Light-absorbing capacity of phytoplankton in the Gulf of Gdańsk in May, 1987

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Pigment index

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Abstract

In order to estimate the efficiency of marine phytoplankton photosynthesis by a direct method, a natural variability of phytoplankton characteristics reflecting its light absorption capacity was studied. Thus, the absolute and specific phytoplankton spectral absorption coefficients and their mean values for the PAR range, as well as the pigment index $I_{441/675}$ were studied. Light absorption was measured on natural marine phytoplankton from the Gulf of Gdańsk. Two hundred and thirty samples drawn from ten depths between 0 and 30 m every six hours during several days were analyzed. The absolute values of the absorption coefficient were observed to vary by a factor of almost 15 from 0.057 m^{-1} to 0.85 m^{-1} (at 441 nm) and from 0.038 m^{-1} to 0.55 m^{-1} (at 675 nm). Phytoplankton absorption coefficients, normalized by the chlorophyll concentration, were equal to 0.021 ± 0.004 m^2 (mg Chl "a")$^{-1}$ at 675 nm and 0.033 ± 0.007 m^2 (mg Chl "a")$^{-1}$ at 441 nm. At 675 nm the value of the absorption coefficient exceeded its mean value within the PAR range 1.2 ± 0.12 times on average. A negative linear correlation was found between the specific absorption coefficients at 675 nm and the Chl "a" concentration, the slope of the regression line increasing with depth.

The pigment index $I_{441/675}$ varied from 1.29 to 2.04. The value of $I_{441/675}$ averaged for each depth increased steadily with depth, starting from 5 m.

1. Introduction

In the studies of ecology of marine phytoplankton photosynthesis it is necessary to estimate the ability of algae to absorb solar energy, *ie* their light absorption capacity (LAC). Using LAC data and the results of optical measure-

ments of the underwater radiation, the amount of energy absorbed by algae under natural conditions may be calculated. The results of such calculations can be utilized for the determination of the balance of energy of solar radiation reaching the water deep. They also allow to establish the real energy efficiency and quantum yield of the primary production process in the sea (Koblentz-Mishke *et al*, 1985).

Light absorption capacity of phytoplankton is also very important in the determination of phytoplankton content and production by means of methods of passive remote sensing (on the basis of data on a colour of the sea), since light absorption by algae pigments significantly influences the spectrum of radiation ascending from the sea (Yentsch, 1960; Prieur, Sathyendranath, 1981).

In order to estimate the light absorption capacity of phytoplankton, the following absolute and specific characteristics are used:

(i) spectral absorption coefficient (a_λ) within a range of photosynthetically active radiation (PAR), *ie* 400–700 nm. Within this spectral range, the wavelengths around 440 nm and 675 nm are the most informative, since at these wavelengths a maximum absorption of phytoplankton pigments occurs *in vivo*. The values of absorption at spectral maxima of pigments are used primarily for the determination of pigment content of seawater by methods which do not comprise pigment extraction, remote methods included;

(ii) the average absorption coefficient in the PAR region ($\bar{a}_\lambda$), characterizing a mean level of the potential capacity of phytoplankton to absorb light;

(iii) the same characteristics as in items 1 and 2, normalized with respect to the chlorophyll concentration (B_a) (Morel and Prieur, 1977).

Using this characteristics, the ratio of the total pigment content to a content of chlorophyll "a" may be determined. This index is less suitable than $I_{430/664}$ for the estimation of biochemical composition and species diversity of phytoplankton due to lower accuracy of its determination. For this reason, $I_{441/675}$ is determined mainly for approximate description of the shape of phytoplankton absorption curve and for an evaluation of the possibility of determination of the content of Chl "a" on the basis of total absorption within the blue spectral range.

Another relative parameter, *viz* $a^*(675)/(\bar{a})^* = a(675)/\bar{a}$, allows to calculate a mean value of absorption coefficients within the PAR range on the basis of absorption curve and for an evaluation of the possibility of determination of the the accuracy of a calculation of a may be estimated by the value of a (675).

Among recent papers on phytoplankton light absorption ability and other absorption properties, the following papers should be mentioned: Morel, Bricaud, 1986; Maske, Haardt, 1987; Kishino *et al*, 1984; Sathyendranath *et al*, 1987. They contain the results of experimental measurements performed both on cultures and on natural phytoplankton, as well as literature reviews.

2. Materials and Methods

Two hundred and thirty samples drawn at two stations in the Gulf of Gdańsk in the beginning of May, 1987, from depths of 0, 1, 2, 3, 5, 7, 10, 15, 20, and 30 m were used in the experiments. At station G-2 (open part of the Gulf), samples were

drawn every 6 hours since midnight of May 1 till midnight of May 4. At station Z in the internal part of the Gulf samples were drawn also every 6 hours since 6 pm May 4, till midnight, May 7. Samples of 2–4.5 l were filtered through Whatman glass-fiber filters (GF/F), 47 mm in diameter. Each filter was cut into two unequal parts. Three quarters of a filter were used for the determination of a Chl "a" content by an extraction method. One fourth of a filter was directly used for recording the spectrum of optical density and subsequent calculation of light absorption coefficients.

