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SHORT COMMUNICATION

Pachygrapsus maurus and *Pachygrapsus transversus* (Crustacea: Decapoda) in the central Mediterranean: new colonizers or overlooked species?

Salvatore Giacobbe[1] · Medea Lo Piccolo[1] · Fabio Crocetta[2]

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Abstract
The warm-Atlantic crabs *Pachygrapsus maurus* (Lucas, 1846) and *P. transversus* (Gibbes, 1850) are two congeneric species showing a tendentially disjoined distribution in the Mediterranean Sea, with cores in the Algero-Provencal and Levantine basins, and sporadic records elsewhere. In the north-central Mediterranean, first records of these taxa date back centuries ago, but subsequently they were no longer reported for almost a century. We hereby report their additional spread in central Mediterranean and discuss the recent proliferation of sightings in the area. The recently ascertained occurrence of both species in the Strait of Messina confirms that some less stenotherm taxa of tropical/subtropical origin may colonize some sheltered habitats despite cooling of surface water due to the local upwelling. By contrast, the different settlement success observed so far in the north-central Tyrrhenian Sea showed that *P. maurus* might be able to further spread and colonize the entire area, whereas *P. transversus* might be hampered by interspecific competition with the autochthonous *P. marmoratus* further than climatic constraints.

Keywords Mediterranean Sea · Zoogeography · Brachyura · Faunal change · Niche overlapping

Introduction

Pachygrapsus maurus (Lucas, 1846) and *P. transversus* (Gibbes, 1850) are two congeneric crabs (infraorder Brachyura) whose distribution spans from the warm-Atlantic to the Mediterranean Sea (D'Udekem d'Acoz 1999) (Fig. 1). Such distribution partially overlaps that of *P. marmoratus* (Fabricius, 1787), a north-eastern Atlantic/Mediterranean species recently expanding its areal until the English Channel (Dauvin 2012; Pezy and Dauvin 2015). All the three crab species share the same rocky habitat from upper subtidal to supratidal. In the eastern Mediterranean, according to Warburg et al. (2011), *P. marmoratus* and *P. transversus* permanently dominated a boulder-shore habitat, suggesting a possible niche overlap (see also Arab et al. 2015). *Pachygrapsus marmoratus*, in particular, possess an opportunistic behavior (Gonzalez-Silvera et al. 2015) and is known to affect by foraging the structure of sub-tropical rocky shores assemblages (Christofoletti et al. 2010). Contrarily to the widespread *P. marmoratus*, both *P. maurus* and *P. transversus* show a tendentially disjoined distribution in the Mediterranean Sea, with cores in the Algero-Provencal and Levantine basins, and sporadic records elsewhere, especially in the north-central areas (Fig. 1). First records from the central Mediterranean of these taxa date back centuries ago, held by Magrì (1911 - *P. maurus*: unconfirmed), Misuri (1914 - *P. transversus*), and Colosi (1923 - *P. transversus*: misidentified as *P. maurus*) (review in Crocetta et al. 2011). Subsequently, both species went unrecorded in the area for just under a century, and only in recent times a proliferation of sightings from central Mediterranean occurred (Italy: Vaccaro and Pipitone 2005; Crocetta et al. 2011; Tiralongo and Lombardo in Lipej et al. 2017; Malta: Crocetta et al. 2011;

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✉ Salvatore Giacobbe
sgiacobbe@unime.it

[1] Department of Chemical, Biological, Pharmaceutical and Environmental Sciences, University of Messina, Viale Ferdinando Stagno d'Alcontres, 31, 98166 Messina, Italy

