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SEASONAL VARIATION OF THE ZOOPLANKTON BIOMASS OVER THE PORTUGUESE CONTINENTAL SHELF

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ABSTRACT

Seasonal variation of the zooplankton biomass off the Portuguese coast is analyzed based on data from samples collected monthly from October 86 through January 89 in four transepts over the continental shelf.

The seasonal cycle of zooplankton biomass has low values during the winter months which increase in early spring and maintain relatively constant till the end of autumn. The maintenance of the zooplankton production levels between spring and autumn is related with the enrichment of the euphotic zone with nutrients and consequent phytoplankton growth as a result of the coastal upwelling caused by persistent northerly winds during this period. This pattern is more noticeable in the northern region where the flat and wide shelf gives origin to environmental conditions that depend essentially from the solar radiation, the depth of mixing and the northerly wind regime.

INTRODUCTION

The location of Portugal on the northern fringe of the subtropical anticyclone belt and on the eastern coast of a large ocean determines most of the climatology and oceanography of its coastal ocean. The seasonal regime of the oceanic semi-permanent high pressure cell of the Azores and the southern migration of the subtropical front regulate the mean wind conditions off the Portuguese coast. Winter winds from the southwest, which produce surface flow from the south and toward the shore alternate with summer winds from the north, which produce flow from the north and away from shore, generating coastal upwelling.

The enrichment in nutrients of the surface waters caused by upwelling have turned this area into a productive region. This is attributable to the high rates of supply of dissolved plant nutrients (primary phosphate and nitrite according to Chelton *et al.*, 1982) to the photic layer which result in phytoplankton productivity. Since phytoplankton are the food source of herbivorous zooplankton which are, in turn, the food source for many pelagic fish, there is correspondingly high productivity at the higher trophic levels as well.

This paper describes the seasonal cycle of the zooplankton abundance in relation to the hydrographic characteristics off the Portuguese coast.

MATERIAL AND METHODS

Zooplankton biomass were determined based on samples collected monthly from October 1986 through January 1989 with few interruptions. Zooplankton was collected along four transepts perpendicular to the coast line within a depth range of 20 m to 200 m (Figure 1). The regions surveyed were Peniche and Figueira da Foz at the northern coast, Sines at southwest and Lagos in the south. The sampling gear was a 0.6 m diameter Bongo net with mesh sizes of 505 and 335 μm and information of the water column temperature was obtained with a bathytermograph.

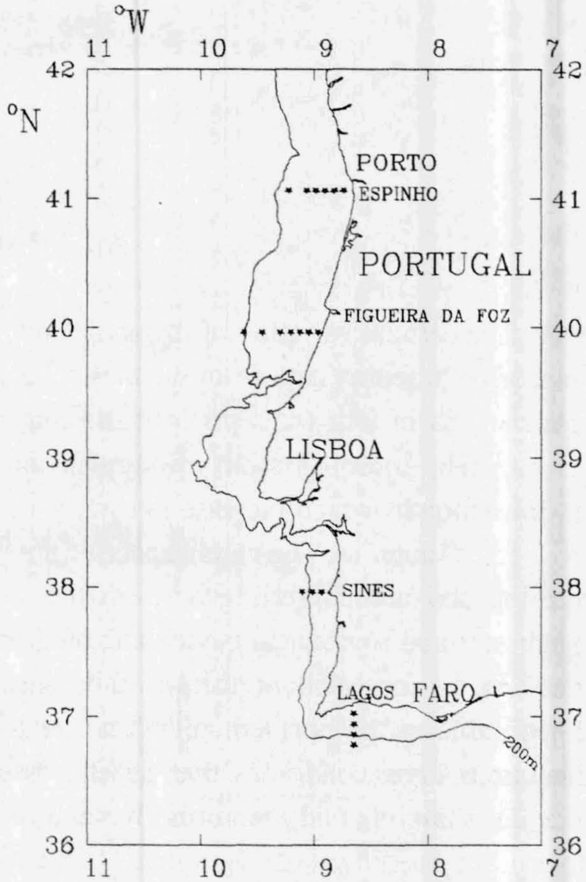

Figure 1. Location of stations and depth contour of the shelf break (200m).

During the surveys, zooplankton was routinely collected by standard oblique net tows as described by Smith and Richardson (1977) from the surface down to a maximum depth 200 m and back to the surface and the volume of the water strained for each net was determined using calibrated flowmeters. Total zooplankton biomass was determined by volume displacement, after removal of large (> 1 cm) organisms, and the values for each net were expressed as ml/1000 m^3.

Time series of monthly means of zooplankton biomass were derived for each of the four areas they represent, by first $\log_e$ transforming the values from each individual net. Then the $\log_e$ transformed values were averaged within each area for each calendar month from 1986 to 1989. The number of net tows per month for each of the four areas is shown in the Table I. The primary motivation for the $\log_e$ transformation is that, since zooplankton growth rates are usually an exponential function of population density, $\log_e$ transformed data are particularly well suited for visualizing and studying productivity (i.e., the rate of change of population): linear segments in plots of $\log_e$ transformed time series represent exponential growth or decay. An additional virtue of the $\log_e$ transformation is that the resulting zooplankton time series are much more nearly Normally distributed (Bernal, 1980) which allows easy determination of the statistical significance of standard error values.

