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PHOTOSYNTHETIC CHARACTERISTICS OF PHYTOPLANKTON IN THE WESTERN BLACK SEA DURING THE AUTUMN BLOOM

In the autumn of 2005 photosynthetic characteristics of phytoplankton were studied along transects from a coast to deep-waters in the western and southern Black Sea. Efficiency of photosynthesis (α^B) varied from 0.012 to 0.068 mg C (mg Chl)$^{-1}$h^{-1}(μE m^{-2} s^{-1})$^{-1}$. Light – saturated rate of chlorophyll a-normalized photosynthesis (P^B_{max}) ranged from 5 mg C (mg Chl)$^{-1}$ h^{-1} in the deep-waters to 12 mg C (mg Chl)$^{-1}$ h^{-1} in the shelf waters. In the shelf area P^B_{max} and α^B varied by a factor of 3. Variability of these parameters was as lower as that of the chlorophyll concentration. The mean α^B and P^B_{max} values at the shelf were higher than those of the deep-water region. The phodoadaptive strategy of phytoplankton was characterized by increasing of α^B at lower light levels. During the warm period of year nutrient effect on photosynthetic parameters was critical in their variability. The total integrated primary production (PP) varied from 0.34 to 2.45 gC m^{-2} day^{-1}. Mean PP values were 1.7 and 0.5 gC m^{-2} day^{-1} in the shelf and deep-waters respectively. Strong correlations between PP, P^B_{max}, α^B and surface chlorophyll concentration have been obtained.

Key words: phytoplankton, photosynthesis, light, primary production, Black Sea

The data obtained during the last decades in the coastal waters of the Black Sea have shown that phytoplankton production have two maximum throughout the year: one occurred in the beginning of spring, second – in autumn. At the same time it has been shown that maximum photosynthesis intensity of phytoplankton (P^B_{max}) increases from winter to summer and then decreases again. The temporal dynamics of the photosynthesis – light curves parameters (an initial slope (α^B) and maximum of the photosynthesis – light curves) are different. Highest α^B values were found in February – March, but they were lower in summer on average. However, there is not much data for the autumn [1, 8]. The analysis of the data has shown that the α^B was not affected by light, and the temperature contribution to the total variability of this parameter was not significant [6, 7]. At the same time, the α^B values were found to increase with the growth of nitrate concentration up to 2 μM. A similar character of the relationship has been found in the North Atlantic and Indian Ocean and it seems to confirm an assumption that nitrates control the variations in the α^B values [16, 17]. Although there is wide scatter of points in the relationship between α^B and nitrate, the Black Sea and Ocean data were described by the same function type, but coefficients of the equations differ [7, 8]. At low concentrations of NO_3 within the surface layer (about 0.05 μM), the α^B mean value for the Black Sea and oceanic phytoplankton were dropped to 0.015 mgC mgChl^{-1}h^{-1}(μE m^{-2} s^{-1})$^{-1}$

[8]. At high NO_3 concentrations (> 2 μM), the α^B values for the Black Sea reached 0.06 mgC mgChl^{-1}h^{-1}(μE m^{-2} s^{-1})$^{-1}$. Although a comparison with data from distinct regions showed some similarities in the dependence of α^B on nitrate. We need more data because the other factors such as phytoplankton species composition could be important. The α^B depends on the light absorption by phytoplankton which is related to the size and taxonomic algae composition. It is well known that the algae with large intracellular content of pigments and the cells of large size have lower specific coefficients of light quanta absorption than the algae with small cellular sizes or low content of pigments [10, 13]. An increase in the intracellular content of pigments is followed by the enlarging of chloroplasts and increasing of the amount of tilackoids and their packaging degree. It results, by analogy with an optically dense system, in the selfshading of pigments and in the decrease of the Chl-a specific coefficient of phytoplankton absorption. The power coefficient in the α^B and chlorophyll concentration relationship and that for a^*_{ph}

- chlorophyll concentration relationship are different [5]. It this case, while chloro-

phyll concentration increases in the in a wide range (0.1–20 mg m^{-3}), the α^B values in the Black Sea will growth (up to 3 mg Chl m^{-3}) and then decrease. For oce-anic phytoplankton, the maximum α^B values were found at 0.4–0.6 mg m^{-3} Chl a concentration, de-creasing by a factor of 1.3-1.8 at lower and higher chl a concentration [12]. Thus we can suggest that in the Black Sea in the range of the chlorophyll concentrations from 0.1 to 20 mg m^{-3} the α^B val-ues will be linked with Chl a concentrations by a dome-shaped curve with a single maximum in the left-hand part of the curve.

