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Studies on chaetognaths off Ubatuba region, Brazil. I. Distribution and abundance

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• *Abstract*: The distribution of chaetognath species off Ubatuba region, São Paulo State, Brazil, was studied during a program of multidisciplinary research. Ten species belonging to the genera *Sagitta, Krohnita* and *Pterosagitta* were identified. *S. enflata* was the dominant species followed by *S. friderici* and *S. hispida*. The species *S. enflata, S. hispida, S. tenuis, S. bipunctata* and *K. pacifica* were found in the Shelf water whereas *S. serratodentata, S. minima, S. hexaptera* and *P. draco* in the Tropical water. Only *S. friderici* was found associated to Coastal water. Hydrological conditions affected population structure, size of individuals and abundance.

• *Resumo*: A ocorrência, distribuição, freqüência dos estágios de maturidade e comprimento total do corpo das espécies do filo Chaetognatha foram estudados. As amostras foram obtidas com o auxílio de rede Bongo, nos verões de 1985 - 1987 e invernos de 1986 e 1987, durante o Projeto "Utilização Racional do Ecossistema Costeiro da Região Tropical Brasileira, Estado de São Paulo". Dez espécies foram identificadas, sendo *Sagitta enflata, S. friderici* e *S. hispida* as espécies mais abundantes. *S. enflata, S. hispida, S. tenuis, S. bipunctata* e *Krohnita pacifica* estão associadas à água de Plataforma enquanto que *S. serratodentata, S. hexaptera, S. minima* e *Pterosagitta draco* à água Tropical. Apenas *S. friderici* mostrou preferência por água Costeira. Diferenças sazonais na estrutura da população, tamanho dos indivíduos, abundância e distribuição estão associados à hidrodinâmica local. Nos verões, os quetognatos apresentaram maior número de estágios maduros nas amostras examinadas, comprimentos maiores e baixa abundância como conseqüência da intrusão da água Central do Atlântico Sul que provocou uma estratificação térmica característica. Em contraposição, nestas amostras, nos invernos, a população é formada por indivíduos de estágios jovens, de comprimentos menores e grande abundância provavelmente resultado da mistura vertical da coluna de água e homogeneidade da estrutura térmica.

• *Descriptors*: Chaetognatha, Distribution, Abundance, Population structure, Ubatuba region, South Atlantic.

• *Descritores*: Chaetognatha, Distribuição, Abundância, estrutura da população, Ubatuba, Atlântico Sul.

Introduction

Physical factors, resource limitation and predation may affect population structure and abundance variability of a community. Planktonic organisms must be able to survive and reproduce in an environment where food, competitors, predators and potential reproducers have heterogeneous distributions (Daly & Macaulay, 1991).

Among the plankton organisms, chaetognaths are a small and evolutionary isolated group but conspicuous in the marine plankton of all over the world (Hyman, 1959, Alvariño, 1965). They have been recognized as one of the major predators, competitors of pelagic community (Alvariño, 1985) and, recently, as an important source of particulate organic matter to deep layers (Dilling & Aldregde, 1993).

Like most zooplankton, chaetognaths are subject to dispersing currents and changing physical-biological

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conditions. Therefore, some species become very useful as hydrological indicators of water masses movements (Mulkana & McIlwain, 1973, Cheney, 1985a) and may contribute to the understanding of biogeographic processes in the sea (Andreu *et al.*, 1989).

In this paper, the population structure, distribution and abundance of chaetognaths were studied over periodic and regular station grid surveys off the northern coast of São Paulo State.

Material and methods

This study was part of a program of multidisciplinary study of tropical ecosystems: "Brazilian Coastal Ecosystems", developed in the Ubatuba region, São Paulo State, from 1985 to 1989.

Zooplankton samples studied in this work were collected on five oceanographic cruises during December 1985, 1986, 1987 and July 1986, 1987. A survey grid of 30 standard plankton stations distributed along six transects was established across the frontal region of Ubatuba, northern coast of São Paulo State (24°10'S-44°30'W and 23°30'S-45°20'W) (Fig. 1).

Oblique hauls were made with a Bongo net fitted with 0.200 mm and 0.303 mm meshed nets provided with flowmeters. Samples were preserved in a seawater solution of 10% buffered formalin. In this study, 124 plankton samples obtained by the 0.303 mm meshed net were analysed.

Concomitantly, hydrographical data were obtained from each station by means of Nansen bottles.

In the laboratory, zooplankton samples were aliquoted with a Motoda splitter (Omori & Ikeda, 1984). Then, chaetognaths were sorted, identified to species, examined for stage of maturity and measured under a stereoscopic microscope (Wild M7).

