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ARTICLE *in* FRESENIUS ENVIRONMENTAL BULLETIN · JANUARY 2008

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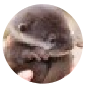

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ENVIRONMENTAL IMPACTS OF INTENSIVE MUSSEL CULTURE IN THE COASTAL WATERS OF THE GULF OF THESSALONIKI (N. GREECE)

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Presented at the 14th International Symposium on Environmental Pollution and its Impact on Life in the Mediterranean Region (MESAEP), Sevilla, Spain, 10 – 14 Oct. 2007

ABSTRACT

The environmental impacts of mussel cultures are related mainly to increased sedimentation and high filtration rates. Numerous mussel culture units are located in the shallow waters (maximum depth 20 m) in NW Thessaloniki Gulf (Greece). Evaluation of the impacts of the mussel units on the quality of the surrounding waters was the aim of this work. The sampling period lasted from January to August 2006, covering a complete culture cycle, from the larvae in the water column to the harvesting of mature mussels. Water samples were collected twice per month from three depths; 1 m and 5 m from the sea surface and 1 m above the bottom, from four sampling locations, three among the units and one outside of them. The parameters measured were dissolved oxygen, suspended solids, nutrients (nitrate, nitrite, ammonia, phosphate and silicate) as well as chlorophyll *a* as a measure of phytoplankton abundance. Low values of dissolved oxygen have been recorded in certain sampling periods. Relatively low values of nutrients were present throughout spring and summer. Chlorophyll *α* values were below 0.2 mg/m^3 indicating a serious impact of the mussel culturing to the ecological status of the water column inside the mussel farming area. Multivariate statistical analysis was applied on the data set in order to assess environmental impacts and reveal the association among the measured parameters.

KEYWORDS: environmental impacts, mussel cultures, Thessaloniki Gulf, nutrients, water quality.

INTRODUCTION

Cultivation of mussels is an internationally important economic activity. In Greece, most of the mussel culturing takes place in the Thessaloniki and Thermaikos Gulfs, an ecologically important coastal area, protected under the national laws and international conventions. Multiple mussel cultures with both the pole and the longline system are located in an area of 2,750 ha. Total annual mussel production is about 10,000 t/y. The sustainability of this economic activity depends on the impacts of mussel populations on the ecosystem. Mussels feed on phytoplankton, detritus and other organic particles which they filter from the water column [1]. The effects of mussel farming include organic enrichment of sediments by mussel faeces and pseudofaeces, deposition of shells and other farm debris and localized depletion of phytoplankton [2]. Large increases in the density of bivalves may potentially change the patterns of nutrient distribution and recycling within an embayment that affects primary production. Moreover, phytoplankton may be nutrient limited, due to low regeneration rates and isolation of the water column from sediment nutrients [3]. Changes in phytoplankton abundance and nutrient cycling have implications on the growth and survival not only of the cultured mussels, but of other organisms as well. Understanding and measuring these effects require a regional-scale assessment and continuous monitoring. Traditionally, water quality assessments in coastal embayments are based on nutrients, dissolved oxygen and chlorophyll a measurements. The values of these parameters are indicators of the eutrophication status of the waters and marine environmental quality [4].

The study area in this work is delineated by forty three longline mussel units (Fig. 1), at a distance of 100-150m from each other, covering 1,200 ha, at the shallow (maximum depth 20m) waters of the Gulf of Thessaloniki. Previous studies in the area report a decrease in the hydrodynamic currents among the longlines [5,6]. Under the prevailing wind conditions, eastern and northeastern currents are developed on the east and north part of the study area, southern and southeastern currents are developed on the west and south part and northwestern currents are mainly developed in the central part of the basin, Fig. 2, [6].

The aim of this study was to evaluate the environmental impacts of the mussel cultures in terms of nutrient enrichment/depletion, dissolved oxygen concentrations, suspended matter and phytoplankton abundance (expressed as chlorophyll *α*) and to investigate the interrelations of the measured parameters during the production cycle.

MATERIALS AND METHODS

The sampling period in this work, lasted from January to August 2006, covering a complete production cycle from the larvae to mature mussels. Water samples were collected twice per month, by means of a Niskin type water sampler from three depths; 1 m, 5 m and 1 m above the bottom, from four sampling locations (Fig. 1). Maximum depth in the area is 20 m.

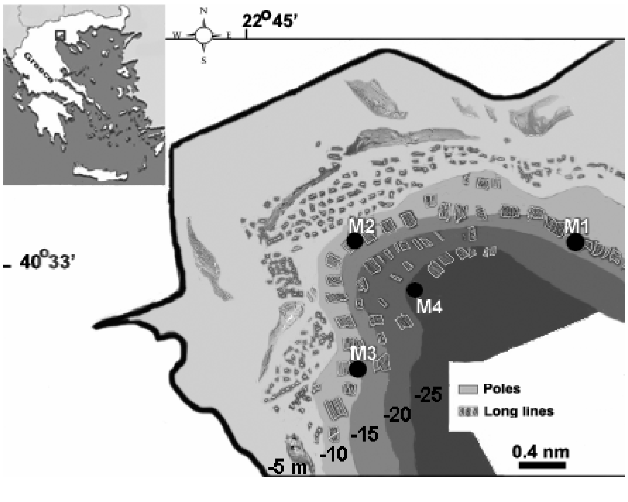

FIGURE 1 - Map of the coastal area in NW Thessaloniki Gulf, with the mussel culture units and the four sampling locations. Photo adapted from HCMR [5].

Continuous profiles of temperature and salinity were also obtained at each site using a CTD recorder in order to assess stratification of the water column. Dissolved oxygen was determined with the iodometric method of Winkler [7]. Nitrate, nitrite, phosphate, silicate and ammonia were measured spectrophotometrically according to Parsons *et al* [8]. Suspended solids were collected on preweighted GF/F filters, subsuequently dried and weighted [9]. Chlorophyll a was determined spectrophotometrically after the extraction in 90% acetone [8].

Principal component analysis was performed on the chemical data including all the sampling periods to reveal the few but most important chemical variables in the cultured mussel area at a low cost of information loss [10].

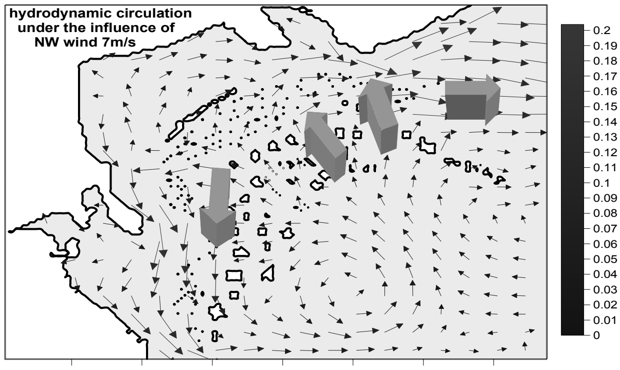

FIGURE 2 - The hydrodynamic circulation under the influence of the prevailing NW wind, in the study area [5].

