

A STUDY OF PHYTOPLANKTON POPULATION DENSITY AND CELL VOLUME IN THE KOTOR BAY, THE SOUTHERN ADRIATIC

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Abstract

The phytoplankton quantity (population density, cell volume) was followed up in the Kotor Bay monthly from December 1981 to December 1982. Particular taxonomic categories of microplankton as well as phytoplankton size fractions were analyzed in detail. The maximum phytoplankton quantity was recorded in February. The microplankton dominated the total phytoplankton cell volume in 76% of samples. However, in 28% of samples it represented more than 90% of the total phytoplankton cell volume. On the basis of frequency distribution of phytoplankton quantity, the Kotor Bay is evaluated as one of the most eutrophicated ecosystems along the eastern Adriatic coast. In distinction from upper layers (0-5 m) with relatively high and variable phytoplankton quantity, deeper layers (20 m) are ecologically more stable. The relationship and ecological significance among microplankton population density, cell volume (biomass) and average cell volume fractions are discussed.

Izvod

ISTRAŽIVANJE GUSTOĆE POPULACIJA I STANIČNOG VOLUMENA FITOPLANKTONA U KOTORSKOM ZALJEVU, U JUŽNOM JADRANU

Količina fitoplanktona (gustoća populacija, stanični volumen) praćena je u Kotorskom zaljevu jednom mjesečno od prosinca 1981. do prosinca 1982. godine. Analizirane su veličinske frakcije fitoplanktona, kao i pojedine taksonomske kategorije mikroplanktona. Maksimalna količina fitoplanktona zabilježena je u veljači. U 76% uzoraka stanični volumen mikroplanktona je dominirao u ukupnom volumenu fitoplanktona, a u 28% uzoraka njegov udio bio je veći od 90%. Na osnovi raspodjele učestalosti količine fitoplanktona, Kotorski zaljev se pokazuje kao jedan od najizloženijih ekosistema autrofikaciji uz istočnu obalu Jadrana. Za razliku od relativno velike i promjenljive količine fitoplanktona u površinskom sloju (0-5 m), veća ekološka stabilnost

registrirana je u dubljim slojevima (20 m). Diskutiran je ekološki značaj odnosa između gustoće populacija, ukupnog staničnog volumena (biomase) i srednjeg staničnog volumena mikroplanktona.

INTRODUCTION

The Kotor Bay is the innermost part of Boka Kotorska, one of the largest and most indented bays on the eastern Adriatic coast. It is surrounded by relatively high mountains, running along the sea coast and rising directly out of the sea to the heights of 1888 m. The hinterland of Boka Kotorska has been found to be the wettest part of Europe with the rainfall reaching the enormous quantities of the yearly average of 5000-5500 mm (Melik 1956). The distribution of precipitation shows the Mediterranean characteristics of annual course with the maximum in winter (December) and the minimum in summer (August). The surrounding mainland area is built of highly permeable limestone mass showing hydrogeological characteristics typical for a carst region. The groundwater drainage towards the sea, as well as underground connections between the ponors (swallow holes) and the vruljas (submarine springs) are evident and intensive especially during the rainy period. These characteristics are important for the salinity and temperature régime of the neritic waters. The eutrophication of the Kotor Bay is relatively intensive. It is natural but also anthropogenic in character, due to waste water discharge from the town of Kotor and other neighbouring settlements.

The phytoplankton of the Kotor Bay has been partially investigated with regard to its taxonomy and population density (Ercegović 1938, Dobrosavljević 1971, Mandić and Stjepčević 1972, Jerković 1977). The program of investigation of phytoplankton population density and biomass in the Kotor Bay was carried out in 1982 by the Biological Institute, Dubrovnik, as a part of a joint plankton research program along the eastern Adriatic coast. The winter aspect of phytoplankton in the Kotor Bay with regard to taxonomy, population density and cell volume has been already published (Viličić 1983). In this paper the annual study of the phytoplankton cell volume in the Kotor Bay has been presented for the first time.

MATERIAL AND METHODS

Samples were collected at one station, monthly from December 1981 to December 1982 (Fig. 1). Totally, 34 Nansen bottle samples for the quantitative analysis of the phytoplankton, salinity and temperature, were taken at three depths (1, 5, 20 m). Salinity was determined by the arginometric titration or using a salinometer. All samples for the phytoplankton analysis were preserved in a two per cent neutralized formaldehyde solution. The phytoplankton cell counts were obtained by the inverted micro-