The identification of chaetognath species was accomplished using descriptions provided by Almeida-Prado (1961a) and Alvariño (1969). The maturity stages were identified based on Reeve's (1970):

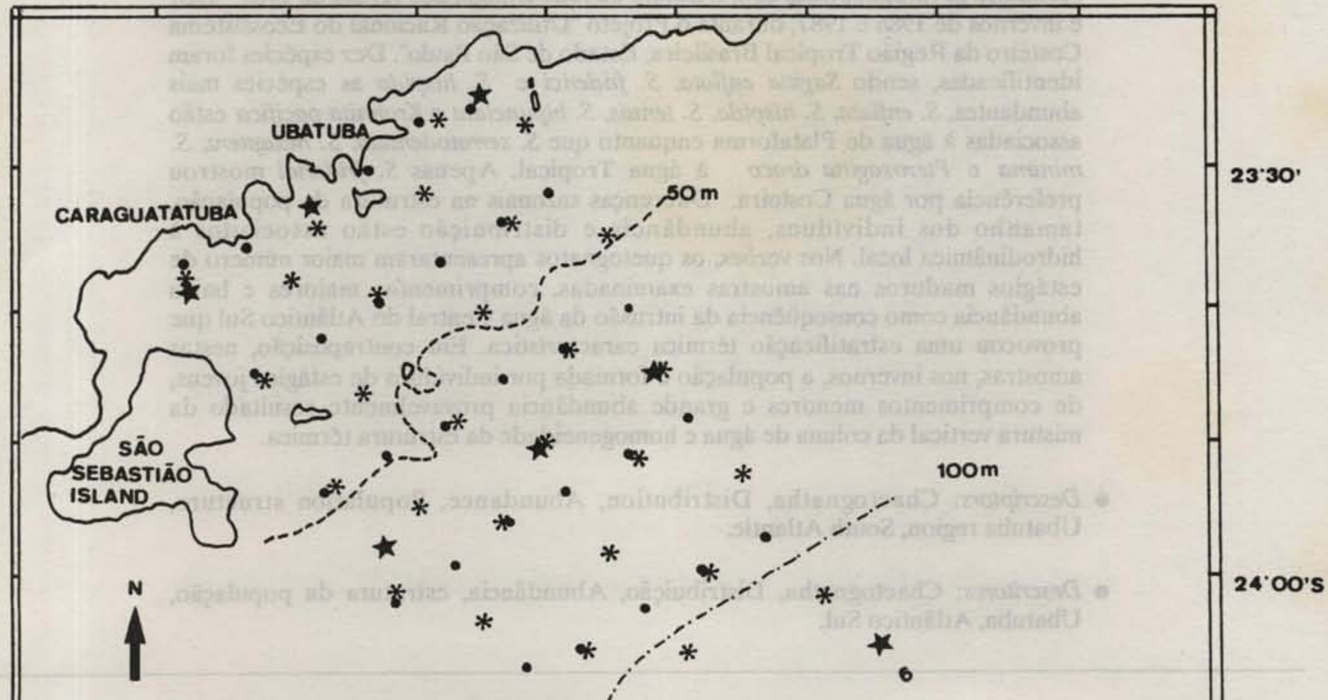

Fig. 1. Location of oceanographic stations along six perpendicular sections off northern coast of São Paulo State (* = Summer 1985 and Winter 1986; ● = Summer 1986 and Winter 1987; ★ = Summer 1987).

stage 0 (juvenile) - no gonads; stage I - gonads being formed; stage II - ova small and all alike in size; stage III - some ova enlarged to mature size, seminal vesicles matured; stage IV - all ova enlarged. For the study of length distribution, specimens were measured from the anterior extremity of the head to the posterior segment, including the caudal fin.

