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Larvae of the blue crab *Callinectes sapidus* Rathbun, 1896 (Decapoda: Brachyura: Portunidae) in the Balearic Archipelago (NW Mediterranean Sea)



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Abstract

The invasive blue crab *Callinectes sapidus* has been frequently recorded during the last years along the NW Mediterranean Sea, leading to established populations. Two megalopae of *C. sapidus* were found during two different oceanographic surveys in open waters of the Balearic Archipelago, in July 2005 and October 2011, previous to the first reference of adult specimens documented in the Balearic sub-basin. The analyzed environmental conditions of the sampling periods allowed us to hypothesize the likely introduction pathways, namely by maritime transport and surface currents. Furthermore, the recorded megalopae seem to enlarge the life history of *C. sapidus* in regard to its native area, where spawning peaks occur in late July and early August.

Keywords: Megalopa, Decapod larvae, Non-indigenous species, Ballast water, Natural dispersion

Introduction

The blue crab *Callinectes sapidus* Rathbun, 1896 is native to the West Atlantic, from Canada to Argentina (Squires 1990), and typically found in brackish waters. It is considered one of the most invasive species in the Mediterranean Sea (Streftaris and Zenetos 2006), where it was cited for the first time in 1947 in Hellenic waters (Serbetis 1959), although fishermen observations date back to 1935 in the Gulf of Thessaloniki (Nehring 2011). In the Mediterranean coast of the Iberian Peninsula, adults of *C. sapidus* have been sporadically recorded since 2004 (Giménez Casalduero et al. 2016). Increasing abundances and established populations have been documented along the subregion in the last decade (Karchle et al. 2016; Fuentes et al. 2019; Box et al. 2020; Mancinelli et al. 2021). However, the species was not

found in the Balearic Archipelago until 2017 (Garcia et al. 2018).

Here, we report the collection of larvae of *C. sapidus* prior to the first citation of the species in the Balearic sub-basin. Moreover, the analyzed environmental conditions and the identified larval stages give the opportunity to explore potential introduction pathways and the life history in new invaded areas.

Materials and methods

Specimens of *Callinectes sapidus* larvae were obtained during two oceanographic surveys carried out in the Balearic sub-basin (Fig. 1). The first survey was carried out within the framework of the projects BALEARES (CTM 2009-07944 MAR) and TUNIBAL (REN 2003-01176), in July 2005, by sampling a grid of stations around the Balearic Archipelago, between 38°N 0.5°E and 42°N 6°E. Zooplankton samples were collected using double-oblique tows with a 335 µm mesh Bongo net (Carbonell et al. 2014). The second survey was performed within the project ANTROMARE (CTM2009-12214-C02-01/

