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Characteristics of deep chlorophyll maximum in the Northeastern Mediterranean with respect to environmental conditions

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Abstract

The vertical distribution of chlorophyll-a was recorded throughout the northern part of the Levantine Basin of the eastern Mediterranean and was related to patterns of the physical dynamics for October 1991–March 1994 period. A well developed deep chlorophyll maximum (DCM) was observed in the northern Levantine Basin (NLB), with concentrations greater than 1 μg/L at depths ranging from 45 to 100 m on average. Chlorophyll-a concentrations ranged between 0.01 (in surface waters, Oct. 1991) and 3.07 μg/L (in subsurface waters, March 1992). In general high concentrations of chlorophyll-a were observed in late winter. In cyclonic regions the depths of the DCM and the nutricline coincided and relatively high concentrations were observed at shallower depths at relatively high percentages of surface light. In anticyclonic regions the DCM (at low level of concentration) were located at the base of the euphotic zone and much above the nutricline. Well defined DCM feature was not prominent since at most of the stations, uniform distributions of chlorophyll-a were observed in the euphotic zone during the cooler winter conditions in 1992. The chlorophyll concentrations were significantly high in this winter when compared with those of ordinary mild winters. Because of the relatively low chlorophyll-a concentration resulting most probably low phytoplankton biomass in the basin and low input of material from the land, a thick euphotic zone forms with an average value of ~ 80 m.

Euphotic zone is nutrient depleted and the concentrations are close to detection limits (e.g. 0.02 μM for phosphate and > 0.05 μM for nitrate) and in general they do not show significant seasonal variations. Nutricline takes place in the euphotic zone in cyclonic regions. In anticyclonic regions, the main nutricline is deep (as deep as 600 m). In cooler winter condititions in 1992, very high concentrations of both nitrate and phosphate (almost equal to deep values) were observed in the euphotic zone in the cyclonic Rhodes region. In deep waters phosphate and nitrate concentrations stay almost constant at the levels of nearly 0.2 and 5.5 μM, respectively.

Keywords: chlorophyll-a; deep chlorophyll maximum; euphotic zone; Northern Levantine Basin; nutricline

1. Introduction

A well-developed deep chlorophyll maximum associated with increased phytoplankton biomass, is a prominent feature of the Mediterranean sea during a large part of the year (Estrada, 1985; Berman et al., 1984; Estrada et al., 1993). Nevertheless the DCM structure is disturbed by moderately strong winter conditions as was observed in the southern Levantine basin in 1989 (Krom et al., 1992).

Chlorophyll concentrations previously recorded in the Levantine basin were low, not exceeding 1 μg/L even in coastal waters (Berman et al., 1984; Dowidar, 1984; Azov, 1986; Abdel-Moati, 1990; Salihoğlu et

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al., 1990; Yılmaz et al., 1994), as, indeed one would expect for extremely oligotrophic waters. In the eastern Mediterranean, the chlorophyll concentrations vary seasonally, the highest concentrations occurring during late winter, with the onset of mixing of the upper water layers (Berman et al., 1984, 1986; Azov, 1986; Salihoğlu et al., 1990; Krom et al., 1991, 1992).

Eastern Mediterranean (deep) waters are poor in nutrients because of limited external inputs to the surface waters (Bethoux, 1981; Dugdale and Wilkerson, 1988). Therefore phytoplankton production is principally dominated by the extend and duration of winter mixing which provides transportation of nutrients from deeper layer (Krom et al., 1992; Yılmaz and Tuğrul, 1996).

In the western Mediterranean and in the other oligotrophic seas, DCM appears to be closely associated with the nutricline (Estrada, 1985; Lohrenz et al., 1988; Cox et al., 1982) and has been compared to the Typical Tropical Structure (TTS) of Herbland and Voituriez (1979). However, while a number of publications deal with the characteristics of the DCM in areas of the Atlantic, Pacific oceans and Western Mediterranean (Anderson, 1969; Venrick et al., 1973; Cullen and Eppley, 1981; Lohrenz et al., 1988 and Estrada et al., 1993), information on the variability of the DCM in the eastern Mediterranean is scarce. In this paper, we attempt to compare seasonal changes in hydrographic variables and examine the relationships between distribution of biological and physical–chemical variables in the water column.

2. Methods

The oceanographic cruises discussed in this work took place between October 1991 and March 1994. October 1991 and July 1993 cruises represent stratified conditions. The March 1992 and 1994 cruises represent cooler and mild winter conditions, respectively. Unfortuanatelly there were no representative data for the summer of 1992 and the winter of 1993. The study area and the positions of the stations, located between longitudes 28°00′ and 36°00′E and latitudes 34°00′ and 36°45′N are shown in (Figs. 1 and 2). Biologically related measurements did not always cover the entire basin (Fig. 2).

Water samples were collected with Go-Flo bottles (Rosette) attached to the Sea-Bird CTD probe down to at least 1000 m. The euphotic zone were subsampled for chlorophyll-a measurements. 0.5–2 L of seawater was filtered through 0.45 μm pore size, 47 mm diameter membrane filters using a vacuum of less than 0.5 atm. At some stations Whatman GF/F filters (with a 0.7 μm pore size) were also used for comparison. The filters were subsequently homogenized in 90% acetone, and the suspension was cleared by centrifugation. A standard fluorometric method was used for chlorophyll-a determination (Holm-

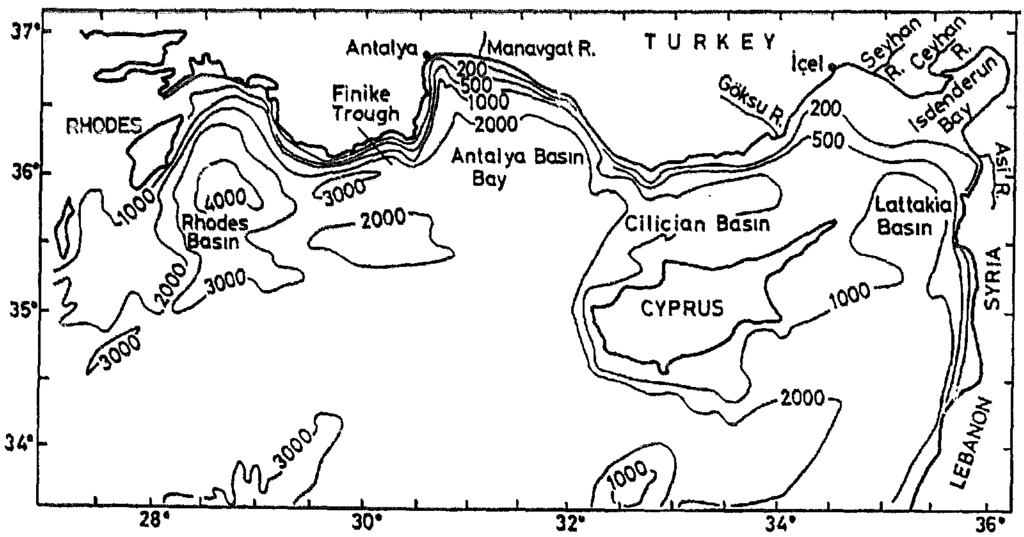

Fig. 1. Location map and bathymetry of the NLB with the nomenculature of major sub-basins.

