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SEASONAL CHANGES IN PHYTOPLANKTON BIOMASS OF SOME EUTROPHIC LAKES

The seasonal cycle and vertical distribution of phytoplankton species composition, biomass, chlorophyll *a* content and alkaline phosphatase activity were studied in two eutrophic lakes, Lake Saadjärv and Lake Pangodi. The samples from L. Saadjärv were collected from May to December and those from L. Pangodi between March and November, 1974. The samples were taken with a Ruttner sampler from the deepest areas of the lakes, from the depths of 1, 3, 5, 7 and 9 m in L. Pangodi and at 1, 5, 10, 15 and 20 m depths in L. Saadjärv. The alkaline phosphomonoesterases 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 concentrations of chlorophyll *a* using the method and calculation described by Talling (1969). The quantitative phytoplankton analyses were carried out by the methods described in earlier papers (Milius, Pork, 1977a, b).

Seasonal variation of phytoplankton biomass, chlorophyll *a* and alkaline phosphatase activity

L. Saadjärv belongs to the group of eutrophic lakes with mesotrophic features: L. Pangodi is a typical eutrophic water body (Mäemets, 1974). During recent years, L. Pangodi has gained some features of hypereutrophy. The phytoplankton of L. Saadjärv is characterized by the *Fragilaria-Tabellaria-Asterionella* community (Pork, 1975). Moderate water blooms, caused by *Anabaena lemmermannii* and *A. hassalii,* are usually observed in summer or in autumn. The phytoplankton of L. Pangodi is characterized by an abundant occurrence of the blue-greens, especially by the species of *Oscillatoria, Aphanizomenon* and *Lyngbya.* The importance of the species of *Oscillatoria* has risen during the few recent years. *Oscillatoria redekei,* dominating the phytoplankton in 1970s, was not recorded in the 1950s. The increase in the number of species and filaments of *Oscillatoria* can be ascribed to artificial eutrophication.

The mean values of phytoplankton biomass in L. Saadjärv are considerably lower than those in L. Pangodi. During the ice-free period the mean for L. Saadjärv is 0.37—4.12 g m^{-3} and that for L. Pangodi 1.76—9.28 g m^{-3}, the maximum values being 11.43 g m^{-3} and 13.0 g m^{-3} respectively. The mean biomass value of the year is 2.2 g m^{-3} in L. Saadjärv and 5.7 g m^{-3} in L. Pangodi.

The data for chlorophyll *a* and alkaline phosphatase activity in both lakes show the same tendency as the phytoplankton biomass values. In

L. Pangodi they were considerably higher than those of L. Saadjärv: the mean chlorophyll *a* values ranged from 12.0 to 62.0 mg m^{-3} in L. Pangodi and from 2.2 to 11.5 mg m^{-3} in L. Saadjärv during the ice-free period. The yearly means of chlorophyll *a* for L. Saadjärv and L. Pangodi were 8.9 and 36.3 mg m^{-3}, respectively.

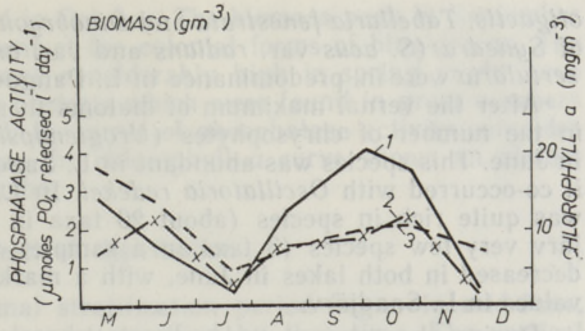

Fig. 1. Seasonal variation of phytoplankton biomass, chlorophyll *a* and phosphatase activity in L. Saadjärv. Total biomass — 1, chlorophyll *a* — 2, phosphatase activity — 3.

The mean alkaline phosphatase activity values ranged from 0.9 to 3.7 μmoles PO_4 released l^{-1} day^{-1} in L. Saadjärv and 2.8—6.5 μmoles in L. Pangodi. The yearly means of phosphatase activity for L. Saadjärv and L. Pangodi were 2.0 and 4.4 μmoles PO_4 released l^{-1} day^{-1}, respectively.

