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Spatio-Temporal Distribution and Population Dynamics of Two Sympatric Species: The Rock Shrimps *Sicyonia dorsalis* Kingsley, 1878 and *Sicyonia typica* (Boeck, 1864) (Penaeoidea: Sicyoniidae) on the Coast of Ilhéus, Bahia, Northeastern Brazil

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Abstract: Rock shrimps (*Sicyonia dorsalis* and *Sicyonia typica*) are commonly caught as by-catch during shrimp trawling along the Brazilian coast, but are not commercially exploited due to their small size and hard carapace. This study evaluated their spatio-temporal distribution, size classes, and sex ratio near the Almada River Estuary, Ilhéus, Bahia, Northeastern Brazil, and tested correlations between environmental factors and species abundance. Samples were collected monthly using double-rig trawl nets in the estuary and along transects at depths of 5–35 m. Bottom water and sediment samples were obtained for analyses of environmental factors. In total, 5336 individuals of *S. dorsalis* and 303 individuals of *S. typica* were collected. No individuals were recorded in the estuary. Both species were significantly more abundant between 25 and 35 m, where fine sediment with high levels of organic matter occurred. Considering the temporal variation, their abundance decreased during the rainy season, coinciding with increased river flow. Organic matter content, salinity, and water transparency were the primary environmental factors influencing abundance. Females were generally larger and predominant compared to males, likely due to life cycle dynamics. Despite being congeneric and sympatric, the species exhibited distinct population patterns, possibly to avoid niche overlap and competition.

Keywords: Almada River; bycatch; environmental factors; sex ratio; shrimp trawling; southern Bahia



Academic Editor: Elena Anufriieva

Received: 4 December 2024

Revised: 9 January 2025

Accepted: 9 January 2025

Published: 13 January 2025

Citation: Tavares, R.G.; Paschoal, L.R.P.; Guimarães, F.J.; Brandão, S.N.; Couto, E.d.C.G. Spatio-Temporal Distribution and Population Dynamics of Two Sympatric Species: The Rock Shrimps *Sicyonia dorsalis* Kingsley, 1878 and *Sicyonia typica* (Boeck, 1864) (Penaeoidea: Sicyoniidae) on the Coast of Ilhéus, Bahia, Northeastern Brazil. *Arthropoda* **2025**, *3*, 1. <https://doi.org/10.3390/arthropoda3010001>

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1. Introduction

Sicyonia (H. Milne Edwards, 1830) is the only genus in the family *Sicyoniidae* (Ortmann, 1898), one of the five shrimp families in the superfamily *Penaeoidea* (Rafinesque, 1815). Its representatives are characterized by a rigid and robust carapace, responsible for its popular name, rock shrimp [1]. Currently, this genus has 52 described species, distributed worldwide in tropical and subtropical regions of the Atlantic, Indian and Pacific oceans [2–4]. Seven species

occur along the Brazilian coast, *Sicyonia burkenroadi* (Cobb, 1971), *Sicyonia dorsalis* (Kingsley, 1878), *Sicyonia laevigata* (Stimpson, 1871), *Sicyonia olgae* (Pérez-Farfante, 1980), *Sicyonia parri* (Burkenroad, 1934), *Sicyonia stimpsoni* (Bouvier, 1905) and *Sicyonia typica* (Boeck, 1864) [1,5,6].

Sicyonia dorsalis and *S. typica* are the most abundant sicyoniids in the bycatch of seabob shrimp fisheries (*Xiphopenaeus* spp.) along the Brazilian coast [7–10]. *Sicyonia dorsalis* occurs in the Western Atlantic, from North Carolina (USA) (35°15' N–75°33' W) to Brazil, from the state of Amapá (5°09' N–51°28' W) to the state of Santa Catarina (26°53' S–48°32' W), at depths of 3 to 100 m, being more frequent up to 80 m. The second species also occurs at similar depths and from North Carolina (USA) (34°12' N–77°48' W) to Brazil, but extends more south to the state of Rio Grande do Sul (32°14' S–51°23' W) [1,11].

Fish trawling is characterized by low selectivity and, consequently, captures high richness and biomass of organisms other than the target species. The bycatch is mostly discarded, as it is not profitable [12–14]. Sicyoniid shrimps are not commercially exploited (i.e., they are discarded) due to their rigid shell and small body size. As they are important constituents of marine trophic webs, disturbances that affect this group can promote the decline of populations that use and/or interact with rock shrimps, thus affecting the functioning of the ecosystem [15–17].

The spatio-temporal distribution of different species of benthic crustaceans is strongly determined by environmental factors, such as temperature, pH, water salinity, granulometry and organic matter content of the sediment. These factors can influence populations in an isolated manner or synergistically, in addition to modulating intra/interspecific relationships [18–20]. For penaeoid shrimps, the importance of water temperature in growth and reproduction is well known and modulates the temporal distribution of the species over the years [21]. Sediment characteristics such as granulometry also influence the spatial distribution of these animals. Shrimps burrow themselves during the day to escape predators, and consequently save energy [22]. Furthermore, the preference for a certain type of sediment will depend on the animal's ability to move water into the gill chamber while buried, so as not to hinder breathing [23]. Fine sediments, in addition to making burying easier, do not seem to impede breathing or block the gills of rock shrimps [21]. Other small peneoids, such as *Rimapenaeus constrictus* (Stimpson, 1874), are unable to circulate water when buried in muddy sediments and therefore avoid it [24–26].

To understand the dynamics of a certain population, in addition to analyzing the spatio-temporal distribution, it is necessary to evaluate the size and sex ratio of its individuals. In crustaceans, frequency distribution patterns by size classes are used to estimate the stability of a population [27]. In Penaeoidea, males are commonly smaller than females [28], and this may indicate differential recruitment pulses and/or mortality rates. Furthermore, according to Wenner [29], the 1♀:1♂ sex ratio proposed by Fisher [30] is more of an exception than a rule for marine crustaceans, and this is due to differences in growth rates, maturity and longevity between the sexes; these aspects can vary temporally and spatially [31].

Only a few studies investigated *S. dorsalis* and *S. typica* along the Brazilian coast, but D'Incao [1] summarized their geographical distribution. Camargo et al. [32] described the ultrastructure of their spermatozoa and inferred their phylogenetic position within the Sycioniidae, and Pantaleão et al. [33] described the larval stages of these species. For *S. dorsalis*, the studies conducted are restricted to the northern coast of Rio de Janeiro (southeast Brazil), where environmental factors were tested in relation to the spatio-temporal distribution of the species [34]; and north of São Paulo (southeast Brazil), where the reproductive biology [16] and the abundance and distribution [15,35] were investigated. For *S. typica*, there is only one unpublished PhD thesis on its population dynamics on the northern coast of São Paulo [36].

We investigated the spatio-temporal, size distributions and sex ratios of *S. dorsalis* and *S. typica* in the region adjacent to the Almada River estuary (Ilhéus, Bahia, northeastern Brazil). In this context, we analyzed the influence of water (temperature, salinity, pH, conductivity, dissolved oxygen, transparency, chlorophyll-*a*) and sediment properties (percentage of organic matter and granulometry), in addition to rainfall and the Almada river flow, on the patterns presented by both species.