Upwelling indices were obtained and determined based on the mean monthly wind observed at the meteorological station of Cabo Carvoeiro (39.35°N;9.4°W) during the years of 1986 and 1987 and at a point located at 40.5° N; 11.0° W during 1988 and 1989.

RESULTS

Winds and Hydrography

Winds along the Portuguese coast are monsoonal. During winter the winds are most frequently from the southwest (November-February) while in summer they are mainly upwelling producing winds (March-October) from the north (Wooster *et al.*, 1976). Short-term wind reversals from the average, 7 days (Afonso Dias, p.c.), produce episodes of downwelling during the upwelling season and upwelling during the downwelling season. As a result of this wind regime, monthly upwelling indices obtained from August, 1986 till June, 1989, (Figure 2) show that the indices were positive, i.e. upwelling favorable from March till October.

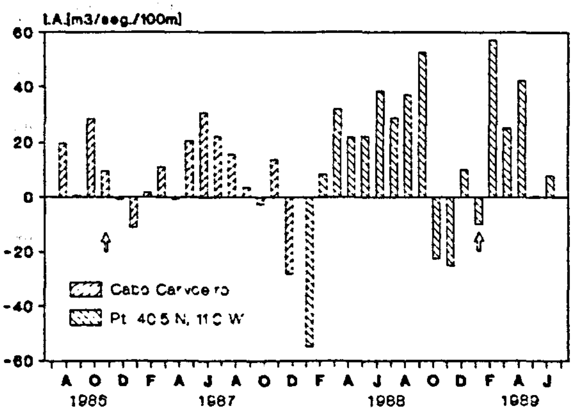

Figure 2. Monthly upwelling indices during the years of sampling. (The arrows limit the sampling period)

The hydrography of the Portuguese coastal ocean is strongly seasonal due, in part, to the variation of air-sea transfer processes as it may be seem in Figure 3, 4 and 5 that represents the monthly evolution of the thermic structure of the water column along the sections off Figueira da Foz, Sines and Lagos during the years of 1987. The evolution of the thermal structure off Espinho is not shown because it was similar to the section off Figueira da Foz. According to those Figures there are a cycle of vertical convection in Winter

(January, February and March) - horizontal thermic stratification during the months of Spring, Summer and Autumn off the Portuguese coast. During this period it is possible to observe in Figure 3 the uplift of the isotherms near the coast indicating coastal upwelling in 16 June, 22 July and 22 September while in August, 15, the isotherms were bent downwards near the coast indicating downwelling. Although the upwelling index during August were positive the downwelling must be due to a short-term wind reversal. In the southwest coast in Sines, the monthly evolution of the thermal structure of the water column (Figure 4) indicate thermal convection in 17, January and vertical thermal stratification in 16 February and 19 March. This vertical thermal stratification is the result of the strong influence of the Subtropical component of the Eastern North Atlantic Central Water (ENACW) that during winter and early spring approached the southern coast. This component is present off the Portuguese at temperatures higher than 13 °C (Fiúza, 1984) and during winter reach the surface forming a poleward surface current (Frouin *et al.*, 1990; Haynes and Barton, 1990). From May on, the water column was horizontally stratified being possible to observe that in 23, July and 14, November the isotherms indicate upwelling due to northerly winds while in 14 August and 6 September they indicate downwelling. Also in the western part of the south coast (Lagos section) the vertical thermal stratification shows the strong influence of the Subtropical component of the ENACW (Figure 5), in January, 10, and in March, 20. In this section upwelling indicating isotherms were found in June, 13 and August, 26. In this part of the south coast upwelling is only induced by winds from the west and the northwest (Fiúza, 1983).

Zooplankton seasonal distribution

Table I presents the monthly means of the zooplankton biomass retained by each mesh size for each transept and total. The number of samples and standard deviation is also presented.

Figure 6 represent the monthly evolution off the portuguese coast of the zooplankton biomass strained by the 335 μm and 505 μm sieves. According to this Figure the zooplankton biomass increase in March and maintained high levels till October after which the biomass decrease. This Figure also shows that the biomass strained by the 335 μm sieve was higher and the levels of production more constant than the retained by the 505 μm. This means that the contribution of the smaller species, that in general are herbivore, for the annual zooplankton production curve is higher, specially during the spring, summer and autumn months (April till October).

In Figure 7 the monthly evolution of the average zooplankton biomass at each transept is presented. In this Figure is possible to observe that there are similarity between the two production curves of the northern region, i.e. Espinho and Figueira da Foz. They both maintained high production levels during the spring, summer and autumn months. In the sections of Sines and Lagos this pattern is much more irregular with values decreasing significantly after the spring boom (May/June). The similarity between the annual zooplankton production cycle off Espinho and Figueira da Foz and their dissimilarity in relation to Sines and Lagos is more notorious when the monthly coefficient of variation of the biomass of each station and transept is compared (Figure 8). In this Figure it is observed that the coefficients of variation of the biomass in the Espinho and Figueira da Foz transepts were very similar among them and that they present the same variation along the year while they are very different from the transepts off Sines and Lagos.

