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SEASONAL CHANGES IN THE PHYTOPLANKTON TAXONOMIC STRUCTURE AND PHOTOSYNTHETIC PIGMENTS IN PELAGIAL AND LITTORAL OF TWO INTERCONNECTED LAKES IN BELARUS

Abstract. The seasonal pattern of phytoplankton taxonomical composition and phytoplankton chlorophyll a content from pelagial and littoral locations with and without macrophyte beds in two interconnected lakes (north-west of Belarus) under contrasting trophic conditions were studied. We estimated influence of hydrochemical parameters on phytoplankton in studied lakes. There was “a clear water phase” in pelagial and low phytoplankton abundance in littoral of mesotrophic Lake Obsterno but we revealed a brief pulse of Chrysophyta and “a late spring bloom” with high total phytoplankton abundance in shallow macrophyte-covered low trophic state Lake Nobisto. It was found some prominent differences in total phytoplankton abundance and taxonomic composition in littoral and pelagial locations of both lakes. We used Phyto-Pam phytoplankton analyser for analysis of algae pigments. Phyto-Pam method allowed roughly identify two types of pigments – pigments of green algae and diatoms and revealed differences in concentrations of pigments between littoral locations and pelagial in both lake types. Results indicated that total chlorophyll a content has a pronounced seasonal cycle with high values during the early fall and low values throughout the late spring in mesotrophic lake and have shown differences in phytoplankton pigments between lakes littoral locations.

Keywords: phytoplankton, pigments, chlorophyll a, seasonal changes, littoral, pelagial, macrophyte beds, mesotrophic lake, shallow lake

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СЕЗОННЫЕ ИЗМЕНЕНИЯ ТАКСОНОМИЧЕСКОЙ СТРУКТУРЫ И ФОТОСИНТЕТИЧЕСКИХ ПИГМЕНТОВ ФИТОПЛАНКТОНА В ПЕЛАГИАЛИ И ЛИТОРАЛИ ДВУХ СООБЩАЮЩИХСЯ ОЗЕР В БЕЛАРУСИ

Аннотация. Исследованы сезонные изменения таксономической структуры и фотосинтетических пигментов фитопланктона в пелагиали, а также в литорали, заросшей разными видами макрофитов, и литорали без зарослей в двух сообщающихся озерах разного трофического статуса (северо-запад Беларуси). Установлено, что для мезотрофного оз. Обстерно характерна «фаза чистой воды» в пелагиали и низкая численность фитопланктона в литорали. В то же время высокая численность хризофитов (Chrysophyta) вызывала «осеннее цветение» фитопланктона в мелководном макрофитном типе оз. Нобисто с низкой трофностью. Выявлены существенные различия в общей численности и таксономической структуре фитопланктона между пелагиалой и литоралой в обоих озерах. С помощью специального метода с использованием прибора Phyto-Pam для определения содержания пигментов различных групп водорослей – зеленых и диатомовых и общего хлорофила a установлено, что общее содержание хлорофила a имело выраженный сезонный цикл с пиком ранней осенью и низким содержанием весной в ме-
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введение. Сезонные изменения таксономической структуры и фотосинтетических пигментов фитопланктона в пелагиали и литорали двух сообщающихся озер в Беларуси / Ж. Ф. Бусева [и др.] // Весц. Нац. акад. навук Беларусі. Сер. біял. навук. – 2020. – Т. 65, № 3. – С. 310–318 (в English). https://doi.org/10.29235/1029-8940-2020-65-3-310-318

Материалы и методы исследования. Озеро Обстерно (55°37’31.9’’N, 27°21’55.2’’E) является мезотрофным и низкотрофным озером, а уровень хлорофилла а в литорали двух исследованных озер существенно различались. Согласно полученным данным, указанный метод может использоваться только для быстрого определения или грубой оценки содержания хлорофилла а в водоемах.

