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Anu MILIUS, Maia PORK

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

For quantitative analyses of phytoplankton, several biomass parameters have been used in limnological research; we used both biological-microscopic techniques (taxonomic identification and enumeration) and biochemical (estimation of chlorophyll *a* and phosphatase activity) determinations.

Biochemical methods for quantitative analyses of phytoplankton have not been used in Estonia up to now, but the chlorophyll *a* content of phytoplankton has been determined in the Soviet Union (Пырина, 1966; Winberg et al., 1973; Пырина et al., 1973; Сидько et al., 1973).

Foreign authors have made a somewhat wider practice of determining the chlorohpyll *a* content in quantitative investigations of phytoplankton (Talling, Driver, 1963; Robertson et al., 1971; Glooschenko et al., 1973, 1974a, b; Berman, Pollingher, 1974, Schindler, Fee, 1974; Vollenweider et al., 1974; etc.).

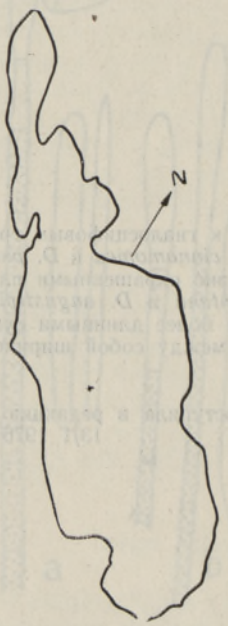

Fig. 1. Map of Lake Saadjärv and the sampling site (+).

In recent years phosphatases, which are very common and widespread enzymes catalyzing the hydrolysis of organic phosphate esters, have come to the attention of researches. A connection between alkaline phosphatase activity and plankton biomass has been established (Jones, 1972a, b).

The present investigation sets as its aim to study the seasonal correlation between phytoplankton biomass, species composition, chlorophyll *a* content and phosphatase activity in Lake Saadjärv, because Estonian lakes have not been investigated from this point of view as yet.

Limnological data

Lake Saadjärv, situated in the eastern part of Estonia, is the sixth largest lake in Estonia (area 707.6 ha). The lake is surrounded by a belt of drumlins which have mostly a clayey moraine ground cover. Soaked fertile rendzina soils predominate, and most of the drumlins are arable. The lake is partly boarded with a narrow strip of marshy meadow, and partly with fields and

pastures. The lake has few influxes, and the outflow is also inconsiderable. The shape of the lake is oblong, stretching from NW to SE (Fig. 1). The mean depth of the lake is 8.0 m, the greatest depth 25.0 m (Eesti järved, 1968). According to the typology of Estonian lakes (Mäemets, 1974), the lake belongs to the group of eutrophic lakes with mesotrophic features.

Materials and methods

Water samples were taken once a month at the deepest point of Lake Saadjärv, at approximately 23 m of depth, from May to December 1974. The samples were collected with a Ruttner water sampler.

In estimating chlorophyll *a*, alkaline phosphatase activity and inorganic phosphate, the number of samples varied from month to month, but each time one sample was taken from a depth of 1 m, one epilimnetic sample above the thermocline and another from the metalimnion below the thermocline, and one sample from hypolimnetic water during stratification. During the autumn circulation the samples were taken at depths of 1, 5, 10, 15 and 20 m. Chloroform was added to the samples of alkaline phosphatase and inorganic phosphatase, and both enzyme activities and chlorophyll concentrations were estimated as soon as possible after collection.

The samples for quantitative phytoplankton analysis were collected at depths of 0, 1, 3, 5, 7, 10, 15 and 20 m, and those for qualitative investigations by means of a plankton net (Müller gauze No. 25). All the phytoplankton samples were fixed in formalin.

The dissolved oxygen was measured by the electrochemical method and the temperature by an electrothermometer. The pH values were determined in the field colorimetrically. The transparency was measured by a Secchi disk.

The activity of alkaline phosphomonoesterases (EC. 3.1.3.) was directly determined in each sample by a slight modification of an earlier method (Reichard et al., 1967; Jones, 1972a), using p-nitrophenylphosphate as substrate, 10 ml water samples of unfiltered and 0.22 µm (Millipore) membrane-filtered were incubated at 25 °C with 1 ml of substrate solution (0,1 g l^{-1} p-nitrophenyl phosphate in 0.1 M Tris-HCl buffer, pH 8.4). The reaction was stopped with 1 ml 1 N NaOH after 72 h of incubation and the coloured end-product estimated spectrophotometrically at 400 nm. Control was prepared for each water sample, and colorimetric measurements were carried out against the control. All determinations were repeated three times. Prior to the use of the alkaline phosphatase assay, a confirmation that the response was of biochemical origin was obtained by checking the linearity of reaction with time and enzyme (i. e. sample) concentration.

Estimates of chlorophyll *a* were made by using the method and calculation described by Talling (1969). A suitable volume of water sample (1—2 l) was drawn through a glass-fibre filter with asbestos powder which was then placed in 96.5 per cent methanol, agitated, boiled gently for a few seconds and then allowed to stand for 5 minutes. The extract was centrifuged and refiltered, and the optical density of the filtrate measured spectrophotometrically at 665 nm. The method does not distinguish possible degradation products, which are included as the optically equivalent quantity of chlorophyll *a*.