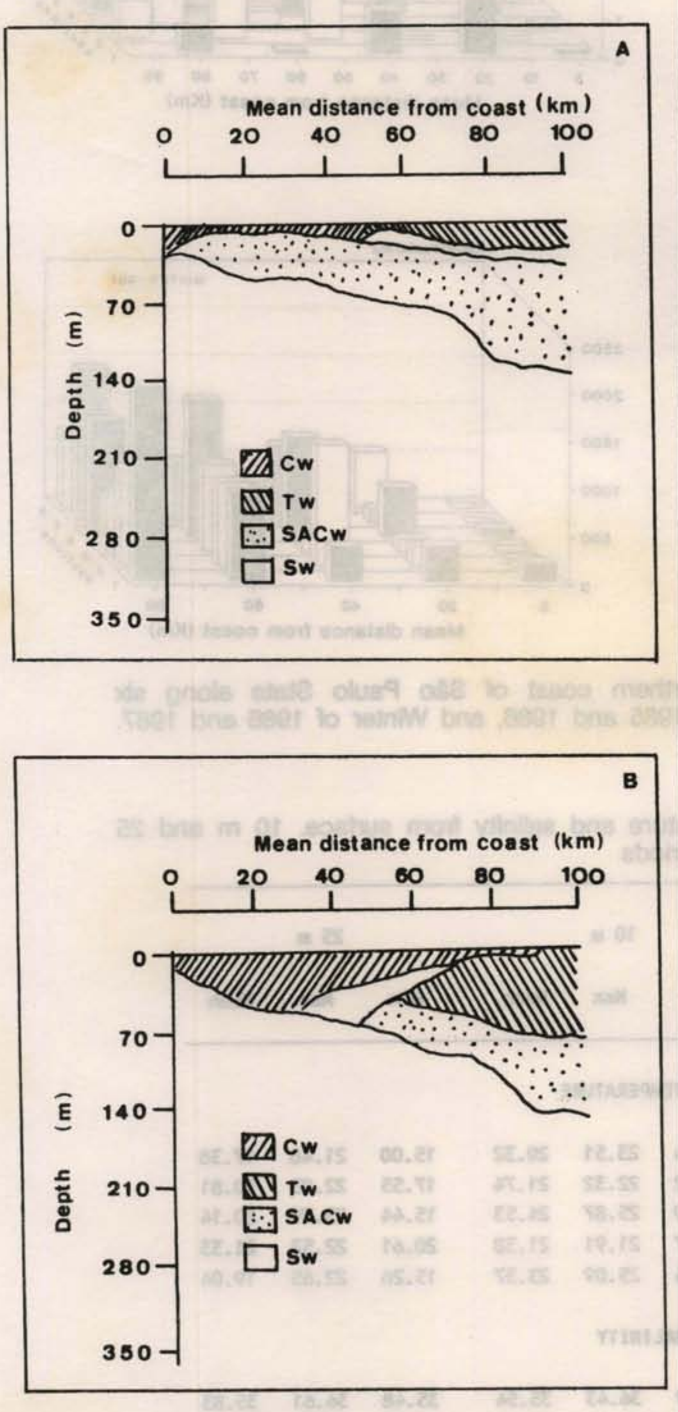

Fig. 2. Vertical distribution of water masses along a transect in the Ubatuba region. A - Summer; B - Winter (based on Castro Filho, 1989).

Chaetognaths abundance was estimated in terms of individuals per m^2 (Tanaka, 1973). Statistical analyses of length measurements were made to compare seasonal differences applying the ANOVA and the LSD test (Fisher, 1948).

Hydrographic structure

The oceanographic structure off Ubatuba, based on Castro Filho (1987, 1988, 1989) and Castro Filho *et al.* (1987), is dominated by 3 water masses: Coastal water (CW), characterized by temperatures higher than 20.0°C and salinities lower than 35.0; Tropical water (TW) with temperature and salinity higher than 20.0°C and 36.0, respectively; South Atlantic Central water (SACW) with temperature and salinity lower than 18.0°C and 35.0. Shelf water (SW) is formed by mixing of SACW, TW and CW. It is characterized by temperature ranging from 20.0°C-23.0°C and salinity from 35.0-36.0.

The water mass distribution pattern is closely related to the winds and to the influence of the Brazilian current. During Summer, the region shows two layers of vertical stratification with the presence of the thermocline. The upper layer is filled with CW which interacts with TW offshore. SACW predominates in the subsuperficial layer during this period (Fig. 2). During Winter, vertical mixing of water is generated by winds. Therefore, the water column is almost isothermal. Shelf Water constitutes a substantial fraction in this period.

Results

Hydrographical data

The temperature and salinity ranges are shown in the Table 1 for surface, 10 m and 25 m. The highest values were observed in the Summer of 1986 and the lowest values were found in the Summer of 1985. In this season, the mean temperature of the water decreased with depth while salinity increased, indicating stratification of the water column. During Winter, temperature and salinity varied little with depth, suggesting vertical mixing of water.

Ocurrence and abundance

Chaetognaths averaged from 0.69% to 6.13% of the total zooplankton collected. Table 2 shows the average, maximum and minimum values of chaetognaths in percentage by number. In general, higher densities (individuals/m^2) were found in the Winter surveys.