Ключевые слова: фитопланктон, пигменты, хлорофилл а, сезонные изменения, литораль, пелагиаль, заросли макрофитов, мезотрофное озеро, мелководное озеро

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The Phyto-Pam (Phyto-PAM phytoplankton Analyzer, Heinz Walz GMBH, Effeltrich, Germany) employs light-emitting-diodes (LED) to excite chlorophyll \(a\) fluorescence alternatingly by 10 \(\mu\)s light pulses at four different wave lengths (470, 535, 620 and 650 nm). The fluorescence pulses were detected by a photomultiplier and amplified under microprocessor-control, resulting in 4 separate continuous signals (4 channels).

Seston samples for carbon, nitrogen and phosphorus analysis were stored in (one liter) plastic bottles that were first washed and rinsed in distilled and deionized water. Particulate samples were collected onto precombusted (5 h in 400 °C) glass fiber filters (Microbio GF/F filters, 0.7 \(\mu\)m porosity, 37 mm diameter) and after filtration dried at 60 °C for 72 h. Final volume of filtering water on GF/F for seston was 0.8–1.2 l. All samples were taken once a day at around 10:00–12:00 o’clock. Flash EA 1112 NC Soil/MAS 200, Thermo Quest, Italy, CHN analyzer was used for carbon (C) and nitrogen (N) measurement. Particulate matter was analyzed for phosphorus (P) content calorimetrically after persulfate oxidation via spectrophotometer [14].

Statistical analyses. All statistical analyses were conducted using Minitab 17. To test the significant differences among habitats with phytoplankton taxonomical composition, we used one-way ANOVA with Tukey post hoc test. Eigen analysis of the correlation matrix via Principal Component Analysis (PCA) was applied to determine correlation between total abundance of phytoplankton dominant groups with elements as well as water chemistry.

Results and its discussion. During this study, water temperature varied from 21.4 °C in May with maximum of 23.6 °C in littoral location to September 14.3 °C in Lake Obsterno. Among all physicochemical and hydrochemical parameters, TDS (115–120 ppm) and pH didn’t change in a significant way but dissolved nitrates, phosphates and ammonium were not balanced in the whole season (Tab. 1). The Secchi disc transparency in Lake Obsterno differed from spring to autumn shifted from 6.5 m maximum in May to 4.2 m minimum in September.

| Table 1. Hydrochemical and physical parameters of Lake Obsterno (2016) |
|-----------------------------|---------------------|-----------------|---------------------|
|                           | Season, location    | Pelagial        | Littoral           |
|                           |                     | May             | September          |
| \(T\), °C                | 21.4                | 22.43 ± 0.5     | 14.4               | 14.3 ± 0.1         |
| pH                        | 8.4                 | 8.5 ± 0.05      | 8.4                | 8.7 ± 0.00         |
| Secchi depth, m           | 6.5                 | 4.2             |
| \(PO_4\) \(mg\cdot l^{-1}\) | 0.39               | 0.37 ± 0.08     | 3.1                | 1.32 ± 0.51       |
| \(NO_3\) \(mg\cdot l^{-1}\) | 0.3                | 0.6 ± 0.10      | 0.3                | 1.1 ± 0.26        |
| \(NH_4\) \(mg\cdot l^{-1}\) | 0.15               | 0.27 ± 0.01     | 0.03               | 0.21 ± 0.08       |

Note. Data for littoral is represented means from all three locations (means ± SD).

In Lake Nobisto during the autumn, temperature, pH, TDS (100–110 ppm) and nitrate (Tab. 2) did not change in a significant way among habitats while \(NH_4\) and \(PO_4\) were different in comparing with Lake Obsterno. The Secchi disc transparency in Lake Nobisto was high (2.9 m till the bottom).

