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The end of the run? New evidence of the complete colonization of the Mediterranean Sea by the Atlantic invader crab *Percnon gibbesi* (Crustacea: Decapoda: Percnidae)

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Abstract

After the finding of several specimens of *Percnon gibbesi* in Elba Island (Tuscan Archipelago), a preliminary census of the populations inhabiting the island coasts was run. Elba Island coasts were investigated by means of underwater linear transects to estimate the crab population density and distribution. The non-native crab population is found in the south and west coast with high density in the southern part of the Island. Crabs share the same habitat of other herbivorous species, such as the crustaceans *Pachygrapsus marmoratus* or *Palaemon elegans*, and the *Paracentrotus lividus* or *Arbacia lixula* sea urchins, but no interactions were observed.

Introduction

Invasion by non-native species is a crucial factor in changing the biodiversity of the Mediterranean Sea. Tropical species have entered the Mediterranean Sea through either the Suez Canal (Lessepsian migration) or the Strait of Gibraltar for decades (Galil, 2006; Por, 2009), but they used to remain in the eastern or western basin, respectively. However, some species from the tropical Atlantic reached the Levant Sea through Gibraltar, while some Red Sea species arrived in the Western Mediterranean Sea (Gambi et al., 2008), causing the "tropicalization" and the "meridionalization" of the eastern and western basin, respectively (Bianchi, 2007; Bianchi et al., 2013).

Moreover, Mediterranean Sea has been warming from 1970 and climate models predict that it will get warmer; by 2070–2099, temperature is projected to rise by 3.1°C, with the exception of the Gulf of Lion and the northern Adriatic Sea (Coll et al., 2010; Raitsos et al., 2010). Recently, a growing number of studies has shown that these two drivers – warming and biological invasions – can act synergistically (the "double trouble" *sensu* Mainka & Howard, 2010). In particular, climate change can facilitate species introduction, colonization and successful reproduction, allowing their persistence and spread (Walther et al., 2009). Several tropical non-native and warm-water native species (the "southerners"), apparently confined by the "14°C isotherm division" in the southern Mediterranean Sea, are colonizing the northern basin because of the northward migration of the temperature barrier (Bianchi & Morri, 1994; Guidetti et al., 2002; Grubelic et al., 2004; Coll et al., 2010).

In this framework, the crab *Percnon gibbesi* (H. Milne Edwards, 1853), also known as Sally lightfoot crab, deserves particular attention. This Atlantic invader entered the Mediterranean Sea in 1999, and it was reported for the first time in Linosa Island, Strait of Sicily (Relini et al., 2000). In about 15 years, it has virtually colonized the entire Mediterranean Sea, becoming one of the most widespread non-native species found in the Mediterranean waters (Katsanevakis et al., 2011).

This crab, belonging to the Percnidae family, shows a subtropical distribution (Manning et al., 1981). *Percnon gibbesi* is omnivore, primarily algivorous, (Cannicci et al., 2004; Deudero et al., 2005; Puccio et al., 2006) usually occuring in subtidal rocky shore habitats, 0–4 m deep (Deudero et al., 2005), with occasional incidence at 11 m (Raineri & Savini 2010). However, it has been recorded down to a depth of 20 m along the West African coast (Fransen, 1991).

The species was likely introduced through shipping (Galil et al., 2002) or by larval drift through the Strait of Gibraltar (Pipitone et al., 2001; Abelló et al., 2003). A third possible vector might be the accidental release from the aquarium trade (Padilla & Williams, 2004; Chucholl, 2013). After the first record in 1999, its population has rapidly expanded in the Mediterranean Sea across several areas, probably for its biological features, such as prolonged larval phases and omnivorous diet (Katsanevakis et al., 2011). Moreover, its spreading can be ascribed to the environmental changes, such as the raising of seawater temperature and the changes in the marine water circulation in the Mediterranean Sea (Bianchi & Morri, 1994; Guidetti et al., 2002; Grubelic et al., 2004; Coll et al., 2010). Currently, it seems to be absent only in the Ligurian Sea and along the coast of Corsica (Fig. 2).