Hansen et al., 1965). A Hitachi F-3000 Model fluorometer was used and calibration was performed using a commercially available chlorophyll-a standard from Sigma.

Nutrient subsamples from bottle casts were put into 50 mL HDPE bottles and the seawater samples for nitrate and phosphate analyses were kept frozen (−20°C) until being processed (maximum 1 month). The nutrient measurements were carried out by using a Technicon II multi-channel Autoanalyser, the methods followed were very similar to those described in Strickland and Parsons (1972) and Grasshoff et al. (1983).

A Licor 185 Model quantameter was used for downward irradiance measurements in the euphotic zone at most of the chlorophyll stations during day

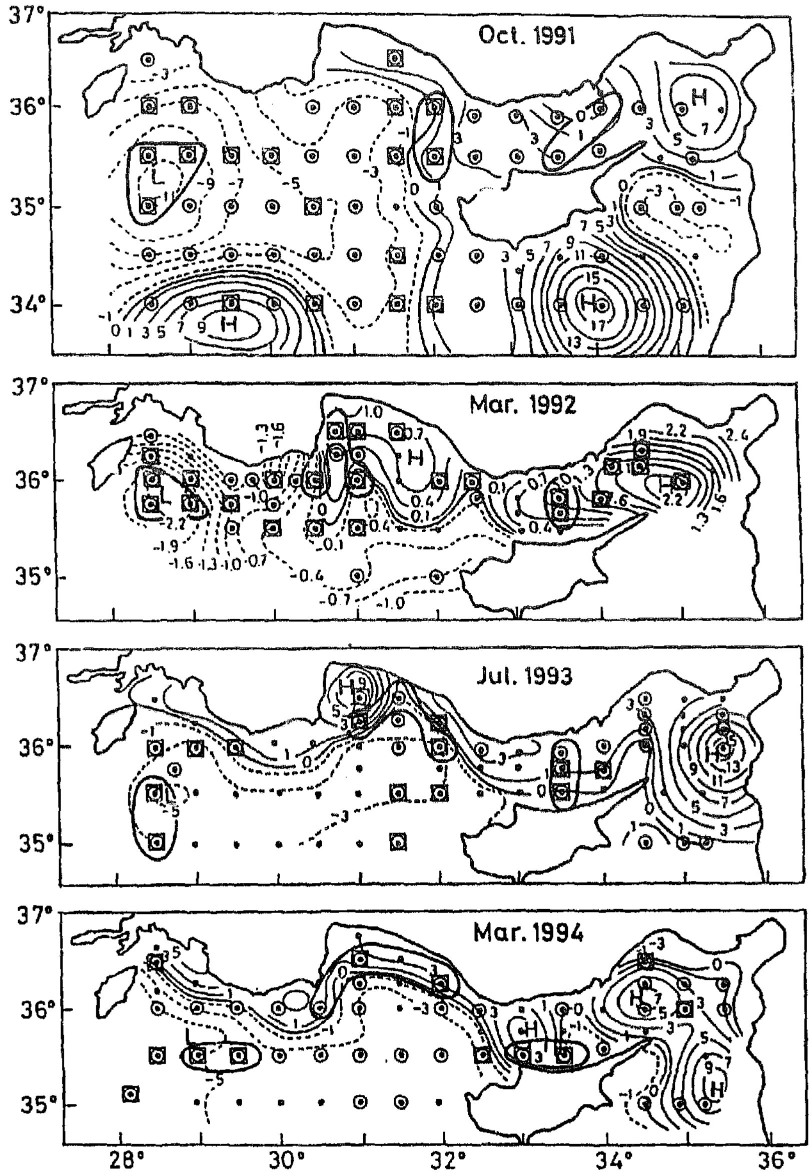

Fig. 2. Locations of hydrographic (●), water sampling stations [marked by (○) for nutrients and (□) for chlorophyll] and surface geopotential height anomalies during (a) Oct. 1991, (b) Mar. 1992 (modified from Sur et al., 1993), (c) Jul. 1993, (d) Mar. 1994 (unpublished data). Dynamic topography contours are given in centimeter units and L and H represent low and high pressures anomalies.

time. This instrument measures Photosynthetically Active Radiation (PAR) within the range of 400–700 nm in $\mu E\ m^{-2}\ s^{-1}$ unit.

3. Results

3.1. Water column structure

The hydrodynamics and hydrochemistry within the northern Levantine Sea display three regions of distinct behavior: the cyclonic Rhodes basin; the anticyclonic Cilician basin and the transitional area between them (Antalya bay or its offshore neighbourhood) (Figs. 1 and 2).

The profiles of March, 1994 and 1992 represent the mild and relatively cooler winter conditions respectively. The cooling of the salty surface waters in winter causes extensive vertical mixing in the upper layer due to the instability of the water column until those depths are reached where the density exceeds that of the sinking waters. This results in the formation of a mixed layer down to a certain depth (Özsoy et al., 1989, 1991, 1993 and unpublished data from

