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A N I N T E R N A T I O N A L J O U R N A L

Seasonal and Spatial Variability of Appendicularian Density and Taxonomic Composition in the Caravelas Estuary (Northeastern Brazil) and Adjacent Coastal Area

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ABSTRACT

This study aimed to identify and assess the seasonal and spatial variations of the appendicularians in the Caravelas River estuary and the adjacent coastal area. Samples were taken during 12 campaigns over five years (2001 and 2003-2006). Ten species were identified; the most abundant were Oikopleura dioica, Oikopleura rufescens, and Oikopleura longicauda. These species represented more than 95% of the total numbers of appendicularians. The remaining species were less frequent and occurred in low densities. The mean density of appendicularians found at the coastal stations (804 ind.m^{-3}.) was higher than in the estuary (66 ind.m^{-3}). However, the differences observed between the estuary and coastal stations were not significant (p=0.54). The samples taken during the dry season showed a higher mean density (587 ind.m^{-3}) than in the rainy season (376 ind.m^{-3}), and the differences between the seasons were statistically significant (p=0.004).

Key words: Oikopleuridae, Fritillariidae, Tropical estuary, Brazil

INTRODUCTION

Coastal systems are distinguished, among natural environments, as important areas of interaction among the sea, land, epicontinental waters, and atmosphere (Yáñes-Arancibia, 1986; Schaeffer-Novelli, 1989). These systems have diverse shoreline features including estuaries, lagoons, bays, coves, and coastal dunes, which, together with coral reefs and upwelling areas, are the most productive environments (Day and Yáñes-Arancibia, 1982).The coastal region of Caravelas in northeastern Brazil contains diverse and productive ecological systems, including the Abrolhos coral reefs, considered as the most important coral reefs of the South Atlantic Ocean. For these reasons, the region around the Caravelas River has good potential for ecotourism and recreation (Andrade and Dominguez, 2002; ANP, 2007).

Appendicularians are considered one of the important links between the primary producers and secondary consumers (Nakamura et al., 1997). This group has great importance in the control of the growth of microalgae (Heinle, 1966), because in the areas where they are abundant, they can filter approximately 30 to 60% of the surrounding water in 24 h (Flood et al., 1992). Appendicularians are numerically well represented, after the Copepoda, in coastal and

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estuarine environments. Studies on the distribution, specific composition, and abundance of appendicularians in oceanic regions of the southwest Atlantic have been carried out by several investigators, e.g., Lohmann (1896, 1931), Lohmann and Buckmann (1926), Lohmann and Hentschell (1939), Fenaux (1967), Björnberg and Forneris (1956a, 1956b, 1958), Forneris (1965), Tundisi (1970), Esnal (1999), Campos (2000), and Bonecker and Carvalho (2006).

Some studies have been carried out in coastal regions, where only species of the family Oikopleuridae (Bonecker et al., 1991; Vega-Pérez, 1993; Bonecker et al., 1998; Dias et al., 1999; Biancalana et al., 2005). In most studies of zooplankton, appendicularians have been treated only to class level (Navas, 1973; Montú, 1980; Nogueira et al., 1988; Lopes et al., 1998; Faro et al., 2000; Petrilho et al., 2005; Tsujimoto et al., 2006).

The aim of this study was to identify and to evaluate the spatial and seasonal variations of the appendicularians in the estuary of the Caravelas River and the adjacent coastal area, in the years 2001, 2003, 2004, 2005, and 2006.

MATERIALS AND METHODS

The estuarine region of Caravelas (17°44' - 17°53'S and 39°04' - 39°12' W) is located in the northeastern Brazil. The estuary is approximately 3,800 m long, 90 m wide and up to 5 m deep, and is bordered by a 66.44 km^2 long. Mangrove forest the estuary is highly dynamic, influenced directly by the estuary of Caravelas Channel and indirectly by the Brazil Current (Leão and Dominguez, 2000). The local atmospheric circulation varies with the seasonal migration of the South Atlantic anticyclone, with northeast winds predominating during the spring and summer, and east and southeast winds in autumn and winter (Leão and Dominguez, 2000). The climate is tropical humid; the rainy season extends from November to April, and the dry season from May to October (Nimer, 1989).