The similarity among the production curves in the northern area reveal a homogeneity in the production system of this area which led that a unique production curve would be determined for this region. Sines and Lagos transepts presented values of zooplankton biomass that were not only very different among them but also the evolution of their coefficient of variation along the year were very different. However these differences were not significant due to the small number of samples. Therefore an unique production curve was found for the southern area. Figure 9 resumed these informations. Although the production levels of the two regions were similar their annual production cycles seemed to be different. According to this Figure and after relatively low production levels in January and February the northern region presented production values that increased till June followed by a small decrease in July. After this month the production levels are maintained more or less constant decreasing again in November and December. In the southern region this pattern was more variable although it is possible to observe significant increases in the production cycle during spring (March/April), summer (July/August) and autumn (October). In Figure 10, which represent the coefficients of variation of the biomass retained by the 335 μm and 505 μm sieves in the two regions by month, supports the idea that the production cycles in the northern and southern regions were different. The monthly coefficient of variation are very similar in the northern region during the spring, summer and autumn while in the southern region its variation is higher along the same period.

DISCUSSION AND CONCLUSIONS

The zooplankton production cycle off the Portuguese coast is characterized by the maintenance of relatively high production levels during spring, summer and autumn months only diminishing in the winter months. The maintenance of the production levels during summer and beginning of autumn seems to result from the enrichment of the euphotic zone with nutrients which in temperate waters is the limiting factor for phytoplankton growth (Chelton *et al.*, 1986). In the Portuguese coast, where runoff is of very little importance during summer and autumn, the first responsible for the enrichment of the euphotic zone must be coastal upwelling. In fact, during the sampling period the wind stress favored the existence of coastal upwelling during March-April to October-November.

Although the general pattern in the portuguese coast is the mentioned above, this is not true when we consider more restricted regions. The differences between the production curves in the northern and southern regions are in accordance with the areas referred by Fiúza (1983) as having different upwelling patterns. According to this author the region north of Nazaré canyon, and where the Espinho and Figueira da Foz transepts were located, is an hydrographic homogeneous area and the upwelling pattern is bidimensional as a result of the wider and flat shelf. The homogeneity in the hydrographic regime is reflected in the zooplankton production cycle where high production levels are maintained during the months of northerly winds as a result of corresponding high primary production levels. In this region, where the enrichment of the euphotic zone in nutrients is more or less constant and the amount of sunlight is high all around the year, the depth of mixing must be the most important factor to limit the phytoplankton growth as can observed by the drop in the production levels in winter when the water column was not stratified.

The differences, although not significantly different, between the production cycles and the coefficients of variation for the Sines and Lagos transepts seemed also to reflect the two kinds of upwelling patterns referred by Fiúza (1983) for this two regions. However, the small number of samples and the great variability in biomass in these two regions do not permit to conclude about the differences in the zooplankton production cycles in these two areas.

ACKNOWLEDGMENTS

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Table I - Monthly means of the zoplankton biomass (Log$_e$ [(ml/1000m^3)+1]) and respective number of samples and standard deviations.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Sieve: 505 μm												
Espinho												
Mean	4.0	2.8	4.6	4.0	4.6	4.3	4.5	4.7	-	4.6	4.4	4.3
N	17	6	12	12	6	6	11	12	-	9	14	12
STD	0.5	1.0	0.8	1.5	0.5	0.3	0.6	0.7	-	0.6	1.2	0.5
Figueira da Foz												
Mean	4.2	4.5	4.6	4.6	4.3	4.9	4.2	4.7	4.5	4.4	4.2	4.4
N	18	7	13	14	7	7	14	7	7	13	21	14
STD	0.6	1.0	0.8	0.8	1.4	0.5	1.0	0.7	0.5	0.4	1.0	0.7
Sines												
Mean	4.2	3.1	4.7	4.0	3.2	3.9	5.2	4.5	4.3	4.7	4.5	4.5
N	8	3	6	3	3	6	6	6	3	3	5	6
STD	0.3	0.2	0.3	0.3	0.7	0.5	1.0	0.4	0.4	0.4	0.5	0.7
Lagos												
Mean	3.5	2.5	5.0	5.2	5.1	4.2	5.0	5.5	4.3	5.2	3.8	4.0
N	8	4	8	8	4	4	8	7	2	4	12	8
STD	0.7	1.2	1.1	0.7	0.3	0.5	0.8	0.3	0.0	0.7	1.1	0.5
Total												
Mean	4.0	3.4	4.7	4.5	4.4	4.3	4.6	4.9	4.4	4.6	4.2	4.3
N	51	20	39	37	20	23	39	32	12	29	52	40
STD	0.6	1.3	0.8	1.2	1.1	0.6	0.9	0.7	0.5	0.6	1.1	0.6
Sieve: 335 μm												
Espinho												
Mean	4.2	3.2	4.9	5.0	5.3	4.9	5.0	5.0	-	5.2	5.0	4.6
N	17	6	12	6	6	6	11	12	-	9	14	12
STD	0.6	1.2	0.9	0.5	0.6	0.8	0.4	0.7	-	0.4	1.0	0.7
Figueira da Foz												
Mean	4.3	4.9	4.8	5.2	5.2	5.5	5.0	5.1	5.1	5.0	4.7	4.6
N	18	7	11	12	7	7	14	7	7	13	21	14
STD	0.9	1.0	0.8	0.5	0.4	0.5	0.5	0.8	0.6	0.6	0.8	0.7
Sines												
Mean	4.6	3.8	5.1	4.8	4.1	5.0	5.5	4.9	5.0	5.0	5.1	4.4
N	8	3	6	3	3	6	6	6	3	3	5	6
STD	0.3	0.2	0.2	0.2	0.6	0.4	0.8	0.3	0.8	0.1	0.6	0.7
Lagos												
Mean	4.1	3.6	5.4	5.3	5.7	5.5	5.5	5.7	5.2	5.9	4.3	4.2
N	8	4	8	7	4	4	8	7	2	4	12	8
STD	0.5	1.1	0.7	0.7	0.4	0.8	0.7	0.7	0.2	0.8	1.2	0.8
Total												
Mean	4.3	4.0	5.0	5.0	5.2	5.2	5.2	5.1	5.1	5.2	4.7	4.5
N	51	20	37	29	20	23	39	32	12	29	52	40
STD	0.7	1.2	0.8	1.1	0.7	0.7	0.6	0.7	0.6	0.6	1.0	0.7

