

## Phytoplankton on the western coasts of Baja California in two different seasons in 1998

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**SUMMARY:** Phytoplankton was studied in two different seasons of 1998 (March-April and December), during two cruises along the western coasts of Baja California, in three zones. Two different protocols for obtaining and studying phytoplankton were followed. In the March-April season, phytoplankton had relatively low species richness and was dominated in cell density (up to 93%) by coccolithophorids (mainly *Emiliania huxleyi*), together with nanoplanktonic centric and pennate diatoms, with abundances ranging from  $5.4 \cdot 10^3$  to  $1.2 \cdot 10^5$  cells  $L^{-1}$ . In December, phytoplankton had higher species richness and was represented by larger, chain-forming diatom species, such as *Pseudonitzschia delicatissima* and *P. pungens*, which were widespread and numerically significant. There was a relative scarcity of coccolithophorids and thecate dinoflagellates, and densities were between  $7 \cdot 10^2$  and  $1.4 \cdot 10^6$  cells  $L^{-1}$ . Hydrographic and oceanographic conditions in March-April were influenced by the occurrence of El Niño and the phytoplankton structure was found to be modified accordingly, with nanoplanktonic coccolithophorids and diatoms being significant contributors to the total abundance. In contrast, post-upwelling conditions might have favoured relatively high densities of *Pseudonitzschia* and other diatoms in December, 1998. Coccolithophorids have not been previously regarded as important contributors to the phytoplankton abundances in Baja California.

**Keywords:** Baja California, coccolithophorids, diatoms, El Niño, phytoplankton.

**RESUMEN:** FITOPLANCTON EN COSTAS OCCIDENTALES DE BAJA CALIFORNIA EN DOS TEMPORADAS DISTINTAS DE 1998. – Se estudió el fitoplancton en dos temporadas diferentes de 1998 (marzo-abril y diciembre), durante dos cruceros en tres zonas de las costas de Baja California. Se siguieron dos protocolos distintos para obtener y estudiar el fitoplancton. En marzo-abril, el fitoplancton tuvo una riqueza de especies baja y estuvo dominado en densidades celulares (de hasta 93%) por cocolitofóridos (principalmente *Emiliania huxleyi*), junto con diatomeas centrales y pennaes nanoplanctónicas, con abundancias desde  $5.4 \cdot 10^3$  a  $1.2 \cdot 10^5$  céls  $L^{-1}$ . Para diciembre, el fitoplancton incrementó la riqueza de especies y estuvo representado por diatomeas más grandes, formadoras de cadenas, que se distribuyeron ampliamente y fueron numéricamente importantes, como: *Pseudonitzschia delicatissima* y *P. pungens*, con relativa escasez de cocolitofóridos y dinoflagelados tecados, con densidades entre  $7 \cdot 10^2$  y  $1.4 \cdot 10^6$  céls  $L^{-1}$ . Las condiciones oceanográficas en marzo-abril indicaron la presencia de El Niño y los resultados mostraron una estructura de fitoplancton modificada por ello, con una contribución importante de cocolitofóridos y diatomeas nanoplanctónicas a la abundancia total. En cambio, en diciembre, las condiciones de post-surgencia pudieron haber favorecido las relativas altas densidades de especies de *Pseudonitzschia* y otras diatomeas. Los cocolitofóridos no habían sido documentados previamente como contribuyentes importantes a la abundancia fitoplanctónica en Baja California.

**Palabras clave:** Baja California, cocolitofóridos, diatomeas, El Niño, fitoplancton.

### INTRODUCTION

The western coastal area of Baja California, Mexico has traditionally been considered a very

rich and productive system, in which the influence of the California Current is remarkable (Parrés Sierra *et al.*, 1997) and upwellings play an important role in keeping this high productivity

(Longhurst *et al.*, 1967; Wang and Walsh, 1976; Parrés Sierra *et al.*, 1997). The phytoplankton of this area have been relatively well-studied: there are studies on composition, distribution, primary productivity and variability of some of its features, as well as the main factors controlling the natural variation of phytoplankton (Smayda, 1975; Estrada and Blasco, 1979; Hernández-Becerril, 1985; Cardona *et al.*, 1990; Millán-Núñez and Loya Salinas, 1993; Cohen Fernández, 2000).

