# UNUSUAL TEMPORAL VARIATIONS IN THE SPATIAL DISTRIBUTION OF CHLOROPHYLL-A IN THE BLACK SEA DURING 1990-1996

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**Abstract.** The chlorophyll-a data set established by Turkey, Ukraine, Russia, Bulgaria and Romania was evaluated for the 1990-1996 period and only the surface chlorophyll-a was evaluated and interpreted for different parts of the Black Sea. Three well defined chlorophyll-a maxima were observed in the surface waters in the shelf region: a winter maximum in January-February, a spring-early summer one in May-June and an autumn peak in September-November. One of the expected results was the high level of chlorophyll-a concentration in shelf waters (0.02-34.0 $\mu gL^{-1}$ as the range of monthly averages) compared to deep regions (0.02-2.5 $\mu gL^{-1}$) throughout the whole year. Chlorophyll-a data related to deeper central part of the Black Sea showed different and unusual trends in terms of seasonal and interannual variability's. A late winter blooming continued with slightly decreasing trend till late spring which collapsed during May. The developments of moderate mid-summer and autumn blooms were also observed. A very unusual development of phytoplankton population in 1992 mid-summer caused formation of a chlorophyll-a peak which was almost at the same order of magnitude with winter-spring bloom.

## 1. Introduction

The Black Sea is a unique marine environment, representing the largest land-locked and anoxic basin in the world. The basin contains oxygen in the upper 150±50 m depth and hydrogen sulphide in the deep waters separated by a permanent pycnocline.



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Eutrophication has started in the last decades due to the increased anthropogenic inputs (most significantly mineralised nutrients) [1, 2] and lead to alterations in the ecosystem, changes in the nutrient regime [3, 4], formation of bottom hypoxia conditions in the north western shelf [5, 6]. Recent collapse of the fishery [7] is closely related to the above processes together with the overfishing.

The Black Sea is located in the temperate latitudes, therefore it characterises prominent fluctuations of abiotic factors and this is reflected on primary production and chlorophyll content of the euphotic zone [8, 9, 10, 11]. The concentration of chlorophyll-a is often determined to estimate the phytoplankton abundance and many researchers refer to it as an index or indicator of phytoplankton biomass. Measurements of chlorophyll-a in the Black Sea has started in 1964 and different aspects of the phytoplankton community, including photosynthetic pigments, have been investigated in numerous works [8, 12, 13, 14]. The analysis and evaluation of recent pooled chlorophyll-a data obtained by the Black Sea riparian countries during joint scientific programmes are carried out and presented for the first time in the present paper.

It is clear that the seasonal and spatial analysis of chlorophyll-a data is complicated due to interannual variations. It should be mentioned here that, in this temperate sea, the interannual variations observed after 1990s were more significant and pronounced than the ones observed in 1970s and 1980s [8, 15]. Interannual variations were studied in the shallow western region [1, 16, 17, 18] and also in the central parts of the basin [8] and it was shown that the trend was the increasing of different index of pelagic productivity (phytoplankton biomass, chlorophyll-a concentration and primary production) during the last 40-50 years (1950s, 1960-1990s). The data of recent years (1990-1996) presented in this paper therefore has a particular interest. The contribution of the last seven years data on this increasing trend is under question because of pronounced interannual variability. The main task of this paper is the evaluation of recent surface chlorophyll-a data in different parts of the Black Sea and also description of seasonal and interannual changes of this parameter.

## 2. Methodology

Coordinated multi-institutional cruises were carried out in the Black Sea after 1990; first within the frame work of the NATO TU-FISHERIES program, continued within the CoMSBlack international program and presently within the NATO TU-BLACK SEA program.

During the recent cooperative field studies, oceanographic stations were located with a nominal spacing of ≈20 km and covered generally the entire basin. Water samples for chlorophyll-a analysis were collected not from all stations visited during each cruise (including the joint surveys), but limited number of stations was enough to understand its temporal and spatial distributions (Table 1). The chlorophyll-a data set established by Turkey, Ukraine, Russia, Bulgaria and Romania was evaluated for the 1990-1996 period and only the surface chlorophyll-a will be considered and interpreted here.



