VIE MILIEU, 1989, 39 (2) : 63-69

NUTRIENTS STATUS IN A EUTROPHIC MEDITERRANEAN LAGOON

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LAGUNE DE MESSOLONGHI
SELS NUTRITIFS
PHYTOPLANCTON
POLLUTION

RÉSUMÉ — Les variations saisonnières de température, de salinité, d'oxygène dissout, de sels nutritifs et de chlorophylle *a* ont été étudiées dans 16 stations de la lagune eutrophique de Messolonghi en 1983-1984. Les Algues, la pluie et les vents sont les facteurs les plus importants qui affectent les fluctuations des sels nutritifs dans l'espace et le temps. Le niveau d'eutrophication est, dans l'ensemble, acceptable dans presque toute la région; une pollution sévère survient seulement à l'extrémité nord de la lagune au-dessous de 10 m (causant des conditions anoxiques) et dans la partie proche du point de décharge des égoûts de la ville. Les résultats sont comparés avec ceux d'autres environnements et leurs relations sont discutées.

MESSOLONGHI LAGOON
NUTRIENTS
PHYTOPLANKTON
POLLUTION

ABSTRACT — Seasonal variation in temperature, salinity, dissolved oxygen, nutrients and chlorophyll *a* were studied at 16 stations in the eutrophic Messolonghi Lagoon during 1983-1984. Algae, rainfall and winds were the most important factors affecting nutrient fluctuations over space and time. The level of eutrophication was generally acceptable in nearly all the area; serious pollution occurred only in the most northerly section of the lagoon below 10 m (causing anoxic conditions) and in the area close to the point of discharge of the city sewage. The results are compared with data obtained from other environments and the relationships discussed.

INTRODUCTION

The aim of this paper is to show the effect of pollution on the levels of nutrients in the lagoon. It has been subjected to relatively few investigations; regarding hydrographic characteristics (Barbetseas and Georgopoulos, 1984) and the plankton (Siokou-Frangou and Gotsis-Skretas, 1985). Measurements of nutrients, salinity, temperature and oxygen contents in the water column enable to find out the state of eutrophication of the lagoon, as well as the presence of stratification and anoxic conditions.

MATERIALS AND METHODS

The Messolonghi Lagoon, which has a surface area of 160 km², is situated in Western Greece (Fig. 1). To the south, it is separated from the Patraikos Gulf by small islets. Around the lagoon, there are seven freshwater pumping stations and two salt works. The lagoon can be divided into three sections : the Aetolikon (A), with a maximum depth of 28 m, the klissova (B ~ 2m), and the proper Messolonghi Lagoon (C ~ 2m). The harbour of Messolonghi has a population of 13 000. The untreated sewage of the town is discharged near station 3 in area B. Drainage of part of the lagoon, for agricultu-

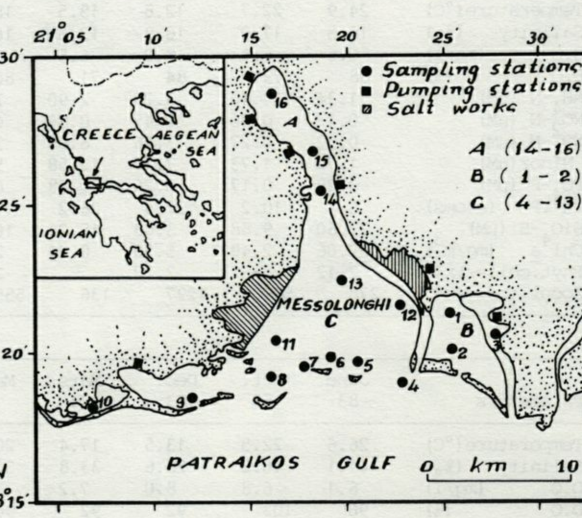

Fig. 1. — Location of the sampling and pumping stations and salt works in the Messolonghi Lagoon.