The chlorophyll concentration was measured by a standard extraction method (SCOR-UNESCO, 1966; Edler L. (ed.), 1979).

Measurements of absorption spectra of the extracts were carried out using a SPECORD UV/VIS spectrophotometer (Karl Zeiss JENA, GDR).

Optical density spectra of seston, *ie* phytoplankton together with the remaining suspended matter deposited on a filter, were recorded using an SP-18 double-beam spectrophotometer (LOMO, USSR).

A wet filter was placed on a glass holder in the centre of a light integrating sphere of the spectrophotometer. A wet filter without seston was used as a blank. Absorption spectra were recorded before and after decolorization of phytoplankton pigments, carried out by means of UV irradiation in the presence of H_2O_2. Optical density spectra of seston deposited on a filter do not coincide with the absorption spectra of phytoplankton *in situ*. In order to determine a real shape of the latter, it is necessary first of all to substract the spectrum of decolorized seston. Then it is important to take into consideration the effect of reflection of light from a filter and broadening of a light beam due to scattering by seston particles and filter material at various wavelengths and various optical densities.

The following formulas were used for calculations:

$$a(\lambda) = 2.3 D(\lambda)/l k^f, \tag{1}$$

where:

$a(\lambda)$ – the spectral absorption coefficient (natural logarithm) [m^{-1}],

$D(\lambda)$ – the spectral optical density (common logarithm),

2.3 – a coefficient of conversion of common logarithm into natural one,

k^f – a correction factor,

l – the length of the recovered light beam pathway without a correction for light scattering (K).

$$l = V_s/S_f, \tag{1a}$$

where V_s is a volume of water sample; S_f is the filtration surface of a filter. In our experiments l varied from 1.4 to 3.1 m.

$$\bar{a} = \frac{1}{300} \int_{400}^{700} a(\lambda) d\lambda, \tag{2}$$

where $\bar{a}$ [m^{-1}] is an absorption coefficient averaged over the PAR spectral range.

$$a^*(\lambda) = a(\lambda)/B_a, \tag{3}$$

where $a^*(\lambda)$ is the specific spectral absorption coefficient [$m^2 mg^{-1}$], B_a is the Chl "a" concentration [$mg\, m^{-3}$].

$$(\bar{a})^* = \bar{a}/B_a, \tag{4}$$

where $(\bar{a})^*$ (commonly denoted as K_c) is a specific absorption averaged over the PAR range [$m^2 mg^{-1}$].

$$I_{441/675} = a(441)/a(675), \tag{5}$$

where $I_{441/675}$ is the pigment index.

3. Results and discussion

Taking into account high values of the chlorophyll concentration (more than 20 mg m^{-3} at st. G-2 and almost 30 mg m^{-3} at st. Z) it can be assumed that our investigations were carried out in the eutrophic region of the Baltic Sea. The corresponding values of optical properties of phytoplankton presented in Table 1 are also relatively large, which confirms the assumption. Table 1 presents the values of absorption coefficients of phytoplankton allowing an evaluation of their variability depending on the time of a day and the depth of sampling, *viz* at the surface (0 m), at the depth of occurrence of a maximum at a vertical profile of the absorption coefficient and at 30 m, *ie* just below the lower limit of euphotic layer.

It follows from Table 1 that the value of an absorption coefficient $a(441)$ in the band of most intensive absorption of phytoplankton with a maximum at 441 nm reached 0.85 m^{-1} (station Z, 5th May, 18.00 h, 3 m of depth).

The maximum values of $a(441)$ observed at stations Z and G-2 ranged from 0.49 to 0.85 m^{-1} (0–7 m) and from 0.29 to 0.46 m^{-1} (0–10 m), respectively. A vertical distribution of the value of $a(441)$ corresponded to the distribution of chlorophyll, reflecting that of phytoplankton biomass. The largest values of $a(441)$ were recorded in the layer of 5–10 m. In the 10–20 m layer, the value of $a(441)$ considerably decreased (Fig.1). At station Z, which appeared to be richer in phytoplankton than that at station G-2, the maximum values of $a(441)$ occurred closer to the surface and a decrease of $a(441)$ at the depth of 20–30 m was more pronounced.

