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SPATIAL VARIATION OF THE ZOOPLANKTON BIOMASS IN RELATION TO THE HYDROGRAPHIC CONDITIONS OFF THE PORTUGUESE COAST

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ABSTRACT

Spatial variation of the zooplankton biomass in relation to the hydrographic conditions off the Portuguese coast is analyzed based on data from surveys covering the entire coast carried out in August 85, November 85, January 86 and March/April 86 and from samples collected monthly from October 86 through January 89 in two transepts over the northern continental shelf.

The spatial distribution of zooplankton seemed to be strongly related to the circulation pattern of the upper layers, to the topology of the coast and continental shelf and to the local wind forcing. In the southwest coast, with a very steep shelf and virtually no shelf break, zooplankton was more abundant offshore during Winter and early Spring. During this period the Subtropical component of the Eastern North Atlantic Central Water in its northward flow approached the coast and transported great amounts of zooplankton. In the northern coast and during Summer and late Autumn zooplankton biomass was concentrated very near the coast and on a band over the mid-shelf. The flat and wide shelf in this region seems to permit the establishment of a two cells cross-stream circulation with a offshore convergence front between the two cells during upwelling.

INTRODUCTION

The Portuguese coast, occupies together with the Galician coast the northern limit of the upwelling areas associated with the North Atlantic anticyclonic gyre. The hydrography and pelagic ecology of this area are strongly seasonal and influenced by the coastal morphology and shelf topography. 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 (Fiúza, 1982). These seasonal changes in the sources of currents flowing through the Portuguese coast and the different upwelling patterns originated by differences in the shelf topography may cause changes in phytoplankton and zooplankton species and standing crops (Cunha, M.E., Moita, M.T., 1991).

This paper describes the hydrography and circulation patterns of the Portuguese coast and summarize the distributions of the zooplankton biomass in relation to the hydrography.

PHYSICAL OCEANOGRAPHY OF THE PORTUGUESE COAST

The water masses present in the upper few hundred meters of the water column over the Portuguese continental margin are two components of the Eastern North Atlantic Central Water (ENACW): the Subpolar component with a origin at the west of the Biscay Bay and conforming the North Atlantic Central Water (NACW) as defined by Sverdrup *et al.* (1942) and the Subtropical component coinciding with the Eastern North Atlantic Water (ENAW) given by Fiúza and Halpern (1982) with a southern origin. These two components flow in oposite directions off the Portuguese coast: the Subpolar component present at levels of more than 27.1 flows to the south while the Subtropical component less dense and more superficial (< 27.0 sigma-t) flows to the north. This component has a maximum influence at SW of Portugal and during winter its presence is decteted at surface as a poleward longshore flow (Frouin *et al.*, 1990; Haynes and Barton, 1990).

Winds

As part of the Iberian upwelling system, the west Portuguese coast experiences upwelling-favorable winds from March-April through October-November (Wooster *et al.*, 1976;Fiúza *et al.*, 1982). During this period, northerly prevailing winds exert southward wind stress, Ekman transport is offshore and the upper layer flow to the south (Fíuza,1984). To balance the offshore transport there are an onshore transport at depth of cold, nutrient-rich slope waters which moves shoreward from depths of 60 to 120m (Fiúza, 1982). From November to February, wind stress is generally northward, Ekman transport is onshore, and downwelling occurs. Whenever short-term, 7 days (Afonso Dias, p.c.), wind reversals from the average there are episodes of downwelling during the upwelling season and upwelling during the downwelling season.

Hydrography and circulation

In addition to local wind forcing, upwelling patterns off Portugal are also determined by the coastal morphology and the shelf/upper slope topography as pointed out by Fiúza (1983). On the wide and flat northern shelf (Figure 1), upwelling is fairly two-dimensional with upwelling centers near the coast and a probable upwelling front at the mid-shelf (Fiúza, 1983). Off the southern part of the west coast three-dimensionality results in the Bay of Setúbal which is induced by large coastal protrusions in association with the pronounced submarine topography of the Lisboa-Setúbal Canyons; south of the cape of Sines, where the topography is more even, the shelf is very steep with virtually no shelf break, the upwelling pattern is more regular and the thermal gradients are compressed towards the shore. At the meridional coast, upwelling occurs occasionally under western local winds. However, during north wind cycles, which may not even reach this southern area, upwelled waters from the west coast may be impinged over the southern shelf break by an easterly extension of an apparent equatorward coastal upwelling current (Fiúza, 1983).

MATERIAL AND METHODS

Zooplankton biomasses were determined based on samples collected from August 1985 till January 1989. Two sets of data were used. One from samples collected in surveys covering the entire coast in August 85, November 85, January 86 and March/April 86 and the other from samples collected monthly from October 1986 through January 1989 with few interruptions. In the first set, the zooplankton was collected in a geographically fixed grid (Figure 1) of 110 hydrographic stations, within a depth range of 20 m to 1000 m, using 1 m diameter and 5 m long ring nets with a mesh aperture of 505 μm, and information on the stratification of the water column was obtained with a Nansen bottle. The second set come from samples collected along 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.

Zooplankton was 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. The night-day difference in the zooplankton standing stock due to the time of sampling was corrected by multiplying the value of the day by the night/day ratio and the values were $\log_e$ transformed.

RESULTS AND DISCUSSION

Winds

Monthly upwelling indices obtained during the years of the sampling, 1985 through 1989, are shown in Figure 2. Positive upwelling indices result from northerly winds. According to this Figure upwelling indices were positive, i.e., upwelling favorable, in general, during Spring, Summer and Autumn.

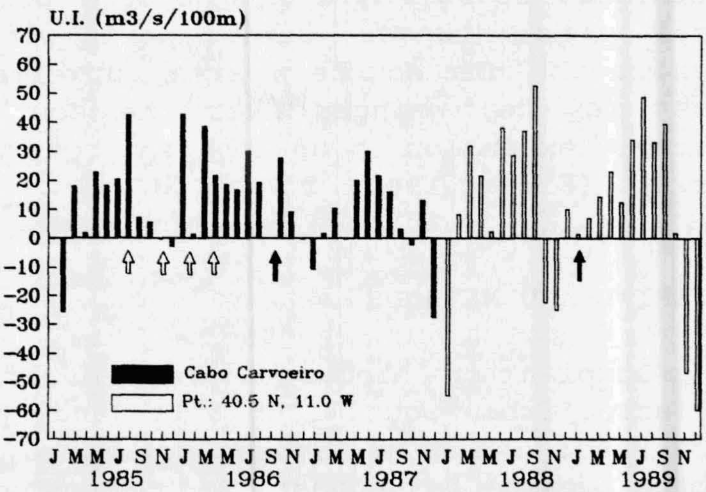

Figure 2. Monthly upwelling indices during the years of sampling. (Months of seasonal surveys - open arrows; limits of monthly sampling - filled arrows)

Hydrography and circulation

The result of the upwelling favorable winds over the oceanographic conditions can be observed during the August/September, 1985 survey, when a typical picture of the distribution of the sea-surface isotherms during the upwelling season was obtained (Figure 3). Surface cold inshore waters (3°C colder than offshore) and bottom contour parallel isotherms in the western coast, reveal that the upwelling process was undergoing in the entire western coast under northerly winds with some intensification at the south of the capes. In the southern coast, a tongue, from what seems to be an easterly extension of the west coast upwelled cold waters, was evident. The water column was strongly stratified and deep dense waters reached the surface near the coast as it may be seen in Figure 4. T-S diagrams of the outer stations (Figure 5) follow the Subtropical and Subpolar components of the ENACW represented in the Figure by the lines referred as $ENACW_t$ and $ENACW_p$ respectively ($ENACW_p$ - according to Sverdrup *et al.* (1942); $ENACW_t$ - according to Fiúza and Halpern (1982)). Figures 6a and 6b represent the vertical distribution of density at the most northern (Caminha) and southwest (Arrifana) sections. These Figures along with Figure 5, reveal that the Subtropical component, present at density levels of less than 27.0, occupies most of the upper layers (250 m) of the water column in the southern region (Figure 6b) and extends its influence till the northern most section (Figure 6a) where it is present in the upper 100m depth levels. More dense, higher than 27.1, the Subpolar component is present at deeper levels, from 120 m in the north (Figure 6a) till the 300 m depth in the southern regions (Figure 6b).

Three months later, in November/December, 1985, sea-surface isotherms in the northern coast were still parallel to the cost line (Figure 7) but the gradient was not as strong as in August. During this cruise the southwest coast was not sampled due to bad weather conditions. The winds were mainly from the southwest but after a day of northerly strong winds there was upwelling of deep dense waters as it may be seen in Figure 8 that represents the vertical distribution of density along the section off Figueira da Foz. According to the T-S diagrams of the outer stations (Figure 9) there was some thermal stratification in the upper 100m of the water column. The Subtropical component of the ENACW invade all the northern shelf while the Subpolar component was present at deeper levels.

