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ORIGINAL ARTICLE

Biological and ecological notes about the snapping shrimp *Alpheus formosus* Gibbes, 1850 from two continental islands in São Paulo State - Brazil

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ABSTRACT

While previous studies on *Alpheus formosus* Gibbes, 1850 focused on taxonomic and phylogenetic issues, the present study provides information on the biology and ecology of this snapping shrimp, a representative coral reef species widely distributed in the Atlantic Ocean. We studied *A. formosus* between 2015 and 2016 on two islands in São Paulo state, Brazil: Laje de Santos and Vitoria Island. We analyzed 47 specimens from Laje de Santos and 44 from Vitoria Island. Individuals ranged in size from 2.0 mm to 13.99 mm CL. The mean number of embryos attached to the pleopods of females was 211.28 ± 312.8 in Laje de Santos and 125.2 ± 177.8 in Vitoria Island. This species should be included in monitoring programs of coral ecosystems they inhabit as *A. formosus* represents a key element in trophic dynamics of these ecosystems.

KEYWORDS

Caridean shrimps, consolidated substrate, ecology, population structure, preserved areas.

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Introduction

The shrimps from the Family Alpheidae are morphologically and ecologically diverse (Bauer, 2004), and are widely distributed with more than 600 species described thus far (De Grave and Fransen, 2011). The genus *Alpheus* Fabricius, 1798 represents almost half of the species comprising the family (Kim and Abele, 1988; Bracken-Grissom and Felder, 2014; Anker *et al.*, 2015). These shrimps are mostly found in tropical and subtropical marine ecosystems (Chace, 1988) inhabiting a wide variety of niches, from tidal pools in estuaries to deep-sea regions (Anker *et al.*, 2006). Representatives of Alpheidae can also live in mutualistic or commensal associations with other decapods, fishes, sponges, and anemones (Boltaña and Thiel, 2001; Bauer, 2004; Anker *et al.*, 2006).

Although *Alpheus* is the most representative genus of its family (Anker *et al.*, 2006; De Grave and Fransen, 2011), studies about its population biology are scarce compared to knowledge about its taxonomy and diversity. This could be due to the presence of several species complexes (Mathews and Anker, 2009; Costa-Souza *et al.*, 2018) and because these species are ecologically enigmatic (Felder, 1982), which according to Costa-Souza *et al.* (2018) makes monthly sampling difficult and contributes to the lack of knowledge about this group. *Alpheus formosus* Gibbes, 1850 can be found in most of the Western Atlantic: Bermuda, North Carolina, Florida, Gulf of Mexico, Bahamas, West Indies, Central America, Colombia, and Venezuela (Christoffersen, 1998; Cunha *et al.*, 2015; Anker *et al.*, 2016).

On the Brazilian coast, it is very common at Atol das Rocas, Fernando de Noronha and from Ceará to Santa Catarina (Christoffersen, 1998; Anker *et al.*, 2008; 2016; Soledade and Almeida, 2013; Cunha *et al.*, 2015). Although *A. formosus* is abundant on the Brazilian coast, there are few studies about its biological and ecological features. The present study aims to elaborate a brief description of some aspects of the biology and ecology of *A. formosus* from two conservation areas in São Paulo state: Laje de Santos and Vitoria Island.

Material and Methods

Sampling

The shrimps were collected quarterly between June 2015 and June 2016 in two different island regions: The Marine State Park of Laje de Santos (MSPLS) and Vitoria Island (Fig. 1). The specimens were sampled in both regions using a combination of techniques, *i.e.*, employing active search by two divers equipped with SCUBA for 1 hour each per diving session, and using Artificial Substrates of Refuge (ASR). The ASR consists of a plastic net structure in a 25 × 25 × 25 cm (height x length x depth) cube shape filled with plastic tubes and small plastic nets as previously described by Alves *et al.* (2019) and da Silva *et al.* (2018). Five ASR were installed in both islands on a rocky surface and removed three months later.

The specimens collected were bagged individually *in situ* and frozen to preserve color and morphological integrity. Subsequently, they were transferred to the laboratory and identified according to specialized taxonomic keys (Anker *et al.*, 2008; Soledade and Almeida, 2013).