2. Materials and Methods

2.1. Study Area

The municipality of Ilhéus ($14^{\circ}46' S$ – $39^{\circ}02' W$) is located on the southern coast of the state of Bahia, in the northeast region of Brazil. In this region, the continental shelf, facing the Western Atlantic Ocean, is narrow and shallow, with a strong bathymetric gradient (Figure 1). The isobaths are close to each other and parallel to the coastline [37]. The area is influenced by two water masses, the Coastal Water (AC) (temperature $> 20^{\circ}C$ and salinity < 36) and the Tropical Water (TA) (temperature $> 20^{\circ}C$ and salinity > 36) [38,39]. The region has a hot and humid tropical climate, with an average annual rainfall of 2000 mm. Rain is abundant and well distributed throughout the year, with no well-defined dry season [40].

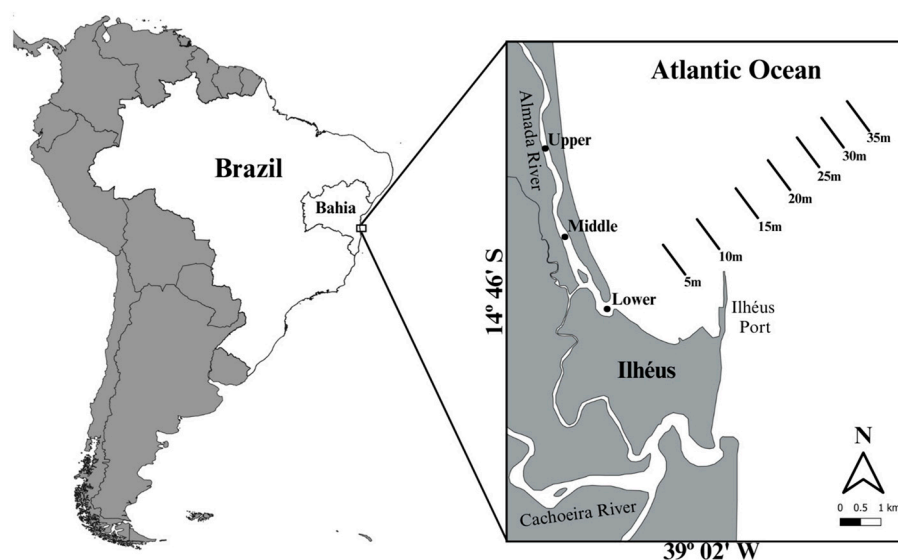


Figure 1. Study area on the coast of Ilhéus, Bahia, Northeastern Brazil. The points indicate the collection sites, at depths between 5 and 35 m, perpendicular to the coastline off the mouth of the Almada River.

2.2. Sampling

Sampling was carried out monthly, between February 2010 and February 2011, at three sampling stations in the Almada River estuary (upper, middle and lower) and along a transect adjacent to its mouth and perpendicular to the coast, where the isobaths of 5, 10, 15, 20, 25, 30 and 35 m were sampled (Figure 1) (Table 1). The trawling was carried out on board a fishing vessel (medium sloop) equipped with double-rig nets (4.5 m opening and 11 m long, with an inter-node distance of 28 mm in the netting and in the final bag), during the day and lasted 30 min. Bottom water and sediment samples were collected at each transect before trawling, with a van Dorn bottle and a van Veen grab. Temperature ($^{\circ}C$), salinity, conductivity (mhos/m) and pH were determined with the WTW multiparameter meter (2FD460 Multi 3420, Geotech Environmental, Denver, CO, USA), and dissolved oxygen (mg/L) with the Hanna meter (HI9146, Hanna Instruments, Smithfield, RI, USA). Water transparency was measured by calculating the disappearance of a Secchi disk in the water column. For chlorophyll-*a* ($\mu g/L$), the trichromatic method was used in acetone

extract, and from this, the phytoplankton biomass was estimated [41]. The flow data for the Almada River and the rainfall index for the coastal region of Ilhéus were obtained from the National Water Agency—ANA [42] and the National Institute for Space Research—INPE [43], respectively.

Table 1. Geographic coordinates of the starting and ending points of the trawls from each collection station taken with a Global Positioning System (GPS) on the coast of Ilhéus, Bahia, northeast Brazil.

	Stations	Start	End
Estuary	Upper	14°43'40.1'' S 39°03'591'' W	14°43'44.5'' S 39°04'013'' W
	Middle	14°44'54.7'' S 39°03'476'' W	14°44'53.0'' S 39°03'481'' W
	Lower	14°46'30.8'' S 39°03'173'' W	14°46'26.7'' S 39°03'187'' W
Ocean	5 m	14°45'56.8'' S 39°02'845'' W	14°46'28.5'' S 39°02'699'' W
	10 m	14°45'14.8'' S 39°01'677'' W	14°45'68.9'' S 39°01'759'' W
	15 m	14°45'00.8'' S 39°00'888'' W	14°45'10.0'' S 39°00'848'' W
	20 m	14°45'73.7'' S 39°00'407'' W	14°45'18.0'' S 39°00'465'' W
	25 m	14°44'87.7'' S 39°00'177'' W	14°45'01.0'' S 39°00'137'' W
	30 m	14°44'55.1'' S 38°59'743'' W	14°43'80.0'' S 39°00'235'' W
	35 m	14°42'26.4'' S 39°00'087'' W	14°42'22.2'' S 39°00'107'' W

The biological material collected in each trawl was sorted on board, stored in boxes with crushed ice and taken to the laboratory, where specimens were identified based on specialized literature [11,44] and stored in a refrigerator at 4 °C. Subsequently, the shrimps were (1) sexed by the presence of the telicum (females) or petasma (males) [2], were (2) measured with an analog caliper (0.01 mm) (carapace length—CL: distance between the posterior margin of the eye orbit and the median point of the posterior margin of the carapace) and (3) quantified. Morphological sexual maturity for each species was established using the lowest CL recorded for males that had fully formed petasma and females that had rigid median and telical plates separated by a slit-shaped opening [45,46]. Rock shrimps with CL below the lowest value recorded for morphological maturity were considered immature (i.e., recruits).

It is worthy of note that some specimens deteriorated due to a power outage at the university. These specimens were counted but could not be measured and sexed. Therefore, size classes and sex ratio distribution analyses do not include these individuals, but population analyses do (see Results section for further details).

In the laboratory, sediment samples were dried in an oven at 60 °C for 72 h. The particle size composition was determined by the dry sieving and pipetting method [47], which provides percentages of sandy, silt and clayey fractions for each sample. Grain size was expressed on the phi scale (Φ), which corresponds to the measure of central tendency [48,49]. The gravimetric method proposed by Dean [50] was used to estimate the organic matter (OM) content, as suggested by Couto [51] for coastal sediments.

2.3. Data Analyses

The abundance of *S. dorsalis* or *S. typica* in different depths and months was analyzed with a two-factor analysis of variance (ANOVA) associated with Tukey's multiple comparison test. The assumption of normality (Kolmogorov-Smirnov test) and homoscedasticity (Levene test) were met. Abundance data were logarithm (log10) or square root transformed, according to Gotelli and Ellison [52].

