

## Lake Trummen restoration project

### II. Bacteria, phytoplankton and phytoplankton productivity

G. CRONBERG, C. GELIN and K. LARSSON

With 8 figures and 1 table in the text

## Introduction

The background and principle course of action of the Lake Trummen Restoration Project are presented in the preceding paper (BENGSSON et al. 1975).

Much of the literature on eutrophication puts emphasis on the phytoplankton blooms and odor nuisances. Eutrophication processes are described from more and more lakes (THOMAS 1969; EDMONDSON 1969) but very seldom the reverse course. Just a few investigations in connection with recovery of aquatic systems have up to now been reported, i. e. Lake Washington (EDMONDSON 1972).

This paper reports the changes in the development of bacteria and phytoplankton populations and the changes in the productivity structure of the phytoplankton community following the suction dredging of the polluted sediment of Lake Trummen.

## Methods

Heterotrophic bacteria were determined by the spread plate technique on the nutrient poor yeast-extract peptone medium (organic content 0.03 %) used by FONDÉN (1968, 1969).

Protein and starch decomposing bacteria were determined by plate count on relatively rich media containing gelatin and soluble starch, respectively. Incubations were performed under aerobic as well as anaerobic conditions.

Sulphate reducing bacteria were examined by plate count on a medium containing sulphate with lead acetate as indicator. Glucose decomposing bacteria were determined by use of the most probable number (MPN) method.

Water samples have been taken at a depth of 0.2 m, sediment samples at 0—5 cm, 15—20 cm (the lower part of the nutrient rich sediment before restoration), and 30—35 cm (upper part of the nutrient poor sediment before restoration).

For quantitative phytoplankton investigations water was collected with a RUTTNER sampler at 0.2 m and fixed with LUGOL's solution. For calculating the phytoplankton biomass (fresh weight), the traditional UTERMÖHL (1958) technique was used. Samples sedimented in chambers of 0.3 and 1 ml and were counted in an inverted microscope at 10 × and 400 × magnification.

Samples from the summers of 1968 and 1969 were so rich in blue-green algae that they were first treated with ultrasound (MSE Ultrasonic Disintegrator, 1 minute at 1 ampère) to split the large colonies of *Microcystis aeruginosa* and *Anabaena* spp.

The species diversity of phytoplankton, was expressed in SHANNON index according to ODUM (1971) and about 1,500 cells were counted.

The phytoplankton productivity was calculated according to STEEMANN NIELSEN (1952, 1965). 130 ml glass bottles were inoculated with usually 2 or 4  $\mu\text{Ci}$  of  $^{14}\text{C}$ - $\text{NaHCO}_3$ . The experimental time was half a day, from noon to 5 p.m. Selection of samples for analysis was made at 1 p.m. and 5 p.m.

from each bottle was directly filtered through a  $0.2\ \mu\text{m}$  membrane, while other subsamples from the bottles were poured through  $45$  and  $10\ \mu\text{m}$  net before filtration through membrane filters. The  $^{14}\text{C}$ -ampoules have been delivered from The International Agency for  $^{14}\text{C}$  Determination, Copenhagen, which also performed the radioactivity measurements of the membrane filters using GM-technique.

## Results and discussion

### Bacteria

The number of aerobic heterotrophic bacteria did not change after the restoration, although it increased during the dredging (Fig. 1).

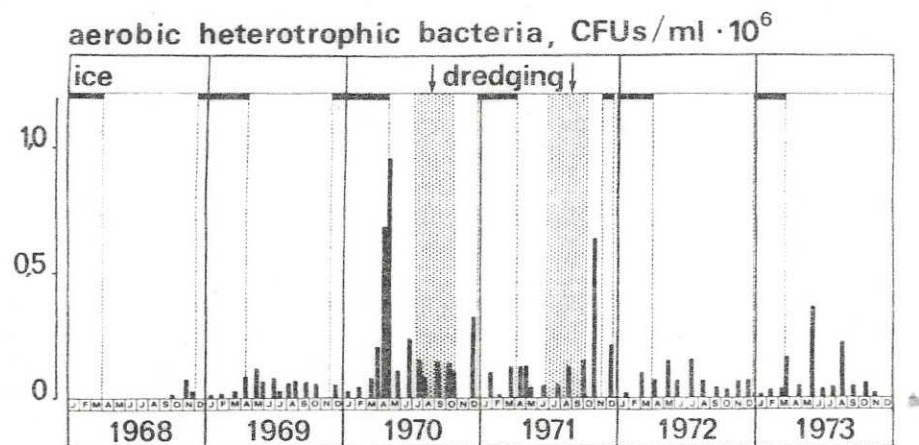


Fig. 1. Development of aerobic heterotrophic bacteria in Lake Trummen October 1968—November 1973 (colony forming units/ml water at 0.2 m depth).