Population Structure and Reproduction

The carapace length (CL) of shrimps was measured under an imaging system of the stereoscopic microscope (Zeiss STEMI V6) from the orbital hood to the posterior margin of the carapace, and individuals were grouped in 2 mm size-class intervals to evaluate and visualize the population structure. The animals were sexed according to the presence (males) or absence (females) of the *appendix masculina* on the endopodite of the second pair of pleopods, and also gonopore positions (Bauer, 2004). The reproductive season was assessed by observing the presence of ovigerous females (females with eggs/embryos adhered to their pleopods) during the sampling period. For further comparisons, the seasons were classified as winter (June), spring (September), summer (January) and autumn (March) according to Sant'Anna Neto (2005). A chi-square test was performed to evaluate the differences in the distribution of the demographic groups (males, non-ovigerous females, and ovigerous females) between the seasons on both islands.

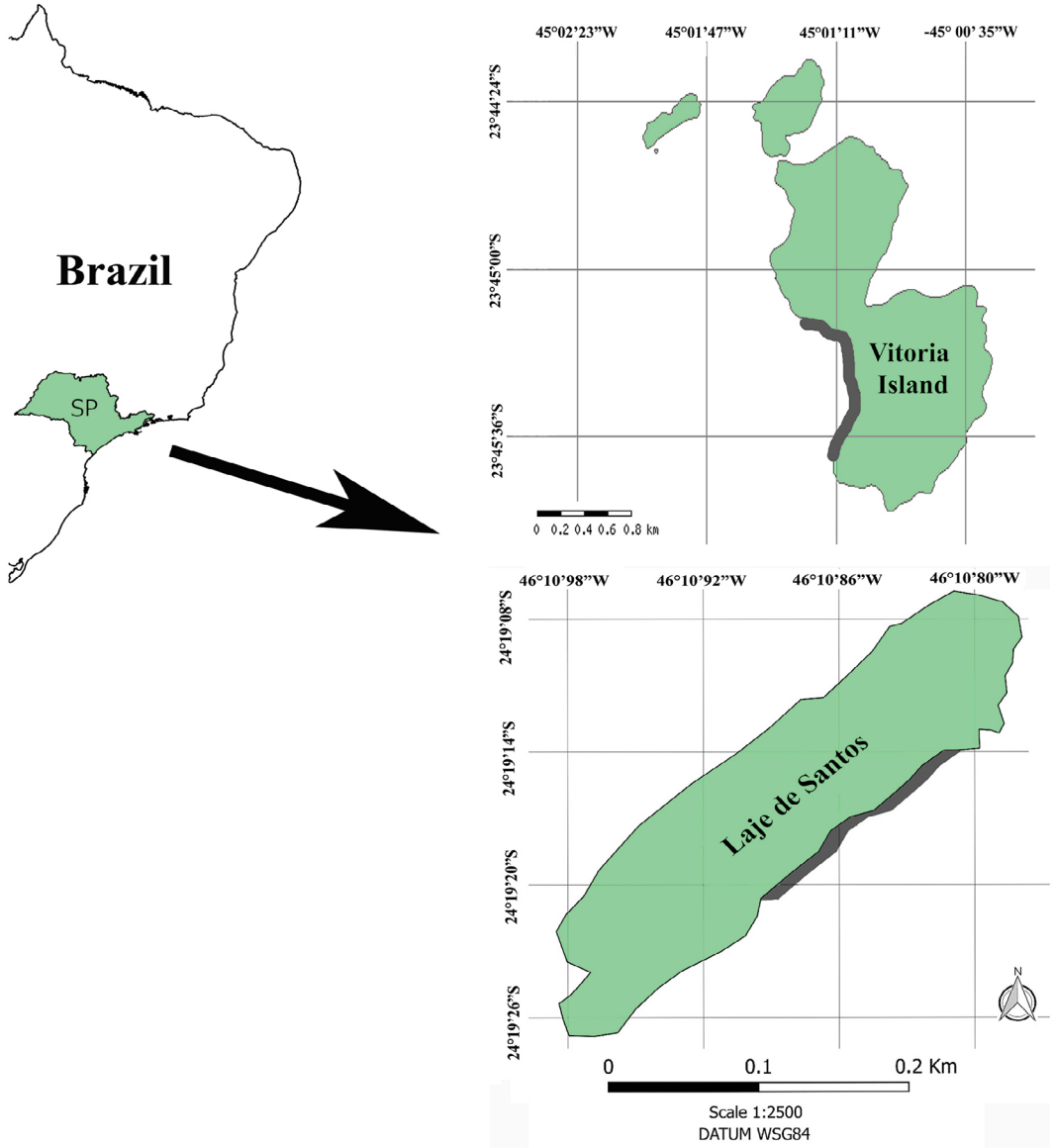

Figure 1. Location of the two continental islands, São Paulo State, Brazil, where the sampling was conducted for the present study (2015–2016).

