# Planktonic Changes Following the Restoration of Lake Trummen, Sweden

By G Andersson, G Cronberg and C Gelin, Institute of Limnology, University of Lund, Fack, S-220 03 Lund 3, Sweden.

**ABSTRACT**

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The plankton communities in Lake Trummen, Sweden, have been studied before and after the restoration of the lake. The changes in the plankton communities are discussed in relation to decreased concentrations of plant nutrients. The biomass of phytoplankton in summer has been reduced by ca 60 percent and the troublesome bloom of blue-green algae has nearly disappeared. The annual production of phytoplankton decreased with ca 30 percent and due to better light conditions the productive layer increased. The number of zooplankton, especially cladocerans, has decreased drastically.

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**An article describing the restoration of severely-polluted Lake Trummen (located in southern Sweden) was published in an earlier issue of *Ambio* (1); therefore only a brief summary of the restoration will be given here. The shallow, formerly oligotrophic Lake Trummen near the town of Växjö was strongly polluted by waste water from the middle of the 1930's until 1958. The inflow of waste water was cut off 1957–58. The lake however did not recover. Preliminary investigations in 1968 and 1969 showed that it was the black sediment deposited during the pollution period that contributed most to the high productivity of the lake during the spring and especially the summer. Plant nutrients released from the black sediment gave rise to extensive blooms of blue-green algae. The restoration of Lake Trummen was carried out during 1970 and 1971 by means of a suction-dredging method, whereby the nutrient-rich sediment was pumped up into settling ponds on land.**

**This paper reports some of the changes in the phyto- and zooplankton communities, comparing conditions in 1969 (the year before the restoration) and 1972 (the year after the restoration). It should be kept in mind, however, that meteorological differences between these two years, in addition to normal year-to-year variations, to a certain degree render the interpretation difficult.**

## METHODS

Water samples were collected at least once a month and the concentrations of phosphate (2), total phosphorus (2, 3), ammonium (4) and Kjeldahl nitrogen (=organic nitrogen+ammonium) were determined. The pH was determined potentiometrically and the Secchi disc transparency–a relative measure of the light penetration in the water–is the depth where the white Secchi disc, 25 cm in diameter, disappears from sight.

Samples for phytoplankton analyses were taken with a Ruttner sampler at least once a month at different depths. The number of algae was counted in sedimentation chambers with the aid of an inverted microscope and the biomass calculated.

Primary production of organic matter by phytoplankton was measured by using the radioactive isotope carbon 14. After addition of radioactive bicarbonate ($HCO_3^-$) to glass bottles, each containing the plankton community from different depths of the lake, these were exposed to natural light conditions corresponding to the light conditions existing at the depths from which the water samples were taken. The experimental time was half a daylight period (noon to sunset). The production is expressed as grams of carbon per $m^3$ and day at the different depths, and by integrating the photosynthesis curve from the surface to the bottom of the productive zone (=trofogenic layer), thus expressing the total production in a given column of water as grams of carbon per $m^2$ lake surface and day.

The horizontal distribution of zooplankton in the lake is very uneven and the number of zooplankton changes rapidly from time to time. In order to obtain representative material, composite samples were taken at 1–2 week intervals. Using a plexiglass tube, water samples were taken from 20 sites and mixed together. Subsamples were taken from this mixture, filtered, and the zooplankton species were counted in an inverted microscope.

## RESULTS AND DISCUSSION

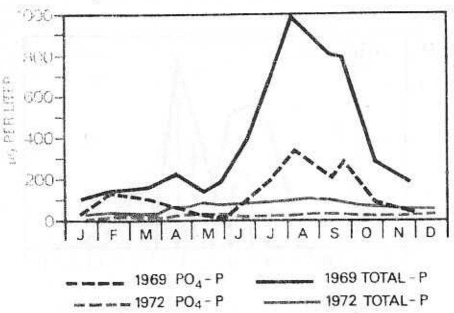
**Plant nutrients:** The aim of the restoration was to reduce the supply of plant nutrients in the lake ecosystem in order to prevent the troublesome bloom of blue-green algae. The results from the first year after the restoration are promising. A comparison of the concentrations of nutrients in the water in 1969 and 1972, respectively, gives a striking picture of the improvements (Figure 1A). The reduction of the important component phosphate is especially remarkable. The earlier storing of ammonium during the winter was less pronounced in 1972 (Figure 1 B), while the change in nitrate concentration is relatively small. However in 1972, plant nutrients were still present in concentrations strong enough to cause large crops of algae (5).

