

Phytoplankton biomass and species composition in a Mediterranean coastal lagoon

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Received 19 August 1992; in revised form 9 February 1993; accepted 23 March 1993

Key words: Phytoplankton, Fusaro lagoon, Tyrrhenian Sea, Mediterranean Sea

Abstract

Phytoplankton populations were investigated weekly at a central station in the Fusaro lagoon (Mediterranean Sea) from 27 November 1989 to 18 June 1990 to assess species composition, temporal succession and standing stock of the different species. Chlorophyll concentrations varied from 1.2 to 73.2 $\mu\text{g l}^{-1}$ in surface waters, and from 1.3 to 53.5 $\mu\text{g l}^{-1}$ at the 4.5 m depth. Phytoplankton communities were dominated by *Prorocentrum micans* Ehrenberg in December and January, and by small-sized diatoms in the rest of the sampling period. In surface waters, a maximum biomass of 9.5 mg C l^{-1} was measured in January, in correspondence with high concentrations (8.1×10^6 cells l^{-1}) of *P. micans*, whereas an abundance peak of 159.9×10^6 cells l^{-1} was registered on the last sampling date due to a massive bloom of a very small diatom, *Minutocellus polymorphus* (Hargraves & Guillard) Hasle, von Stosch & Syvertsen. On the whole, phytoplankton populations of the Fusaro lagoon showed distinct characters as compared to those of southern Tyrrhenian coastal waters and of other lagoons.

Introduction

Coastal lagoons are boundary environments between continental and marine ecosystems characterized by the presence of numerous diverse interfaces. This results in great typological diversity which is discernible even within a small geographic scale. Biological communities within these systems vary markedly from one lagoon to another and generally have peculiar characteristics which differentiate them from adjacent marine and continental biomes.

In the last three decades, many efforts have been made to define phytoplankton species

distributions and successions in both marine (Margalef, 1967; 1978; Levasseur *et al.*, 1984) and lacustrine (Sommer, 1989) environments. Although not applicable to all situations, descriptive and previsional models developed to date provide a stimulating basis for discussion and further improvements. The lack of generalizations for phytoplankton distributional and successional patterns for coastal lagoons is probably due to a combination of high intrinsic complexity and variability of these systems as well as the scarcity of sound detailed observations.

In 1989–90, phytoplankton species composition and biomass were investigated at weekly

intervals during a 7 months period in the Fusaro lagoon, with the aim of characterizing phytoplankton communities and their successional pattern and to assess the relative contribution of the different species to the biomass. This study was part of a research project which included zooplankton sampling, as well as environmental and bacteriological analyses in the water and sediments of the lagoon. The sampling was to be conducted over a whole year, but was forcedly interrupted by the finding of *Vibrio cholerae* in the lagoon (S. Dumontet, pers. com.).

Study area

The Fusaro lagoon (Fig. 1) is a coastal lagoon located along the southern Tyrrhenian coast about 10 miles west of Naples. It is semi-circular in shape, with a maximum length and width of ca. 1700 and 800 m, respectively, and an average

depth of 3 and maximum depth of 6 m. As a consequence of recent dredging activities, an artificial trench 8–12 m deep is situated along the western bank of the lagoon.

Water exchange between the Fusaro lagoon and the Tyrrhenian Sea occurs through three artificial channels excavated across the barrier beach that delimits the western side of the lagoon. This exchange is generally low due to the combined effects of narrow and shallow channels along with a reduced tidal excursion (tide range = 30 cm). Daily exchange was calculated to be 1/840 of the whole water mass (Leccese & Speziale, 1967) but this also depends on the maintenance status of the channels which tend to become occluded with silt. Natural freshwater inputs are negligible, whereas several untreated sewage outlets which drain a densely populated area are located along the eastern bank of the lagoon.

In the course of the year, surface water temperatures generally vary between 6 and 30 °C and are mainly driven by air temperature more than by the influence of seawater. Daily excursions generally do not exceed 3 °C (Sacchi & Renzoni, 1962).

The reduced water exchange and evaporation regime result in salinity values (35–38 PSU) which are slightly lower than those of external waters. Lower values (> 32 PSU) are recorded in periods of scarce evaporation and heavy rainfalls, which correspond to winter and spring. Surface values are often slightly lower as compared to bottom waters (Magazzù & Panella, 1969). As generally occurs in shallow waters, wind can disrupt vertical gradients, which can rapidly be restored when the weather is calm (Sacchi & Renzoni, 1962). In the course of this investigation, salinity values ranged from 33.72 to 37.25 PSU (Table 1).

Nutrient concentrations in this lagoon have always been higher than in external waters (Korringa & Postma, 1957; Carrada, 1973), but in recent years the heavy load of sewage discharge has notably increased eutrophic conditions (Rigillo Troncone, 1990; Carrada *et al.*, 1991). Averages and ranges for nutrient concentrations

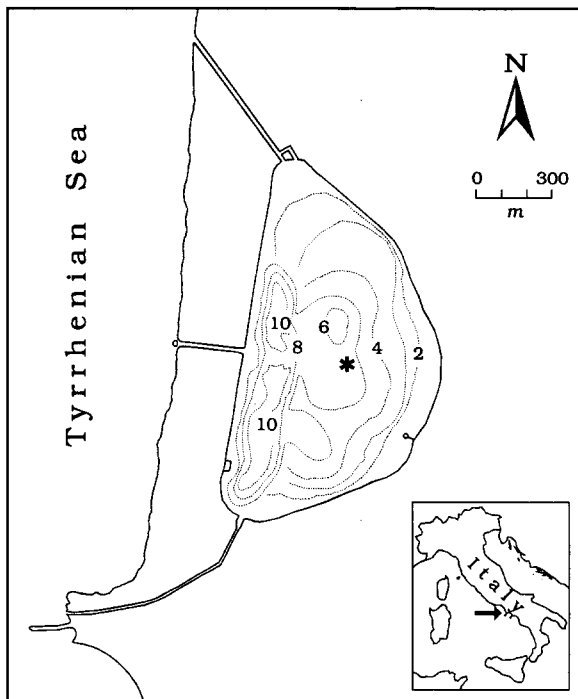


Fig. 1. Map of the Fusaro lagoon showing the sampling station marked by an asterisk.

Table 1. Minimum, maximum, mean values and standard deviation of some environmental parameters measured during the sampling period (S. Dumontet, pers. com.).

	min	max	avg	sd
Salinity (PSU)				
surface	33.72	36.94	35.72	0.98
bottom	33.87	37.25	36.38	0.80
NO ₃ ⁻ -N (μg l ⁻¹)				
surface	0.39	19.82	6.82	5.63
bottom	0.35	19.00	6.16	5.19
NH ₄ ⁺ -N (μg l ⁻¹)				
surface	0.04	4.03	1.40	1.25
bottom	0.12	17.99	3.21	4.07
NO ₂ ⁻ -N (μg l ⁻¹)				
surface	0.11	1.85	0.52	0.40
bottom	0.07	1.52	0.43	0.32
PO ₄ ³⁻ -P (μg l ⁻¹)				
surface	0.13	2.44	0.44	0.47
bottom	0.10	3.86	0.60	0.74
SiO ₄ ²⁻ -Si (μg l ⁻¹)				
surface	6.15	74.26	31.67	20.76
bottom	7.30	74.09	33.23	20.08

measured in the period of our investigation are reported in Table 1.

