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SEASONAL VARIABILITY IN PHYTOPLANKTON AND BACTERIOPLANKTON DISTRIBUTION IN THE SEMI-ENCLOSED TEMPERATE GULF (GULF OF TRIESTE, ADRIATIC SEA)

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ABSTRACT

Distribution of nutrients, total carbohydrates, phytoplankton, cyanobacteria, nanoflagellates and bacterial abundance was studied simultaneously focusing on the annual cycle at two locations in the Gulf of Trieste (Adriatic Sea). The central-western area was affected by seasonal freshwater nutrient pulses from local rivers, while the eastern part was characterised by the influence of more saline/oligotrophic waters of southern origin. In 1992, spring pulse of high freshwater input was followed by diatom bloom, low bacterioplankton abundance, and increased concentration of high molecular weight carbohydrates. Due to somewhat lower freshwater inflow, there was no comparable bloom in spring 1993. We believe that the accumulation of dissolved carbohydrates occurred as a result of bacterial abundance being controlled by predators, heterotrophic nanoflagellates, rather than due to nutrient limitation or low temperature. Throughout the summer, oligotrophic conditions in the water column and the processes of transformation of organic carbon matter through a 'microbial loop' type of food web are of greater significance. At the layers bellow pycnocline, regeneration processes are dominant.

Key words: phytoplankton, cyanobacteria, heterotrophic bacteria, heterotrophic nanoflagellates, total carbohydrates, Gulf of Trieste

VARIAZIONI STAGIONALI NELLA DISTRIBUZIONE DI FITOPLANCTON E BATTERIOPLANCTON IN GOLFO SEMI-CHIUSO E TEMPERATO (GOLFO DI TRIESTE, MARE ADRIATICO)

SINTESI

In due postazioni nel Golfo di Trieste (Mare Adriatico), sono state simultaneamente studiate le distribuzioni di nutrienti, carboidrati totali, fitoplancton, cianobatteri, nanoplancton e l'abbondanza di batteri, evidenziandone il ciclo annuale. L'area centro-occidentale è risultata influenzata da apporti stagionali di nutrienti da fiumi locali, mentre quella orientale si è rivelata caratterizzata dall'influenza di acque più saline/oligotrofiche di origine meridionale. Nel 1992 l'alto apporto primaverile di acque dolci è stato seguito da fioritura di diatomee, scarsa abbondanza di batterioplancton ed elevata concentrazione di carboidrati ad alto peso molecolare. Nella primavera del 1993, in seguito a un minor apporto di acque dolci, non si è ripetuta una simile fioritura. Gli autori suppongono che l'accumulo di carboidrati disciolti si sia verificato a causa del controllo dell'abbondanza dei batteri da parte di predatori, nanoflagellati eterotrofici, piuttosto che a causa della scarsità di nutrienti o della bassa temperatura. Durante l'estate risultano maggiormente importanti le condizioni oligotrofiche nella colonna d'acqua ed i processsi di trasformazione della materia organica attraverso la rete trofica legata al ciclo microbico. I processi di rigenerazione sono dominanti negli strati sottostanti il picnoclino.

Parole chiave: fitoplancton, cianobatteri, batteri eterotrofi, nanoflagellati eterotrofi, carboidrati totali, Golfo di Trieste

INTRODUCTION

Inorganic nutrients are transformed and transported in a complex pattern in marine environments and primary production is, in most cases, limited by the availability of inorganic nitrogen or phosphorous (Dugdale & Goering, 1967; Hecky & Kilham, 1988; Currie, 1990; Thingstad & Rassoulzadegan, 1995). In many coastal marine environments, such as the northern Adriatic Sea, external riverine inputs and regeneration processes are the major sources of nutrients supporting the requirements of primary producers (Degobbis & Gilmartin, 1990).

The connection between phytoplankton dynamics and environmental fluctuations due to river runoff and seasonal stratification has been well established in temperate areas (Kiørboe *et al.*, 1990; Harding, 1994). Freshwater pulses introducing new nutrients into the marine environment are the predominant factor determining changes of phytoplankton production, biomass and community structure in the Gulf of Trieste (Malej *et al.*, 1995, 1997; Malačič *et al.*, 1997; Mozetič *et al.*, 1998), as well as in northern and middle Adriatic (Krstulović *et al.*, 1995; Harding *et al.*, 1999) and the NW Mediterranean Sea (Klein *et al.*, 1997).

Microbial communities are crucial for global biogeochemical cycles through their decomposition of organic and inorganic nutrient regeneration (Azam, 1998). Complex interaction within communities and variety of environment elements play critical role in marine biogeochemistry.

Seasonal and diel patterns of microbial abundance, production and grazing on bacteria, the main energy consumers in response to photosynthesis, have been observed in different aquatic environments (Cole *et al.*, 1988). In temperate coastal areas with substantial seasonal variation in environmental regimes, bacterial growth and numbers vary similarly (Scavia & Laird, 1987), but it is still unclear what factors determine the dynamics of the pelagic bacterial community. Seasonal bacterial growth has been shown to be limited by number of factors, such as temperature, predation, substrate supply (organic and inorganic nutrients), and viral infection (Wikner & Hagström, 1991; Caron 1991; Proctor & Fuhrman, 1992; Shiah & Ducklow, 1994; Carlson & Carol, 2001; Pomeroy & Wiebe, 2001). The relatively low variability of bacterial abundance in aquatic environments has given rise to the speculation that bacterial abundance is tightly regulated by the different factors operating on bacteria (Sanders *et al.*, 1992).

The main purpose of our study was to identify the major patterns of temporal and spatial variability of microplankton abundance at two locations in the Gulf of Trieste (Adriatic Sea). One location was affected by significant seasonal freshwater nutrient pulses from local rivers, while the second was characterised by the predominant influence of more saline/oligotrophic waters of southern origin. Water column stratification, distribution of nutrients and total carbohydrates (TCHO) were analysed in relation to phyto- and bacterioplankton abundance. In this study we draw attention to factors that influence the seasonal dynamic of bacterial communities, such as temperature, substrate availability, nutrient supply, and the effect of protistan predation.

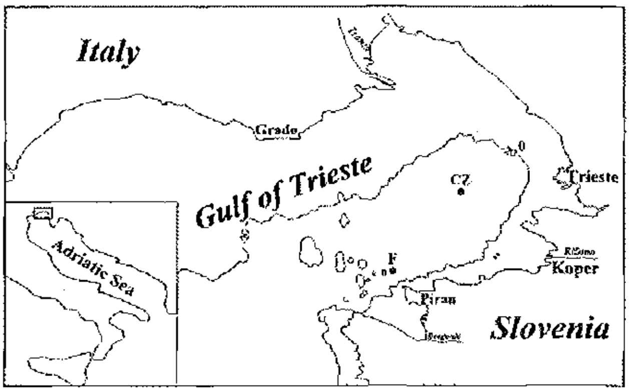

Fig. 1: Location of sampling sites (stations CZ and F) in the Gulf of Trieste (northern Adriatic Sea).
Sl. 1: Vzorčevalna mesta (postaji CZ in F) v Tržaškem zalivu (severni Jadran).

