Spatial distribution of phytoplankton fluorescence parameters in the period of spring homothermy formation in Lake Baikal

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Measurement results on spatial distribution (vertical and horizontal) of phytoplankton chlorophyll and its photosynthetic activity are discussed. The fluorescence parameters were used in the measurements. A fraction of micro-algae biomass, being in the photosynthesis region, in the total photosynthetics biomass distributed throughout the water column, was estimated. The phytoplankton assessment above the thermocline shows the algae fraction to be between 30 and 50% of the whole amount. Consequently, less than a half of photosynthesizing organisms of Lake Baikal can participate in "water–atmosphere" gas exchange in the period of spring homothermy formation.

Introduction

Based on high purity and stable chemical composition of water in Lake Baikal, it can be expected that just here there is a potential ability to distinguish sufficiently correctly physical, chemical, and biological components of the complicated process of "water–atmosphere" gas exchange. With these expectations, we conducted a series of complex experiments on studying the carbonic acid gas exchange processes in the "water surface – atmosphere" system in 2002 at Baikal.[1] On the base of the numerous results[2–9] and the data obtained by us in the littoral zone of the lake,[10,11] it has been revealed that the biological component is the main seasonal and interannual variable in this process.

The photosynthesis process evidently plays the key part in variations of concentrations of carbonic acid, oxygen, and biogenic elements in water. At the same time, classical methods for accounting for the plankton algae biomass and measuring the photosynthesis intensity are quite labored and time-consuming, which is the serious obstacle to their use in the monitoring mode. The corresponding express-methods of fluorescence analysis can partly replace them.[12]

The aim of this work was to reveal the regularities of spatial (vertical and horizontal) distribution of phytoplankton chlorophyll and its photosynthetic activity, measured by fluorescence parameters as applied to the gas exchange problem; and in assessment of the fraction of micro-algae biomass, being in the photosynthesis region, in the total photosynthetics biomass in the water column in the period of spring homothermy formation in Lake Baikal.

Figure 1 shows the location of stations for the Baikal water sampling for the period of complex expedition of LI SB RAS on board the Research Vessel *G.Yu. Vereshchagin* on June 10–21, 2006.

Analysis of the results

Water samples were taken from depths of 0, 25, 50, 100, 200, 300 m and then every 100–200 m down to the bottom by Nansen bathometers of 5 liters in volume. During 2006, 20 complete profiles were obtained in all. Later on, the following parameters of low induction of phytoplankton chlorophyll fluorescence[1,12] were determined in laboratory conditions for each profile:

1) fluorescence signal at the bound level F_s;

2) fluorescence signal when adding a disconnector of the electron-transport chain (diuron in our case) in the sample under study. The fluorescent signal in this case increases up to the maximum level F_d and is connected with the concentration of chlorophyll and biomass of uniform phytoplankton with an accuracy of about 30%.

To estimate the photosynthesis intensity, the coefficient of photosynthetic activity (CPA) of phytoplankton was used, calculated by the equation[12]

$$\text{CPA} = (F_d - F_s)/F_d.$$

The pattern of CPA spatial distribution in Lake Baikal during the expedition is shown in Fig. 2. It is evident, that CPA allows different zones to be distinguished. The most "powerful" zone with a