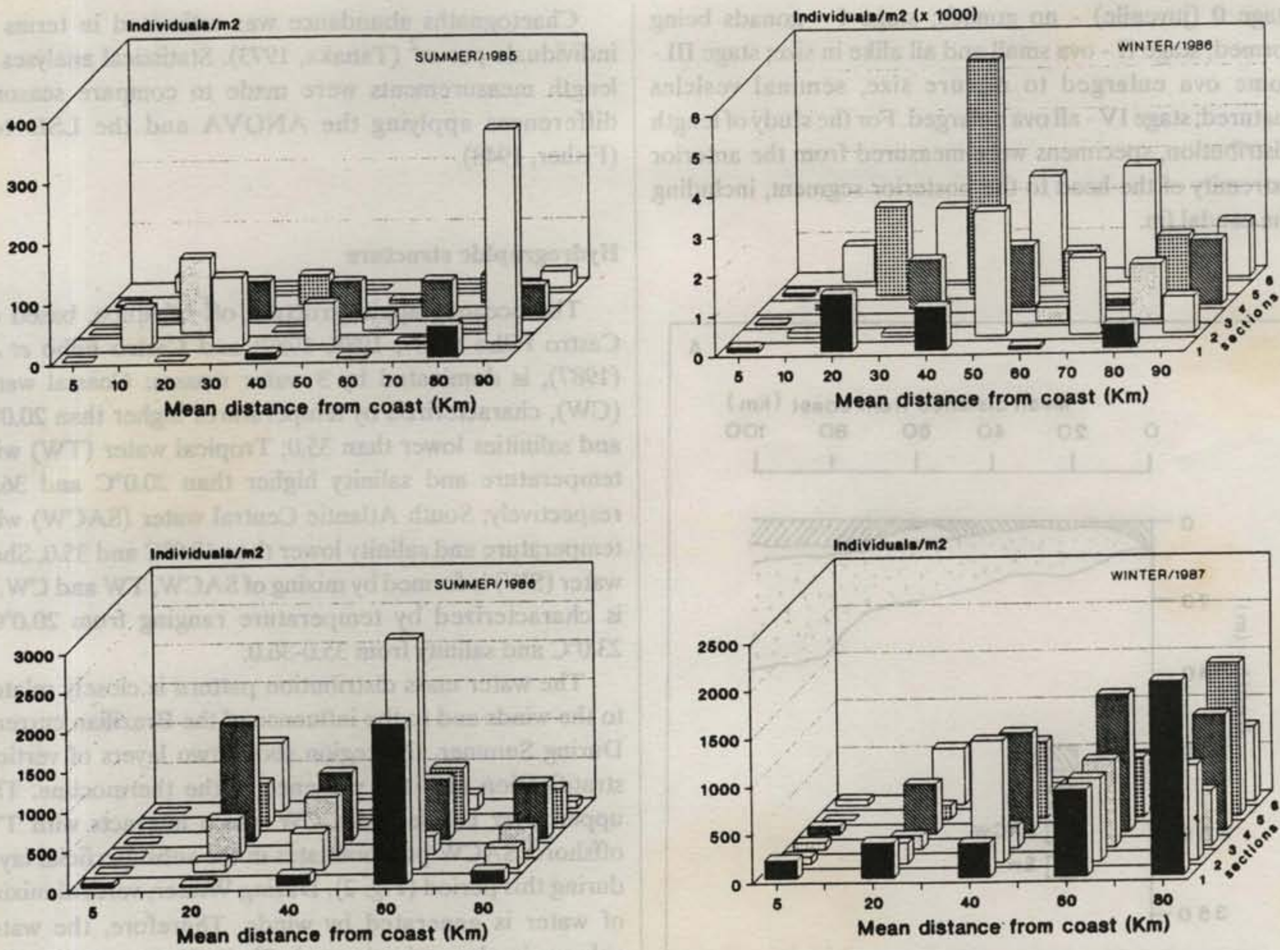

Fig. 3. Distribution of *Sagitta enflata* off northern coast of São Paulo State along six perpendicular sections during Summer of 1985 and 1986, and Winter of 1986 and 1987.

Table 1. Means and range values of temperature and salinity from surface. 10 m and 25 m depth obtained during the sampling periods

Cruise	Surface			10 m			25 m		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
				TEMPERATURE					
Summer/1995	20.55	23.54	22.51	15.44	23.51	20.32	15.00	21.48	17.38
Winter/1986	20.90	22.32	21.79	20.92	22.32	21.74	17.55	22.03	20.81
Summer/1986	24.34	26.85	25.44	19.49	25.87	24.53	15.44	23.79	20.14
Winter/1987	20.71	22.50	21.47	20.47	21.91	21.38	20.61	22.52	21.33
Summer/1987	23.82	25.46	24.63	20.24	25.09	23.37	15.26	22.65	19.04
				SALINITY					
Summer/1985	35.01	36.11	35.44	35.09	36.43	35.54	35.48	36.61	35.83
Winter/1986	35.45	36.23	35.78	35.41	36.24	35.82	35.69	36.23	35.90
Summer/1986	34.17	36.02	35.24	35.01	36.71	35.43	35.32	36.77	35.88
Winter/1987	33.49	35.30	34.47	33.50	35.50	34.59	34.49	36.11	35.07
Summer/1987	34.78	36.38	35.52	35.01	36.37	35.61	35.41	36.45	35.97

Table 2. Means and range values in percentage by number of total chaetognaths collected

Cruise	Mean	Range	Nº of Collections
Summer/1985	0.69	0.055-2.57	27
Winter/1996	4.94	1.267-10.70	28
Summer/1986	3.94	0.017-14.87	30
Winter/1987	6.13	1.578-26.99	30
Summer/1987	1.31	0.007-2.70	9

Ten chaetognath species belonging to three genera were identified in the plankton samples: *Krohnita pacifica* Aida, *Sagitta enflata* Grassi, *Sagitta friderici* Ritter- Zàhony, *Sagitta hispida* Conant, *Sagitta tenuis* Conant, *Sagitta serratodentata* Krohn, *Sagitta minima* Grassi, *Sagitta hexaptera* d'Orbigny, *Sagitta bipunctata* Quoy & Gaimard and *Pterosagitta draco* (Krohn). In this study, the species *S. friderici* and *S. tenuis* were considered two distinct species based on Almeida-Prado (1961a, b) and McLelland (1980, 1989).

The most abundant species were *S. enflata*, *S. friderici* and *S. hispida* whereas the less abundant and unfrequent were *S. bipunctata, S. hexaptera* and *P. draco*. Considerably large number of specimens of chaetognath species were found in the Winter, except *S. friderici* and *S. tenuis* (Table 3).

Hydrographical structure off Ubatuba region influenced the distribution of chaetognath species. Defined distribution pattern was observed in some species. High density of *S. enflata* occurred between the isobath of 50-100 m, indicating that this species was associated to Shelf water (Fig. 3). *S. friderici* concentrated near the coast where Coastal water was present (Fig. 4). The species *S. serratodentata, S. hexaptera* and *P. draco* were found in Tropical water (Fig. 5).

The remaining species showed a complicated distribution pattern, however seasonal abundance suggests that *S. hispida. S. tenuis, S. bipunctata* and *K. pacifica* were associated to Shelf water, whereas *S. minima* to Tropical water.