| Table 2. Hydrochemical parameters of Lake Nobisto (autumn 2017) |
|-----------------------------|---------------------|---------------------|
|                           | Location            | Pelagial            |
|                           |                     | Bare littoral       |
|                           |                     | Bull rush           |
| \(T\), °C                | 9.6                 | 9.6                 | 9.8                |
| pH                        | 8.6                 | 8.5                 | 8.6                |
| Secchi depth, m           |                      | 2.9                 |
| \(PO_4\) \(mg\cdot l^{-1}\) | 2                   | 1.84                | 1.04               |
| \(NO_3\) \(mg\cdot l^{-1}\) | 0                   | 0                   | 0.2                |
| \(NH_4\) \(mg\cdot l^{-1}\) | 0.77                | 0.93                | 1.56               |
During this study, total chlorophyll $a$ concentrations ranged from 6.25 to 36.24 µg·l$^{-1}$ in Obsterno and from 9.51 to 19.10 µg·l$^{-1}$ in Nobisto, averaging 22.84 ± 8.84 and 14.29 ± 4.79 µg·l$^{-1}$ in Obsterno and Nobisto respectively (Fig. 1, 2). Peak concentrations occurred during late spring in yellow water-lily zone in Lake Obsterno. In general, chlorophyll $a$ was lower in Nobisto than in Obsterno. The minimum chlorophyll $a$ concentrations were typically observed at the pelagial zone of Lake Obsterno at the end of May where we noted “a clear water phase” as recorded in many studies [15]. Spring phytoplankton usually characterizes the “diatom bloom”, so brown pigments appeared in Lake Obsterno. The shallow location without macrophyte cover (bare littoral) is more turbid lake’s area where the pigments of green algae were identified properly in our phytoplankton samples of that location which is completely in agreement with Happey and Woods research in 1988 [16].

The chlorophyll $a$ content revealed differences in pigments in accordance with dominant groups such as green algae and diatoms in autumn and late May in Obsterno as well as diatoms in Nobisto during autumn. The Secchi disc transparency in Obsterno from May to September decreased greatly (from 6.5 to 4.2 m) in combination the shift in dominant groups from diatoms to green algae. Taxonomical composition of phytoplankton has shown differences in lakes during season as well as in littoral and pelagial locations. In Lake Obsterno in May *Chrysophyta* and then *Bacillariophyta* were the most abundant algae groups in pelagial, bare littoral, rush beds and yellow water-lily zone respectively. In autumn, *Bacillariophyta* was the most widespread group in all habitats (Tab. 3). According to the phytoplankton community composition of Lake Nobisto, during autumn in pelagial *Chrysophyta* but in bare littoral and bulrush,
Bacillariophyta were the dominant groups (Tab. 4). Cyanophyta were absent in May in pelagial and bare littoral and had minimum values in rush beds and yellow water lily zone in Lake Obsterno. In lake Nobisto we identified minimum values of Cyanophyta in all habitats in autumn. Meanwhile during May and September within all habitats of both lakes, no chlorophyll content for blue-green algae (Cyanophyta) by using Phyto Pam technique was obtained. As noted by Moore in 1978 [17], numerous factors may be involved in the ecological success of blue-green algae. One proposed explanation for low dominance of blue-green algae is limited phosphorus since nitrogen-fixing species usually are those who dominate [18] which is in agreement with our data and low trophic state of both lakes.

Table 3. Taxonomical composition of phytoplankton community of Lake Obsterno: abundance (ind/l) and C:N, N:P ratios of seston within season (from May to September) 2016

| Habitat               | Phytoplankton group | Mean ± SD       | C:N       | N:P       |
|-----------------------|---------------------|-----------------|-----------|-----------|
| Pelagial              | Bacillariophyta     | 162 491 ± 115 054<sup>AB</sup> | 5.5–7.37  | 107.71–35.61 |
|                       | Chlorophyta         | 25 004 ± 27 994<sup>BC</sup> |           |           |
|                       | Chrysophyta         | 63 969 ± 64 405<sup>BC</sup>  |           |           |
|                       | Cryptophyta         | 20 304 ± 15 370<sup>CD</sup>  |           |           |
|                       | Cyanophyta          | 15 612 ± 17 451<sup>CD</sup>  |           |           |
| Bare littoral         | Bacillariophyta     | 98 464 ± 29 471<sup>AB</sup>  | 5.75–7.56 | 106.29–11.75 |
|                       | Chlorophyta         | 17 418 ± 24 188<sup>CD</sup>  |           |           |
|                       | Chrysophyta         | 77 290 ± 66 710<sup>BC</sup>  |           |           |
|                       | Cryptophyta         | 35 814 ± 14 255<sup>CD</sup>  |           |           |
|                       | Cyanophyta          | 4 345 ± 5 397<sup>CD</sup>    |           |           |
| Rush beds             | Bacillariophyta     | 295 566 ± 195 662<sup>AB</sup> | 5.72–8.78 | 101.06–6.42 |
|                       | Chlorophyta         | 415042 ± 789 308<sup>AB</sup> |           |           |
|                       | Chrysophyta         | 28 040 ± 17 210<sup>AB</sup>  |           |           |
|                       | Cryptophyta         | 63 796 ± 56 275<sup>AB</sup>  |           |           |
|                       | Cyanophyta          | 29 714 ± 34 133<sup>AB</sup>  |           |           |
| Yellow water-lily zone| Bacillariophyta     | 76 995 ± 54 563<sup>AB</sup>  | 6.14–7.31 | 82.62–1.38 |
|                       | Chlorophyta         | 16 439 ± 15 694<sup>AB</sup>  |           |           |
|                       | Chrysophyta         | 63 057 ± 48 209<sup>AB</sup>  |           |           |
|                       | Cryptophyta         | 56 198 ± 38 639<sup>AB</sup>  |           |           |
|                       | Cyanophyta          | 5 583 ± 4 598<sup>AB</sup>    |           |           |

