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Particulate matter and phytoplankton in the Ionian Sea

Ionian Sea
Particulate matter
Chlorophyll
Phytoplankton
Bacteria

Mer Ionienne
Matière en suspension
Chlorophylle
Phytoplancton
Bactéries

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ABSTRACT

Some results of a cruise carried out within the Project on the Physical Oceanography of the Eastern Mediterranean (POEM BC-091, October 1991) are reported and discussed. The major aim of this work was to study, in the upper layers of the Ionian basin the distribution of particulate matter, phytoplankton and bacteria, with emphasis on the influence of North Atlantic Water. Some tentative conclusions may be drawn from the results:

- the examined situation (October) is representative of the final stage of a probably annual cycle of production in an oligotrophic system;
- the well-developed Deep Chlorophyll Maximum between 75 and 100 m (mainly due to degradation products) does not match the biomass maximum. Possible explanations of this are: a) phytoplankton photo-adaptation processes; b) sinking to deep layer of senescent cells, relicts of previous blooms; c) grazing activity by proto- and meta-zooplankton.
- North Atlantic Water is probably more productive when compared with the surrounding Ionian waters during this seasonal situation, although this is still to be confirmed by data collected in connected areas, such as the Sicily Channel and the Aegean Sea.

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RÉSUMÉ

Particules en suspension et phytoplancton dans la mer Ionienne

Les répartitions de la matière en suspension, du phytoplancton et des bactéries sont étudiées à partir de résultats obtenus dans les couches superficielles de la mer Ionienne au cours d'une campagne organisée dans le cadre du Programme « Océanographie Physique de la Méditerranée Orientale » (POEM BC-091, octobre 1991).

Les conclusions provisoires sont les suivantes :

- la situation examinée (octobre) est représentative de la phase finale d'un cycle de production, probablement annuel, dans un système oligotrophique ;
- Le maximum profond de chlorophylle (DCM) bien marqué entre 75 et 100 m de profondeur (dû principalement aux produits de dégradation) ne coïncide pas avec le maximum de la biomasse. Différentes explications sont proposées : a) les processus de photo-adaptation du phytoplancton ; b) l'enfoncement dans la couche profonde des cellules en cours de dégradation, témoins des blooms précédents ; c) le broutage par le proto- et le méta-zooplancton ;

– l'Eau Nord-Atlantique (NAW) est probablement caractérisée par une productivité plus grande que celle des eaux environnantes de la mer Ionienne durant cette période ; cependant, cette évaluation doit être confirmée par les données qui ont été recueillies dans les zones adjacentes des stations du Canal de Sicile et de la Mer Égée.

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INTRODUCTION

The Eastern Mediterranean has been the object of several studies; special emphasis has been attached by many authors (Béthoux, 1989; Azov, 1986; Kimor *et al.*, 1987) to the extremely oligotrophic conditions of the basin because of the dramatic decrease of fertility proceeding from west to east (Sournia, 1973). Available information on various biological aspects mainly focus on the Levantine basin (Kimor and Wood, 1975), in particular on the offshore areas of Egypt and Israel (Berman *et al.*, 1984; Kimor *et al.*, 1987; Dowidar, 1984; Abdel-Moati, 1990; Salihoglu *et al.*, 1990) and the Aegean (Becacos-Kontos, 1968).

As regards the Ionian basin, the little existing information about hydrochemistry and biological cycling derives from the POEM project (Artegiani *et al.*, 1990; Bregant *et al.*, 1992; Boldrin *et al.*, 1992; Bianchi *et al.*, 1992; Rabitti *et al.*, 1992).

Seasonal alternations between stratification and mixing processes, together with their biological implications, as described for the Western Mediterranean (Estrada, 1985), Southern Adriatic (Marasovic and Pucher Petkovic, 1988) and Aegean (Becacos-Kontos, 1968), can be hypothesized, being supported only by few experimental data.

The oligotrophic conditions of the Ionian basin are confirmed both by a few primary production data (Magazzù and Decembrini, 1992), although in very restricted areas, and by low nutrient concentrations detected at the surface (Bregant *et al.*, 1992).

In this paper, some results of a cruise performed within the Project on the Physical Oceanography of the Eastern Mediterranean (POEM BC-091, October 1991) are reported and discussed. The major aim of this work was to study, in the upper layers of the Ionian basin, the distribution of particulate matter, phytoplankton and bacteria, with emphasis on the influence of North Atlantic Water.

MATERIALS AND METHODS

The results of the present paper refer to a multidisciplinary cruise carried out from 4-24 October 1991 in the Ionian basin, on board the R/V Bannock of the CNR, Italy. During this cruise the station grid shown in Figure 1 was covered for standard hydrological measurements, while biological sampling was carried out on eleven stations along transects chosen on the basis of results from previous cruises and intended to cover the main basin features. In these «biological» stations a SEABIRD CTD was used, with a SEATECH in situ fluorometer and a Beckman oxygen probe, coupled to a General Oceanics rosette (12 l bottle).

The parameters considered (apart from classical hydrological and hydrochemical measurements) were Particulate Organic Carbon (POC), Particulate Nitrogen (PN), total chlorophyll *a* and degradation products, phytoplankton species composition and abundance, and bacteria counting.

Eighty-three samples were collected for POC, PN and total chlorophyll determinations at six standard depths (surface

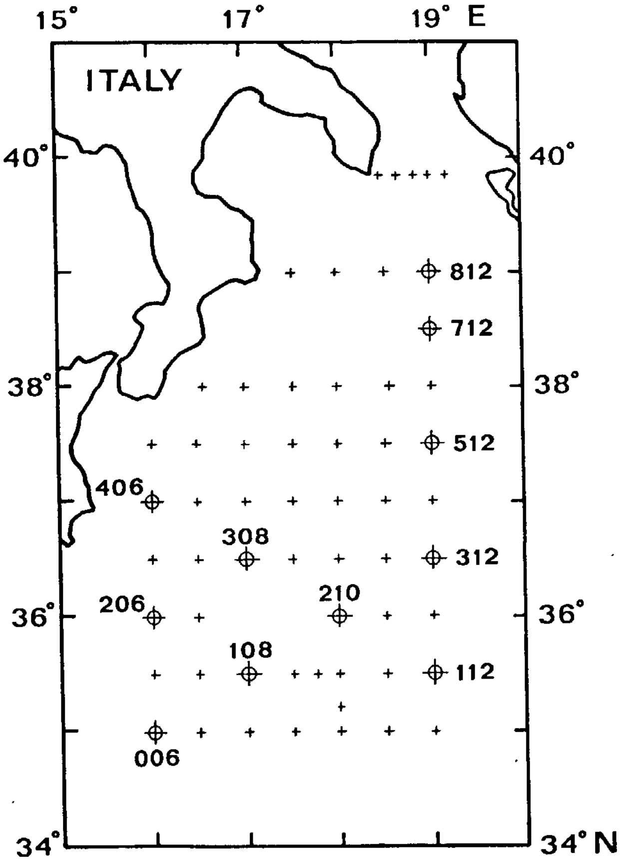


Figure 1

Study area and station grid. Biological stations are identified by numbers.

