Seasonal variation in body size and diet of the sea star *Astropecten marginatus* (Paxillosida, Astropectinidae) off coast of Paraná, Southern Brazil

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Abstract: The sea star *Astropecten marginatus* has a neotropical distribution and is a highly abundant and frequent species in shrimp trawling by-catchin many places along the Brazilian coast. This has caused its threat to extinction and in addition, its bio-ecological aspects are poorly known. Thus, the main objective of this study was to analyze the seasonal variations of population length structure and feeding habits of the sea stars *A. marginatus* inhabiting off state of Paraná, Southern Brazil. The analyzed specimens were collected in February (summer), April (fall), June (winter) and October (spring) of 2008 from shrimp by-catch trawling. In the laboratory, each individual had its length measured and then weighed on an analytical scale. Afterwards, the stomach contents of 10 individuals of each of two most frequent length classes were seasonally analyzed. The relative frequency and abundance for each prey category was determined and, then combined into an index of alimentary importance. A total of 994 individuals of *A. marginatus* were collected with length ranging from 7.0 to 56.2mm, but most individuals were in the 20.1-25mm length classes. Individuals larger than 40mm were only collected in the spring while a few recruits (<10mm) were found in fall and winter. The total weight of individuals ranged from 0.1 to 15.3g and the weight-length relationships showed a negative allometric growth (b<2.54). Regarding its food consumption, this sea star explored eleven food items, with cumaceans and mollusks as the most frequent items. High frequency of empty stomach was recorded at fall. Seasonal differences in the amount explored preys and ingested items as well as in the prey composition were also observed. Higher amount of explored prey categories and ingested items were recorded at winter-spring than summer-fall periods. Predominance in prey category changed from gastropods (summer and fall) to cumaceans (winter and spring). The importance of gastropods as main prey category at summer and fall should be carefully considered since it was coincidently observed with high frequency of empty stomach and low amount of ingested items. The observed seasonal differences in feeding behavior pattern were mainly associated to low prey availability and to changes in the sea star feeding rates, and probably reflected in some biological traits such as small body size of the population inhabiting waters off the Paraná coast, Southern Brazil. Rev. Biol. Trop. 62 (1): 59-68. Epub 2014 March 01.

Key words: Asteroidea, Echinodermata, population length structure, food items, seasonal variation, prey availability.

The seastars (Echinodermata, Asteroidea) are predominantly carnivorous generalists (Sloan, 1980). They inhabit different types of substrates and have an important role as high-level predator in intertidal and subtidal communities (Jangoux, 1982; Ganmanee, Narita, Iidas, & Sekiguchi, 2003).

The order Paxillosida has ambulacral feet without suckers and an incomplete digestive tract, morphological features considered

primitive (Jangoux, 1982; Blake, 1987, 1989), although some molecular studies show the opposite (Matsubara et al., 2005, Janies, Voight, & Daly, 2011; Mah & Foltz, 2011). Regarding their feeding habits, the paxillosids swallow their prey whole digesting it inside the stomach cavity and, this intraoral digestion reflects an adaptation to life in soft-bottom substrates (Blake, 1987; Ventura, 2013).

Members of the family Astropectinidae, including the genus *Astropecten* (Gray, 1840), inhabit tropical, subtropical and temperate waters (Bitter & Penchaszadeh, 1983; Soto, 2000; Loh & Todd, 2011). This genus is exclusively carnivorous and an active predator with a generalist diet, and has negative effects on the density of its prey (Jangoux, 1982). These organisms are able to find and capture their preferred prey buried into the sediment (Wells, Wells, & Gray, 1961; Bitter & Penchaszadeh, 1983). The selectivity of its prey is influenced by several factors such as the prey size, which depends on its body size and constraints imposed by the mechanism of intraoral digestion (Ventura, Grillo, & Fernandes, 2001). The availability of prey also exerts influence on the diet, as their distribution and abundance are determined by environmental conditions (McClintock & Lawrence, 1985; Beddingfield & McClintock, 1993; Monteiro & Pardo, 1994; Gaymer, Himmelman, & Johnson, 2001; Gil & Zaixso, 2008). The genus *Astropecten* is able to distinguish the "quality" of their prey using its chemo-receptive abilities (Sloan, 1980) and thus to select prey with higher nutritional quality and energy (Beddingfield & McClintock, 1993). As a consequence, it is the most specialized trophic group of asteroids (Jangoux, 1982).

