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Spatial Heterogeneity of Phytoplankton in an Estuary of Cantabria, Northern Spain

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ABSTRACT

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Phytoplankton distribution and structure in the estuary of Cantabria, Northern coast of Spain, Bay of Biscay, was studied. Samples were taken monthly at three stations situated between the upper reaches of the tide (st-3) and the mouth of the estuary (st-1), and included near-shore and middle points. The stations are characterized as: Station 1 (st-1)—the most saline, with a low concentration of nutrients, high temperatures; Station 2 (st-2)—less saline but has elevated contents in nutrients, low temperature; and Station 3 (st-3)—the least saline but with higher nutrient content, low temperature.

The phytoplankton communities did not vary among stations (they were euryhaline species, in most cases). However, the response of the community to the different environments varied as follows: Station 1—elevated productivity and low biomass; Station 2—elevated productivity, low diversity and biomass; and Station 3—low productivity and diversity and the highest biomass.

ADDITIONAL INDEX WORDS: *Estuary, phytoplankton, spatial distribution, gradient, biomass, productivity.*

INTRODUCTION

HULBERT *et al.* (1960) and HULBURT (1963) observed that the oceanic waters generally had a greater diversity of phytoplankton than the coastal waters. PATTEN (1962) found that the diversity of net phytoplankton progressively increased with distance from the river mouth. These observations suggest that the response of a phytoplankton community to regionally different environmental conditions is reflected in its structural properties (MUKAI and TAKIMOTO, 1985).

The purpose of this study was to evaluate the response of the phytoplankton community to the different environments created by the mixing of fresh and neritic water. Distribution and structure of the phytoplankton community were studied along the estuary (saline gradient), throughout both a tidal and an annual cycle.

STUDY AREA

The estuary of the River Pas (northern Spain, Bay of Biscay) (Figure 1), shows a typical geomorphology of a ria with a mean depth of 4 metres and is a partially mixed estuary (PEREZ, 1987).

The tides are semidiurnal with a fortnightly alternating cycle of spring tides and neap tides. The interval of two consecutive tides corresponds to the semilunar wave M_2 (12 h 25′). The tide amplitude rank is around 4 metres in spring tides and approximately 2 metres in neap tides. The maximum prism of current tide is 4.550.000 m^3 (CANTERAS and PEREZ, 1986).

The Rainfall and Temperature data were provided by the Meteorological Centre of Santander (Spain) (Latitude 43°, 27′, 53″; Longitude 03°, 49′, 08″). During the study period, the maximum levels of rainfall occurred in Autumn and Winter, with a secondary maximum in Spring (April and May). May was the most rainy month (346.6 mm) and September the driest (3.6 mm) (Figure 2).

Temperature gradually increases toward summer with a maximum of 24.6°C in July and a winter minimum of 7°C in January (Figure 2).

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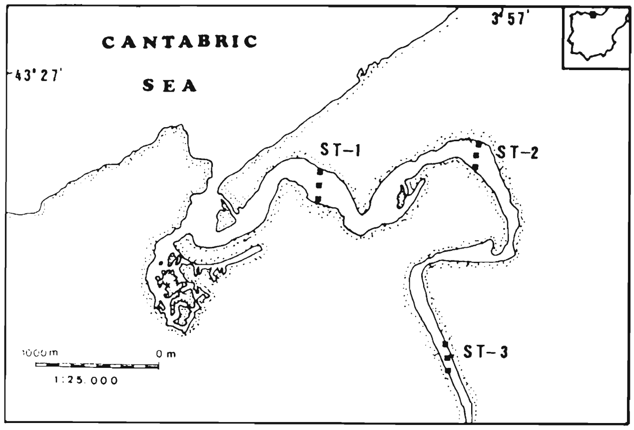

Figure 1. Map of the Pas estuary (northern Spain) showing the location of the 3 studied stations.

