1994 GAIA 8 9-18

BIOLOGICAL CHARACTERISTICS OF THE PLANKTON ASSOCIATED TO A SHELF-BREAK FRONT OFF THE GALICIAN COAST

A. BODE[1]; M. VARELA[1]; E. FERNANDEZ[2]; B. ARBONES[2]; N. GONZALEZ[1]; R. CARBALLO[1]; M.T. ALVAREZ-OSSORIO[1]; R. ANADON[3] & S. BAQUERO[1,3]

[1] Inst. Español Oceanografía. Centro Costero. Apdo. 130. E-15080-La Coruña. España.
[2] Inst. Invest. Marinas (CSIC). Eduardo Cabello, 6. E-36208. Vigo España
[3] Lab. Ecología. Depto. B.O.S. Univ. Oviedo. Campus del Cristo. E-33071-Oviedo. España.

ABSTRACT: A large (> 900 nm2) phytoplankton-rich patch (> 200 mg Chl-a m-2) was found off the NW Galician shelf in May 1994. On the shelf side, it was limited by a density front which separated thermally stratified oceanic waters from vertically mixed coastal waters. The structure was observed for several days, having a complex topology which suggest strong influence of hydrodynamic processes. The bulk of phytoplankton biomass sank approximately 15 meters in two days, probably as a consequence of the combined effects of convergence of surface currents near the shelf break and bloom decaying. There were several indicators of the decline of the phytoplanktonic populations: high phytoplanktonic biomass and low nutrient concentrations, along with low chlorophyll-specific carbon fixation rates and shallow euphotic layers. High nutrient concentrations, particularly nitrate and nitrite, were characteristic of the layers below the chlorophyll maximum, suggesting rapid recycling of the organic matter. The phytoplankton species characteristic of the patch were chain forming diatoms, and also cyanobacteria (especially abundant at the shelf-break). The zooplankton biomass was very variable through the area, having the coastal zone the highest values, mainly because the contribution of mesozooplankton (200-1000 μm), whereas both macrozooplankton (> 2000 μm) and microzooplankton (40-200 μm) dominated the biomass distributions at the oceanic side of the front. Further studies are being made to ascertain the implications of this structure, and similar ones reported for the NW Spanish shelf, in the regional biogeochemistry of carbon and the efficiency in the transfer of organic matter through the food-web, particularly in relation to pelagic fisheries.

INTRODUCTION

Oceanic fronts are known by their important consequences in the nearby ecosystems. Sometimes their associated dynamics stimulate biological productivity through the fertilization of the euphotic zone with nutrient-rich waters (Holligan, 1981). Other cases are reported in which convergent currents cause plankton accumulation and even active downwelling with rapid particle transport to the deep layers (Varela et al., 1991, Fernández et al., 1993). Probably both mechanisms occur in different times and areas of the shelf, according to the active hydrodynamics of these structures. Most of the studied fronts in the European shelf were related to tidal stirring (Simpson and Pingree, 1978, Holligan, 1981) or upwelling forcing (Botas et al., 1990, Varela et al., 1991) on the mid-shelf. Several studies described important differences between planktonic communities caused by fronts originated by the passage of poleward currents near the shelf-break in the Southern Bay of Biscay (Botas et al., 1988; Bode et al., 1990, Fernández et al., 1992, 1993). These fronts have been reported through the spring along the NW Spanish coast, when most of the recruitment of the main regional pelagic fisheries also occurs (Chesney and Alonso-Noval, 1989), but to date there were no reports of their effects on the dynamics of the planktonic ecosystems in the Galician coast.

In this paper we describe the main physical and biological characteristics of a large (> 900 nm^2) phytoplankton patch associated to a thermal front off the NW Galician shelf, with a preliminar interpretation of the dynamics of the pelagic ecosystem.

METHODS

Observations and results reported in this paper were obtained during cruise AMBAR-594 on the R/V Cornide de Saavedra in May 1994 on the Galician shelf (Fig. 1). Temperature, salinity, light (PAR) and 'in situ' fluorescence vertical profiles were recorded using a SBE25 CTD. In addition a high-resolution transect of temperature, conductivity and fluorescence was measured by pumping surface waters (2 m depth) and collecting discrete samples every approximately 0.3 nm. Samples for dissolved inorganic nutrients (nitrate, nitrite, ammonium, and phosphate, Autoanalyser), pigment analysis (chlorophyll-a, fluorometric determination of acetone extracts), phytoplankton productivity (C-14, 'in situ' simulated, 2-3 h incubations), and microplankton composition were collected using bottle casts inmediately after the CTD casts. Phytoplankton composition was determined using either Lugol's preserved samples observed with an inverted microscope (diatoms, dinoflagellates and phytoflagel-