Oxygen concentrations show wide fluctuations during the year, with maximal diurnal values (<400%) in spring and minimal, undersaturating values in summer (Sacchi & Renzoni, 1962; Carrada, 1973). Anoxic conditions, generally restricted to bottom layers in summertime for the past years, have recently been more frequently recorded presumably due to the increased anthropogenic load, especially in the deepest, dredged area (Carrada *et al.*, 1991). In the summer following this study, a fish-kill caused by anoxia was reported by the press.

The above-mentioned physical and chemical parameters show much wider fluctuations in peripheral sites of the lagoon (Rigillo Troncone, 1969; Carrada, 1973).

Benthic communities of the Fusaro lagoon have been the object of several studies in the past (Sacchi & Renzoni, 1962; Carrada *et al.*, 1965; Russo & Ferro, 1980; Ferro & Russo, 1982; Sordino *et al.*, 1989; Procaccini & Scipione,

1992), whereas little information is available for planktonic populations. First reports date back to the beginning of this century (Carazzi, 1900) when the lagoon was exploited for oysters. Successively, the lagoon has been the site of prosperous mussel farming (Korringa & Postma, 1957), which has been interrupted since 1973 after the outbreak of a cholera epidemic (Carrada *et al.*, 1991). In recent years, blooms of the toxic dinoflagellate *Gymnodinium catenatum* Graham were noted (Carrada *et al.*, 1988) in the early autumn period. An annual phytoplankton cycle at a peripheral station close to the eastern bank of the lagoon showed maximum values of 160 μg Chl *a* l⁻¹ in October 1988, mainly due to a bloom of *Gymnodinium* sp. (Carrada *et al.*, 1991).

Materials and methods

A weekly sampling program was conducted at a central station (Fig. 1) in the Fusaro lagoon from 27 November 1989 to 18 June 1990. Water samples were taken at the surface by bucket samples and at the 4.5 m depth (*ca* 1 m distance from the bottom) by a Niskin bottle. For chlorophyll *a* analyses, a volume of water varying from 250 to 1200 ml was filtered on 0.5 μm fiber glass GFF filters. Pigments were extracted with 90% neutralized acetone and their concentrations were determined spectrophotometrically using the equations indicated by SCOR-UNESCO (1966).

Phytoplankton samples were fixed with CaCO₃ neutralized formaldehyde to give a final concentration of 1.6% and examined with an inverted microscope (ZEISS IM 35) at a magnification of 360×. Depending on phytoplankton concentrations, subsamples varying from 0.2 to 20 ml were allowed to sediment in combined sedimentation chambers. Two transects, representing 1/34 of the bottom plate, were examined for counts. For each sample, counts were also made following the same method on a 50 ml subsample to evaluate the concentration of less abundant species. The latter numbers were only used for single species temporal variations and were not summed to total densities.

For species identification, the principal taxonomic texts were those indicated in Zingone *et al.* (1990). The identification of some problematic species, such as *Cyclotella caspia*, *Minutocellus polymorphus*, *Thalassiosira pseudonana*, *Diplopelta symmetrica*, *Diplopsalopsis latipeltata*, *Proto-peridinium hiobis*, *P. bispinum*, *Pyramimonas* cfr. *disomata*, *Pseudoscurfieldia marina*, *Chrysochromulina pringsheimii*, was confirmed at transmission or scanning electron microscopy. Algae which could not be identified to the species or genus level were assigned to suprageneric groups. Unidentified centric diatoms and phytoflagellates were further subdivided into small ($< 10 \mu\text{m}$) and large ($> 10 \mu\text{m}$) forms and dinoflagellates into small ($< 15 \mu\text{m}$) and large ($> 15 \mu\text{m}$) naked or thecate forms. For colonial cyanophyceans, which were occasionally sampled when the Niskin bottle was too close to the bottom, only the number of colonies was recorded.

The percentage similarity index (PSI) (Whittaker, 1952) between surface and bottom samples was calculated using all the identified species, genera and suprageneric groups.

Cell volumes were calculated for 42 photosynthetic taxa which on the average comprised 99% and 98% of total cell numbers in surface and bottom waters, respectively. A distinction between photosynthetic and non-photosynthetic species was made using the information available in the literature (Chretiennot-Dinet, 1990; Larsen & Sournia, 1991). Small unidentified flagellates and dinoflagellates were always included, despite the probable presence of heterotrophic species. The contribution of colonial cyanophyceans to the total biomass was not estimated. Cell sizes were determined on more than 100 specimens for the most abundant species and averaged for a single sample or several samples depending on the variability in species size. Cell volumes were calculated by assigning cells to one geometrical body or, in some cases, to a combination of more geometrical bodies, and applying standard formulae. Carbon content was calculated using the relationship reported by Strathmann (1967).

Results

In surface waters, chlorophyll *a* concentrations varied from 1.2 to $73.2 \mu\text{g l}^{-1}$, reaching highest values for the sampling period in January, with a peak on 8 January (Fig. 2a). From February onwards, lower values were recorded, ranging from 1.2 to $32 \mu\text{g l}^{-1}$. At the 4.5 m depth, chlorophyll concentrations showed marked fluctuations throughout the sampling period, with values varying from 1.3 to $53.5 \mu\text{g l}^{-1}$ (Fig. 2b).

A complete list of the species identified in the Fusaro lagoon is reported in Tables 2 and 3.

Temporal variations for the 14 most abundant taxa in surface and bottom waters are reported in Fig. 3.

At the surface, total cell densities varied from 2.3 to $159.9 \times 10^6 \text{ cells l}^{-1}$ with marked weekly variations which mainly characterized the popu-

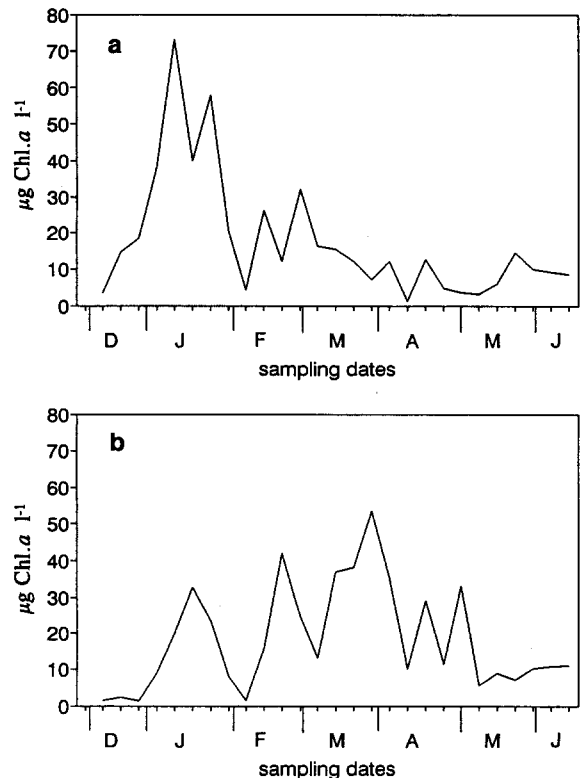


Fig. 2. Weekly variations of chlorophyll *a* concentration at 0 m (a) and at the 4.5 m depth (b) at the sampling station of the Fusaro lagoon.

Table 2. List of the most important photosynthetic taxa in the Fusaro lagoon, including their mean volume and carbon content.

