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SEASONAL VARIATION OF PHYTOPLANKTON BIOMASS, CHLOROPHYLL *a* CONTENT AND ALKALINE PHOSPHATASE ACTIVITY IN LAKE VIITNA PIKKJÄRV

Lake Viitna Pikkjärv is situated in the Rakvere District, on the borderline between the North-Estonian Plain and the Kõrvemaa Area, thus belonging to the belt of marginal glacial formation (Ряхни, 1963). The lake is elongated in a north-southerly direction (Fig. 1). The land around it has a soil covering of sand and gravel; podzols and sod-podzolic soils pure in nutrients predominate. The surroundings and the shores are covered with coniferous forests. The area of the lake is 16 ha, the maximum depth is 7 m (Eesti järved, 1968). The lake feeds chiefly on phreatic water; it has no visible inflows or outflows.

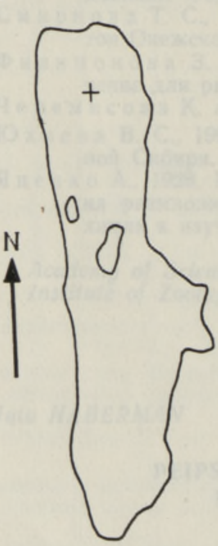

Fig. 1. Map of Lake Viitna Pikkjärv and the sampling site (+).

L. Viitna Pikkjärv is one of the few Estonian oligotrophic lakes (Mäemets, 1974), but during the recent years it has gained some features of eutrophication. This is due to an intensive use of the lake and its vicinities as a place of recreation.

The hydrochemical investigations on L. Viitna Pikkjärv were carried out during 1971—72. The results have been summarized and published (Starast et al., 1974; Симм et al., 1975). The phytoplankton studies on it are few in number. The only reported investigations were made by Pork and Kõvask (Eesti järved, 1968) in 1956—57 and in 1971—72 by Kõvask (Кываск, 1973). No data on the chlorophyll content of L. Viitna Pikkjärv have been published. The present study was carried out in order to investigate the seasonal cycle and the vertical distribution of chlorophyll *a*, the alkaline phosphatase activity, the phytoplankton biomass and the species composition in L. Viitna Pikkjärv.

Material and methods

The sampling program, consisting of seven samplings, was carried out between March and November, 1975. The water samples were collected with a Ruttner sampler in the deepest area of the lake (depth ca 5—6 m), at depths of 0, 1, 3, 4 m during each sampling. All phytoplankton samples were fixed in formalin, whereas chloroform was added to the alkaline phosphatase and the inorganic phosphate samples. The alkaline phosphomonoesterase activity (EC 3.1.3) was determined using a slight modification of the methods by Reichardt et al. (1967) and Jones (1972a, b), and the inorganic phosphate content by means of the molybdate blue method (Алекин, 1954). The concentrations of chlorophyll *a* were determined using the method and calculation described by Talling (1969).

The quantitative phytoplankton sample concentration and the biomass calculations are given in an earlier study (Milius, Pork, 1977). The seasonal data on the biomass, the chlorophyll *a* and the phosphatase activity are based on the average values of the vertical distribution.

In addition to this, at each sampling the dissolved oxygen was measured by an electrochemical method and the temperature by an electrical thermometer. The pH values were determined colorimetrically in the field, by means of a scale. The transparency was measured by a Secchi disc.

Results

Physical and chemical data

The water of the lake was green in tone. Transparency varied from 3.1 m to 4.8 m, extending to the bottom of the lake in late autumn.

A homogeneous temperature pattern was encountered in L. Viitna Pikkjärv. The temperatures in the middle of March were the lowest and close to 2 °C. The maximum temperatures occurred in July and August (21.5 and 23.0°, respectively). A rapid cooling of water began during late September and early October (to 10°) which was followed by a continuing sinking of the temperature in early November (3°). The vertical distribution of temperature was almost uniform — the lake is homothermal.