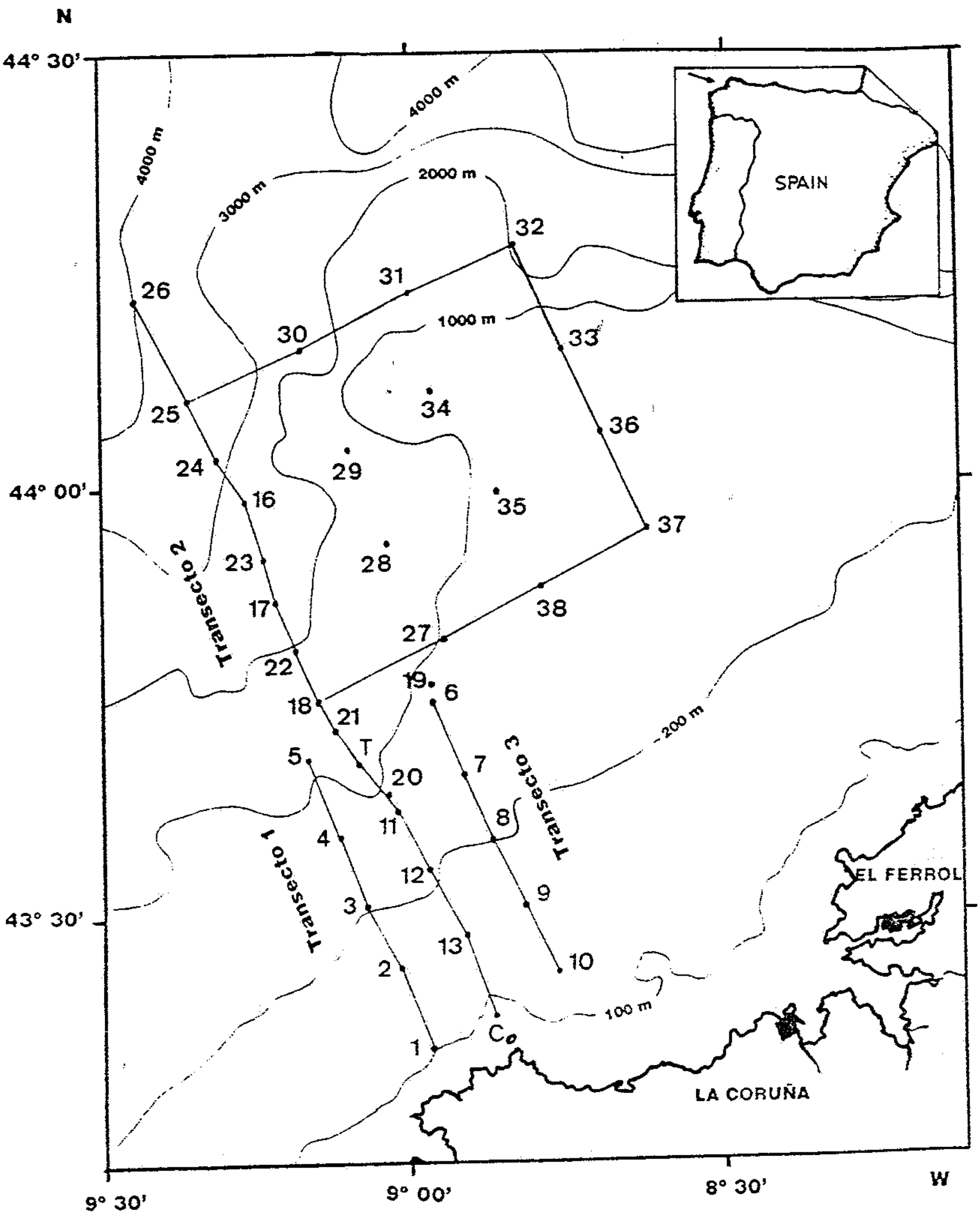

Figure 1. Map of the study area with location of stations

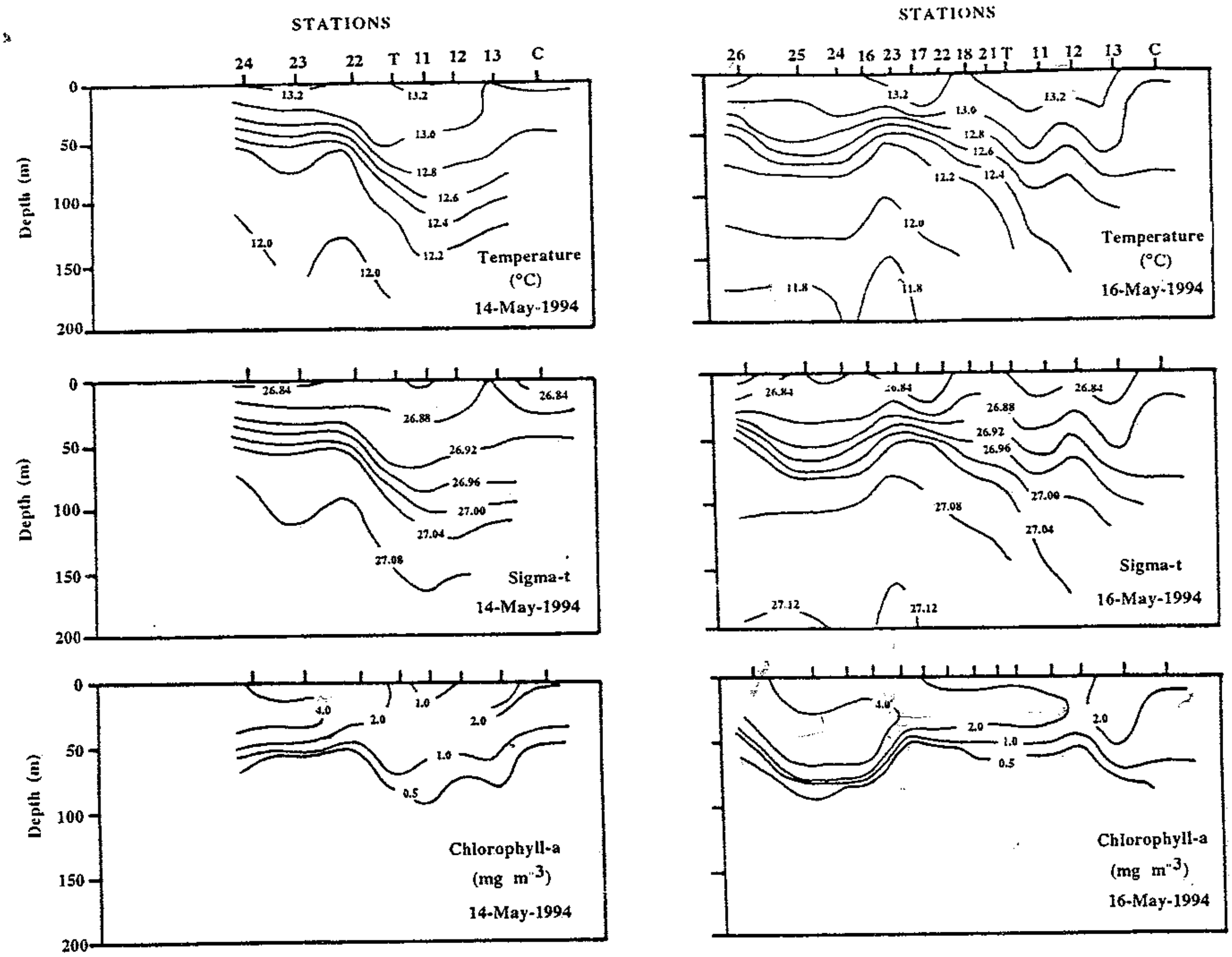

Figure 2. Temperature (top), sigma-t (center) and chlorophyll-a distributions (bottom) on the central across-shelf transect measured two days apart.

lates larger than 10 µm), or glutaradehyde preserved samples observed with an epifluorescence microscope equipped with UV and blue excitation filters (cyanobacteria and small flagellates). The latter technique also allowed quantification of heterotrophic bacteria and heterotrophic flagellates. Mesozooplankton biomass (> 200 µm) was estimated as dry weight of several fractions (200-500, 500-1000, 1000-2000, and >2000 µm) using vertical hauls from 100 m depth to surface. Dry-weight values were converted to carbon biomass using the factors given in Cushing et al. (1958). Microzooplankton biomass (40-200 µm) was calculated as in Beers and Stewart (1970) from samples collected with vertical hauls (0-100 m depth) and filtered through 200 and 40 µm mesh nets.