The highest phytoplankton biomass was found in L. Saadjärv, showing essentially two seasonal peaks, one in spring and the other, a higher one, in autumn (Fig. 1). In L. Pangodi three peaks of phytoplankton development were recorded: one in spring, another one in August, and the third one in November (Fig. 2). The chlorophyll *a* content and phosphatase activity of the samples followed the seasonal variation shown by the phytoplankton biomass.

In spring after the break-up of the ice an outburst of diatoms and chrysophytes was observed in both lakes (the vernal peak of phytoplankton), but the species composition was different. In L. Saadjärv (biomass 2.8 g m^{-3}) the predominant species were *Cyclotella comta* var.

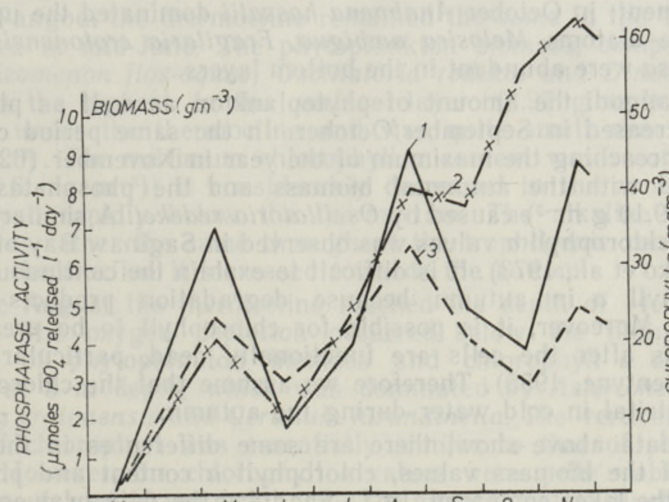

Fig. 2. Seasonal variation of phytoplankton biomass, chlorophyll *a* and phosphatase activity in L. Pangodi. Designations see under Fig. 1.

oligactis, Tabellaria fenestrata and *Dinobryon divergens,* while the species of *Synedra* (*S. acus* var. *radians* and var. *angustissima*) and *Dinobryon sertularia* were in predominance in L. Pangodi (biomass 7.0 g m^{-3}).

After the vernal maximum of diatoms there was a significant increase in the number of chrysophytes (*Uroglenopsis americana*) in both lakes in June. This species was abundant in L. Saadjärv, whereas in L. Pangodi it co-occurred with *Oscillatoria redekei.* In L. Pangodi the phytoplankton was quite rich in species (about 20 taxa in a sample), but in L. Saadjärv very few species (3 taxa in a sample) were observed. The biomass decreased in both lakes in June, with a marked increase in chlorophyll *a* values in L. Saadjärv.

During the summer and autumn the seasonal cycle of phytoplankton was different in the two lakes. In L. Saadjärv the summer minimum of phytoplankton biomass and chlorophyll *a* were recorded in July. This appeared to be due to the limited amount of phosphate in the water (Milius, Pork, 1977a). The lake was thermally and chemically stratified at that time. The algal growth in the upper epilimnion caused phosphate depletion, whilst the phosphate in the lower hypolimnion, slightly increased from diffusion and sedimentation of dead algae, was not returned to the surface to enable a renewed growth.

L. Pangodi as a highly eutrophic lake is considerably richer in nutrients, and the mass development of phytoplankton, as a rule, takes place during the whole ice-free period. The values of biomass and chlorophyll *a* increased continuously, reaching the summer maximum in August (9.28 g m^{-3} and 40 mg m^{-3}, respectively). The alkaline phosphatase activity showed the same peaks as the biomass; the highest peak was observed in August.

The autumnal phytoplankton maximum was observed in both lakes. In L. Saadjärv it occurred at the end of September and in October (biomass 4.1 and 3.5 g m^{-3}, chlorophyll *a* 9.9 and 11.5 mg m^{-3}). The increase of phosphatase activity was relatively small. The diatoms and blue-green algae were dominant: in September *Microcystis pulverea, Anabaena lemmermannii, A. hassalii, Fragilaria crotonensis* and *Asterionella formosa* were prominent; in October *Anabaena hassalii* dominated the upper layer, whereas the diatoms *Melosira ambigua, Fragilaria crotonensis, Asterionella formosa* were abundant in the bottom layers.

