

## Rapid Communication

## First records of the crayfish *Procambarus clarkii* (Girard, 1852) (Decapoda, Cambaridae) in Lake Varano and in the Salento Peninsula (Puglia region, SE Italy), with review of the current status in southern Italy

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### Abstract

The occurrence of the red swamp crayfish *Procambarus clarkii* is documented in the surroundings of Lake Varano (Puglia region, SE Italy), testifying to the ongoing diffusion of this invasive crayfish in north-eastern Puglia, an area characterised by an extensive network of natural and artificial watercourses. In addition, the species is recorded for the first time in the Salento Peninsula, in the south-western part of the region. The hydrology of the area is dominated by karstic phenomena, and the ecological consequences of the colonization of hypogean environments by *P. clarkii* are discussed. These records, in conjunction with a number of recent observations made in Puglia and in other regions of southern Italy including Sicily and Sardinia, indicate that the species is far more widespread in the area than previous studies have suggested.

**Key words:** red swamp crayfish, invasive species, brackish environment, karstic environment, range expansion

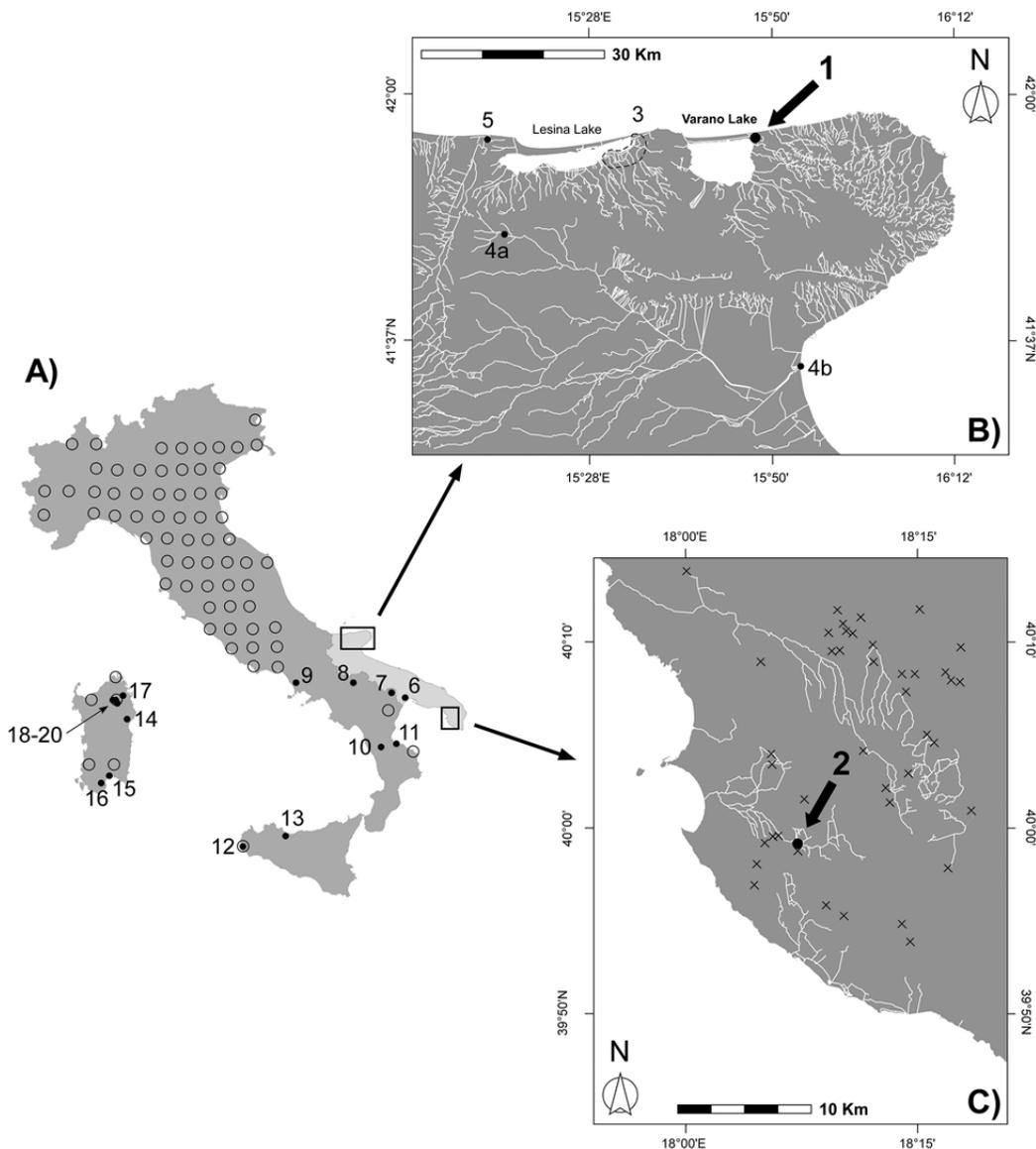
### Introduction

The red swamp crayfish *Procambarus clarkii* (Girard, 1852) is native to north-eastern Mexico and southern USA. It has been introduced worldwide except Antarctica and Oceania and to date is considered the most cosmopolitan freshwater crayfish species (Hobbs et al. 1989; Liu et al. 2011; Loureiro et al. 2015). In Europe, the first introductions of *P. clarkii* occurred in Spain in the 1970s for aquaculture purposes (Habsburgo Lorena and Laurent 1979). Subsequently, the species dispersed eastward across the continent, invading a wide range of lentic, lotic, and brackish environments including highly polluted waters (Gherardi 2006; Kouba et al. 2014; Souty-Grosset et al. 2016).

The species was introduced into Italy in 1977 and was recorded in the wild for the first time in 1989 (Delmastro 1992). The current distribution is mostly