[2] Stazione Zoologica Anton Dohrn – Villa Comunale, I-80121 Naples, Italy

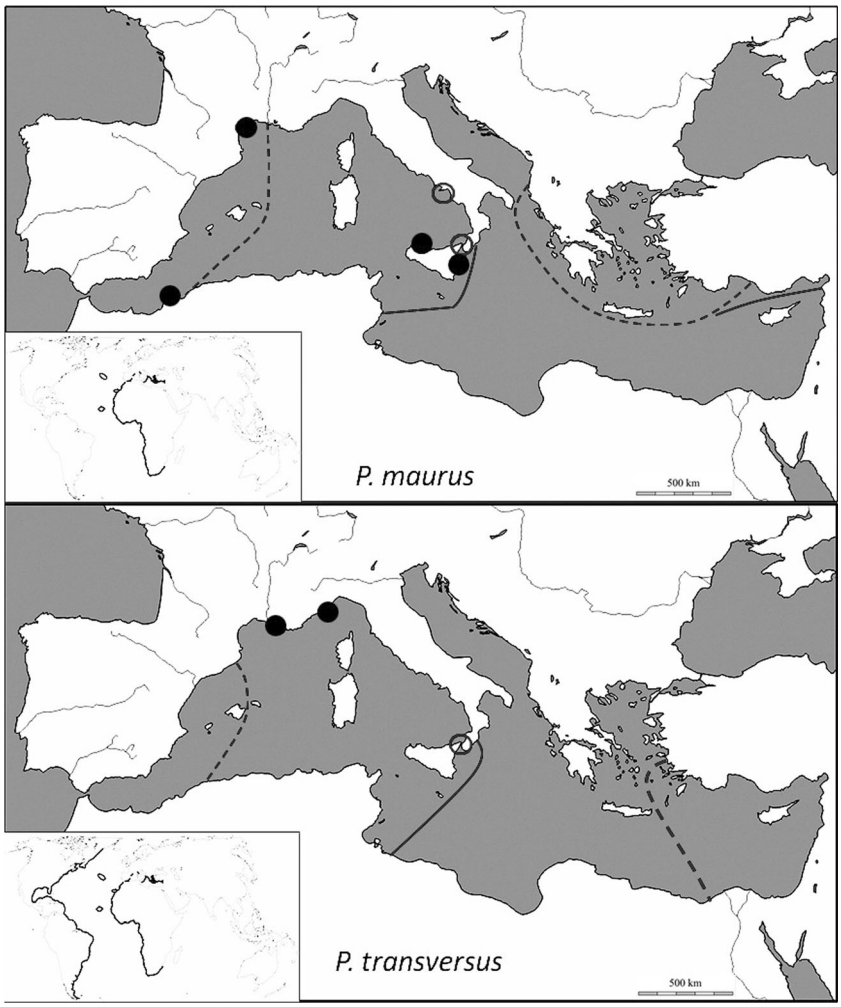

Fig. 1 Mediterranean and global distribution of *Pachygrapsus maurus* (upper pannel) and *P. transversus* (lower pannel). Full circles: dated records (before 1920); dashed lines: presumptive distribution before 2000; entire lines: presumptive distribution after 2000; empty circles: present records

Tunisia: Zaouali et al. 2008; Shaiek et al. 2017), although the known distribution in this area remains overall patchy.

In the present paper we report additional localities for both *P. maurus* and *P. transversus* in the north-central Mediterranean Sea (Messina Strait area and Gulf of Naples, Italy), therefore further documenting the presence of these taxa in the Mediterranean. In this respect, some hypothesis on their increased and wider occurrence are proposed, and the role of the Strait of Messina as ecological gateway is briefly discussed.

Materials and methods

Messina Strait area

Specimens of *P. maurus* and *P. transverus* were first observed in April 2017 in the "Capo Peloro Lagoon" reserve (sampling site: 38°15'38 N; 15°37'39E), during regular investigations started in April 2014. Marine and brackish areas were monthly monitored by snorkeling and SCUBA diving from tide level to 2.5 m depth, both in diurnal and nocturnal hours. Water temperature and salinity were recorded by multiparameter Eutech instrument probe. Frequency of the newcomer species in respect to the native *P. marmoratus* has been monthly evaluated up to date (September 2017) as number of individuals captured in 10 m transect (four replicates), and released after determination of width (±1 mm), sex (male, ovigerous or not-ovigerous female), and developmental stage (juvenile, subadult, adult). Photographs *in situ* were taken with a Canon G12 camera. In vivo observations have been carried on individuals of both species maintained in aquarium for 48 h before release. Some randomly collected specimens have been dry preserved or stored in 75% ethanol. Carapace width and length (CW × CL) of all preserved specimens were measured to the nearest 0.05 mm by Vernier calipers. All voucher specimens were deposited in the Benthic Ecology Laboratory, University of Messina (code repository: BEL124CRGANZ3Ce).