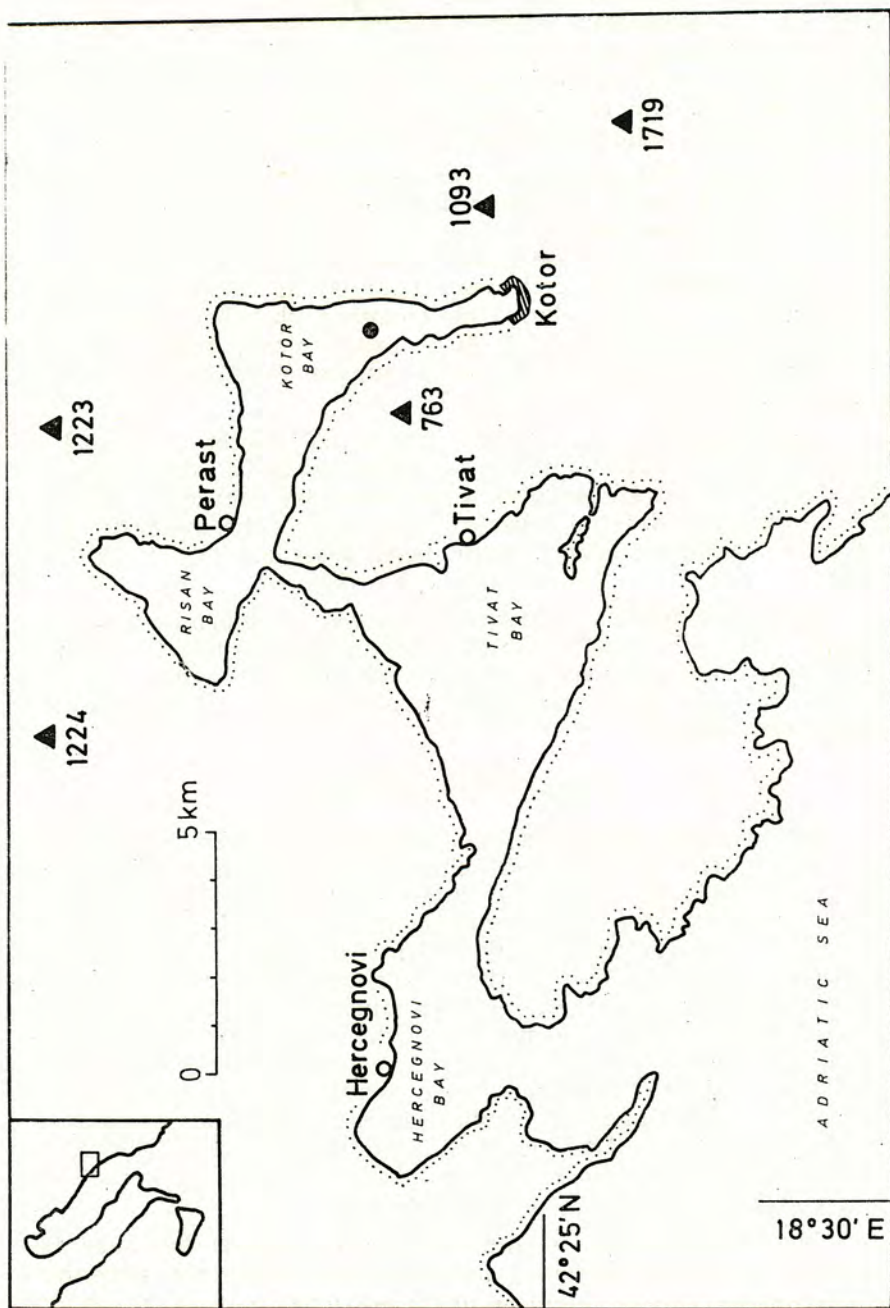


Fig. 1. A map of Boka Kotorška and station location in the Kotor Bay
 Sl. 1. Karta Boka Kotorške i položaj postaje u Kotorškom zaljevu

scope method (Utermöhl 1958). Samples of 25 or 50 ml were analyzed microscopically after a sedimentation time of 24 hours. The phytoplankton cells 3-15 μm in diameters were defined as nanoplankton, cells larger than 15 μm as microplankton. Cells smaller than 15 μm linked together in chains and single cells with hair-like spines, which make such cells longer than 15 μm , were also defined as microplankton. The counting of microplankton cells was performed under the magnification of 200 and 80 X. For the smaller, more abundant cells, transects across the central part of the counting chamber base plate were made with a higher-power lens. The nanoplankton cells were counted in 20-50 randomly selected fields of vision along the counting chamber bottom plate under the magnification of 320 X. To avoid miscountings only easily identifiable nanoplankton cells were counted. Precision of the counting method was ± 10 per cent.

Assuming that the biomass was equal to the total cell volume, the latter was calculated according to Smayda (1978). The cell dimensions in all samples were measured simultaneously with cell countings under the inverted microscope. The methods of cell volume calculations have already been described (Viličić 1985a, 1985b).

The microplankton mean cell volume is determined by dividing the total cell volume with the population density. The monthly determined mean cell volume data were distributed into three cell volume fractions and presented graphically as a time-frequency distribution (Fig. 9).

RESULTS AND DISCUSSION

The salinity values in the Kotor Bay varied between 8.48 and 38.80‰. The salinity was high and more constant in the deeper layers and variable in the near surface layers (Fig. 2). Low salinity was registered at the surface during the period of intensified precipitation (October-January). Freshwater discharge was also higher in March and April due to the intensified melting of snow from the surrounding mountains. A high quantity of allochthonous materials is carried into the system at the same time (natural eutrophication). The yearly variations in seawater temperature ranged from 8.7 to 28.3°C. The maximum temperature recorded in the Kotor Bay was higher in comparison to other analyzed locations along the southern Adriatic neritic region (Viličić 1985a). The stable meteorological and hydrographical situation was registered in a period between May and September.

The concentration of nutrients in the Kotor Bay has been followed up during previous investigations where the phosphorus concentrations ranged between 0.03 and 0.30 $\mu\text{g-at/l PO}_4\text{-P}$ (Dobrosavljević 1971).