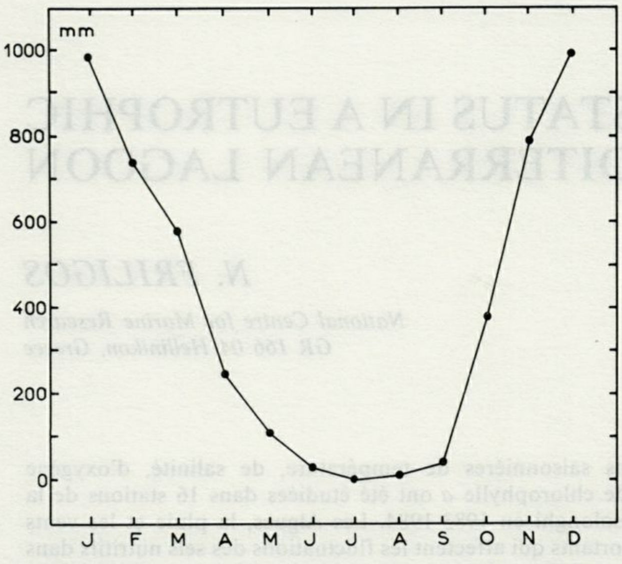

Fig. 2. — Mean monthly precipitation (mm), adapted from Karapipieris (1974).

ral purposes, where the surface area being reduced from 190 to 160 km². Freshwater is the result of seasonal response to rainfall, with its maximum in winter (Fig. 2; Karapiperis, 1974).

Samples were taken from a network of 16 stations seasonally from June 1983 to March 1984 (Fig. 1). Temperature measurements were made with reversing thermometers attached to NIO bottles. The salinity was determined with an autolab inductive salinometer. Dissolved oxygen was determined according to Carritt & Carpenter (1966). Water samples for nutrient determinations were transferred to 100 ml polyethylene bottles; there were deep frozen. In the laboratory the samples were thawed, filtered through membrane filters (HA Millipore) and analysed with a Technicon CSM_6 autoanalyser. Nutrients were analysed by the methods of Strickland & Parsons (1968). The Whatman GF/C filters used in the filtration for the analyses of chlorophyll-*a* were refrigerated in a dessicator prior to extraction with 90 % acetone; pigment concentration was measured with a Turner III fluorometer according to the method of Holm-Hansen *et al.* (1965).

RESULTS

Table I shows the seasonal mean values of the parameters in each section of the lagoon (station 3, point of discharge of the city effluents, is excluded from section B).

Table I. — Average surface values of the physico-chemical and plankton parameters in the Messolonghi Lagoon.

Parameters	Area A June 83	Oct. 83	Dec. 83	Mars 84	Mean	σ	Area B June 83	Oct. 83	Dec. 83	Mars 84	Mean	σ
Temperature (°C)	24.9	22.7	12.8	15.5	18.0	5.7	21.6	25.0	13.2	18.9	19.7	5.0
Salinity (‰)	16.5	17.0	16.9	13.6	16.0	1.6	40.6	47.4	32.2	31.3	37.9	7.6
D.O (mg/l)	6.6	6.1	8.0	6.5	6.8	0.8	6.5	6.5	9.5	7.0	7.4	1.4
D.O (%)	88	79	84	71	80	7	93	103	116	91	101	11
NH_4-N (µM)	1.34	1.40	3.26	2.90	2.22	0.99	0.64	0.08	1.06	1.05	0.70	0.46
NO_2-N (µM)	0.12	0.06	0.45	0.80	0.36	0.34	0.11	0.05	0.21	0.13	0.13	0.07
NO_3-N (µM)	0.32	0.27	3.46	8.88	3.23	4.05	0.20	0.18	1.37	0.57	0.58	0.56
Ninor (µM)	1.78	1.73	7.17	12.58	5.81	5.18	0.95	0.31	2.64	1.75	1.41	1.00
PO_4-P (µM)	0.29	0.17	0.26	0.48	0.30	0.13	0.14	0.06	0.11	0.18	0.12	0.50
ΣN:P (atoms)	6.1	10.2	27.6	26.2	17.5	10.9	6.8	5.2	24.0	9.7	11.4	8.6
SiO_4-Si (µM)	37.60	9.88	3.63	15.26	16.59	14.79	16.00	10.76	4.26	3.02	8.51	6.04
Chl <u>a</u> (mg/m^3)	2.06	2.49	5.50	0.24	2.57	2.18	1.85	7.20	0.63	0.42	2.52	3.18
Phyt.cells/$1x10^6$*	2.12	–	2.22	–	2.17	0.06	3.77	–	3.52	–	3.64	1.78
Zoopl.indiv/m^3*	278	509	1297	136	555	518						