The zooplankton material was collected in 12 campaigns from 2001 through 2006, in different sampling periods (Table 1). Sampling was done at seven stations, two of them in the inner estuary and the mouth of the estuarine zone of the Caravelas River, and the others in the adjacent coastal region out to the 20-m isobath in the north-south direction (Fig. 1). Zooplankton samples were taken in triplicate in horizontal surface hauls using a conical net (200 µm mesh, 0.6 m diameter, 2 m long). A flowmeter (General Oceanics Inc.) was attached to the net mouth in order to determine the volume of water filtered. The hauls were diurnal, each lasting for three minutes. Samples were fixed in 4% buffered formalin diluted with seawater.

In the laboratory, the zooplankton samples were divided with a Folsom Plankton Splitter, when required (McEwen et al., 1954), and at least 100 individuals were sorted (Frontier, 1981). The subsamples were never less than 1/8 of the total sample. The appendicularians were identified to species level according to Flores-Coto (1974), Esnal (1999) and Bonecker and Carvalho (2006).

For the spatial distribution, the stations were separated into two groups according to their locations in relation to the Caravelas River. Stations 1 and 2, located in the inner area of the river and the estuary, respectively, were classified as estuarine and stations 3, 4, 5, 6, and 7, located in the adjacent coastal area, as coastal (Fig. 1). The dry and rainy seasons were delimited according to rainfall data and the local climate. The samples taken in February, March, April, and October were considered as from the rainy season, and the remainder from the dry season.

A nonparametric Mann-Whitney U-test was used at a significance level of $p=0.05$ to identify the statistical differences among the stations of the estuary and the adjacent coastal area and between the dry and rainy seasons. This was followed by a Bonferroni test (test of p correction). The program used was Bioestat 4.0. All the specimens identified were deposited in the appendicularian collection of the Zooplankton and Ichthyoplankton Integrated Laboratory of the Federal University of Rio de Janeiro, Brazil (DZUFRJ).

Table 1 - Sampling campaigns carried out in the Caravelas River estuary.

Years	Campaign number	Months	
		Rainy	Dry
2001	1		October
2003	3	February	July, October
2004	2		May, October
2005	3	February, March, April	
2006	3	March	June, September