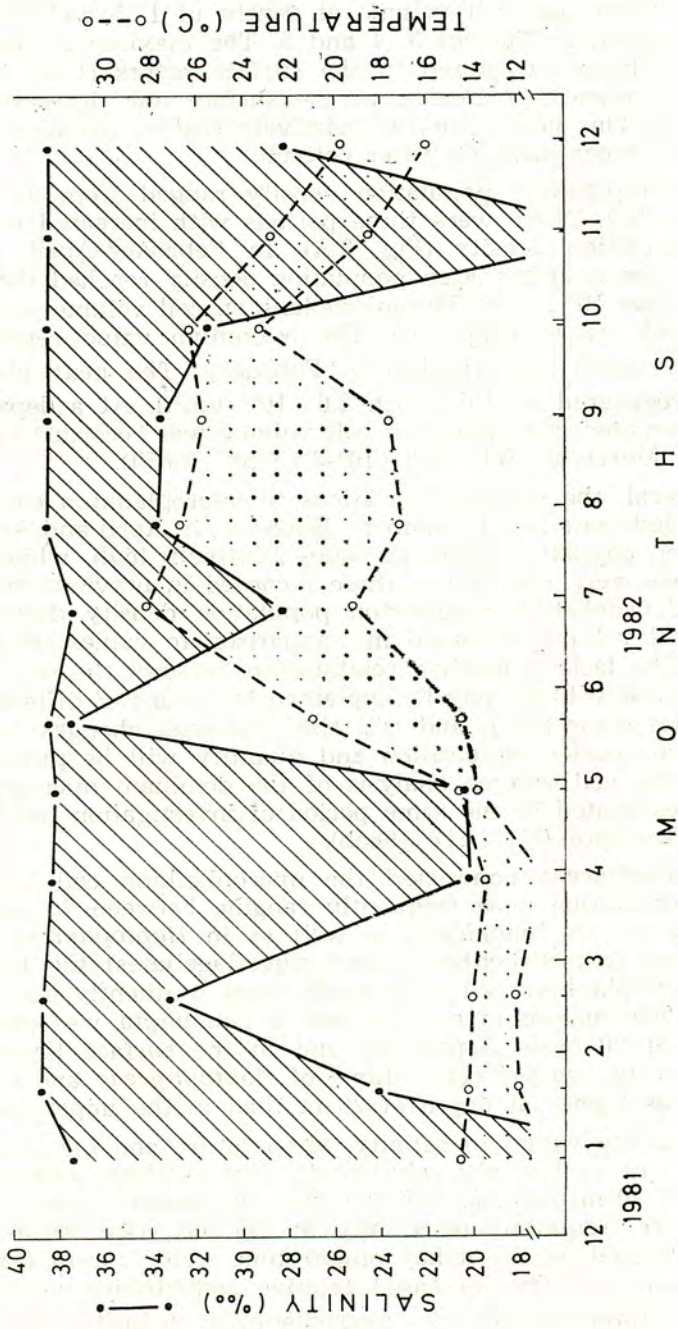


Fig. 2. The minimum-maximum range and monthly variations in salinity and temperature in the Kotor Bay

Sl. 2. Raspon između minimalnih i maksimalnih vrijednosti, te mjesečne promjene saliniteta i temperature u Kotorskom zaljevu

The seasonal variations of microplankton and nanoplankton population density and cell volume at depths of 1, 5 and 20 meters are presented in Figures 3, 4 and 5. The maximum quantity values were always registered in the surface layers (1 or 5 m). Variations in quantity increased at the surface and decreased in deeper layers. This points out the relatively higher ecological stability of the deeper parts of water column.

The microplankton population density ranged from 9.3×10^3 to 2.9×10^6 cells/l. There were three periods with increased microplankton population density (Fig. 3 A). In February-April, June and August, the microplankton population density reached the values higher than 10^6 cells/l. The microplankton cell volume reached only two peak values (Fig. 3 B). The maximum value representing $6.2 \times 10^9 \mu\text{m}^3/\text{l}$ was reached in February. The next highest value was registered in July with $2.6 \times 10^9 \mu\text{m}^3/\text{l}$. At a depth of 20 m the increased microplankton cell volume was recorded in the period from March to July (2.2×10^8 - $3.4 \times 10^8 \mu\text{m}^3/\text{l}$).

In general, the seasonal variations in microplankton cell volume paralleled those in cell numbers. However, in April and August microplankton population densities were relatively high, while cell volume values were just below those recorded in previous month. In July and October microplankton population density decreased while the cell volume increased in comparison to values recorded previously. The lack of positive relationship between the cell density and the cell volume may be explained by means of differences in the species composition and cell size. Seasonal changes in the microplankton species composition and quantity will be published separately. The cell volume analysis of the dominant microplankton species estimated in the same period of investigation has been presented elsewhere (Viličić 1985b).

Bacillariophyceae dominated the microplankton cell volume with the contribution most frequently ranging between 70 and 80 percent (Fig. 4). In *Dinophyta*, as well as in *Haptophyceae* and *Chrysophyceae* (coccolithophorids and silicoflagellates) the contribution in microplankton cell volume was most frequently less than 10 percent. The maximum cell volume of *Dinophyta* was evident at a depth of 20 m in September and in the surface layers in July. The yearly average cell volume of *Haptophyceae* and *Chrysophyceae* was higher at depth of 20 m than in the upper layers.

The absolute values of salinity, temperature and microplankton quantity, as well as the relative stability of these parameters at a depth of 20 m, seem to indicate that the deeper layers of the Kotor Bay are frequently (especially during increased freshwater discharge) affected by the upbay oligotrophic water current coming from the open sea. The increased relative contribution of coccolithophorids (*Haptophyceae*) in microplankton quantity can also