Parameters	Area C June 83	Oct. 83	Dec. 83	Mars 84	Mean	σ	Station S June 83	Oct. 83	Dec. 83	Mars 84	Mean	σ
Temperature (°C)	26.6	22.5	13.5	17.4	20.0	5.7	21.0	22.0	13.2	18.1	18.6	3.9
Salinity (‰)	41.1	46.2	28.6	33.8	37.4	7.8	22.9	35.2	24.0	17.7	22.4	11.3
D.O (mg/l)	6.1	6.8	8.0	7.2	7.0	0.8	5.0	6.8	8.0	6.5	6.6	1.2
D.O (%)	96	103	92	92	96	5	64	96	89	87	84	14
NH_4-N (µM)	0.47	0.18	2.82	1.60	1.27	1.20	0.74	2.04	11.16	12.26	6.55	5.99
NO_2-N (µM)	0.09	0.04	0.15	0.17	0.11	0.06	0.11	0.09	10.28	3.05	3.38	4.80
NO_3-N (µM)	0.21	0.24	1.72	0.27	0.61	0.74	0.17	0.34	3.44	10.17	3.53	4.67
Ninor (µM)	0.77	0.46	4.69	2.04	1.99	1.92	1.02	2.47	24.88	25.48	13.46	13.54
PO_4-P (µM)	0.19	0.06	0.41	0.98	0.26	0.16	0.77	0.28	2.93	0.69	1.17	1.19
ΣN:P (atoms)	4.1	7.7	11.4	5.4	7.18	3.20	1.3	8.8	8.5	36.9	13.89	15.74
SiO_4-Si (µM)	29.66	7.28	5.18	2.28	11.10	12.54	17.78	14.50	76.67	20.90	32.46	29.58
Chl <u>a</u> (mg/m^3)	1.09	3.96	0.59	0.20	1.46	1.71	4.73	21.00	9.70	0.54	8.99	8.84
Phyt.cells/$1x10^6$*	1.03	–	2.20	–	1.62	0.84	44.31	–	11.72	–	28.01	23.05
Zoopl.indiv/m^3*	223	579	7	102	227	250	185	4514		654	1784	2375