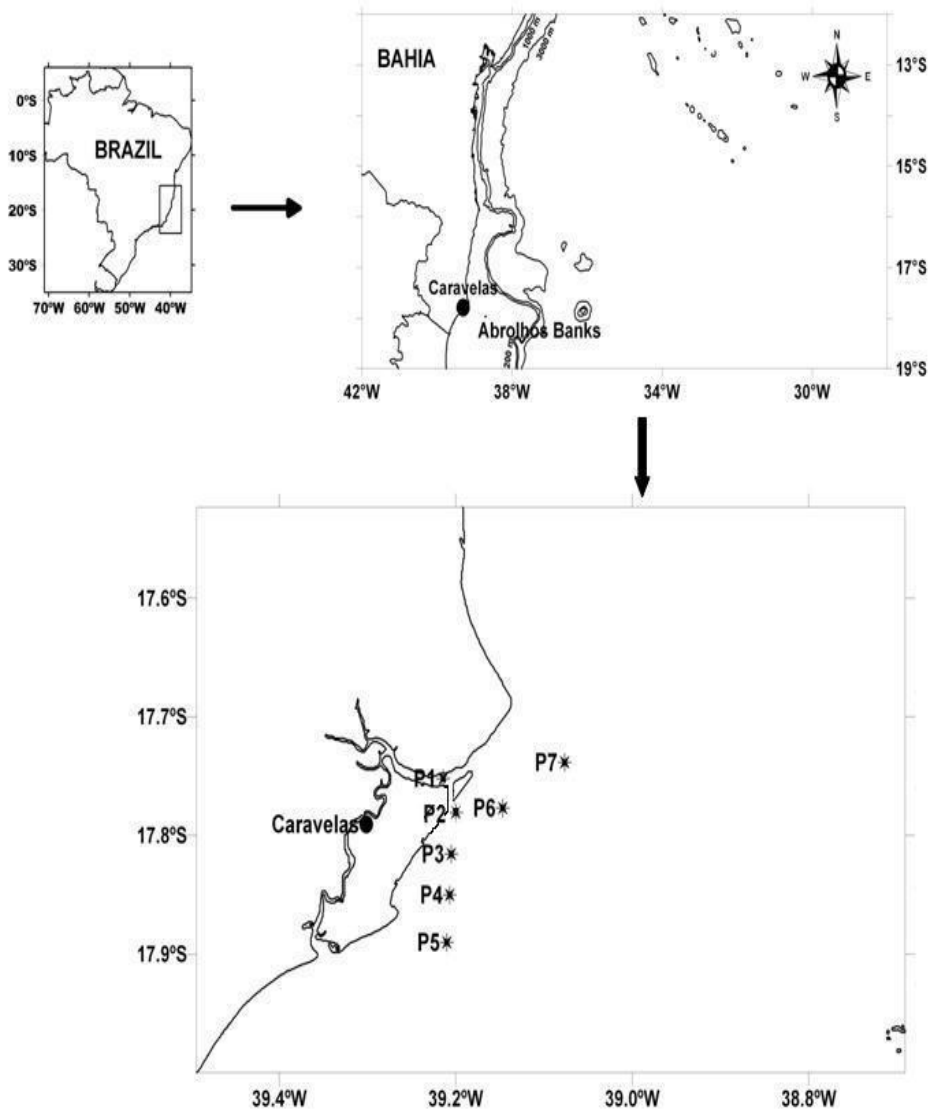

Figure 1 - Location of the sampling stations in the Caravelas River and adjacent coastal area.

RESULTS

During the 12 campaigns, 10 species were identified, 7 belonging to the family Oikopleuridae and 3 to the family Fritillariidae. The most frequent species was *Oikopleura dioica*, which occurred in all the samples, followed by *O. longicauda* (11 samples) and *O. rufescens* (7 samples). *O. cornutogastra, O. albicans, F. tenella, F. borealis,* and *Appendicularia sicula* each occurred in only one sample (Table 2).

Table 2 - Appendicularians collected in 12 campaigns in the Caravelas River and adjacent coastal area.

Year	2001		2003		2004			2005		2006		
Month	Oct	Feb	Jul	Oct	May	Oct	Feb	Mar	Apr	Mar	Jun	Sep
Oikopleura rufescens Fol, 1872	x	x	x	x	x	x	x	-	-	-	-	-
Oikopleura dioica Fol, 1872	x	x	x	x	x	x	x	x	x	x	x	x
Oikopleura longicauda (Vogt, 1854)	x	x	x	-	x	x	x	x	x	x	x	x
Oikopleura fusiformis Fol, 1872	-	x	-	-	x	x	x	-	-	x	-	-
Oikopleura cophocerca (Gegenbaur, 1855)	-	-	-	x	-	x	-	-	-	x	-	-
Oikopleura cornutogastra Aida, 1907	-	-	-	-	-	-	-	-	x	-	-	-
Oikopleura albicans (Leuckart, 1854)	-	-	-	-	-	-	-	x	-	-	-	-
Fritillaria tenella Lohmann, 1896	-	x	-	-	-	-	-	-	-	-	-	-
Fritillaria borealis Lohmann, 1896	-	-	-	-	-	-	-	x	x	-	-	-
Appendicularia sicula Fol, 1874	-	-	-	-	-	-	-	-	x	-	-	-
Total of species	**3**	**5**	**3**	**3**	**4**	**5**	**4**	**4**	**5**	**4**	**2**	**2**

All the species (10) occurred in the adjacent coastal area (coastal). Only five species were found in the estuary (Table 3). The highest mean density of appendicularians was found in the coastal region (804 ind.m^{-3} SD=1400). In this area, the variation of the mean in relation to the minimum and maximum values was quite accentuated. In the estuary region, the value of the mean was 158 ind.m^{-3} (SD=256) and the dispersion in relation to the minimum and maximum values was much lower compared to the coastal stations (Fig. 2).