	Volume (μm^3)	Carbon (pg)
DIATOMS		
Centric diatoms < 10 μm	50.27	7.37
<i>Asterionella glacialis</i> Castracane	315.27	29.65
<i>Chaetoceros affinis</i> Lauder	1817.64	111.87
<i>Chaetoceros</i> cfr. <i>calcitrans</i> Takano	32.55	5.30
<i>Chaetoceros costatus</i> Pavillard	595.23	48.00
<i>Chaetoceros curvisetus</i> Cleve	553.65	45.43
<i>Chaetoceros dipyrenops</i> Meunier	845.23	62.61
<i>Chaetoceros seiracanthus</i> Gran	2110.63	125.29
<i>Chaetoceros socialis</i> Lauder	166.71	18.29
<i>Chaetoceros</i> spp. (single)	1000.00	71.12
<i>Chaetoceros</i> spp.	800.00	60.05
<i>Cyclotella atomus</i> Hustedt	54.31	7.82
<i>Cyclotella caspia</i> Grunow	202.84	21.22
<i>Cyclotella striata</i> (Kützing) Grunow	551.69	45.31
<i>Cylindrotheca closterium</i> (Ehrenberg) Reimann & Lewin	98.96	12.32
<i>Minutocellus polymorphus</i> (Hargraves & Guillard) Hasle, von Stosch & Syvertsen	16.06	3.10
<i>Nitzschia delicatissima</i> Cleve	53.23	7.70
<i>Nitzschia pseudodelicatissima</i> (Hasle) Hasle	227.82	23.18
<i>Skeletonema costatum</i> (Greville) Cleve	169.24	18.50
<i>Thalassiosira pseudonana</i> Hasle & Heimdal	54.31	7.82
DINOFLAGELLATES		
Naked dinoflagellates < 15 μm	258.46	42.57
Naked dinoflagellates > 15 μm	3703.94	427.03
<i>Alexandrium pseudogonyaulax</i> (Biecheler) Horiguchi ex Kita & Fukuyo	38292.87	3228.35
<i>Dinophysis sacculus</i> Stein	7572.51	793.27
<i>Gymnodinium elongatum</i> Hope	636.17	92.87
<i>Gyrodinium</i> sp.	42369.26	3523.92
<i>Oxytoxum variabile</i> Schiller	368.61	57.90
<i>Prorocentrum micans</i> Ehrenberg	11097.33	1104.48
<i>Prorocentrum triestinum</i> Schiller	879.65	122.96
Peridinioid sp. a	1182.48	158.87
OTHERS		
<i>Dinobryon coalescens</i> Schiller	32.31	7.03
<i>Dinobryon faculiferum</i> (Willén) Willén	37.11	7.93
<i>Dinobryon</i> sp.	32.31	7.03
Undetermined cryptophyceans	113.85	20.93
Cryptophycean sp. 1	264.23	43.39
<i>Hemiselmis</i> sp.	25.82	5.79
<i>Pyramimonas</i> cfr. <i>disomata</i> Butcher	24.97	5.63
<i>Pyramimonas</i> spp.	60.90	12.18
<i>Tetraselmis wetsteinii</i> (Schiller) Throndsen	83.56	16.01
<i>Eutreptiella</i> cfr. <i>marina</i> Cunha	1407.43	184.73
Undetermined phytoflagellates < 10 μm	27.36	6.09
Undetermined phytoflagellates > 10 μm	796.33	59.84

Table 3. List of other taxa recorded in the Fusaro lagoon. Identifiable heterotrophic taxa are marked by an asterisk.

DIATOMS	DINOFLAGELLATES
Centric diatoms > 10 µm	Thecate dinoflagellates < 15 µm
Pennate diatoms < 15 µm	Thecate dinoflagellates > 15 µm
Pennate diatoms > 15 µm	<i>Alexandrium</i> sp.
<i>Achnanthes</i> sp.	'Cachonina-like'
<i>Amphora</i> spp.	<i>Diplopelta symmetrica</i> * Pavillard
<i>Bacteriastrium delicatulum</i> Cleve	<i>Diplopsalopsis latipeltata</i> * Balech & Borgese
<i>Cerataulina pelagica</i> (Cleve) Hendey	<i>Gonyaulax polyedra</i> Stein
<i>Chaetoceros brevis</i> Schütt	<i>Gonyaulax spinifera</i> (Claparède & Lachmann) Diesing
<i>Chaetoceros danicus</i> Cleve	<i>Gyrodinium</i> cfr. <i>fusiforme</i> Kofoid & Swezy
<i>Chaetoceros</i> cfr. <i>debilis</i> Cleve	<i>Polykrikos kofoidi</i> * Chatton
<i>Chaetoceros decipiens</i> Cleve	<i>Proocentrum gracile</i> Schütt
<i>Chaetoceros didymus</i> Ehrenberg	<i>Protoperidinium bipes</i> * (Paulsen) Balech
<i>Chaetoceros lacinosus</i> Schütt	<i>Protoperidinium bispinum</i> * (Schiller) Balech
<i>Chaetoceros</i> cfr. <i>perpusillus</i> Cleve	<i>Protoperidinium</i> cfr. <i>breve</i> * (Paulsen) Balech
<i>Chaetoceros wighamii</i> Brightwell	<i>Protoperidinium diabolus</i> * (Cleve) Balech
<i>Chaetoceros</i> spp. (spores)	<i>Protoperidinium hirobis</i> * (Abé) Balech
<i>Cocconeis scutellum</i> Ehrenberg	<i>Protoperidinium parthenopes</i> * Zingone & Montresor
<i>Cocconeis</i> spp.	<i>Protoperidinium quinquecorne</i> * (Abé) Balech
<i>Coscinodiscus</i> sp.	<i>Protoperidinium</i> spp.*
<i>Cyclotella</i> spp.	<i>Pyrophacus horologii</i> Stein
<i>Dactyliosolen blavyanus</i> (H. Peragallo) Hasle	<i>Scrippsiella trochoidea</i> (Stein) Loeblich III
<i>Grammatophora marina</i> (Lyngbye) Kützing	'Scrippsiella-like'
<i>Grammatophora</i> sp.	<i>Thoracosphaera heimii</i> (Lohmann) Kamptner
<i>Hemiaulus sinensis</i> Greville	
<i>Lauderia annulata</i> Cleve	OTHERS
<i>Leptocylindrus danicus</i> Cleve	<i>Calycomonas</i> cfr. <i>wulffii</i> * Conrad & Kufferath
<i>Leptocylindrus minimus</i> Gran	<i>Ciliophrys infusionum</i> * Cienkowski
<i>Licmophora</i> sp.	<i>Meringosphaera mediterranea</i> Lohmann
<i>Melosira</i> cfr. <i>nummuloides</i> (Dillwyn) Agardh	<i>Leucocryptos</i> sp.*
<i>Nitzschia prolongatoides</i> (Manguin) Hasle	Undetermined prasinophyceans
<i>Nitzschia</i> sp.	<i>Pseudoscourfieldia marina</i> (Throndsen) Manton
<i>Pleurosigma</i> sp.	<i>Tetraselmis</i> sp.
<i>Proboscia alata</i> (Brightwell) Sundström	<i>Chrysochromulina pringsheimii</i> Parke & Manton
<i>Rhabdonema minutum</i> Kützing	<i>Phaeocystis</i> sp.
<i>Rhizosolenia fragilissima</i> Bergon	Undetermined coccolithophorids
<i>Rhizosolenia setigera</i> Brightwell	<i>Anoplosolenia brasiliensis</i> (Lohmann) Deflandre
<i>Sriatella unipunctata</i> (Lyngbye) Agardh	<i>Emiliania huxleyi</i> (Lohmann) Hay & Mohler
<i>Thalassionema bacillaris</i> (Heiden) Kolbe	Undetermined euglenophyceans
<i>Thalassionema nitzschioides</i> (Grunow) Hustedt	<i>Eutreptiella</i> sp.
<i>Thalassiosira allenii</i> Takano	Undetermined cyanophyceans
<i>Thalassiosira mediterranea</i> (Schröder) Hasle	<i>Spirulina</i> sp.
<i>Thalassiosira</i> spp.	<i>Paulinella ovalis</i> * (Wulff) Johnson, Hargraves & Sieburth

lation from February onwards (Fig. 4a). Variations in density and species composition can be schematically grouped into four periods of different lengths.