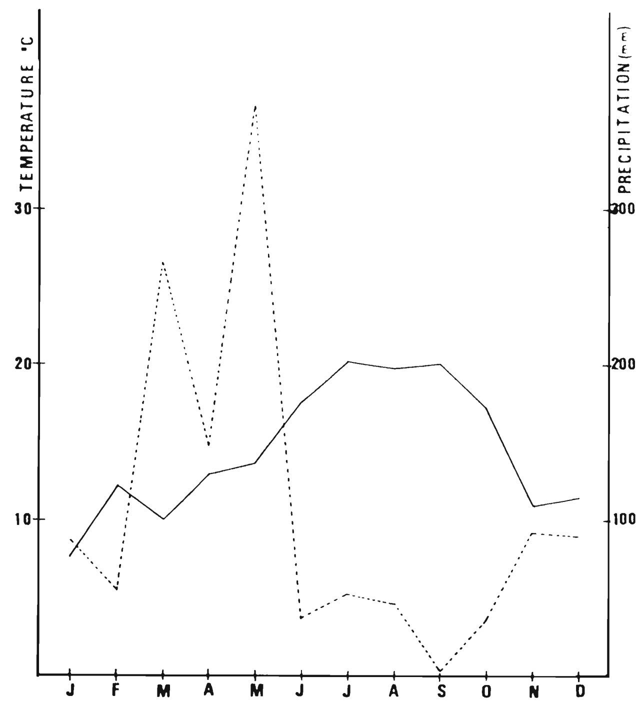

Figure 2. Monthly variation of total precipitations (mm) (- -), average air temperature (°C) (- -) and average water temperature (°C) (-.-).

METHODS

Samples were collected monthly, over an annual cycle at three different stations placed along the longitudinal axis of the estuary (Figure 1).

At each station five different points were fixed: the river banks (left, LA and right, LB) and a central point of maximum depth where samples were collected at the surface (CS), midway (CM) and bottom (CF). Samples (8 l. Van Dorn bottles) were taken during the tidal cycle (at the high and low tidal time).

All water samples were analyzed for: pH, temperature, conductivity, alkalinity, dissolved oxygen, salinity, nitrates, nitrites, ammonium, phosphates, silicates, chlorophyll *a*, total number of cells, primary production. The analytic methods described by STRICKLAND and PARSONS (1972) were used to measure the nutrients. The chlorophyll *a* was analyzed using the method of ROS (1979) and the primary production following the method of STEEMAN-NIELSEN (1952).

The diversity index (SHANNON and WEAVER, 1963) was calculated as an index of the structural properties of the phytoplankton community. This was estimated with the whole identified species, including the nannoplankton. Other indexes used included: uniformity index (PIELOU, 1966), MARGALEF index (D_{430}/D_{665}) and assimilation index (mg C (mg Chl $a)^{-1}$ h^{-1}).

The statistical significance of differences in averages for each variable was obtained by means of an analysis of variance. A hierarchic factorial analysis (GRAYBILL, 1961; CHING CHU LI, 1969) was designed to determine the three sources of variation: The tidal cycle (low tide and high tide), volume of water (LA, LB, CS, CM, CF) and annual cycle.

To obtain a global comprehensive and single view of the main variation tendencies in the estuary, two principal components analyses following LEBART and MORINEAU (1982) were applied. On the first, all physical and chemical parameters measured in every sample collected (360) along the sampling cycle were considered; in the second, only the results for biological variables were included. A logarithmic transformation was realized for a greater part of the variables. This kind of analysis has been used by FLOS (1979), to describe annual hydrographic cycles, BLASCO *et al.* (1980).

RESULTS

Salinity values ranged from 34.5‰ in September to 0.3‰ in May. An increasing gradient was always observed on the longitudinal axis from land to sea and from surface to bottom (Figure 3).

The nutrients showed strongly seasonal, spatial and tidal variations. Highest relative values in Winter and in May, at the most fluvial station (st-3) and always at low tide. Following extreme values were obtained:

Nitrates: 102 μg at N/L (in November, at low tide, at station 3), and 3 μg at N/L (in August, at high tide, at station 1) (Figure 4).
Phosphates: 6 μg at P/L (in November, at low tide, at station 3), and 0.0 μg at P/L (in Summer and always at high tide).

Chlorophyll *a* values ranged from 25 mg m^3 to 0.5 mg m^3 with lowest levels in Winter and at the end of Spring. A small increase occurred in March although maximum biomass occurred in June (Figure 5). Chlorophyll *a* concentration was always higher at low tide than at high tide.

Two hundred and thirty nine species were identified, 164 of which were diatoms (Bacillariophyceae), 56 dinoflagellates (Dinophyceae), 5 Cryptophyceae, 4 Euglenophyceae, 1 Zygophyceae. The nannoplankton ($\leq$ 20 μ) appeared during the entire cycle and accounted for over 50% of the total biomass in the summer months and in the early autumn.

