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ORIGINAL ARTICLE

First record of parasitism by *Probopyrus pandalicola* (Isopoda, Bopyridae) on the freshwater prawn *Macrobrachium acanthurus* (Decapoda, Palaemonidae) and ecological interactions

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Abstract In this study, we aimed to record, for the first time, parasitic infestation by the isopod *Probopyrus pandalicola* on the prawn *Macrobrachium acanthurus*, as well as to register some ecological interactions. We hypothesized that the parasitic infection is able to negatively affect the prawn's nutritional condition and that this interaction can modify growth relationships in male individuals. We collected both parasitized (n = 25) and parasite-free (n = 25) individuals in several locations of the Contas River, state of Bahia, Brazil, which had their morphometric characteristics determined, including of the parasites. Relative growth models were constructed for both groups in order to compare slopes and intercepts and determine if the growth patterns are modified by the parasite. We also determined the body condition of the prawns, which was also compared between the two groups. Our results clearly demonstrated that the parasitic infection is able to induce modifications in relative growth patterns in male individuals and that this isopod is capable of reducing the nutritional condition of the prawns. This study indicates that this parasite can induce deleterious effects in the prawn, but individually. Further studies should be conducted to assess the relevance of our findings in conservation and management.

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Introduction

The genus *Macrobrachium* (Bate, 1868) includes species commonly found in lentic and lotic environments (Coelho and Ramos-Porto 1984) and are also widely exploited in both aquaculture and artisanal fisheries, being an important source of economic development in many latin american regions (Thompson 1980; Maciel and Valenti 2009; García-Guerrero et al. 2015). The species *Macrobrachium acanthurus* (Wiegmann, 1836) is a prawn that usually inhabits estuarine and freshwater environments across Latin America, where they can be found underneath rocks and among aquatic vegetation (Coelho 1963). Because of its large body size (females can attain around 108 mm and males 138 mm of body size) (Valenti et al. 1986), this prawn is very commonly exploited by artisanal fisheries around many regions in Latin America (New et al. 2000).

Parasitic interactions among isopods and prawns are common and reasonably well known in the scientific literature, mainly given that many parasitic isopods are crustacean specific and feed on their hemolymph (Walker 1977; Boxshall et al. 2005). More specifically, ectoparasitic isopods from the family Bopyridae usually infect prawns as their definitive hosts and remain attached to their branchial chambers until it dies (Beck 1980b; Chaplin-Ebanks and Curran 2007), mainly because of the capacity of the female isopod to avoid being released along with the old exoskeleton by instantly latching onto the new structure, allowing the parasite to grow along with its host (Cash and Bauer 1993). This happens in many species of the genus *Macrobrachium* (Collart 1990; Román-Contreras 1996;

Oliveira et al. 2000; Conner and Bauer 2010; Vargas-Ceballos et al. 2016). Impacts from these infections can vary from castration, feminization in males (specifically consisting of impairment of claw growth and modification of growth patterns), behavioural and metabolic disturbances (Neves et al. 2000; Lester 2005; Chaplin-Ebanks and Curran 2007; Calado et al. 2008; Dumbauld et al. 2011). However, the intensity or even the presence of these effects can vary from specie to specie, and thus it is important to investigate the species-specific responses, as this may be important information for ecological studies, conservation, and aquaculture management (Ninawe and Selvin 2009). To date, there is no report of parasitic infection by bopyrid isopods in the freshwater prawn *Macrobrachium acanthurus.*

The species *Probopyrus pandalicola* (Packard, 1879) is a highly distributed parasitic isopod that is known to infect several species within the family Palaemonidae (Beck 1980b; Conner and Bauer 2010; Sherman and Curran 2015). Although some research demonstrated that the infection by this isopod does no visible harm in the respective hosts (Morris 1948; Calado et al. 2006), other studies showed that it is capable of inducing harmful effects in the vitality of juvenile hosts (Anderson 1990), sexual sterilization (Sherman and Curran 2015), impairment of growth and reproductive traits (Van Wyk 1982) and induce feeding behaviour disturbances (Bass and Weis 1999). This highlights even more the necessity of assessing the specific response of each species to this parasite, given the highly diverse nature and the conjoint of factors that are able to influence the interactions between hosts and parasites (Williams and Boiko 2012).

