Verhandlungen der Gesellschaft für Ökologie, Kiel 1977 (1978):

# Phytoplankton population dynamics in Plußsee (East-Holstein, Germany)

Barbara Hickel

Der Plußsee bei Plön (Ostholstein) nimmt in vieler Hinsicht eine Sonderstellung unter den ostholsteinischen Seen ein: Er ist tief (29 m), windgeschützt und stets lange (6 Monate) thermisch geschichtet, mit sehr hoch (5 m) gelegener Sprungschicht. Auch die Phytoplanktonpopulationen sind von denen anderer Seen recht verschieden und weisen trotz ähnlicher hydrographischer Bedingungen im Plußsee von Jahr zu Jahr eine sehr unterschiedliche Sukzession auf. Aus 13 Jahren Plußsee-Untersuchungen wird diese anhand qualitativer und quantitativer Angaben über Phytoplanktondaten dreier Jahre (1969, 1974, 1976) beschrieben.

1969 wurden 3 Perioden mit Planktonwucherungen festgestellt. Das Maximum nach Eisbedekkung im Frühjahr wurde von Nanoplanktonarten gebildet, das Sommermaximum aus *Anabaena flos-aquae* und Grünalgen, ein drittes Maximum im November aus Oscillatorien. 1974 konnte man 5 Perioden mit Plankton-Massenentwicklungen unterscheiden. Die erste im März bestand aus Diatomeen, darauf folgte eine Massenentwicklung von Nanoplanktern und nach einer Depression im Juni eine Wucherung von *Oscillatoria redekei*. Zwei weitere Maxima wurden vor allem aus Cryptomonaden und *Ceratium* sowie *Oscillatoria redekei* gebildet. 1976 waren 4 Perioden mit Massenentwicklungen zu unterscheiden. Die Frühjahrsblüte wurde von Peridineen und Diatomeen gebildet, darauf folgten *Eudorina* und Cryptomonaden. Das Sommermaximum bestand aus *Oscillatoria redekei* und Peridineen.

Gemeinsam war allen 3 Jahren eine Depression nach der Frühjahrsblüte. Die Frühjahrsblüte wurde überwiegend aus Nanoplanktern gebildet (< 10 µm), das Sommermaximum aus Blaualgen, deren sperrige Trichome nicht vom Zooplankton gefressen werden. Die Planktonwucherungen beschränkten sich während der Stagnationsperiode auf das obere Epilimnion und reichten etwa drei Monate nicht tiefer als 3 m. Sestonanalysen und mikroskopische Untersuchungen unterstützen die Annahme, daß sich der Umsatz partikulärer Substanz weitestgehend im Epilimnion abspielt und eine Anreicherung von partikulärem organischen Material im Hypolimnion nicht erkennbar wird. Das Seston im Epilimnion bestand fast ganz aus Plankton. Diese Ausnahme-Situation im Plußsee verglichen mit anderen Seen hat wichtige Folgen für die Möglichkeit der Erforschung des limnischen Ökosystems.

## 1. Introduction

The lakes of East-Holstein are naturally eutrophic lakes of the Baltic type with additional man made enrichment within the last decades (OHLE 1955, 1965). Within this area lakes of different trophic states can be found, from the Selenter See with a Secchi disk transparency of 5 m to the hypereutrophic Rottensee with 0.2 m during the summer stagnation period.

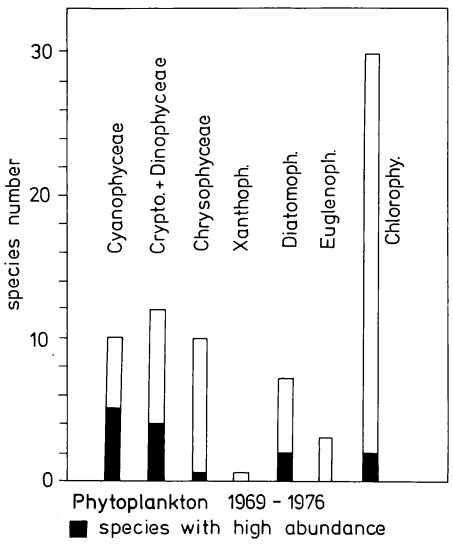


Fig. 1: Total species numbers and species with high abundance of the different taxa of the phytoplankton in Plußsee.