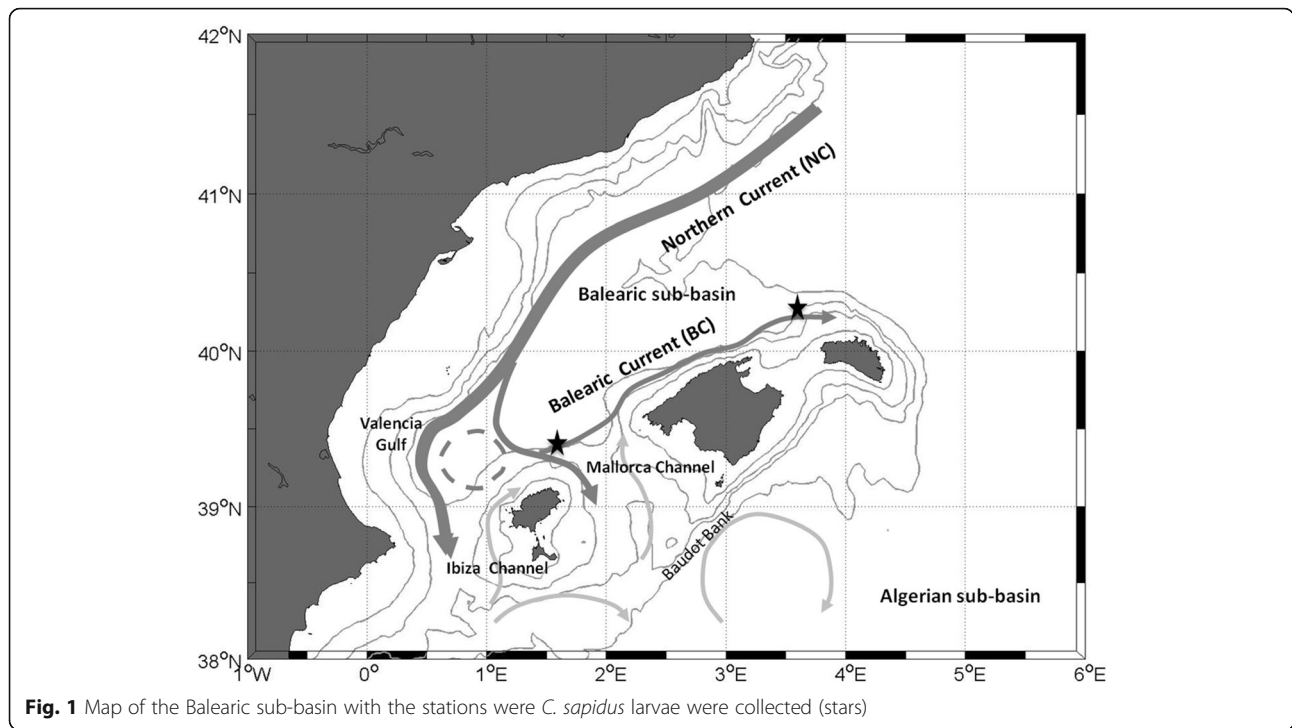
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MAR), in October 2011, by sampling 28 stations throughout the Balearic sub-basin, from the Catalanian coast to the Balearic Archipelago. Four zooplankton samples were taken at midwater through oblique hauls with a 500 µm mesh WP2 net (Carbonell et al. 2021).

Environmental conditions of the sampling periods were assessed through Sea Surface Temperature (SST; Copernicus: SST_MED_SST_L4_REP_OBSERVATIONS_010_021), from temperature satellite data, and surface currents derived from the Sea Surface Height (SSH; Copernicus: SEALEVEL_MED_PHY_L4_REP_OBSERVATIONS_008_051), from altimetry satellite data.

All specimens were identified according to Costlow and Bookhout (1959), along with identification keys of Brachyura of the Northeast Atlantic Ocean (Ingle 1992). The larvae were stored at the Centro Oceanográfico de Baleares (COB, IEO-CSIC, Palma de Mallorca) and at the Institut de Ciències del Mar (ICM-CSIC, Barcelona), respectively.

Results and Discussion

Two larvae of *Callinectes sapidus* were collected during two different oceanographic surveys in open waters of the Balearic Archipelago (Fig. 1; Table 1).

The first specimen, captured in July 2005, was initially published as *Portunus* spp. (Carbonell et al. 2014). However, due to the increasing number of *C. sapidus* adult records in the NW Mediterranean Sea, a through full revision of the decapod larvae stored at the COB (IEO-CSIC) was performed. One megalopa was re-identified as *C. sapidus* following the description by Costlow and Bookhout (1959), in which the dorsal carapace and the ventral posterior sternum aspects, with a pair of prominent cornua on the posterior margin of the 5th sterna segment, distinguish the species from other *Portunus* spp. Morphological features of the first megalopa were registered, including a carapace length of 3 mm and developed pleopods (Fig. 2). The second larva, captured in October 2011, was also identified as a megalopa, although neither biological nor biometric information was obtained (Carbonell et al. 2021). Both specimens were clearly identified by their pointed rostrum with the horizontal placement of the rostral spine, the abdominal pleopods, the appearance of chelae and the cornua project from the posterior edge of cephalothorax (Costlow and Bookhout 1959).