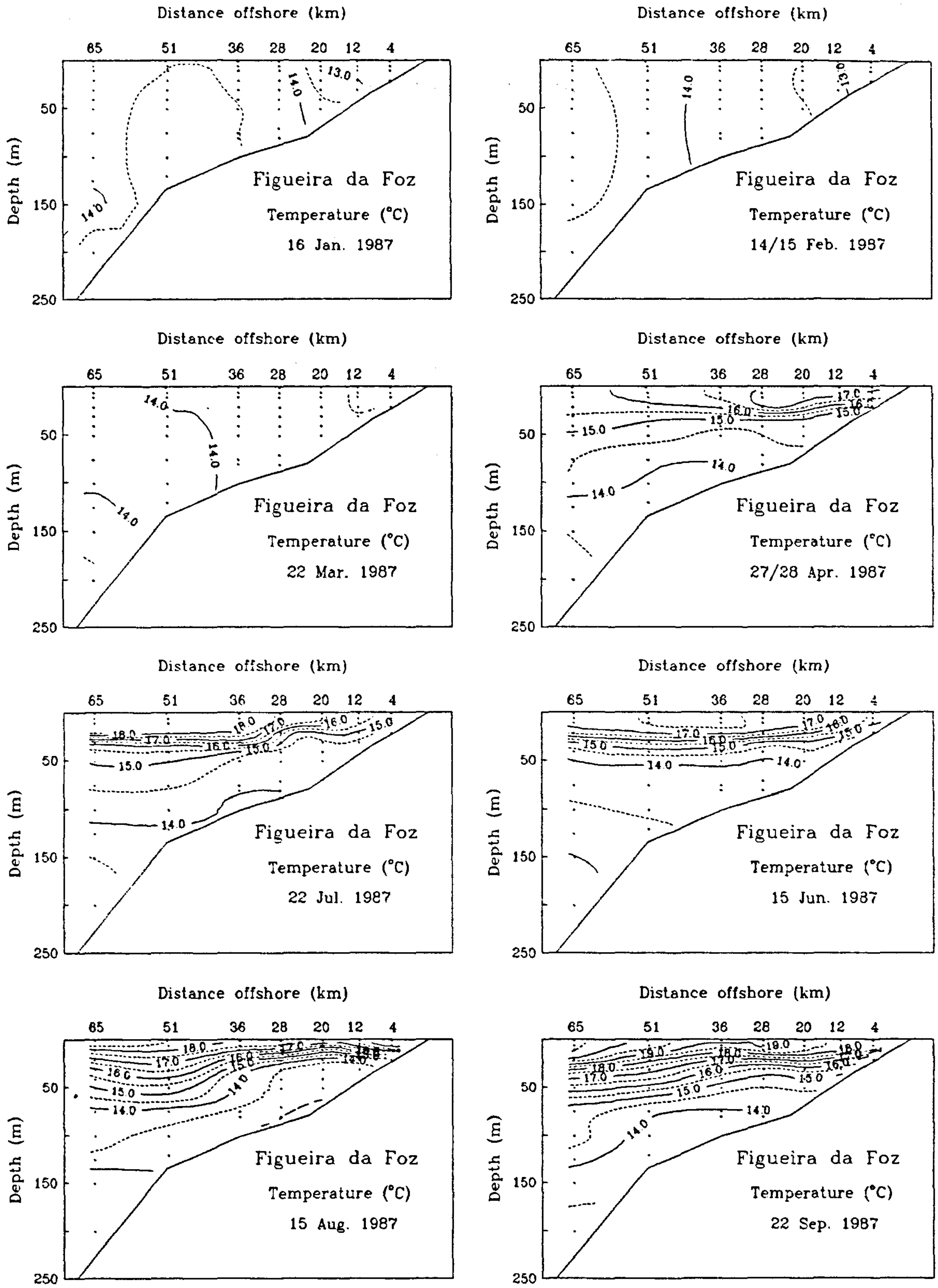

Figure 3. Monthly evolution of the thermic structure of the water column along the section off Figueira da Foz. (Continue in next page)