In this study, we aimed to record, for the first time, infection by a bopyrid isopod in the species *Macrobrachium acanthurus* and assessed some ecological outcomes of the host-parasite interaction. More precisely, we tested the hypothesis that the parasitic infection is able to reduce nutritional condition (H1) and modify patterns of growth in male individuals (feminization) (H2). Both hypotheses are based on the fact that parasitic infections, since they rely on host exploitation for growth and reproduction, can limit the host's available energy reserves by a conjoint of factors (Sánchez et al. 2018).

Materials and methods

During fieldwork (a total of six samples realized each two months in the year 2017), we manually collected specimens of *Macrobrachium acanthurus* by passing sieves in the marginal vegetation in several locations in the Contas River, located in the north-eastern state of Bahia, Brazil (Fig. 1). It is the most important river in its respective basin

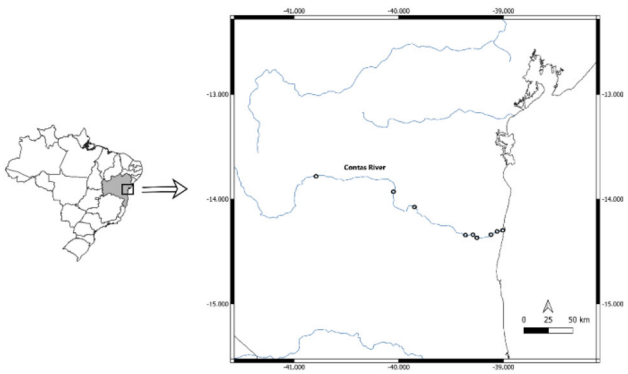

Fig. 1 Location of the sampling sites (black circles) in the Contas River, state of Bahia, Brazil

and one of the largest in the state of Bahia, allowing the presence of a diverse range of economic activities such as agriculture and fishing because of its large water flow and habitat diverisity (SRH 2007; de Barros et al. 2020) In the laboratory, the prawns were dissected towards removing the parasitic isopods and identified regarding sex, measured their total length (tip of the telson to the proximal end of the rostrum) with a 0.01 mm precision calliper and obtained their weight (precision of 0.01 g) (the shrimps were weighed after removing the isopod). We then used the key provided by Markham (1985) to properly identify the species *Probopyrus pandalicola*, which also had their length measured. All examined material is currently stored in the Natural History Museum of the Federal University of Alagoas (UFAL), Maceió, AL, Brazil (Coleção de Carcinologia, register number CB001).

We utilized the Fulton's condition factor, defined by the formula $K = (W/L^3)0.10^5$ (Froese 2006) to assess the shrimp's body condition, where "W" is the weight in grams and "L" is the body length (TL) in mm. The multiplication by 10^5 intended to bring K close to unity. Basically, this formula states that, in a given length, the more mass the individual has, better the nutritional condition is (Froese 2006). As suggested by Sánchez et al. (2018), condition indexes are a reliable approach to measuring infection-fitness relationships, whereas it can also be utilized towards investigating outcomes of anthropogenic impacts in populations (de Barros et al. 2020). Then, to test the first hypothesis (H1) we utilized a *t* test to verify if there is any difference in the nutritional condition between parasitized and parasite-free individuals. We also analysed the relationship between parasite body size (female length) and host body size (total length) using a Pearson correlation test. To test the second hypothesis (H2), we constructed log–log relative growth models of the relationship CC x TL for both parasitized and parasite-free males. Then, we applied an analysis of covariance (ANCOVA) to test for parasite induced differences in relative growth by

comparing slopes (Andrade and Estévez-Pérez 2014). The data were previously tested for normality and homogeneity of variances by the Shapiro–Wilk and Levene's test, respectively, before any other statistical analysis. Null hypothesis were rejected when $p < 0.05$ (Zar 2010).

Results

We analysed a total of 50 male individuals, from which 25 had the isopod parasite in their branchial chambers (Fig. 2) (TL ranging from 18.6 to 35.6 mm) and also 25 had no infestation (TL ranging from 25.6 to 70.4 mm) (Table 1). We had no record of bilateral infestation and the ratio between infestation in the right and left branchial chambers was very close to 1:1. Host size was strongly correlated with parasite size (Fig. 3).

We found that the Fulton's Condition Factor was significantly smaller in the infested prawns (Fig. 4), hence confirming our first hypothesis (H1). Similarly, the analysis of covariance (ANCOVA) demonstrated that patterns of growth in male infested individuals were different than those of parasite-free prawns ($F = 24.48$, $p < 0.001$) (Fig. 5). This confirmed the second hypothesis (H2).