Astropecten marginatus (Gray, 1840) has a neotropical distribution (Caribbean Sea to the extreme South of Brazil, the State of Rio Grande do Sul) inhabiting sandy substrates between depths of one to 130m (Tommasi, 1970; Jangoux, 1982; Clark & Downey, 1992). Due to its high frequency and abundance, the species is considered an important item in shrimp by-catch fisheries (Kotas, 1998; Branco & Verani, 2006) and, it is threatened with extinction in many Brazilian coastal states (MMA, 2004). Despite its abundance and importance, knowledge on the biology and ecology of *A. marginatus* is scarce. Some biometric and ecological information about this species may be found in studies off the coast of Venezuela (Roa, 1967), Brazil (Tommasi, 1970; Monteiro & Pardo, 1994), and Suriname (Walenkamp, 1976, 1979). Furthermore, species feeding habits had only been studied for populations off Venezuelan (Soto, 1984; Ortega, Martín, & Díaz, 2011) and Southeastern Brazilian coasts (Monteiro & Pardo, 1994).

The main objective of this study was to analyze the seasonal variations in the population length structure and in prey composition of sea stars *Astropecten marginatus* inhabiting off state of Paraná, Southern Brazil.

MATERIALS AND METHODS

The coast of Paraná is characterized by a shallow continental shelf with a smooth topographic gradient (Veiga, 2005). The substrate is mostly sand, mud and clay from continental and fluvial origin (Angulo, 1992; Lorenzi, 2004). The climate is classified as *Cfa*, according to Köppen-Geiger (i.e., rainy temperate [C], raining all year around [f] and average temperature of the warmest month above 22°C[a]) (Maack, 1968; Vanhoni & Mendonça, 2008).

The analyzed specimens of *A. marginatus* were taken from the by-catch of artisanal sea-bob shrimp *Xiphopenaeus kroyeri* (Heller, 1862) fishery carried out off the coast of Paraná. In this region, shrimp trawling are normally carried out at depths ranging from five to 25m (Andriguetto-Filho, 1999). Samples were collected in February (summer), April (fall), June (winter), and October (spring) of 2008, by local fishers always at Shangri-lá beach (25°37'20" S - 48°24'36" W). Specimens of *A. marginatus* were separated from the rest of the by-catch and immediately fixed in formalin (10%).

In laboratory, the length of each individual was measured from the center of the disc to the end of its longest arm with a caliper (0.05mm

precision). Each specimen was dried on paper towel and then weighed with an analytical scale (0.1mg precision). The specimens of *A. marginatus* were grouped into different length classes at intervals of 5mm, which was determinate by Sturges' Rule (Sturges, 1926).

The weight-length relationship was estimated by least square regressions with preceding ln-transformation of dependent (weight in g) and independent (length in mm) for each season. Regressions coefficients were tested for significant deviations from zero (ANOVA). Slopes of different regression equations were compared with each other employing multiple ANCOVA and, intercepts with the Y-axis with an ANOVA (i.e., after removal of the interaction term).

Furthermore, ten individuals of each one of two most frequent length classes (i.e., Class IV=20.1-25mm and Class V=25.1-30mm) were separated to analyze stomach contents. We adopted this procedure because some length classes were either not observed or did not have enough individuals at all sampling periods. The stomach of each individual was removed through an incision in the aboral region and transferred to Petri dishes where the items were identified and quantified under a stereo microscope. The relative frequency (F%=number of stomachs contained item "*i*"/total number of stomachs) and abundance (N%=total number of individuals of item "*i*"/total individuals of all items) for each prey category was determined (Hyslop, 1980). These two frequencies were combined into an index of alimentary importance: AI=(F%*N%)/Σ(F%*N%), modified from the equation of Kawakami & Vazzoler (1980). Differences in both number of prey categories types and number of ingested items among individuals of different length classes and sampling periods were determined using a two-way ANOVA. All data were tested for normality (Kolmogorov-Smirnov test) and homogeneity of variances (Cochran test) prior to their use in statistical tests (Underwood, 1997). The number of ingested items were transformed to log(x+1) to assure variance homogeneity and normal distribution. In cases in which the ANOVA result was significant ($p<0.05$), Tukey's multiple comparison test was applied to determine specific differences (Underwood, 1997). The similarity in the *A. marginatus* food items between two most frequent length classes and among sampling periods were assessed by applying the Simplified Morisita index (Horn, 1966). A suitable coefficient for proportion analyses with little influence of the sample size (Krebs, 1999), on the AI values of each item, where the results were displayed in the form of UPGMA clustering method dendrogram. In a complementary way, a two-way PERMANOVA was used to test the null hypothesis of no difference in prey composition among length classes and sampling periods (Anderson, 2001).