RESULTS AND DISCUSSION

Table 1 presents summary statistics for the chemical measurements, salinity, temperature and density, in the mussel farms area. Low values of dissolved oxygen were measured (range between 1.8-6.2 ml O_2/l), especially near the bottom (Fig. 6). Suboxic to anoxic bottom conditions is an environmental impact of mussel cultures related to high biodeposition processes [11].

In Figs 3 and 4, temperature and salinity variation in the four stations and the different depths, is presented. Figure 5 depicts large density differences between the upper water layers (1m from the surface) and the deeper ones (10m from the surface), showing stratified conditions, while during the winter months the water column is homogenized.

The concentration of suspended solids presented high variation (0.04-343 mg/l, mean 35.39), which is probably related to the culturing practices (Fig. 7). Phosphate concentrations ranged from 0.01-1.02 μg-at P/l, with mean value 0.25 μg-at P/l (Fig. 8). Higher values of phosphate were observed in station M1, while the lowest concentration was recorded in station M4, located outside the mussel units (Fig. 9). The values of phosphate correlate well with ammonia values (PCA plot, Fig.15). Ammonia concentrations varied from 1.5 to 15.14 μg-at N/l (mean value 5.02 μg-at N/l), Fig. 10. Phosphate and ammonia values were elevated at the maximum depth, near the bottom. Nitrate values ranged from 0.13 to 9.81 μg-at N/l (mean value 2.34 μg-at N/l), Fig. 11. Nitrite values ranged between 0.01-1.07 μg-at N/l (mean 0.21 μg-at N/l) and were elevated in the bottom depth (Fig.12). Silicate ranged from 1.51-21.44 μg-at Si/l, with a mean value of 7.97 μg-at Si/l (Fig.13). Silicates presented the higher concentrations in the surface waters and the lower in the depth of 5 m were the mussel longlines are located. Mean values of nutrients were slightly elevated in the stations with the mussel farms (M1-M3) compared to station M4 outside of them. However, nutrient values are rather low for a mariculture area. It seems that nutrients are removed from the water column or, during the stratification period, the cultures are isolated from the bottom nutrients. The impact on nutrient levels is one of the different environmental effects of fish farming (high input of nutrients) and mussel cultures (high biodeposition), [11]. Large increases in the density of bivalves may change the patterns of nutrient distribution and recycling within an embayment [3]. Chlorophyll *α* values were extremely low and ranged from 0.01-0.2 mg/m^3 (Fig. 14). The removal of phytoplankton from the water column in the mussel farms is an important issue in setting thresholds for the environmental parameters, in order to support ecological quality and good growing conditions for the mussels [12].

TABLE 1 - Summary statistics for the chemical parameters, chlorophyll *α* and the hydrographic parameters inside the mussel farms in NW Thessaloniki Gulf.

Parameter	min	max	mean	median	s.d
D.O (ml O_2/l)	1.8	6.2	4.13	4.06	0.92
Suspended Solids (mg/l)	11	343	40.31	26	56.17
Silicate (μg-at Si/l)	1.51	21.44	7.97	7.13	4.63
Phosphate (μg-at Pi/l)	0.01	1.02	0.25	0.14	0.24
Nitrate (μg-at N/l)	0.13	9.81	2.34	2.09	1.77
Nitrite (μg-at N/l)	0.01	1.07	0.21	0.09	0.24
Ammonia (μg-at N/l)	1.50	15.14	5.02	4.36	2.68
Chlorophyll *α* (mg/m^3)	0.01	0.20	0.04	0.03	0.04
Salinity ‰	28.41	37.60	35.28	35.34	1.67
Temperature ^{o}C	7.09	27.65	17.11	16.41	7.06
Density (kg/m^3)	1017.88	1028.70	1025.53	1025.47	2.56

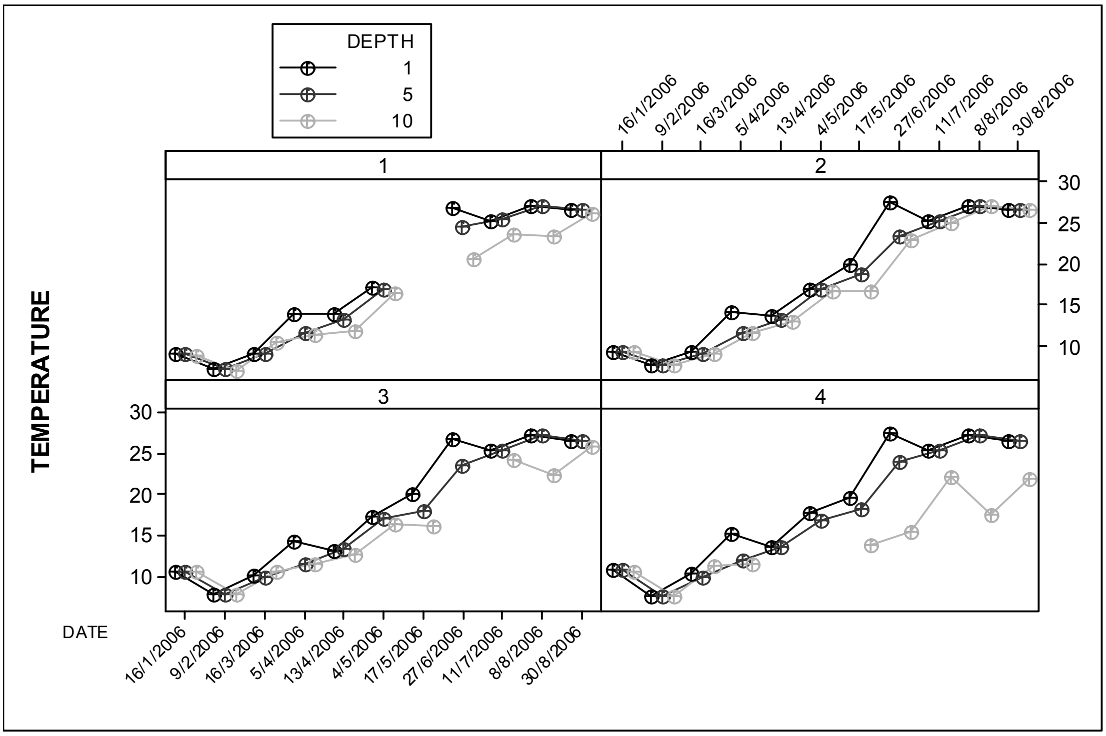

FIGURE 3 - Temperature variation in the four stations, in the three different depths.

