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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?

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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, Froglia, 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 m^2. 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 ºC, 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, 36º 20.74'N - 5º 12.70'W, 42-46 m, 14.8ºC, 1 ovigerous

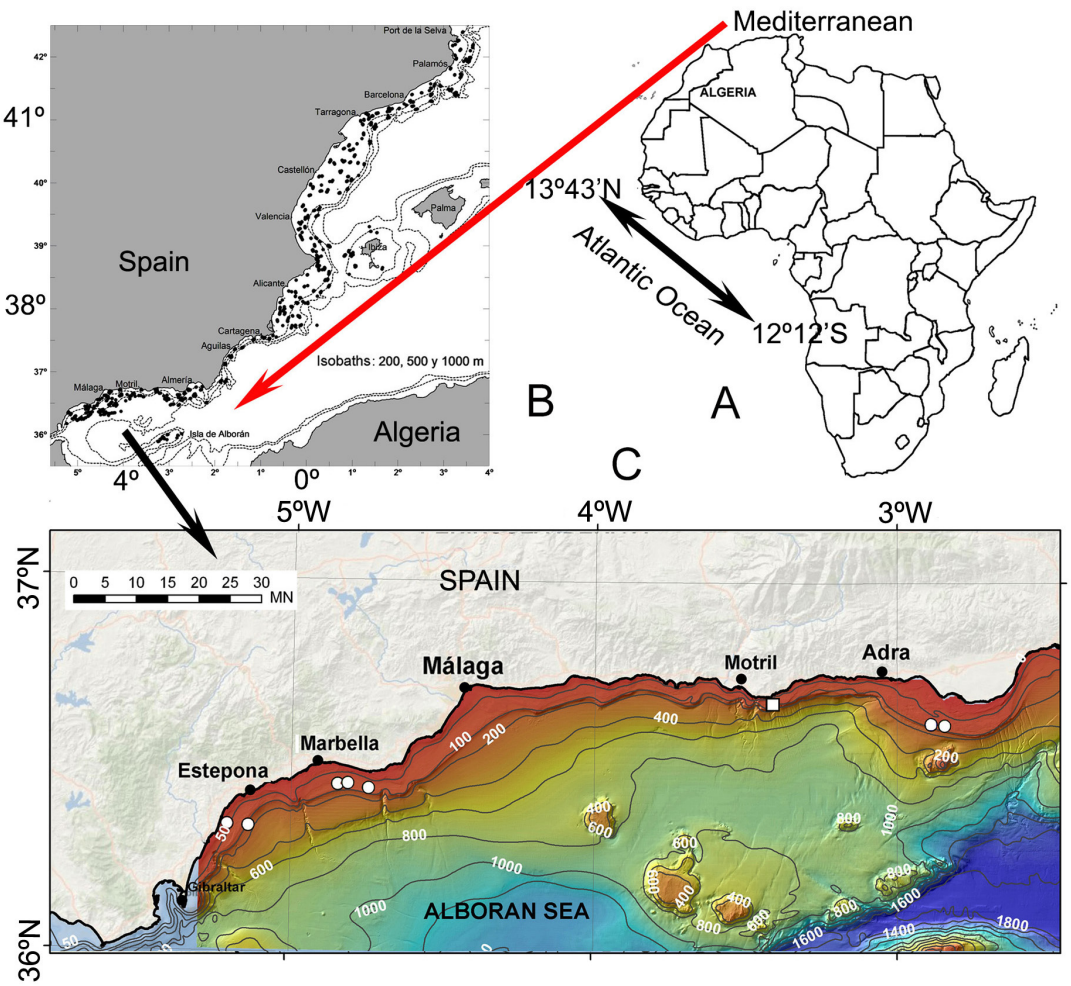

Fig. 1: A- General biogeographic distribution (indicated by the arrow) of *Pagurus mbizi*. B- Sampling stations of the MEDITS_ES trawl surveys project. C- Sampling stations with presence of *Pagurus mbizi* in the Alboran Sea, northern sector (white points: MEDITS_ES samples; white square: RECALA samples).