The influence of environmental factors (temperature, salinity, water transparency, pH, dissolved oxygen, organic matter content and phi) on the differential abundance of males and females was analyzed using canonical correspondence analysis (CCA). The significance of the environmental variables ($\alpha = 0.05$) was tested using the ENVFIT function, which obtains the measurement of the coefficients of determination (r^2) for each variable and, through a randomization procedure (999 permutations), tests its significance. The CCA was performed in the R 3.3.1 software [53], with the function available in the Vegan package [54]. All calculations and other statistical analyses were also performed using the R 3.3.1 software [53].

Population dynamics were analyzed through the frequency distribution of male and female individuals, in size classes of carapace length (CL) with 1 mm intervals, determined by the Sturges equation [55]. The normality of frequency distributions for each sex was assessed using the Shapiro-Wilk test ($\alpha: 0.05$). The sex ratio was evaluated in both species using the chi-square test ($\chi^2 - \alpha: 0.05$) with the expected ratio of 1♀:1♂. The mean CL values obtained for males and females of both species throughout the study did not meet the assumptions of normality, therefore they were compared using the non-parametric Mann-Whitney (U) test [52].

3. Results

3.1. Environmental Factors

The environmental variables showed few fluctuations during the study period (Figures S1 and S2 and Table S1). A slight temperature decrease was recorded in June ($25.3\text{ }^\circ\text{C} \pm 0.24$), July ($24.6\text{ }^\circ\text{C} \pm 0.23$) and August 2010 ($25.1\text{ }^\circ\text{C} \pm 0.65$), and from the shallow to the deeper transects. Salinity (36.5 ± 1.77) and conductivity ($55.4\text{ mhos/m} \pm 3.31$) varied little over the months, but tended to increase with increasing depth. Water at all sampling stations was well oxygenated ($5.2\text{ mg/L} \pm 0.81$) and slightly alkaline, or neutral pH (8.1 ± 0.27). Between June and September 2010, the lowest water transparency (June: 2.2 ± 0.58 ; September 2.6 ± 0.88) values and the highest concentrations of chlorophyll-a were recorded (June: $2.1\text{ }\mu\text{g/L} \pm 0.67$; September $2.1\text{ }\mu\text{g/L} \pm 1.61$). Transparency increased while chlorophyll-a levels decreased with depth.

Clay sediment predominates in all transects, but sand is the second predominant type of grain at 5 m and 10 m, while silt is the second type of grain most recurrent in the remaining transects (i.e., 15 to 35 m). Organic matter content increased with increasing depth (Figure S3). Rainfall did not show large variations throughout the study period, but slightly higher volumes were recorded in April (3444.25 mm), July (3523 mm) and December 2010 (2898.5 mm), when higher Almada River flow was also measured (April: $1099.316\text{ m}^3/\text{s}$; July: $650.955\text{ m}^3/\text{s}$; December: $182.961\text{ m}^3/\text{s}$) (Figure S4).

3.2. Spatio-Temporal Distribution of *Sicyonia dorsalis* and *Sicyonia typica*

A total of 5639 individuals were collected, of which 5336 were identified as *Sicyonia dorsalis* and 303 as *S. typica*. No individuals were captured in the three transects sampled within the Almada River estuary. Regarding the spatial distribution, throughout the entire study period, *S. dorsalis* was significantly more abundant at 15, 25 and 35 m depths (df:

211 6; SS: 672.57; MS: 112.10; F: 5.43; $p < 0.001$), while *S. typica* was more abundant at 35 m (df: 212 6; SS: 3.04; MS: 0.51; F: 3.61; $p < 0.01$). For the last species, a high abundance was recorded in March 2010 at 15m. Both species showed few specimens with low abundance or were absent in shallower depths (5 and 10 m) (Figure 2). Temporally, *S. dorsalis* was significantly more abundant in March 2010 and in the last three sampling months (df: 12; SS: 216 1091.03; MS: 90.92; F: 4.40; $p < 0.001$), with the greatest abundance in February 2011, while *S. typica* was most abundant in March 2010 (df: 12; SS: 3.60; MS: 0.30; F: 2.14; $p: 0.02$). Both species were less abundant from April to November 2010 (Figure 3).

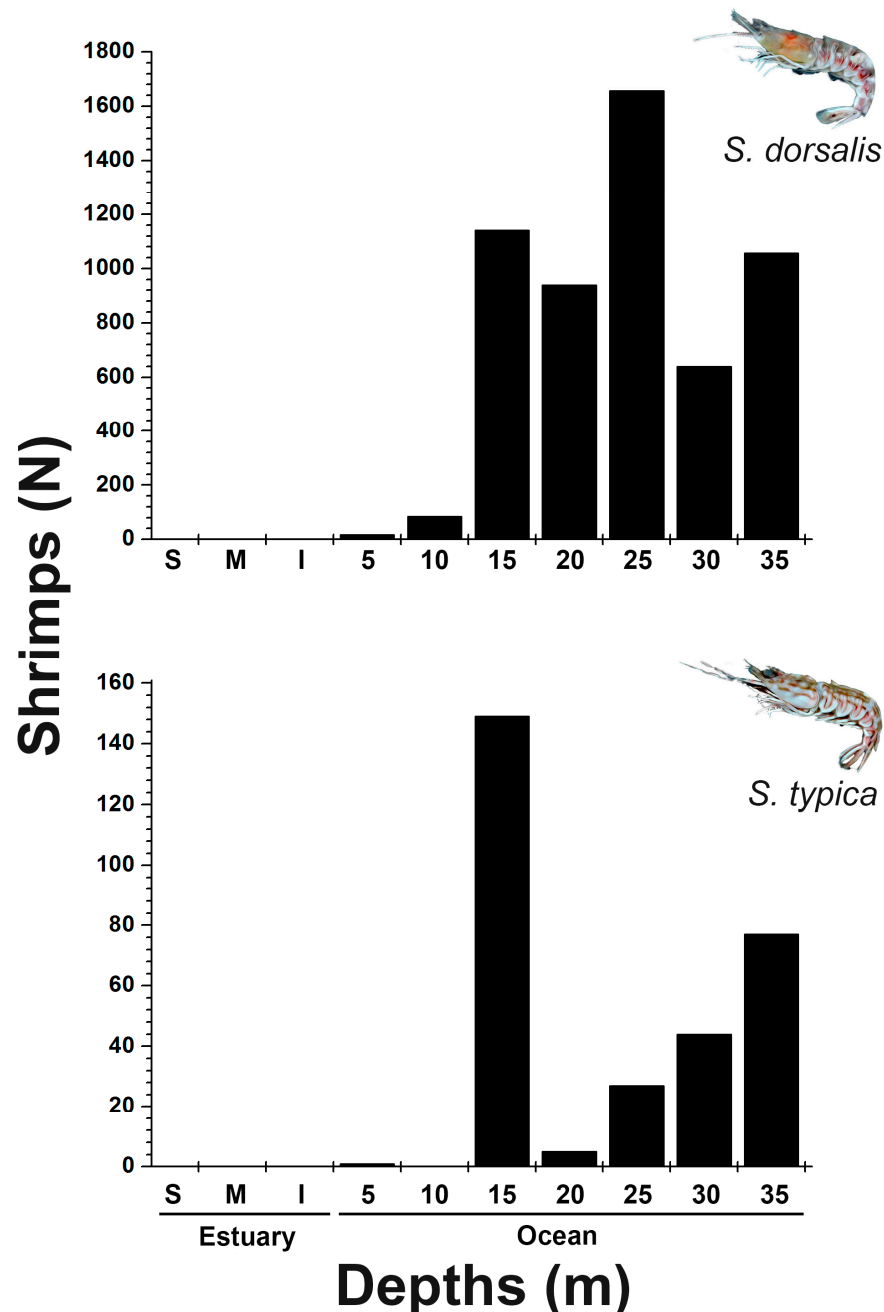


Figure 2. Spatial distribution of *Sicyonia dorsalis* and *Sicyonia typica* collected between February 2010 and February 2011, in the Almada River estuary (upper—S, middle—M and lower—I) and off the mouth of Almada River at depths between 5 and 35 m, in transects perpendicular to the coastline of Ilhéus, Bahia, Brazil.