In January, 1986, the distribution of the sea surface temperature (Figure 10) indicate that the subtropical warm water aproched the coast from the south, causing at the southern coast a strong thermic front. This is confirmed by the distribution of the high salinity lines in Figure 11 that represents the vertical distribution of salinity at the most southwest section. During this cruise the water column was not thermally stratified as it might be seen in Figure 12 which represents the T-S diagrams of the outer stations. This Figure show the influence of low salinity waters due to runoff in the northern region of Portugal (stations 2, 12 and 13) while in the southern region the Subtropical component reached the surface. This component was also present through most of the upper layers of the northern coast as indicated by the position of the 27.0 sigma-t line in Figure 13, that represent the vertical distribution of the density along the northern most section (Caminha).

The distribution of the sea-surface temperature during the March/April, 1986 cruise, is shown in Figure 14. The warm waters of the Subtropical component of the ENACW still approached the coast by the south. This is confirmed by the vertical distribution of the more saline waters in Figure 15 which represent the vertical distribution of salinity at the most southwest section. The upper layers of the water column were still vertically homogeneous and there was a progressive influence of low salinity waters due to runoff till the latitude of Lisbon, as may be seen in Figure 16 where the T-S diagrams of the outer stations is represented. South of Lisbon the Subtropical component reached the surface. This component do not reached the northern section as shown by the position of the line of 27.1 sigma-t in Figure 17 that represents the vertical distribution of density along the section off Caminha.

Zooplankton spatial distribution

The spatial distribution of the zooplankton biomass during the Summer of 1985, when upwelling was active through most of the coast, is represented in Figure 18. In the northern shelf (north of Lisboa) the lines of equal zooplankton abundance seemed to indicate southern advection as a result of the establishment of a southward flow during upwelling. Zooplankton was abundant in the north and over the mid-shelf in what seems to be a convergence front. In the southwest shelf there was no apparent pattern in the distribution of the zooplankton with exception at the south where the low values seemed to related also with the advection of the upwelled waters in the Cape. To the southeast the highest zooplankton values were found near the coast.

In late Autumn, 23 November/2 December, 1985, the zooplankankton concentration off the northern coast (Figure 19) was higher in the north and over a broad band over the mid-shelf. Although the wind where not upwelling favorable during the cruise, the broad band could result from offshore advection caused by a day of northerly strong winds that blew when this region was sampled. In the south there was no particular pattern in the zooplankton distribution.

In January, 1986, when the Subtropical component of the ENACW most influenced the southern coast, zooplankton was abundant offshore at the southwest and approached the coast at the southeast (Figure 20). In the northern shelf zooplankton was more abundant at the north.

The distribution of zooplankton in March/April, 1986,

(Figure 21), was similar to the distribution found in January. Although the abundance of zooplankton was higher, it was also concentrated offshore at the southwest and near the coast at the southeast seeming to be transported to the north. In the northern coast zooplankton was abundant over the shelf.

In the attempt to confirm the existence of a convergence zone over the northern shelf the data from the monthly sampling at Espinho and Figueira da Foz were also used. Due to the short-term wind reversals during the upwelling season it was expected that the presence of a convergence zone would be indicated by higher biomass means and higher coefficients of variation. Figure 22 represents the result of the mean zooplankton biomass and the coefficient of variation at each station at the Espinho and Figueira da Foz transepts.

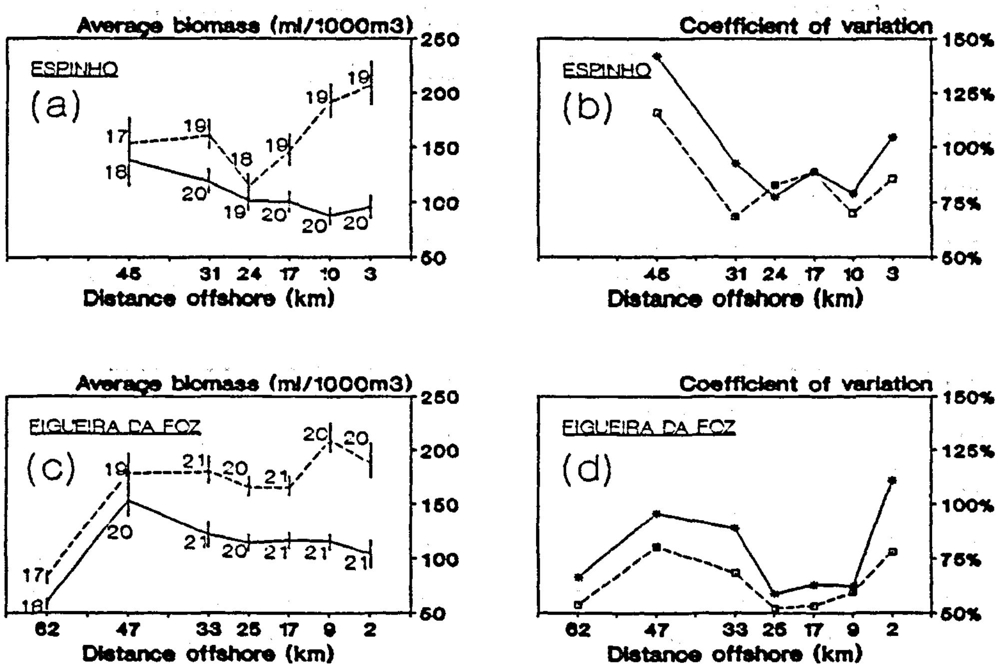

Figure 22. Average biomass [(a) and (c)], and coeficients of variation of the biomass [(b) and (d)] along the sections off Espinho and Figueira da Foz. (Dashed line - 335 μm mesh size; continous line - 505 μm mesh size)

In both transepts the mean biomass (Figure 22a and 22c) of the smaller organisms (>335 μm) were higher than the larger (>505 μm) while the coefficients of variation behave inversely (Figure 22b and 22d). With exception of the last station at the transept of Figueira da Foz the biomass distribution along the two transepts were similar with an increase to the large of the biomass of the larger organisms while the smaller organisms were more abundant in two regions, near the shore and before the shelf break. In the transept of Figueira da Foz where the last station was over the shelf break both biomass decreased sharply. The biomass coefficient of variation collected by the two nets behave similarly along the transepts with higher values near the coast and at mid-shelf.

CONCLUSIONS

The hydrologic characteristics of the coastal waters off Portugal during the studied period presented a systematic north to south gradient. The thermohaline field was conditioned by the Subtropical component of the Eastern North Atlantic Water that strongly influenced the southern coast with warmer and more saline waters and diminished its influence to the north. Seasonal variation was due to coastal upwelling, run-off and to the seasonal cycle of thermal stratification (Summer and late Autumn) - vertical convection (Winter and early Spring). In the northern coast, with a large and flat shelf, these three last actions were determinant.

The spatial variation of zooplankton seemed to be strongly related to those hydrologic characteristics, to the circulation pattern of the upper layers, to the topography of the coast and continental shelf and to the local wind forcing.

The southwest coast, with a very steep shelf and virtually no shelf break, is very much influenced by the Subtropical component of the ENACW in its northward flow. During Winter and Spring this component approached the coast and preserve is thermohaline characteristics at the surface (Figures 11 and 15) transporting noticeable amounts of zooplankton (Figures 20 and 21). On the wide northern shelf, zooplankton distribution shows strong dependence on the wind regime, with a probable convergence front at mid-shelf during the upwelling season as indicated by the high concentration of zooplankton (Figures 18, 22a and 22c) and high coefficients of variation of the biomass (Figures 22b and 22c). This offshore convergence front may be associated with the sinking of phytoplankton populations and consequent increase of zooplankton between a possible two cells of cross-stream circulation as suggested by Walsh (1976) for the wide shelf areas of the Atlantic eastern boundary currents.

