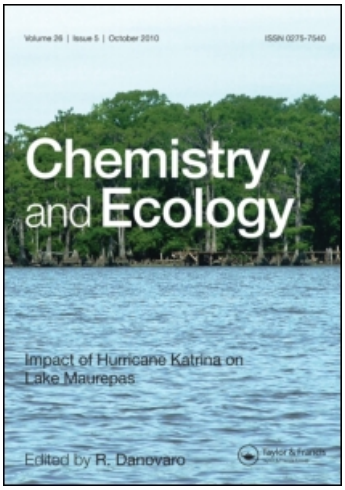

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Carbon partitioning among the first trophic levels in the North Western Adriatic Basin

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CARBON PARTITIONING AMONG THE FIRST TROPHIC LEVELS IN THE NORTH WESTERN ADRIATIC BASIN

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In the frame of PRISMA II Project samples for plankton analyses were carried out during four cruises (June, 1996; February and June, 1997; February, 1998) in order to assess the relative importance in term of biomasses of the three main size fractions (pico- $<2\,\mu m$, nano- 2–20 μm and micro-plankton $>20\,\mu m$). Spatial and temporal distribution of the three plankton fractions were described as abundance and contribution to the total carbon content in an area between Po River mouth and Rimini. The relative contribution of picoplankton resulted higher in the offshore zone, while that of nanoplankton in the inshore waters. In February 1998 microphytoplankton, mainly constituted by diatoms, was very abundant in the inshore waters. Micro-zooplankton was always very scarce. Cluster analyses performed on these data grouped the stations on the basis of their community structure, and agreed with the hydrological features. Small size classes contributed more significantly to the total plankton carbon content in most of the situations. Microplankton fraction contribution was relevant only during spring diatom bloom of February 1998 and with a less extent in the confined coastal summer blooms.

Keywords: Carbon partitioning; trophic level; Adriatic Basin

INTRODUCTION

A typical fall-winter feature of the northern Adriatic is the persistence of a frontal system separating the inshore area close to the Po River mouth from the offshore remaining area (Franco and Michelato, 1992). In this period the Po outflows form a coastal layer of buoyant water when the rest of the basin is generally vertically mixed. In late spring and summer, a strong pycnocline forms across the whole basin and the Po river outflow spreads eastward into the interior of the basin. During both periods, the rate of the biological processes is enhanced by the freshwater input (Malej *et al.*, 1999). Consequently the retention and diffusion of diluted waters control the biogeochemical fluxes along the water column in the frontal system and in its inshore and offshore sides. The coastal area off the Po River mouth is characterized by a high but variable phytoplankton biomass and production (Franco, 1973; Gilmartin and Revelante, 1981;

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Hopkins, in press). A marked west to east gradient of standing crop and production was also observed (Smodlaka and Revelante, 1983). Northern Adriatic phytoplankton is generally characterized by a nanoplankton fraction that exhibits the highest abundance, particularly in the coastal areas. Diatoms, whose temporal and spatial distribution is tightly coupled with pulsing riverine inputs, mainly constitute the microphytoplankton fraction. Their highest abundance generally corresponds to spring and autumn, and is more remarkable in the coastal waters (Fonda Umani, 1996). Besides the red tide events (Sellner and Fonda Umani, 1999) occurred in the 1970's and 1980's, dinoflagellates are scarce and characteristic of a summer period. For this area, the first data on picoplankton were obtained within the frame of PRISMA 1 project, and indicated that the contribution of autotrophic picoplankton to the total autotrophic biomass is higher in the most oligotrophic offshore waters where micro-phytoplankton biomass is lower. Heterotrophic bacteria are more abundant in the coastal waters where the production of organic matter is higher (Fonda Umani, 1998). Regarding the functioning of the grazing chain and the microbial food web, results of PRISMA 1 show a higher number of relationships among different classes of prey and predators in spring and in the coastal area where the trophic level is higher, suggesting that the increase in primary production enhances the predation rates, thus resulting in a more efficient transfer of energy towards the upper level consumers (Del Negro *et al.*, in press).