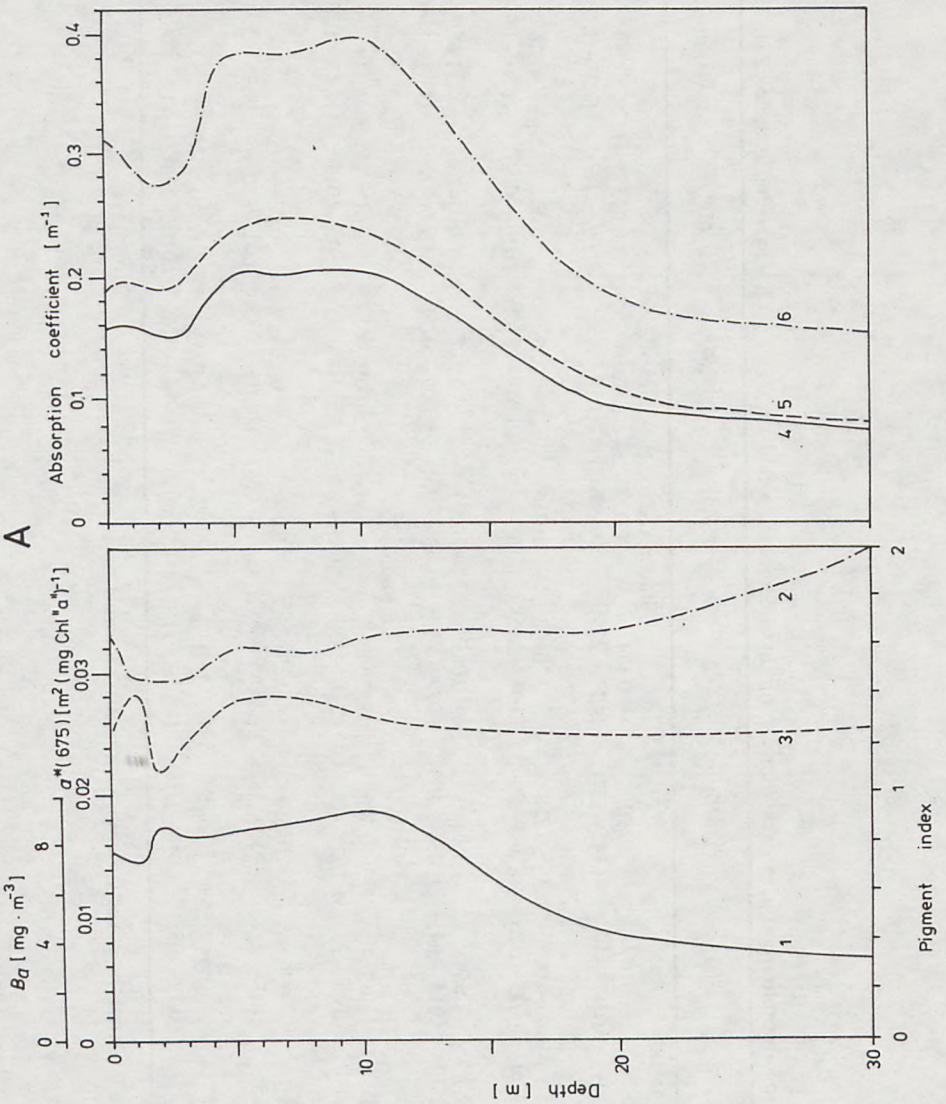
Figure 2 illustrates the changes of $a(441)$ with time. At station G-2, a certain regularity of these fluctuations has been noticed. The minimum values of this characteristics were observed at 6 pm, while the maximum values were observed over the time interval from 6 am till noon. Observations at station Z revealed a different time distribution of $a(441)$ in time. The changes of $a(441)$ were not cyclic. Moreover, the maximum values of $a(441)$ were observed at 6 pm, *ie* at the same time when they were minimum at station G-2.

It follows from Table 1 and Figure 1 and 2 that the changes of a at 441 nm and at other characteristic wavelengths, *ie* at the chlorophyll red maximum (675 nm) and at a minimum of phytoplankton absorption (605 nm), as well as changes of a, were synchronous, although less pronounced.

Table 1. Phytoplankton absorption coefficients at station G-2 (mean values for the period 0 h May 1 – 0 h May 4) and at station Z (18 h May 4 – 0 h May 7)*