TABLE 1. Field studies and number of chlorophyll-a stations in the Black Sea

| Year | Research Vessels (# of cruises) | # of CHL Stations |
|---|---|---|
| 1990 | AKA(4), ML(1), RF(1), BIL(3) | 56, 143, 21, 55 |
| 1991 | AKA(1), BIL(2), VIT(3), PV(2), PK(1) | 29, 51, 37, 68, 46 |
| 1992 | AKA(2), PV(3), BIL(1), VIT(1) | 67, 41, 22, 19 |
| 1993 | HYD(1), PV-PK(2), BIL(2) | 4, 47, 43 |
| 1994 | HYD(1), HOP(1), PK(1), BIL(1), AKA(1) | 21, 15, 66, 18, 16 |
| 1995 | HYD(2), AKA(1), PK(1), BIL(1), SM(1) | 12, 2, 21, 27, 24, 7 |
| 1996 | AKA(2) | 9 |

**Abbreviation:** BIL: R/V Bilim (TURKEY); ML: R/V M. Lomonosov; PV: R/V Prof. Vodyanitsky, PK: R/V Prof. Kolesnikov; HOP: R/V Hydrooptic (UKRAINE); AKA: R/V Akademik, HYD: R/V Hydrograph; SM: R/V Steaua de Mare (BULGARIA&ROMANIA); VIT: R/V Vityaz; RF: R/V Rift(RUSSIA).

Division of the whole Black Sea into 14 subregions facilitates the description of the temporal and spatial variability of chlorophyll-a (Fig. 1). These sub-regions were selected by considering the bottom topography, surface circulation patterns (surface currents) [19] and the surface chlorophyll-a maps constructed using the Nimbus-7 CZCS data for 1978-1986 period [20]. North western shelf (S) [NWS(1): <50m and NWS(2): 50-200m] occupies relatively large area and it is distinctively separated from the other sub-regions of the Black Sea. It is the coldest part of the basin during winter and the most productive region in summer. The shelf area is susceptible to strong influence of large rivers (Danube, Dnepr and Dnestr), and thus, it is under the stress of heavy marine pollution. The shelf gets narrower in the south western Black Sea [SWS(1): <50m and SWS(2): 50-200m] and the surface chlorophyll-a concentration is observed to be high throughout the whole year, although higher concentrations were observed during the late spring-early summer period. Since the north eastern [NES(1+2): <200m], south eastern [SES(1+2): <200m] and southern [SS(1+2): <200m] shelves are quite narrow, these regions were not classified as shallow (>50m) and deep (50-200m) sub-regions. Continental shelf slope(SL) regions (200-1000m) in the western (WSL), north eastern (NESL) and southern (SSL) parts of the Black Sea are under the influence of Rim current and the small scale quasi-permanent cyclonic and anticyclonic eddies generated between Rim current and the coast [19]. It should be mentioned here that, in the southern part of the basin [SS(1+2): <200m and SSL] high levels of phytoplankton patches episodically observed during summer are connected with the coastal upwelling processes [14, 21]. South eastern parts of the sea [SES(1+2): <200m, SESL and SEACG] generally characterised by the prominent anticyclonic gyres (ACG) [19] and show some differences in the level of primary production relative to the central basin [8, 22]. The deep central parts (>1000m) was classified as the western (WCG) and eastern (ECG) regions; both are characterised by permanent and relatively large-scale cyclonic gyres [19]. The WCG and ECG regions have shown to differ in their biomass content and primary productivity [8].

The main problem to be tackled in the analysis of the pooled data collected during joint research programmes are the differences in the sampling and analysis techniques used by each laboratory. In the present work, the chlorophyll-a concentrations were determined by three standard methods: spectrophotometric (Russia [23, 24]; Turkey [23, 25]; Bulgaria [23, 24] and Romania [23, 25], fluorometric (Ukraine [26] ) and spectrofluorometric (Turkey [25] ).

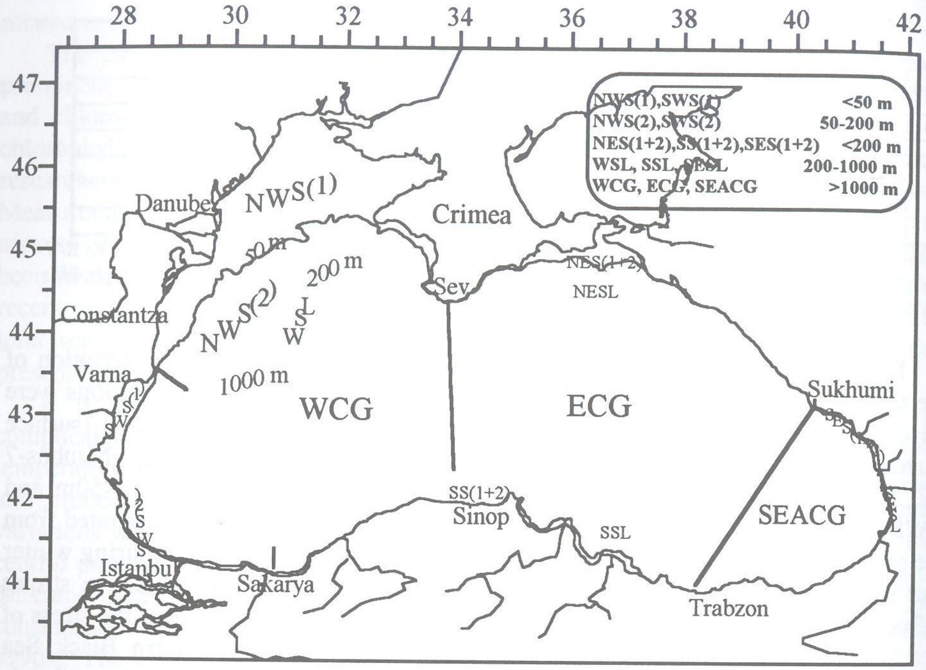


*Figure 1.* Bathymetry, location map of the Black Sea and sub-regions for interpretation of surface CHL data