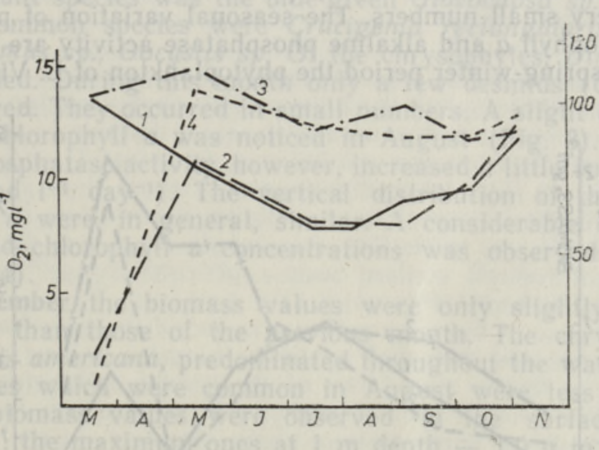

Fig. 2. Oxygen concentration and saturation of water with oxygen. O_2 mg l^{-1} surface layer (*1*), bottom layer (*2*); O_2 % surface layer (*3*), bottom layer (*4*).

Most of the time the lake is rich in oxygen. The oxygen content in the surface layers was 8—13 mg O_2 l^{-1} (saturation 85—112%), in the bottom layers 0.9—12 mg O_2 l^{-1} (saturation 7—96%, see Fig. 2). The oxygen concentration in the surface layers differed a little from that in the bottom layers (about 1 mg O_2 l^{-1}) during the summer period. The bottom layer of the water may have been enriched by photosynthesis as well (the light penetrated into the water down to the bottom) or by the mixing of water, the lake being homothermal at that time. The oxygen stratification occurred only under the ice-cover at the end of winter when the oxygen concentration decreased to 0.9 mg O_2 l^{-1} near the bottom. The oxygen saturation percentage dropped sharply in the 3—4.5 m layer (e. g., in March by 1 m — 102%, 2 m — 84%, 3 m — 43%, 4 m — 17% and 4.5 m — 7%). During the winter the oxidation at the bottom layer of the water consumed over 80 per cent of the oxygen deposited in autumn.

The pH of the lake is slightly acid (6.0 to 6.8). The seasonal variation of hydrogen-ion concentration is insignificant; the pH of the surface layers varies within the range from 6.2 to 6.8, and in the bottom layers the variation is from 6.0 to 6.7.

The content of inorganic dissolved phosphate in the water was uniform throughout the year, varying from 0.1 to 8.6 μg of phosphate l^{-1}; the seasonal variation of phosphorus compounds is not yet formed in the lake.

Seasonal cycles and vertical distribution

The phytoplankton biomass of L. Viitna Pikkjärv is low and poor in species. The species content of the community started in the lake previously has changed in recent years. At present, desmids are hardly found in open water, and the role of the greens and the blue-greens has grown, which testifies to a slight eutrophication of the lake.

28 algal taxa were determined during 1975. The species of green algae predominated. Several of them, e. g., *Grucigenia quadrata, Tetraedron minimum* and *Ankistrodesmus sp.* were constantly observed in the samples. Chrysophytes exceeded the others in number; *Uroglenopsis americana* was especially prominent. Of the blue-greens the tiny *Gloeocapsa sp.* was fairly abundant. The diatoms in the open water were poor in species and occurred in very small numbers. The seasonal variation of phytoplankton biomass, chlorophyll *a* and alkaline phosphatase activity are given in Fig. 3. During the spring-winter period the phytoplankton of L. Viitna Pikkjärv