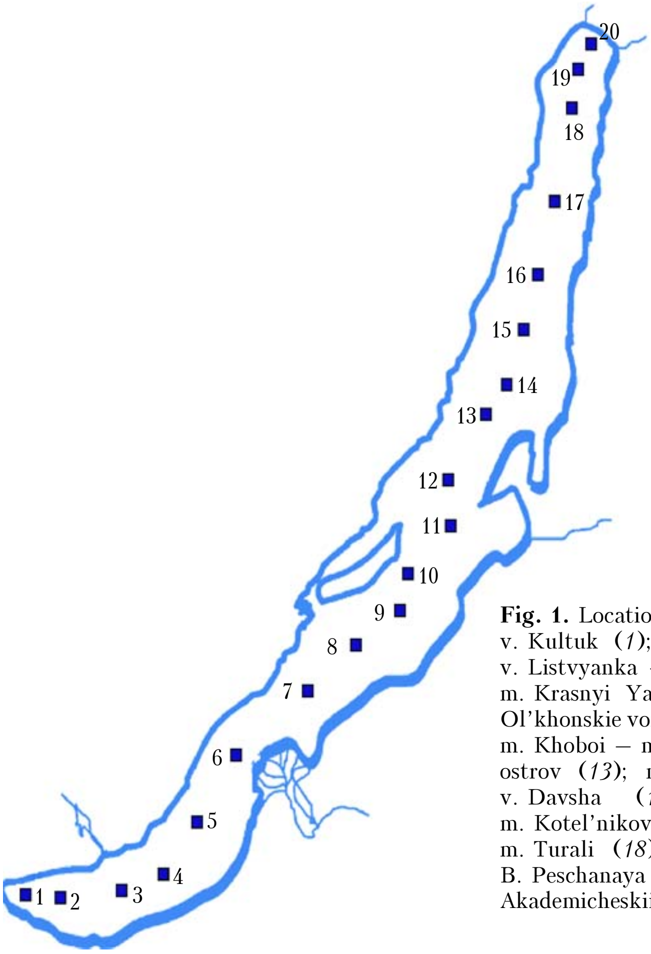


Fig. 1. Location of stations for the water sampling: 15 km from v. Kultuk (*1*); centers of sections: v. Maritui – r. Solzan (*2*); v. Listvyanka – v. Tankhoi (*3*); m. Kadil'nyi – r. Mishikha (*4*); m. Krasnyi Yar – ch. Kharauz (*6*); r. Anga – r. Sukhaya (*7*); Ol'khonskie vorota – v. Boldakovo (*8*); 10 km from m. Izhimei (*10*); m. Khoboi – m. Krestovyi (*11*); m. Pokoiniki – Bol'shoi Ushkanii ostrov (*13*); m. Zavorotnyi – r. Sosnovka (*14*); m. Elokhin – v. Davsha (*15*); m. Cheremshanyi – r. Kaban'ya (*16*); m. Kotel'nikovskii – r. Amnundakan (*17*); v. Baikal'skoe – m. Turali (*18*); r. Tyya – m. Nemnyanko (*19*); 10 km from B. Peschanaya (*5*); m. Ukhan – m. Tonkii (*9*); on the Akademicheskii ridge (*12*); 7 km from Nizhneangarsk (*20*).

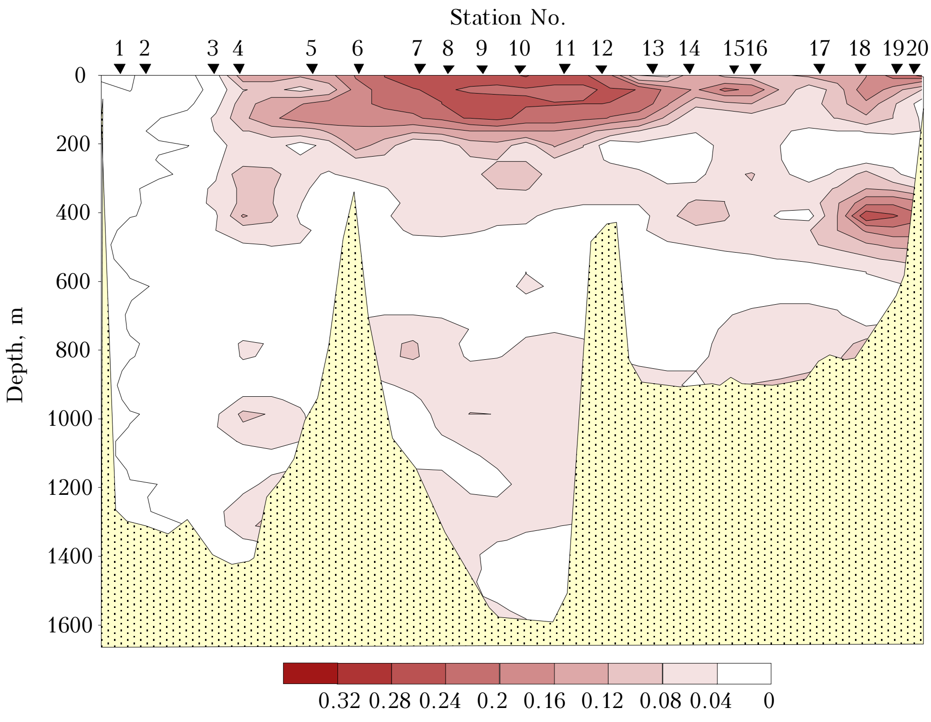


Fig. 2. Spatial distribution of CPA in June, 2006 (measurements of fluorescence parameters were beginning from the 4th station).

sufficiently high CPA is in the central part of the lake; two zones with CPA = 0.2 are in the northern part; CPA values of about 0.12 were observed in the southern part of the lake. Hence, it follows from these results and earlier data[2–9] that it is reasonable to analyze separately the fluorescence parameters for the southern, central, and northern parts of Lake Baikal.

First, analyze the vertical temperature distribution in the southern, central, and northern parts of Lake Baikal (Fig. 3). The corresponding data show the predominance during the expedition period of the inverse temperature stratification with the clearly pronounced mesothermal maximum at depths from 150 to 200–250 m in all parts of the lake. The surface temperature varied from 2.6–3.1°C in the southern and central parts to 2.1–2.6°C in the northern part of the lake. The layer of temperature jump occurred at depths from 40–130 to 90–170 m in the southern, from 70–115 to 130–170 m in the central, and from 50–70 to 90–150 m in the northern part of the lake. The conditions of vertical exchange in the observation period answered to the phase of active development of the spring temperature convection in the upper layers of the lake, accompanied by an increase of the mixed upper level in size as the surface temperature approached to iots values in the mesothermal maximum region (3.5–3.6°C). The conversion to full homothermy, was registered only in the center of the Kadil'nyi–Mishikha section in the southern part of the lake. Here the temperature was uniform (about 3.5ºC) down to 320 m. The jump layer was essentially weaken also in the zone of defrosting effect of the Verkhnyaya Angara river waters at the stations in the center of the Tyya–Nemnyanka section and at a distance of 7 km from Nizhnii Angarsk, where the surface temperature rose to 3.3–3.4°C.

The profiles of fluorescence signal F_d are shown in Fig. 4 for the same zones as for the temperature analysis.