The present study is aimed: a) to investigate phytoplankton photosynthetic parameters in autumn as a function of water mass distribution and environment; b) to identify phytoplankton properties, which could be associated with irradiance and nutrients status, and derive parameterization of their relationships.

Materials and methods. The data presented were collected in 15-day long cruise (from September 28 to October 14, 2005) in the western Black Sea on the research vessel "Vladimir Parshin" (Fig. 1). Total 22 stations were fullfield, 15 from them were situated along the meridian
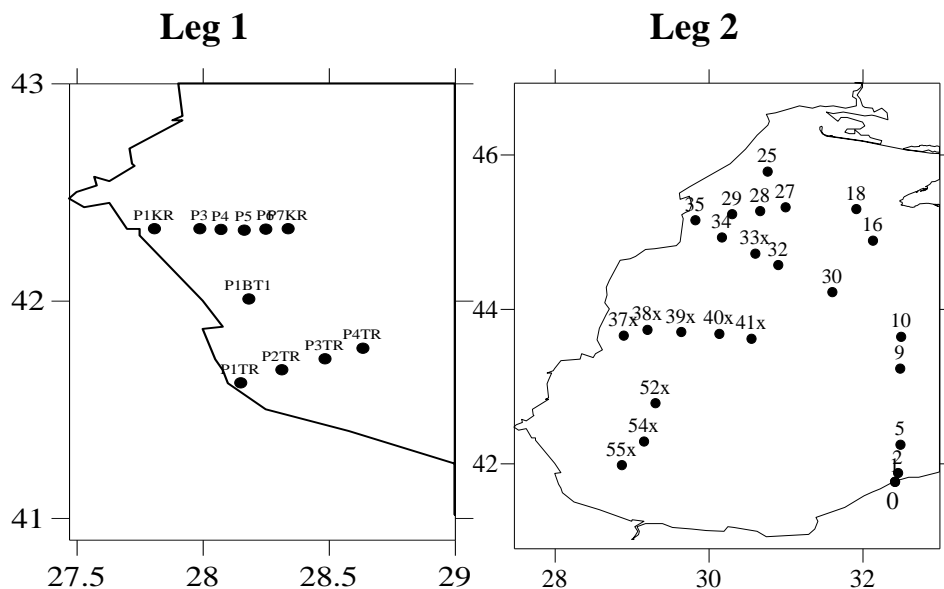

Fig. 1 Scheme of the biological stations in September (Leg 1) - October (Leg 2)
Рис. 1 Схема биологических станций в сентябре (1 этап) – октябре (2 этап)

transect and 7 to the Bulgarian and Romanian coasts. The stations were occupied daily between 0600 and 1100 LT. Water sampling was performed with a conductivity-temperature-depth (CTD) equipped with fluorometer, Licor quantum meter measuring PAR and rosette with 12 x 5l Go-Flow bottles. The phytoplankton samples collected from 2 depths with 100 and 1% incident irradiance on the bio-optical stations were examined for the effect of light on the phytoplankton photosynthesis. On the whole, 29 experiments were made.

Chlorophyll *a* concentration (Chl). Chl concentration were determined by fluorometry in 500 – 1000 ml volume samples after low vacuum filtration through 25 mm GF/F (Whatman) and stored in liquid nitrogen before analysis in the laboratory. Chl was extracted with 90% acetone under low temperature (9^0C) and dark conditions for 18h.

Nutrient concentration. Nitrate, phosphate, and silicate were measured on board within a few hours of collection using an autoanalyser and standard techniques [18].

Light penetration in the water column and irradiance at the sea surface. Light penetration was measured using a quantum meter measuring PAR attached to CTD equipment. Measurements were made with 1m intervals within the euphotic zone at local noon ± 3h. Average value of K_d for the photic zone was computed for each bio- optical station by equation $E(z)= E_0 \exp (-K_d z)$ using log-transformed light on depth z. The computed K_d values (m^{-1}) are plotted against surface chlorophyll concentration. Despite the fact that the chlorophyll samples were collected in surface layer (0-2m), there was a significant correlation (p<0.01) between K_d and chlorophyll concentration: $K_d = 0.13$ Chl $^{0.43}$ (n=23, $r^2 = 0.79$, 0.4≤ Chl ≤13.0 mg/m^{-3}). The attenuation coefficient and the Secchi disk depth (S) within the euphotic layer are related: $K_d = 1.37 (\pm 0.23)/ S$ (n = 23, r^2 =0.89, 3≤ S ≤ 15m). This equation was used to estimate K_d and then to compute Ez, the percentage of light available at the sampling depths.

