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INTRODUCTION

Domestic sewage contains high concentrations of chemical compounds with phosphorus and nitrogen which are required by phytoplankton and thus often result in increased primary production. Among the methods of charting the magnitude and geographic extent of this man-made eutrophication are measurements of chlorophyll *a*, phytoplankton carbon and phytoplankton cell numbers from standing crop and by estimating the phytoplankton productivity using the C^{14} method.

This report present the results found in January 1973 during the second cruise of the Saronikos Systems Project (SSP) whose purpose was to study the influence of pollution on the marine ecosystem of the Saronikos Gulf. More specifically this paper concentrates on the quantitative increase in chlorophyll *a*, phytoplankton carbon and cell numbers from the baseline outside the Saronikos Gulf to those found in areas influenced by the sewage outfall at the apex of the Gulf; the geographic distribution of the eutrophified region within the Saronikos Gulf; and the possible movement of the eutrophic water mass past the sewage outfall into the Gulf.

METHODS AND MATERIALS

During the SSP cruise in January 1973, 63 6-L water samples were collected for chlorophyll *a* determinations, and 70 samples were collected for the determination of phytoplankton carbon values and phytoplankton cell numbers. For filtering the water, a membrane filter of 50 mm diameter and

pore size 0.45 μm was used. The chlorophyll filters were analysed in accordance with methods recommended by UNESCO (1966).

For the quantitative enumeration of the phytoplankton, a Zeiss inverted microscope was used and 5 to 20 percent of the area of the sedimentation chamber (50 ml capacity) was examined. To convert the enumerated phytoplankton into carbon values, referred to as P_c, the following method was used. For every phytoplankton species whose individual dimensions varied, at least 20 individual measurements were made. The various dimensions were averaged and converted to plasma volume using the geometric formulas of Kovala and Larrance (1966). P_c was calculated using the formula of Strathmann (1966). The results tallied well in almost all cases when compared with results of the Food Chain Research Group of the Institute of Marine Resources (Strickland and Eppley, 1969). Previous work was done by Hopkins and Becacos-Kontos (1972) showing the distribution of nutrients, light data and drogue movement in Saronikos Gulf. Furthermore, in 1970 the R/V *THOMPSON* collected data on nutrients, physical parameters, primary production and N^{15} uptake experiments in different parts of Saronikos Gulf. A list of phytoplankton species from that area was published by Ignatides (1969) and Gudenberg (1973). Quantitative reports on the phytoplankton standing stock in the form of phytoplankton carbon and details of cell numbers are not yet available for the Aegean Sea.

RESULTS AND DISCUSSION

None of the stations along profiles I, II and III (Figure 1) had any significant pycnocline so that vertical convection was likely occurring to at least 50 m. Thus nutrients and phytoplankton were probably mixed to this depth. The main source of nutrients was that advected horizontally from the outfall. Further discussion on the physical parameters and nutrient distribution are given by Coachman, Hopkins and Dugdale (1975).

In order to establish the increase of chlorophyll *a* values in the polluted area, it was necessary to establish a baseline in the surrounding Aegean Sea. Comparable data are given in Table 1. The values for Milos and the northeast coast of Evvia (Gudenberg, 1973, present paper) were determined by the same method and, therefore, provide a good comparison. The values of chlorophyll *a* in Milos and the northeast coast of Evvia (Gudenberg, 1973) were taken during the maximum oligotrophic period in the summer of 1972. For this reason, the baseline value of chlorophyll *a* in January is assumed to be higher. A mean of 0.2 mg chlorophyll a/m^3 in the euphotic zone can be considered as a baseline value. The values found in December-January 1972 and 1973 on the coast of Evvia (Table 1) are higher and it is assumed that there was a runoff effect with a slight effect of eutrophication. The baseline values in the southern part of the Saronikos Gulf are assumed to fall between the results found in summer in Milos Bay and in December-January near the Evvia coast. Chlorophyll *a* values obtained during cruise SSP2 along profiles I, II, and III (Figure 1) are shown in Figures 2, 3 and 4. The sewage outfall lies east of station DE 6—7. Transect IV is excluded in this report.