All *vertical fluorescence profiles* of phytoplankton chlorophyll are characterized by a clearly pronounced maximum in the upper 100 m layer (Fig. 4).

The F_d maximum is tightly bound with the temperature distribution and located either in the upper part of the jump layer or higher its upper boundary in the layer with quasi-homogeneous temperature distribution (Table 1).

In a number of profiles in deep layers of *Southern Baikal*, the second maximum of chlorophyll fluorescence intensity was distinctly pronounced, two times lower than the main one (see Fig. 4, the southern part). Intermediate maxima were also revealed at all the stations of pelagial of *Northern Baikal* within the deep zone below 200 m. Their occurrence can be associated with dynamic processes resulting in deep lowering of waters from the upper layers. Such processes are connected with the development of depth temperature convection in the period of spring warming of the lake in the conditions of decreased vertical stability of water mass. According to observations in June, 1992–1993 and July, 1997 [Ref. 13], these processes resulted in depth concentration maxima of heterotrophic microorganism, that indicates relatively fast organic matter incoming from the photic zone. In June, 2006, the depth convection signs were determined by the presence of cold water intrusion in the near-bottom layer at the station near B. Peschanya in the southern part, as well as at almost all deep-water stations of the northern part of the lake. Note, that the depths maxima F_d were not revealed in *Central Baikal* at the same period, despite near-bottom cold intrusion occurrence. A weak increase of chlorophyll fluorescence was recorded here only at the central station of m. Ukhan – m. Tonkii section.

The CPA distribution is characterized by the main maximum in the upper 100 m layer at all stations of Southern and Central Baikal, except for the station located in the m. Kadil'nyi – Mishikha river section (Fig. 5). The observed exception in the CPA distribution answers the water homothermy in the site.

In the northern part of Lake Baikal, the depth CPA maxima are equal to the half of the CPA value in the upper 100 m layer or exceed it. The coincidence of positions of fluorescence and phytoplankton CPA maxima is noted quite often (see Figs. 4 and 5).

Assessment of the fraction of micro-algae biomass being in the photosynthesis region

Before analyzing the obtained data on fluorescence as applied to the biomass estimation, the following remarks are necessary.

The preliminary analysis of fluorescence profiles for the whole depth range has shown that the values of F_d signal at depths lower than 200–300 m are close to the signals of distilled water ($F_d = F_s$ for the distilled water) for virtually all realizations.

Table 1. The depth of F_d maximum and upper and lower boundaries of the layer of the temperature jump, m

Parameter	Number of station								
	South Baikal		Central Baikal			North Baikal			
	4	5	7	9	10	13	14	15	18
F_d	100	100	25	100	50	100	25	25	50
Jump layer	is absent	94–130	96–142	92–144	115–142	105–160	54–138	52–104	45–90