female. MEDITS07, haul 8, Estepona (Málaga), 20-05-2007, 36º 20.21'N -5º 08.41'W, 133-150 m, 13.7ºC, 1 male. MEDITS09, haul 10, Marbella (Málaga), 10-04-2009, 36º 21.15'N - 4º 50.92'W, 76-77 m, 13.6ºC, 1 male. MEDITS12, haul 12, Marbella (Málaga), 28-04-2012, 36º 27.13'N - 4º 50.97'W, 76 m, 4 males. MEDITS12, haul 28, Adra (Almería), 04-05-2012, 36º 37.33'N-2º 53.17'W, 85 m, 13.3ºC, 6 males and 1 ovigerous female. MEDITS13, haul 11, Marbella (Málaga) 10-05-2013, 36º27.38'N - 4º42.32'W, 70 m, 1 ovigerous female; MEDITS13, hauld 12, Cabo Pino (Málaga), 10-05-2013, 36º 27.24'N - 4º49.20'W, 80 m, 1 ovigerous female; MEDITS13, haul 44, Almerimar (Almería), 20-05-2013, 36º37.79'N - 2º55.99'W, 84 m, 1 male. RECALA St 2.3 (replicate 1), Calahonda-Castell de Ferro (Granada), 19-07-2010, 36º41.56 N - 3º20.76 W / 36º41.57 N - 3º20.98 W, 78-66 m, 13.77ºC, 1 male. RECALA St 4.3 (repl. 1), Calahonda-Castell de Ferro (Granada), 08/03/2011, 36º42.70 N - 3º18.09 W / 36º42.90 N - 3º18.32 W, 76-70 m, 13.99ºC, 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

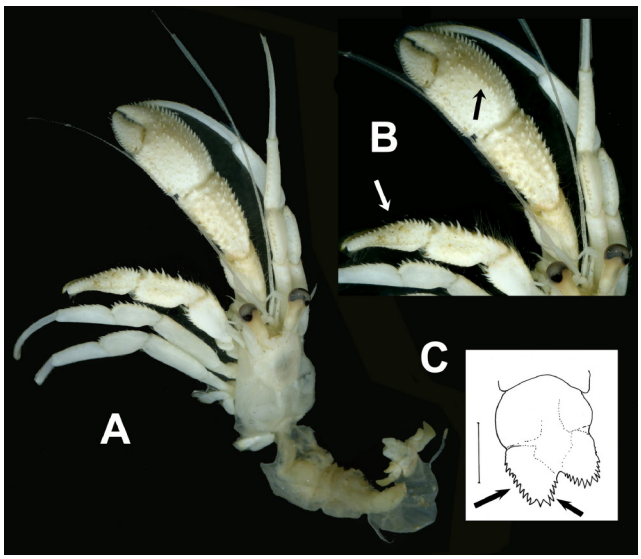

Fig. 2: Male specimen of *Pagurus mbizi* (MEDITS 2012 L28), 3.9 mm carapace shield length. Overview (A), details of chelipeds (B) and telson (C, scale 1 mm).

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* Garcia-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	Nº	%D
Anapagurus alboranensis	47	7.9
Philocheras sculptus	34	5.7
Similipecten similis	33	5.5
Anapagurus longispina	26	4.4
Ophiocten affinis	20	3.4
Ebalia deshayesi	16	2.7
Calyptraea chinensis	15	2.5
Parvicardium minimum	15	2.5
Philocheras bispinosus	13	2.2
Trophonopsis muricata	12	2.0
Dischides politus	9	1.5
Turritella communis	7	1.2
Nassarius pygmaeus	7	1.2
Mangelia costulata	7	1.2
Anadara polii	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% CO_3 - St 2.3, 78-66 m) and mud (33.21%, with 18.25% gravel, 1.27% OM, 4.65% CO_3 - 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 13.8-14ºC, 38.0 psu (RECALA) respectively, the values of mixed Mediterranean-Atlantic waters. However, in MEDITS_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 12º12'S and 13º43'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 (TºC= 13.61-19.95ºC), while *P. pubescentulus* inhabited deeper waters, between 200 and 300 m (10.85º-13.92ºC). 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; Schubart *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.

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