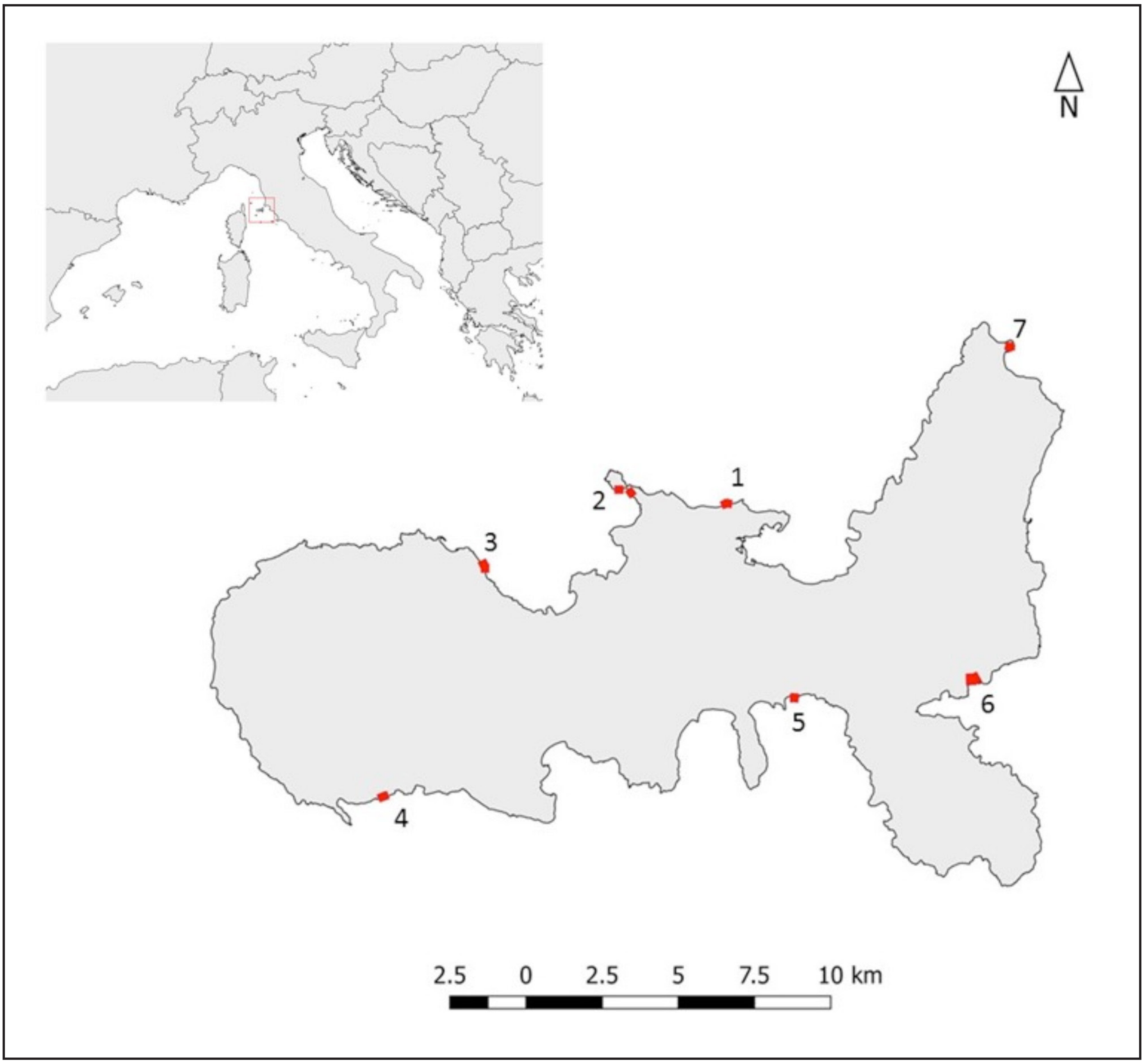

Figure 1. Investigated localities (in red) by means of linear transects in Elba Island from August to September 2015.

In this study, the results of a survey conducted in Elba Island are reported. The survey was conducted after the sighting of many *P. gibbesi* individuals during an environmental education activity of "Citizen Science" in the Tuscan Archipelago National Park. This is the first preliminary investigation on the ecology of this invasive species in this protected area.