In L. Pangodi the amount of phytoplankton as well as phosphatase activity decreased in September/October. In the same period chlorophyll *a* increased reaching the maximum of the year in November (62 mg m^{-3}). It coincided with the autumnal biomass and the phosphatase activity maximum (9.10 g m^{-3}) caused by *Oscillatoria redekei.* A similar autumnal increase in chlorophyll *a* values was observed in Saginaw Bay of L. Huron (Glooschenko et al., 1973). It is difficult to explain the continuous increase of chlorophyll *a* in autumn because degradation products were not determined. Moreover, it is possible for chlorophyll to be preserved for long periods after the cells are functionally dead, particularly in cold water (Vallentyne, 1955). Therefore we assume that the chlorophyll was partially detrital in cold water during the autumn.

As the data above show, there are some differences in the seasonal dynamics of the biomass values, chlorophyll *a* content and phosphatase activity in the lakes compared. In L. Saadjärv the data in question agree more or less, with some exceptions. The vernal biomass peak was observed earlier (in May), whereas the chlorophyll *a* peak was observed a month later (in June). The same fluctuations were found in autumn: the autumnal peak of biomass was observed in September, 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. The phosphatase activity which was considerably high in spring might have been partially called forth by bacteria which were found in great numbers in the samples. In L. Pangodi the curve of phosphatase activity coincides with that of biomass, whereas the chlorophyll *a* curve shows an almost even rise from July to November.

Vertical distribution

In L. Saadjärv the thermal stratification period began in **mid-June,** whereas L. Pangodi had already stratified by that time. The vertical distribution of the phytoplankton biomass, chlorophyll *a* and phosphatase activity are indicated in Fig. 3. The highest phytoplankton biomass was observed in the layer of 5—7 m in L. Saadjärv, and chlorophyll *a* showed the highest values between 1—7 m.

The vertical distribution of phytoplankton in L. Pangodi was a follows: the highest biomass was observed in the surface layer at 1—3 m (3.9 g m^{-3}) and the total biomass as well as the biomass of the blue-greens (*Oscillatoria redekei*) and the chrysophytes (*Uroglenopsis americana*) markedly decreased between 3—5 m depth (thermocline at 4.5 m), but the amount of diatoms (*Melosira ambigua, Asterionella formosa*), tended to increase at the depth of 5 m. The values of chlorophyll *a* and phosphatase activity were somewhat uniform throughout the trophogenic zone (1—4 m); below the thermocline they rapidly dropped towards the bottom.

In L. Saadjärv a complete stratification was observed in **July.** The thermocline was found at 9—11 m. The highest biomass (1.2 g m^{-3}) was observed in the upper layer; the value slowly decreased with the depth and was 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.

In L. Pangodi the thermocline remained the same in the 4—5 m zone as recorded in mid-June. The phytoplankton biomass, composed mainly of *Aphanizomenon flos-aquae, Oscillatoria redekei* and *Dinobryon sertularia,* was the highest in the surface layer (8.97 g m^{-3}); it sharply decreased under the thermocline and was quite small near the bottom (0.58 g m^{-3}). The maximum chlorophyll *a* content was recorded at 3 m depth (26.6 mg m^{-3}); it considerably decreased in the zone of 4—5 m and dropped rapidly below the thermocline. The alkaline phosphatase activity was rather the same throughout the trophogenic zone (1—4 m); below the thermocline it increased towards the bottom.