Inorganic phosphate was determined by the molybdate blue method (Алекин, 1954).

The phytoplankton samples were concentrated by sedimentation to the volume of 10 ml (50×). The Goryayev counting-chamber for blood cells was used, as the nannoplankton predominates in the lake. The number of cells and colonies per ml was calculated for every species. The biomass values were calculated from the volume of each species concerned. The calculation was based on the measurements of phytoplankton species of lakes Võrtsjärv and Peipsi-Pskov (Лауристе, 1974a) and on the current

measurements of the species of Saadjärv. The biomass of the blue-greens *Microcystis* sp. sp., *Gomphosphaeria lacustris*, *Coelosphaerium kuetzingianum* and *Aphanothece clathrata* was calculated as the biomass of colonies. The results were expressed in g m^{-3}. The seasonal data on biomass, chlorophyll *a* and phosphatase activity are based on the average values of the vertical distribution.

Results

Physical and chemical data

The basic observational programme for this study included the determination of colour and transparency, measurements of dissolved oxygen concentration and temperature, pH values and content of inorganic phosphate.

The colour of the water in Lake Saadjärv was yellowish green. The transparency value was highest in March (6.2 m). During the spring maximum of phytoplankton biomass (in May), the transparency was reduced to 3.2 m (Fig. 2). An increase in June (3.5 m) and July (5.5 m) was followed by a decrease to 3.8 m in August. During the autumn the transparency increased from 0.5 to 0.9 m within a month, declining to 5.6 m in early December.

The seasonal variation in temperature and dissolved oxygen concentration are shown in Figs 3 and 4. The temperature varies within the range from 0.9 to 2.0° throughout the water column in March. The warming-up of the lake begins in early spring. Complete homothermy was observed in May, the temperature being 7—8° (Fig. 3). Thermal stratification started in June (surface temperature 13.0°, bottom temperature 7.3°). The vertical differences in the oxygen content were not yet completely developed (Fig. 4). The highest surface temperature recorded was about 20° in July (10.3° at the bottom). The thermocline was 9—11 m in July and 14—15 m

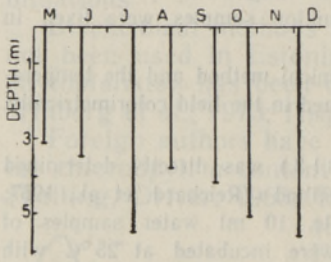

Fig. 2. Transparency values.

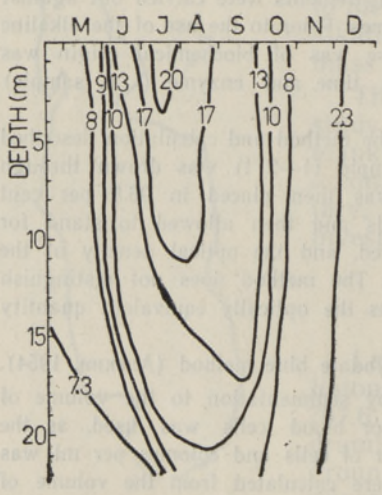

Fig. 3. Seasonal temperature isopleths (°C).

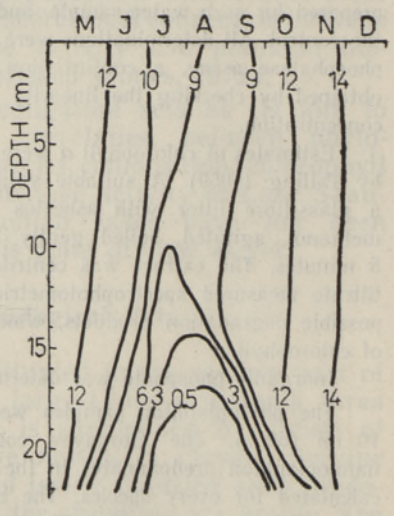

Fig. 4. Seasonal oxygen isopleths (mg l^{-1}).

in August. In late September the thermocline reached the depth of 18—19 m, and complete circulation was observed in October. During the autumn the temperature dropped rapidly. In early December the temperature was below 3°.

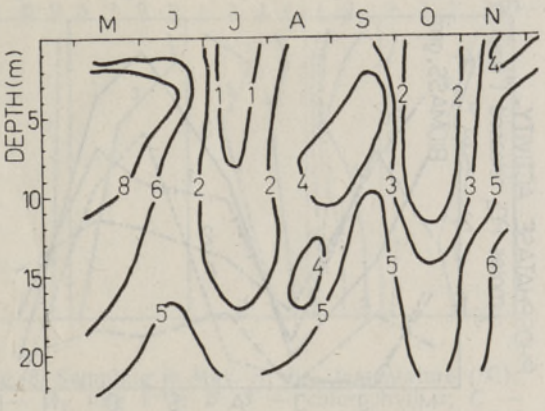

Fig. 5. Seasonal isopleths of inorganic phosphate (μg l^{-1}).