MATERIAL AND METHODS

Sampling

Sea water samples for chemical and biological parameters were collected monthly at two locations in the Gulf of Trieste (northern Adriatic) in the period from January 1992 to December 1993 (Fig. 1). One sampling station was located in the central part of the Gulf with a water column depth of 24 m (station CZ- 45°37'24"N, 13°37'55"E), the other (station F- 45°32'18"N, 13°33' 00"E) in the south-eastern part with a depth of 21 m. Each time sea water was sampled at four to five depths (0.2, 5, 10, 15 and above bottom) using 5l Niskin bottles.

Methods

Basic hydrographical and chemical parameters - At each station, temperature, salinity, fluorescence and oxygen were recorded with a CTD probe (Fine-scale profiler, University of Western Australia, a Sea Tech Inc. fluorometer). Temperature and salinity data were used to calculate the "bulk density gradient" (c) as follows:

$$c = (\sigma_{Tb} - \sigma_{Ts}) / H$$

where σ_{Tb} and σ_{Ts} are bottom and surface water densities, respectively, and H is water column depth (m).

Concentrations of inorganic nutrients were analysed in unfiltered samples using standard colorimetric methods (Grasshoff, 1976). Total carbohydrates (TCHO) were analysed in unfiltered samples using a phenol-sulphuric acid reaction with glucose as a standard (Strickland & Parsons, 1972).

Cell counts and biomasses - Cells of bacteria and heterotrophic nanoflagellates (HNAN) were counted with epifluorescence microscopy in formalin preserved (2%) water samples. Bacteria were counted after staining with DAPI according to the protocol by Porter & Feig (1980) and HNAN using primuline according to Caron (1983). Autofluorescent live cyanobacteria were counted in green excitation light (Takahashi *et al.*, 1985). Samples for phytoplankton counts were preserved with neutralised formaldehyde (1.5% final concentration). Subsamples of 50 ml were sedimented overnight and cells counted on an inverted microscope following the method of Utermöhl (1958). Chlorophyll *a* (Chl *a*) was analysed in acetone extracts using a Turner 112 fluorimeter (Strickland & Parsons, 1972).

RESULTS

Physical characteristics of the water column

The yearly mass flow of the river Soča into the Gulf of Trieste was higher during 1992, as was the inflow during the April-August period, in contrast to the lower values in 1993 (Fig. 2, top). Freshwater inputs were maximal in March-April and October-November in 1992 and October-November in 1993. This dynamics clearly affected bulk density gradient of the water column at station CZ but considerably less at the station F (Fig. 2, bottom). Water column was well mixed from December to February with minimal temperatures of about 7.0-7.5°C. Seasonal surface heating was reflected in thermal stratification, which was evident as increased bulk density gradient at both stations from May to September. Besides this broad annual peak of bulk density gradient, two additional peaks related to decreased salinity in the surface layer appeared at location in the central part of the Gulf (station CZ) in spring and autumn. Typical difference between the two stations during spring 1992 is evident also from CTD profile. The surface layer with salinities around 30 ppt at station CZ (in contrast to more than 35 ppt at station F) was characterised by high fluorescence values and increased oxygen concentration, even though that thermal stratification was not established as yet. The similar situation could be found in autumn (not shown).

Seasonal distribution of nutrients and phytoplankton

In 1992, the distribution of nitrate from January to April showed a marked surface peak, decreasing below

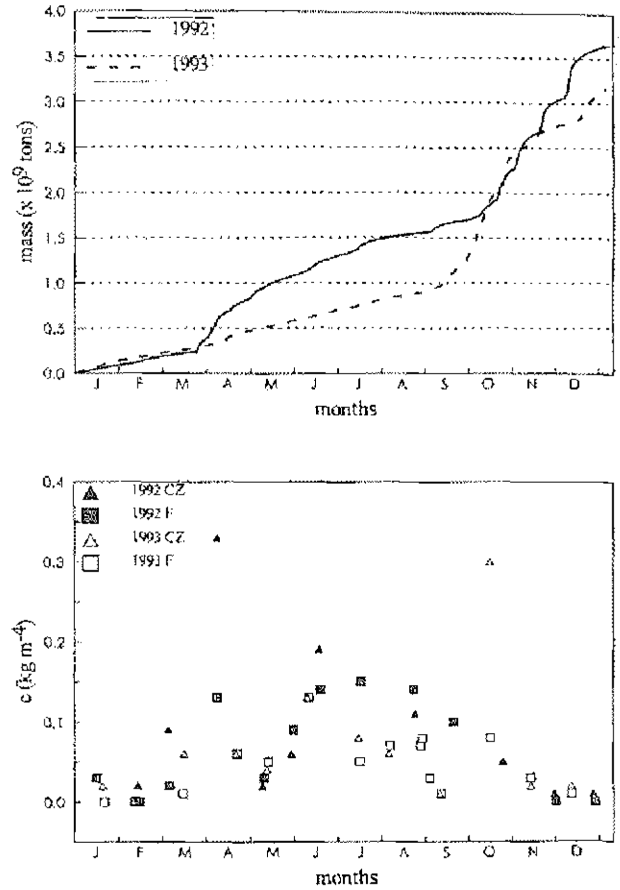

Fig. 2: The cumulative mass flow of the river Soča into the Gulf of Trieste (top) and the annual distribution of bulk density gradient (bottom) during 1992 and 1993.
Sl. 2: Kumulativni vnos mase sladke vode iz reke Soče v Tržaški zaliv (zgoraj) in letna porazdelitev gostotnega gradienta (spodaj) v letih 1992 in 1993.

5 m depth (Fig. 3). The concentrations of nitrate increased up to 15.12 µM at station CZ and 8.57 µM at station F in spring 1992 and were rather high during the same period in 1993 (up to 8.53 µM).

In contrast to nitrate, ammonium (Fig. 4) and phosphate (data not shown) concentrations showed bottom maximum (5.85 and 0.59 µM, respectively) during summer-early autumn in both years. These peaks were especially evident at station CZ indicating regenerative processes. Silicate concentrations displayed similar trend in bottom layer as did ammonium and phosphate, with peak value 13.99 µM of silica at station CZ in August 1992. At the surface, silicate winter concentrations around 5-6 µM were reduced soon to concentrations below 2 µM parallel to the development of the spring diatom bloom.

