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Range expansion of *Procambarus clarkii* (Girard, 1852) (Decapoda: Cambaridae) in southern Brazil

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ABSTRACT

The crayfish *Procambarus clarkii* (Girard, 1852) is a native species from the south-central region of the USA and northeastern Mexico that has been introduced to all continents except Antarctica and Oceania. In Brazil, *P. clarkii* has 17 established populations, all found in the southeastern region. The studied specimens were obtained at Ribeirão Claro municipality (23°11'38"S 49°45'28"W) in Paraná State, southern Brazil, in fish ponds from a private property near the Paranapanema River reservoir. Sampling was performed in September 2013 and March 2015, yielding a total of 13 crayfish specimens. Interviews with residents and workers at the sampling sites revealed that the aquarium trade could be an important introductory pathway, since the first crayfish observed had been released into nature shortly after being purchased at a pet shop in the neighboring state of São Paulo; even though current legislation forbids their importation, transportation, and commercialization.

KEYWORDS

Alien biology, ecological plasticity, exotic crayfish, illegal, species expansion

The red swamp crayfish *Procambarus clarkii* (Girard, 1852) is native to south-central USA (Louisiana) and northeastern Mexico (Hobbs and Jass, 1989). This species shows ecological plasticity, being able to thrive in harsh environments (Dörr *et al.*, 2006) because of its high reproductive output and brief developmental period, and ability to modify its feeding habits (Anastácio *et al.*, 2014). The red swamp crayfish is a widespread invasive

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species (Magalhães *et al.*, 2005; Chucholl, 2011; Loureiro *et al.*, 2015) that can be found on all continents except Australia and Antarctica (Hernández *et al.*, 2008; Loureiro *et al.*, 2015). It has commercial value as a food source and as pets in the aquarium trade (Magalhães *et al.*, 2005; Loureiro *et al.*, 2015). However, the commercialization of this species may ultimately harm aquatic habitats and the organisms dependent on these habitats (Usio and Townsend, 2004), including native populations of crayfish, fish, amphibians, and macroinvertebrates (Rodríguez *et al.*, 2005).

Since 1985, 17 established populations of *P. clarkii* have been recorded in Brazil, all located in the southeast region of São Paulo State (Magalhães *et al.*, 2005; Loureiro *et al.*, 2015). The specimens were introduced either accidentally or deliberately via the aquarium trade (Loureiro *et al.*, 2015). The aim of this study is to present the first record of this species in Paraná State, southern Brazil, expanding its range of invasion in the country.

The specimens of *P. clarkii* were sampled in Ribeirão Claro (23°11'38"S 49°45' 28"W) in Paraná State, south of Brazil, in a fishpond from a private property near the Paranapanema River reservoir (Fig. 1). Samplings were performed in September 2013 and March 2015, and all animals were captured with a hand-net and individually placed in bags to ensure morphological integrity.

In the laboratory, the crayfish were identified using Hobbs (1974). Each specimen had its carapace length (CL) measured with a caliper (0.01-mm specificity). Ten specimens were stored in 70% ethanol and deposited in the Scientific Collection of the Study Group on Crustacean Biology, Ecology and Culture from the Institute of Biosciences of Botucatu, São Paulo State University (Nebecc – IBB – Unesp). Three selected specimens were fixed in 70% ethanol (one male morphotype I, one male morphotype II, and one female) and deposited in the Carcinological Collection of the Museum of Zoology of the University of São Paulo (MZUSP #36845).

Figure 1. Map showing records of *Procambarus clarkii* (Girard, 1852) in Brazil. White circles indicate previous records from Magalhães *et al.* (2005) and Loureiro *et al.* (2015). White triangle represents the present record.

Thirteen crayfish were sampled, five of which were male [one morphotype I and four morphotype II] (Fig. 2D–F) and eight of which were female. Thirteen specimens were examined, ten in September 2013 and three in March 2015, revealing a mean CL size of 26.9 ± 4.9 mm (MZUSP #36845; collector: M. Antunes). Respondents who live and work in the sampling region reported that one crayfish was purchased in a pet store in São Paulo State to be kept as a pet in January 2013. After a couple of days, the specimen was released into the fishpond and local workers and fishermen began to notice the permanence of *P. clarkii* on site. The crayfish were observed walking along the fish ponds, and even managed to damage one of the ponds due to its burrowing behavior (Fig. 2A–C).