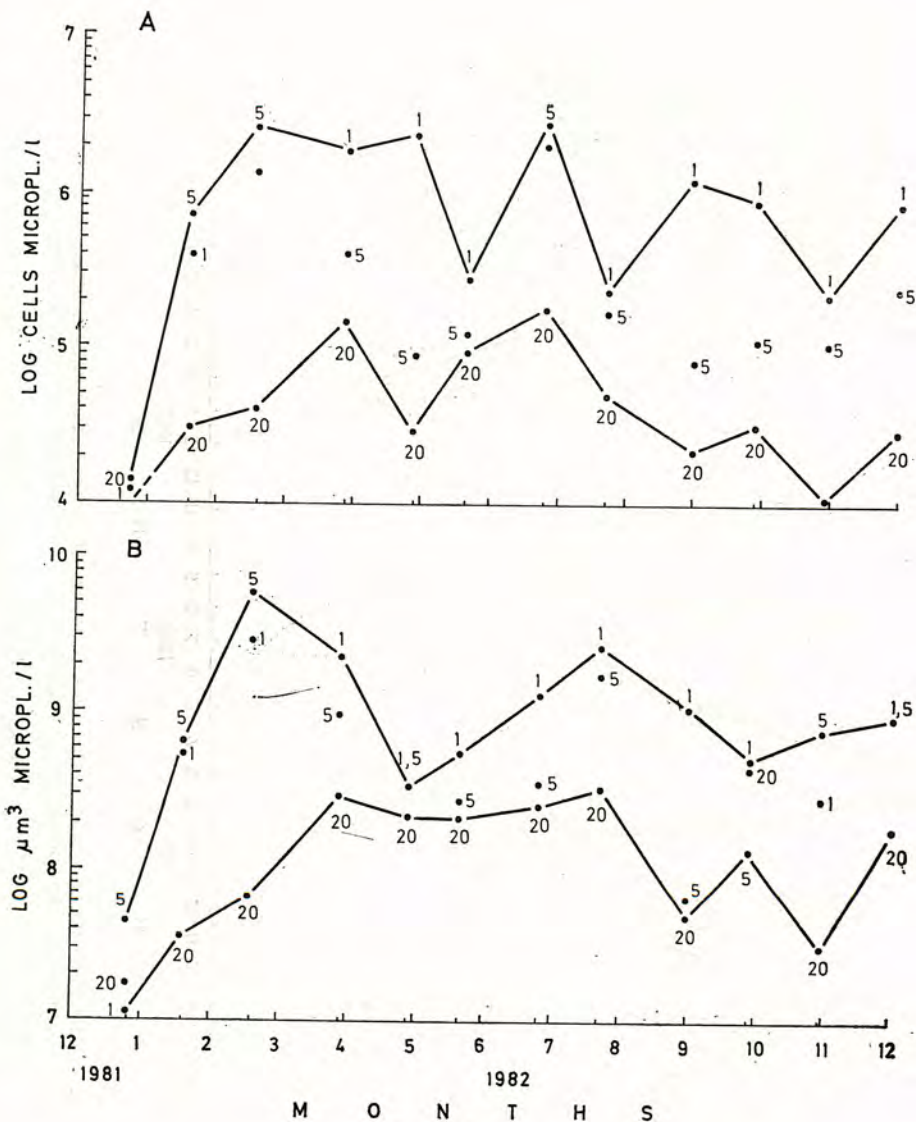


Fig. 3. The minimum-maximum range and monthly variations in the microplankton population density (A) and microplankton cell volume (B) in the Kotor Bay. Determinations were made at depth of 1, 5 and 20 meters.

Sl. 3. Raspon između minimalnih i maksimalnih vrijednosti, te mjesečne gustoće populacija (A) i ukupnog staničnog volumena (B) mikroplanktona u Kotorskom zaljevu. Mjerenja su izvršena na dubinama od 1, 5 i 20 metara.

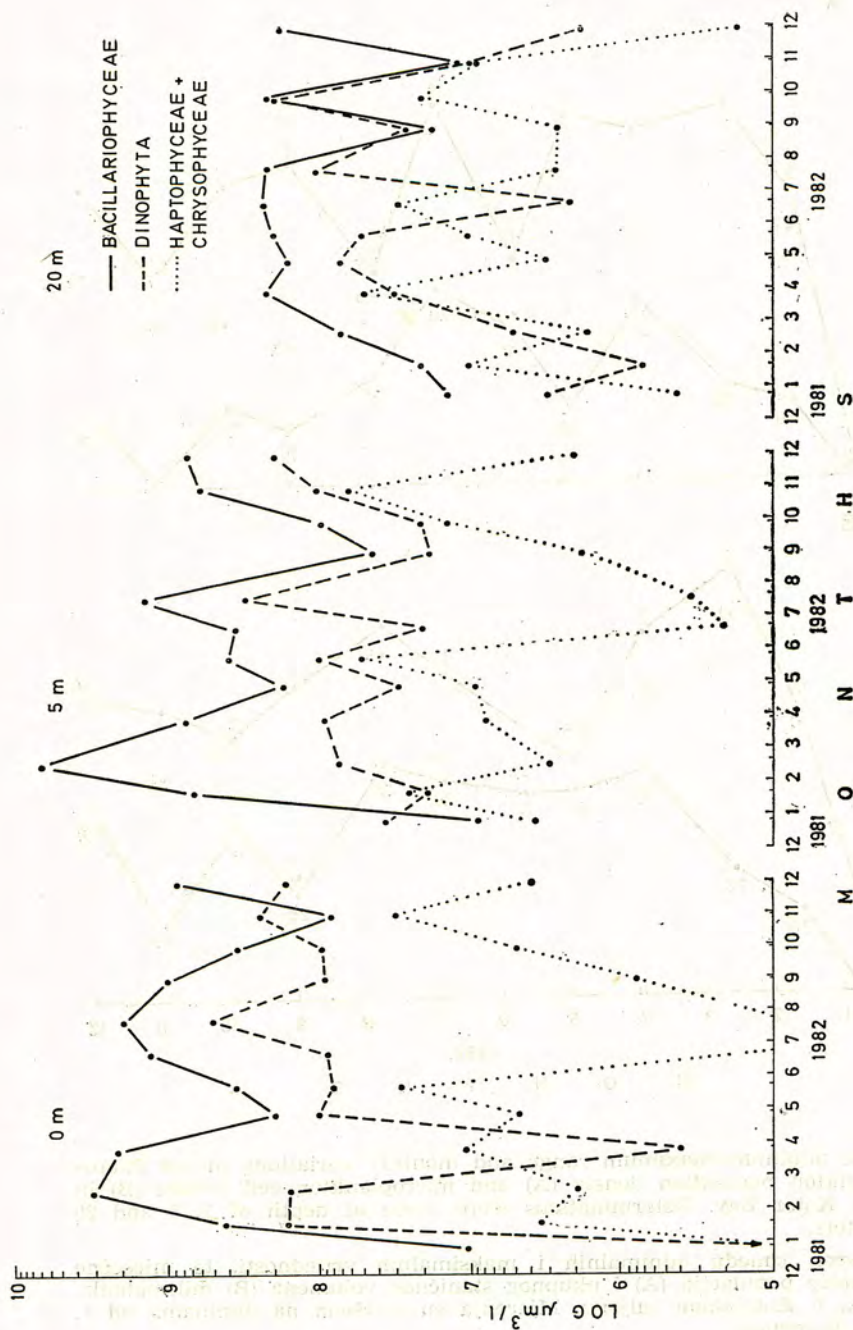


Fig. 4. Monthly variations in the cell volume of three taxonomical categories of microplankton at depths of 1, 5 and 20 meters in the Kotor Bay.

Sl. 4. Mjesečne promjene staničnog volumena triju taksonomskih kategorija mikroplanktona na dubinama od 1, 5 i 20 metara u Kotorском zaljevu.

be used as an indicator of the Mediterranean and open sea (oligotrophic waters (Pucher-Petković et al. 1971, Zore-Armanda and Pucher - Petković 1976). From the innermost part of the Kotor Bay, the water mass is frequently going backwards, forming a downbay surface more eutrophicated current.