In the first period, from December to January, cell numbers did not exceed 10.2×10^6 cells l^{-1}

in surface waters. The dominant species in this period was *Prorocentrum micans*, which reached 92.5% of total cell numbers on 8 January, while small phytoflagellates including small cryptophyceans were also abundant. At times, *Prorocentrum micans* cells containing the parasitic di-

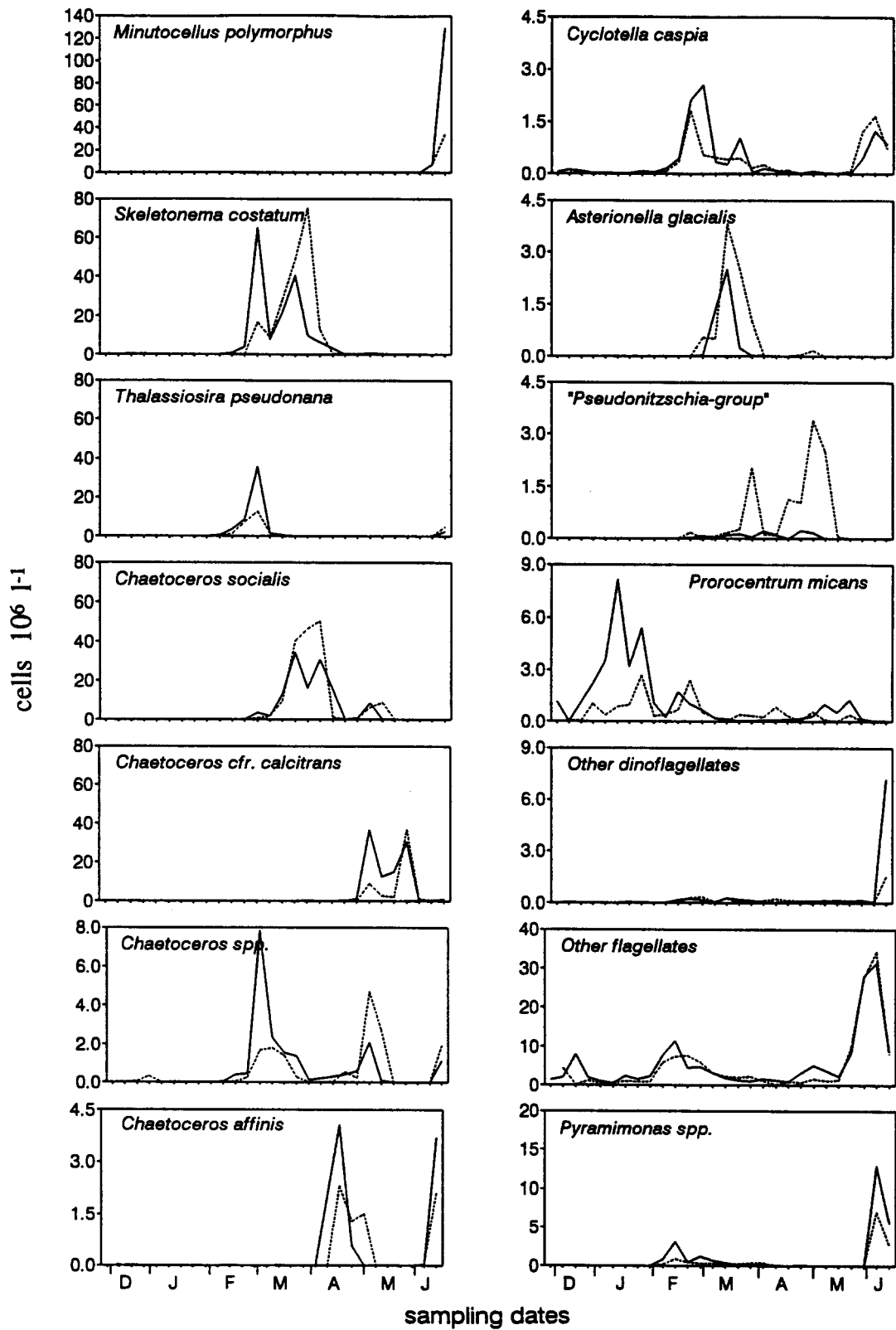


Fig. 3. Temporal variations of the most abundant autotrophic taxa at 0 m (solid line) and at the 4.5 m depth (dashed line).

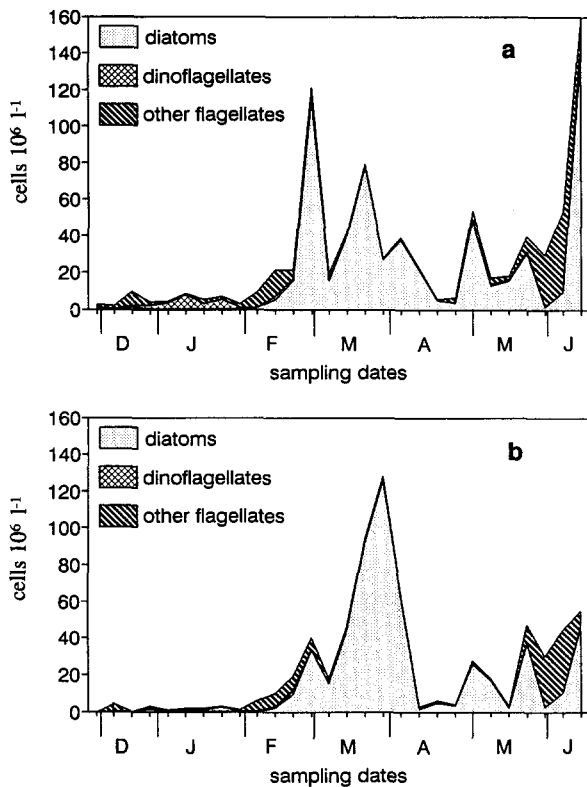


Fig. 4. Temporal variations for total cell numbers of different phytoplankton groups at 0 m (a) and at the 4.5 m depth (b). Identifiable heterotrophic species are not included.

noflagellate *Amoebophrya ceratii* (Koeppen) Cachon were observed. Diatoms, mainly *Skeletonema costatum* and several *Cyclotella* species, did not exceed 16% of total cell numbers in this period. Following the decline of the *P. micans* bloom at the end of January, small flagellates dominated the population for a couple of sampling dates.