Lake Saadjärv, as compared to other Estonian lakes, is relatively rich in oxygen, although in recent years the oxygen regime has been liable to decrease. The vertical distributions of oxygen showed rapid changes below the thermocline during the summer period. Supersaturation with oxygen above the thermocline was observed in July (105%). The degree of saturation below the thermocline was 40 per cent, and oxygen depletion occurred near the bottom; at 19 m depth the saturation with oxygen was only 4 per cent. Oxygen depletion below the thermocline occurs in August and September, the degree of saturation being 5 per cent.

The oxygen concentration is at its maximum during vernal and autumnal circulation, the degree of saturation of the water with oxygen is 107 per cent in May and 105 per cent in October.

The pH of the lake water is slightly alkaline. The seasonal variation of hydrogen-ion concentration is insignificant; the pH of the surface layers varies within the range from 8.25 to 8.4. There is a general tendency for pH to decrease with the depth up to 7.6 to 7.45 during the summer period. This is due to the free CO_2 content which increases with the depth.

Proceeding from the concentration of biogenic elements in unpolluted surface water, the content of inorganic phosphate in the lake may be estimated as low, ranging from 0.8 to 9.0 μg P l^{-1}. As compared to earlier studies the content of phosphate has increased (Eesti järved, 1968).

The vertical distribution of inorganic phosphate was nearly the same every month, showing a general tendency to increase towards the bottom of the lake (Fig. 5). The highest inorganic phosphate values were observed in May. They fell slightly in June, and phosphate depletion was observed in the surface layers in July. As seen in Fig. 5, in the 5 m zone a little phosphate was found in July, and the content of phosphate increased to 2.0 μg l^{-1} near the bottom layers, from where it could not return to circulation due to the summer stagnation. In August and September the phosphate content increased rapidly, evidently because of biological destruction. A decrease to about 2 μg P l^{-1} in October was followed by an increase to about 5 — 6 μg P l^{-1} in early December.

Seasonal and vertical distribution

The phytoplankton of Lake Saadjärv has been investigated several times, but seasonal studies started only in 1972. The phytoplankton of Lake Saadjärv is rich in species, but with moderate biomass values.

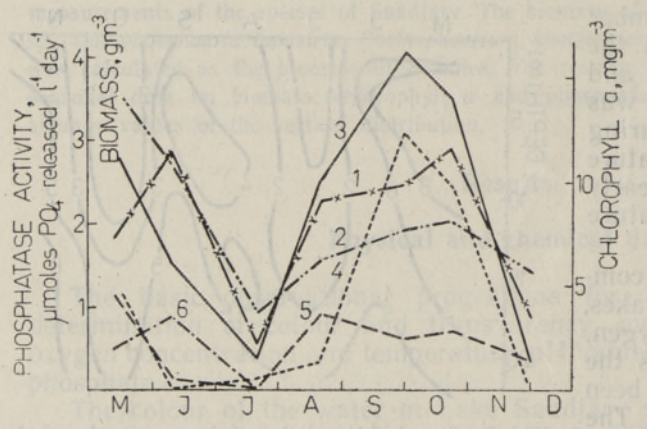

Fig. 6. Seasonal variation of chlorophyll *a* (*1*), phosphatase activity (*2*) and phytoplankton biomass: total biomass (*3*), blue-greens (*4*), diatoms (*5*), chrysophytes (*6*).

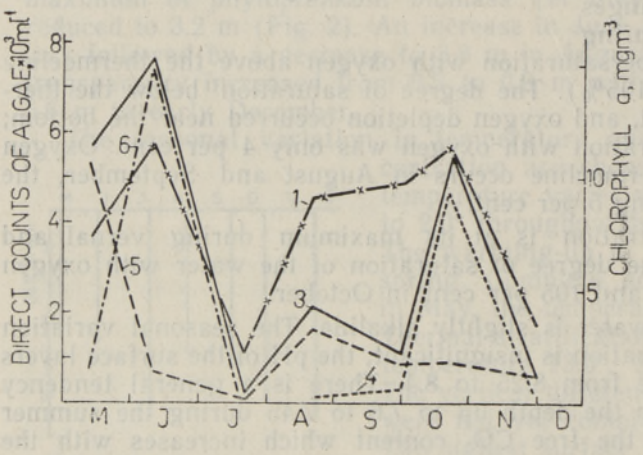

Fig. 7. Seasonal variation of chlorophyll *a* and direct counts of algae. Symbols as in Fig. 6.

About 270 taxa of algae were recorded (including the littoral samples). Diatoms predominate as regards the number of species and cells, especially in spring and autumn, but they are less abundant in summer. Among them *Cyclotella comta* var. *oligactis* (Ehr.) Grun., *Fragilaria crotonensis* Kitt., *Asterionella formosa* Hass. and *Melosira ambigua* (Grun.) O. Müll. are the most frequent ones.