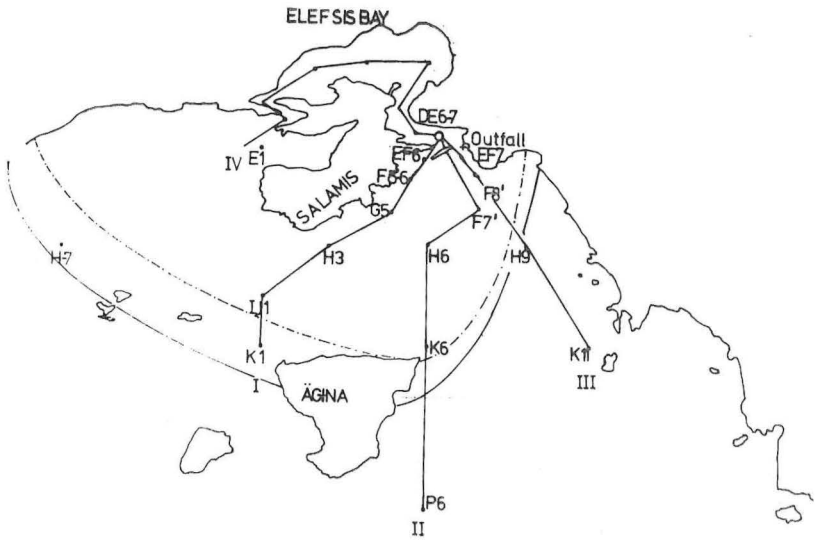

Fig. 1 — The Saronikos Gulf showing profiles I, II, III and IV of the Saronikos Systems Project. The continuous line encloses the eutrophic zone based on phytoplankton carbon (P_c) and the broken line the area where chlorophyll a exceeded baseline values.

Table 1. Mean chlorophyll *a* values (mg/m³) for selected stations in unpolluted areas of the Aegean Sea.

Area	Sta.	Date	Mean Chlorophyll *a* (mg/m³)	Reference
Petalion Gulf				
South Saronikos Gulf	10	March 1970	0.11	ANONYMOUS (1971)
Milos		Sept 1972	0.117	GUDENBERG (1973)
Northeast coast of Evvia	3	Aug 1972	0.148	GUDENBERG (1973)
Northeast coast of Evvia	3	Dec Jan 1972	0.21	GUDENBERG (this paper)
Northeast coast of Evvia	2	Dec Jan 1973	0.24	GUDENBERG (this paper)

The area covered by profiles I, II and III represents a separate biotope. Different sources of pollution, which have yet to be located exactly, are intervening in the ecosystem. The influence of the outfall in the vicinity of the station EF 7 has still not been measured quantitatively.

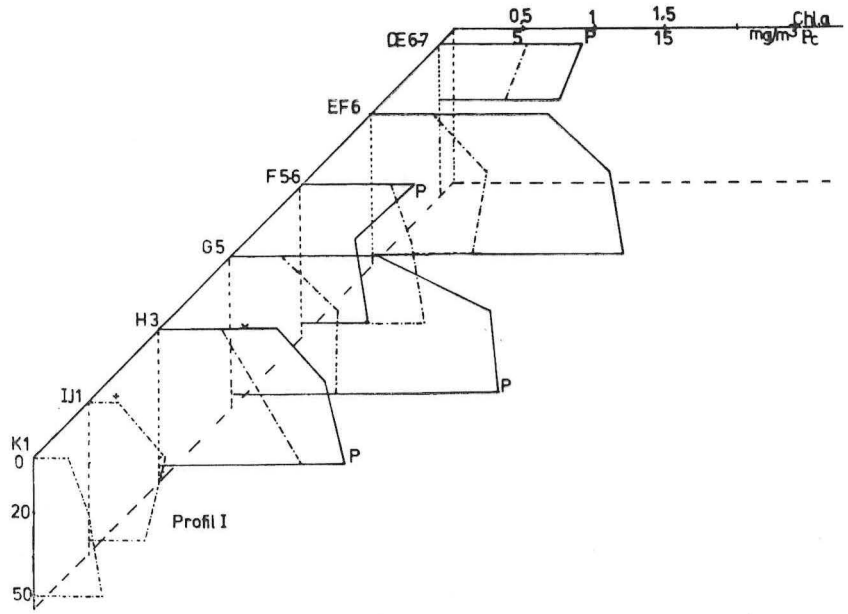

Fig. 2 — Profile I showing phytoplankton carbon (P_c mg/m³ — continuous line) and chlorophyll a (mg/m³ — broken line) from the surface to 50 m. Baseline values for chlorophyll a (+) and phytoplankton carbon (v) are indicated. »P« represents the maximum value of PO_4.