One of the main aims of the PRISMA II project – subproject Biogeochemical fluxes to assess the efficiency of the ecological processes at the frontal system and to evaluate the role of sedimentation against advective transport. In this context it is a fundamental issue to investigate the organic matter and inorganic nutrients recycling operated by the microbial community and by the "grazing chain" (Azam, 1998). One of the first objectives related to this approach was to quantify the contribution to the total carbon budget of the three size plankton classes ($< 2\,\mu m$, 2–20 μm, $>20\,\mu m$) in the two seasonal situations. It is well known that the classical grazing food chain develops in shallow turbulent environments where nutrient availability is pulsed or episodic. A large phytoplankton cells blooms appears in spring and following episodic nutrient enrichment of the euphotic zone, because their predators are insufficient in controlling their population sizes. On the opposite, the microbial food web is typical of low energy environment, mostly based on regeneration processes (Kiorboe, 1996). The present study aimed to analyse the temporal and spatial variation of pico-, nano-, microphyto- and micro-zooplankton distribution, both in abundance and biomass as carbon content, during four seasonal cruises to evaluate the relative importance of different food webs.

MATERIALS AND METHODS

In the Adriatic Sea, four seasonal cruises were carried out from June 1996 to February 1998. Six stations were selected along transects crossing the frontal system in the area between Po River mouth and Rimini (Fig. 1). Sampling were carried out by means of a SBE 32 Carousel equipped with multiparametric probe SBE 9/11 plus (SEABIRD Electronics) and 10 l Niskin bottles at 3 depths (surface, intermediate and bottom) for micro-zoop1ankton and six depths for the other parameters. Subsamples (100 ml) of buffered formalin preserved water (final concentration of 2%) were stained with DAPI (4,6-diamidino-2-phenylindole) according to Porter and Feig (1980) for picoplankton

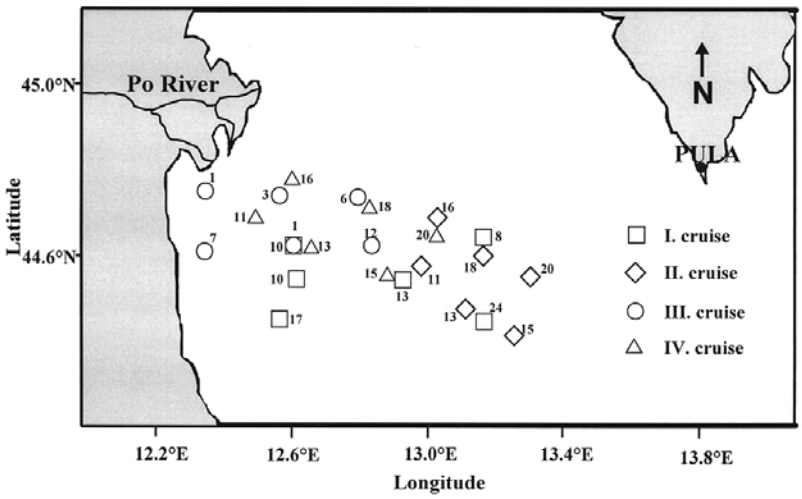

FIGURE 1 Map of sampling stations of four PRISMA II cruises.

analysis; subsamples (250 ml) of glutaraldehyde preserved water (final concentration of 1%) were stained with DAPI and primulin for nanoplankton analysis (Caron, 1983; Martinussen and Thingstad, 1991). Subsamples of 500 ml and 2000 ml of buffered formalin preserved water (final concentration of 3%) were submitted to microphyto- and microzoo-plankton analyses.

Enumeration of pico- and nano-planktonic organisms were done by a Leitz Dialux microscope equipped with epifluorescent light (50 W HBO mercury lamp) and a 100X oil immersion objective. Picoplankton abundance was converted to carbon by assuming at 20 fg cell^{-1} (Lee and Fuhrman, 1987). Nanoplankton biovolume was estimated measuring length and width of an average of 100 cells per sample and converted into biomass by assuming a content of 0.11 pg C μm^{-3} (Edler, 1979).

Microphytoplankton counting and identification was carried out according to the Utermöhl method (Zingone *et al.*, 1990). The cell volume was calculated on linear cell sizes and subsequently converted in carbon biomass according to Strathmann equations (Edler, 1979; Smayda, 1978).

Enumeration and sizing of representative subsamples of microzooplankton were based on the inverted microscope method according to Utermöhl (1958). Measurements of the specimens were made by using a calibrated ocular micrometer. Calculate body or lorica volumes were converted to tintinnid carbon content using the equation proposed by Verity and Langdon (1984). Ciliate and nauplius volume was converted to carbon using the factor of Putt and Stoecker (1989).

Cluster analysis was performed on quantitative data using the correlation coefficient and obtaining a dendrogram for each cruise (Burba *et al.*, 1992).