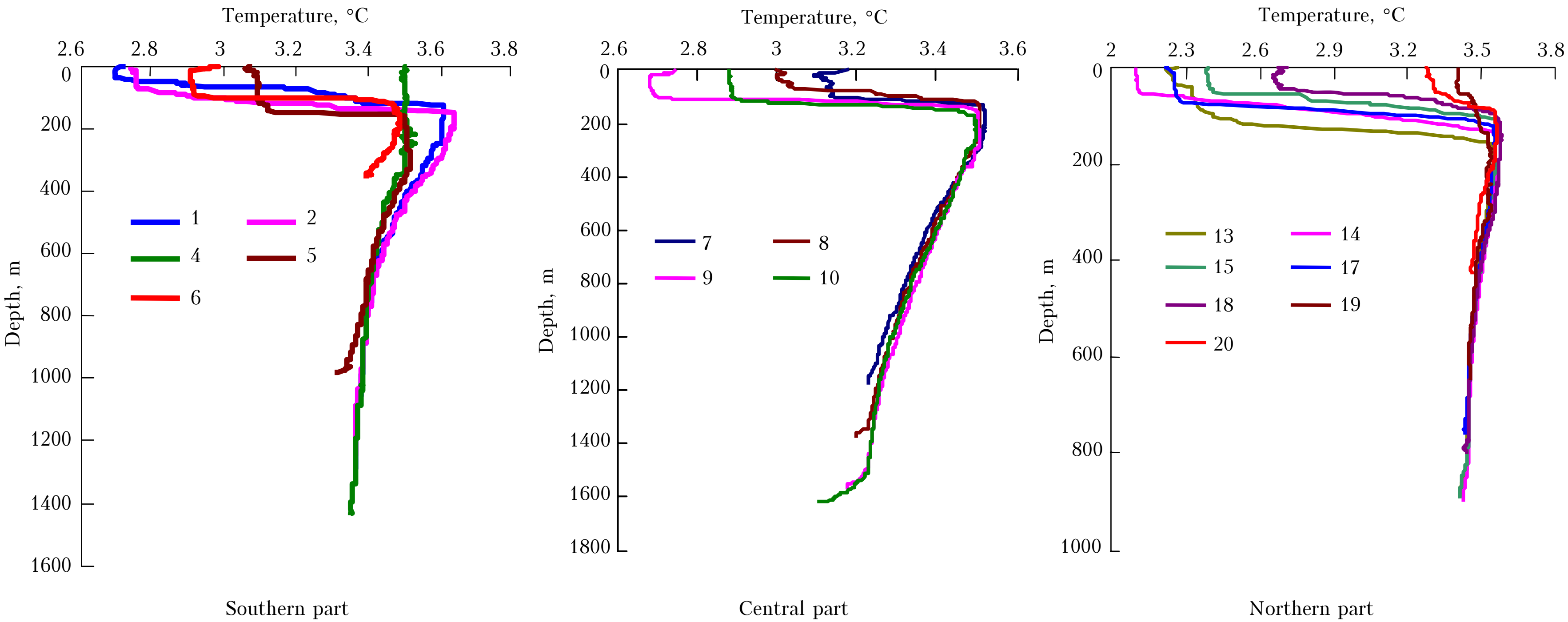
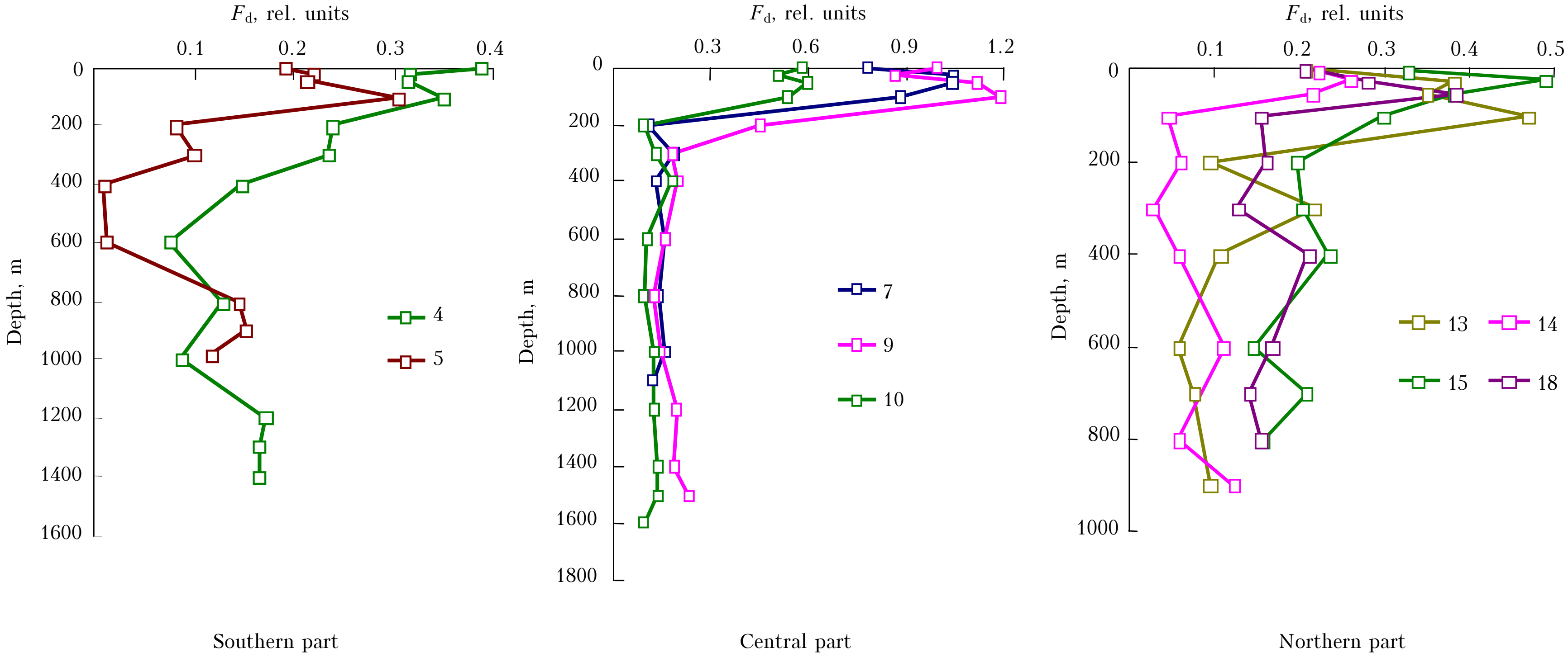


Fig. 3. Vertical temperature distribution in June, 2006 for different zones of Lake Baikal.