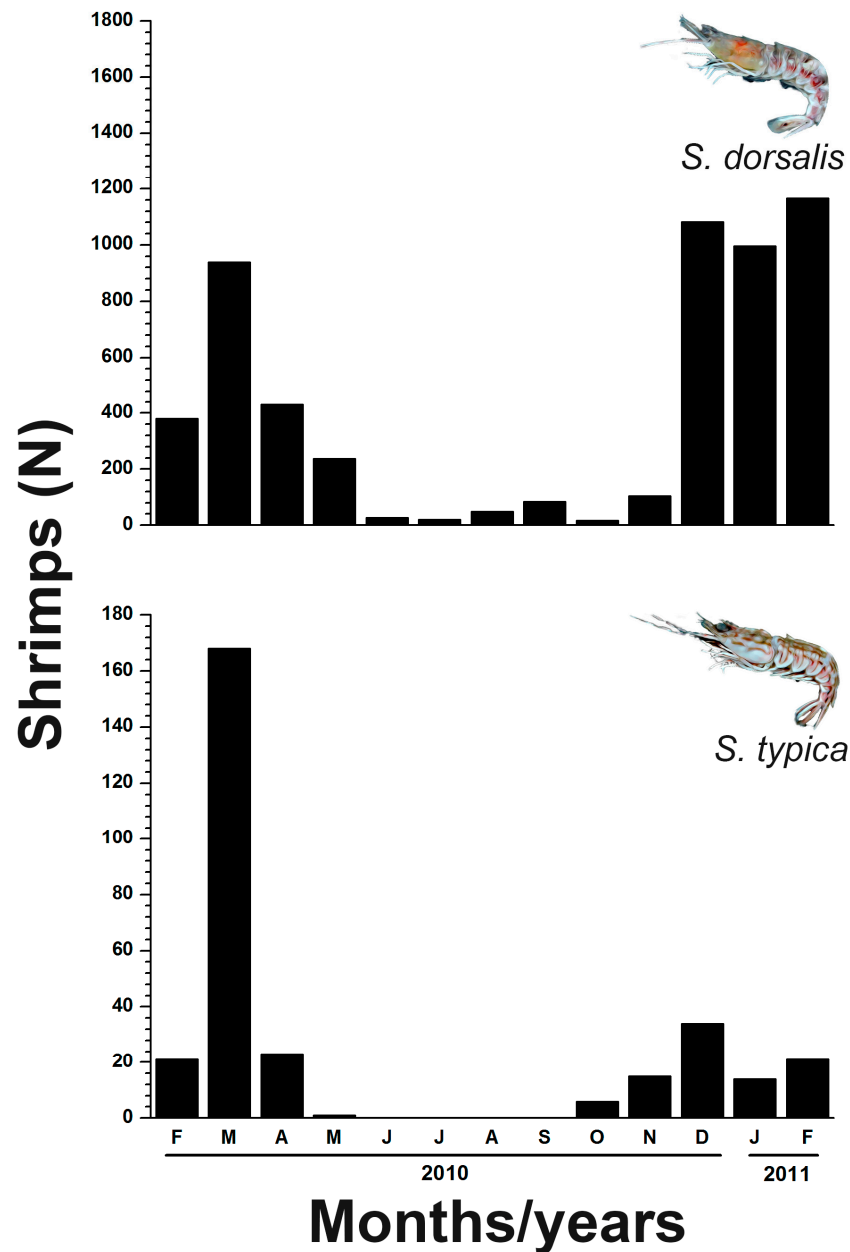


Figure 3. Temporal distribution of *Sicyonia dorsalis* and *Sicyonia typica* collected between February 2010 and February 2011, in the Almada River estuary (upper—S, middle—M and lower—I) and off the mouth of Almada River at depths between 5 and 35 m, in transects perpendicular to the coastline of Ilhéus, Bahia, Brazil.

The first two axes of the CCA explained 93.92% of the data variability in sex distribution of both *Sicyonia* species and environmental variables (Figure 4). Organic matter content in the sediment, as well as water salinity and transparency were the factors that most influenced the distribution and abundance of individuals (Table S2). Both females and males of *S. dorsalis* were more abundant in areas with intermediate depths (10, 20 and 25 m), and greater transparency, oxygenation, temperature and OM content, as well as slightly lower salinity. For *S. typica*, females and males showed differences in their spatial distribution in relation to environmental variables. Females were related to deeper areas (30 and 35 m) with lower temperature, oxygenation and transparency, and slightly higher pH, while males were associated with the intermediate depth (15 m), with higher salinity, lower transparency, and lower OM content.

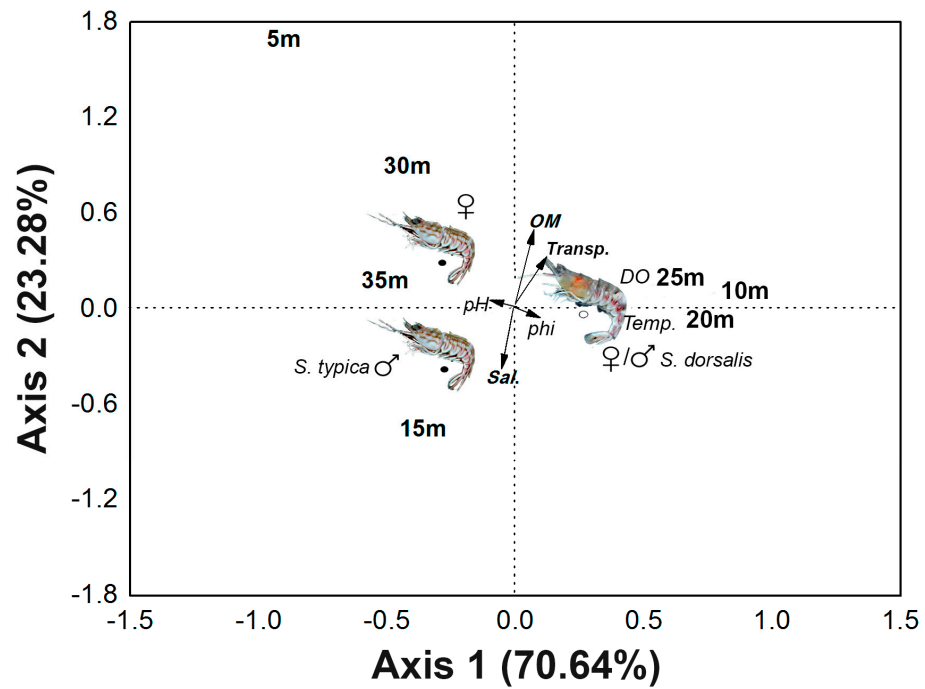


Figure 4. Canonical ordination diagram for individuals of *Sicyonia dorsalis* and *Sicyonia typica*, and environmental data obtained between February 2010 and February 2011, at depths between 5 and 35 m, perpendicular to the coastline off the mouth of the Almada River, Ilhéus, Bahia Brazil. (OM: Organic Matter; Transp: Transparency; DO: Dissolved Oxygen; Temp: Temperature; Salt: Salinity).