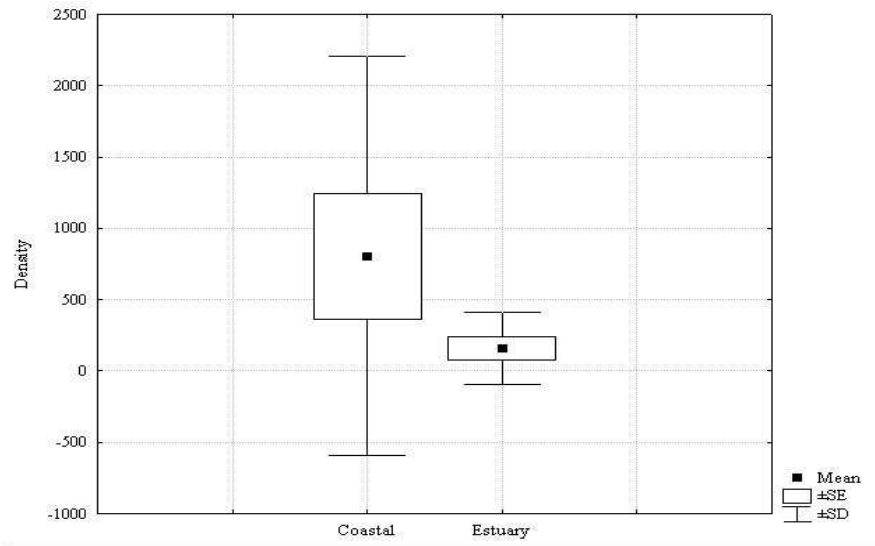

Figure 2 - Mean density, standard error (SE), and standard deviation (SD) of appendicularians collected in the estuary and coastal areas.

The difference between the densities was not statistically significant (p=0.54). There was also no significant difference between the two areas, with respect only to the densities of the two most abundant species, *O. dioica* and *O. rufescens* (p=0.65). The statistical analysis also showed no spatial difference in the densities of *O. longicauda* and *O. fusiformis*, the third and fourth most abundant species (p=0.16). *O. rufescens*, *O. dioica*, and *O. longicauda* were the most abundant species in the study area, comprising more than 95% of the total numbers of appendicularians (Table 3). The species dominance was different in the two environments. In the estuary, *O. rufescens* showed the highest mean density, followed by *O. dioica*. The inverse relationship occurred at the coastal stations, where *O. dioica* was the most abundant (46%), followed by *O. rufescens* (38%) (Table 3).

In respect to the other species, only *O. cophocerca* was more abundant in the estuary. *O. longicauda* and *O. fusiformis*, the third and fourth most abundant species, were more abundant in the coastal stations. *O. cornutogastra, O. albicans, F. tenella, F. borealis*, and *A. sicula* occurred only in the coastal area.

Table 3 - Minimum, maximum, mean density (ind.m^{-3}), standard deviation (SD), and relative abundance (%) of appendicularian species identified in the estuary and coastal areas.

	Estuary					Coastal				
	Min	**Max**	**Mean**	**SD**	**%**	**Min**	**Max**	**Mean**	**SD**	**%**
Oikopleura rufescens	0.00	242.00	26.16	61.45	39.64	0.00	1060.00	50.98	164.25	38.03
Oikopleura dioica	0.00	179.58	24.55	41.83	37.19	0.00	931.00	61.12	177.07	45.59
Oikopleura longicauda	0.00	169.39	13.00	39.62	19.69	0.00	252.72	18.85	45.08	14.06
Oikopleura fusiformis	0.00	14.00	0.90	3.16	1.43	0.00	44.00	1.64	6.70	1.22
Oikopleura cophocerca	0.00	26.00	1.35	5.38	2.05	0.00	6.70	0.18	0.90	0.13
Oikopleura cornutogastra	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.01	0.03	<0.01
Oikopleura albicans	0.00	0.00	0.00	0.00	0.00	0.00	0.23	0.01	0.03	<0.01
Fritillaria tenella	0.00	0.00	0.00	0.00	0.00	0.00	61.00	1.21	7.95	0.90
Fritillaria borealis	0.00	0.00	0.00	0.00	0.00	0.00	3.88	0.08	0.50	0.06
Appendicularia sicula	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.01	0.01	<0.01

All the species (10) were observed in the rainy season; but only five appeared in the dry season (Table 4). There was a significant difference in the mean densities of the appendicularians between the dry and rainy seasons (p=0.004). In the temporal comparison, the highest mean density occurred in the dry season (587 ind.m^{-3} SD=1219). Also in this period, a wide dispersion of the minimum and maximum values in relation to the mean was observed in the rainy season, the mean density of the appendicularians was 376 ind.m^{-3} (SD=576). The variation of the minimum and maximum values in relation to the mean in this period was lower compared to the dry season (Fig. 3). In the dry season, the most abundant species was *O. dioica* (67.49 ind.m^{-3} SD=195), followed by *O. rufescens* (49.45 ind.m^{-3} SD=165). In the rainy season, the most abundant species was *O. longicauda* (39.30 ind.m^{-3} SD=61), followed by *O. rufescens* (36.10 ind.m^{-3} SD=105) (Table 4). *O. rufescens, O. dioica,* and *O. cophocerca* showed density peaks in the dry season, and *O. longicauda* and *O. fusiformis* were the most abundant species in the wet season. *O. cornutogastra, O. albicans, F. tenella, F. borealis,* and *A. sicula* occurred exclusively in the rainy season (Table 4).