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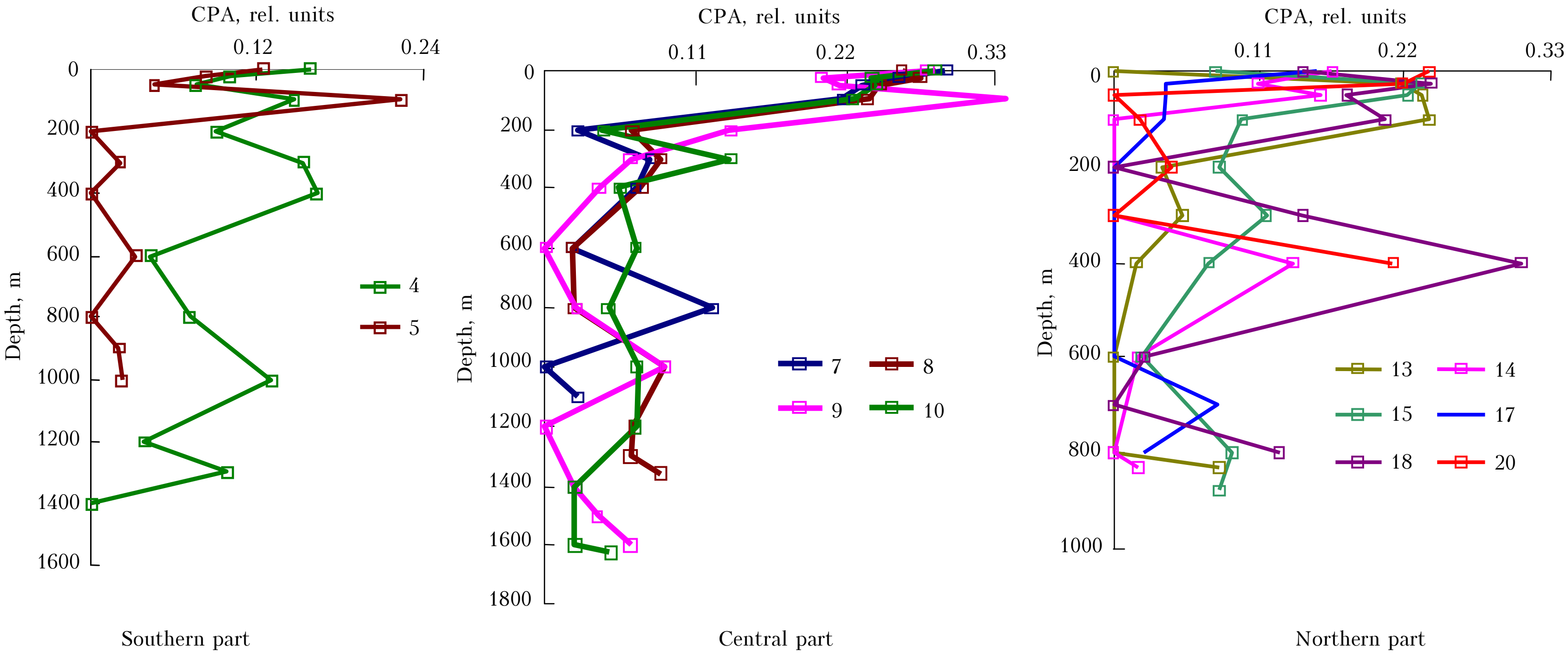

Fig. 5. Vertical CPA distribution in June, 2006 for different zones of Lake Baikal.

This F_d value is considered as the background one for our device; therefore, it is subtracted from the signals for each sample when processing the results. Hence, the data obtained from depths lower than 200 m, evidently, are quite erroneous; and when estimating chlorophyll concentrations, the errors in some realizations can attain 100%. Just by this reason, all the below values are to be considered as assessed and can be hardly used in highly accurate calculations.

The following data were used in assessment of the thickness of photosynthesis layer. As is known, the Baikal water clarity S by the Secci disk attains 40 m at the homothermy occurrence.[14] Hence, the thickness of the water layer, where photosynthesis is effective,[15] is $2.5S = 100$ m.

Table 2 presents the mean values and rms deviations of phytoplankton chlorophyll fluorescence intensity, as well as CPA in the upper 100 m (photic) layer.

Table 2. The mean intensity of chlorophyll fluorescence and CPA in the upper 100 m layer of Lake Baikal

Parameter	South	Center	North
Fluorescence, rel. units	0.34 ± 0.11	0.84 ± 0.24	0.27 ± 0.11
CPA	0.14 ± 0.06	0.25 ± 0.04	0.14 ± 0.08

Provided the fluorescence intensity is proportionate to the phytoplankton chlorophyll concentration and its biomass, we can calculate the fraction (in percents) of the micro-algae biomass, being in the photosynthesis region, in the total biomass of photosynthetics, distributed in the water column. The fraction of phytoplankton, being in the photic layer, in its total biomass is given in Table 3.

Table 3. The fraction (%) of phytoplankton, being in the photic layer, in the total biomass in the water column

	South	Center	North
Value range	15–25	20–35	15–30

An opinion exists that the sunlight can penetrate at a depth of 500 m in Baikal waters.[16] It is clear, that the solar radiation intensity at large depths is very low, but some phototrophs are capable to photosynthize at such illuminance as well. In the period of measurements, the layer of temperature jump was not lower than 200 m. The main maximum of (fluorescence) phytoplankton biomass was observed in the region of thermocline. From here, the phytoplankton percentage above the thermocline was assessed in different parts of Lake Baikal (Table 4).

Table 4. The fraction (%) of phytoplankton above the thermocline in the total biomass in the water column

	South	Center	North
Value range	30–42	38–52	30–47

The obtained data show that more than a half of all phytoplankton is beyond the photic layer in the period of spring photothermy development. These results are in good agreement with conclusions of Ref. 15, where the vertical distribution of water biota was analyzed.

Thus, since the other part of biomass is mainly concentrated under the thermocline, this part of phototrophs cannot directly influence the absorption of carbon dioxide in the "atmosphere–water" system.

Conclusion

Let us note the most interesting feature of the biota CPA distribution over the lake waters. The biota activity in Southern Baikal (the middle of hydrological spring) and Northern Baikal (just after the ice breakup) is characterized in total by low CPA values. At the same time, the beginning of hydrological spring in the Central Baikal is accompanied by an intensive effect of water photosynthetics.

