Influence of the north trade winds on the biomass and production of neritic plankton around Gran Canaria island

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SUMMARY: The effect of the wind shear field on the southwest border of Gran Canaria Island (Canary Islands) causes the development of a marine front that fluctuates under the influence of the North Trade Winds. This front separates two areas on the island shelf: one of turbulence and one of calm, the latter in a wake of warm water to the south of the island. Monthly studies of biomass and production in phyto- and zooplankton and activity of the meiofauna have been done during the winter and spring of 1986-87, respectively, mainly from two stations approximately 50 m deep, one in each of the above-mentioned areas. Values of nutrients, primary production and mesozooplankton biomass and activity were higher than those provided by other authors for oceanic waters of the archipelago. Nonetheless, significative differences were found on both sides of the front. In the area of turbulence, phytoplankton was less abundant but more active, coinciding with higher concentrations of nitrate, as compared with the area of calm. Low values of cell numbers found in both areas may be explained by the grazing pressure of relatively large patches of mesozooplankton found towards the wind shear field, and also by physical processes causing dispersion at the more exposed station. Unlike the ocean, where the productive season is restricted to the late winter or early spring, in coastal waters planktonic production may be rather high troughout most of the year due to the action of the North Trade Winds, which continuously mix the surface waters.

Key words: neritic plankton, trade winds, marine fronts, Atlantic Ocean.

INTRODUCTION

The Canary Islands are surrounded by waters considered oligotrophic by several authors (DE LEÓN & BRAUN, 1973; BRAUN, 1980; BRAUN & DE LEÓN, 1974; BRAUN & REAL, 1981, 1984; REAL *et al.*, 1981; BRAUN *et al.*, 1976, 1985, 1986), with small amounts of nutrients in the euphotic zone and a low primary production (except during the late winter bloom). In oceanic areas, a seasonal thermocline develops from about 50 to 120 meters in depth throughout most of the year, limiting the supply of nutrients to the surface zone (DE LEÓN & BRAUN, 1973). Nutrients are only brought to the surface in small amounts; phytoplankton is scarce, and small forms which grow under limited nutrient concentrations prevail (BRAUN & REAL, 1981; BRAUN *et al.*, 1985). The surface waters are mixed only during the winter, the nutrients then reach their highest levels, and a bloom is produced during the late winter or early spring. However, nutrients are quickly depleted and the bloom is short-lived, returning to the low productive situation (DE LEÓN & BRAUN, 1973; BRAUN, 1980). As primary production is low most of the year, the upper trophic levels are also unproductive and the zooplankton, like the phytoplankton, is scarce in the ocean (BRAUN, 1981; FERNÁNDEZ DE PUELLES, 1986).

On the other hand, relatively large patches of zooplankton may be found in coastal waters to the south of the islands. In particular, around Gran Canaria Island, high accumulations of mesozooplankton were found but restricted to the south of the island. The more active individuals feed close to the boundaries between the calm and turbulent waters on both sides of the island wake (HERNÁNDEZ-LEÓN, 1986).

It was difficult to believe that this secondary production could be maintained throughout the year by primary production as low as that found in the nearby oceanic waters. For this reason, a program was dedicated to the study of the seasonal variations in the waters to the southwest of Gran Canaria. The aim of this work was to compare the productivity of this coastal area with data from adjacent oceanic waters obtained by different authors. Stations in the calm area and near the wind shear field where the highest metabolic activity of zooplankton had been found were studied. Preliminary results for the winter and spring periods are given in this paper.

MATERIALS AND METHODS

The field data were obtained in a coastal area to the southwest of Gran Canaria. Seven stations (E1 to E7) ranging from 40 to 100 meters in depth were sampled five times between Novembre 1986 and May 1987 for zooplankton and meiofauna studies. From among these stations, two (E1 and E3), approximately 50 m deep, were selected for phytoplankton studies in December 1986, one on each side of the visual boundary between the calm and the turbulent waters affected by the wind (Fig. 1).

Wind intensity and direction data were obtained from the Instituto Nacional de Meteorología, at Gran Canaria airport.