and 20, 50, 75, 100 and 150 m). An additional depth was sampled at the in situ fluorescence maximum. 3 to 5 l of water were filtered for POC and PN samples, at mild vacuum through Whatman GF/F precombusted filters, and later stored at - 20 °C. For chlorophyll analysis, about 2 l of water were filtered through Whatman GF/F filters, and then stored at - 20 °C. For POC and PN analysis, a Perkin-Elmer 2400 CHN Elemental Analyzer was used, connected to a Perkin-Elmer AD-4 Autobalance. Inorganic carbon was removed by vapour phase acidification (Hedges and Stern, 1984).

Chlorophyll *a* and phaeopigment samples were filtered onto Whatman GF/F glass-fiber filters and analysed subsequently on land, following the fluorimetric determination described by Holm-Hansen *et al.* (1965): measurements were performed before and after acidification with two drops of HCl 1N on a Perkin-Elmer LS-5B luminescence spectrometer. Instrumental response, calibrated against a SIGMA chlorophyll *a* standard, was linear over the considered range.

Samples for phytoplankton species determination were collected at four depths (surface, 20 and 50 m, and at the chlorophyll maximum depth), fixed with formalin and later counted using 100 cm^3 settling chambers with an inverted microscope (Utermöhl, 1958; Zingone *et al.*, 1990).

Cell sizes were measured to calculate cell volume (Edler, 1979). Phytoplankton carbon was calculated by multiplying cell or plasma (for diatoms) volume by 0.11 (Strathtman, 1967) and by 0.13 for thecate dynoflagellates (Smetacek, 1975).

For bacteria analyses seven samples, taken at the same depths as the POC samples, were collected aseptically in each station plus three additional samples at 400 and 1 000 m and at the deepest level. The samples were preserved in 2 % formalin, stored in sterile glass bottles at 4 °C in the dark, and counted within one month. Bacterial abundance was estimated by an epifluorescence direct counting technique. Aliquots of water samples were filtered on to black 25-mm Nuclepore filters (0.2 μm pore size) and stained with 4'-6 diamidino - 2 phenylindole (DAPI; Porter and Feig, 1980). For each filtered sample twenty fields with about 20-30 bacteria per field were counted, to obtain a final number of at least 400 bacteria.

RESULTS AND DISCUSSION

Hydrology

The main hydrographic feature influencing the surface layer of the Ionian Sea is the intrusion of North Atlantic Water (NAW), flowing eastward from the Sicily Channel. The salinity minimum, which is the signature of NAW, is found in the upper 50 m throughout the year (Manzella *et al.*, 1988). This body of water, which meanders into the Ionian basin, occupies the upper 100 m of the water column, with salinity ranging from 37.5 in the straits of Sicily to 38.6 near the Cretan Passage (Theocaris *et al.*, 1993). The NAW jet shows different patterns in winter (towards the north-east) and summer (towards the north; POEM group, 1992). Another peculiar hydrological structure is a transient anticyclonic eddy, observed during some oceanographic cruises carried out within the POEM project.

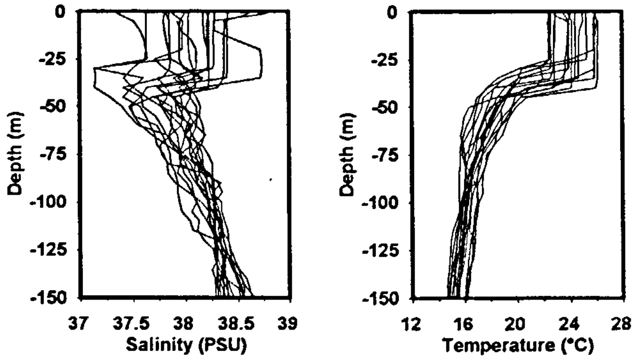


Figure 2

Vertical profiles of salinity and temperature.

During the sampling period (October 1991), the following hydrographical characteristics were observed (Bregant *et al.*, 1992; Paschini, personal communication):

- a surface mixing layer 25-30 m thick (Fig. 2), with a temperature of about 24 °C; at the bottom of the thermocline (150 m) the observed temperature was about 15 °C;

- vertical salinity profiles in the basin (Fig. 2) show an evident minimum at 40-50 m in some stations, related to the spreading of the Northern Atlantic Water, which is evident in the horizontal distribution map of the salinity at 50 m (Fig. 3);

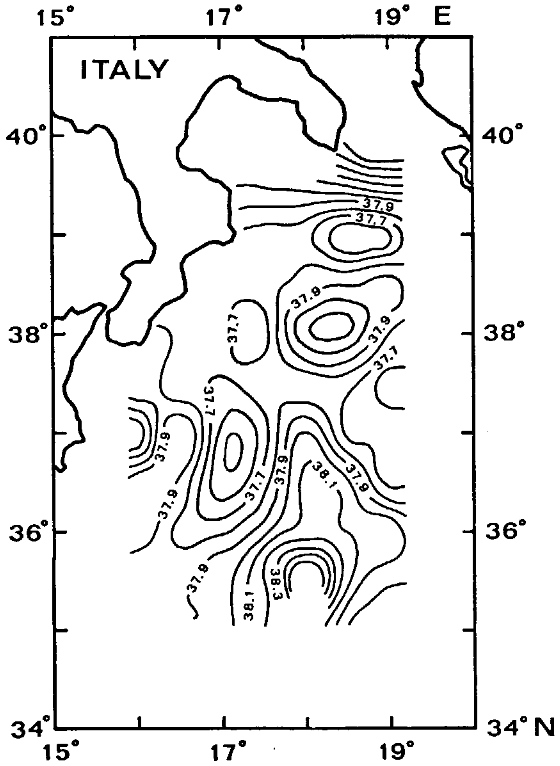


Figure 3

Salinity distribution at depth of 50 m.