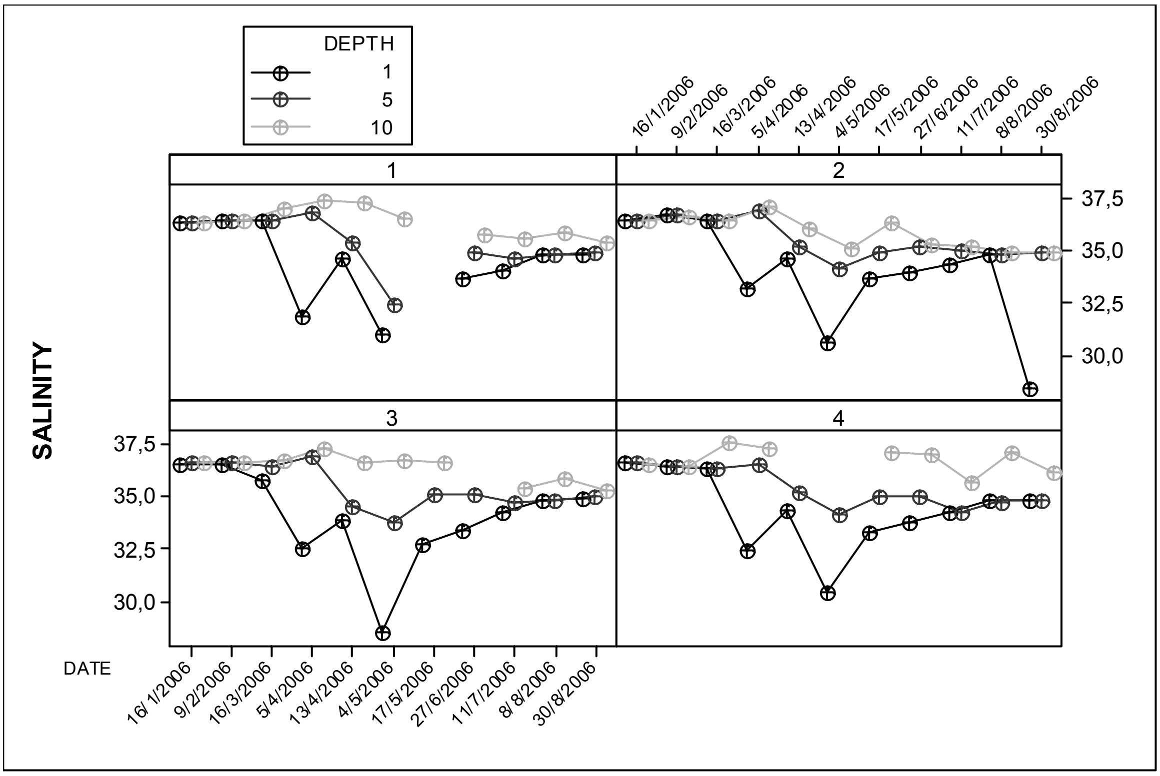

FIGURE 4 - Salinity variation in the four stations, in the three different depths.

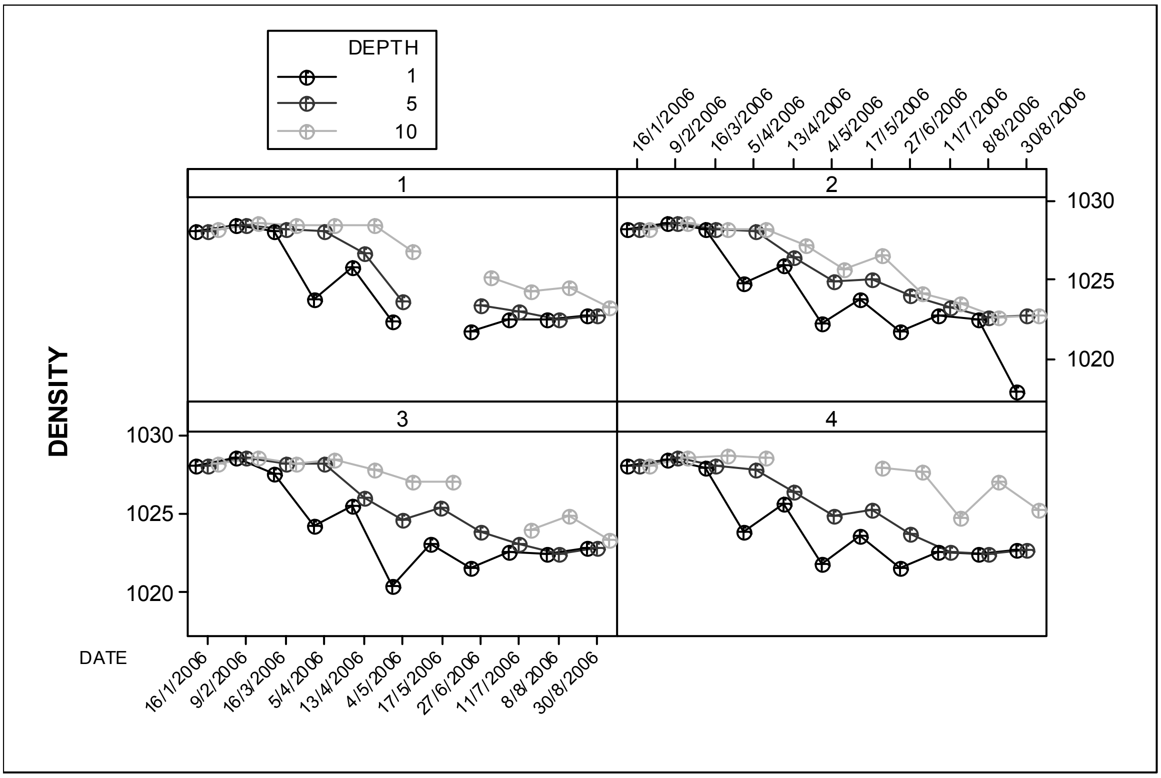

FIGURE 5 - The variation of density values in the four stations, in the three different depths, during the sampling period.