Diatoms and “armoured” dinoflagellates have been studied in greater detail than other taxonomic groups and they are usually regarded as the dominant phytoplankton in the area (Allen, 1923, 1924, 1934; Balech, 1960), and more recently (Hernández-Becerril, 1988, 1989, 1995, 1998; Hernández-Becerril and Tapia, 1995). Other groups (e.g. coccolithophorids and other flagellates) or size fractions (e.g. nanoplankton and picoplankton) have not been recognized as important contributors to the diversity, biomass and primary productivity. In nearby locations, in the California current system, coccolithophorids and other flagellates have been identified and counted (in terms of cell numbers and cellular volume) (Reid *et al.*, 1970), the relative importance of microplankton (netplankton) and nanoplankton has been stressed (Malone, 1971; Mullin, 1998), and the contribution to biomass and productivity of fractions of phytoplankton (smaller and larger than 8  $\mu\text{m}$ ) in a coastal area off Baja California has been studied (González Morales and Gaxiola-Castro, 1991).

The El Niño 1997-1998 event caused a pronounced effect on the climate, the hydrographic and oceanographic conditions, and the biological communities of the Pacific Ocean (Lynn *et al.*, 1998; Hayward *et al.*, 1999). This event reached a second peak of intensity in early 1998 and relaxed considerably by the middle of 1998. By the end of 1998 it disappeared completely from Baja California waters (Lavaniegos *et al.*, 2002), giving way to the strong La Niña event (Hayward *et al.*, 1999).

In this paper, results of the structure of the phytoplankton (in terms of species composition, abundance and distribution) collected during two cruises along the western coasts of Baja California, in two different seasons of 1998, one under the influence of El Niño and the other in contrasting conditions, are presented and discussed.

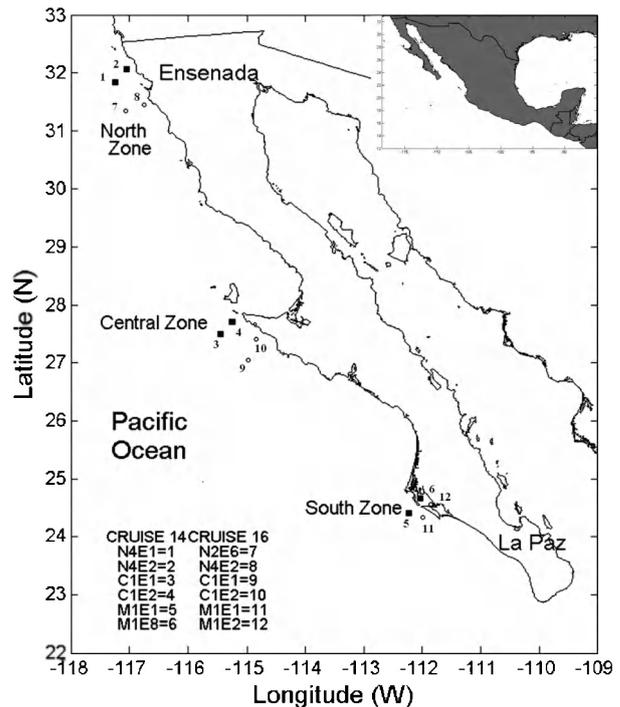


FIG. 1. – Map of the study area, showing sampling station during two cruises: Stations 1-6 from the cruise SIMSUP 14 (March-April, 1998), Stations 7-12 from the cruise SIMSUP 16 (December, 1998).

## MATERIAL AND METHODS

Sampling for this study was carried out during two cruises, on board “El Puma”: SIMSUP XIV (March-April, 1998) and SIMSUP XVI (December, 1998), along the western coasts of Baja California, Mexico, in three different zones (north, centre and south) (Fig. 1). Samples were taken basically following two distinct protocols: (1) In March-April, 1998, which is considered the decline of the El Niño 1997-1998 event, phytoplankton was collected with a Niskin bottle (usually 4 L) from three depths at 6 fixed stations (two in the three different zones) and filtered through Millipore 0.45  $\mu\text{m}$  meshed-filters with a vacuum pump (less than 100 mm Hg). The filters were immediately rinsed with a buffered (pH 7.5-8) solution, air dried at room temperature, and then stored in plastic Petri dishes (Winter *et al.*, 1999; Bollmann *et al.*, 2002). (2) In December, 1998, phytoplankton was taken with a Niskin bottle (4 L) from three depths at 14 fixed stations. Approximately 250 ml was then fixed with Lugol’s solutions and placed in dark bottles until analysis. Variables measured in both cruises were obtained by a CTD instrument, including temperature, salinity and dissolved oxygen (vertical profiles).