RESULTS

Cell concentrations of different planktonic assemblages are reported in Table I. In June 1996 micro-phytoplankton and micro-zooplankton showed the highest abundance in

TABLE I Cell concentrations (n. cell l^{-1}) of different planktonic assemblages in the Northern Adriatic Basin

June 1996	**st1 0 m**	**15 m**	**26 m**	**st8 0 m**	**15 m**	**36 m**	**st10 0 m**	**5 m**	**30 m**	**st13 0 m**	**5 m**	**38 m**	**st17 0 m**
Autotrophic picoplankton	4.36E+07	6.84E+07	2.01E+07	2.83E+07	4.10E+07	2.55E+07	4.65E+07	1.63E+07	4.30E+07	1.03E+08	8.32E+06	1.37E+08	8.26E+07
Heterotrophic picoplankkton	7.40E+08	3.75E+08	4.88E+08	3.15E+08	9.36E+08	3.16E+08	3.47E+08	1.22E+08	1.99E+08	4.90E+08	1.73E+08	9.28E+08	3.77E+08
Autotrophic nanoplankton	2.11E+06	1.67E+06	5.12E+05	1.45E+06	1.63E+06	6.38E+05	1.18E+06	1.99E+05	5.89E+05	2.70E+05	4.40E+05	1.16E+05	4.57E+05
Heterotrophic nanoplankton	8.36E+05	7.32E+05	6.16E+05	6.77E+05	8.14E+05	3.03E+05	7.15E+05	3.19E+05	4.51E+05	9.85E+05	8.14E+05	3.09E+05	1.49E+05
Diatoms	4.03E+05	2.52E+03	4.24E+03	1.80E+04	1.48E+03	1.99E+03	1.91E+05	1.41E+05	3.20E+03	3.37E+05	7.86E+04	3.24E+03	2.13E+05
Dinoflagellates	5.42E+04	5.44E+03	7.08E+03	1.76E+03	1.88E+03	2.36E+03	1.96E+04	3.00E+04	8.00E+02	2.63E+04	1.78E+04	7.80E+02	2.39E+04
Coccolithophorids	0.00E+00	0.00E+00	4.00E+01	8.00E+01	2.00E+01	3.20E+02	0.00E+00	0.00E+00	2.00E+01	1.60E+02	0.00E+00	9.40E+02	8.00E+01
Total phytoflagellates	1.46E+04	4.00E+01	8.00E+01	0.00E+00	6.60E+02	3.40E+02	6.40E+02	4.40E+03	1.00E+02	1.76E+03	2.97E+03	1.60E+02	3.20E+02
Others	1.16E+05	7.56E+03	1.48E+03	2.40E+02	1.88E+03	1.92E+03	5.84E+03	2.24E+04	8.00E+01	1.38E+04	1.35E+04	7.00E+02	2.95E+04
Ciliates other than Tintinnids	3.43E+03	6.12E+02	4.45E+02	6.68E+02	4.62E+02	2.13E+03	1.88E+03	7.28E+02	2.94E+02	9.64E+02	3.98E+02	3.68E+02	8.14E+02
Tintinnids	3.60E+01	3.20E+01	2.00E+02	1.52E+02	1.40E+01	1.54E+02	2.80E+01	4.00E+00	3.20E+02	1.40E+01	4.00E+00	1.26E+02	1.00E+01
Micrometazoa	2.08E+02	4.00E+01	4.50E+01	5.40E+01	1.60E+01	1.60E+01	1.96E+02	1.56E+02	1.80E+01	1.40E+01	7.60E+01	3.20E+01	1.44E+02
February 1997	**st11 3 m**	**26 m**	**42 m**	**st13 1 m**	**12 m**	**37.7 m**	**st15 3 m**	**34 m**	**47 m**	**st16 1.5 m**	**19 m**	**38 m**	**st18 2 m**
Autotrophic picoplankton	1.11E+06	1.81E+06	2.30E+06	2.24E+06	3.81E+06	1.58E+07	1.86E+07	2.04E+07	1.32E+07	3.54E+06	2.53E+06	2.55E+07	2.24E+06
Heterotrophic picoplankton	4.18E+08	8.54E+08	8.90E+08	6.61E+08	4.48E+08	8.80E+08	6.69E+08	7.61E+08	7.49E+08	5.30E+08	9.45E+08	3.16E+08	5.69E+08
Autotrophic nanoplankton	4.28E+06	1.90E+06	1.89E+06	4.64E+06	2.94E+06	1.88E+06	3.05E+06	1.38E+06	1.06E+06	3.86E+06	2.37E+06	3.03E+06	2.85E+06
Heterotrophic nanoplankton	4.12E+06	7.07E+05	7.96E+05	4.70E+05	1.80E+06	7.85E+05	4.97E+05	8.95E+05	6.30E+05	1.30E+06	8.17E+05	7.95E+05	5.41E+05
Diatoms	4.17E+06	2.85E+04	5.80E+04	3.17E+06	2.38E+05	1.05E+05	1.11E+06	1.19E+04	1.48E+04	3.53E+06	2.57E+05	1.69E+05	2.22E+06
Dinoflagellates	2.13E+04	1.60E+02	0.00E+00	1.34E+04	5.40E+02	0.00E+00	8.00E+02	2.40E+02	8.00E+01	2.40E+03	8.00E+02	4.00E+02	1.00E+03
Coccolithophorids	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E+02	2.40E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total phytoflagellates	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.40E+03	2.40E+02	8.00E+01	6.40E+03	0.00E+00	3.00E+02	1.00E+03
Others	6.65E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.96E+03	1.04E+04	7.12E+03	3.44E+03	3.36E+04	5.10E+03	1.90E+03	2.00E+03
Ciliates other than Tintinnids	1.11E+03	2.02E+02	1.26E+02	9.60E+02	3.30E+02	2.00E+02	4.10E+02	3.34E+02	4.14E+02	2.10E+02	1.80E+02	3.84E+02	1.52E+03
Tintinnids	1.32E+02	2.40E+01	6.00E+00	6.40E+01	2.00E+00	1.00E+01	0.00E+00	6.00E+00	6.00E+00	2.80E+01	1.20E+01	5.00E+01	8.40E+01
Micrometazoa	8.60E+01	2.20E+01	1.20E+01	6.00E+01	4.80E+01	2.20E+01	7.40E+01	1.40E+01	4.00E+00	5.60E+01	3.40E+01	1.60E+01	1.08E+02