3.3. Frequency Distribution by Size Classes

Due to sample loss (see Section 2 “Material and Methods”), the number of individuals used in the size analyses was smaller than the total captured. For *S. dorsalis*, 2328 individuals were sexed and measured, 1777 females and 551 males. The mean carapace length (CL) was 9.83 ± 0.98 mm for females (CL range: 4.43 to 14.3 mm) and 8.41 ± 0.91 mm for males (CL range: 4.25 to 12.79 mm). For *S. typica*, 132 specimens were analyzed, 73 females with 14.06 ± 1.09 mm, ranging from 10.98 to 17.48 mm CL, and 59 males with 12.45 ± 0.80 mm, ranging from 9.37 to 14.7 mm CL. Females were significantly larger than males in *S. dorsalis* (U: 176041, $p < 0.001$) and *S. typica* (U: 2475, $p < 0.001$) (Figure 5).

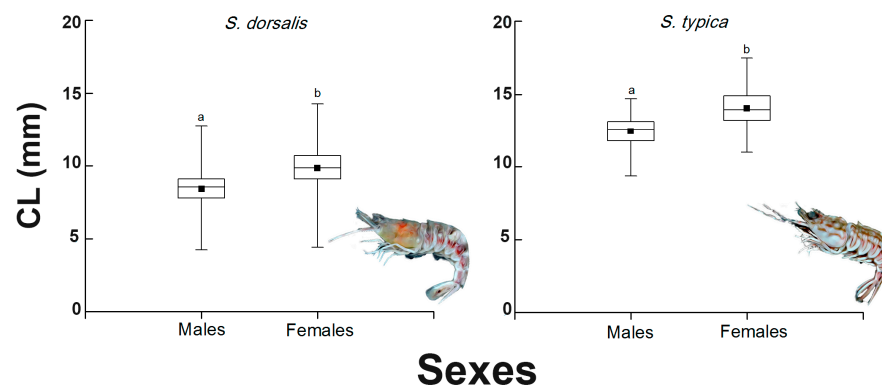


Figure 5. Minimum and maximum values (whiskers), means (black squares) and standard deviation (boxes) of carapace length for *Sicyonia dorsalis* and *Sicyonia typica* collected between February 2010 and February 2011, at depths between 5 and 35 m, perpendicular to the coastline off the mouth of the Almada River, Ilhéus, Bahia Brazil.

The grouped distribution by size classes (disregarding time series), for both *S. dorsalis* and *S. typica*, showed a unimodal pattern. The distribution was non-normal for both

sexes in *S. dorsalis* ($\sigma = W: 0.73—p: 0.002$; $\text{♀} = W: 0.76—p: 0.003$) and *S. typica* males ($\sigma = W: 0.81—267 p: 0.03$). Only females of the latter species showed normality in frequency distributions ($\text{♀}268 = W: 0.94—p: 0.62$). For *S. dorsalis*, the 9–10 mm size class was most frequent among females, while the 8–9 mm size class was most common among males. For *S. typica*, the 13–14 mm size class was most common for females and the size class 12–13 mm was most common for males. In both species, the frequency peaks of females and males were close to each other (Figure 6).

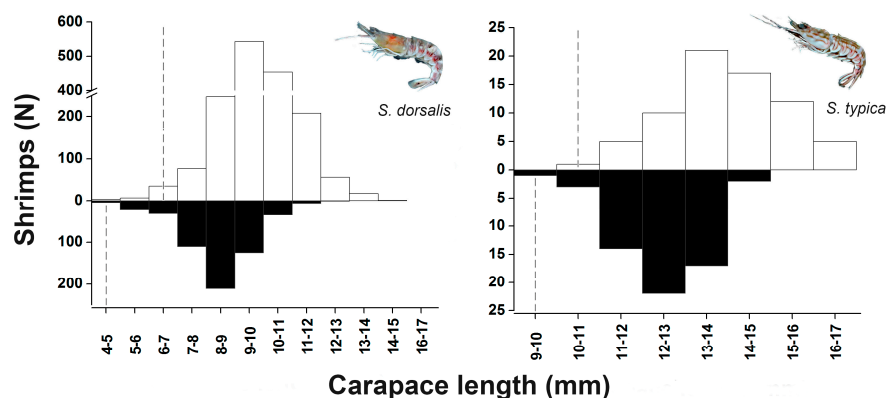


Figure 6. Accumulated frequency distribution of female (white) and male (black) individuals of *Sycionia dorsalis* and *Sycionia typica* by carapace length classes collected between February 2010 and February 2011, at depths between 5 and 35 m, perpendicular to the coastline off the mouth of the Almada River, Ilhéus, Bahia Brazil. The dashed lines indicate the recruitment of juveniles into the population.

Both species showed bimodal or polymodal patterns in their spatial and monthly size class frequency distributions. As for the spatial distribution, the two species were practically absent in the shallowest stations (5 and 10 m). *Sycionia dorsalis* was most abundant at 25 m, but also presented high abundance at 15, 20 and 35 m, while *S. typica* was most abundant from 15 and 35 m (Figure 7). In the temporal analyses, we observed two frequency peaks for *S. dorsalis*, the first peak between February and April 2010, followed by a drastic decrease from May 2010 to November 2010, and a second peak from December 2010 to February 2011, where females were more abundant. In *S. typica*, a similar pattern was observed; however, it had far lower abundances and an absence of animals from May to September 2010 (Figure 8).

The smallest morphologically mature male and female showed 4.4 and 6.4 mm CL for *S. dorsalis*, respectively, and 9.7 and 10.1 mm CL for *S. typica*, respectively. Only 1% of individuals sampled for both species were recruits. All *S. dorsalis* recruits were captured in February 2010. One immature male of *S. dorsalis* was captured at 15 m. The immature females of *S. dorsalis* (N: 21) were distributed between 15 to 35 m. While for *S. typica*, one immature male was captured at 25 m and one immature female was captured at 15 m, both collected in March 2010 (Figures 6–8).

3.4. Sex Ratio

Sycionia dorsalis females were predominant ($3.01\text{♀}:1\text{♂}—\chi^2: 276.13; p < 0.001$), while for *S. typica*, the sex ratio was close to $1\text{♀}:1\text{♂}$ ($1.20\text{♀}:1\text{♂}—\chi^2: 0.55; p: 0.05$). Regarding time series, a similar pattern was observed for both species, with a deviation in favor of males only in the first sampling months. In the remaining months, females were more abundant (Figure 9A). In relation to depth, *S. dorsalis* females were predominant in all collection points. The same was observed for *S. typica*, with the exception of depths of 15 and 20 m, where males were predominant (Figure 9B). In relation to the size classes, the deviation was in favor of males in the lower classes, and females in the higher size classes (Figure 9C).