In relation to the abundance (cell/ml, Table 1) and specific composition of the phytoplankton, three periods could be distinguished in the annual cycle: the first period, in which the number of individuals was small, averaging 100 cells/ml and during which there was a bloom in March. The community consisted of species of clearly fluvial influence, for instance *Asterionella formosa, Rhoicosphenia curvata, Scenedesmus quadricauda, Leptocylindrus minimus, Thalassionema nitzschioides*. During the second period from June to October there was a clear rise in the biomass, which reached its maximum in July. In this period species of neritic influence appeared, for instance *Rhizosolenia stolterforthii, Bacteriastrum delicatulum, Corethron* sp., *Nitzschia delicatissima, Crytomonas* sp. The third period, from October to December, showed a reduction in the biomass. Opportunistic species occurred, for instance *Skeletonema costatum*, and large diatoms, for instance *Biddulphia rhombus, Biddulphia regia, Nitschia longissma.*

The diversity index (Figure 6), of all stations, was high in February, April and May (Mean =

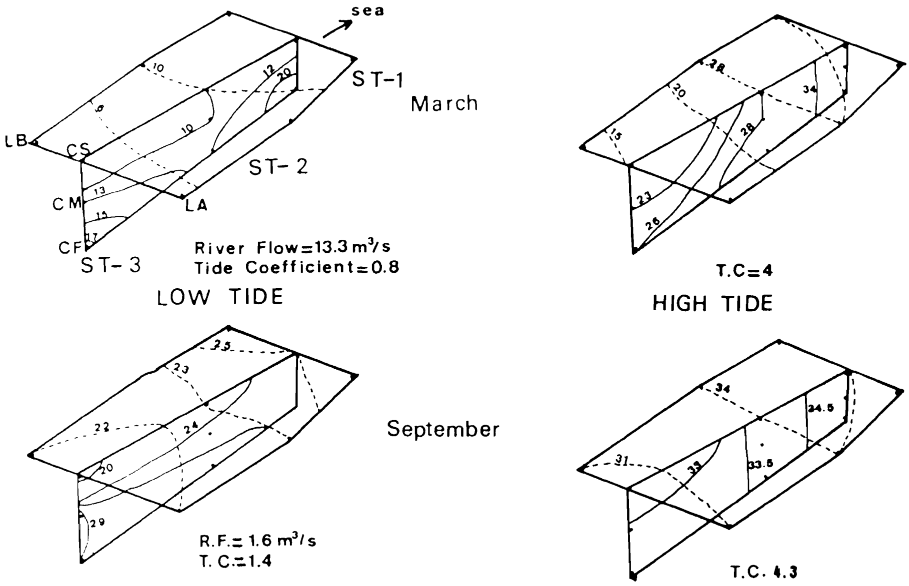

Figure 3. Differences in distribution of salinity (%.) between March and September, corresponding to the distribution two seasons of the year, with different values of the river flow (R.F.) and Tide coefficient (T.C.).

3 bits/cell) then decreased with fluctuating values during the rest of the year. No significant differences were found over the tidal cycle.

Maximum values of primary production (Figure 7) were obtained in October (Mean = 27.6 mg C/m^3/h at st-3) and the minima in April (Mean = 0.37 mg C/m^3/h). No significant difference ($p \leq 0.05$) in production were found over a tidal cycle although highest values were always detected at low tide.

The assimilation index (Figure 8) varied seasonally and with depth at each station. The highest index values were obtained in October at station 2. These values were lower at the surface and varied widely from one station to another and during the tidal cycle.

The results found in the principal component analysis (PCA) realized with 11 physical and chemical variables, measured along the annual cycle were the following: The three first axes of the PCA accounted for about 72.5% of the total variance, corresponding 46.9% to I, 16.1% to II and 9.5% to III. First axis was set by those variables that define the environmental characteristics of the water: factors related to water density (temperature and salinity) on the one hand; factors related to nutrients, on the other hand. Component II correlated positively with the nitrites (0.79), ammonium (0.72) and dissolved oxygen (0.68) values. The third component correlated strongly with the pH (0.85) values. Figure 9 represents the relative coordinates of the stations in the subspace of the components I, II and III. They are clearly differentiated on the longitudinal axis of the estuary.

The second principal component analyzed was performed with the eight biological variables analyzed on the 360 samples collected. The analysis selected three components which accounted for about 74% of the total initial information. Component I (41.2% of the total variance) correlated strong positively with variables indicating the community structure (Shannon-diversity index and uniformity index). Component II (17% of the total variance) showed a good correlation with chlorophyll *a* (0.95) and abundance (total number of cells) (0.64) values. It can be identified as a biomass axis. Component III (15%) correlated positively with the assimilation index and primary production values. The relative coordinates at each station were calculated (Figure 10). The highest values of component I were detected at station 1, followed by stations 3 and 2. Station 3 showed the highest values of component II, followed by stations 1 and 2. Component III pre-

