Decapoda): potential impacts and mitigation measures

Maria Alexandra Chícharo[1*], Tânia Leitão[1], Pedro Range[1], Cristina Gutierrez[2], Jesus Morales[2], Pedro Morais[1] and Luís Chícharo[1]
[1]*CIMAR/CCMAR – Centro de Ciências do Mar, Faculdade de Ciências do Mar e do Ambiente, Campus de Gambelas, Universidade do Algarve, 8005-139 Faro, Portugal*
[2]*Instituto Andaluz de Investigación y Formación Agraria, Pesquera, Alimentaria y de la Producción Ecológica (IFAPA) Centro "Agua del Pino", Ctra. Punta Umbria-Cartaya s/n. 21450 Cartaya, Huelva, España*
E-mail: mchichar@ualg.pt (MAC), tania_leitao@hotmail.com (TL), prange@ualg.pt (PR), pmorais@ualg.pt (PM), lcchichar@ualg.pt (LC), jmorales@cica.es (JM), cgutierrez@cica.es (CG)
**Corresponding author*

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Abstract

The cnidarian *Blackfordia virginica* and the adult of the caridean prawn, *Palaemon macrodactylus* are first recorded from the Guadiana Estuary. The habitats and environmental conditions under which these species were found are described and the potential impacts and mitigation measures for their introduction are discussed. The first observations of adults of these species were made in July 2008, at the transitional zone of the estuary (brackish area). Most samples taken in the middle-estuary were characterized by large densities of *B. virginica* (> 100 individuals 100 m^{-3}), while *P. macrodactylus* was recorded in much smaller densities (<0.01 individuals m^{-2}). Despite a comprehensive survey of invertebrates done between 1999 and 2003, neither of these species was previously detected in the Guadiana estuary. These observations may, therefore, coincide with the introduction of these species to the Guadiana estuary. Small planktonic crustaceans are generally described as the main food items for *B. virginica*. Our results show that the presence of the medusa was usually associated with a reduction of densities of all zooplanktonic organisms, including eggs of *Engraulis encrasicolus*. The reduction of planktonic biomass could have severe implications for organisms at upper trophic levels, such as *E. encrasicolus*, which use the Guadiana estuary as a nursery area and feed mostly on small planktonic crustaceans. Moreover, the potential consumption of eggs by *B. virginica* could potentially increase the impact on the nursery function of the estuary. The other alien species detected, *P. macrodactylus*, appears to be a strong invader, able to colonise a wide geographical range. It has a strong osmoregulatory capacity, and is known to inhabit a wide range of salinities, particularly if compared to similar native species (*Crangon crangon* and *Palaemon longirostris*). There is clear potential for the occurrence of competition for food between *P. macrodactylus* and the native prawn, due to dietary overlapping. The Guadiana estuary is under Mediterranean climate influence and is expected to be strongly impacted by climatic changes in the next decades. Other threat-factors are also present, such as increasing regulation by dams, the construction of new harbors, and increase shipping activity. It is important, therefore, to study the impact of these new invasions in this estuary and, based on the ecohydrology approach, propose mitigations measures to be applied in this system and other similar ecosystems worldwide.

Key words: alien species, Leptomedusae, Caridea, Gulf of Cadiz, dams, ecohydrology

Extensive development has occurred in the Guadiana River basin over the past century: the consequent reduction in river flow contributed to decreases in water quality (Rocha et al. 2002). Several dams, including the Alqueva dam, were completed in early 2002, creating a water body with a potential area of 250,000 ha. Under specific circumstances, this intensification of flow regulation can cause severe changes in downstream ecosystems. Changes were already demonstrated for planktonic assemblages (Chicharo et al. 2006b; Domingues et al. 2007), fish (Chicharo et al. 2006a), and macrocrustaceans (Leitão 2008). The ecohydrology approach can be used to avoid eutrophization of downstream ecosystems, by improving freshwater management (Chicharo et al. 2006b; Morais et al. 2009).

The timing of introductions is fundamental to better understand the dynamics of biological

invasions. The first occurrence of two marine alien species, the cnidarian *Blackfordia virginica* Mayer, 1910 and the caridean prawn *Palaemon macrodactylus* M. J. Rathbun, 1902 are first recorded from the Guadiana Estuary. Their habitats, environmental conditions and potential impacts are described. Guidelines for monitoring and possible mitigation measures are also proposed.