Note. Grouping information using Tukey test for the abundance of phytoplankton community, different labels (A, B, C, D) show significant differences of main phytoplankton groups among habitats at p < 0.05.

In Obsterno during May, we achieved a range of 6.47, 6.73, 6.68, 7.16 for C:N and 243.3, 239, 224 and 193.61 for N:P ratio respectively in pelagial, bare littoral, rush beds and yellow water lily zone. In September, C:N ratio of seston was greater than in May for pelagial, bare littoral, rush beds and yellow water lily zone followed by 9.39, 9.36, 8.65 and 8.47. In September N:P ratios were measured by an exceed range of above 1000 (8227, 2348, 2945 and 6392) respectively for pelagial, bare littoral, rush beds and yellow water lily zone which could be a reason of great phosphorus depletion and/or high nitrogen concentration. In May, phosphorus content of seston varied from 6.69 μg/l in littoral and 6.59 μg/l in pelagial but in September, it was recorded as 4.20 μg/l in littoral and 0.80 μg/l in pelagial locations.

Principal Component Analysis of C:N and N:P ratios with phytoplankton abundance expressed some positive but weak correlation in May and September which is followed as: C:N with Dinophyta (PC = 0.394), Chrysophyta (PC = 0.362), Bacillariophyta (PC = 0.305), Chrysophyta (PC = 0.362) and Chlorophyta (PC = 0.261); N:P with Cyanophyta (PC = 0.031), Dinophyta (PC = 0.281), Cryptophyta (PC = 0.598), Chrysophyta (PC = 0.015) and Bacillariophyta (PC = 0.409). Principal Component Analysis of phosphate and Cryptophyta abundance (PC = 0.640) showed a strong correlation but Chrysophyta (PC = 0.024), Cyanophyta (PC = 0.007) and Dinophyta (PC = 0.174) revealed a poor correlation in Lake Obsterno.

Analysis of variance with post hoc and Tukey test showed the significant differences among phytoplankton groups seasonally (F = 6.09, p = 0.000). Grouping information using Tukey method in Lake Obsterno...
Obsterno showed the abundance of *Bacillariophyta* is significantly different from the other groups in pelagial and bare littoral. As showed in the Tab. 3, mean abundance of *Bacillariophyta* is higher than others. Beside it, *Bacillariophyta* had a significant difference with rest of phytoplankton groups during seasons (Tab. 3).

In Lake Nobisto lake during September, C:N ratios were recorded in 10.47, 12.13 and 11.61 respectively for pelagial, bare littoral and bull rush and were higher than its values in Lake Obsterno. N:P showed a range of 31.09, 73.73 and 15.28 for mentioned habitats and were different from those in Lake Obsterno. PCA analysis didn’t express an average or strong correlation between phytoplankton groups and CNP as well as water chemistry. *Chrysophyta* (349–740 ind/l) in May and *Bacillariophyta* (104–453 ind/l) in September were identified as the most abundant groups from spring to autumn. Grouping information using Tukey method in Lake Nobisto showed that abundance of *Bacillariophyta*, *Chlorophyta*, *Chrysophyta*, *Cryptophyta* and *Euglenophyta* in pelagial are significantly different from the abundance of other groups in bare littoral and bull rush during autumn (Tab. 4).