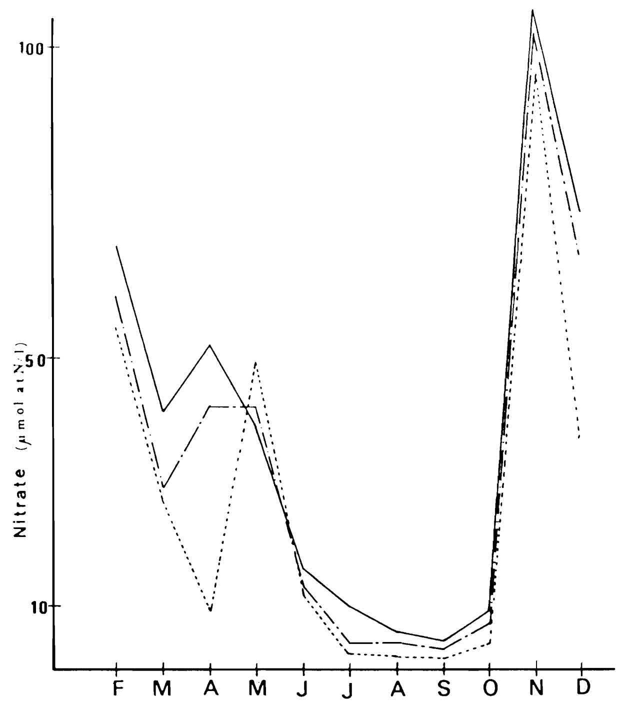

Figure 4. Seasonal variations in the average (n = 10) nitrate concentration (μgat N /1) at each studied station (- - - St-3; - - - St-2; -.-.- St-1).

sented higher values at station 1, followed by stations 2 and 3.

DISCUSSION

There were no observed differences in any measured parameter vertically or horizontally at any one station. Vertical homogeneity can be explained by the shallow depth of the estuary, where tidal currents and wind action provide sufficient energy for the frequent vertical water movement. Similar explanations were given by MARGALEF *et al.* (1955), BLANCO (1985), and RIAUX and DOUVILLE (1980).

The phytoplankton response varied along the longitudinal axis of the estuary. The external environment modifies physiological responses which, in turn, control the cell division rate. Thus environmental gradients can be related to community structure. The gradients created by the mixing of fresh and neritic water produce a variety of physical and chemical characteristics, which modify the habitats of the phytoplankton (MUKAI and TAKIMOTO, 1985).

The results of the PCA analyses can be used to partition the Ria into three habitats with the following characteristics:

Station 1: highest salinity levels, low nutrient concentrations high temperatures, high productivity and diversity, and low biomass.

Station 2: lower salinity levels, high nutrient concentrations, low temperature, high productivity and low diversity and biomass.

Station 3: lowest salinity, highest nutrient concentrations, low temperature, low productivity and diversity, and maximum biomass.

Small-size diatoms, which are typical of well mixed waters (LEVASSEUR *et al.*, 1984), dominated during the whole cycle. The phytoplankton communities detected during the study did not show important variations from one station to another (they belonged mainly to the euryhalynes species, PEREZ (1987). Nevertheless, the responses of the community were environ-

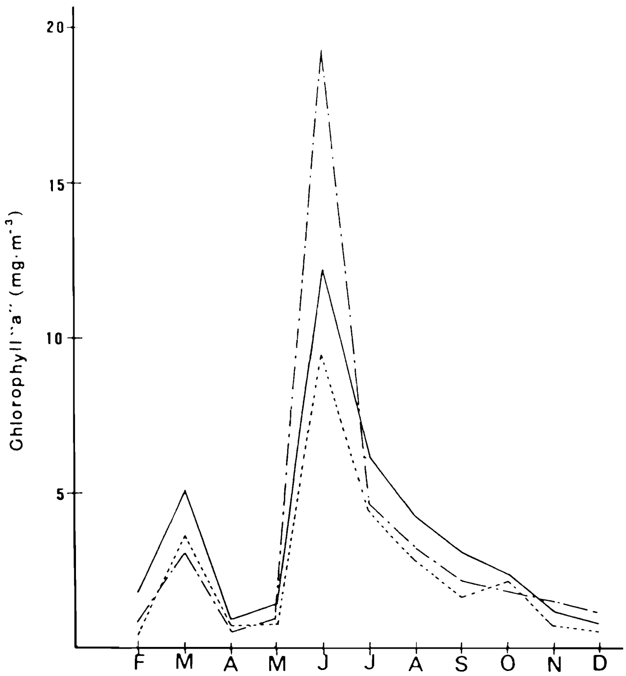

Figure 5. Seasonal variations in chlorophyll *a* (mg. m^{-3}) mean (n = 10) values at each studied station (- - - St-3; - - St-2; -.-.- St-1).