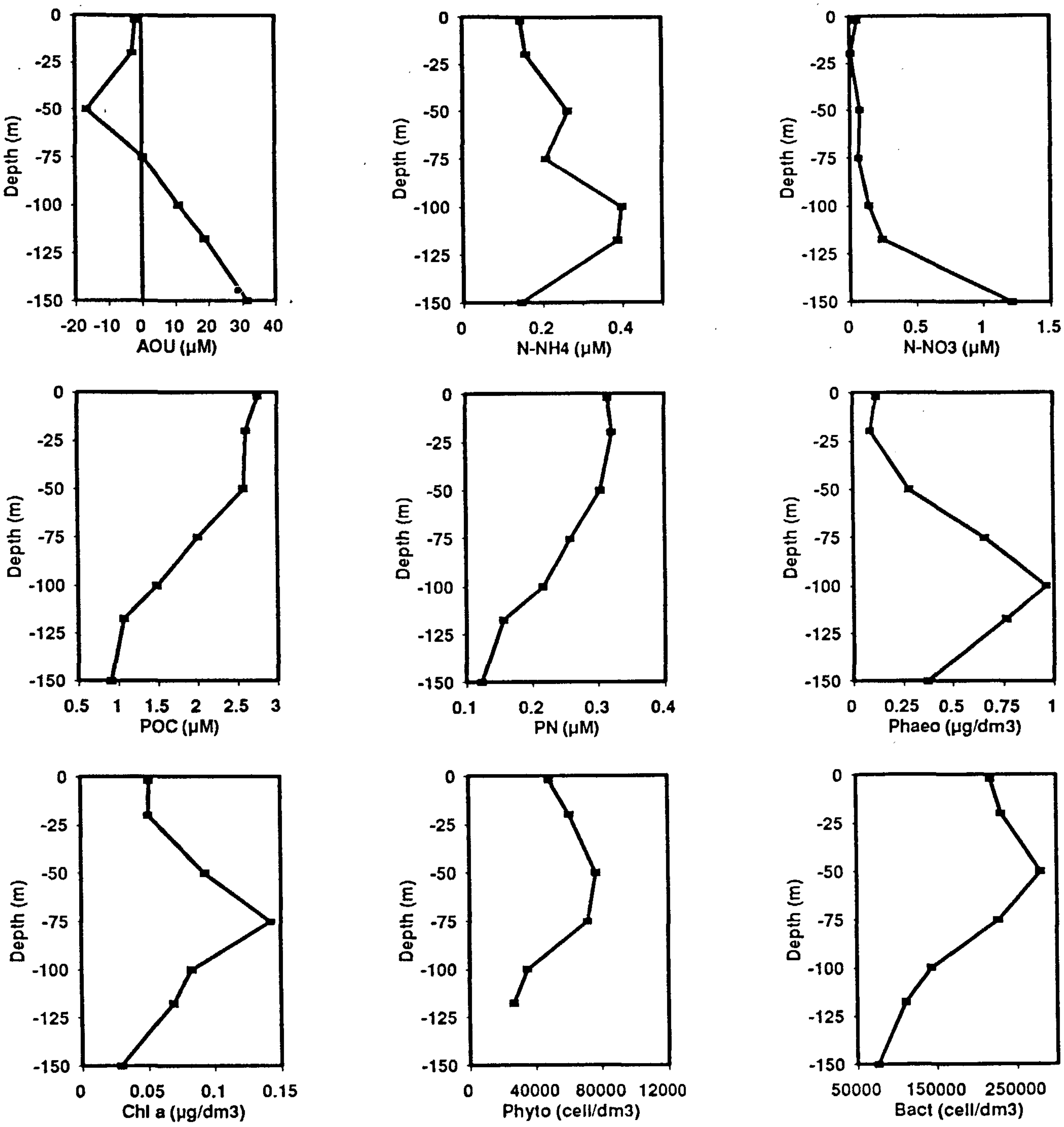


Figure 4

Averaged vertical profiles of properties (oxygen and nutrient data from Bregant et al.*, 1992).*

– in the northernmost stations of the Ionian basin proper, salinity values lower than 38 were also observed at the surface, due to the diffusion of NAW in the northern part of the basin;

– in the Strait of Otranto area salinity values were higher than 38.2 down to the bottom, where the outflow of Southern Adriatic waters occurs;

– minimum values of Apparent Oxygen Utilization (AOU; Richards, 1965) were observed at a depth of 50 m, with oxygen concentrations between 240 and 260 µM (Fig. 4);

– nutrient concentrations (Fig. 4) were very low in the layer from 0 to 120 m (mean 0.1 µM for N-NO_3, 0.05 µM for P-PO_4, 1 µM for Si-SiO_4, 0.2 µM for N-NH_4). Nitrates and silicates then increased, with a nutricline at about 120-150 m, whereas ammonia showed a maximum at 100-120 m.

Chlorophyll *a*, POC and PN

Vertical distribution of chlorophyll *a* shows a Deep Chlorophyll Maximum [DCM (Fig. 4)] at 75 m, with a mean

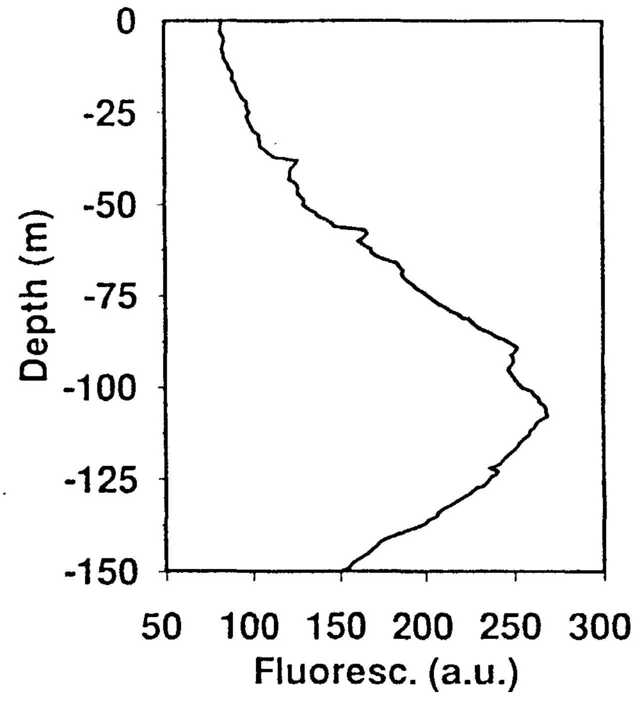


Figure 5

Averaged vertical profile of in situ fluorescence (in arbitrary units).

value of 0.14 µg dm^{-3}. Above and below the DCM, chlorophyll *a* concentrations decrease respectively to 0.05 and 0.02 µg dm^{-3}. These values are representative of oligotrophic waters and fit those reported by Berman *et al.* (1984) for the Levantine basin, but are lower than those reported by Abdel-Moati (1990) for Egypt offshore areas and by Magazzù and Decembrini (1992) for the Ionian.