limited to freshwater habitats of north and central Italy (Kouba et al. 2014; Souty-Grosset et al. 2016). With some exceptions, southern Italy appears relatively immune. Qualitative, episodic information is available for Basilicata, Calabria, Sardinia, and Sicily (Morpurgo et al. 2010 and literature cited) while in the Puglia region the records are to date limited to the Lake Lesina area (Florio et al. 2008).

Here we report on the occurrence of *P. clarkii* in Lake Varano area, and we document the first observation of the species in the Salento Peninsula, representing the most eastward record of the species in Italy to date. Qualitative information of preliminary observations performed in the last year are summarised, and the ecological implications are addressed. This study is completed by an overview of the most recent records made by regional institutions and citizens in Puglia, as well as in other regions of southern Italy.



**Figure 1.** Records of *Procambarus clarkii* in the Puglia region (B: Gargano plain; C: Salento Peninsula) and in southern Italy (A). In the general map of the peninsula (A), numbers correspond with location codes reported in Supplementary Table S1, empty circles reproduce the distribution reported by Kouba et al. (2014), while the Puglia region is indicated in light grey. In B) and C) the perennial and ephemeral drainage networks are reported in white. In the map relative to the Melissano record (C), crosses identify karstic sinkholes (“vore”) recorded by the Province of Lecce ([http://www.sit.provincia.le.it/sitwww/vore/dati/intro/ruolo\\_SIT.htm](http://www.sit.provincia.le.it/sitwww/vore/dati/intro/ruolo_SIT.htm), accessed 31/10/2016).

## Methods

Puglia is the southeastern-most region of Italy, extending from NW (Daunia) to SE (Salento) for a length of 350 km between the Adriatic and Ionian Seas (Figure 1). Most of the region is flat or slightly rolling, with more than 60% of the territory below 200 m asl (Elia and Santamaria 2013). Significant reliefs are only located in the NW (Daunian sub-Appennines) and NE (Gargano Promontory) sectors

of the region, characterized by a number of ephemeral and perennial watercourses and waterbodies. In the southern parts of the region, in contrast, the superficial freshwater network is limited. The Salento Peninsula, in particular, rests on a Mesozoic carbonate basement overlain by Neogene and Quaternary deposits; karst processes are frequent, and the surface drainage network is generally lacking (Selleri et al. 2003).