RESULTS

1. Physical structure

Temperature distributions show stronger stratification off the shelf break, compared with the inner shelf (Fig. 2). The water column was rather mixed near the coast, with surface temperatures warmer than 13.2 °C. A distinct thermal front resulted off station T, located at the shelf-break, where the distribution of isotherms revealed a thermocline near 50-60 m depth. The isopycnals followed the same trend indicated by the isotherms. The position of the thermocline, both in the horizontal and in the vertical planes, was variable in consecutive measurements of the coast-to-ocean transect, displaying a wave-like structure with the upper position near the oceanic side of the front. High 'in situ' fluorescence, indicative of high phytoplankton biomass, was associated to this structure, having the maximum values on top of the thermocline (30-40 m depth) and on the oceanic side.

The water-column integrated distribution of chlorophyll-a indicated a large phytoplankton-rich area of more than 40 squared-nm off the shelf break (Fig. 3), resulting in more than twice the concentration of chlorophyll measured near the coast. Patches with more than 300 mg Chlorophyll-a m^{-2} appeared evenly distributed in the off-shelf area, suggesting a complex pattern of the structure. The transect indicated in Figure 3 resulted with surface distribution of temperature in peaks and valleys of approximately 10-15 nm of amplitude and maximum range of 0.3 °C, with a decreasing trend off-shore (Fig. 4). This trend was also measured with surface salinity, but in this case the peaks and valleys can not be clearly distinguished. The surface distribution of chlorophyll-a (calculated from the fluorometer 'in vivo' records) showed an increasing trend off-shore, except from a patch of relatively high chlorophyll near the coast (Fig. 4). There was no evidence of strong association between the physical characteristics and the surface chlorophyll-a concentrations, but the onset of the chlorophyll increment at the position 12 nm of the transect was coincident with the first marked temperature decrease, and also with the position of the shelf-break (Fig. 3).

2. Inorganic nutrients

The distributions of nitrate, nitrite and phosphate along the central transect revealed a common trend (Fig. 5). The highest concentrations were measured at both extremes of the transect and minimum values at the shelf-break station, where waters at 200 m depth still have low concentration of nutrients (< 2 µM nitrate l^{-1}, <0.3 µM phosphate l^{-1}). The surface waters off the shelf-break had low concentrations, but high values (up to 5 µM nitrate l^{-1}, 0.4 µM phosphate l^{-1}) were measured in waters 10 m below the chlorophyll maximum. The subsurface maximum of nutrients occurred at the station where the highest subsurface concentrations of chlorophyll-a were measured (Stat. 16), and its position was deeper towards the shelf-break (Stat. T). In contrast with the inner-shelf stations, the nitrate and nitrite concentrations at off-shelf stations decreased again below 125 m depth, but generally increased again at 200 m. Phosphate generally increased with depth (Fig. 5), and the ammonium concentrations (not show) were low but patchy along the transect.

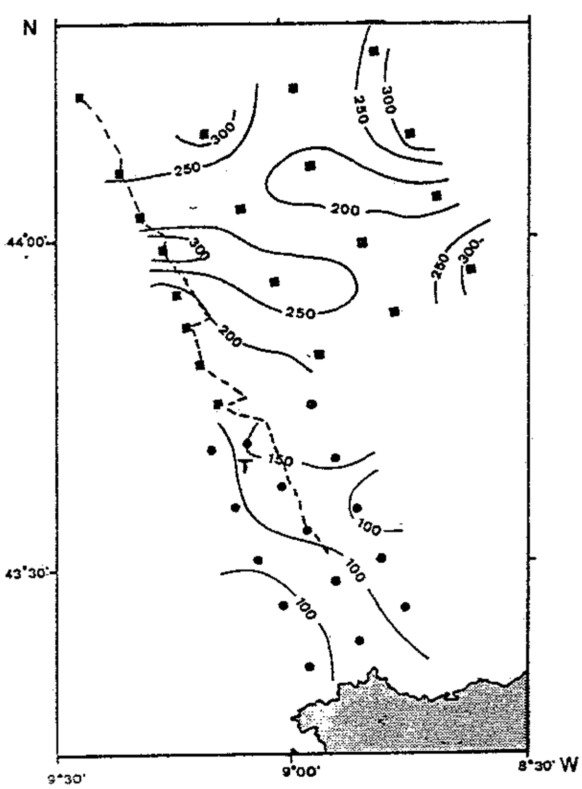

Figure 3. Distribution of integrated chlorophyll-a (mg m^{-2}) through the study area. The track of the high-resolution surface transect is indicated as a discontinnuous line. The position of the shelf-break station T is also indicated.