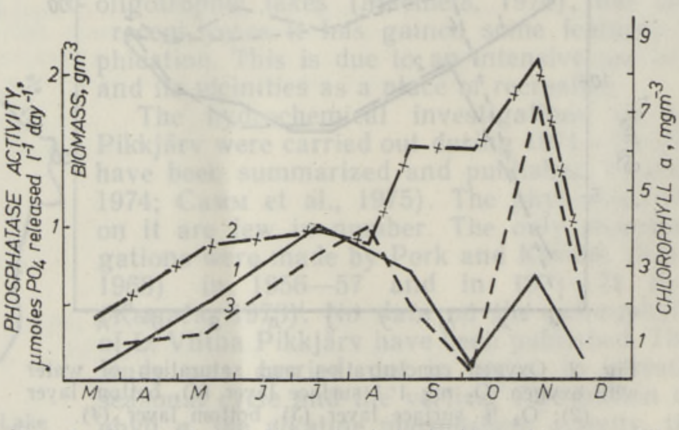

Fig. 3. Seasonal variation of phytoplankton biomass (*1*), chlorophyll *a* (*2*) and phosphatase activity (*3*).

was poor in species and showed very low biomass concentrations ranging from 0.03 to 0.08 g m^{-3} throughout the water column in **March**. The phytoplankton community was mainly composed of phytoflagellates. The chlorophyll *a* (1.5—1.9 mg m^{-3}) and alkaline phosphatase activity (0—0.3 μmoles PO_4 released l^{-1} day^{-1}) were also low and uniform throughout the water column under the ice-cover.

After the melting of ice in late April, the phytoplankton biomass concentrations increased. In mid-**May** they were about five times higher than the winter biomass values. Chlorophyll *a* values increased only about twice as compared to the data obtained in March (Fig. 3). The phosphatase activity curve showed a similar increase. Chrysophytes predominated during May. The vertical distribution pattern of chlorophyll *a* was also similar to that of the phytoplankton biomass, increasing in the direction of the bottom (Fig. 4). This increase was caused by chrysophytes whose biomass increased nearly twice at the bottom as compared to the surface biomass values. The chlorophyll data indicated a similar increase at the bottom, whereas the phosphatase activity was the same both in the surface layers and at the bottom.

The highest biomass values (1.0 g m^{-3}) were found in **July**. In contrast to this, no chlorophyll *a* peak was found in this month. The chlorophyll *a* content increased only a little (from 3.5 to 3.8 mg m^{-3}), and the phosphatase activity increased to the same extent as the biomass (Fig. 3). The phytoplankton was relatively rich in species. It was mainly composed of pyrrophytes (*Ceratium hirundinella*), green algae, such as *Ankistrodesmus sp., Tetraedron minimum, Oocystis sp., Elakatothrix gelatinosa*, and blue-greens (*Gloeocapsa sp.*). The latter were found in large numbers, but their small dimensions did not increase the total biomass concentration considerably. The vertical curve of chlorophyll *a* supported the biomass results. The maximum values of biomass and chlorophyll *a* were observed at the bottom. This appeared to be due to the concentration of *Ceratium hirundinella* at the bottom.

During **August** the phytoplankton was the richest in species (14 species). It was composed of greens, blue-greens and chrysophytes. The most abundant species was the blue-green *Gloeocapsa sp.* Of the greens, the most common species were *Crucigenia rectangularis, C. quadrata, Ankistrodesmus sp., Oocystis sp.* Of the chrysophytes, *Dinobryon bavaricum* prevailed. During this month only a few desmids (*Cosmarium sp.*) were observed. They occurred in small numbers. A slight decrease of biomass and chlorophyll *a* was noticed in August (Fig. 3). In contrast to this, the phosphatase activity, however, increased a little (up to. 1.0 μmoles PO_4 released l^{-1} day^{-1}). The vertical distribution of the biomass and chlorophyll *a* were, in general, similar. A considerable decrease in the biomass and chlorophyll *a* concentrations was observed in the bottom layer (Fig. 4).

In **September** the biomass values were only slightly lower (up to 0.7 g m^{-3}) than those of the previous month. The chrysophytes, e. g., *Uroglenopsis americana*, predominated throughout the water column. The other species which were common in August were less abundant. The minimum biomass values were observed in the surface layer (only 0.24 g m^{-3}), the maximum ones at 1 m depth — 1.0 g m^{-3} (Fig. 4). The phosphatase activity also decreased nearly at the same rate as the biomass values.