The incident photosynthetic available radiation (PAR, λ = 400 – 700 nm) was measured on the deck with photometer each 30 min and then was daily integrated. Incident irradiance was con-sidered for analysis and computations of primary production.

Photosynthesis-irradiance experiments and in situ simulated primary production. Photosynthesis-irradiance relationships (P-I) were measured by the method [2]. The P-I experiments were curried out in special linear incubator [2], which was illuminated with an incandescent lamp (50W, 12V) and refrigerated with thermostatic bath. As a special filter for correction of the lamp spectrum we used 10% CuSO$_4$, poured in a "frontal window" of the incubator. In the incubator the samples were exposed at different light levels from 10 to 2000 µEm^{-2}s^{-1}. The irradiance at each position in the incubator was checked regularly during the cruise with a spherical sensor.

P-I experiments were carried out at 22 stations (22 experiments – for surface samples (100% PAR) and 7- for deeper samples (1 % PAR). The depths to which 1% of surface irradiance penetrated were determined based on PAR profile measured by sensor attached to CTD-rosette. From each sampling depth 22 subsamples were collected in 50 ml tissue culture flasks and inoculated with 10 µCi of NaH^{14}CO$_3$. For each curve three flasks were covered with black plastic and placed at the end of the incubator to check dark carbon fixation. After the incubation time (1 h), samples were filtered under low vacuum pressure through 25mm nuclepore filters (with 0.45 µm diameter of pore). The filter was placed in a 20 ml glass scintillation vial, covered with 0.5 ml 0.5 N HCl to remove the unfixed inorganic ^{14}C, and held uncapped under a hood at room temperature to dry overnight. Then 10 ml aliquot of liquid scintillation cocktail was added to the dried filters. Time-zero controls were treated identically, except that they were acidified immediately.

Total added $NaH^{14}CO_3$ was measured by collecting 0.01 ml working $NaH^{14}CO_3$ solution, adding 0.2 ml Ethanolamine (Sigma) to prevent the radio-labelled inorganic CO_2 from escaping to the atmosphere and immediately adding scintillation cocktail. The samples were kept in scintillation vials with scintillation cocktail until measurements with automatic liquid scintillation counter RACK - BETA (LKB Wallac) in the Institute (IBSS).

To correct for spectral characteristic of experimental lamp, measured values of α^B were normalized for an ideal "white" spectrum (i.e. with $E(\lambda)$ assumed to be constant from 400 to 700 nm) as outlined in Babin et al. [3]. This normalization was made using:

$$\alpha_{cor}^{B}(white) = \alpha^B(exp) \, \bar{a}_{ph/white} / \bar{a}_{ph/lamp}, \qquad (1)$$

where the subscript "white" refers to values for hypothetical white illumination and "exp" refers to experimental values measured on the actual sources (lamp), $\bar{a}_{ph/white} / \bar{a}_{ph/lamp}$ spectrally averaged phytoplankton absorption coefficients for white light and experimental lamp spectrum, correspondently. Photosynthesis rate per a hour, normalized to the chlorophyll concentration was fitted with the equation of Platt et al.[14] to determine the parameters P_{max}^{B} - light- saturated rate of chlorophyll -normalized photosynthesis (mg C (mg Chl)$^{-1}$ h^{-1}), α^B – the initial slope of P-I curve (mg C (mg Chl)$^{-1}$h^{-1}(μE m^{-2} s^{-1})$^{-1}$), β^B – the photoinhibition parameter (mg C (mg Chl)$^{-1}$h^{-1}(μE m^{-2} s^{-1})$^{-1}$.

Daily water – column primary production (PP, mg C m^{-2} d^{-1}) down to the 1% surface irradiance depth was estimated. Samples for phytoplankton production were collected at depths corresponding to 100, 85, 68, 42, 32, 15, 10, 3, and 1%. Irradiance in each incubator was adjusted to the irradiance at each sampling depth using neutral density filters. The water samples were inoculated with 0.5ml $NaH^{14}CO_3$ (10 μCi per sample)

and incubated on the deck from dawn to sunset (12h). For each depth one bottle was "dark" and placed at the end of the incubator to check dark carbon fixation. During the incubation surface water was continuously pumped through the incubator to maintain the incubation temperature close to surface one. After incubation the samples were filtered onto a 25 mm Nuclepore filters (with 0.45 μm diameter of pore) and then treated as described above for P-E curve samples. A total phytoplankton production (mgC m^{-2} d^{-1}) and Chl a content (mg m^{-2}) within the euphotic layer were obtained by trapezoidal integration of volumetric values of phytoplankton production (mgC m^{-3} d^{-1}) and Chl (mg m^{-3}) from the depth profiles.

