

The tropical African hermit crab *Pagurus mbizi* (Crustacea, Decapoda, Paguridae) in the Western Mediterranean Sea: a new alien species or filling gaps in the knowledge of the distribution?

J.E. GARCÍA RASO¹, F. SALMERÓN², J. BARO², P. MARINA^{1,2} and P. ABELLÓ³

¹ Dept. Biología Animal, Universidad de Málaga, Campus de Teatinos s/n. 29071 Málaga, Spain

² Centro Oceanográfico de Málaga – IEO, Puerto Pesquero, s/n. Apdo. 285, 29640 Fuengirola, Málaga, Spain

³ Institut de Ciències del Mar – CSIC, Passeig Marítim de la Barceloneta, 37-49, 08003 Barcelona, Spain

Corresponding author: garciaraso@uma.es

Handling Editor: Argyro Zenetos

Received: 3 June 2013; Accepted: 5 December 2013; Published on line: 30 December 2013

Abstract

We report the first occurrence in Europe and the Mediterranean Sea of a tropical Atlantic hermit crab, *Pagurus mbizi* (Forest, 1955), based on the capture of twenty specimens (all sizes and ovigerous females) collected along the northern shores of the Alboran Sea that prove the existence of a well-established population of this species and the importance of this geographic area as a transitional and settlement zone for Atlantic species, making the Alboran Sea one of the richest marine biodiversity areas in the Mediterranean Sea. Some morphological comparative data, with the related hermit crab *Pagurus pubescentulus*, are given. In addition, data on the habitat and geographical distribution of the species, as well as the probable pathways of introduction, are commented.

Keywords: *Pagurus mbizi*, Mediterranean Sea, distribution, habitat, non-native species, pathway introduction.

Introduction

Hermit crabs are a highly diverse group of decapod crustaceans, with more than 1000 species, 127 genera and 6 families (De Grave *et al.*, 2009) described within the superfamily Paguroidea alone. The genus *Pagurus* Fabricius, 1775 is considered to be ancient, and with a high degree of species diversity (172 species currently recognised around the world, McLaughlin *et al.*, 2010), but many aspects of their taxonomy, systematics and evolution are still poorly documented (Matzen *et al.*, 2011). In the Northeast Atlantic Ocean and Mediterranean Sea, the genus *Pagurus* is represented so far by 13 species (Zariquiey Alvarez, 1968; Ingle, 1993; Udekem d'Acoz, 1999; Frogliá, 2010; García Muñoz *et al.*, in press). A high morphological similarity among some species has resulted in the recognition of two differentiated subdivisions and nine species groups (McLaughlin, 1974; Ingle, 1985), but their validity, in general, should be checked. In the Mediterranean Sea, eight species have been reported: *Pagurus alatus* Fabricius, 1775, *Pagurus anachoretus* Risso, 1827, *Pagurus chevreuxi* (Bouvier, 1896), *Pagurus cuanensis* Bell, 1846, *Pagurus excavatus* (Herbst, 1791), *Pagurus forbesii* Bell, 1846, *Pagurus pseudosculptimanus* García Muñoz, Cuesta & García Raso in press, *Pagurus prideaux* Leach, 1815 and *Pagurus pubescentulus* (A. Milne-Edwards & Bouvier, 1892).

Here, we report, for the first time, the occurrence of *Pagurus mbizi* (Forest, 1955) in European waters and in the Mediterranean Sea, based on the capture of twenty specimens (all sizes and ovigerous females) collected along the northern shores of the Alboran Sea. This first record of an African hermit crab in the Alboran Sea, with a well-established population, highlights the importance of this restricted geographic area as a settlement and/or transition zone for Atlantic species.

Material and Methods

Samples were obtained during the MEDITS_ES trawl surveys project and RECALA projects, both carried out by the “Instituto Español de Oceanografía” (IEO). The aim of the first survey, on board R/V “Cornide de Saavedra”, along the Mediterranean coasts of the Iberian Peninsula, was to obtain long term annual series of trawl surveys (this study started in 1994 at European Union level) in the Mediterranean Sea. Along the Iberian Peninsula coastal zone, it so far comprises 20 trawl surveys in spring, distributed from the Strait of Gibraltar to Cape Creus. A total of 2327 valid hauls have been performed between 40 and 800 m depth (Figs 1B, C). All these hauls were conducted during daylight hours and

lasted 30 minutes on the continental shelf (depths ≤ 200 m) and 60 minutes on the upper and middle continental slope (200-800 m). Temperature and salinity on the bottom were obtained for most samples using a CTD SBE 37-SM located in the floatline of the trawl gear.

