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First record of *Palaemon macrodactylus* Rathbun, 1902 (Decapoda, Palaemonidae) in the western Mediterranean

A. P. TORRES[1], A. DOS SANTOS[2], J. A. CUESTA[3], A. CARBONELL[1], E. MASSUTÍ[1], F. ALEMANY[1] and P. REGLERO[1]

[1] Instituto Español de Oceanografía. Centre Oceanogràfic de les Balears. Moll de Ponent s/n, 07015 Palma, Spain
[2] Instituto Português do Mar e da Atmosfera (IPMA), Avenida de Brasília s/n, 1449-006 Lisbon, Portugal
[3] Instituto de Ciencias Marinas de Andalucía, CSIC, Avenida República Saharaui, 2, E-11519 Puerto Real, Cádiz, Spain

Corresponding author: asvin.perez@ba.ieo.es

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Abstract

The Mediterranean Sea is one of the world's hotspots for marine bio-invasions. Most invasions are first documented based on an initial record of occasional adult captures. However, reports of larval stages could indicate that there is an adult population that is reproducing and therefore well established in the area. The spread of the oriental shrimp, *Palaemon macrodactylus,* from its native estuarine waters of southeast Asia to new regions worldwide is well documented. We report the first record of this species in the Mediterranean based on the presence of its larval stages in plankton samples. Decapod larvae were collected in five offshore plankton surveys performed off the Balearic Islands (western Mediterranean), and zoeae III and VI of the oriental shrimp were found among them. Taking into account the duration of the successive developmental stages, and the hydrodynamic characteristics of the study area, these larvae were most probably spawned by adult populations not yet documented. The larvae were found in marine waters despite the fact that adults usually inhabit brackish waters. Our study is a good example of how plankton studies can help to detect larval stages of invasive species before the adult populations are detected.

Keywords: *Palaemon macrodactylus,* first record, planktonic larvae, western Mediterranean, Balearic Islands, decapods.

Introduction

Most benthic marine invertebrates have planktonic larval stages that spend from hours to months in the pelagic environment before settling to the bottom. It is during these early life stages that there is the highest dispersal, which determines the connectivity among populations (Cowen & Sponaugle, 2009). Larval transport can occur by natural means, through currents, as well as through anthropogenic pathways and vectors. One of the main introduction vectors of marine alien species worldwide is ship ballast water (Galil, 2009), in which a species can reach areas far from its native distribution range and could become an invasive species in the newly colonized area.

Palaemon macrodactylus Rathbun, 1902 is an estuarine shrimp native to the western Pacific that has been described in waters around Japan (Rathbun, 1902), China and Korea (Newman, 1963). Little is known about its early life history stages; however, its adult biology and its expansion and colonization period in different estuaries around the world are well described in the literature. In marine waters, well-established populations have only been reported in the port of Mar de Plata (Argentina) (Vázquez *et al*., in press).

In 1957, *P. macrodactylus* adults were reported for the first time in the eastern Pacific, which was the first finding of this species outside its native habitat (Newman, 1963). Adult specimens have been reported in the eastern Atlantic, on estuarine coasts of Europe, where they extended from the south to the north in one decade, and later in the western Atlantic, and in 2009 they were recorded in the Black Sea (Lavesque *et al*., 2010, and references therein). The chronology and geographic distribution with all the records are shown in Figure 1.