It is well known that in fluorometric-spectrofuorometric analysis, chlorophyll-a and phaeopigments-a concentrations are measured separately, whereas spectrophotometry measures their sum directly. On the other hand, chlorophyll-a and phaeopigments-a concentrations determined by these three methods generally agree with each other [27]. Differences in the sampling and some deviations from the standard methods, have partly distorted a number of results, necessitate realistic and special investigations on methodology by all laboratories in the future. For the present case, it has been accepted that only the sum of chlorophyll-a and phaeopigments-a concentrations will be evaluated and for simplicity, this sum will be abbreviated as CHL.

All the data presented here were checked for the quality assurance through the Data Base Management System established in METU, Institute of Marine Sciences (TURKEY). Comparison of CHL data from the surface waters of the neighbouring stations obtained during the joint cruises showed insignificant difference between the measurements for summer (from June to September). On the average, the ratios of the largest to the smallest value do not exceed 1.3 (Table 2, Samples 1-13). This result testifies to the comparability of data received from different laboratories. Differences were more significant for the transition period from summer to autumn and between



samples collected with an excessive lag time (Table 2, Samples 14-35). Moreover, we can see seasonal changes in CHL concentration; increase in concentration in autumn with respect to summer.

TABLE 2. Surface chlorophyll-a (CHL,) concentrations of joint or neighbouring stations in the Black Sea during 1990-1991.

| Year | Sample No | Cruise No and R/V | Lat | Long | Date | CHL μL-1 | Ratio* |
|---|---|---|---|---|---|---|---|
| 1990 | 1<br>2 | 15 BIL<br>53 ML | 42.83<br>43.17 | 33.75<br>33.75 | 02/Oct<br>01/Oct | 0.79<br>0.69 | 1.14 |
| 1991 | 3<br>4 | 16 BIL<br>33 PV | 42.00<br>42.00 | 40.25<br>40.25 | 11/Jun<br>11/Jun | 0.33<br>0.41 | 1.24 |
| 1991 | 5<br>6 | 17 BIL<br>28 PK | 43.20<br>43.20 | 34.20<br>34.20 | 10/Sep<br>19/Sep | 0.54<br>0.58 | 1.07 |
| 1991 | 7<br>8 | 17 BIL<br>28 PK | 42.80<br>42.80 | 37.75<br>37.75 | 13/Sep<br>09/Sep | 0.19<br>0.21 | 1.11 |
| 1991 | 9<br>10 | 17 BIL<br>28 PK | 42.20<br>42.20 | 39.75<br>39.75 | 15/Sep<br>10/Sep | 0.56<br>0.37 | 1.51 |
| 1991 | 11<br>12<br>13 | 28 PK<br>17 BIL<br>AKA | 43.50<br>43.50<br>43.50 | 31.75<br>31.75<br>31.75 | 21/Sep<br>06/Sep<br>11-16/Sep | 0.97<br>0.49 0.79 | 1.98<br><br>1.61 |
| 1990 | 14 15 | 53 ML | 44.83<br>44.83 | 32.25<br>32.25 | 27/Sep<br>30/Oct | 0.49 1.73 | 3.53 |
| 1990 | 16 17 | 53 ML | 43.50<br>43.50 | 32.75<br>32.75 | 27/Sep<br>31/Oct | 0.27<br>1.22 | 4.52 |
| 1990 | 18 19 | 53 ML | 43.82<br>43.82 | 32.72<br>32.72 | 30/Sep<br>31/Oct | 0.28<br>0.63 | 2.25 |
| 1990 | 20 21 | 53 ML | 44.17<br>44.17 | 32.75<br>32.75 | 30/Sep<br>31/Oct | 0.22 1.43 | 6.50 |
| 1990 | 22 23 | 53 ML | 44.50<br>44.50 | 32.75<br>32.75 | 30/Sep<br>31/Oct | 0.37<br>1.04 | 2.81 |
| 1990 | 24 25 | 15 BIL<br>53 ML | 42.83<br>42.83 | 37.75<br>37.75 | 23/Sep<br>08/Oct | 0.37<br>0.76 | 2.05 |
| 1990 | 26 27 | 15 BIL<br>53 ML | 42.83<br>43.17 | 34.25<br>34.25 | 27/Sep<br>02/Oct | 0.17 0.52 | 3.06 |
| 1991 | 28 29 | 23 VIT | 43.52<br>43.52 | 32.20<br>32.20 | 22/Aug<br>07/Nov | 0.26<br>1.47 | 5.65 |
| 1991 | 30 31 | 23 VIT | 43.27<br>43.27 | 34.00<br>34.00 | 21/Aug<br>08/Nov | 0.15 0.68 | 4.53 |
| 1991 | 32 33 | 23 VIT | 43.40<br>43.40 | 37.00<br>37.00 | 20/Aug<br>09/Nov | 0.18 1.07 | 5.94 |
| 1991 | 34 35 | 23 VIT | 42.33<br>42.33 | 39.33<br>39.33 | 18/Aug<br>11/Nov | 0.12 1.69 | 14.08 |