In late **August** the thermocline reached the depth of 14—15 m in L. Saadjärv. The oxygen depletion occurred below the thermocline. The maximum of phytoplankton biomass and chlorophyll *a* content were observed at 5 m depth, which was dominated by *Asterionella formosa, Fragilaria crotonensis* and *Ceratium hirundinella.* The vertical distribution pattern of chlorophyll was essentially similar to that of phytoplankton biomass. However, the chlorophyll *a* values were quite stable above the thermocline (about 10 mg m^{-3}), while the biomass values fluctuated. There was a sharp drop of chlorophyll *a* values from 9.5 to 2.8 mg m^{-3} and those of biomass from 3.25 to 1.37 g m^{-3} in the thermocline. A good correlation was stated between the values of chlorophyll *a* and phosphatase activity in the epilimnion. The chlorophyll *a* values declined

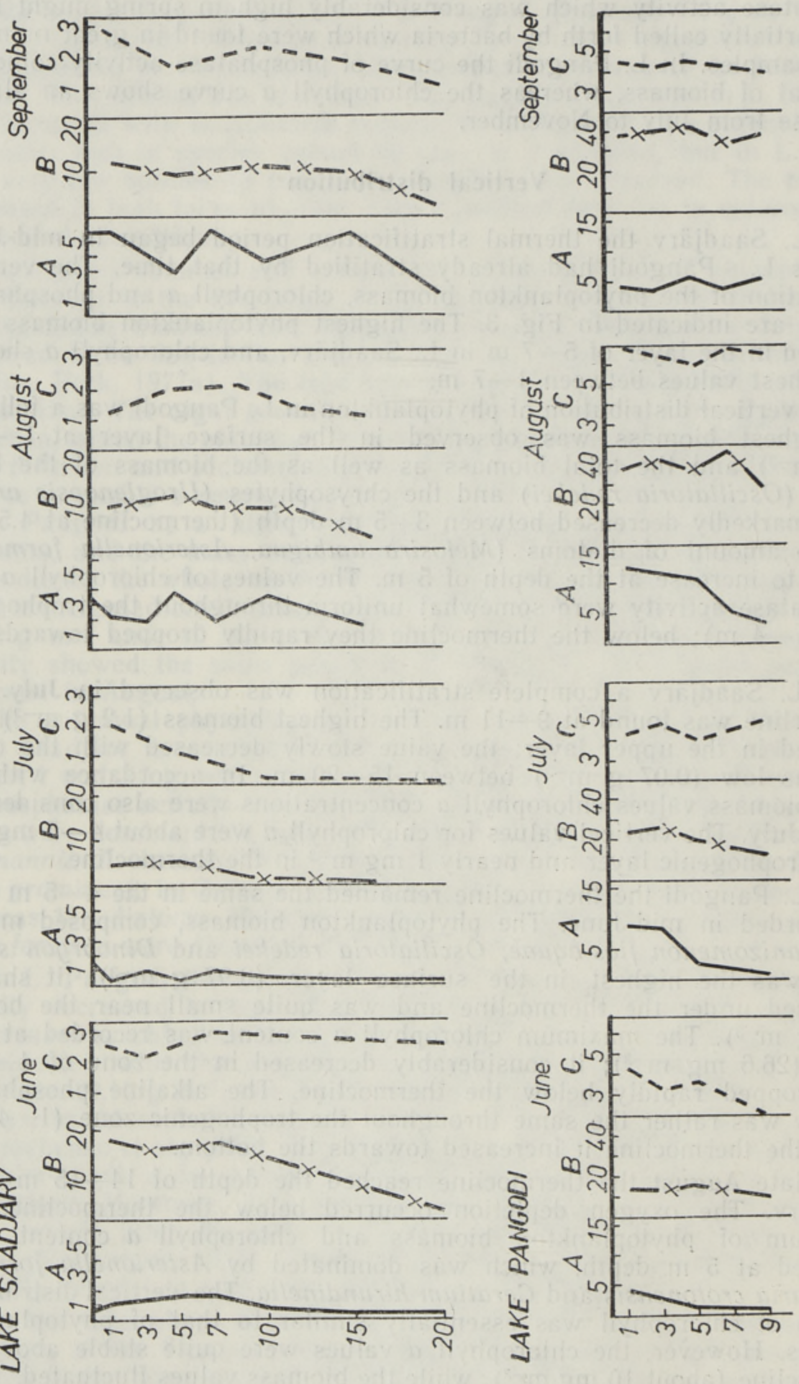

Fig. 3. Vertical distribution of phytoplankton biomass (A), chlorophyll *a* (B) and phosphatase activity (C) in lakes Saadjärv and Pangodi.

rapidly in the metalimnion, while the values of the phosphatase activity remained nearly the same, decreasing only a little in the direction of the bottom.