The curves of nanoplankton quantity (Fig. 5) showed a more or less monotonous seasonal course, with the population density ranging from 1.3×10^6 to 6.4×10^6 cells/l and cell volume from 6.8×10^7 to $3.2 \times 10^8 \mu\text{m}^3/\text{l}$, respectively. The maximum was reached in June, in terms of both cell number and volume. The next highest nanoplankton cell density and volume was recorded in October, similar to the previous findings in the neritic region of the southern Adriatic (Viličić 1985a). In distinction from *Bacillariophyceae*, as the main representative group of microplankton which usually develops higher quantities in the surface than in the deeper layers, the vertical distribution of nanoplankton quantity is irregular. Sometimes it reached the maximum value near the surface and at other times in deeper layers. If compared with other groups of phytoplankton, the average nanoplankton cell volume is similar as the one in *Dinophyta*.

The intensive development of the total phytoplankton cell volume (Fig. 6) was recorded in the surface layers (1 and 5 m) in February ($6.4 \times 10^9 \mu\text{m}^3/\text{l}$) and July ($2.7 \times 10^9 \mu\text{m}^3/\text{l}$). At a depth of 20 m the high values of phytoplankton cell volume (3.7×10^8 - $7.8 \times 10^8 \mu\text{m}^3/\text{l}$) were recorded in a period from March to July. The autumnal peak in 1982 was not as high as expected. The two peak values recorded at the surface, correspond closely to those of *Bacillariophyceae*, as a quantitatively dominant phytoplankton group (compare Fig. 4).

The relative contribution of microplankton to the total phytoplankton cell volume was based on 34 measurements providing information on microplankton over nanoplankton domination (Fig. 7). The microplankton component was dominant in the total phytoplankton cell volume in 76% of measurements (nanoplankton in 24%). However, in 28% of measurements microplankton represented more than 90% of the total phytoplankton cell volume.

To define the ecological properties of the analyzed ecosystem, it is very important to define the frequency distribution of the phytoplankton quantity in a period of at least one year (Fig. 8). Rather high microplankton population density ($> 10^6$ cells/l) and volume ($> 10^9 \mu\text{m}^3/\text{l}$); nanoplankton population density ($> 5 \times 10^6$ cells/l) and volume ($> 2.5 \times 10^8 \mu\text{m}^3/\text{l}$); as well as total phytoplankton cell volume ($> 10^9 \mu\text{m}^3/\text{l}$), were relatively frequently recorded in the Kotor Bay. The most frequent values were also high (10^5 - 5×10^5 cells/l in microplankton; 10^6 - 2.5×10^6 cells/l in nano-

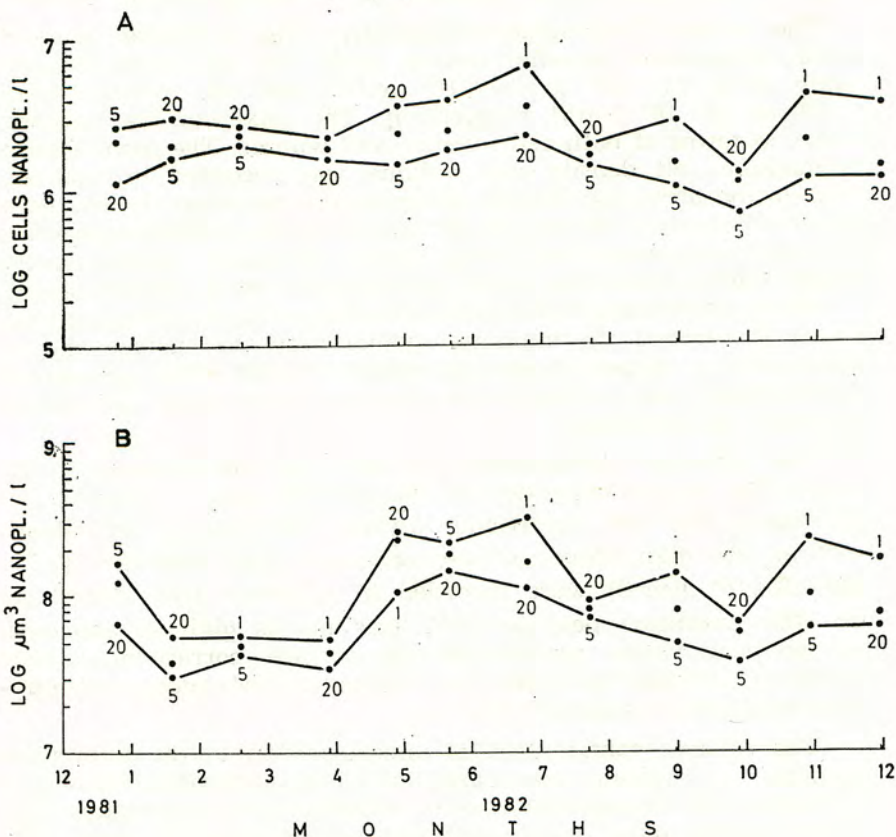


Fig. 5. The minimum-maximum range and monthly variations in the nanoplankton population density (A) and nanoplankton cell volume (B) in the Kotor Bay. Determinations were made at depths of 1, 5 and 20 meters.

Sl. 5. Raspon između minimalnih i maksimalnih vrijednosti, te mjesečne promjene gustoće populacija (A) i ukupnog staničnog volumena (B) nanoplanktona u Kotorskom zaljevu. Mjerenja su izvršena na dubinama od 1, 5 i 20 metara.