Depth, [m]	$a(441)$	$a(605)$	$a(675)$	$\bar{a}$	$a^*(441)$	$a^*(675)$	$(\bar{a})^*$	$a(441)/a(675)$	$a(675)/\bar{a}$
					Station G-2				
0	0.330 (.235 – .444)	0.073 (.047 – .104)	0.206 (.145 – .271)	0.174 (.133 – .237)	0.029 (.016 – .044)	0.018 (.010 – .026)	0.015 (.009 – .023)	1.59 (1.38 – 1.68)	1.16 (1.09 – 1.28)
Layer of maximum values	0.382 (.285 – .455)	0.090 (.075 – .123)	0.253 (.206 – .299)	0.201 (.094 – .255)	0.040 (.030 – .054)	0.026 (.019 – .036)	0.022 (.016 – .028)	1.76 (1.59 – 1.99)	1.30 (1.21 – 1.37)
30	0.119 (.057 – .170)	0.029 (.016 – .045)	0.071 (.038 – .109)	0.065 (.032 – .089)	0.023 (.014 – .031)	0.017 (.009 – .025)	0.014 (.007 – .025)	1.67 (1.38 – 1.99)	1.10 (0.97 – 1.26)
					Station Z				
0	0.611 (.386 – .780)	0.161 (.106 – .221)	0.376 (.258 – .458)	0.340 (.216 – .432)	0.030 (.025 – .036)	0.019 (.015 – .031)	0.017 (.015 – .019)	1.61 (1.47 – 1.79)	1.12 (1.01 – 1.19)
Layer of maximum values	0.648 (.49 – .85)	0.174 (.123 – .221)	0.395 (.301 – .554)	0.354 (.249 – .466)	0.046 (.038 – .054)	0.028 (.0.022 – .035)	0.026 (.022 – .03)	1.9 (1.74 – 2.04)	1.20 (1.14 – 1.25)
30	0.116 (.087 – .150)	0.025 (.0.19 – .033)	0.063 (.047 – .078)	0.060 (.045 – .071)	0.039 (.029 – .050)	0.021 (.015 – .026)	0.020 (.016 – .026)	1.84 (1.63 – 2.04)	1.04 (0.92 – 1.16)

* in brackets are given the ranges of variability within the indicated periods


A
Absorption coefficient [m⁻¹]
0
0.1
0.2
0.3
0.4
4
5
6
Depth [m]
0
10
20
30
B_a [mg · m⁻³]
0
4
8
a^*(675) [m² (mg Chl "a"⁻¹)]
0
0.01
0.02
0.03
1
2
3
Pigment index
0
1
2