* AFTER SIOKOU-FRANGOU AND GOTSIS-SKRETAS 1985

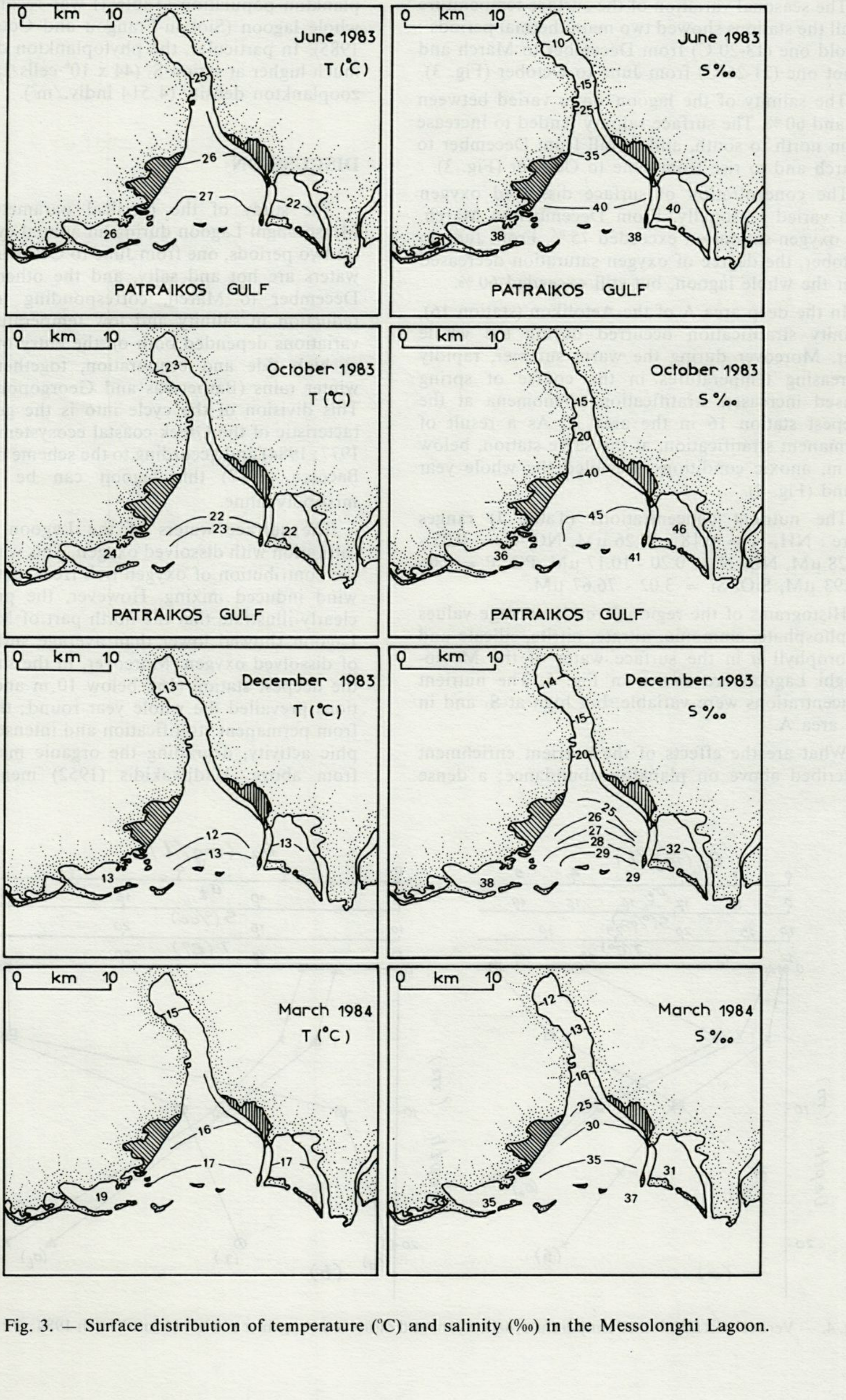

Fig. 3. — Surface distribution of temperature (°C) and salinity (‰) in the Messolonghi Lagoon.

The seasonal variation of the surface temperature at all the stations showed two main thermal periods : a cold one (13-20°C) from December to March and a hot one (21-26°C) from June to October (Fig. 3).

The salinity of the lagoon water varied between 12 and 60 ‰. The surface salinity tended to increase from north to south, and to fall from December to March and to rise from June to October (Fig. 3).

The concentration of surface dissolved oxygen also varied seasonally. From December to March, the oxygen saturation exceeded 75 %. From June to October, the degree of oxygen saturation decreased over the whole lagoon, but still exceeded 60 %.

In the deep area A of the Aetolikon (station 16), salinity stratification occurred during the whole year. Moreover during the warm summer, rapidly increasing temperatures in the course of spring caused increased stratification phenomena at the deepest station 16 in the area A. As a result of permanent stratification, at the same station, below 10 m, anoxic conditions prevailed the whole year round (Fig. 4).