The observed negligible abundance of phytoplankton classes containing chlorophyll *b* (Throndsen, 1993), indicates that the results obtained after acidification, in pigment analyses, are due mainly to degradation products (phaeopigments). These show the maximum concentration at 100 m (0.95 µg dm^{-3}), with values around 0.1 at the surface and 0.35 µg dm^{-3} at 150 m.

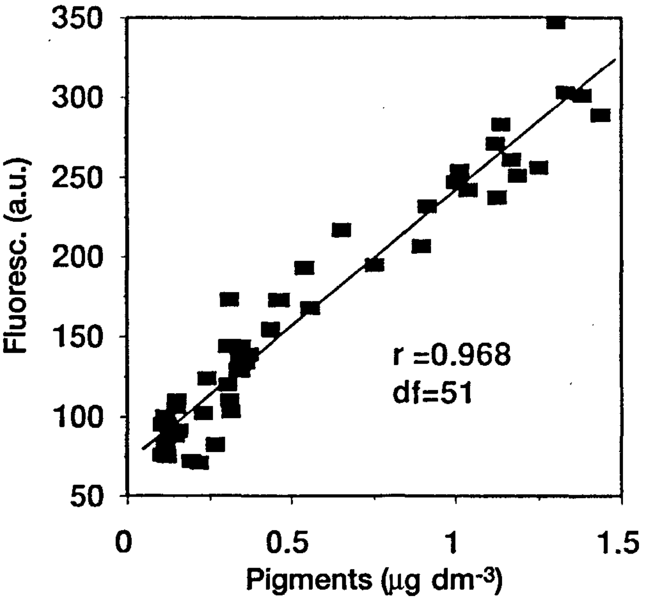


Figure 6

Total pigment concentration vs. in situ fluorescence values (in arbitrary units, r = Pearson coefficient, df = degrees of freedom).

Vertical continuous fluorescence profiles (Fig. 5) are closely related to the distribution of total pigments, as shown by the significance of the correlation ($r = 0.968$, $p < 0.001$, Fig. 6), with maxima at 100 m. This phaeopigment maximum is deeper than the DCM, and a similar trend is reported by Abdel-Moati (1990).

Chlorophyll *a*/phaeopigment ratios are always below 1, as described by Estrada (1981) in the Western Mediterranean at depths exceeding 100 m.

These conditions are indicative of zooplankton grazing processes on the phytoplankton community (Welschmeyer and Lorenzen, 1985), as demonstrated also by relatively high concentrations of NH_4 at these depths (Bregant *et al.*, 1992), or cellular lysis (Gieskes *et.al.*, 1978). A similar increase of reduced products of dissolved inorganic nitrogen, but near the DCM, was described by Estrada (1985), Kiefer *et al.* (1976) and Dortch (1987). This can be attributed to excretion processes by phytoplankton or to bacterial activity.

Particulated Organic Carbon (POC) and Particulated Nitrogen (PN) show maxima between the surface and 50 m. Values are around 2.6 µM for POC and 0.32 µM for PN in the surface layers, and then decrease down to less than 1.0 µM for POC and 0.15 µM for PN at 150 m. In the upper 100 m, nitrogen is present mainly in particulate form, whereas below 100 m the dissolved forms of NH_4 and NO_3 prevail. Taking into account all the samples collected in the Ionian Basin, the POC observed values range from 0.3 to 4.5 µM. These values are lower than those measured in different seasonal conditions in the same area (August 1987: observed range 1.9-10.7 µM; April 1992: observed range 1.6-9.5 µM; Boldrin and Rabitti, unpublished data) and by Abdel-Moati (1990) in the Southeastern Mediterranean. Moreover, they are very close to those reported for the Sargasso Sea (Altabet, 1990).

Phytoplankton and bacteria

As regards the phytoplankton community, small cells (less than 15 µm), represented mainly by nanoflagellates, naked dinoflagellates and coccolithophorids, prevail. Diatoms show abundances in the range of 10^3-10^4 cells dm^{-3}. Low biomasses, as well as the dominance of small cells may be related to the low nutrient concentrations detected in the area (Azov, 1985). The list of species is reported in Table 1.

The vertical distribution of Utermöhl-phytoplankton shows a peak (around 8 10^4 cells dm^{-3}), generally located at 50 m, with minima (2-3 10^4 cells dm^{-3}) below 100 m (Fig. 4). Nanoflagellates represent the prevailing group in the whole euphotic layer, whereas coccolithophorids show a peak at 50 m and diatoms and dinoflagellates increase in percentage with depth (Fig. 7). The phytoplankton maxima do not match the DCM. This discrepancy, also reported by Dortch (1987) and Abdel-Moati (1990), may be related to a photoadaptation phenomenon that occurs in deep phyto-

DIATOMS

Amphora sp.
Bacteriastrum sp.
Chaetoceros affinis Laud.
Chaetoceros cfr. *decipiens* Cl.
Chaetoceros cfr *radians* Schütt
Chaetoceros didymus Ehr.
Chaetoceros peruvianus Brightw
Chaetoceros spores
Chaetoceros spp.
Cocconeis sp.
Coscinodiscus sp.
Dactyliosolen mediterraneus (Peragallo) Hasle
cfr. *Detonula pumila* (Castracane) Schütt
Grammatophora sp.
Hemiaulus hauckii Grun.
Lauderia borealis Gran
Leptocylindrus danicus Cl.
Navicula sp.
Nitzschia closterium W. Sm.
Nitzschia delicatissima Cl.
Nitzschia longissima (Bréb.) Grun.
Nitzschia lorenziana Grun.
Nitzschia pseudodelicatissima Hasle
Nitzschia sigma Sm.
cfr. *Nitzschia* sp.
Nitzschia spp.
Phaeodactylum tricornutum Bohlin
Rhizosolenia alata Brightw.
Rhizosolenia calcar avis Schultze
Rhizosolenia cfr. *hebetata* (Bail.) Gran f. *semispina* (Hensen) Gran
Rhizosolenia fragilissima Berg.
Rhizosolenia stolterfothi Perag.
Synedra cfr. *affinis* Ktz.
Synedra sp.
Thalassionema bacillaris (Heiden) Kolbe
Thalassionema nitzschioides Grun.
Thalassiosira spp.
Thalassiothrix frauenfeldii Grun.
Undetermined diatom spores
Undetermined Centric diatoms
Undetermined Pennatae diatoms

