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The late winter/spring bloom and succession of diatoms during four years in Lake Maarsseveen (The Netherlands)

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With 5 figures in the text

Introduction

The fresh-water ecosystem of Lake Maarsseveen, a man-made water body in the central Netherlands, has been chosen as a long-term research project.

The data presented in this contribution are part of the analysis of the composition, quantity and seasonal periodicity of the most abundant algae occurring in the epilimnion from 1977 to 1980. Preliminary data were gathered in 1976 by HOPMAN-ROCK (1977).

The literature on small interval sampling is scarce, though a detailed description of the variation in numbers per unit of time and the change of the predominance of species is the basis of the analysis by experimentation of the processes that govern periodicity and succession. Since the generation time of phytoplankters is measured in hours or a few days (SOURNIA 1974; WERNER 1977) the routine sampling programme has to compromise between limits set by the biology of the algae and the time available for counting. Lake Maarsseveen was sampled twice a week. This made possible a well documented record of yearly variation in the numbers of diatoms and their time of maximum bloom, too.

The diatoms involved are *Asterionella formosa, Stephanodiscus astraea, S. astraea* var. *minutula, Fragilaria crotonensis,* and *Cyclotella comta.*

Lake Maarsseveen

Lake Maarsseveen was made by excavation of sand in a peat-bog area in the early seventies. The trough-shaped lake is oligo-mesotrophic and supplied principally by precipitation and ground-water, and drained via an outlet at the northern shore (see Fig. 1).

The vernal diatom maxima (except that of *Cyclotella comta*) develop under isothermal conditions. The thermal stratification starts in April/May and the break-down is completed in November. The thermocline is at around 10 m depth. Minimum oxygen concentrations were found in autumn before the overturn (1 ppm isopleth from 17—19 m downwards in 1976—1978; KERSTING 1981). In late winter and early spring, diatoms are predominant in the phytoplankton standing crop.

Methods

The phytoplankton was collected twice a week around noon with a 3-litre VAN DORN sampler from an anchored platform on styrofoam floats (station 1, Fig. 1). A water column of 10 m, approximately representing the epilimnion, was sampled with depth intervals of 1 m. These column samples were pooled and 1 litre was separated for sedimentation of the algae after preservation with iodine. The sedimented algae were brought in a 100 ml vessel and subsampled with a 1 ml HENSEN pipette. As enumeration procedure the standard method of the inverted microscope was used after settling of the subsamples in 10 ml, flat-bottomed tubes (diameter 24 mm). The portion of the bottom area of the tube counted and the magnification applied varied with algal density. For statistical reasons three integral 10 litres column samples were taken at every sampling day and each of these three main samples were counted in triplicate after subsampling. The phytoplankton of the littoral zone (station 2, Fig. 1; 1977) was sampled very carefully with a bucket to avoid contamination with cells adhered to bottom and macrophytes.

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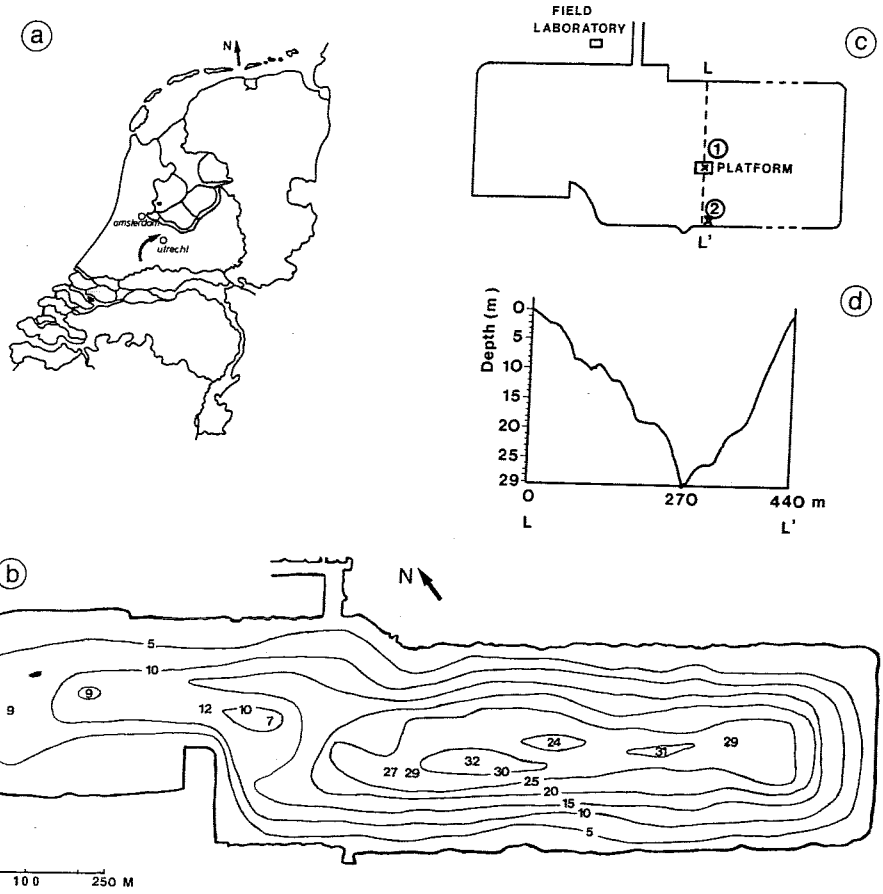