Results and discussion. Light and phytoplankton. Light (PAR, μmol m^{-2} s^{-1}) penetrated deeper in the offshore than in the coastal waters, because of the lower Chl content. In the coastal waters relatively high values chlorophyll concentration and the attenuation coefficient (0.16 – 0.38 m^{-1}) were observed. Chl a concentration ranged from 1.2 to 12.8 mg m^{-3} and decreased from the coast to offshore. The lower values were observed in the deep waters, where Chl concentrations were 0.4 – 1.0 mg m^{-3}. A negative relationship between the depth of the euphotic layer and the surface Chl a concentration was found:

$$Z_{eu} = 35.6 \times Chl^{-0.43} \ (r^2 = 0.79, n=23) \qquad (2)$$

where Z_{eu} is the euphotic depth (m) corresponding to 1% PAR and Chl is chlorophyll a concentration in the surface layer (mg m^{-3}). A discrepancy with equation for Case 1 waters [11] is very small. Therefore we can conclude that by optical characteristics Black Sea at the time of sampling belonged to Case 1 waters.

Phytoplankton production. Primary production values, measured in the euphotic layer in the western Black Sea permit the identification of several regions with differing productivity. The data indicate that photosynthetic rates differ by a factor of 10 in different sea regions. Relatively high

primary production (0.70 – 2.40 gC m^{-2} day^{-1}) were recorded in the shelf waters around Bulgaria, Ukraine, and Turkey (Fig. 2).
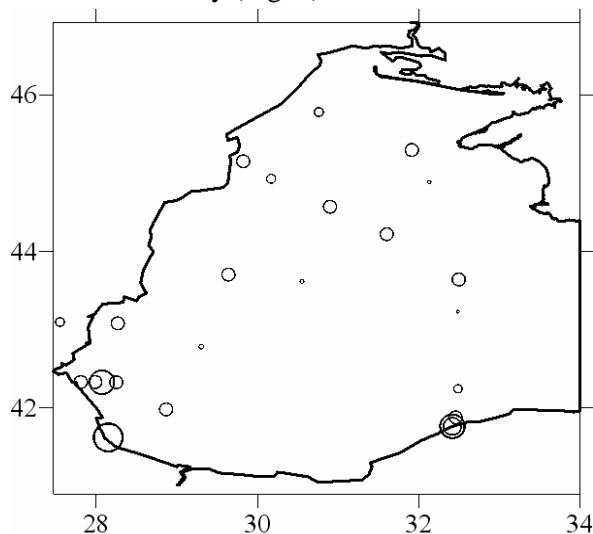

Fig. 2. Variability of primary production in September- October in studied region (symbol sizes are proportional to primary production from 0.34 to 2.8 gC m-2 day-1).

Рис. 2 Изменчивость первичной продукции в сентябре – октябре 2005 г. в районе исследований (размер символов пропорционален величинам первичной продукции от 0.34 до 2.8 гС м$^{-2}$ сут$^{-1}$

The lowest productivity levels were recorded (0.34 – 0.87 gC m^{-2} day^{-1}) in central regions of halistatic zone (st. 5, 9, 10, Fig. 1).

These data show that water circulation in the studied regions effect the phytoplankton production. It especially applies to both neritic regions and the continental slope regions, where the major Black Sea current (RIM) occurs. Complex systems of localized multidirectional eddies occur due to variation in winds and depth and shape of the coast line, promoting exchange between surface and deep waters [9]. This is especially observed in the continental slope zone near Bulgaria and Turkey, where high production rates are measured (Fig. 2). The surface Chl concentration and integrated primary production correlated throughout the transects, the regression analysis showed that changes in surface Chl explained about 80% of the total variability (Fig. 3).

The relationship between ratio of the euphotic layer integrated primary production (PP) and phytoplankton biomass (Chl $_{tot}$) and the surface irradiance (E$_0$) were computed as:

$$PP/Chl_{tot} = \psi\, E_0 \qquad\qquad (3)$$

The data from all period (n=10) were described by the regression with ψ equal to 0.52±0.08 gC (g Chl a)$^{-1}$ (m^2 E^{-1})$^{-1}$ (n=10, r^2=0.60). The ψ values were in a range 0.36-0.66 gC (g Chl a)$^{-1}$ (m^2 E^{-1})$^{-1}$ and comparable with the values observed in other locations of the world Ocean [16].
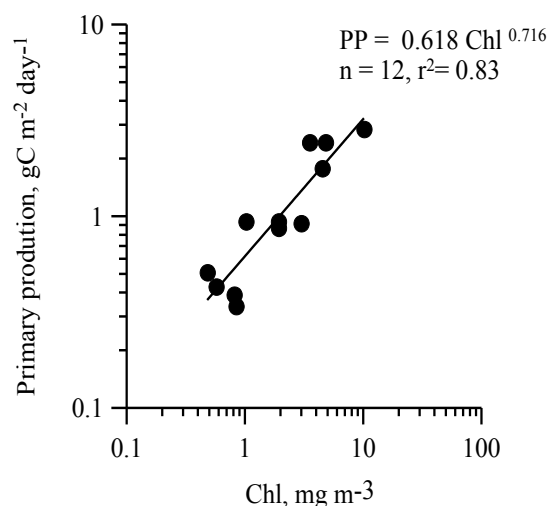

Fig. 3. Relationship between the total primary production and chlorophyll a concentration in the surface layer.

Рис. 3 Зависимость общей первичной продукции от концентрации хлорофилла a в поверхностном слое

Photosynthesis-irradiance experiments (P-E). Analysis of P-E response indicated on weak photoinhibition with irradiances higher than 500 μE m^{-2}s^{-1} for surface samples (Fig. 4). The mean parameter of photosynthesis saturation (E$_k$) was 224 ±108 μE m^{-2}s^{-1} for surface layer and 73 ±22 μE m^{-2}s^{-1} at the 1% PAR$_0$. The E$_k$ values for surface layer in the shelf and open regions were statistically different. In the coastal zone the mean values was equal to 270±119 and in the open regions - 178±53 μE m^{-2}s^{-1} (Table 1).

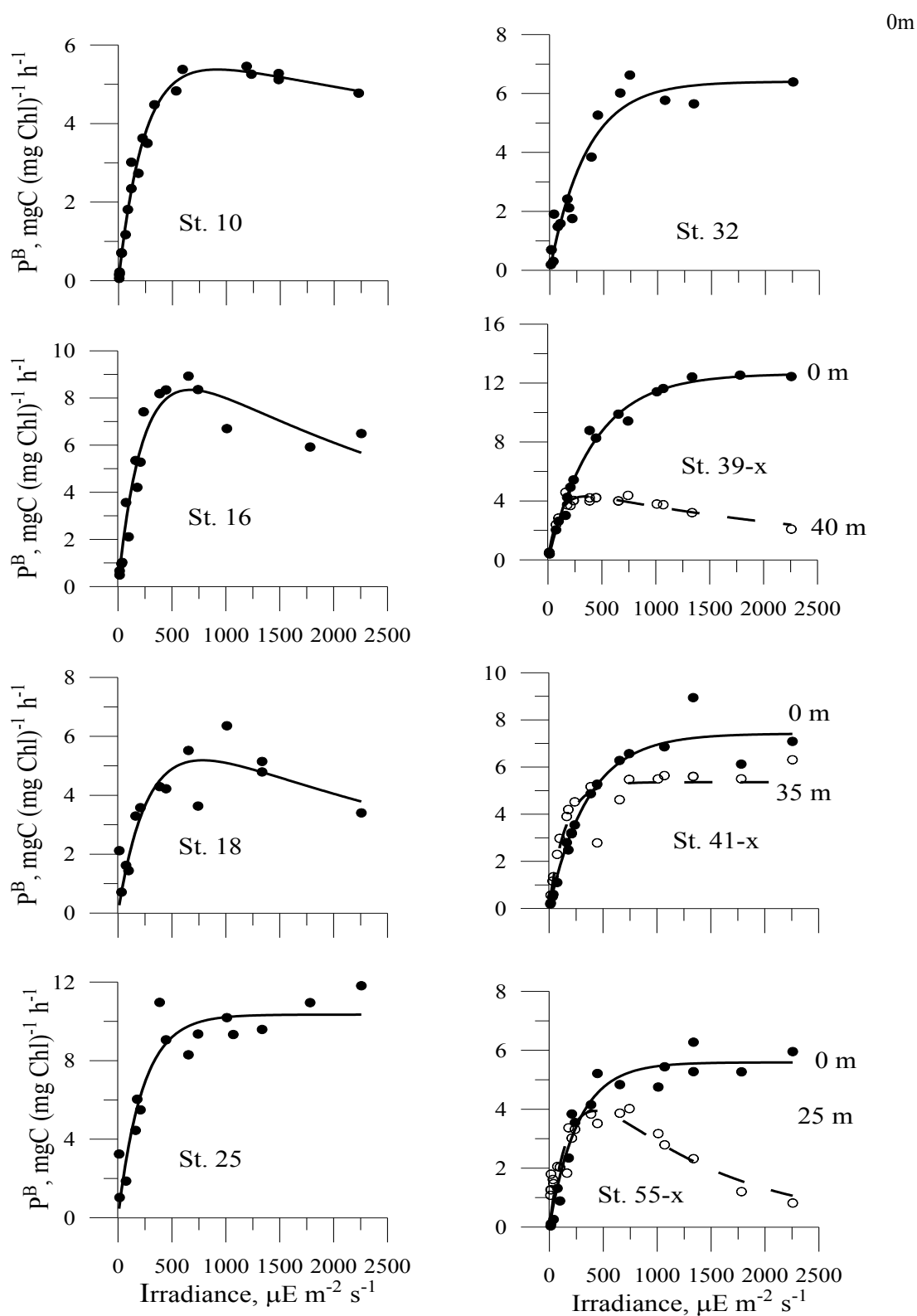Fig. 4 Typical curves of the relationship between the photosynthesis of phytoplankton and irradiance in surface layer and for deeper samples (1 % PAR). The data were fitted following [14]; Рис. 4 Типичные световые зависимости скорости фотосинтеза фитопланктона в поверхностном слое и на глубинах, куда проникает 1% солнечной радиации. Линия – расчет по уравнению Т. Плата с соавторами [14], точки – экспериментальные данные.