Despite the lower biomass concentrations, the chlorophyll *a* data showed extremely high values in early September (Fig. 3). Furthermore, the chlorophyll *a* concentrations remained high during the autumn. No satisfactory explanation for this differentiation can be given at present. However, the vertical curve of chlorophyll *a* supported the vertical biomass results. The minimum value of chlorophyll *a* (3.8 mg m^{-3}) was observed in the surface layer, and the maximum value (7.3 mg m^{-3}) at 1 m depth (Fig. 4).

In **October** the biomass values were very low, decreasing up to the spring-winter level in March (the average biomass 0.08 g m^{-3}, Fig. 3).

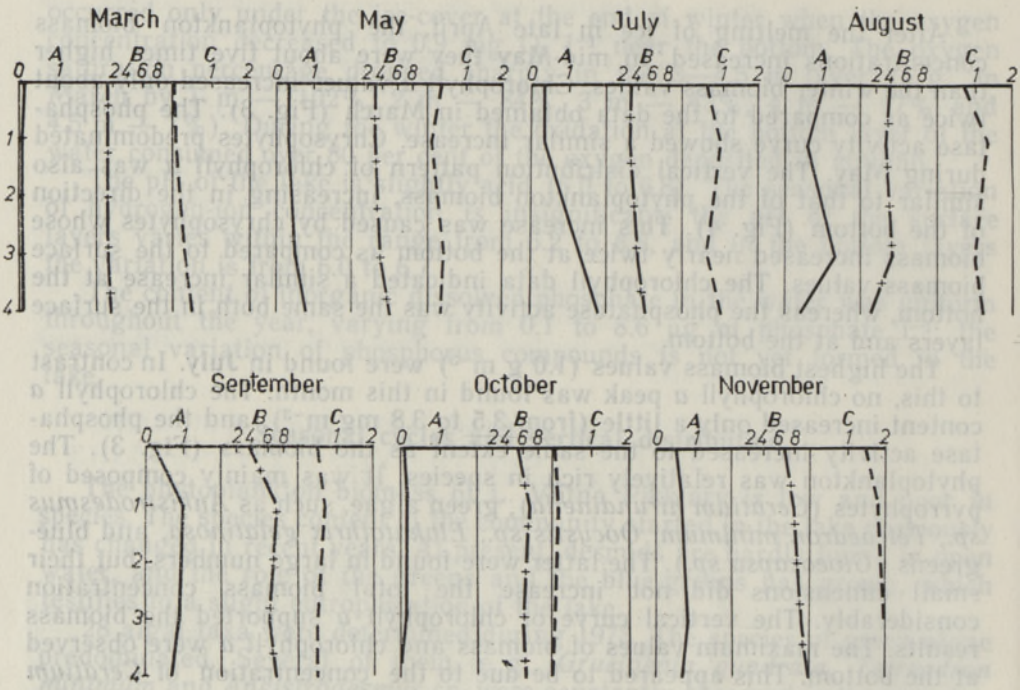

Fig. 4. Vertical distribution of phytoplankton biomass (*A*), chlorophyll *a* (*B*) and phosphatase activity (*C*).

The highest biomass value was observed at 1 m depth (0.13 g m^{-3}), decreasing in the direction of the bottom. The phytoplankton was poor in species. *Uroglenopsis americana*, which was dominant in September, disappeared, but the diatoms (*Tabellaria fenestrata*) and the greens (*Ankistrodesmus sp.*) were found in larger numbers than in the previous month. The minimum phosphatase activity values for the year were recorded in October, as well. The chlorophyll *a* values decreased only a little. The chlorophyll content was approximately uniform from the surface to the bottom (Fig. 4).