Such regularity is observed in phytoplankton biomass distribution, determined by the F_d value, in the upper 100 m water layer. The highest F_d was recorded in the Central Baikal, where the hydrological spring began at that time.

The phytoplankton assessment above the thermocline shows the algae fraction to be between 30 and 50% of the whole amount in different parts of Lake Baikal. Therefore, in this period, more than a half of phototrophs are concentrated in the aphotic zone of the lake, where photosynthesis is improbable. Consequently, less than a half of photosynthesizing organisms of Lake Baikal can participate in "water–atmosphere" gas exchange in the period of spring homothermy formation.

Acknowledgements

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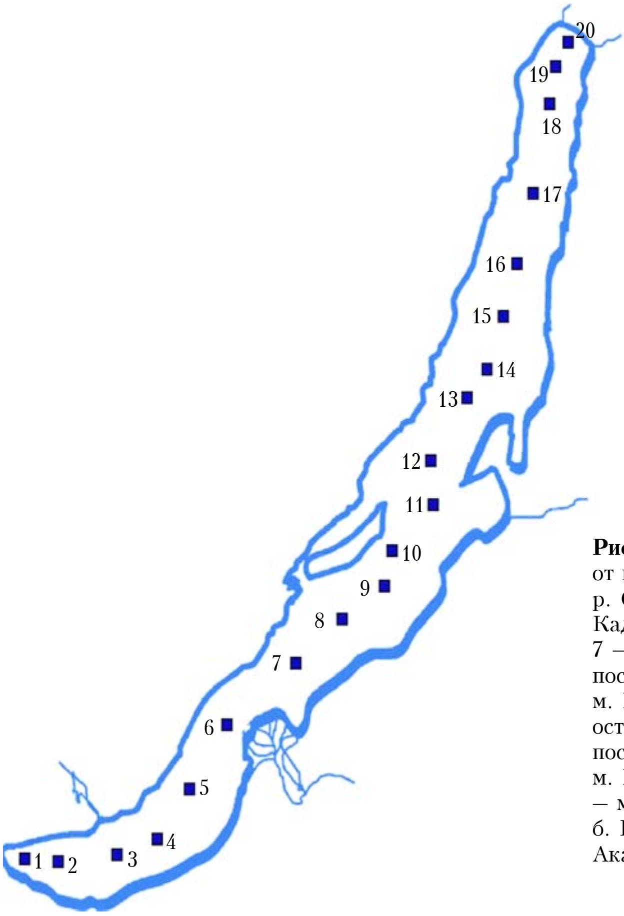
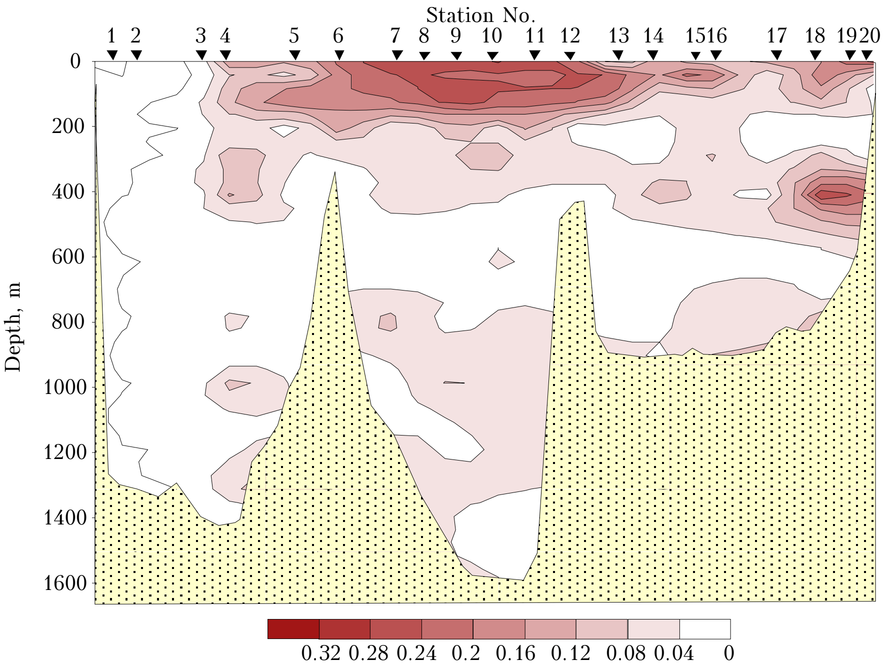


Рис. 1. Расположение станций отбора проб воды: 1 — 15 км от пос. Култук; *центры разрезов*: 2 — пос. Маритуй — р. Солзан; 3 — пос. Листвянка — пос. Танхой; 4 — м. Кадильный — р. Мишиха; 6 — м. Красный Яр — пр. Харауз; 7 — р. Анга — р. Сухая; 8 — Ольхонские ворота — пос. Болдаково, 10 — 10 км от м. Ижимей; 11 — м. Хобой — м. Крестовый; 13 — м. Покойники — Большой Ушканий остров; 14 — м. Заворотный — р. Сосновка; 15 — м. Елохин — пос. Давша; 16 — м. Черемшаный — р. Кабанья; 17 — м. Котельниковский — г. Амнундакан; 18 — пос. Байкальское — м. Турали; 19 — р. Тыя — м. Немнянко; 5 — 10 км от б. Песчаной; 9 — м. Ухан — м. Тонкий; 12 — на Академическом хребте; 20 — 7 км от г. Нижнеангарска