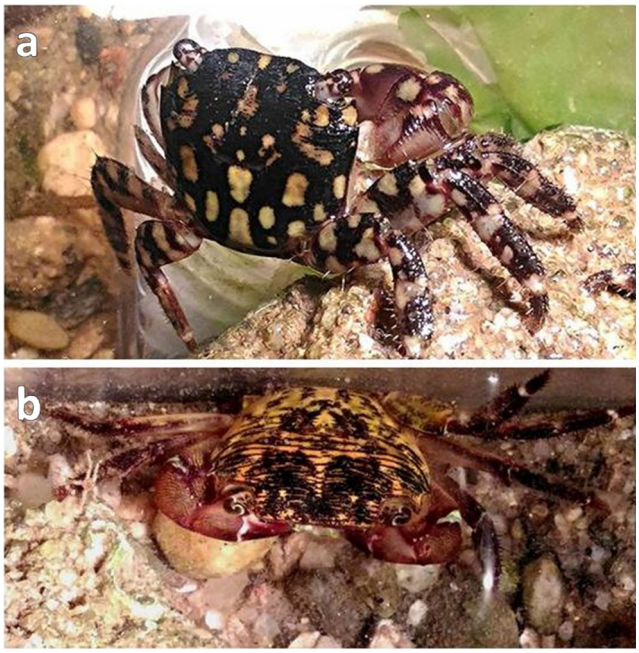

Fig. 2 Field photos of *Pachygrapsus maurus* (BEL124CRGANZ3CeM2) (**a**) and *P. transversus* (BEL124CRGANZ3CeT1) (**b**)

Gulf of Naples

The biota associated with mussel farm buoys off Miseno (Bacoli, Gulf of Naples, Italy) (40°46'41 N, 14°02'27E) was regularly investigated since 2005, by hand scraping the surface of the buoys at tide level. The only specimen of *P. maurus* so far collected, soon after pinning and fixation in pure alcohol, was dry preserved and deposited in the Stazione Zoologica Anton Dohrn Museum, Naples.

Material examined (Messina):

Pachygrapsus maurus. April 2017: specimen M1 (15.0 × 14.1 mm), female, ovigerous; M2 (15.0 × 14.0 mm) male (Fig. 2a); M3 (15.4 × 13.6 mm) male; M4 (13.0 × 10.5 mm), female, ovigerous; M5 (12.0 × 11.4 mm), male; M6 (9.0 × 8.0 mm), male; M7 (10.0 × 9.1 mm), male; May 2017: M8 (12.4 × 9.0 mm), male; M9 (14.0 × 13.3 mm), male; M10 (15.3 × 14.2 mm), male; M11(12.2 × 10.3 mm), female, ovigerous; M12 (16.4 × 14.2 mm), female, ovigerous.

June 2017: M13 (14.0 × 11.8 mm), female, ovigerous; M14 (20.2 × 18.0 mm), female; M15 (19.0 × 15.0 mm), male.

All specimens showed the *P. maurus* typical color pattern, black-brown with yellowish or, more rarely, bluish spots (Fig. 2a).

Pachygrapsus transversus. April 2017: T1 (16.4 × 12.6 mm), female (Fig. 2b); T2 (19.5 × 11.4 mm), male; T3 (19.0 × 11.9 mm), male.

May 2017: T4 (20.0 × 12.7 mm), female; T5 (11.3 × 9.4 mm), male.