Seawater samples were collected in 5-liter Niskin bottles at four standard depths (5, 15, 25, and 40 m). From each bottle, subsamples were drawn for analysis of inorganic nutrient salts, chlorophyll *a*, phytoplankton taxonomic composition and productivity. Temperature was measured at the above depths with reversing thermometers, and the compensation depth of the algae was derived from Secchi Disk readings. No criteria were used to select incubation depths from light intensity depths. It was assumed that there was no significant inhibition of photosynthesis by light in the water column, since more than 10 % of the surface light always reached the bottom.

Nutrient samples were stored in a freezer during the cruises and kept frozen at − 20 °C in the laboratory until analysis. Nitrate, nitrite, phosphate and silicate were spectrophotometrically measured using the methods of WOOD *et al.* (1967), BENDSCHNEIDER & ROBINSON (1952), MURPHY & RILEY (1962) and MULLIN & RILEY (1962), respectively.

After filtering 4 liters of seawater through Watman GF/F filters, chlorophyll *a* concentrations were estimated by the absorbance method using the spectrophotometric equations of Jeffrey & Humphrey as described in PARSONS *et al.* (1984). The phytoplankton samples were preserved by adding a few drops of Lugol iodine solution and stored in the dark in 250-ml plastic bottles. Cells larger than 5μm were counted directly on gridded Millipore HA filters after filtering 100 ml of the sample. Often, duplicate samples were settled in 100 ml chambers and cells were counted with an inverted microscope at × 200 and × 400 magnifications.

Primary production was measured during February, April and May, using the ^{14}C method of Steeman-Nielsen, as described in PARSONS *et al.* (1984). After adding 4 μCi $H_2{}^{14}CO_3$, duplicate clear and dark 125-ml bottles were incubated *in situ* at midday for 2 to 4 hours at the same vertical depths where water samples had been obtained in the cast. Incubations were terminated by gentle filtration of samples on 0.45 μm Millipore HA filters. Filters were dried over-

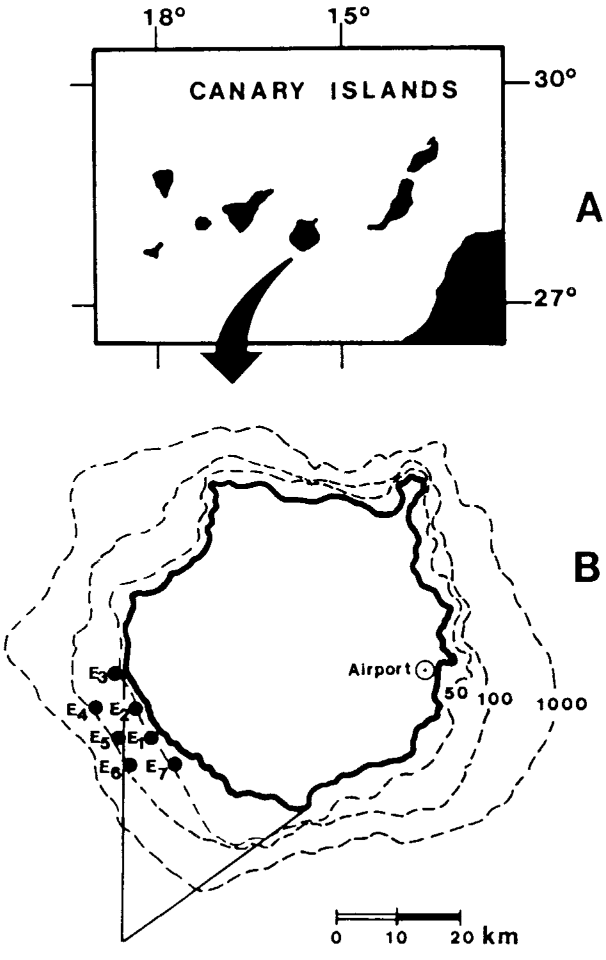

FIG. 1. — A) Canary Islands area. B) Gran Canaria Island. North Trade Winds play an important role in the development of a wake of warm and calm water to the south of the island (area enclosed by triangle). Sampling stations (E1 to E7) were placed on both sides of the front between the calm and turbulent waters.

night, fumed for one minute over concentrated HCl to remove dissolved ^{14}C, placed in 15 ml of scintillation cocktail (Aquasol-2), and assayed in a Lkb 1211 rackß liquid scintillation counter with an external standard.