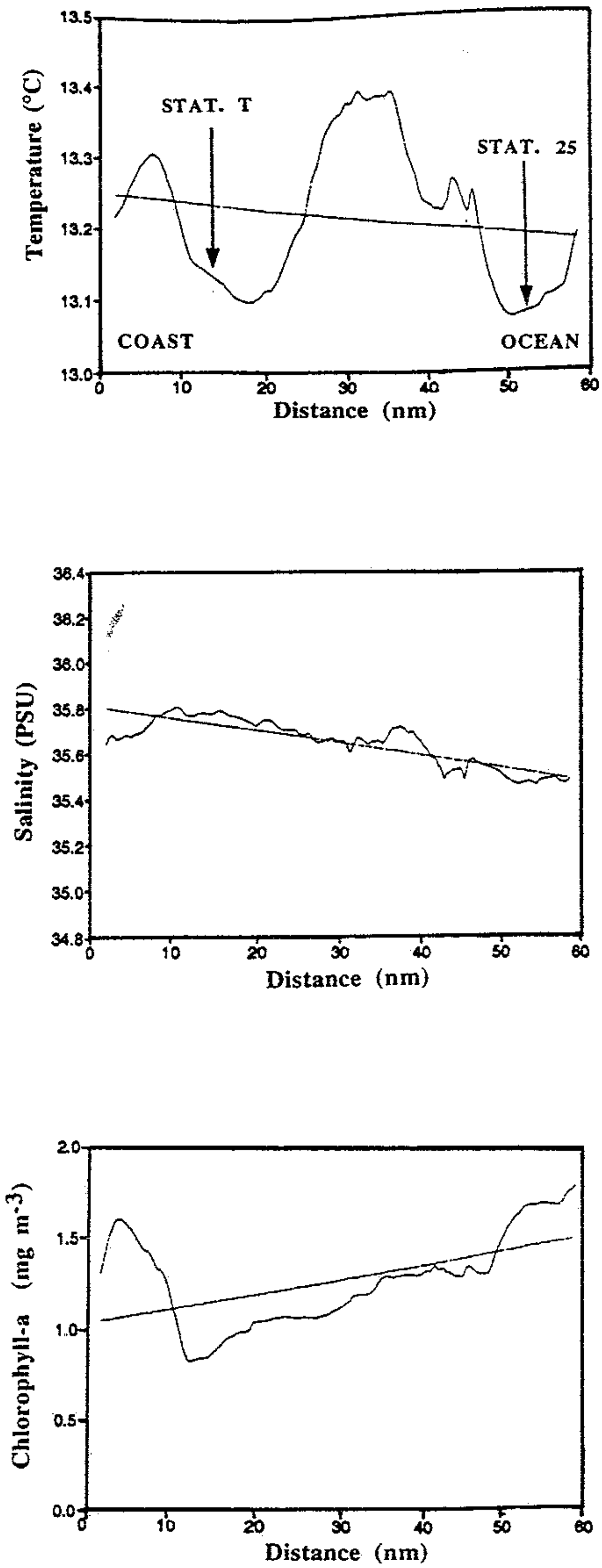

Figure 4. Variations of surface temperature (top), salinity (center) and chlorophyll-a (bottom) along the high-resolution across-shelf transect shown in Fig. 3. The position of the shelf-break and oceanic stations, and the linear trend of each variable is also indicated.

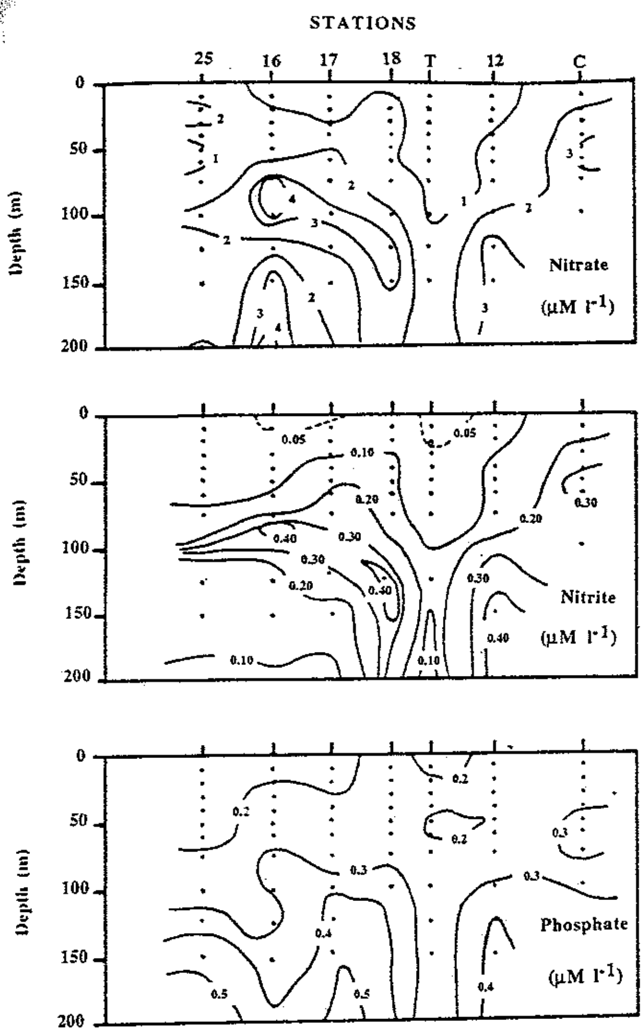

Figure 5. Distribution of inorganic nutrients: nitrate (top), nitrite (center), and phosphate (bottom) along the central across-shelf transect.

3. Plankton composition and activity

We selected 3 stations representative of the areas limited by the front: the coastal, near-shore zone (Stat. C), the shelf-break (Stat. T) and the oceanic environment (Stat. 25). The coastal station had low abundance of phytoplankton, composed mainly by small dinoflagellates, while diatoms dominated off-shore (Fig. 6 top). The diatoms were mostly the chain-forming Nitzschia cf pungens and colonies of Solenicola setigera., the latter more abundant at the shelf-break station (Fig. 6 bottom). These diatoms were well distributed in the water-column, reaching significant densities even at 50 m depth. The abundance of flagellates was quite similar in the selected stations, but higher numbers were recorded near the coast, where Cryptophyceae dominated. Most of the flagellates were autotrophs, except in some deep samples (Fig. 7). High abundances of cyanobacteria were measured at the shelf-break station (Fig. 7), particularly at a subsurface maximum at 30 m depth, while abundances decreased at both sides of this station, and at depth. This maximum was coincident with a minimum in the abundance of heterotrophic bacteria, that also reached high abundances at the shelf-break.

The vertical profiles of chlorophyll-a and carbon fixation of the three zones were very different (Fig 8 Top). The coastal station was characterised by a production profile similar to the chlorophyll distribution, with an exponential decrease downwards. At the shelf-break, the chlorophyll displayed a marked subsurface maximum between 15 and 35 m, whereas the production decreased approximately linearly with depth. The oceanic station displayed high chlorophyll concentration through the water column, and a shallower limit of the euphotic zone (> 1% of the radiation PAR received at the surface). The rates of production measured at this station, were low. The chlorophyll-specific production (CSPR) was maximal at the surface of the shelf-break station, but decreased to almost zero at the depth of the chlorophyll maximum. This rate was also very low through the water column of the oceanic station. The frequency of dividing cells (an indicator of bacterial productivity) was very low in coastal waters, both for cyanobacteria and heterotrophic bacteria (Fig. 8 bottom). Higher frequencies were measured offshore, particularly for cyanobacteria in the samples taken at the shelf-break, and at the lower limit of the euphotic zone in the oceanic station.