The nutrient concentrations (Table I) ranges were : NH_4-N = 0.18 - 12.26 μM, NO_2-N = 0.05 - 10.28 μM, NO_3-N = 0.20 - 10.17 μM, PO_4-P = 0.06 - 2.93 μM, SiO_4-Si = 3.02 - 76.67 μM.

Histograms of the regional yearly average values of phosphate, ammonia, nitrate, nitrite, silicate and chlorophyll *a* in the surface water of the Messolonghi Lagoon are shown in Fig. 5. The nutrient concentrations were variable, but high at S_3 and in the area A.

What are the effects of the nutrient enrichment described above on plankton abundance; a dense plankton population (Table I) was recorded in the whole lagoon (Siokou-Frangou and Cotsis-Skretas, 1985). In particular, the phytoplankton density was much higher at sation S_3 (44×10^6 cells/l) as well as zooplankton density (4 514 indiv./m^3).

DISCUSSION

The study of the physical parameters of the Messolonghi Lagoon during an annual cycle indicates two periods, one from June to October, when the waters are hot and salty, and the other one from December to March, corresponding to a slight reduction in salinity and low temperatures. These variations depended both on the entry of sea water at high tide and evaporation, together with the winter rains (Barbetseas and Georgopoulos, 1984). This division of the cycle into is the general characteristic of the Greek coastal ecosystems (Friligos, 1977; 1984) and according to the scheme of Pora and Bacescu (1977) this lagoon can be considered mixopolyhaline.

The surface waters of the Lagoon were near saturation with dissolved oxygen. This was due to (I) the contribution of oxygen rich fresh water and (II) wind induced mixing. However, the present data clearly illustrate that the north part of Messolonghi Lagoon showed lower than average surface values of dissolved oxygen. Moreover, in the same area at the deepest station (16), below 10 m anoxic conditions prevailed the whole year round; this resulted from permanent stratification and intense heterotrophic activity, degrading the organic matter falling from above. Hadjikakidis (1952) mentioned the