A sharp increase of biomass values was found in early **November**. The biomass concentrations increased up to the biomass values of September. This may be due to the abundance of the greens (*Ankistrodesmus sp.*) and the small blue-greens. The chlorophyll *a* concentrations increased also, but not so markedly as the biomass values. However, in early November, the maximum values of chlorophyll *a* in L. Viitna Pikkjärv for the year were found (8.4 mg m^{-3}, see Fig. 3). A sharp increase in the values of phosphatase activity was recorded in November, likewise (mean values 1.8 μmoles PO_4 released l^{-1} day^{-1}). The vertical distribution of the biomass, chlorophyll *a* and phosphatase activity showed a similar tendency to increase a little towards the bottom (Fig. 4).

Discussion

The mean values of phytoplankton biomass in L. Viitna Pikkjärv were extremely low, the mean concentrations ranging from 0.06 to 1.0 g m^{-3}. The maximum and minimum values were recorded in July and in March, 1.83 and 0.03 g m^{-3}, respectively. The mean biomass value of the year was 0.55 g m^{-3}. Two peaks of phytoplankton development were recorded during the annual cycle, one in mid-summer, in July, with an average value of 1.0 g m^{-3}, and a slightly lower one in early November, with 0.7 g m^{-3}. Analogous seasonal cycles of the phytoplankton biomass were found during the years 1971/72 (Кываск, 1973). In regard to the biomass production and its seasonal cycle, L. Viitna Pikkjärv is, therefore, different from L. Nohipalu Valgjärv, the most oligotrophic lakes in Estonia. The biomass values of L. Nohipalu Valgjärv are lower than those of L. Viitna Pikkjärv, and its seasonal cycle appears to be unimodal with the spring peak. The differences were also reflected in the dissimilarities of the seasonal composition of phytoplankton communities. Similar features of phytoplankton biomass values and its seasonal cycles (with peak in July and November) were noticed in L. Huron (an oligotrophic lake) at the mid-lake station (Vollenweider et al., 1974).

The change of the phytoplankton aspects in L. Viitna Pikkjärv cannot be clearly distinguished. It was especially difficult to get a clear-cut picture of the dynamics; during the spring period *Ceratium hirundinella* and *Dinobryon bavaricum* were more abundant in the phytoplankton. Later they were found only in the layers near the bottom.

The chlorophyll *a* data for L. Viitna Pikkjärv were also low, the mean values ranging from 1.6 to 8.4 mg m^{-3}. The yearly mean of chlorophyll *a* was 4.7 mg m^{-3}. There appeared to be a fair correlation between the seasonal cycle of the chlorophyll *a* and the phytoplankton biomass up to early August. The chlorophyll was the lowest in the winter months and relatively high (3.8 mg m^{-3}) at the time of the mid-summer phytoplankton peak, with a secondary peak in early September (6.2 mg m^{-3}). After the summer maximum in July the biomass values decreased, whilst the chlorophyll *a* values increased continually from September onwards, reaching the maximum in early November. The sharp increase in the chlorophyll *a* content may be due to changes in the composition of phytoplankton communities. In September the phytoplankton community was changed; it was poorer in species than in the previous month, but the chrysophytes, such as *Uroglenopsis americana*, predominated, showing lower biomass values but a rather high chlorophyll *a* content. The same discrepancy between the biomass and chlorophyll values was found in L. Saadjärv in June, when the dominant species was the above-mentioned alga (Milius, Pork, 1977). The second peak in the biomass was observed in early November, coinciding with the maximum values of chlorophyll *a* (8.4 mg m^{-3}) for the year.

The alkaline phosphatase activity followed the seasonal variations shown by the phytoplankton biomass, with a few exceptions, in August and November. The first peak of phosphatase activity was found in August, not in July, as was the case with the biomass, and the secondary peak in November was higher than the first one in August. The peak in November might have been partially called forth by bacteria which were found in great numbers in the samples. The mean values of phosphatase activity ranged from 0.03 to 1.8 μmoles PO_4 released l^{-1} day^{-1}, and the yearly mean of phosphatase activity for L. Viitna Pikkjärv was 0.67 μmoles PO_4 released l^{-1} day^{-1}.