coastal stations (stations 1, 10, 13 and 17) in the upper layers, decreasing towards the bottom. Among diatoms, *Chaetoceros* was the most abundant species. Ciliates other than tintinnids were significant in the micro-zooplankton community. Total nanoplankton reached abundances about 10^6 cell l^{-1}. Total picoplankton, mostly constituted by the heterotrophic component, ranged from 10^8 to 10^9 cell l^{-1} (Tab. I). Cluster analysis, applied to the first cruise data, distinguished three groups: the first group corresponds to the fresh water inputs, which seems to flow below the pycnocline more offshore, the second group to offshore surface waters and the third one to intermediate layers. The first group was characterized by the highest values of total picoplankton and a high percentage of autotrophic picoplankton. The second group was best characterized by a high abundances of diatoms, mainly due to *Cerataulina pelagica* and *Thalassiosira* spp. and the third group by intermediate abundances of the same diatom species.

In February 1997 picoplankton abundance and nanoplankton distribution were similar along the water column. Microphytoplankton showed a strong difference between the surface community structure, characterized by high abundances of diatoms and the other depths were characterized by lower densities. Microzooplankton showed the maximum concentration of ciliates other than tintinnids at the surface of station 11 and 18 (Tab. I). Cluster analysis distinguished three main groups: the first was again constituted by surface sample of the station closest to the coast and to intermediate and bottom samples inside the flow of the coastal current, the second one corresponded to an intermediate water mass and the third one to the offshore stations surface. The surface sample of station 20 was included among the intermediate, bottom depth due to its high values of total picoplankton and particularly of the autotrophic fraction, which were generally typical of intermediate and bottom depths. Low values of total picoplankton and high values of total nanoplankton and heterotrophic nanoplankton characterized the first group. Among the nanoplankton small diatoms were found, such as *Skeletonema costatum* which was the responsible of the spring bloom.

In June 1997 the plankton structure was completely different from June 1996 and the abundance was generally lower. Inside the plankton community, the autotrophic component of the nanoplankton prevailed. The heterotrophic picoplankton fraction showed strong fluctuations along the water column. Microphytoplankton was more abundant in the coastal stations and drastically decreased in the offshore stations. Ciliates other than tintinnids were abundant only at surface layer of the stations 3, 7 and 12 (Tab. I). The cluster analysis distinguished three main groups: in this case, the sampling stations were very close to the river input and only the two offshore stations appeared distinguished by the other ones. The two offshore stations were characterized by low abundances of all the planktonic components, while the inshore stations were characterized by high values of nanoplankton and a high abundance of diatoms, being *Chaetoceros decipiens*, *Pseudo-nitzschia delicatissima* and *Dactyliosolen fragilissimus* the most representative species.