**Abbreviation:** BIL: R/V Bilim (TURKEY); ML: R/V M. Lomonosov; PV: R/V Prof. Vodyanitsky, PK: R/V Prof. Kolesnikov (UKRAINE); AKA: R/V Akademik (BULGARIA&ROMANIA); VIT: R/V Vityaz (RUSSIA).

*Ratio: Maximum observed CHL over minimum observed CHL

## 3. Results and Discussion

### 3.1. RESULTS

Monthly averages for the whole set of CHL data obtained from south western shelf (SWS) between 1990 and 1996 are presented in Fig. 2. The results shown here are related to the data set which were collected during Bulgarian and Romanian cruises. Time series were separately shown for very shallow part (<50m) and relatively deep part (50-200m) for each cruise in Figs. 2A and 2B respectively. The graphs were arranged using a single average value for the corresponding month and for the each year (Fig. 2A-A and 2B-B) in order to show interannual variability. In the first case, one can easily see the range of average CHL concentration for the whole cruises. Although the lines on Figs 2A and 2B and on the Figs. 2A-A and 2B-B show a seasonal shift of average CHL for each year and it can be accepted that both curves practically coincide; in other words, the seasonal trends seem to be similar for both representations (e.g. A↔A-A and B↔B-B sets). In a general view, three precise peaks of CHL maxima were observed in the surface waters of south western part of the Black Sea; namely, a winter maximum in January-February; a spring-early summer peak in May-June and an autumn peak in September-November. Once a minimum was observed in October in the relatively deep part of the shelf (50-200m) and this was not repeated during the study period. Comparison of the data sets for shallow and deep parts of the SWS indicates that the winter peak was more pronounced, for example, CHL concentration reached up to ~34 $\mu gL^{-1}$ (11 $\mu gL^{-1}$ on the average and approximately 2.5 times larger than the May and October levels) in the shallow part in February 1996. On the other hand, the interannual variability was quite significant due to the very low values (e.g. 1.43 $\mu gL^{-1}$ in February 1990) during the same months of different years. This is also true for other peaks, such as the one observed in May (the change was almost an order of magnitude). A well-developed maxima, observed in May in the relatively deep part (50-200m) of the SWS region, was about 2.5 times larger than the peaks observed in January and November in the same area.

Interannual variability of the late spring blooms could not be carried out for the relatively deep part of the shelf because of the availability of limited data set. The seasonal variability of surface CHL in the western slope (WSL), western cyclonic (WCG) and eastern cyclonic (ECG) deep regions are separately presented in Fig. 3. All three regions showed a set of maxima which reflect the differences in the mechanisms for the formation of phytoplankton standing stocks in different time periods. The trends in time series differ from the coastal regions and the characteristic seasonal properties involves a basic winter maximum (in January-February), slight increase in CHL concentration in April with respect to March, deep minimum in May, a slight maximum in June-July, reputation of minimum in August and a prominent maximum in November in the continental slope and deep parts of the Black Sea (Fig.3). The winter maximum has similar CHL concentrations for three regions (2.5 $\mu gL^{-1}$ on average) and this is 3-3.5 times higher than the concentrations of pre-bloom periods (e.g. December), 2-2.5 times higher than those of the post-bloom periods (e.g. March-April) and even more than 30 times higher than the prominent minimum observed in May. The unusual summer maxima in WSL in June and in WCG and ECG regions in



July were clearly observed in 1992. The average CHL concentration during that period ranged in between 1 and 2 $\mu gL^{-1}$ and the peak was much pronounced in the ECG region. Further, a minimum was observed in August in these regions but the minimum was not as sharp as the one observed in May. When Fig. 3 is compared with Fig. 2, it is clear that interannual changes in the shelf region (>200m) is more pronounced than the ones observed in the deep regions (both for the continental slope and the central cyclonic regions). For example, average CHL concentrations in August fluctuated in between 0.16-0.23 $\mu gL^{-1}$ for 1991, 1992,1993 and 1995 in the WCG region and whereas in ECG region it varied between 0.17-0.26 $\mu gL^{-1}$ for the same periods in 1991 and 1993.