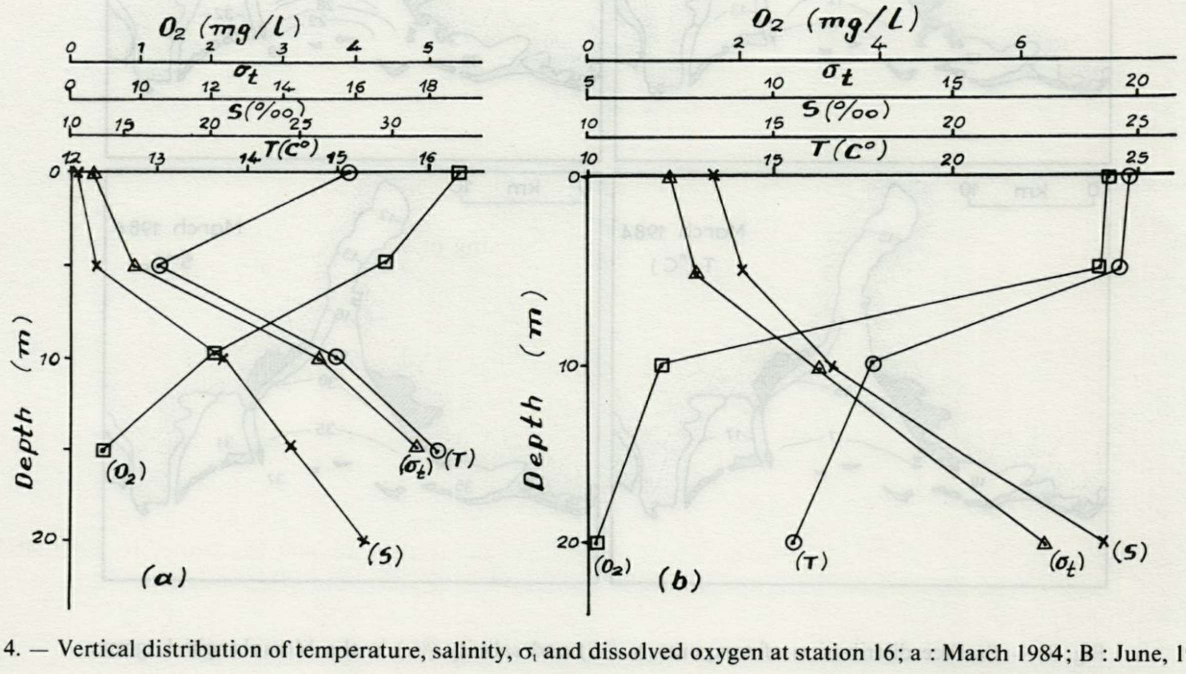

Fig. 4. — Vertical distribution of temperature, salinity, σ_t and dissolved oxygen at station 16; a : March 1984; B : June, 1983.

presence below 10 m of H_2S, the concentration of which increased with depth. He attributed the decrease in the concentration of dissolved oxygen in the deep waters mainly to decomposition of organic matter and the production of H_2S to anaerobic decomposition of this matter, where dissolved oxygen was depleted.

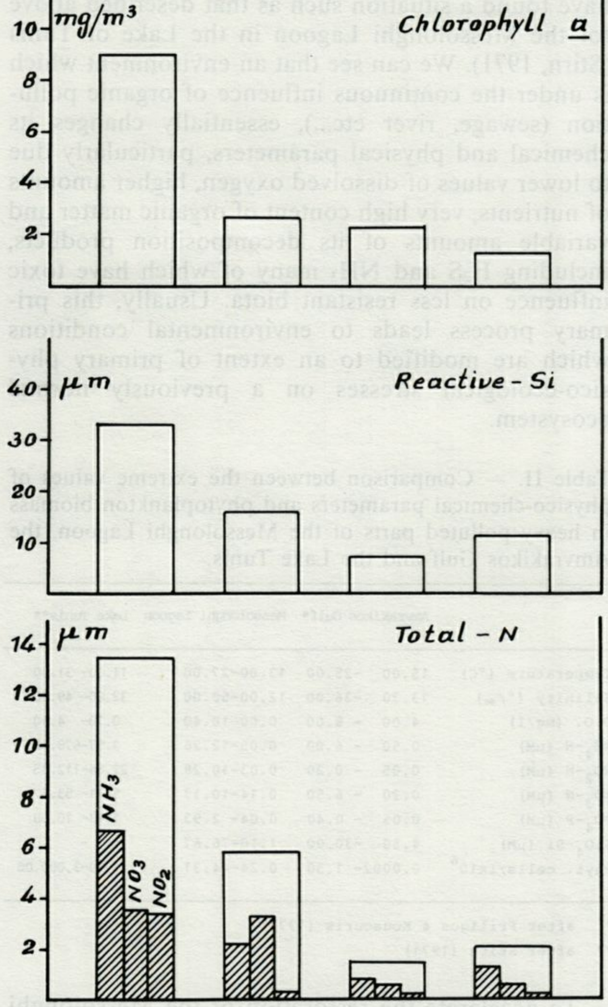

Fig. 5. — Histograms of regional average concentrations of nutrient salts in the waters of the Messolo̊nghi Lagoon.

The concentrations of nutrients were higher than those observed in the Mediterranean Sea. The level of inorganic nitrogen was high at S_3 and following the area A. At S_3 is the dumping site of the untreated sewage of the town. Ammonia, which is the more reduced from of the nitrogenous salts, dominated in the waters of the lagoon except in the area A, which receives much drain water. During the annual cycle, the mean contents of ammonia, nitrite and nitrate showed two minima; these occurred June and October and corresponded to phytoplankton blooms.