**pH and transparency:** The result of the decreased concentrations of nutrients is a lower production and a smaller biomass of phytoplankton (see below). Before the restoration, the intense production gave rise to abnormally high pH values during summer (Figure 1C). One effect of the restoration has been a normalization of the pH conditions. As a consequence of the reduction in phytoplankton biomass and in the number of zooplankton, the water is now less turbid and thus the transparency values are accordingly higher (Figure 1D), i e the light conditions are better.

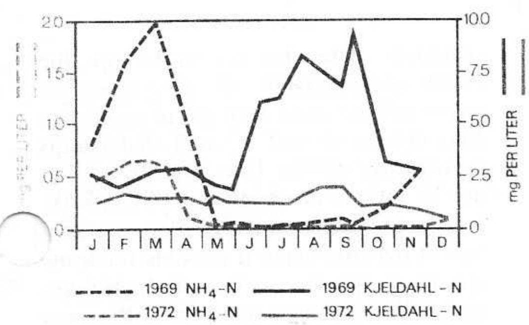
**Phytoplankton:** During the winter of 1969 the lake was poor in phytoplankton (Figure 2). In the middle of May–after the breakup of the ice–the diatoms, mainly *Melosira*, developed a maximum. The diatoms were succeeded by blue-green algae. The dominant species, *Aphanizomenon flos-aquae*, formed a water bloom with a biomass of 91 mg/l in June (Figure 2). However, this bloom was of short duration and during July–September a new, excessive bloom appeared, consisting mainly of the blue-green algae *Microcystis aeruginosa*. In October the *Microcystis* population diminished and the diatoms–especially *Melosira*–caused an autumn peak. The permanently blooming water during the summer was typical for Lake Trummen before the restoration.

In the late winter of 1972 there was a development of algae under the ice. It was, however, quite a different population than earlier. It consisted of different *Chrysophyceae* species, namely *Dinobryon divergens*, *D bavaricum*, *D cylindricum*, and different species of *Mallomonas*, *Synura*, plus *Glenodinium* belonging to the group of *Pyrrophyta*. After the breakup of the ice, this population disappeared and was followed by a rich development of *Oscillatoria*, the blue-green algae that caused the greatest bio-

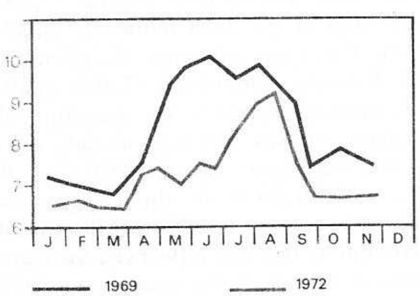
**Figure 1. A–D. Seasonal variation of phosphorus and nitrogen concentrations, pH, and transparency in Lake Trummen, 1969 and 1972. All samples taken from the centre of the lake.**




**A. Phosphate expressed as phosphorus ($PO_4$–P) and total phosphorus (Total–P).**




**B. Ammonium expressed as Ammonium nitrogen ($NH_4$–N) and Kjeldahl nitrogen (Kjeldahl–N).**




**C. pH conditions.**


**D. Secchi disc transparency.**

mass of phytoplankton in 1972: 41 mg/l (Figure 2). In the first half of August the diatoms, mostly *Melosira*, were abundant and were followed by a water bloom of short duration consisting of *Anabaena flos-aquae*. Later in the autumn the phytoplankton population diminished.