For the determination of the heterotrophic bacteria a medium as little selective as possible was wanted. The chosen nutrient poor medium gave about 100 times more CFU (colony forming units) than Difco Nutrient Agar. Part of the autochthonous "oligo-carbophilic" microflora (OVERBECK 1974) seems therefore to be trapped on this medium. Before the restoration the organic content in the water was 100–180 mg/l. After the restoration the content was about 50 mg/l and a higher proportion consisted of dissolved substances (BENGTTSSON et al. 1975). This decrease in organic material seems not to be sufficient to affect the occurrence of bacteria as determined on this medium.

No correlation between the seasonal variation of phytoplankton and heterotrophic bacteria was observed. The bacterial fluctuation was rather irregular although there were generally low numbers in the winter and an increase occurred at the end of the ice periods. The particularly high spring maximum in 1970 was developed after an unusually long ice period with oxygen deficiency and a fish kill. A similar maximum was observed for the protein but not for the starch decomposing bacteria indicating the role of the proteins from dead fish. During 1973 the fluctuation in number of heterotrophic bacteria was great-

er than before. The maximum in June was followed by an unusually large population of *Bosmina longirostris* (ANDERSSON et al. 1975).

The number of heterotrophic bacteria that develop under anaerobic conditions increased 10 fold after the restoration, but still represented only about  $1/10$  of the number of aerobic heterotrophic bacteria.

The number of starch decomposing bacteria decreased by 50–60 % and that of protein-decomposing by 90–95 % (calculated from yearly averages) (Fig. 2, 3). This decrease is valid for both aerobically and anaerobically growing CFU. The seasonal fluctuation of starch decomposing bacteria showed a rather good correlation with that of the phytoplankton. The starch and protein decomposing bacteria were of practical reasons cultivated on more nutrient-rich media. The

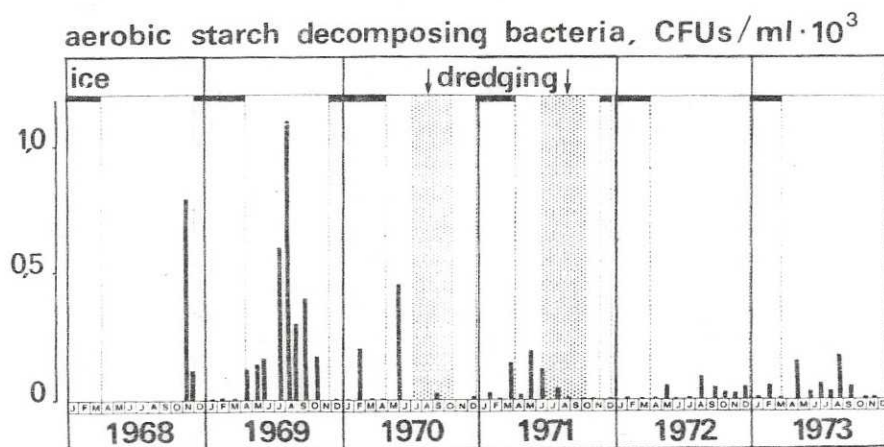


Fig. 2. Development of aerobic starch decomposing bacteria in Lake Trummen November 1968–November 1973 (colony forming units/ml water at 0.2 m depth).