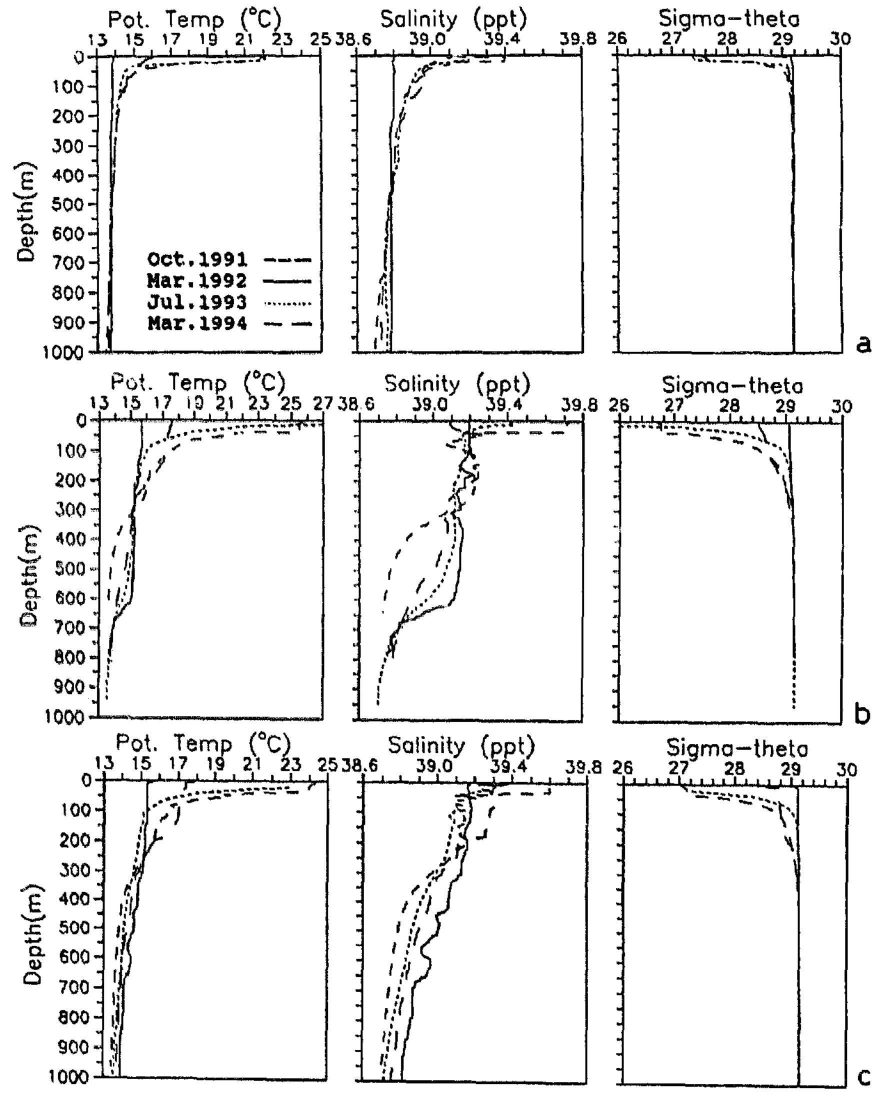

Fig. 3. Vertical profiles of potential Temperature, Salinity and Sigma-theta for selected regions namely as (a) Rhodes cyclone (CYC), (b) Cilician anticyclone (ACYC) and (c) Antalya bay (P + F) in the NLB (METU/IMS, 1993, 1995). The profile stations are circled by dark solid line in Fig. 2.

these authors) e.g. it was 200 m during the winter of 1994 (Fig. 3a) in the Rhodes gyre. Comparison of the observed temperature, salinity and density profiles (Fig. 3a) reveals that the upper layer of the Rhodes gyre had been mixed even more thoroughly by deep winter convection in 1992. An isothermal (~ 13.8°C) and isohaline (~ 38.8 ppt) water mass extended from surface to a depth of at least 1000 m. This salinity and temperature were, in fact, little higher than those previously measured in the Levantine Deep Water (LDW) which is characterised by a temperature of 13.6°C and a salinity of 38.7 ppt below 500 m (Özsoy et al., 1989, 1991) confirming that the LDW had become mixed with the warmer and more saline surface waters. In the Rhodes gyre, LDW have been seen to rise into the lower parts of the euphotic zone during summer–autumn months. The upper layer of the cyclonic Rhodes gyre, occupied by salty and warm waters (Fig. 3a), was separated from the LDW by a relatively sharp pycnocline located at around 50 m. This density stratification in the Rhodes gyre can be completely destroyed in cooler winters, as was observed in 1987 (Gertman et al., 1990) and more recently in 1992 (Sur et al., 1993).

The upper layer of the Cilician Basin, where small scale anticyclonic eddies are generally observed (Özsoy et al., 1989, 1991, 1993), possesses different hydrography relative to the Rhodes cyclonic region. The Cilician surface waters are more saline and warmer and separated from the intermediate layer by a very sharp seasonal stratification at 50–100 m during summer–autumn period (Fig. 3b). The vertically homogeneous water layer formed between the less saline waters (< 39 ppt) of Atlantic origine (which is observed below the seasonal halocline) and the LDW during stratifications is termed as the Levantine Intermediate Water (LIW) which is characterised by a temperature of around 15.5°C and salinity of 39.1 ppt (Hecht et al., 1988; Özsoy et al., 1989) and its thickness changes both seasonally and regionally. During winter convection, LIW mixed thoroughly with the salty surface waters to form a vertically mixed upper layer down to 500 m in the mild winter of 1994 (unpubl. data) but down to 600–650 m during the cooler winter of 1992 (Sur et al., 1993).

In Antalya bay, the permanent halocline which was observed between 200 and 350 m during mild winter of 1994 descended to about 600–700 m under cooler winter conditions of 1992 (Fig. 3c). A well defined seasonal stratification was observed at around 50 m in summer–autumn period while traces of Atlantic water could be observed only in October 1991. In this region fronts are frequently observed such as significantly formed during 1992 winter (Fig. 2).

3.2. Nutrients

Long-term data on hydrography and nutrients illustrate the role of winter convective mixing on the spatial and temporal variations of the nutrient distribution in the NLB (Salihoğlu et al., 1990; Yılmaz and Tuğrul, 1996).

Nutrient concentrations were vertically uniform throughout the water column down to a depth of about 1000 m since deep convection had mixed the nutrient-poor, more saline surface waters of the Rhodes gyre with the relatively nutrient rich LDW in March 1992 (Fig. 4a). However, the concentrations of nutrients in the surface layer of the cyclonic Rhodes Gyre have been recorded to be very similar to the characteristic deep water values (0.2 μM for phosphate and 5.5 μM for nitrate) as the consequence of deep concective mixing but deep waters had relatively lower values due to dilution with the nutrient-poor surface waters. In March 1994, a perfectly mild winter, a well defined nutricline existed in the upper layer (50–125 m) (Table 1) of the Rhodes gyre and/or at the lower parts of the euphotic zone (Fig. 4a). A relatively sharp nutricline is always observed at around 50 m under stratified conditions which coincides closely with the sharp salinity and density gradient (pycnocline) in the Rhodes gyre (Figs. 3a and 4a). In the euphotic zone, the concentrations diminish to trace levels in summer-autumn period, being less than 0.03 and 0.2 μM for phosphate and nitrate, respectively (Fig. 4a). However, the surface concentrations increased to the levels of about 0.5 μM for nitrate and insignificantly for phosphate during the mild winter of 1994.

Below the euphotic zone, vertical distributions of nutrients appear to show different features from cyclonic to anticyclonic regions. In the anticyclonic and partly in peripherial regions, there exists a nutrient-poor aphotic zone coinciding consistently with the LIW layer which is subject to vertical mixing with the surface waters during winter months. The nutrient-poor LIW is, therefore, well defined in the anticyclonic regions but it does not form in cyclonic regions (Fig. 4a–c). The nutrient concentrations of this layer remain almost constant with depth down to the permanent nutricline, but vary with season (e.g. up to 0.1 μM for phosphate and 3 μM for nitrate during July 1993) and region. In the core of the anticyclonic eddies, the nutrient-poor aphotic layer may extend down to 300 and 500 m as experienced in October 1991 and July 1993, respectively (Fig. 4b). Close examination of the profiles in Figs. 3b,c and 4b,c also shows that the top of the nutricline has been established permanently at depths corresponding to the lower boundary of the LIW layer throughout the basin; its depth and thickness vary in space and time, but its upper and lower boundaries are defined respectively by the 29.00–29.05 and the first appearance of the 29.15 density surfaces as previously reported by Yılmaz and Tuğrul (1996). The upper boundary of the prominent nutricline in the Cilician basin, located at relatively shallow depths (200–500 m) during normal winters, such as 1994. In the stratified months the prominent nutricline was located between 300–450 m and 500–600 m depth range for October 1991 and July 1993, respectively (Fig. 4b; Table 1).

In Antalya bay, continuous vertical and lateral fluxes of nutrients through the fronts cause effective nutrient enrichment of the upper layers above nutricline. Nutricline was located between 100–300 m depth range in the stratified months in this region. In the mild winter conditions (1994) this depth range changed between 150 and 250 m (Table 1). A regular increasing trend with depth was observed for nutrients in this area during cooler 1992 winter starting with relatively higher euphotic zone concentrations (e.g. ~0.05 μM for phosphate and ~1.5 μM for nitrate) not showing a developed nutricline.