June 2017: T6 (20.4 × 17.0 mm), female. Summer 2017: T7 (20.0 × 16.0 mm), male.

In *P. transversus* the color of the carapace was variously marbled, with dominant yellowish patches on a dark green background. The claws were pink to brownish (Fig. 2b).

Material examined (Naples):

Pachygrapsus maurus. May 2017: SZN – CRU0001 (8.5 × 6.8 mm), female.

Results

In Sicily, adult individuals of both *P. maurus* (Fig. 2a) and *P. transversus* (Fig. 2b) have been recorded between April and June 2017 in the Capo Peloro Lagoon (Fig. 1), inside the canal that connects Lake Ganzirri to the sea. All records occurred along almost 20 m of concrete artificial levees, near the sea mouth of the canal, above sea-level, independently from the tidal phase. Water temperature and salinity respectively ranged from 12 ± 2 °C and 33.3 ± 0.8 psu in April, to 18.1 ± 2.5 °C and 35.4 ± 0.6 psu in June. Diurnal oscillations of both parameters have been also recorded, in accordance with tidal flow and related exchanges of marine/brackish waters. Additional data are given in Online Resource 1. The two species occurred between the supralittoral and the upper intertidal, sharing their habitat with the indigenous *P. marmoratus*, whose frequency was at least ten times greater than the two congeneric species together (Fig. 3).

Pachygrapsus marmoratus was also found throughout the whole Capo Peloro area, both in transitional and marine coastal waters; in this latter environment it shared the upper subtidal rocky bottoms with the invasive grapsoid crab *Percnon gibbesi* (H. Milne Edwards, 1853). Active *P. maurus* and *P. transversus* were observed only after sunset, the former feeding upon green algae, whilst the latter exclusively inside holes and crevices, differently than *P. marmoratus*, which was frequent and active both in diurnal and nocturnal hours. In aquarium, 20 *P. maurus* and 8 *P. transversus* randomly coupled (44 observations), showed intra and interspecific attacks (11 and 6 observations, respectively) up to cannibalism (one observation), suggesting a relationship with the loss of a single cheliped in males of both *P. maurus* (20% of individuals) and *P. transversus* (42% of individuals) observed on field. Males of *P. maurus* numerically prevailed on females (56 and 22 individuals, respectively), whilst almost the same number of males and females was found in the less abundant *P. transversus* (14 and 10 individuals, respectively), in accordance with the deposited samples composition (see materials examined). Furthermore, 19 of the 22 *P. maurus* females were ovigerous, whilst no ovigerous females of *P. transversus* have been recorded. In *P. maurus* males, carapace width ranged

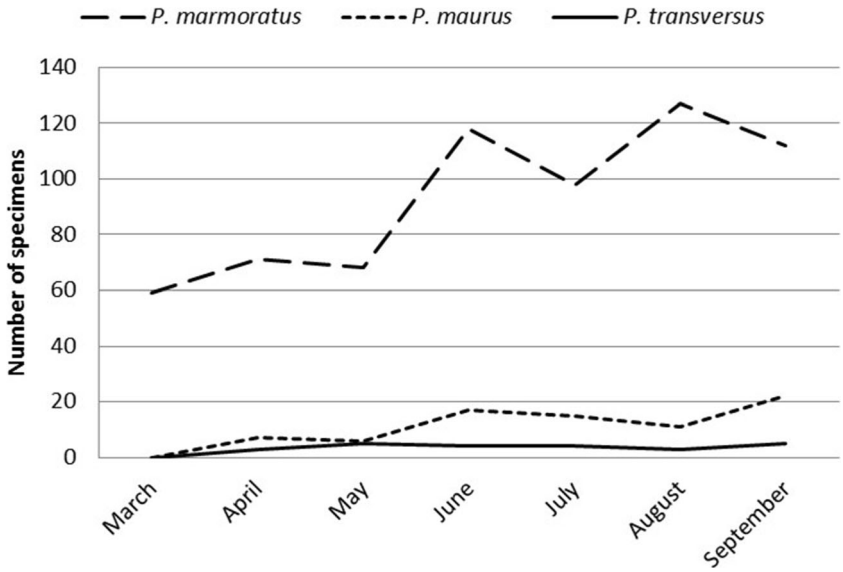

Fig. 3 Number of individuals of *Pachygrapsus maurus*, *P. transversus*, and *P. marmoratus* contextually observed from March to September 2017