Phytoplankton was analyzed with protocol 1 as follows: small pieces (approximately 1 cm<sup>2</sup>) of the filters containing phytoplankton were cut then mounted onto slides. An oil immersion was added to clear the filters, then they were covered by a coverslip and observed with a light microscope (LM), using bright field and total magnifications of 600× or 1250×, to count and confirm species identification respectively (Bollmann *et al.*, 2002, in most details, except the use of immersion oil and the bright field microscopic technique). Preliminary species identification and cell counting were made in LM. The number of cells per litre was estimated from data such as the number of organisms counted, areas of counting and filter, and volume filtered (Bollmann *et al.*, 2002). Observations were also made by scanning electron microscopy (SEM) to confirm identification of tiny species, using small pieces of filters treated conventionally for SEM. Very few cells were found to be collapsed (due to the possible effect of changing pH or vacuum pressure). Samples fixed with Lugol's solution (protocol 2) were studied using an inverted microscope, following the usual settling in chambers and routine counting procedures (Hasle, 1978).

We used two different protocols to study the phytoplankton in this study, which may prevent direct comparisons being made between different seasons (March-April, 1998 and December, 1998). Our basic purpose when filtering samples (protocol 1) was to obtain the preservable fraction of the phytoplankton, especially the coccolithophorids, although the filters also contained diatoms, thecate (and resistant naked) dinoflagellates, silicoflagellates and other groups which have siliceous or carbonate coverings. This method underestimates the contribution of fragile "phytoflagellates", such as forms of Prasinophyceae, Cryptophytes, other Haptophytes, and also some picoplanktonic forms.

The number of coccolithophorids is estimated more accurately using this method (Bollmann *et al.*, 2002), as we can confirm identification and counting by SEM. Therefore, we were able to establish a phytoplankton community dominated by this group, and the diatoms, the group considered the most significant in terms of species diversity, abundance, and biomass in the study area, are not excluded by this method.

Samples taken and studied following the method for inverted microscope were analyzed very soon after collection, which prevents a possible dissolu-

tion of coccoliths from coccolithophorids. Hence, we were able to count this group when analyzing samples. Observation of other flagellates and nanoplanktonic diatoms (i.e. *Chrysochromulina* sp., *Fragilariopsis pseudonana*, *Meringosphaera mediterranea*, *Myrionecta rubra*, *Nitzschia bicapitata*) following this protocol allowed us to be confident with the phytoplankton composition and estimated abundances.

## RESULTS

### Hydrographic conditions and phytoplankton, March-April, 1998

Surface temperature data for March-April, 1998, were higher (by more than 1°C) than those usually reported in other studies for this season (Lynn *et al.*, 1998). The thermocline in most stations was located between 50 and 60 m, except in a shallow station (Fig. 2). There was only a significant change in salinity in a station situated in Bahia Magdalena (M1 E8), and in the remaining stations it did not change considerably (Fig. 2). Dissolved oxygen showed variation similar to temperature (Fig. 2).

The phytoplankton showed low species diversity, with up to 82 species identified. Its composition exhibited a community predominated by nanoplanktonic forms, in which coccolithophorids were important contributors to the abundance, mainly the species *Emiliana huxleyi* and *Gephyrocapsa oceanica* (Table 1). Diatoms were represented by small-sized, solitary and lanceolate/centric species, some of them of tropical affinity such as *Asteromphalus sarcophagus*, *Fragilariopsis pseudonana*, *Nitzschia bicapitata* and some *Thalassiosira* species, which were numerically significant. A few diatoms of fresh-water/brackish habitats also occurred in some samples. Thecate dinoflagellates appeared to be rather scarce, whereas the numbers of "naked"/unarmoured dinoflagellates were slightly higher. The heterotrophic flagellate *Meringosphaera mediterranea* was a very common, widespread species, and silicoflagellates were very common too, although not abundant.

The abundances of phytoplankton were low to relatively high, ranging between 5.4 10<sup>3</sup> and 1.2 10<sup>5</sup> cells L<sup>-1</sup>, with the coccolithophorids making up to a maximum of 93% of the total abundance (Table 2), and in some points reaching a ratio of 21:1 with