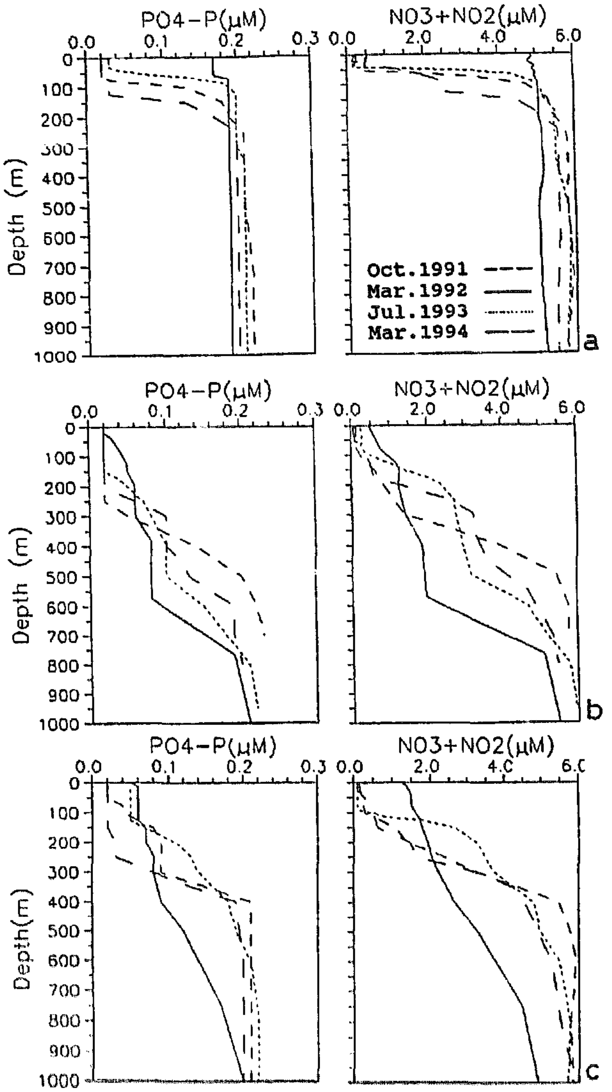

Fig. 4. Vertical profiles of dissolved nutrients [as phosphate (PO_4) and nitrate + nitrite ($NO_3 + NO_2$)] for the same stations in which the hydrographic data is represented (see Fig. 3a–c).

3.3. Light and chlorophyll

Levantine basin is one of the most transparent water body among the world oceans. The depth of 1% of the surface light is relatively deep in the NLB and shows temporal and spatial differences. In general, it is greater in summer than in winter, due to decrease in phytoplankton abundance of the water column. The winter of 1994 was extraordinarily warm and the phytoplankton biomass indices were relatively lower (e.g. chlorophyll concentration was low in general) resulting in a relatively thick euphotic layer (Tables 2 and 3). The depth of 1% of the surface light is shallow in cyclonic areas such as in the Rhodes gyre and its adjoining waters where the shallowness of the nutricline is observed and the phytoplankton abundance is relatively high com-

Table 1
Comparison of nutricline depths —mostly the top of the nutricline (ND)—and depth of Deep Chlorophyll Maxima (DDCM) in the NLB

Date	CYC		ACYC		P + F	
	ND (m)	DDCM (m)	ND (m)	DDCM (m)	ND (m)	DDCM (m)
Oct. 1991	50–100	50–100	300–450	75–130	200–300	75–130
Mar. 1992	–	–	400–600	–	–	–
Jul. 1993	50–75	55–80	500–600	75–115	100–300	75–110
Mar. 1994	50–125	40–50	200–500	60–85	150–250	50–80

CYC = Cyclonic areas.
ACYC = Anticyclonic areas.
P + F = Peripheral and Frontal areas.

pared to anticyclonic regions. The depth of 1% of the surface light was determined in the range of 55–95 m with an average value of 80 m for the whole NLB (Table 2).

The deep chlorophyll-a maxima, a common feature of the Mediterranean, have clearly been observed in the NLB (Fig. 5). Eddy systems and frontal events influence the vertical and horizontal distribution of chlorophyll-a and hence the magnitude and depth of DCM (Figs. 2 and 6). The DCM usually formed at shallower depths in cyclonic eddy fields (such as the Rhodes gyre) (Figs. 5 and 6) and, in general, the depth of DCM coincided with the depth of the top of the nutricline (Table 1). The DCM were broader in shape and were observed at relatively shallower depths in mild winter conditions of 1994, in comparison with summer months (Fig. 5). In relatively cooler winter conditions (during March 1992), the DCM was not well developed and relatively high chlorophyll values were observed in the euphotic zone. The concentrations at the near surface were much greater than the surface concentrations during stratified seasons and they were comparable with DCM concentrations. The mean concentration of Chl-a was 0.45 μg/L for the water column in the cyclonic Rhodes region in March 1992 (Table 3). Well defined DCM structures were observed in the summer months (Fig. 5) e.g. with relatively high concentrations, ranging from 0.85 to 1.24 μg/L with an average value of 1.0 μg/L in the Rhodes region in July 1993 (Table 3).

DCM was observed to form and to be maintained at deeper layers in the anticyclonic basins than in those of cyclonic regions both for winter and summer months (Figs. 5 and 6; Table 3). In general, they were located at the base of the euphotic zone or below it and well above the nutricline. The nutricline was certainly below the euphotic zone (Fig. 4; Table 1), e.g., as deep as 200–600 m in such areas. As expected the chlorophyll concentrations were rela-

Table 2
The monthly averages of depths to which 1% of surface light penetrated (compensation depth) and the average light level at the DCM (%I_o) in the Northern Levantine Basin concerning the eddy fields

Date	1% Light depth(m)			%I_o at DCM		
	CYC	ACYC	P + F	CYC	ACYC	P + F
Oct. 1991	77	95	80	1	0.9	0.8
Mar. 1992	59	66	55	–	–	–
July 1993	73	90	86	3	0.5	1
Mar. 1994	85	90	82	5	1	3
Overall range for the NLB	55–95 m			0.5–5%		

CYC = Cyclonic areas.
ACYC = Anticyclonic areas.
P + F = Peripheral and frontal areas.

tively low compared to Rhodes gyre e.g. DCM concentrations ranged between 0.20–0.35 μg/L during March 1994 (Table 3). Infact the concentrations were slightly lower than those found in previous winters in the same region (Ediger, 1995). Mixing extended over the whole basin, water column being throughly mixed down to 600 m in the anticyclonic Cilician basin in 1992 winter. As a consequence a common DCM structure was not observed in this region and the concentration ranged between 0.27–0.51 μg/L (Table 3). Chl-a concentrations were relatively high and the average concentration at DCM was determined to be 0.77 μg/L in the anticyclonic Cilician basin in July 1993 (Table 3) and the shapes of the DCM were much more pronounced (Fig. 5). Average chlorophyll concentrations at the DCM have been observed to be relatively low (e.g., 0.11 μg/L on average) in the Cilician Basin for October 1991 (Fig. 5; Table 3).

