The primary production and optical status of the NE Mediterranean and Black Sea

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Abstract- Primary production, chlorophyll-a concentration and downwelling irradiance were measured in the Northeastern (NE) Mediterranean and Southern Black Sea during 1991-1994 period. In the NE Mediterranean, the depth corresponding to 1% of the surface light is relatively deep and shows temporal and spatial differences. This depth was greater in summer than it was in winter and shallow in cyclonic regions (e.g. Rhodes gyre) and its adjoining waters when compared to anticyclonic regions. The overall mean of 1% of surface light was 78 m in the NE Mediterranean for this period. Mean downward attenuation coefficient was determined as 0.057 m^{-1} in the region. The average attenuation coefficient was always observed to be higher in the cyclonic region than it was in anticyclonic regions, and frontal zones adjoining the gyre possessed the highest values. The euphotic zone was quite thin during the 1992 winter the average depth of 1% of the surface light decreased to 55-60 m and the average downward attenuation coefficient increased up to 0.085 m^{-1} in the Rhodes gyre and its adjoining waters. Chlorophyll-a concentrations ranged between 0.02-3.07 µg\L in the upper 150m of the water column and exhibited a maximum in the lower part of the euphotic zone. A well developed Deep Chlorophyll Maximum (DCM) was observed in the NE Mediterranean. In cyclonic regions, the depth of DCM were observed at shallower depths, at relatively high percentages of surface light. In anticyclonic regions, the DCM (at low level of concentrations) were located at the base of the euphotic zone. Well defined DCM feature was not observed at most of the stations, uniform distributions of chlorophyll-a were observed in the euphotic zone during the cooler winter conditions in 1992. Depth integrated primary production was measured 38.5 mgC\$m^2$\d for autumn and 286 mgC\$m^2$\d for winter in cyclonic region in the NE Mediterranean. The thickness of the euphotic zone (1% of the surface light) varied ranged between 27-35 m in the southern Black Sea. Attenuation coefficient varied between 0.146-0.210 m^{-1}.Chlorophyll-a concentration in the euphotic zone ranged from 0.1-7 µg\L and a sub-surface chlorophyll-a maxima was formed near the base of the euphotic zone. Production rate varied between 194 and 687 during a year (Yılmaz et al., 1998). NE Mediterranean and the Black Sea are known to be in different trophic status, the first one is being oligotrophic and the second one is euptrophic or mesotrophic; but this data set show that NE Mediterranean (at least Rhodes section) is not quite oligotrophic and the southern Black Sea seems to be at mesotrophic level for the study period.

Keywords- Primary production, chlorophyll-a, Black Sea, NE Mediterranean

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 1µg/L even in coastal waters (Berman et al.,1984; Dowidar,1984; Azov, 1986; Abdel-Moati, 1990; Salihoğlu et al., 1990; Yılmaz et al., 1994), as, indeed one would expect for extremely oligotrophic waters. The Black Sea is relatively productive, very deep, land-locked basin connected to the Aegean basin of the eastern Mediterranean through the Sea of Marmara via the straits of Bosphorus and Dardanels. According to Vedernikov and Demirov (1993) and Sorokin (2002), primary production in the Black Sea displays two phytoplankton maxima throughout the year; the major one occurs in early spring while a secondary peak appears in autumn. Recently, additional summer blooms have frequently been observed in both the coastal and open waters (Hay et al.,1990,1991 and Sorokin, 2002). Primary production is relatively low in the open sea (90-300 gC m^{-2} y^{-1}) compared to the northwestern shelf area (up to 500 gC m^{-2} y^{-1}) (Sorokin, 2002). The aim of this study to make comparison between NE Mediterranean and Southern Black sea with respect to Chlorophyll-a, light penetration and primary production.