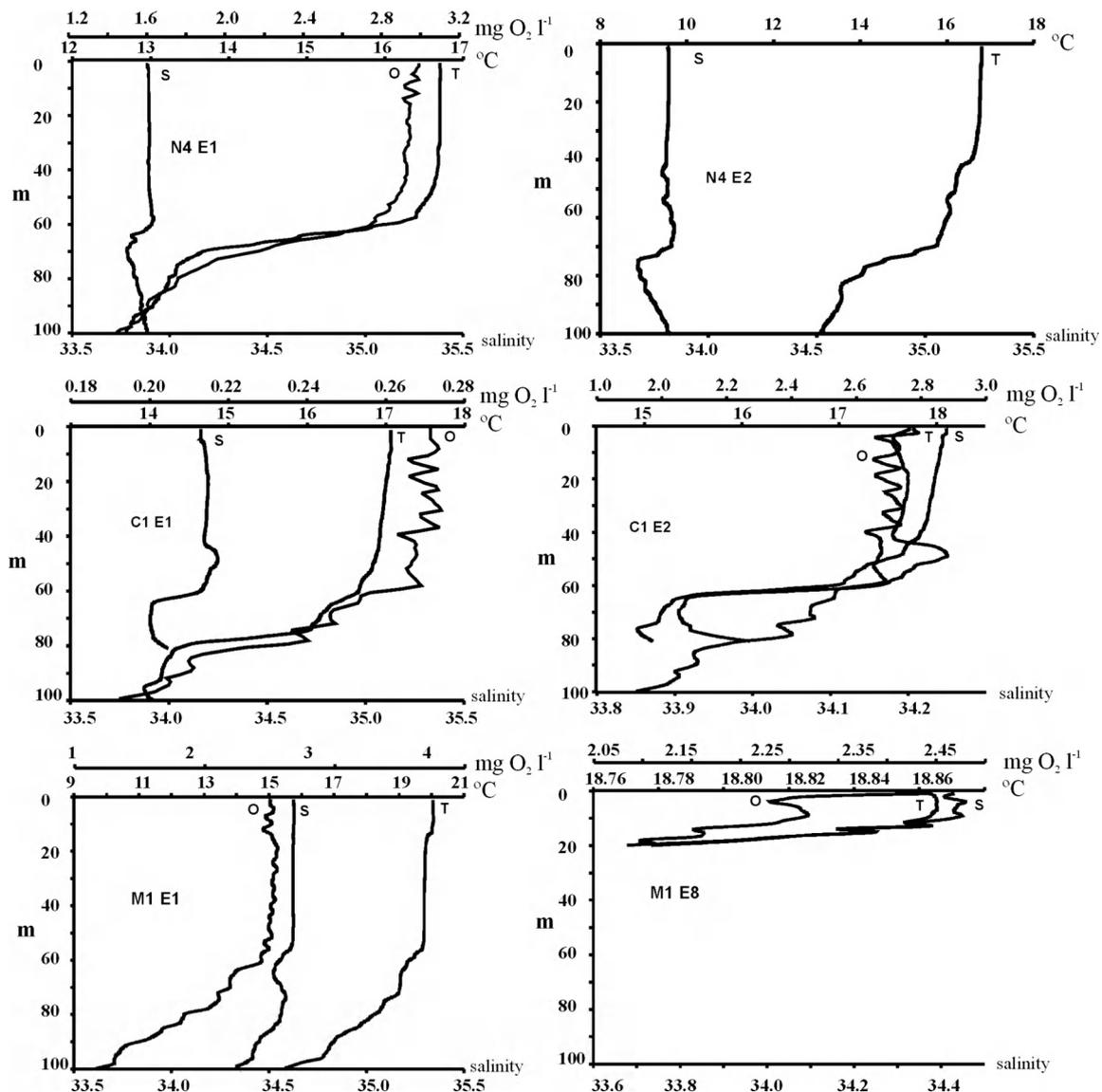


FIG. 2. – Vertical profiles of temperature, salinity and dissolved oxygen at stations from the cruise SIMSUP 14 (March–April, 1998).

regard to diatoms. These abundances were rather homogeneous (about the same magnitude order) with respect to both horizontal and vertical distribution of phytoplankton in most stations, except C1 E1 (zone centre), where we found the maximum values of phytoplankton abundances at the surface and subsurface, with a high contribution from the coccolithophorids ( $1.1 \cdot 10^5$  and  $0.95 \cdot 10^5$  cells  $L^{-1}$  respectively) (Table 2).

#### Hydrographic conditions and phytoplankton, December, 1998

Surface temperatures were usual for this time of the year. Well-defined thermoclines were only detected at stations of the northern and central

zones. They were not found below 45 m (Fig. 3). Salinity showed no considerable variation (not even in a station at Bahia Magdalena, M1 E2), and dissolved oxygen again varied in parallel to temperature, except in station N2 E6 (Fig. 3).

The number of species in the phytoplankton was relatively higher than in the precedent season, with up to 121 species identified, with somewhat homogeneous communities containing large- and medium-sized chain forming diatoms. Two species, *Pseudonitzschia delicatissima* and *P. pungens* were widespread and significant contributors to the total phytoplankton abundance (Table 1). Other traditionally common diatoms, such as species of *Chaetoceros* were not as abundant as in other sea-

TABLE 1. – Dominant species in cell densities during March–April, 1998, and December, 1998 respectively.