The phytoplankton is composed of species characteristic for calcium rich, eutrophic waters of temperate zones where diatoms, *Cyanophyceae* and *Chlorophyceae* are dominant. *Chrysophyceae* and desmids, typical for Scandinavian lakes, are unimportant. The number of species seems to be relatively low, as compared to Danish and Swedish lakes. UTERMÖHL (1925) observed 150 common species in 60 lakes and HICKEL (1975, unpubl. data) found about 200 species in 13 lakes. The seasonal distribution of the phytoplankton of these lakes can be characterized by a maximum of diatoms in spring and autumn and massive developments of *Cyanophyceae* or *Chlorophyceae* and *Peridiniales* in the summer.

The special characteristics of the Plußsee (ALBRECHT et al. 1978, OVERBECK 1978) as compared to other East-Holstein lakes is its greater depth (29 m) and its wind sheltered site in a depression surrounded by forest. Besides the low influence of wind on the hydrography of the lake the small water exchange rate is important. The distinct temperature stratification from May to October entails a very shallow epilimnion of 3-4 m depth. Fig. 1 shows the numbers of species of the different taxa. Only a small number of the 73 species found contributes to blooms. This portion is especially high among the *Cyanophyceae* (50%) and low among the *Chlorophyceae* (16%) which are most numerous in species numbers. The appearance of many species of the *Chlorophyceae* is less constant as compared to the *Cyanophyceae*. In 1976 several chlorococcal green algae were found which had not been observed for a long period, or were new records for the lake.

The absence of some plankton algae in Plußsee which are common in other lakes of East-Holstein is apparent. This is ascribed to the special hydrographic and probably hydrochemical property of the Plußsee. *Microcystis* which forms blooms in many other lakes of the area is absent in Plußsee and among the diatoms *Melosira* spp. and *Stephanodiscus astraea* are not found. Small diatoms like *Stephanodiscus hantzschii* var. *pusillus* or *Asterionella formosa* constitute the diatom maxima, which are species with a lower sinking rate than the mentioned large diatoms (however, *Melosira islandica* has been found in the sediment in 2 m depth indicating a change in species composition).

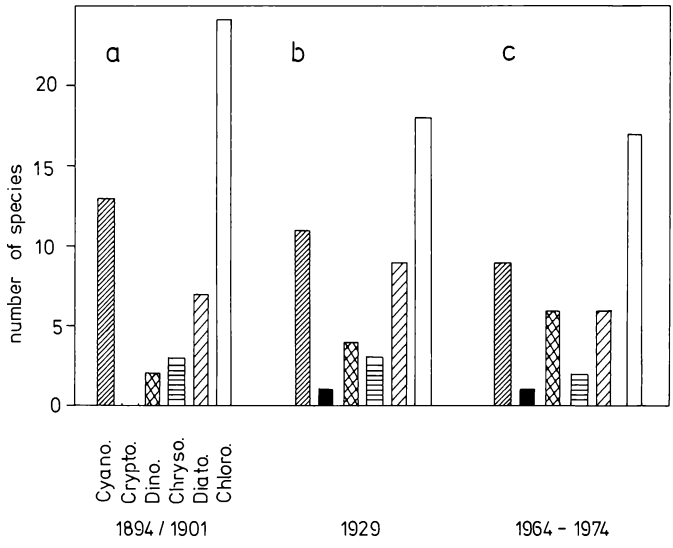


Fig. 2: Comparison of phytoplankton species numbers in Plußsee found in 1894/1901 (a), 1929 (b) and 1964-1974 (c).

The phytoplankton species composition in Plußsee, one of the earliest investigated lakes of the world, has been studied in the course of 80 years. Long-term changes in qualitative phytoplankton composition have been found during this period (HICKEL 1975). Fig. 2 demonstrates the species composition in the years 1894/1901, 1929, 1964-1974. Tab. 1 shows the number of species within different taxa, which have disappeared since 1894, those only recently found and those which remained constant over the 80-year-period.