The nutrient input caused an accumulation of phytoplankton biomass in March-April 1992, with chlorophyll levels of up to 7.32 µg Chl *a* l^{-1} at station CZ and 3.50 µg

***Tab. 1:** Two-year (1992-1993) average and maximum concentrations of selected nutrients, phytoplankton biomass (Chlorophyll a), bacterial, cyanobacterial and nanoflagellate (HNAN) abundance at stations F and CZ.*
***Tab. 1:** Dvoletna (1992-1993) povprečja in najvišje koncentracije izbranih hranil, fitoplanktonske biomase (klorofil a), bakterijske, cianobakterijske in nanoflagelatne abundance na postajah F in CZ.*

	station F		station CZ	
	average	max	average	max
Phosphate (µM)	0.15±0.13	0.60	0.13±0.1	0.45
Nitrate (µM)	1.84±1.36	8.57	2.02±2.29	15.12
Ammonium (µM)	1.49±0.90	5.96	1.56±0.94	5.85
Chlorophyll a (µg l^{-1})	0.90±0.63	3.85	1.14±1.0	7.32
Bacteria (cells l^{-1})	$4.4 \times 10^8 \pm 3.0 \times 10^8$	1.7×10^9	$6.9 \times 10^8 \pm 4.3 \times 10^8$	1.9×10^9
Cyanobacteria (cells l^{-1})	$1.2 \times 10^7 \pm 1.4 \times 10^7$	5.8×10^7	$3.3 \times 10^7 \pm 3.2 \times 10^6$	7.6×10^7
HNAN (cells l^{-1})	$9.2 \times 10^5 \pm 9.3 \times 10^5$	6.1×10^6	$1.2 \times 10^6 \pm 7.1 \times 10^5$	3.2×10^6

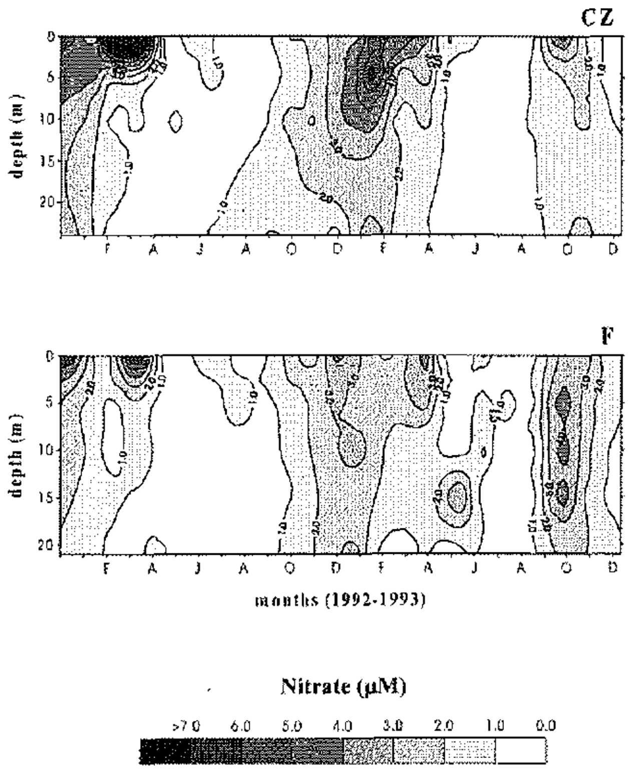

***Fig. 3:** Temporal and vertical distributions of nitrate concentrations at stations CZ and F during 1992 and 1993 (* the different shades of black in the figure correspond to the different concentrations).*
***Sl. 3:** Časovna in globinska porazdelitev koncentracij nitrata na postajah CZ in F v letu 1992 in 1993 (* različna intenziteta črne barve na sliki ustreza različnim koncentracijam).*

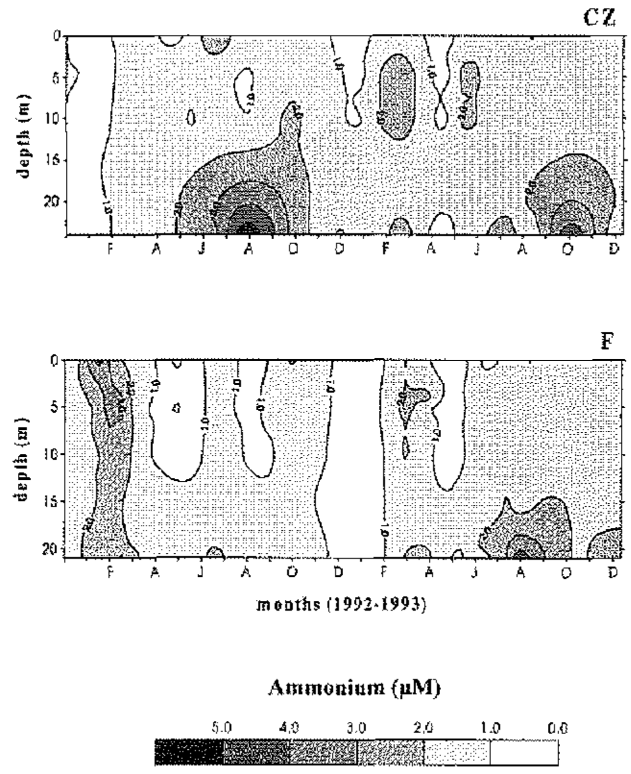

***Fig. 4:** Temporal and vertical distributions of ammonium concentrations at stations CZ and F during 1992 and 1993. (* see comment at figure 3).*
***Sl. 4:** Časovna in globinska razporeditev koncentracij amonija na postajah CZ in F v letih 1992 in 1993. (* glej razlago pri sliki 3).*

Chl *a* l^{-1} at station F (Fig. 5). Among eucaryotic plankton, diatoms dominated winter-early spring bloom 1992 (Fig. 6), with a peak of 8.33 x 10^6 cells l^{-1} and 3.49 x 10^6 cells l^{-1} at stations CZ and F, respectively.

The stratification of water column developed later in May, when low concentrations of phytoplankton biomass were measured throughout the water column (0.49-0.94 µg Chl *a* l^{-1}) at both stations and in both years. Microflagellates and cyanobacteria reached peak abundance in August-September in both years. In 1993, additional seasonal peaks of cyanobacteria were observed in May, followed by a decrease in June and July (Fig. 7a), and in November. The numbers varied between 0.85 x 10^7 to 7.55 x 10^7 cells l^{-1} at station CZ and from 0.59 x 10^7 to 5.80 x 10^7 cells l^{-1} at station F, and higher abundance was recorded in 1993. An additional input of nutrients in October-November along with autumn cooling, stronger winds, and mixing of the water column provoked a second diatom bloom. This winter-spring diatom bloom was more evident at station CZ in 1992 (phytoplankton biomass up to 2.28 Chl *a* µg l^{-1}) but less obvious in 1993.

In general, the yearly mean and maximum concentrations of inorganic nutrients (except phosphate) and the chlorophyll biomass were lower at station F in comparison to concentrations at station CZ (Tab. 1).

Annual distribution of heterotrophic pelagic bacteria and nanoflagellates

In 1992, the annual dynamic of heterotrophic bacterial abundance showed two peaks, one in January and the other in mid-September, in comparison to consistent increase of bacterial abundance in 1993 up to the October maximum (Fig. 7b). In the winter period, the bacterial abundance declined sharply in February, when seawater reached the lowest temperature. Bacterial numbers varied between 0.24 x 10^8 and 1.72 x 10^9 cells l^{-1} at station F and 0.48 x 10^8 and 1.89 x 10^9 cells l^{-1} at station CZ.

Throughout the water column, heterotrophic bacteria were uniformly distributed in the winter-spring period. During the summer, the high concentrations were recorded in the upper 10 meters, while in September and October the highest values were found above the bottom. High bacterial abundance above the bottom co-occurred with a peak of ammonium (r^2=0.43, $p<0.001$) during the same months.