Total zooplankton biomass decreased from the coast to the oceanic side of the front, but macrozooplankton (> 2000 µm) followed the opposite trend (Fig. 9). The coastal station resulted with a unimodal distribution of biomass, with the highest values in the 500-1000 µm size-class. The shelf-break and oceanic stations had bimodal biomass distributions, especially in the latter where both macrozooplankton (> 2000 µm) and microzooplankton (40-200 µm) were the main contributors to the zooplankton biomass. The microzooplankton of these stations was composed mainly by nauplii and juvenile stages of Calanoid and Cyclopoid copepods (more than 80% of total abundance of individuals per sample), while large copepods and appendicularians formed the bulk of the macrozooplankton biomass.

DISCUSSION

The described structure was mainly characterised by a large patch of phytoplankton of more than 900 nm^2 off the shelf-break. The main limit was a marked thermal front close to the shelf break, which separates stratified oceanic waters from the more vertically mixed shelf waters. Similar fronts are known from long time ago in the northern Eupean shelf (eg. Simpson and Pingree, 1978), but in these cases there was a shallow shelf (50 m average depth) washed by relatively strong tidal currents during the thermal stratification period. Other shelf fronts recognized in the NW Iberian shelf were associated to coastal upwelling caused by NE wind-forcing, both in the Galician coast (Varela et al., 1991) and in the Cantabrian Sea (Botas et al., 1990). The results reported in this paper

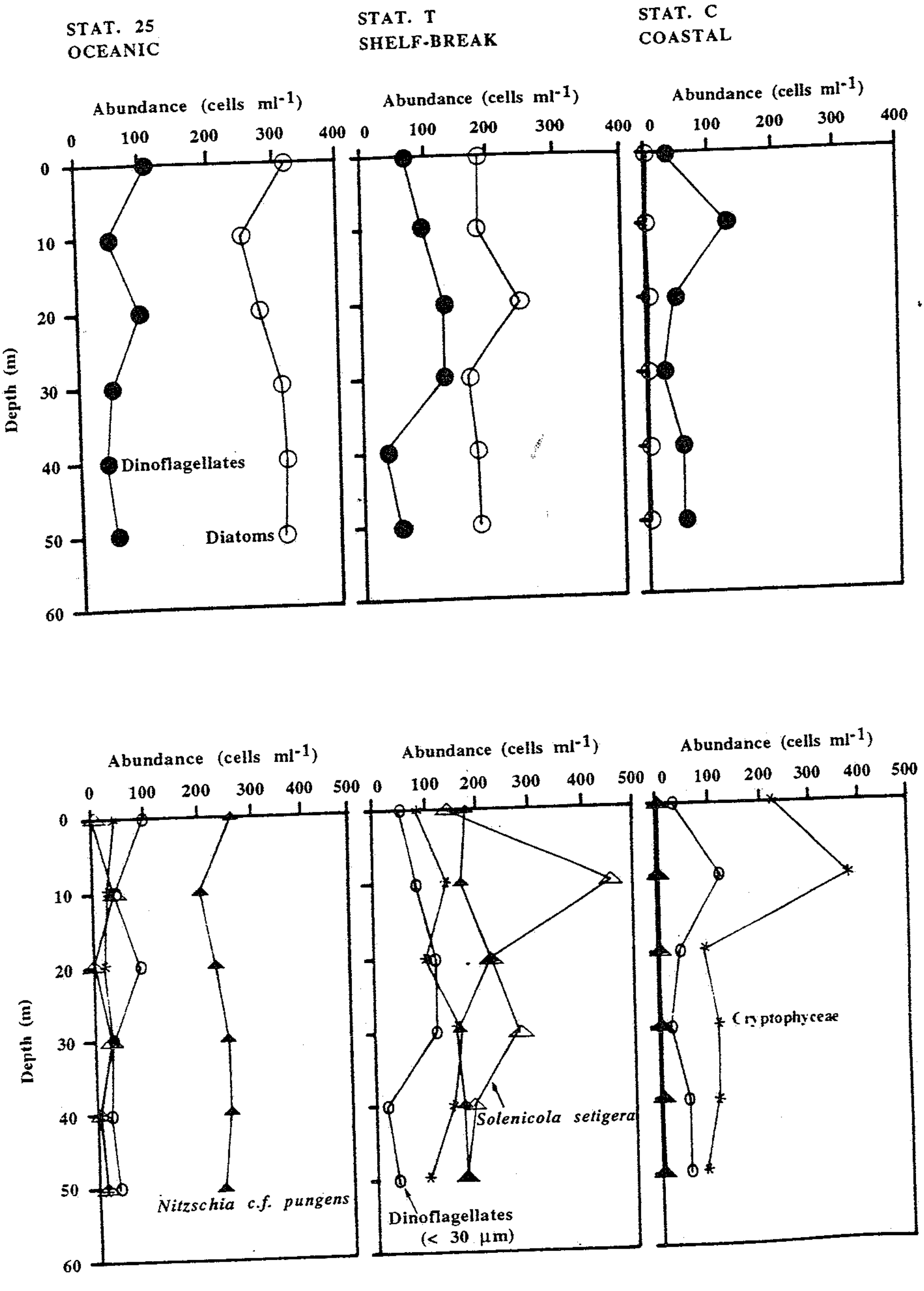

Figure 6. Vertical profiles of abundance of the main phytoplanktonic groups and species in three selected stations.

