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Seasonal variability of phytoplankton biomass and community composition in Blanes Bay (1992-1994)

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ABSTRACT

Temporal variability of phytoplanktonic biomass and community composition in Blanes Bay (Spanish Mediterranean coast) were examined during two years (March 1992-March 1994) . The results demonstrate that the seasonal variability of phytoplankton biomass in Blanes Bay was different from the general seasonal patterns described for phytoplankton in temperate waters, with maximum phytoplankton biomass in February-March, rather than in spring. Phytoplankton communities in Blanes Bay, composed of diatoms, dinoflagellates and picoplankton, were dominated by centric diatoms during winter-spring and autumn, while in summer they were dominated by dinoflagellates. Phytoplankton biomass appears to be more controlled by the variability of microplanktonic communities than by pico-sized phytoplankton. The results indicated that interannual variability of total phytoplankton biomass and the partitioning of biomass among phytoplankton groups may be high, and more important than seasonal events.

Key words: Phytoplankton, biomass, chlorophyll *a*, community structure.

RESUMEN

Variabilidad estacional de la biomasa fitoplanctónica y composición de la comunidad en la bahía de Blanes

La variabilidad de la biomasa fitoplanctónica y la composición de la comunidad en la bahía de Blanes se analizaron durante dos años (marzo 1992-marzo 1994). Los resultados demuestran que la variabilidad estacional de la biomasa fitoplanctónica en la bahía de Blanes difiere de las pautas generales de estacionalidad descritas para el fitoplancton en aguas templadas, presentando un máximo de biomasa de fitoplancton en febrero-marzo, y no en primavera. Las comunidades fitoplanctónicas en la bahía de Blanes, compuestas por diatomeas, dinoflagelados y picoplancton, están dominadas por diatomeas céntricas durante los periodos de invierno-primavera y otoño, mientras que en verano están dominadas por dinoflagelados. La biomasa fitoplanctónica parece estar más controlada por la variabilidad de la comunidad microplanctónica que por el picoplancton. Los resultados indican que la variabilidad interanual en la biomasa total de fitoplancton y la contribución de los principales grupos fitoplanctónicos a la biomasa total puede llegar a ser alta y más importante que la variabilidad estacional.

Palabras clave: *Fitoplancton, biomasa, clorofila* a, *estructura de la comunidad.*

INTRODUCTION

The dynamics of phytoplankton are governed, on a seasonal scale, by the interplay between light and temperature, and the associated changes in water-column structure and nutrient supply, which control seasonal phytoplankton blooms (Atkins, 1928; Riley, 1942; Margalef, 1945; Svedrup, 1953; Harris, 1986; Mann and Lazier, 1991). These seasonal changes also control the seasonal variation in phytoplanktonic community structure (Gran and Braarud, 1935; Smayda, 1980; Round, 1981; Lobban, Harrison and Ducan, 1985), mostly through seasonal variation in light and the nutrients regime (Margalef, 1978; Sournia, 1982; Harris, 1986; Kiørbe, 1993), which controls growth, and turbulence, which controls losses through sedimentation associated with species cell size (Malone, 1980; Fogg, 1986; Harris, 1986; Sournia, 1982).

The seasonal dynamics of phytoplankton on the Spanish Mediterranean coast has been studied by several authors (Establier, Lubián and Blasco, 1986; 1987; Estrada, 1979; Margalef and Ballester, 1967; Margalef, 1945; 1971; Estrada, 1980). Margalef and Castellví (1967) proposed a seasonal pattern for the production and biomass of phytoplankton on the Catalan coast that considered, in addition to spring and autumn blooms, a winter bloom associated with coastal upwelling. The model of seasonal phytoplankton development could be even more complex for littoral waters, where intermittent riverine inputs may confound the seasonal pattern described for phytoplankton biomass and communities.

In this study, we examined the seasonal variation of phytoplanktonic biomass and community structure in Blanes Bay (42°18.26' N, 3°18.11' E), which received intermittent inputs from a torrential river (Tordera River), during two years (March 1992-March 1994). This made it possible to evaluate the timing and variability of the occurrence of phytoplankton blooms during the year, and to elucidate seasonal patterns in community structure in a Mediterranean littoral ecosystem.