Blue-greens (*Anabaena hassalii* (Kütz.) Wittr., *Microcystis pulverea* (Wood) Forti emend. Elenk., *Aphanothece clathrata* W. et G. S. West and *Gomphospaeria lacustris* Chod.) predominated in the standing crop in late summer and autumn. The chrysophytes — in earlier years *Dinobryon sociale*, in 1974 *Uroglenopsis americana* — had their maximum occurrence in spring (at the end of May and during June). The pyrrophytes (*Ceratium hirundinella*) occurred in moderate quantities during the summer. The total volume of green algae was very low as this group was represented by very tiny species (*Ankistrodesmus* sp., *Scenedesmus* sp. sp., *Oocystis* sp.). The maximum of green algae was during July and August. The phylum of the euglenophytes was very poor in species and the number of cells. They were represented in the samples during a period from July to September. The mean values of phytoplankton biomass varied from 0.37 to 4.12 g m^{-3} (from 170 to 7700 colonies and cells ml^{-1}), the maximum value of the surface sample was 11.44 g m^{-3}, Figs 6 and 7. These values are much lower as compared with those of the biomass in

other Estonian eutrophic lakes investigated (Лауристе, Локк, 1973; Лауристе, 1974b), but quite similar to the mesotrophic lakes of Latvia (Вайнштейн et al., 1969).

The vertical distribution of the total phytoplankton biomass and that of the main groups as well as cell numbers, chlorophyll *a* and phosphatase activity estimates, dissolved oxygen concentration and temperature are indicated by months in Figs 8—14.

The spring peak of phytoplankton biomass was recorded in early **May** during the vernal circulation (Fig. 6). In spring phytoplankton, the diatoms predominated as regards the cell numbers. The colonial blue-greens (*Coelosphaerium kuetzingianum* Naeg., *Aphanothece clathrata*) and chrysophytes were observed in small numbers. The biomass of diatoms revealed a comparatively low value because *Cyclotella comta* var. *oligactis* predominated (total biomass 2.9 g m^{-3}, diatoms 1.1 g m^{-3}). The number of colonial blue-greens was small. Nevertheless, in the biomass they were of some importance.

There appeared to be a fair correlation between the chlorophyll *a* estimates and the phosphatase activity (Fig. 8*B*, *C*), although a few discrepancies should be noted. The phosphatase activity was higher towards the bottom of the lake than chlorophyll *a* concentrations would indicate. The phosphatase activity also correlated well with both the biomass of phytoplankton and the direct counts of algae (Fig. 8*C*, *D* and *E*), with the

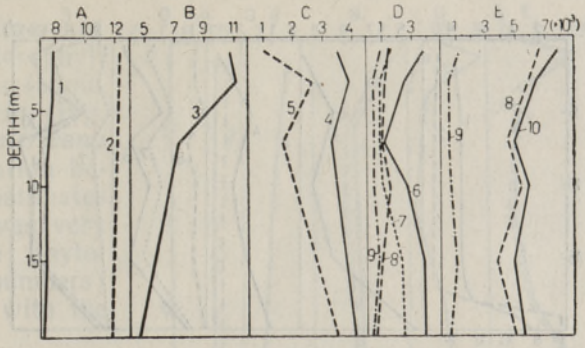

Fig. 8. Sampling in May. *A*: *1* — temperature (°C), *2* — O_2 (mg l^{-1}); *B*: *3* — chlorophyll *a*; *C* — phosphatase activity (moles phosphate released l^{-1} day^{-1}); *4* — activity of unfiltered sample, *5* — activity of membrane-filtered sample; *D*: *6* — total biomass, *7* — blue-greens, *8* — diatoms, **9** — chrysophytes; *E* — number of cells and colonies (m l^{-1}): *10* — total number.

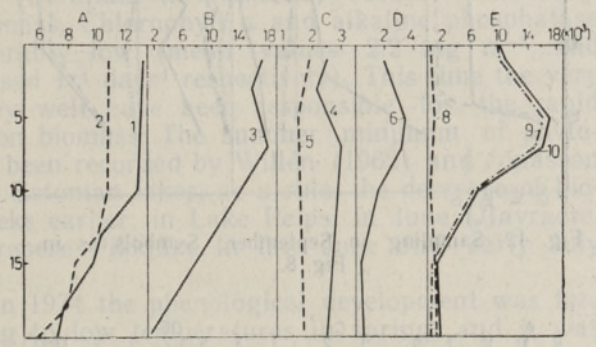

Fig. 9. Sampling in June. Symbols as in Fig. 8.

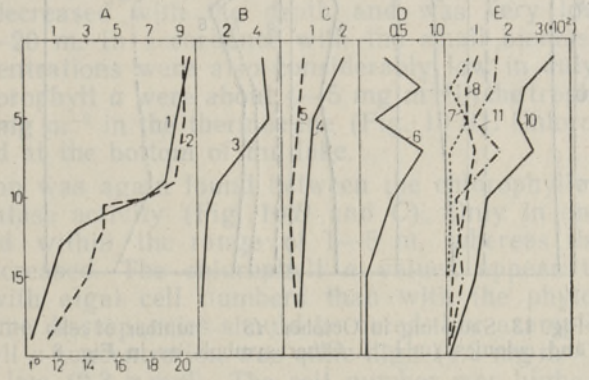

Fig. 10. Sampling in July. *11* — green algae. Other symbols as in Fig. 8.