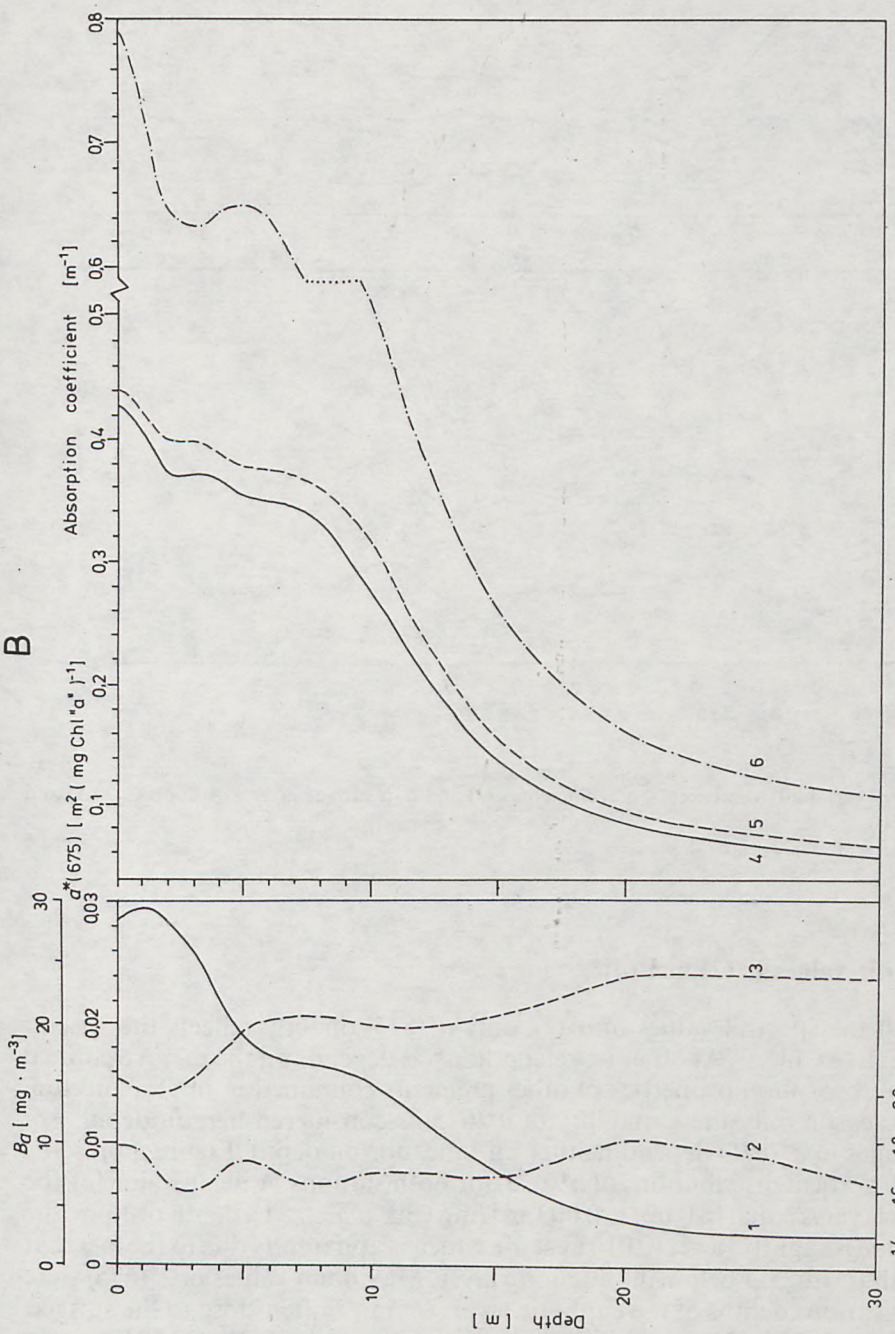


Fig. 1. Depth profiles: A – station G-2, 0 h, May 3; B – station Z, 18 h, May 6
1 – chlorophyll "a", B_a, [mg m^{-3}]; 2 – pigment index $I_{441/675}$; 3 – specific absorption coefficients $a^*(675)$, [m^2 (mg Chl "a")$^{-1}$]; 4 – mean specific absorption coefficient $(\bar{a})^*$ [m^2 (mg Chl "a")$^{-1}$]; 5, 6 – spectral absorption coefficients $a(441)$ and $a(675)$, [m^{-1}]

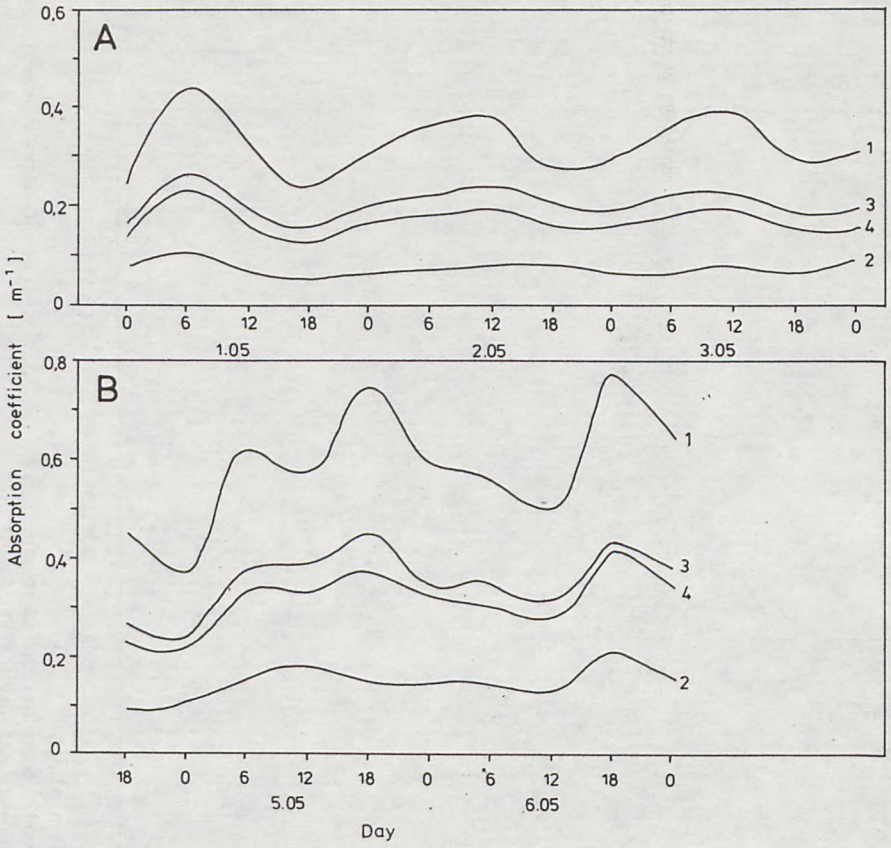


Fig. 2. Daily variability of absorption coefficients $a(\lambda)$ and $\bar{a}$ in surface layer at station G-2 (A) and station Z (B)
1 – $a(441)$, 2 – $a(605)$, 3 – $a(675)$, 4 – $\bar{a}$

3.1 Specific values $a^*(\lambda)$ and $(\bar{a})^*$.

Of all the spectral values of $a^*(\lambda)$, only $a^*(675)$ directly reflects the specific absorption of Chl "a". At other vawelengths $a^*(\lambda)$ depends on the relative content and light absorption properties of other pigments contained in phytoplankton. For this reason only the variability of $a^*(675)$ is considered here in detail.