This study was done in the Guadiana estuary and adjacent coastal area (SE-Portugal/SW-Spain) (Figure 1). This mesotidal estuary is approximately 70 km long, with the lower 50 km delimiting the border between Portugal and Spain. It occupies a total area of 22 km^2, with an average depth of 6.5 m and tidal amplitudes ranging from 1.3 to 3.5 m. The Guadiana River flow varies substantially among and within years, as is characteristic in regions of Mediterranean climate. The average annual rainfall in the Portuguese basin fluctuates between 561 and 600 mm, with considerable variation among years. This variability in rainfall is reflected in the Guadiana River flow, which oscillates between 8 and 63 m^3s^{-1} during dry years, between 170 and 190 m^3s^{-1} in typical years, and between 412 and 463 m^3s^{-1} in wet years (Bettencourt et al. 2003). In this study, the Guadiana estuary was divided into three sub-areas: upper, middle and lower estuary (Figure 1). The upper area is considered the freshwater section, still with a tidal influence but with salinity close to zero (tidal freshwater < 0.5 PSU). The middle section is the salinity-mixing zone (0.5–25 PSU), whereas in the lower area, salinity is usually very close to seawater (> 25 PSU). From 1999 to 2003, a comprehensive survey of invertebrates along the Guadiana estuary showed that the species we are now reporting were not present in the estuary during that period.

From 1 to 16 July 2008, a survey of zoo-planktonic and macrobenthic organisms was done in the Guadiana estuary. Medusae were captured with horizontal plankton tows, at 1m depth and constant speed of 2 knots, during 5-10 min at ebbing tide, using a conical WP2 net (1.60 m x 0.37 m, 200 µm mesh-size), equipped with a Hydro-Bios flowmeter. Prawns were captured with an otter trawl, composed of a conical-shaped net with a stretched mouth of 3 m, an overall length of 25 m and equipped with two otter boards weighing 12 kg each. The net was composed of two panes. The outer pane, made from 30-mm stretched mesh net, protected the inner pane, which was made from 10-mm stretched mesh net. The benthic trawlings were done along transects, 870 meters long. All samples were immediately preserved after collection with buffered formaldehyde (4% v/v).

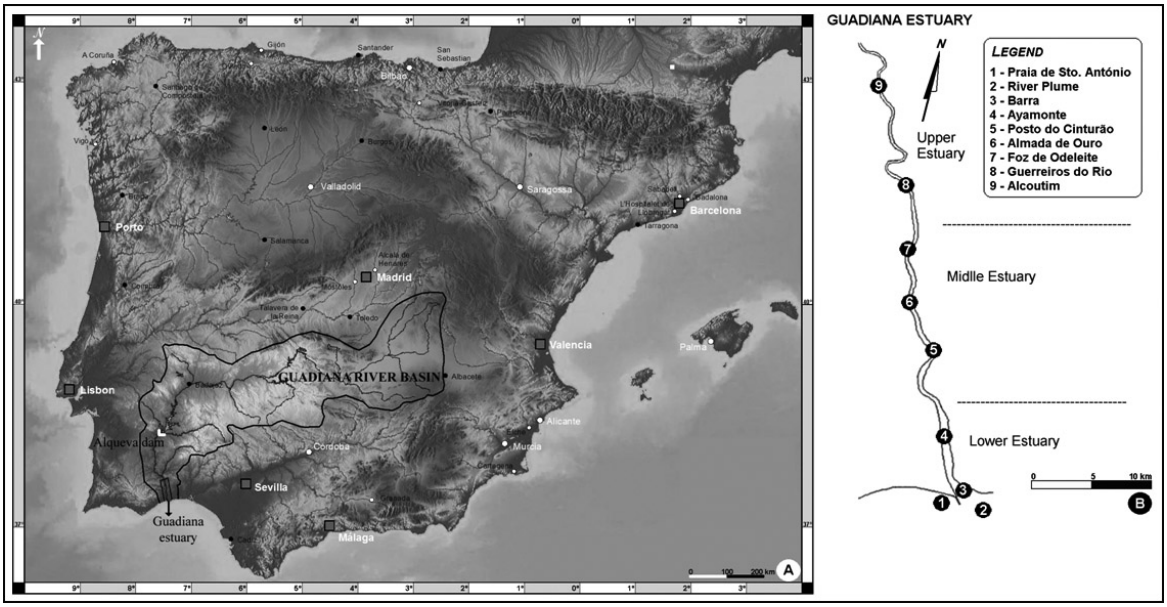

Figure 1. Location of the Guadiana estuary in the Iberian Peninsula (A) and of the sampling stations in the estuary and in the adjacent coastal area (B)