The vertical distribution of heterotrophic bacteria followed similar seasonal pattern at both stations. The yearly maximum concentration was lower at station F in comparison to concentration at station CZ (Tab. 1). On a yearly basis, there was a significant correlation between bacterial abundance and temperature (r^2= 0.62, $p<0.001$), and no correlation between bacterial abundance and Chl *a* concentration or inorganic nutrients, with exception of ammonium at the bottom level. Minimal bacterial abundance coincided with the end of spring Chl *a* maximum.

Both cyanobacteria and heterotrophic bacteria showed a decline when HNAN dominated. In our samples, nonpigmented HNAN, such as chrysomonads, were the dominating species. The number of HNAN ranged from 0.11 x 10^6 to 6.15 x 10^6 cells l^{-1} (Fig. 7c). The maximum concentration was recorded in June and September in 1992, while in the following year abundance was lower (up to 2 x 10^6 cells l^{-1}), with peaks in May-June, August, and November. Although the composition of the HNAN fauna varied during the study period, some groups remained important throughout the year. The most common forms were flagellates with a length between 1 and 5 µm. The composition of this fauna was dominated by non-pigmented chrysomonads with an average volume of 15.8 µm³. Smaller types, such as a bicoecid flagellate with an average volume between 1 and 3 µm³, were constantly present, constituting up to 33% of the total counts.

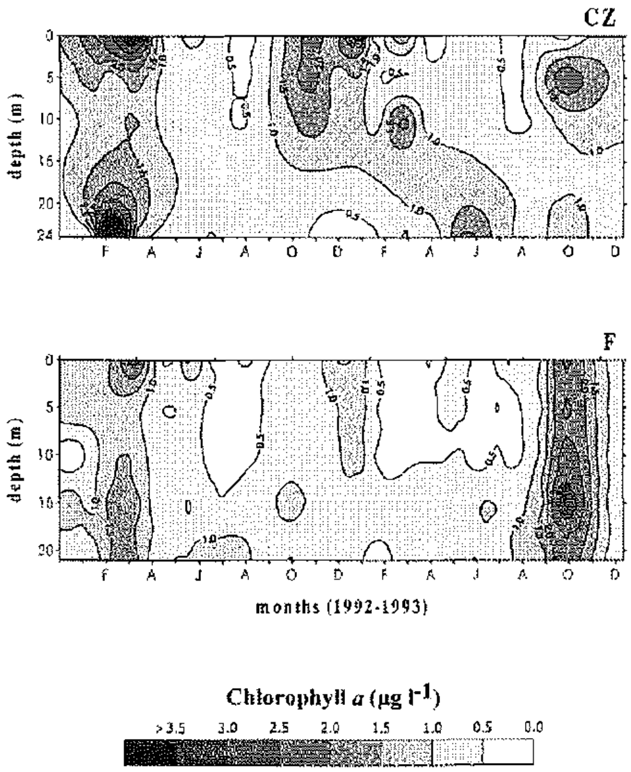

Fig. 5: Temporal and vertical distribution of phytoplankton biomass (Chl a) concentrations at stations CZ and F during 1992 and 1993. (* see comment at figure 3).

Sl. 5: Časovna in globinska razporeditev fitoplanktonske biomase (Chl a) na postajah CZ in F v letih 1992 in 1993. (* glej razlago pri sliki 3).

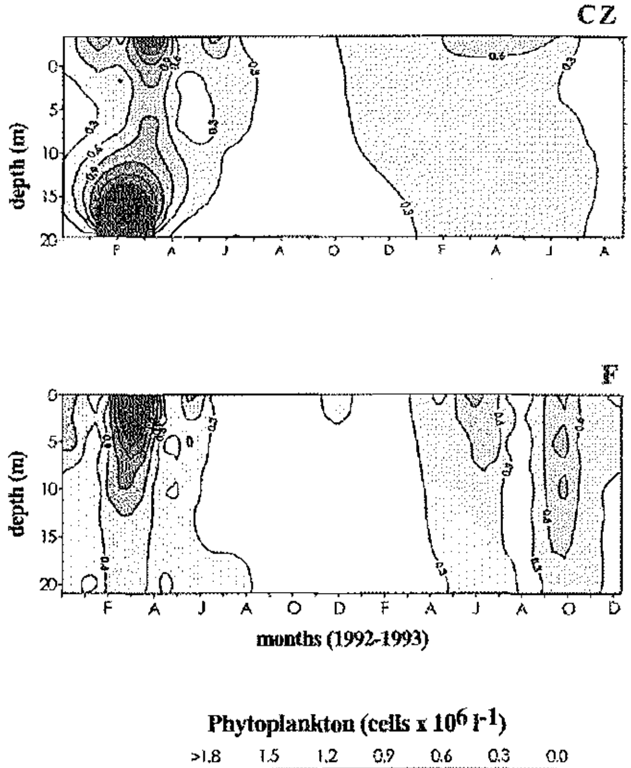

Fig. 6: Temporal and vertical distributions of phytoplankton abundance at stations CZ and F during 1992 and 1993. (* see comment at figure 3).
Sl. 6: Časovna in globinska razporeditev fitoplanktonske abundance na postajah CZ in F v letih 1992 in 1993. (* glej razlago pri sliki 3).

Variations in total carbohydrates concentrations (TCHO)

Concentrations of total carbohydrates were low (< 150 µg l^{-1}) and showed little variability in the bottom layer at both stations and throughout the studied period (Fig. 8). The upper water column exhibited rather different dynamics during the two years of our study: in 1992, very high values were determined in February-March period, which were presumably related to a diatom bloom (Chl *a* > 7 µg l^{-1}, abundance > 8 x 10^6 cells l^{-1}). There was no comparable bloom in 1993 and TCHO concentrations were low during winter-spring. In 1993, higher values were measured during the summer (July-August). Fractionation of TCHO into high and low molecular fraction was carried out only when values over 200 µg l^{-1} were determined, *i.e.* in February-March 1992 and July-August 1993. While February-March high concentrations of TCHO were predominantly high molecular weight carbohydrates (ratio HMW:LMW > 3), summer high concentrations were characterised by dominance of low molecular weight carbohydrates (HMW:LMW < 0.5).

DISCUSSION

In this study we have followed distribution and abundance of phytoplankton, cyanobacteria and heterotrophic bacteria, simultaneously focusing on the annual cycle at two locations in the Gulf of Trieste (Adriatic Sea). The Gulf of Trieste is a semi-enclosed gulf with the main freshwater inputs from its north-western coast (annual average flow about 150 m^3s^{-1} (Olivotti *et al.*, 1986) and peaks over 1000 m^3s^{-1} (Malačič *et al.*, 1997)). The general circulation pattern is predominantly counter clockwise in the lower layer and of variable size in the surface layer. This circulation can be modulated by prevailing winds (Stravisi, 1983). The physiography of the area includes a limited water exchange and low river inflow, especially during the summer. These conditions may therefore strongly influence the nutrient balance and the succession of plankton organisms.