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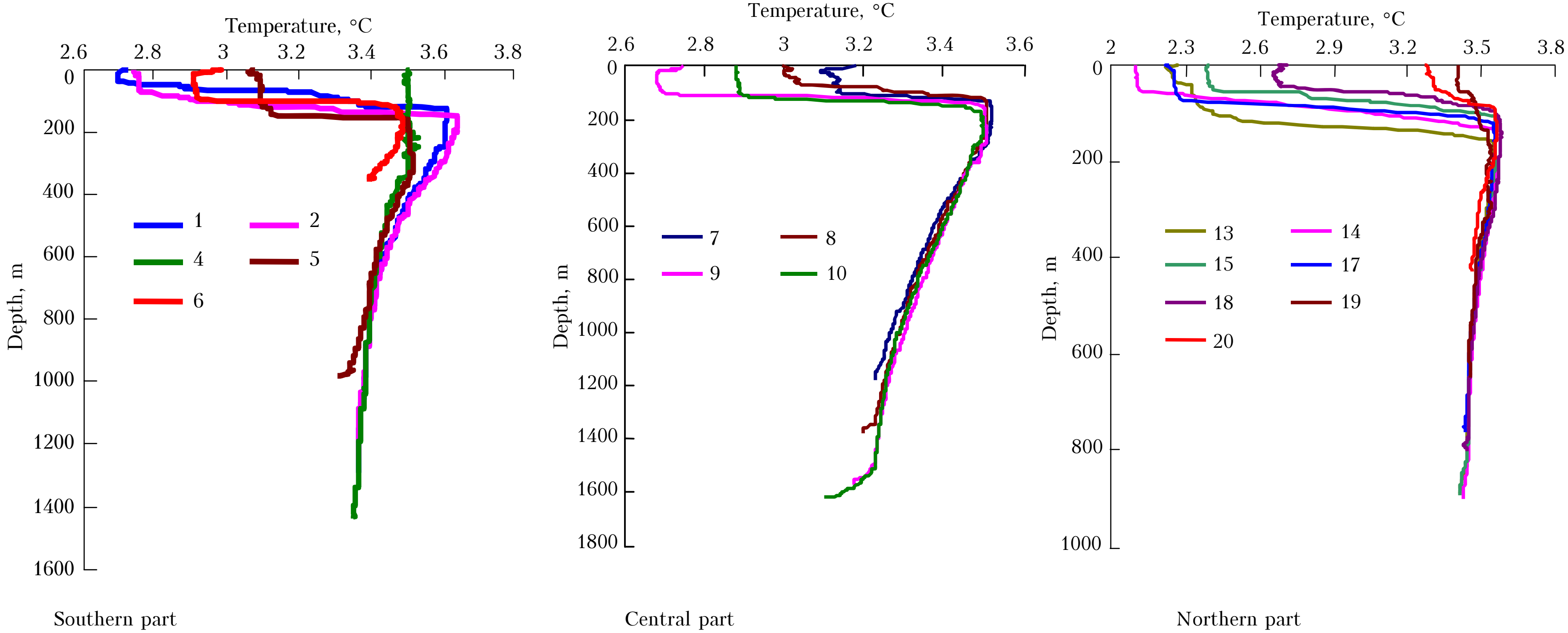