ACKNOWLEDGE

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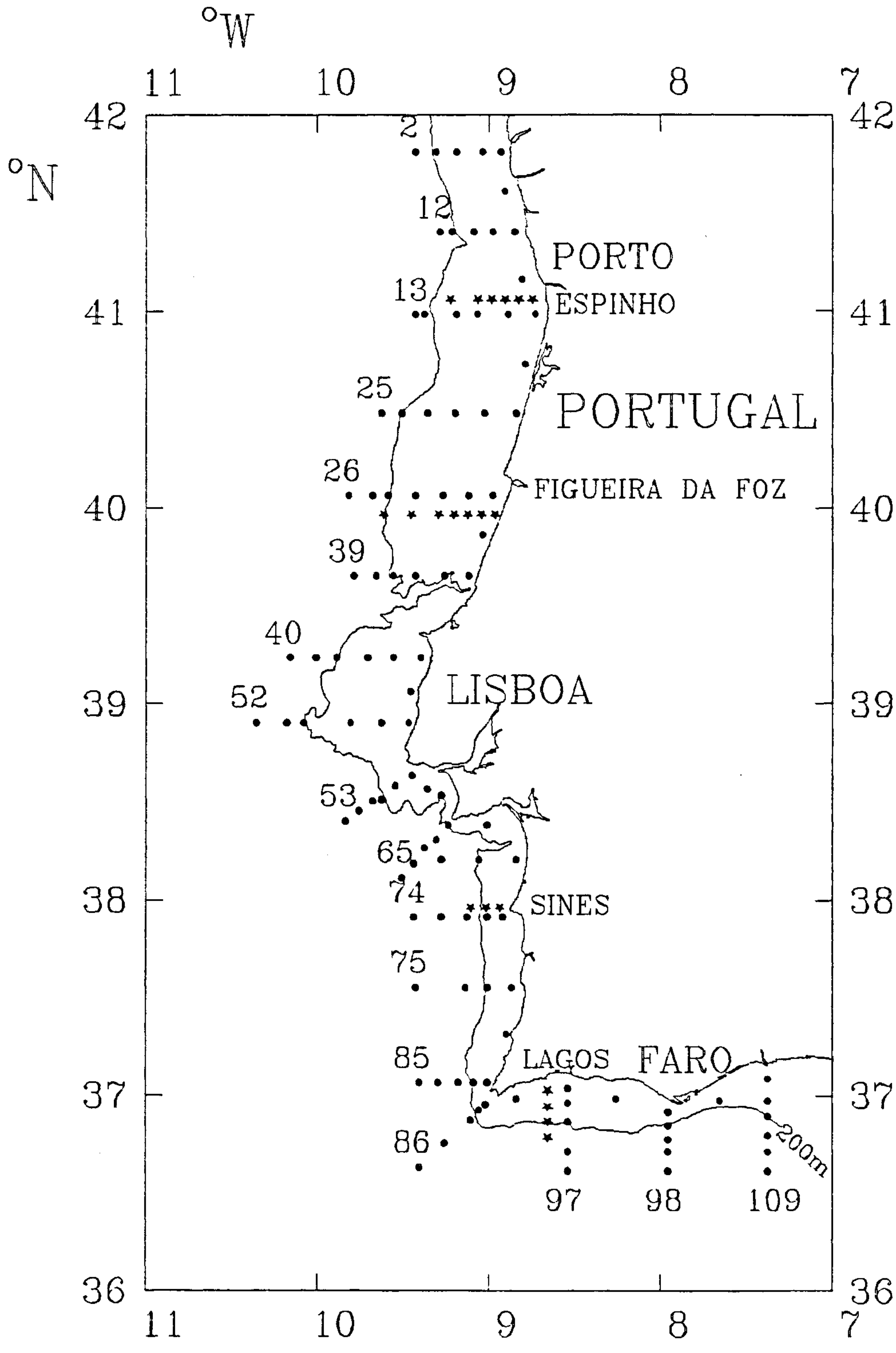

Figure 1. Location of stations and depth contour of the shelf break (200m). (Dots - seasonal surveys; stars - monthly sampling)

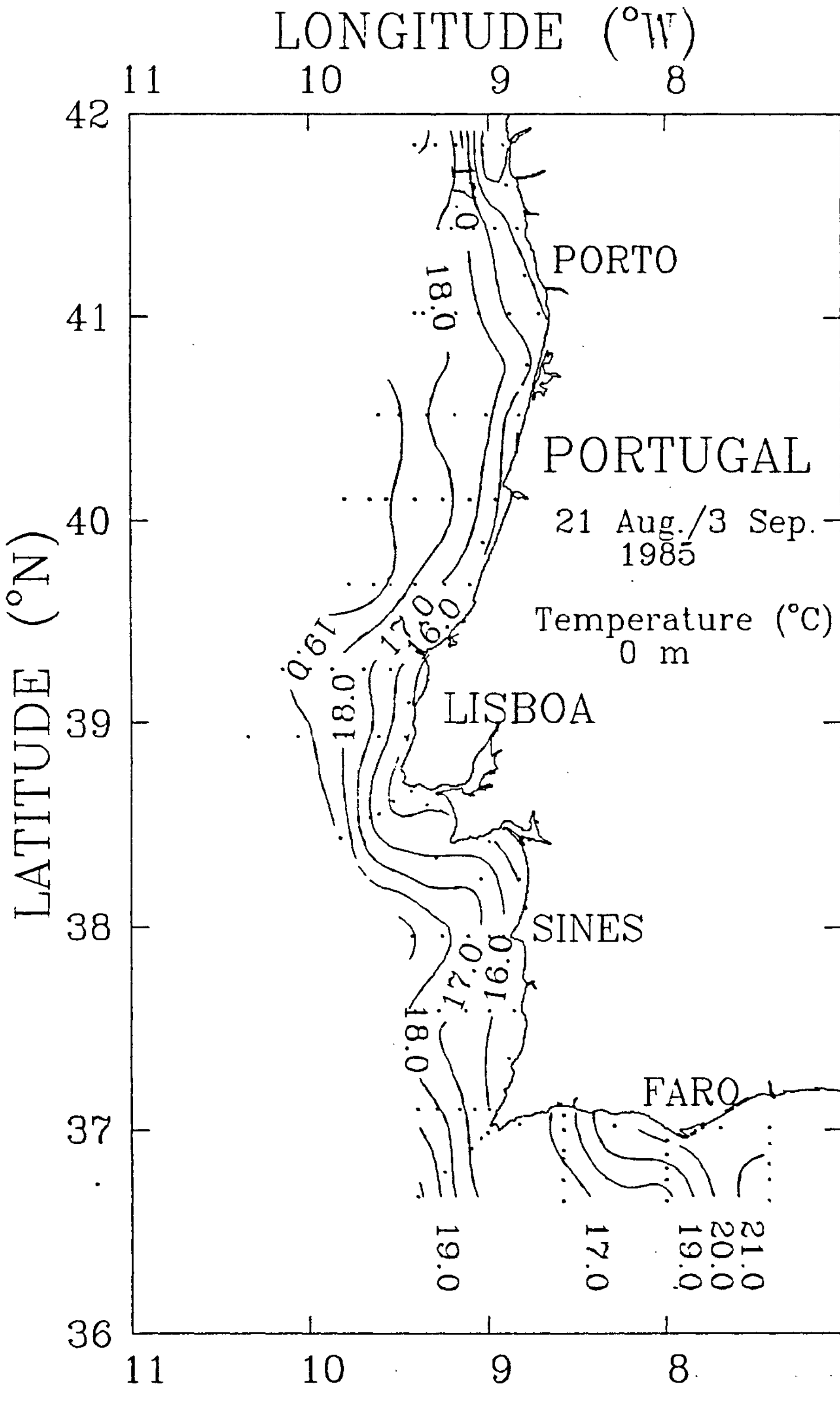

Figure 3. Sea-surface temperature off the Portuguese coast from 21 August till 3 September, 1985.

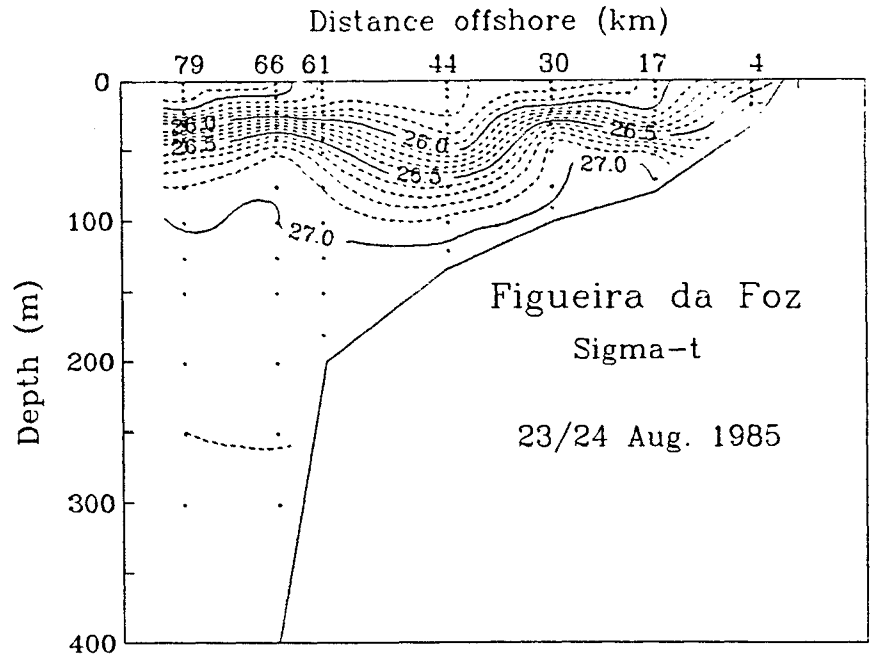

Figure 4. Vertical distribution of density along the section off Figueira da Foz. (Outer station number: 26)