During the course of our study, we encountered two contrasting situations. In 1992, a marked late winter-early spring freshwater input caused intense diatom bloom in the central-western area of the Gulf (station CZ) but reaching also the eastern part (station F). On the other hand, the winter-spring freshwater inflow during 1993 affected the central part of the Gulf of Trieste only slightly and consequently the winter-spring phytoplankton biomass was modest throughout the Gulf. Situation during autumn of both years was quite similar, although the effect of freshwater input seemed to be more marked in 1992.

Typically, the upper part of the water column in the centre of the Gulf had higher phytoplankton biomass and diatoms were more important taxa than in the eastern area, reflected also in the prevalence of fucoxantin over other accessory pigments (Terzić *et al.*, 1998). Such conditions were particularly evident during the winter-spring of 1992 with more abundant freshwater inputs.

The higher fluorescence in the deeper water column at station CZ was related to sinking of late winter diatom bloom as indicated by similarity of taxonomic composition between this community and surface one from previous month. Similar, few meters deep fluorescence humps were usually recorded from April to October at varying depths (16 to 23 m) and were much more prominent at station CZ than F. Clearly, the station F was less influenced by freshwater inputs.

Oligotrophic conditions in the water column above the pycnocline supported lower phytobiomass and prevalence of cyanobacteria, small eucaryotes and heterotrophic bacteria in both summers throughout the Gulf. The layer below pycnocline was characterised by regenerated and rather high nutrient concentrations. In this layer, phytobiomass was higher than at the surface dominated by large algae (>8 µm). The period of maximum concentration of ammonium above the bottom coincided with the low oxygen in the overlying water

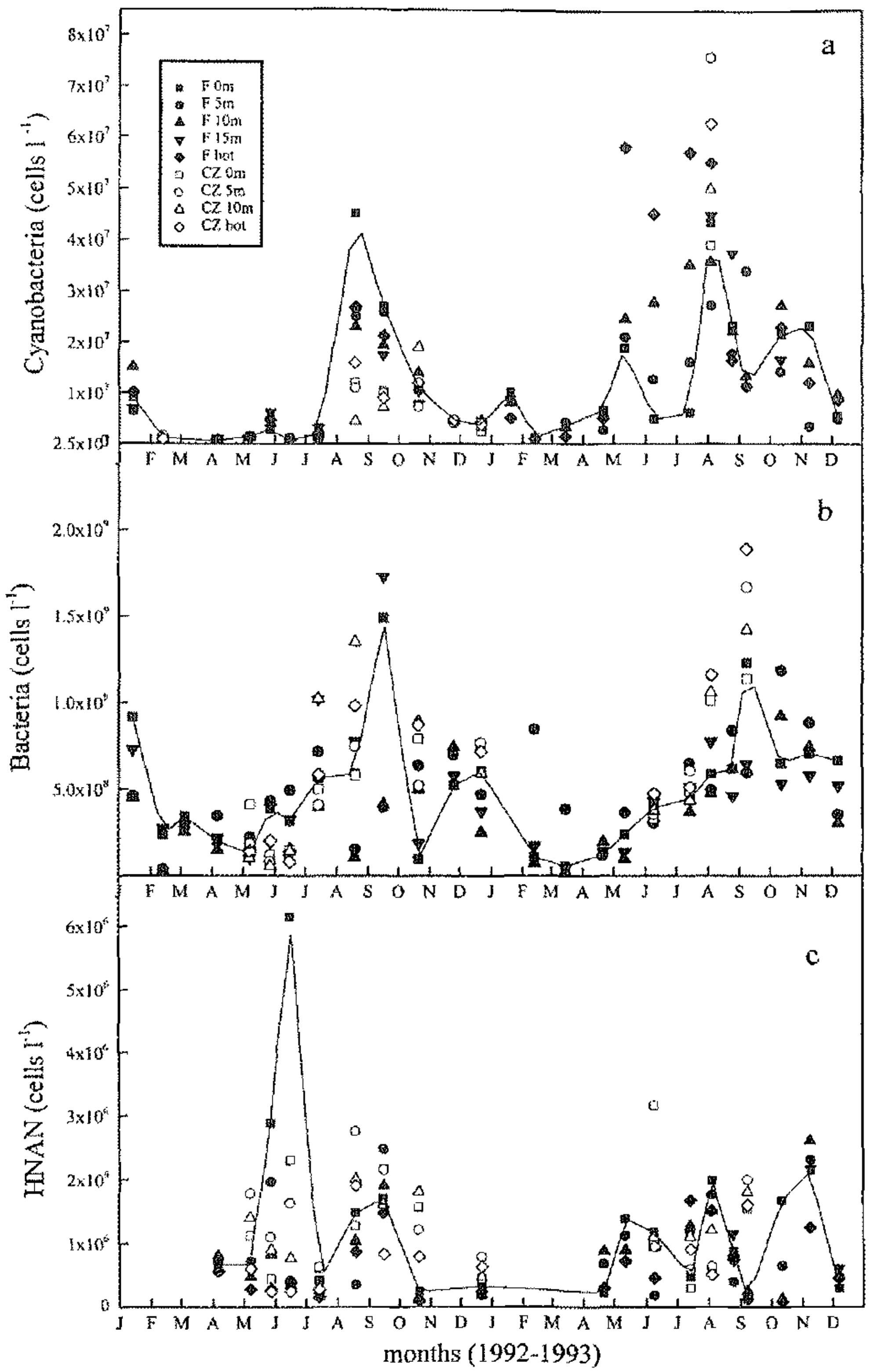

Fig. 7: Seasonal distribution of cyanobacteria (a), heterotrophic bacteria (b) and heterotrophic nanoflagellates HNAN (c) at different depths at stations F and CZ in the Gulf of Trieste during 1992 and 1993.
Sl. 7: Sezonska razporeditev cianobakterij (a), heterotrofnih bakterij (b) in heterotrofnih nanoflagelatov (HNAN) (c) na različnih globinah postaj F in CZ v Tržaškem zalivu v letih 1992 in 1993.

(<40% saturation) and high abundance of heterotrophic bacteria. The influence of processes occurring at the interface of marine sediment and overlying water on organic carbon and nitrogen cycling was recorded also in previous years in the shallow Gulf of Trieste (Faganeli, 1983; Turk, 1992; Kemp & Faganeli, 1999).

In a course of two years, a marked seasonal variability of marine unicellular cyanobacteria bacterioplankton community, and HNAN occurred. The abundances were within the range reported from other areas, *e.g.* Adriatic Sea (Krstulović & Šolić, 1990; Fuks, 1995), English Channel (Linley *et al.*, 1983), Chesapeake Bay (Malone *et al.*, 1994), NE coast of USA and South California (Fuhrman & Azam, 1982), Kiel Bight (Meyer-Reil, 1977), Mediterranean Sea (Hagström *et al.*, 1988). On a seasonal scale, the changes in the population size of the entire heterotrophic bacterial community were within a factor of 50%. Seasonality of bacterioplankton species was shown recently by several investigators, using whole-genome probes (Pinhassi & Hagström, 2000; Hagström *et al.*, 2000; Fandino *et al.*, 2001). The community of heterotrophic bacteria in the sea is dominated by relatively few species undergoing regular, repeatable seasonal successions. Although different bacterial phylotypes are dominant in different seasons, single species might persists at high abundance for long periods (up to several weeks) (Rehnstam *et al.*, 1993).