from 9.0 mm (recorded in April) to 19.9 mm (in September), whilst in females from 12.2 mm (April) to 22.4 mm (August). In *P. transversus* males, carapace width ranged from 11.3 mm (April) to 20.0 mm (August), whilst in females ranged from 16.4 mm (April) to 20.6 mm (September).

Discussion

The reported new records of *P. maurus* and *P. transversus* from central Mediterranean come from areas widely studied in the past. In the Capo Peloro lagoon, Bottari et al. (2005) characterized the crab fauna of Ganzirri salt-marsh, only reporting *P. marmoratus* together with *Eriphia verrucosa* (Forskål, 1775) and *Brachynotus sexdentatus* (Risso, 1827). The carcinofauna of the Gulf of Naples has been the subject of a general review (Moncharmont 1981) and of various recent articles (e.g. Gambi et al. 1992; Zupo 2006), which have never mentioned *P. maurus* and *P. transversus*, but no studies were previously carried out on the fauna associated with mussel farms. This raises the question on the origin of these crabs, with four main hypotheses to be potentially speculated. The first one is that both species co-occurred with *P. marmoratus* in central Mediterranean Sea since centuries, but their correct distribution has been presumably overlooked just due to relatively small sizes, not exhaustive field studies, and misidentifications/taxonomic impediments, as suggested by Crocetta et al. (2011) and Tiralongo and Lombardo in Lipej et al. (2017). Such hypothesis agrees with the cryptic behavior of both *P. maurus* and *P. transversus*, and therefore, the few individuals potentially sampled so far could have been assigned by default to juveniles of *P. marmoratus* in previous studies. A second hypothesis is that current distribution of both species, as well as the new records reported herein and published in recent years, may be due to anthropic introduction. In this view, both species are known to live as fouling biota or associated with drifting debris, which both guarantee the possibility to be transported over long distances (Holthuis and Gottlieb 1958; Williams 1984; Garcia 1994). According to the mentioned hypothesis, *P. transversus* and allied taxa (see Schubart et al. 2005) are widely known as travelling on ships' hulls since centuries (e.g. Wolff 1954; Christiansen 1969; Thiel and Gutow 2005), and in this line their first finding in the Mediterranean was among ship fouling biota in Marseilles harbor (France), being described as a species new to science, *Pachygrapsus advena* Catta, 1876. A similar phenomenon also holds true for *P. maurus*, sometimes observed on floating objects (e.g. García Socias and Gracia 1988). Both species, in a third hypothesis, may have till centuries constituted bridge populations between eastern Atlantic-western Mediterranean and eastern Mediterranean, only recently spreading in the whole central Mediterranean. Both the historical and recent records of such two thermophilic species may be consistent with a "natural" dispersal event driven by the Mediterranean surface circulation. Increased influx of Atlantic waters due to NAO positive anomalies (Mariotti and Struglia 2002), in fact, may facilitate larval drift through the strait of Gibraltar, and even allow extra-Mediterranean pelagic organisms to reach the Levantine basin (Çevik et al. 2006). In this line, spreading in the north-central Mediterranean Sea has been also recently noticed for another tropical crab flag-species, *Ocypode cursor* (Linnaeus, 1758), originally showing a disjoined distribution and recently colonizing the north-central Mediterranean Sea (Deidun et al. 2017). Finally, the fourth hypothesis is that old records (see above in the introduction) of both *P. maurus* and *P. transversus* from the central Mediterranean Sea might represent past ephemeral settlements due to fluctuations in Atlantic water influx. This may justify the absence of follow-up records from the central Mediterranean until the recent