The RECALA project was carried out in the northern margin of the Alboran Sea, in the marine Site of Community Importance named “Cliffs and sea-beds of Calahonda-Castell de Ferro, Granada, Spain”, included within the Natura 2000 network (code ES6140014, Official Journal of the EU, Commission Decision of 22.12.2009) (Fig. 1C). In this site, samples were taken using a small rock dredge, with a rectangular frame of 42×22 cm and equipped with a 4 mm mesh size net. Dredging time was 5 minutes for each haul (during daytime and at sunset) at a speed of about 1.8 knots, which represents a length of about 278 m and an estimated swept area of about 117 m². In total, twelve stations were analysed. Temperature of near-bottom waters was measured with a CTD probe. Sediment granulometry was determined with a column of standard sieves, and organic matter in the sediment was measured by ignition at 500 °C, for 1 h.

Species identification was based on Forest (1955).

Other reference works such as Ingle (1993) proved useful, especially for comparisons with *P. pubescentulus*. Measurements (shield length (SL) and width (SW)) were taken using a stereoscopic microscope with a precision of 0.01 mm.

The collected specimens have been deposited at the Biological Reference Collections of the Instituto de Ciencias del Mar – CSIC in Barcelona (reference numbers: ICMD-20120622-01 to -04), at the “Instituto Español de Oceanografía” of Málaga and at the University of Málaga.

Results

A total of twenty individuals of the hermit crab *Pagurus mbizi* were collected.

Pagurus mbizi (Forest, 1955)

Eupagurus mbizi Forest, 1955: 116-120, figs. 25, Pl. IV 1 to 4.

Pagurus mbizi - Forest, 1961: 234; - Forest, 1966: 158; - Le Loeuff & Intès, 1999: 544,549; - Le Loeuff *et al.*, 2000: 15.

Material examined:

MEDITS06, haul 9, Estepona (Málaga), 06-05-2006, 36° 20.74'N - 5° 12.70'W, 42-46 m, 14.8°C, 1 ovigerous