Marine bacteria are non-randomly distributed vertically and horizontally as response to concentration gradients in microenvironments. Some of the factors, such as substrate composition, temperature changes and grazing pressure, which influence the growth of bacteria have been subject to control the intra-annual variability.

In the Gulf of Trieste, bacterial abundance declined sharply when the lowest temperature was measured in February in both years. Since spring phytoplankton bloom begins while the water is still near its yearly minimum temperature, bacterial growth and activity could be inhibited by low temperature. A positive correlation between temperature and bacterial abundance was established during this study, and had been observed in other aquatic environments, especially during the non-summer seasons (Siah & Ducklow, 1994; Pomeroy & Wiebe, 2001). The higher relative importance of temperature over substrate has been observed when substrate supply was not limiting for bacteria growth (Shiah & Ducklow, 1994). In our measurements, spring phytoplankton bloom was followed by low phosphate and nitrate concentration throughout the water column and by an increase of TCHO concentration, predominantly due to high molecular weight fraction in February-March 1992. The lag in bacterial abundance, which occurred and marked dispersion or accumulation of phytoplankton-derived TCHO, must have taken place before being taken up by bacteria. The ability of bacteria to use carbon-rich substrate has been limited when phosphorous was lacking in our control enrichment experiments (Fajon *et al.*, 1999). Similar results were found also in other marine waters when accumulation of dissolved organic carbon occurred when bacterial growth was limited by inorganic nutrients (Williams, 1995; Thingstad & Lignell, 1997).

However, interaction of temperature with substrate availability on bacterial dynamic was evident, a lag phase in biomass increase may reflect the presence of predators - HNAN. Both cyanobacteria and heterotrophic bacteria showed a decline when HNAN dominated. HNAN abundance increased after the spring bloom of diatoms in 1992, and abundance was 3 times higher compared to the following year. The majority of the bacterial biomass could be utilised by protozoa, as shown by previous measurements of HNAN and the recorded grazing on bacteria in our laboratory and *in situ* experiments (Turk *et al.*, 1992; Turk & Hagström, 1997). The importance of protozoan grazing on bacteria has been stressed in different marine environments (Wikner & Hagström, 1991; Šolić & Krstulović, 1994; Šolić *et al.*, 1998).

During the summer stratification period, the organisms of microbial food web dominate the plankton population throughout the water column. High concentrations of TCHO, characterised by dominance of low molecular weight carbohydrates (August 1993), cooccurred with high abundance of heterotrophic bacteria, hence, the processes of transformation of organic carbon matter through a 'microbial loop' type of food web might be more important.

In the results discussed above we have demonstrated the influence of an initial pulse of freshwater from local river at the station in the central-western area of the Gulf on physical, chemical and biological parameters, compared to the other station, which is characterised by predominant influences of more saline/oligotrophic waters of southern origin. In two consecutive years, different pattern of phytoplankton and bacterioplankton seasonal distribution occurred, due to main factors controlling their distribution, such as different pulses of freshwater derived nutrients or control by predators.

ACKNOWLEDGEMENTS

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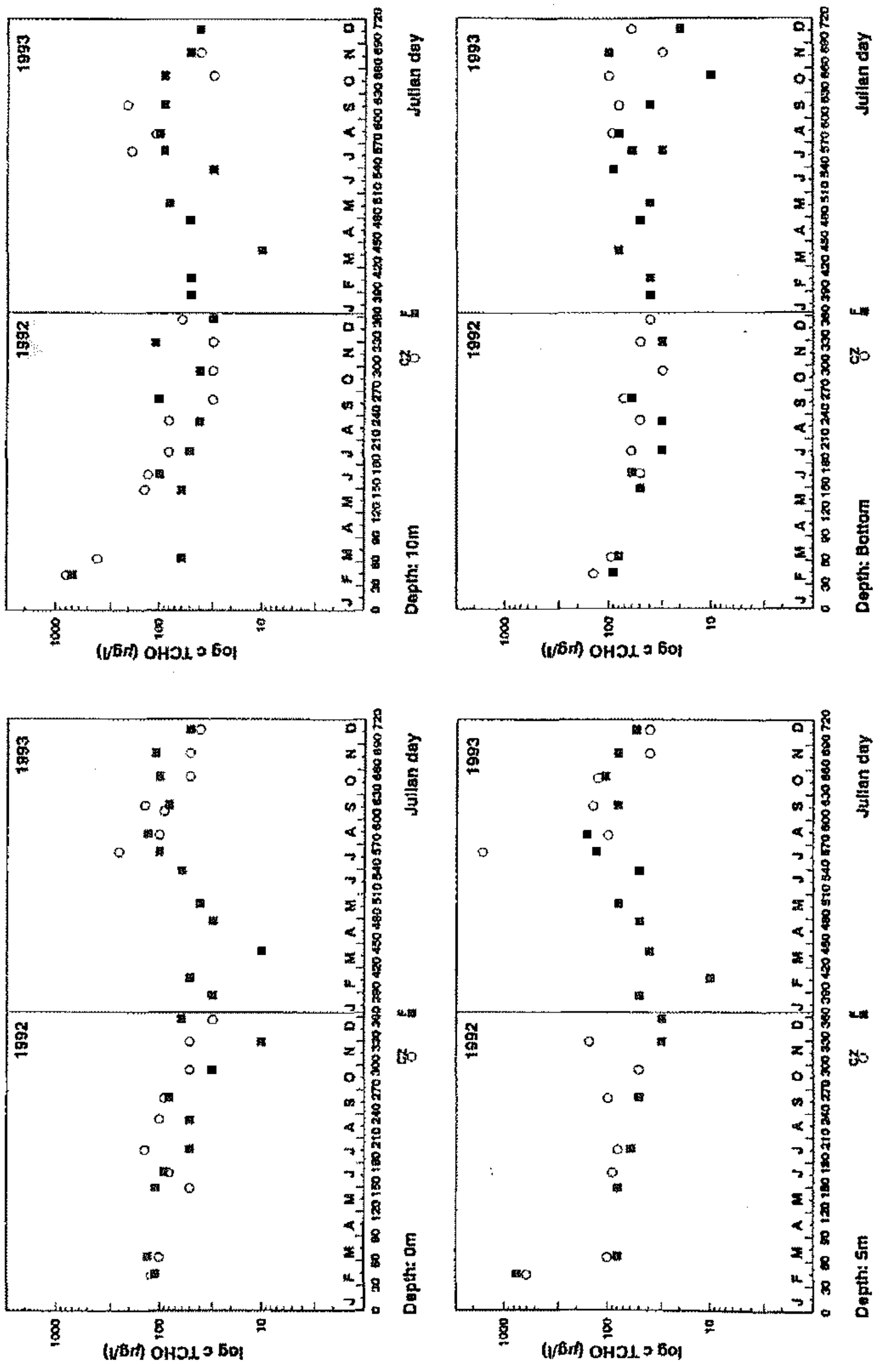

Fig. 8: Seasonal variation in total carbohydrates concentration at different depths at stations CZ (O) and F (●) in the Gulf of Trieste during 1992 and 1993.