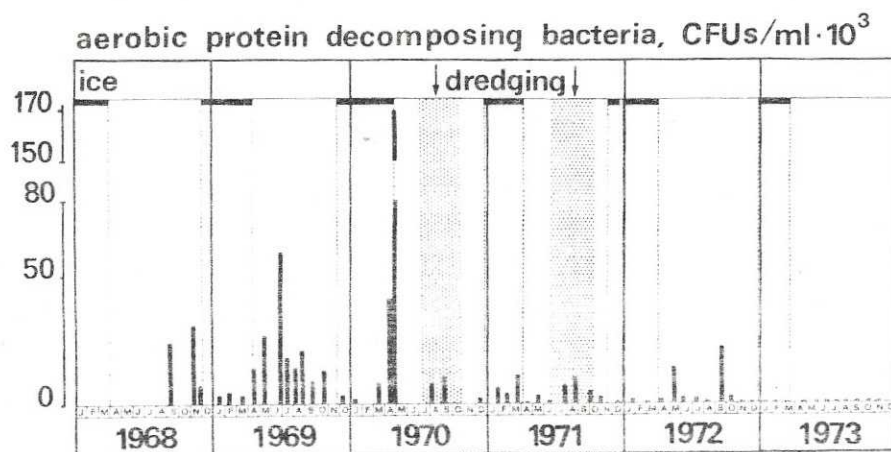


Fig. 3. Development of aerobic protein decomposing bacteria in Lake Trummen September 1968–November 1973 (colony forming units/ml water at 0.2 m depth).

bacteria growing on these media may be more nutrient demanding and therefore more easily affected by the decrease in organic material. The reduction in starch decomposers may be attributed to the lower phytoplankton biomass but was probably also related to the removal of macrophytes in the littoral.

There has also been a successive reduction in the number of glucose decomposing bacteria (also cultivated on a rich medium), which now constitutes about 25 % of the number before restoration.

Most of the examined groups of bacteria occurred in highest numbers at the sediment surface before the restoration and the numbers continuously decreased through the black polluted sediment. Anaerobically growing heterotrophic and sulphate-reducing bacteria were, however, most abundant 15–20 cm below the sediment surface. The underlying brown nutrient poor sediment contained comparably low numbers of bacteria.

After the dredging the occurrence of bacteria has been more concentrated to the new surface sediment. In this layer the number of most of the bacteria was the same as before. Aerobic protein decomposing and sulphate reducing bacteria, however, both decreased in number by about 50 % and the occurrence of anaerobically growing bacteria increased. The exposed sediment contains lower concentrations of phosphorus and nitrogen than the original polluted surface sediment. The content of free glucose is of the same order of magnitude as before (BENGTSSON et al. 1975).

#### Phytoplankton and phytoplankton productivity

Before restoration during winter and early spring the biomass and productivity of phytoplankton was low. The diatoms, mainly *Melosira* spp. and *Synedra* spp., were most abundant during spring and autumn. During the period June through September Lake Trummen was characterized by heavy blooms of blue-green algae and the average SECCHI disk transparency was 23 cm in 1968 and 18 cm in 1969 (Tab. 1). In June *Aphanizomenon flos-aquae* and *Anabaena spiroides* dominated. Later on in July the most abundant species were *Anabaena spiroides*, *Raphidiopsis mediterranea* and *Microcystis aeruginosa* (Figs. 4, 5).

Tab. 1. Mean SECCHI disk transparency (cm) and mean SHANNON diversity index (bits/cell) from June through September 1968–1973 in Lake Trummen, Sweden.

Year	1968	1969	1970	1971	1972	1973
SECCHI disk transparency (cm)	23	18	82	70	66	75
SHANNON diversity index (bits/cell)	1.6	1.0	3.7	2.4	2.4	3.0

Typically for a polluted lake the greatest productivity, calculated both per unit volume and per unit area, was recorded in August and September when the occurrence of *Microcystis aeruginosa* was greatest (ANDERSSON et al. 1973). During this period the pH was about 10, the dissolved organic and inorganic con-

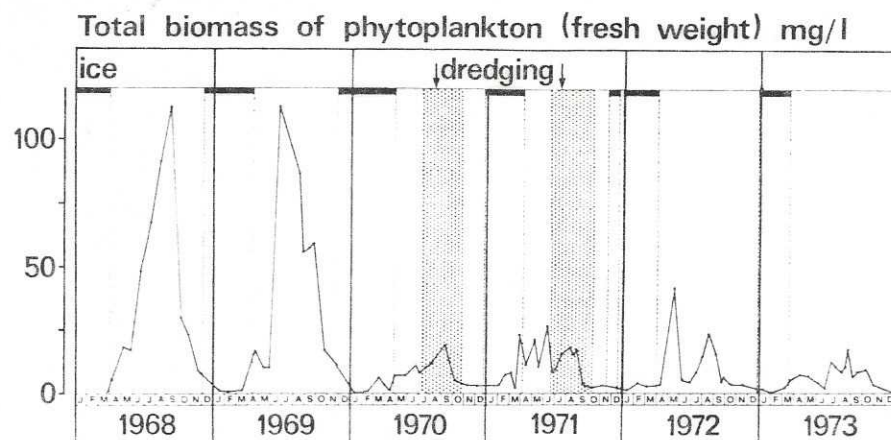


Fig. 4. Development of phytoplankton biomass (fresh weight) during 1968–1973 at 0.2 m depth in Lake Trummen; Sweden.