Today the number of phytoplankton species in Plußsee is relatively low. Nearly all species are euplanktic. Despite a very regular pattern of hydrographic stratification in the course of the different years as well as certain physical and chemical water properties, the phytoplankton succession showed great differences from one year to the next. The phytoplankton population dynamics are characterized in the following using qualitative and quantitative data for three years out of a 13-years-period of research.

Table 1: Changes in phytoplankton species composition in Plußsee within 80 years (1894 and 1974): numbers of species (a) disappeared, (b) new and (c) constant.

| | a | b | c |
|---|---|---|---|
| total | 25 | 17 | 24 |
| *Cyanophyta* | 7 | 3 | 6 |
| *Cryptophyceae* | 0 | 1 | 0 |
| *Dinophyceae* | 1 | 5 | 1 |
| *Chrysophyceae* | 2 | 1 | 1 |
| *Diatomophyceae* | 2 | 1 | 5 |
| *Chlorophyta* | 13 | 6 | 11 |

## 2. Phytoplankton succession in Plußsee

In winter 1968/69 the lake was ice-covered from the middle of December until April. In February no phytoplankton was found under the 6 cm thick ice sheet, in March a mass development of a small *Cyanophyceae* was observed (Fig. 3). This was followed by another

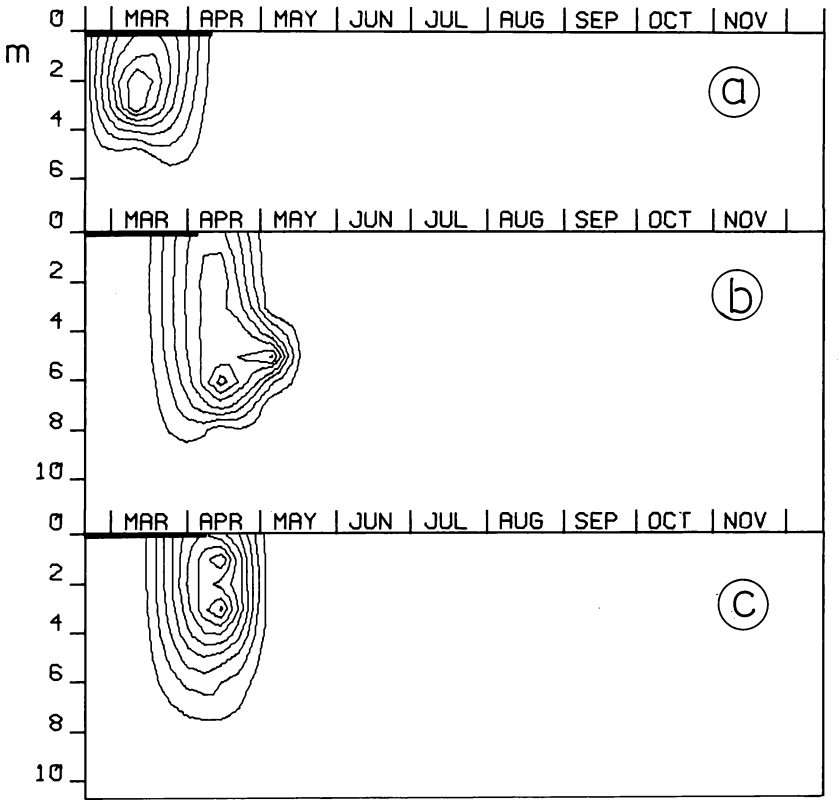


Fig. 3: Succession of phytoplankton under ice and after ice-break in spring 1969 (biomass mg/l): (a) ultraplankter 1, isolines 0.01-0.01-0.07 mg/l, (b) *Stephanodiscus hantzschii*, isolines 1-1-7 mg/l, (c) ultraplankter 2, isolines 0.05-0.05-0.45 mg/l.
(1-1-7 means: distance of isolines 1 mg/l, starting with 1 mg/l, ending with 7 mg/l).