DINOFLAGELLATES

cfr. *Alexandrium* sp.
Amphidinium cfr. *acussimum* Lohm.
Amphidinium sp.
Ceratium cfr. *lineatum* (Ehr.) Cl.
Ceratium pentagonum Gourret
Cladopyxis setifera Lohm.
cfr. *Cochlodinium* sp.
Dinophysis cfr. *parvula* (Schütt) Balech
Gonyaulax cfr. *polygramma* Stein
Gonyaulax sp.
Gymnodinium cfr. *caput* Schill.
Gymnodinium elongatum Hope
Gymnodinium sp. > 15 µm
Gymnodinium sp. < 15 µm
Gyrodinium fusiforme Kof. & Sw.
Gyrodinium sp. > 15 µm
Gyrodinium sp. < 15 µm
Histioneis cfr. *oxypteris* Schill.
Mesoporos sp.
Oxytoxum adriaticum Schill.
Oxytoxum caudatum Schill.
Oxytoxum cfr. *ovale* Schill.
Oxytoxum cfr. *pyramide* Dodge & Saunders
Oxytoxum cfr. *viride* Schill.
Oxytoxum gracile Schill.
Oxytoxum laticeps Schill.
Oxytoxum sphaeroideum Stein
Oxytoxum variabile Schill.
Oxytoxum spp.
cfr. *Phalacroma* sp.
Prorocentrum aporum (Schill.) Dodge
Prorocentrum balticum (Lohm.) Loeb.
Prorocentrum micans Ehr.
Prorocentrum minimum (Pav.) Schill.
Prorocentrum cfr. *cordatum* (Ostenfeld) Dodge
Prorocentrum cfr. *maximum* (Gourret) Schill.
Prorocentrum cfr. *rotundatum* Schill.
Prorocentrum triestinum Schill.
Prorocentrum sp.
Protoperidinium cfr. *globulus* (Stein) Balech
Protoperidinium cfr. *tuba* (Schill.) Balech
Protoperidinium sp.
Naked dinoflagellates > 15 µm
Naked dinoflagellates < 15 µm
Thecat dinoflagellates > 15 µm
Thecat dinoflagellates < 15 µm
Undetermined dinoflagellates

COCCOLITHOPHORIDS

cfr. *Anacanthoica acanthos* (Schill.) Deflandre
cfr. *Anacanthoica cidaris* (Schlauder) Bernhard & Rampi
cfr. *Anacanthoica ordinata* (Kampt.) Bernhard & Rampi
Anacanthoica sp.
Anoplosolenia brasiliensis (Lohm.) Deflandre
Calciosolenia murrayi Gran
Calciosolenia sinuosa Schlauder
cfr. *Calyptrosphaera gracillima* Kampt.
cfr. *Calyptrosphaera pirus* Kampt.
cfr. *Calyptrosphaera uvella* Schill.
cfr. *Calyptrosphaera* sp.
Coccolithus pelagicus (Wallich) Schill.
Coccolithus wallichi (Lohm.) Schill.
Discophaera tubifer (Murr. & Black) Lohm.
Emiliania huxleyi (Lohm.) Hay & Mohler
cfr. *Gephirocapsa oceanica* (Kampt.)
Halopappus adriaticus Schill.
Halopappus cfr. *quadribrachiatus* Schill.
cfr. *Helicosphaera carteri* (Wallich) Kampt.
Helladosphaera cornifera (Schill.) Kampt.
Homozigosphaera spinosa Kampt.
cfr. *Homozigosphaera stellulata* (Lecal) Bernhard & Rampi
Ophiaster formosus Gran
Ophiaster hydroideus (Lohm.) Gran
Ophiaster sp.
cfr. *Pontosphaera haeckeli* Lohm.
Pontosphaera steueri Kampt.
Pontosphaera syracusana Lohm.
Rhabdosphaera cfr. *subopaca* Bernhard
Rhabdosphaera claviger Murr. & Black.
Rhabdosphaera hispida Lohm.
cfr. *Rhabdosphaera multistylis* Schill.
Rhabdosphaera stylifer Schill.
Rhabdosphaera tignifer Schill.
Rhabdosphaera spp.
Syracolithus clypeatus (Lecal) Bernhard & Rampi
Syracolithus dentatus (Lohm.) Bernhard & Rampi
cfr. *Syracosphaera cupulifera* Schill.
Syracosphaera cfr. *histrica* Kampt.
Syracosphaera cfr. *mediterranea* Lohm.
Syracosphaera pulchra Lohm.
cfr. *Syracosphaera spinosa* Lohm.
Syracosphaera spp.
Umbellosphaera tenuis (Kampt.) Paasche
Zigosphaera cfr. *regalis* Lecal
Zigosphaera sp.
Undetermined coccolithophorids

PHYTOFLAGELLATES

Haptophyceans

cfr. *Chrysochromulina* sp.
Corymbellus aureus Green
Undeterminined haptophyceans

Chrysophyceans

Calycomonas sp.
Dyctiocha speculum Ehr.
Meringosphaera mediterranea Lohm.
Pseudokefirion sp.
Undetermined crypsophyceans

Cryptophyceans

Cryptomonas sp.
Hillea fusiformis (Schill.) Schill.
cfr. *Leucocryptos marina* (Braarud) Halldal
Undetermined cryptophyceans

Euglenophyceans

Eutreptiella cfr. *hirudoidea* Butcher
Undetermined euglenophyceans

Prasinophyceans

cfr. *Pachysphaera* sp.
Pseudoscourfieldia sp.
Pyramimonas sp.
Tetraselmis sp.
Undetermined prasinophyceans