MATERIALS AND METHODS

Sampling was conducted during two years, from March 1992 to March 1994, in Blanes Bay (northwest Mediterranean). The sampling frequency was twice a week during the first year (March 1992-February 1993) and once a week during the second year (March 1993-March 1994). Subsurface (-0.5 m) water samples were collected in clean 5 l plastic bottles from an outboard motor at a fixed station (42°18.26' N, 3°18.11' E), and transported immediately to the laboratory for phytoplankton analysis.

At the laboratory, 500 ml were filtered through a Whatman GF/F filter for fluorometric analysis of chlorophyll a concentration (Parsons, Maita and Lalli, 1984). The filters were homogenised and kept refrigerated in the dark while pigments were extracted in 90% acetone for about 6 h. Fluorescence was then measured in a Turner Designs fluorometer calibrated with pure chlorophyll *a* (Sigma Co.) (Holm-Hansen and Riemann, 1978). An additional sample (250 ml) was preserved with glutaraldehyde (sample final concentration of 1.5%) for microscopic examination of phytoplankton cells. A subsample of these samples (about 70 ml) was filtered at low pressure onto black Nuclepore filters (0.8 µm nominal pore size), and then stained with 1 ml of DAPI (4 · 6-diamidino-2-phenylindole, a DNA-specific stain) (Martinussen and Thingstad, 1991) solution (10 $\mu g \cdot ml^{-1}$) for 5-10 min without vacuum. Filters were then washed twice with filtered seawater before they were mounted on a glass slide over a drop of Zeiss immersion oil, and stored frozen until microscopic examination at the laboratory.

Epifluorescence microscopy, which allows unambiguous discrimination of autotrophic (i.e. containing chlorophyll *a*) from heterotrophic cells, was used to identify, enumerate, and measure phytoplankton cells. The phytoplankton cells collected on the filters were examined using a Zeiss Axioplan microscope equipped with an epifluorescence unit provided with a UV filter set (Zeiss filter 487701). The filters were examined at 400 and 1000 magnifications to count cells larger (40-50 fields) and smaller (30 fields) than 5 µm, respectively. Cells with diameters smaller than 5 µm were classified as picophytoplankton, and divided into prokaryotic and eukariotic cells, depending on whether chlorophyll autofluorescence was distributed over the cell or packed into chloroplasts, respectively. Phytoplanktonic cells with diameters between 5 and 20 µm were considered as nanophytoplankton, and cells with diameter > 20 µm were classified as microplankton (Sieburth, Smetacek and Lenz, 1978). Nano- and microphytoplankton was classified into genera. The average cell volume for each phytoplankton group identified in each sample was

computed, by approximation to the nearest simple geometric shape, from the dimensions (at 1 000 ×) of about 20 measured cells. The biovolume ($\mu m^3 \cdot ml^{-1}$) of the different phytoplankton groups in each sample was calculated as the product of the cell density (cell · ml^{-1}) and average cell volume ($\mu m^3 \cdot cell^{-1}$).

RESULTS

The seasonal pattern of chlorophyll *a* concentrations was characterised by the recurrent presence of two blooms per year (figure 1), one in winter (mid-January to late February, depending on the year), and another bloom in mid-summer (late July - August). The summer blooms reached about 3 mg chl $a \cdot m^{-3}$ in both years, but the size of the winter bloom differed considerably from year to year (figure 1). The bloom of March 1992 reached the highest chlorophyll *a* concentration observed to date in Blanes Bay (5.75 mg · chl $a \cdot m^{-3}$), whereas that of winter 1992 was comparable to the summer blooms (figure 1). The lowest chlorophyll *a* concentrations (about 0.1 mg · m^{-3}) were observed, in both years, during autumn. Chlorophyll *a* concentrations showed considerable nonseasonal variability at scales of weeks, some attributable