Fig. 1. a: Situation of Lake Maarsseveen (about 30 km east of Amsterdam). b: Bathymetric map (made by Dr. P. J. Roos). c: Schematic map with sampling stations; 1. floating platform, depth 28 m; 2. vegetation of *Phragmites australis*, depth 30 cm. d: Depth along the transect including the two sampling stations.

From *Stephanodiscus astraea* the variety *minutula* was distinguished as the small size class of about 8—10 μm (see also FURNASS 1978).

Temperature profiles were measured weekly at 1 m intervals with a YSI telethermometer accurate to 0.05 °C.

Orthophosphate was measured according to MURPHY & RILEY (1962) and reactive silicate (using a Cenco automated analyser) according to a modification after ARMSTRONG (1951). Nitrate was automatically measured according to STAINTON et al. (1974), after quantitative reduction to nitrite by a cadmium-copper couple (WOODS et al. 1967; NYDAHL 1976); (the amount of nitrite in the lake was negligible). The results are given as means of the value at 0, 5 and 10 m depth.

Results

In Figs. 2—5 bloom and succession in the open-water zone of *Asterionella formosa*, *Stephanodiscus astraea*, *S. astraea* var. *minutula*, *Fragilaria crotonensis*, and *Cyclotella comta* are given for 1977, 1978, 1979 and 1980, respectively. Only

densities of 10 cells and over per ml are included since lower numbers can hardly be counted accurately. In 1977 (Fig. 2) the blooms of *Asterionella* (like in 1978—1980 occurring roughly synchronously with those of *Stephanodiscus*), *Fragilaria* and *Cyclotella* showed a clear temporal separation. In 1978 (Fig. 3) a mass development of *Asterionella*, coinciding with the blooms of *Stephanodiscus* as well as with a small bloom of *Fragilaria*, was followed by the maximum of *Cyclotella*. The concurrence of *Asterionella* and *Fragilaria* was also seen in 1976 (HOPMAN-ROCK 1977) when sampling was performed between 16 March and 29 June. In 1979 (Fig .4) *Asterionella* had two maxima, the second showing its upbuilding synchronously with that of *Cyclotella*. *Fragilaria* was not encountered above the 10 cells/ml level. The results of 1980 (Fig. 5) are similar to those of 1977, be it that the main peaks of *Asterionella* and *Fragilaria* were followed by some pulses during the bloom of *Cyclotella*.

The succession of the algal populations of the species studied in the open water zone were also analysed in the littoral zone from the beginning of February until the middle of May 1977 (Fig. 2). It was too elaborate to be continued. The only differences observed were the greater fluctuations in densities of *Asterionella*, *Stephanodiscus* and *Cyclotella*, and the lower densities of *Fragilaria* in the littoral. PIECZYNSKA (1971) also found species to be abundant both in the open water and in the littoral.