Maturity stages

S. enflata and *S. friderici* s howed different frequency distribution of maturity stages. In general, younger stages (0 and I) were more abundant during Winter of 1986 and 1987, and Summer of 1986, whereas the older stages II and IV predominated in the Summer of 1985 and 1987. (Fig. 6)

S. hispida exhibited high numbers of stages 0 and I during all sampling periods, except in the Summer of 1987, when stage III dominated.

In the remaining species, stages I, II and III were observed over all the periods.

Body length

The analysis of variance showed no significant differences in the total length of the chaetognaths at stages 0 and I. At stage II, there was a significant difference between specimens lengths found in the Summer of 1985 and 1987, and the other periods. The specimen size was similar in both Summer of 1985 and 1987 surveys; and in the Winter of 1986, 1987 and Summer of 1986. Body length of stages III and IV were not compared due to the few numbers found.

Table 3. Frequency of occurrence, means of percentage by number and density (individuals/m^2) of chaetognath species collected

Species	1985 Summer			1986 Winter			1986 Summer			1987 Winter			1987 Summer		
	(F)	(%)	(D)	(F)	(%)	(D)	(F)	(%)	(D)	(F)	(%)	(D)	(F)	(%)	(D)
S. enflata	88.89	35.74	52.37	100.0	60.21	1285	90.0	51.47	563.2	100.0	65.19	625.3	100.0	47.54	703.4
S. friderici	96.29	40.34	115.8	92.86	17.16	177.9	93.33	17.32	93.86	86.67	17.51	97.74	66.67	39.30	137.5
S. hispida	85.18	12.76	33.39	100.0	14.25	223	96.67	29.28	246.5	93.33	9.02	78.17	88.89	15.78	57.27
K. pacifica	29.62	13.74	36.71	85.71	8.29	206	56.67	4.30	26.83	80.0	6.61	52.85	22.22	11.57	50.57
S. minima	51.85	6.92	7.27	57.14	3.75	65.33	43.33	3.26	19.09	80.0	6.18	69.95	55.55	9.64	75.43
S. tenuis	62.96	12.71	24.74	10.71	1.50	24.61	33.33	3.24	15.04	6.67	0.47	5.79	-	-	-
S. serratodentata	48.15	9.12	7.63	3.57	2.2	23.4	20.0	13.43	55.69	13.33	2.37	17.95	33.33	7.32	70.18
S. bipunctata	7.41	5.6	8.67	7.14	1.27	17.81	3.33	3.51	10.73	-	-	-	-	-	-
S. hexaptera	-	-	-	-	-	-	10.0	2.24	8.88	3.33	1.02	11.33	-	-	-
P. draco	-	-	-	-	-	-	3.33	2.32	7.96	6.67	2.66	26.07	11.11	4.17	17.73