| Habitat     | Phytoplankton group | Mean ± SD      | C:N  | N:P  |
|-------------|---------------------|----------------|------|------|
| Pelagial    | *Bacillariophyta*   | 128 151 ± 64 114<sup>AB</sup> | 10.74 | 31.09 |
|             | *Chlorophyta*       | 35 182 ± 25 732<sup>AB</sup>                   |
|             | *Chrysophyta*       | 349 740 ± 382 704<sup>AB</sup>                   |
|             | *Cryptophyta*       | 24 583 ± 22 678<sup>AB</sup>                   |
|             | *Cyanophyta*        | 12 396 ± 11 408<sup>AB</sup>                   |
|             | *Euglenophyta*      | 53 516 ± 71 750<sup>AB</sup>                   |
| Bare littoral| *Bacillariophyta*   | 106 270 ± 42 018<sup>A</sup>                   | 12.13 | 73.73 |
|             | *Chlorophyta*       | 31 329 ± 6 917<sup>B</sup>                   |
|             | *Chrysophyta*       | 129 959 ± 110 072<sup>AB</sup>                   |
|             | *Cryptophyta*       | 24 392 ± 20 845<sup>B</sup>                   |
|             | *Cyanophyta*        | 8 655 ± 8 352<sup>B</sup>                   |
|             | *Euglenophyta*      | 20 122 ± 19 254<sup>B</sup>                   |
| Bull rush   | *Bacillariophyta*   | 104 453 ± 80 017<sup>B</sup>                   | 11.61 | 15.28 |
|             | *Chlorophyta*       | 28 802 ± 18 720<sup>B</sup>                   |
|             | *Chrysophyta*       | 95 117 ± 48 946<sup>B</sup>                   |
|             | *Cryptophyta*       | 30 234 ± 28 200<sup>B</sup>                   |
|             | *Cyanophyta*        | 11 185 ± 7 984<sup>B</sup>                   |
|             | *Euglenophyta*      | 35 729 ± 30 108<sup>B</sup>                   |

Note. Grouping information using Tukey test for the abundance of phytoplankton community, different labels (A, B) show significant differences of main phytoplankton groups among habitats at *p* < 0.05.
Obsterno appeared more abundant in late summer and early autumn where temperature and light were higher than spring [16]. Both Cryptophyta and Chrysophyta exploit nutrient and light gradients [23] and conditions associated with enrichment (increased turbidity and organic materials) favour their growth which is in agreement with our obtained data with highest abundance of Cryptophyta and Chrysophyta in May for both lakes. On the other hand, most cryptophytes and many chrysophytes are small monads, and grazing regulation should significantly modify their response to nutrient enrichment [24]. Chrysophyta have been shown to be frequently phosphorus limited, but they respond unpredictably to enrichment [23]. The comparatively strong relationship between phosphate and Cryptophyta abundance (PC = 0.640) in our data suggests that this group is more influenced by phosphorus. On the other side a poor correlation between phosphate with Chrysophyta, Cyanophyta and Dinophyta suggest that they could be affected by pH and alkalinity [23] which is common among many of these taxa than phosphorus [25, 26]. According to the PEG-model of plankton seasonal succession toward the spring, nutrient availability and increased light permit unlimited growth of phytoplankton, especially in Cryptophyta and small diatoms. In the middle of warm season, by more soluble phosphorus, Cryptophyta become predominant as its clear in studied lakes. By seasonal changes and light limitation from spring to autumn, macrophytes and vegetation become important particularly in shallow lakes as it happened in both our studied lakes [27]. Macrophytes are known to affect nutrient cycling in lakes causing changes in phytoplankton biomass, growth and leading to competition among different taxa [28], but there is no effect on the presence or absence of macrophytes on the total biomass of diatoms [29] as its shown in our survey suggesting not only hydrochemical but other factors affect on phytoplankton dynamics.