Changes in $a^*(675)$ depend neither on time, nor on depth. Figure 3 presents the mean vertical distributions of $a^*(675)$ for both stations. A mean value for the 0 – 20 m layer is equal to 0.021 ± 0.003 m^2 (mg Chl "a")$^{-1}$. At a depth of 30 m, the mean value is slightly lower (0.014 at st. Z), which is apparently due to the fact that this depth is situated below the euphotic layer. Maximum values of $a^*(675)$ were found at various depths of the euphotic layer, yet most often close to the surface.

The range of $a^*(675)$ variability was rather wide – from 0.01 to 0.036 m^2 (mg Chl "a")$^{-1}$, except one determination at 30 m, where $a^*(675)$ was equal to 0.005.

The occurrence of a negative linear correlation between $a^*(675)$ and the

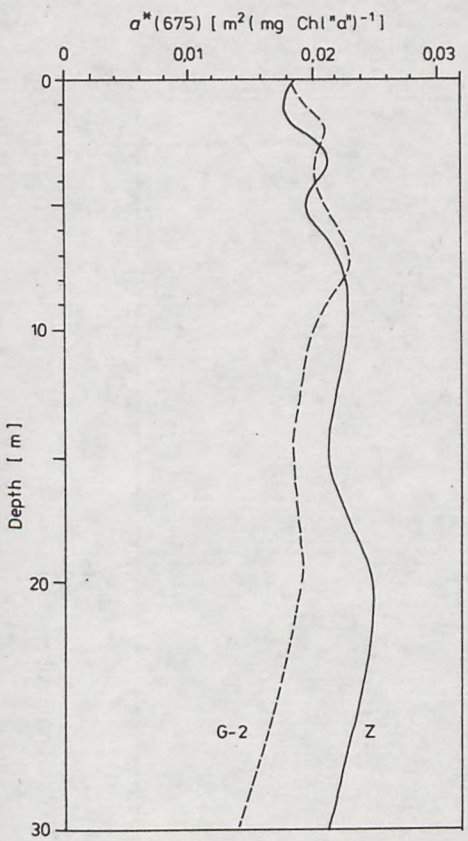


Fig. 3. Depth profiles of specific absorption coefficient $a^*(675)$ averaged over the entire period studied

chlorophyll concentration has been established. The slope of the regression line decreased gradually with depth. As an example, Figure 4 presents the dependence of $a^*(675)$ on the chlorophyll "a" content for two layers: 0–5 m and 15–30 m, the regression lines being described by the following equations:

$$a^*(675) = 0.035 - 0.001\ B_a,$$

$$a^*(675) = 0.044 - 0.004\ B_a.$$

The course of the remaining regression lines may be determined on the basis of separate sets of data for particular depths.

The specific absorption coefficient at 441 nm varied over the range of 0.016–0.054 m^2 (mg Chl "a")$^{-1}$ in the 0–20 m layer. At a depth of 30 m it varied over the range of 0.014–0.054, the mean value being 0.033 ± 0.007 m^2 (mg Chl "a")$^{-1}$. This parameter also did not exhibit any regular dependence on the time of a day and depth. However, a specific feature may be observed for vertical distributions of $a^*(441)$ and $a^*(675)$, *viz* in the 0–2 m and 30 m layers their values were lower than at the remaining depths.