Sl. 8: Sezonske spremembe koncentracij celokupnih ogljikovih hidratov na različnih globinah postaj CZ (O) in F (●) v Tržaškem zalivu v letih 1992 in 1993.

SEZONSKA RAZPOREDITEV FITOPLANKTONA IN BAKTERIOPLANKTONA V POLZAPRTEM ZALIVU (TRŽAŠKI ZALIV, JADRANSKO MORJE)

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POVZETEK

Predstavljena je prostorska in časovna razporeditev hranilnih soli, celokupnih ogljikovodikov, abundance fitoplanktona, cianobakterij, heterotrofnih nanoflagelatov in bakterij na dveh postajah Tržaškega zaliva (severni Jadran) v letu 1992 in 1993. Spomladanski vnos hranilno bogate sladke vode povzroči naraščanje števila kremenastih alg predvsem v centralnem delu zaliva, medtem ko so koncentracije klorofila nižje in vrstna sestava fitoplanktona v vzhodnem delu Tržaškega zaliva pod vplivom oligotrofnih vod južnega Jadrana. Ta razlika je bila opazna posebno v zimsko-spomladanskem obdobju leta 1992. Po spomladanskem cvetenju kremenastih alg v letu 1992 so bile izmerjene povišane koncentracije celokupnih ogljikovih hidratov, predvsem visoko-molekularne frakcije. Število heterotrofnih bakterij je v pozno pomladanskem obdobju nizko, kar je verjetno posledica številnih dejavnikov, kot so temperatura, razpoložljiva količina in vrsta substrata ter predacija heterotrofnih nanoflagelatov. Čeprav so potrebni dodatni podatki za zanesljivejše vrednotenje rezultatov raziskave, le-ti kažejo, da dinamiko populacije heterotrofnih bakterij kontrolirajo v veliki meri predatorji, heterotrofni nanoflagelati.

Poleti, v obdobju stratificiranega vodnega stolpca, prevladujejo mikroflagelati, enocelične cianobakterije, heterotrofne bakterij in so pomembni procesi transformacije organske snovi preko "mikrobne prehranjevalne zanke". V območju pod piknoklino prevladujejo regeneracijski procesi in razmeroma visoke koncentracije hranilnih soli (amonija) se ujemajo z nizkimi koncentracijami kisika in visokim številom heterotrofnih bakterij.

Ključne besede: fitoplankton, cianobakterije, heterotrofne bakterije, heterotrofni nanoflagelati, hranila, celokupni ogljikovi hidrati, Tržaški zaliv

REFERENCES

Azam, F. (1998): Micobial control of oceanic carbon flux: the plot thickens. Science, 280, 694-696.

Caron, D. A. (1983): Technique for enumeration of heterotrophic and phototrophic nanoplankton, using epifluorescence microscopy, and comparison with other procedures. Appl. Environ. Microbiol., 46, 491-498.

Caron, D. A. (1991): Evolving role of protozoa in aquatic nutrient cycles. In: Reid, P. C., C. M. Turley & P. H. Burkill *(eds.)*: Protozoa and their role in marine processes. Springer-Verlag, Berlin, 387-415.

Carlson, P. & D. A. Carol (2001): Seasonal variation of phosphorus limitation of bacterial growth in a small lake. Limnol. Oceanogr., 46, 108-120.

Cole, J. J., S. Findlay & M. L. Pace (1988): Bacterial production in fresh and saltwater ecosystems: a cross-system overview. Mar. Ecol. Prog. Ser., 43, 1-10.

Currie, D. J. (1990): Large scale variability and interactions among phytoplankton, bacterioplankton, and phosphorus. Limnol. Oceanogr., 35, 1437-1455.

Degobbis, D. & M. Gilmartin (1990): Nitrogen, phosphorus and biogenic silicon budgets for the northern Adriatic Sea. Oceanol. Acta, 13, 31-45.

Dugdale, R. C. & J. J. Goering (1967): Uptake of new and regenerated forms of nitrogen in primary productivity. Limnol. Oceanogr., 12,196-206.

Faganeli, J. (1983): Organic nitrogen and phosphorus in the gulf of Trieste (North Adriatic). Arch. Oceanogr. Limnol., 20, 153-177.

Fajon, C., G. Cauwet, P. Lebaron, S. Terzić, M. Ahel, A. Malej, P. Mozetič & V. Turk (1999): The accumulation and release of polysaccharides by planktonic cells and the subsequent bacterial response during a controlled experiment. FEMS Microb. Ecol., 29, 351-363.

Fandino, L. B, L. Riemann, G. F. Steward, Long R. A. & F. Azam (2001): Variation in bacterial community structure during a dinoflagellate bloom analyzed by DGGE and 16S rDNA sequencing. Aquat. Microb. Ecol., 23, 119-130.

Fuhrman, J. & F. Azam (1982): Thymidine incorporation as a measure of heterotrophic bacterioplankton production in marine surface waters: evaluation and field results. Mar. Biol., 66, 109-120.

Fuks, D. (1995): Uloga bakterioplanktona u ekosustavu sjevernog Jadrana. Ph.D. Thesis, Sveučilište u Zagrebu, 155 str.

Grasshoff, K. (1976): Methods of seawater analysis. Verlag Chemie, Weinheim.

Hagström, Å., F. Azam, A. Andersson, J. Wikner & F. Rassoulzadegan (1988): Microbial loop in an oligotrophic pelagic marine ecosystem: possible roles of cyanobacteria and nanoflagellates in the organic fluxes. Mar. Ecol. Prog. Ser., 49, 171-178.

Hagström, Å., J. Pinhassi & U. L. Zweifel (2000): Biogeographic diversity among marine bacterioplankton. Aquat. Microb. Ecol., 21, 221-230.

Harding, L. W. (1994): Long-term trends in the distribution of phytoplankton in Chesapeake Bay: roles of light, nutrients and streamflow. Mar. Ecol. Prog. Ser., 104, 267-291.

Harding, L. W., D. Degobbis & R. Precali. (1999): production and fate of phytoplankton: Annual cycles and interannual variability. In: Malone, T. C., A. Malej, L. W. Harding, N. Smodlaka & R. E. Turner (eds.): Ecosystems at the land-sea margin drainage basin to coastal sea. Coast. and Environ. Studies, 55, 131-172.

Hecky, R. E. & P. Kilham (1988): Nutrient limitation of phytoplankton in freshwater and marine environments: A review of recent evidence on the effects of enrichment. Limnol. Oceanogr., 33, 796-822.

Kemp, W. M., J. Faganeli, S. Puškarić, E. M. Smith & W. R. Boynton (1999): Pelagic- benthic coupling and nutrient cycling. In: Malone, T. C., A. Malej, L. W. Harding, N. Smodlaka & R. E. Turner (eds.): Ecosystems at the land-sea margin drainage basin to coastal sea. Coast. and Environ. Studies, 55, 295-340.