Lake Varano (41°52'46.30"N; 15°44'48.67"E) is a coastal lagoon located on the north side of the

Gargano Promontory, comprising an area of ca. 65 km<sup>2</sup> with an average water depth of approximately 4 m (Spagnoli et al. 2002). Two artificial channels connect the lake with the Adriatic Sea. Freshwater inputs are contributed by three main tributaries (Tonno, Antonino, and San Francesco streams) and by a number of underwater and surficial springs located in the south-eastern part of the basin.

Episodic, unconfirmed reports in summer 2015 and during the period June–July 2016 indicated the occurrence of *Procambarus clarkii* in a brackish channel (salinity range: 15–31, Practical Salinity Scale; Cilenti, unpublished data) located east of the basin collecting drainage waters from surrounding farmlands and pastures (Figure 1B). In September 2016, two *P. clarkii* specimens were captured in the channel using fyke-nets set in place overnight by local fishermen and transferred to the laboratory. Taxonomic identification was performed using Mazzoni et al. (2004) as a reference. In addition, total (TL) and carapace (CL, distance between the centre of the anterior interorbital margin and the centre of the posterior margin) lengths were measured to the nearest mm using a calliper, while individual wet weights were determined to the nearest 0.01 g using a digital balance. Sex determination was performed by verifying the occurrence of diagnostic characters (i.e., position of gonopores, lack of ischium hooks, and presence of *annulus ventralis* in females).

Almost contemporaneously, in July 2016 both adult and juvenile *P. clarkii* individuals were repeatedly observed among the reed roots and leaf litter or hiding in crevices in an artificial drainage ditch in the neighbourhood of the city of Melissano (Lecce) (39°58'21.20"N; 18°7'19.64"E), located in the south-western area of the Salento Peninsula (SE Italy; Figure 1C) (M. G. and F. S. C. pers. obs.). The ditch originates north of the residential zone, and ends in a sinkhole (locally named “vora”), a karstic depression typical of the whole area (Figure 1C). The initial and central sections of the water course flow through an agricultural area, and have natural beds and vegetated banks dominated by reed stands [*Phragmites australis* (Cav.) Trin ex. Steudel]. Three adult specimens were captured during daylight with a hand-held net, identified, sexed, and had their total and carapace length measured *in vivo* using the aforementioned procedures.

Studies recording the occurrence of *P. clarkii* in southern Italy were searched using the online databases ISI Web of Science, Scopus, PubMed, and JSTOR in November 2016. A multiple search criterion was adopted, using combinations of the keywords “*Procambarus clarkii*” with Puglia/Basilicata/Campania/Calabria/Sicily/Sicilia/Sardinia/Sardegna.

Occurrence data were integrated with unpublished records personally communicated to the authors; information found by performing general searches on the world wide web; reports by the Regional Agency for the Protection of the Environment (ARPA) of the Puglia region and other regional agencies available online; as well as records made by citizens and presented in public websites.

## Results

The two *Procambarus clarkii* specimens captured in the Lake Varano channel were adults, one male and one female, with a TL of 70 and 77 mm, a CL of 32 and 37 mm, and an individual wet weight of 9.55 and 13.49 g, respectively. Crayfish captured in the Melissano ditch were all adult males, with TLs of 101.4, 84.3, and 61.4 mm, and CLs of 54.8, 46.6, and 22.4 mm.

In Figure 1 and Supplementary material Table S1 a summary of the collected information regarding the current distribution of *P. clarkii* in the Puglia region and, in general, in southern and insular Italy is presented.