Other

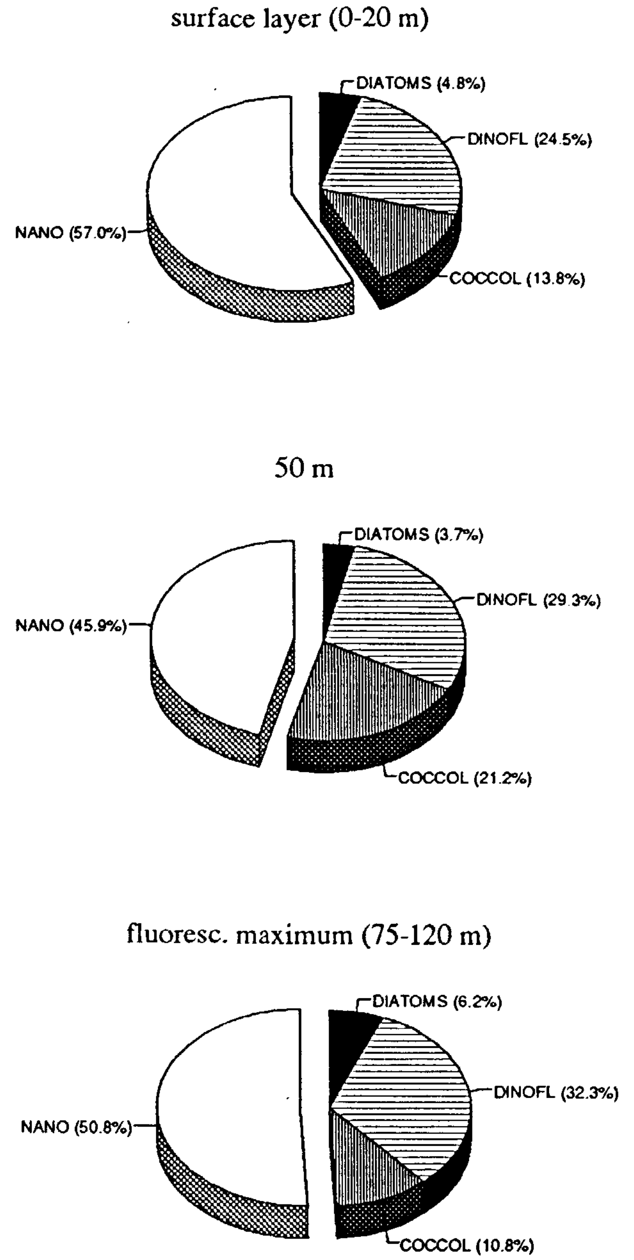
Undetermined phytoflagellates < 10 µm
Undetermined phytoflagellates > 10 µm
Undetermined chlorophyceans

Coccoids forms

incertae sedis

Table 1

List of phytoplankton species.


surface layer (0-20 m)

50 m

fluoresc. maximum (75-120 m)

Figure 7

Relative abundance of main phytoplankton groups at surface, at 50 m and at in situ fluorescence maximum (all stations averaged).

plankton communities, leading to increase in the intracellular chlorophyll concentration (Estrada, 1985; Kimor *et al.*, 1987), as shown by low carbon/chlorophyll ratios (< 30) observed at the DCM. An important role may also be played by the presence of a large fraction of phytoplankton cells smaller than 3 μm (picoplankton), which was not taken into account.

Many studies have in fact reported the prevalent contribution of picoplankton to primary production (Berman *et al.*, 1984). Picoplankton was shown to be more important in oceanic than in neritic environments and to contribute to primary production in the pelagic areas by about 62 %, from June to January (Azov, 1986).

In general, phytoplankton abundances observed in the Ionian are higher than those measured in the Sicily Channel in the same period (Zingone, personal communication). They are similar to those reported for the Levantine Basin (Kimor and Wood, 1975) and lower than those of the Western Mediterranean (Estrada, 1985) and Strait of Otranto (Viličić *et al.*, 1989).

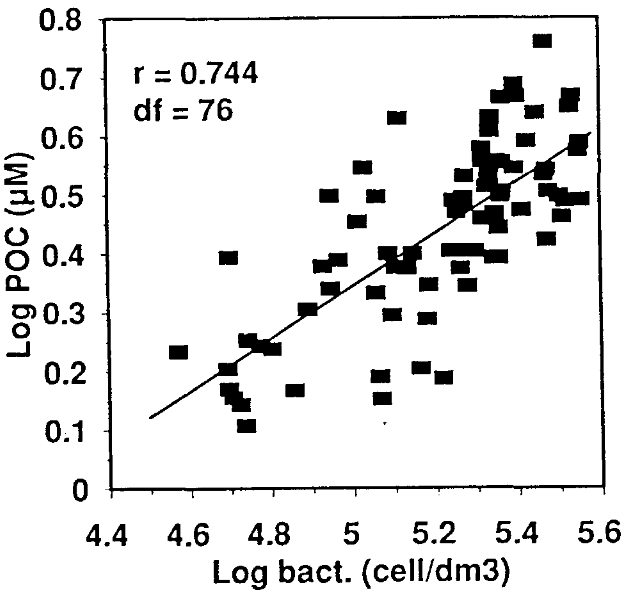


Figure 8

Bacteria vs. Particulate Organic Carbon concentrations. Data are log-transformed (r = Pearson coefficient, df = degrees of freedom).

The phytoplankton biomass, expressed as cellular carbon concentration, ranges between 1 and 8 μg C dm^{-3}, and accounts only for 10 % of the total POC, with maxima of 15 % at 50 m. The main taxonomic group is represented by dinoflagellates, which seem to be widespread in oligotrophic environments (Estrada, 1985).

Bacterial abundances range from a maximum of 3.5 10^{8} cell dm^{-3} (at the surface) to a minimum of 0.8 10^{8} cells dm^{-3} in deep waters. The vertical distribution of bacteria shows almost the same pattern of phytoplankton: the population densities are greatest above the thermocline (Fig. 4), with increasing values from the surface to about 50 m, then they decrease rapidly just below the thermocline, where the abundance is generally halved, and more slowly at greater depths. The average values in the euphotic layer (2.17 10^{8} cells dm^{-3}) are lower than those calculated for the Central Adriatic in the same season (6.2 10^{8} cells dm^{-3}; Krstulovic and Sobot, 1982) and in a narrower range than those estimated by Azam *et al.* (1983) for offshore waters (0.5-10 10^{8} cells dm^{-3}). Bacteria abundances are significantly correlated with the POC (Fig. 8) and with phytoplankton abundances.

The lack of any significant relationship between chlorophyll *a* and bacterial abundance follows the pattern observed by Cho and Azam (1990) in the Central North Pacific gyre (for chlorophyll *a* values lower than 0.5 μg dm^{-3}), but with lower values and ranges for both chlorophyll and bacteria. The data points for bacterial abundance fall within a narrower range (0.8-3.5 10^{8} cells dm^{-3}, i.e. 4-fold variation) than for chlorophyll values (0.01-0.25 μg dm^{-3}, i.e.