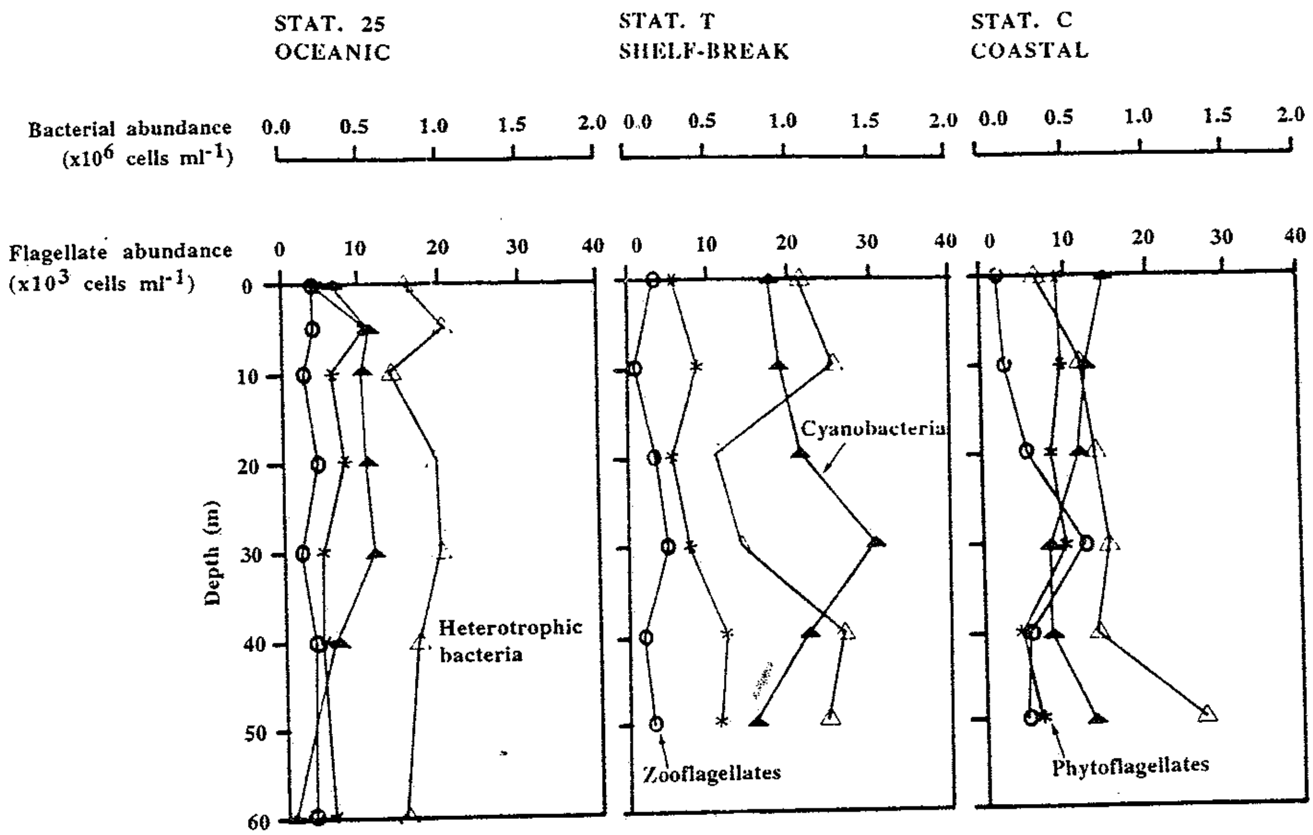

Figure 7. Vertical profiles of abundance for the main groups of microplankton and bacteria in three selected stations.

indicate that this type of front was more related to currents associated to the shelf-break, like those described in the Southern Bay of Biscay (Botas et al., 1988; Bode et al., 1990, Fernández et al., 1992, 1993). In the latter cases the fronts were recognized through the spring, with a weak to moderate thermal stratification in surface waters, and were related to poleward surface currents flowing parallel to the shelf break. The bulk of phytoplankton biomass was always near the shelf break, but in the case reported here the phytoplankton-rich area extended for more than 30 nm in both along- and off-shelf directions. The hydrography of the studied area was also highly dynamic, as suggested by the patterns of isopycnals and waves in the chlorophyll and nutrient distributions, with a downwelling towards the shelf-break. The same effect was reported in the fronts of the Bay of Biscay, as a consequence of converging currents at the shelf-break (Fernández et al., 1993). Further studies on the dynamics of the upper water masses of the studied area are in progress (Bode et al., in prep.) to ascertain the origin and likely forces that cause and maintain this structure.

The phytoplankton composition of the phytoplankton-rich zone was characteristic of an early spring bloom in this area (Valdes et al., 1991, Fernández and Bode, 1994): mainly chain-forming diatoms or epiphytic colonies (like those of S. setigera), which form relatively large particles and may have hydrodynamic advantages in turbulent waters (e.g. Margalef, 1994). There were several indicators that at the time of the cruise the bloom was in a late stage. First, there were low nutrient concentrations of surface waters, particularly at the shelf-break station, that would not be sufficient to maintain the measured phytoplankton biomass. Second, there was a deepening of approx. 15 m in the position of the subsubface chlorophyll maximum measured after two days (Fig. 2). And third, the results of the productivity incubations yielded low production rates, and very low efficiency (CSPR) at the maximum of phytoplankton biomass. In addition, there was a significative biomass and production of cyanobacteria, particularly at the chlorophyll maximum of the shelf break station, which would take advantage of its ability to take up dissolved nitrogen gas and reproduce despite the low concentrations of nitrogen salts and ammonium. The layer of high nutrient concentration just below the chlorophyll maximum, suggest rapid nutrient regeneration from the accumulated organic matter. This is suggested mainly by the similarity between the distributions of nitrate and nitrite, but not between these and the distribution of phosphate, which does not form a distinct subsurface maximum, and releases rapidly from the organic matter. The nitrogen regeneration could be made through biological processes, as estimated in the same area by Bode and Varela (1994) , but unfortunately there were no measures of biological activity below 60 m.

The relatively large size of the primary producers, along with the amount of accummulated biomass at this structure, have important biogeochemical and trophic implications. It has been reported that only a small fraction of the phytoplankton produced during the spring bloom at similar latitudes of the Atlantic Ocean is transferred to