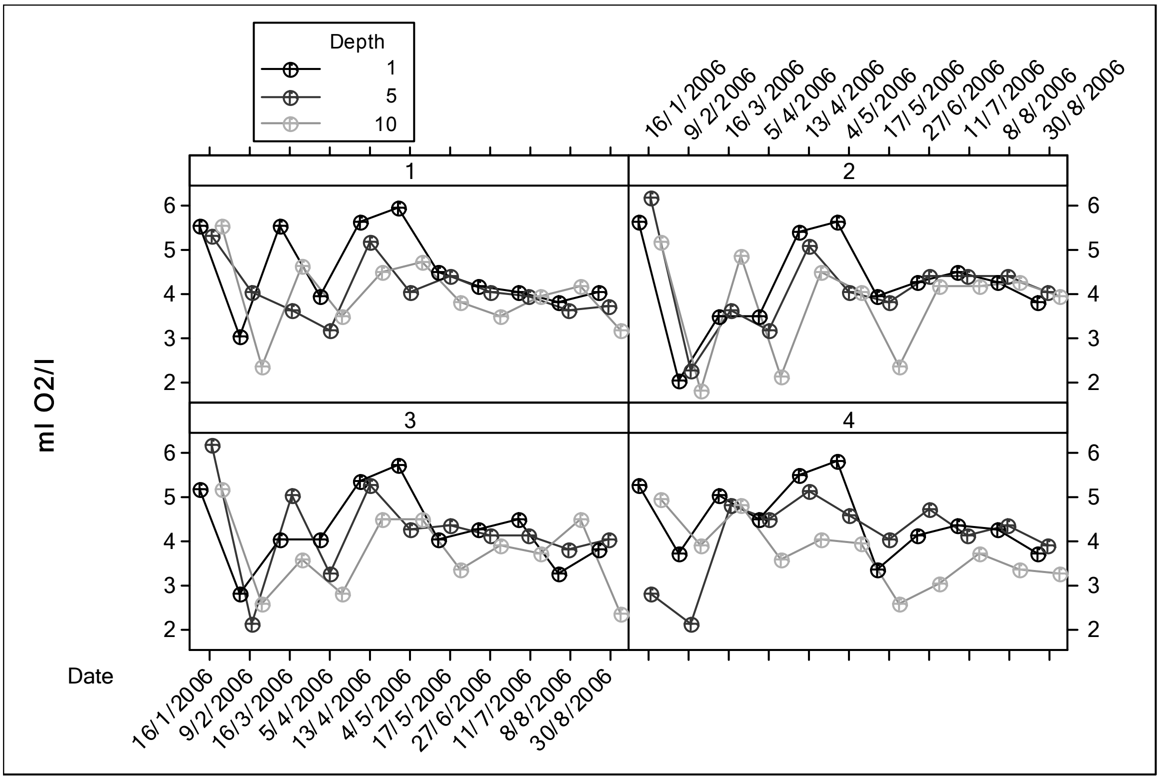

FIGURE 6 - Variation of the values of dissolved oxygen in the three depths and the four stations.

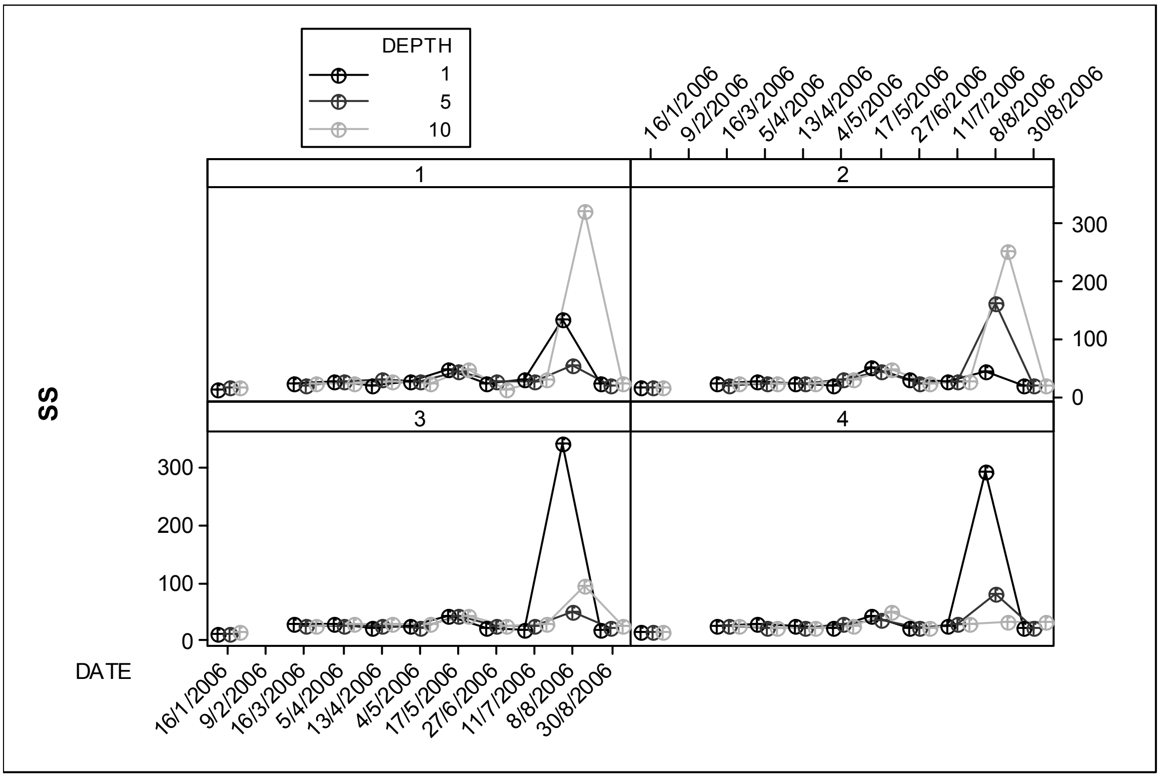

FIGURE 7 - Variation of the concentration of suspended solids among the depths and the sampling locations.