Unfortunately, there are still large gaps in the current information on the larval ecology of *P. macrodactylus*. Estuarine species follow two main life cycle strategies (Strathmann, 1982): one strategy involves the adaptation of all life cycle stages to the estuarine conditions; and the other strategy involves exporting larval stages to adjacent offshore marine areas. In laboratory conditions, the oriental shrimp needs around 15-20 days (6-7 zoeal stages) after hatching before it metamorphoses into a first

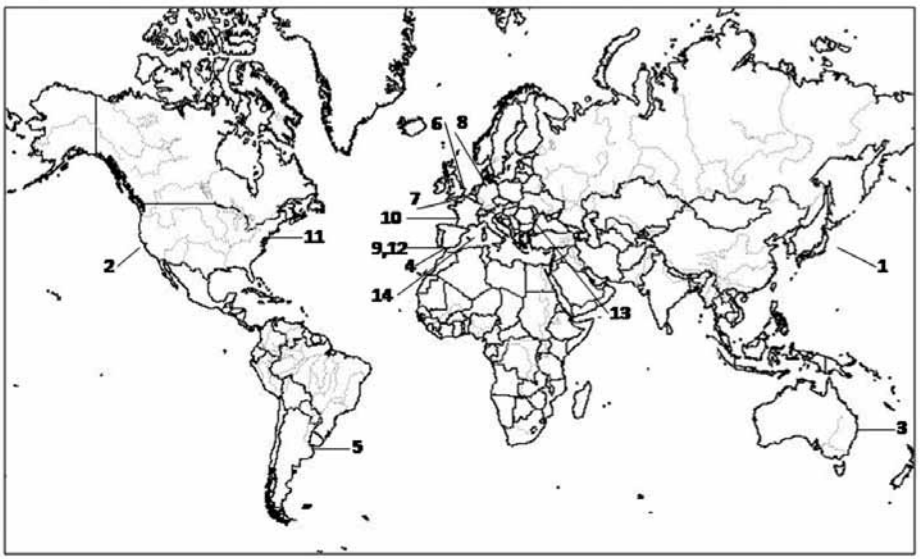

Fig. 1: Chronology of the appearance of *P. macrodactylus* around the world, showing the distribution of worldwide points (updated from González-Ortegón *et al.,* 2007, and the references therein). *1(O/E)* north coast of China, Korea and Japan. *2(A/E)* Pacific coast of North America. *3(A/E)* southwestern Australia. *4(A+L/E)* Gulf of Cádiz, Spain. *5 (A/M)* Mar del Plata harbour, Argentina. *6(A/E)* Suffolk, U.K. *7(A/E)* North Sea (Belgium, Netherlands and north France). *8(A/E)* Mouth of the Geeste River and Hooksiel, Germany. *9(L/E)* Guadiana River, Spain (Cuesta and González-Ortegón unpublished data). *10(A/E)* Gironde estuary, France. *11(A/E)* New York estuary, North America. *12(A/E)* Guadiana River, Spain. *13(A/M+E)* Constana harbour and Varna Lake, Black Sea. *14(L/M)* Present work in Balearic Islands. *(O:* origin area; *A:* adult phase; *L:* larval phase, *E:* estuarine habitat; *M:* marine habitat)

juvenile (Little, 1969). *P. macrodactylus* larvae are easily identified by the presence of a dorsal hooked spine on the third abdominal segment (Fig. 2; Fig. 3a, b), which is not present in any other known European palaemonid larvae (González-Ortegón & Cuesta, 2006). The larvae are planktonic and are very abundant in the plankton of delta areas during summer (Siegfried, 1980).

P. macrodactylus larvae were collected in two of five intensive multidisciplinary surveys conducted around the Balearic Islands (western Mediterranean). These samples are the first record of this species in the Mediterranean Sea. Information on the larval developmental stages and oceanic situation off the Balearic Islands is given and discussed. This study aims to inform the scientific community of the presence of a new invasive species and lay the foundations for assessing the possible interaction between the exotic shrimp and native carideans in future works. We report the presence of oriental shrimp larvae, which have been detected before the adult population.