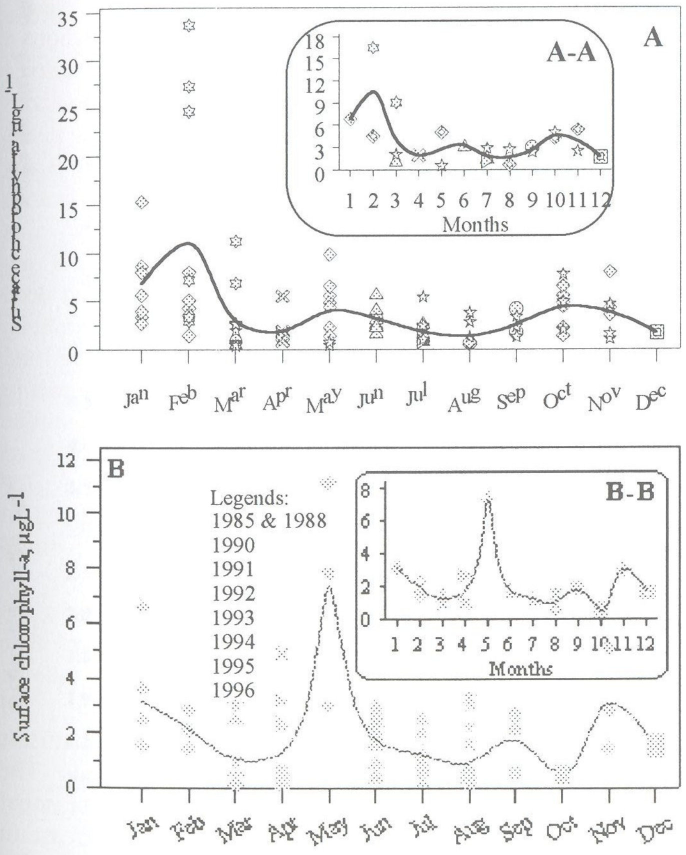


*Figure* 2. Seasonal variability of surface CHL in shallow (A) and deep (B) shelf. A-A, B-B frames reveal interannual variability

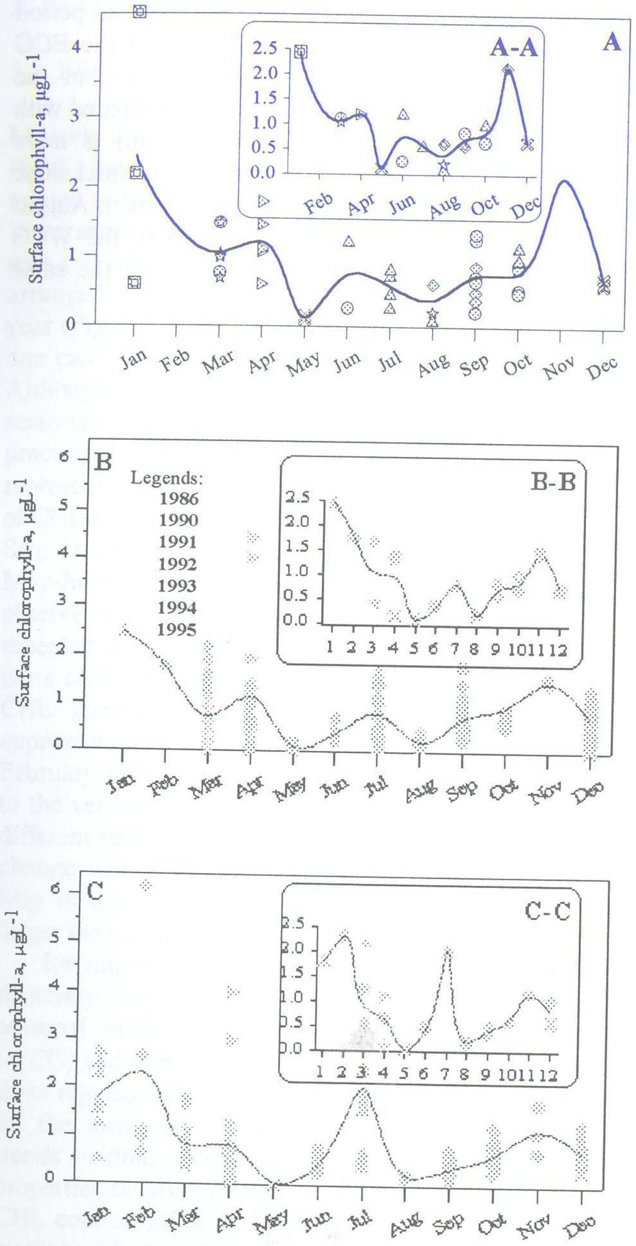


Figure 3. Seasonal variability of surface CHL in southwestern slope region (A), western (B) and eastern (C) cyclonic gyres of the Black Sea. A-A, B-B and C-C attachment frames represent the interannual variability for each corresponding region.