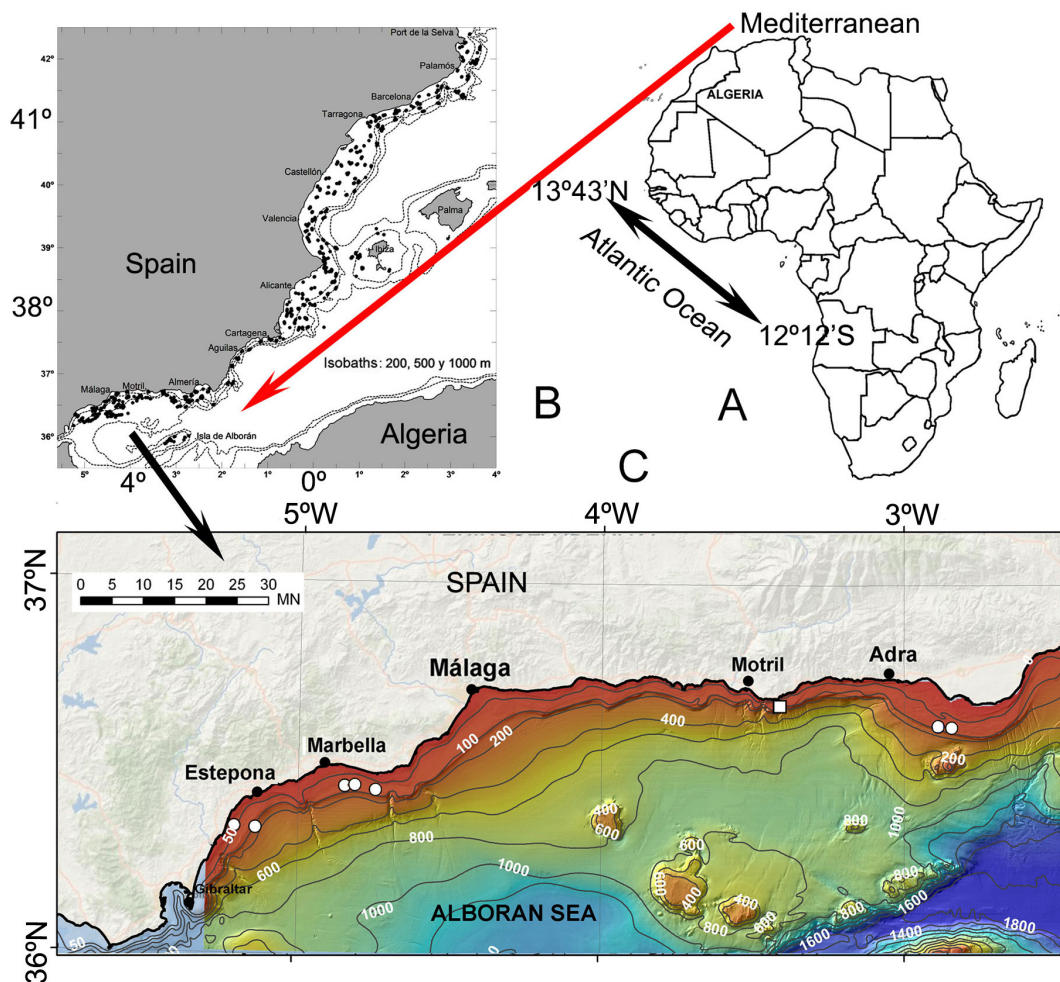


Fig. 1: A- General biogeographic distribution (indicated by the arrow) of *Pagurus mbizi*. B- Sampling stations of the MEDITS_ES trawl surveys project. C- Sampling stations with presence of *Pagurus mbizi* in the Alboran Sea, northern sector (white points: MEDITS_ES samples; white square: RECALA samples).

female. MEDITS07, haul 8, Estepona (Málaga), 20-05-2007, 36° 20.21'N -5° 08.41'W, 133-150 m, 13.7°C, 1 male. MEDITS09, haul 10, Marbella (Málaga), 10-04-2009, 36° 21.15'N - 4° 50.92'W, 76-77 m, 13.6°C, 1 male. MEDITS12, haul 12, Marbella (Málaga), 28-04-2012, 36° 27.13'N - 4° 50.97'W, 76 m, 4 males. MEDITS12, haul 28, Adra (Almería), 04-05-2012, 36° 37.33'N-2° 53.17'W, 85 m, 13.3°C, 6 males and 1 ovigerous female. MEDITS13, haul 11, Marbella (Málaga) 10-05-2013, 36°27.38'N - 4°42.32'W, 70 m, 1 ovigerous female; MEDITS13, haul 12, Cabo Pino (Málaga), 10-05-2013, 36° 27.24'N - 4°49.20'W, 80 m, 1 ovigerous female; MEDITS13, haul 44, Almerimar (Almería), 20-05-2013, 36°37.79'N - 2°55.99'W, 84 m, 1 male. RECALA St 2.3 (replicate 1), Calahonda-Castell de Ferro (Granada), 19-07-2010, 36°41.56 N - 3°20.76 W / 36°41.57 N - 3°20.98 W, 78-66 m, 13.77°C, 1 male. RECALA St 4.3 (repl. 1), Calahonda-Castell de Ferro (Granada), 08/03/2011, 36°42.70 N - 3°18.09 W / 36°42.90 N - 3°18.32 W, 76-70 m, 13.99°C, 3 females (1 ovigerous).

Morphological features

This species resembles *Pagurus pubescentulus*, in which the males also have 3 unpaired pleopods. However, there are some morphological differences, well described and illustrated by Forest (1955), which allow clear identification of both species. In *P. mbizi* (Fig. 2), the ocular peduncles are longer; the outer surface of the right cheliped palm is regularly convex with conspicuous and acute tubercles, but more developed in a central line; the outer propodial surface of the left cheliped is medially elevated and with a prominent longitudinal row of acute tubercles; the merus of the right cheliped has only 2-3 upper distal teeth; and the posterior left lobe of the telson is straight or slightly concave (not convex).

Coloration (Fig. 3): Forest (1966) gave information on the coloration. Our specimens have a shield with a dark brown point in the middle, body with orange colouration in life, with patches of dark orange, ocular peduncles generally white, with a tinge of reddish-brown or orange proximally.

Size: the shield length of the specimens ranged from 2.5 to 6.7 mm (males 2.81 to 6.7 mm, females (ovigerous) 2.5 to 5.0 mm). The average value of the relationship shield length/width is 0.9 (0.83 to 1.0).

Associated fauna and habitat

In the MEDITS_ES project, the area sampled in each haul was extensive, limiting the accuracy regarding the sediment characteristics and the associated fauna. However, and within paguroids, only *Dardanus arrosor* (Herbst, 1796) co-occurred with *P. mbizi* in all the surveys. In general, *D. arrosor* and the crabs *Liocarcinus depurator* (Linnaeus, 1758) were the dominant species at the stations where *P. mbizi* was caught. Other common