Table 1. *Monthly variation of mean values (M; n = 10), standard deviation (D) and coefficient of variation (M/D) of total number of cells (cells/ml) at each station.*

E-3

	F	M	A	M	J	J	A	S	O	N	D
M	151	444	158	103	4077	10263	3285	4229	1570	473	202
D	50	279	53	46	2379	8294	1435	5033	1200	277	55
D/M	0.3	0.6	0.3	0.4	0.6	0.8	0.4	1.2	0.8	0.6	0.3

E-2

	F	M	A	M	J	J	A	S	O	N	D
M	147	343	157	80	6620	9364	1994	3975	1084	344	191
D	96	208	49	20	3627	11371	1614	3243	707	252	21
D/M	0.6	0.6	0.3	0.3	0.6	1.2	0.8	0.8	0.7	0.7	0.1

E-1

	F	M	A	M	J	J	A	S	O	N	D
M	102	279	204	82	9069	5496	2048	2286	1120	406	207
D	34	179	94	26	4266	4040	1512	1748	743	348	62
D/M	0.3	0.6	0.5	0.3	0.5	0.7	0.8	0.7	0.7	0.9	0.3

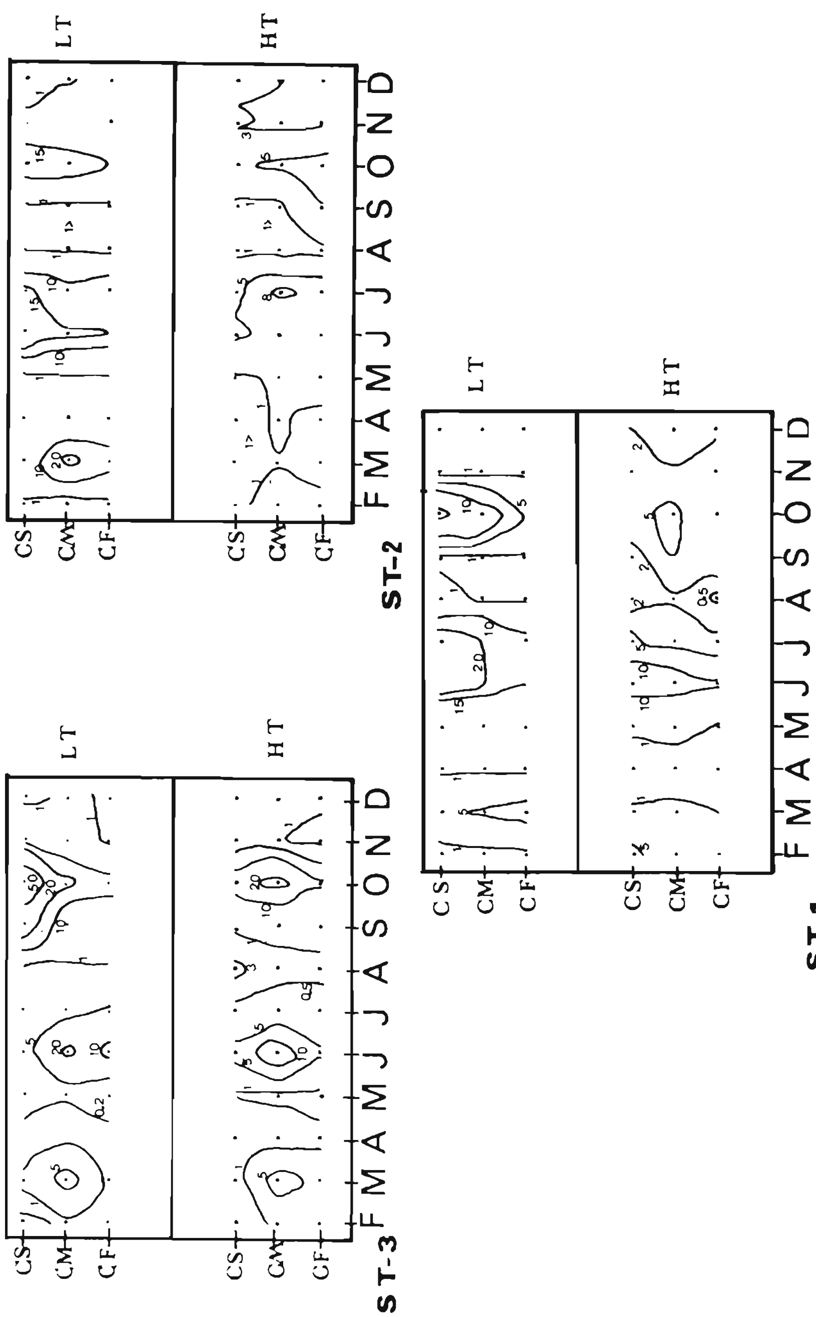

Figure 6. Seasonal variations in the Shannon diversity index at the central point (see text for CS, CM, CF) of each station at High Tide (HT) and Low Tide (LT).