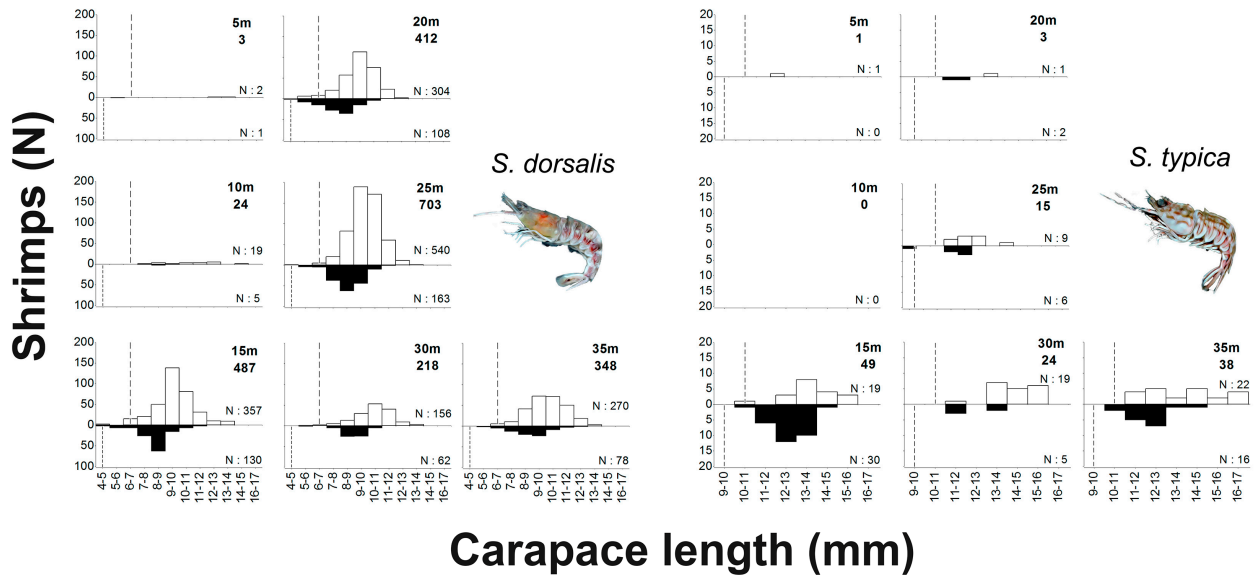


Figure 7. Spatial distribution of the frequency of female (white) and male (black) individuals of *Sicyonia dorsalis* and *Sicyonia typica*, by size classes collected between February 2010 and February 2011, at depths between 5 and 35 m, perpendicular to the coastline off the mouth of the Almada River, Ilhéus, Bahia Brazil. Values in bold correspond to the total number of animals captured in each month. The dashed lines indicate the recruitment of juveniles into the population.

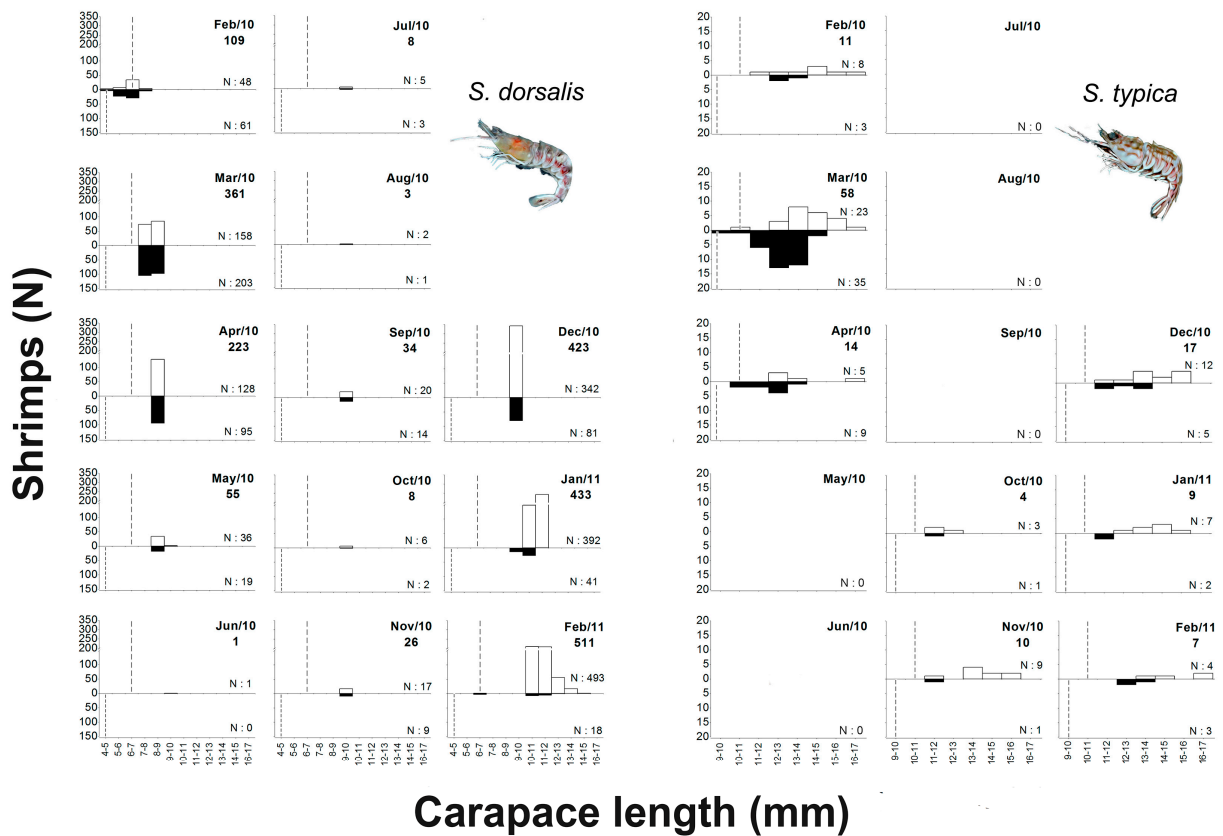


Figure 8. Monthly distribution of the frequency of female (white) and male (black) individuals of *Sicyonia dorsalis* and *Sicyonia typica*, by size classes collected between February 2010 and February 2011, at depths between 5 and 35 m, perpendicular to the coastline off the mouth of the Almada River, Ilhéus, Bahia Brazil. Values in bold correspond to the total number of animals captured in each month. The lines indicate the recruitment of juveniles into the population.