In Puglia, beside the occurrences described in this study and in Florio et al. (2008) in Lake Lesina, three more records were reported in streams and coastal ponds in the northern area of the region (Arpa Puglia 2013).

For the Basilicata region, no quantitative recent information is available confirming the qualitative records already reported in Kouba et al. (2014), referring to observations made in 2010 in the World Wild life Fund oasis of San Giuliano Lake, and in the high course of the Bradano River (Caricato et al. 2013). Similarly, in the Campania region the species is reported to be invasive in the Caserta area, to the point that control and eradication efforts are currently made by local environmental organisations. However, no quantitative assessments have been made to date and the actual abundance and distribution range of the red swamp crayfish in this region is virtually unexplored (Stinca 2013). Similarly, in Calabria, Morpurgo et al. (2010) (reported by Kouba et al. 2014) indicated the occurrence of the species only in the Tarsia Lake (Maiorca et al. 2013), an artificial basin located in the middle course of the River Crati (Sperone et al. 2015; AA.VV 2016). In 2012, the crayfish was qualitatively reported along the whole watercourse, from the spring to the mouth, being abundant also in the brackish waters of the “Foce del Crati” Regional Reserve. The data collected for the Sardinia region generally confirm the qualitative records presented in Kouba et al. (2014). In the northern part of the island, the species was

episodically recorded between 2000 and 2002 in the Gallura area (Orrù et al. 2009) and since 2006 in two watercourses of the River Coghinas drainage system (Riu de Sa Conca and Riu Padrogiano; Puzzi et al. 2010). In 2010, the actual range of the crayfish appeared far more extended (Puzzi 2010). Noticeably, a new episodic record in 2015 suggests a southward expansion in watercourses along the Tyrrhenian coasts. In the southern sectors of the island, *P. clarkii* is now established in several streams of the Molentargius-Saline Regional Park, and is currently invading the brackish environments of the neighbouring saltworks system (Musu 2016).

In Sicily, besides the occurrence originally recorded in 2003 in the Nature Reserve “Lago Preola e Gorghi Tondi” (D’Angelo and Lo Valvo 2003; Maccarone et al. 2016), in 2012 several *P. clarkii* individuals were collected in the “Rosa marina” reservoir in the northern sector of the island (Di Leo et al. 2014).

## Discussion

The most recent analysis of the distribution of *Procambarus clarkii* in Europe is from Kouba et al. (2014). From this overview is clear that the species range in Italy is mostly restricted to the northern and central parts of the peninsula, with only sporadic records in southern regions (Figure 1A) and main islands. The present study actually extends this view: the direct observations made in the Varano Lake area and in the Salento Peninsula, together with the data collated from the literature and from other sources, indicate that the species occurs in multiple locations in the Puglia region, and that is spreading in the rest of southern Italy, including both freshwater and brackish systems.

The records reported in this study for the Puglia region indicate that the species i) is expanding its range in the area of the Gargano plain, with a general tendency towards colonizing the network of natural and artificial watercourses southward and ii) has reached the Salento Peninsula. Other allochthonous crustacean species introduced in to northern Italy have been already documented to expand their distribution southward in a relatively short time period, as occurred in the case of the calanoid copepod *Boeckella triarticulata* (Thomson, 1883) (Alfonso and Belmonte 2008). Indeed, in September 2016 *P. clarkii* was observed for the first time in watercourses within the Regional Park “Terra delle Gravine” (Liuzzi C., personal communication; Table S1, Figure 1). Two interconnected aspects deserve to be discussed. The first regards the origin of the specimens sampled in the Melissano drainage ditch. In lotic systems, *P. clarkii* is characterised by a high dispersion rate,