nanoplankton bloom after ice break, which again was succeeded by a diatom bloom (*Stephanodiscus hantzschii*, 34 x $10^6$ cells/l). In July *Anabaena flos-aquae* was dominant following a depression in June and disappeared after one month. *Oscillatoria* was abundant at the end of November (Fig. 4). *Oscillatoria* was distributed from the metalimnion in the whole water column with the beginning of the vertical circulation. *Chlorophyceae* and Cryptomonads were abundant in summer after the development of *Anabaena*. *Cryptomonas* was restricted to the metalimnion for most of the time. The phytoplankton biomass, as estimated carbon (EPPLEY et al. 1970), showed a maximum in spring (Fig. 5). This is in contrast to other years when the bloom of blue-green algae in summer constituted the maximum of the phytoplankton biomass. First results of a model of the turnover of organic carbon were acquired for this year (KRAMBECK et al. 1978).

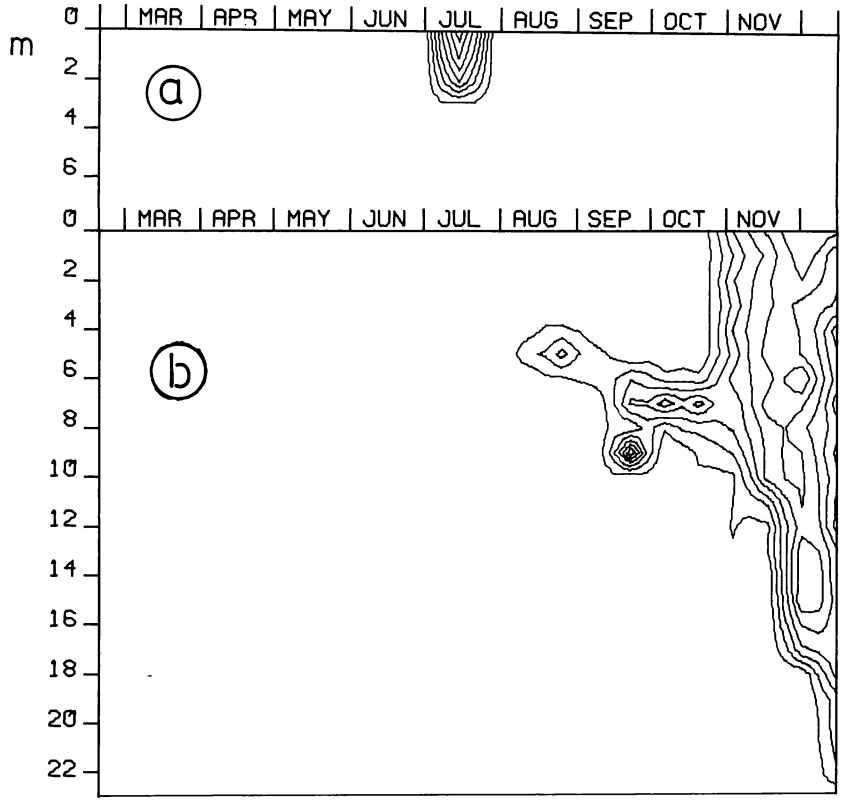


Fig. 4: Depth-time distribution of the biomass of (a) *Anabaena flos-aquae* (isolines 1-1-8 mg/l) and (b) *Oscillatoria* sp. (isolines 0.1-0.1-0.7 mg/l) in Plußsee in 1969.

In 1974 the lake was not ice-covered. Fig. 6 shows the depth of the thermocline and of the 1% depth of light penetration. The thermocline was at 2.5 m depth when the lake was stratified in April and later at 3.5 m. The circulation period started at the beginning of November. The 1% depth of light (as estimation of the lower limit of the euphotic zone) was situated above the thermocline for most of the time. The growth of phytoplankton started in March with a diatom bloom of *Stephanodiscus hantzschii* and *Asterionella formosa*. This population was distributed in the upper 8 m of the unstratified water column. The flagellate *Rhodomonas lacustris* and the diatom *Synedra acus* were abundant in early spring. The phytoplankton population in April was composed of species which occurred only in this period in 1974 (mostly nanoplankton < 10 µm, *Chrysochromulina*, *Chlorella*, *Monoraphidium*, *Rhodom. lacustris*). After a depression of phytoplankton development in May the typical blue-green algae dominated in June. One of the most