Mesozooplankton was caught in one vertical haul using a WP-2 triple net, a version of the standard WP-2 net (UNESCO, 1968), from 0-50 m or 0-75 m, depending on the depth of the water column. One of the samples obtained was immediately frozen in liquid nitrogen (-196 °C) until analysis in the laboratory, to determine biomass (as proteins) and Electron Transport System (ETS) activity. Proteins were assayed following the method proposed by LOWRY *et al.* (1951), using Bovine Serum Albumine (BSA) as standard. ETS activity was determined in accordance with PACKARD (1969), OWENS & KING (1975), and KENNER & AHMED (1975). Details of the procedure are described in HERNÁNDEZ-LEON (1988b). ETS data were calculated for the *in situ* temperature using the Arrhenius equation, taking 15 Kcal/mol as the activation energy (PACKARD *et al.*, 1975).

Sediments were collected with a van Veen grab (0.035 m^2), filtered through a 50μm mesh and mixed well. From each sample, two subsamples were placed in 50 ml plastic core barrels and stored in liquid nitrogen until analysis. In the laboratory, elutriation of sediment was carried out using the technique of BOISSEAU (1957). The ETS activity of the meiofauna was measured in the same way as for the plankton.

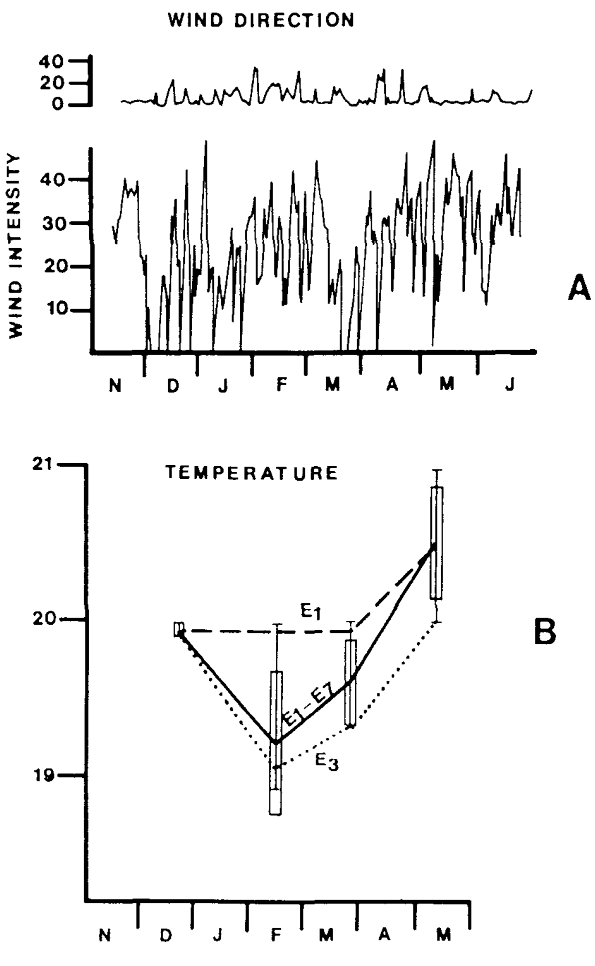

FIG. 2. A) Daily variations in the wind direction (in degrees) and intensity (in Km/h). Towards the summer, wind pulses are more intense and constant in direction. B) Seasonal changes in the surface water temperature (°C) at E1 (dashed line), E3 (dotted line) and in the entire area (E1 to E7) (solid line). Extreme values, mean values and standard deviations are given for the entire area.

RESULTS

During the sampling period, the North Trade Winds were characterized by a great constancy, although an increase in intensity and a lesser variation in direction were observed towards the end of the spring season (Fig. 2A).