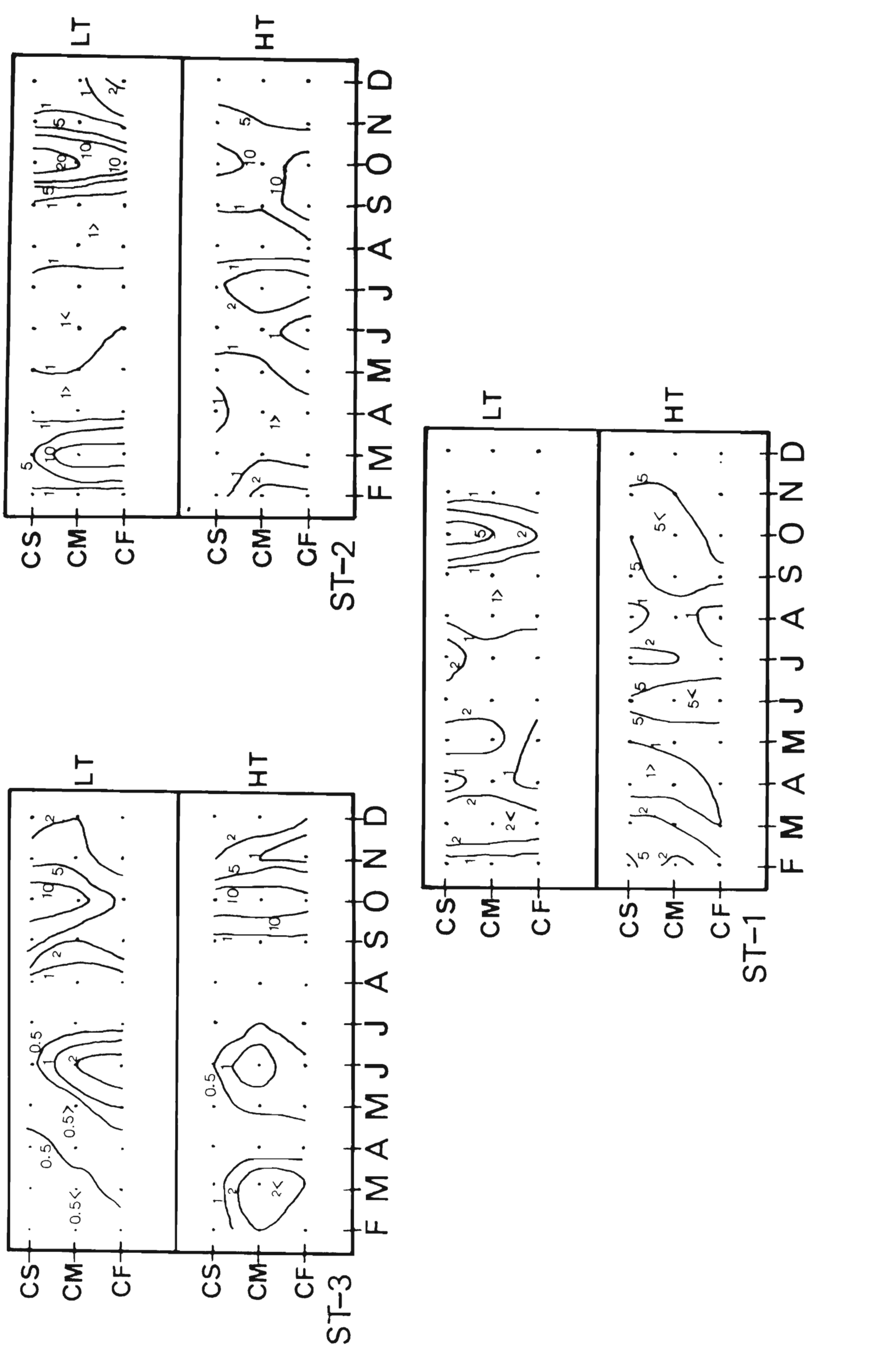

Figure 7. Changes in primary production (mgCm^{-3} h^{-1}) versus time and depth at the central point of each station at High Tide (HT) and Low Tide (LT).