In order to evaluate the number of embryos attached to the female pleopods, only females with non-damaged embryos were selected, and embryos were counted with a manual counter. Embryos were categorized into two embryonic developmental stages: Stage I, with no eyes formed, and Stage II, with evident eyes formed (see Corey and Reid, 1991). Considering the low number of females carrying embryos in Stage I and II, we provide the mean embryo number of *A. formosus* ovigerous females, and no statistical analyses were performed to compare mean values between stages.

Results

We collected 47 specimens in Laje de Santos and 44 in Vitoria Island. All specimens identified in the present study presented a variable "dark brown-red background", sometimes with a more yellowish tone; the distinctive dorsal white longitudinal band, however, was a consistent characteristic that did not vary among specimens from both islands (Fig. 2).

At Laje de Santos (Fig. 3), shrimp abundance peaked in spring with total of 23 individuals: males were predominant with 13 specimens sampled; non-ovigerous females were abundant in summer and

absent in autumn; ovigerous females were absent in the summer and highest abundance was observed in spring. The Chi Square test showed the following abundance differences: Summer non-ovigerous Females × Ovigerous Females (p=0.0015), and Summer Ovigerous Females × Males (p=0.014).

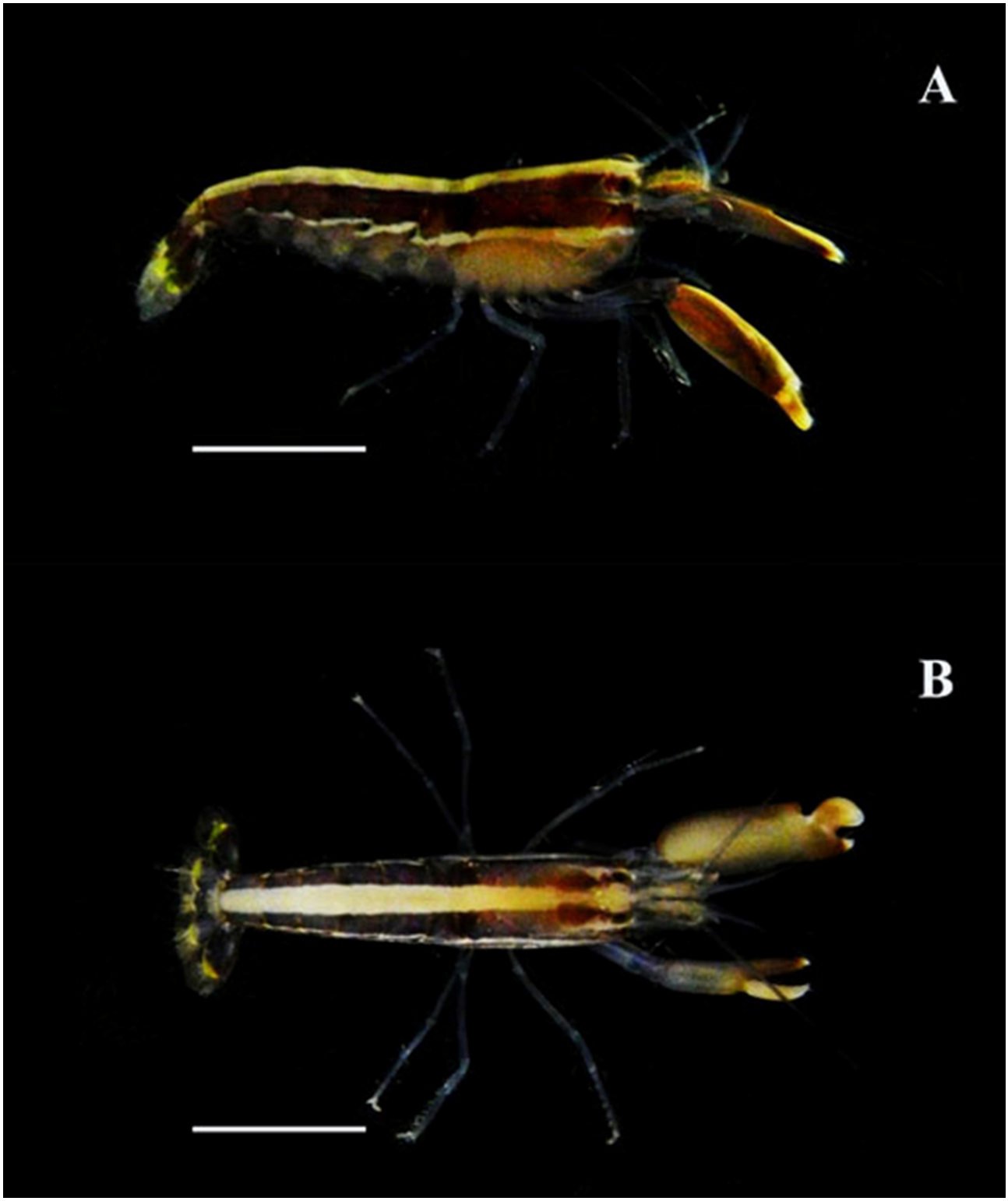

Figure 2. *Alpheus formosus*: color pattern from individuals collected at Laje de Santos and Vitoria Island, São Paulo State, Brazil (2015-2016). (**A**) Lateral view; (**B**) dorsal view.