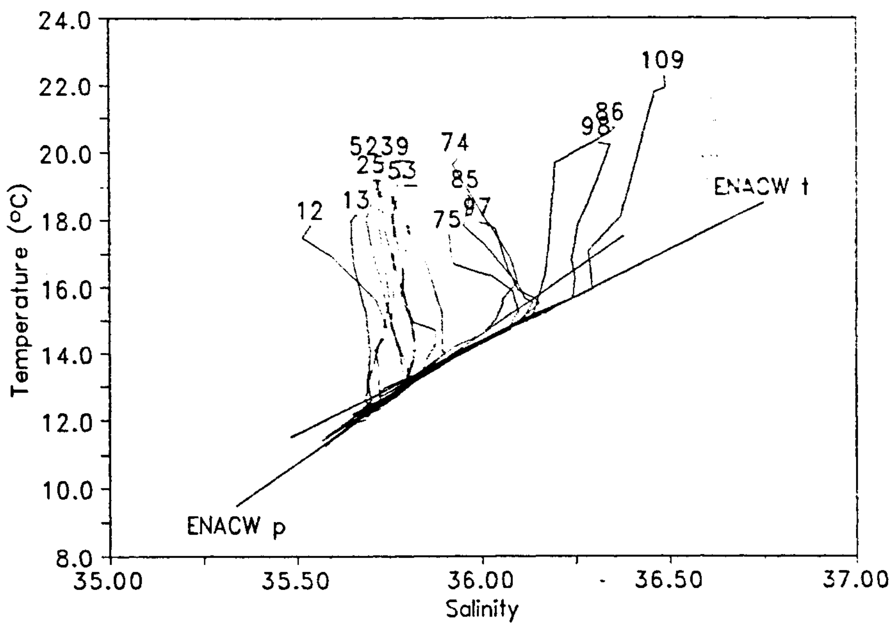

Figure 5. T-S diagrams of the outer stations, 21 August - 3 September, 1985.

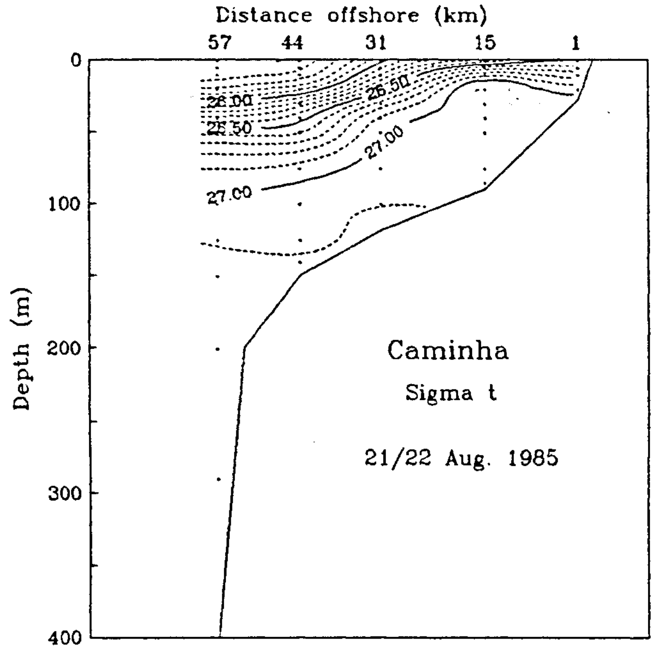

Figure 6a. Vertical distribution of density along the section off Caminha. (Outer station number: 2)

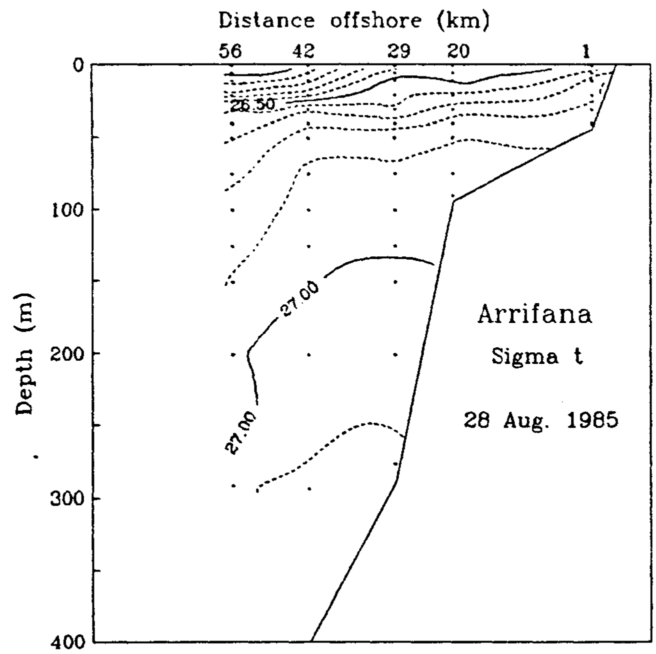

Figure 6b. Vertical distribution of density along the section off Arrifana. (Outer station number: 85)

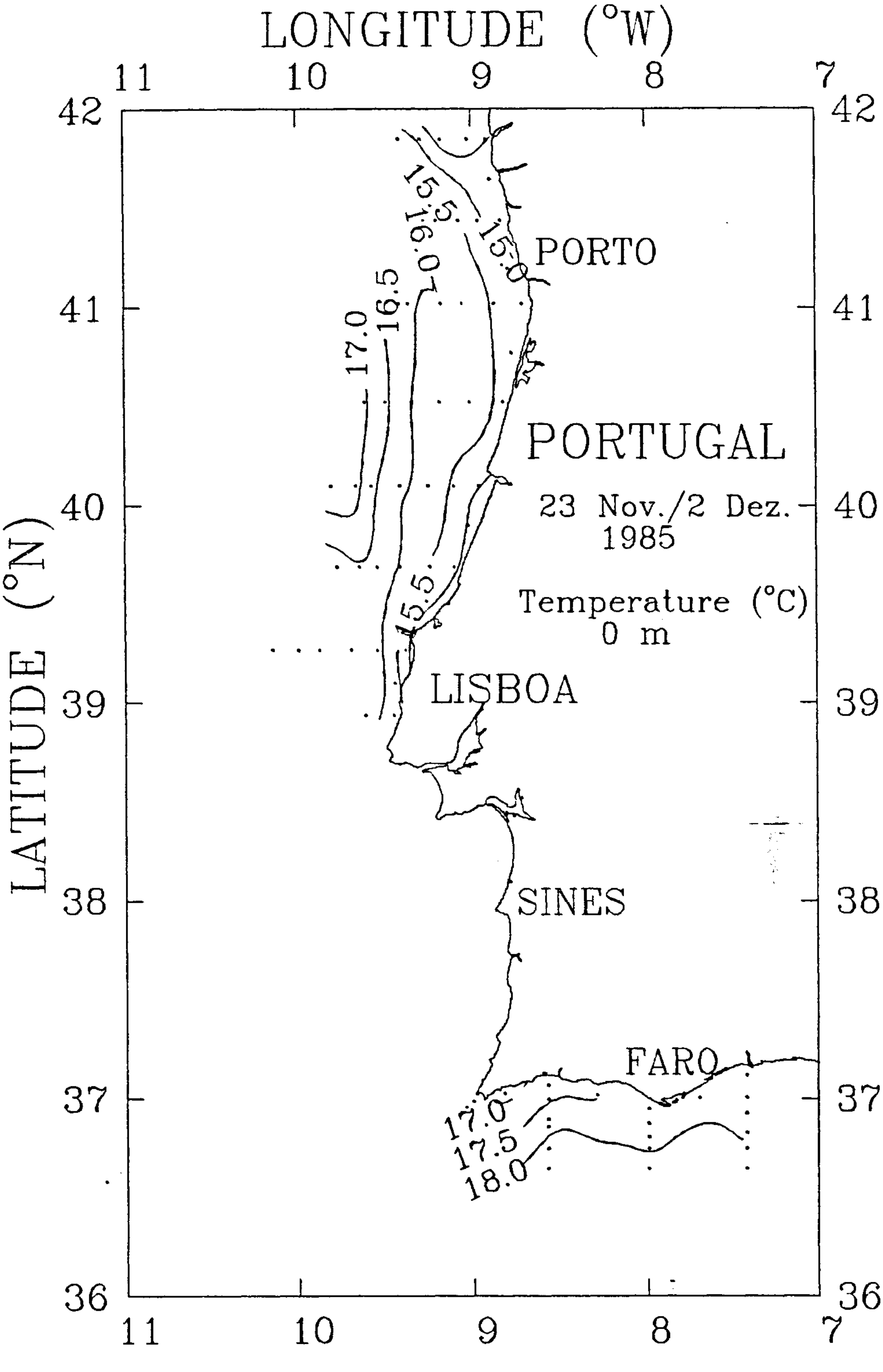

Figure 7. Sea-surface temperature off the Portuguese coast from 23 November till 2 December, 1985.