Populations of successors synchronously increased at the breakdown of their predecessors: the series *Cyclotella/Fragilaria/Stephanodiscus* and *Asterionella* in 1977; *Cyclotella/Fragilaria* and *Asterionella* as well as *Fragilaria/Stephanodiscus* in 1978; *Cyclotella/Fragilaria* (and *S. astraea*)/*A. astraea* var. *minutula* and *Asterionella* in 1980. In 1979 *Cyclotella* had a temporal separation from the first peak of *Asterionella* as well as from the blooms of both forms of *Stephanodiscus*.

Asterionella rapidly increased from a mid-winter density between 10 and 100 cells/ml in all four years. The maximum, varying between 180 (in 1980) and 7000 cells/ml (in 1978), showed a small plateau with fluctuating numbers before the collapse started, which was rapid again, with a dramatic breakdown in 1978. The duration of the bloom was varying but longest in 1978. In 1979 and 1980 secondary, vernal pulses were following. Both forms of *Stephanodiscus* also started from mid-winter levels in 1977 and 1978. They demonstrated irregular bloom patterns in 1977, 1978 and 1979, contrary to 1980. The maximum numbers of *S. astraea* varied between 35 (in 1979) and 200 cells/ml (in 1980), those of *S. astraea* var. *minutula* between 100 (in 1979) and 700 cells (in 1980). More regular waxing and waning was observed in 1980. In all years the blooms ended before May. *Fragilaria* gradually increased (in particular in 1977 and 1978) from February/March onwards, showed a peak-shaped maximum in 1977 and 1980, whereas the maximum numbers varied between less than 10 (in 1979) and 700 cells/ml (in 1980). This species collapsed rapidly in May with some small secondary pulses in 1980. *Cyclotella comta*, succeeding the other diatoms, was a regularly blooming species in late spring/early summer. Rise and fall were rapid, in 1977 with two adjacent peaks. The maximum numbers varied between 100 (in 1978) and 300 cells/ml (in 1979).

In 1978, 1979 and 1980 the lake was temporarily frozen, but the bloom developments of *Asterionella* and *Stephanodiscus* were not disturbed by the ice cover