Comparing the years 1969 and 1972, the most marked differences in the development of phytoplankton were:

1. The biomass of phytoplankton decreased drastically (Figure 2).
2. The massive water bloom of *Microcystis aeruginosa* disappeared completely (Figure 3).
3. Spring and autumn maxima of diatoms used to occur before restoration. However, in 1972 the diatoms were most abundant in August.
4. In the late winter of 1969, the water was poor in plankton; but in the late winter of 1972 a development of *Chrysophyceae* and *Glenodinium* developed under the ice.
5. 1972 the amount of nannoplankton had increased.

**Phytoplankton production:** During the winters 1968/69 and 1971/72, the production was insignificant because of bad light conditions caused by a thick ice cover. Immediately after the breakup of the ice in 1969 the production increased rapidly, favored by tremendous quantities of plant nutrients released from the sediment. As is characteristic for a polluted lake within the northern temperate region, the greatest production per day was recorded in August (Figure 4), when blue-green algae were most abundant. The blue-greens caused bad light conditions and the Secchi disc transparency was ca 0.2 m (Figure 1D). During this period, the gross production was of the order of magnitude of 10 g C/m$^3$ · day in the superficial layer. During the period from July–early September, the productive zone was less than 0.5 m (Figure 5).

The greatest production per m$^2$ lake surface and day was 3.6 g C on August 7 (Figure 4) but usually the figure was about 2.5 g C during the summer. The annual production was calculated to be 345 g C/m$^2$ lake surface.

When the ice broke up in 1972, the concentrations of plant nutrients as well as inorganic carbon were lower than those

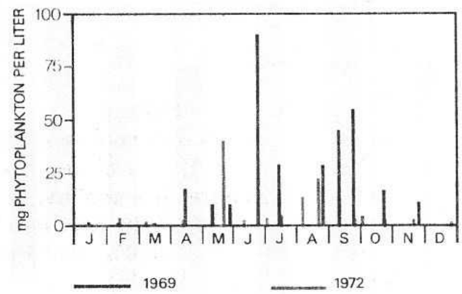
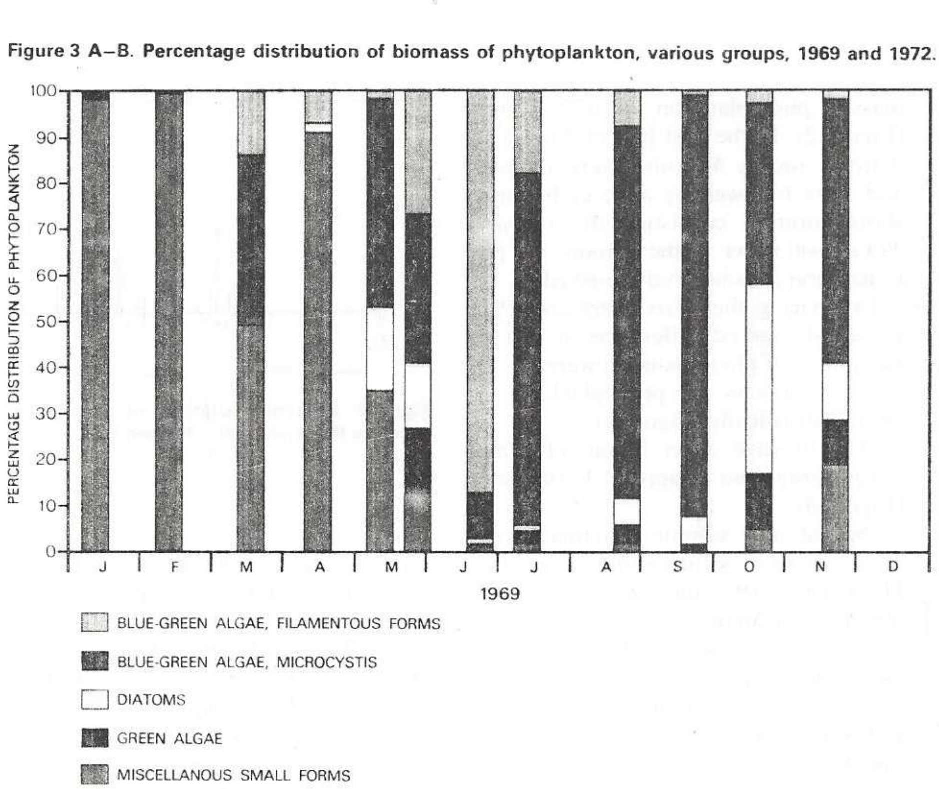