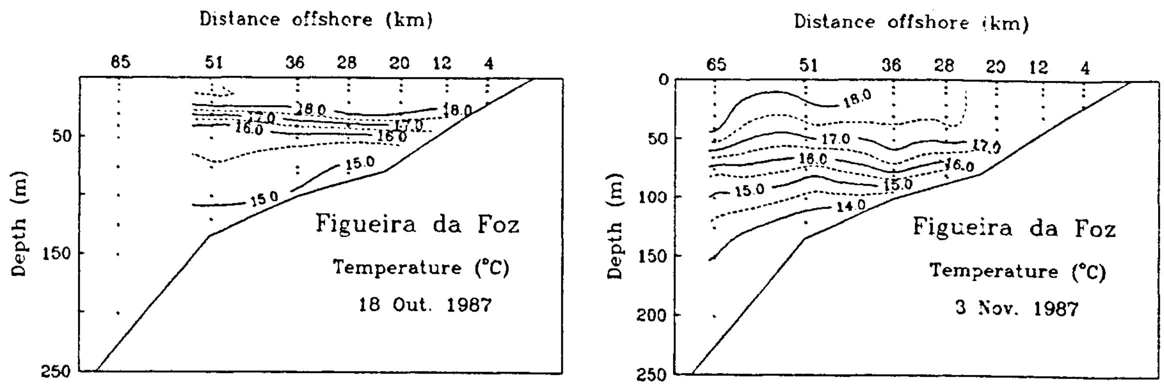

Figure 3. Monthly evolution of the thermic structure of the water column along the section off Figueira da Foz. (Continuation of the preceding page)