In February 1998 the frontal system clearly separated inshore from offshore stations and the differences between inshore and offshore was particularly evident for the microphytoplankton community. At the coastal stations diatoms were very abundant (*e.g.*, 16.9×10^6 cell l^{-1} at surface of station 16) whilst offshore their density did not exceed 1.10^6 cell l^{-1}. Picoplankton, almost exclusively constituted by heterotrophic

TABLE I Cell concentrations (n. cell l^{-1}) of different planktonic assemblages in the Northern Adriatic Basin (Continued)

June 1997	**st1 0 m**	**6 m**	**18 m**	**st3 0 m**	**15 m**	**27 m**	**st6 0 m**	**14 m**	**34 m**	**st7 0 m**	**7 m**	**17 m**	**st10 0 m**
Autotrophic picoplankton	1.17E+07	1.18E+07	5.63E+06	1.50E+07	9.51E+06	8.04E+06	5.20E+07	3.51E+07	2.72E+07	1.34E+07	1.90E+07	6.97E+06	8.04E+06
Heterotrophic picoplankton	1.25E+09	7.79E+07	9.58E+08	1.47E+09	1.34E+09	1.07E+09	1.47E+09	1.36E+09	1.85E+09	1.47E+09	5.84E+08	6.92E+08	5.22E+07
Autotrophic nanoplankton	9.35E+06	3.62E+06	7.29E+05	1.16E+07	3.07E+06	1.53E+06	3.87E+06	2.90E+06	5.19E+05	5.68E+06	5.75E+06	2.30E+06	4.09E+06
Heterotrophic nanoplankton	2.90E+06	8.40E+05	2.65E+05	1.30E+06	1.08E+06	1.11E+06	2.13E+06	9.28E+05	1.55E+05	2.25E+06	1.90E+06	4.42E+05	1.53E+06
Diatoms	1.94E+05	1.44E+04	3.36E+04	1.41E+06	8.05E+04	6.99E+04	4.00E+02	1.12E+03	2.08E+03	1.88E+05	4.70E+03	4.05E+03	1.20E+03
Dinoflagellates	1.07E+04	8.80E+03	3.36E+04	1.68E+04	4.32E+03	1.44E+03	7.40E+03	6.40E+02	4.00E+02	1.24E+04	5.10E+03	2.77E+04	3.60E+03
Coccolithophorids	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total phytoflagellates	0.00E+00	1.02E+04	0.00E+00	1.02E+04	1.92E+03	1.60E+02	8.40E+03	1.26E+04	7.20E+02	4.60E+03	1.72E+04	2.25E+03	1.44E+04
Others	1.58E+04	1.48E+04	2.67E+03	5.80E+03	1.44E+03	4.80E+02	2.36E+04	2.56E+03	2.56E+03	1.40E+04	7.70E+03	4.50E+02	9.00E+03
Ciliates other than Tintinnids	1.36E+03	2.35E+02	2.64E+02	5.39E+03	1.44E+03	1.26E+03	2.96E+02	3.94E+02	8.04E+02	3.95E+03	2.80E+02	3.44E+02	8.60E+02
Tintinnids	2.54E+03	6.50E+01	6.20E+01	1.40E+03	8.00E+00	5.00E+00	0.00E+00	0.00E+00	4.00E+00	1.61E+03	2.00E+01	4.00E+00	4.20E+02
Micrometazoa	2.10E+02	1.35E+02	4.80E+01	1.52E+02	4.40E+01	2.00E+01	3.40E+01	4.80E+01	1.00E+01	2.80E+02	8.00E+01	6.40E+01	1.20E+01
February 1998	**st11 0 m**	**13 m**	**24 m**	**st13 2 m**	**19 m**	**30 m**	**st15 2 m**	**20 m**	**37 m**	**st16 0 m**	**10 m**	**27 m**	**st18 2 m**
Autotrophic picoplankton	1.41E+07	1.14E+07	1.05E+07	2.95E+07	5.84E+07	1.85E+07	5.20E+07	3.51E+07	3.72E+07	1.69E+07	1.18E+07	1.17E+07	2.52E+07
Heterotrophic picoplankton	3.03E+09	1.86E+08	2.52E+09	1.70E+09	1.19E+09	1.73E+09	1.47E+09	1.36E+09	1.68E+09	2.85E+09	1.22E+09	2.59E+09	1.22E+09
Autotrophic nanoplankton	4.70E+06	2.64E+06	4.42E+05	2.86E+06	1.90E+06	6.18E+05	2.60E+06	1.46E+06	8.17E+05	6.74E+06	3.85E+06	1.15E+06	3.11E+06
Heterotrophic nanoplankton	2.18E+06	1.76E+06	1.09E+06	1.77E+06	1.23E+06	9.72E+05	3.16E+06	2.07E+06	1.33E+06	3.17E+06	1.79E+06	1.35E+06	2.19E+06
Diatoms	2.79E+06	6.43E+04	3.06E+04	6.43E+05	2.81E+04	1.67E+04	8.02E+04	1.89E+04	1.58E+04	1.69E+07	3.99E+06	7.25E+05	9.64E+05
Dinoflagellates	4.88E+03	4.00E+02	0.00E+00	2.80E+03	4.00E+02	0.00E+00	8.80E+02	8.00E+02	4.80E+02	1.20E+04	3.28E+03	8.00E+02	9.60E+02
Coccolithophorids	5.60E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E+03	1.44E+03	0.00E+00	1.60E+02
Total phytoflagellates	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E+01	0.00E+00	8.00E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Others	3.04E+03	1.92E+03	1.60E+02	1.20E+04	2.80E+03	4.80E+02	4.64E+03	3.20E+03	5.12E+03	2.68E+04	2.37E+04	1.52E+03	4.32E+04
Ciliates other than Tintinnids	1.00E+03	5.38E+02	6.00E+01	4.64E+02	2.60E+02	1.40E+02	2.30E+02	2.26E+02	1.10E+02	3.00E+03	1.47E+03	1.46E+02	4.56E+02
Tintinnids	9.32E+02	1.30E+02	3.50E+01	1.22E+02	5.00E+01	7.00E+01	1.80E+01	2.40E+01	4.00E+01	1.50E+03	1.90E+02	5.60E+01	8.20E+01
Micrometazoa	4.80E+01	5.00E+01	1.50E+01	8.80E+01	4.50E+01	3.50E+01	3.20E+01	3.20E+01	1.50E+01	2.00E+01	1.86E+02	2.60E+01	1.16E+02