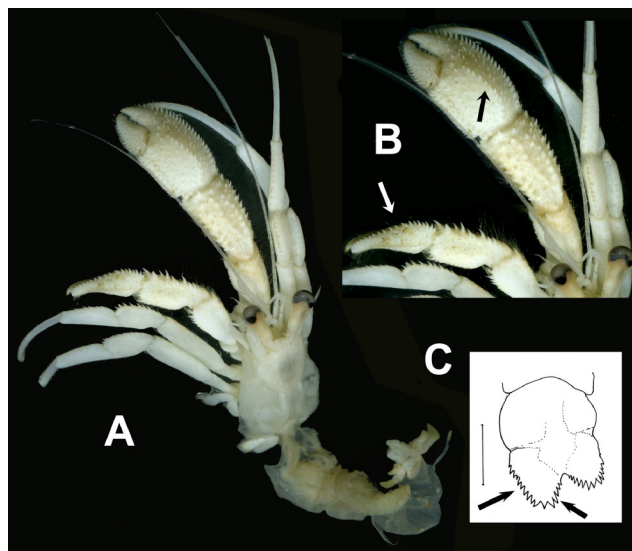


Fig. 2: Male specimen of *Pagurus mbizi* (MEDITS 2012 L28), 3.9 mm carapace shield length. Overview (A), details of chelipeds (B) and telson (C, scale 1 mm).



Fig. 3: Live ovigerous female *Pagurus mbizi*.

decapods found in these samples were the hermit crabs *Anapagurus laevis* (Bell, 1845), *Pagurus prideaux* and *Pagurus excavatus*; all of them typical species of continental shelf muddy bottoms. The gastropod shell inhabited more frequently by *P. mbizi* was *Nassarius denticulatus* (Adams, 1852).

In the RECALA project, the area of each haul is smaller, allowing for better characterization of the associated fauna. Quantitative data for St 2.3 are given in Table 1. The data for St 4.3 are qualitative, but the dominant species was the bivalve *Timoclea ovata* (Pennant, 1777) followed by *Corbula gibba* (Olivi, 1792); among decapods, another three species were caught: *Philocheras bispinosus* (Hailstone, 1835), *Ebalia deshayesi* Lucas, 1846, and *Anapagurus alboranensis* García-Gómez, 1994, all of them typical species inhabiting soft bottoms,

Table 1. Dominant species from RECALA sample St 2.3 (78-66 m depth). Abundance (N) and dominance (%D) values. Decapods in bold.

Spp	N°	%D
<i>Anapagurus alboranensis</i>	47	7.9
<i>Philocheras sculptus</i>	34	5.7
<i>Similipecten similis</i>	33	5.5
<i>Anapagurus longispina</i>	26	4.4
<i>Ophiocten affinis</i>	20	3.4
<i>Ebalia deshayesi</i>	16	2.7
<i>Calyptrea chinensis</i>	15	2.5
<i>Parvicardium minimum</i>	15	2.5
<i>Philocheras bispinosus</i>	13	2.2
<i>Trophonopsis muricata</i>	12	2.0
<i>Dischides politus</i>	9	1.5
<i>Turritella communis</i>	7	1.2
<i>Nassarius pygmaeus</i>	7	1.2
<i>Mangelia costulata</i>	7	1.2
<i>Anadara polii</i>	7	1.2

more frequently on the so called “coastal detritic”, with shell debris and coarse sand, and also on muddy fine sandy bottoms. In these samples the sediment was medium sand (23.61%, with 14.25% gravel, 3.95% OM, 28.5% CO₃ - St 2.3, 78-66 m) and mud (33.21%, with 18.25% gravel, 1.27% OM, 4.65% CO₃ - St 4.3, 70 m).

The specimens were collected in water with temperatures and salinities between 13.3-13.8°C, 38.0-38.2 psu (MEDIT_ES) and 13.8-14°C, 38.0 psu (RECALA) respectively, the values of mixed Mediterranean-Atlantic waters. However, in MEDITES_ES 2006 (the first and westernmost capture) the water features show a higher Atlantic influence (14.8°C, 37.5 psu). Minimum and maximum depths of capture were 42 and 150 m.

Discussion

Biogeographical distribution, habitat and associated fauna

According to Forest (1955, 1961) and Le Loeuff & Intès (1999), this species lives along the West African Equatorial Zone, between 12°12'S and 13°43'N, but it was never found further north than Senegal. In this zone, Forest (1955) described an apparent replacement between two close *Pagurus* species: *P. mbizi* and *P. pubescentulus*. The former living between 95 and 220 m (T°C= 13.61-19.95°C), while *P. pubescentulus* inhabited deeper waters, between 200 and 300 m (10.85°-13.92°C). Later, Forest (1961) found *P. mbizi* within a broader bathymetric range, between 30 to 260-650 m. Le Loeuff & Intès (1999) found *P. mbizi* in Côte-d'Ivoire between 30-60 m (continental shelf), which is in agreement with our data from the Alboran Sea, because its occurrence is between 50-150 m (more abundant around 70 m) but not deeper. Perhaps it is due to the narrow continental shelf in the

northern Alboran Sea, where the shelf-break is located at a depth of around 110 m (Vazquez, 2001).