Figure 4. represents seasonal variability in CHL, in the SWS region, both for the shallow and deep shelf areas and in combined form (Fig. 4A and Fig. 4A-A) and for



the WSL (200-1000m), WCG and ECG regions (>1000m) and in combined form (Fig. 4B and Fig. 4B-B). Because of the similarities in their trends in the sub-regions of both the shelf and deep regions (including the shelf slope region), the graphs were combined and displayed in Figs. 4A-A and 4B-B. A general view for the deep central cyclonic region represented by a late winter bloom, continuation with slightly decreasing trend in the concentration till late spring and then moderate mid-summer and autumn blooms.

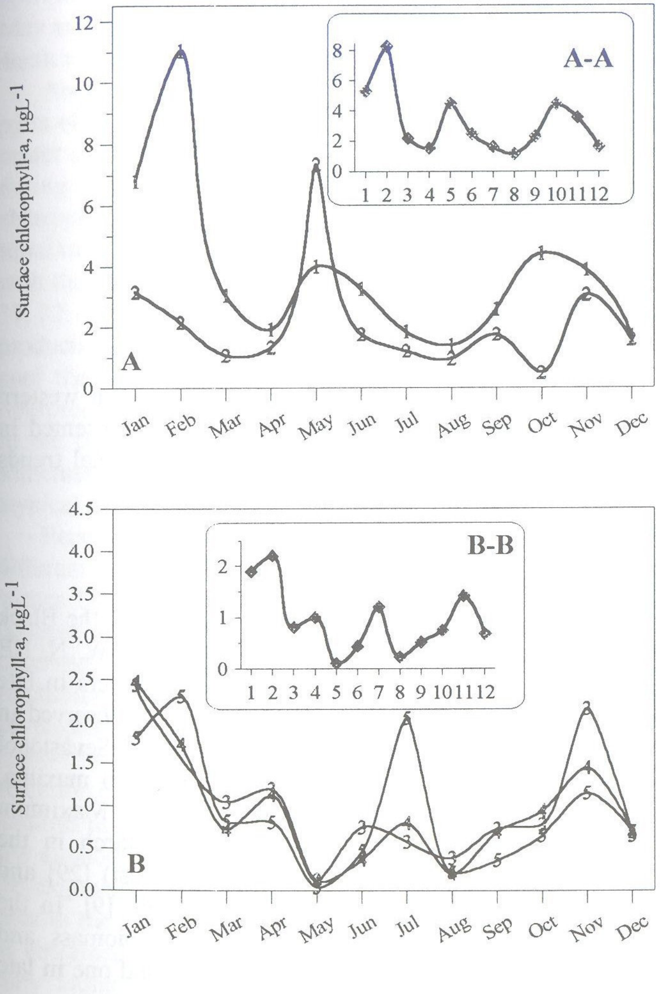


Figure 4. Seasonal variability of surface CHL in the southwestern shelf (SWS)(A) and in the deep parts (> 200m) of the Black Sea. Lines represent different subregions [1: SWS(<50m); 2:SWS (50-200m), 3:WSL(200-1000m); 4:WCG(>1000m) and 5:ECG(>1000m). A-A and B-B frames show the seasonal trends for shelf and open sea respectively.

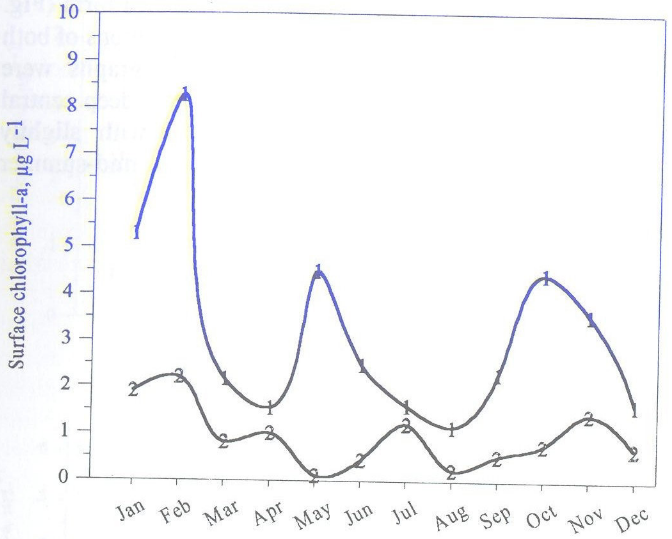


Figure 5. Seasonal variability of surface CHL in the southwestern shelf (Line 1) and in the slope+deep regions (>200m) (Line 2) in the Black Sea.

The seasonal variability of CHL for two distinct regions, namely south western shelf (<200m) and the deep regions (>200m and mostly >1000m) were presented in Fig. 5 in order to see the similarities and dissimilarities between the seasonal trends and changes in magnitudes in terms of average concentrations.