RESULTS

A total of 994 *Astropecten marginatus* were collected with length ranging from 7.0 to 56.2mm. Most of them were in the 20.1-25mm length classes (i.e., 31.2% of total individuals). Individuals larger than 40mm were only collected in the spring while a few recruits (<10mm) were found in fall and winter (Fig. 1). Total weight of individuals ranged from 0.1 to 15.3g. All weight-length relationships were highly significant ($p<0.01$), with coefficient of determination ranging around 0.95 (Table 1). Seasonal differences in regression slopes were not significant (ANCOVA: df=3, f=0.41, p=0.75) and, the observed values ($b<2.54$) indicate a negative allometry.

From the 80 stomachs analyzed, 19% were empty. The highest frequency of empty stomachs was observed at fall (Table 2). In general, *A. marginatus* explored eleven prey categories and, cumaceans and mollusks were the most frequents (Table 2). Higher mean values of explored prey categories (ANOVA, df=3, F=12.28, $p<0.001$) and ingested items (df=3, F=15.54, $p<0.001$) were observed in the individuals collected at winter-spring than summer-fall ones (Fig. 2).

The seasonal analysis of the diet of the two most common length classes showed the

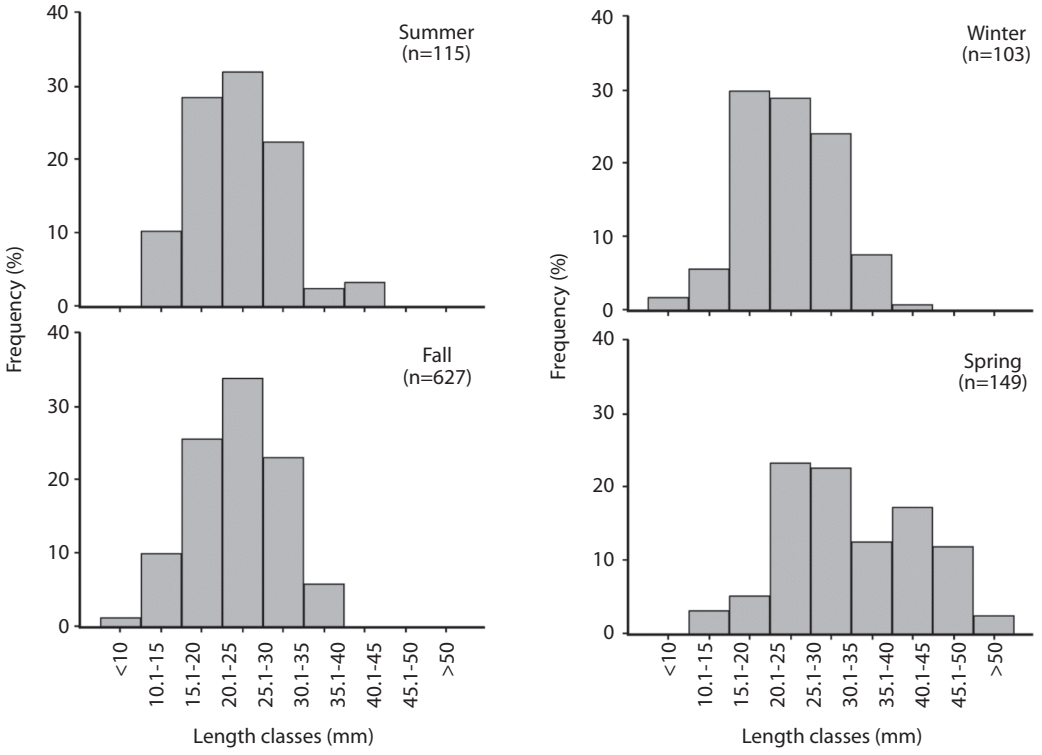

Fig. 1. Histograms of length distribution of *Astropecten marginatus* collected at Paraná coast in each season of 2008.