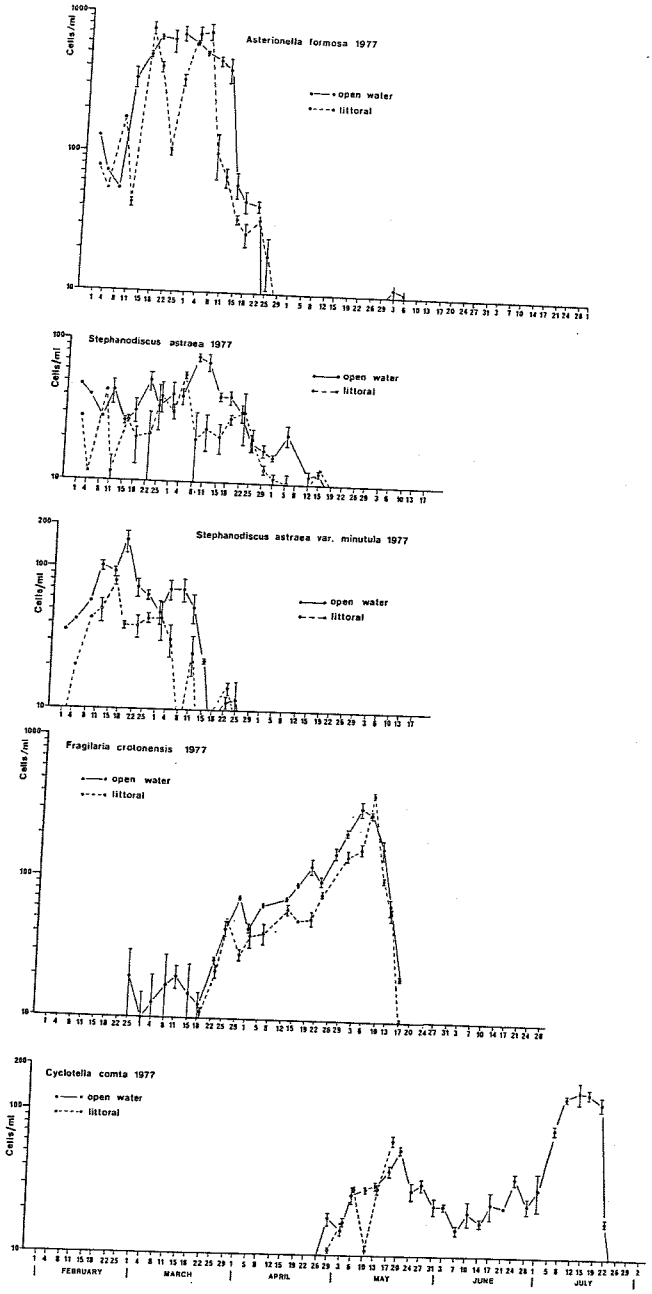

Fig. 2. Integral numbers of live cells/ml (± S. E.) of *Asterionella formosa*, *Stephanodiscus astraea*, *S. astraea* var. *minutula* (8—10 μm), *Fragilaria crotonensis*, and *Cyclotella comta* in the top 10 m in 1977.

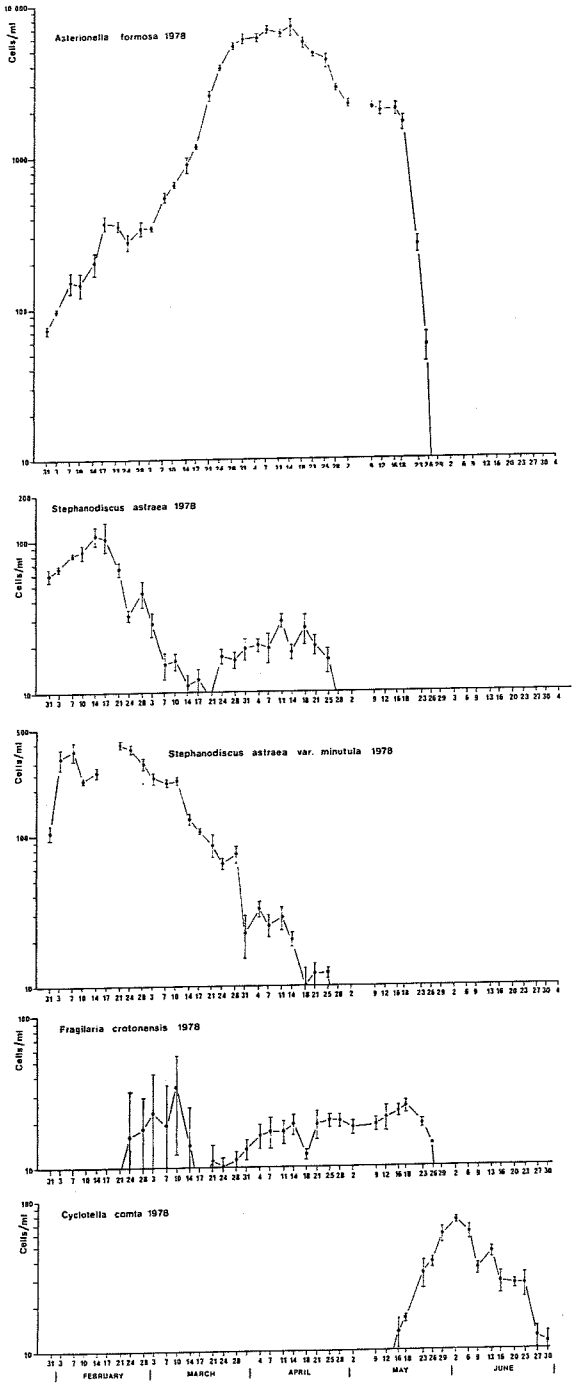

Fig. 3. See Fig. 2; 1978.