SST and SSH with derived surface currents observed in the sampling days are shown in Fig. 3. The

Table 1 Larvae of *C. sapidus* located within the frame of two oceanographic surveys

Date	Station	Latitude	Longitude	Tow depth (m)	Bottom depth (m)
10/07/2005	624	40° 33.46' N	3° 60.10' E	70-0	1600
18/10/2011	A3W11	39° 29.20' N	1° 34.18' E	910-0	995



Fig. 2 Megalopa of *C. sapidus* captured in the Balearic sub-basin in July 2005

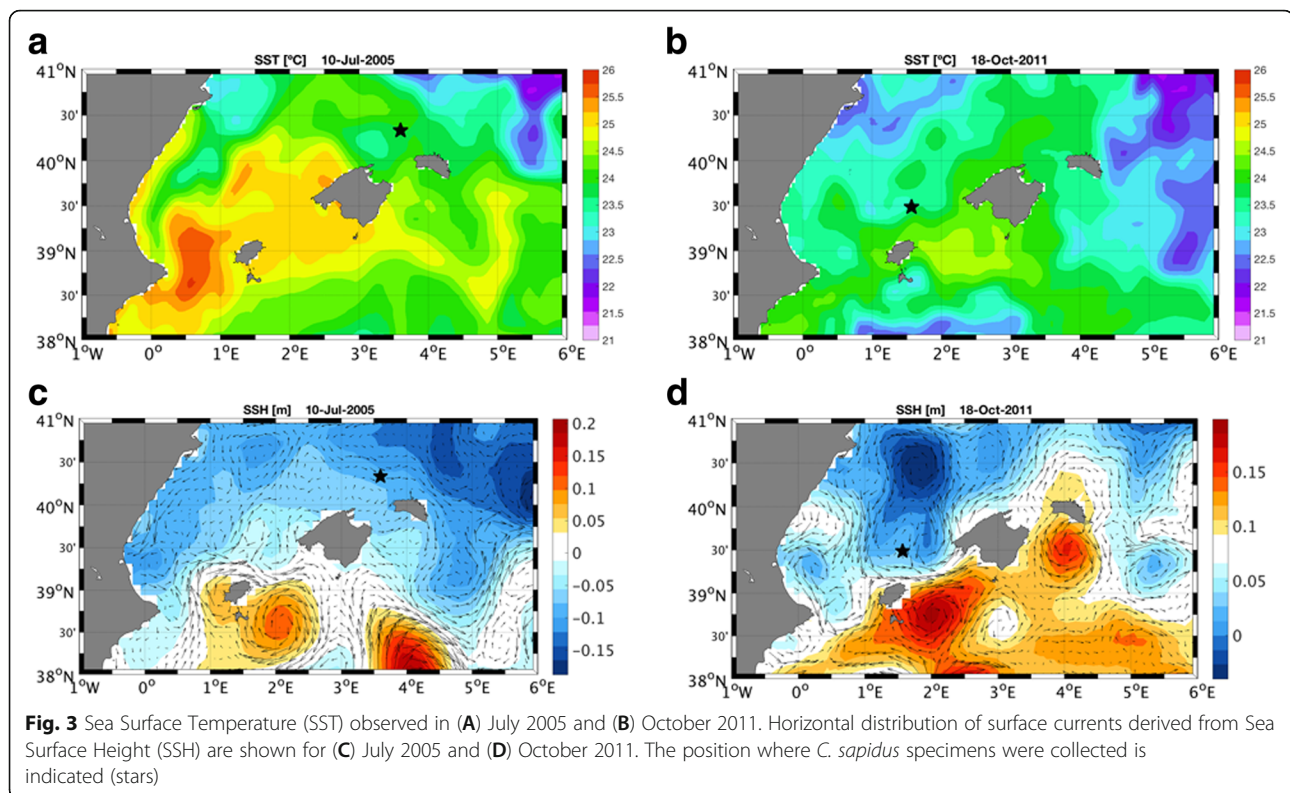
temperature in the study area was between 23 and 24 °C in both periods (Fig. 3A and B). In July 2005, the most intense hydrographic feature was the circulation of recent Atlantic Water that progressed northwards through the Ibiza Channel and recirculated around Ibiza through the Mallorca channel; whilst at the north of the archipelago, the dynamics, not so clearly defined, corresponded to the cyclonic circulation characteristic of the Balearic Sea (Fig. 3C; Balbín et al. 2013). The low hydrographic dynamics found in the Menorca slope suggest that the first megalopa could have been transported to the area by alternative vectors. Zoeal development in open waters requires between 3 and 4 weeks before metamorphosis to the megalopal stage (Epifanio 2019), thus even though natural dispersion could be plausible, it seems less likely due to the long distance that the dispersion entails in the NC stream. In this case, human-mediated vectors such as maritime transport seem a reasonable explanation.