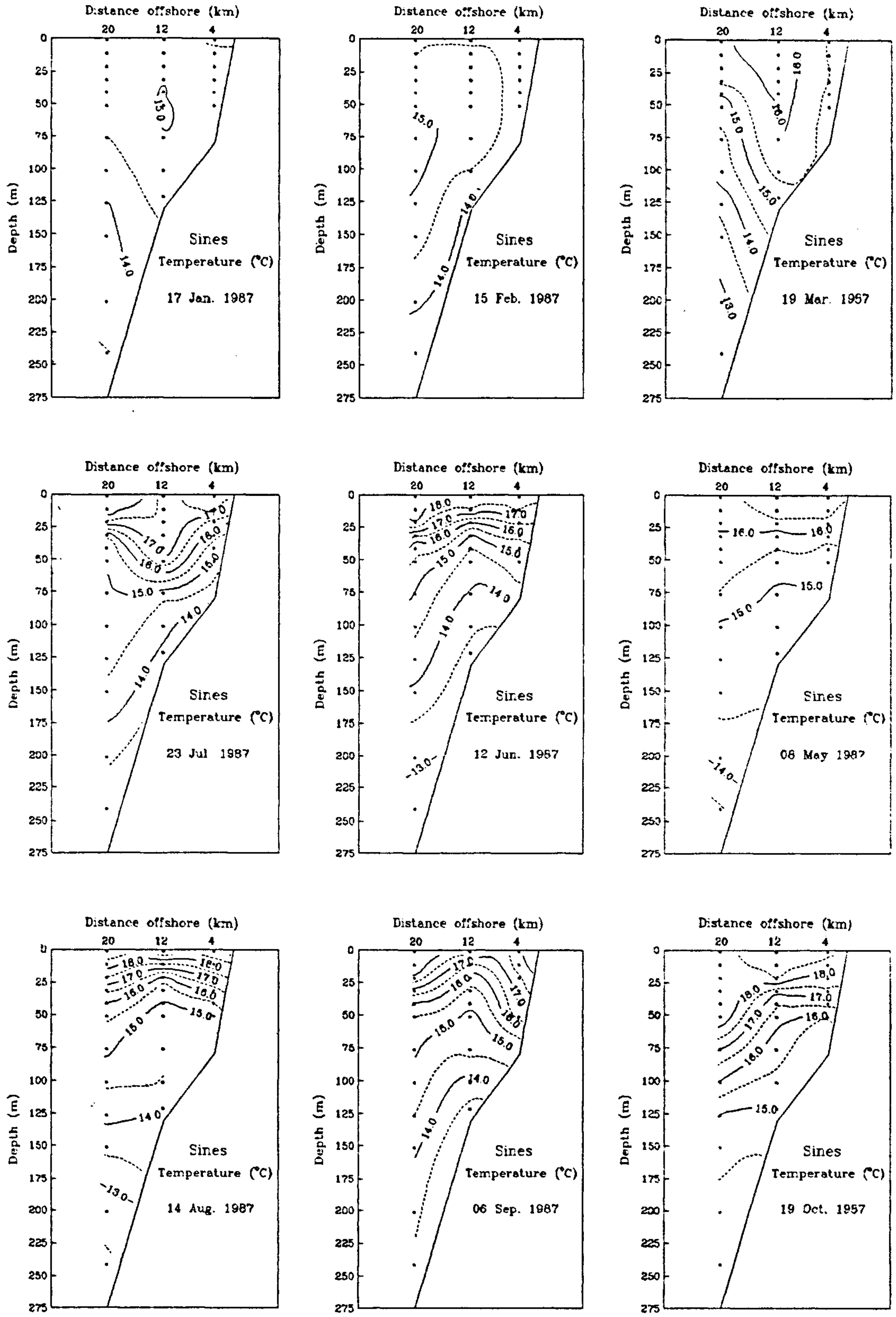

Figure 4. Monthly evolution of the thermic structure of the water column along the section off Sines. (Continue in next page)

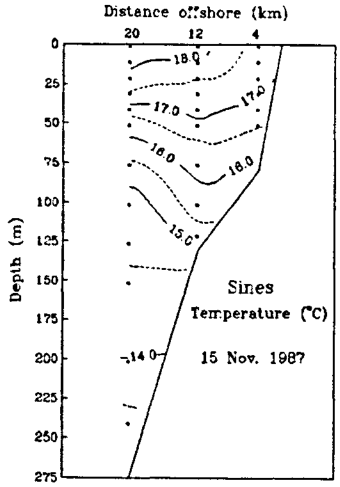

Figure 4. Monthly evolution of the thermic structure of the water column along the section off Sines. (Continuation of the preceding page)