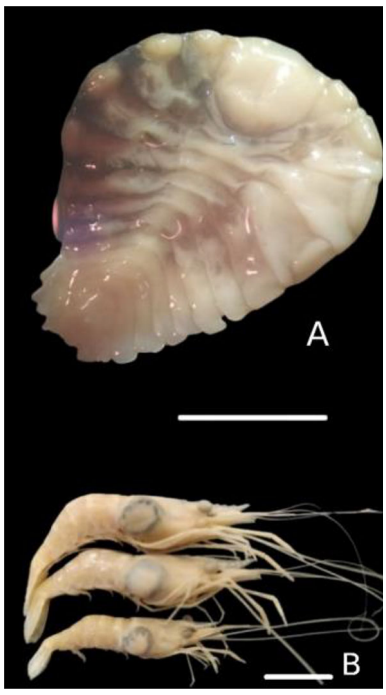

Fig. 2 Ventral view of a female of *Probopyrus pandalicola* (**a**) and infested shrimps (**b**). Above scale is equal to 5 mm, while below scale is equal to 12 mm

Discussion

This is the first study to record and briefly analyse the relationship between the palaemonid prawn *Macrobrachium acanthurus* and the parasitic isopod *Probopyrus pandalicola*. We observed that this parasite is able to induce strong modifications in the growth patterns in male prawns. More specifically, our results suggested that parasitized individuals grew much slower because they had the relationship between carapace length (CL) and total length (TL) altered, as represented by the equation parameters in the Fig. 5. This can possibly be a result of the haemolymph loss caused by the feeding of the parasite (Walker 1977). The subsequent loss of nutrients caused by it can disturb and inhibit the synthesis of hormonal compounds that are thought to stimulate maturation processes (Fingerman 1997; Subramoniam 2011; Swetha et al. 2011). Finally, it is likely that the parasitized individual becomes sexually sterile (Sherman and Curran 2015). Although some decapod crustaceans have evolved to be adapted to nutrient loss and even starvation for considerable periods of time (Vinagre and Chung 2016), this can in fact also cause modification of growth patterns, altered survival and body composition in some other species that are not (Wu et al. 2004). Veritably, parasitic infections are known to produce a significant negative effect in reproductive aspects of many marine species (Hua et al. 2017), including in infestations by isopods on crustaceans (Beck 1980a; Abu-Hakima 1984; Sherman and Curran 2015). Likewise, the work conducted by Dumbauld et al. (2011) suggested that the infection by a bopyrid isopod in the mud shrimp *Upogebia pugettensis* limited their maximum size and weight, besides causing a considerable decrease in population size. Similar work conducted by Smith et al. (2008) also revealed impairment of mass gain in the same species. In Palaemonidae prawns, specifically, little is known about the effects of bopyrid isopods. Research by Anderson (1990) suggested lethal effects of this parasite in species of *Palaemonetes*, which had higher mortality rates when compared to non-infected prawns. The study by Sherman and Curran (2015) demonstrated a clear sexual sterilization in the daggerblade grass shrimp *Palaemonetes pugio* (Holthuis, 1949), an effect that can potentially affect recruitment processes depending on the magnitude of the infection. For the same species, there are reports of decreased survival time, although it appears to also interact with temperature (Sherman and Curran, 2013).

We also observed that the parasitic infestation can generate a remarkable decrease in the body condition of the prawns, represented in this study by the Fulton's Condition Factor (K). Indeed, the negative relationship between parasitic infestations and body/nutritional condition indexes is

Table 1 Means and standard deviations of Total Length and Weight for both parasitized and parasite free individuals, as well as of the isopod

Host			Parasite
Parameter	Parasitized (n = 25)	Parasite-free (n = 25)	
Total length (mm)	26.9 ± 4.39	39.91 ± 10.46	7.5 ± 1.5
Weight (g)	0.34 ± 0.22	1.59 ± 1.48	0.02 ± 0.01

