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The alien spreading of *Chama pacifica* Broderip, 1835 (Mollusca: Bivalvia: Chamidae) in the Mediterranean Sea

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Abstract: A detailed Mediterranean synonymy (= list of published records) and distributional map is offered for the Pacific jewel-box *Chama pacifica* Broderip, 1835, an alien mollusk invasive in the deep eastern Mediterranean Sea. A more detailed examination of the single specimen published from the Thermaikos Gulf led us to consider it as a juvenile of the native congeneric *C. gryphoides* Linnaeus, 1758. Concomitantly, the presence of *C. pacifica* along the Greek shores is here first recorded on the basis of 4 adult live specimens sampled at Fokià Bay (Kàrpathos Island). Dates of first record in the Mediterranean for each country in which the species was recorded are reviewed with respect to the recent bibliography. On the basis of the specimens directly examined or reported in the literature, the first record date for Turkey and Lebanon is 1999, and for Greece, 2011. Finally, a discussion regarding the Mediterranean spreading of *C. pacifica* is offered.

Key words: *Chama pacifica*, Chamidae, alien Mollusca, Mediterranean Sea, Greece

1. Introduction

Biological pollution is a common phenomenon worldwide (Molnar et al., 2008) and although marine invasions have been widely documented all over the world (Molnar et al., 2008), they are very conspicuous in the Mediterranean Sea, as pointed out in several recent contributions (e.g., Zenetos et al., 2010). The large Pacific jewel-box *Chama pacifica* Broderip, 1835 is a very peculiar species usually considered as one of the most variable cosmopolitan chamids (Huber, 2010) recently included in the *CIESM Atlas of Exotic Species in the Mediterranean* (Zenetos et al., 2004). Its shell shows a strongly irregular outline from suboval to subcircular, including reports of narrower or elongated forms. It is a quite large bivalve species (shells growing up to about 100 mm in length or width), solid and inequivalve, with the lower valve (left valve, LV) usually bigger and deeper than the upper one (right valve, RV), which is usually flat. The ligament is external and the umbones are spirally coiled prosogyrate. The shell sculpture is typically different on each valve, with short- to medium-sized spines that are often more pronounced on the left side (seen from the external) of each valve. Internally with a hinge plate thick with characteristic pachyodont teeth and finely crenulated margins (sometimes not fully visible). Two large, subequal, ovate, and dorsoventrally elongate adductor muscles scars. Pallial line entire and with no sinus. External color highly variable, from white to pink-red, spines often white. Internal color usually half white and half rose red (half rose red on the right side in the RV and on the left side in the LV, seen from the internal).

In the present paper, the pattern of geographical and temporal spread of *Chama pacifica* Broderip, 1835 in the Mediterranean is reexamined following assembly of additional records based on published and as of yet unpublished data, offering a detailed Mediterranean synonymy (= list of published records) and distributional map, reviewing first record dates and reporting the first record in Greece on the basis of sampled specimens and reevaluation of the sole previous record from the area.

2. Materials and methods

Chama pacifica Broderip, 1835 is considered an alien in accordance with the definition proposed by the International Union for Conservation of Nature (IUCN) (http://www.iucn.org/themes/pbia/wl/docs/biodiversity/cop6/invasives.doc).

Literature was surveyed for Mediterranean records and first record dates of *C. pacifica*, particularly that concerning faunistics, taxonomy, and biogeography. Gathered data were used to build an updated Mediterranean distribution and synonymy.

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In this study, specimens (spm, spms) and shells (RV, LV) belonging to *C. pacifica* were collected by snorkeling and scuba diving, mainly within the frame of the French–Lebanese program of scientific cooperation CEDRE (material from Lebanon, legit Ghazi Bitar, Jean-Georges Harmelin, and Helmut Zibrowius; material from Greece, legit Paolo Russo; material from Turkey, legit Giovanni Buzzurro and Panayotis Ovalis; material from Cyprus, legit unknown). Specimens from Greece and Turkey are currently stored in the private collection of Paolo Russo (Venice, Italy), the specimen from Cyprus is in the private collection of Fabio Crocetta (Naples, Italy), and specimens from Lebanon are currently stored at the Charles Darwin Department of Biology and Biotechnology, La Sapienza University (Rome, Italy) under the care of Marco Oliverio. High-resolution color photos of the controversial specimen from Greece (see below: Mediterranean published distribution and relevant notes) were also examined. Samples recorded were measured with vernier calipers. Sizes reported are in millimeters and given as shell height (SH, from the umbone area to the opposing valve margin) × shell length (SL, perpendicular from the height line).