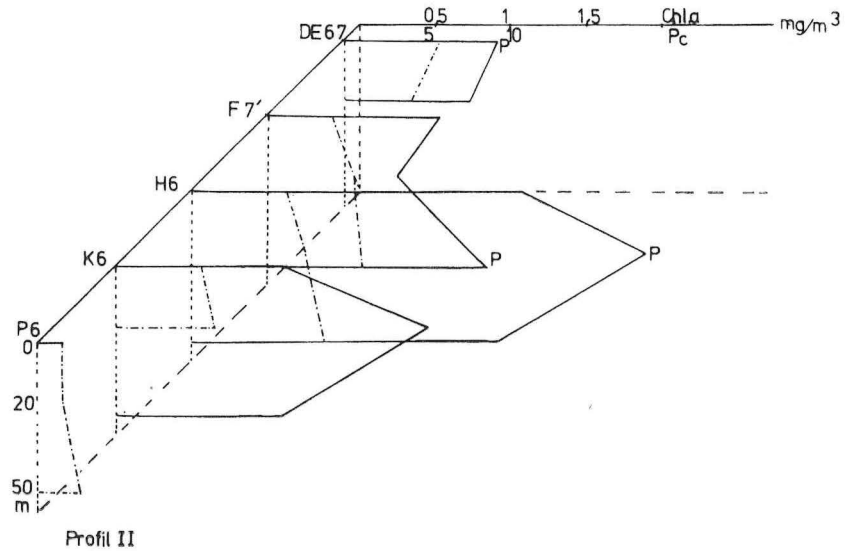

Fig. 3 — Profile II showing phytoplankton carbon (P_c mg/m³ — continuous line) and chlorophyll a (mg/m³ — broken line) from the surface to 50 m. »P« represents the maximum value of PO_4.

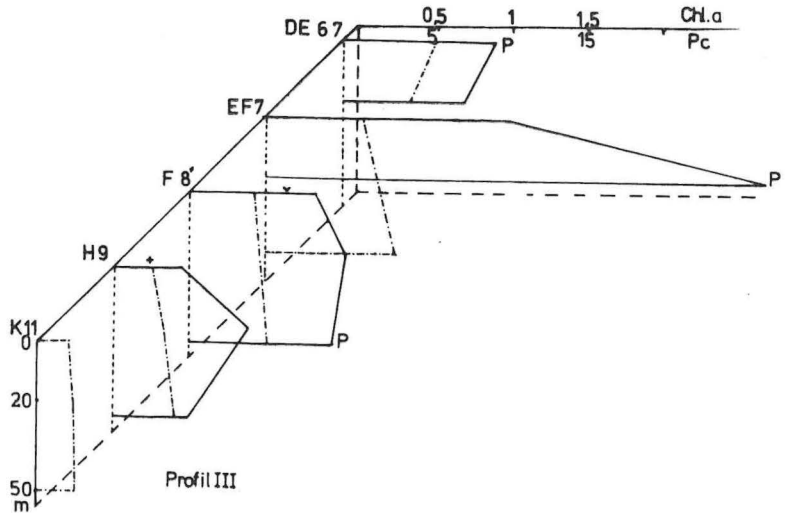

Fig. 4 — Profile III showing phytoplankton carbon (P_c mg/m^3 — continuous line) and chlorophyll a (mg/m^3 — broken line) from the surface to 50 m. Baseline values for chlorophyll a (+) and phytoplankton carbon (v) are indicated. »P« represents the maximum value of PO_4.