Table 1 Photosynthetic characteristics of phytoplankton
Табл.1 Фотосинтетические характеристики фитопланктона

Number station	Bottom	Depth, m	P_{max}^B	α^B	I_K	P_S	β
p.Varna	14	0	9.70	0.054	180	-	-
G	38	0	9.71	0.068	143	-	-
P1-KR	48	0	13.0	0.073	179	24.9	0.013
P3-KR	48	0	12.5	0.063	198	15.9	0.0017
P6-KR	90	0	8.80	0.025	352	37.8	0.006
0	35	0	5.30	0.015	353	-	-
1	35	0	3.2	0.011	291	-	-
1	35	0	5.17	0.013	398	-	-
2	601	0	6.2	0.022	282	27.4	2.47
2	601	20	2.99	0.043	69	-	-
5	2178	0	5.41	0.023	235	-	-
9	2000	0	4.60	0.037	124	5.05	0.0004
9	2000	25	3.70	0.086	43	4.07	0.001
10	1890	0	5.40	0.039	138	6.04	0.0006
16	103	0	8.6	0.066	130	10.8	0.0031
18	48	0	5.20	0.035	148	6.91	0.002
25	31	0	10.3	0.062	167	-	-
30	1076	0	5.95	0.043	138	-	-
30	1076	20	1.16	0.054	21	-	-
32	100	0	6.40	0.022	291	-	-
34	41	0	5.83	0.012	486	-	-
35	21	0	10.4	0.027	385	-	-
39	73	0	12.6	0.046	274	-	-
39	73	40	5.70	0.065	88	5.02	0.004
41-x	1100	0	7.41	0.028	265	-	-
41-x	1100	35	5.35	0.052	103	-	-
52-x	1000	0	4.49	0.026	173	-	-
54-x	1980	23	3.25	0.067	48	-	-
55-x	1000	0	5.79	0.034	170	-	-
55-x	1000	23	4.00	0.057	70	6.62	0.005

Comments: P_{max}^B - maximum photosynthesis rate, normalized on chlorophyll *a* concentration, mg C (mg Chl)$^{-1}$ h^{-1}; α^B - efficiency of photosynthesis, mg C (mg Chl)$^{-1}$ h^{-1}(μE m-2 s^{-1})$^{-1}$); I_K – light intensity saturating photosynthesis, μE m-2 s^{-1}; P_S – parameter of photosynthesis-irradiance curve, mg C (mg Chl)$^{-1}$ h^{-1}, β - the photoinhibition parameter (mg C (mg Chl)$^{-1}$h^{-1}(μE m^{-2} s^{-1})$^{-1}$

Примечание: P_{max}^B - максимальная скорость фотосинтеза, нормированная на хлорофилл *a*, мгС (мг Chl)$^{-1}$ ч$^{-1}$; α^B – эффективность фотосинтеза, мгС (мг Chl)$^{-1}$ ч$^{-1}$(μE м-2 с$^{-1}$)$^{-1}$); I_K – насыщающая фотосинтез интенсивность света, μE м$^{-2}$ с$^{-1}$; P_S – параметр световой зависимости фотосинтеза, mg C (мг Chl)$^{-1}$ h^{-1}, β – параметр фотоингибирования (мг С (мг Chl)$^{-1}$ч$^{-1}$(μE м$^{-2}$ с$^{-1}$)$^{-1}$