In the second period, from the second half of February to the end of May, diatoms dominated the population reaching maximum concentrations of 114.92×10^6 cells l^{-1} (94.3% of total cell number) on 26 February. In these months, blooms of different, small-sized species (*Cyclotella caspia*, *Thalassiosira pseudonana*, *Skeletonema costatum*, *Chaetoceros socialis*, *C. affinis*, *C. cfr. calcitrans*) succeeded and overlapped one another (Fig. 3). These blooms persisted for a number of weeks (4 for *T. pseudonana* to 8 for *S. costatum*) with one

or two peaks in cell concentrations. In most cases blooms of more than one species co-occurred (Fig. 3), whereas in a few cases (*C. cfr. calcitrans*, *M. polymorphus*) the dominant species comprised up to 80% of the entire population. It is also worth reporting that epiphytic, colorless flagellates, such as *Bicosoeca* sp., were often found in association with *Skeletonema costatum*, *Thalassiosira pseudonana* and *Chaetoceros* spp. and ciliate suctorians were seen on *Chaetoceros affinis* colonies. Small, unidentified flagellates were the second major group in this period, reaching 45.8% on 23 April, whereas dinoflagellates, mainly represented by *Prorocentrum micans*, comprised concentrations higher than 5.7% only in May.

At the end of May – beginning of June, diatoms rapidly declined for a couple of sampling dates, whereas small phytoflagellates reached their highest concentration (44.5×10^6 cells l^{-1}) for the whole sampling period. Particularly notable was the bloom on 11 June due mainly to *Pyramimonas* cfr. *disomata* and various cryptophyceans. In late spring, several dinoflagellate species, such as *Dinophysis sacculus*, *Prorocentrum triestinum*, *Gymnodinium elongatum*, *Alexandrium pseudogonyaulax*, were also recorded.

Finally, on the last sampling date (18 June), maximum cell numbers of 159.9×10^6 cells l^{-1} were registered in surface waters. The phytoplankton population at this time was dominated by a bloom of a small, single-cell diatom, *Minutocellus polymorphus*, which represented 80.8% of the total population.

With the exception of a few sampling dates, phytoplankton densities in the 4.5 m depth samples were lower than those recorded at the surface (Fig. 4b). Maximum cell numbers of 128.5×10^6 cells l^{-1} were registered on 26 March, corresponding to a bloom of *Skeletonema costatum* and *Chaetoceros socialis*. On the whole, phytoplankton communities at depth did not differ greatly from those at the surface as reflected by the percentage similarity index (Fig. 5). However, two main periods were noted having marked differences. The first, 18 December–15 January, had notably lower concentrations of *Prorocentrum micans* in bottom waters, whereas in the second

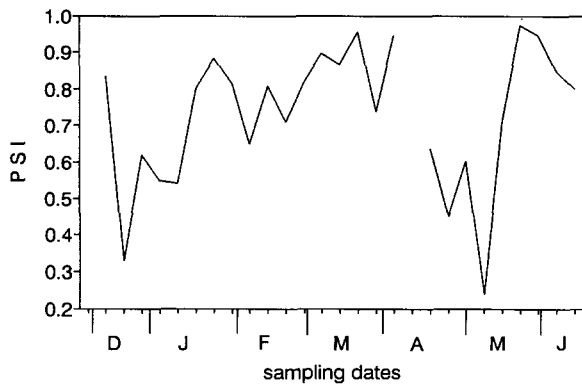


Fig. 5. Percentage Similarity Index (PSI) between surface and 4.5 m samples.

period (23 April–7 May) differences were mainly due to heterogeneity in the vertical distribution of diatoms, such as *Chaetoceros* cfr. *calcitrans*, *C. socialis* and *Nitzschia* spp. belonging to the *Pseudonitzschia*-group (Fig. 3). In most cases, these diatoms were more abundant in surface waters at the beginning of their bloom and at depth after one or more weeks. In bottom waters, a considerable number of *Chaetoceros* species, mainly *C. socialis* and *C. seiracanthus*, were found to contain resting spores. At times, relatively high numbers (up to 0.5×10^6 colonies l^{-1}) of unidentified colonial cyanophyceans were recorded, which were probably sampled only when the bottle went too close to the bottom, as indicated by the presence of abundant detritus.

A completely different trend from cell numbers was observed for biomass values expressed as phytoplankton carbon content (Fig. 6). At the surface (Fig. 6a), highest biomass values, with a peak of $9.5 \text{ mg C } l^{-1}$ on 8 January, were measured in early winter, while in the following period lower values showing a reduced range of variation ($0.3\text{--}2.3 \text{ mg C } l^{-1}$) were recorded. With a single exception on 11 December, *Prorocentrum micans* contributed 70.9–99.9% of the total biomass from the beginning of the sampling period until the 19 February and throughout May. The contribution of diatoms to the total biomass was relevant in March–April and on the last sampling date. Small phytoflagellates were in most cases scarcely important and constituted a significant part of the

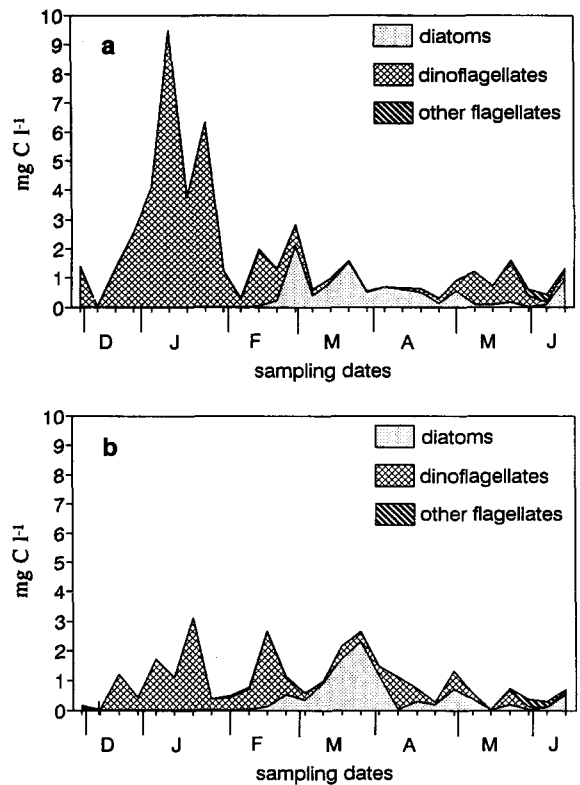


Fig. 6. Temporal variations for total carbon content of different phytoplankton groups at 0 m (a) and at the 4.5 m depth (b). Identifiable heterotrophic species are not included.

total biomass only on the last sampling dates. As compared to surface waters, at the bottom (Fig. 6b), biomass values were notably lower (up to $3.1 \text{ mg C } l^{-1}$ on 22 January), especially in the first part of the sampling period, due to the uneven vertical distribution of *P. micans* in the water column. As in surface waters, *P. micans* and small diatom species were the main contributors to the total standing crop in these waters.

The correlation between chlorophyll and carbon concentrations was very high in surface waters ($r = 0.96$, $n = 26$), whereas it appeared less evident for the 4.5 m depth ($r = 0.77$, $n = 26$), which is explainable on the basis of possible contamination of these samples with macroalgae and detritus accumulating at depth. The carbon:chlorophyll ratio, which was only calculated for surface samples, ranged from 13.4 to 373.3, with an average of 104.8.