The sediment characteristics referred to in the West African studies (previously cited) are: muddy sandy and muddy bottom, with shells and sometimes with rocks, which is in agreement with our data, muddy bottoms or medium sandy bottoms with abundant gravel and, also, with shells.

In the study of the macrobenthic communities on the continental shelf of Côte-d'Ivoire, a tropical oceanic area with upwelling, Le Loeuff & Intès (1999) and Le Loeuff *et al.* (2000) found seasonal changes in the faunistic composition and structure of the benthic communities. *P. mbizi* was caught in this area during the upwelling, cold, period. Le Loeuff & von Cosel (1998) found a higher faunal richness in the regions with upwelling than in the typical tropical regions. Upwellings are common in the northern Alboran Sea (Vargas-Yáñez & Sabatés, 2007) (study area). It is noteworthy that the rare decapod species *Bythocaris cosmetops* Holthuis, 1951, probably related with this oceanographic phenomenon, has also been caught recently in the RECALA area (García Raso *et al.*, 2011), which shows a high richness, with uncommon species (unpublished data).

Occurrence and origin

The first occurrence of *Pagurus mbizi* in Spanish waters was detected in 2006 and confirmed in 2007 and 2009; in all these cases there were single individuals collected in the westernmost sector of the Alboran Sea. Later, in 2010-2011, further specimens were collected in Granada (central zone of Alboran), and in 2010, 2012 and 2013 the species was collected at both extremes of the area (the westernmost area and also near Almeria - Cape Gata) and the number of individuals was larger. This, together with the existence of juveniles and of several ovigerous females, shows that a well-established population inhabits and completes its life cycle in the Alboran Sea.

The settlement and development of a stable population of a tropical Atlantic species in the Alboran Sea could be facilitated by climate change, because sea surface temperature has obviously increased in the last decades (Nykjaer, 2009; Mateo & García Raso, 2011) and because a mixture of Atlantic and Mediterranean waters with upwelling occurs in this restricted area. The species has not been captured beyond of the Eastern limit of the Alboran Sea, in spite of the high intensity of samplings carried out (Fig. 1B). This distribution limit coincides with the Almeria-Oran Front, a semi-permanent dynamic oceanographic front (Tintoré *et al.*, 1988), considered as a more or less effective barrier to gene flow and/or species dispersion for some species (Quesada *et al.*, 1995; Patarnello *et al.*, 2007; Alberto *et al.*, 2008; Palero *et al.*, 2011). The location of the Alboran Sea and the above mentioned oceanographic structures contribute to the biogeographical differentiation of this area, characterized by the occurrence of spe-

cies with strong Atlantic affinities, such as the decapods *Brachynotus atlanticus* Forest 1957 (García Raso, 1984), *Calocarides coronatus* (Trybom, 1904) (García Raso, 1996), *Penaeopsis serrata* (Bate, 1881) (Abelló & Torres, 1998), *Hymenopenaeus debilis*, 1882 (Cartes *et al.*, 2000), *Cryptosoma cristatum* Brulle, 1837 (García Raso, 1993), *Galathea capillata* Miyake & Baba, 1970 (García Raso & Manjón-Cabeza, 2002), among others, which makes the Alboran Sea one of the richest marine biodiversity areas in the Mediterranean Sea (García Muñoz *et al.*, 2008; García Raso *et al.*, 2010).

Consideration as to whether this occurrence represents the onset of an alien species in the Alboran Sea

The question as to whether the species has been introduced as a consequence of human activities, or not, is difficult to ascertain because: (1) the Strait of Gibraltar is the natural gateway to the Mediterranean Sea for Atlantic species, (2) knowledge about the animal communities living along the North Atlantic African littoral is incomplete, and (3) the information is frequently based on general and/or relatively old studies. Also, the surface influx of Atlantic water entering the Mediterranean through the Strait of Gibraltar (Hopkins, 1985) may facilitate the natural drift of larvae from the Atlantic. However, neither larvae (González-Gordillo *et al.*, 2001) nor adults of this species have been found in the Gulf of Cadiz, even during recent expeditions (López De La Rosa, 1997). This may be due to the lack of an appropriate settlement habitat, since the Gulf of Cadiz (European sector) is a mainly muddy area with high terrigenous mud input from river discharges, while this habitat is scarce in the Alboran Sea where apparently *P. mbizi* has managed to develop stable populations. No references reporting the species are known in recent studies carried out along the coasts and slope of central West Africa (Muñoz *et al.*, 2012). Additionally, it can also be considered that the North of Africa (Atlantic sector) is practically unknown regarding hermit crab faunistics. Neither has this species been captured before 2006 in the Alboran Sea, in spite of the annual sampling expeditions performed in previous years.