3. Results

3.1. *Chama pacifica* Broderip, 1835

3.1.1. Published records

Chama broderipii Reeve - Tillier and Bavay, 1905: 177; *Chama broderipi* [sic!] Reeve - Pallary, 1912: 166, tab. XVII (III), fig. 8; *Chama broderipi* Rve - Moazzo, 1939: 71; *Chama reflexa* Reeve - Moazzo, 1939: 71; *Chama reflxa* [sic!] Reeve 1846 - Çeviker, 1999: 26; *Chama reflexa* Reeve 1846 - Çeviker, 1999: 27; *Chama reflexa* - Çeviker, 2001: 40, fig. 3; *Chama pacifica* Broderip, 1834 [sic!] - Mienis et al., 1993: 13–18; Bogi and Galil, 1997: 43–44, figs: 8–9; Çeviker, 2001: 45–46, fig. 21; Zibrowius and Bitar, 2003: 70; Zenetos et al., 2004: 262–263, figure; Mienis, 2004: 119; Türkmen et al., 2005: 107–110; Buzzurro and Cecalupo, 2006: 29; Delongueville and Scaillet, 2006: 30–31, fig. 2; Delongueville and Scaillet, 2007: 58, 62, 64, 66, 68, fig. 40; Zenetos et al., 2009: 2, 6; Delongueville and Scaillet, 2010: 3–5, fig. 6; Bakır et al., 2012: 180; *Chama pacifica* Boderip [sic!], 1834 - Çeviker, 2001: 41; *Chama pacifica* (Broderip, 1834) [sic!] - Bitar et al., 2005: 313; Delongueville and Scaillet, 2006: 29; *Chama pacifica* - Bitar et al., 2007: 437; Bitar, 2010: 452; *Chama pacifica* Broderip, 1835 - Zurel et al., 2011: 1–9.

Not *Chama pacifica* sensu Manousis et al. (2010).

Unpublished material examined

Cyprus:

Larnaca Bay: June 2009 - 5 m on stones - 1 spm: 39.2 × 31.5.

Greece:

Fokià Bay (Kàrpathos Island): August 2011 - 1.5 m on stones - 4 spms: 52 × 31.9 (Figure 1a); 49.5 × 50.6 (Figure 1b); 45.8 × 32.3; 44.6 × 31.9.

Lebanon:

Ramkine Island: May 2000 - 3 m - 2 RV: 40 × 38.5; 43.5 × 33.3. May 2000 - 13 m, sediment - 6 RV: 31.6 × 29.6; 31 × 32.3; 29 × 26; 28.5 × 21; 15 × 11; 14.5 × 12; 2 LV: 18.9 × 13; 17.5 × 13.1. June 2000 - 13–14 m, sediment - 1 RV: 5.8 × 7.2. July 2003 - 7 m, cave - 1 RV: 49.3 × 43.2; 1 LV: 26 × 21. July 2003 - 15 m, cave - 2 spms: 19.2 × 11; 18 × 11.2.

Anfeh: October 1999 - 10 m - 1 spm: 29 × 32.5.

Ras El Chakaa: October 1999 - 3–5 m, cave - 1 RV: 5 × 4.5.

Chak El Hatab: July 2003 - 14 m, cave - 1 RV: 4 × 3.9.

Selaata: October 1999 - 5–6 m, concretions - 1 spm: 9 × 8. October 1999 - 5–6 m, cave - 2 spms: 9.5 × 6.1; 9 × 6.5. October 1999 - 6–7 m - 1 spm: 15.8 × 11. October 1999 - 9 m, cave - 6 RV: 9 × 7.2; 6 × 6.9; 5.5 × 4.9; 4.2 × 4.2; 3.5 × 3.2. May 2001 - 30 m - 2 RV: 12.5 × 14.5; 9.5 × 7.5. September 2002 - 21 m, cave - 3 spms: 58 × 55; 27.5 × 19.5; 18.5 × 16; 1 RV: 48.5 × 41.5; 1 LV: 56 × 49; 49.2 × 46. July 2003 - 20 m, cave - 7 spms: 61.5 × 52; 51.5 × 47; 50.5 × 43; 19.5 × 13.5; 13.5 × 1.1; 13.5 × 8.1; 10.5 × 5; 4 RV: 42 × 36.2; 34.5 × 34; 32.4 × 27.2; 5 × 4.5; 2 LV: 29 × 23.2; 21.7 × 20.5.

Kfar Abida: April 2000 - 7–8 m, cave - 1 spm: 51 × 5.