## 3.2. DISCUSSION

The seasonal variability of primary production and chlorophyll-a content in the Black Sea has been extensively studied within the inshore waters covering W, NW, N, NE coastal waters. In general, more than two maxima (one in the spring, others in late summer and autumn) are observed in primary production rates. The one observed in the spring is more pronounced [1, 10, 11, 28, 29]. In the shallow parts of Sevastopol Bay [10], seasonal variation of chlorophyll-a concentrations displayed two maxima, one in spring (March-May) and the other in autumn (September-October). Maximum chlorophyll-a concentrations were observed between November and March in the continental slope region near Sevastopol (3-10 miles away from the coast) [29] and during winter (December-January) and in late summer near Gelendzhik [9]. In the shallow NE shelf region (<30m) that three peaks in phytoplankton biomass and chlorophyll are observed; first one is in spring (March or May), the second one in late summer and the third one in autumn (November) [9].

In the present study, three precise peaks of CHL maxima were observed in the surface waters of south western shelf region of the Black Sea; namely, a winter maximum in January-February; a spring-early summer one in May-June and an autumn peak in September-November. There is an agreement between the recent and previous observations in terms of seasonal tendencies for different coastal regions in



the Black Sea although slight shifts in the blooming time periods have been observed which is common in such areas because of variability's in the controlling factors.

One of the most interesting and well defined outcome of the analysed data sets is the observation of high level of CHL concentration in shelf waters compared to deep regions throughout the whole year (Fig. 5). Similar results are also observed from the characteristic distribution of this pigment in (Nimbus-7) satellite maps derived for the 1978-1986 period [20]. It should be mentioned here that maximum contrast between open and shelf waters is recorded during blooming periods in coastal waters (January, May and October). The tendency for a decrease of CHL concentration with increasing depth was valid also within limits of the shelf during whole year except May (Fig.4 A).

About half of the total primary production of the Black Sea is created in the central parts of the basin at depths greater than 1000m [30]. Half a year observations at the center of the western cyclonic gyre in 1961 and 1962 [28] and shorter investigations during 1980s [22, 31] showed that pronounced seasonal variations in production and chlorophyll content between April and November were absent. On the other hand, some investigators have reported blooming of phytoplankton in this region associated with the high levels of primary production and chlorophyll concentrations [13, 14, 15, 31, 32, 33, 34, 35, 36, 37]. The lack of periodic data on the seasonal variability of the productivity and chlorophyll content in the central Black Sea [8, 15] has resulted to pool the disparate measurements taken over three decades (1960-1991) in order to interpret the generalised picture. The winter-spring and late-fall peaks are discernible in the central parts of the Black Sea in the development of phytoplankton, which sometimes merge to a single relatively long maximum during cold seasons. This is atypical pattern observed in subtropical waters in the temperate regions [9, 38].

Recent chlorophyll-a data related to deeper, central parts of the Black Sea showed different and unusual trends in terms of seasonal and interannual variability's. A late winter bloom has continued, with slightly decreasing trend, till late spring which collapsed in May. The developments of moderate mid-summer and autumn blooms are observed after May. In winter period, low stability of the upper water column (including the euphotic zone) in the oceanic waters prevents phytoplankton development [38]. In contrast to oceanic waters, shoaling of the main pycnocline (up to 30-40m) in the central cyclonic gyres during winter-early spring is conductive to the retention of the bulk of the algae in the photosynthetic layer [ 14, 15, 34]. Such specific features in the hydrological structure, combined with intensified influx of nutrients into the euphotic zone [39, 40, 41, 42], creates favourable conditions for phytocoenosis developments. The region with high chlorophyll content occupies considerably large area in the basin during winter-spring blooming [34]. Some fraction of phytoplankton is entrained by turbulent mixing beneath the photosynthetic layer, but this happens only along the periphery of the cyclonic gyres. The physical processes, mainly circulation patterns, eddy fields and mixing processes influence the distribution and biochemical cycling of the elements which are effective on biological production as it was confirmed by the present results.

The present results differ from previous observations reported for different regions of transition zone between temperate and tropical waters of the World oceans(30-45°

N). In such regions two CHL maxima are usually observed throughout the year. The more pronounced peak is noted in winter [43, 44] or winter-spring [45, 46, 47]. Summer or autumn months were typical periods of the second one having the less prominent CHL maximum. Based on satellite data for transition zone in the North Atlantic ocean, it was reported that the winter-spring and fall maxima or only a single long-term winter maximum were observed [48].