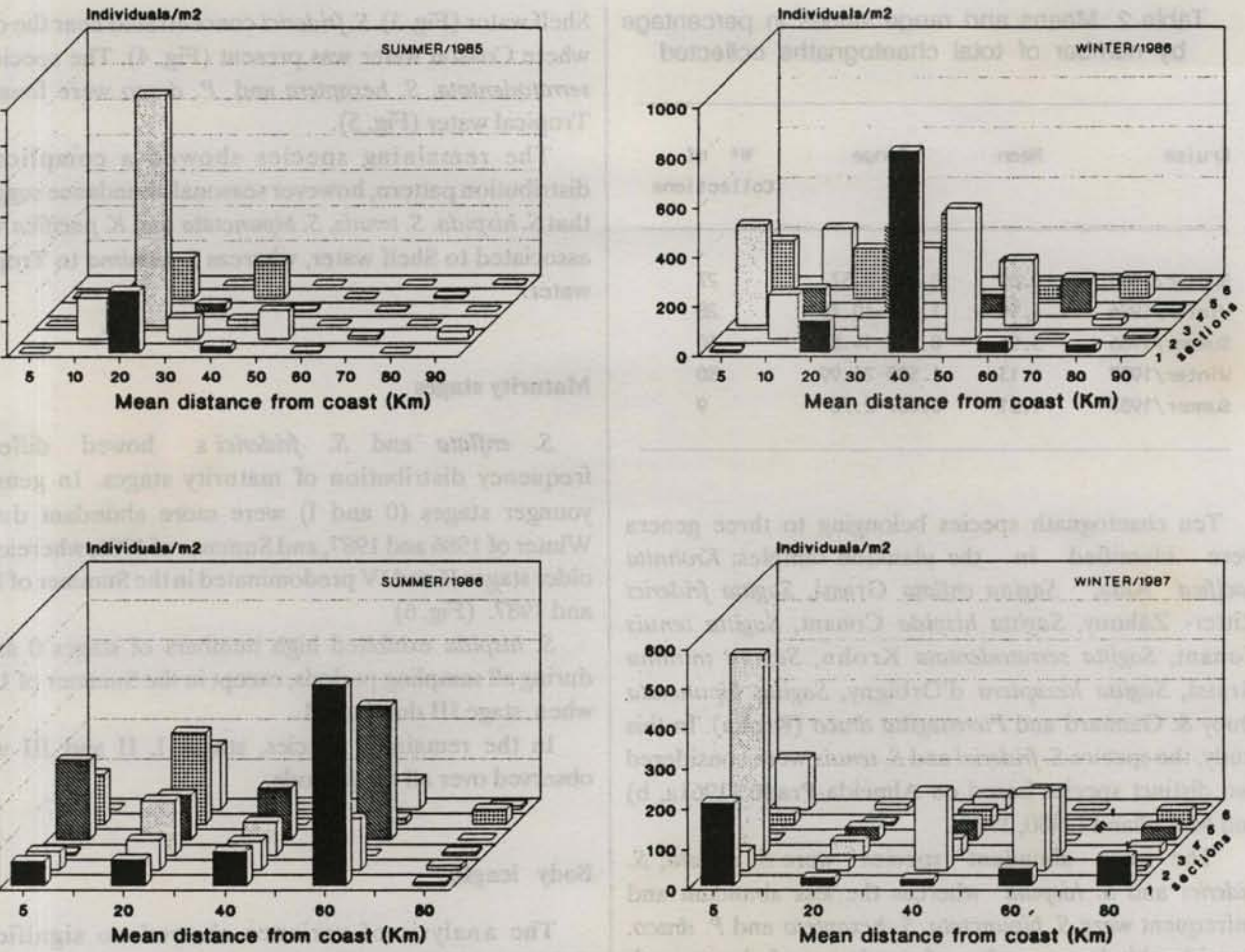

Fig. 4. Distribution of Sagitta friderici of northern coast of São Paulo State along six perpendicular sections during Summer of 1985 and 1986, and Winter of 1986 and 1987.

The mean length of chaetognath species at each maturity stage in the Summer and Winter is shown in the Table 4.

Discussion

In marine ecosystems, hydrodinamic events control all the biological processes in the plankton, mainly the phytoplankton production (Mann, 1991). Intense vertical stratification of the water column leads to nutrient limitation of primary production in the photic zone which may support only low production of mesozooplankton and higher trophic levels. On the other hand, vertical mixing of the water column may bring nutrients to the surface and provide suitable conditions for the growth of phytoplankton which, in turn, supports a substantial production at higher trophic levels (Kiorbe & Nielsen, 1990). Thus, apparently high rates of mesozooplankton productivity are associated with periods or areas characterized by turbulent mixing and weak vertical stratification of the water column (Peterson & Bellantoni, 1987).

According to Cheney (1985b), distributional patterns of chaetognaths depends closely on the changes of oceanographic structure, which is affected by the seasonal cycle of winds. In this study, we observed higher abundance of chaetognaths in the Winter, when the Ubatuba region was dominated by intense vertical mixing (Castro Filho *et al.*, 1987). In contrast, in the Summer, the abundance of these organisms was low, probably due to the presence of vertically stratified waters caused by the intrusion of the South Atlantic Central water.

The occurrence and distribution of chaetognaths in an area is influenced by hydrological conditions, since some species are closely associated to specific water masses (Heydorn, 1959; Grant, 1991). In Ubatuba, seasonal and spatial distribution indicated that *S. enflata, S. hispida, S. bipunctata* and *K. pacifica* were associated to Shelf water, whereas *S. minima, S. hexaptera, S. serratodentata* and *P. draco* to Tropical water. These results confirms previous findings recorded by Almeida-Prado (1961a, b, 1968) in Brazilian waters.