Species	Maximum density (cells L <sup>-1</sup> )	Mean
MARCH-APRIL, 1998		
<i>Emiliania huxleyi</i>	73000	22036
<i>Gephyrocapsa oceanica</i>	35200	9344
<i>Nitzschia bicapitata</i>	2500	980
<i>Fragilariopsis pseudonana</i>	1420	640
<i>Syracosphaera pulchra</i>	1230	560
<i>Thalassiosira oestrupii</i> var. <i>venrickae</i>	820	230
Total number of species: 82		
DECEMBER, 1998		
<i>Pseudonitzschia delicatissima</i>	114681	14071
<i>Pseudonitzschia pungens</i>	95567	8107
<i>Chaetoceros curvisetus</i>	99815	7056
<i>Guinardia delicatula</i>	165650	6917
<i>Guinardia striata</i>	116804	6454
<i>Detonula pumila</i>	146536	5972
<i>Chaetoceros lorenzianus</i>	82825	5037
<i>Chaetoceros debilis</i>	110433	4591
<i>Chaetoceros compressus</i>	114681	3911
<i>Chaetoceros laciniatus</i>	46722	2481
<i>Chaetoceros brevis</i>	31416	2327
<i>Eucampia cornuta</i>	29732	1673
<i>Skeletonema</i> cf. <i>costatum</i>	31856	1616
<i>Chaetoceros radicans</i>	35343	1464
<i>Chaetoceros tortissimus</i>	26546	1242
<i>Dactylosolen fragilissimus</i>	27915	1119
<i>Prorocentrum triestinum</i>	11781	1158
<i>Nitzschia bicapitata</i>	23562	983
<i>Guinardia flaccida</i>	24313	983
<i>Ceratium furca</i>	1815	84
<i>Prorocentrum micans</i>	1062	25
<i>Ceratium fusus</i>	708	16
Total number of species: 121		

sons, and species of *Rhizosolenia* and *Thalassiosira* only appeared sporadically. Flagellates were rather scarce (including coccolithophorids and thecate dinoflagellates).

Phytoplankton abundances varied notably, from 7 10<sup>2</sup> to 1.4 10<sup>6</sup> cells L<sup>-1</sup>, with the lowest abundances in the northern and central zones and the highest ones at the surface layer in the southern zone (Bahía Magdalena and surroundings), where the maximum density reached more than a million cells L<sup>-1</sup> (Table 2). Generally, phytoplankton cell numbers were higher in surface and subsurface waters (up to 50 m) (Table 2).

## DISCUSSION

### Hydrographic and oceanographic conditions: the El Niño effect

Available data (either obtained from the field, Fig. 2, or from other sources, e.g. Lynn *et al.*, 1998; Hayward *et al.*, 1999; Lavaniegos *et al.*, 2002) sup-

TABLE 2. – Phytoplankton abundances (cells L<sup>-1</sup>) in March–April, 1998, and December, 1998, with dominance (%) of coccolithophorids (*Emiliania huxleyi* and *Gephyrocapsa oceanica*) and *Pseudonitzschia* species respectively. Stations as in Figure 1.

MARCH-APRIL, 1998					
Station N4E1		Station N4E2			
5 m	54 749	5 m	50 643		
30 m	56 118	30 m	71 995	88%	
50 m	57 760	50 m	62 120	93%	
Station C1E1		Station C1E2			
5 m	126 744	5 m	6 296		
30 m	105 666	30 m	5 475		
50 m	20 257	50 m	7 938		
Station M1E1		Station M1E8			
5 m	20 530	5 m	13 961		
30 m	20 257	10 m	9 857		
50 m	20 530	15 m	16 972		
DECEMBER, 1998					
Station N2E6		Station N2E8			
5 m	53 233	5 m	4 720		
25 m	36 216	25 m	43 733		
52 m	56 632	50 m	13 686		
Station C1E1		Station C1E2			
5 m	84 430	5 m	7 854	58%	
25 m	92 028	50 m	79 639		
50 m	1 745	100 m	11 892	53%	
Station M1E1		Station M1E2			
5 m	320 050	5 m	1 414 395		
50 m	675 442	17 m	642 049		
80 m	152 908				

port the general condition: El Niño was occurring in Baja California waters at the time that collections were made for March–April, 1998. The temperature profiles showed that the thermocline was relatively deep (up to 50–60 m), with the sub-surface and surface water being relatively homogeneous (Fig. 2). Temperatures of the sub-surface and surface water were slightly higher than the general average for this time in the study area. Chlorophyll *a* data for January–February, 1998, showed an increase in surface concentration and a strong gradient onshore-offshore, with higher values in the coastal zone. Whereas by summer and autumn, 1998 (July, September–October respectively), chlorophyll *a* concentrations were significantly lower (Lavaniegos *et al.*, 2002, 2003).