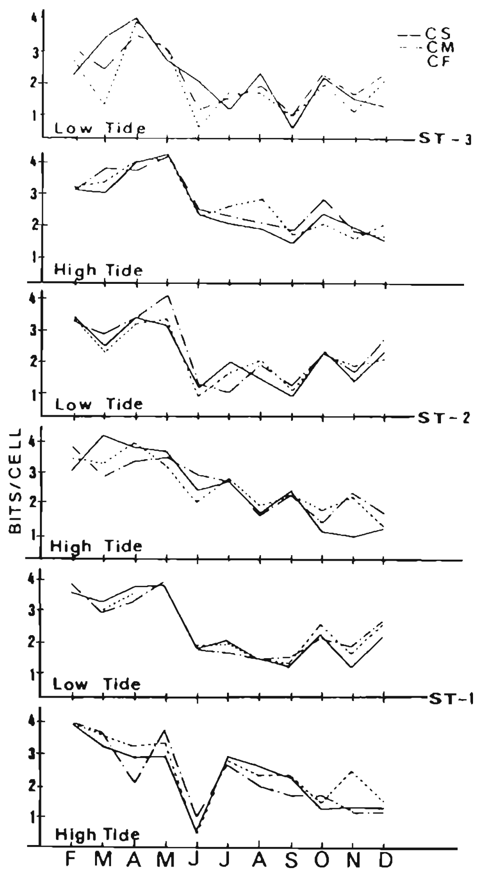

Figure 8. Evolution of the assimilation index values versus time and depth at the central point (see text for CS, CM, CF) of each station at High Tide (HT) and Low Tide (LT).

mentally linked. Station 1 is mostly marine an station 3 is less influenced by the sea than station 2. Station 2 is subjected to the highest environmental fluctuations between the river and coastal water conditions. The gradual increasing of nutrients (st-1 to st-3) provoked a high level of biomass (Table I) and a reduction of diversity at station 3; whereas at station 1, where the nutrients diminished, the biomass was lower and the diversity higher. Station 2 showed the lowest diversity indexes. The greater variation of the physical and chemical parameters at the station 2 could justify the presence of a community with a lower specific diversity and, consequently, with a lower degree of organization (MARGALEF, 1974).

The highest values of assimilation index were found at station 1 during high tide. That is, the photosynthetic efficiency was higher when salinity and temperature increased and the nutrients concentration decreased. At the stations 2 and 3 the biomass and the values of assimilated carbon were higher; nevertheless, the photosynthetic efficiency was lower. According to SMAYDA (1983) changes in cellular osmotic pressure and ionic composition may also affect the cellular activities important to estuarine survival. These include chlorophyll synthesis (McLACHLAN, 1961) and rates of photosynthesis (NAKANISHI and MONSI, 1965; QASIN *et al.*, 1972).

FLOS (1985), reported that the highest productivity of the Abra estuary (Bilbao, Spain) and the surrounding waters occurred in the outer area of the estuary. Our findings show both a productivity and diversity increasing along the longitudinal axis of the estuary towards the sea. Nevertheless, abundance is often higher in predominantly fluvial waters. Similar results were obtained by McCORMICK and QUIN (1975), SIROIOS and FREDERICK (1977), RIAUX and GRALL (1982), and IGNIATIDES (1984).

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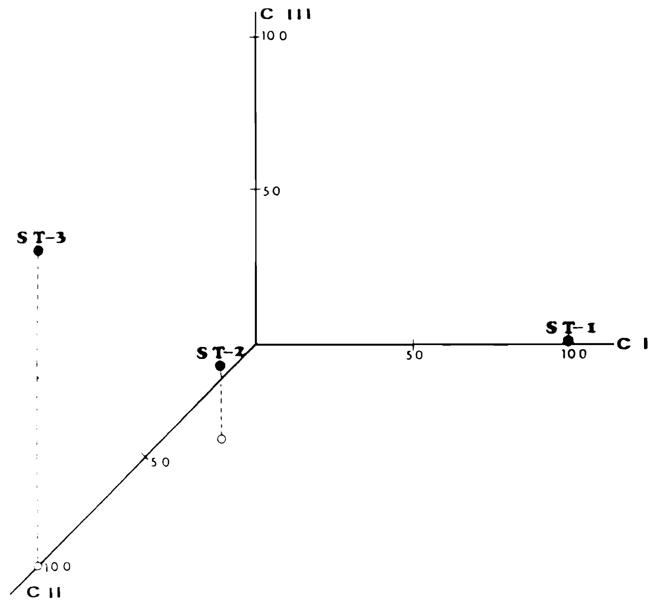

Figure 9. Results of the principal components analysis (PCA) performed with physical and chemical variables data. Relative coordinates of the stations, on the subspace defined by first, second and third components.