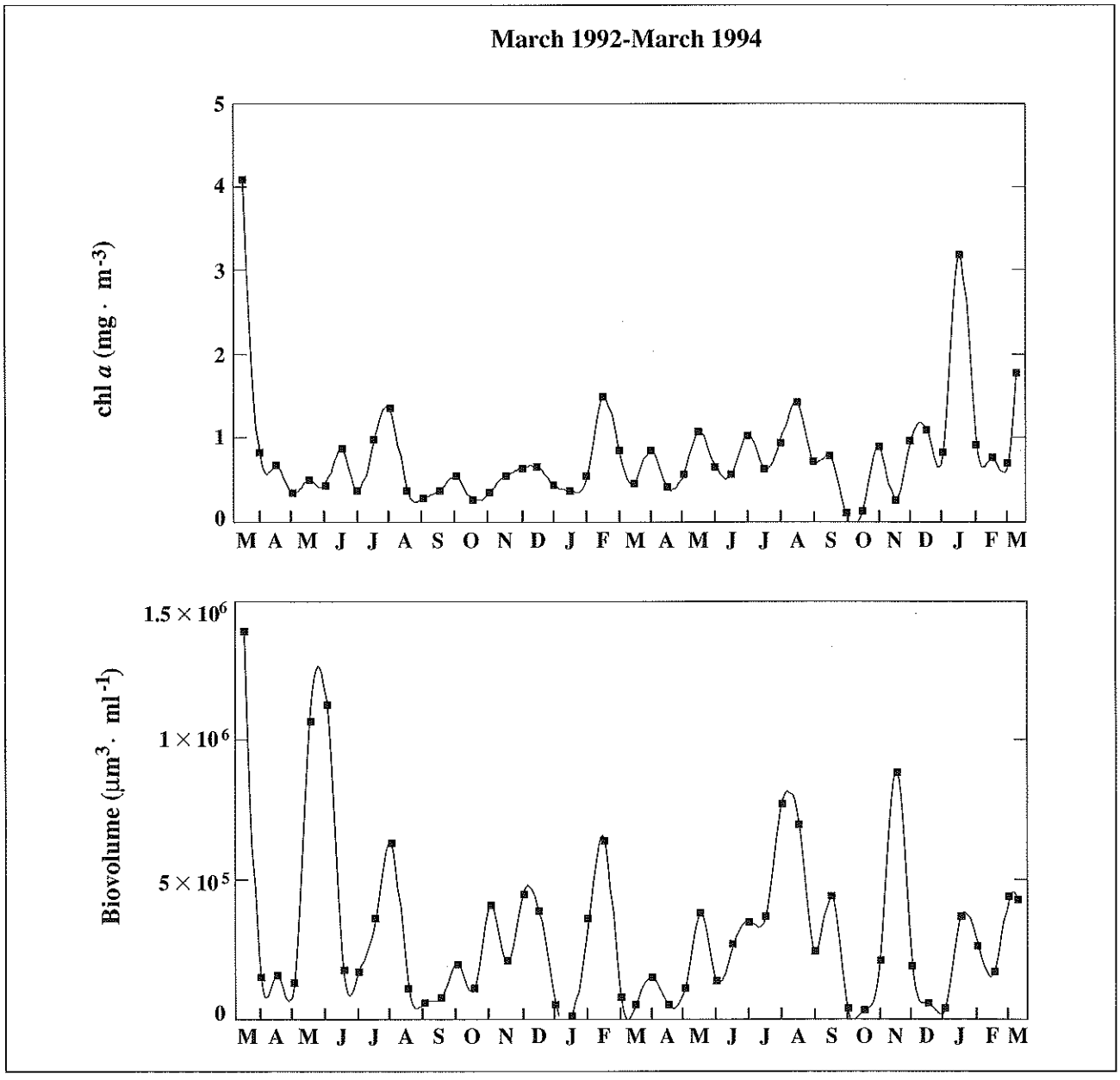

Figure 1. The time course of chlorophyll *a* concentrations and phytoplankton biovolume (averaged by 15-day intervals) in Blanes Bay (1992-1994).

to perturbations, such as heavy rainfall and high turbulence, and the associate dynamics of water masses (Cebrián, Duarte and Pascual, in this volume).