The water temperature showed a trend similar to the one described for the nearby surface oceanic waters by various authors (DE LEÓN & BRAUN, 1973; BRAUN, 1980; BRAUN & REAL, 1984). However, there were significant differences between E1 and E3. Although the temperature was homogeneous at all depths at both stations, the water at E1 (inside the wake) remained warmer during the cooling of the winter months, reaching a difference in February of about 1 °C between the two (Fig. 2B). This situation may be a common feature to the south of the Canary

TABLE 1. — Comparative values between oceanic and coastal areas. (*) data from DE LEÓN & BRAUN (1973), BRAUN *et al.* (1976), BRAUN (1980), BRAUN & REAL (1984), BRAUN *et al.* (1985), FERNÁNDEZ DE PUELLES (1986) and HERNÁNDEZ-LEÓN (1986). (**) data from the present work; E1 and E3 are stations in calm and turbulent waters, respectively. Range = extreme mean values; Mean = mean of the mean values, or range of mean values given by the above authors.

	*Oceanic areas**		*Coastal areas***			
			E_1		E_3	
	Range	*Mean*	*Range*	*Mean*	*Range*	*Mean*
Nitrate (μM NO_3)	0.1-1.5	0.5	0.34-2.05	1.02	1.14-4.76	2.45
Nitrite (μM NO_2)			0.02-0.13	0.07	0.04-0.12	0.06
Phosphate (μM PO_4)	0.02-0.18	0.11	0.12-0.20	0.17	0.14-0.24	0.19
Silicate (μM SiO_4)	1-15	4.5	0.74-1.28	1.04	0.85-1.1	0.96
Chlorophyll *a* (μg l^{-1})	0.1-1	0.2-0.3	0.14-0.30	0.19	0.06-0.35	0.18
Cell numbers (cells ml^{-1})		13	0.3-2.7	1	0.24-0.35	0.3
Primary production (mg C m^{-3} h^{-1})	0.15-0.78	0.39	0.18-0.66	0.46	0.49-1.05	0.77
Assimilation number (mg C mg^{-1} Chl *a* h^{-1})	3.3-5.7	2.8	3.3-4		4.5-5.5	
			Range		Mean	
Zooplankton biomass (proteins m^{-3})	1.27-2.55	1.87	1.61-4.34		2.88	

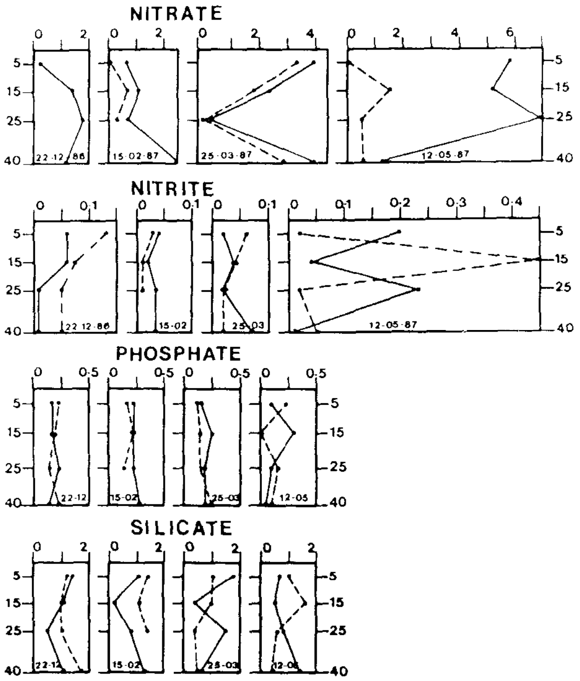

FIG. 3. — Vertical profiles of nitrate (μM NO_3), nitrite (μM NO_2), phosphate (μM PO_4) and silicate (μM SiO_4) at E1 (dashed line) and E3 (solid line).

Islands. In a recent work, HERNÁNDEZ-LEÓN & MIRANDA-RODAL (1987) found, in offshore waters to the south of Tenerife Island, an area of vertical mixing coinciding with the wind shear field. This area was located in the front between the waters inside and outside the wake, exhibiting differences in temperature of about 1 °C.