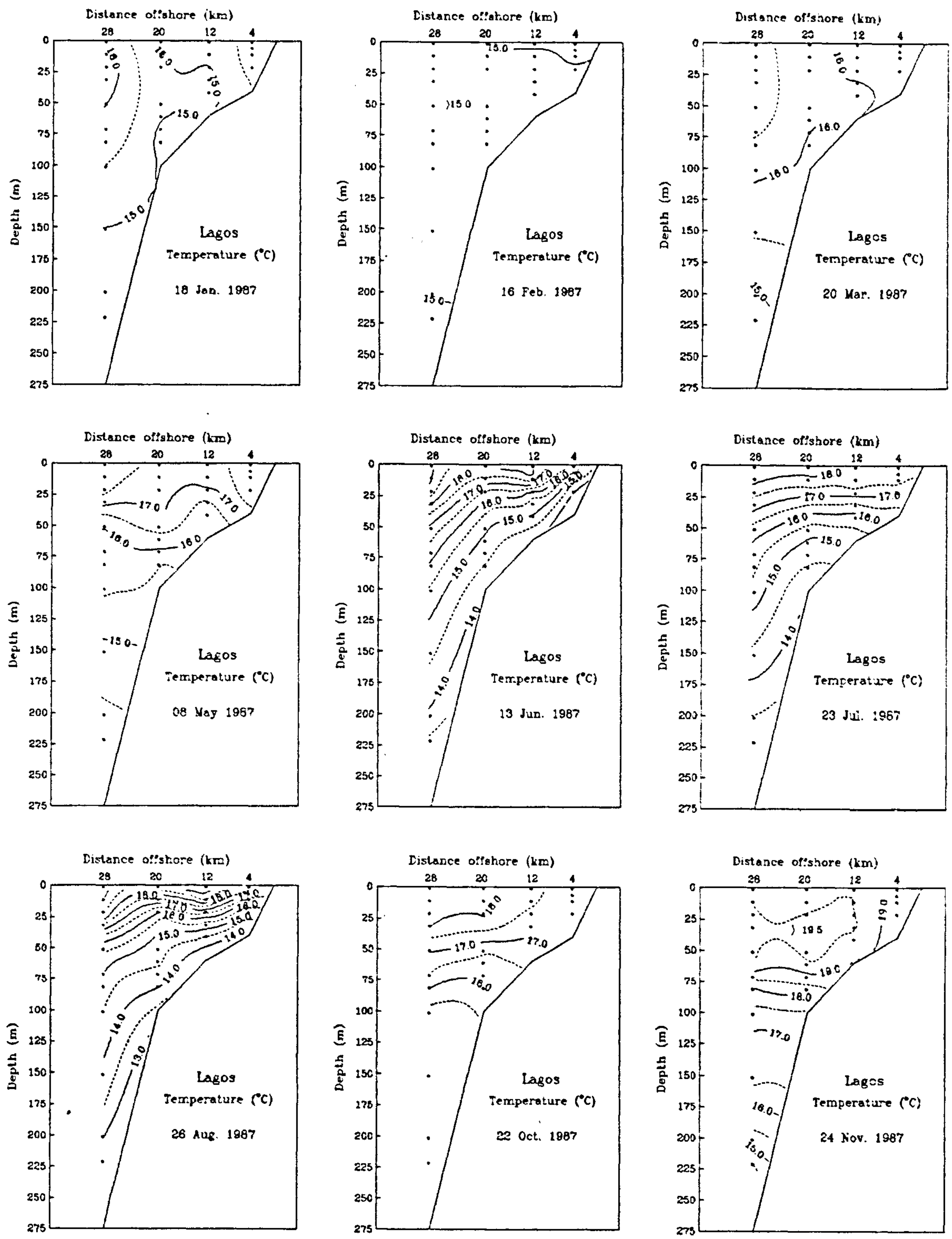

Figure 5 Monthly evolution of the thermic structure of the water column along the section off Lagos.

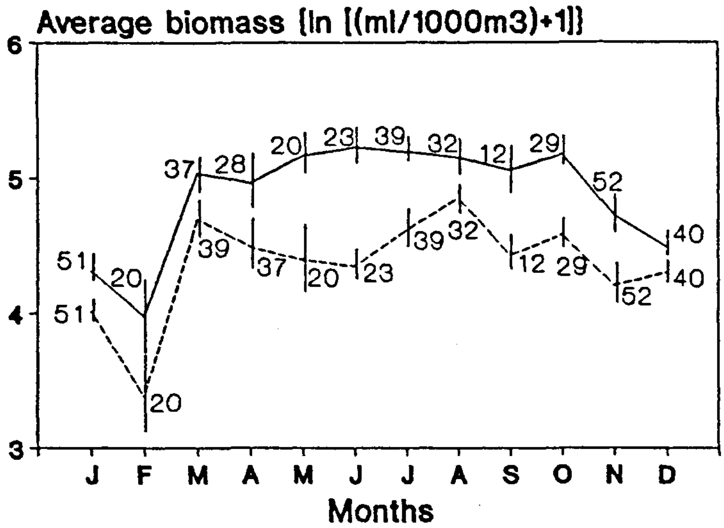

Figure 6. Monthly evolution of the mean zooplankton biomass off the Portuguese coast. (Vertical lines: standard error; continuous line: strained by 335 μm; dashed line: strained by 505 μm)

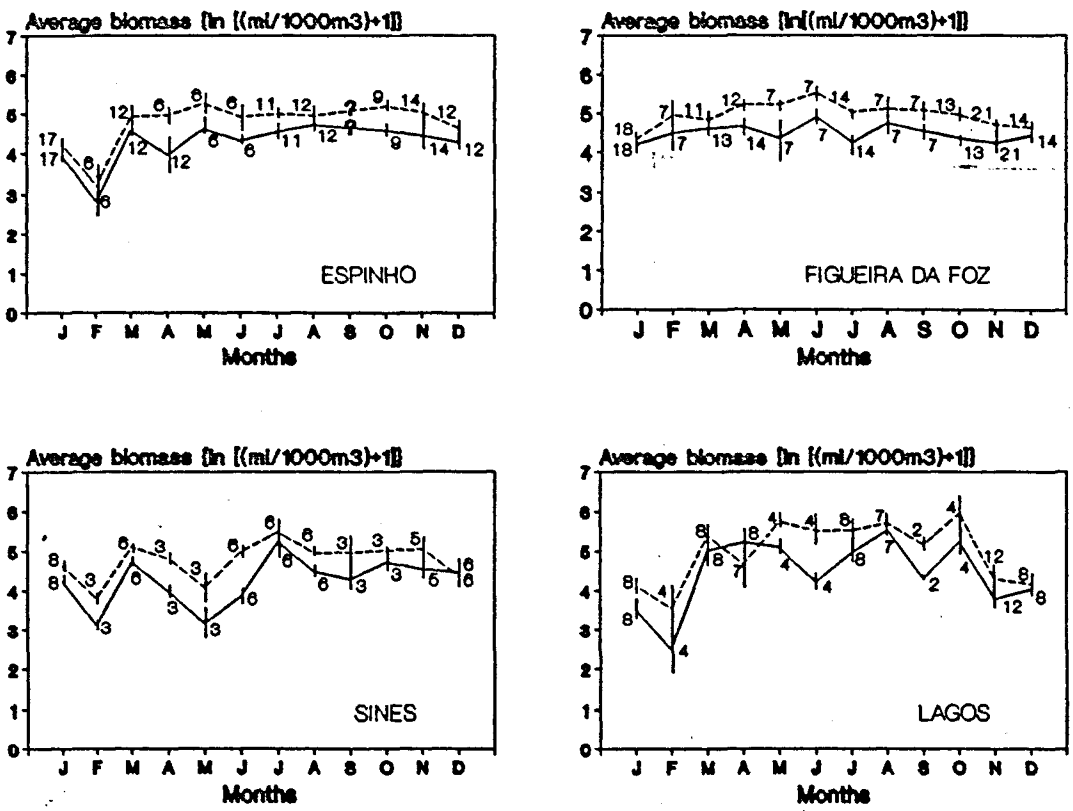

Figure 7. Monthy evolution of the mean zooplankton biomass off the four studied sections. (Vertical lines: standard error; continuous line: strained by 505 μm; dashed line: strained by 335 μm)