The mean values of chlorophyll *a* ranged between 0.51 and 0.65 mg/m^3. This range is 2.5 to 3.0 times higher than the assumed baseline. If one compares the end points of the profile, one can see that at station KI of profile I, the baseline value was not reached, whereas in the coordinates KII (III) and P6 (II), the value typical of an unpolluted area was reached. The area of the influence of eutrophication based on chlorophyll *a* is shown in Figure 1. The maximum value of 0.84 mg/m^3, is near the outfall (station EF 7) and is 4.2 times higher than the baseline (Figure 5).

Phytoplankton Carbon (P_c)

In order to determine the phytoplankton baseline for January, unpublished data of the author, taken in January 1972 and 1973 from stations on the northeast coast of Evvia, were used. The values of phytoplankton carbon for both samplings were very similar, the mean being 7.4 mg P_c/m^3 for the entire eutrophic zone. At station H 9, the southernmost station on profile III, the mean was found (Figures 2, 3 and 4). The border line of the area of influence of sewage on the phytoplankton biomass is shown in Figure 1. In this area, a mean value of 14.4 mg P_c/m^3 was found for the upper 50 m. It increased to a maximum of 36 mg P_c/m^3 at the sewage outfall which was 4.9 times the P_c of the unpolluted area (Figure 5).

Phytoplankton Cell Numbers (P_z)

The baseline value for the numbers of phytoplankton cells (P_z) was obtained by using the same comparative method which was applied to the other

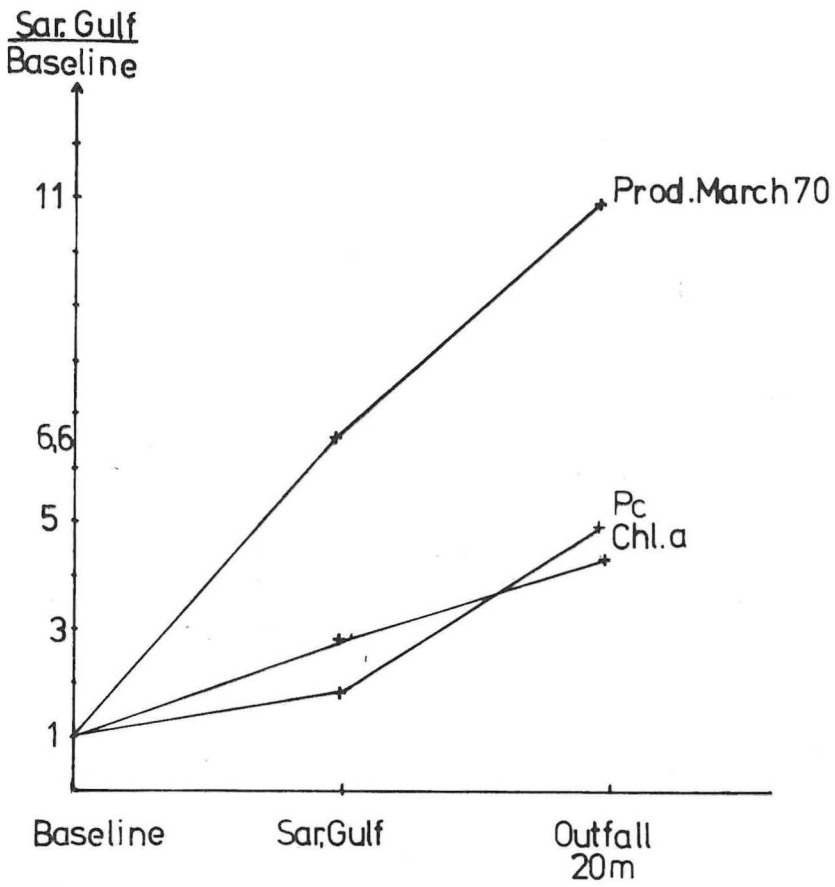

Fig. 5 — Ratio of baseline values of primary productivity, phytoplankton carbon (P_c) and chlorophyll a to polluted areas in Saronikos Gulf.

parameters. The count was made using the Utermöhl technique. In oligotrophic areas, sedimentation chambers with a volume of 100 ml were used; in eutrophic areas, chambers with a volume of 50 ml were used. The main components of the phytoplankton were diatoms, dinoflagellates and coccolithophores. On the northeast coast of Evvia, the average number of cells in the euphotic zone in February 1973 was 500 P_z/10 ml. In the Saronikos Gulf (station H 9), where based on chlorophyll *a* and the phytoplankton carbon the eutrophic effects were decreasing, the average number of cells in the euphotic zone was 400 P_z/10 ml. This value can be regarded as characteristic for the unaffected areas in the Aegean in winter 1973. Near the outfall, the average number of cells was 1326 P_z/10 ml, which was 3.3 times that at station H 9.