The vertical distribution of the biomass, chlorophyll *a* and alkaline phosphatase activity showed a similar tendency to increase in the direction of the bottom, whereas the maximum values were observed in the bottom layers. The concentration of the biomass near the bottom layers in oligotrophic lakes has been recorded elsewhere, e. g., in L. Nohipalu Valgjärv, where the biomass of the surface layers differed from those of the bottom layers about 20 times (Kõvask, 1975)*. It can be presumed that the difference is caused by sunken specimens. In some cases other species predominated near the bottom. The increase of the biomass and chlorophyll *a* in the bottom layers of shallow oligotrophic lakes can be explained by relatively good light conditions near the bottom (the light penetrated to the bottom).

To sum up, at present L. Viitna Pikkjärv is basically oligotrophic, but during recent years it has gained some features of eutrophication. The conclusion is based upon the biomass and chlorophyll *a* values for oligotrophic and eutrophic lakes by Vollenweider et al. (1974) and Dobson et al. (1974).

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VIITNA PIKKJÄRVE FÜTOPLANKTONI BIOMASSI, KLOROFÜLLI *a* SISALDUSE JA ALUSELISE FOSFATAASSE AKTIIVSUSE SESOONNE DÜNAAMIKA

Resümee

1975. aastal uuriti Viitna Pikkjärve fütoplanktoni biomassi, liigilise koostise, klorofülli *a* sisalduse ja fosfataasse aktiivsuse sesoonset dünaamikat. Fütoplanktoni aastases tsüklis täheldati kaht maksimumi (juulis ja novembris) ning kaht miinimumi (oktoobris ja talvel). Biomassi väärtused on väga madalad (0,03—1,8 g m^{-3}), aasta keskmine 0,55 g m^{-3}. Madalad on ka klorofülli *a* väärtused, aasta keskmine 4,7 mg m^{-3}. Klorofülli *a* sesoonne dünaamika korreleerus hästi biomassi dünaamikaga kuni augusti alguseni. Madalaim oli klorofülli *a* sisaldus talvel ja suhteliselt kõrge (3,8 mg m^{-3}) fütoplanktoni maksimumi korral juulis; teine maksimum (6,2 mg m^{-3}) oli septembris, kui dominantliigiks oli *Uroglenopsis americana*. Septembris-oktoobris vähenesid biomassi väärtused (oktoobris kuni talviste väärtusteni), kuna klorofülli *a* sisaldus jäi kõrgeks ning saavutas aasta maksimumi (8,4 mg m^{-3}) novembris.

Biomass, klorofülli *a* sisaldus ja fosfotaasne aktiivsus vertikaalsihis üldiselt korreleeruvad, kusjuures maksimumväärtusi täheldati põhjakihtides. Ühtlasi on klorofüllisisaldus suurel määral sõltuv fütoplanktoni liigilisest koostisest.

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Сезонные изменения биомассы, содержания хлорофилла *а* и щелочной фосфатазной активности фитопланктона в озере Вийтна Пиккъярв

Резюме

В течение 1975 года проводились наблюдения за сезонной динамикой и вертикальным распределением биомассы, видового состава, содержания хлорофилла *а* и фосфатазной активности фитопланктона оз. Вийтна Пиккъярв. Годовой цикл фитопланктона имеет два максимума (в июле и ноябре) и два минимума (в октябре и зимой). Показатели биомассы фитопланктона и содержание хлорофилла *а* низкие (среднегодовые значения 0,55 *г/м*³ и 4,7 *мг/м*³ соответственно). Сезонный ход содержания хлорофилла аналогичен изменению биомассы до августа. Второй максимум содержания хлорофилла наблюдается в сентябре (6,2 *мг/м*³), доминирует *Uroglenopsis americana*. Третий максимум — (8,4 *мг/м*³) в ноябре.

Вертикальное распределение биомассы, содержания хлорофилла *а* и фосфатазной активности в общем коррелируют. В сезонной динамике лучше коррелируют показатели биомассы и фосфатазной активности. Содержание хлорофилла *а* в большей степени зависит от видового состава фитопланктона.

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