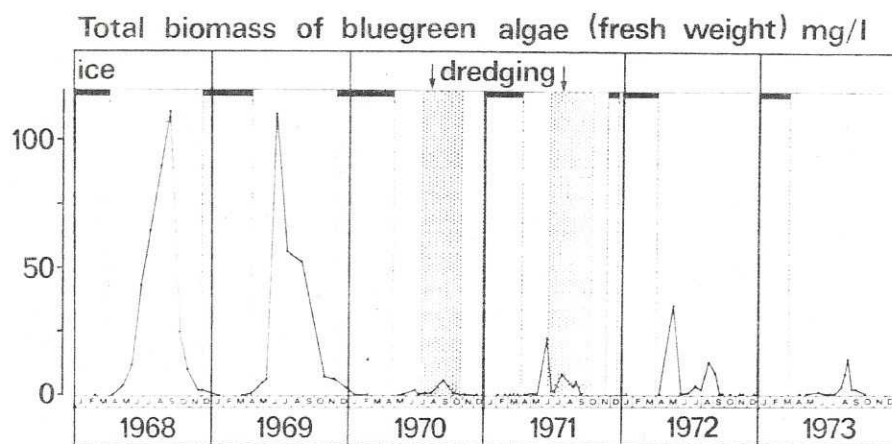


Fig. 5. Development of blue-green algae biomass (fresh weight) during 1968–1973 at 0.2 m depth in Lake Trummen, Sweden.

tent of nutrients in the water was high (BENGTSSON et al. 1975), favoring the development of blue-green algae (SHAPIRO 1973) and causing a low diversity of the phytoplankton community (Fig. 6).

The euphotic zone was less than 0.5 m and the total phytoplankton productivity ( $A_{max}$ ) was about  $10 \text{ g C} \cdot \text{m}^{-3} \cdot \text{day}^{-1}$  in the top 20 cm. Only 20–40% of the total production per  $\text{m}^3$  was photosynthesized by algae able to pass through a  $45 \mu\text{m}$  plankton net (Fig. 7).

From June through September 1968 and 1969 the mean biomass was  $75 \text{ mg/l}$  and the average species diversity low, 1.3 bits/cell. The mean annual phytoplankton productivity during 1968 and 1969 was calculated to  $370 \text{ g C} \cdot \text{m}^{-2}$  (Fig. 8).

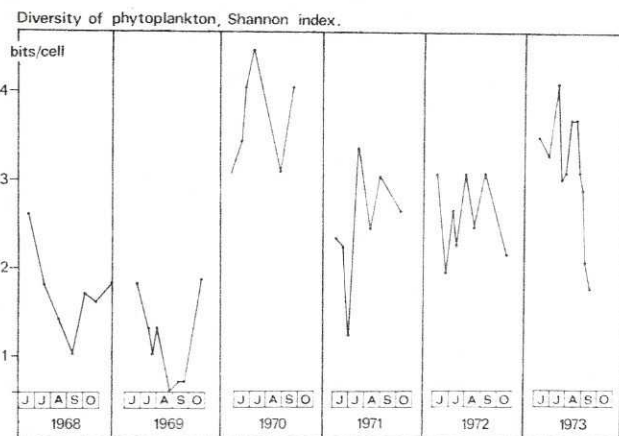


Fig. 6. Changes in species diversity from June through September at 0.2 m depth in Lake Trummen, Sweden. The SHANNON index was used and expressed in bits/cell.