The concentrations of nutrient salts (especially nitrate) were high compared to those found in the superficial oceanic waters (Table I). The phosphate and silicate values were the most constant in space and time. Nitrate and nitrite, however, showed a considerable increase from March to May, more pronounced at E3 than at E1 (Fig. 3).

Phytoplankton cell numbers were much lower than those reported for oceanic areas (BRAUN *et al.*, 1976; BRAUN, 1980) (Table I). However, within these reduced values, a greater number of cells and a more well-defined vertical distribution were seen at E1 than at E3. At the former, diatoms were concentrated on the surface at the end of the winter, and in the spring as the water got warmer, cells were found at deeper levels (Fig. 4). This scarcity of cells was the cause of the low chlorophyll *a* values (Fig. 5), even lower than in oceanic waters (Table I). Moreover, at no time during the sampling period did a late winter or spring bloom occur, or else it was not seen, the lower values for chlorophyll *a* and cell number corresponding to March and April, when zooplankton peaked (Figs. 7 and 8). The relationship between chlorophyll *a* and cell number (Fig. 5) showed high values of chlorophyll per cell, considerably higher in cells at E3 than at E1. Although on a comparative basis these results may indicate the presence of a more active phytoplankton in the turbulent area, absolute values may not be accurate at all, since the smallest cells were not counted. Primary production increased towards May at both stations, the values for the previous months being slightly higher at E3 than at E1 (Fig. 7). These values were of approximately the same magnitude as those for the ocean during the late winter bloom (Table I). Primary production was distributed almost homogeneously through the water column, except in May when there was a maximum concentrated at the surface (Fig. 6). Assimilation number values in February and April (Figs. 6 and 7) were similar to those reported BRAUN & REAL (1984) for coastal waters throughout the

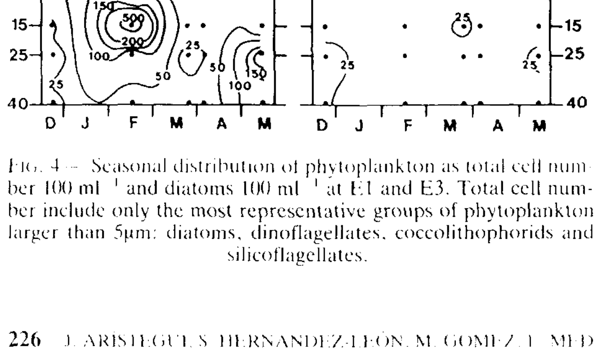

FIG. 4. — Seasonal distribution of phytoplankton as total cell number 100 ml^{-1} and diatoms 100 ml^{-1} at E1 and E3. Total cell number include only the most representative groups of phytoplankton larger than 5μm: diatoms, dinoflagellates, coccolithophorids and silicoflagellates.

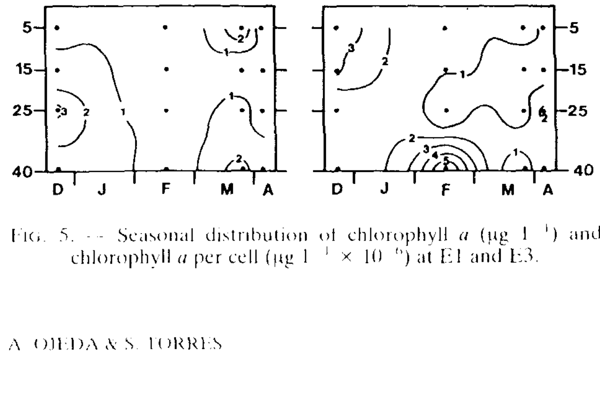

FIG. 5. — Seasonal distribution of chlorophyll *a* (μg l^{-1}) and chlorophyll *a* per cell (μg l^{-1} × 10^{-6}) at E1 and E3.