Methods

The oceanographic cruises discussed in this work took place between 1991 and 1994. October 1991 and July 1993 cruises represent stratified conditions, the March 1992 and 1994 cruises represent cooler and mild winter conditions respectively in the NE Mediterranean. September 1991, July 1992 and August 1993 cruises represent stratified conditions and April 1993 and 1994 represent before the development of seasonal stratification in the Southern Black Sea. The study area and the positions of the stations are illustrated in Fig. 1. Water samples were collected with Go-Flo bottles (rosette) attached to the Sea-Bird CTD probe. The euphotic zone was subsampled for chlorophyll-a and primary production measurements. A standard fluorometric method was used for total chlorophyll-a determination (Holm-Hansen et al., 1965). The rates of carbon fixation by phytoplankton in the samples taken from the surface and from 90%, 75%, 25%, 10% and 1% surface light depths were determined by tracing the conversion of dissolved inorganic radioactive carbon (^{14}C) into particulate organic carbon. Incubator experiments were performed under artificial growth conditions (Gargas, 1975). A Licor 185 Model quantameter was used for downward irradiance measurements in the euphotic zone at most of the chlorophyll stations during daytime. This instrument measures Photosynthetically Active Radiation (PAR) within the range of 400-700nm in µE/m^2/s unit.

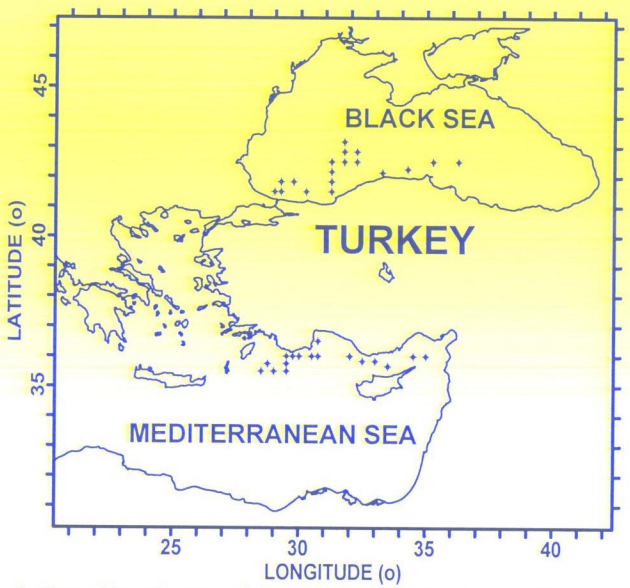

Fig. 1. General location map of the study area showing the sampling stations.

Results and Discussion

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 neighborhood) (Ediger and Yılmaz 1996).

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 NE Mediterranean 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 (Table 1.). 1994 winter was extraordinarily warm winter and the phytoplankton biomass indices were relatively less (e.g. chlorophyll concentration was low in general) resulting relatively thick euphotic layer (Table 1 and Fig. 2). The depth of 1 % of the surface light is shallow in cyclonic areas and its adjoining waters (P+F) (Table 1.) where the shallowness of the nutricline is observed (Ediger and Yılmaz 1996) and the phytoplankton biomass is relatively high compared to anticyclonic regions (Fig. 2.). The depth of 1 % of the surface light was determined in the range of 55-95m with an average value of 78m for the whole NE Mediterranean (Table 1). The downward attenuation coefficient Kd, calculated from the measurements of light intensity in offshore waters was found to range between 0.04 and 0.085 m^{-1} with an average value of 0.057±0.014 m^{-1} (Table 1.). The average downward attenuation coefficient for the stations located in cyclonic regions and frontal areas were higher than that calculated for the anticyclonic regions. Downward attenuation coefficients (except March 1992) were in good

agreement with data given by Megard and Berman (1989) for the southern Levantine pelagic waters. The deep chlorophyll-a maxima, a common feature of the Mediterranean, have clearly been observed in the NE Mediterranean (Fig. 2). Eddy systems and frontal events influence the vertical and horizontal distribution of chlorophyll-a and hence the magnitude and depth of DCM (Fig. 2). The DCM usually formed at shallower depths in cyclonic eddy fields (Fig. 2) and, in general, the depth of DCM coincided with the depth of the top of the nutricline (Ediger and Yılmaz 1996). The DCM was broader in shape and was observed at relatively shallower depths in mild winter conditions of 1994, in comparison with summer months (Fig. 2). 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. Well-defined DCM structures were observed in the summer months (Fig. 2). 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 (Fig. 2). 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 (Ediger and Yılmaz 1996). As expected the chlorophyll concentrations were relatively low compared to Rhodes gyre. Mixing extended over the whole basin, water column being thoroughly mixed down to 600 m in the anticyclonic Cilician basin in 1992 winter (Ediger and Yılmaz 1996). As a consequence a common DCM structure was not observed in this region. Chl-a concentrations were relatively high at DCM in the anticyclonic Cilician basin in July 1993 (Fig. 2) and the shapes of the DCM were much more pronounced (Fig. 2). Between 1991 and 1994, the Chl-a profiles from Peripheral and Frontal area (P+F) usually exhibited a broad and prominent maximum (DCM) at a 30-90 m depth range. The DCM was located at the base of the euphotic zone or below it.