Our study presents a new southernmost record for *P. clarkii* in Brazil (Paraná State). The authors offer a possible dispersion pathway, namely, active dispersal through water bodies that connect hydrographic basins (*i.e.*, rivers and ponds). Additionally, *P. clarkii* is easily available for sale in the pet and aquarium trades (Magalhães *et al.*, 2005; Loureiro *et al.*, 2015) even though the current legislation forbids its importation, transportation, and commercialization (IBAMA, 2008).

Since both male morphotypes were sampled, we can assume that the population is established and reproducing on-site. Once the population of *P. clarkii* is established, it can damage local fauna and flora (Rodríguez *et al.*, 2005). The red swamp crayfish is an effective grazer and can destroy aquatic macrophytes, initiating a cascade of detrimental events on the entire local fauna, since fishes, amphibians, and some macroinvertebrates use macrophytes as a refuge for their larvae (Rodríguez *et al.*, 2005). This crayfish exhibits burrow-construction behavior that can be used to manipulate its environment, thus altering sediment characteristics, impoverishing water quality, and increasing turbidity (Huner and Barr, 1991; Angeler *et al.*, 2001; Barbaresi and Gherardi, 2006). Possible contact between *P. clarkii* and other endemic crayfish is viewed as a major threat to the native crayfish, mainly because of the possibility of *Aphanomyces astaci*, a fungal-like organism (Oomycete), transmission. The pathogen chronically infects North American endemic crayfish, such as *P. clarkii* (see Peiró *et al.*, 2016).

Twelve species of native Brazilian crayfish are currently described, of which eight are endemic, belonging to the genus *Parastacus* Huxley, 1879 and restricted to southern Brazil, *i.e.*, Santa Catarina and Rio Grande do Sul States (Ribeiro *et al.*, 2016; 2017; Huber *et al.*, 2018; Miranda *et al.*, 2018; Ribeiro *et al.*, 2020). Another group that could be threatened by the red swamp crayfish is the Aeglidae, a group of freshwater anomurans native to southern South America, with many endemic species (Pérez-Losada *et al.*, 2009). Currently, there are 55 species of *Aegla* distributed in Brazilian basins (Páez *et al.*, 2018; Trombetta *et al.*, 2019) with many species vulnerable and already endangered (Moraes *et al.*, 2017).

If *P. clarkii* continues to spread further south, it could soon threaten native Brazilian decapod species, since invasive crayfish are known to dominate native crayfish when fighting for a resource, securing the resource for longer and behaving more aggressively (Dalosto *et al.*, 2015). The Parastacidae inhabiting Brazilian territory are often located in hydrographic basins that connect to Argentina and Uruguay (Ribeiro *et al.*, 2020). Thus, this scenario poses a risk to endemic parastacids if red swamp crayfish invade other countries in South America, as predicted by Palaoro *et al.* (2013).

The original collection ponds were revisited three years later, and the locals reported a decrease in the sightings of *P. clarkii*. The amount of crayfish caught in fishnets also decreased due to the farming of fish belonging to the genera *Serrasalmus* Lacepède, 1803 and *Hoplias* Gill, 1903 for sport-fishing purposes. Later, in 2018, the local fishermen and residents reported only carapace traces along the pond margins. It is important to observe that these cultivated fish species [*Serrasalmus marginatus* Valenciennes, 1837, *Serrasalmus maculatus* Kner, 1858 and *Hoplias malabaricus* (Bloch, 1794)] occur naturally in the region (Duke Energy, 2008). The introduction of these predatory fish is an effective tool in crayfish management, representing an intense predation pressure that may be an effective alternative for extensive capture that yielded, according to Loureiro *et al.* (2018), no satisfactory results.