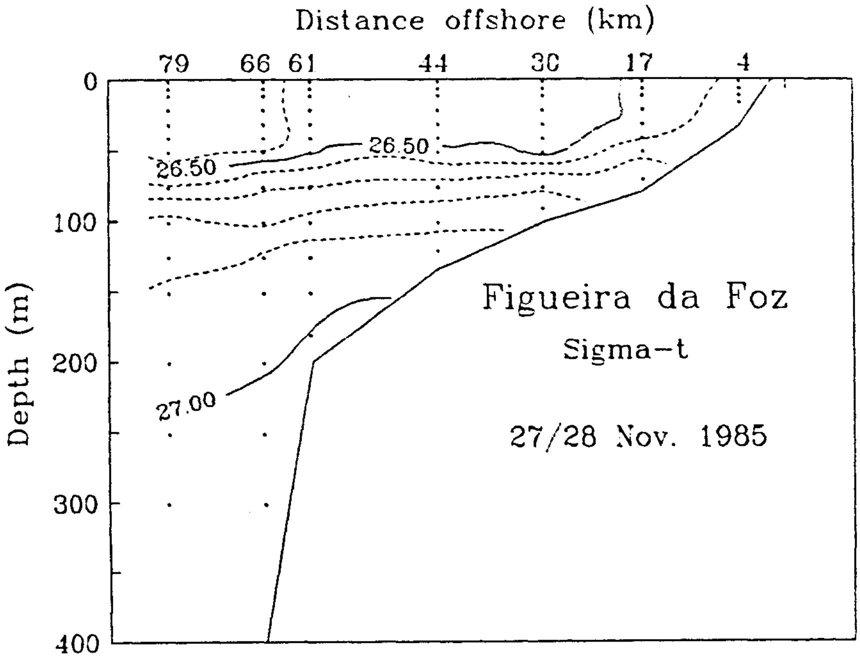

Figure 8. Vertical distribution of density along the section off Figueira da Foz. (Outer station number: 26)

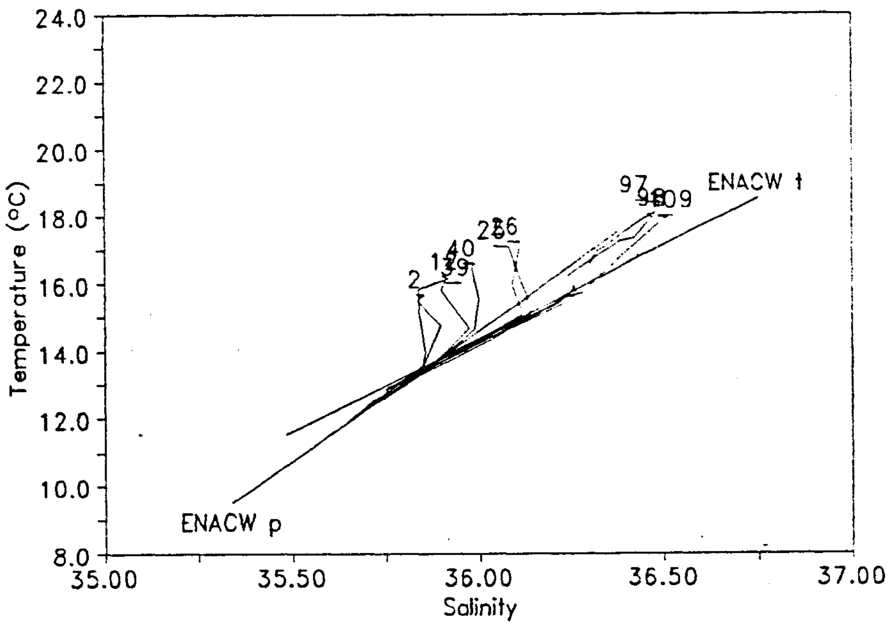

Figure 9. T-S diagram of the outer stations, 23 November - 2 December, 1985.

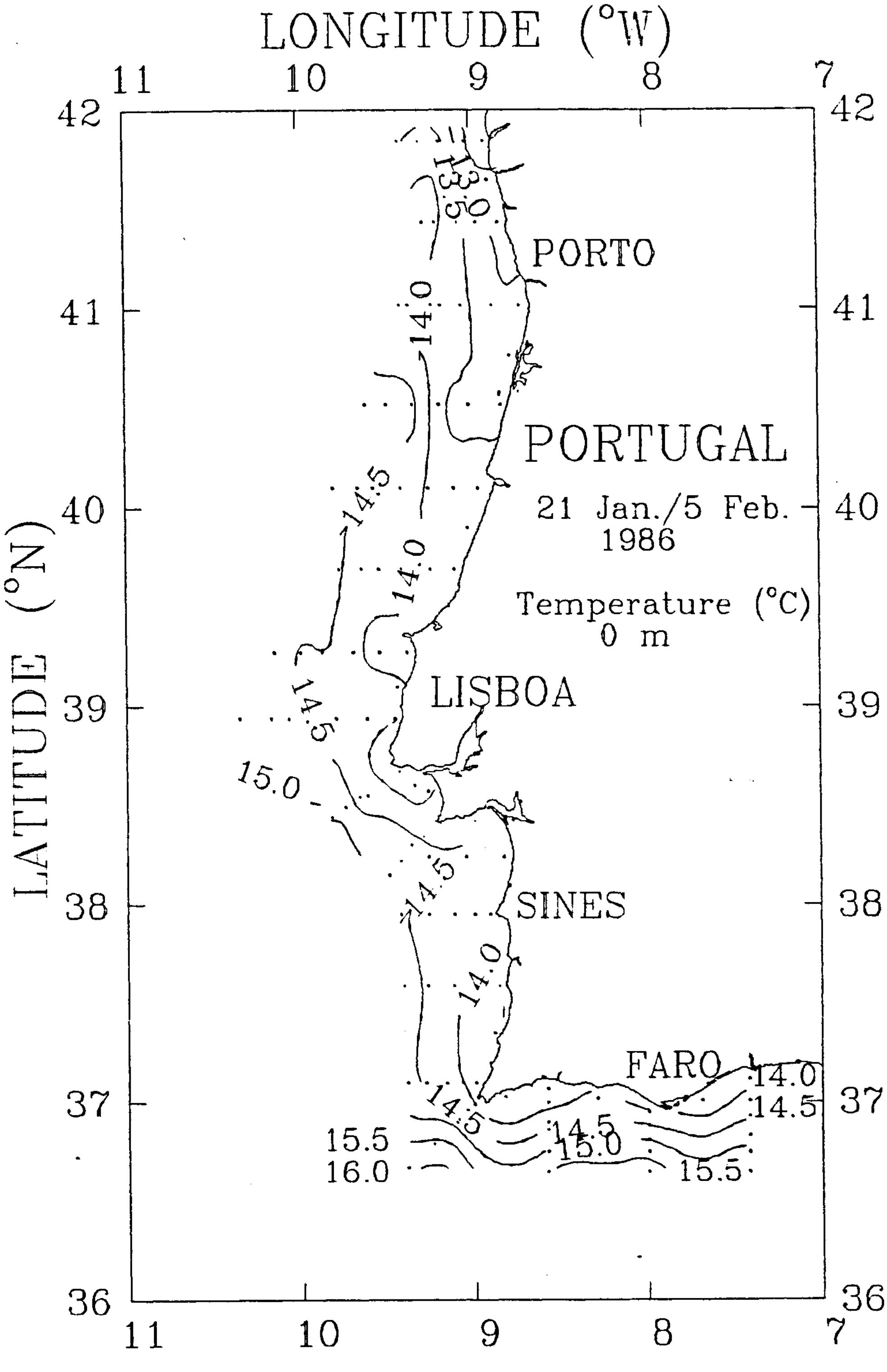

Figure 10. Sea-surface temperature off the Portuguese coast from 21 January till 5 February, 1986.

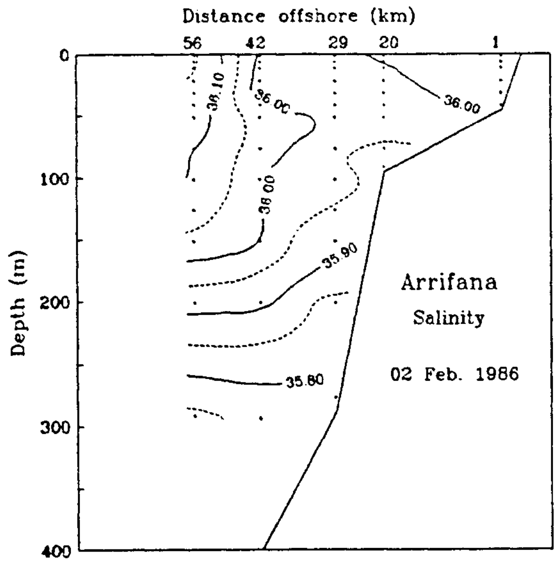

Figure 11. Vertical distribution of salinity along the section off Arrifana. (Outer station number: 85)