Table 4 - Minimum, maximum, mean density (ind.m^{-3}), standard deviation (SD), and relative abundance (%) of appendicularian species identified during the rainy and dry seasons.

	Rainy					Dry				
	Min	**Max**	**Mean**	**SD**	**%**	**Min**	**Max**	**Mean**	**SD**	**%**
Oikopleura rufescens	0.00	548.00	36.10	105.01	33.62	0.00	1060.00	49.45	165.24	41.28
Oikopleura dioica	0.14	179.58	27.13	40.69	25.26	0.00	931.00	67.49	194.90	56.34
Oikopleura longicauda	0.00	252.72	39.26	60.75	36.56	0.00	42.00	1.40	6.21	1.17
Oikopleura fusiformis	0.00	44.00	2.67	8.71	2.49	0.00	14.00	0.56	2.13	0.47
Oikopleura cophocerca	0.00	0.01	0,01	0.00	<0.01	0.00	26.00	0.88	3.87	0.74
Oikopleura cornutogastra	0.00	0.20	0.01	0.03	0.01	0.00	0.00	0.00	0.00	0.00
Oikopleura albicans	0.00	0.23	0.01	0.04	0.01	0.00	0.00	0.00	0.00	0.00
Fritillaria tenella	0.00	61.00	2.07	10.38	1.93	0.00	0.00	0.00	0.00	0.00
Fritillaria borealis	0.00	3.88	0.13	0.66	0.13	0.00	0.00	0.00	0.00	0.00
Appendicularia sicula	0.00	0.04	0.01	0.01	<0.01	0.00	0.00	0.00	0.00	0.00

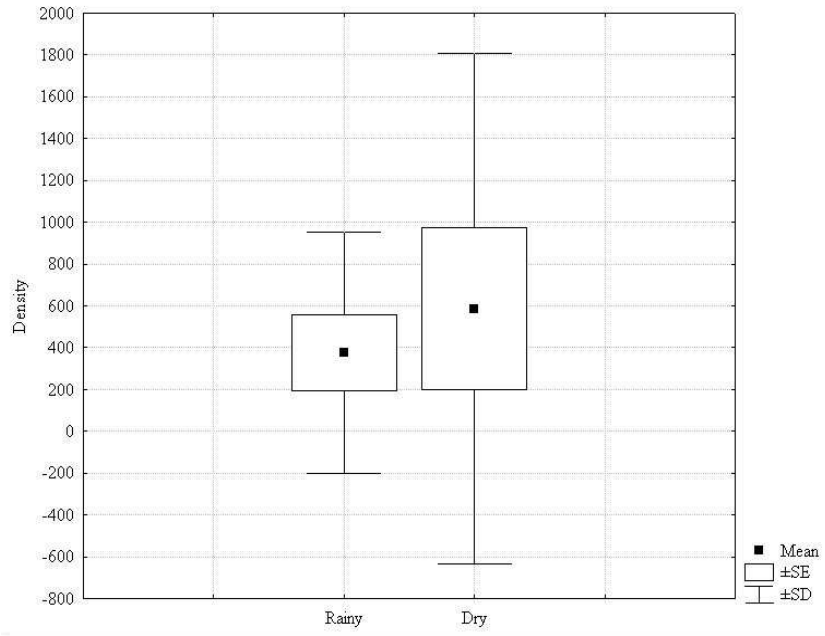

Figure 3 - Mean density, standard error (SE), and standard deviation (SD) of appendicularian species identified during the rainy and dry seasons.

DISCUSSION

The higher density of appendicularians in the dry season found in the present study differed from the findings of Campos (2000), who observed an increase in mean density of the group in spring (rainy season). This difference could be related to the locations of the studies, because the area studied was strongly influenced by the continental waters, and the other study was done in ocean waters. No significant difference was found between the estuary and coastal areas. Flores-Coto (1974) also observed no definite pattern in the distribution of appendicularians between the samples collected in a coastal and an estuarine area. Some of the species identified in the Caravelas River estuary were previously recorded from coastal regions. *O. longicauda, F. borealis, O. fusiformis,* and *O. rufescens* were dominant in Toyama Bay, Japan (Tomita et al., 2003). *O. dioica* and *O. cophocerca* were found in the Macaé River estuary by Beltrão (2003). On the

northern coast of Chile, Aravena and Palma (2002) observed a dominance of *O. longicauda*, *O. albicans*, and *O. cophocerca*.

