Primary production of the skerries area of Lake Ladoga in spring and summer, 2003

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Introduction

It is known that one original cause of an anthropogenic eutrophication reservoir can be a steadily increasing concentration of biogenic elements (mainly phosphorus) in the water. The chlorophyll *a* index is preferred by researchers because of its rapid reaction to the eutrophication process and the simplicity of its definition, it provides a rapid quantitative indication of the trophic status of the reservoir. The most sensitive parameter for estimating trophic status, however, is frequently the primary production level, which is connected with the discrepancy between estimates of trophic status on a chlorophyll *a* basis and primary production values. The intensity of photosynthesis can be different at the same chlorophyll *a* content, as photosynthesis depends on the age of the seaweed (algal component). In addition, the common measure of chlorophyll content in natural waters can include not only active but also inactive, dead chlorophyll cells. In view of the fact that there are sometimes divergences in estimates of reservoir trophic state obtained using the above parameters, it is desirable to use them in combination.

Material and methods

In connection with the acceleration of anthropogenic eutrophication in Lake Ladoga, a study of primary production processes has been taking place there since 1975. Up to 1990, primary production was measured by autoradiography and algological methods (Petrova 1982, Petrova *et al.* 1992, Gutelmakher 1986), while from 1992 onwards it has been determined only in summer and by a bottle method with oxygen updating (Letanskaya 2000, 2002). The purpose of the work has been to obtain primary production data for the spring period and to compare these with the data from the previous years. A radioisotope modification of the bottle method was used to measure primary production in 2003 (Romanenko & Kuznetsov 1974).

The determinations were made in May at 15 sampling stations distributed over the whole water area of the lake and in August at 14 stations in the northern part of the lake. Primary production *in vitro* was measured on board the research vessel. Light and dark bottles containing water from the surface layer were incubated in an aquarium for 24 hours and primary production values per square metre were calculated using the formula:

$$\Sigma A = A_{max} \cdot K_{ph} \cdot S,$$

where A_{max} = maximum photosynthesis, K_{ph} = coefficient of the change in photosynthesis with depth, S = transparency, in m.

Results

A heterogeneous distribution of the intensity of photosynthetic processes was observed in the lake during the spring, evidently brought about by spatial differentiation in the temperature of the surface water. The maximum gradient in the level of production and sharp distinctions in temperature between water masses were noted. The surface water layer warmed up to 10–12 ° by the end of May in the areas with depths of up to 10 m (the Bay of Volkhov in the south and the estuary of the River Svir in the south-east). Of the inflowing water from the rivers Volkhov and Svir were concentrated in these areas as they are separated from the main part of lake by a thermobar.

According to G.F. Raspletina (1992), the water mass in this area constantly has a higher P_{total} concentration than the other parts of the lake, and it stands out during the spring by virtue of its higher P_{min} (up to 9 mg l^{-1}), which is accompanied by increased photosynthetic activity, the intensity of which reached 100–470 mg C l^{-1} day^{-1} during the period studied. The temperature of the surface water layer in the frontal zone (of depth 26 m; station 14) was 4.2 °C. This zone was characterized by a low level of photosynthesis, the intensity of which did not exceed 55 mg C l^{-1} day^{-1} (Table 1).

At the end of May 2003, only a small area in the southern part of the lake had photosynthesis values over 50 mg C l^{-1} day^{-1}, the average value for this part of the lake being 170 and the range from 54.9 to 470.4 mg C l^{-1} day^{-1}. This average was almost a half of the production value for the spring seaweed complexes (300 mg C l^{-1} day^{-1}) received from TAO (Petrova & Antonov 1987), and 1.7 times less than the average of the summer photosynthesis values for the last few years (290 ± 30 mg C l^{-1} day^{-1}) (Letanskaya 2002).

Lower intensities of photosynthesis were recorded in the south-western part of the lake (stations C, E), despite the shallower depths (not more than 5 m). These were similar to the photosynthesis values for the warmer waters of the Bay of Volkhov (up to 9–13 °C). This area was smaller than the southern one involved in the spring cyclonic movements of water masses, and the water there had a low phosphorus content (not more than 20 mg l^{-1}) (Gusakov *et al.*

Table 1. Parameters of photosynthetic processes in the littoral zone of the southern part of Lake Ladoga.