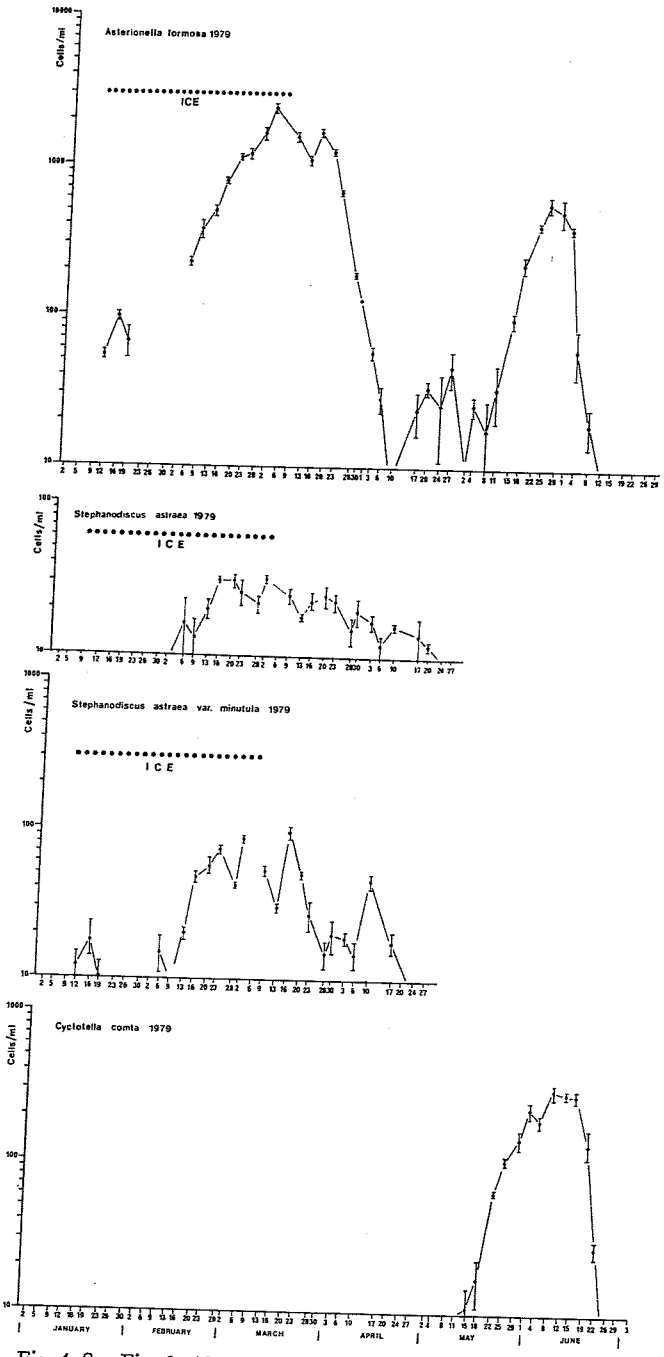

Fig. 4. See Fig. 2; 1979.