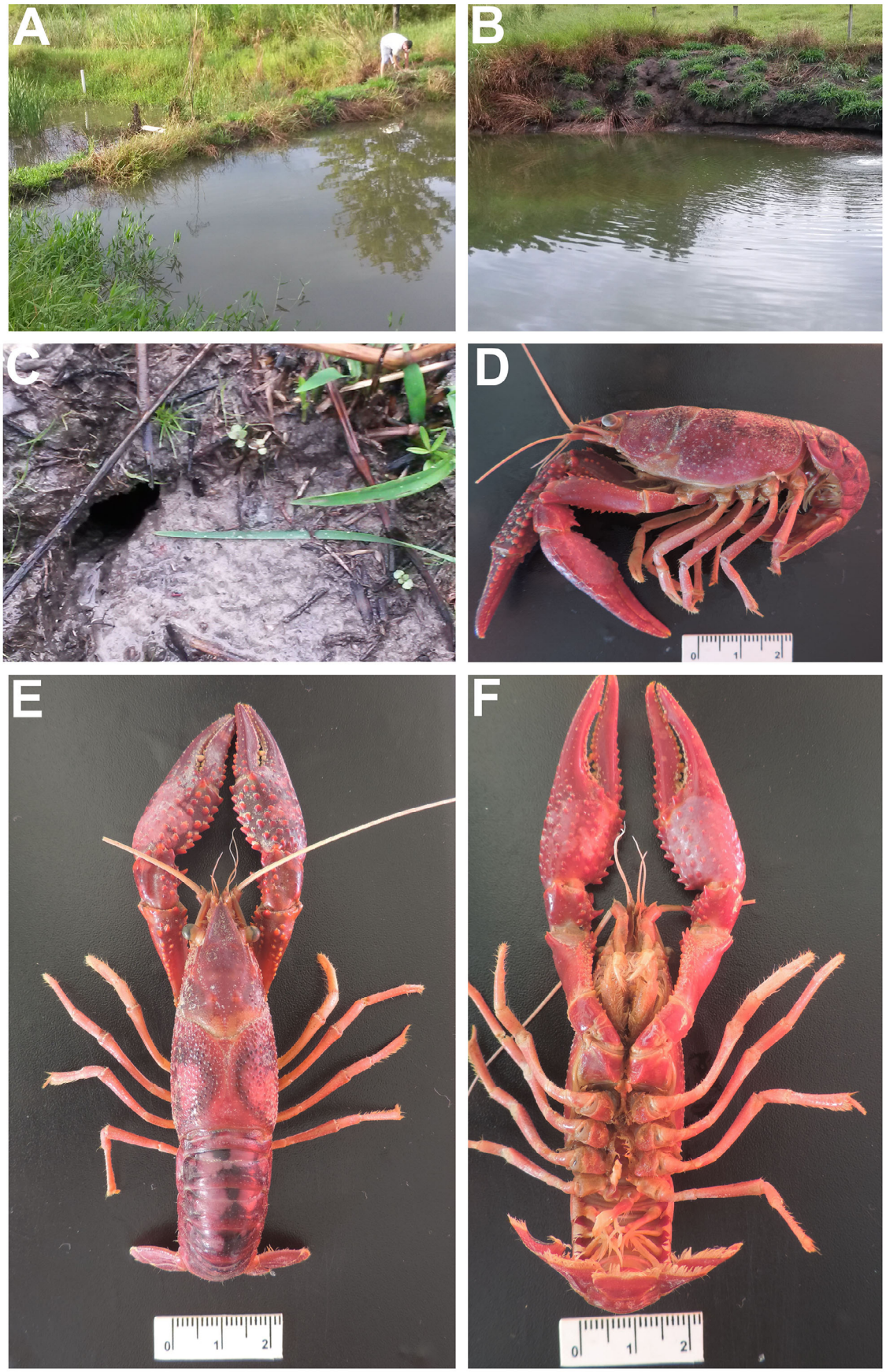

Figure 2. Sampling sites: **A–C**. *Procambarus clarkii* (Girard, 1852) individuals, morphotype I male (reproductive form): **D–F**, lateral, dorsal, and ventral views, respectively. Images by: Antunes, M.

Given these considerations, Brazilian laws regulating the commerce of *P. clarkii* should be enacted and enforced, and regions with *P. clarkii* populations should be regularly monitored due to the imminent risk of invasion of this species further south. This invasion could potentially threaten native Brazilian crayfish and aeglids, which are less aggressive than the invasive crayfish and display high levels of endemism, thus, with a potential to cause irreversible damage. Furthermore, the pond sampled is close to the Paranapanema River basin, which includes several lotic systems that could be a potential invasion pathway. Lotic systems may accelerate invasion processes, as recorded in northern Brazil where *Macrobrachium rosenbergii* (De Man, 1879) co-occurs with native species (Silva-Oliveira *et al.,* 2011; Iketani *et al.,* 2016). Therefore, continuous monitoring of the status of the *P. clarkii* and its potential effects on the biodiversity of the basin is of great importance in order to impose actions to avoid damage to local biological communities.

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