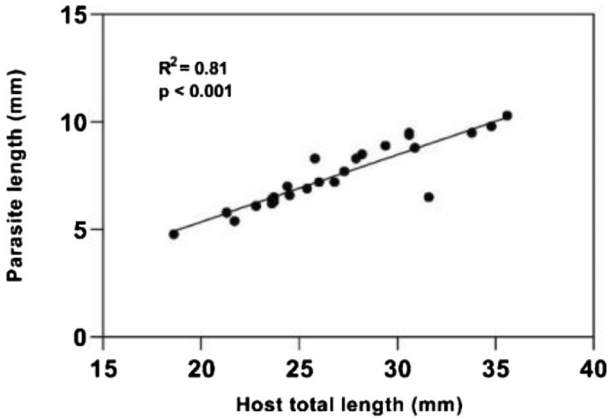

Fig. 3 Correlation between host total length and parasite total length

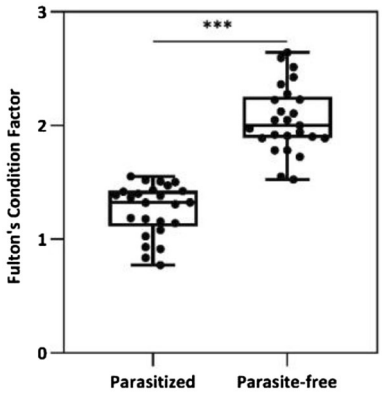

Fig. 4 Comparison of the Fulton's Condition Index between infested and non-infested individuals

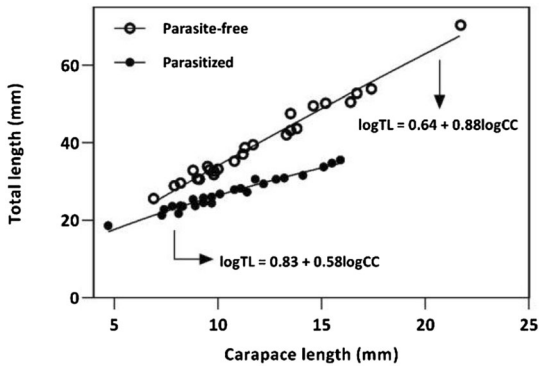

Fig. 5 Growth regression lines and equations of male parasitized and parasite-free individuals

well established in the literature, with a mix of factors being able to influence it (Sánchez et al. 2018). It is mainly acknowledged on the limitation of the host's movements (e.g. foraging/looking for resources, directly linked to energy gains) (Ghai et al. 2015), energetic outcomes of fighting the parasites back (even though that evidence in the scientific literature for immunity expenses are so far blended) (Bonneaud et al. 2003; Eraud et al. 2005; Nilsson et al. 2007), environmental factors that can lead to increased probability of transmission such as resource scarcity (Ostfeld et al. 2005; Becker et al. 2015) and fluid loss (Walker 1977; Smith et al. 2008). Particularly, in the studied shrimp, it is more likely that the relative contribution of fluid loss and limitation of movements are far more important in explaining the worsened nutritional condition, since the loss of haemolymph in crustaceans are commonly linked to nutrient loss and limitation of movements can modify feeding behaviours and also provide an important diminution of nutrient intake (Felten and Guerold 2001; Lester 2005).

Anderson (1990) stated that *Probopyrus pandalicola* reaches its infective stage at estuaries, which are also home to the prawn *Macrobrachium acanthurus.* This means that the infection usually occurs in early life stages, since estuarine environmental conditions are essential for the larvae to develop into a juvenile (Choudhury 1971; Gamba 1982; Bertini et al. 2014). The limitations of our study consisted, specifically, in the lack of any temporal record, excluding the possibility to assess the dynamics of the relationship over a timescale. Similarly, we were not able to record the parasite prevalence in the general prawn population. Because of it, more studies should be conducted in order to acquire data on this and determine the ecological relationships at a greater extent, as it should help to draw better strategies towards fishing and aquaculture management, as well as conservation. Although our data clearly demonstrated that patterns of growth in males of *Macrobrachium acanthurus* were modified, other minor limitation consisted in the lack of male cheliped growth

data, which is thought to be a better indicator of feminization in shrimps (Choi et al. 2004; Smith et al. 2008).

We therefore conclude that our data demonstrated clear impacts by the bopyrid parasitic isopod *Probopyrus pandalicola* on the host prawn *Macrobrachium acanthurus*, which consisted in impairment of growth in male individuals, possibly pointing out to feminization, and worsened nutritional condition, probably as a result of nutrient loss and impaired foraging/feeding. Although our data remains conclusive about some ecological impacts of the host-parasite relationships, more studies should be conducted regarding temporal variation and prevalence of this parasite in the host population, in order to assess the extent of those outcomes.

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Compliance with ethical standards

Conflict of interest The authors have no conflicts of interest to disclose.

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