Phytoplankton biovolume was highest during the bloom of March 1992 (3.9×10^6 $\mu m^3 \cdot ml^{-1}$), with the remaining blooms exceeding 1×10^6 $\mu m^3 \cdot ml^{-1}$ (1.4×10^6, 1.3×10^6 and 1.2×10^6 $\mu m^3 \cdot ml^{-1}$) during July 1992, February 1993, and August 1993, respectively (figure 1). Annual average phytoplankton biovolume was higher for the first sampling year (3.5×10^5 $\mu m^3 \cdot ml^{-1}$, March 1992- February 1993) than for the second one (2.6×10^5 $\mu m^3 \cdot ml^{-1}$, March 1993-March 1994). Phytoplankton biomass was, as described by biovolume, poorly – albeit significantly – related to the pattern of chlorophyll *a* concentration ($r = 0.5$, $P < 0.05$; figure 2). Although some of the periods of enhanced biovolume corresponded to blooms reflected in chlorophyll *a* concentrations (e.g. March and July of 1992, February and August 1993, figure 1), other periods of high biovolume were observed at relatively low chlorophyll *a* values (May 1992 and in Autumn 1993, figure 1). Phytoplankton biovolume reflected the bloom of summer 1993 much better than chlorophyll *a* did, with a clear bloom that reached maximum values in July, in contrast to an oscillating pattern of chlorophyll *a* values during the same period (figure 1).

Phytoplankton communities in Blanes Bay were dominated by diatoms, dinoflagellates and picoplankton, which included both cyanobacteria and eukariotic cells (table I). The abundance of the different phytoplanktonic groups showed high variation from the first year to the second (table I). The abundance of diatoms was higher the first year of sampling (figure 2), representing 88 % and 48 % of the total phytoplankton biovolume, respectively. The genera *Chaetoceros* and *Nitzschia* were the most important contributors to diatom biomass during the two years (table I). Dinoflagellates, however, were significantly more abundant during 1993-1994 (table I), when they contributed 40 % of the total phytoplankton biomass, in contrast with the 2.5 % that they supplied during the first sampling year. Picoplanktonic cells represented, on average, about 10 % (9.5 % and 12 % for the first and second year, respectively) of the total phytoplankton biovolume. Eukariotic picoplankton abundance was on average slightly higher the first year (table I), whereas cyanobacteria tended to be more abundant during the second year, despite the fact that their maximal abundance was reached during the first year (table I).

The biovolume of diatoms showed great temporal variation, although they were present in the community year-round (figure 2). Diatom biovolume showed contrasting seasonal patterns during the first and second years, with the greatest abundances observed in spring 1992 and fall 1993, although minima were observed in December-January during both years (figure 2). Dinoflagellates were most abundant during summer (figure 3), when they contributed considerably to total phytoplankton biovolume (figure 1), accounting for the summer phytoplankton blooms observed (figure 1). The dinoflagellate communities were dominated by *Dinophysis* sp. and *Alexandrium minutum* (Halim, 1960), which are toxic species that have been reported for other littoral zones on the Spanish Mediterranean coast (Delgado *et al.*, 1990). The biomass of autotrophic picoplankton (both eukariotic and prokariotic cells) showed slight variation over time (figure 4), although this was somewhat greater during the first year. Picoplanktonic biomass increased during the late-winter and mid-summer bloom periods (figure 4). Cyanobacteria reached maximum cell density in summer (table I).

Table I. The maximum and mean density for the major phytoplankton groups present in Blanes Bay along with their mean cell size, for the two sampled years (1992-1994).