colonization of the area reported in the last decades. Notwithstanding the limitation of faunal approaches, we hereby highlight that the settlement of tropical/subtropical taxa in the Strait of Messina and along the entire Italian coasts of the Tyrrhenian Sea is almost rare, late, and mostly confined to peripheral or sheltered areas. In fact, the Strait of Messina has been recently considered a stand-alone biogeographic sector, harboring a wealth of floristic-faunistic peculiarities, including both Pliocene Atlantic remnants and endemisms (Bianchi 2007). Such peculiarities are tied to a tidal induced upwelling, which interposes a baffle of colder waters between the warmer adjacent Ionian and Tyrrhenian seas (Azzaro et al. 2007).

On the other hand, based on our field observations, we here highlighted that ecological plasticity of both species, and in particular that of *P. maurus*, may be higher than expected. Crocetta et al. (2011) generalized the *P. maurus* habitat in wave-exposed and topographically complex rocky shores. Such opinion disagrees with the Messina records, in sheltered-brackish environments whose hydrodynamism is exclusively of tidal origin, and the same holds for recent records from Tunisia (Shaiek et al. 2017). At the same time, with regards a possible competition between the congeneric species, *P. marmoratus* has always been found to be dominant when it co-occurs with *P. transversus* (Flores and Paula 2001; Hasan et al. 2008). Arab et al. (2015) suggested that the competition may be minimized by earlier settlement of *P. transversus* juveniles. Nevertheless, since crabs assess each other visually by means of cheliped exhibition to decide the outcome of contests, *P. marmoratus* has some competitive advantage over *P. transversus*, that is smaller in size and whose chelipeds are weaker indicator of morphometric maturity (Protopapas et al. 2007). Our observation testified that *P. marmoratus* prevailed in space resource partitioning, monopolizing the open territories and obliging *P. transversus* to exploit marginal habitats as holes and crevices. Since the larger males of *P. marmoratus* defends territories that do not overlap but are shared with small males and females (Cannicci et al. 2002), individuals of the small sized *P. maurus* might be tolerated because have not been perceived as competitors. Such different interaction of the "endemic" vs the two Grapsidae newcomers, in accordance with the high frequency of mutilate *P. transversus*, agrees with the low occurrence of this latter species when it shares habitat with the two congeneric taxa (Vaccaro and Pipitone 2005; Crocetta et al. 2011). The observed greater size of females than males in both species, unlike the literature data (Arab et al. 2015; Noël 2015), if verified, might represent a further effect of such interspecific male competition. Similar eco-ethological constraints might explain the lack of ovigerous *P. transversus* females during the reproductive season, rather than a lesser acclimation capacity toward lower temperatures since contrasting with the wide latitudinal distribution of such species.

Conclusion

The recent sequence of records of *P. maurus* and *P. transversus* marks progressive steps in areal expansion of both species, presumably driven by the Mediterranean Sea surface circulation and favored by northward shift of the 15 °C February isotherm. Such ongoing dispersal event usually encounters an ecological gate in the Strait of Messina, which hampers most thermophilic taxa to spread in the close Tyrrhenian basin. However, this did not seem to work at least for *P. maurus*, already recorded in northern (Crocetta et al. 2011) and now in southern Tyrrhenian. Present records nevertheless confirm that less-stenotherm taxa of tropical/subtropical origin may settle in lagoons and other sheltered environments, where they may constitute bridgehead populations before disseminating in the adjacent Tyrrhenian basin. A patchy colonization of the Strait, followed by further northwards colonization of *P. maurus* is thus predictable, differently from *P. transversus*, whose settlement might be hampered by interspecific competition further than by climatic constraints.

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Compliance with ethical standards

Conflict of interest All authors declare that they have no conflict of interest.

Ethical approval In this article all applicable international, national, and/or institutional guidelines for the care and use of animals were followed.

Sampling and Field Studies have been authorized by the "Provincia Regionale di Messina", official management body of the reserve (permission n. 557/VIII DIR, 12.03.2014).

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