Between 1991 and 1994, the Chl-a profiles from Antalya bay usually exhibited a broad and prominent maximum (DCM) at a 50–130 m depth range. The DCM were located at the base of the euphotic zone or below it and above the nutricline (Tables 1 and 2). In general the chlorophyll concentrations were observed to be similar to those of cyclonic region but more higher concentration values (e.g. 0.75 μg/L on average for the DCM, Table 3) were observed in such areas as was specially experienced in the winter of 1992 (Fig. 5; Table 3). Mean values of 0.45 and 0.50 μg/L for March 1992, representing the cooler winter mixing in the Rhodes gyre and its adjacent waters in Antalya bay respectively, were almost twice the concentrations observed in late winters. Integrated chlorophyll-a values show that the cyclonic Rhodes gyre and its adjacent waters are more productive than the anticyclonic region in the NLB (Table 3).

The highest observed chlorophyll concentration was 3.07 μg/L (at 10 m) and to a depth (surface to 125 m) integrated value of 238 mg/m^2 at a station (36°00′N, 30°00′E) near Finike Trough in the Antalya region during March 1992 (Table 3). At this station chlorophyll-a concentration was still high

Table 3
The level of chlorophyll-a for offshore waters of the NLB for 1991–1994 period concerning the eddy fields

Time	CHL-A (μg/L)		INTG (mg/m^2)		DCM * (μg/L)		D-DCM (m)	
	Range	X	Range	X	Range	X	Range	X
Oct 91(CYC)	0.04–0.16	**0.07**	6–20	**12**	0.07–0.56	**0.26**	50–100	**75**
Oct 91(ACYC)	0.01–0.07	**0.05**	7–12	**9**	0.04–0.20	**0.11**	75–130	**100**
Oct 91(P + F)	0.01–0.09	**0.05**	3–17	**9**	0.03–0.25	**0.13**	75–130	**98**
Mar 92(CYC)	0.38–0.49	**0.45**	29–55	**44**	0.36–0.64	**0.51**	–	–
Mar 92(ACYC)	0.19–0.45	**0.28**	15–47	**28**	0.27–0.51	**0.35**	–	–
Mar 92(P + F)	0.20–1.10	**0.50**	21–90	**42**	0.32–1.35	**0.75**	–	–
Mar 92(CYC) (Finike Trough)	–	**1.71**	–	**238**		**3.07**	–	–
Jul 93(CYC)	0.28–0.57	**0.42**	31–50	**39**	0.85–1.24	**1.00**	55–80	**67**
Jul 93(ACYC)	0.23–0.24	**0.22**	25–37	**30**	0.71–0.86	**0.77**	75–115	**95**
Jul 93(P + F)	0.19–0.47	**0.32**	30–50	**38**	0.42–1.24	**0.82**	75–110	**91**
Mar 94(CYC)	0.20–0.57	**0.35**	20–54	**36**	0.37–1.08	**0.70**	40–50	**45**
Mar 94(ACYC)	0.10–0.15	**0.12**	10–14	**12**	0.20–0.35	**0.22**	60–85	**77**
Mar 94(P + F)	0.12–0.25	**0.17**	14–26	**20**	0.30–0.45	**0.40**	50–80	**70**

CHL-A = averages of water column chlorophyll-a.
INTG = averages of integrated chlorophyll-a.
DCM = averages of deep chlorophyll maxima.
D-DCM = averages of depth of DCM.
X = mathematical averages.
* = DCM was not observed in March 1992 thus the maximum values of the water column were taken into account.
CYC = cyclonic areas.
ACYC = anticyclonic areas.
P + F = peripherial and/or frontal areas.

(0.75 μg/L) at deeper layers (125 m). A small scale cyclonic eddy was formed at this station with a doming feature ascending to 100 m and fronts are observed surrounding this eddy (Fig. 2). Such high chlorophyll concentrations have never previously been observed in the offshore waters of the eastern Mediterranean (Berman et al., 1986; Azov, 1986; Abdel-Moati, 1990 and Krom et al., 1991, 1992).

The lowest value 0.01 μg/L which is the detection limit, obtained in surface and/or below euphotic zone (100–150 m) in the anticyclonic and peripherial regions in October 1991 sampling period.

4. Discussion

The formation, maintenance and location of the DCM were controlled by light attenuation and nutrient availability in the NLB. In general, the required light level, for the formation and maintenance of the DCM was found to be relatively low (average depth corresponding to 0.5–5% of surface light) and the DCM was frequently located at the compensation depth, especially in the adjacent waters of the Rhodes gyre. In winter, when the nutrient availability in the upper layers was favorable due to convective mixing and when the incident light intensity decreased, the DCM was located at a depth of 1–5% or even higher of the surface light. This was quite clear for the Rhodes basin where the nutricline reached the lower boundary of the euphotic zone or in the euphotic zone and the DCM could be observed at higher light percentages relative to other regions. The light available at the DCM depth was in general 1% or less of the surface light in the NLB (Table 2) and this was

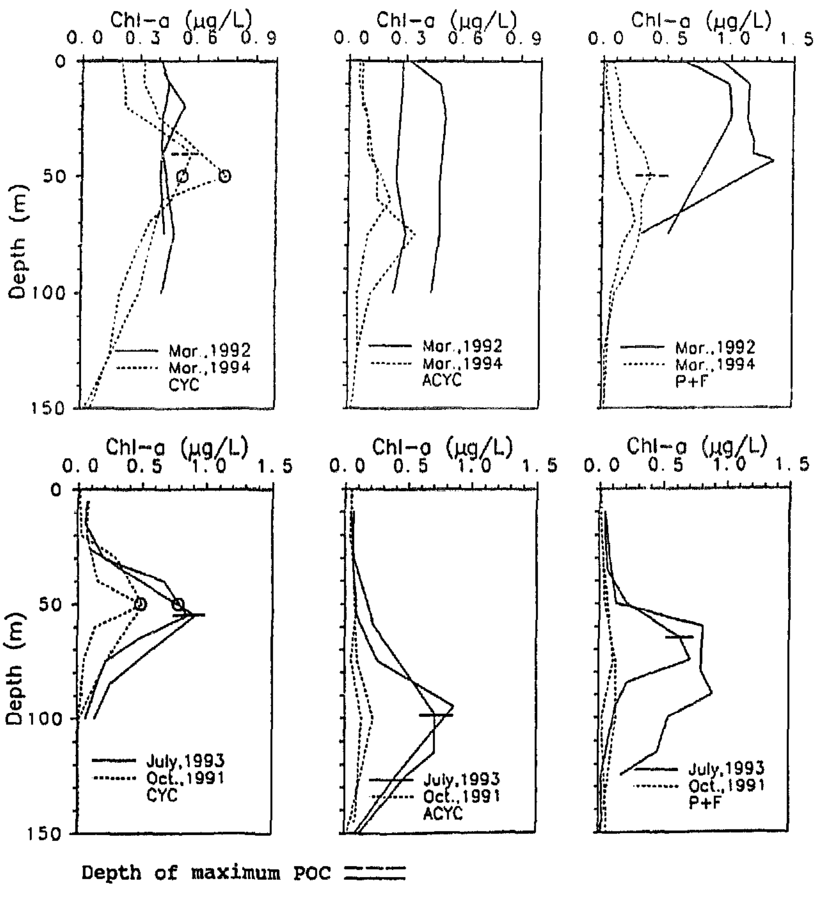

Fig. 5. Vertical profiles of total chlorophyll-a at the selected stations concerning the eddy fields in the NLB. The profile stations are circled by dark solid line in Fig. 2.

similar to the light intensity at the depth of the DCM in the southern Levantine basin (Berman et al., 1984), in a front in the south-west of the Azores (Fasham et al., 1985), and in the Sargasso Sea (Cox et al., 1982).