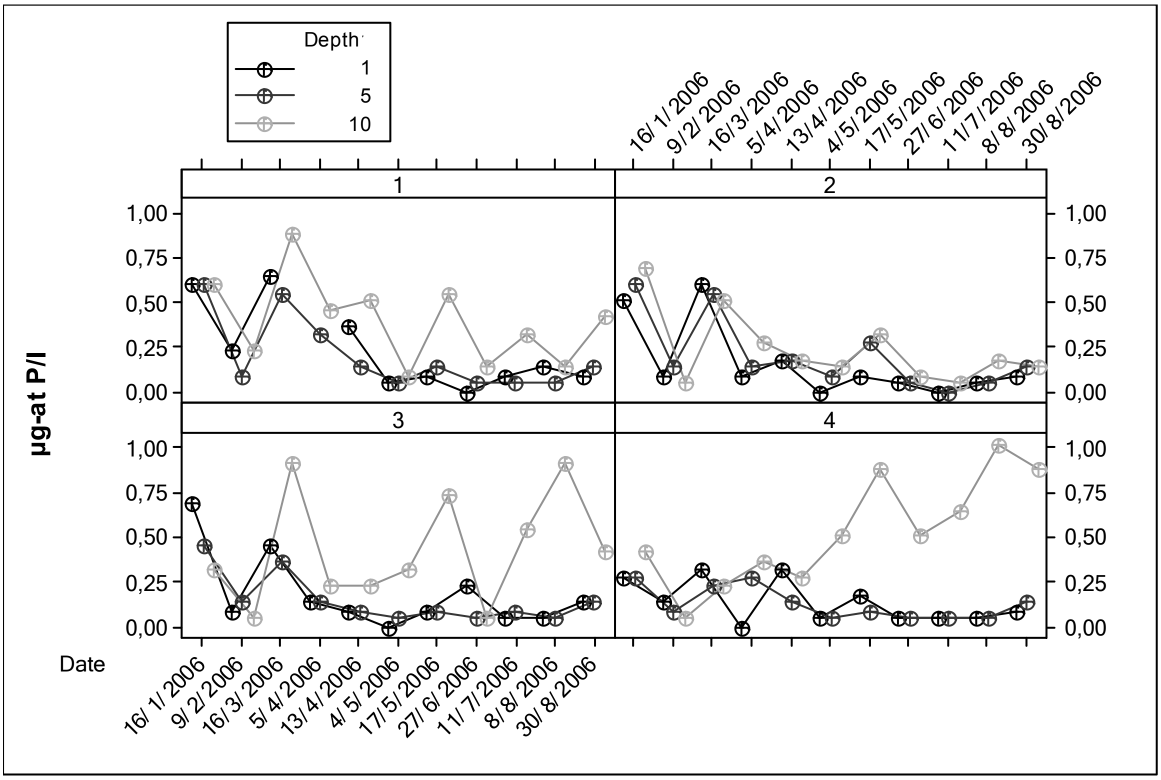

FIGURE 8 - Variation of the concentration of phosphate in the sampling locations and the three depths.

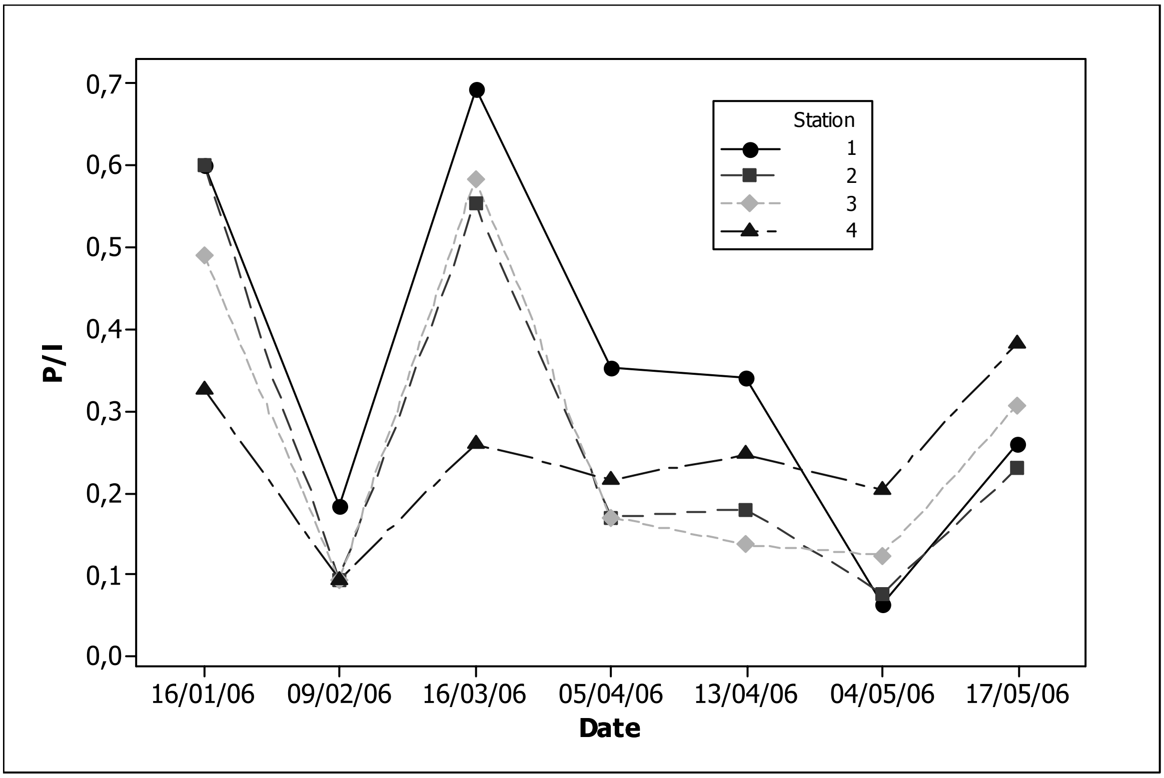

FIGURE 9 - Variation of the mean values of phosphate in the four sampling locations, during the spring months.

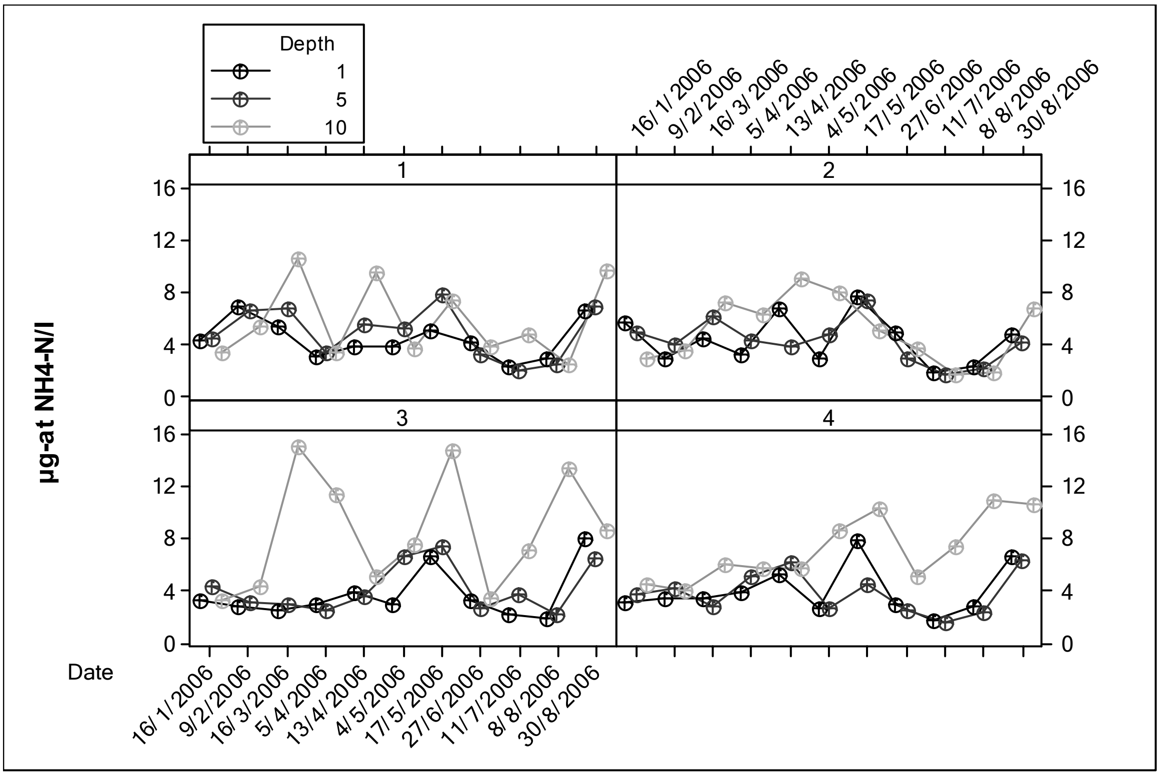

FIGURE 10 - Variation of the concentration of ammonia in the three depths and the four sampling locations.