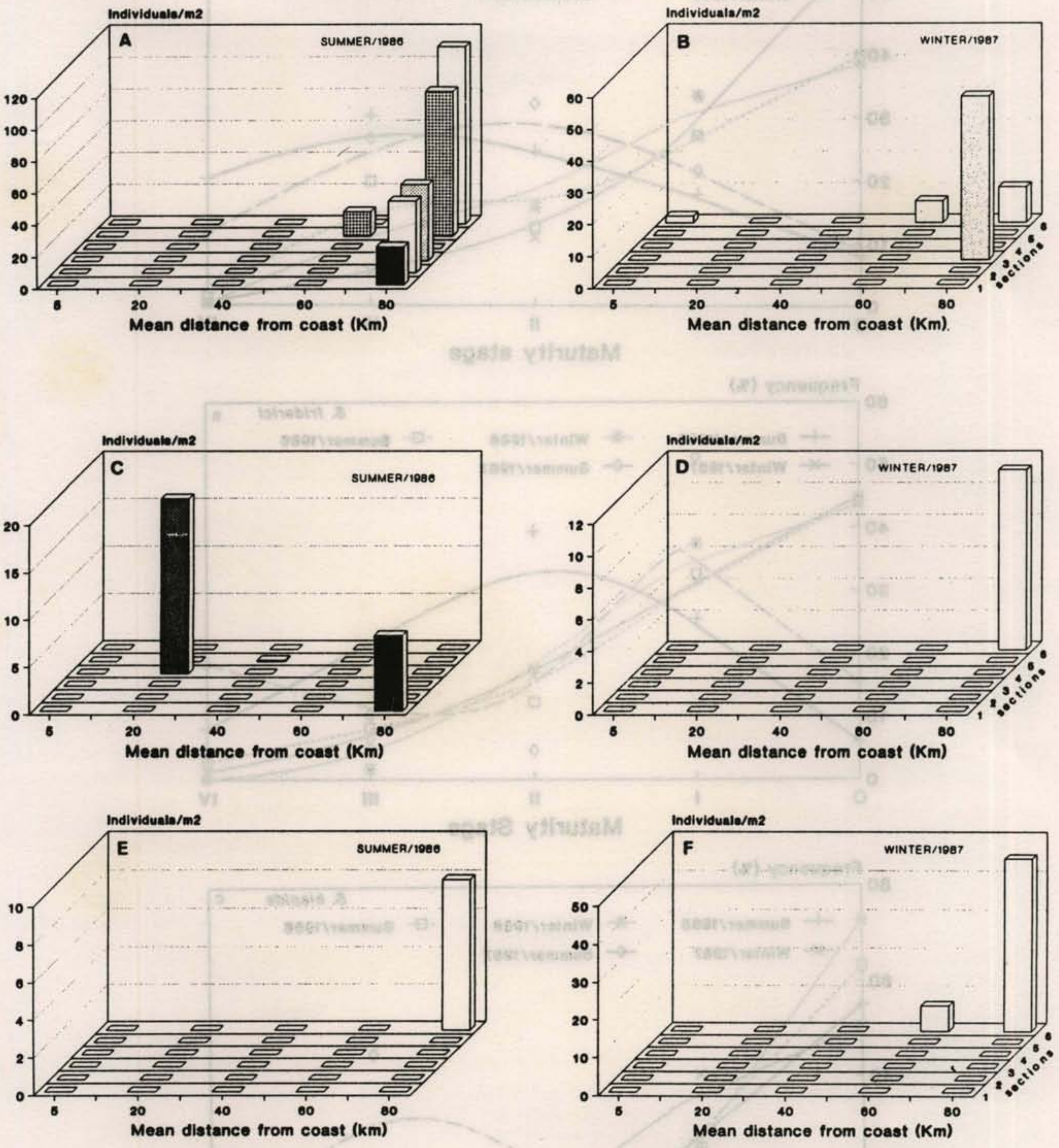

Fig. 5. Distribution of *Sagitta serratodentata* (A, B), *S. hexaptera* (C, D) and *Pterosagitta draco* (E, F) of northern coast of São Paulo State.

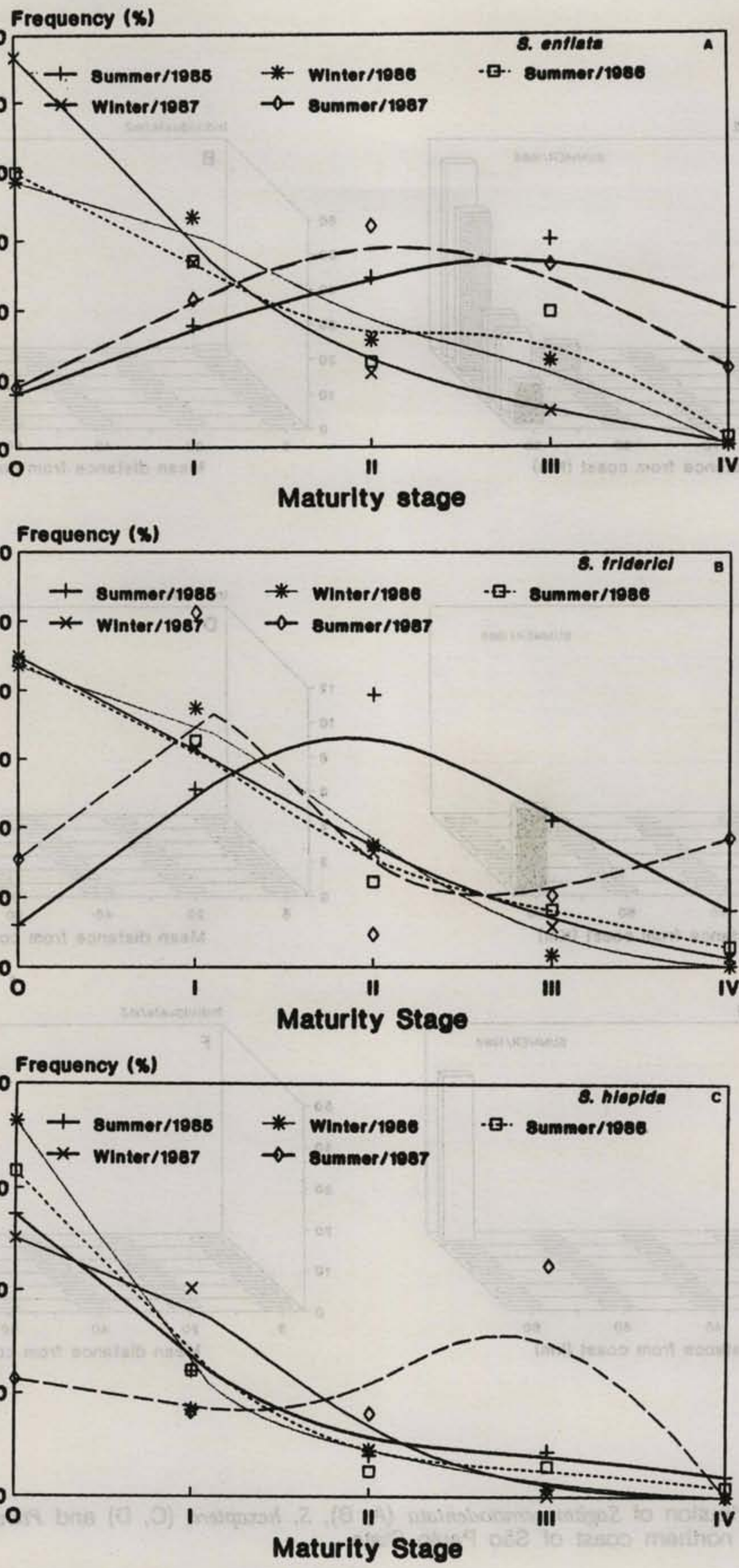

Fig. 6. Frequency distribution of maturity stage of chaetognath species during Summer and Winter surveys. A - *S. enflata*; B - *S. friderici*; C - *S. hispida*.