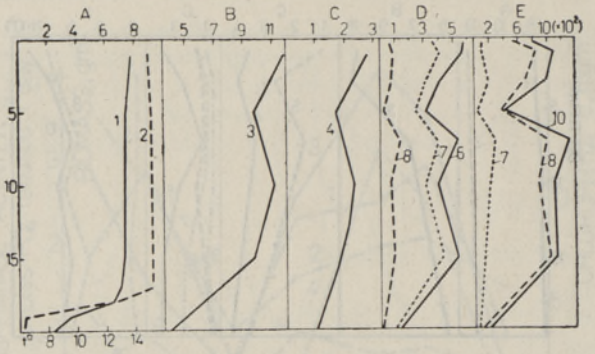

Fig. 11. Sampling in August. *12* — pyrrophytes. Other symbols as in Fig. 8.

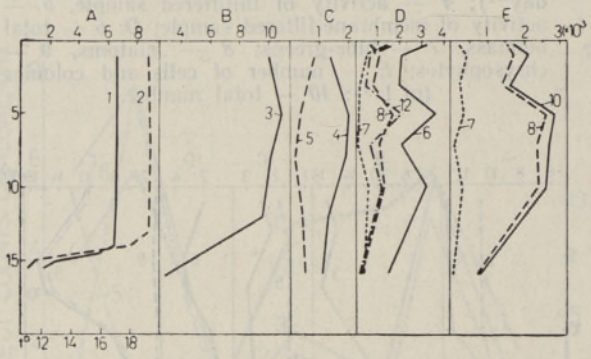

Fig. 12. Sampling in September. Symbols as in Fig. 8.

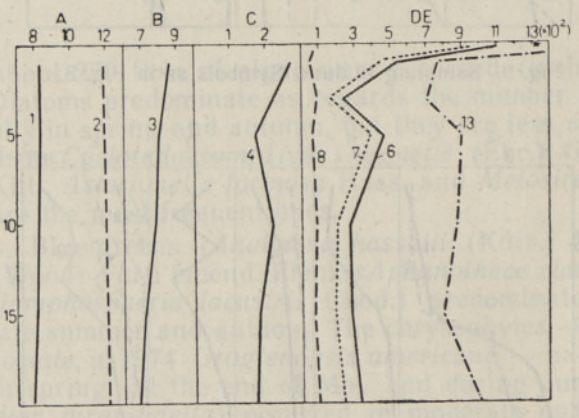

Fig. 13. Sampling in October. *13* — number of cells and colonies (m l^{-1}). Other symbols as in Fig. 8.

exception of the 1 m zone where the phosphatase activity was lower than the biomass and cell numbers would indicate.

The biomass of the blue-greens tended to increase fairly with the increased phosphatase activity towards the bottom of the lake. This agrees with the findings of Jones (1972a) who noticed that where a zone of blue-green algae occurred there was a considerable stimulation in the phosphatase activity.

After the diatoms maximum an outburst of chrysophytes (*Uroglenopsis americana* Lemm.) followed in early **June** (Fig. 7). The phytoplankton was very poor in species, only about 4 taxa were recorded in every sample. The total biomass and phosphatase activity had decreased (mean values 1.47 g m^{-3} and 2.7 µmoles phosphate released l^{-1} day^{-1}), but the number of cells and chlorophyll *a* concentrations had increased (mean values 7700 ml^{-1} and 11.5 mg m^{-3}, see Figs 6 and 7). According to Willen (1962), after the vernal water circulation but before the stable summer stratification there was also often a period of decreasing of total phytoplankton volumes in some Swedish lakes. This period was characterized by maxima of some chrysophytes preferring a temperature of water below 15°.

Thermal stratification started in June (Fig. 9*A*). The temperature and the dissolved oxygen concentration were homogeneous up to 10 m; below that depth, the values declined slowly towards the bottom. The highest phytoplankton biomass was observed in the layer of 5—7 m. At the depth of 15 m it decreased sharply. *Uroglenopsis americana* had disappeared,

but the amount of *Cyclotella comta* had increased a little. Chlorophyll *a* showed the highest values (about 17 mg m^{-3}) between 1—7 m (Fig. 9*B*). When *Uroglenopsis americana* was dominant, the correlation between the chlorophyll *a* estimates and phosphatase activity was very good. The curve of the phytoplankton biomass (and cell numbers) also correlated fairly well with the chlorophyll *a* estimates.

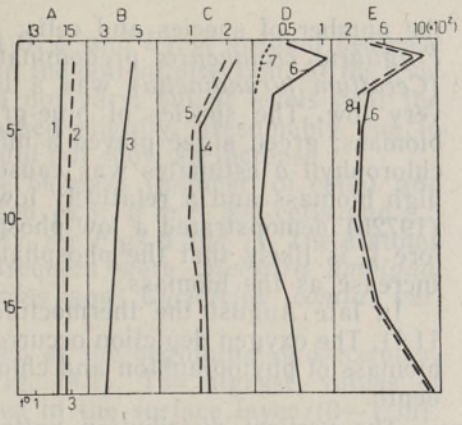

Fig. 14. Sampling in December. Symbols as in Fig. 8.