TABLE 1
Parameters of linear regressions with preceding ln-transformation of dependent (weight in g) and independent (length in mm) variable describing weight/length relationships for *Astropecten marginatus* collected at the state of Paraná, Brazil in each season of 2008

Season	Intercept (CI)	Slope (CI)	N	R^2
Summer	-7.21 (-7.50 / -6.92)	2.49 (2.39 / 2.58)	115	0.96
Fall	-7.29 (-7.43 / -7.14)	2.54 (2.49 / 2.59)	627	0.95
Winter	-7.22 (-7.54 / -6.90)	2.50 (2.40 / 2.60)	103	0.96
Spring	-7.16 (-7.48 / -6.85)	2.50 (2.41 / 2.60)	149	0.95

CI: Confidential intervals, N: number of observations, R^2: coefficient of determination.

existence of two groups (Fig. 3). The first group comprises individuals collected during the summer and fall, and had gastropods as main food item (AI>0.78; Table 2). Those collected in spring and winter, which had cumaceans as main food item (AI>0.62; Table 2), were placed together in another group (Fig. 3). In addition, this analysis reveals no differences between two length classes. Also, prey composition was significantly different among individuals collected at spring-winter and summer-fall (PERMANOVA, pseudo-F=10.181,

TABLE 2
Prey composition of two predominant length classes of *Astropecten marginatus* collected in each season of 2008 at the state of Paraná, Brazil

Prey categories	Summer						Fall						Winter						Spring					
	Class IV			Class V			Class IV			Class V			Class IV			Class V			Class IV			Class V		
	%F	%N	AI	%F	%N	AI	%F	%N	AI	%F	%N	AI	%F	%N	AI	%F	%N	AI	%F	%N	AI	%F	%N	AI
Gastropoda	0.60	0.56	0.78	0.70	0.56	0.79	0.40	0.67	0.82	0.50	0.74	0.89	0.50	0.09	0.06	0.50	0.09	0.05	0.20	0.03	0.01	0.50	0.07	0.06
Bivalvia	0.30	0.25	0.17	0.30	0.25	0.15	0.20	0.26	0.16	0.20	0.21	0.10	0.90	0.20	0.24	0.50	0.14	0.09	0.70	0.13	0.13	0.70	0.23	0.27
Cumacea	0.10	0.06	0.01	0.10	0.06	0.01	-	-	-	0.10	0.05	0.01	0.80	0.61	0.66	0.90	0.76	0.86	0.80	0.73	0.81	0.60	0.59	0.62
Amphipoda	-	-	-	-	-	-	-	-	-	-	-	-	0.40	0.07	0.04	0.10	0.01	<0.01	-	-	-	-	-	-
Isopoda	-	-	-	-	-	-	-	-	-	-	-	-	0.10	0.01	<0.01	-	-	-	0.10	0.01	<0.01	0.30	0.06	0.03
Brachyura	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.10	0.01	<0.01
Tanaidacea	-	-	-	-	-	-	0.10	0.07	0.02	-	-	-	-	-	-	-	-	-	0.40	0.10	0.05	0.20	0.04	0.01
Ophiuroidea	-	-	-	-	-	-	-	-	-	-	-	-	0.10	0.01	<0.01	-	-	-	-	-	-	-	-	-
Pycnogonida	-	-	-	-	-	-	-	-	-	-	-	-	0.10	0.01	<0.01	-	-	-	-	-	-	-	-	-
Echinoidea	0.10	0.06	0.01	0.20	0.13	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fish (Larvae)	0.10	0.06	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Empty stomachs		20%			20%			60%			30%			-			-			10%			10%	

F%: relative frequency, N%: relative abundance, AI: alimentary importance index, classes: IV=20.1-25mm, V=25.1-30mm.