Table 4. Grouped means of total length (mm) of each maturity stage of each chetognath species collected in the Summer and Winter surveys

	Maturity Stages				
	0	I	II	III	IV
Species	V-I	V-I	V-I	V-I	V-I
S. enflata	0.13=	1.40>	1.50>	4.56>	0.22>
S. friderici	0.82<	0.54>	1.42>	3.63>	5.54>
S. hispida	0.18=	0.39=	2.91>	4.07>	-
K. pacifica	-	-	0.09>	0.53>	0.51>
S. minima	2.42>	-	0.90>	1.61>	2.25>
S. tenuis	0.30>	0.60>	0.12=	0.66=	-
S. serratodentata	-	0.96>	0.89>	1.25>	1.15<
S. bipunctata	-	-	-	-	6.95>

Almeida-Prado (1968) related *S. friderici* to Coastal water with temperature ranging from 21.0°C to 27.0°C. However, Stone (1969) and Stuart & Verheye (1991) characterized *S. friderici* as an indicator of a cold water mass. Recently, large numbers of *S. friderici* were recorded in a low temperature water mass off Ubatuba region by Vega-Pérez & Liang (1992). In this study, higher numbers of *S. friderici* were found in the Summer collections suggesting that this species has affinity to the cold water mass (SACW), but is able to tolerate warmer temperatures.

S. tenuis is considered eurihaline preferring upper layer waters (Alvariño, 1965). According to Mclelland (1984), this species shares basically the same habitat as *S. friderici*, but it likes higher salinities. Almeida-Prado (1961a) recorded *S. tenuis* in coastal and mixed waters off Ubatuba. Our findings suggest that *S. tenuis* has preference to low temperature, but it can tolerate a wide range of salinity.

On the other hand, the distribution and abundance of chaetognath species also shows a close relationship with their food (Alvariño, 1969). They are abundantly collected in areas rich in copepods, their main prey item (Pearre, 1973; Edmunds *et al.*, 1983). In Ubatuba region, higher abundance of chaetognaths was found in the Winter and between 50 - 100 m isobaths, where the greatest quantities of copepods were also observed (Vega-Pérez, 1993).

Maturity stages and individual size

Seasonal changes of population composition have been observed in some species as *S. serratodentata* (Bainbridge, 1963). This fact may be related to the changes of the oceanographic structure. Lough & Trites (1989) observed higher numbers of juvenile stages of *S. elegans* in the mixed waters and adults in the weakly stratified waters of Georges Bank. We found similar results in Ubatuba region. Larger quantities of younger stages of *S. enflata* and *S. friderici* were observed in intense vertical mixed waters (Winter) and more mature stages in stratified and cold waters (Summer).

Large quantities of juvenile chaetognaths found in the plankton samples have been attributed to the mortality of adults after breeding (Owre, 1960, Reeve, 1970), vertical migration (Raymont, 1983), reproduction (Almeida-Prado, 1968, Steeman-Nielsen, 1971), sampling depth (Almeida-Prado, 1968; Gibbons, 1992) and type of net used (Stone, 1969).

According to Russel (1932a, b) the size reached by chaetognaths is conditioned among other factors by temperature. Generally, specimens that develop in the cold waters attain larger sizes than those in warmer waters (Boltovskoy, 1975). Reeve (1970) and Reeve & Walter (1972) demonstrated in laboratory experiments that growth rate and maximum size reached by *S. hispida* depend on the temperature. Our findings show that differences of total length between Summer and Winter surveys were closely related to the temperature of the water mass.

Steeman-Nielsen (1962) hypothesized that zooplankton of rich food environments is smaller because it spends less energy searching and catching its food and allocated it to reproduction and growth. Thus, higher abundance of copepods observed during Winter (Vega-Pérez, 1993), which represent potential food to chaetognaths off Ubatuba, may influence the growth of these organisms.

Our results show that the population structure, abundance and distribution of chaetognaths depend closely on the hydrodinamic structure and presence of food.

Conclusions

1. Ten chaetognath species belonging to three genera were identified in the 124 plankton samples analized: *Sagitta, Krohnita* and *Pterosagitta*.

2. The most abundant species were *Sagitta enflata, S. friderici* and *S. hispida*.

3. In general, younger stages (0-I) were more abundant in the Winter of 1986 and 1987, whereas the older stages (II-IV) predominated in the Summer of 1985 and 1987.

4. The differences of total length observed in the Summer and Winter surveys were associated to the temperature of the water mass.

5. Higher abundance of chaetognath specimens were found in the Winter samples taken between 50 - 100 m isobaths.

6. The hydrodinamic structure off the northern coast of the São Paulo State influenced the occurrence, abundance and distribution of chaetognaths.

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