On Vitoria Island (Fig. 4), the snapping shrimps were more abundant during spring and autumn. Males were found during all sampling periods, and were most abundant in autumn. Non-ovigerous females were most abundant in spring with nine specimens and were absent in summer and winter. Ovigerous females were most present in winter and autumn with three specimens sampled in each season, and absent in the summer. The results of the Chi Square test revealed differences in abundance in spring for Non-ovigerous Females × Ovigerous Females (p=0.011).

In Laje de Santos, specimens ranged in size classes from 2 mm CL to 13.99 mm CL, with the 4.0–5.99 mm CL size class predominating. Non-ovigerous females were mainly found in the size classes of 4.0–5.99 mm CL and 6.0–7.99 mm CL, males in the size class 4.0–5.99 mm CL, and ovigerous females in 6.0–7.99 mm CL and 8.0–9.99 mm CL (Fig. 5). In Vitoria Island, common size classes ranged from 2 mm CL to 11.99 mm CL, and the 4.0–5.99 mm CL size class contained most of the analyzed individuals, including males and non-ovigerous females. Most ovigerous females were present in the size class 10.0–11.99 mm CL (Fig. 6).

Ovigerous females from Laje de Santos (N = 7) ranged in size from 5.98 mm to 12.22 mm CL; four individuals carried embryos in Stage I, the other three females had Stage II-embryos attached. The number of embryos ranged from six (final stage) to 847 (initial stage); mean embryo number for Laje de Santos was 211.2 ± 312.8. In Vitoria Island, seven ovigerous females were collected, but we counted the embryos of only four of them due to the degradation of embryos in the other three specimens. Female sizes ranged between 6.06 mm to 11.51 mm CL with all embryos in Stage II; embryo number ranged from 2 to 383 (mean 125.2 ± 177.8).

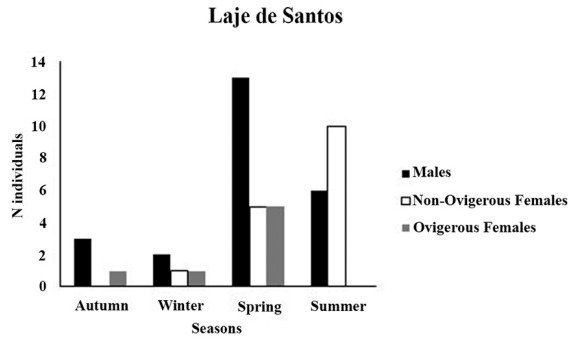

Figure 3. Abundance of *Alpheus formosus* individuals during all seasons (2015–2016) collected at Laje de Santos, São Paulo State, Brazil.

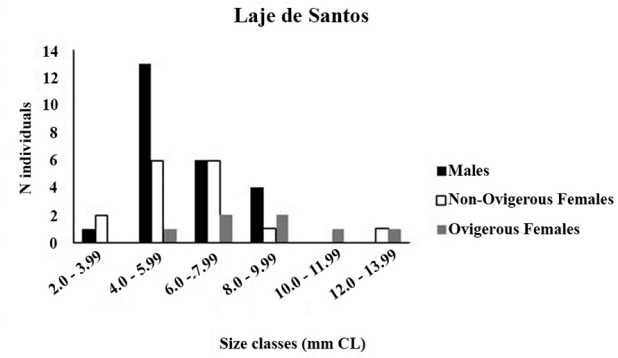

Figure 5. Size-class distribution of *Alpheus formosus* collected at Laje de Santos, São Paulo State, Brazil.