In L. Pangodi the thermocline has disappeared and a complete homothermy was recorded in late August, whereas the vertical distribution of oxygen showed a gradual decrease towards the bottom. The blue-greens (*Aphanizomenon flos-aquae, Oscillatoria redekei, Oscillatoria sp.*) had the most important place in the phytoplankton occurring in the upper layers of the water column (1—5 m). The diatoms (*Melosira ambigua, M. granulata*) were represented by a moderate biomass with the maximum value in the layer of 5—7 m. In August the green algae had their maximum biomass value of the year (0.72 g m^{-3}) at 7 m depth. The maximum chlorophyll *a* content was recorded at the same depth as the biomass maximum of the green algae. The vertical distribution of the phosphatase activity was homogeneous throughout the water column, but increased a little in the direction of the bottom.

In late **September** the thermocline persisted in L. Saadjärv; it had already reached the layer near the bottom (18—19 m). The oxygen depletion occurred at 19 m depth. The phytoplankton biomass, chlorophyll *a* and phosphatase activity showed more or less the same values above the thermocline. The values of the first two decreased markedly below the thermocline, while the values of phosphatase activity were less decreased. The cell number of *Fragilaria crotonensis* tended to increase towards the bottom and was the highest at 15 m.

In L. Pangodi stratification was broken down in September. The phytoplankton biomass values did not vary markedly from the upper to the bottom layers. At the depth of 5 m the biomass and chlorophyll *a* increased a little, whilst at 7 m depth they decreased, especially chlorophyll *a*. Near the bottom, at 9 m depth, they both increased.

In L. Saadjärv a complete circulation period was observed in October. However, in the surface layer the amount of phytoplankton and chlorophyll *a* had increased to a great extent due to the blooming of *Anabaena hassalii*. At the depth of 1 m the amount of phytoplankton and chlorophyll *a* had markedly decreased. Below 1 m depth the diatoms *Melosira ambigua, Asterionella formosa, Cyclotella comta* var. *oligactis* dominated. On the whole the number of cells was approximately the same throughout the water column, with a slight increase near the bottom.

In L. Pangodi the chlorophyll *a* content and phytoplankton biomass were uniform throughout the water column during the autumnal circulation period in October and November.

With the establishment of the ice cover (in L. Saadjärv at the end of December, in L. Pangodi at the beginning of December) the winter stagnation period began. The vernal circulation period started after the ice melted in April and lasted for about six weeks in L. Pangodi and two months in L. Saadjärv.

Chlorophyll *a* content of phytoplankton

Several authors have investigated the correlation between the chlorophyll content of phytoplankton and biomass values. Attempts have been made to find the biomass by determining chlorophyll *a* because it is easier and less time-consuming than the counting of cells and colonies. The data on the chlorophyll content being diverse even within one lake, no reliable coefficient has been calculated up to now. Our results show a great variablity of the chlorophyll content of phytoplankton in lakes

Saadjärv and Pangodi. In general the chlorophyll contents increase with the decreasing of biomass values both in vertical distribution and in seasonal changes of phytoplankton. We assume that the chlorophyll *a* content depends on the species composition as well as on some other factors (e. g., the stage of development of algae, the light intensity and nutrient concentration, etc.). It has been suggested that the main factors are light intensity (Ahlgren, 1970), inorganic nitrogen (Трифонова, 1976), and both the light intensity and inorganic nitrogen (Kenneth, 1976).

During the ice-free period the chlorophyll *a* content of phytoplankton ranged from 0.16 to 2.5 per cent in L. Saadjärv and from 0.27 to 1.65 of fresh weight in L. Pangodi, the median values being 0.4 and 0.6 per cent, respectively. The above values are lower than those in L. Hjälmaren (Willen, 1976), higher than those in L. Krasnoye (Трифонова, 1976), but coincide with the data of Pyrina (Пырина и др., 1973) and Vinberg (Винберг и др., 1971).

The chlorophyll content was relatively low in both lakes in May when diatoms dominated the phytoplankton: 0.25 per cent (biomass 2.9 g m^{-3}) in L. Saadjärv and 0.3 per cent (biomass 7.0 g m^{-3}) in L. Pangodi. These values are quite similar to the data of Yelizarova (Елизарова, 1974) on the chlorophyll content of diatomaceous plankton.