During the whole sampling period, a number of heterotrophic species were recorded in the lagoon (Fig. 7). Among these, small chrysophyceans (*Calycomonas* cfr. *wulffii*) and choanoflagellates at times attained very high concentrations (up to 4.3×10^6 and 2.9×10^6 respectively). Medium and large sized heterotrophic dinoflagellates showed different patterns of temporal variations. *Diplopsalopsis latipeltata*, *Diplopelta symmetrica* and *Protoperidinium bispinum* reached higher concentrations in early winter and in May, whereas *Polykrikos kofoidi* was only recorded from late January through April.

Discussion

As expected of coastal lagoons, which are considered highly productive environments (Votolina, 1975; Nixon, 1982; Carrada & Fresi, 1988), values for chlorophyll, biomass and cell concentrations measured in the Fusaro lagoon in the period of investigation were generally high. Due to differences in cell size and single species biomass, a poor correspondence was found between cell numbers and chlorophyll, as well as between cell numbers and total carbon content. The carbon:chlorophyll ratio was in most cases higher as compared to values of 20–60 commonly reported in the literature (Parsons *et al.*, 1961; Steele, 1962). However, it should be noted that the latter values generally refer to open waters, since very few studies conducted in marine coastal waters and lagoons include both chlorophyll and phytoplankton carbon content evaluations. The striking difference between phytoplankton cell number and carbon content which was found in this study strongly supports the opportunity of including both kinds of information in phytoplankton studies.

Maximal chlorophyll values which were measured in the Fusaro lagoon are in the upper range reported to date for other lagoons and, for the Mediterranean Sea, are only comparable to values recorded in proximity to the sea-mouth of the Berre Lagoon, France in 1985 (Arfi, 1989), in the Sacca del Canarin, Italy (Solazzi *et al.*,

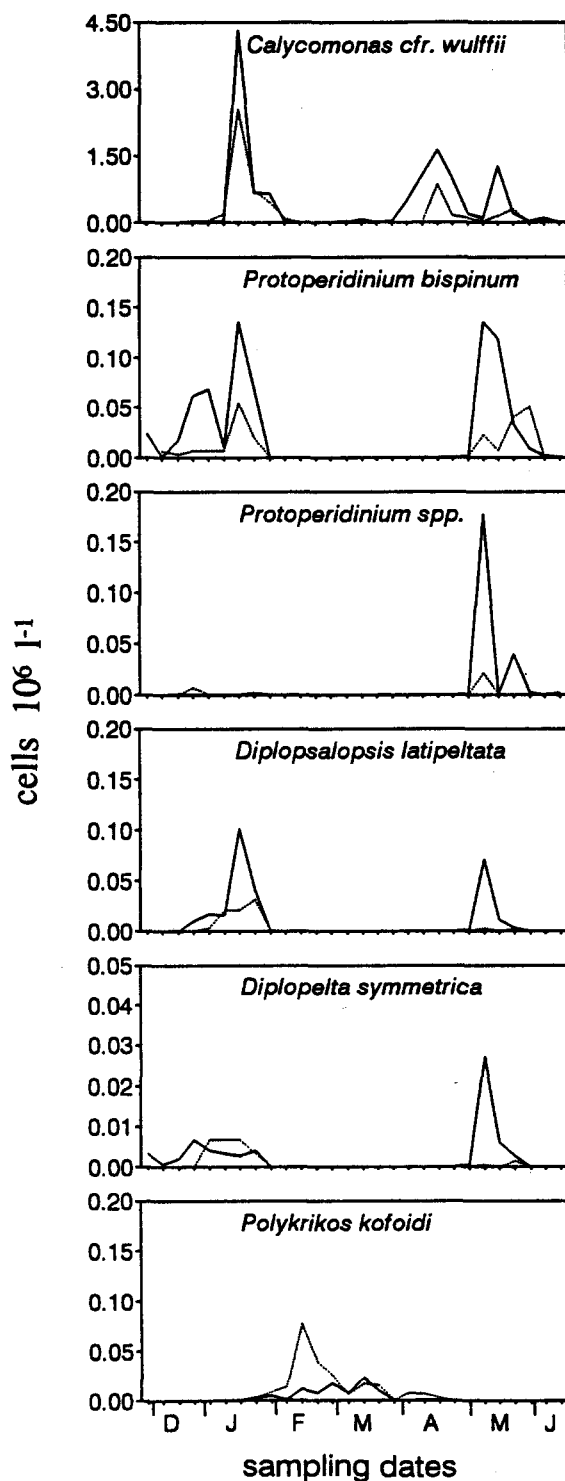


Fig. 7. Temporal variations of the most abundant heterotrophic taxa at 0 m (solid line) and at the 4.5 m depth (dashed line).

1981–82) and in the Manguio lagoon, France (Vaulot & Frisoni, 1986). The high values observed are consistent with the general eutrophic condition of the lagoon which derives from the presence of untreated discharges along its banks (Rigillo Troncone, 1990).

More peculiar are the temporal variations and succession of phytoplankton species in the lagoon. The maximal standing stock was registered in January, which corresponds to minimal annual production in the majority of Mediterranean lagoons (Magazzù, 1977). In spring, notwithstanding the high cell numbers recorded, total biomass was much lower due to the small size of the blooming species. Obviously, we cannot exclude that other biomass peaks can occur in the lagoon later in the year, possibly in autumn, as described by Carrada *et al.* (1991) for October 1988.

Quantitative and qualitative differences in species distribution between surface and bottom waters were registered in the lagoon in several sampling dates. In winter, they were mainly attributable to the capacity of *Prorocentrum micans* of actively swimming towards the surface, whereas in spring passive sinking of aged diatom populations resulted in higher cell numbers in bottom waters. In any case, these differences imply that vertical gradients for physical parameters may occur and stabilize the water column. In the course of this study, which included the period of the year when heavy rainfalls and scarce evaporation result in minimum salinity values, salinity was often lower in surface waters (Table 1).

In the period of investigation, we observed numerous epiphytic, parasitic and phagotrophic events within the plankton community. In many cases, diatoms were colonized by zooflagellates such as *Bicosoeca* sp. or by Suctorians and *P. micans* was often parasitized by *Amoebophrya ceratii*, which is considered capable of contributing to the decline of dinoflagellate blooms (Nishitani *et al.*, 1984). Some of the frequently recorded heterotrophic species, such as *Diplopelta symmetrica* and *Diplopsalopsis latipeltata*, were observed to feed on *P. micans* in mixed cultures (Dale *et al.*, 1993) and reached their maximum concentrations in correspondence of maximum densities of their

prey (Figs 3 and 7). All these interactions among species would be frequently enhanced in lagoons as well as in harbours and other semi-enclosed areas, possibly due to the proximity to the bottom or to the benthic vegetation (Margalef, 1969).

On the whole, the main bulk of the phytoplankton population was constituted by less than 20 species, due to the persistence and re-occurrence of single species. Although the sampling period did not include the whole year, and hence the species number could be underestimated, some notable differences were evident in phytoplankton composition in the lagoon as compared to coastal waters of the Gulf of Naples (Scotto di Carlo *et al.*, 1985; Zingone, unpublished data). Only a few of the small diatom species which bloomed in the lagoon in spring, such as *Chaetoceros* cfr. *calcitrans*, *C. socialis* and *Cyclotella caspia*, produce comparable blooms in coastal waters of the Gulf of Naples in the same period of the year, whereas other species such as *Cerataulina pelagica*, *Leptocylindrus* and *Rhizosolenia* spp., which are commonly and often massively present in coastal waters of the Gulf of Naples, were only occasionally recorded in the lagoon. It is also worth noting the almost complete absence from the lagoon of *Emiliania huxleyi* and other coccolithophorids, which represent a high percentage of the phytoplankton population in Tyrrhenian coastal waters in winter and early spring (Marino *et al.*, 1984). Other notable differences from external coastal waters concern the presence and at times the dominance of species such as *Prorocentrum micans* and *Thalassiosira pseudonana*, which have been rarely recorded in coastal Gulf of Naples waters and of other species, such as *Minutocellus polymorphus* and *Alexandrium pseudogonyaulax*, which have never been found there. The massive presence of *Gymnodinium catenatum* and *Gymnodinium* sp. in autumn (Carrada *et al.*, 1988; Carrada *et al.*, 1991) also represents a distinct feature for the lagoon as compared to external coastal waters.