El Barbara: June 2000 - 26–28 m - 2 spms: 17 × 13.5; 11.2 × 11.2; 4 RV: 6.9 × 6; 6.2 × 6.1; 5.5 × 5; 4.5 × 4.2; 4 LV: 9 × 5.5; 7 × 5.1; 5 × 4.2; 4.2 × 3.

Jbail: October 1999 - 16 m, cave sediment - 1 RV: 5.9 × 5.1.

Beirut: June 2000 - 1 RV: 7.6 × 6.5. September 2002 - 3–10 m - 3 spms: 35.5 × 32.5; 17 × 12; 14 × 10. September 2002 - 10 m - 3 spms: 15.9 × 11.1; 7 × 5.5; 5.1 × 4.9. September 2002 - around 15 m - 1 spm: 34.2 × 23. September 2002 - around 20 m - 1 spm: 19.5 × 15; July 2003 - 3–11 m - 1 spm: 9.3 × 7.

El Zahrani: June 2000 - 14 m - 1 RV: 5.1 × 5.2. June 2000 - 24 m - 3 spms: 18.1 × 13; 7 × 7; 4.2 × 4.

El Kassmieh: October 1999 - 44 m, sediment - 14 RV: 18.9 × 19; 10.5 × 8.5; 8.2 × 8.1; 8 × 7.7; 8 × 7; 7.5 × 7.5; 6.1 × 5.5; 6 × 5.5; 6 × 5.1; 6 × 5; 6 × 6.5; 4.5 × 4.5; 4.1 × 5; 2.2 × 2.2; 1 LV: 9.5 × 11.

Turkey:

İskenderun: June 2005 – 1.5 –2 m of depth on stones - 1 spm: 54.8 × 36.4. August 2009 - 5 m on stones - 3 spms: 50.3 × 32.6; 41.8 × 23.4; 22.7 × 14.2.

3.1.2. Mediterranean published distribution, first record dates, and relevant notes

So far, *Chama pacifica* Broderip, 1835 records are limited to the eastern Mediterranean Sea (see Sciberras and Schembri, 2007; Zenetos et al., 2010a; Antit et al., 2011; Katsanevakis et al., 2011; Crocetta, 2012). A recent record of one *C. pacifica* juvenile specimen from the Thermaikos Gulf (Manousis et al., 2010) has been a matter of debate,

leading to divergent opinions. Zenetos et al. (2011) considered it as a misidentification (of another alien species - *Chama aspersa* Reeve, 1846), while Zurel et al. (2011) and Tzomos et al. (2012) accepted it as *C. pacifica*. Tzomos et al. (2012) stated the first record date from Greece in 2005 on the basis of the above-cited paper. Here, a more detailed examination of high-resolution color photos of this specimen allowed us to clarify the issue. Even if intraspecific variation within *Chama* species is high, the external sculpture with very weak and regular spines (usually more pronounced and less regular in *C. pacifica*), the internal yellow color pattern (usually purplish in *C. pacifica*), and the shape of the adductor muscle scars of the right valve (usually narrower and more elongated in *C. pacifica*) clearly point to a juvenile of the native *Chama gryphoides* Linnaeus, 1758. Published distribution, first record dates, and relevant notes are summarized in the Table and Figure 1c.

4. Discussion

Widespread and presumably native from the Indo-West Pacific, *Chama pacifica* Broderip, 1835 invaded the Mediterranean Sea at least at the beginning of the last century (Tillier and Bavay, 1905), becoming first established and then invasive among the fouling communities from the intertidal to the infralittoral zone of the deep eastern Mediterranean Sea (Zenetos et al., 2010a). *C. pacifica*, in fact, constitutes a leading taxa in its habitat, both in biomass and numbers (Fishelson, 2000; Zurel et al., 2011), mainly found on hard substrates and able to thrive in harbor environments. It outnumbered the native low water congener *Chama gryphoides* Linnaeus, 1758 (Mienis, 2003; Galil, 2007). The surface of its shell provides strongholds for a diverse community of algae and invertebrates (Fishelson, 2000).