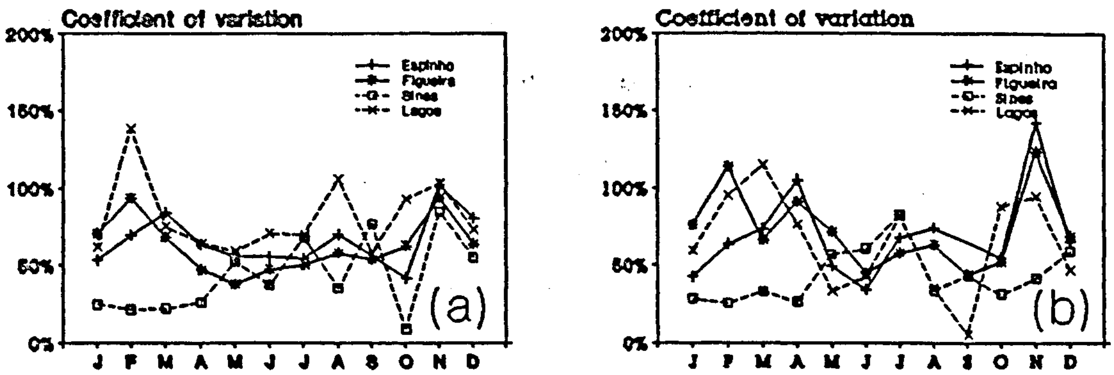

Figure 8. Monthly evolution of the coefficient of variation of the mean of the non-log$_e$ zooplankton biomass along the sampled sections. ((a) - strained by 335 μm; (b) - strained by 505)

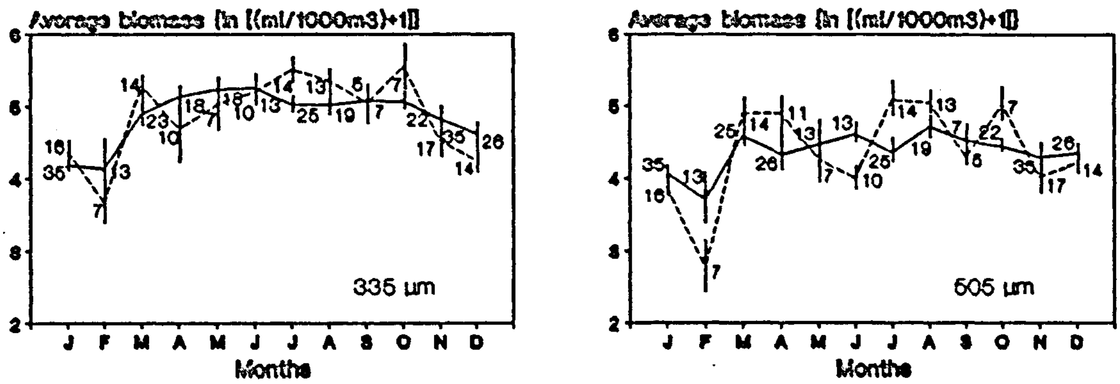

Figure 9. Monthly evolution of the mean zooplankton biomass in the northern region (continuous line) and in the southern region (dashed line). (Vertical lines: standard error)

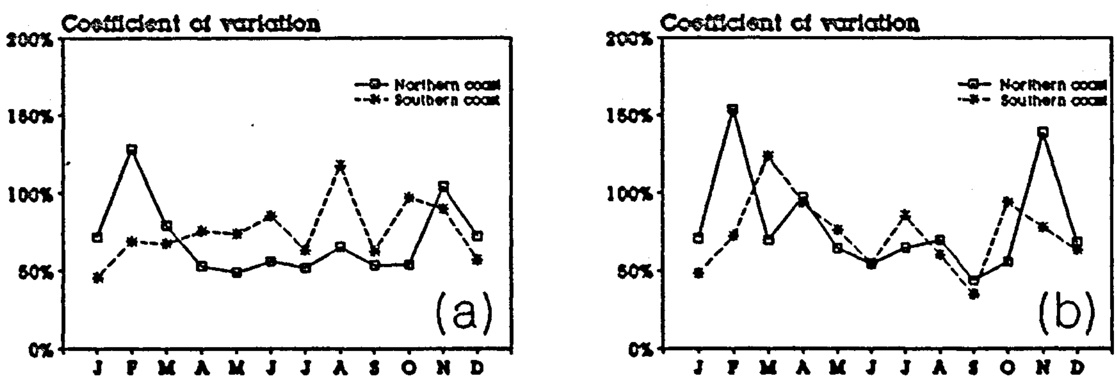

Figure 10. Monthly evolution of the coefficient of variation of the mean of the non-log$_e$ zooplankton biomass off the northern and southern coasts. ((a) - strained by 335 μm; (b) - strained by 505 μm)