**Conclusion.** A synthesis of patterns in average spring and autumnal abundance of major phytoplankton taxonomic groups in mesotrophic Lake Obsterno show that all groups increase in abundance with soluble phosphorus at different degrees, but only Cryptophyta showed a strong correlation over the season. However, neither abundance of dominant phytoplankton groups, nor chlorophyll a content didn’t show any correlations of taxonomic composition with the range of nutrient levels observed. Contrary, in shallow low trophic Lake Nobisto mainly nutrient deficiency and competition with macrophytes leads to development and changing defined phytoplankton groups especially in pelagial. We also approve that Phyto-Pam has been limited by the fact that it cannot distinguish between different phytoplankton groups, like green algae, diatoms and blue-green algae and it’s just a quick method for analysis of the main algal pigments.

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**References**

1. Gerten D., Adrian R. Climate-driven changes in spring plankton dynamics and the sensitivity of shallow polymictic lakes to the North Atlantic Oscillation. *Limnology and Oceanography*, 2000, vol. 45, no. 5, pp. 1058–1066. https://doi.org/10.4319/lo.2000.45.5.1058
2. Lampert W., Sommer U. *Limnology – the ecology of lakes and streams*. 1st ed. New York, Oxford University Press, 1997. 382 p.
3. Marker A. F. H., Nusch E. A., Rai H., Riemann B. The measurements of photosynthetic pigments in freshwaters and standardization of methods: conclusions and recommendations. *Archiv für Hydrobiologie*, 1980, vol. 14, pp. 91–106.
4. Lorenzen C. J. Determination of chlorophyll and phaeo-pigments: spectrophotometric equations. *Limnology and Oceanography*, 1967, vol. 12, no. 2, pp. 343–346. https://doi.org/10.4319/lo.1967.12.2.0343
5. Jeffrey S. W. An improved thin-layer chromatographic technique for marine phytoplankton pigments. *Limnology and Oceanography*, 1981, vol. 26, no. 1, pp. 191–197. https://doi.org/10.4319/lo.1981.26.1.0191
6. Sondergaard M. Seasonal variations in the loosely sorbed phosphorus fraction of the sediment of a shallow and hypertrophic lake. *Environmental Geology and Water Sciences*, 1988, vol. 11, pp. 115–121. https://doi.org/10.1007/BF02587770
7. Lorenzen C. J. A method for the continuous measurement of in vivo chlorophyll concentration. Deep Sea Research and Oceanographic Abstracts, 1966, vol. 13, no. 2, pp. 223–227. https://doi.org/10.1016/0011-7471(66)91102-8.

8. Falkowski P. G., Kolber Z. Variations in chlorophyll fluorescence yields in phytoplankton in the world oceans. Australian Journal of Plant Physiology, 1995, vol. 22, no. 2, pp. 341–355. https://doi.org/10.1071/pp950341.

9. Kolber Z., Falkowski P. G. Use of active fluorescence to estimate phytoplankton photosynthesis in situ. Limnology and Oceanography, 1993, vol. 38, no. 8, pp. 1646–1665. https://doi.org/10.4319/lo.1993.38.8.1646.

10. Schreiber U., Bilger W. Progress in chlorophyll fluorescence research: major developments during the past years in retrospect. Progress in Botany, 1993, vol. 9, pp. 151–173.

11. Kolbowski J., Schreiber U. Computer-controlled phytoplankton analyser based on 4 wavelengths PAM chlorophyll fluorometer. Photosynthesis: from Light to Biosphere. Dordrecht, 1995, pp. 825–828.

12. Staehr P. A., Baastrup-Spohr L., Sandjensen K., Stedmon C. Lake metabolism scales with lake morphometry and catchment conditions. Aquatic Sciences, 2012, vol. 74, no. 1, pp. 155–169. https://doi.org/10.1007/s00227-011-0207-6.

13. They N. H., Motta-Marques D., Souza R. S. Lower respiration in the littoral zone of a subtropical shallow lake. Frontiers in Microbiology, 2013, vol. 3, art. 434. https://doi.org/10.3389/fmicb.2012.00434.

14. Murphy J., Riley J. P. A modified single-solution method for the determination of phosphorus in natural waters. Analytica Chimica Acta, 1962, vol. 27, pp. 31–36. https://doi.org/10.1016/S0003-2670(00)88444-5.