In June the chlorophyll content increased considerably — 0.78 per cent in L. Saadjärv and 0.8 per cent in L. Pangodi, while the biomass decreased (1.47 g m^{-3} and 1.76 g m^{-3}). The phytoplankton was dominated by chrysophytes (*Uroglenopsis americana*).

In L. Saadjärv the chlorophyll content was very high in July (2.3—2.5 per cent), whereas the biomass value was low (0.37 g m^{-3}). The diatoms and blue-green algae dominated in the phytoplankton, but the cell number of green algae was also relatively high. It was found that when the green algae were prominent, the chlorophyll *a* percentage was high. The chlorophyll *a* values, as a rule, are the highest when the species belonging to various taxonomic groups co-exist in the phytoplankton (Пырина, Елизарова, 1975). The chlorophyll content was lower in August (0.20—0.40%) when *Asterionella formosa, Fragilaria crotonensis* and *Ceratium hirundinella* were dominant, as well as in September (0.18—0.34%), when the species of *Microcystis* were prominent.

In L. Pangodi in July and August the chlorophyll *a* content was relatively low in the upper layers (0.27%, biomass 8.97 g m^{-3} and 12.82 g m^{-3}), but it increased in the lower layers. It can be assumed the chlorophyll *a* was partially detrital in the water of hypolimnion, or the increase was caused by the decrease of light intensity. A similar increase in the chlorophyll content of phytoplankton has been observed in other water-bodies (Hobson, Ketcham, 1974). The phytoplankton was dominated by *Aphanizomenon flos-aquae* and *Oscillatoria redekei.* The chlorophyll content increased in late autumn. As to literature, Yelizarova (Елизарова, 1974) has noted a decrease in late autumn, whereas Kenneth (1976) has found that the chlorophyll content was the highest in autumn and winter when the supplies of inorganic nitrogen were ample and the daily incident radiation was lowest. In L. Pangodi the chlorophyll content was the highest during October — 1.20—1.78 per cent, although the biomass decreased. It is possible for chlorophyll to be preserved for long periods after the algal cells are functionally dead in cold water. The species of *Oscillatoria* and *Aphanizomenon flos-aquae* were dominant in phytoplankton. In November at the blooming of *Oscillatoria redekei* the chlorophyll content was 0.68 per cent in L. Pangodi (biomass 7.10 g m^{-3}). In L. Saadjärv the chlorophyll content ranged from 0.16 to 0.29 per cent when diatoms dominated the phytoplankton in October, but it increased considerably in December (0.95%). The data we dispose of are insufficient to exactly point out which factor is responsible for the decrease or increase in the chlorophyll content, but we believe the species content to be rather important.

REFERENCES

Ahlgren, G., 1970. Limnological studies of Lake Norrviken, a eutrophicated Swedish lake. II Phytoplankton and its production. Schweiz. Z. Hydrol. **32** (3) : 353—394.

Glooschenko, W. A., Moore J. E., Vollenweider, R. A., 1973. Chlorophyll *a* distribution in Lake Huron and its relationship to primary productivity. Proc. 16th Conf. Great Lakes Res., Huron, Ohio. Ann Arbor: 40—49.

Hobson, L. A., Ketcham, D. E., 1974. Observations on subsurface distributions of chlorophyll «a» and phytoplankton carbon in the Northeast Pacific Ocean. J. Fish. Res. Board Canad. **31** (12) : 1919—1925.

Jones, J. G., 1972a. Studies on freshwater bacteria: association with algae and alkaline phosphatase activity. J. Ecol. **60** (1) : 59—75.

Jones, J. G., 1972b. Studies on freshwater micro-organisms: phosphatase activity in lakes of differing degrees of eutrophication. J. Ecol. **60** (3) : 777—791.

Kenneth, H. N., 1976. Nutrient-phytoplankton relationships in the Holland Marsh, Ontario. Ecol. Monogr. **46** (2) : 179—199.