In **July** there was a very small amount of phytoplankton (mean values 0.37 g m^{-3}, 166 cells and 1.5 colonies ml^{-1}, see Figs 6 and 7), but the number of species had increased. Green algae and diatoms predominated numerically. The blue-greens (*Gloeocapsa limnetica* (Lemm.) Hollerb., *Microcystis flos-aquae* (Wittr.) Kirchn.) and pyrrophytes (*Ceratium hirundinella*) occupied the most important place in the biomass. Chlorophyll *a* and alkaline phosphatase activity were also considerably low (mean values 2.2 mg m^{-3} and 0.9 μmoles phosphate released l^{-1} day^{-1} respectively). This time the very low phosphate content may well have been responsible for the rapid decline of the phytoplankton biomass. The summer minimum of phytoplankton biomass has also been recorded by Willén (1962) and Jónasson and Kristiansen (1967). In Estonian lakes, as a rule, the decrease of biomass takes place some weeks earlier: in Lake Peipsi in June (Лауристе, 1974b), and in Lake Kaarepere Pikkjärv in late June and early July (Eesti järved, 1968).

It must be noted that in 1974 the phenological development was late for about two weeks owing to low temperatures in spring, and it was reflected in the development of the phytoplankton.

The thermocline was found at 9—11 m depth in July (Fig. 10*A*). The highest biomass (1.2 g m^{-3}) was observed in the surface layer; the value slowly decreased with the depth and was very low (0.07 g m^{-3}) between 15—20 m. In accordance with the small biomass values, chlorophyll *a* concentrations were also considerably low in July. The vertical values for chlorophyll *a* were about 4—5 mg m^{-3} in the trophogenic layer and nearly 1 mg m^{-3} in the thermocline (Fig. 10*B*). Chlorophyll *a* almost disappeared at the bottom of the lake.

A fairly good correlation was again found between the chlorophyll *a* estimates and the phosphatase activity (Fig. 10*B* and *C*). Only in one case the activity decreased within the range of 1—5 m, whereas the chlorophyll *a* estimate increased. The chlorophyll *a* values appear to correlate slightly better with algal cell numbers than with the phytoplankton biomass. Here some discrepancies should be noted. For example, at 1 m depth the chlorophyll *a* concentration was quite high (4.2 mg m^{-3}), but the biomass was very low (0.3 g m^{-3}). The cell number was highest at the depth of 1 m (350 cells and 4 colonies ml^{-1}).

During **August** the amount of phytoplankton increased considerably (mean values 2.5 g m^{-3}, 2066 cells and 8 colonies ml^{-1}), whereas the increase in chlorophyll *a* and the phosphatase activity was not so high (Figs 6 and 7). The diatoms took the most important place as regards

the number of species and cells; among them *Asterionella formosa* and *Fragilaria crotonensis* predominated. The total volume of pyrrophytes (*Ceratium hirundinella*) was a little higher, but the cell number was very low. The species of blue-greens were represented in a moderate biomass; green algae played a minor role. The moderate increase of the chlorophyll *a* estimates was caused by the dominance of species with a high biomass and a relatively low concentration of chlorophyll *a*. Jones (1972b) demonstrated a low phosphatase activity of *Ceratium* sp. Therefore it is likely that the phosphatase activity did not have such a high increase as the biomass.

In late August the thermocline reached a depth of 14—15 m (Fig. 11*A*). The oxygen depletion occurred below the thermocline. The maximum biomass of phytoplankton and chlorophyll *a* content were observed at 5 m depth.

The vertical distribution pattern of chlorophyll *a* is mainly similar to that of phytoplankton biomass. However, the chlorophyll *a* values were quite stable above the thermocline (about 10 mg m^{-3}, see Fig. 11*B*), while the biomass values fluctuated. There was a sharp drop of the chlorophyll *a* estimates from 9.5 to 2.8 mg m^{-3} and that of cell numbers from 2600 to 850 (biomass from 3.25 to 1.37 g m^{-3}) in the thermocline. A good correlation was again seen between the chlorophyll *a* estimates and the phosphatase activity in the epilimnion. The chlorophyll *a* estimates declined rapidly in the metalimnion, while the values of phosphatase activity remained nearly the same, decreasing only a little in the bottom direction.

In late **September** the average phytoplankton biomass exceeded that of late August nearly twice (Fig. 6), owing to the development of colonial forms of blue-greens (*Microcystis pulverea, Aphanothece clathrata, Gomphosphaeria lacustris*). Diatoms played an important role numerically (about 700 cells ml^{-1}), the most common being *Fragilaria crotonensis* and *Cyclotella comta* var. *oligactis*. Despite the high values of biomass, the chlorophyll *a* estimates had not increased significantly (Fig. 6).

In late September the thermocline persisted and already reached the levels near the bottom at 18—19 m (Fig. 12*A*). The oxygen depletion occurred at 19 m depth. The phytoplankton biomass, chlorophyll *a* estimations and phosphatase activity showed more or less the same values above the thermocline, but decreased rapidly below the thermocline as was observed in August, while the values of phosphatase activity were less decreased.

In **October** the average biomass values had decreased to 3.5 g m^{-3}, but the number of cells had increased considerably (1676 cells and 14 colonies ml^{-1}), and chlorophyll *a* showed the autumnal peak (mean values 11.5 mg m^{-3}, see Figs 6 and 7). A strong waterbloom occurred. It was caused by *Anabaena hassalii. Microcystis pulverea, Aphanothece clathrata* and *Gomphosphaeria lacustris* were less abundant. The total number of species had decreased during October. The diatoms were the richest in species. Among them *Melosira ambigua* occurred most abundantly.