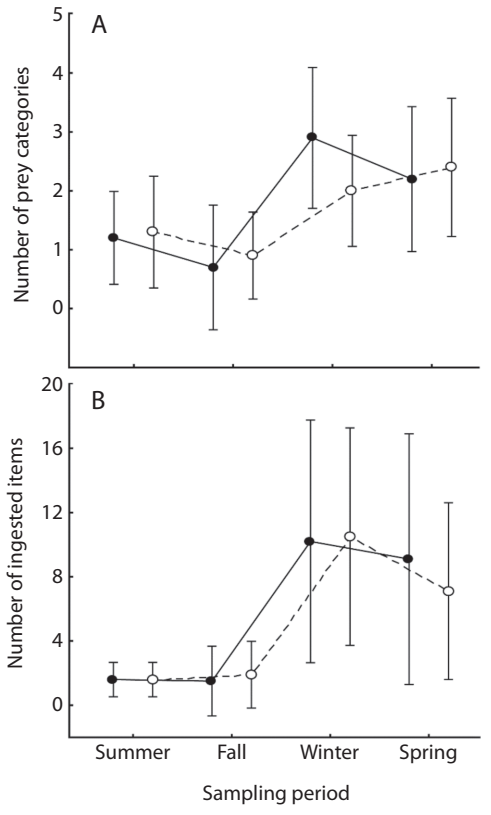

Fig. 2. Mean (± standard deviation) number of explored prey categories (**A**) and ingested items (**B**) by *Astropecten marginatus* length classes IV (●) and V (○) collected at Paraná coast in each season of 2008. (Sea star length classes: IV=20-25.1mm, V=25-30.1mm).

p=0.001), but no difference was observed between the analyzed length classes (pseudo-F=0.245, p=0.848).

DISCUSSION

The individuals of *Astropecten marginatus* inhabiting off the state of Paraná showed lower length than from other places. The most frequent length classes in this study (20.1-25mm) were lower than observed by Monteiro & Pardo (1994) for the population from state of São Paulo, Southeastern Brazil (40-50mm) or by Soto (1984) and Ortega et al., (2011) from the coast of Venezuela (30-34mm and 31-46mm, respectively). The maximum recorded length (56.2mm) are also lower than those observed for others Caribbean populations, where were recorded maximum sizes around 78mm (Roa, 1967; Walenkamp, 1976, 1979; Ortega et al., 2011).

The observed seasonal differences in length could be related either to recruitment or to migration. Although the recruitment of *Astropecten* is unpredictable (Christensen, 1970), for the species *A. irregularis* an increase in the abundance of juveniles has been reported in fall (Freeman, Richardson & Seed, 2001). Otherwise, the absence of large individuals of *A. latespinosus* during winter could be related to offshore migration (Nojima, 1983), which

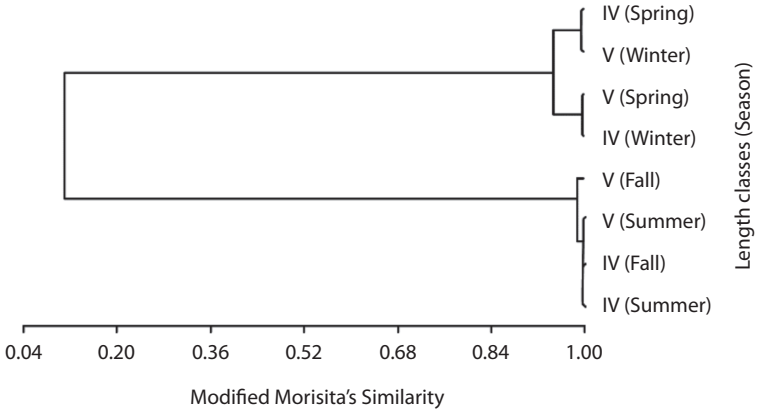

Fig. 3. Similarity of the diet of two most frequent length classes of *Astropecten marginatus* collected at Paraná coast in each season of 2008. Dendrogram based on Alimentary Importance index (AI) using simplified Morisita Index (Sea star length classes: IV=20.1-25mm, V=25.1-30mm).

was also observed in other coastal echinoderms (Borzone, 1999).

The weight-length relationships showed a negative allometry, confirming that organisms invest more in length than in weight, as has been observed for other species of *Astropecten* off the Brazilian coast (Ventura, Junqueira & Fernandes, 1994).

Regarding feeding behavior on the genus *Astropecten*, several studies conducted worldwide have found primarily mollusks, especially bivalves (Christensen, 1970; Penchaszadeh, 1973; Nojima, 1988, 1989; Freeman, Richardson & Seed, 1998; Brogger & Penchaszadeh, 2008; Loh & Todd, 2011) and gastropods (Soto, 2000, Ganmanee et al., 2003; Juan, Cartes & Demestre, 2007) as main prey. The same feeding pattern has also been observed for *A. marginatus* inhabiting the Caribbean Sea (Soto, 1984; Ortega et al., 2011) and Brazil (Monteiro & Pardo, 1994). Furthermore, temporal differences in the amount of ingested items and in the food preferences have also been observed.