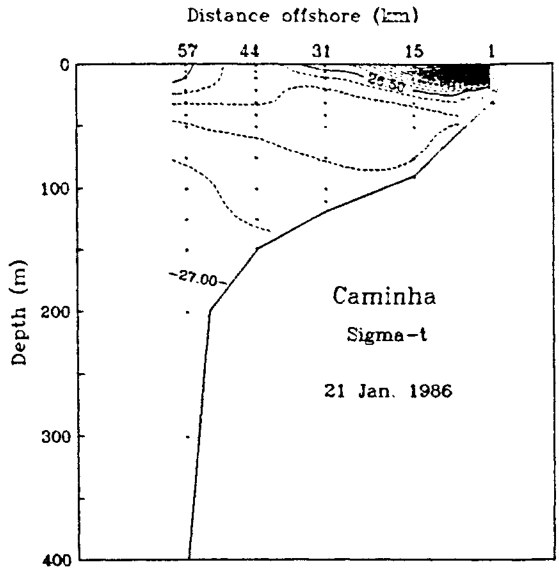

Figure 13. Vertical distribution of density along the section off Caminha. (Outer station number: 2)

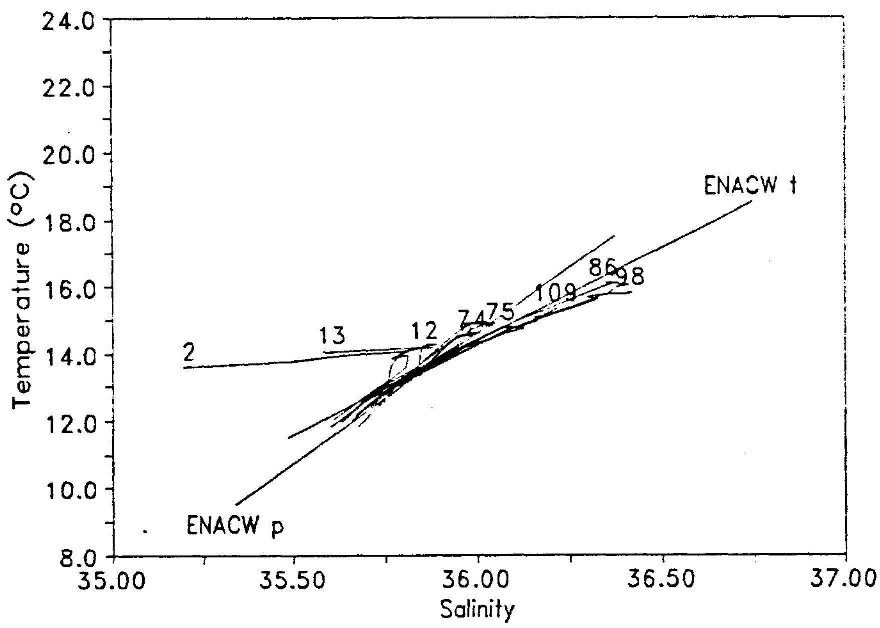

Figure 12. T-S diagrams of the outer stations, 21 January - 5 February, 1986.

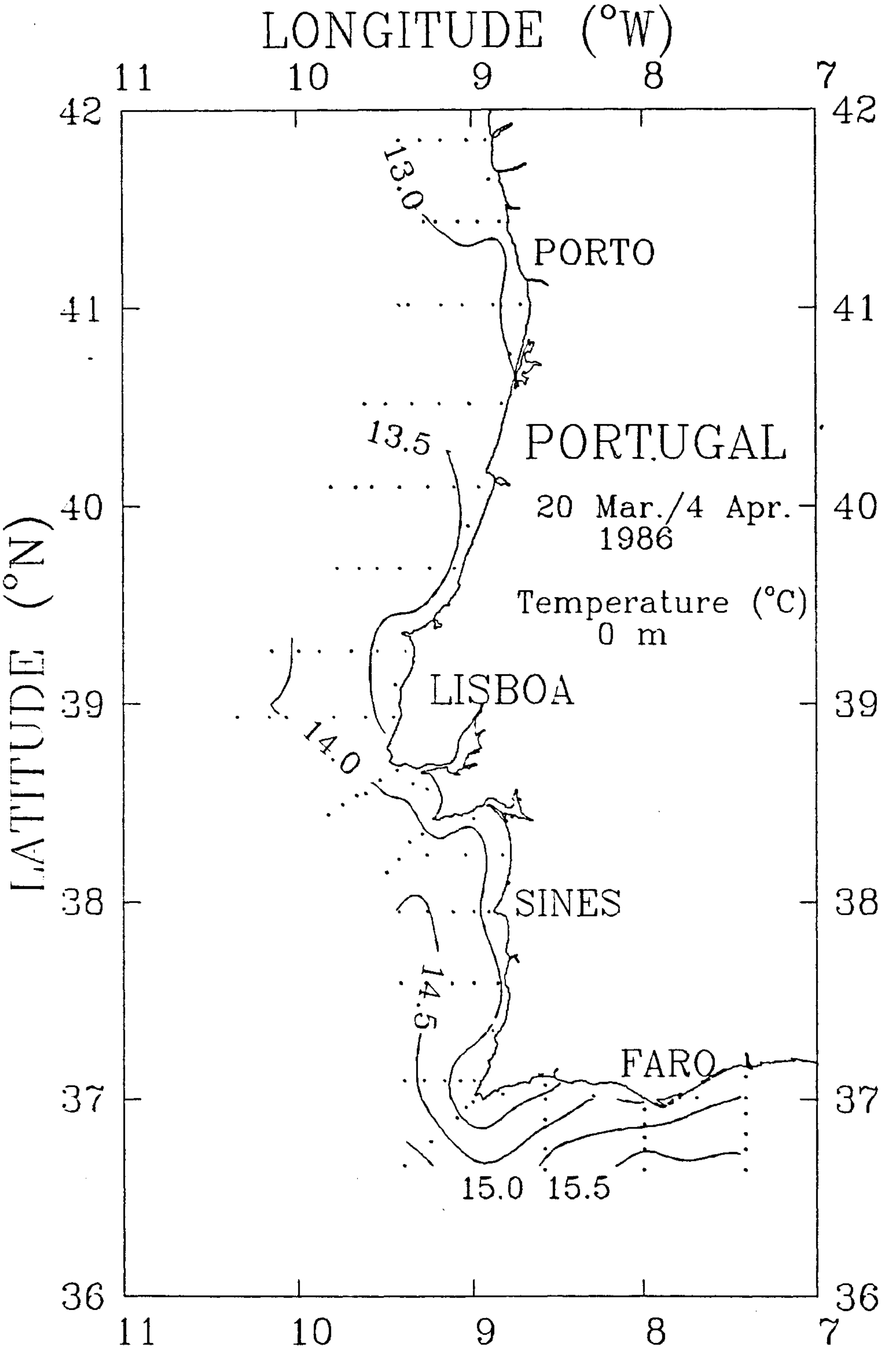

Figure 14. Sea-surface temperature off the Portuguese coast from 20 March till 4 April, 1986.

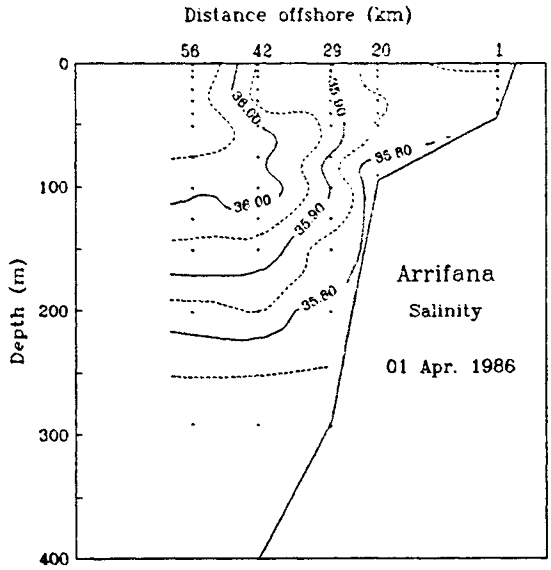

Figure 15. Vertical distribution of salinity along the section off Arrifana. (Outer station number: 85)

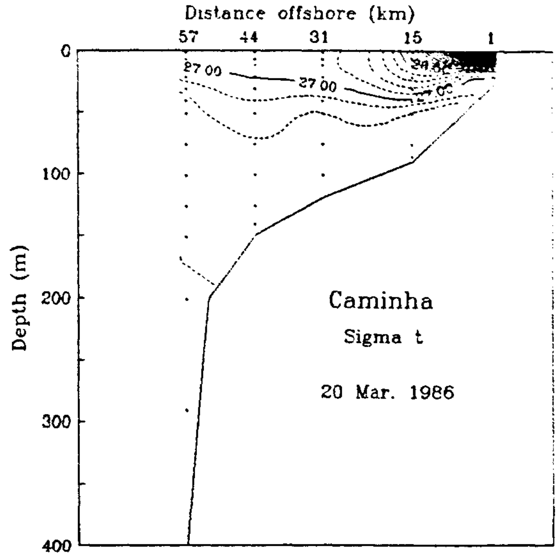

Figure 17. Vertical distribution of density along the section off Caminha. (Outer station number: 2)