Milius, A., Pork, M., 1977a. Seasonal variation of phytoplankton biomass, chlorophyll *a* and alkaline phosphatase activity in Lake Saadjärv. ENSV TA Toimet. Biol. **26** (1) : 36—48.

Milius, A., Pork, M., 1977b. Seasonal variation of phytoplankton biomass, chlorophyll *a* and alkaline phosphatase activity in Lake Pangodi. Eesti NSV TA Toimet. Biol. **26** (2) : 128—137.

Mäemets, A., 1974. On Estonian lake types and main trends of their evolution. Estonian Contributions to IBP **7** : 29—62.

Pork, M., 1975. The diatom communities in Estonian lakes. Some aspects of botanical research in the Estonian S.S.R. Tartu : 46—53.

Reichardt, W., Overbeck, J., Steubing, L., 1967. Free dissolved enzymes in lake waters. Nature **216** : 1345—1347.

Talling, J. E., 1969. Sampling techniques and methods for estimating quantity of biomass: general outline of spectrophotometric methods. IBP Handbook 12. Oxford: 22—24.

Vallentyne, J. R., 1955. Sedimentary chlorophyll determination as a paleobotanical method. Can. J. Bot. **33** : 304—313.

Willen, E., 1976. Phytoplankton in Lake Hjälmaren. Acta Universit. Upsaliensis **378** : 1—18.

Винберг Г. Г., Бабицкий А. В., Гаврилов С. И. и др., 1971. Биологическая продуктивность озер разного типа. В кн.: Биопродуктивность озер Белоруссии. Минск.

Елизарова В. А., 1974. Содержание фотосинтетических пигментов в единице биомассы фитопланктона Рыбинского водохранилища. Тр. Ин-та биол. внутр. вод АН СССР. Рыбинск **28** (31) : 46—66.

Пырина И. Л., Гецен М. В., Елизарова В. А., 1973. Некоторые показатели продукционной способности фитопланктона тундровых Харбейских озер. В кн.: Круговорот вещества и энергии в озерах и водохранилищах. Ч. I. Лиственичное на Байкале.

Пырина И. Л., Елизарова В. А., 1975. Содержание хлорофилла в фитопланктоне некоторых пресных водоемов. В кн.: Круговорот вещества и энергии в озерных водоемах. Новосибирск : 85—89.

Трифонова И. С., 1976. Фитопланктон и его продукция. В кн.: Биологическая продуктивность озера Красного и условия ее формирования. Л. : 69—103.

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FÜTOPLANKTONI BIOMASSI SESOONNE DÜNAAMIKA MÕNEDES EUTROOFSETES JÄRVEDES

Resümee

1974. aastal uuriti kahe eutroofse järve, Saadjärve ja Pangodi järve fütoplanktoni biomassi, klorofülli *a* sisalduse ja aluselise fosfataasse aktiivsuse sesoonset dünaamikat ning vertikaalset levikut. Saadjärves täheldati nimetatud nähtuste aastases tsüklis kaht maksimumi: üht kevadel (domineerisid räni- ja koldvetikad) ja teist sügisel (sini- ja ränivetikad). Tugevasti eutrofeerunud Pangodi järves ilmnes kolm maksimumi: kevadel (domineerisid räni- ja koldvetikad), suvel ja hilissügisel (sinivetikad). Enamasti kulgevad nimetatud nähtuste aastase dünaamika ja vertikaalse leviku kurvid paralleelselt.

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СЕЗОННЫЕ ИЗМЕНЕНИЯ БИОМАССЫ ФИТОПЛАНКТОНА В НЕКОТОРЫХ ЭВТРОФНЫХ ОЗЕРАХ

Резюме

В озере Саадъярв годовой цикл биомассы, содержания хлорофилла *a* и фосфатазной активности имеет два максимума. Весенний максимум вызван диатомовыми и хризофитовыми, осенний — синезелеными и диатомовыми. В сильно эвтрофном оз. Пангоди годовой цикл фитопланктона имеет три максимума. Во время весеннего максимума доминировали диатомовые и хризофитовые, летний и осенний максимумы вызваны синезелеными. Показатели щелочной фосфатазной активности и биомассы хорошо коррелирует. Показатели хлорофилла *a* частично совпадают с показателями биомассы.

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