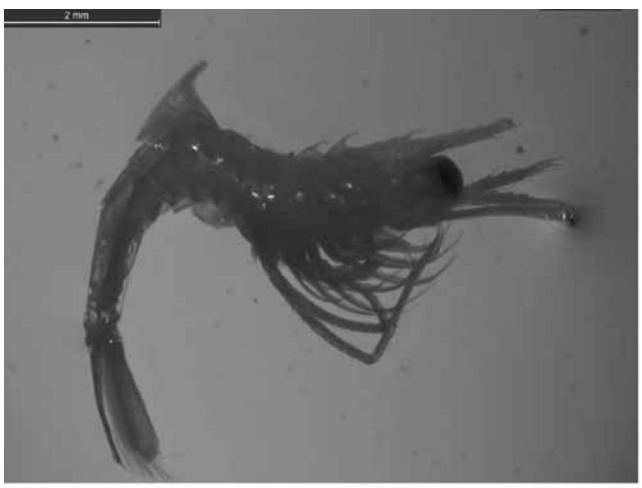

Fig. 2: *Palaemon macrodactylus,* Zoea VI, captured in the Balearic Sea in 2005.

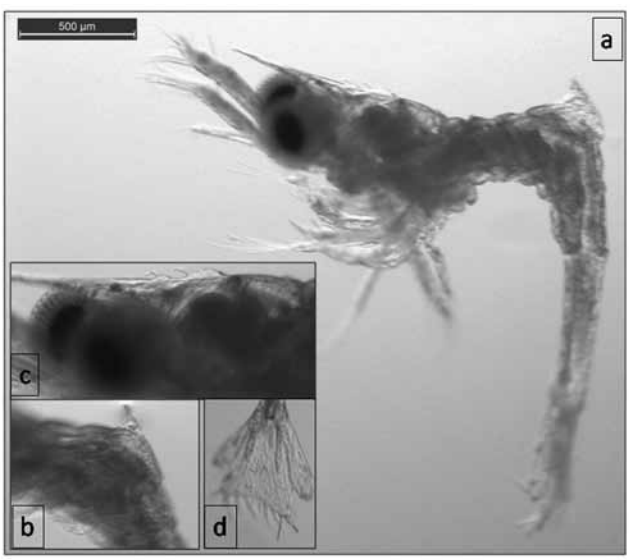

Fig. 3: *Palaemon macrodactylus,* Zoea III captured in the Balearic Sea in 2010, general view (a) whole lateral view, (b) abdominal dorsal spine detail, (c) rostral dorsal spines and (d) telson.

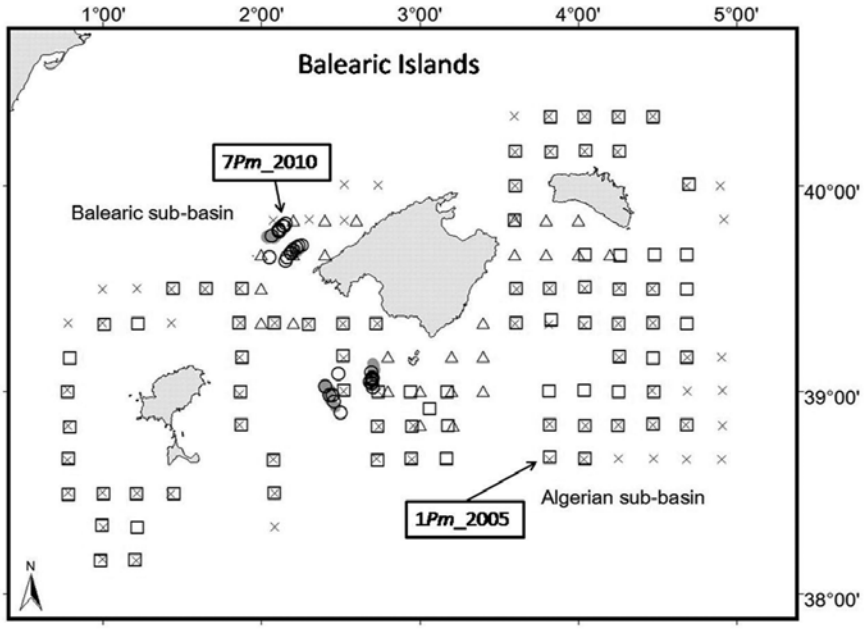

Fig. 4: Study area (Balearic Islands point 14_Fig.1), showing sampling stations (triangles 2001; squares 2004; crosses 2005; grey dots 2009; transparent circles 2010). *Palaemon macrodactylus* capture points (Pm) and numbers for 2005 and 2010.