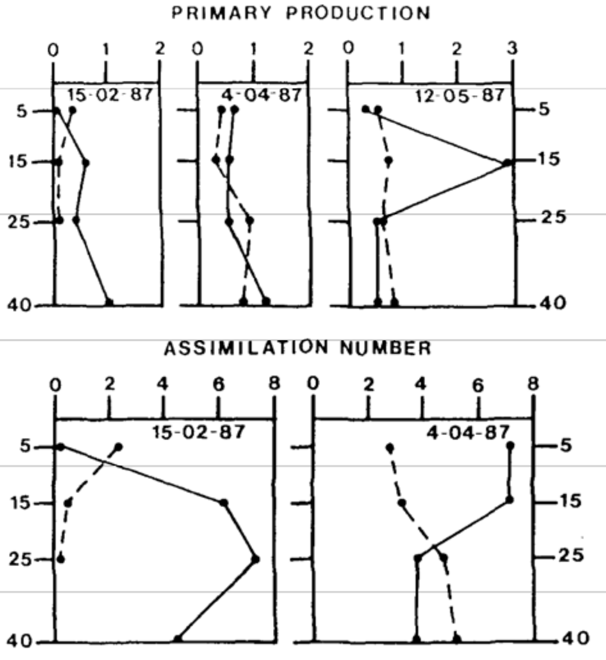

FIG. 6. — Vertical profiles of primary production (mgC m^{-3} h^{-1}) and assimilation number (mgC mgChla^{-1} h^{-1}) at E1 (dashed line) and E3 (solid line).

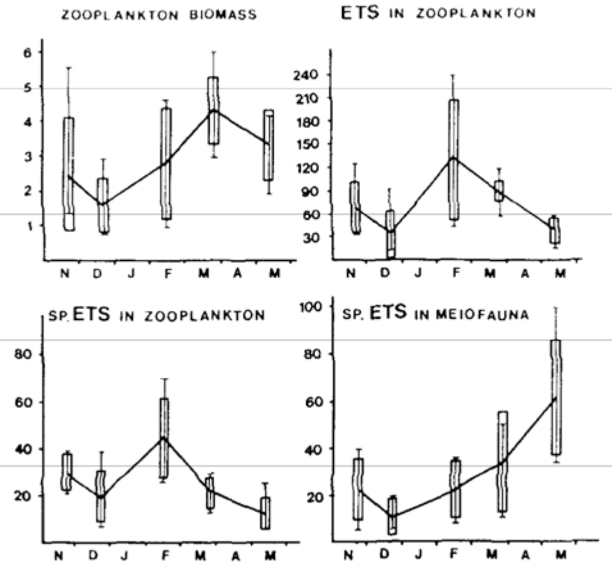

FIG. 8. — Seasonal changes in biomass (mg Proteins m^{-3}), ETS per unit of volume (µl O_2 m^{-3} h^{-1}) and ETS specific activity (sp. ETS) (µl O_2 mgProt.$^{-1}$ h^{-1}) in the mesozooplankton, and ETS specific activity (sp. ETS) (µl O_2 mg Prot.$^{-1}$ h^{-1}) in the meiofauna of the sediment. Extreme values, mean values and standard deviations are given for the entire area.