A complete circulation period was observed in October. The temperature had declined about 8° and the dissolved oxygen concentrations had increased to 12 mg l^{-1} (Fig. 13*A*). In the surface layer (0—1 m) the amount of phytoplankton and chlorophyll *a* had increased to a great extent due to the presence of *Anabaena hassalii*, reaching the peak volume values of the year (11.44 g m^{-3}, 33 500 cells ml^{-1} and 164 mg m^{-3} respectively). At the depth of 1 m, the amount of phytoplankton and chlorophyll *a* had sharply decreased to 5.27 g m^{-3} (752 cells and 22 colonies ml^{-1})

and to 8.6 mg m^{-3} respectively (Fig. 13 *B*, *D* and *E*). *A* gradual decrease occurred in the chlorophyll *a* estimates in the bottom direction. At the level from 1 to 15 m the biomass values did not vary, but at levels near the bottom the phytoplankton values increased slightly, presumably due to dead cells, as the chlorophyll *a* content did not show an increase.

In early **December** both the average biomass (number of cells) and the chlorophyll *a* estimates had decreased (0.37 g m^{-3}, 590 cells and 2.5 colonies ml^{-1} and 3.5 mg m^{-3} respectively, see Figs 6 and 7). The diatoms were absolutely dominant. The most frequent were *Melosira ambigua*, *Tabellaria fenestrata* var. *asterionelloides* and *Cyclotella comta* var. *oligactis*.

A complete homothermy was observed at the beginning of December. The temperature dropped below 3° (Fig. 14*A*). The highest values of biomass and cell numbers were observed in the surface layer (0—1 m). A decrease was recorded from 1—15 m. Near the bottom the amount of phytoplankton increased due to diatoms, as was observed in October. The chlorophyll *a* estimates gradually decreased towards the bottom of the lake, while the vertical distribution pattern of phosphatase activity was similar to the phytoplankton biomass.

Discussion

The highest values of phytoplankton biomass were found in Lake Saadjärv, showing essentially two seasonal peaks, one in spring, with an average value of 2.8 g m^{-3} and the other, a higher one, in autumn, with an average of 4.1 g m^{-3}. The chlorophyll followed the seasonal variation shown by the phytoplankton biomass. However, it revealed a few discrepancies. The vernal biomass peak was observed earlier (in May), whereas the chlorophyll *a* peak was observed a month later (in June). During the spring peak, diatoms and colonial mucuous blue-greens predominated, whereas the chlorophyll *a* content was relatively lower. In June the phytoplankton was mainly composed of chrysophytes (*Uroglenopsis americana*), showing lower biomass values, but a quite high chlorophyll *a* content.

The same fluctuations were found in autumn: the autumnal peak of mean biomass values was observed in September, a month earlier, whereas the chlorophyll *a* peak was found in October. The biomass peak in September was caused by the development of the colonial forms of blue-greens *Microcystis pulverea, Gomphosphaeria lacustris* and *Aphanothece clathrata*, whereas chlorophyll *a* showed discernibly lower values. This can be explained by the fact that the chlorophyll content of colonial mucuous forms is relatively low as compared with the high biomass values.

A similar discrepancy between biomass and chlorophyll *a* was observed in Lake Ontario (Vollenweider et al., 1974). It was found that in summer the biomass values showed a pronounced peak, whereas chlorophyll *a* showed significantly lower values when green and blue-green algae dominated the community. Our results showed that in Lake Saadjärv, with the increase of cell numbers of green algae in July, the concentration of chlorophyll *a* was relatively high, while the biomass values were low.

The chlorophyll *a* and biomass peaks were found in October due to the waterbloom of *Anabaena* in the surface layer, while other chlorophyll *a* values were lower than in September. An analogous autumnal chlorophyll *a* peak, which occurred a month later than the phytoplankton biomass maximum, was also observed in the Saginaw Bay of Lake Huron (Vollenweider et al., 1974).

It appears that the accumulations of *Microcystis* and other colonial

forms in September were related to the increased phosphate concentration in the lake; *Anabaena* accumulations in October to the decreased phosphate concentration. The content of inorganic phosphate varied between 4 to 6 μg l^{-1} in the water column in September and decreased up to 1.6 μg l^{-1} in October. The same relationship between the distribution of *Microcystis aeruginosa* and *Anabaena flos-aquae* and the environmental factors examined was found by Hodgkiss (1974). His results show that *Microcystis* accumulations are related to increased concentrations of ammonia -N, nitrate -N and phosphate, and *Anabaena* accumulations decreases in phosphate content. It can be suggested that in September, when the water was relatively warm, an intensive destruction of organic matter took place, whereas in October, with the cooling of water, the organic matter destruction diminished and *Anabaena* waterbloom intensively consumed the free inorganic phosphate.

Very low biomass and chlorophyll *a* values were observed in July. This appeared to be due to limited amounts of phosphate. The lake was thermally and chemically stratified at that time, so that algal growth in the upper epilimnion caused phosphate depletion, whilst a little increased phosphate in the lower hypolimnion from diffusion and sedimentation of dead algae was not returned to the surface to enable renewed growth.