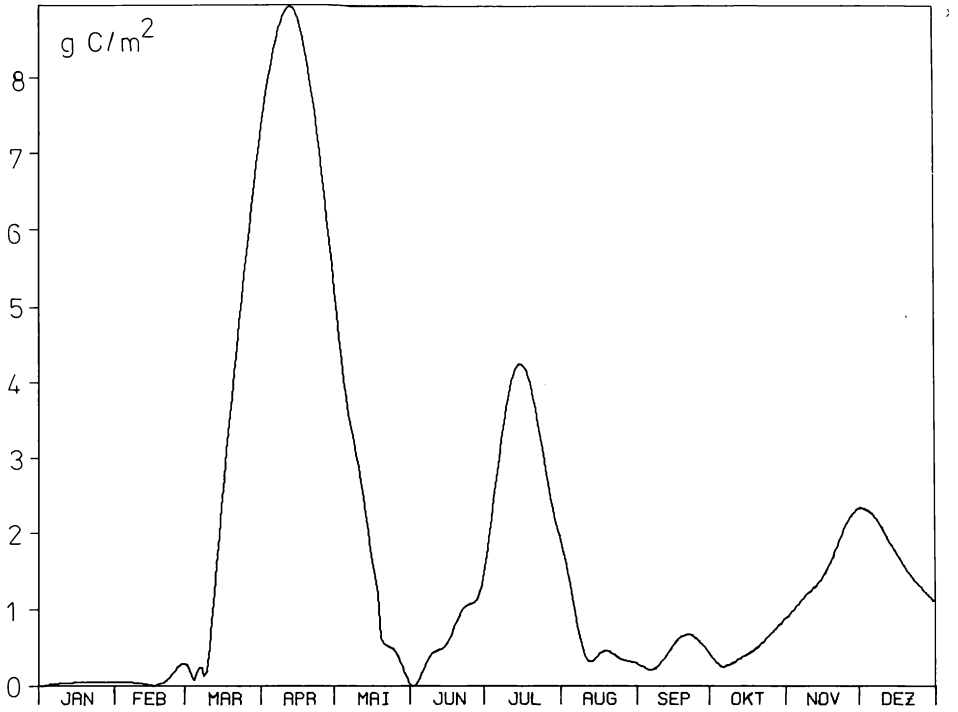


Fig. 5: Seasonal distribution of phytoplankton biomass (as estimated carbon) of the epilimnion in Plußsee in 1969.

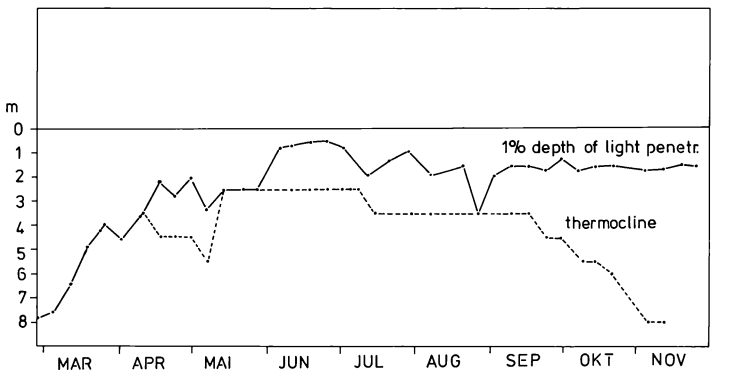


Fig. 6: The thermocline and the 1% depth of light penetration in Plußsee in 1974. (1%-depth calculated from Secchi depth.)