Considering the conspicuous records of *C. pacifica* in the Suez Canal (Moazzo, 1939), from where it presumably invaded the Mediterranean via natural dispersal, and its published distribution, where records in Cyprus paradoxically precede those in Lebanon and Syria (see Table and Figure 1c), 2 hypotheses of Mediterranean spreading may be suggested. The first is that this alien bivalve has followed the main pathway of Lessepsian immigrants spreading within the Mediterranean by prevailing currents; in this view, *C. pacifica* was likely present in Lebanon before 1999, and in Syria before 2003, the dates of its first published records, but it went unrecorded due to lack of specific samplings. The second is that its records from Cyprus and Turkey could be man-mediated (e.g., via shipping). The Gulf of İskenderun, in fact, is not only one of Turkey's largest ports on the Mediterranean Sea but it also serves as an important naval training base (Zenetos et al., 2010b). A molecular approach may solve the question. Regarding the presence of *C. pacifica* along the Greek coasts, although this is just speculation, *C. pacifica* may have colonized Greek coasts via natural dispersal from neighboring Turkish shores. This seems to be confirmed by the fact that Kàrpathos Island is quite far from any commercial route.

In addition, our record raises to 49 the number of alien Mollusca species accepted as reported from Greece (Eleftheriou et al., 2011; Zenetos et al., 2011). Consequently, the presence of a third alien *Chama* species in the area (*C. pacifica* together with *C. aspersa* Reeve, 1846 and *C. asperella* Lamarck, 1819; see Ovalis and Zenetos, 2007) locally outnumbers native *Chama* spp. (*C. gryphoides* Linnaeus, 1758 and *C. circinata* Monterosato, 1878). Finally, besides the recent arrival of *C. pacifica* on Kàrpathos Island (previous research held by one of us [P.R.] in 2007 did not reveal its presence) and

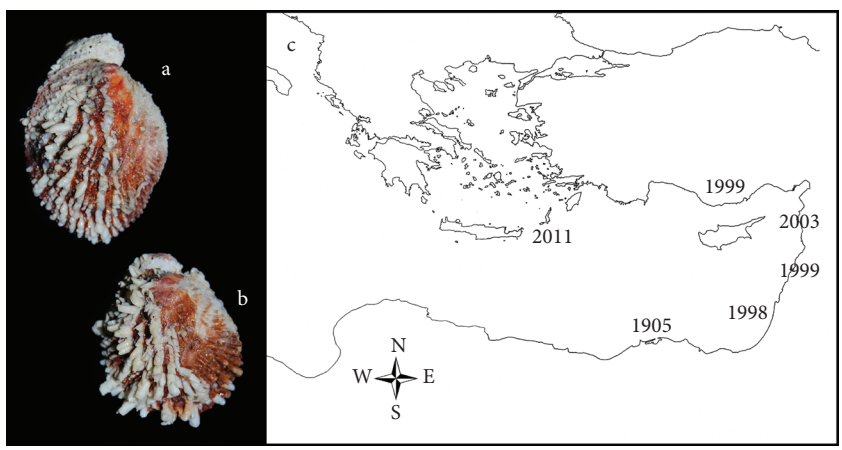

Figure 1. *Chama pacifica* Broderip, 1835. a) and b) Specimens from Fokià Bay (Kàrpathos Island, Greece): 52.0 × 31.9 and 49.5 × 50.6. c) Mediterranean spreading and first record dates.

Table. *Chama pacifica* Broderip, 1835 Mediterranean published distribution, first record dates, and relevant notes.

Country	First record date	Main bibliographic references from the area	Relevant notes
Egypt	1905	Tillier and Bavay, 1905; Pallary, 1912.	First recorded from Egypt without an exact finding date.
Israel	1988	Mienis et al., 1993; Bogi and Galil, 1997; Delongueville and Scaillet, 2007; Galil, 2007.	
Lebanon	1999	Zibrowius and Bitar, 2003; Bitar et al., 2007; present paper.	First recorded from Lebanon without an exact finding date (research held "since 1999": Zibrowius and Bitar, 2003). The material here analyzed allows us to determine its first record as in 1999.
Syria	2003	Bitar et al., 2005.	
Cyprus	1998	Zenetos et al., 2009; Delongueville and Scaillet, 2010.	
Turkey	1999	Çeviker, 1999; Çeviker, 2001; Buzzurro and Cecalupo, 2006; Zenetos et al., 2010b; Albayrak, 2011; Çinar et al., 2011; present paper.	A recent review of alien species from Turkey stated the first record of *C. pacifica* in 2000 (Çinar et al., 2011) on the basis of Çeviker (2001). This finding date has been accepted by Tzomos et al. (2012). Bibliographic research allows us to state the first record at least to 1999, when the species was first figured from Turkey (without an exact finding date) by Çeviker (1999).
Greece	2011	Present paper.	See "Mediterranean published distribution, first record dates, and relevant notes."

taking into account what is reported for the deep eastern Mediterranean shores, it is possible to envisage that this alien bivalve will soon become established along the Greek shores. Future observations are needed to confirm our hypotheses.

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