Methods

Seven sites were investigated with snorkelling equipment from August to September 2015. Two linear transects from 20 to 50 m (depending on habitat complexity) were identified in each site and they were covered in about 40-50 min.

Number of crabs, mean, standard deviation, carapace size, latitude and longitude, with, water depth in cm, type of substrate and benthonic species sharing the same habitat of *P. gibbesi* were recorded (Tab 1 and 2). Figure 1 shows investigated localities that were progressively numerated one to seven as reported in Tab 1. When possible, specimens were hand collected and preserved in 70% ethanol. Moreover, type of habitat and interactions with other species were noted.

Results

Mean number, standard deviation and estimated carapace width CW of individuals per site are reported in Tab 1. *Percnon gibbesi* was found along the southern coast of Elba Island in boulder-strewn sea bottoms covered by a thin film of algae in Seccheto and in rocky shores with poor algae coverage in Golfo Stella. Few specimens were observed in similar habitat in the western coasts in Porto Azzurro and Cavo. The four sites, apparently without *P. gibbesi* crabs, are characterized by turf-forming algae bottoms (Tab 2). Individuals were recorded from 0.1 to 1 m depth, but the crabs were able to reach quickly depth of about 2-3 m when disturbed.

In Seccheto, *P. gibbesi* shares the habitat with several others decapods species like *Pachygrapsus marmoratus* (Fabricius, 1787) and *Palaemon elegans* (de Man, 1892), but direct interactions (predation, aggressive or elusive behaviour) between these species were not observed. In Golfo Stella, *P. gibbesi* coexists with different species of sea urchins: *Paracentrotus lividus* (Lamarck, 1816) and *Arbacia lixula* (Linnaeus, 1758). Population density was nearly 2.20 and 0.55 crabs per meter in Seccheto and Golfo Stella, respectively. Other species observed in the same habitat together with *P. gibbesi* were reported in Tab 2.

Eight specimens only were collected for their musealization at the Natural History Museum of Florence University, Zoology Section "La Specola", of which 4 females and 4 males, with carapace width ranging from 20.05 to 23.95 and from 19.46 to 29.12 mm, respectively. Among these specimens, three female individuals were ovigerous.

Discussion

Katsanevakis et al. (2011) provided the detailed distribution of the Mediterranean *Percnon gibbesi* populations and they identified the Adriatic and the Ligurian Sea as the unique areas where the species was not yet recorded. Since that, the species was reported for Adriatic Sea by Dulčić & Dragičević (2015) and it was also reported in August 2015 at Lido di Genova by an amateur photographer (http://www.naturamediterraneo.com/forum/topic.asp?TOPIC_ID=256867) confirmed by Bianchi et al. (2016). With this paper, the colonization of *P. gibbesi* in Tuscan archipelago and in the northern Tyrrhenian Sea was confirmed. The establishment of the species could be argued for the presence of populations composed of numerous adults, young

Tab 1 Investigated sites (numbers in brackets show the numeric progression of sites in Fig 1 and Tab 2), number of *P. gibbesi* individuals found in transect 1 (N1) and transect 2 (N2); Mean of registered individuals; Sd: Standard deviation; CW: estimated carapace width.

Site	N1	N2	mean N	Sd	CW (in cm)
Portoferraio, Capo d'Enfola (2)	0	0			
Portoferraio, Punta Capo Bianco (1)	0	0			
Marciana Marina, Punta Schioppo (3)	0	0			
Cavo, Capo Castello (7)	1	2	1.5	0.7	>3
Golfo Stella, Campo Norsi (5)	12	10	11	1.4	0.5<i<4
Campo nell'Elba, Seccheto (4)	50	38	44	4.2	0.5<i<4
Porto Azzurro, Barbarossa Beach (6)	1	0	0.5	0.7	

Tab 2 Investigated sites (numbers in brackets show the numeric progression of site in Fig 1 and Tab 2), latitude and longitude, Length: transect length; M': duration of transect in minutes; water depth in cm, type of substrate and benthonic species sharing the same habitat.