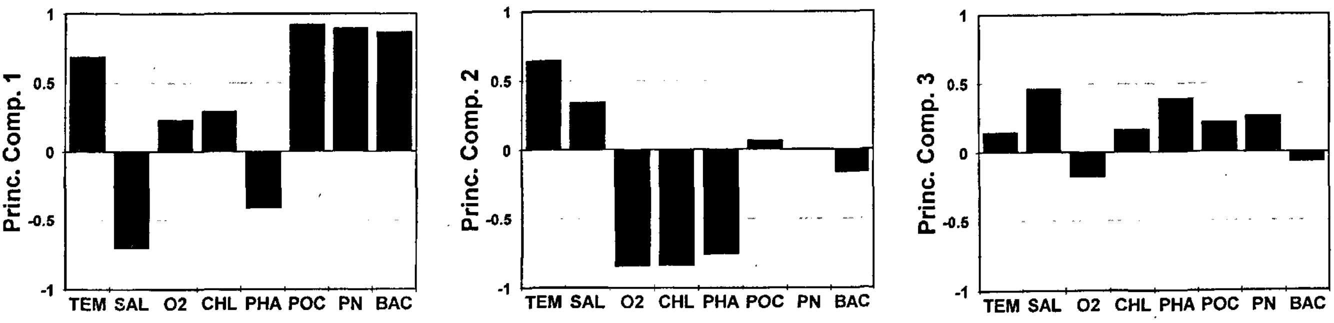


Figure 9

Composition of first three Principal Components in terms of original variables (TEM = temperature, SAL = salinity, O2 = oxygen concentration, CHL = chlorophyll a, PHA = phaeopigment, POC = Particulate Organic Carbon, PN = Particulate Nitrogen, BAC = bacteria concentration).

25-fold variation), possibly indicating increased oligotrophic conditions.

Water mass characterization

With the aim of characterizing the various water masses down to 150 m, a Principal Component Analysis (R-Mode) was applied to the following set of variables: temperature, salinity, dissolved oxygen, chlorophyll *a*, phaeopigments, particulate nitrogen, particulate organic carbon, bacteria counts.

The first three eigenvalues account for 85.6 % of total variance. The contribution of single variables is shown in Figure 9.

The best clustering was found by the score projection on factor plane I and III, which grouped all samples into four clusters, corresponding respectively to: a) North Atlantic Water (NAW); b) Ionian Surface Water (ISW); c) a layer characterized by *in situ* fluorescence maximum (FM); and d) deepest layers [DL (Fig. 10)].

The main properties of these four clusters are reported in Table 2.

On the basis of PCA results, phytoplankton data were grouped following the same clustering (Tab. 3). The highest abundances occur in the NAW avg = 6.9 10^4 cells dm^{-3}), intermediate abundances in the ISW (avg = 5.7 10^4 cells dm^{-3}), and the lowest at FM (avg = 3.2 10^4 cells dm^{-3}). The abundance of main taxonomic groups along a NW-SE transect, crossing the NAW jet interesting stations 308 and 210, is shown in Figure 11.

In order to identify species characteristic of various water masses, species abundances were grouped into three classes following the clustering of the water masses. To test how significant these differences could be, a one-way ANOVA was carried out: NAW is characterized by several species, *Emiliania huxleyi* and naked dinoflagellates > 15 µm being the most abundant; ISW is dominated by unidentified nanoflagellates and *Rhizosolenia* spp.; in FM mainly *Halopappus adriaticus* and unidentified pennate diatoms occur. Because of their homogeneous diffusion throughout the basin, several species were found with no significative differences among the various water masses (Tab. 3).

										FITOPLANCTON				
		DEPTH m	TEMP °C	SAL PSU	CHL *a* µg dm^{-3}	PHAEO µg dm^{-3}	POC µM	PN µM	BACT cell cm^{-3}	TOTAL cell cm^{-3}	DIAT cell cm^{-3}	DINO cell cm^{-3}	COCCO cell cm^{-3}	NANO cell cm^{-3}
NORTH ATLANTIC WATER (NAW)	count	20	20	20	20	20	20	20	20	15	15	15	15	15
	avg	33	20.37	37.83	0.08	0.21	2.42	0.30	265900	68	3	20	13	31
	stdev	23	2.48	0.22	0.03	0.13	0.46	0.05	59649	29	1	9	8	15
	min	2	16.38	37.48	0.02	0.06	1.90	0.23	187254	28	1	8	4	11
	max	75	24.93	38.21	0.15	0.52	3.66	0.41	359216	117	5	38	28	64
IONIAN SURFACE WATER (ISW)	count	15	15	15	15	15	15	15	15	12	12	12	12	12
	avg	34	22.23	38.25	0.07	0.32	2.68	0.31	214643	57	2	13	8	34
	stdev	34	3.93	0.17	0.05	0.38	0.59	0.07	52769	17	2	3	3	16
	min	2	15.56	37.84	0.02	0.05	1.88	0.20	106587	32	0	7	2	16
	max	100	26.15	38.47	0.16	1.19	3.87	0.46	294483	99	7	17	12	79
IN-SITU FLUORESCENCE MAXIMUM (FM)	count	11	11	11	11	11	11	11	11	9	9	9	9	9
	avg	116	16.07	38.29	0.09	0.99	1.39	0.21	133298	31	2	9	3	15
	stdev	18	0.34	0.11	0.03	0.18	0.21	0.03	40905	10	1	4	2	6
	min	100	15.56	38.08	0.04	0.52	1.02	0.17	77885	18	1	4	1	5
	max	150	16.57	38.47	0.16	1.29	1.84	0.26	226723	48	3	18	7	24
DEEPEST LAYERS (DL)	count	12	12	12	12	12	12	12	12					
	avg	140	15.57	38.42	0.02	0.36	0.70	0.10	79898					
	stdev	16	0.44	0.10	0.01	0.14	0.25	0.04	40384					
	min	100	14.95	38.26	0.01	0.20	0.43	0.03	37269					
	max	150	16.44	38.60	0.05	0.74	1.39	0.17	165434					

Table 2

Average properties of water masses, clustered through Principal Component Analysis.

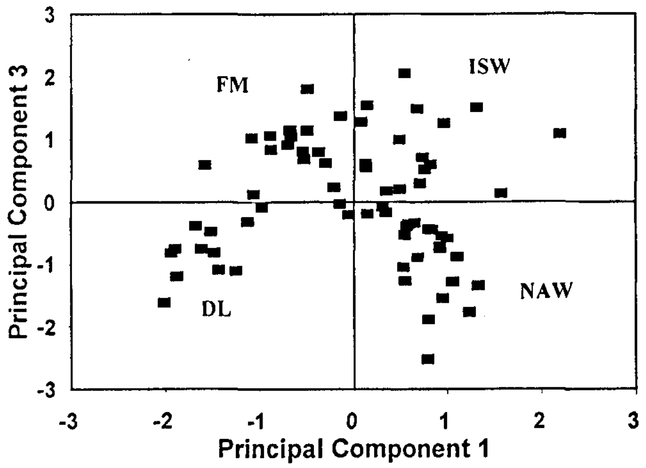


Figure 10

Score projection on Principal Components on factor plane I and III (NAW = North Atlantic Water, ISW = Ionian Surface Water, FM = samples from in situ fluorescence maximum, DL = Deepest Layers).