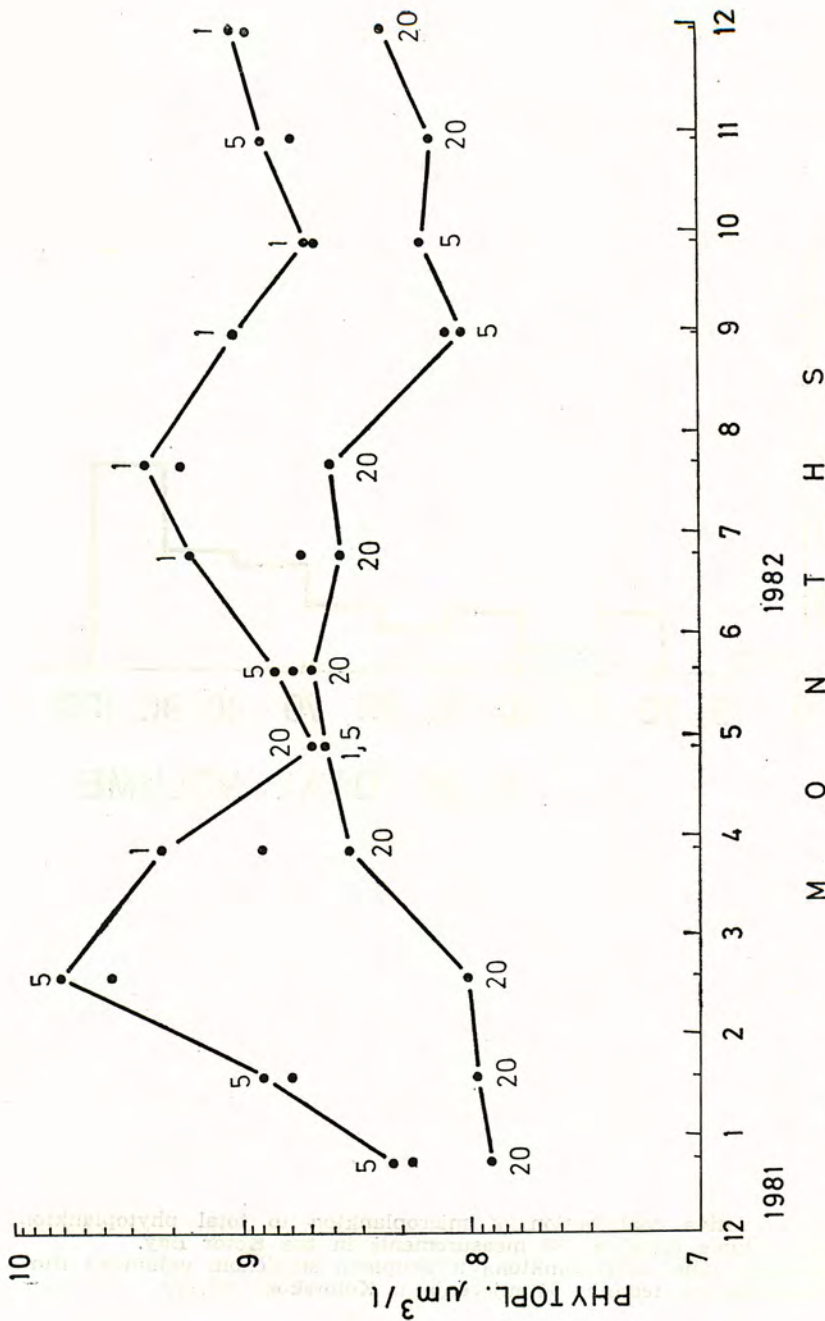


Fig. 6. The minimum-maximum range and monthly variations in the total phytoplankton cell volume in the Kotor Bay. Determinations were made at depths of 1, 5 and 20 meters.

Sl. 6. Raspon između minimalnih i maksimalnih vrijednosti, te mjesečne promjene staničnog volumena ukupnog fitoplanktona u Kotorskom zaljevu. Mjerenja su izvršena na dubinama od 1, 5 i 20 metara.

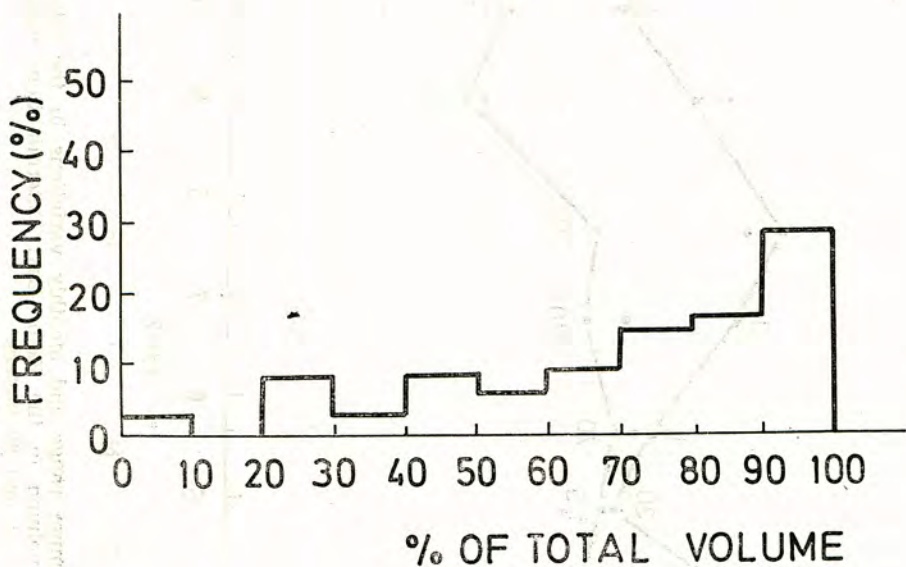


Fig. 7. The relative contribution of microplankton to total phytoplankton cell volume based on 34 measurements in the Kotor Bay.

Sl. 7. Relativni udio mikroplanktona u ukupnom staničnom volumenu fitoplanktona na temelju 34 mjerenja u Kotorskom zaljevu.

plankton; $10^8-5 \times 10^8 \mu\text{m}^3/\text{l}$ in microplankton, nanoplankton and total phytoplankton). The phytoplankton quantity is an important evidence of the trophic state of marine ecosystems, i. e., it may be correlated to the intensity of eutrophication. The development of phytoplankton populations depends upon the concentration of nutrients and other ecological factors such as light, temperature, salinity, composition and quantity of organic matter, currents and grazing. During a greater part of the year the composition of various ecological factors is not favourable for phytoplankton growth. The favourable growth conditions in subtropical seas are usually reestablished in spring and autumn. However, the most important characteristic of phytoplankton is the complicated spatial and temporal dynamics of its growth and the quantity distribution. Therefore, it is difficult to find any ecological or phytoplankton characteristics that occur repeatedly in one place, every year at the same time. Besides the determination of minimum, maximum and most frequent phytoplankton quantity, it is not necessary to know the spatial and temporal dynamics of phytoplankton. Such a spectrum of values may be accurately estimated only if sampling is carried out continuously and frequently enough throughout the year. Following these principles, and on the basis of frequency distribution of phytoplankton quantity, the categorization of ecosystems and evaluation of eutrophication have been proposed for the central and southern Adriatic Sea (Viličić in preparation). According to the same categorization and phytoplankton quantity data presented in this paper, the Kotor Bay may be evaluated as one of the most eutrophicated environments in the neritic eastern Adriatic area.