Table 1. Depth of 1 % Surface Light (D) and downward attenuation coefficients (K_d) in the NE Mediterranean (CYC:cyclonic region, ACYC:anticyclonic, P+F:peripheral and frontal area)

Location	Oct-1991		Mar-1992		Jul-1993		Mar-1994	
	D	K_d	D	K_d	D	K_d	D	K_d
CYC	77	0.051	59	0.079	73	0.068	85	0.047
ACYC	95	0.050	66	0.064	90	0.041	90	0.047
P+F	80	0.050	55	0.085	86	0.045	-	-
NE Med. (Overall)	D 78±13; K_d 0.057±0.014							

The highest observed chlorophyll concentration was 3.07 µg/L (at 10m) in Antalya region during March 1992 (Fig. 3). At this station chlorophyll-a concentration was still high (0.75 µg/L) at deeper layers (125 m). 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).

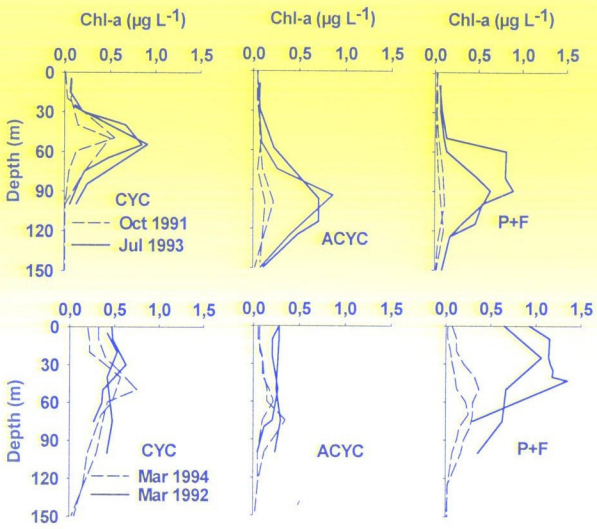

Fig. 2. Vertical profiles of chlorophyll-a concerning eddy fields in the NE Mediterranean

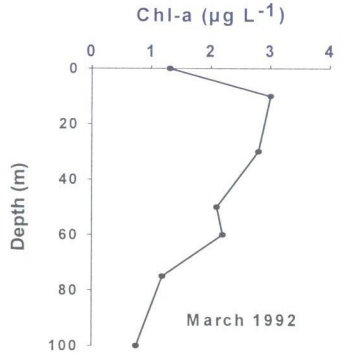

Fig. 3. Vertical profile of Chlorophyll-a obtained in the NE Mediterranean for the March 1992 sampling period

Depth integrated Primary Production (PP) in cyclonic region was 38.5 mgC\m^2\d for October 1991 and 286 mgC\m^2\d for March 1992 in the NE Mediterranean respectively (Table 2). PP was estimated to be 457 mgC\m^2\d in the frontal region in March 1992. In the anticyclonic region the PP was estimated in the water column to be 250 mgC\m^2\d during March 1992 sampling period (Table 2).

Table 2. Daily primary production rates (PP mgC\m^2\day) integrated for the euphotic zone in the NE Mediterranean

NE Med	Oct 1991	Mar 1992
CYC	38	286
ACYC	-	250
P+F	-	457

Table 3. Depth of 1 % Surface Light (D) and downward attenuation coefficients (K_d) in the Southern Black Sea

Location	April 1993		April 1994	
	D	K_d	D	K_d
Bosphorus	28	0.210	-	-
WesternCyc	27	0.186	35	0.146