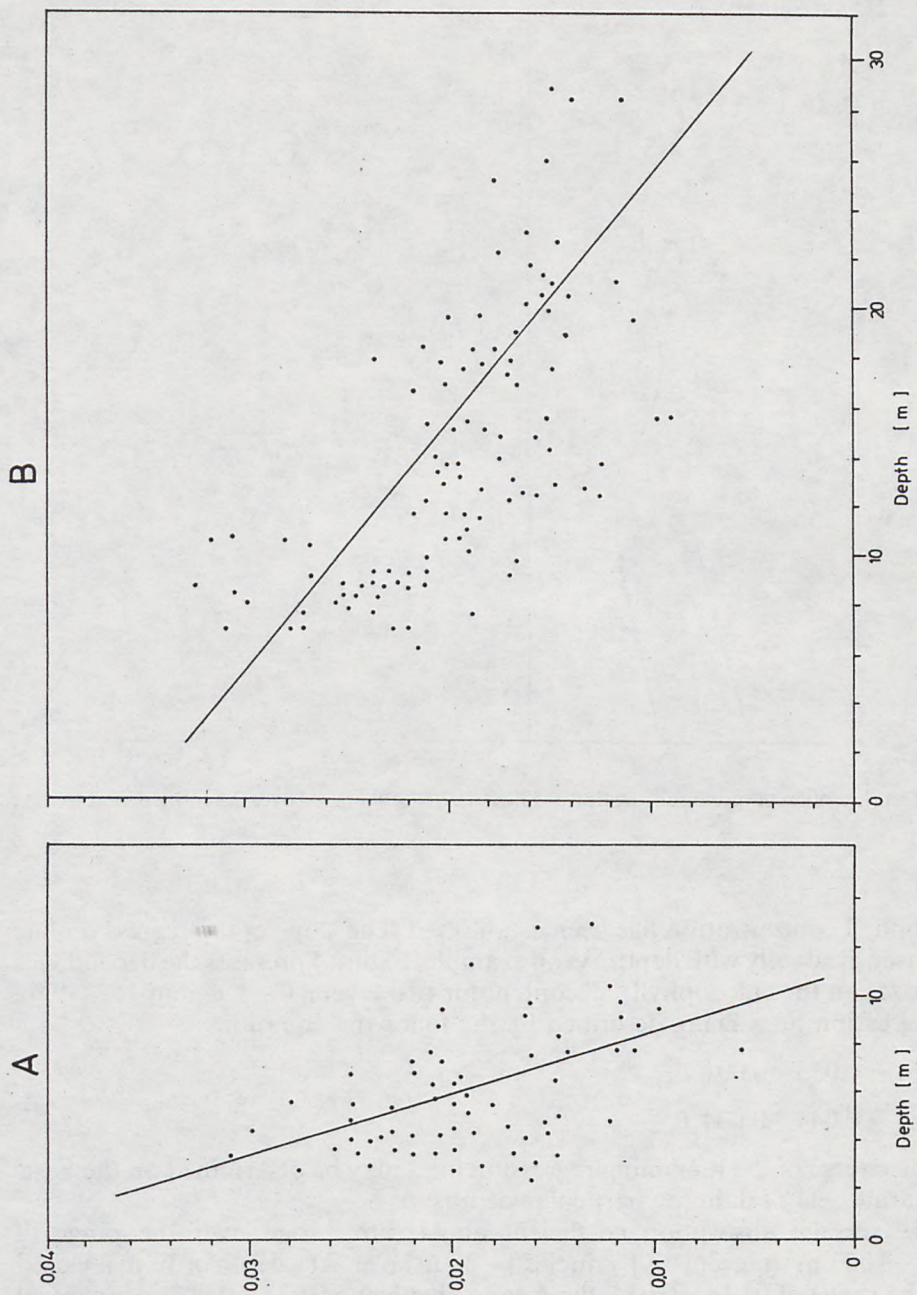


Fig. 4. Dependence of specific absorption coefficient $a^*(675)$ on chlorophyll concentration
A – in 15–30 m layer; B – in 0–5 m layer

The mean specific absorption coefficient $(\bar{a})^*$ revealed similar properties as $a^*(675)$ and $a^*(441)$. Its value ranged from 0.007 to 0.028 m^2 (mg Chl "a")$^{-1}$, the mean being equal to 0.017 m^2 (mg Chl "a")$^{-1}$ and varying from 0.015 to 0.018 m^2 (mg Chl "a")$^{-1}$ at various depths. The variations range of K_c reported herein is shifted to larger values compared to data of Atlas and Bannister (1980), who reported the values of 0.005 to 0.020 m^2 (mg Chl "a")$^{-1}$. Similarly to the case of $a^*(675)$, the value of $(\bar{a})^*$ revealed a negative correlation with B_a, *viz* for the 0–7 m layer:

$\bar{a}^* = 0.028 - 0.00056\ B_a$ (station Z),

$\bar{a}^* = 0.037 - 0.00168\ B_a$ (station G-2),

and for the 15–30 m layer (both stations):

$\bar{a}^* = 0.044 - 0.004\ B_a$.

The slope of the regression line for $\bar{a}^*$ with chlorophyll "a" concentration increased with depth similarly to the cases of the characteristics considered above.

3.2 Relative values

The values of the pigment index varied within a considerably narrower range: from 1.29 to 2.04 (a mean for 230 samples was equal to 1.6). Variations of the pigment index seemed random in a case of individual experimental data sets. However, if mean values at certain depths are taken into account for the two stations, certain regularities of their distribution can be established. A difference between the mean values of $I_{441/675}$ determined at the two stations is evident (within the 0–20 m layer at st. G-2 $I_{441/675} = 1.5-1.6$, while at st. Z $I_{441/675} = 1.6-1.8$). Moreover, the value of this characteristic was practically constant for all the samples from the 0–5 m layer. At greater depths a small, yet steady increase of $I_{441/675}$ up to 1.7 was observed. This increase of the value of the pigment index with depth has been confirmed by the data on pigment index of the extracted pigments.

The $a(675)/\bar{a}$ ratio has been the last of the characteristics considered in the research. From a dispersion of the results presented in Figure 5, the value of a may be calculated using the data on $a(675)$ with an error smaller than 15%, assuming that the value of the $a(675)/\bar{a}$ ratio is equal to 1.2. The accuracy of the calculation can be higher provided the dependence of the mean value of $a(675)/\bar{a}$ on $\bar{a}$ is taken into consideration.