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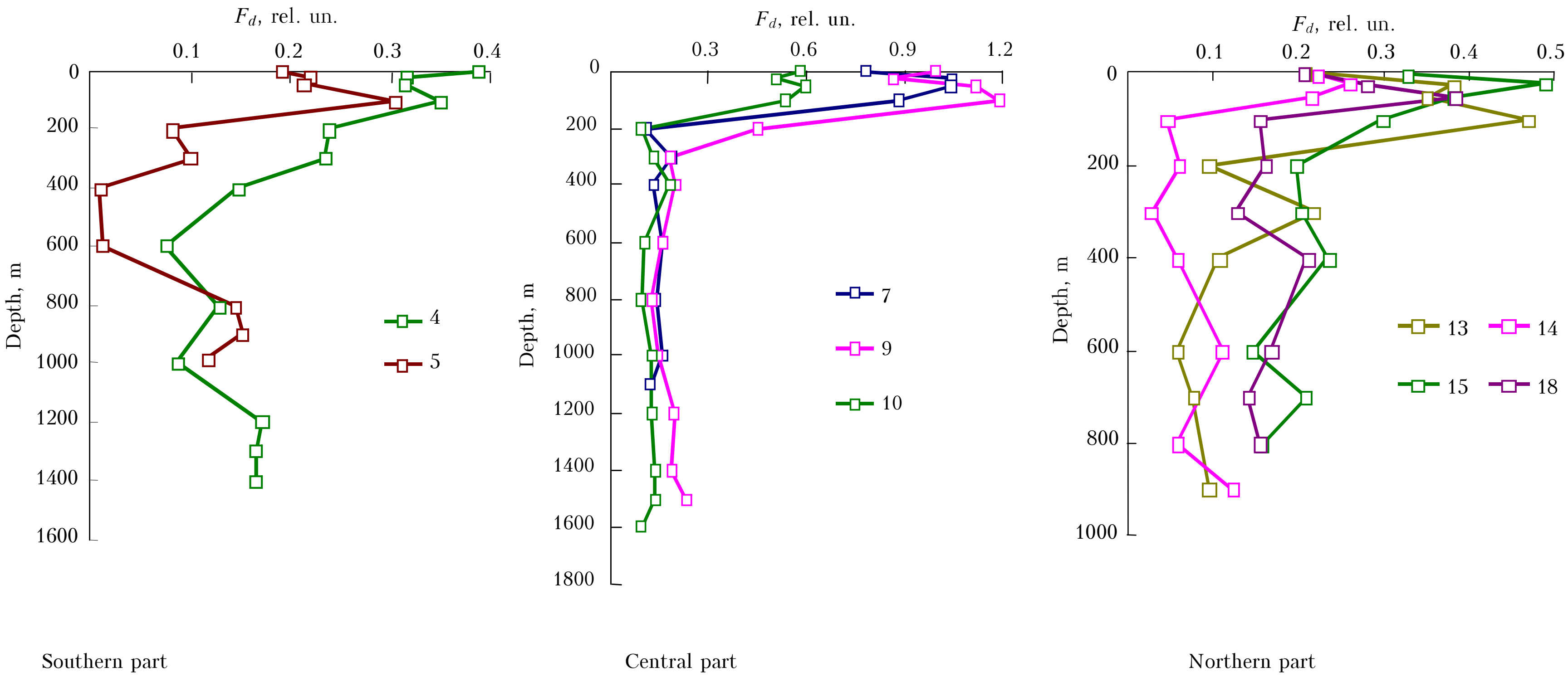

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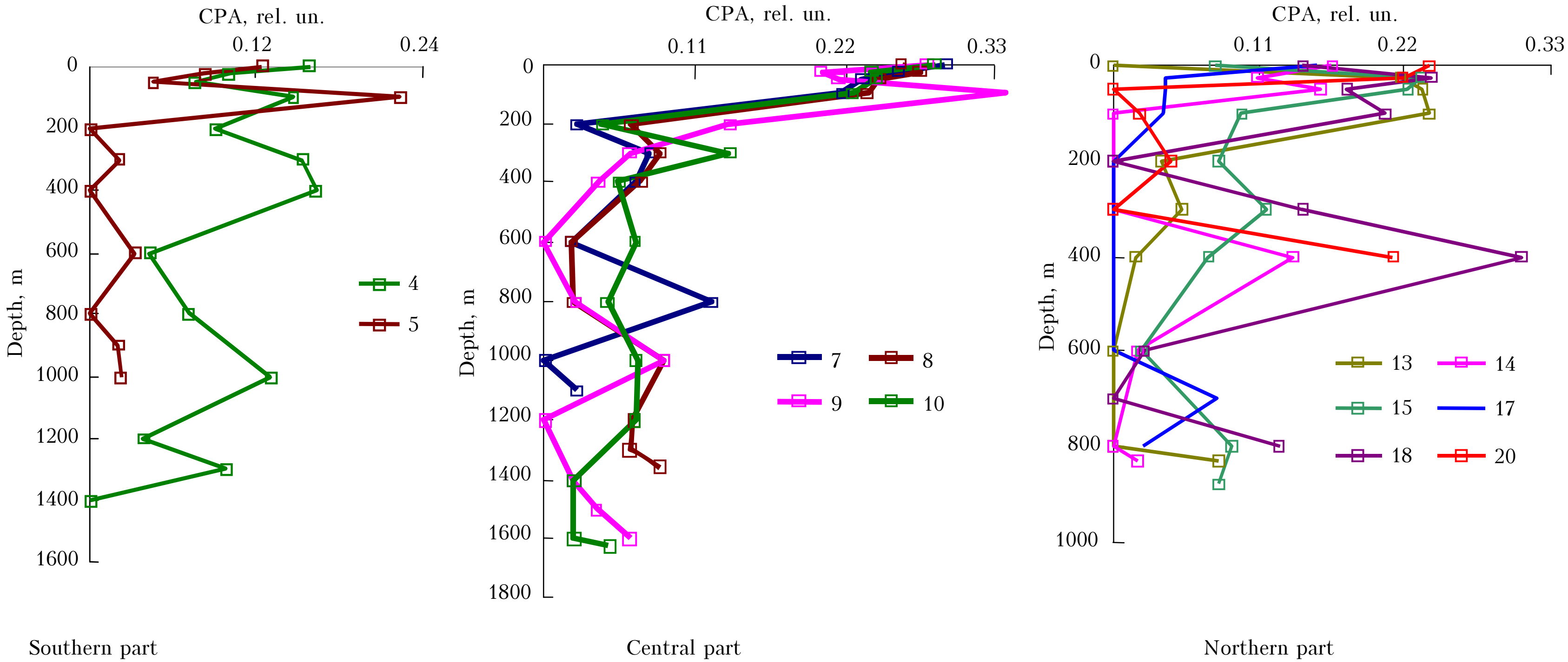

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