Some of the above mentioned species, such as *M. polymorphus* and *T. pseudonana*, are typical of enclosed and semi-enclosed basins, or estuarine waters, which may at times be heavily eutrophied

and where they often form intense blooms (Guillard & Ryther, 1962; Watanabe *et al.*, 1980; Smayda & Villareal, 1989). As for *P. micans*, it is very common in Mediterranean coastal lagoons as well as in other coastal and estuarine waters in the rest of the world, although it is generally reported as typical of summer and early autumn phytoplankton (De Angelis, 1962; Giacobbe & Maimone, 1990).

The scarcity of phytoplankton and zooplankton species and the biological independence of the lagoon from the adjacent sea had already been noted about a century ago, when the lagoon was exploited for oyster farming (Carazzi, 1900). Therefore it can hardly be explained based only on eutrophication, which is often responsible for strong selection and consequent species number reduction in some coastal environments (Pucher-Petković & Marasović, 1980). From a functional point of view, the Fusaro lagoon shows close affinities with the lagoons of the Italian Pontine region (Mid-Tyrrhenian coast). Although characterized by a notably wider range of variability for salinity and temperature, these lagoons share with the Fusaro lagoon the scarcity of tidal range and the generally poor exchange with the sea, which prevent massive intrusion of seawater. As a consequence, phytoplankton populations in these lagoons, although mainly of marine origin, are not the result of passive transport: marine inflow only acts as an insemination for phytoplankton species (Sommani, 1954), which are then selected by the environment. However, as already pointed out for Polychaetes (Sordino *et al.*, 1989), in the Fusaro lagoon species are not selected against a salinity gradient, as often occurs in most lagoons.

In this environment, the scarcity of hydrographic exchange with the sea, which has always been recognized as a key factor, both in theoretical and applied terms, and has recently been further emphasized by Guelorget & Perthuisot (1983) in the frame of their 'confinement theory', is not associated with a salinity gradient, as in the case of most coastal lagoons. This peculiar condition allows for the better definition of the effects of confinement on phytoplankton populations, which are markedly different from adjacent

coastal waters, although the mechanisms through which this occurs is open to debate. Undoubtedly, an important role is played by the hydrodynamic regime which may greatly influence phytoplankton populations (Bakker & De Paw, 1974; Levasseur *et al.*, 1984). On the other hand, high water residence times may favour interactions among species, including competition and trophic relationships, which would enhance the role of biological control in driving community patterns.

In the recent past, when the Fusaro lagoon was managed according to rational criteria, by keeping its sea-mouths in efficient working conditions and by exploiting its shellfish and finfish resources, thus removing excess biomass, the seasonal cycles of the different biological compartments had a better defined pattern (Carazzi, 1900; Sacchi & Renzoni, 1962; Carrada, 1973). Nowadays, mismanagement, irrational exploitation and uncontrolled eutrophication have strongly impaired the biological, economical and aesthetic value of this water body.

Acknowledgements

We thank Dr S. Dumontet for kindly providing environmental data and Dr D. Marino for helpful criticism of the manuscript.

References

- Arfi, R., 1989. Annual cycles and budget of nutrients in Berre Lagoon (Mediterranean Sea, France). *Int. Revue ges. Hydrobiol.* 74: 29–49.
- Bakker, C. & N. De Paw, 1974. Comparison of brackish water plankton assemblages of identical salinity ranges in an estuarine tidal (Westerschelde) and stagnant (Lake Veere) environment (S. W. Netherlands). *I. Phytoplankton. Hydrobiol. Bull.* 8: 179–189.
- Carazzi, D., 1900. Ricerche sul plancton del lago Fusaro in rapporto con la ostricoltura. *Boll. Notizie agrarie (Min. Agr. Ind. Comm.)* 30: 1270–1287.
- Carrada, G. C., 1973. Profilo ecologico di una laguna salmastra flegrea: il lago Fusaro. *Archo Oceanogr. Limnol.* 18: 145–164.
- Carrada, G. C. & E. Fresi, 1988. Le lagune salmastre costiere. Alcune riflessioni sui problemi e sui metodi. In G. C. Carrada, F. Cicogna & E. Fresi (eds), *Le Lagune Costiere*:

- Ricerca e Gestione. CLEM, Massa Lubrense (Napoli): 35–56.
- Carrada, G. C., R. Casotti & V. Saggiomo, 1988. Occurrence of a bloom of *Gymnodinium catenatum* Graham in a Tyrrhenian coastal lagoon. Rapp. Comm. int. Mer Médit. 31: 61.
- Carrada, G. C., C. F. Sacchi & M. Rigillo Troncone, 1965. Ricerche sulla valenza ecologica dei Briozoi salmastri. Boll. Pesca Piscicol. Idrobiol. 20: 153–208.
- Carrada, G. C., R. Casotti, M. Modigh & V. Saggiomo, 1991. Presence of *Gymnodinium catenatum* (Dinophyceae) in a coastal Mediterranean lagoon. J. Plankton Res. 13: 229–238.
- Chrétiennot-Dinet, M. J., 1990. Chlorarachniophycées, Chlorophycées, Chrysophycées, Cryptophycées, Euglénophycées, Eustigmatophycées, Prasinophycées, Prymnesiophycées, Rhodophycées et Tribophycées. In A. Sournia (ed.), Atlas du Phytoplancton Marin. Editions C.N.R.S., Paris, France, 261 pp.
- Dale, B., M. Montresor, A. Zingone & K. Zonneveld, 1993. The cyst-motile stage relationships of the dinoflagellates *Diplopelta symmetrica* and *Diplopsalopsis latipeltata*. Europ. J. Phycol., in press.
- De Angelis, C. M., 1962. Distribuzione ed ecologia di alcune specie di dinoflagellati di acque salmastre. Pubbl. Staz. Zool. Napoli 32 (suppl.): 301–314.
- Ferro, R. & G. F. Russo, 1982. Le biocenosi bentoniche del lago Fusaro. II – Malacofauna. Boll. Soc. Natur. Napoli 91: 3–19.
- Giacobbe, M. G. & G. Maimone, 1990. Abbondanza fitoplanctonica negli stagni salmastri dell'area lagunare di Oliveri-Tindari. Oebalia 16 (suppl.): 671–673.
- Guelorget, O. & J. P. Perthuisot, 1983. Le domaine paralique. Expressions géologiques, biologiques et économiques du confinement. Trav. Lab. Géol. E. N. S., Paris, 16, 136 pp.
- Guillard, R. R. L. & J. H. Ryther, 1962. Studies of marine planktonic diatoms. I. *Cyclotella nana* Hustedt, and *Detonula confervacea* (Cleve) Gran. Can. J. Microbiol. 8: 229–239.
- Korringa, P. & H. Postma, 1957. Investigations into the fertility of the Gulf of Naples and adjacent salt water lakes, with special reference to shellfish cultivation. Pubbl. Staz. Zool. Napoli 29: 229–284.
- Larsen, J. & A. Sournia, 1991. The diversity of heterotrophic dinoflagellates. In J. Larsen & D. J. Patterson (eds), The Biology of Free-Living Heterotrophic Flagellates. Systematics Association Special Volume 45, Clarendon Press, Oxford: 313–332.
- Leccese, A. & V. Speziale, 1967. I laghi Fusaro e Miseno e l'inquinamento delle loro acque. Jonica Editrice, Taranto, 87 pp.
- Levasseur, M., J. C. Therriault & L. Legendre 1984. Hierarchical control of phytoplankton succession by physical factors. Mar. Ecol. Prog. Ser. 19: 211–222.
- Magazzù, G., 1977. Usefulness of the Marsala lagoon for aquaculture. I. Nutrients and primary production. Rapp. Comm. int. Mer Médit. 24: 81–82.
- Magazzù, G. & S. Panella, 1969. Ciclo di osservazioni chimico-fisiche nel lago del Fusaro. Boll. Pesca Piscicol. Idrobiol. 24: 171–183.
- Margalef, R., 1967. Some concepts relative to the organization of plankton. Oceanogr. mar. Biol. ann. Rev. 5: 257–289.
- Margalef, R., 1969. Comunidades planctónicas en lagunas litorales. In A. Ayala-Castañares & F. B. Phleger, Lagunas Costeras. Un Simposio. Mem. Simp. intern. Lagunas costeras. UNAM-UNESCO, Mexico: 545–562.
- Margalef, R., 1978. Life-forms of phytoplankton as survival alternatives in an unstable environment. Oceanol. Acta 1: 493–509.
- Marino, D., M. Modigh & A. Zingone, 1984. General features of phytoplankton in the Gulf of Naples and adjacent waters. In O. Holmes-Hansen, L. Bolis & R. Gilles (eds), Marine Phytoplankton and Productivity. Lect. Notes on coast. and estuar. Stud. 8: 98–100.
- Nishitani, L., R. Hood, J. Wakeman & K. K. Chew, 1984. Potential importance of an endoparasite of *Gonyaulax* in paralytic shellfish poisoning outbreaks. In E. P. Ragelis (ed.), Seafood Toxins, Amer. chem. Soc., Symp. Ser. 262: 139–149.
- Nixon, S. W., 1982. Nutrient dynamics, primary production and fisheries yields of lagoons. In P. Lasserre & H. Postma (eds), Coastal Lagoons, Oceanol. Acta (suppl.): 357–371.
- Parsons, T. R., K. Stephens & J. D. H. Strickland, 1961. On the chemical composition of 11 species of marine phytoplankters. J. Fish Res. Bd Can. 18: 1001–1016.
- Procaccini, G. & M. B. Scipione, 1992. Observations on the spatio-temporal distribution of Crustacean Amphipods in the Fusaro coastal lagoon (Central Tyrrhenian Sea; Italy) and some notes on their presence in Mediterranean lagoons. P.S.Z.N.I: Mar. Ecol. 13: 203–224.
- Pucher-Petković, T. & I. Marasović, 1980. Développement des populations phytoplanctoniques caractéristiques pour un milieu eutrophisé (Baie de Kaštela, Adriatique centrale). Acta adriat. 21: 79–94.
- Rigillo Troncone, M., 1969. Note idrografiche su alcuni ambienti periferici del lago Fusaro. Pubbl. Staz. Zool. Napoli 37: 1–11.
- Rigillo Troncone, M., 1990. Criteri di contenimento d'impatto per il recupero di una risorsa ambientale. Il Lago Fusaro. Ingegneria ambientale 19: 734–745.
- Russo, G. F. & R. Ferro, 1980. Le biocenosi bentoniche del lago Fusaro. I – Osservazioni faunistiche. Boll. Soc. Natur. Napoli 89: 1–13.
- Sacchi, C. F. & A. Renzoni, 1962. L'écologie de *Mytilus galloprovincialis* (LAM.) dans l'étang littoral du Fusaro et les rythmes annuels et nyctéméraux des facteurs environnants. Pubbl. Staz. Zool. Napoli 32 (suppl.): 255–293.
- SCOR-UNESCO, 1966. Determination of photosynthetic pigments in sea water. Monographs on Oceanographic Methodology, 64 pp.

- Scotto di Carlo, B., C. R. Tomas, A. Ianora, D. Marino, M. G. Mazzocchi, M. Modigh, M. Montresor, L. Petrillo, M. Ribera d'Alcalà, V. Saggiomo & A. Zingone, 1985. Uno studio integrato dell'ecosistema pelagico costiero del Golfo di Napoli. *Nova Thalassia* 7 (suppl. 3): 99–128.
- Smayda, T. J. & T. A. Villareal, 1989. The 1985 'browntide' and the open phytoplankton niche in Narragansett Bay during summer. In E. M. Cosper, V. M. Bricej & E. J. Carpenter (eds), *Novel Phytoplankton Blooms. Coastal est. Studies* 35: 159–187.
- Solazzi, A., C. Tolomio, M. Marzocchi, C. Salafia, F. Cavolo & M. Montresor, 1981–82. Delta del Po. III – Ricerche fitoplanctoniche e idrologiche nella Sacca del Canarin (novembre 1978–ottobre 1979). *Nova Thalassia* 5: 19–30.
- Sommani, E., 1954. Il lago Lungo – Caratteristiche idrobiologiche di un ambiente salmastro. Osservazioni generali e biologiche. *Boll. Pesca Piscicol. Idrobiol.* 9: 30–53.
- Sommer, U. (ed.), 1989. *Plankton Ecology. Succession in Plankton Communities.* Springer Verlag, Berlin, 369 pp.
- Sordino, P., M. C. Gambi & G. C. Carrada, 1989. Spatio-temporal distribution of Polychaetes in an Italian coastal lagoon (Lago Fusaro, Naples). *Cah. Biol. mar.* 30: 375–391.
- Steele, J. H., 1962. Environmental control of photosynthesis in the sea. *Limnol. Oceanogr.* 7: 137–150.
- Strathmann, R. R., 1967. Estimating the organic carbon content of phytoplankton from cell volume or plasma volume. *Limnol. Oceanogr.* 12: 411–418.
- Vaulot, D. & G. F. Frisoni, 1986. Phytoplanktonic productivity and nutrients in five Mediterranean lagoons. *Oceanol. Acta* 9: 57–63.
- Voltolina, D., 1975. The phytoplankton of the lagoon of Venice: November 1971–November 1972. *Pubbl. Staz. Zool. Napoli* 39: 206–340.
- Watanabe, K., A. Hino & R. Hirano, 1980. Some observations on 1978 red tide blooms in Shonai Estuary, Shizuoka Prefecture. *Bull. Plankton Soc. Japan* 27: 87–98.
- Whittaker, R. H., 1952. A study of summer foliage insect communities. *Ecol. Monogr.* 22: 1–44.
- Zingone, A., G. Honsell, D. Marino, M. Montresor & G. Social, 1990. Fitoplancton. In M. Innamorati, D. Marino, I. Ferrari & M. Ribera d'Alcalà (eds), *Metodi nell'Ecologia del Plancton Marino.* *Nova Thalassia* 11: 183–198.