No. of station	Depth, m	T, °C	Transparency, m	Photosynthesis intensity, mg C l^{-1} day^{-1}	Integral primary production, mg C m^{-2} day^{-1}
Bay of Volkhov and south-eastern area					
17	6.5	11.6	1.5	129.8	175.2
4	10.5	9.5	1.8	97.3	157.6
1	4.5	12.8	0.7	470.4	296.1
5	7.0	10.5	1.4	301.4	379.8
14	26.0	4.2	1.5	54.9	74.1
South-western area					
C	4.8	8.8	3.5	76.8	242.0
E	5.0	13.1	2.5	62.0	139.5
West coast					
61	14.0	7.2	2.0	22.2	40.0
38	11.6	5.1	3.3	54.9	163.1
60	5.5	8.4	1.8	121. 2	196.3
A	10.0	8.0	2.5	50.0	112.5

1987), which may be the explanation for the lower intensity of photosynthesis, the levels at the two sampling sites being 62 and 77 mg C l^{-1} day^{-1}.

The littoral zone on the west coast was quite different from the southern area, being characterized by minor influence from the inflowing water, and weak warming of the surface water. Its water temperature does not exceed 8 °C before the end of May (Naumenko & Karetnikov 2002). The intensity of spring photosynthesis here was minimal (20–55 mg C l^{-1} day^{-1}) and increased photosynthesis values (121.2 mg C l^{-1} day^{-1}) were only recorded close to the shoreline (station 60, depth 5.5 m). Analysis of the long-term data showed that the lowest summer production indices were also to be found in this area of the lake, because of the activity of hydrodynamic processes. The currents in this area also flowed faster than in other areas, which can greatly affect the survival of seaweed (algae) (Okhlopkova 1966, Letanskaya 2002).

During the research period last year the majority of Lake Ladoga (the northern pelagic area and the central part) lay outside the thermobar, so that the temperature of the water mass was extremely low (below 4 °C) and transparency was high (from 3.5 to 55 m). The distribution of photosynthesis

Table 2. Intensity of photosynthesis (mg C l^{-1} day^{-1}) and integrated production (mg C m^{-2} day^{-1}) in the central and northern areas of Lake Ladoga.

No. of station	Depth, m	T, °C	Transparency, m	Intensity of photosynthesis	Integrated production
			Central part		
82	66.0	1.9	4.2	9.5	35.9
55	72.0	1.75	5.5	8.2	40.6
25	36.0	3.7	3.5	4.2	13.2
			Northern part		
S	86.0	5.26	4.6	2.0	8.3
105	233.0	2.3	4.5	4.6	18.6
Sortavala	22.0	12.2	1.0	338.4	304.6

processes was fairly uniform within this area and their intensity was low (2.0–9.5 mg C l^{-1} day^{-1}) (Table 2).

Special conditions were experienced during this period in the skerry zone of the northern part of the lake. The surface layer of the water in the Bay of Sortavala warmed up to 12.2 °C despite its substantial depth (22.0 m), and the presence of a thermobar promoted a local concentration of sewage there that was enriched with biogenic elements. Photosynthetic processes in this area developed to an intensity comparable with that noted in the Bay of Volkhov, –338.4 mg C l^{-1} day^{-1} (Table 2).

The spatial distribution of integrated production (ΣA) was more uniform than that of the surface photosynthesis layer, because of the significant influence of the depth of the photosynthetic layer on its value. In the western area, for example, ΣA exceeded 100 mg C m^{-2} day^{-1} despite the low intensity of surface photosynthesis but higher level of water transparency. The maximal ΣA values were 157.6–379.8 (average 278) mg C m^{-2} day^{-1} in the Bay of Volkhov and 304.6 mg C m^{-2} day^{-1} in the Bay of Sortavala. The average value of ΣA for the area located outside the thermobar in the southern part of the lake was 231.7 mg C m^{-2} day^{-1}, or about 270 mg C m^{-2} day^{-1} if the skerry area is taken into account (Bay of Sortavala). This is comparable with the average ΣA of 311.5 mg C m^{-2} day^{-1} for the coastal zone in spring 1984–1989 (Petrova *et al.* 1992).