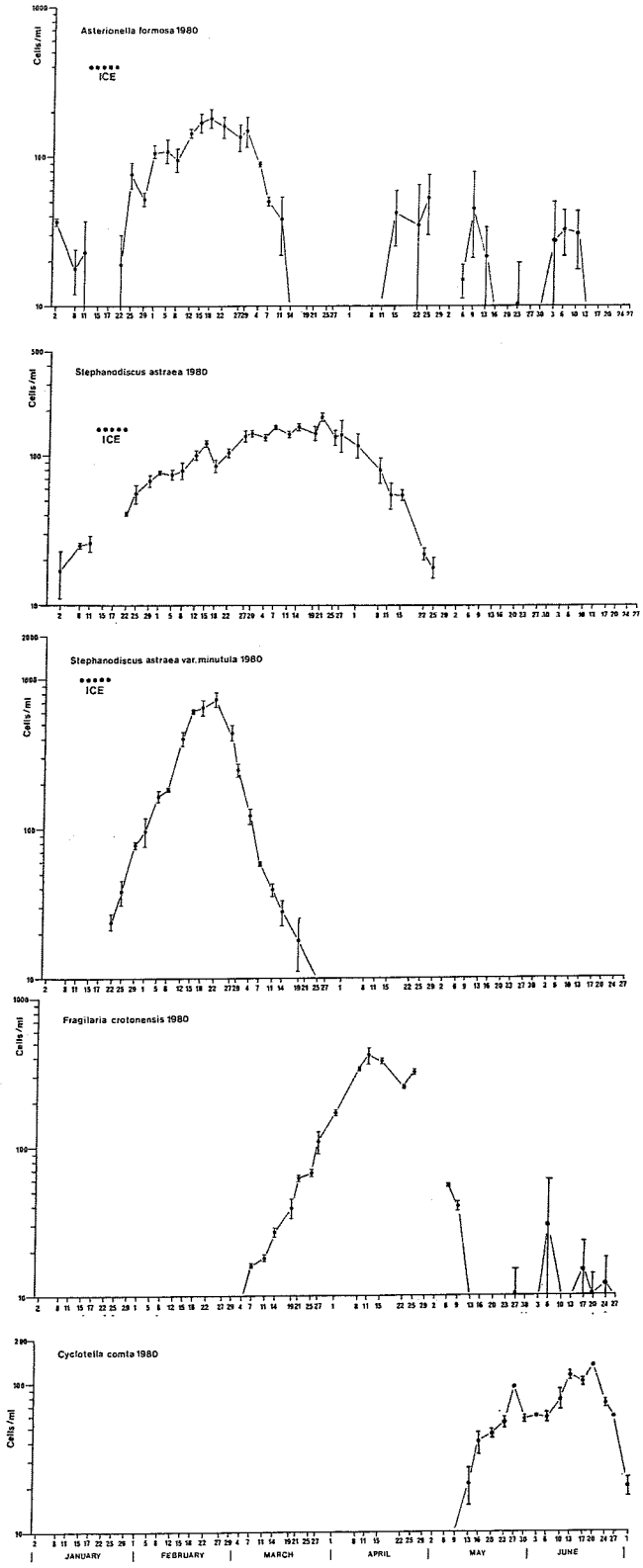

Fig. 5. See Fig. 2; 1980.

(Figs. 4 and 5). FERRARI & CAMURRI (1973) mentioned a complete outburst and collapse of *A. formosa* in an ice-bound Apennine lake from January until April.

Orthophosphate, silicate and nitrate were measured weekly in 1978 and 1980. In 1978 the concentration of phosphate was about 5 µg/l around 1 February, less than 1 µg/l from 5 February until 1 May, after that increasing up to 7 µg/l at 13 June, and 0.5 µg/l at 20 June. The concentration of silicate was 1.0—1.5 mg/l until the end of March and 0.5—1.0 mg/l afterwards. The nitrate concentration varied between 0.30 and 0.45 mg/l. In 1980 the phosphate concentration was 10 µg/l in January, dropped from 10 to 2.5 µg/l between 29 January and 14 February, gradually decreased to less than 1 µg/l until 20 March, and kept that level until 1 July. The concentration of silicate was 1.75—2.00 mg/l from 2 January until 1 April and decreased very gradually to 0.95 mg/l at 24 June. The nitrate concentration varied between 0.35 and 0.50 mg/l.

Discussion

Asterionella, though varying in maximum density and duration of blooming, is a regularly occurring early-spring species. This is in accordance with the long-term periodicity data of LUND (1964) for Windermere, as well as of BETHGE (1953) for a pond. The blooms of *Asterionella* and *Fragilaria* concurred in 1978. Both species belong to the same dry weight class (LUND 1964), whereas they grow almost equally fast in culture (TALLING 1955) and show no interactions by external metabolites when cultured together (TALLING 1957). In Lake Maarsseveen *Asterionella* greatly outnumbered *Fragilaria* in 1978, but, at lower maximum numbers of *Asterionella* in 1979 *Fragilaria* did not bloom at all. LUND (1964) also mentioned years with concurrent blooms of both species (and dominance of *Asterionella*) and years in which *Asterionella* was not accompanied by *Fragilaria*. *Stephanodiscus* and *Cyclotella* occurred at fairly regular times every year.

The mean temperatures of the top 10 m of water at the time of maximum abundances of *Asterionella* were about 5.5 (in 1977), 6.5 (in 1978), 3 (in 1979) and 4 °C (in 1980). For *S. astraea* these values were 5.5, 2, 3 and 4.5 °C, resp.; for *S. astraea* var. *minutula* 4.5, 4 and 4 °C; for *Fragilaria* 10.5 (1977), 4 (1978) and 7 °C (1980), and for *Cyclotella* 12.5, 14, 13.5 and 15.5 °C. The onset of flowering in Lake Maarsseveen might be related to temperature. *Fragilaria* started waxing at 5 (25 February 1977), 2 (24 February 1978; but more clearly at 21 March at 5 °C) and 4.5 °C (7 March 1980). *Cyclotella* started at 10 (29 April 1977), 11.5 (16 May 1978), 11 (15 May 1979) and 10.5 °C (13 May 1980), which was all the more conspicuous since the times involved differed. However, this relationship is probably less simple for *Fragilaria* in 1980 since the temperature of about 4 °C was already reached in the first half of February.