fraction, presented the highest densities in all the study period (Tab. I). Nanoplankton distribution decreased from the surface to the bottom in all the stations. All the microzooplankton fractions showed very low values. From cluster analyses, we could basically distinguish two groups: in the first, all the inshore stations and again some bottom samples of offshore stations, which appeared related to a deepening of surface waters, were grouped. High values of diatoms (*Pseudo-nitzschia delicatissima* and *Skeletonema costatum*) and autotrophic nanoplankton characterized the first group; the second, corresponding to the offshore stations, was characterized by low values of phytoplankton, particularly low values of microzooplankton and high percentage of heterotrophic nanoplankton on the total of this fraction.

The relative carbon contribution of the three size plankton classes in the different groups identified by a cluster analysis in each cruise are presented in Figure 2. Generally microphyto- and total nanoplankton were the major contributors to the total carbon amount (Tab. II).

In June 1996, in the first of the three groups identified by cluster analysis, 52% and 33% of the total carbon content were due to microplankton and nanoplankton. The second group showed very similar percentages (50% was due to microplankton); in the third group nanoplankton contributed to the total carbon content for about 73%. In all the three groups picoplankton was scarcely represented (Fig. 2). Consequently the two first groups were mainly constitued by a microplankton fraction while to the third group, corresponding to the most offshore and deeper samplers, corresponded the highest percentage of pico- and nanoplankton fractions.

In June 1998, nanoplankton contributed for 35%, 36% and 42% in the first, second and third group and, except for the second group in which microplankton prevailed at 47%, this appeared to be the most important fraction in terms of carbon content. Picoplankton carbon ranged from 17% to 27% (Fig. 2). Thus, in this case, the largest size fraction never contributed more than 47% to the total carbon content. The highest percentage of microplankton corresponded to all the depths of the offshore station 12, where the lowest salinity was detected (Catalano pers. comm.).

In February 1997 in all the three groups, nanoplankton always resulted the major component accounting for 69%, 65% and 59%; microplankton was the second contributor in the first two groups and picoplankton prevailed with a 33% in the third one (Fig. 2). In this case microplankton fraction never prevailed indicating that the spring bloom was not yet developed.

In February 1998 there were two main groups: in the first, microplankton accounted for 60%, picoplankton reached 23% and nanoplankton contributed for 17%; in the second group, picoplankton reached 44%, followed by nanoplankton (34%), and microplankton (22%) (Fig. 2). During this cruise, in the coastal stations, diatoms were actively blooming, while in the offshore ones the winter community was still present.