The distribution of dissolved phosphate was more or less similar to that of the total dissolved nitrogenous salts phosphate concentrations were variable, but high at S3 and in the area A. In general, they were lower than 0.5 μM. The smaller ones occurred in October. In A at S^{16}, near the bottom, the levels were around 5 μM. These high concentrations, like those quoted for other Mediterranean lagoons (Blank *et al.*, 1967; Chassany de Casabianca, 1979), correspond to a very high decomposition rate. This fast recycling of phosphate could explain also the small $\Sigma N:P$ ratios (1.3-10.0) during the hot period.

As in the case of other nutrients the highest regional average values of silicate were found in the waters at S_3 and in the area A. The mean concentration of silicates increased from December to June. Its annual change compared to that of salinity showed that it reached its maximum at the end of the period of reduction of salinity. This is in agreement with that other authors, in particular Peterson (1975), have observed. It appears that the surface waters take out important amounts of silica. This accumulates until the beginning of summer, when the temperature, the insolation and the stability are such as to cause a phytoplankton bloom, which results in the silicates decreasing, as well as the other nutrients (nitrogen and phosphorus). The June and October chlorophyll *a* peaks corroborated the existence of these blooms.

The level of phytoplankton biomass appears rather interesting, since the level of chlorophyll *a* ranges between 0.2 to 21 mg/m^3 with two maxima corresponding to the two blooms. The one at the beginning of summer is due to the enrichment from mainland waters, the other in autumn makes use of the nutrients from remineralization brought to the surface by the stirring of water in October.

Because ot the high concentrations of nutrients, red tide tends to occur in the lagoon. It was observed by Hadjikakidis (1952) in 1951 and in 1985 (N.C.M.R. data). Also, the worsening of the environmental conditions is suggested by the fish production drop (Fig. 6). In 1973, it had fallen from 1,600 tn in 1964 to 400 tn, while, in 1983, it had diminished further to 200 tn (Claoudatos & Apostolopoulos, 1984). However, overfishing may have also contributed to this reduction in catches.

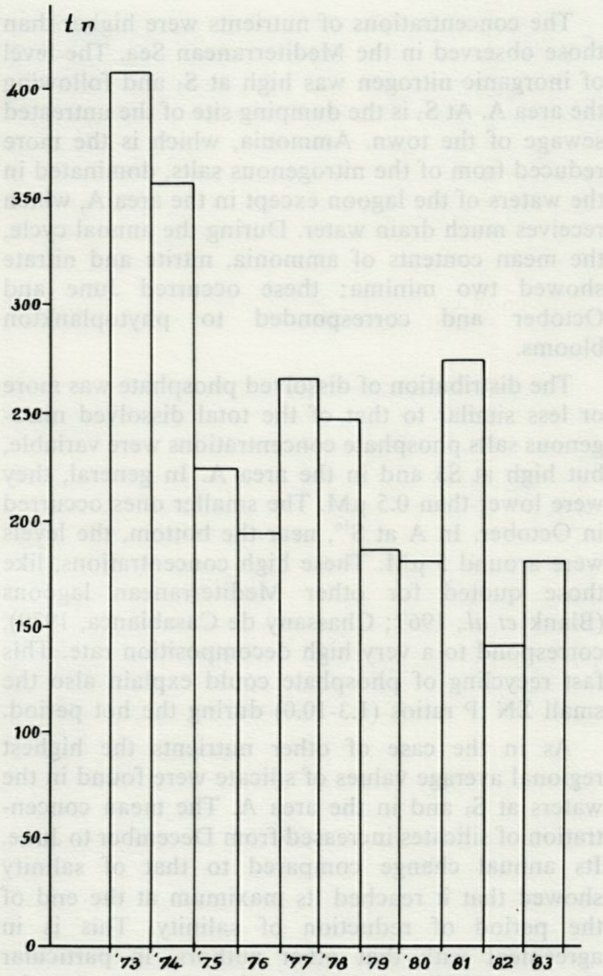

Fig. 6. — Production of the fish farms of the Messolonghi Lagoon, from 1973 to 1983, adapted from Klaoudatos and Apostolopoulos (1984).