Primary Production

Only the data of the R/V *THOMPSON* from cruise 47 in March 1970 (A n o n y m o u s , 1971) are available for primary production. These results can only be used with reservations, as they were taken in another season and year (1970). The C^{14} uptake from the neighboring Petalion Gulf and from the unpolluted part of the Saronikos Gulf was 3.4 mgC/m^3/day. This value, compared with those taken by the author in January and February 1973 (G u d e n b e r g , 1974) on the northeast coast of Evvia, seems realistic. The measurements of the *THOMPSON* taken in the Saronikos Gulf gave a mean of 22.6 mg C/m^3/day and near the point of outfall, a mean of 37.4 mg C/m^3/day. All these values are integrated over the euphotic zone. Thus it is possible to see that the maximum value increased 11 times more than that of the baseline value of the neighboring unpolluted areas (Figure 5).

Phytoplankton Composition

A few brief remarks should be made concerning the phytoplankton composition. A list of phytoplankton species found up to 1972 in the Saronikos Gulf was published by G u d e n b e r g (1973). The quantitative distribution of diatoms and dinoflagellates, which depended on the distance from the source of pollution, is shown in Figure 6. It can be seen that the proportion of dinoflagellates in phytoplankton carbon reached 90 precent in stations near the outfall. *Ceratium furca* was the predominant species.

In order to portray the degree of eutrophication of the area of Saronikos Gulf affected by waste disposal from the point of view of nutrients, the nutrient values from the representative stations are shown in Table 2. The in-

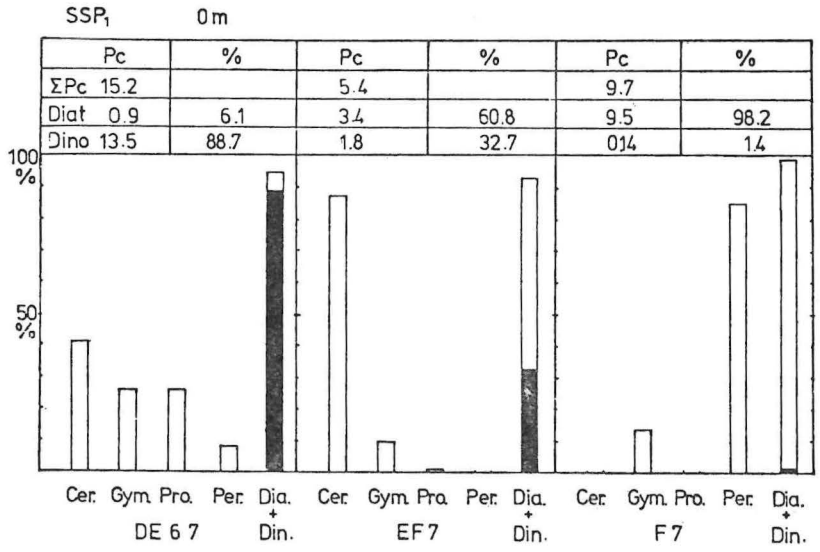

Fig. 6 — Quantitative surface distribution of diatoms and dinoflagellates in relation to distance from pollution source, increasing from left to right.

crease between the station near the outfall and the unaffected station for SiO_4 is 1.7 times and for NO_3 an increase of as much as 42 times. The nutrient values are taken from Data Report »SSP2« (1973).

Table 2. Compilation of phytoplankton biomass and surface nutrient concentrations from three representative locations in the Saronikos Gulf including an unpolluted area (used as baseline data), a mean from the area affected by pollution, and from the immediate source of pollution.