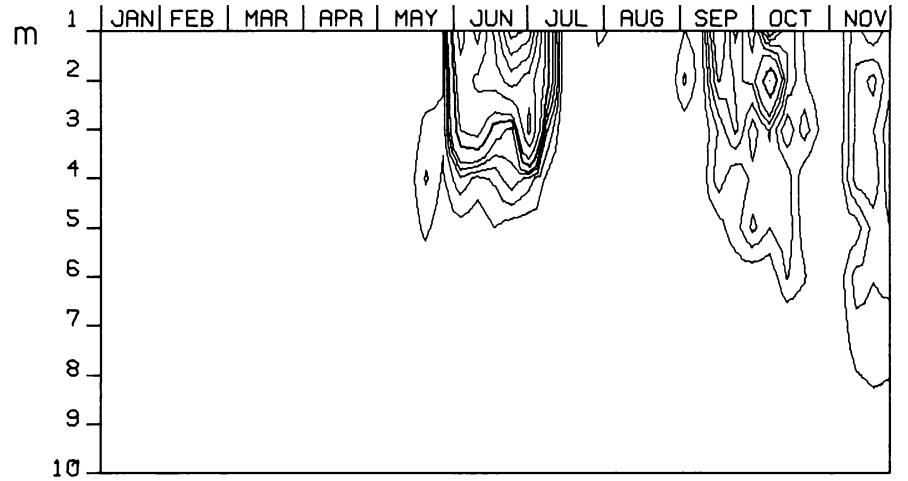


Fig. 7: Depth-time distribution of the biomass of *Oscillatoria redekei* (fresh weight) in Plußsee in 1974 (isolines: 1-1-5, 10-5-35 mg/l).

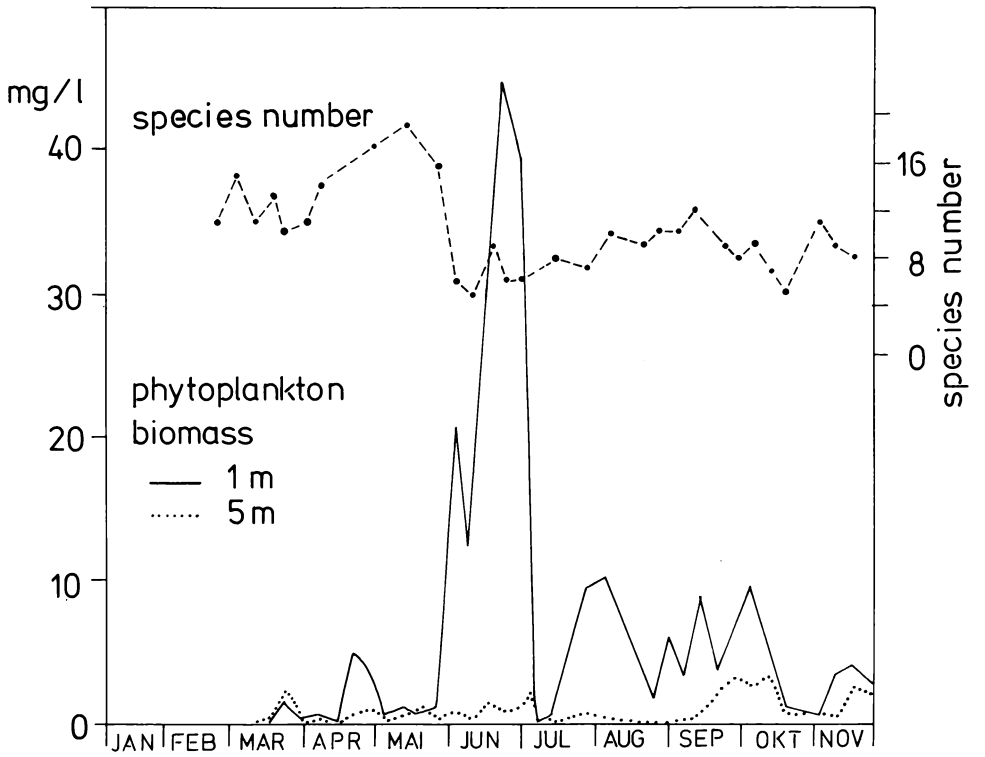


Fig. 8: Seasonal distribution of phytoplankton biomass (fresh weight) at 1 m and 5 m depth and species numbers of phytoplankton in Plußsee in 1974.