We consider that these conditions had a strong influence on the phytoplankton community and were the reason for the composition of the phytoplankton with a strong numerical dominance of nanoplanktonic forms, especially coccolithophorids and small-sized diatoms with similar abundances from surface to 50 m.

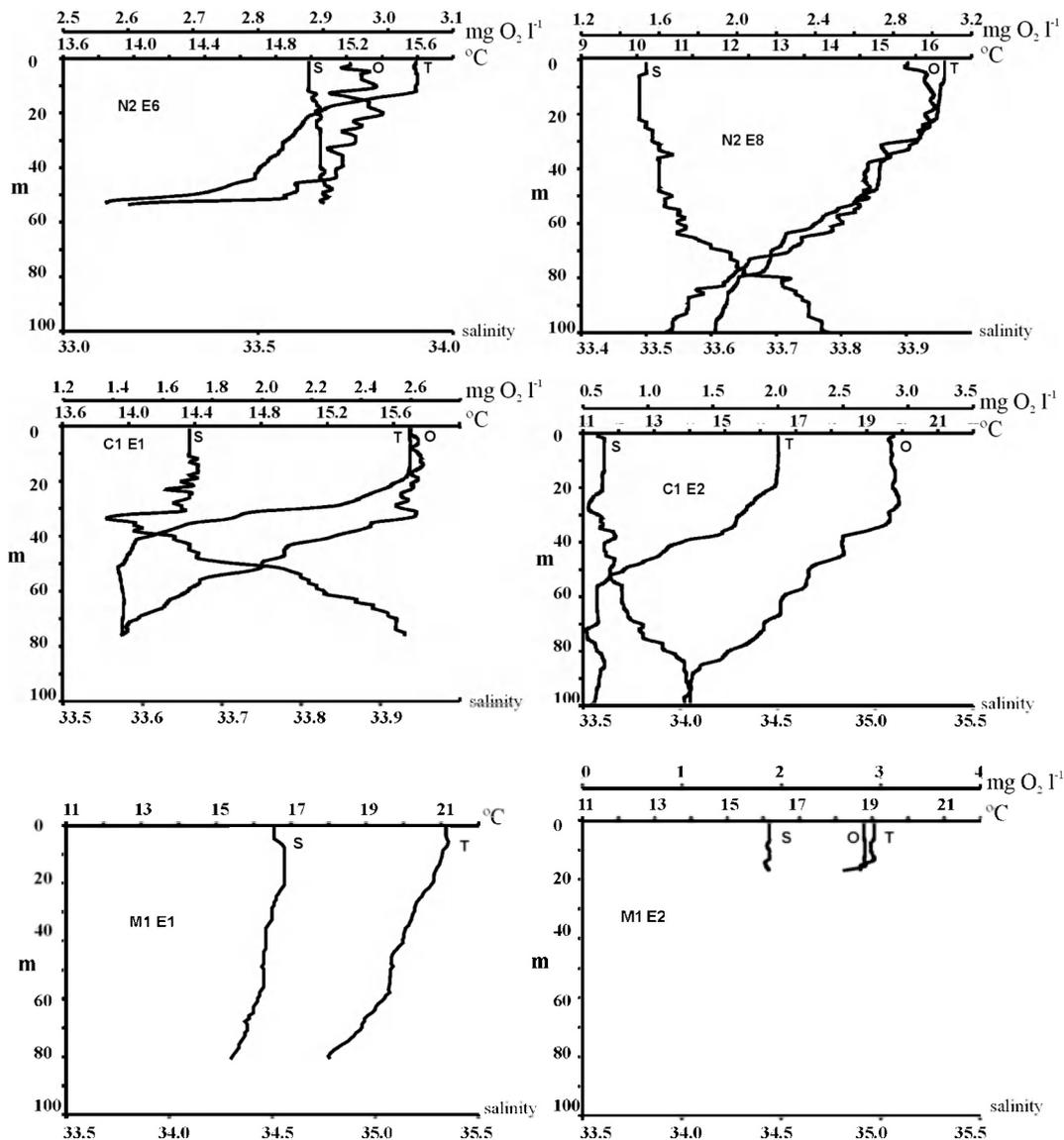


FIG. 3. – Vertical profiles of temperature, salinity and dissolved oxygen at stations from the cruise SIMSUP 16 (December, 1998).