Therefore, a possible scenario could be an introduction by human activities such as shipping, which is one of the most frequent gateways to European waters (Katsanevakis *et al.*, 2013); either through ballast water or fisheries discards. On the latter possibility, for the Alboran Sea there are references of African mollusc species, such as *Marginella glabella* (Linnaeus, 1758), inhabited by hermit crabs (Spada & Maldonado, 1974), which are abundant on the bottom of fishing harbours; this could support its introduction by trawler boats returning from West African fisheries to their Mediterranean base-ports (Luque *et al.*, 2012). On the other hand, it is curious that the gastropod shell inhabited more frequently by *P. mbizi*, *Nassarius denticulatus*, is also a West African species

with a limited Mediterranean distribution in the Alboran Sea (Gofas *et al.*, 2011), which means that this part of the Mediterranean does harbour a stock of naturally occurring West African fauna.

If this new record for European and Spanish Mediterranean waters is to be considered an “alien species” it increases the limited number of introduced decapods in the West Mediterranean sector (Zenetos *et al.*, 2010; Schu-bart *et al.*, 2012; Torres *et al.*, 2012; Castejón & Guerao, 2013) and it would represent the first record of an “alien” hermit crab for the Mediterranean Sea.

Acknowledgements

We wish to thank all participants in the MEDITS trawl survey series for all their help and support, especially the chief scientists, Drs. Luis Gil de Sola and Cristina García. We also thank participants in the RECALA project, “Preliminary study for the protection, management and determination of a fishing reserve in the marine area of the municipalities of Calahonda and Castell de Ferro, Granada Province”, developed under the collaboration agreement between the Andalusian Council for Agriculture and Fisheries and the Spanish Institute of Oceanography (IEO), with the collaboration of the University of Malaga, and Dr. Serge Gofas for his interesting comments and revision of the text. PA acknowledges partial support from research project CTM2010-22218-C2.

References

- Abelló P., Torres, P., 1998. Occurrence of *Peneopsis serrata* (Bate, 1881) (Decapoda, Penaeidae) in the Mediterranean Sea. *Graellsia*, 54, 115-117.
- Alberto, F., Massa S., Manent, P., Diaz-Almela, E., Arnaud-Haond, S. *et al.*, 2008. Genetic differentiation and secondary contact zone in the seagrass *Cymodocea nodosa* across the Mediterranean–Atlantic transition region. *Journal of Biogeography*, 35, 1279-1294.
- Cartes, J.E., Abelló, P., Torres, P., 2000. The occurrence of *Hymenopenaeus debilis* (Decapoda: Aristeidae: Solenocerinae) in Mediterranean waters: a case of pseudopopulations of Atlantic origin? *Journal of the Marine Biological Association of the United Kingdom*, 80, 549-550.
- Castejón, D., Guerao, G., 2013. A new record of the American blue crab. *Callinectes sapidus* Rathbun, 1896 (Decapoda: Brachyura: Portunidae), from the Mediterranean coast of Iberian Peninsula. *BioInvasions Record*, 2 (2), 141-143.
- De Grave, S., Pentcheff, N.D., Ah Yong, S.T., Chan, T-Y., Crandall, K.A. *et al.*, 2009. A classification of living and fossil genera of decapod Crustaceans. *Raffles Bulletin of Zoology*, 1, 1-109.
- Forest, J., 1955. Crustacés Décapodes, Pagurides. Expédition Oceanographique Belge dans les Eaux Côtières Africaines de l'Atlantique Sud (1948-1949). Resultats Scientifiques. *Intitut Royal des Sciences Naturelles de Belge. Bruxelles*, III 4, 23-147.
- Forest, J., 1961. Pagurides de l'Afrique occidentale. *Atlantide*