When two succeeding maxima of one species occurred the second peak showed a steeper slope (see also TALLING 1955) in case of *Asterionella* (1979) and *Cyclotella* (1977). This will be due to a higher cell division rate at higher temperature (FURNASS 1978) since it was not demonstrated by *S. astraea* and *Fragilaria* (1978) which had two maxima at smaller temperature intervals earlier in the season. The initiation of algal outburst sometimes coincided with a sudden rise in temperature. It was seen in *Cyclotella* in 1977 (in particular the second peak) and in 1979 (with increasing temperatures from 15 and 11 °C onwards, resp.), but not in 1978

and 1980 when the initiation took place under temporarily constant temperature conditions (11—12 and 13—14 °C, resp.)

The decrease of the phosphate concentration in the beginning of February in 1978 as well as in 1980 to less than 1 µg/l coincided with the development of the maxima of *Asterionella* and *Stephanodiscus*. LUND (1950) mentioned this phosphate concentration for the greater part of the spring-growth period of *Asterionella* in Windermere. The increase and decrease of phosphate in Lake Maarsseveen in May/June 1978 roughly followed the outburst and decline, resp., of *Cyclotella*. The rise and fall of *Fragilaria* occurred at very low phosphate concentrations. These changes were not seen in 1980 though *Cyclotella* flowered in the same period. The level of silicate showed a trend of very small decrease in both years, but did not drop below about 0.5 mg/l. LUND (1950) stated that diatoms cannot develop populations when the concentration of silicate is less than 0.5 mg/l (unless, as was demonstrated in culture (HUGHES & LUND 1962), small amounts of phosphate were added) but stressed that every lake must be considered separately. In Lake Maarsseveen diatom populations collapsed at more than thrice the concentration (average value of measurements at 0, 5 and 10 m depth) mentioned by LUND. The concentration of nitrate varied without any trend between 0.30 and 0.50 mg/l in both years.

The relationship between littoral and open-water populations of algae can be considered in two ways. STOCKNER (vide ROUND 1971) found that *Cyclotella stelligera* and *Tabellaria flocculosa* build up populations in the littoral zone of lakes in spring and then disperse into the plankton in summer. On the other hand, according to LUND (1949) the littoral deposits receive cells from the plankton but there is no evidence (in Windermere) that the littoral acts as a centre of production of cells for the plankton. The sudden fall during the maximum of *Asterionella* in Lake Maarsseveen (Fig. 2) might be due to a strong off-shore wind which was predominating during that period. GEORGE & HEANEY (1978) found that organisms tending to remain near the surface become concentrated down-wind. The depth at our sampling station in the littoral (Fig. 1) was very shallow indeed.

The understanding of algal periodicity is still (ROUND 1971) hidden in a complex action of abiotic and biotic factors. This study, supplying a detailed analysis of the waxing and waning of vernal diatom species, is meant as a first step to further analysis, descriptively (numbers of cells per colony; cell size variation; fungal parasitism [see CANTER 1949; LUND 1965]) as well as experimentally (nutrient uptake kinetics; bioassays), which has been started by the second author.

Summary

The diatoms from the open-water zone, sampled twice a week and given as integral numbers of the top 10 m of water, showed a succession in blooming according to the series *Asterionella formosa*, *Stephanodiscus astraea*, *Fragilaria crotonensis*, and *Cyclotella comta*. There were yearly variations in the time, amplitude and duration of blooming. The onset of blooming of *Fragilaria* and *Cyclotella* occurred at about 5 and 10 °C, respectively. Collapsing diatom populations were observed at silicate concentrations of 1.8—2.0 mg/l. Phosphate concentrations varied between 1 and 2.5 µg/l, and nitrate concentrations varied between 0.30 and 0.50 mg/l.

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