In contrast to our results, higher number of consumed prey is usually observed during warm seasons and it is primarily associated to an increase of prey availability promoted by recruitment process of benthic community or an increase of feeding rates of sea stars (Christensen, 1970; Doi 1976; Ganmanee et al., 2003; Caregnato, Wiggers, Tarasconi & Veitenheimer-Mendes, 2009). Considering the temperature influence on animal metabolism, a faster feeding rate could result in a lower residence time of food items at sea star stomachs and thus, higher frequencies of empty stomachs or low amount of ingested items can be expected as observed in our results, especially if prey availability is low. Changes in food preference also result from prey availability in the environment. Nojima (1988) observed that adults of *Astropecten latespinosus* modified its feeding behavior from shellfish predators to non-selective deposit feeder when preferred preys are scarce or absent. Penchaszadeh (1973) also observed seasonal changes in food preferences of *A. brasiliensis*, changing from shellfish (mainly *Mytilus* sp.) as preferred prey in the summer to cumaceans in the fall. These changes were related to changes in availability and vulnerability of prey.

The genus *Astropecten* is a good benthic sampler as it has a generalist diet, considering as a tool for comparative studies of sand-bottom communities (Wells et al., 1961). Although there is no data about the structure of the benthic community of the inner shelf in the state of Paraná, high frequency and abundance of cumaceans as food item possibly reflects the unavailability of mollusks in the region. Even so, gastropods were the main prey category explored at summer and fall. However, this pattern must be carefully analyzed since it can have been biased due high frequency of empty stomach and low amount of ingested items observed in these periods.

Considering that the quantity and quality of ingested food are the main factors responsible for seastar growth (Scheibling, 1980), the lower length observed for *Astropecten marginatus* inhabiting off the state of Paraná probably reflects its feeding behavior imposed by available of local preys.

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RESUMEN

Variaciones estacionales en el tamaño corporal y dieta de la estrella de mar *Astropecten marginatus* (Paxillosida, Astropectinidae) frente a la costa de Paraná, sur de Brasil. La estrella de mar *Astropecten marginatus* presenta una distribución neotropical y debido a su abundancia es frecuente encontrarla como captura incidental durante actividades de pesca de arrastre; actividad por la cual se encuentra amenazada en muchos lugares a lo largo de la costa brasileña. En este estudio se analizaron las variaciones estacionales de la estructura de la población y se determinaron los principales componentes de la dieta

de *A. marginatus* frente a la costa de Paraná, sur de Brasil. Las muestras analizadas provinieron de las capturas de la pesca de arrastre recogidas en febrero (verano), abril (otoño), junio (invierno) y octubre (primavera) 2008. De cada individuo se midió la longitud y se pesó, posteriormente se analizó el contenido estomacal de 10 organismos de cada una de las dos clases de talla más frecuentes por cada temporada. Se analizaron 994 ejemplares de *A. marginatus*, los cuales presentaron una longitud que varió entre 7.0-56.2mm, con mayor frecuencia de individuos entre 20.1-25mm. Los organismos mayores (>40mm) se encontraron solamente en la primavera, mientras aquellos con talla inferior a los 10mm se obtuvieron durante el otoño y el invierno. El peso de los individuos se mantuvo entre los 0.1-15.3g. La relación entre el peso y talla mostró un crecimiento alométrico negativo (b<2.54). En cuanto a la dieta, esta especie consumió un total de once presas, de las cuales los cumáceos y moluscos fueron los grupos más consumidos. Una mayor cantidad de presas exploradas se registró en el invierno-primavera de los períodos de verano-otoño. El predominio de la presa cambió de gasterópodos (verano y otoño) a cumáceos (invierno y primavera). Las diferencias estacionales en el patrón de alimentación podrían estar asociadas a una baja disponibilidad de presas y a los cambios en las tasas de alimentación, lo cual se ve reflejado en algunos rasgos biológicos, como el pequeño tamaño del cuerpo esta población.

Palabras clave: Asteroidea, Echinodermata, estructura etaria de la población, componentes alimenticios, variación estacional, disponibilidad de presas.

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