In the winter months the DCM was generally located in the upper mixed layer (MLD) when the mixing deepened on the MLD to about 200–500 m during ordinary mild winters. In cooler winter in 1992, high chlorophyll concentration values were observed near surface and well defined DCM was not observed. The euphotic zone was rendered homogeneity in terms of chlorophyll concentration in major part of the NLB. Usually, the studied area was visited in late winter–early spring (February–March) when the seasonal stratification would start to form very soon and the DCM were observed in the MLD in this period. On the other hand when the seasonal stratification was established, DCM was located at the lower parts of the salinity gradient zone or just below it. Monthly averages of the depth of the DCM fluctuated between 45–100 m throughout the basin,

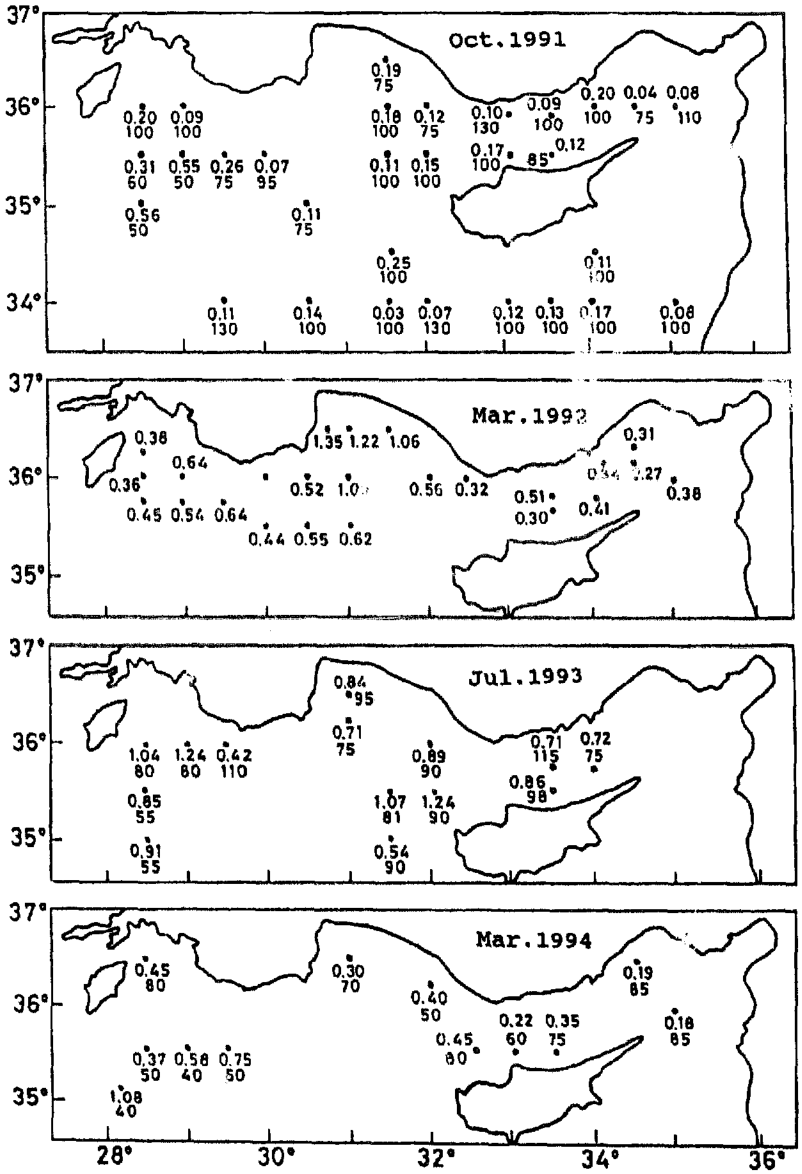

Fig. 6. Spatial distribution of DCM as its magnitude (upper line, μg/L) and the depth (lower line, m) in the NLB.

the depth being shallower during mixing months and deeper during stratified months (Table 3). The eddy fields also affected the depth of the DCM and, in general, the DCM was located at relatively shallow depths in the cyclonic region and in adjacent waters having frontal zones but at the base of the euphotic zone in anticyclonic areas such as the Cilician basin (Tables 2 and 3, Figs. 5 and 6).

When Chl-a data were plotted against the hydrographic data (Fig. 7) (temperature, salinity and sigma-theta) for the whole NLB, it was observed that hydrography and eddy systems influence the DCM. The DCM occurred at narrow ranges of temperature (14–16°C), salinity (38.9–39.2 ppt) and isopycnocal surfaces (28.90–29.15) throughout the basin (Fig. 7). As proposed by Cullen (1982), a decrease in the sinking rate of phytoplankton leads to their accumulation at a certain depth therefore forming the DCM. Lande and Wood (1987) showed that this kind of buoyancy regulation near the pycnocline could greatly enhance the residence time of sinking particles in the euphotic zone. Some high Chl-a concentrations were observed at 14°C, 38.85 ppt and densities of 29.15 during March 1992 associated with the chimney area in the Rhodes region and its adjacent waters in Antalya bay near Finike Trough (Fig. 7).

In the cyclonic regions, such as the Rhodes region, the nutricline formed in the euphotic zone or just below it during summer-autumn period when stratification was established. The depth of the DCM was coincident with this depth in such areas. In the euphotic zone, the phytoplankton rapidly consumed the nutrients (which is provided by winter mixing) during spring, after which the population was decreased. Below the stratification, nutrient concentrations were much higher and nutrients can diffuse upwards from the deeper layers. The continuous availability of nutrients in this region, possibly combined with the accumulation of sinking phytoplankton in these relatively nutrient-rich waters, may account for the establishment and maintenance of the DCM with relatively high chlorophyll concentrations compared to other regions. The deep phytoplankton layer makes a significant contribution to the total