Site	Lat	Long	Length	M'	Depth (cm)	Substrate	Observed benthonic species
(2)	42.823890	10.270117	40±1	30		turf-forming algae bottoms	*Pachygrapsus marmoratus; Arbacia lixula, Palaemon elegans, Patella caerulea*
(1)	42.820073	10.312758	50±1	40		turf-forming algae bottoms	*Salpa salpa, Arbacia lixula*
(3)	42.801367	10.212475	20±1	25		turf-forming algae bottoms	*Arbacia lixula, Salpa salpa, Patella caerulea, Pachygrapsus marmoratus*
(7)	42.866000	10.423180	20±1	30	10<p<80	mostly nude rocky bottom	*Arbacia lixula, Salpa salpa, Patella caerulea, Pachygrapsus marmoratus*
(5)	42.763353	10.336358	30±1	40	10<p<80	mostly nude rocky bottom	*Arbacia lixula, Salpa salpa, Patella caerulea, Pachygrapsus marmoratus, Paracentrotus lividus*
(4)	42.734350	10.173693	20±1	40	10<p<100	boulder-strewn bottom	*Arbacia lixula, Patella caerulea, Pachygrapsus marmoratus, Paracentrotus lividus, Palaemon elegans*
(6)	42.769278	10.408361	50±1	40		turf-forming algae bottoms	*Arbacia lixula, Salpa salpa, Patella caerulea, Pachygrapsus marmoratus*

individuals and several ovigerous females in Elba Island. An abundant number of individuals, both young and adults, were also observed and recorded in Capraia Island (G. Stasolla, pers. obser.). Along with the new records from Ligurian Sea (Bianchi et al., 2016) the complete settlement of the Mediterranean Sea could be assumed. The extensive spread of *P. gibbesi* along the whole Mediterranean Sea, can be ascribed to the direct influence of the increased temperature and to the variation in water circulation patterns (Astraldi et al., 1995), factors that play a major role for species with prolonged larval phases as *P. gibbesi*.

In general, the distribution and densities of *P. gibbesi* seems to be related also with the availability of a specific habitat, without macroalgae and with abundant shelters (Pipitone et al. 2001; Sciberras and Schembri 2008; Katsanevakis et al. 2010; Pirkenseer, 2013). The pattern of distribution on Elba island (see Tab 2 and Fig. 1) seems to be in relation to the boulder-strewn sea bottoms (Seccheto and Campo Norsi). In fact, *P. gibbesi* were observed in very low densities (Barbarossa beach and Capo Castello) or they were not observed (Punta Capo Bianco) in sites characterized by massive presence of turf-forming algae. Other grazers, such as *Paracentrotus lividus* are rarely found in this kind of habitat, while they occur in high densities in barren grounds or, at lower densities in surfaces with erected algae cover, without shelter (Gago et al., 2001).

Furthermore, the northern coasts of Elba Island are quite exposed to currents and winds, and these features could negatively influence the species distribution.