	MAXIMUM (CELL · ML^{-1})		MEAN (CELL · ML^{-1})		CELL VOL. (μM^3)
	1st YEAR	2nd YEAR	1st YEAR	2nd YEAR	
Chaetoceros	1 584	646	141	44	859 ± 56
Nitzschia	1 121	548	74	21	1 274 ± 12
Rhizosolenia	204	438	8	13	2 526 ± 200
Thalassiosira	196	77	7.5	7	2 246 ± 1 328
Skeletonema	26	36	0.5	1.6	576 ± 281
Autotrophic dinoflagellates	196	3 000	28	269	441 ± 151
Eukariothic picoplankton	23 571	15 857	1 996	1 570	23 ± 2
Prokariothic picoplankton	60 785	20 548	2 911	4 777	2.5 ± 0.5

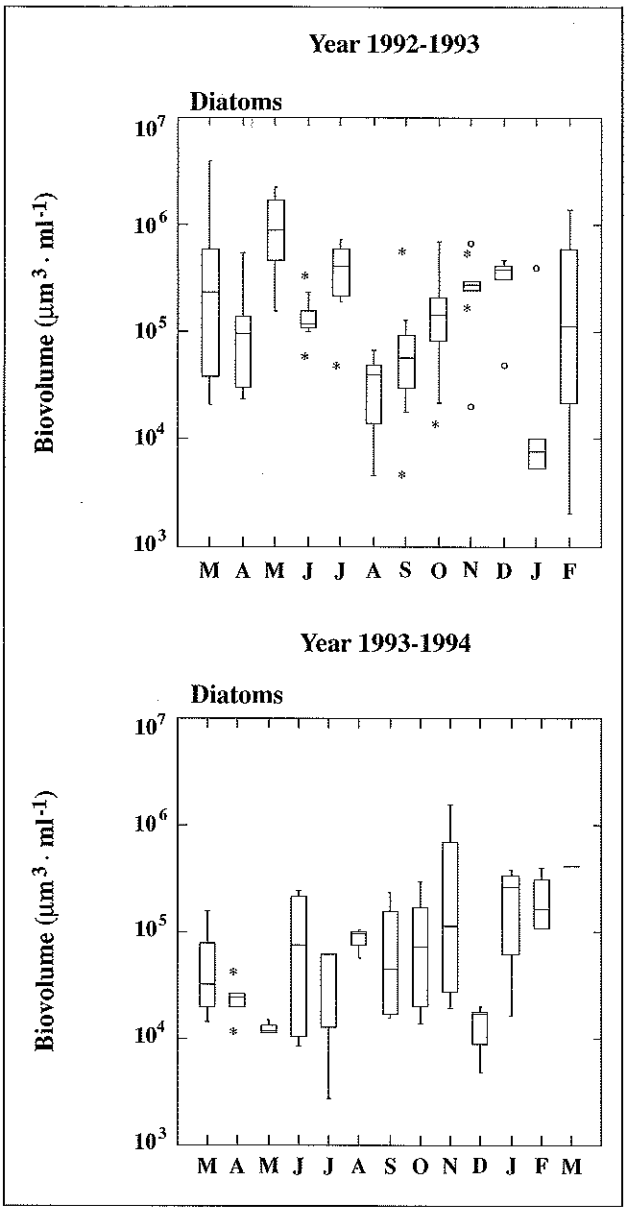

Figure 2. Box plots showing the monthly distribution of diatom biovolume in Blanes Bay (1992-1994). Boxes encompass 50 % of the data, and bars extend to the 95 % cl, with symbols (asterisks and open circles) representing extreme values.

DISCUSSION

The results demonstrate that the seasonal variability of phytoplankton biomass in Blanes Bay, during the two years studied, was different from the general seasonal patterns described for phytoplankton in temperate waters (e.g. Atkins, 1928; Riley, 1942; Harris, 1986). Phytoplankton biomass (as chlorophyll *a* concentration) in Blanes Bay showed important blooms during winter (usually late February) and summer (figure 1), which were composed of diatoms and dinoflagellates, respectively. Phytoplankton biovolume showed, in addition to the blooms evident in chlorophyll *a* concentrations, another important bloom in autumn (figure 1), mostly attributable to *Nitzschia*, which are presumably resuspended from sediments during autumn storms.