- Report, 6, 203-250.
- Forest, J. 1966. Crustacés Décapodes: Pagurides. 17. Campagne de la Calypso dans le Golfe de Guinée aux îles Principe, São Tomé et Annobon (1956). *Annales de l'Institut Océanographique*, 44, 125-172.
- Froggia, C., 2010. Crustacea, Malacostraca, Decapoda. *Biologia Marina Mediterranea*, 17 (suppl. 1), 519-534.
- García Muñoz, J.E., Cuesta J.A, García Raso J.E. in press. Taxonomic study of the *Pagurus forbesii* "complex" (Crustacea: Decapoda: Paguridae). Description of *Pagurus pseudosculptimanus* sp. nov. from Alborán Sea (Southern Spain, Western Mediterranean Sea). *Zootaxa*.
- García Muñoz, E.J., Manjón-Cabeza, M.E., García Raso, J.E., 2008. Decapod crustacean assemblages from littoral bottoms of the Alboran Sea (Spain, west Mediterranean Sea): spatial and temporal variability. *Scientia Marina*, 72 (3), 437-449.
- García Raso, J.E., 1984. Brachyura of the coast of Southern Spain. *Spixiana*, 7 (2), 105-113.
- García Raso, J.E., 1993. New record of other African species of Crustacea Decapoda, *Cycloes cristata* (Brulle), from European and Mediterranean waters. *Bios*, 1 (1), 215-221.
- García Raso, J.E., 1996. Crustacea Decapoda (excl. Sergestidae) from Ibero-Moroccan waters. Results of Balgim-84 expedition. *Bulletin of Marine Science*, 58, 730-752.
- García Raso, J.E., Manjón-Cabeza, M.E., 2002. A new record of *Galathea capillata* for Europe and Spain, and notes on *Philocheras bispinosus* (Decapoda). *Crustaceana*, 75 (3-4), 383-393.
- García Raso, J.E., Gofas, S., Salas, C., Manjón-Cabeza, M.E., Urra, J. et al., 2010. *El mar más rico de Europa: Biodiversidad del litoral occidental de Málaga entre Calaburras y Calahonda*. Edit. Junta de Andalucía. Consejería de Medio Ambiente Junta de Andalucía, Málaga, 138 pp.
- García Raso, J.E., Marina, P., Baro, J., 2011. *Bythocaris cosmetops* (Decapoda: Caridea: Hippolytidae) in the western Mediterranean Sea. *Marine Biodiversity Records*, 1-4, Vol. 4; e52, doi: 10.1017/S1755267211000467
- Gofas, S., Salas, C., Moreno, L., (coord.). 2011. *Moluscos marinos de Andalucía*. Vol. I, 1-342; vol II, 343-789. Málaga: Servicio de Publicaciones e Intercambio Científico, Universidad de Málaga.
- González-Gordillo, J.I., Dos Santos, A., Rodríguez, A., 2001. Checklist and annotated bibliography of decapod Crustacea larvae from the Southwestern European coast (Gibraltar Strait area). *Scientia Marina*, 65, 275-305.
- Hopkins, T.S., 1985. Physics of the sea. p. 100-125. In: *Key Enviroments. Western Mediterranean*. Margalef, R. (Ed.). Pergamon Press, Oxford.
- Ingle, R., 1985. Northeastern Atlantic and Mediterranean hermit crabs (Crustacea: Anomura: Paguroidea: Paguridae). I. The genus *Pagurus* Fabricius, 1775. *Journal of Natural History*, 19, 745-769.
- Ingle, R., 1993. *Hermit crabs of the Northeastern Atlantic Ocean and Mediterranean Sea*. British Museum (Natural History). Chapman & Hall, London, 495 pp.
- Katsanevakis, S., Zenetos, A., Belchior, C., Cardoso, A.C., 2013. Invading European Seas: assessing pathways of introduction of marine aliens. *Ocean and Coastal Management*, 76, 64-74.
- Le Loeuff, P., Intès, A., 1999. Macrobenthic communities on the continental shelf of Côte-d'Ivoire. Seasonal and diel cycles in relation to hydroclimate. *Oceanologica Acta*, 22 (5), 529-550.
- Le Loeuff, P., Konan, J., Zabi, G.S., von Cosel, R., 2000. L'écosystème benthique au large de Grand-Bassam (Côte-d'Ivoire). Situations comparées en saisons froides 1969 et 1998 (résultats de la campagne BENCHACI, 15-17 août 1998). *Document Scientifique et Technique du Centre IRD Bretagne*, 85, 1-45.
- Le Loeuff P., von Cosel, R., 1998. Biodiversity patterns of the marine benthic fauna on the Atlantic coast of tropical Africa in relation to hydroclimatic conditions and paleogeographic events. *Acta Oecologica*, 19 (3), 309-321.
- López De La Rosa, I., 1997. Crustáceos Decápodos capturados durante las campañas del IEO ARSA 0393 y ARSA 1093 en el Golfo de Cádiz: distribución batimétrica. *Publicaciones Especiales, Instituto Español de Oceanografía*, 23, 199-206.
- Luque, A.A., Barrajon, A., Remon, J.M., Moreno, D., Moro, L., 2012. *Marginella glabella* (Mollusca: Gastropoda: Marginellidae): a new alien species from tropical West Africa established in southern Mediterranean Spain through a new introduction pathway. *Marine Biodiversity Records*, 1-5. Vol. 5, e17; doi:10.1017/S1755267212000012.
- Mateo, A., García Raso, J.E., 2011. Temporal changes in the structure of the crustacean decapod assemblages associated with *Cymodocea nodosa* meadows from the Alboran Sea (Western Mediterranean Sea). *Marine Ecology*, 33 (3), 302-316.
- Matzen da Silva, J., dos Santos, A., Cunha, M.R., Costa, F.O., Creer, S. et al., 2011. Multigene molecular systematics confirm species status of morphologically convergent *Pagurus* hermit crabs. *PLoS ONE*, 6 (12), e28233. doi:10.1371/journal.pone.0028233.
- McLaughlin, P.A., 1974. The hermit crabs (Crustacea, Decapoda, Paguroidea) of Northwestern North America. *Zoologische Verhandelingen*, 130, 1-396.
- McLaughlin, P.A., Komai, T., Lemaitre, R., Rahayu, D.L., 2010. Annotated checklist of anomuran decapod crustaceans of the world (exclusive of the Kiwaoidea and families Hirostylidae and Galatheididae of the Galatheoidea) Part I - Lithoidea, Lomisoidea and Paguroidea. *The Raffles Bulletin of Zoology*, 23, 5-107.
- Muñoz, I., García-Isarch, E., Sobrino, I., Burgos, C., Funny, R. et al., 2012. Distribution, abundance and assemblages of decapod crustaceans in waters off Guinea-Bissau (northwest Africa). *Journal of the Marine Biological Association of the United Kingdom*, 92 (3), 475-494.
- Nykjaer, L., 2009. Mediterranean Sea surface warming 1985-2006. *Climate Research*, 39, 11-17.
- Palero, F., Abelló, P., Macpherson, E., Beaumont, M., Pascual, M., 2011. Effect of oceanographic barriers and overfishing on the population genetic structure of the European spiny lobster (*Palinurus elephas*). *Biological Journal of the Linnean Society*, 104, 407-418.
- Patarnello, T., Volckaert, F.A.M.J., Castilho, R., 2007. Pillars of Hercules: is the Atlantic-Mediterranean transition a phylogeographical break? *Molecular Ecology*, 16, 4426-4444.
- Quesada, H., Zapata, C., Alvarez, G., 1995. A multilocus allozyme discontinuity in the mussel *Mytilus galloprovincialis*: the interaction of ecological and life-history factors. *Marine Ecology Progress Series*, 116, 99-115.
- Schubart, C.D., Guerao, G., Abelló, P., 2012. First record and