Kiørboe, T., H. Kaas, B. Kruse, F. Mohlenberg, P. Tiselius & G. Ćrtebjerg (1990): The structure of the pelagic food web in relation to water column structure in the Skagerrak. Mar. Ecol. Prog. Ser., 59, 19-32.

Klein, C., J. R. Dolan & F. Rassoulzadegan (1997): Experimental examination of the effects of rainwater on microbial communities in the surface layer of the NW Mediterranean Sea. Mar. Ecol. Prog. Ser., 158, 41-50.

Krstulović, N. & M. Šolić (1990): Long-term study of heterotrophic bacteria as indicators of eutrophication of the open Middle Adriatic Sea. Estuar. Coast. Shelf Sci., 30, 611-617.

Krstulović, N., T. Pucher-Petković & M. Šolić (1995): The relation between bacterioplankton and phytoplankton production in the middle Adriatic Sea. Aquat. Microb. Ecol., 9, 41-45.

Linley, E. A. S., R. C. Newell, & M. I. Lucas (1983): Quantitative relationships between phytoplankton, bacteria and heterotrophic microflagellates in shelf waters. Mar. Ecol. Prog. Ser., 12, 77-89.

Malej, A., P. Mozetič, V. Malačič, S. Terzić & M. Ahel (1995): Phytoplankton responses to freshwater inputs in a small semi-enclosed gulf (Gulf of Trieste, Adriatic Sea). Mar. Ecol. Prog. Ser., 120, 111-121.

Malej, A., P. Mozetič, V. Malačič & V. Turk (1997): Response of summer phytoplankton to episodic meteorological events (Gulf of Trieste, Adriatic Sea). PSZNI: Mar. Ecol., 18, 273-288.

Malačič, V., J. J. Naudin & M. Celio (1997): Plume hydrology in the Gulf of Trieste-PALOMA experiment. In: Ecosystem Research Report, the Adriatic Sea. EU/Environment Series, Brussels.

Malone, T., H. W. Ducklow, E. R. Peele & S. E. Pike (1994): Picoplankton carbon flux in Chesapeake Bay. Mar. Ecol. Prog. Ser., 78, 11-22.

Meyer-Reil, L. A. (1977): Bacterial growth rates and biomass production. In: Rheinheimer, G. (ed.): Microbial Ecology of a Brackish Water Environment. Springer-Verlag, Berlin, 223-235.

Mozetič, P., S. Fonda Umani, B. Cataletto & A. Malej (1998): Seasonal and inter-annual plankton variability in the Gulf of Trieste (northern Adriatic). ICES Journal of Marine Science, 55, 711-722.

Olivotti, R., J. Faganeli & A. Malej (1986): Eutrophication of coastal waters-Gulf of Trieste. Water Sci. Technol., 18, 303-316.

Pinhassi, J. & Å. Hagström (2000): Seasonal succession in marine bacterioplankton. Aquat. Microb. Ecol., 21, 245-256.

Pomeroy, L. R. & W. J. Wiebe (2001): Temperature and substrates as interactive limiting factors for marine heterotrophic bacteria. Aquat. Microb. Ecol., 23, 187-204.

Porter, K. G. & Y. S. Feig (1980): The use of DAPI for identifying and counting aquatic microflora. Limnol. Oceanogr., 25, 943-948.

Proctor, L. M. & J. A. Fuhrman (1990): Viral mortality of marine bacteria and cyanobacteria. Nature, 343, 60-62.

Rehnstam, A. S., S. Bäckman, D. C. Smith, F. Azam & Å Hagström (1993): Bloom of sequence-specific culturable bacteria in the sea. FEMS Microb. Ecol., 102, 161-166.

Sanders, R. W., D. A. Caron & U.G. Berninger (1992): Relationships between bacteria and heterotrophic nanoplankton in marine and freh waters: an inter-ecosystem comparison. Mar. Ecol. Prog. Ser., 86, 1-14.

Scavia, D. & G. A. Laird (1987): Bacterioplankton in Lake Michigan: dynamics, controls, and significance to carbon flux. Limnol. Oceanogr., 32, 1017-1033.

Shiah, F. K. & H. W. Ducklow (1994): Temperature and substrate regulation of bacterial abundance, production and specific growth rate in Chesapeake Bay, USA. Mar. Ecol. Prog. Ser., 103, 297-308.

Šolić, M. & N. Krstulović (1994): The role of predation in controlling bacterial and heterotrophic nanoflagellate standing stocks in the coastal Adriatic Sea: seasonal patterns. Mar. Ecol. Prog. Ser., 114, 219-235.

Šolić, M., N. Krstulović, N. Bojanić, I. Marasović & Ž. Ninčević (1998): Seasonal switching between relative importance of bottom-up and top-down control of bacterial and heterotrophic nanoflagellates abundance. J. Mar. Biol. Ass. U. K., 78, 755-766.

Strickland, J. D. H. & T. R. Parsons (1972): A practical handbook of seawater analysis. Fish. Res. Bd. Canada Bull., 167, 1-310.

Stravisi, F. (1983): Some characteristics of the circulation in the Gulf of Trieste. Thalass. Jugosl., 19, 355-363.

Takahashi, M., K. Kikuchi & Y. Hara (1985): Importance of picocyanobacteria biomass (unicellular, blue-green algae) in the phytoplankton population of the coastal waters of Japan. Mar. Biol., 89, 63-69.

Terzić, S., M. Ahel, G. Cauwet & A. Malej (1998): Group-specific phytoplankton biomass/dissolved carbohydrate relationships in the Gulf of Trieste (Northern Adriatic). Hydrobiologia, 363, 191-205.

Thingstad, T. F. & F. Rassoulzadegan (1995): Nutrient limitation, microbial food webs, and 'biological C-pump': suggested interactions in a P-limited Mediterranean. Mar. Ecol. Prog. Ser., 117, 299-306.

Thingstad, T. F. & R. Lignell (1997): A theoretical approach to the question of how trophic interactions controle carbon demand, growth rate, abundance and diversity. Aquat. Microb. Ecol., 13, 19-27.

Turk, V. (1992): The microbial food web: time scales and nutrient dynamics in the Gulf of Trieste. Ph.D. Thesis, University of Umea.

Turk, V., Rehnstam, A. S., Lundberg, E. & A. Hagström (1992): Release of bacterial DNA by marine nanoflagellates, an intermediate step in phosphorus regeneration. Appl. Environ. Microbiol., 58(11), 3744-3750.

Turk, V. & A. Hagström (1997): Seasonal distribution of nanoflagellates and bacterivory in the Gulf of Trieste (North Adriatic). Period. Biolog., 99(2), 205-208.

Utermöl, H. (1958): Zur Vervollkommung der quantitativen Phytoplankton-Methodik. Mit. Int. Verein. Theor. Angew. Limnol., 9, 1-38.

Williams, P. J. LeB (1995): Evidence for the seasonal accumulation of carbon-rich dissolved oorganic material, its scale in comparison with changes in particulate material and the consequential effect on net C/N assimilation ratios. Mar. Chem., 51, 17-29.

Wikner, J. & A. Hagström (1991): Annual study of bacterioplankton community dynamics. Limnol. Oceanogr., 36, 1313-1324.