	Unpolluted areas	Station H3 — (reference station with average eutrophication)	Maximum values from the immediate vicinity of the outfall	Increase between the unaffected area and near the outfall.
Chlorophyll a (mg/m³)	0.2	0.51—0.65	0.84	4.2
Phytoplankton carbon (P_c mg/m³)	7.4	14.4	36	4.8
Phytoplankton cell numbers (P_c/10 ml)	400	600	1326	3.3
C^{14} uptake (1970) (mg C/m³/day)	3.4	22.6	37.4	11
PO_4 (μgat/L)	0.13	0.15	1.06	8
SiO_4 (μgat/L)	3.42	4.78	5.98	1.7
NO_3 (μg at/L)	0,12	1.43	5.04	3
NO_3 (μg at/L)	0.12	1.43	5.04	42
NO_2 (μg at/L)	0.12	0.11	0.39	3
NO_4 (μg at/L)	0.44	1.1	3.29	7.5

Preliminary conclusions can be made about the circulation of the polluted watermass from the outfall through the Saronikos Gulf. In Figures 7, 8 and 9, representing profiles I, II and III, the zones of extention of chlorophyll *a* and P_c in decreasing values can be seen. In profile I, the zone of maximum chlorophyll *a* (0.8 to 0.9 mg/m³) and P_c (17 to 28 mg C /m³) reach more than 30 km across five stations to the southwest of the Saronikos Gulf. It is to be noted that these zones were found at a depth of 20 m or more. This was also observed in the other profiles. It is still to be explained as to whether biological, chemical, or physical reasons are the cause of this. In profile II the zone of maximum value of chlorophyll *a* and P_c did not begin until station H 6 and ended after 21 km at station K 6.

In profile I, the polluted watermass appears to curve off towards the southeast near station H 6. Profile III shows that the influence of pollution extended only 12 km and did not reach H 9 (at least in January) and the southern coast of Attikis was mostly free from effects of the outfall. These distributions suggest a circulation flowing southwest from the outfall that

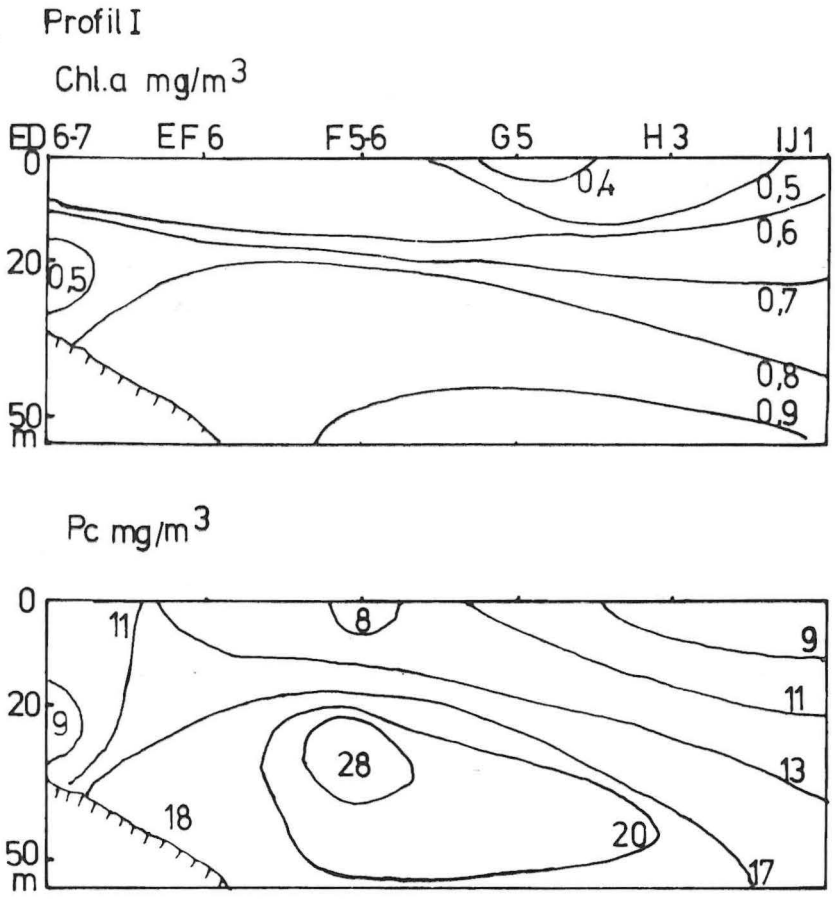

Fig. 7 — Contours of chlorophyll a (mg/m³) and phytoplankton carbon (P_c mg/m³) along profile I from the surface to 50 m. Note the decrease of both parameters from F5 — 6 southward and the absence of baseline values at IJI.