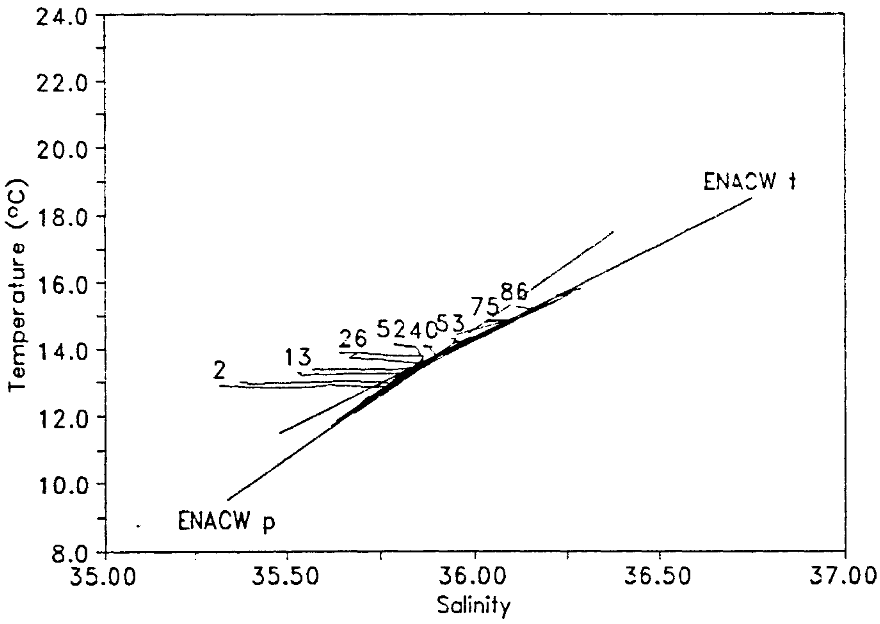

Figure 16. T-S diagrams of the outer stations, 20 March - 4 April, 1986.

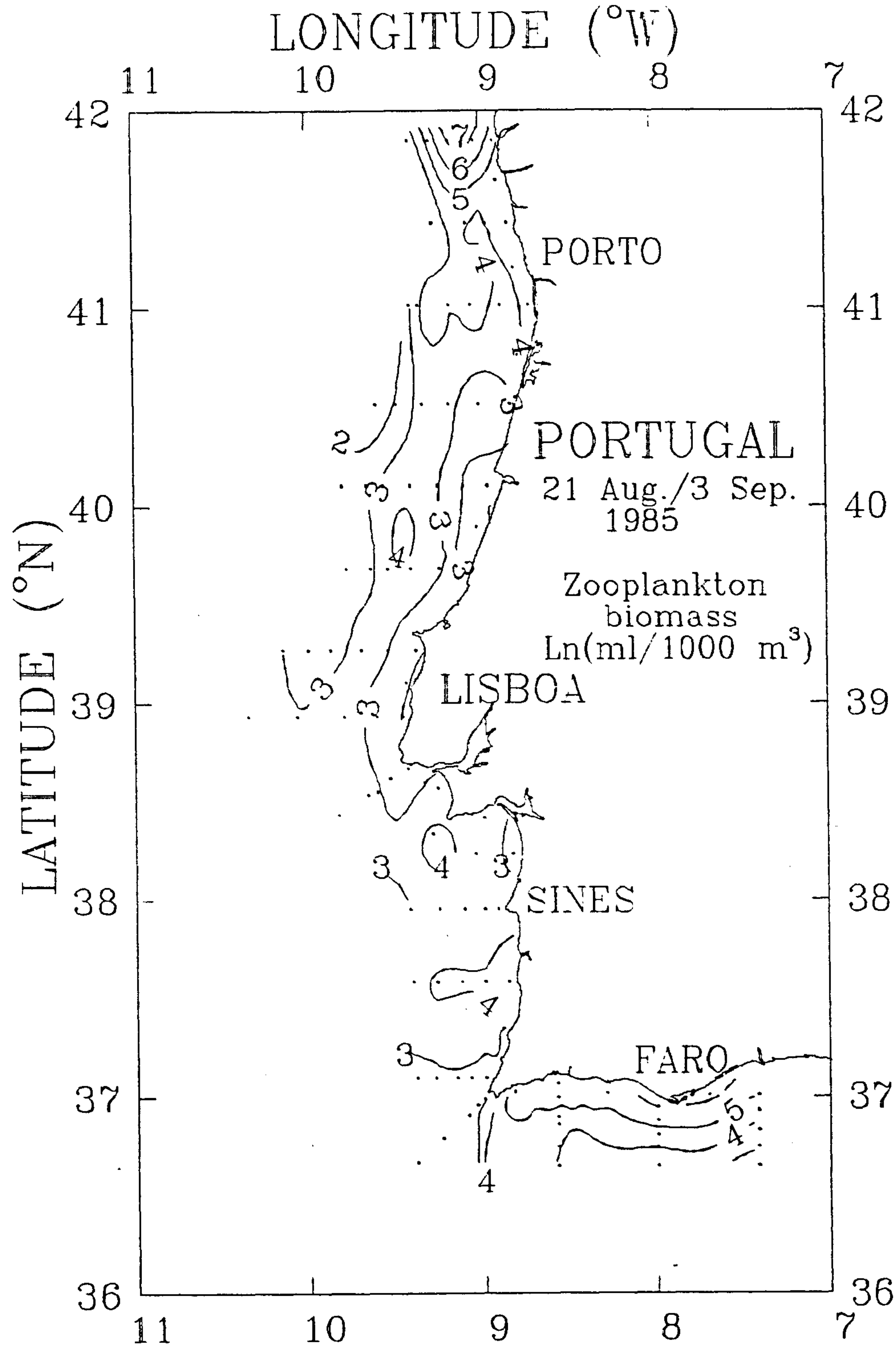

Figure 18. Zooplankton biomass distribution off the Portuguese coast, 21 August-3 September, 1985.

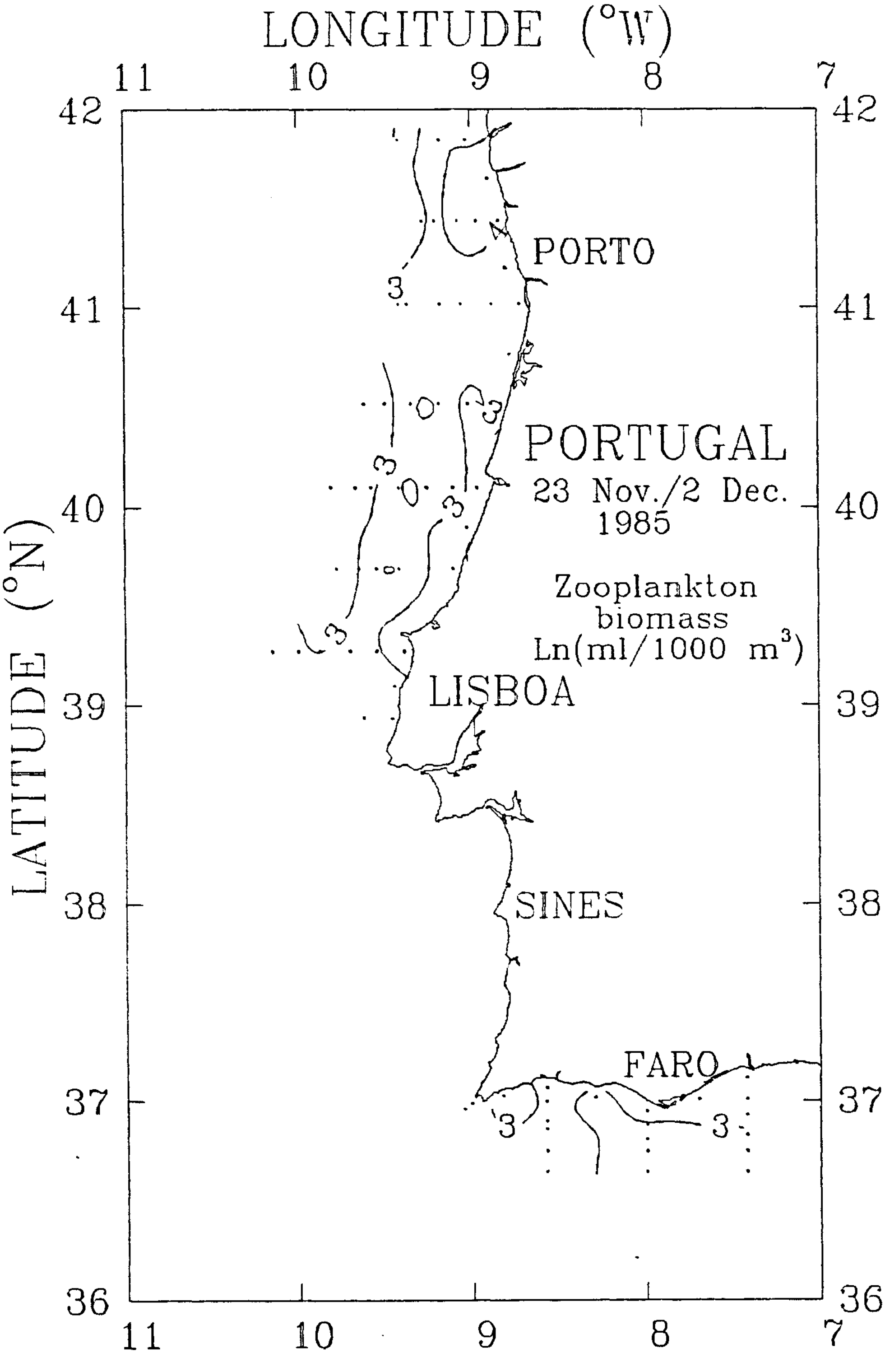

Figure 19. Zooplankton distribution off the Portuguese coast, 23 November-2 December, 1985.