The seasonal pattern described is in agreement with that reported by Margalef and Castellví (1967) for the Spanish Mediterranean coast, and the occurrence of a late-winter phytoplankton bloom appears to be a general feature of the northwest Mediterranean (*cf.* review in Estrada, Vives and Alcaraz, 1985). Considerable variability in phytoplankton biomass unrelated to these events was ob-

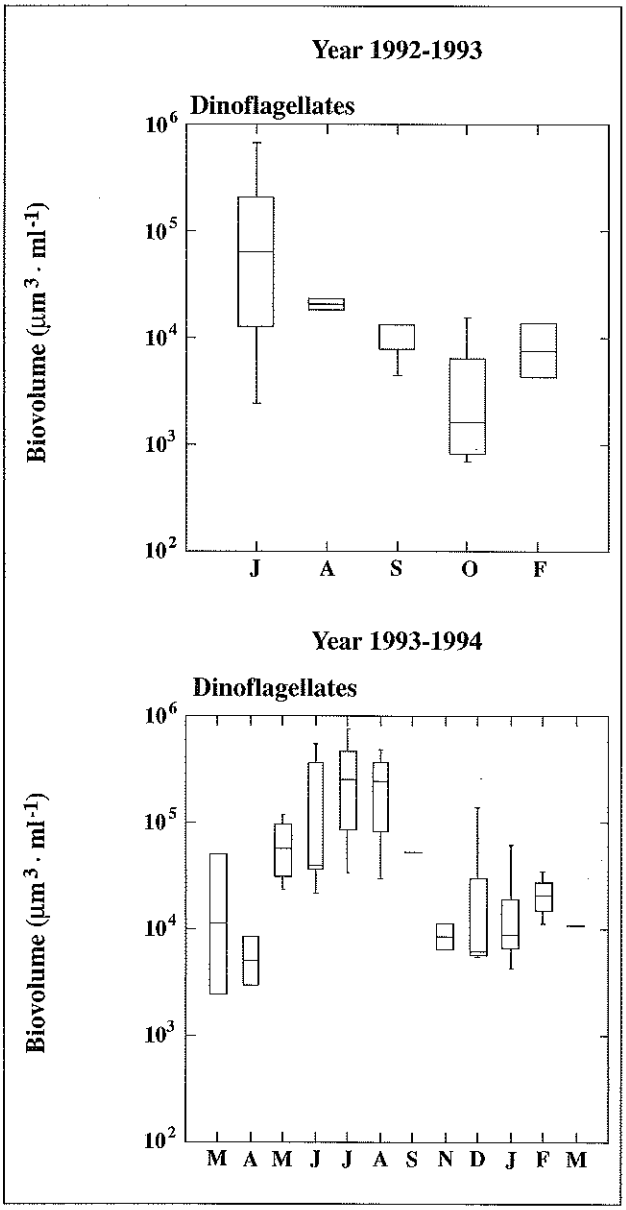

Figure 3. Box plots showing the monthly distribution of dinoflagellate biovolume in Blanes Bay (1992-1994). Box design as in figure 2.