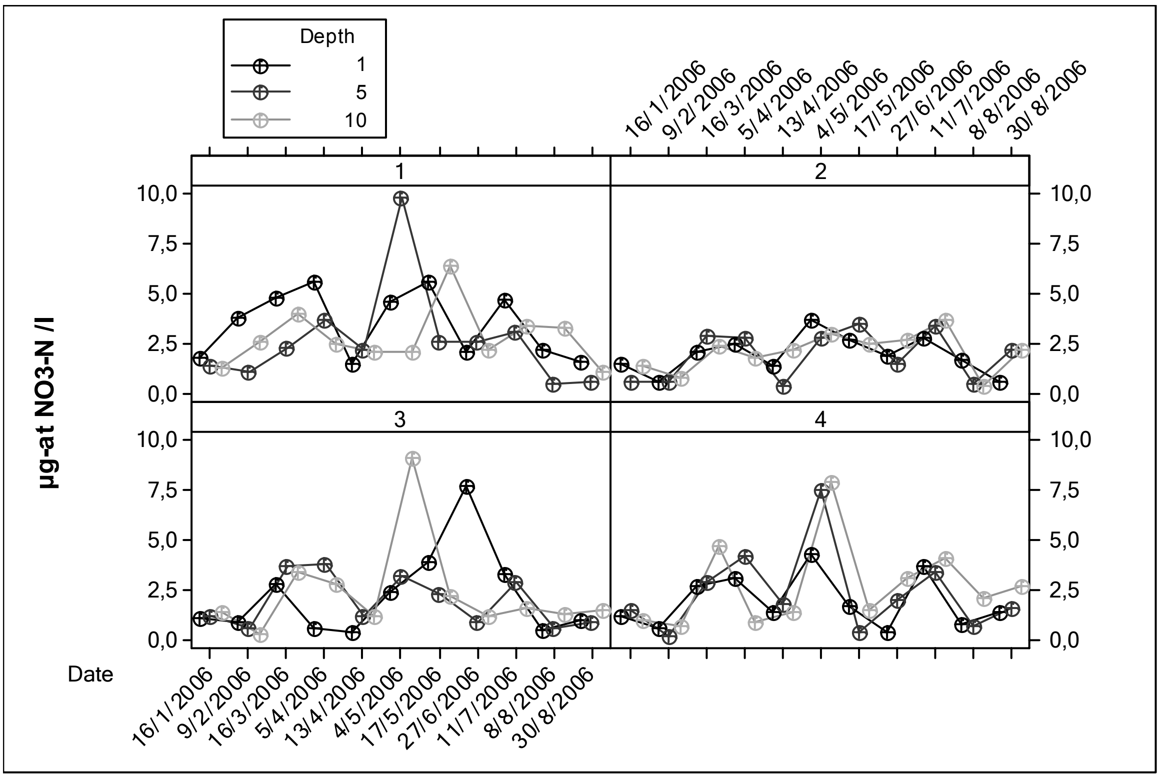

FIGURE 11 - Variation in the concentration of nitrate in the three depths and the sampling locations.

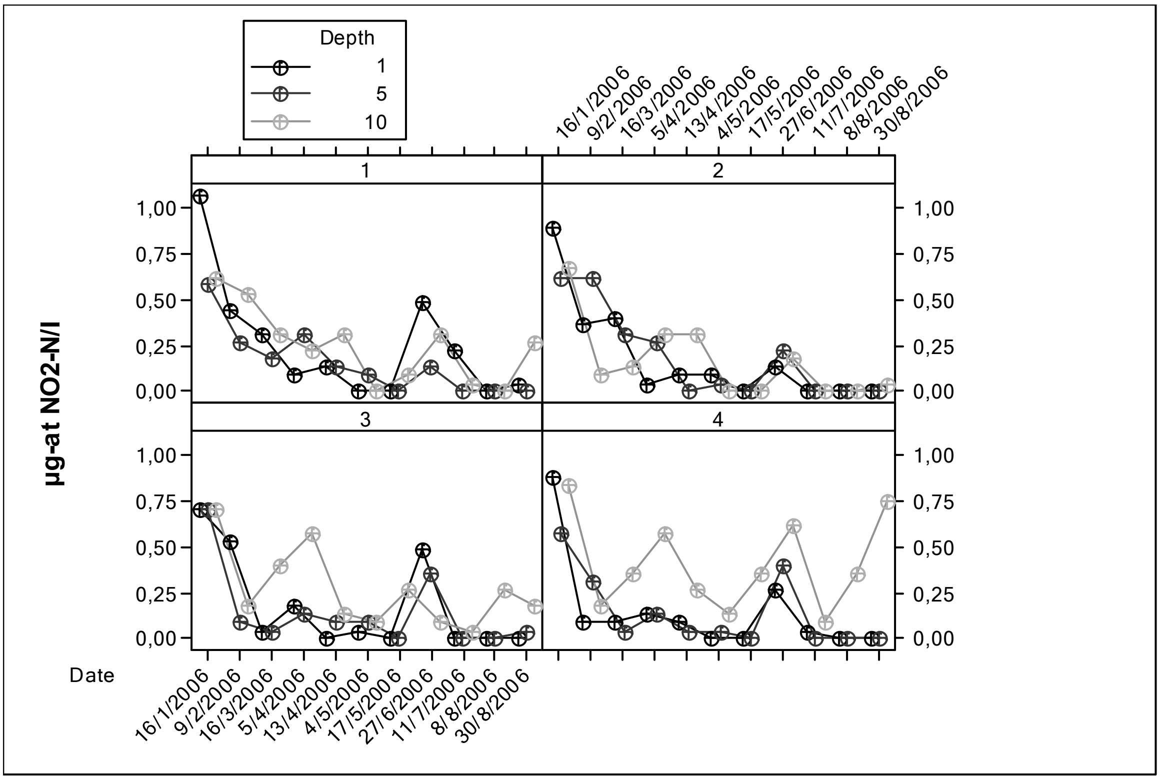

FIGURE 12 - Variation in the concentration of nitrite in the three depths and the sampling locations.

