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First record of the brown mussel (*Perna perna*) from the European Atlantic coast

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The occurrence of the brown mussel Perna perna *is reported for the first time from the European Atlantic coast, on the southern Portuguese coast. Several specimens of this mytilidae species were identified in exposed rocky intertidal habitats in Vilamoura (37°04′19.70″N 8°07′19.71″W) and Ilha do Farol (36°58′29.38″N 7°51′42.51″W). It is suggested that, under warming climate conditions, this subtropical/tropical species might have extended its geographical distribution from North Africa.*

Keywords: brown mussel, *Perna perna*, Portugal, European Atlantic coast, range expansion

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INTRODUCTION

The brown mussel *Perna perna* (Linnaeus, 1785) is a subtropical/tropical species that is widely distributed along Madagascar, the east African coast (from central Mozambique to False Bay), the west coast of Africa (from Luderiz Bay north into the Mediterranean) and from the Strait of Gibraltar (African side) to the Gulf of Tunis (Berry, 1978). It is also present in Sri Lanka, southern India and on the Atlantic coast of South America where it was reported in Venezuela, Uruguay, and Brazil as well as in the West Indies (Berry, 1978; Vakily, 1989; Wood *et al.*, 2007). In Brazil, *P. perna* has been reclassified as an old introduction, most likely dating from the 16th Century (Silva & Barros, 2011).

In the United States, *P. perna* invaded Texas (Gulf of Mexico) shores in 1990 (Hicks & Tunnell, 1993). This mussel species is thought to have been introduced to this area via ballast water release (Hicks & Tunnel, 1993), and its invasion has attracted much attention because of its potential threat to shipping safety and to cooling water systems of coastal power stations (Hicks & McMahon, 2002; Rajagopal *et al.*, 2003). *Perna perna* has recently been detected on an oil rig in New Zealand waters but vigorous efforts by the Biosecurity New Zealand system strongly reduced the likelihood of a successful population establishment (*Manawatu Standard*, 2008).

Perna perna has never been observed along the European Atlantic coast, despite several extensive surveys of intertidal communities having been conducted since the mid-1950s (e.g. Fischer-Piétte, 1958, 1963; Santos, 2000; Boaventura *et al.*, 2002; Fa *et al.*, 2003; Arauújo *et al.*, 2005; Guerra-García *et al.*, 2006; Lima *et al.*, 2006, 2007; Pereira *et al.*, 2006).

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MATERIALS AND METHODS

Study area and sampling

Extensive field surveys were carried out during low spring tides between April and November 2011 on rocky intertidal shores along the southern Portuguese coast, from Vilamoura (37°04′19.70″N 8°07′19.71″W) to Tavira (37°06′58.48″N 7°37′43.86″W). All locations were visited at least twice (covering winter and summer months) and each location included two sites from 500 m to 1 km apart. At each site, two observers performed approximately 60 minutes searches across all microhabitats present.

Identification

Key morphological and behavioural characters were used to identify *Perna perna* specimens (Siddal, 1980; Vakily, 1989; Nicastro *et al.*, 2010). A main diagnostic feature is the pattern of the scars left at the area of muscle attachment on shells. In *Mytilus* spp., the scar left by the posterior adductor and retractor muscles is united forming a continuous band along the dorsal margin of the pallial line (Siddal, 1980). In contrast, these two muscles attach separately on the shell in *Perna* spp., resulting in a discontinuous scar (Figure 1). Another key character is the anterior adductor muscle which is present although small, in *Mytilus* spp. but absent in all *Perna* spp. (Siddal, 1980). Moreover, the shell of *P. perna* adults presents a brown to red-maroon colour with some irregular light brown and green areas (Siddal, 1980). Despite mussel shell plasticity, the width (the maximum distance along the lateral axis between the two valves of the closed shell) and the height (the maximum distance along the dorso-ventral axis across the mid-axis of the shell) can also be used to identify *P. perna* specimens (shells are typically higher than wider: Marques *et al.*, 1998).

Finally, gaping (periodic valve movement during emersion) is an ideal diagnostic behavioural trait to distinguish between *Mytilus galloprovincialis* and *P. perna* individuals. During

Fig. 1. Left valve of a *Perna perna* specimen: the characteristic posterior double scar is shown.

emergence, intertidal mussels either keep the valves closed, minimizing water loss and utilizing anaerobic metabolism (non-gaping species), or periodically open the valves allowing more efficient aerobic metabolism but increasing the risk of desiccation (gaping species: Widdows *et al.*, 1979; Famme & Kofoed, 1980). In contrast to the non-gaping *M. galloprovincialis*, *P. perna* is a gaping species (Nicastro *et al.*, 2010).