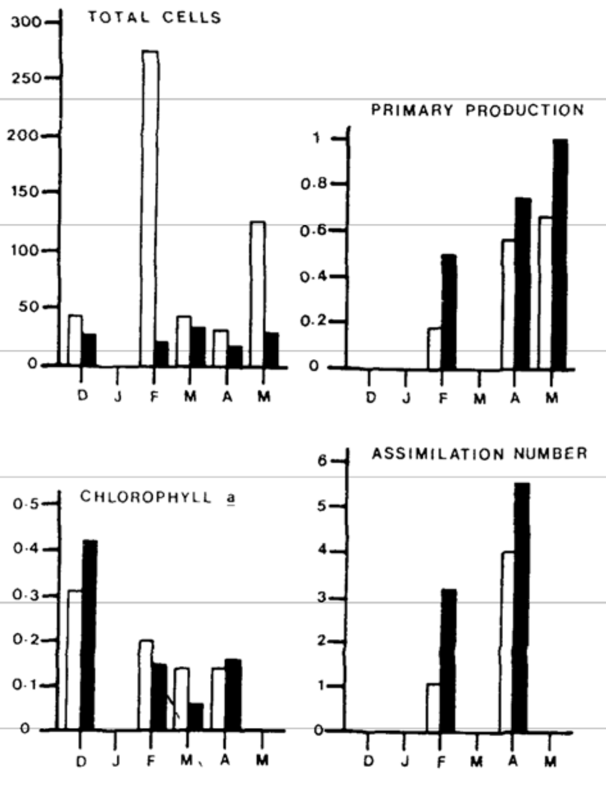

FIG. 7. — Mean values for total cell number (cells 100 ml^{-1}), chlorophyll *a* (µg l^{-1}), primary production (mgC m^{-3} h^{-1}) and assimilation number (mgC mgChla^{-1} h^{-1}) at E1 (white bars) and E3 (black bars).

year, and for oceanic waters during the mixing period (Table I), always being higher at E3 than at E1.

Despite the intervals between the sampling periods, the evolution of the biomass and ETS activity in the mesozooplankton followed trends similar to those found in other coastal and offshore areas of the archipelago (HERNÁNDEZ-LEÓN, 1987; 1988a), with a peak in the ETS activity that preceded that of biomass. However, in contrast with previous works, a coupling was observed between the specific activity and the ETS measured on a unit-volume basis. The spatial distribution of the biomass denoted the presence of accumulations in the wind shear field. From November to May, a biomass nucleus was formed and varied only slightly in position, a second nucleus appearing near the first one in February (Fig. 9).

In the sediment (Fig. 8), the maximum of ETS specific activity in the meiofauna was seen in May, delayed in relation to those of biomass, ETS and specific activity observed in the zooplankton.

DISCUSSION

In comparison to oceanic waters, the values for nutrients, primary production and assimilation numbers found in coastal waters to the south of Gran Canaria Island were relatively high, comparable in magnitude to values cited in the literature for the short productive period of the oceanic cycle in the