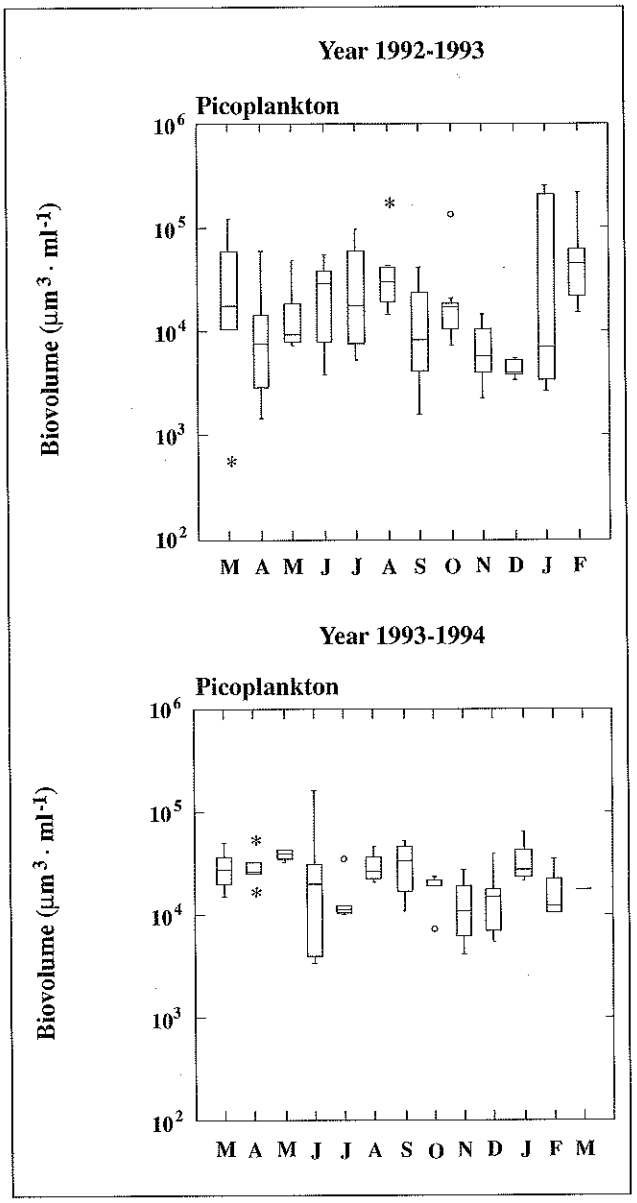

Figure 4. Box plots showing the monthly distribution of picoplankton biovolume in Blanes Bay (1992-1994). Box design as in figure 2.

served (figure 1), indicating that other, nonseasonal factors should be important in determining phytoplankton biomass in Blanes Bay. Some of this variability should be attributable to interannual variability. The spring of 1992 was one of the rainiest on record, and a continuous supply of nutrients from river discharge was maintained until mid-July, when the thermocline was finally established. In contrast, the spring of 1993 was characterised by calm waters and a rapid thermocline development (late May), favoured by the stabilising effect of a low-salinity water mass, likely derived from the Rhone River, observed along the Costa Brava coast (Cebrián, Duarte and Pascual, in this volume). These differences, which are characteristic of the Mediterranean climate (Maheras, 1988) are, no doubt, responsible for the greater biomass in 1992-1993, compared to 1993-1994. Accordingly, factors operating at interannual scales may have a much greater bearing than seasonal events in controlling the phytoplankton populations of the northwest Mediterranean littoral.

Observation of the temporal changes in phytoplankton community structure show these communities to be highly dynamic. Diatoms and dinoflagellates dominate the communities in winter and summer, respectively. Prokaryotic picoplankton also showed an enhanced abundance during summer blooms. This is in agreement with the patterns of dominance of small (e.g. cyanobacteria) and mobile (e.g. dinoflagellates) phytoplankters in stratified and oligotrophic waters (i.e. summer waters), while diatoms (with large cells or colonies) dominate the turbulent waters typical of winter and fall (Margalef, 1978; Malone, 1980; Kiørbe, 1993). Picophytoplankton biomass in Blanes Bay was much less variable, and accounted for a smaller fraction of the overall biomass, than that of diatoms and dinoflagellates, in agreement with the results reported for other temperate areas (Malone, 1980; Furuya and Marumo, 1983).

In summary, the seasonal development of phytoplankton biomass in Blanes Bay differed from that described for temperate waters (e.g. Atkins, 1928; Riley, 1942; Harris, 1986), in the presence of an important phytoplankton bloom in February-March, which appears to be a general feature of the Mediterranean (Estrada, Vives and Alcaraz, 1985, Delgado, Latasa and Estrada, 1992), and the absence of a bloom associated with the establishment of the thermocline. However, phytoplankton communities showed patterns of variation similar to those described in the past (Margalef, 1978; Malone, 1980; Kiørbe, 1993). Our results suggest that seasonal factors exert a loose control on phytoplankton communities on the northwest Mediterranean littoral, and that the large interannual differences in weather that characterise the Mediterranean climate may be the dominant source of variability in phytoplankton.

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