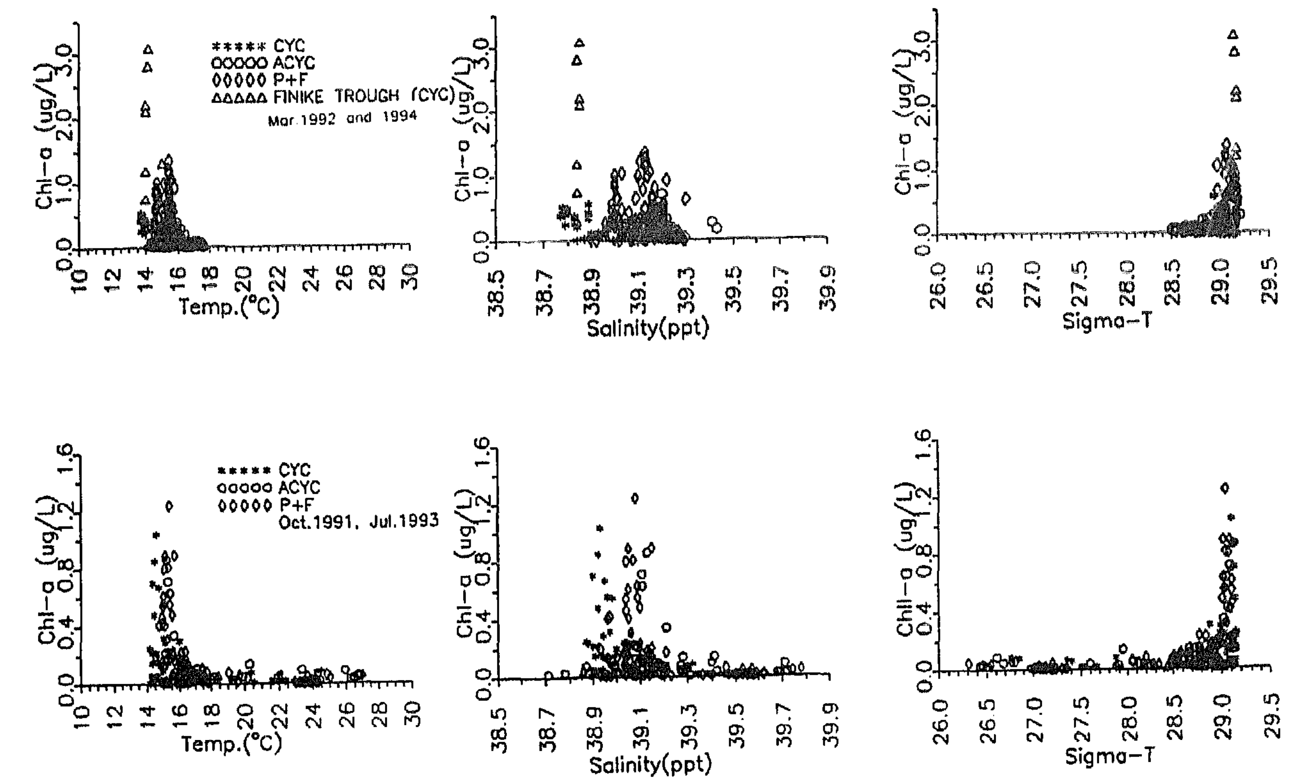

Fig. 7. Relationship between chlorophyll-a and hydrographic parameters (temperature, salinity and sigma-theta) for the NLB concerning the eddy fields.

primary production in such waters (Kirk, 1983). The main question is that, whether or not the chlorophyll maximum represents the true biomass (e.g., phytoplankton carbon) in the NLB. However, DCM may have been the result of an increase in either the biomass of the phytoplanktonic species or in the chlorophyll content of the cell at certain depths in oligotrophic seas (Li et al., 1992). Unfortunately there are no primary productivity measurements for this region. A limited number of particulate organic carbon (POC) data obtained in the studied area showed that there is a close correlation between the POC and Chl-a profiles and the DCM was probably due to the increase in phytoplankton density. This coincidence generally occured only where the water column is stabilized by a pycnocline formation and a good example is July 1993 when the POC maxima coincided with the DCM (Fig. 5).

The mechanism of formation of the DCM in the NLB seems to be similar to that of the eastern tropical Atlantic Ocean. The close and relatively stable coupling between physical and biological processes in the eastern tropical Atlantic Ocean has permitted the characterization of hydrographic and biological features into "typical tropical structure (TTS) (Herbland and Voituriez, 1979). It has been shown that TTS is a continuum of pattern, ultimately controlled by the input of nutrients from below, supplied by upwelling or turbulent mixing (Cullen, 1982). The oligotrophic extreme of TTS was characterized by a deep main stratification and nutricline, low chlorophyll concentrations, and minimal primary production. Hydrographic and biological features change together along the continuum, culminating in the productive extreme of TTS, shallow stratification and nutricline, high chlorophyll and production. These conditions were provided in the anticyclonic and cyclonic regions of the NLB respectively. If the nutrient flux was sufficient to elevate nutrient concentrations in the surface layers, TTS breaks down and the DCM was not observed (Cullen, 1982) as was seen during the winter of 1992.

As the vertical distribution of nutrients was highly influenced by the physical environment, such as the eddy fields in the NLB; the dynamics also directly affected the formation and maintenance of the DCM at a certain depth. The intensity of winter mixing modified the vertical transportation of nutrients and when relatively high concentration of nutrients became available in the euphotic zone, the magnitude, behaviour and most probably the composition of phytoplankton biomass changed and hence the structure of chlorophyll distribution. Comparison of Chl-a data with the data from other sites of the Mediterranean revealed that concentrations measured in the northern Levantine basin during cooler winter in 1992 and for the summer in 1993, exceeded the values reported for the southern Levantine basin [0.06–0.12 μg/L (Berman et al., 1986); 0.15–0.23 μg/L (Krom et al., 1991, 1992); 0.15–0.35 μg/L (Abdel-Moati, 1990)], but they were comparable to the concentrations of the western Mediterranean [0.1–0.8 μg/L (Berland et al., 1988); 0.12–0.84 μg/L (Estrada, 1985); 0.1–1.0 μg/L (Lohrenz et al., 1988)], indicating how the intensity of winter mixing affects the nutrient transportation mechanism and hence the feature of DCM in the basin.

Finally, the NLB is a very dynamic sea and the distribution of chemical and biologically related parameters are influenced by the physical dynamics. The NLB is not as oligotrophic as previously reported. Cyclonic and frontal regions represent a significant proportion of the regional phytoplanktonic biomass and probably the primary production.

References

Abdel-Moati, A.R., 1990. Particulate organic matter in the subsurface chlorophyll maximum layer of the Southeastern Mediterranean. Oceanol. Acta, 13: 307–315.

Anderson, G.C., 1969. Subsurface chlorophyll maximum in the Northeast Pacific Ocean. Limnol. Oceanogr., 14: 386–391.

Azov, Y., 1986. Seasonal patterns of phytoplankton productivity and abundance in nearshore oligotrophic waters of the Levant basin. J. Plankton Res., 8: 41–53.

Berland, B.R., Benzhitski, A.G., Burlakova, Z.P., Georgieva, L.V., Izmestieva, M.A., Kholodov, V.I. and Maestrini, S.Y., 1988. Conditions hydrologiques estivales en Mediterranée, repartition du phytoplancton et de la matière organique. Oceanol. Acta, pp. 163–177.

Berman, T., Townsend, D.W., El Sayed, S.Z., Trees, G.C. and Azov, Y., 1984. Optical transparency, chlorophyll and primary productivity in the Eastern Mediterranean near the Israeli coast. Oceanol. Acta, 7: 367–372.