It is uncertain if the presence of this species affect

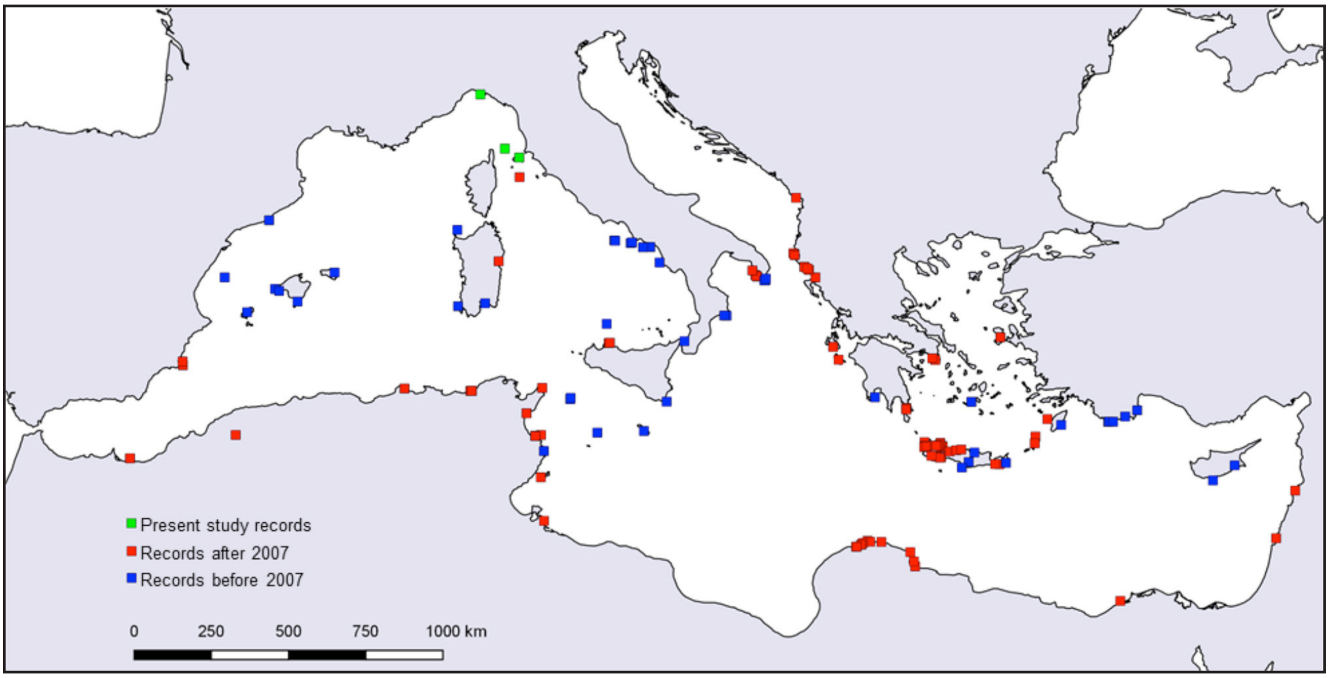

Figure 2. Spreading of *P. gibbesi* in the Mediterranean Sea from the year of first sighting (1999) until now (based on published records until October 2016). Blue squares represent records before 2007; red squares represent records after 2007; Green squares represent reported localities in the present paper.

native species, as actually, evidences of negative interactions or impacts on environment or biodiversity are not available. *Percnon gibbesi* is a potential competitor for space and nutritional resources with the native *Pachygrapsus marmoratus* and other Mediterranean grazers such as the sea urchins *P. lividus* and *Arbacia lixula*. Laboratory experiments indicated that *P. marmoratus* is unlikely to be excluded from its natural habitat by *P. gibbesi* (Sciberras & Schembri, 2008). During the survey, other decapods such as *P. marmoratus* and *Palaemon elegans*, sharing the same habitat and similar feeding habits of *P. gibbesi*, did not have interactions with the non-native crab, even when they were very close (distance from individuals lower than 10 cm).

Herbivory is particularly intense in marine environments, with approximately 70% of benthic primary production being consumed by herbivores (Poore et al., 2012). Changes in herbivorous communities may cause shifts in which the dominant "habitat forming" organisms might be removed or replaced by a different group of organisms.

Ocean warming has been implicated as a factor for both of these changes (Steneck, 2002; Ling, 2008). For instance, the alien herbivorous rabbit fish of the genus *Siganus*, has become abundant along the eastern part of the Mediterranean. Experimental evidence showed that this fish has transformed shallow rocky reefs, removing all canopy-forming macroalgae and preventing the establishment of new algae. Its grazing activity has shifted the system towards deforested areas covered by a thin layer of epilithic algae and detritus (Sala et al., 2011; Vergés et al., 2014). The shift has occurred across of hundreds of kilometres, and has led to a 60% reduction in overall benthic biomass and 40% decrease in species richness (Vergés et al., 2014). Even if the rabbit fish distribution is restricted to the south eastern Mediterranean Sea, thanks to warming, rabbit fish are responding by expanding their distribution westwards (Rilov & Galil, 2009).

Similar to *Siganus* species, *P. gibbesi* is virtually invading the whole Mediterranean Sea, reaching high densities as along the south coast of Elba Island. Impacts on shallow hard-substrate benthic communities and possible cascade effects on trophic webs cannot be predicted because of the absence of information on the grazing activity of the crab and the trophic interactions with other species. In this framework, further researches are necessary to assess the potential impact of *P. gibbesi* invasion of the Mediterranean Sea. Thus, the spread of this species in the Mediterranean Sea might be a further evidence of global climate change.

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