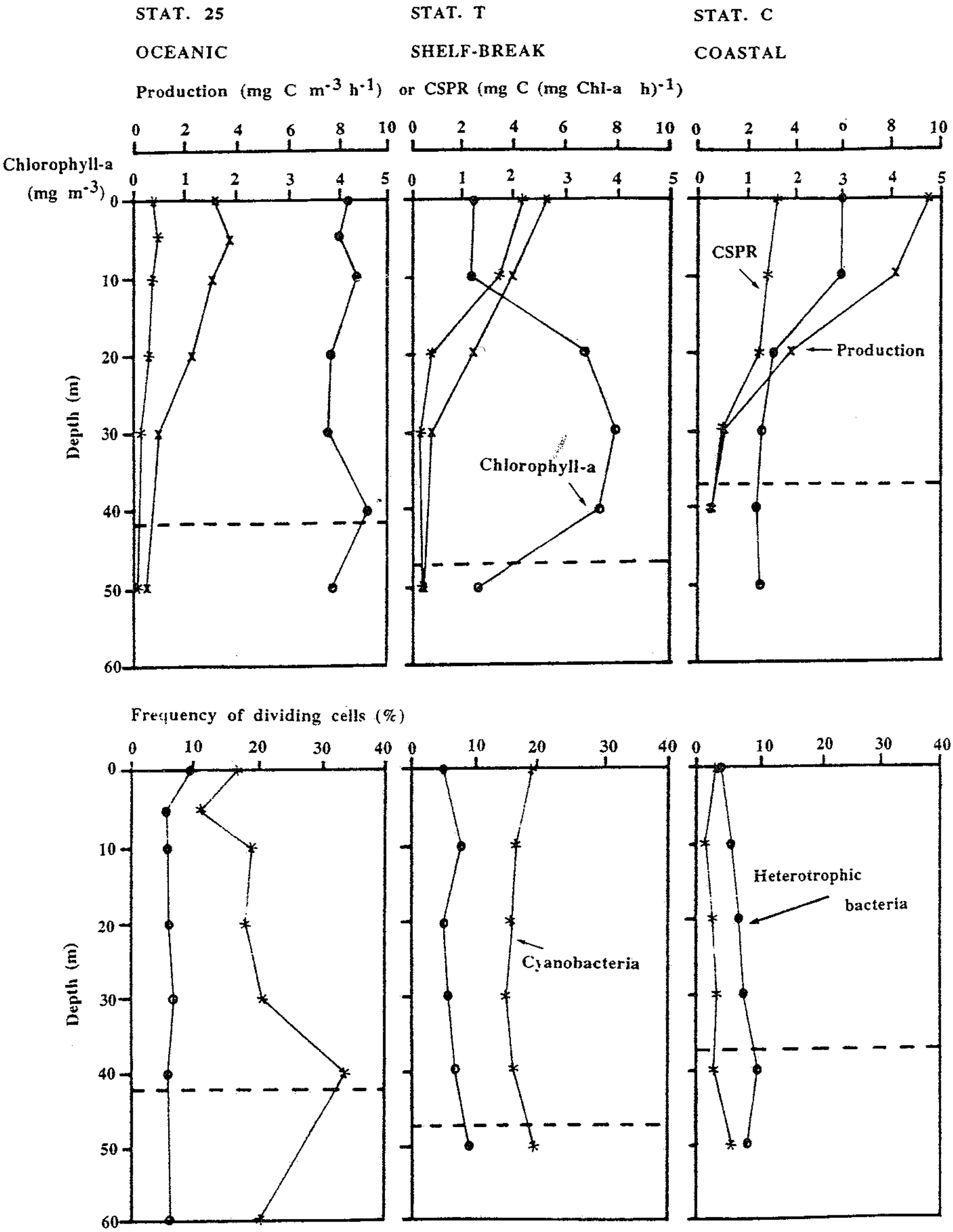

Figure 8. Vertical distributions of chlorophyll-a, primary production, and chlorophyll-specific production rates (CSPR, top), and frequency of dividing bacterial cells (bottom) in three selected stations The broken line shows the depth of the euphotic layer (>1% PAR at the surface).

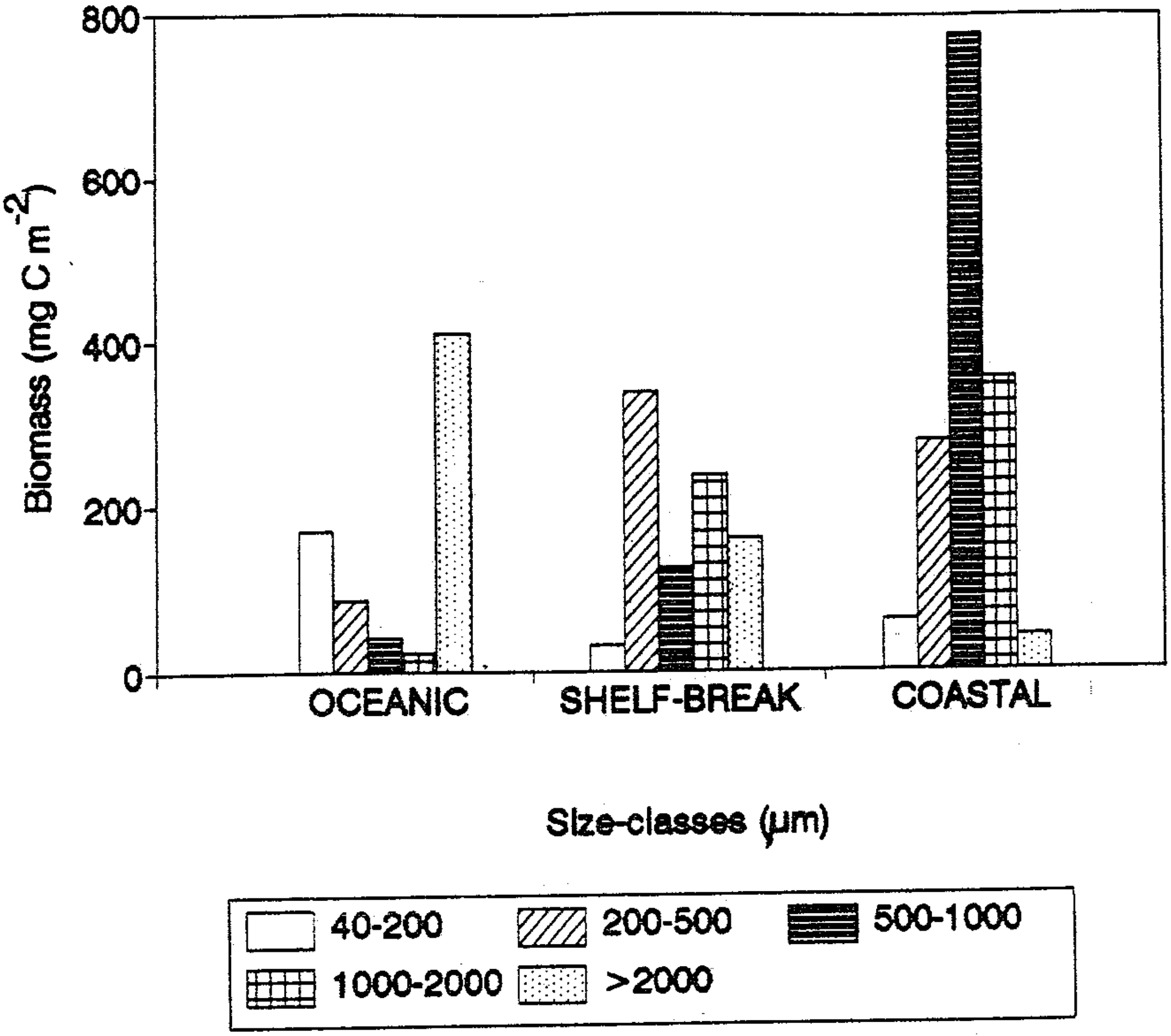

Figure 9. Distribution of zooplanktonic carbon-biomass by size-classes in three selected stations.