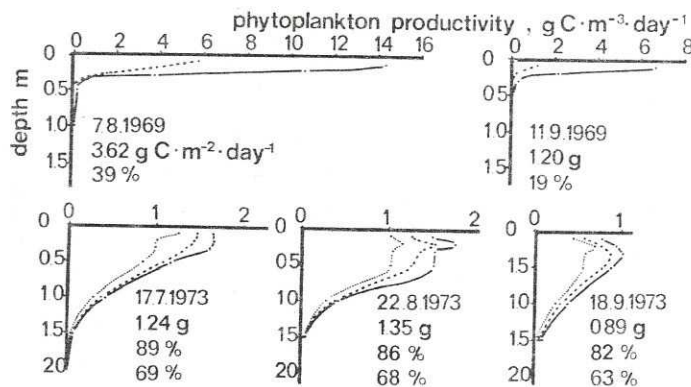


Fig. 7. Depth-distribution of photosynthetic rates during late summer 1969 and 1973 in Lake Trummen, Sweden. The percentage figures denote the productivity of algae passing through a 45  $\mu\text{m}$  plankton net (1969) or 45 and 10  $\mu\text{m}$  plankton nets (1973) in relation to the total phytoplankton productivity ( $\text{g C} \cdot \text{m}^{-3} \cdot \text{day}^{-1}$ ). — photosynthetic rate of the total phytoplankton community, --- photosynthetic rate of algae passing through a 45  $\mu\text{m}$  plankton net, ..... photosynthetic rate of algae passing through a 10  $\mu\text{m}$  plankton net.

After restoration the phytoplankton development changed drastically. During the unusually mild winters of 1972 and 1973 species belonging to Chrysophyceae were abundant under the thin and transparent ice and the populations consisted of mainly *Mallomonas eoa* (CRONBERG 1973), *Synura* spp. and *Dinobryon* spp. Spring and autumn peaks of diatoms failed to appear. Instead, diatoms were most abundant during the summer together with small miscellaneous forms, green algae and some blue-green algae, i.e. *Anabaena flos-aquae*, *Microcystis delicatissima* and *Aphanothece elipsoidea*. The biomass of

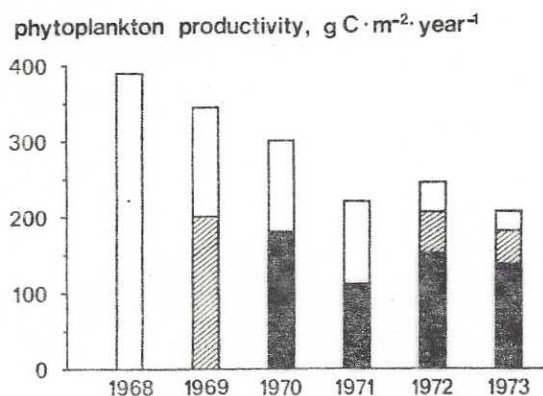


Fig. 8. The annual phytoplankton productivity 1968—1973 in Lake Trummen, Sweden. Black areas denote the productivity of algae passing through a 10  $\mu\text{m}$  plankton net (1970—1973) and the hatched plus the black areas the productivity of algae passing through a 45  $\mu\text{m}$  plankton net (1969, 1972, 1973).

blue-green algae decreased drastically and some species disappeared completely, for example *Oscillatoria agardhii* and *Raphidiopsis mediterranea*. The abundance of *Aphanizomenon flos-aquae* and *Microcystis aeruginosa* diminished greatly (Figs. 4, 5).

The phytoplankton diversity increased due to the quite different environmental conditions with low content of inorganic nutrients of the water (Fig. 6). Depending on the decrease of the phytoplankton biomass the light conditions of Lake Trummen improved. The mean SECCHI disk transparency from June through plankton productivity ( $A_{\text{max}}$ ) was usually less than  $2 \text{ g l} \cdot \text{m}^{-3} \cdot \text{day}^{-1}$ . The productivity calculated per unit area was still high due to the increase of the trophogenic layer (Fig. 7).

Selective filtrations during August and September 1973 using 45 and 10  $\mu\text{m}$  plankton nets showed that more than 80 and 60 %, respectively, of the total productivity per unit area was assimilated by algae able to pass through these nets. The mean biomass of phytoplankton from June through September 1972 and 1973 was 10 mg/l and the mean diversity index 2.7 bits/cell. The mean annual phytoplankton productivity during these two years was  $225 \text{ g C} \cdot \text{m}^{-2}$ . More than 60 % of the annual total production was photosynthesized by algae passing through a 10  $\mu\text{m}$  net (Fig. 8). The low content of inorganic nutrients in the restored lake, above all phosphorus, favored the development of nanoplankton, which are supposed to be metabolically more active than netplankton due to higher surface area/volume ratios (WILLIAMS 1964). As the abundance of nanoplankton increased after restoration and as the nanoplankton has greater assimilation number ( $P_{\text{max}}$ ) relative to the netplankton (GELIN & RIPL in manuscr.) it may be of importance for the development of zooplankton (ANDERSSON et al. 1975).