Material and Methods

Five multidisciplinary oceanographic cruises were conducted off the Balearic Islands during the summers of 2001, 2004, 2005 and 2010, and in the winter of 2009 (western Mediterranean; Fig. 4). The first three cruises (2001, 2004 and 2005) focused on the horizontal distribution of meroplankton. About 196 stations were sampled using a 60-cm Bongo net towed at ~2 knots on oblique hauls from 70 m depth to the surface (Alemany *et al*., 2010). The 2009 and 2010 cruises were aimed at studying the vertical distribution of the meroplankton in two areas of western and southern Mallorca, among other objectives. A total of 218 depth-stratified mesozooplankton samples were collected with the Hydrobios multinet in 2009 and a multiple opening/closing net and environmental sensing system (MOCNESS; Olivar *et al*., 2012) in 2010. The mouth openings of these nets were 0.25 m^2 in 2009 and 1 m^2 in 2010, and the mesh size was 333 µm. Both devices were towed at ~2 knots, performing oblique stratified sampling from the near bottom to the surface at the 200 m and 900 m isobaths.

Immediately after sampling, all samples were preserved in ~4% borax-buffered formaldehyde, prepared using seawater. Once in the laboratory, samples were sorted for decapod larvae. Decapod zoeae were identified to species level and developmental stage, using the identification key developed by Dos Santos and González-Gordillo (2004). The larvae of *Palaemon macrodactylus* larvae were confirmed using the description by Little (1969). Total length (TL) (from the tip of the rostrum to the posterior end of the telson) and carapace length (CL) (from the tip of the rostrum to the posterior dorsal end of the carapace) were measured for all specimens.

All specimens have been deposited at the Centre Oceanogràfic de les Balears, in Palma de Mallorca (Spain), with catalogue numbers Tunibal05_E1517Or215 and ID2_0710_E18N8.

Results

A total of eight *Palaemon macrodactylus* larvae were found in the summer samples. In 2005, one zoeal stage VI, with developed pleopods but without setae (Fig. 2) and measuring 4.8 mm TL and 1.5 mm CL, was found in the upper 70 m of the water column off southeastern Mallorca (Balearic Islands; 38º40.20' N and 3º49.20' E), at a sampling station situated over the 2000 m isobath (Fig. 4). In 2010, another seven specimens were found over the 900 m isobath off western Mallorca (39º51.00' N and 2º14.40' E; Fig. 4), all at the same sampling station and in the same depth layer (0-25 m). The 2010 larvae were zoeae in stage III: they had two dorsal spines on the carapace (Fig. 3c) and had not yet developed pleopods (Fig. 3a). In addition, in these larvae the sixth somite of the pleon was separated from the telson and uropods, consisting of rudimentary uro-endopods and setose uro-exopods (Fig. 3d). The seven specimens measured on average 2.55 mm TL (±0.11 SD) and 0.73 mm CL (±0.05 SD).