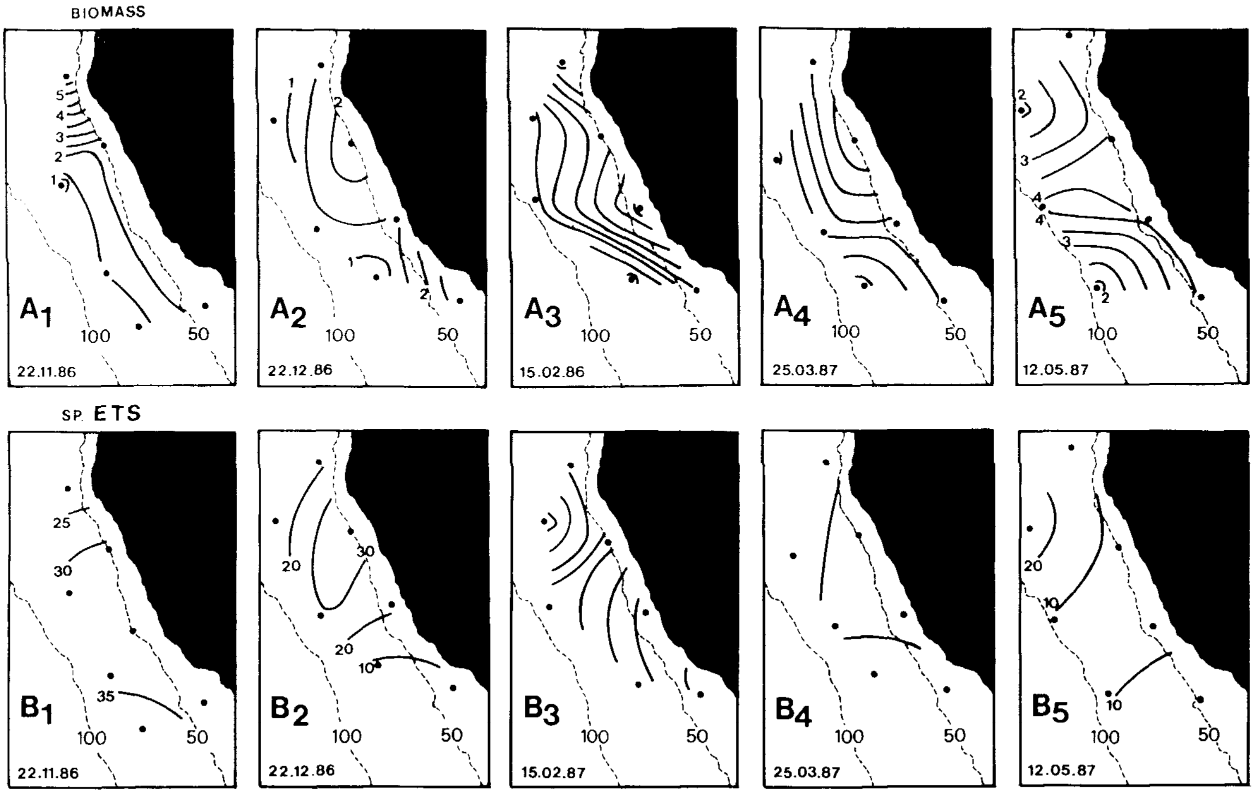

FIG. 9. — Seasonal variations in spatial distribution of (A1 to A5) biomass (mg Proteins m^{-3}) and (B1 to B5) ETS specific activity (sp. ETS) (µl O_2 mg Prot.$^{-1}$ h^{-1}) in the mesozooplankton.

Canary Island waters. However, there are also significant differences between the calm and turbulent waters on the shelf, represented in this work by E1 and E3, respectively. Though the water column was always mixed at both stations, E3 was affected by stronger advection and a more turbulent regime, caused by the continuous action of the North Trade Winds. As a result, nutrients were more readily distributed at E3 than at E1, and the phytoplankton-was therefore more active (with higher assimilation numbers) at E3 station. These populations of active phytoplankton thriving in turbulent waters could fit into the concept of *r*-strategists described by MARGALEF (1974, 1978) for diatoms and related forms. However, comparative data of chlorophyll, primary production and cell numbers must be interpreted with caution. Our taxonomic study did not include the smallest nanoplankton and the picoplankton, which have been recently found to play an important role even in coastal waters, when microphytoplankton is scarce (JOINT, 1986). Thus, although the greater part of chlorophyll *a* after the increase in nutrients probably belongs to cells larger than 5 µm, the smallest forms may be largely responsible for the chlorophyll values registered in December. The very low number of cells always observed at E3 may be due in part to the dispersion caused by physical advection. However, grazing seems to play an important role in governing the abundance of phytoplankton in the entire area. Coinciding with the biomass peak in mesozooplankton, there was a sharp decrease in cells at E1, which only increased again after the zooplankton peak drops in May. A recent study also carried out off the south coast of Gran Canaria (ARÍSTEGUI *et al.*, unpublished data) confirms this idea, revealing a close interdependence between the microphytoplankton and mesozooplankton.

The late winter maximum in the ETS activity preceded a biomass maximum in the mesozooplankton, and occurried close to the turbulent area where phytoplankton showed its highest productivity. The subsequent increase in the metabolic activity of the meiofauna of the sediment would correspond to the supply of faecal pellets and dead particulate organic material which sank down to the bottom after the zooplankton maximum. The new regenerated products would be easily distributed in the water column as a result of the strong wind, constant in direction and intensity from March to May. This increase in the concentration of nutrients salts (particularly nitrate) affected the entire area, but mainly the zone exposed to the wind, and induced an increase in primary production.

Much more work must be done in order to

understand the mechanisms that govern the planktonic production in self waters and the spatial distribution of their populations. However, this first approach shows that large populations of mesozooplankton are concentrated to the south of Gran Canaria, where relatively high primary production can be found. This is possibly due to the persistent effect of the North Trade Winds which give rise to an unstable zone where the water is mixed and nutrients are made available in the entire column.

These results tend to confirm the idea that neritic ecosystems, on more or less extensive shelves to the south of the Canary Islands, are more productive than oceanic systems, and are able to mantain an important secondary production of consumers.

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