the mesozooplankton (Harrison et al., 1993). Most of the produced biomass is consumed by microheterotrophs or sediments quickly after the collapse of the bloom, as was reported for the northern latitudes (Olesen, 1994). The distribution of zooplankton biomass in the studied area suggest a phase-out in the production cycles in relation with the phytoplankton, as reported for the Atlantic (Colebrook, 1979). The coastal zone showed a biomass pattern characteristic of late spring in this area (Valdés et al., 1991), with high zooplankton biomass and low chlorophyll, while the oceanic area was characterised by peaks in the biomass of the smallest and largest zooplankters. This suggests that only species with rapid reproduction cycles like the microzooplankton, or special life-cycle strategies (like large vertical excursions of the macrozooplankton), can take advantage of blooms like the one described here. The persistency of these fronts and their associated planktonic communities in the NW Iberian shelf remains to be studied, if only because their potential effects on the recruitment success of the important pelagic fisheries in the area.

ACKNOWLEDGEMENTS:

We are grateful to the captain and crew of the R/V Cornide de Saavedra for assistance during the cruise, and also to all the participant technicians and scientists. We are especially indebted to T. Rellán, G. Casas, J. Sostres, J. Lorenzo, I. Gonzalez for expert technical assistance. F. Arenas took special care of the high-resolution surface transect. We also thank J.M. Cabanas for facilitating the coordination between cruise-legs. This work was supported by funds of CICYT Projects AMB93/0014 and AMB92/0834, and also by funds of the Instituto Español de Oceanografia and the Instituto de Investigaciones Marinas de Vigo (CISC).

REFERENCES:

Beers, J.R. and Stewart, G.L. 1970. Numerical abundance and estimated biomass of microzooplankton. Bull. Scrips Inst. Oceanogr. 17·67-87

Bode, A. and Varela, M. 1994. Olanktonic carbon and nitrogen budgets for the N-NW Spanish shelf· The role of pelagic nutrient regeneration during upwelling events. Sci. Mar. 58(3):221-231

Bode, A., Fernández, E., Botas, A. and Anadón, R. 1990. Distribution and composition of suspended particulate matter related to a shelf-break saline intrusión in the Cantabrian Sea (Bay of Biscay). Oceanologica Acta. 13:219-228

Botas, J.A., Bode, A., Fernández, E. and Anadón, R. 1988. Descripción de una intrusión de agua de elevada salinidad en el Cantábrico central: Distribución de los nutrientes inorgánicos y su relación con el fitoplancton. Inv. Pesq. 52:561-574

Botas, J.A., Fernández, E., Bode, A. and Anadón, R. 1990. A persistent upwelling off the Central Cantabrian Coast (Bay of Biscay). Estuar. Coast Shelf. Sci. 30:185-189

Chesney, E.J. and Alonso-Noval, M. 1989. Coastal upwelling and the early life-history of sardines (Sardina pilchardus) along the Galician coast of Spain. Rapp. P.V. Reun. Cons. Int. Explor. Mer. 191:63-69

Colebrook, J. M. 1979. Continuous Plankton Records: seasonal cycles of phytoplankton and copepods in the North Atlantic Ocean and the North Sea. Mar. Biol. 51:23-32

Cushing, D.H., Humphrey, G.F., Banse, K. and Laevastu, T. 1958. Report of the Committee on terms and equivalents. Rapp. Proc. V. CIEM. 144:15-16

Fernández, E. and Bode, A. 1994. Succession of phytoplankton assemblages in relation to the hydrography in the southern Bay of Biscay: A multivariate approach. Sci. Mar. 58:191-205

Fernández, E., Bode, A., Botas, A. and Anadón, R. 1991. Microplankton assemblages associated with saline fronts during a spring bloom in the Central Cantabrian Sea: differences in trophic structure between water bodies. J. Plankton Res. 13:1239-1256

Fernández, E., Cabal, J., Acuña, J.L., Bode, A., Botas, A. and García-Soto, C 1993. Plakton distribution across a slope current-induced front in the southern Bay of Biscay. J. Plankton Res. 15:619-641

Harrison, W.G., Head, E.J.H., Horne, E.P.W., Irwin, B., Li, W.K.W., Longhurst, A.R., Paranjape, M.A. and Platt, T. 1993. The North Atlantic Bloom Experiment. Deep-Sea Res.II. 40(1/2):279-305

Holligan, P.M. 1981. Biological implications of fronts on the northwest European continental shelf. Phil. Trans. R. Soc. London. A302:547-562

Margalef, R. 1994. Through the looking glass: how marine phytoplankton appears through the microscope when graded by size and taxonomically sorted. Sci. Mar. 58(1-2):87-101

Olesen, M. 1994. The fate of an early diatom spring bloom in the Kattegat. Ophelia 37(1):51-66

Simpson, J.H. and R.D. Pingree. 1978. Shallow sea fronts produced by tidal stirring. In: Bowman, M.J. and Esaias, W. E. (eds). Oceanic fronts in coastal processes. Springer-Verlag. Berlin. 29-42

Valdés, L., Alvarez-Ossorio, M.T., Lavín, A., Varela, M. and Carballo, R. 1991. Ciclo anual de parámetros hidrográficos, nutrientes y plancton en la plataforma continental de La Coruña (NO, España). Bol. Inst. Esp. Oceanogr. 7(1):91-137

Varela, M., Diaz-del-Rio, G., Alvarez-Ossorio, M.T. and Costas, G. 1991. Factors controlling phytoplanktoin size-class distribution in the upwelling area of the Galician continental shelf (NW Spain). Sci. Mar. 55:505-518