RESULTS AND DISCUSSION

Several individuals of *Perna perna* were first observed in Vilamoura (37°04′19.70″N 8°07′19.71″W) and Ilha do Farol (36°58′29.38″N 7°51′42.51″W), south coast of Portugal on 1 and 3 July 2011, and their presence was followed during the consecutive months. *Perna perna* was interspersed within beds of the dominant mussel species *Mytilus galloprovincialis* in the lower eulittoral zone (hereafter referred to as the mussel zone; Figure 2).

All key features such as the light-brown colour, the double posterior muscle scar, the absence of an anterior adductor muscle and the gaping behaviour confirmed that all individuals belong to *P. perna* species. Furthermore, *P. perna* specimens were higher than wider as previously described by Marques *et al.* (1998), on average 2.4 and 1.7 mm for height and width respectively.

Perna perna and *M. galloprovincialis* overlap in their distributions on the Atlantic coast of North Africa and the Mediterranean coast of Algeria (Abada-Boudjema & Dauvin, 1995). In these regions, the two species co-occur in high abundance and have reached a distributional equilibrium through partial habitat segregation (Bownes & McQuaid, 2006). The upper and the lower areas of the mussel zone are dominated by *M. galloprovincialis* and *P. perna* respectively, while the two species overlap in the mid-mussel zone. Moreover, *M. galloprovincialis* shows similar patterns of zone segregation with *Perna viridis* in Hong Kong (Lee & Morton, 1985) and *Perna canaliculus* in New Zealand (McDonald *et al.*, 1991). Previous studies showed that partial habitat segregation of these two species results from a combination of biotic and physical conditions along a gradient of multiple stresses (e.g. Zardi *et al.*, 2006; Rius & McQuaid, 2009; Nicastro *et al.*, 2010). In contrast, the mussel zone in southern Portugal is characterized by a lack of vertical segregation with few *P. perna* individuals sparingly distributed within the dominating *M. galloprovincialis*. Low population density and lower habitat occupancy is typical of marginal populations, which exist at the ecological edges of a species range living under unfavourable ecological conditions (Sagarin *et al.*, 2006). A continuous monitoring of the structure and dynamics of mixed populations of the two mussel species will be important to define the impact of *P. perna* and to understand if the distribution of these coexisting species is stable or if it will evolve to the same vertical patterns observed in other regions.

The presence of *P. perna* on the Portuguese southern coast is a striking shift of the previous northern distributional boundary along the Moroccan coastline (Siddal, 1980; Vakily, 1989; Wood *et al.*, 2007). *Perna perna* has larvae with a long pelagic stage that, under favourable conditions, can disperse over large distances (100s km) before settling (McQuaid & Phillips, 2000). Such a large dispersal potential could have allowed dispersal from North African populations and colonization of European shores. Over the last 50 years, sea surface temperatures along the Portuguese coast have consistently increased (Lima *et al.*, 2007). The range expansion of the subtropical/tropical species *P. perna* is consistent with general predictions of species distributional shifts under warming climate scenarios, which anticipate northwards expansions of warm-water taxa (Parmesan & Yohe, 2003; Helmuth *et al.*, 2006; Mieszkowska *et al.*, 2007; Hawkins *et al.*, 2009). Genetic characterization is needed to determine the exact origin of *P. perna* Portuguese populations and also to understand if multiple introductions have occurred over time.

Intertidal mussels are fascinating models for studies of climate-induced range shifts over small (intertidal) and large (latitudinal) spatial scales (Harley, 2011). *Perna perna*, together with other key species, whose distributional ranges are changing along the Portuguese coastline (e.g. *Fucus* spp.: Viejo *et al.*, 2011) is an ideal model organism to study climatic-driven biogeographical changes.

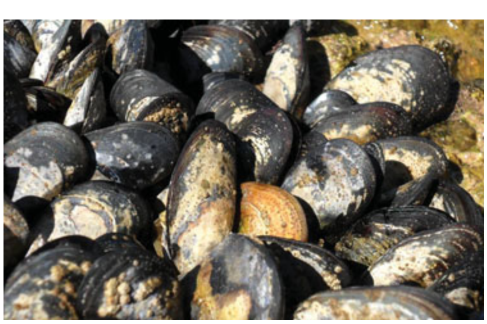

Fig. 2. Isolated brown mussel (*Perna perna*) in the centre of a blue mussel bed (*Mytilus galloprovincialis*) from Vilamoura on 1 July 2011.

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