## Summary

The number of aerobic heterotrophic bacteria in the water did not change after the restoration of Lake Trummen. A marked decrease of protein, starch and glucose decomposing bacteria was observed. In the sediment all the examined physiological groups of bacteria were concentrated to the uppermost 5 cm, where most of them occurred in the same number as before.

In connection with the restoration the mean biomass of phytoplankton from June until September decreased from 75 to 10 mg/l due to the lower abundance of blue-green algae. The productivity structure of the phytoplankton communities was changed. In spite of the decrease of the mean annual productivity from 375 to 225 g C · m<sup>-2</sup>, the yearly productivity of algae with a mean diameter less than 45 µm did not change. More than 60 % of the annual phytoplankton production was photosynthesized by algae less than 10 µm. The diversity of phytoplankton increased when the fertility of Lake Trummen decreased.

## References

- ANDERSSON, G., BERGGREN, H. & HAMRIN, S., 1975: Lake Trummen restoration project. III. Zooplankton, macrobenthos and fish. — *Verh. Internat. Verein. Limnol.* 19, 1097—1106.
- ANDERSSON, G., CRONBERG, G. & GELIN, C., 1973: Planktonic changes following the restoration of Lake Trummen, Sweden. — *Ambio* 2, (1—2), 44—47.
- BENGTSSON, L., FLEISCHER, S., LINDMARK, G. & RIPL, W., 1975: Lake Trummen restoration project. I. Water and sediment chemistry. — *Verh. Internat. Verein. Limnol.* 19, 1080—1087.
- CRONBERG, G., 1973: Development of cysts in *Mallomonas eoa* examined by scanning electron microscopy. — *Hydrobiologia* 43, (1—2), 29—38.
- EDMONDSON, W. T., 1969: Eutrophication in North America. — In: *Eutrophication; causes, consequences, correctives*, Int. Symp. on Eutrophication, Nat. Acad. Sci., Washington, p. 661.
- 1972: The present condition of Lake Washington. — *Verh. Internat. Verein. Limnol.* 18, 284—291.
- FONDÉN, R., 1968: A yeast-extract peptonagar for the determination of heterotrophic bacteria in lakes. — *Vatten* (2) 161—166.
- 1969: Heterotrophic bacteria in Lake Mälaren and Lake Hjälmaren. — *Oikos* 20, 344—372.
- ODUM, E. P., 1971: *Fundamentals of Ecology*. — W. B. Saunders Company, p. 144.
- OVERBECK, J., 1974: Microbiology and biochemistry. — *Mitt. Internat. Verein. Limnol.* 20, 198—228.
- SHAPIRO, J., 1973: Bluegreen algae: Why they become dominant. — *Science* 179, 382—384.
- STEEMANN NIELSEN, E., 1952: The use of radioactive carbon (C<sup>14</sup>) for measuring organic production in the sea. — *J. Cons. Int. Explor. Mer.* 18, 117—140.
- 1965: On the determination of the activity in <sup>14</sup>C-ampoules for measuring primary production. — *Limnol. Oceanogr. Suppl.* 10, 247—252.
- THOMAS, E. A., 1969: The process of eutrophication in central european lakes. — In: *Eutrophication: causes, consequences, correctives*, Int. Symp. on Eutrophication, Nat. Acad. Sci., Washington, p. 661.
- UTERMÖHL, H., 1958: Zur Vervollkommnung der quantitativen Phytoplankton-Methodik. — *Mitt. Internat. Verein. Limnol.* 9, 1—39. Stuttgart.
- WILLIAMS, R. B., 1964: Division rates of salt marsh diatoms in relation to salinity and cell size. — *Ecology* 45, 877—880.

## Discussion

SHAPIRO: Could you explain why the lake seemed to be getting better in early 1970 even though little dredging had been done?

GELIN: Unfortunately the unusual long ice period 1969/70 caused oxygen deficiency and a large scale fish kill. This probably influenced the zooplankton and phytoplankton population just before starting the dredging.

HORNE: Although there has been a most satisfying percentage decrease in numbers of blue-green algae since restoration, are there never the less any nuisance scums still present causing any complaints?

GELIN: No. Complaints do not now occur, but the lake is still eutrophic.