$a(675)/\bar{a} = 2.84a + 0.9$ (for $a < 0.12$),

$a(675)/\bar{a} = -0.54a + 1.3$ (for $a > 0.12$).

A relatively constant value of the $a(675)/a$ ratio indicates that the vertical profiles of $a^*(675)$ and their dependence on B_a correspond to the dependence of $\bar{a}^*$ or K_C, which is illustrated in Figures 3 and 4.

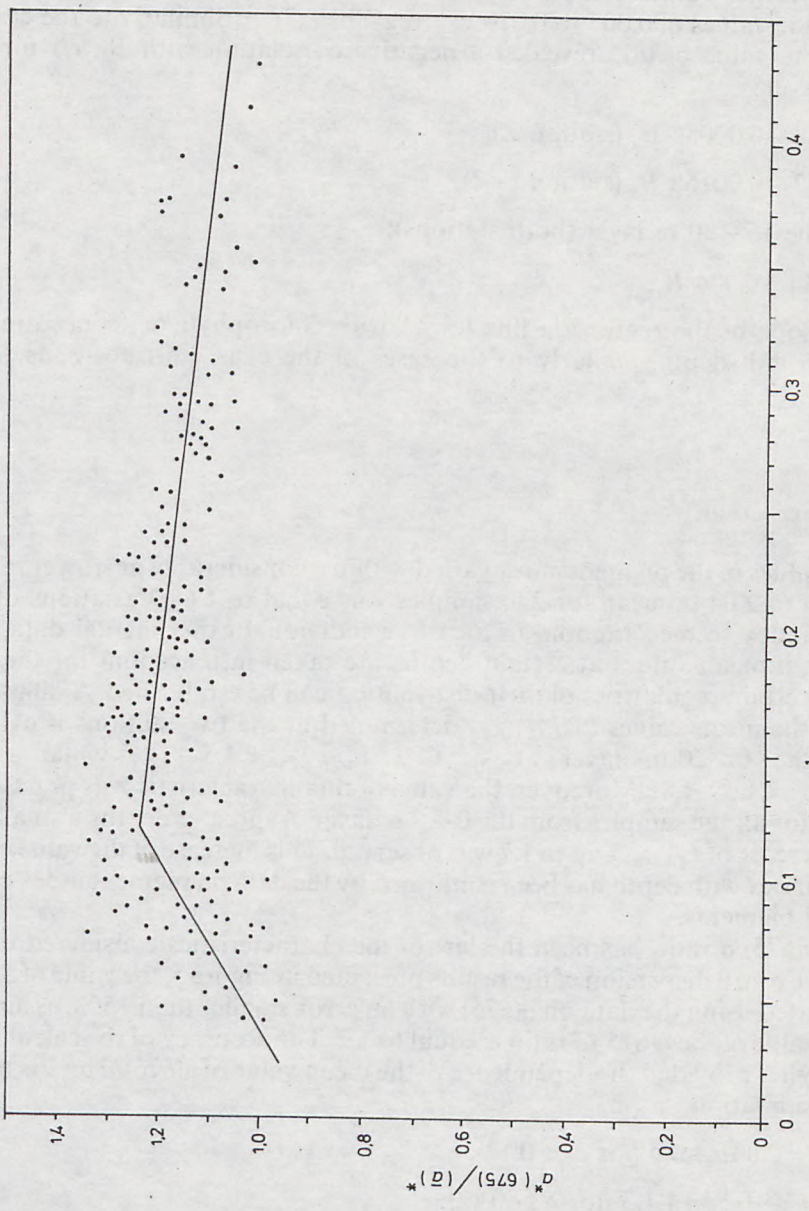


Fig. 5. Dependence of the ratio $a^*(675)/(\bar{a})^*$ on the mean absorption coefficient $\bar{a}$

4. Conclusions

Vertical distributions of the absorption characteristics at all wavelengths were identical and corresponded to the distribution of phytoplankton in the euphotic layer at the research stations.

Insignificant changes of the absorption characteristics in the 0–5 m layer indicate a homogeneity of this layer. The absence of any regular dependence of the vertical distribution of $a(\lambda)$ on the time of a day implies a certain instability of hydrophysical conditions in the regions where the stations were located. This instability has also been confirmed by fluorimetric data (Karabashev *et al*, 1990).

The fact that the specific absorption coefficients $a^*(\lambda)$ did not depend on depth indicate that their regular variations due to light adaptation of phytoplankton or other reasons were masked by variations due to hydrological instability.

An insignificant variability of the pigment index and identical changes of $a(\lambda)$ at various wavelengths seem to indicate that both the taxonometric content and general physiological state of phytoplankton were almost stable during our investigations. In other words, factors determining the shape of absorption spectra of phytoplankton did not exhibit significant variations.

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