The initial slope of photosynthesis-irradiance curve (α^B) was variable. The mean α^B value for whole data set for surface layer was 0.032±0.019 mgC mg Chl^{-1} h^{-1}(μE m^{-2} s^{-1})$^{-1}$. The maximum α^B value was fixed in the Bulgarian shelf waters (0.039±0.024 mgC mg Chl^{-1} h^{-1}(μE m^{-2} s^{-1})$^{-1}$). In surface waters of open regions α^B was 0.033±0.007 and in deeper layer (1% PAR) – 0.055±0.01 mgC mg Chl^{-1} h^{-1}(μE m^{-2} s^{-1})$^{-1}$ on average. The P_{max}^B values in large space scales varied from 3.2 to 12.6 mg C (mg Chl)$^{-1}$ h^{-1} and the mean P_{max}^B in the shelf was 8.51±3.28, in the open waters - 5.57±0.98 mg C (mg Chl)$^{-1}$ h^{-1}. As we can see, in the autumn, the values of P_{max}^B in the shelf waters, where greater chlorophyll concentration were observed, were 1.5 time as great as in the deep-water regions. At the same

time the α^B values were only 1.2 time lower for open waters. The correlation between the maximum rate of photosynthesis (P_{max}, mgC m^{-3} h^{-1}) and the chlorophyll *a* concentration was found to be described by a power function (Fig.5). The relationship between the maximum rate of photosynthesis and the initial slope of the light curve (α, mgC m^{-3} h^{-1}(μE m^{-2} s^{-1})$^{-1}$) and chlorophyll concentration was also described by a power function, but a power coefficient was smaller than for P_{max}^B. The P_{max}^B and α^B values increased by a factor of 1.5 and of 1.2 correspondently while the chlorophyll concentration rose in 10 times.

The effect of nutrient concentrations on α^B values were investigated at 4 stations in the coastal waters near the Bulgaria. The nitrate concentration within the 0 to 15 m layer varied from 0.05 to 2.5, silicate – from 0.05 to 8.5, phosphorus – from 0.03 to 0.20 μM. The α^B values ranged from 0.025 to 0.068 mgC mg Chl^{-1} h^{-1} (μE m^{-2} s^{-1})$^{-1}$. The minimum values of α^B, nitrate and silicate were observed at st. P6RK (depth 100m), while the α^B maximum were confined at the 40 – 50 m depths. These differences are not occasional. This dependence was described as Michaelis-Menthen type by following equation:

$$\alpha^B = 0.071 \times N / (0.095 + N), \qquad (4)$$

where N is nitrate concentration, μM. To estimate the effects of nitrate and silicate, as well as their contributions to the changes in the values of the α^B we used the multiple regression:

$$\alpha^B = 0.0245\ (0.003) + 0.016\ (0.005)N + 0.0013 (0.0013)Si, \quad r^2 = 0.91, \qquad (5)$$

where N are nitrate, Si - silicate concentrations, μM; in brackets - standard deviation. The greatest contribution to the total variability of α^B values was made by the concentration of nitrate, while the silicate affects it slightly. The same relationship was found earlier during summer, but the coefficients of an equation differ [7, 8]. At low and high concentrations of NO$_3$ within the surface

layer the α^B values for autumn bloom were two time greater, than for summer. Our results do not support the view of J. Cullen *et al.* [5] that the nutrients influence weakly on photosynthetic parameters if phytoplankton acclimates to ambient irradiance regime. Data obtained in the Black Sea show that nutrients are a major factor regulating photosynthesis efficiency and the standing stock of phytoplankton. The α^B values in coastal and offshore waters differ in 1.4 times. It allows to make a conclusion that phytoplankton was limited by NO$_3$ in open sea. The spatial distribution of nutrients is likely to determine variability in photosynthetic phytoplankton characteristics. The photosynthetic parameters in response to changes of nutrients might be a key factor initiating an autumn bloom in the Black Sea.

The change of photosynthetic parameters from deep-waters to shallower regions confirm the hypothesis that high surface chlorophyll values in the coastal are associated with high photosynthetic parameters of phytoplankton. On the other hand our data aren't in an agreement with the alternative hypothesis for lack of relation between photosynthetic parameters and chlorophyll concentration. Thus, phytoplankton responds to the variations in the environmental conditions generally by rather great fluctuations in its biomass and partly by changes of photosynthetic parameters.