Temporal variations in the average microplankton cell volume also have a particular ecological significance. In the Kotor bay the predominance of the smallest cell size fraction ($V < 1000 \mu\text{m}^3/\text{cell}$) was evident during the warmer part of the year (Fig. 9). The fraction of cells with $V < 2000 \mu\text{m}^3/\text{cell}$ dominated during the winter microplankton bloom. The cell fractions with $V > 1000 \mu\text{m}^3/\text{cell}$ appeared usually in alternation with smaller cell fraction. The phytoplankton cell size depends upon various ecological factors and on the growth phase of the present population. In general, the growth of many species is more intensive at higher temperatures and in sufficiently eutrophicated ecosystems. The cell size may be used as a measure to distinguish between more mature and less mature stages of the phytoplankton community. In the early stage of the ecosystem development, i. e., the period of more frequent cell divisions, the smaller phytoplankton cells are present in greater numbers. In the more mature (less active) stage of phytoplankton community, the larger cells are more frequently present. This simplified interpretation agrees with the »strategy of ecosystem development« described by Odum (1969), but patchiness, zooplank-

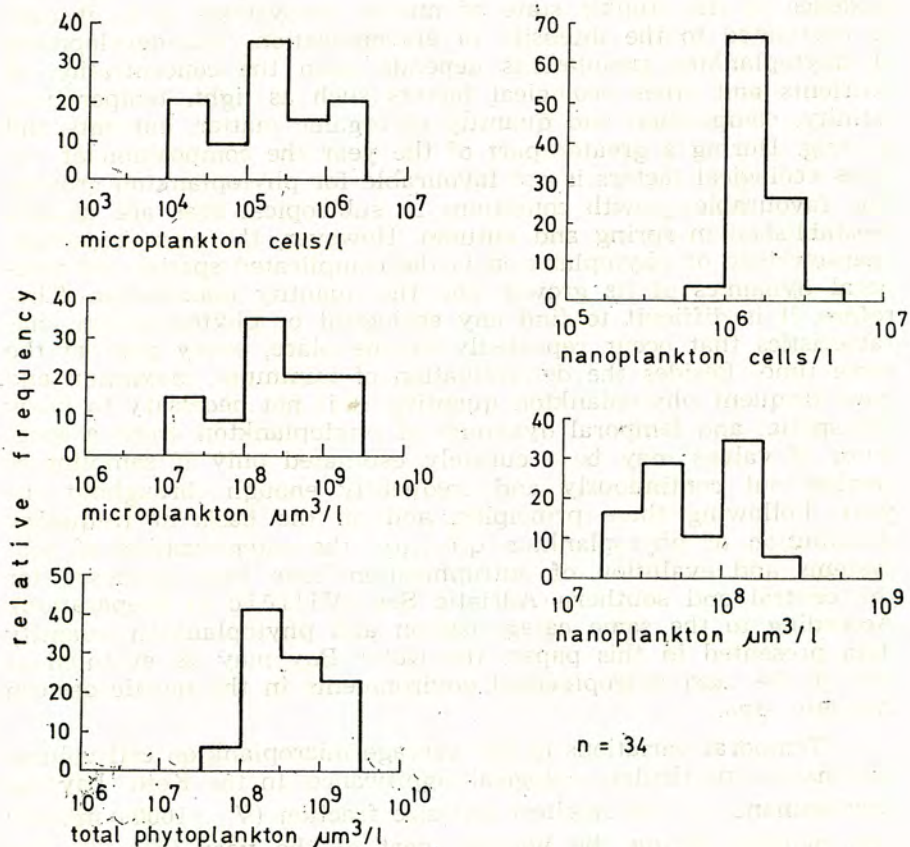


Fig. 8. Frequency distribution of phytoplankton (total, microplankton, nanoplankton) population density and cell volume, based on 34 determinations in the Kotor Bay. Classes of quantity are designated by a logarithmic scale where each decade is divided into two classes in microplankton and total phytoplankton (10^n , 5×10^n , 10^{n+1} etc.), and into four classes in nanoplankton (10^n , 2.5×10^n , 5×10^n , 7.5×10^n , 10^{n+1} etc.).

Sl. 8. Raspodjela učestalosti gustoće populacija i staničnog volumena fitoplanktona (ukupnog, mikroplanktona, nanoplanktona), na temelju 34 mjerenja u Kotorskom zaljevu. Razredi količinskih vrijednosti su označeni logaritamskom skalom gdje je svaka dekada podijeljena na dva razreda kod mikroplanktona i ukupnog fitoplanktona (10^n ; 5×10^n ; 10^{n+1} itd.), te u četiri razreda kod nanoplanktona (10^n ; 2.5×10^n ; 5×10^n ; 7.5×10^n ; 10^{n+1} itd.).