Black Sea (Overall) D: 30±7; K_d: 0.185±0.06

The observed light penetration in the upper water column of the southern Black sea during April 1993 and 1994 indicated the thickness of the euphotic zone to range between 27-35m (Table 3.). Downward attenuation coefficient varied between 0.146 and 0.21 m^{-1}. Seasonal Chlorophyll-a data from different regions (cyclonic, anticyclonic and rim current) of the southern Black Sea are displayed in Fig. 4a,b. A sub-surface chlorophyll maximum was formed near the base of the euphotic zone during summer sampling period (Fig. 4a.) and the concentrations were observed as high as 7 µg\L during July 1992 sampling period in Rim current region. Sub-surface chlorophyll maximum was located in the range of 15-30m in cyclonic region during summer sampling period and concentrations were relatively high compared to anticyclonic region (Fig. 4a.). The chlorophyll concentrations in the euphotic zone were relatively low (<1 µg\L) in the anticyclonic region (Fig. 4a). Maximum chlorophyll concentrations (close to 5 µg\L) were observed near surface during April 1993 sampling period in cyclonic region. In April 1994 sampling period chlorophyll concentrations in the euphotic zone were generally low (<0.5 µg\L) (Fig. 4b.) in all regions. However chlorophyll-a concentrations in cyclonic and Rim current regions were relatively higher than anticyclonic regions in the southern Black Sea during sampling periods (Fig. 4a,b).

Depth integrated productivity ranged from 194 in the Bosphorus region to 687 $mgCm^{-2}d^{-1}$ in cyclonic eddy in June 1996, yielding an average of 385 $mgCm^{-2}d^{-1}$ for the seasons of 1995-1996 (Table 4.) (Yılmaz et al., 1998).

Table 4. Daily primary production rates (PP mgC\m^2\day) integrated for the euphotic zone in the Southern Black Sea (Yılmaz et al., 1998)

S Black sea	Apr 1995	Sep 1995	Jun 1996
Bosphorus	247	405	194
CYC			687

Comparison of Chl-a data with the data from other sites of the Mediterranean revealed that concentrations measured in the northeastern Mediterranean 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 (0.12-0.84 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. Production rates determined by Yılmaz et al., 1998 in the southern Black Sea were close to presented in this study for the NE Mediterranean during March 1992 sampling period. These production rates were also similar to those reported for western Mediterranean (330-600 $mgCm^{-2}d^{-1}$) (Lohrenz et al., 1988).

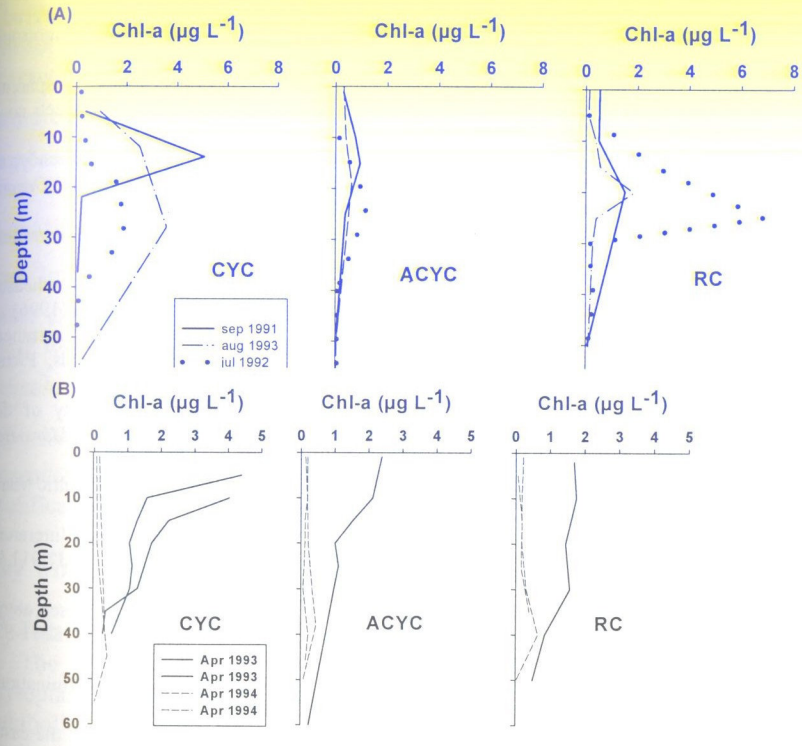

Fig. 4. Vertical profiles of chlorophyll-a concerning the eddy fields in the Southern Black Sea (A) during summer (B) during April sampling period

Finally, both the NE Mediterranean and southern Black Sea is a very dynamic sea and the distribution of biologically related parameters is influenced by the physical dynamics. NE Mediterranean and the Black Sea are known to be in different trophic status, the first one is being oligotrophic and the second one is mesotrophic or euptrophic; but this data set show that NE Mediterranean is not as oligotrophic as previously reported and the southern Black Sea seems to be at mesotrophic level for the study period.

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