After a period of weaker than normal upwelling through late spring and summer 1998 from San Francisco to southern Baja California, the positive index anomaly indicates slightly above normal upwelling in late 1998 and early 1999 (Hayward *et al.*, 1999). In fact, typical colder surface waters associated with upwelling in coasts off Baja California were observed during October 1998 (Aguirre-Hernández *et al.*, 2004). Our hydrographic data also support these observations, indicating upwellings still occurring during December 1998, with post-upwelling conditions at different zones throughout the study area (Fig. 3). These circumstances may have favoured the spread and relatively high abundances of certain diatom species, such as

*Pseudonitzschia delicatissima* and *P. pungens*, in December, 1998. A closely related species, *Pseudonitzschia australis*, exhibited high abundances in Southern California from February to August, even forming blooms by March, 1991 (Lange *et al.*, 1994). This has been associated with the intrusion of cool, nutrient-rich waters, which are a product of upwellings (Lange *et al.*, 1994).

The extensive spread of the *Pseudonitzschia* species was evident from May, 1998 on the western coasts of the USA, such as Washington (Adams *et al.*, 2000; Horner *et al.*, 2000) and California, especially by July, 1998 (Bargu and Silver, 2003), including some cases of intoxication in Californian waters due to blooms of some toxic species (Trainer

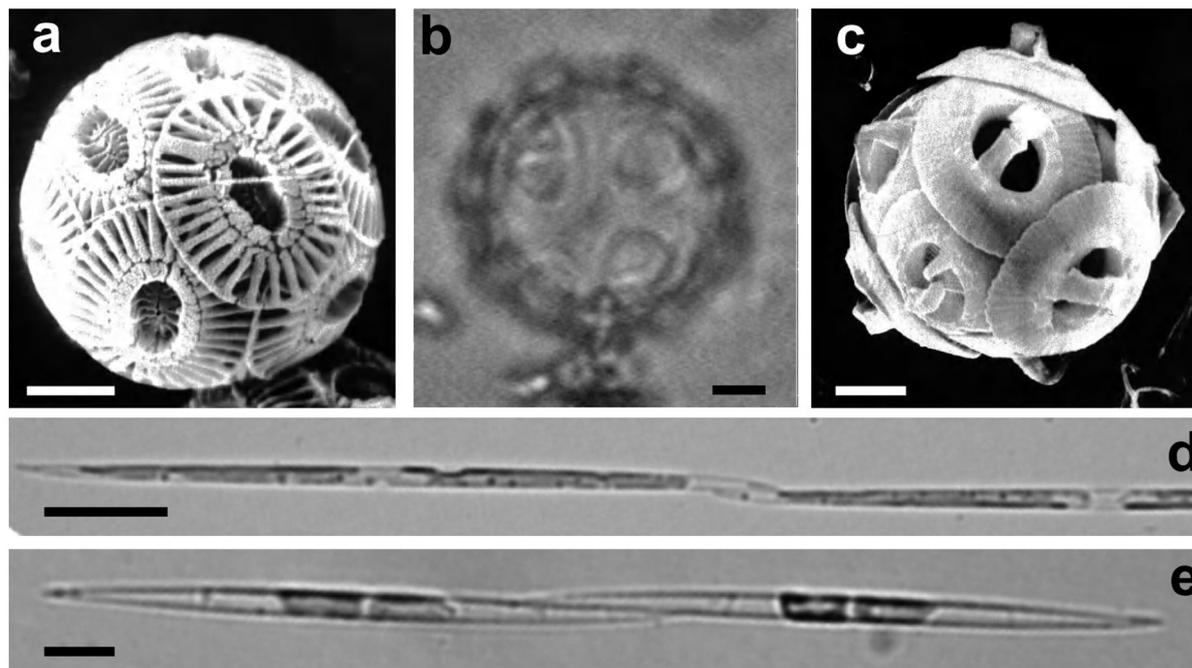


FIG. 4. – Important species during March-April and December, 1998; a, the coccolithophorid *Emiliana huxleyi*, SEM; b, c, *Gephyrocapsa oceanica*, another coccolithophorid, LM and SEM respectively; d, e, the chain-forming, pennate diatoms *Pseudonitzschia delicatissima* and *P. pungens* respectively, LM. Scale bars = 10  $\mu\text{m}$  (d, e) and 2  $\mu\text{m}$  (a-c).