**Figure 2. Seasonal variations of phytoplankton biomass (fresh weight), 1969 and 1972.**

of 1969 (Figures 1A and 1B). Light conditions were better and the productive layer much thicker, except for a period in the middle of August when a bloom of *Anabaena flos-aquae* developed (Figure 5). During this bloom, when the chlorophyll *a* content of the surface water was ca 150 mg/m$^3$, the production was estimated to be 2.4 g C/m$^2$ · day. Usually it varied from 1.0 to 2.0 g C/m$^3$ · day at depths with optimal light conditions and 1.5–2.0 g C/m$^2$ · day during the period from June to September. The vertical distribution of phytoplankton production was different when comparing the summer of 1969 with that of 1972 (Figure 5). But the difference between the two years is less pronounced regarding the production per m$^2$ lake surface and day. This is due to the fact that photosynthesis can now take place at greater depths after the reduction of blue-green algae. The annual production in 1972 was calculated to be 245 g C/m$^2$, a decrease with ca 30 percent compared with 1969. In 1972 a much greater part of the total phytoplankton production was caused by small phytoplankton organisms (nannoplankton) compared to 1969. Lake Trummen is still eutrophic according to Rodhe's definition (6). However, in 1972 excavations made in connection with construction work were still being performed in the surroundings and water from these was drained to the lake, presumably favoring phytoplankton production.

**Zooplankton:** During the winter of 1969, bad oxygen conditions caused a near-complete extermination of zoo-

Figure 3 A–B. Percentage distribution of biomass of phytoplankton, various groups, 1969 and 1972.



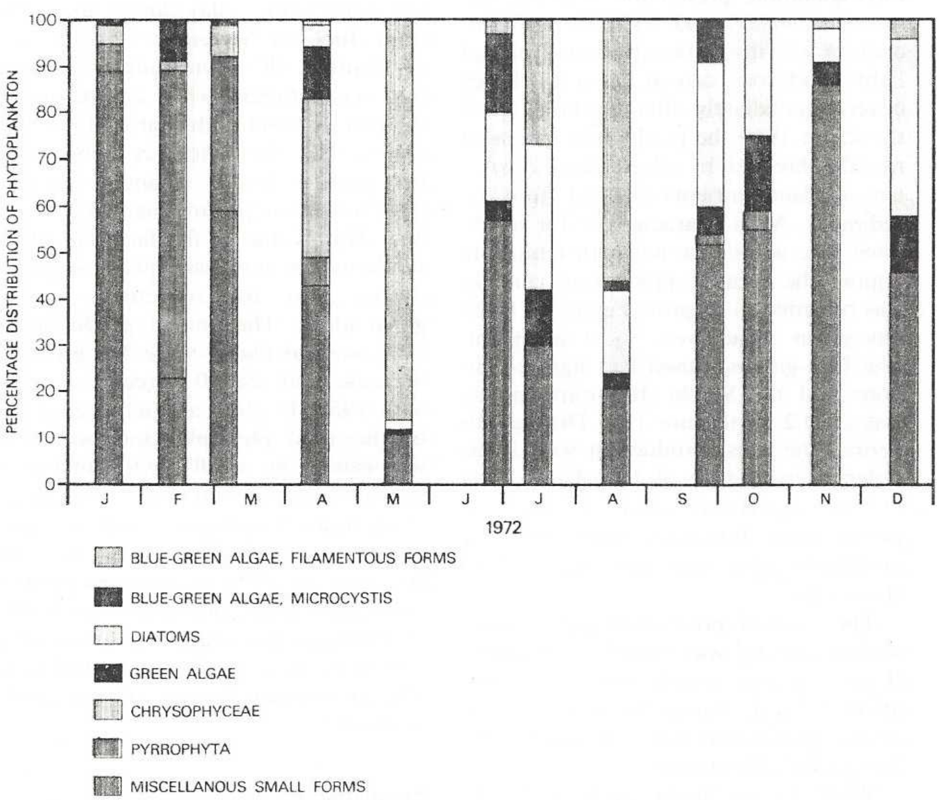
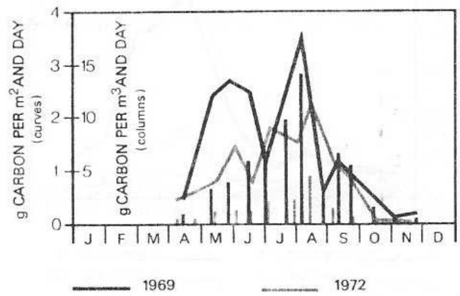