DISCUSSION AND CONCLUSIONS

The northern Adriatic system has been described several times as a very variable shallow basin (Franco and Michelato, 1992; Fonda Umani, 1996, Malej *et al.*, 1999). Our results confirm this high seasonal and interannual variability. Summer results

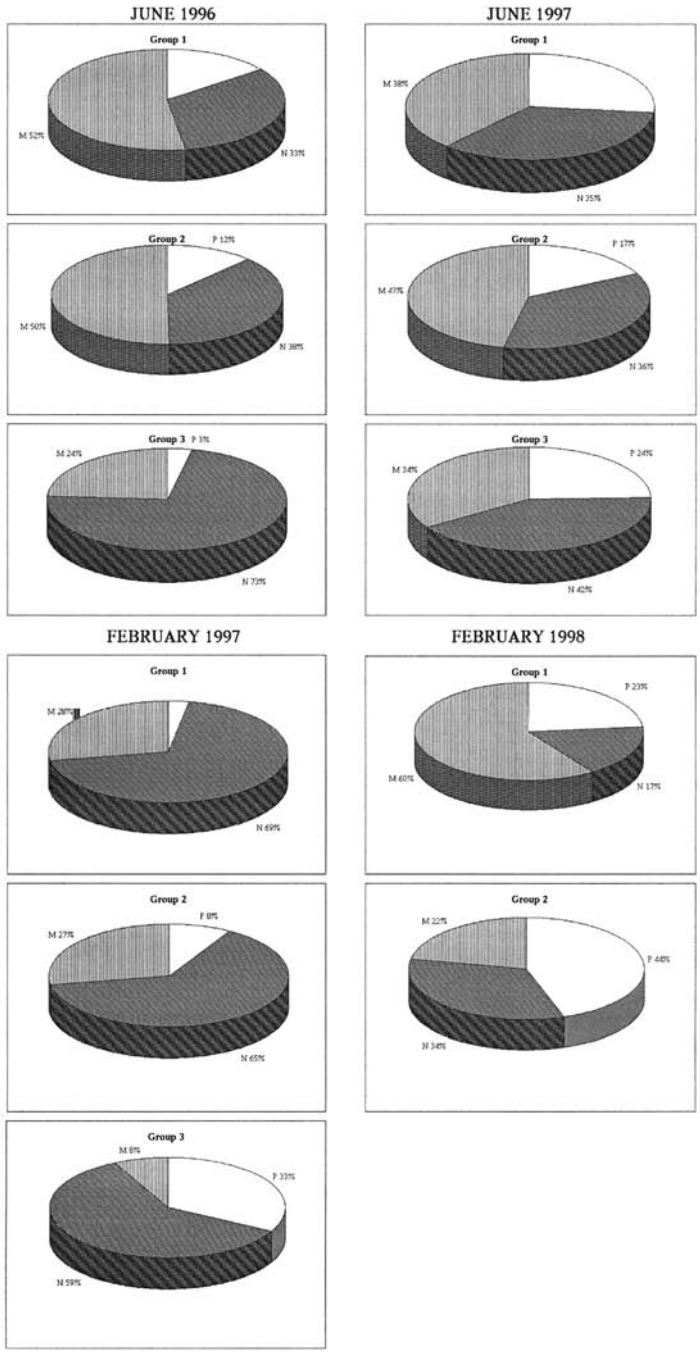

FIGURE 2 Carbon distribution, as percentage, among pico-(P), nano-(N) and micro-plankton (M) in each survey, in the different groups identified by cluster analysis.

indicated a contribution of the microplankton fraction in the coastal area greater in 1996 than in the following year, when microplankton fraction never reached a 50% of the total plankton carbon. In June 1996 the area characterized by the prevalence of the microplankton fraction is larger and a more efficient transfer of energy through the

TABLE II Biomass of different size classes of the Northern Adriatic planktonic assemblage