On the other hand, the cyclonic circulation at the Balearic Sea was observed to be more intense in October 2011, when the BC was strengthened by the NC due to the presence of a strong anticyclonic gyre in the south part of the Mallorca channel that avoided neither the normal circulation southwards of the NC nor the clear

northward progress of recent Atlantic Waters (Fig. 3D; Balbín et al. 2013). Therefore, the observed hydrographic conditions allow us to hypothesize that the second megalopa found in the Mallorca slope could have been transported in the stream of the NC.

The NC receives significant advective fluxes on its path along the Iberian Peninsula that might reach the Balearic Islands, likely providing a larval pool from existing populations in the mainland. The presence of coastal lagoons in the northern part of the archipelago and a shallow shelf appear to be optimal factors for the settlement of megalopae (Garcia et al. 2018). Adult specimens of *C. sapidus* have been sporadically observed in the Balearic sub-basin since 2004 (P. Abelló, *pers. comm.*), although the species was not documented until 2012 (Castejón and Guerao 2013; Mancinelli et al. 2017); therefore solitary individuals could have been previously undetected.

Ballast water has been considered so far the most likely introduction vector of *C. sapidus* propagules from its native range (Nehring 2011). In fact, the found megalopae match within some maritime routes of ferries operating between the mainland and the Balearic Archipelago. The first larva, collected in the open slope of Menorca, might fit with the ferry route between



Ciudadella (Menorca Island) and Barcelona (Catalan Community), but slightly drifted away by the BC. The second larva, located in the open slope of Mallorca, seems to go well with the ferry route between Valencia (Valencian Community) and Palma (Mallorca Island) across the Mallorca Channel. The evidence of the larvae long before the record of adult populations in the archipelago (Garcia et al. 2018) seems to corroborate alternative vectors.

The dispersion model observed in the Atlantic coast of North America demonstrated that *C. sapidus* larvae are not only retained in the parent estuary, but on the contrary they are able to spread from short to medium distance off the coast (Epifanio 1995; Johnson and Perry 1999). Our findings may support the dispersion model through the open ocean that make the islands vulnerable to secondary introduction of non-indigenous species through their early life stages (Evans et al. 2015).

In the present study, the megalopae were recorded in early July and mid-October, which seems to enlarge the larval history of *C. sapidus* in regard to its native area. Yet, invasive populations might show differing life history dynamics than the native ones, and in the Eastern Mediterranean spawning has been reported from much earlier (i.e. from mid spring) and lasting longer (up to eight months) than in the *C. sapidus* native range

(Sumer et al. 2013; Kevrekidis and Antonadiou 2018; Türeli et al. 2018), where reproduction occurs throughout the summer with a spawning peak in late July and early August (Epifanio 1995). Given the monthlong duration of larval development (Epifanio 2019), the earlier and longer reproductive period of *C. sapidus* in the Mediterranean squares well with the findings of megalopae in both July and October, and could be an additional factor favoring the dispersal of the species in the Mediterranean Sea.

Conclusions

The two megalopae of *Callinectes sapidus* found in the Balearic Archipelago, in two different periods between summer and autumn, and long before than adult specimens were recorded in the islands, could have different introduction pathways. The first larva found in the Menorca slope could be a primary introduction by maritime transport, although natural dispersion cannot completely be discarded. The major presence of coastal lagoons and the shallow shelf could favor the megalopal settlement and later establishment of populations in this area. Measures such as avoiding ballast water emptying in the proximity of the islands could be an effective way to reduce and control blue crab populations. For the larva found in the Mallorca slope, secondary introduction through

natural dispersion seems more feasible. The topographical complex of Balearic channels makes the archipelago vulnerable to secondary introduction of non-indigenous species, thus increasing the distributional range in the introduced area. This natural pathway may well difficult effective measures of species elimination and control in the area.

Abbreviations

BC: Balearic Current; NC: Northern Current; SSH: Sea Surface Height; SST: Sea Surface Temperature

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Authors' contributions

AC and LPG conceived the publication, and wrote the manuscript. JEC and VP supplied the second specimen. AC identified both larvae. RB provided the oceanographic landscape and contributed to analyze the hydrographic dynamics. All authors participated in discussion of the results and critically reviewed the manuscript. The author(s) read and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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