**Figure 4. Seasonal variation of phytoplankton production, 1969 and 1972. Columns indicate production in g carbon per m³ and day at the optimum depths. Curves show production in g carbon per m² and day in the whole of the productive water column.**

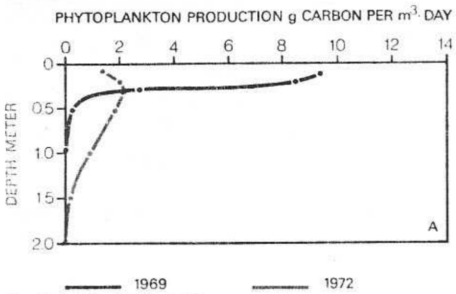



plankton. After the ice broke up, the rapid development of phytoplankton gave rise to a great increase in rotifers in May (Figure 6) and of small cladocerans (Crustacea) during June and July (Figure 7). Intense production of phytoplankton during the summer and large quantities of detritus made it possible for some species to occur in extremely high numbers. The maximum numbers of the most common rotifers were: *Anuraeopsis fissa* (12,000 ind/l), *Filinia longiseta* (9,000 ind/l), and *Trichocerca pusilla* (5,500 ind/l), and of the most numerous cladocerans: *Chydorus sphaericus* (3,200 ind/l), and *Bosmina longirostris* (2,100 ind/l).

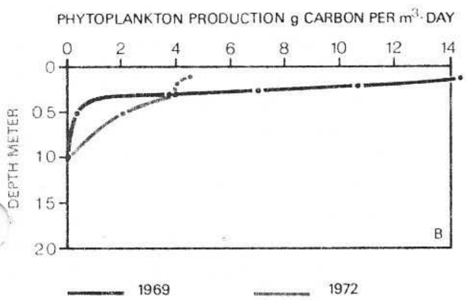
A marked change in the quantities of zooplankton was observed already during the restoration period (1970–71). A large-scale fish-kill in the oxygen-free lake in the spring of 1970 caused reduced predation by fish and influenced the composition. However, the changes in 1972 must mainly be an effect of the restoration. Due to the lower production of phytoplankton and the removal of detritus, the supply of food for zooplankton was reduced. Therefore the number of zooplankton during the summer of 1972 was relatively low compared with that of 1969. It is especially the summer maxima of the small cladocerans *Chydorus sphaericus* and *Bosmina longirostris* which have failed to appear, but also the summer peaks of some rotifers have been reduced.

Expressed as percentage of the number in 1969, the abundance in 1972 dur-

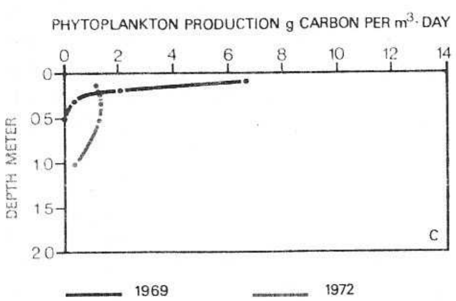
Figure 5 A–C. Vertical distribution of phytoplankton production during three summer months, 1969 and 1972, expressed as g carbon per m³ and day. Values below diagrams is the production in the productive water columns given as g carbon per m² lake surface and day (integrated values).