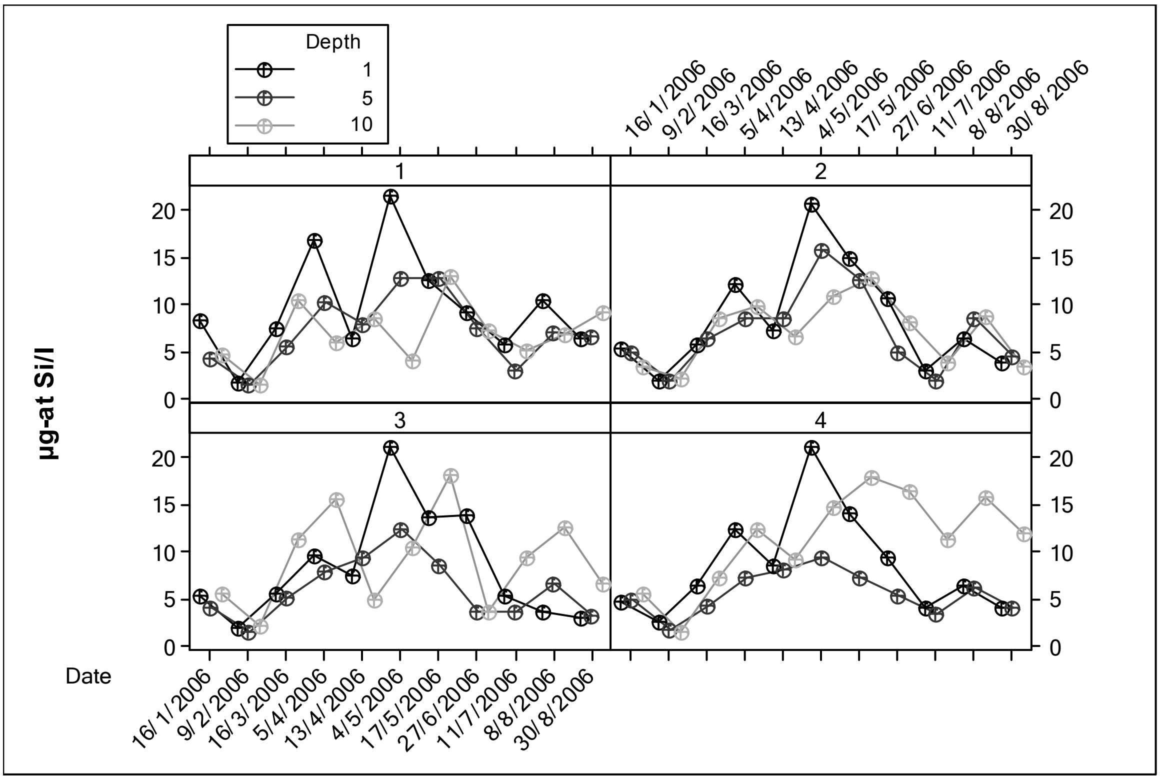

FIGURE 13 - Variation in the concentration of silicate in the three depths and the sampling locations.

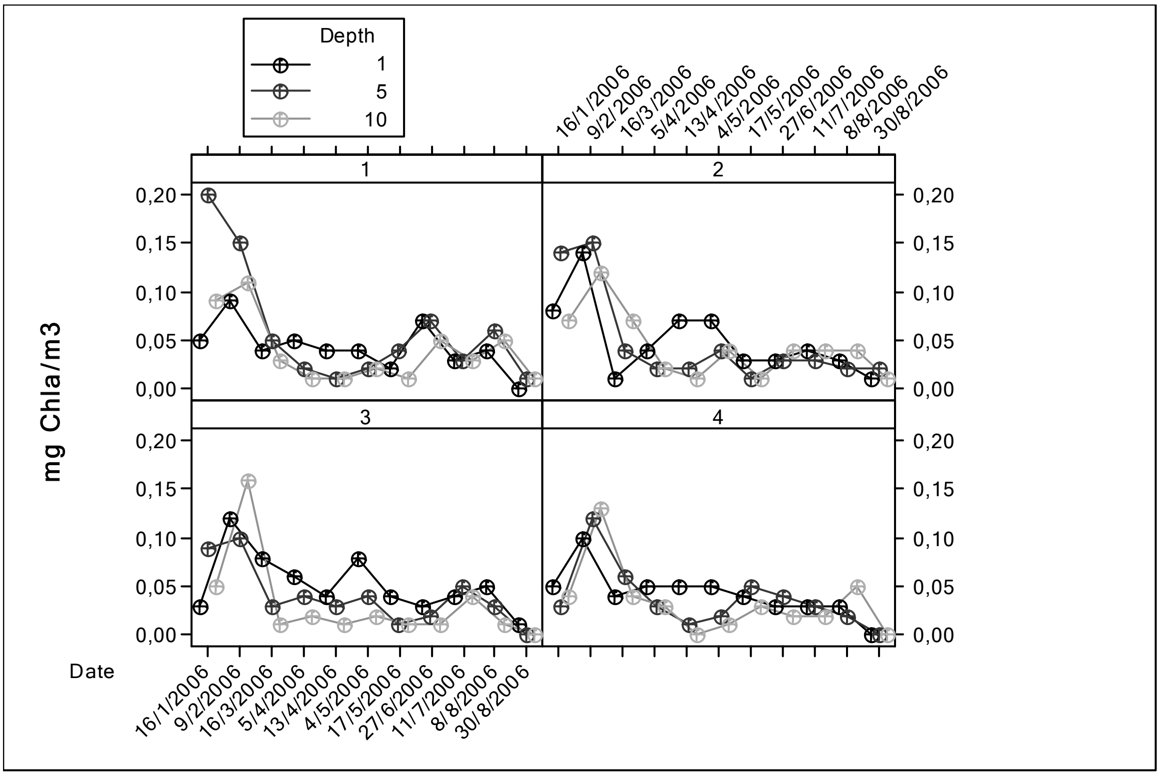

FIGURE 14 - Variation of the concentration of chlorophyll ***α*** **among the depths and the sampling locations.**

(a)