15. Sommer U., Gliwicz Z. M., Lampert W., Duncan A. PEG-model of seasonal succession of planktonic events in fresh waters. Archiv für Hydrobiologie, 1986, vol. 106, no. 4, pp. 433–471.

16. Happy-Wood C. M. Ecology of freshwater planktonic green algae. Growth and reproductive strategies of freshwater phytoplankton. Cambridge, 1988, pp. 103–133.

17. Moore J. W. Distribution and abundance of phytoplankton in 153 lakes, rivers, and pools in the Northwest Territories. Canadian Journal of Fisheries and Aquatic Sciences, 1978, vol. 55, no. 15, pp. 1765–1773. https://doi.org/10.1139/b78-210.

18. Flett R. J., Schindler D. W., Hamilton R. E., Campbell N. E. R. Nitrogen fixation in the Precambrian Shield lakes. Canadian Journal of Fisheries and Aquatic Sciences, 1980, vol. 37, no. 3, pp. 494–505. https://doi.org/10.1139/80-064.

19. Eloranta P. Melosira distans var. tenella and Eunotia zasuminensis, two poorly known planktonic diatoms in Finnish lakes. Nordic Journal of Botany, 1986, vol. 6, no. 1, pp. 99–103. https://doi.org/10.1111/j.1756-1051.1986.tb00865.x.

20. Reynolds C. S. Phytoplankton periodicity: the interaction of from, fuction and environmental variability. Freshwater Biology, 1984, vol. 44, no. 2, pp. 111–142. https://doi.org/10.1111/j.1365-2427.1984.tb00027.x.

21. McQueen D. J., Lean D. R. S. Influence of water temperature and nitrogen to phosphorus ratios on the dominance of blue-green algae in lake St. George, Ontario. Canadian Journal of Fisheries and Aquatic Sciences, 1987, vol. 44, no. 3, pp. 598–604. https://doi.org/10.1139/f87-073.

22. Tilman, D., Kiesling K., Sterner R., Kilham S., Green, blue-green and diatom algae: taxonomic differences and catchment conditions. Limnology and Oceanography, 1995, vol. 40, no. 6, pp. 943–972.

23. Sandgren C. D. The ecology of chrysophyte flagellates: their growth and perennation strategies as freshwater phytoplankton. Growth and reproductive strategies of freshwater phytoplankton. Cambridge, 1988, pp. 9–104.

24. Watson, S., McCauley E. Contrasting patterns of net and nanoplankton production and biomass among lakes. Canadian Journal of Fisheries and Aquatic Sciences, 1988, vol. 45, no. 5, pp. 915–920. https://doi.org/10.1139/f88-112.

25. Caron D. A., Dam H. G., Kremer P., Lessard E. J., Madin L. P., Malone T. C., Napp J. M., Pelle E. R., Roman M. R., Youngbluth M. J. The contribution of microorganisms to particulate carbon and nitrogen in surface water chemistry of the Sargasso Sea near Bermuda. Deep-Sea Research. Part I: Oceanographic Research Papers, 1995, vol. 42, no. 6, pp. 943–972. https://doi.org/10.1016/0967-0637(95)00027-4.

26. Downing J. A., McCauley E. The nitrogen: phosphorus relationship in lakes. Limnology and Oceanography, 1992, vol. 37, no. 5, pp. 936–945. https://doi.org/10.4319/lo.1992.37.5.0936.

27. Cox E. J. Identification of Freshwater Diatoms from Live Material. London, Chapman & Hall Publ., 1996. 158 p.

28. O’Dell K. M., Van Arman J., Welch B. H., Hill S. D. Changes in water chemistry in a macrophyte-dominated lake before and after herbicide treatment. Lake and Reservoir Management, 1995, vol. 11, no. 4, pp. 311–316. https://doi.org/10.1080/07438419509354212.

29. Beklioglu M., Moss B. Mesocosm experiments on the interaction of sediment influence, fish predation and aquatic plants with the structure of phytoplankton and zooplankton communities. Freshwater Biology, 1996, vol. 36, no. 2, pp. 315–325. https://doi.org/10.1046/j.1365-2427.1996.00092.x.

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