Conclusion. Despite the evidence of significant biological responses on physical forcing, little attention has been focused on assessing of changing photosynthetic parameters. The changes of Chl concentration and primary production along the transects reflect the interaction between the physicochemical fields and the biological responses of planktonic ecosystem. The surface Chl concentration and integrated primary production correlated throughout the transects, the regression analysis showed that changes in surface Chl explained about 80% of the total variability. The experimental data showed that in autumn the

photosynthetic parameter values in the shelf waters with higher chlorophyll concentrations observed were on averaged 1.5 times higher compared to the deepwater region. The coefficients of variation of photosynthetic parameters were higher in the shelf, than in the deep-water regions. The maximum photosynthesis and light-limited photosynthesis rates increased non-linearly with growth of chlorophyll concentration. The results presented showed 2-fold variation in efficiency of photosyn-

thesis related to changes in nitrate concentration. The information on the photosynthetic parameters could be used as indicator of the environmental status for the plankton ecosystem in the Black Sea.

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Фотосинтетичні характеристики фітопланктону в західній частині Чорного моря в період осіннього цвітіння З. З. Фіненко, Т. Я. Чурілова, О. В. Пархоменко, С. Тугрул. Фотосинтетичні характеристики фітопланктону були досліджені уздовж розрізів від берега в глибоководну частину в західному і південному районах Чорного моря восени 2005 р. Ефективність фотосинтезу (α^B) змінювалася від 0.012 до 0.068 мг С (мг Chl)$^{-1}$ч$^{-1}$(μE м$^{-2}$ с$^{-1}$)$^{-1}$, а максимальна швидкість фотосинтезу, нормована на хлорофіл а (P^B_{max}), - від 5 С (мг Chl)$^{-1}$ч$^{-1}$ в глибоководній частині до 12 С (мг Chl)$^{-1}$ч$^{-1}$ в шельфових водах. У районі шельфу величини P^B_{max} і α^B змінювалися в 3 рази. Ступінь варіабельності цих параметрів був таким же як і концентрації хлорофілу. Середні величини α^B і P^B_{max} на шельфі перевищували значення для глибоководного району. Стратегія фотоадаптації фітопланктону полягала в підвищенні α^B із зменшенням освітленості. У теплий період року біогенні речовини визначали мінливість фотосинтетичних параметрів. Величини інтегральної первинної продукції (PP) змінювалися від 0.34 до 2.45 гС м$^{-2}$ добу$^{-1}$. В середньому PP складали - 1.7 і 0.5 гС м$^{-2}$ добу$^{-1}$ в шельфовому і глибоководному районах, відповідно. Одержані кореляційні залежності між PP, P^B_{max}, α^B і поверхневою концентрацією хлорофілу *а*.
Ключові слова: фітопланктон, фотосинтез, світло, первинна продукція, Чорно море

Фотосинтетические характеристики фитопланктона в западной части Чёрного моря в период осеннего цветения З. З. Финенко, Т. Я. Чурилова, А. В. Пархоменко, С. Тугрул. Фотосинтетические характеристики фитопланктона были исследованы вдоль разрезов от берега в глубоководную часть в западном и южном районах Черного моря осенью в 2005 г. Эффективность фотосинтеза (α^B) изменялась от 0.012 до 0.068 мг С (мг Chl)$^{-1}$ч$^{-1}$(μE м$^{-2}$ с$^{-1}$)$^{-1}$, а максимальная скорость фотосинтеза, нормированная на хлорофилл *а* (P^B_{max}), - от 5 мг С (мг Chl)$^{-1}$ч$^{-1}$ в глубоководной части до 12 мг С (мг Chl)$^{-1}$ч$^{-1}$ в шельфовых водах. В районе шельфа величины P^B_{max} и α^B изменялись в 3 раза. Степень вариабельности этих параметров была такой же, как и концентрации хлорофилла. Средние величины α^B и P^B_{max} на шельфе превышали значения для глубоководного района. Стратегия фотоадаптации фитопланктона заключалась в повышении α^B с уменьшением освещенности. Осенью биогенные вещества определяли изменчивость фотосинтетических параметров. Величины интегральной первичной продукции (PP)изменялись от 0.34 до 2.45 гС м$^{-2}$ сут$^{-1}$, в среднем - 1.7 и 0.5 гС м$^{-2}$ сут$^{-1}$ в шельфовом и глубоководном районах, соответственно. Найдены зависимости PP, P^B_{max} и α^B от поверхностной концентрации хлорофилла *а*.
Ключевые слова: фитопланктон, фотосинтез, свет, первичная продукция, Чёрное море