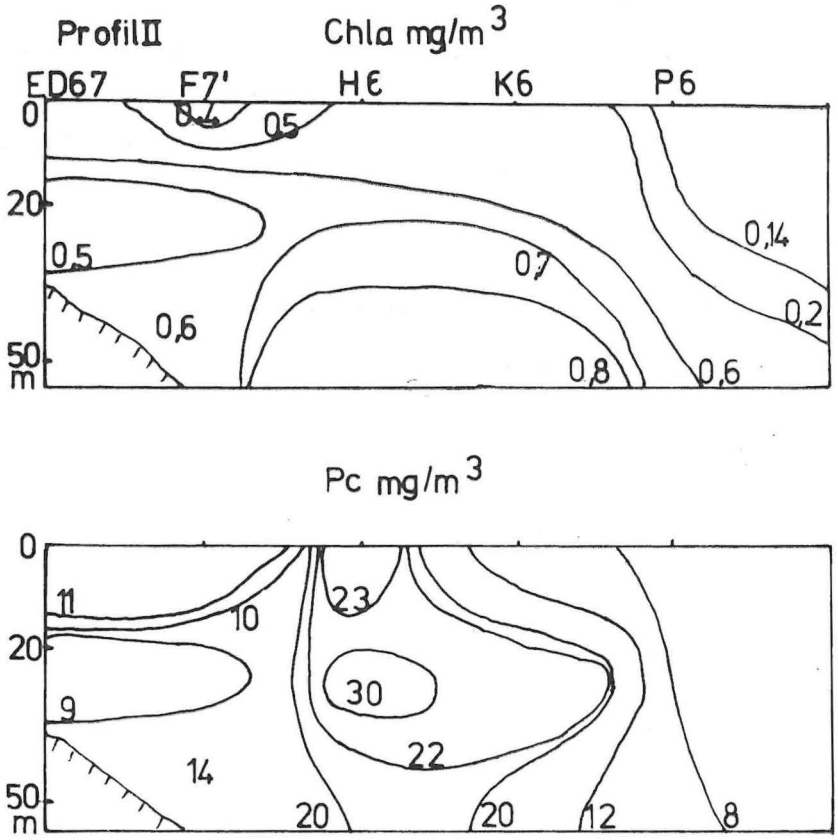

Fig. 8 — Contours of chlorophyll a (mg/m³) and phytoplankton carbon (P_c mg/m³) along profile II from the surface to 50 m. Note the maximum chlorophyll a at 20 m at station H 6.