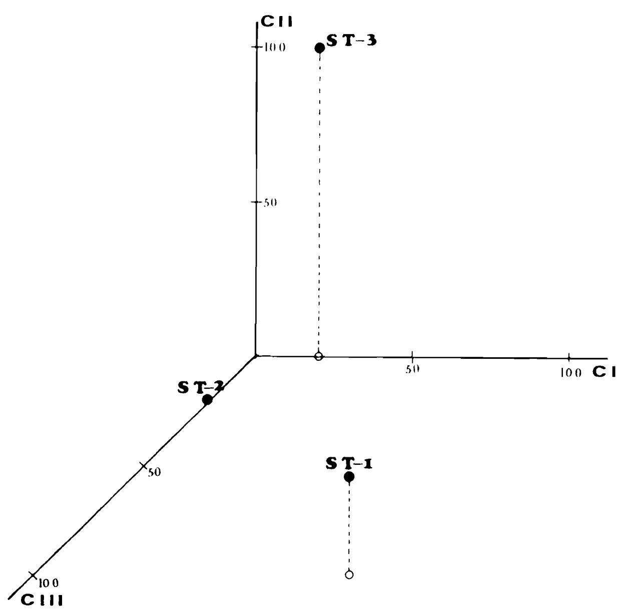

Figure 10. Results of the principal components analysis performed (PCA) with biological variables data. Relative coordinates of the stations, on the subspace defined by first, second and third components.

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□ ZUSAMMENFASSUNG □

Untersucht wurden Verteilung und Struktur des Phytoplanktons im Cantabria Ästuar (Biskaya - Spanien) an 3 Stationen im oberen (Station 3), im mittleren (Station 2) und im unteren Bereich (Station 1) des Ästuars. Die Proben wurden monatlich einmal genommen. Die Station 1 zeigte den höchsten Salzgehalt und die größten Temperaturen, aber eine geringe Nährstoffkonzentration. Bei Station 2 waren Salzgehalt und Temperatur geringer, dafür ergab sich ein erhöhter Nährstoffgehalt. Für Station 3 wurden ein noch geringerer Salzgehalt und geringere Temperaturen, dafür aber ein sehr hoher Nährstoffgehalt ermittelt. Die Unterschiede zwischen den Phytoplankton gesellschaften an den Meßstellen waren gering, in fast allen Fällen handelt es sich um euryhaline Arten. Die Reaktionen des Phytoplanktons auf die unterschiedlichen Umweltbedingungen waren dagegen verschieden. Für die Stationen 1 und 2 ergab sich jeweils eine erhöhte Produktivität bei geringer Biomasse, für Station 3 dagegen eine geringe Produktivität bei großer Biomasse. Bei den Stationen 2 und 3 war die Artenarmut bemerkenswert.—*Reinhard Dieckmann, WSA Bremerhaven, West Germany (FRG).*

□ RÉSUMÉ □

Etudie la distribution et la structure du phytoplancton dans l'estuaire de Cantabrie (côte Nord de l'Espagne, golfe de Gascogne). Chaque mois, des échantillons ont été prélevés en trois stations réparties entre la station 3, située au niveau de la remontée extrême de la marée en amont, et la station 1, à l'embouchure de l'estuaire. Ces stations englobent le proche littoral et les points intermédiaires. Elles sont caractérisées par:

station 1: la plus forte salinité, faible concentration en éléments nutritifs, basse température;

station 2: salinité moins élevée, teneurs élevées en éléments nutritifs, basse température;

station 3: présente la moins forte salinité et la plus faible concentration en éléments nutritifs, basse température. Les communautés de phytoplancton trouvées dans cette étude ne varient pas selon les stations (la plupart sont des espèces euryhalines), toutefois la réponse des communautés aux différents environnements varie:

–station 1: productivité élevée, biomasse faible;

–station 2: productivité élevée, faible diversité et biomasse faible;

–station 3: faible productivité, diversité et biomasse plus élevée.—*Catherine Bressolier, Labo. Géomorphologie E.P.H.E., Montrouge, France.*

□ RESUMEN □

Se ha estudiado la distribución y estructura del fitoplancton en un estuario de Cantabria (N. España, Golfo de Vizcaya).

Mensualmente se recogían muestras en 3 estaciones situadas entre la cabecera (estación 3) y la desembocadura (estación 1) del estuario. En cada una se estudiaron las orillas y los puntos medios. Las estaciones quedaron caracterizadas como:
Estación 1 (st-1): La más salina, con baja concentración de nutrientes y altas temperaturas.
Estación 2 (st-2): Menos salina con alto contenido en nutrientes y bajas temperaturas.
Estación 3 (st-3): La menos salina, con mayor contenido en nutrientes y temperatura baja.

Las comunidades de fitoplancton encontradas en el estudio no variaron a lo largo de las estaciones (fueron especies eurihalinas, en la mayoría de los casos). Sin embargo, lo que si varió fue la respuesta de la comunidad a los diferentes ambientes creados:
Estación 1: De elevada productividad y biomasa baja.
Estación 2: Elevada productividad, diversidad y biomasa bajas.
Estación 3: Productividad y diversidad bajas y la mayor biomasa.—*Department of Water Sciences, University of Cantabria, Santander, Spain.*