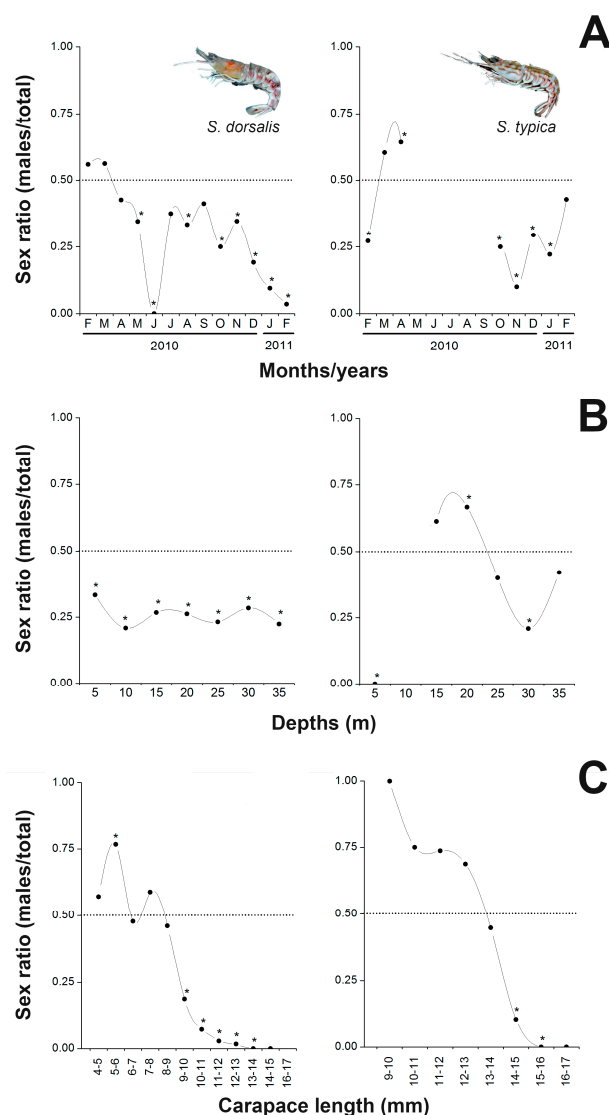


Figure 9. Sex ratio (males/total individuals) monthly (A), spatial (B) and by size classes (C) of individuals of *Sicyonia dorsalis* and *S. typica* collected between February 2010 and February 2011, at depths between 5 and 35 m, perpendicular to the coastline off the mouth of the Almada River, Ilhéus, Bahia Brazil. * Statistically significant at $p < 0.05$.

4. Discussion

Sicyonia dorsalis and *S. typica* showed similar spatio-temporal distribution and sex ratio patterns. Both species were absent in the Almada River estuary. In the coast, the sicyoniids presented a bimodal distribution with peaks in summer months and a predominance of females in the population. However, despite being congeneric and sympatric species, they showed differences in body size, spatio-temporal abundance and preference in relation to space occupation in response to environmental variables. These differences are possibly related to avoidance of niche overlap.

The absence of sicyoniids in the estuary is related to the life cycle of these animals [15,16,35]. Among the four types of life cycle proposed by Dall et al. [21] for shrimps, sicyoniids fall into type III—exclusively oceanic, with the post-larval stage occurring outside estuaries, in protected waters close to the coast with higher salinities.

Along the bathymetric gradient sampled, *S. dorsalis* was considerably more abundant than *S. typica*. This may be related to the depths sampled herein, since *S. typica* appears to be more abundant in deeper areas [36,56], while *S. dorsalis* is more frequent in shallower

waters [15,35]. Previous works conducted along the Brazilian coast have shown that *S. dorsalis* is predominant or exclusive in shallower areas up to 20 m [7–9,19,20,57–60], while *S. typica* was collected exclusively deeper than 30 m [56]. The previously mentioned works, with the exception of Vasques et al. [8], who conducted their study in the northeastern region (Bahia state—tropical zone), focused on the Southeastern (São Paulo and Rio de Janeiro states) and Southern (Santa Catarina and Paraná states) regions of Brazil, most of them in the subtropical zone of this country. Our results suggest that the abundance of *S. typica*, although small, increases with depth, which was also observed by Pralon [36] on the northern coast of São Paulo state (subtropical zone). In the present study, the highest abundance of this species was recorded at 15 m. It was due to the large number of specimens obtained in March 2010. The two species were practically absent at shallower depths (5 and 10 m), which was not expected for *S. dorsalis*. Our data also showed that, unlike what was recorded for higher southern latitudes [15,35], *S. dorsalis* is present with high abundances in areas up to 35 m deep, overlapping the distribution of *S. typica*.

The few or no specimens of the two species found in shallower depths (5 and 10 m) may be related to the granulometry (i.e., higher proportion of sand and lower of clay < 60%). The highest clay fraction (75%) was at 15 m depth, and all deeper stations (20 to 35 m) show clay percentages above 65%. The silt fraction also increases as depth increases, being less than 10% in the two shallower transects (5 and 10 m) and greater than 25% in the deeper areas (Figure S3). Thus, the difference between our data and those obtained for the northern coast of São Paulo [15,35], which showed greater abundances of *S. dorsalis* in shallower waters, may be better related to the sediment type, rather than depth. The importance of the fine fraction for these species is highlighted by Piantkoski et al. [34], who found higher abundances at their deepest station (at 15 m), which showed a larger proportion of fine sediment. In the present study, we sampled a wider depth range (5 to 35 m) and covered a longer period, and higher abundance was recorded in areas with the highest phi, where higher percentage of silt and clay were observed. Therefore, we suppose that for both species, the particle size is more important than depth, although *S. typica* tends to be slightly more abundant at greater depths.

Additionally, higher abundances have been associated with high organic matter content in the sediment, which is an important resource for crustaceans [21]. As a consequence, sicyoniid shrimp are more abundant in areas with a higher percentage of organic matter, which accompanies the greater fraction of finer particles, since they retain large amounts of organic matter [15,34,36]. However, Costa et al. [35] suggested that the organic matter does not seem to play an important role in the distribution of these shrimp species in southeastern Brazil.

The sicyoniid species studied herein were significantly more abundant in areas deeper than 25 m. In Ilhéus, seabob shrimp (*Xiphopenaeus* spp.) are mostly trawled manually from small vessels and usually in areas shallower than 20 m [61]. Therefore, the impact of fishing on sicyoniid populations is possibly smaller compared to other organisms that occupy shallower depths.

The abundance of *S. dorsalis* and *S. typica* presented two peaks, which were interspersed by a period of drastic decrease in the monthly frequency of individuals. The decreased abundance between the two peaks coincided with the greatest rainfall and, consequently, with the highest flow recorded for the Almada River (see Figure S4 in Supplementary Materials). We therefore suggest that a greater river discharge may impact the distribution of these species in two ways. Firstly, the water mass brings a large supply of nutrients, increasing primary productivity and the concentration of chlorophyll-a in the water column, and low water transparency. Consequently, less light reaches the bottom, inhibiting the growth of microphytobenthos, reducing the food resources for the shrimps.

Secondly, the higher precipitation and river flow causes a reduction in salinity, which negatively affects the exclusively marine sicyoniid shrimps. In this way, lower salinities could act as ecological and physiological barriers, preventing their representatives from inhabiting areas under freshwater influence, and forcing their displacement to deeper areas further away from the river mouth.

Temperature is another relevant environmental factor for the distribution of peneoids, being directly related to feeding, growth, reproduction, movement and survival dynamics of these animals [21]. On the coast of São Paulo (southeastern Brazil), the migration of *S. dorsalis* appears to be associated with the intrusion of the South Atlantic Central Water (ACAS) (temperature < 20 °C and salinity < 36) [15]. Although salinity has fluctuated little in our study area at the depths at which these two species are most abundant, there is a drop in temperature that can act as an inhibitory factor for the presence of these shrimps in the period of lower abundance. The relationship between abundance and temperature observed in the present work was similar to the pattern observed on the coast of southeastern Brazil [15,34–36].