The effect of pollution on the Messolongi Lagoon can be clearly illustrated by comparing the concentrations of nutrients and phytoplankton biomass (maximum values) of the present study with those from unpolluted Amvrakikos Gulf, which lies on the N.W. coast of Greece and is an extension of the Ionian Sea, and in the shallow polluted lake of Tunis in the North African coastal waters. The Amvrakikos is a shallow semi-enclosed area, characterized by low salinities, especially along the north coast receiving the waters from important rivers (Friligos & Koussouris, 1977). During the summer months, the Lake of Tunis develops extreme symptoms of eutrophication and, during calm periods, the entire water column may become anaerobic, with blooms of red sulfur-reducing, photosynthetic bacteria and fish kills that seriously damage the fishery in the lake (Stirn, 1971). It should be noted that the maximum values of nutrients referred to the heavily polluted parts of the compared lagoons. The maximal concentrations of ammonia and nitrate were about twice those in the Amvrakikos. The maximal values of phosphate and nitrite were respectively about 7 and 50 times those in the Amvrakikos. Also, the maximum values of the phytoplankton biomass was 30 times that in the Amvrakikos. However, the maximal values of nutrients and phytoplankton biomass in the Lake Tunis were higher than those in the Messolonghi Lagoon.

Thanks to the above mentioned investigation we can compare biocenological modifications and chemical changes in three water environments which physical parameters are different (Table II). We have found a situation such as that described above for the Messolonghi Lagoon in the Lake of Tunis (Stirn, 1971). We can see that an environment which is under the continuous influence of organic pollution (sewage, river etc...), essentially changes its chemical and physical parameters, particularly due to lower values of dissolved oxygen, higher amounts of nutrients, very high content of organic matter and variable amounts of its decomposition products, including H_2S and NH_3 many of which have toxic influence on less resistant biota. Usually, this primary process leads to environmental conditions which are modified to an extent of primary physico-ecological stresses on a previously normal ecosystem.

Table II. — Comparison between the extreme values of physico-chemical parameters and phytoplankton biomass in heavy polluted parts of the Messolonghi Lagoon, the Amvrakikos Gulf and the Lake Tunis.

	Amvrakikos Gulf*	Messolonghi Lagoon	Lake Tunis**
Temperature (°C)	15.00 -25.00	13.00-27.00	11.00- 31.00
Salinity (°/∞)	13.30 -36.00	12.00-60.00	32.00- 49.00
D.O. (mg/l)	4.00 - 8.00	0.00-10.40	0.70- 4.90
NH_4-N (μM)	0.50 - 6.00	0.05-12.26	3.57-678.58
NO_2-N (μM)	0.05 - 0.20	0.03-10.28	22.86-112.85
NO_3-N (μM)	0.20 - 6.50	0.14-10.17	5.71- 53.57
PO_4-P (μM)	0.05 - 0.40	0.04- 2.93	1.93- 10.00
SiO_4-Si (μM)	4.50 -30.00	1.10-76.67	-
Phyt. cells/1x10^6	0.0002- 1.50	0.24-44.31	1.80-3,000.00

* after Friligos & Kousouris (1974)
** after Stirn (1971)

To accelerate the restoration of the Messolonghi Lagoon to a better condition, the quality of the water input to the Lagoon must be improved, at least by limiting the amounts of oxygen-demanding wastes and of phosphorus entering into the environment. This can be done by full biological treatment of sewage, which merely oxidizes the organic matter and does little to remove nitrate or phosphate from the sewage. Phosphate are easily precipitated and removed by a variety of waste water treatment processes. Also, drainage of part of the lagoon for agricultural purposes should be avoided.

ACKNOWLEDGEMENTS — The author would like to acknowledge, Dr. S. Claoudatos and, in particular, S. Barbetseas for making technical reports available and for helpful consultation and discussions.

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Reçu le 24 février 1987; received February 24, 1987
Accepté le 18 août 1988; accepted August 18, 1988