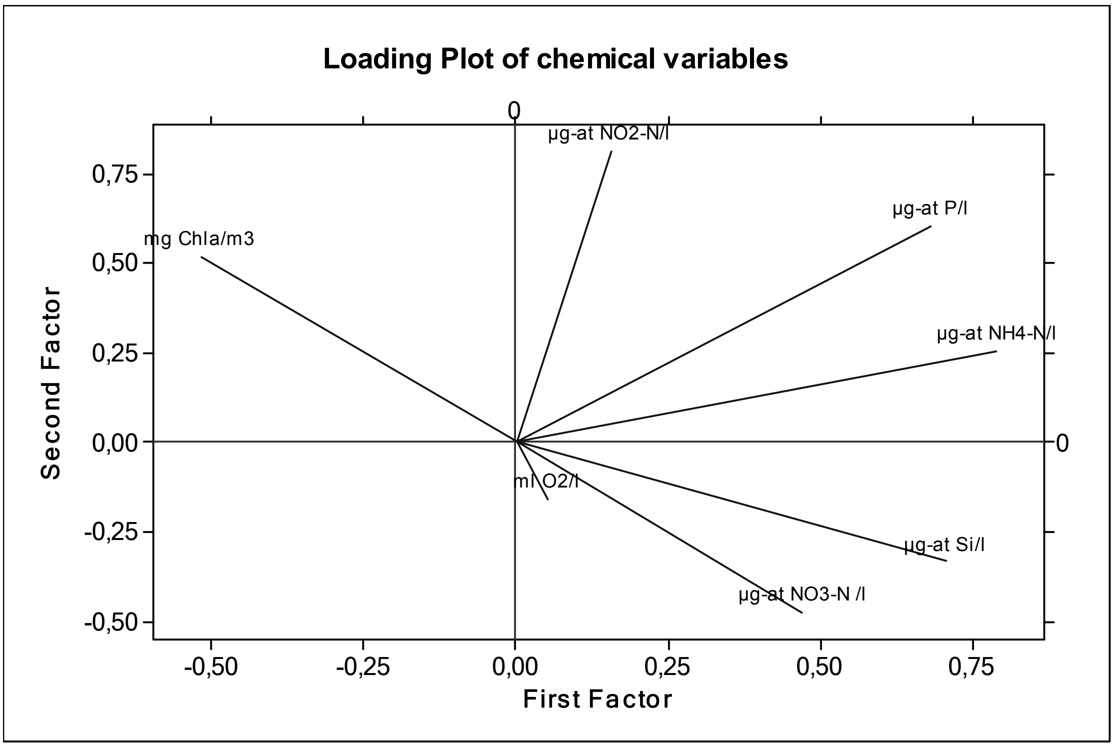

FIGURE 15a - Biplot arrangement of chemical parameters at different sampling periods. Points enclosed by the polygon indicate depth greater than 10m.

(b)

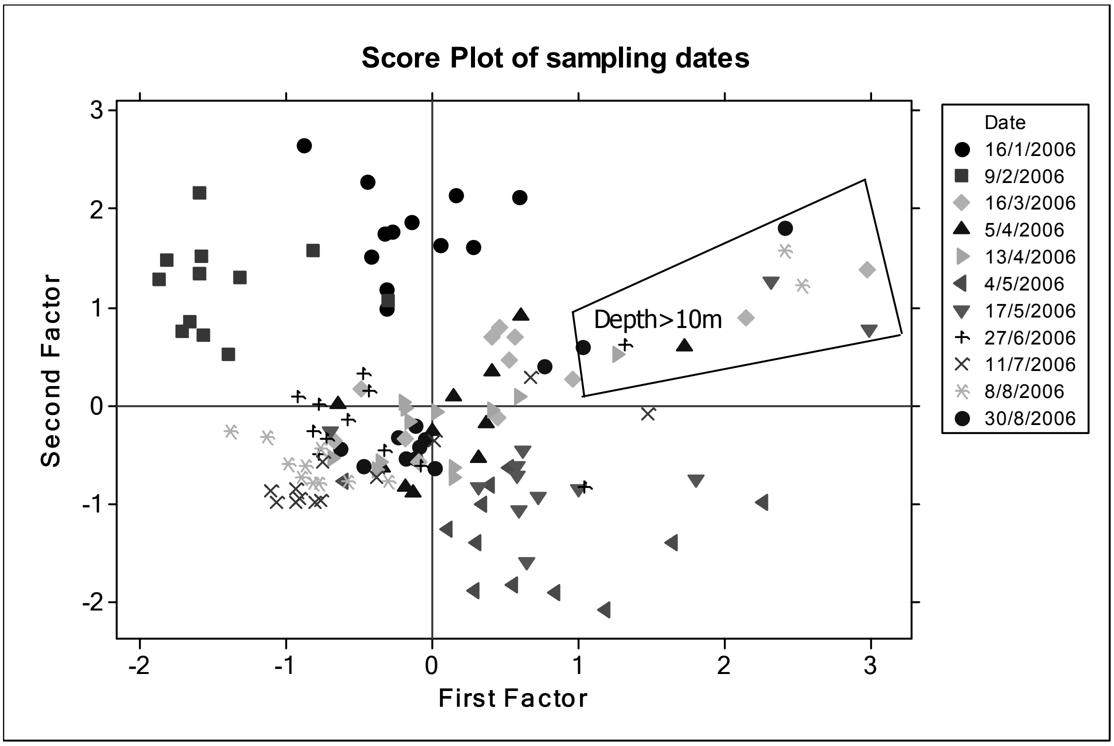

FIGURE 15b - Biplot arrangement of chemical parameters according to the Principal component analysis. Points enclosed by the polygon indicate depth greater than 10m.

Principal component analysis revealed that the first two major axes explained the 54.5% of the total variation (Fig. 15). Ammonium, silicate and phosphate are important in the formation of the first major component (30.1%) because their correlation coefficients with that axes approach the values 0.79, 0.71 and 0.68 respectively. Nitrite forms mainly the second axis (24.4%) showing a positive correlation of 0.809. The length of the arrows indicates the magnitude of the variable effect and the angle between arrows indicates the strength of the correlation between variables (0^o and 180^o equals to ±1.00 and 90^o to zero correlation). Samples close to an arrow (compare the corresponding quartiles of figures a and b) indicate particular effect of the corresponding variable. Thus, nitrate and silicate appear in high concentrations in May and correlate strongly negatively with chlorophyll abundance rich in February and January. Nitrite is highly concentrated in January, whereas high values of phosphate and ammonia, positively correlated each other, are indicative at depths higher than 10m. Low values of the last two variables appeared in summer (July and August).

CONCLUSIONS

The interaction among mussels, nutrients and phytoplankton during their seasonal changes form a complicated system that affects the water quality. The low values of dissolved oxygen are characterized as hypoxia and may cause adverse impacts in the marine organisms. Low values in phytoplankton biomass, expressed as chlorophyll *α* were measured, a common environmental impact of bivalve cultures related to the high filtration rates of the water. Nutrient values were elevated near the bottom and at normal to low levels in the water column. This fact is attributed to the stratification of waters and the isolation of the water column from the sediments nutrients. The station that is located outside the longlines, presented lower values of nutrients. Ammonia, silicate and phosphate are mainly responsible for the variation among the measured parameters.

ACKNOWLEDGEMENTS

This research was partially funded by the European Social Fund & National Resources – EPEAEK II - ARCHIMIDIS Project.

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Received: December 19, 2007
Revised: April 09, 2008
Accepted: May 08, 2008

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FEB/ Vol 17/ No 11b/ 2008 – pages 1945 – 1955