Discussion

We report the presence of *P. macrodactylus* larvae off the Balearic Islands, which is the first record of this species in the Mediterranean. Several hypotheses could be considered to explain the presence of these larvae. One would be that these larvae come directly from ballast water discharges, since previous studies have demonstrated that larvae remain viable in ship tanks (Chu *et al.,* 1997). In fact, the first report of oriental shrimp larvae in the Guadalquivir estuary, the nearest place to our study area where this species has been recorded, proposed that ballast water was the vector of transport (Cuesta *et al.,* 2004). However, this hypothesis is very unlikely considering that the larvae we found were very young, the sampling site is far from the main commercial shipping routes, and the larvae appeared in different years, forming a relatively dense patch in the last year. A second hypothesis would be that the larvae are transported by currents to our study area in the Balearic Sea from the nearest known settled adult population, since surface Atlantic water entering the Mediterranean from the Gulf of Cadiz, part of which later reaches the Balearic archipelago, would facilitate the spread of larvae to this sea. Taking into account the estimated age of the larvae collected in our samples, 4-5 days old (zoea III) and 13-15 days old (zoea VI), and the current velocities (Pinot *et al*., 2002), it is highly improbable that there is a connection between the Atlantic adult population and the larvae collected off the Balearic Islands. Finally, the third hypothesis would be that undetected adult populations have colonized nearby Mediterranean estuarine areas on the Spanish Mediterranean Levantine coast or in the Balearic archipelago. Therefore, the larvae found in 2010 northwest of Mallorca Island could have originated in any of the estuaries in this area, e.g. the Ebro Delta (Spain). Mainland coastal areas are mainly connected with the Balearic Sea through the Northern Current, which flows southwards along the continental margin and forms the Balearic Current, which flows along the northern margin of the Balearic Islands (Pinot *et al*., 2002; López-Jurado *et al*., 2008). However, it seems unrealistic that the larvae found in 2005 southeast of Mallorca could reach this area of the Balearic Islands from the Spanish coast in such a short time, given the predominant currents. It is much more probable that these larvae, and even those found in 2010, come from adult populations settled in the Balearic Islands. This archipelago does not have large estuaries, but there are several small areas of saline brackish waters as well as shallow marine areas with extensive seagrass beds (Del Hoyo, 1992) that this species could inhabit. The dominant currents around the Balearic Islands explain why fish larvae from adults reproducing in coastal areas are found in open marine waters (Torres *et al*., 2011), and could also explain the presence of oriental shrimp larvae in these open marine waters.

The fact that the hypothetical *Palaemon macrodactylus* populations that have colonized some areas of the western Mediterranean have not yet been detected could be attributed to the fact that adult forms of some decapods are difficult to catch, for example *Jaxea nocturna*, for which the larvae were also found before the adults (Fitzgerald, 1951). Another possibility is that, due to their morphological similarity, *P. macrodactylus* could be confused with the native *Palaemon serratus* and *Palaemon elegans*, which occupy the same habitats (González-Ortegón & Cuesta, 2006). This often occurs within the framework of field sampling surveys not directed specifically at detecting allocthonous species, because if the analysis is not carried out by specialized taxonomists, individuals of non-native species can be attributed to similar congeneric native species.

In any case, the presence of these larvae in open marine waters, where have not been previously found, suggests that the life cycle strategies of this estuarine species could include exporting the larval stages to offshore marine areas, increasing their dispersal capacity in relation to estuarine species that spend their entire life cycle in brackish waters. This capacity to spread increases the possibilities of the oriental shrimp becoming an invasive species, and thus a potential problem for native carideans populations. It is possible that *P. macrodactylus* could compete successfully with these indigenous species for food and habitat, as Ashelby *et al*. (2004) suggested. Like many Mediterranean carideans, *P. macrodactylus* is largely carnivorous (Siegfried, 1982), such as *Gnathophyllum elegans*, *Palaemon* spp., *Periclimenes* spp., *Pontophilus spinosus*, *Crangon crangon* and *Philocheras* spp. Interactions between *P. macrodactylus* and *Palaemon* spp. or *Crangon* spp., its congeneric genres in the Mediterranean, have been detected in several parts of the world (González-Ortegón *et al*., 2010). Since an invasive species can only be eradicated if it is detected in time, monitoring of all larval phases is crucial for minimizing the impact of bioinvasions, as suggested by González-Ortegón & Cuesta (2006).

Summing up, this work proves that collecting early life history stages in the plankton can help to detect invasive species earlier and hopefully prevent their negative impacts.

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