Observations on primary production and phytoplankton time evolution in oligotrophic areas indicate the existence of seasonal cycles, with two productivity maxima alternating, respectively in autumn and at the end of the winter, due to gradual changes in the hydrological properties of the water column. Vertical mixing processes occurring during winter cause nutrients mineralized in deep waters to become available in the euphotic layer, where they are utilized by phytoplankton during spring. Subsequently, a sub-surface chlorophyll maximum, characteristic of the stratification period, is produced and maintained (Strass and Woods, 1991; Kiefer and Kremer, 1981).

As regards the whole Mediterranean, Azov (1986) observed production maxima in early spring (March), with a less pronounced peak in late autumn (October, November), while Dowidar (1984) reported chlorophyll maxima in winter and spring.

Experimental data regarding the instability period in the water column of the Ionian are not available, as in sur-

	NAW		FM		ISW	
	avg	std	avg	std	avg	std
NAW						
Emiliana huxleyi	5 331	3 054	1 260	1 113	2 726	1 441
Naked Dinoflagellates > 15 µm	4 482	1 845	2 787	1 070	3 753	2 375
Coccolitophorids not id.	3 782	3 910	1 205	1 104	2 352	1 775
Oxytoxum spp.	1 634	1 140	199	227	441	514
Anacanthoica spp.	1 091	1 663	0	0	539	1 023
Thecate Dinoflagellates > 15 µm	355	342	61	161	303	525
Navicula sp.	346	395	136	197	95	228
FM						
Halopappus adriaticus	14	49	381	476	63	210
Pennate Diatoms not id.	156	258	226	298	0	0
ISW						
Nanoflagellates not id.	26 853	13 607	11 725	4 536	30 514	16 043
Rhizosolenia spp.	213	307	0	0	335	312
UBIQUITARIOUS TAXA						
Naked Dinoflagellates < 15 µm	8 024	4 784	5 184	2 670	5 499	2 919
Thecate Dinoflagellates < 15 µm	5 230	4 378	1 315	1 252	1 326	995
Cryptophyceans	2 424	1 837	1 106	1 404	2 914	2 587
Prasinophyceans	1 340	2 122	767	752	718	847
Umbellosphaera tenuis	1 305	1 802	61	161	0	0
Rhabdosphaera spp.	766	903	189	276	943	932
Prorocentrum spp.	663	894	342	462	564	593
Nitzschia sp.	644	824	198	288	109	201
Thalassiosira sp.	532	626	195	280	423	979
Helladosphaera cornifera	333	500	30	80	138	251
Syracosphaera spp.	269	461	61	105	41	91
Ophiaster spp.	237	328	379	380	320	738
Discophaera tubifer	181	278	30	80	41	91
Nitzschia closterium/longissima	173	255	490	655	437	838
Leptocylindrus mediterraneus	172	455	0	0	62	205
Calyptrosphaera spp.	135	327	0	0	16	53
Nitzschia delicatissima complex	106	381	192	509	0	0
Chaetoceros spp.	44	110	152	208	155	413
Calciosolenia spp.	27	98	30	80	207	502
Dictyocha speculum	14	49	61	105	0	0
Zigosphaera spp.	0	0	0	0	32	106
Leptocylindrus danicus	0	0	64	170	0	0
Euglenophyceans not id.	0	0	91	169	32	105
Chlorophyceans not id.	0	0	95	252	32	105

Table 3

Means and standard deviations of taxa (cells dm-3). Taxa not «ubiquitous» show significant differences among various water masses, calculated by one-way ANOVA.

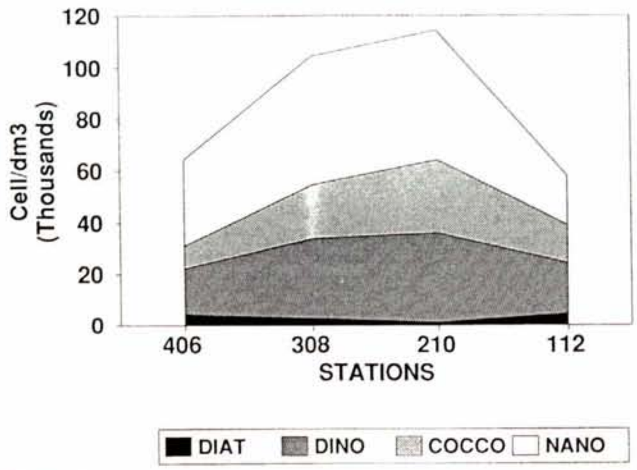


Figure 11

Abundance of main phytoplankton groups along NW-SE transect, at 50 m depth. Stations 308 and 210 are fully interested by North Atlantic Water (NAW).

rounding areas like the Southern Adriatic (Marasovic and Pucher-Petkovic, 1988; Viličić *et al.*, 1989).

The hydrological pattern of October 1991 was characterized by late summer stratification on the water column and an almost complete depletion of nutrients (particularly PO_4 and NO_3) in the euphotic layer, where the particulate form of nitrogen prevailed over the dissolved form. Total and autotrophic biomasses were very low when compared to those reported for oligotrophic basins. Unpublished data (Boldrin and Rabitti), previously collected in the same area in different seasonal conditions, show significantly higher POC values, averages ranging from 4.78 μM in April to 4.20 μM in August, while in this study (October) their mean values were 1.89 μM. These variations lead us to hypothesize the presence of a seasonal cycle in production processes in the Ionian too.

The influence of North Atlantic Water is shown by higher organic matter concentration when compared with Ionian Surface Water: integrated POC values (0-150 m) are higher than 300 10^3 μM m^{-2} (lower than 300 10^3 μM m^{-2} outside the North Altlantic Water stream). Moreover, the POC transferred from the surface to 150 m (expressed as percentage of the value found at surface) is higher in NAW (> 30 %) when compared with Ionian Surface Water (< 25 %).

In general, in the Ionian basin, the highest biomass values (both for phytoplankton and bacteria) are located at 50 m in the NAW and at the surface outside it.

CONCLUSIONS

Some tentative conclusions may be drawn from these results:

- the examined situation (October) is representative of the final stage of what is probably an annual cycle of production in an oligotrophic system;
- the well-developed Deep Chlorophyll Maximum between 75 and 100 m (mainly due to degradation products) does not match the biomass maximum. Possible explanations of this are: a) phytoplankton photo-adaptation processes; b) sinking to deep-layer of senescent cells, relicts of previous blooms; c) grazing activity by proto- and meta-zooplankton.
- North Atlantic Waters is probably more productive when compared to the surrounding Ionian waters during this seasonal situation, although this is still to be confirmed by data collected in connected areas, such as the Sicily channel and the Aegean Sea.

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