June 96	**st1 0 m**	**15 m**	**26 m**	**st8 0 m**	**20 m**	**36 m**	**st10 0 m**	**5 m**	**30 m**	**st13 0 m**	**5 m**	**38 m**	**st17 0 m**
Picoplankton	15.66	8.87	10.17	6.34	3.16	6.83	7.86	2.77	4.84	11.86	3.63	21.29	9.19
Nanoplankton	35.93	28.82	16.25	21.08	44.84	10.14	20.88	45.41	10.07	48.32	145.8	8.46	65.37
Micro-phytoplankton	124.88	2.163	5.79	88.15	2.49	0.63	80.73	77.33	1.23	22.98	15.74	1.54	73.97
Micro-zooplankton	89.05	2.987	4.155	4.26	1.523	2.684	5.683	3.134	2.992	2.21	1.254	3.473	3.284
February 97	**st11b 3 m**	**26 m**	**42 m**	**st13a 1 m**	**12 m**	**37.7 m**	**st15b 3 m**	**34 m**	**47 m**	**st16a 1.5 m**	**19 m**	**38 m**	**st18b 2 m**
Picoplankton	8.38	17.11	17.85	13.25	9.03	17.91	13.75	15.22	15.24	10.66	18.94	6.83	5.42
Nanoplankton	383.9	6.71	136.79	233.21	101.67	109.89	72.96	60.08	58.93	153.25	113.4	107.65	99.24
Micro-phytoplankton	204.64	3.38	6.86	146.02	14.69	11.07	95.56	7.07	1.02	157.39	13.49	9.64	113.91
Micro-zooplankton	4.97	0.99	0.65	5.46	2.44	1.14	2.99	2.07	1.07	1.79	1.46	1.34	8.34
June 97	**st1a 0 m**	**6 m**	**18 m**	**st3b 0 m**	**15 m**	**27 m**	**st6a 0 m**	**14 m**	**34 m**	**st7b 0 m**	**7 m**	**17 m**	**st10a 0 m**
Picoplankton	25.13	15.82	19.26	29.6	26.92	21.5	30.37	27.94	37.58	29.6	12.06	13.97	12.06
Nanoplankton	103.7	31.43	10.82	110.74	18.74	10.13	25.74	27.33	4.08	41.02	31.96	11.45	28.41
Micro-phytoplankton	66.65	29.9	47.8	67.61	25.66	10.77	4.53	1.54	1.05	75.91	6.73	84.36	18.16
Micro-zooplankton	16.23	7.85	4.63	15.79	11.42	10.46	0.81	7.3	3.74	16.23	1.87	2.59	3.37
February 97	**st11a 0 m**	**13 m**	**24 m**	**st13b 2 m**	**19 m**	**30 m**	**st15a 2 m**	**20 m**	**37 m**	**st16a 0 m**	**10 m**	**27 m**	**st18b 2 m**
Picoplankton	60.8	39.55	50.65	34.58	24.94	34.9	30.37	27.94	34.26	57.42	24.63	52.06	24.94
Nanoplankton	60.48	31.93	4.73	46.86	20.3	7.87	36.73	15.9	7.07	67.6	63.22	12.36	36.1
Micro-phytoplankton	81.1	4.95	1.46	47.51	5.62	13.29	6.8	2.85	15.18	645.82	134.21	48.59	42.33
Micro-zooplankton	11.77	1.56	0.53	4.18	2.04	0.61	1.2	1.31	0.3	16.45	8.14	0.95	4.5

grazing chain might have been supposed. In June 1997, only in an offshore station (station 12) the microplankton fraction fairly higher corresponding to a less diluted water body, probably deriving from a freshwater input some days before the cruise. These "blobs" characterize the exchanges of diluted waters across the frontal system and were detected several times by Bergamasco *et al*. (in press) in the same area and period. This summer bloom was due to its confined extension and short living time and could not be efficiently grazed by upper level consumers, resulting in a sinking flux of the organic particulate material. Small size fractions clearly prevailed in summer in offshore and deeper waters indicating a more efficient microbial loop related to regenerative processes. By February 1997, in the whole area, winter features still lasted: nano- and picoplankton fractions clearly prevailed and the autotrophic fraction of picoplankton considerably contributed to primary producer biomass particularly in the offshore area. It seems that photolimitation (Malej and Fonda Umani, 1998), which is the most important controlling factors of the winter primary production at these latitudes, is still influencing the plankton community, favouring autotrophic picoplankton production. In February 1998 the cruise was carried out ten days later than in 1997 and we observed an intense diatom bloom confined in the coastal area clearly separated by the frontal system from the offshore stations where picoplankton production still prevailed.

The northern Adriatic system was claimed by several authors in the past as an eutrophic region, and particularly in the area close to the Po River delta. Eutrophic systems are characterized by high microplankton biomass, mostly due to diatom blooms. Our results, even if very limited in space and time, suggest on the contrary that only in few situations, microplankton fractions and thus grazing chain prevails, while in most of the cases and in wider smaller size classes it is more important in term of organic production and utilization.

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