important *Cyanophyceae* in Plußsee is *Oscillatoria redekei*, which showed mass developments in summer for 7 out of the 13 years. *Oscillatoria redekei* was dominant in June-July in 1974 and again in September-October of the same year (Fig. 7). *Aphanizomenon gracile* appeared associated with *Oscillatoria redekei* and was abundant from June until December. *Oscillatoria redekei* and *Aphanizomenon gracile* constituted 98.7% of the phytoplankton biomass (fresh weight) concentrated in the epilimnion (1-3 m depth). At a depth of 5 m (metalimnion) only an unsignificant portion was found even during the peak phytoplankton blooms in summer (Fig. 8). The phytoplankton population moved downward in September following the lowering of the thermocline. The number of phytoplankton species decreased during the blooms of blue-green algae to a minimum of six species (Fig. 8).

Additional quantitative measurements of particulate organic carbon (POC) and nitrogen (PN) have shown, that not only production of POC but also decomposition takes place to a high degree in the uppermost layers of the water column. The concentration of POC and PN in the hypolimnion did not change in the course of the year even during the plankton blooms in the epilimnion, indicating no significant influence of sedimenting phyto- plankters to the seston of the hypolimnion. This was confirmed by microscopic analysis.

From the following evidence it was concluded that nearly all seston in the epilimnion was in fact plankton (inclusive bacteria), the lack of detritus particles in the microscopical analysis, the percentage of POC in seston (corresponding to pure plankton suspensions) and the coincidence of POC measured and POC calculated from phytoplankton cell counts. This is an indication of the existence of an almost pure plankton suspension in this natural water body during several months, which has many consequences for methodology and presents possibilities for in-situ physiological work, since a high portion of the detritus which cannot be separated from the phytoplankton in other water bodies, would not interfere in the Plußsee epilimnion.

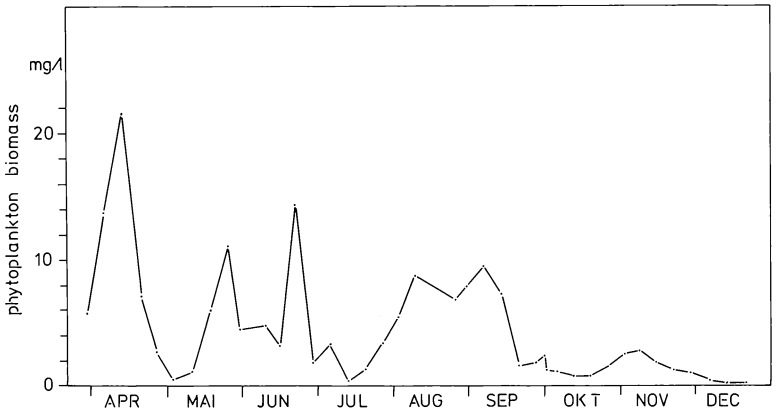


Fig. 9: Seasonal distribution of phytoplankton biomass (fresh weight) of the epilimnion (0-4 m) in Plußsee in 1976.

The phytoplankton biomass (fresh weight) in 1976 is given in Fig. 9. The spring maximum was composed of diatoms and *Peridiniales* succeeded by Flagellates *(Eudorina, Cryptomonas)*. The summer maximum of biomass was constituted of *Oscillatoria redekei* and *Peridiniopsis elpatiewskyi*. At the end of September the blue-green algae had disappeared and *Rhizochrysis scherffelii* was dominant. In this year some other species, which were rarely found or not observed in Plußsee before were also abundant.

## 3. Summary

The Plußsee near Plön (East-Holstein, Germany) is a deep, wind sheltered lake with a very stable thermal stratification during the six summer months and has peculiar phytoplankton populations. Despite similar hydrographic situations the phytoplankton succession patterns varied in different years. These patterns are demonstrated from qualitative and quantitative plankton data of three years (1969, 1974, 1976) out of a 13-years-investigation period. In addition, quantitative seston analysis (in 1974) was used to stress the importance of the phytoplankton in the total particulate organic material.