We first observed *Blackfordia virginica* in the Guadiana in July 2008, at the transitional zone of the estuary (brackish area). High densities of medusae (> 100.100 m^{-3}) were collected in most samples from the Middle estuary, with a maximum 3170.100 m^{-3} in station 4 (Posto Cinturão, geographic coordinates 37º15'30"N, 7º25'58"W). Lower densities of prawns (*Palaemon macrodactylus*) were recorded (<1 m^{-2}), with a maximum value of 0,006 m^{-2} at Station 6 (Guerreiros do Rios, geographic coordinates 37º23'30"N, 7º26'29"W). Maximum densities of both species were recorded in the brackish area of the estuary, where salinity ranged from 8 to 28 PSU. Considering the results of our long-term monitoring of invertebrates in this estuary (mainly between 1999-2003) and despite several discontinuities, the recent findings of *B. virginica* and *P. macrodactylus* could represent the starting point of their introduction, allowing the study of the initial phases of this process and its ecological consequences.

Blackfordia virginica is thought to be native to the Black Sea (Mills and Sommer 1995), but is well known for inhabiting and colonizing different estuarine areas of the world. Currently, the known distribution of *B. virginica* also includes sites in North America, the Chesapeake and San Francisco bays (Theil 1935); South America, Brazil near Recife and Argentina (Genzano et al. 2006); India, in the Ganges estuary, near Cochin and in the Vasishta Godavari estuary (Sai Sastry and Chandramohan 1989); China, in the south China Sea and in the Fujian Province in the east China Sea Zhang (1982); Western Europe in the Loire estuary in France (Denayer 1973) and the Mira estuary in Portugal (Re 1996); and in eastern Europe in the Black Sea, the Caspian Sea, and Lake Belona, Romania (Mills and Sommer 1995; Lin and Zhang 1990; Mills and Rees 2000). In the Guadiana estuary this species could have been introduced in either the medusa or the polyp stages (or both), probably by nautical activities. The finding of an alien species does not necessarily imply that a successful invasion has occurred. We did, however, found specimens of both sexes, over a wide range of sizes (6-19 mm) and maturation stages and in such large numbers that would suggest local reproduction (Figure 2).

There is no published information about the effects of *B. virginica* on surrounding macrofauna or planktonic communities. The analysis of the gut contents of this alien medusa by Mills and Sommer (1995) indicated that they feed nearly exclusively on small planktonic crustaceans and no fish larvae or eggs were seen in any of the stomachs. Nevertheless, our results showed that stations where *B. virginica* was present had reduced densities of all zooplanktonic organisms, including eggs of European anchovy *Engraulis encrasicolus* (Linnaeus, 1758) (Figure 3). Elsewhere, similar populations of alien ctenophores have been recorded to grow so large as to consume most of the summer zooplankton production (up to 80%).

This almost complete depletion of the food supply occurred so quick that devastated the populations of small pelagic fish, severely affecting commercial catches (Studenikina et al. 1991). If similar reductions of planktonic biomass can be caused by *B. virginica*, the small pelagic fishes, such as *Engraulis encrasicolus*, which use the Guadiana estuary as a nursery area (Chícharo et al. 2002) are expected to respond in

Figure 2. *Blackfordia virginica* from the Guadiana estuary (Photograph by Pedro Range)

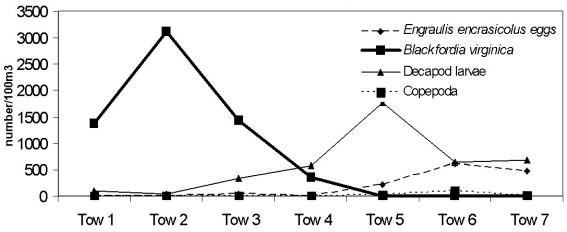

Figure 3. Variations of zooplankton density in several consecutive mesozooplankton tows done in the middle estuary during the 1 July 2008 survey

the same way as described in other systems. Furthermore, the cumulative impact of alien species and intense construction of dams in the Guadiana basin, by Portugal and Spain, has been previously related to the decrease of estuarine productivity and reductions in the anchovy population (Morais et al. 2009). According to these authors, the maximum abundance of anchovy eggs and larvae registered in 2002 (after Alqueva dam) decreased 14.5 times, relative to the maximum registered in July 1988 (before Alqueva dam), a year of moderate inflow and with higher estuarine production (Chícharo and Teodósio 1991). This suggests that the impact in the estuarine nursery function will probably be very important, but further studies are needed to clarify this issue.