When the levels of phosphorus are high, relatively more of dissolved inorganic phosphate may be present in the water, or possibly as a result of luxury consumption, stored intracellularly by the algae (Kuenzler, Ketchum, 1962), and enzymatic hydrolysis is inhibited. The effect of a low external inorganic phosphate concentration on the induction of alkaline phosphatase in phytoplankton and bacteria is well documented (Fitzgerald, Nelson, 1966). The level of inorganic phosphate below which the enzymes are induced appears to lie in the range from 0.5 to 1.0 mg phosphate l^{-1}. The concentrations of phosphate in Lake Saadjärv were well below this level (0.8—9.0 μg l^{-1}). Therefore, the phosphatase system of the microflora may be permanently derepressed. The levels of phosphatase activity did, however, appear to increase, although not significantly, with increasing the degree of enrichment with phosphorus of the water under study. Our results show that alkaline phosphatase activity is linked with phytoplankton biomass, since these two variables correlated positively. The free phosphatase activity (i. e. of 0.22 μm membrane filtered samples) was more variable, but followed the same pattern in which the activity ranged from 0.03 to 2.0 μmoles phosphate released l^{-1} day^{-1}. The positive correlation of biomass and alkaline phosphatase activity was also obtained by Jones (1972a, b).

The results obtained in this study indicate that the relationship between chlorophyll *a*, phosphatase activity and phytoplankton biomass appears to be governed. The seasonal pattern of phytoplankton biomass and chlorophyll *a* in Lake Saadjärv is similar to that of the seasonal variation of phytoplankton biomass and chlorophyll *a* found in the Saginaw Bay of Lake Huron (Vollenweider et al., 1974). In regard to seasonal cycles of phytoplankton, Lake Saadjärv is essentially similar to Swedish and Danish lakes (Willén, 1962; Jónassen and Kristiansen, 1967; Kristiansen, 1971).

A similar seasonal pattern of phytoplankton biomass was observed in Lake Saadjärv during the period of 1971—1973 (Кываск et al., 1975) and in Lake Peipsi-Pskov during 1964—1966 (Лауристе, 1974b). The seasonal variation of phytoplankton and chlorophyll *a* in Lake Saadjärv might be considered characteristic of Estonian eutrophic lakes with mesotrophic features.

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Academy of Sciences of the Estonian SSR,
Institute of Zoology and Botany

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Anu MILIUS, Maia PORK

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

Resümee

1974. aastal uuriti Saadjärve fütoplanktoni biomassi, liigilise koostise, klorofülli *a* sisalduse ja fosfataasse aktiivsuse sesoonset dünaamikat ja korrelatsiooni. Fütoplanktoni aastases tsüklis täheldati kaht maksimumi (kevadel ja sügisel) ning kaht miinimumi (suvel juulis ja talvel). Kevadel (mais-juunis) moodustasid peamise hulga fütoplanktonist räni- ja koldvetikad, sügisel (septembris-oktoobris) sinivetikad. Suvisel miinimumiperioodil oli fütoplankton liigirikas, kuid teda leidus väga vähe.

Biomassi, klorofülli *a* sisalduse ja fosfataasse aktiivsuse aastane dünaamika ning vertikaalne levik üldiselt korreleeruvad. Parim on korrelatsioon biomassi ja fosfataasse aktiivsuse vahel. Klorofülli *a* sisalduse maksimum esineb umbes kuu aega pärast biomassi maksimumi. Ühtlasi on klorofüllisisaldus suurel määral sõltuv fütoplanktoni liigilisest koostisest.

Eesti NSV Teaduste Akadeemia
Zooloogia ja Botaanika Instituut

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Ану МИЛИУС, Майа ПОРК

СЕЗОННЫЕ ИЗМЕНЕНИЯ БИОМАССЫ, СОДЕРЖАНИЯ ХЛОРОФИЛЛА *a* И ЩЕЛОЧНОЙ ФОСФАТАЗНОЙ АКТИВНОСТИ ФИТОПЛАНКТОНА В ОЗЕРЕ САДЪЯРВ

Резюме

В течение 1974 года в оз. Саадъярв проводились наблюдения за сезонной динамикой и вертикальным распределением биомассы, видовым составом, содержанием хлорофилла *a* и фосфатазной активностью фитопланктона. Годовой цикл фитопланктона имеет два максимума (весной и осенью) и два минимума (летом и зимой). Весенний максимум (в мае—июне) вызван диатомовыми и хризофитовыми, осенний (в сентябре—октябре) — сине-зелеными. В период летнего минимума (в июле) фитопланктон богат видами, но биомасса очень низка.

Годовые изменения и вертикальное распределение биомассы, изменения содержания хлорофилла *a* и фосфатазной активности в общем коррелируют. Лучше коррелируют показатели биомассы и фосфатазной активности. Максимумы содержания хлорофилла *a* отстают от максимумов биомассы (приблизительно на один месяц). Содержание хлорофилла *a* в бóльшей степени зависит от видового состава фитопланктона.

Институт зоологии и ботаники
Академии наук Эстонской ССР

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