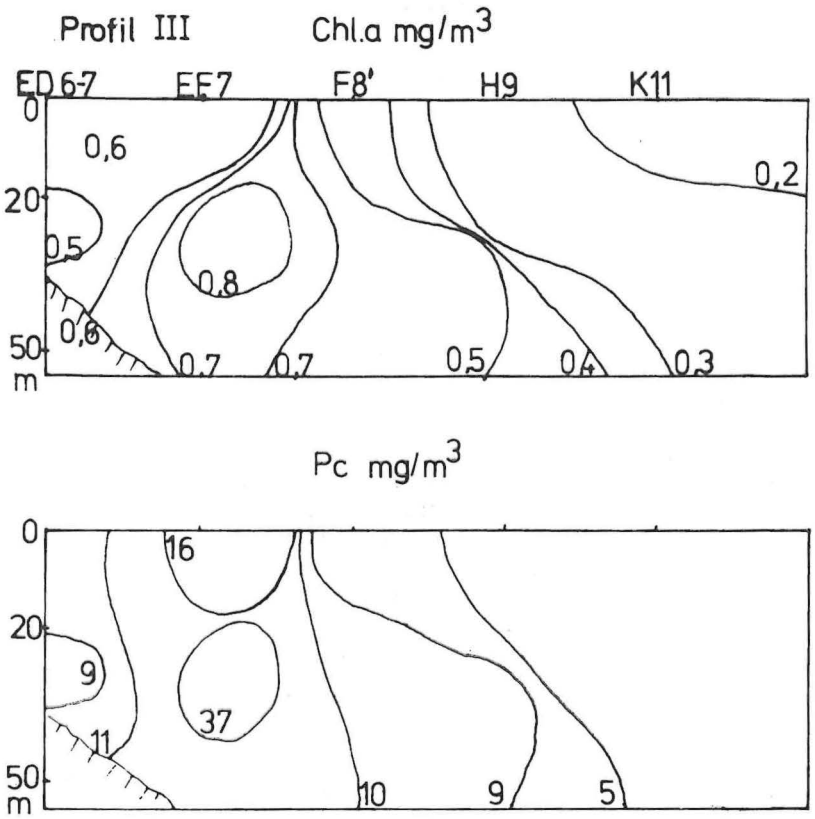

Fig. 9 — Contours of chlorophyll a (mg/m³) and phytoplankton carbon (P_c mg/m³) along profile III from the surface to 50 m. Baseline values occurred before station H 9.

carried water along Salamis Island and towards Aigina Island. It also suggests that unpolluted water was entering the Saronikos Gulf along the southern coast of Attikis.

SUMMARY

The influence of the sewage from Athens and Piraeus introduced at the apex of the Saronikos Gulf was measured in January 1973 using the chlorophyll *a*, phytoplankton carbon, phytoplankton cell numbers and C^{14} uptake determined for March 1970.

To recognize the amount and the extent of the eutrophication, baseline values for chlorophyll *a*, phytoplankton carbon, cell numbers in January 1973 and for C^{14} uptake in March 1970 were found.

From measured chlorophyll *a* and phytoplankton carbon data, the extention of the polluted area can be defined. The eutrophic zone extended to the western region more than 30 km into the Gulf of Megara, in the south about 21 km to the north coast of Aigina and in the eastern part 12 km. The mean values of the three parameters in the polluted area (the outfall excluded) represented increases over baseline values of a two fold for chlorophyll *a*, a 2.7 fold for phytoplankton carbon, and a 6.6 fold for C^{14} uptake. The corresponding maximum values near the outfall represented respectively 4.2 and 4.9 and 11 fold increases over the baseline values.

The difference in the extent of the eutrophic area, using the distribution of chlorophyll *a* and P_c, between the east and west is obvious. It may be explained by a circulation flowing counter clockwise in the upper Saronikos such that Aegean water is brought in along the Attikis coast, mixed with sewage outfall water, and then moved south and southwest towards Aigina.

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KRATAK SADRŽAJ

Proučavan je utjecaj otpadnih voda Atene i Pireja na zaljev Saronikos mjerenjem klorofila *a*, fitoplanktonskog ugljika i broja stanica u siječnju 1973, te pomoću C^{14} u ožujku 1970. Kao polazna točka poslužile su osnovne vrijednosti spomenutih parametara za siječanj 1973, odnosno za ožujak 1970.

Zagađeno područje moglo se odrediti pomoću izmjerenih vrijednosti za klorofil *a* i fitoplanktonski ugljik. Eutrofna zona protezala se prema zapadu više od 30 km u unutrašnjost zaljeva Megara, na jug oko 21 km prema sjevernoj obali Aigine a na istok 12 km. Srednje vrijednosti ovih triju parametara u zagađenom području (isključeno mjesto istjecanja kanala) porasle su u odnosu na osnovne vrijednosti 2 puta za klorofil *a*, 2.7 puta za fitoplanktonski ugljik i 6.6 puta za fotosintetsku aktivnost (C^{14}). Odgovarajuće vrijednosti blizu ispusta kanala bile su 4.2, 4.9 i 11 puta više od bazičnih vrijednosti.

Na osnovi distribucije klorofila *a* i fitoplanktonskog ugljika uočena je razlika između istočne i zapadne strane. Ova razlika mogla se rastumačiti cirkulacijom vode u obrnutom smjeru kazaljke na satu u gornjem Saronikosu. Na taj se način donosi egejska voda uz obalu Attikisa, miješa s otpadnim vodama i pomiče prema jugu i jugozapadu u pravcu Aigine.