Females of both species had a higher CL than males, which is considered the most common pattern among peneoid shrimps [28]. The larger dimensions reached by females would be directly related to the optimization of reproductive success, since larger females tend to produce more oocytes and be more effective in reproduction [62,63]. This morphometric pattern was also recorded for *S. dorsalis* [16] and *S. typica* [36] on the coast of São Paulo (southeastern Brazil).

Sycionia typica shows a larger carapace length than *S. dorsalis* both in the present study and on the northern coast of São Paulo, where females of *S. typica* had an average of 12.28 ± 2.57 mm CL (range: 5.3 to 20 mm CL) and males had an average of 10.62 ± 2.28 mm CL (range: 4.8 to 18.4 mm CL) [36], while *S. dorsalis* presented females with an average of 9.4 ± 1.7 mm CL (range: 3.2 to 19.5 mm CL) and males with an average of 7.0 ± 1.8 mm CL (range: 3.5 to 14.4 mm CL) [16]. As expected by Bergman's rule [64], the maximum values recorded for the two species were higher in São Paulo state (southeastern Brazil, subtropical zone) and may be related to environmental factors (e.g., temperature, salinity, among others) as well as intrinsic factors (e.g., longevity, late maturity, among others). However, it is interesting to note that the CL average values were higher in Bahia state (northeastern Brazil—tropical zone), with a distribution of individuals concentrated in the bigger size classes, suggesting a greater participation of large adults at the population, or a size selection bias due to the mesh used (15 mm on the northern coast of São Paulo state and 28 mm in Bahia state). Such selection bias could also explain the low representation of immature individuals (recruits) in the population, which made it impossible to observe recruitment pulses during the study period. However, previous work suggests that tropical and subtropical sicyoniid shrimps present continuous recruitment throughout the year with peaks in certain months [16,36,46,65].

According to Fisher [30], the expected sex ratio for species without parental care is 1♀:1♂, since the effort invested in the production of both sexes must be the same. However, the skewed sex ratio for females in this work shows that rock shrimp are yet another exception to this rule, as proposed by Wenner [29]. The author pointed out that this deviation from the expected ratio is common for marine crustaceans and associated this variation with factors related to the life cycle, such as differential growth rates, migration and mortality between the sexes. Furthermore, Wenner [29] classified crustaceans into four sex ratio types according to the body size: common, reverse, intermediate and anomalous. The reverse pattern fits better both *Sycionia* species analyzed herein, where males are more common in smaller size classes and decrease in abundance or even disappear as females become more abundant in larger size classes.

Castilho et al. [16] also found a deviation in favor of females in *S. dorsalis*, and proposed three hypotheses: (i) capture bias—males are smaller than females and would escape the net more easily. However, both their data and ours indicated that deviation remains in favor of females and also exists in larger size classes, where both sexes were collected; (ii) the reproductive behavior of the species—Bauer [66], when analyzing the reproductive behavior of *S. dorsalis* in the laboratory, observed that this species is polyandrous and polygynous (i.e., both sexes copulate with more than one partner). The author suggested that such behavior probably favors the deviation of the sex ratio in favor of females; (iii) *Sycionia dorsalis* can possibly present protandrous hermaphroditism, since the number of males decreases after a certain carapace length, which could mean a sex change as the animal grows. However, protandrous hermaphroditism was only recorded for carid shrimps [67–69], with no record for peneoids [16,46].

5. Conclusions

In this study, we observed that the spatial distribution of *Sycionia dorsalis* and *S. typica* on the coast of Ilhéus (Bahia state) was strongly related to finer grain size and the OM rich sediment. Furthermore, temperature, salinity and rainfall, together with the flow of the Almada River, interferes with water transparency and chlorophyll-*a* levels, directly influencing the distribution of both species on a temporal scale. Regarding population dynamics, the two species followed a similar pattern to that recorded for the southeastern region of Brazil, with a predominance of females that are larger than males, and in the study area, both species are larger than the animals from southeastern Brazil. Therefore, from the information presented here, it will be possible to evaluate future environmental scenarios, mainly regarding the impacts of trawling on these animals, as well as outline management and conservation strategies for both species for Bahia state. However, more studies are needed to evaluate details of the reproductive biology, growth and longevity of *Sycionia dorsalis* and *Sycionia typica*.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/arthropoda3010001/s1>, Table S1—Environmental factors and abundance of *Sycionia dorsalis* and *Sycionia typica* recorded at each transect and month of river Almada, Ilhéus, Bahia, Northeastern Brazil; Table S2—Results of the Canonical Correspondence Analysis (CCA) and coefficient of determination (r^2) for environmental variables (descriptors) of the sampling sites in Almada River (Bahia state, northeastern Brazil), and significance of correlations obtained by the ENVFIT function (999 permutations). Values in bold are significant at <0.05. This data was used in Figure 4; Figure S1—Monthly variation of environmental factors analyzed between February 2010 and February 2011 in Ilhéus, Bahia, Brazil; Figure S2—Spatial variation of environmental factors analyzed between February 2010 and February 2011, at depths between 5 and 35 m, perpendicular to the coastline off the mouth of the Almada River, Ilhéus, Bahia, Brazil; Figure S3—Characteristics of the sediments analyzed between February 2010 and February 2011, at depths between 5 and 35 m, perpendicular to the coastline in front of the mouth of the Almada River, Ilhéus, Bahia, Brazil; Figure S4—Monthly accumulated rainfall volume in the coastal region of Ilhéus and monthly accumulated flow of the Almada River, Bahia, Brazil, analyzed between February 2010 and February 2011.

Author Contributions: Conceptualization, E.d.C.G.C., S.N.B. and F.J.G.; methodology, L.R.P.P., R.G.T. and F.J.G.; software: L.R.P.P.; validation, R.G.T., L.R.P.P., E.d.C.G.C. and F.J.G.; investigation, R.G.T., L.R.P.P., E.d.C.G.C. and F.J.G.; data curation, R.G.T., L.R.P.P., E.d.C.G.C. and F.J.G.; writing, all authors; supervision, R.G.T., L.R.P.P., E.d.C.G.C. and F.J.G.; project administration, E.d.C.G.C., S.N.B. and F.J.G. All authors have read and agreed to the published version of the manuscript.

Funding: This study was funded by the Fundação de Amparo à Pesquisa do Estado da Bahia (FAPESB). R.G.T. was supported by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES, Brazil) [88887.606746/2021-00 and 88887.842662/2023-00]. LRPP was supported by the São Paulo Research Foundation (FAPESP) [#2022/09727-0].

Data Availability Statement: All data are included in this manuscript.

Acknowledgments: This study was financed by the postdoctoral fellowship (2194/2010) to FJG by the Fundação de Amparo à Pesquisa do Estado da Bahia (FAPESB) and complied with the Brazilian environmental legislation (MMA-ICMbio, license 20315-1). The first author would like to thank the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES, Brazil) for the master's scholarship (88887.606746/2021-00) and the ongoing doctoral scholarship (88887.842662/2023-00) associated to the Graduate Program in Zoology (PPGZOO) from the State University of Santa Cruz (UESC). LRPP acknowledges the São Paulo Research Foundation (FAPESP) for his postdoctoral fellowship 2022/09727-0.

Conflicts of Interest: The authors declare no conflicts of interest.

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