- evidence of an established population of the North American mud crab *Dyspanopeus sayi* (Brachyura: Heterotremata: Panopeidae) in the western Mediterranean. *Scientia Marina*, 76 (1), 79-85.
- Spada, G., Maldonado, A., 1974. Nota preliminare sulle specie di molluschi a diffusione prevalentemente atlantica e presenti anche nel Mediterraneo nel mare di Alboran. *Quaderni della Civica Stazione Idrobiologica di Milano*, 5, 51-69.
- Tintoré, J., La Violette, P.E., Bladé, I., Cruzado, A., 1988. A study of an intense density front in the eastern Alboran Sea: The Almeria-Oran front. *Journal of Physical Oceanography*, 18, 1384-1397.
- Torres, A.P., Dos Santos, A., Cuesta, J.A., Carbonell, A., Massutí, E. *et al.*, 2012. First record of *Palaemon macrodactylus* Rathbun, 1902 (Decapoda, Palaemonidae) in the western Mediterranean. *Mediterranean Marine Science*, 13/12, 278-282.
- Udekem d'Acoz, C. d', 1999. Inventaire et distribution des crustacés décapodes de L'Atlantique nord-oriental de la Méditerranée et des eaux continentales adyacentes au nord de 25°N. *Patrimoines naturels (M.N.H.N./S.P.N.)*, 40, 1-383.
- Vargas-Yáñez, M., Sabatés, A., 2007. Mesoscale high-frequency variability in the Alboran Sea and its influence on fish larvae distributions. *Journal of Marine Systems*, 68, 421-438.
- Vázquez, J.T., 2001. *Estructura del margen continental del Mar del Alboran*. Ph. D. Thesis. Universidad Complutense de Madrid, Madrid, 347 pp.
- Zariquiey Álvarez, R., 1968. Crustáceos decápodos ibéricos. *Investigación Pesquera*, 32, 1-510.
- Zenetos, A., Gofas, S., Verlaque, M., Cinar, M.E., García Raso, J.E. *et al.*, 2010. Alien species in the Mediterranean Sea by 2010. A contribution to the application of European Union's Marine Strategy Framework Directive (MSFD). Part I. Spatial distribution. *Mediterranean Marine Science*, 11(2), 381-493.