*et al.*, 2000, 2001). This distribution was also documented in more tropical waters from the Mexican Pacific from November, 1998, until April, 1999, from Baja California to warmer waters around Mazatlán, México (Gómez-Aguirre, 1999; Meave *et al.*, 2000). This large-scale distribution may be explained in terms of local events (for instance post-upwellings and heavy precipitations, among others), but also on a larger meteorological and oceanographic scale as the effect of La Niña.

### Phytoplankton structure

In our results from March-April, 1998, the coccolithophorid *Emiliana huxleyi* (Fig. 4a) was the most significant contributor to the cell abundance of phytoplankton, although it did not reach spectacular densities (less than  $1.2 \cdot 10^5$  cells  $\text{L}^{-1}$ ) or produce real blooms (as documented by Tyrell and Merico, 2004, in other parts of the world) (Tables 1 and 2). It was usually found together with *Gephyrocapsa oceanica* (Fig. 4b, c), which occurred in lower abundances (Table 1). *Emiliana huxleyi* appears as the species involved in most blooms of coccolithophorids world-wide and it is considered cosmopolitan (Tyrell and Merico, 2004). Some recent studies show that this species has high genetic variability, possibly with different physiological responses to

different oceanographic conditions (Brand, 1982; Young and Westbroek, 1991; Medlin *et al.*, 1994).

Coccolithophorids are usually regarded as an important and abundant phytoplankton group in warm, stratified and oligotrophic waters (Brand, 1994). They often bloom in many areas, including coastal areas. They also reach high populations in mature upwelled waters (Balch, 2004). However, no previous report has been made on numerical dominance of coccolithophorids in the phytoplankton of Baja California, although a paper dealing with the floristic of this group in the same study area was recently published (Hernández-Becerril *et al.*, 2001), and previous plankton studies in La Jolla, California, USA, included coccolithophorids (with a maximum *Emiliana huxleyi* abundance of  $5 \cdot 10^5$  cells  $\text{L}^{-1}$ , in August, 1967, Reid *et al.*, 1970).

Nanoflagellates and naked dinoflagellates yielded considerable densities only at the surface, in the northern and central zones of Baja California in autumn and winter, 1998, in a previous plankton study during different seasons between September, 1997 and October, 1998, whereas centric diatoms were only abundant in autumn, 1997 (Lavaniegos *et al.*, 2003). This information is consistent with our results.

Diatoms have traditionally been regarded as the most significant group in the study area, as they are

usually dominant in these upwelling regions. The relative scarcity of this group in the March-April season and the presence and relative abundance of some rather unusual species in the study area, such as the diatom *Asteromphalus sarcophagus*, which is considered to be a tropical form, confirm the intrusion of warmer water into the system. Furthermore, the association of diatoms in the tropical-subtropical species complex *Nitzschia bicapitata/N. bifurcata* (both species were found in this season) has been previously recognized in Pacific waters (Lee and Fryxell, 1996; Fryxell, 2000).

Other evidence of changing oceanographic conditions and their effects on phytoplankton comes from micropaleontologists: terrigenous input into Santa Barbara Basin, California, USA, was significantly higher during El Niño 1997-1998, which reflects higher rainfall and runoff into the basin (Lange *et al.*, 2000). Diatom fluxes were an order of magnitude lower than in the 1996 non-El Niño period, the proportion of warm water flora increased significantly, and by winter of 1998 organic carbon fluxes were unusually high (perhaps indicating the significant populations of coccolithophorids) (Lange *et al.*, 2000). We also found indicators of a freshwater influence, such as the diatom *Cocconeis placentula*, in very low numbers.

In conclusion, the phytoplankton community found for March-April, 1998 along the coasts of Baja California was different to the usual community there, and reflects the particular conditions of El Niño 1997-1998. The usual composition of the phytoplankton for April in the system of Baja California/California is rich in diatoms. The community detected for December, 1998 is more typical and reflects more periodical environmental conditions. Our results of this season (concentrated in Table 1) are very similar to those provided by Venrick (1998) in her study of phytoplankton from a neighbouring area (southern California) in April 1993 and 1995, with similar significant species (within the maximum rank) such as the diatoms *Pseudonitzschia* spp. (Figs 4d, e), *Chaetoceros compressus*, *C. debilis*, *C. radicans* and *Skeletonema costatum*.

However, despite the structure of the phytoplankton community (composition, abundance and distribution) being different in the two periods studied on Baja Californian coasts, other ecological parameters seemed to remain the same during El Niño 1997-1998 in California, USA, such as the

general relation between biomass of large phytoplankton and the depth of the nitricline (Mullin, 2000).

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