A. July 21, 1969: 2.41 g
July 6, 1972: 1.87 g

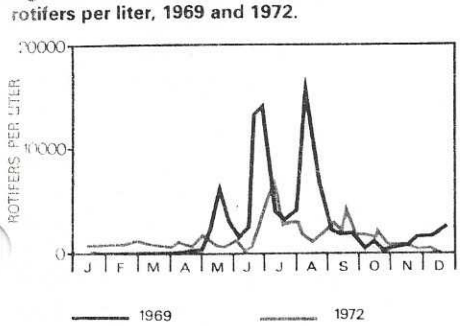



B. August 7, 1969: 3.62 g
August 16, 1972: 2.39 g




C. September 11, 1969: 1.20 g
September 7, 1972: 1.24 g

Figure 6. Seasonal variations in total number of rotifers per liter, 1969 and 1972.




ing the summer (mean values for June–September) was as follows for the three main zooplankton groups: rotifers 41 percent, cladocerans 1.6 percent, and copepods (excluding young stages) 64 percent.

On the other hand, better oxygen conditions during the winter made it possible for some species to survive under the ice. The rotifer genera *Keratella* and *Polyarthra*, which were nearly absent in 1969, occurred in the winter of 1972 in relatively high numbers (Figure 6).

The most striking difference between 1969 and 1972 is that the number of some zooplankton species have declined dramatically, especially some species which generally are considered as indicators of eutrophy, e g *Brachionus angularis*, *Trichocerca pusilla*, *Keratella quadrata* and *Chydorus sphaericus* (as plankter). The latter species declined from ca 1,300 ind/l 1969 to 5 ind/l 1972 (mean values for June–September). The composition of species has been changed only to a small degree. For instance, the earlier very abundant rotifer *Anuraeopsis fissa* was not observed in 1972.

## CONCLUSIONS

In this report some examples of the effect of the restoration on chemical and planktonic conditions in Lake Trummen are presented. Other changes that occurred, e g concerning the development of bacteria, periphyton, macrophyte vegetation, bottom fauna, fish and so on are being studied by the research team. It should be considered, however, that many organisms react more slowly than planktonic ones. Thus the recording of the total effects of restoration will take additional time. The running limnological investigations are scheduled to continue another year, they will be followed by a control program, which will continue until 1980.

The Lake Trummen restoration project has given–besides all the technical and ecological experiences–good possibilities to study an ongoing development that is the reverse of the common pollution-eutrophication process. The situation in Trummen one year after restoration proves that it is possible to get rapid improvements in even a very severely damaged recipient.

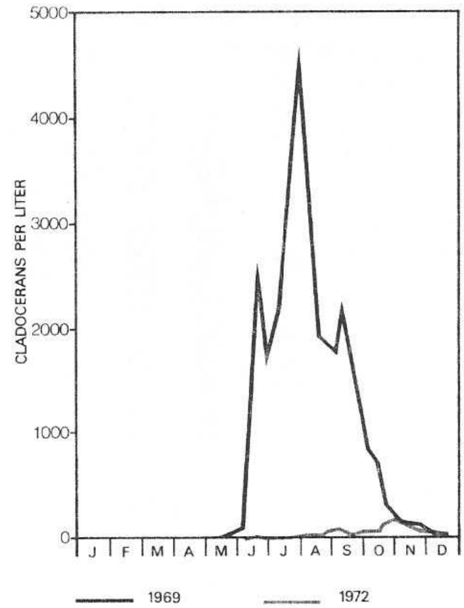



Figure 7. Seasonal variations in the total number of cladocerans per liter, 1969 and 1972.

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7. The authors thank W Ripl, Institute of Limnology, University of Lund, Sweden, for data on plant nutrients.
8. The investigation was financed mainly by the Research Committee of the National Swedish Environment Protection Board.
9. Received January 18, 1973.