In 1969 three periods of phytoplankton development were observed. The maximum in spring after ice-break was composed of nanoplankton (< 10 µm), in summer *Anabaena flos-aquae* was dominant and green algae subdominant. *Oscillatoria* sp. formed a third maximum in November.

In 1974 five periods of phytoplankton mass developments could be distinguished, diatoms in March were succeeded by a mass development of nanoplankton species; after a depression in June a bloom of *Oscillatoria redekei* occurred. Two further maxima were formed by *Cryptomonas* and *Ceratium* and again by *Oscillatoria redekei*.

In 1976 four periods of mass developments were observed. The spring maximum was composed of *Peridiniales* and diatoms succeeded by *Eudorina* and *Cryptomonas*. The summer maximum was formed by *Oscillatoria redekei* and *Peridiniopsis elpatiewskyi*.

In all three years a depression of phytoplankton development was observed after the spring outburst. The blooms in spring were mostly composed of nanoplankton (< 10 µm) and the summer maximum of *Cyanophyceae* (large species not eaten by zooplankton). The phytoplankton blooms were restricted to the upper epilimnion when the lake was stratified and concentrated in the upper 3 m for about three months.

An analysis of seston and microscopical studies revealed that the turnover of organic particulate substances occurred in the epilimnion without an accumulation of particulate organic material in the hypolimnion. The seston of the epilimnion was almost completely composed of plankton. This special situation in Plußsee as compared to other lakes involves important consequences for the study of limnetic ecosystems.

## Danksagung

Herrn Prof. Dr. J. OVERBECK sei an dieser Stelle besonders gedankt für die Phytoplankton-Membranfilterpräparate von 1969. Herrn Dr. H.-J. Krambeck und Herrn G. Kobischke bin ich für die Anfertigung der Computergraphiken sehr verpflichtet. Für ihre engagierte Assistenz bei allen Arbeiten danke ich Frau Monika Wulf. Herrn Dr. W. Hickel danke ich herzlich vor allem für die Hilfe bei den Sestonanalysen sowie für wertvolle Hinweise und Kritik des Manuskripts. Die Arbeit wurde gefördert von der Deutschen Forschungsgemeinschaft.

## Literatur

ALBRECHT D., MÜNSTER U., STABEL H.-H., 1978: Untersuchungen zum Stoffhaushalt des Plußsees. Verh. Ges. f. Ökologie (Kiel 1977).

EPPLEY R.W., REID F.M.H., STRICKLAND J.D.H., 1970: The ecology of the plankton off La Jolla, California in the period April through September, 1967. III. Estimates of phytoplankton crop size, growth rate, and primary production. Bull. Scripps Inst. Oceanogr. 17: 33-42.

HICKEL B., 1975: Changes in phytoplankton species composition since 1894 in two lakes of East-Holstein, Germany. Verh. Int. Ver. Limnol. 19: 1229-1240.

KRAMBECK H.-J., HICKEL B., HOFMANN W., OVERBECK J., 1978: Mathematische Modelle als integrierende Hilfsmittel des Limnologen, dargestellt am Ökosystem Plußsee. Verh. Ges. f. Ökologie (Kiel 1977).

OHLE W., 1955: Die Ursachen der rasanten Seeneutrophierung. Verh. Int. Ver. Limnol. 12: 373-382.

- 1965: Nährstoffanreicherung der Gewässer durch Düngemittel und Meliorationen. Münchener Beitr. 12: 54-83.

OVERBECK J., 1978: Zur Geschichte und Methodik der limnischen Ökosystemforschung. Verh. Ges. f. Ökologie (Kiel 1977).

UTERMÖHL H., 1925: Limnologische Phytoplanktonstudien. Die Besiedlung ostholsteinischer Seen mit Schwebpflanzen. Arch. Hydrobiol. Suppl 5: 1-527.

## Adresse

Dr. Barbara Hickel
Max-Planck-Institut für Limnologie
Abteilung Allgemeine Limnologie
August-Thienemann-Str. 2
D-2320 Plön