Berman, T., Azov, Y., Schneller, A., Walline, P. and Townsend, D.W., 1986. Extent, transparency, and phytoplankton distribution of the neritic waters overlying the Israeli coastal shelf. Oceanol. Acta, 9: 439– 447

Bethoux, J.P., 1981. Le phosphore et l'azote en mer Mediterranée, bilans et fertilité potentielle. Mar. Chem., 10: 141–158.

Cox, J.L., Wiebe, P.H., Ortner, P. and Boyd, S., 1982. Seasonal development of subsurface chlorophyll maxima in slope water and Northern Sargasso sea water of the northwestern Atlantic ocean. Biol. Oceanogr., 1: 271–285.

Cullen, J.J., 1982. The deep chlorophyll maximum: Comparing vertical profiles of chlorophyll-a. Can. J. Fish. Aquat. Sci., 39: 791–803.

Cullen, J.J. and Eppley, R.W., 1981. Chlorophyll maximum layers of the Southern California Bight and possible mechanisms of their formation and maintenance. Oceanol. Acta, 4: 23–32.

Dowidar, N.M., 1984. Phytoplankton biomass and primary production of the south-eastern Mediterranean. Deep-Sea Res., 31: 983–1000.

Dugdale, R.C. and Wilkerson F.P., 1988. Nutrient sources and primary production in the eastern Mediterranean. Oceanol. Acta, 9: 179–184.

Ediger, D., 1995. Interrelationships among primary production chlorophyll and environmental conditions in the Northern Levantine Basin. Thesis. METU, Inst. Mar. Sci., Erdemli, 187 pp.

Estrada, M., 1985. Deep phytoplankton and chlorophyll maxima in the western Mediterranean. In: M.M. Apostopoulou and V. Kiortsis (Editors), Mediterranean Marine Ecosystems. Plenum, New York, pp. 247–277.

Estrada, M., Marrase, C., Latasa, M., Berdalet, E., Delgado, M. and Riera, T., 1993. Variability of deep chlorophyll maximum characteristics in the Northwestern Mediterranean. Mar. Ecol. Progr. Ser., 92: 289–300.

Fasham, M.J.R., Platt, T., Irwin, B. and Jones, K., 1985. Factors affecting the spatial pattern of the deep chlorophyll maximum in the region of the Azores front. Progr. Oceanogr., 14: 129–165.

Gertman, I.F., Ovchinnikov, I.M. and Popov, Y.I., 1990. Deep convection in the Levantine Sea. Rapp. Comm. Int. Mer Medit., 32, 172 pp.

Grasshoff, K., Ehrhardt, M. and Kremling, K., 1983. Determination of nutrients. In: Methods of Seawater Analysis. Chemie, Weinheim, 2nd ed., pp. 125–188.

Hecht, A., Pinardi, N. and Robinson, A.R., 1988. Currents, water masses, eddies, and jets in the Mediterranean Levantine basin. J. Phys. Oceanogr., 18: 1320–1353.

Herbland, A. and Voituriez, B., 1979. Hydrological structure analysis for estimating the primary production in the tropical Atlantic Ocean. J. Mar. Res., 37: 87–101.

Holm-Hansen, O., Lorenzen, C.J., Holmes, R.W. and Strickland, Y.M.H.A., 1965. Fluorometric determination of chlorophyll. J. Cons. Perm. Int. Explor. Mer., 30: 3–15.

Kirk, J.T.O., 1983. Light and photosynthesis in aquatic ecosystems. Cambridge Univ. Press, 2nd ed., 508 pp.

Krom, M.D., Kress, N. and Brenner, S., 1991. Phosphorus limitation of primary productivity in the eastern Mediterranean. Limnol. Oceanogr., 36: 424–432.

Krom, M.D., Brenner, S., Kress, N., Neori, A. and Gordon, L.I., 1992. Nutrient dynamics and new production in a warm core eddy from the Eastern Mediterranean. Deep-Sea Res., 39: 467–480.

Lande, R. and Wood, A.M., 1987. Suspension times of particles in the upper ocean. Deep-Sea Res., 34: 61–72.

Li, W.K.W., Dickie, P.M., Irwin, B.D. and Wood, A.M., 1992. Biomass of bacteria, cyanobacteria, prochlorophytes and photosynthetic eukaryotes in the Sargasso Sea. Deep-Sea Res., 39(3/4): 501–519.

Lohrenz, S.E., Wiesenburg, D.A., Depalma, I.P., Johnson, K.S. and Gustafson, D.E., 1988. Interrelationships among primary production, chlorophyll, and environmental conditions in frontal regions of the western Mediterranean Sea. Deep-Sea Res., 35: 793–810.

METU/IMS, 1993. National Monitoring Program, Mediterranean Sub-Project, 1992 period Final Report. Middle East Tech. Univ. Inst. Mar. Sci., Erdemli-İçel, 35 pp. (in Turkish).

METU/IMS, 1995. National Monitoring Program, Mediterranean Sub-project, April 1993–April 1995 period Final Report. Middle East Tech. Univ. Inst. Mar. Sci., Erdemli-İçel, 102 pp. (in Turkish).

Özsoy, E., Hecht, A. and Ünlüata, Ü., 1989. Circulation and hydrography of the Levantine Basin. Results of POEM coordinated experiments 1985–1986. Progr. Oceanogr., 22: 125–170.

Özsoy, E., Hecht, A., Ünlüata, Ü., Brenner, S., Oğuz, T., Bishop, J., Latif, M.A. and Rosentraub, Z., 1991. A review of the Levantine Basin circulation and its variability during 1985–1988. Dyn. Atmos. Oceans, 15: 421–456.

Özsoy, E., Hecht, A., Ünlüata, Ü., Brenner, S., Sur, H.Ý., Bishop, J., Oğuz, T., Rosentraub, Z. and Latif, M.A., 1993. A synthesis of the Levantine basin circulation and hydrography, 1985–1990. Deep-Sea Res., 40(6): 1075–1119.

Salihoğlu, İ., Saydam, C., Baştürk, Ö., Yılmaz, K., Göçmen, D., Hatipoğlu, E. and Yılmaz, A., 1990. Transport and distribution of nutrients and chlorophyll-a by mesoscale eddies in the Northeastern Mediterranean. Mar. Chem., 29: 375–390.

Strickland, J.D.H. and Parsons, T.R., 1972. A Practical Handbook of Seawater Analysis. Bull. Fish. Res. Board. Can., 167, 2nd ed.

Sur, H.İ., Özsoy, E. and Ünlüata, Ü., 1993. Simultaneous deep and intermediate depth convection in the Northern Levantine Sea, winter 1992. Oceanol. Acta, 16: 33–43.

Venrick, E.L., Mcgovan, J.A. and Mantyla, A.W., 1973. Deep maxima of photosynthetic chlorophyll in the Pacific Ocean. Fish. Bull.,71: 41–52.

Yılmaz, A. and Tuğrul, S., 1996. The effect of cold and warm-core eddies on the distribution and stoichiometry of dissolved nutrients in the Northeastern Mediterranean. J. Mar. Syst. submitted.

Yılmaz, A., Ediger, D., Baştürk, Ö., and Tuğrul, S., 1994. Phytoplankton fluorescence and deep chlorophyll maxima in the Northeastern Mediterranean. Oceanol. Acta, 17: 69–77.