with a speed of 1–11 mday<sup>-1</sup>; in addition, it can survive outside the water and can move along the banks during the night for foraging (Gherardi et al. 2000, 2002; Aquiloni et al. 2005). This may be the case for the Lake Varano and Candelaro stream records (Table S1): the species was first recorded in Lesina in 2008, and it is likely that it has spread in the network of natural and artificial water courses of the area. The hypothesis of a natural range expansion from populations located in northern Puglia, however, is unlikely for the Melissano record, given the considerable distance and the lack of continuous superficial hydrography. Souty-Grosset et al. (2016), in listing the modes of arrival of *P. clarkii* in European waters, clearly pointed out that intentional introduction constitutes the most important method of range expansion. Thus, it is probable that the species has been deliberately introduced into the Melissano ditches. This raises the question regarding the perception—or lack of—by local populations of the threat represented by this invasive species, and the need of effective actions to increase their awareness.

The second aspect is related to the geology of the area. The Louisiana crayfish has long been recognized as a destructive invader in epigeal freshwater habitats. In addition, as an opportunistic omnivore feeding on macrophytes, leaf litter, and invertebrates, it can deeply impact the structure of macrobenthic communities and food web structure (Loureiro et al. 2015; Souty-Grosset et al. 2016).

The Salento Peninsula is characterized by a limited and ephemeral surface hydrography, while caves and other hypogean environments are widely distributed. The Melissano area is characterised by a number of karstic sinkholes (see Figure 1C); thus, the potential invasion of cave habitats is possible, and represents a further element of concern for this species. Cave habitats are vulnerable freshwater ecosystems whose structure and functions are still to be thoroughly explored (Gibert et al. 2009; Stoch and Galassi 2010; Griebler et al. 2014). Notably, hypogean populations have been already observed in Italy and Portugal (Mazza et al. 2014), but no information is available on the impact of the species on the stygofauna, either in native or invaded habitats [but see Venarsky et al. 2014 for a recent investigation on the cave-obligate southern cave crayfish *Orconectes australis* (Rhoades, 1941)]. In cave systems of the Salento Peninsula, several endemic invertebrate species occur [e.g., *Typhlocaris salentina* (Caroli, 1923), *Metaingolfiella mirabilis* (Ruffo, 1969), *Salentinella gracillima* (Ruffo, 1947), *Hadziaminuta* (Ruffo, 1947), *Stygiomysis hydruntina* (Caroli, 1937), *Spelaeomysis bottazzii* (Caroli, 1924), *Monodella stygicola* (Ruffo, 1949), see also: Masciopinto et al. 2006; Inguscio et

al. 2010], whose response to the impact of the crayfish is to date unpredictable.

In conclusion, in the present study we provided a detailed and updated picture of the current distribution of *Procambarus clarkii* in the Puglia region and in the rest of southern Italy. It is worth noting the considerable unevenness in the quality of available information, a scarcity of quantitative studies, and a general lack of updated data. This is rather disconcerting given that the species is included in the list of alien species of concern as an annex to EU regulation 1143/2014 on alien species, and has long been acknowledged as invasive in Italy (Barbaresi and Gherardi 2000); and that all regions concerned with the invasion have implemented legislative measures of control (Morpurgo et al. 2010). More detailed information on the ecology and biology of southern Italian crayfish populations is needed in order to be integrated with data on their occurrence and abundance, taking as a reference the example of Sicily (Buscaino et al. 2012; Bellante et al. 2015; Maccarrone et al. 2016), and other studies carried out in northern and central Italy (e.g., Ficetola et al. 2012; Dörr and Scalici 2013). In addition, it is worth noting that most of the records herein listed were from parks or reserves. This is a point of further concern since the negative effects of the species on the aquatic biodiversity of lentic and lotic systems are well known. It is apparent that the current efforts made by environmental institutions to protect animal and vegetal biodiversity in these areas need to be necessarily integrated with parallel management action of control, mitigation, and eradication of the crayfish, in Italy as well in other EU member countries.

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## Supplementary material

The following supplementary material is available for this article:

**Table S1.** Summary of recent records of *Procambarus clarkii* in southern and insular Italy.

This material is available as part of online article from:

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