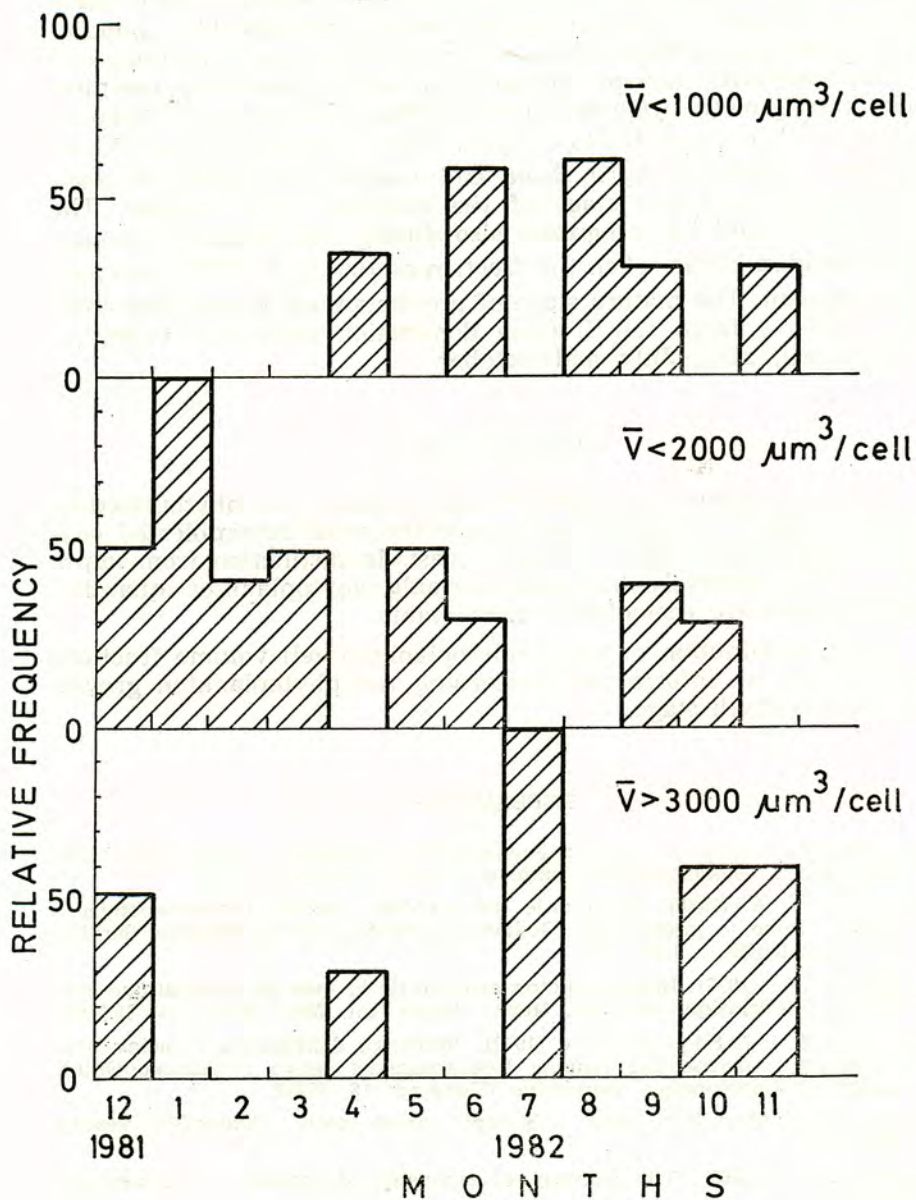


Fig. 9. Monthly distribution of three mean microplankton cell volume fractions, based on 34 determinations in the Kotor Bay.

Sl. 9. Mjesečna raspodjela triju srednjih volumnih frakcija mikroplanktona na temelju 34 mjerenja u Kotorskom zaljevu.

ton grazing and other ecological factors may complicate the interpretation. Anyway, the comparison among microplankton population density, cell volume (biomass) and distribution of average cell volume fractions, may provide an information concerning the phytoplankton growth cycle and growth stage. The determination of smaller cell volume fractions ($V < 1000 \mu\text{m}^3/\text{cell}$) in the Kotor Bay was evident in April, June and August, and could be associated with the active stage of the ecosystem development. The same stage could be recognized also during the January-February phytoplankton bloom when the fraction of $1000 < V < 2000 \mu\text{m}^3/\text{cell}$ was dominant. The mature stage of phytoplankton community coinciding with a large cell fraction domination could be evident in March-April, May, July and October.

CONCLUSIONS

On the basis of relatively high quantity of phytoplankton, the Kotor Bay is evaluated as one of the most eutrophicated ecosystems along the eastern Adriatic coast. In distinction from upper layers with relatively high and variable phytoplankton quantity, deeper layers are ecologically more stable.

The distribution of mean microplankton cell volume fractions may provide an information concerning the phytoplankton growth cycle and growth stage.

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ISTRAŽIVANJE GUSTOĆE POPULACIJA I STANIČNOG VOLUMENA FITOPLANKTONA U KOTORSKOM ZALJEVU, U JUŽNOM JADRANU

Damir VILIČIĆ

Re z i m e

Fitoplankton Kotorskog zaljeva istraživan je od prosinca 1981. do prosinca 1982. godine. Gustoća populacija i stanični volumen različitih veličinskih i taksonomskih kategorija fitoplanktona analiziran je u tri sloja. Maksimalna količina fitoplanktona zabilježena je u veljači 1982. godine. *Bacillariophyceae* dominiraju u ukupnoj količini mikroplanktona, njihov udio u staničnom volumenu mikroplanktona iznosi većinom 70-80%. Mikroplankton dominira u ukupnom volumenu fitoplanktona u 76% analiziranih uzoraka (nanoplankton u 24%). U 28% uzoraka je udio mikroplanktona u ukupnom volumenu fitoplanktona veći od 90%. Analizirajući količinu mikroplanktona ($9,3 \times 10^3 - 2,9 \times 10^6$ stanica/l, $1,1 \times 10^7 - 6,2 \times 10^9 \mu\text{m}^3/\text{l}$) nanoplanktona ($1,3 \times 10^6 - 6,4 \times 10^6$ stanica/l, $6,8 \times 10^7 - 3,2 \times 10^8 \mu\text{m}^3/\text{l}$), i ukupnog fitoplanktona ($8,7 \times 10^7 - 6,4 \times 10^9 \mu\text{m}^3/\text{l}$), te godišnju raspodjelu učestalosti količine, zaključeno je da Kotorski zaljev pripada skupini najjače eutrofiziranih ekosistema uz istočnu obalu Jadranskog mora. Za razliku od površinskih slojeva (0-5 m) u kojima je količina fitoplanktona relativno velika i promjenljiva, dublji slojevi (20 m) su ekološki stabilniji. Analiziran je odnos između gustoće populacija, ukupnog staničnog volumena (biomase) i srednjih volumnih frakcija stanica mikroplanktona, te njegov značaj kao orijentacionog pokazatelja stadija rasta i razvojnih ciklusa mikroplanktona.