An unexpected and atypical maxima observed in May in shelf waters and in July 1992 in deep regions have given a new perspective in terms of seasonal variability in the Black Sea. It is probable that May peak may be attributable to the influence of riverine input of nutrients into the north western shelf of the Black Sea [49]. Since the south western shelf is relatively rich in phytoplankton biomass (in terms of CHL) because of the entrainment of the nutrient and POM-enriched surface waters of the north western shelf by the alongshore currents [21]. The unusually high CHL concentration in the mid-summer of 1992 in open waters is not comparable to the other years in view of the lack of mid-summer data during the study period (1990-1996). This unusual maximum of CHL could be attributable to the observed bloom of coccolithophorids and dinoflagellates at the same time [50, 51]. Unfortunately there was no basin-wide cruise during the winter/spring period of1992; the water column was presumably mixed strongly resulting due to the severe winter conditions resulting a thick mixed layer and consequent enrichment of the euphotic zone by nutrients. This mid-summer bloom may be continuation of spring bloom changing in character from mostly new to regenerative type of production/biomass formation/accumulation. Similarly, in the NE Mediterranean, the physical, chemical and biological environments were unusual and the all indices related to phytoplankton biomass and production rates were significantly high in the springs and even in the summer seasons of 1992 and 1993 [52, 53] due to extreme cooling which evidently took place in these years. Cold Intermediate Water formation with extreme properties was observed in the Black Sea in 1992 [54], when deep water formation simultaneously occurred in the Rhodes region in the north eastern Mediterranean [55]. The strong cooling in 1992 changed the main pycnocline structure in the Black Sea, effects of which lasted for few years after the event [54]. In 1992, the cooling appears to be linked with the persistent anomalous atmospheric pattern that occurred in the Eastern Mediterranean /Black Sea region [56]. Unfortunately such events are not supported by the satellite maps [20] since in general low CHI. concentrations are observed in the central parts of the Black Sea during summer months. On the other hand, recent investigations showed that moderate summer blooms have frequently been observed in both coastal and open waters in the Black Sea [14, 21, 57, 58, 59].

The main factors responsible for the winter-spring bloom in the open waters of the Black Sea is the intensification in the flux of nutrients into the euphotic zone due to specific features of the hydrological structure (e.g. shoaling of the main pycnocline and intensification of the convective and wind induced mixing in the upper water column or in the euphotic zone) [8, 41, 42, 60, 61, 62]. The termination of winter-spring bloom is determined by the formation of the seasonal pycnocline that usually takes place during second half of March [61, 62]. Most likely similar factors are responsible



for initiation and ceasing of winter bloom in shelf waters, but the role of the main pycnocline in shallow regions is governed by the bottom. It should be mentioned that the termination of winter-spring blooming in deep regions in March (Fig. 5) is inconsistent with usual patterns of annual variability of CHL [8] and may be resulted by the early initiation of spring in 1995; that was accompanied with low CHL concentration in March (Fig. 3).

It is necessary to note that, the blooming of phytoplankton in the Black Sea is still the most interesting and poorly investigated phenomenon. In general, CHL concentrations were observed to be high during late winter-early spring, showing the presence of a phytoplankton bloom. The formation and the maintenance characteristics of late inter- early spring phytoplankton blooms vary rather quickly and possess significant annual differences. Typical examples are the spring 1994 and 1995 blooms when the observed CHL concentrations were extremely low (<0.2 and <1 $^{\mu L-1}$ respectively), comparable to ordinary summer concentration levels. Late autumn cruises during 1990-1992 have shown a typical increase of CHL concentration in the center of the Black Sea due to the start of vertical mixing processes, the destruction of the seasonal thermocline and the active upward transport of nutrients into the euphotic layer. The relatively high CHL concentration in the center of the sea maintain throughout the winter period or prior to he phytoplankton bloom. As can be seen from the figures, the beginning of this process and its intensity may differ annually and spatially which complicates the interpretations related such processes in the sea.

## 4. Conclusions.

Recent chlorophyll-a data showed that, phytoplankton blooming periods in the Black Sea have changed in the last decade and there are significant shifts both in the shelf area and the deep regions. Interannual variations in phytoplankton biomass (in terms of CHL concentration observed after 1990s) were more significant and pronounced than those observed in 1970s and 1980s. Three precise peaks of chlorophyll-a maxima were observed in the surface waters of the shelf region, namely a winter maximum in January-February; a spring-early summer one in May-June and an autumn peak in September-November. Chlorophyll-a data related to the deeper central part of the Black Sea also showed different and unusual trends in terms of seasonal and interannual variability's. A late winter blooming has continued, with a slight decrease, till late spring which collapsed during May. The developments of moderate mid-summer and autumn blooms are also observed. A very unusual development of phytoplankton population in July 1992 caused the formation of a chlorophyll-a peak which was almost at the same order of magnitude with winter-spring bloom. One of the expected results was the high level of chlorophyll-a concentration in shelf waters compared to deep regions throughout the whole year.

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**BASIC CHARACTER**
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KRIVEN
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*National*
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