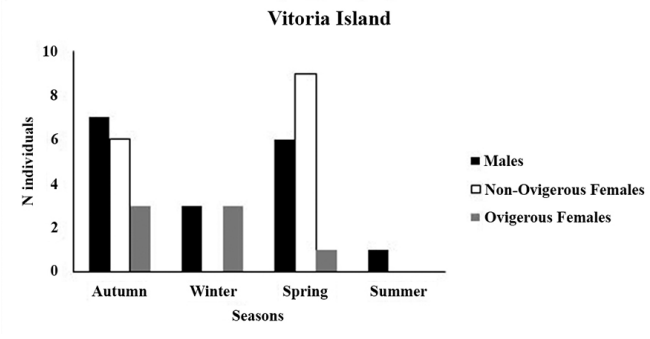

Figure 4. Abundance of *Alpheus formosus* individuals during all seasons (2015–2016) collected at Vitoria Island, São Paulo State, Brazil.

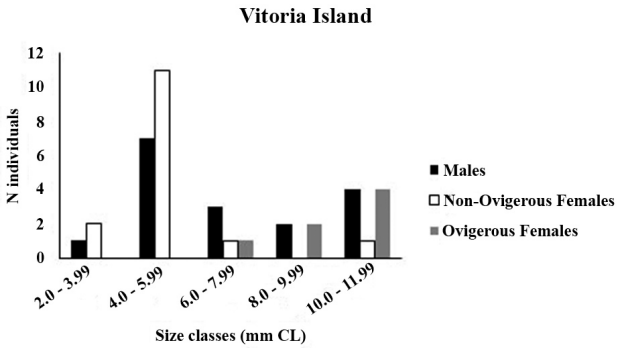

Figure 6. Size-class distribution of *Alpheus formosus* individuals collected at Vitoria Island, São Paulo State, Brazil.

Discussion

The color pattern of the snapping-shrimp *A. formosus* resembles the other conspecific shrimp: *Alpheus panamensis* Kingsley, 1878 (previously considered junior synonym of *A. formosus*). The color of *A. formosus* is very particular with a characteristic "dark brown-red" background, a broad yellow band running mediodorsally from the tip of the rostrum to the telson, a narrow and irregular white longitudinal band on each side of the abdomen, and bluish to purplish walking legs (Anker *et al.*, 2008). Even though the specimens sampled in this study showed variations in their dark brown-red background color patterns, the other characteristics described above were similar.

Among the caridean shrimps, *A. formosus* is one of the most common snapping shrimps in American tropical waters (Kim and Abele, 1988). In Laje de Santos and Vitoria Island, our results suggest well-established populations because all demographic groups were sampled across the seasons with an abundance peak in the spring, despite the low number of specimens. On the southeastern Brazilian coast, abundance peaks of decapods (Negreiros-Fransozo and Fransozo, 1992; Lima *et al.*, 2014; da Silva *et al.*, 2018) are associated with the warmer seasons (spring and summer) characterized by nutrient-rich water masses and high primary production (Schettini *et al.*, 1998; Sant'Anna Neto, 2005). These favorable environmental conditions may explain the elevated number of *A. formosus,* especially during spring (Figs. 3, 4).

Ovigerous females of almost all size classes were found in both localities, presenting larger sizes than males and non-ovigerous females. This pattern of larger ovigerous female is expected since embryos adhere to the pleopods in a lateral cavity formed between the first and third pleura, which enlarge as the female grows. Therefore, larger females would have more space to carry embryos, and consequently, higher fecundity rates (Corey and Reid, 1991; Clarke, 1993; Bauer, 2004).

In both sampling locations, ovigerous females were mostly found from the 6 mm CL onwards, which agrees with the pattern found for many alpheid shrimps especially with other conspecific *Alpheus* spp. (Corey and Reid, 1991; Pavanelli *et al.*, 2008; 2010; Harikrishnan *et al.*, 2010; Costa-Souza *et al.*, 2014; Pescinelli *et al.*, 2016).

The mean number of embryos attached to pleopods of *A. formosus* is relatively low when compared to similar-sized congeners. The maximum number of embryos attached to pleopods of *A. formosus* observed is close to those of species with more than 11 mm CL (Bauer, 1991; Corey and Reid, 1991; Pavanelli *et al.*, 2008; 2010; Harikrishnan *et al.*, 2010; Costa-Souza *et al.*, 2014; Pescinelli *et al.*, 2017). Such inter- and intraspecific variation is related to genetic and environmental (temperature, salinity, photoperiod) factors (Sastry, 1983).

Being a common species in coral reefs and rocky bottoms, *A. formosus* is a key element in trophic dynamics of these ecosystems (Chace, 1972; Wenner and Boesch, 1979; Anker *et al.*, 2008). Therefore, knowledge about its ecology is important to understand the trophic interactions in these valuable ecosystems. A monitoring program of this species and the ecosystem should be implemented to properly assess local conditions, which may help to develop adequate management tools for conservation purposes.

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