O. dioica was the most frequent and abundant species in all the samples. This confirmed the preference of this species for the coastal and estuarine systems, where it reached high densities (Tundisi, 1970; Lopes et al., 1998; Esnal, 1999; Campos, 2000; Shiganova, 2005; Bonecker and Carvalho, 2006). The second species in terms of overall abundance was *O. rufescens*. This species occurred in coastal and oceanic waters, but less often in oceans (Esnal and Castro, 1977).

Appendicularians are widely distributed in all marine environments, mainly in mixed waters over the continental shelf (Esnal, 1999). This pattern was observed in the present study, where the highest frequency and abundance were found in the ocean stations. *O. dioica* was the most abundant species in the coastal stations. This species is highly adapted to the spatial gradient of salinity and variations in the concentration of particulate matter (Tundisi, 1970). In the estuary stations, *O. rufescens* reached its highest densities. This contrasted with the observations of Campos (2000), who found the highest abundance of this species in oceanic regions. *O. cophocerca* was more abundant at the estuary stations. This differed from the findings of Fenaux (1968), who characterized the species as oceanic.*O. longicauda* and *O. fusiformis* were more abundant in the coastal stations. The two species are found in both coastal and oceanic regions (Bonecker and Carvalho, 2006) and are frequent in both cold and warm waters (Esnal, 1999). Fenaux (1968) them considered as the two most important appendicularians off the Brazilian coast.

Among the species found exclusively at the ocean stations, *O. cornutogastra* was characteristic of shelf waters (Forneris, 1965). *O. albicans* is characteristic of ocean waters, and is generally absent from the coastal regions (Esnal and Castro, 1977). This explained the low density of the species in the study area. *F. tenella* is present in low densities off the Brazilian coast (Bonecker and Carvalho, 2006). Campos (2000) characterized it as a cold-water species. *F. borealis* is an oceanic species, according to Björnberg and Forneris (1958) and Tomita et al. (2003). But Esnal and Castro (1977) found it in coastal waters. *A. sicula* was classified as scarce by Esnal (1999) in the South Atlantic. This observation coincided with data from the present study, where this species was the least often collected.

In the Caravelas region, the highest abundance of appendicularians was found in the dry period. This confirmed the results of Campos (2000) and Esnal et al. (1985), who also observed the highest densities during the dry season. *O. rufescens*, *O. dioica*, and *O. cophocerca* showed their peaks of density in the dry season. *O. rufescens* was also more abundant in the dry season (Campos, 2000), but it was more abundant in the rainy season as well (Tundisi, 1970). *O. dioica* reached a peak of density between December and March in the rainy season (Esnal et al., 1985). This pattern was also found by Campos (2000) but differed from present results.

O. cophocerca was more abundant in the rainy season (Campos, 2000). Other species are also usually more abundant in the rainy period, such as *O. longicauda* and *O. fusiformis* (Tundisi, 1970, Campos, 2000). These patterns differ from present findings. *O. cornutogastra* and *O. albicans*, showed density peaks in the rainy season (Campos 2000). *F. tenella* and *F. borealis* were found by Campos (2000) to be more abundant in the dry season in contrast to present observations.

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RESUMO

Esse trabalho teve como objetivo identificar e avaliar as variações espaciais e sazonais das apendiculárias no estuário do rio Caravelas e área costeira adjacente (17°35' – 18°22' S e 39°8' – 39°55'W). As coletas foram realizadas em 12 campanhas durante cinco anos (2001 e 2003 - 2006). Foram identificadas dez espécies, sendo que *Oikopleura dioica, O. rufescens e O. longicauda* foram as mais abundantes. Estas três espécies representaram mais de 95% do total de apendiculárias coletadas. As outras espécies foram

menos freqüentes e ocorreram em baixas densidades. A densidade média de apendiculárias encontrada nas estações e costeiras (804 ind.m^{-3}) foi maior que na de estuário (158 ind.m^{-3}). As diferenças encontradas entre as estações de estuário e costeiras não foram significativas (p=0,73). As campanhas realizadas durante o período seco apresentaram densidade média (587 ind.m^{-3}) maior que do período chuvoso (376 ind.m^{-3}). As diferenças entre os períodos chuvoso e seco foram estatisticamente significativas (p>0,01).

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