Not a lot of data are available on primary production in the skerry area, mostly on account of the limited summer season, which is the most representative time for estimating eutrophication. The horizontal distribution of primary production in summer is based on data from the parts of the lake already studied. As a rule water samples have been collected in the deep-water

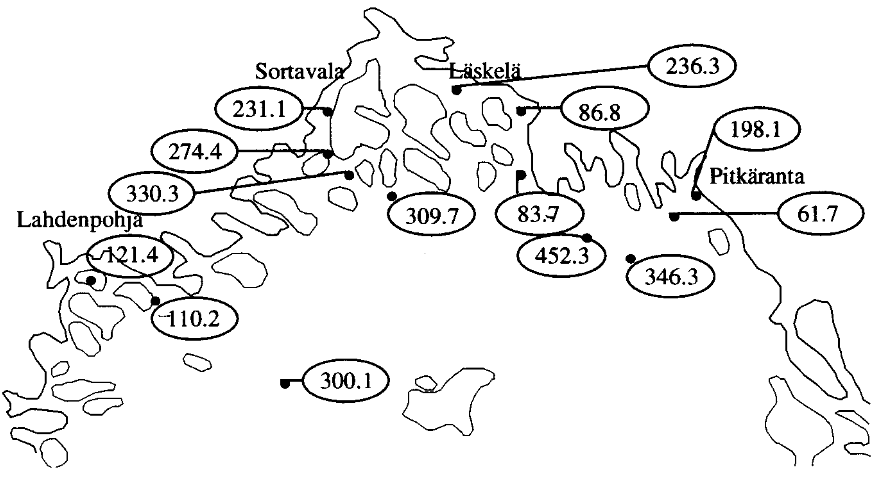

Fig. 1. Distribution of primary production in the skerry area of Lake Ladoga in summer, mg C m^{-2} day^{-1}.

areas of Lake Ladoga at the end of July or beginning of August, which is why the highest values for primary production in summer 2003 were observed in the areas with early phytoplankton development (where the summer phase of primary production prevailed at the time). The values for water transparency there were 2.9 and 3.2 m (stations 105 and 204, respectively), and those for photosynthesis intensity 115 and 157 mg C l^{-1} day^{-1}. Daily integrated production in the trophogenic layer corresponded to 300 and 452 mg C m^{-2}, and the same level (346.3 mg C m^{-2} day^{-1}), was reached in water from the area off Pitkäranta (station 99). In the bays influenced by discharges of sewage, photosynthesis values were from 17 up to 175 mg C l^{-1} day^{-1}. The summer peak in the development of primary production processes at coastal shallow sites had apparently been passed by the time. Average values for surface photosynthesis intensity were distributed as follows: about 163 mg C l^{-1} day^{-1} in the outer part of the Sortavala skerry zone, 95 in the Läskelä area, and 56 at Lahdenpohja. The low photosynthesis values in the Bay of Pitkäranta (about 40 mg C l^{-1} day^{-1}) were caused by upwelling, which affected an extensive area of this bay. The values for integrated primary production in summer 2003 are indicated on Fig. 1.

The average value for primary production in the skerry area, 366 mg C m^{-2} day^{-1}, I corresponded to the characteristics of a mesotrophic reservoir. By comparison, the average value for primary production there in the past has been 419 mg C m^{-2} day^{-1} (Letanskaya 2002). Thus the value recorded here is only marginally below the long-term average and lies within the limits of inter-annual fluctuation.

Table 3. Integrated primary production in skerry areas of Lake Ladoga, mg C m^{-2} day^{-1}.

Area	August 1994	August 1995	July 1996
Profundal	349	166	156–211
Pitkäranta	203	207	357
Sortavala	1030	286–566	238
Lahdenpohja	230	104	200
Läskelä	424	44–162	128

For comparison, data on summer primary production in the areas subject to serious anthropogenic pressure (bays in the skerry areas) during recent years are presented in Table 3.

According to the results obtained, a high level of spring plankton productivity was not indicated in 2003, and the level of the primary production in the southern and skerry parts of the coastal zone (which warmed up to 10 °C) was comparable to the parameters of mesotrophic ecosystems.

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