The other alien species recorded during July 2008 in the Guadiana estuary, *Palaemon macrodactylus* (Figure 4) is native to Asia: Japan, Korea and China (Beguer et al. 2007). Cuesta et al. (2004) and Gonzalez-Ortegon et al. (2005) have previously mentioned this species for the Guadiana estuary (in May 2004) but only based qualitative survey of larval phases in the lower estuary. This indicates that the introduction must have occurred in the first months of 2004, because no larvae or adults of *P. macrodactylus* were present during our comprehensive survey of invertebrates in the Guadiana estuary, between 1999 and 2003. As far as we are aware, our observations from July 2008 were the first records of adult of this species in the Guadiana estuary.

Palaemon macrodactylus was first introduced in California (USA) in the 1950s, before being recently detected in several European estuaries, e.g. in Spain (Guadalquivir and Guadalete Estuaries, Salado River, San Pedro River - Cuesta et al. 2004); England (Orwell Estuary, Suffolk - Ashelby et al. 2004); the Southern Bight of the North Sea (d'Udekem d'Acoz et al. 2005) and France (Beguer et al. 2007). During the same period, a first specimen was recorded in southern Atlantic waters, in the harbor of Mar del Plata, Argentina (Spivak et al. 2006). According to these records, *P. macrodactylus* appears to be a strong invader, able to colonize a wide geo-graphical range. It is a strong osmoregulator and is known to inhabit a wide range of salinities (1-36 PSU) (González-Ortegón et al. 2006). Nevertheless, only few specimens have been collected so far in the Guadiana estuary and only in the middle and upper areas.

Figure 4. *Palaemon macrodactylus* from the Guadiana estuary (Photograph by Pedro Range)

Many introduced species have been shown to have detrimental effects on indigenous biota.The possibility that *P. macrodactylus* may compete with indigenous species for food and habitat, and that it may have an advantage over more vulnerable species, has been previously suggested (Ashelby et al. 2004). Like other carideans, *P. macrodactylus* is largely carnivorous, feeding mainly on animal fragments (at least 75%), with plant material constituting a smaller proportion of its diet. Dietary overlap with the European Caridea is, therefore, to be expected (Ashelby et al. 2004). Interespecific competition with native populations of *Palaemon longirostris* H. Milne-Edwards, 1837 seems particularly likely to occur in the future, if densities of the alien species increase.

According to Rikke et al. (2008), most of the biological invasions of estuarine ecosystems occur in the brackish part of estuaries, where invasive species can amount to about 20% of the total number of species present These authors also report that hard substrates tend to be more invaded than soft substrates. *B. virginica* can tolerate salinities of 3 to 35 PSU and is eurythermal (Moore 1987). Its presence in the middle estuary, where salinity range between 8-28 PSU and where rocky substrates start to occur (Gonzalez 1995), seems to corroborate the proposed general patterns.

The vectors of introduction of *Blacfordia virginica* and *Palaemon macrodactylus* in the Guadiana estuary are still unclear. The hypothesis most often cited in the literature is introduction via ship ballast water, because all localities where these introduced species have been reported are, or are nearby to, large

international harbours or shipping traffic (González-Ortegón et al. 2007). In fact, with such a considerable shipping traffic in the Gulf of Cadiz, it is expectable that many alien species are continuously injected here. This strengthens the conclusion that any temperate estuary with or near by heavy international ship traffic must be considered a susceptible "hot spot" for invasion (Carlton 1985). Moreover, the dredging of the Guadiana estuary, scheduled for 2011 by the Harbour Autorities of Portugal and Spain ("Instituto Portuário dos Transportes Marítimos - Portugal" and "Agencia Pública de Puertos de Andalucía –Spain") and the construction of new harbours in the Guadiana estuary, to allow navigation of larger ships until upstream areas, will increase this potential threat. The invasions are also facilitated by the intense regularization of Guadiana flow to the estuary, which is known to encourage the establishment of alien species (Bunn and Arthingthon 2002). The Guadiana is a temperate estuary under the influence of a Mediterranean climate and, therefore, is classified as very vulnerable to global change (IPCC 2007), which also contributes to increase the invasion potential.

Eradicating an invasive species can only be achieved if it is detected on time, but the best policy is still to prevent the invasion from occurring, which seems to be possible in the case of these two species. Specific actions have been proposed to prevent new invasions and mitigate the ones already present in the Guadiana estuary. These include intense monitoring of all larval phases and adequate flow management by the dams in the Guadiana catchment, to promote the creation of freshets, simulating natural flow regimes and discourage invasions (Chícharo et al. 2006a, b and Wolanski et al. 2008). Nevertheless, as advised by Boero et al. (2004), only with a deep insight into the functioning of ecological systems, based on a wide long term pool of in situ observations may this be achieved.

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