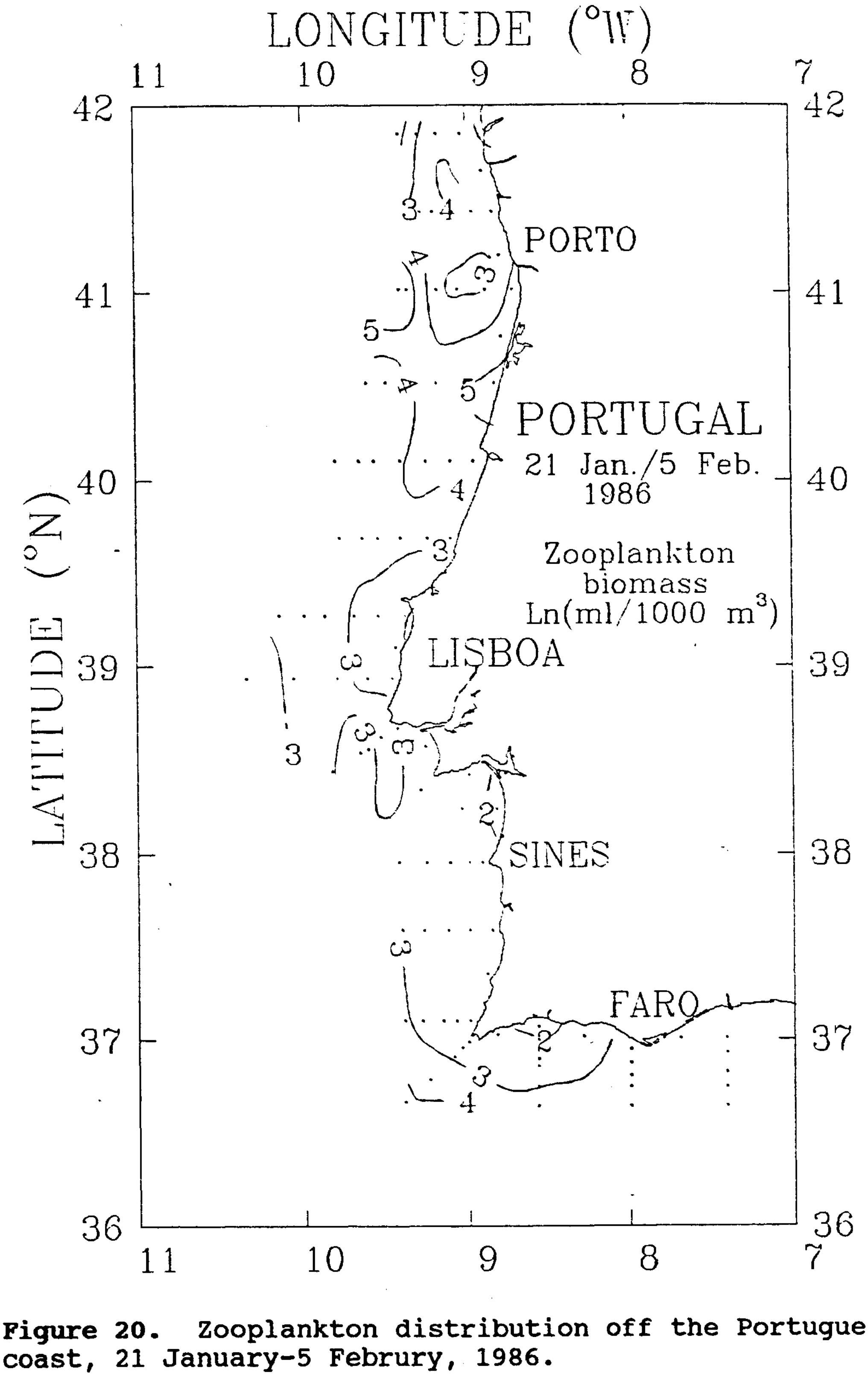

Figure 20. Zooplankton distribution off the Portuguese coast, 21 January-5 Februry, 1986.

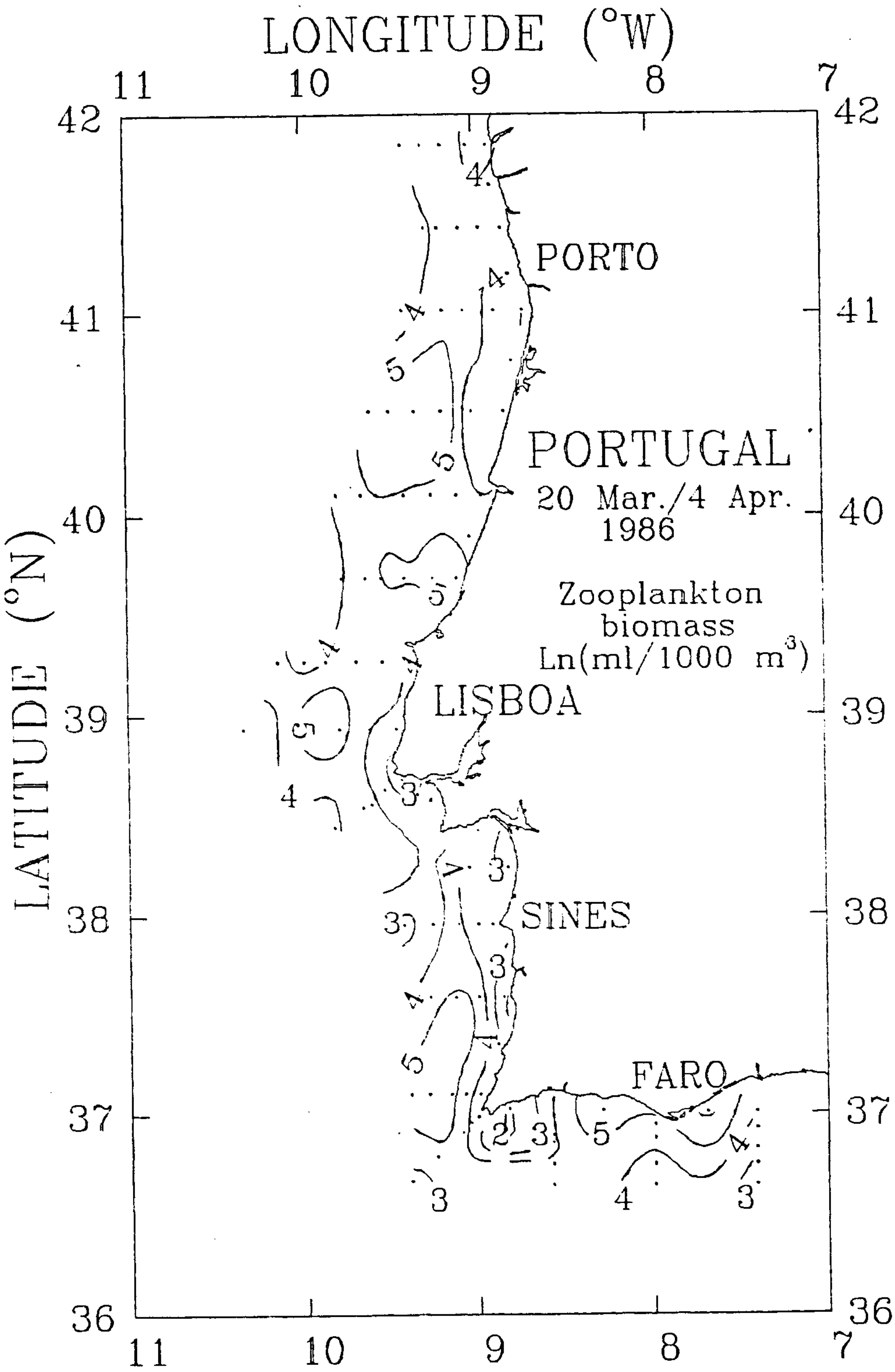

Figure 21. Zooplankton distribution off the Portuguese coast, 20 March-4 April, 1986.