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The occurrence of *Gonyostomum semen* (Ehr.) Diesing in Finnish lakes

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Abstract

Since the early nineteen-eighties swimmers have complained of the nuisance effect of *Gonyostomum semen* in Finnish lakes. This alga causes an unpleasant slimy coating on the skin after swimming. Although it was first identified in Finland in 1894, the first complaints concerning *G. semen* were reported to the Finnish water authorities in 1978. During the period 1978–1989 a total of 110 water samples were qualitatively microscoped for *G. semen*. According to the results the alga seems to have spread from the south-eastern part of Finland throughout the southern part of the country and northwards almost to the Arctic circle.

139 quantitative samples from monitored lakes were also analysed. The alga seems to prefer dystrophic and eutrophic conditions.

Introduction

Gonyostomum semen (Ehr). Diesing belongs to the class Raphidophyceae. It has been reported from several Nordic countries, where its occurrence has increased during recent years (Cronberg *et al.*, 1988; Hongve *et al.*, 1988; Eloranta & Järvinen, 1991).

The earliest observations of mass developments were made in Lake Helgasjön, Sweden, in 1948 (Sörensen, 1954). No reports of nuisance effects to swimmers were reported to the Finnish authorities before 1978. Not even those people, living close to lakes in which *G. semen* has caused inconvience to swimmers since the 1980's, have reported any problems in earlier years.

The aim of this work was to investigate the occurrence of *G. semen* in Finnish lakes according to data of the National Board of Waters and the Environment. First the records concerning the mass developments of alga with nuisance effects were summarized. Secondly the results of two nation-wide surveys of 139 lakes in 1982 and 1986 were investigated in order to evaluate the abundance of *G. semen* in these lakes.

The data of physico-chemical water quality were used to estimate possible environmental factors favouring this alga in Finnish lakes.

Earlier occurrence of *Gonyostomum semen* in Finland

G. semen was reported in Finland for the first time at the end of nineteenth century in a small pond outside Helsinki (Levander, 1894). Between

1929 and 1976 this alga was not reported in Finland. However, during a nation-wide microscopy survey in 1971 in this research institute the alga was observed in a few water samples conserved with formaldehyde. The identification caused problems and after some discussion these cells were erroneously identified as *Microcystis* sp. According to Rosén (1981), formaldehyde destroys the fragile cell, and even Lugol solution may cause some damage.

Materials and methods

Qualitative samples

A total of 110 qualitative samples containing *G. semen* were originally taken because of problems caused by the alga to swimmers. Most of the lakes were rather small in size and only one per cent of the qualitative samples taken were from lakes included in monitoring programs. The samples, taken between 1978 and 1989 by the water- and environment authority, were qualitatively studied under the microscope. The first *Gonyostomum* samples in 1978 were examined without conservation liquid, which facilated the identification. Most of the samples were taken near the shore or from the surface water layer.

Quantitative samples

The monitoring of phytoplankton in Finnish lakes started in 1963. It includes 139 large or medium-sized lakes, with a median area of 80 km^2, which are sampled every five years. The samples were taken from the main body of the lake as composite samples from the uppermost epilimnion (0–2 m). Three to five samples taken with a two-meter long (5 cm diameter) plexiglass tube were thoroughly mixed in a bucket. Starting in 1982 samples were preserved with acetic Lugol solution (National Board of Waters, 1982) instead of formaldehyde as used earlier. The size of settled samples was 50 ml. The phytoplankton species composition was determined at magnifications of $\times 800$ and $\times 200$ using an inverted phase contrast microscope. In this study the phytoplankton results of July 1982 and of July 1986 were examined.

Only few water quality samples were taken from the studied lakes simultaneously with the phytoplankton samples. Therefore annual means of variables given in Table 1 were used. Sampling depth was 0–2 m. In addition total depth, the ratio of total nitrogen to total phosphorus and the ratio of dissolved nitrogen to phosphate phosphorus were used in the statistical analyses.

The water quality material including *G. semen*

Table 1. Analytical methods.

Variable(s)	Analytical method
pH	Electrometrically at 25 °C with pH-meter calibrated with known buffer solutions
Conductivity	Conductometric determination with temperature compensating cell; in lab
Colour	Nonfiltered, comparative determination
NH_4-N	Spectrophotometric determination with hypochlorite and phenol
NO_3-N	Reduction of NO_3 to NO_2, Hg-Cd (Cu-Cd) column, colourimetric determination of azo-colour
Total N	Oxidation with $K_2S_2O_8$ and determination of NO_3 as above
PO_4-P	Spectrophotometric determination (phosphomolybdate)
Total P	Preservation with H_2SO_4, pH < 2. Oxidation with $K_2S_2O_8$. Spectrophotometric determination
Alkalinity	Titrimetric determination, detection interpoint pH 4.5 and endpoint pH 4.2
Oxygen	Ad H_3PO_4 and azide, titration acc. to Winkler
Oxygen saturation	Saturation calculated from tables by Montgomery
Turbidity	After sedimentation of coarse particles, nephelometric determination with Hach turbidimeter
Transparency	Secchi disk
Chlorophyll *a*	Extractable in acetone (90%), spectrophotometric determination specific for chlorophyll *a* (monochromatic method)

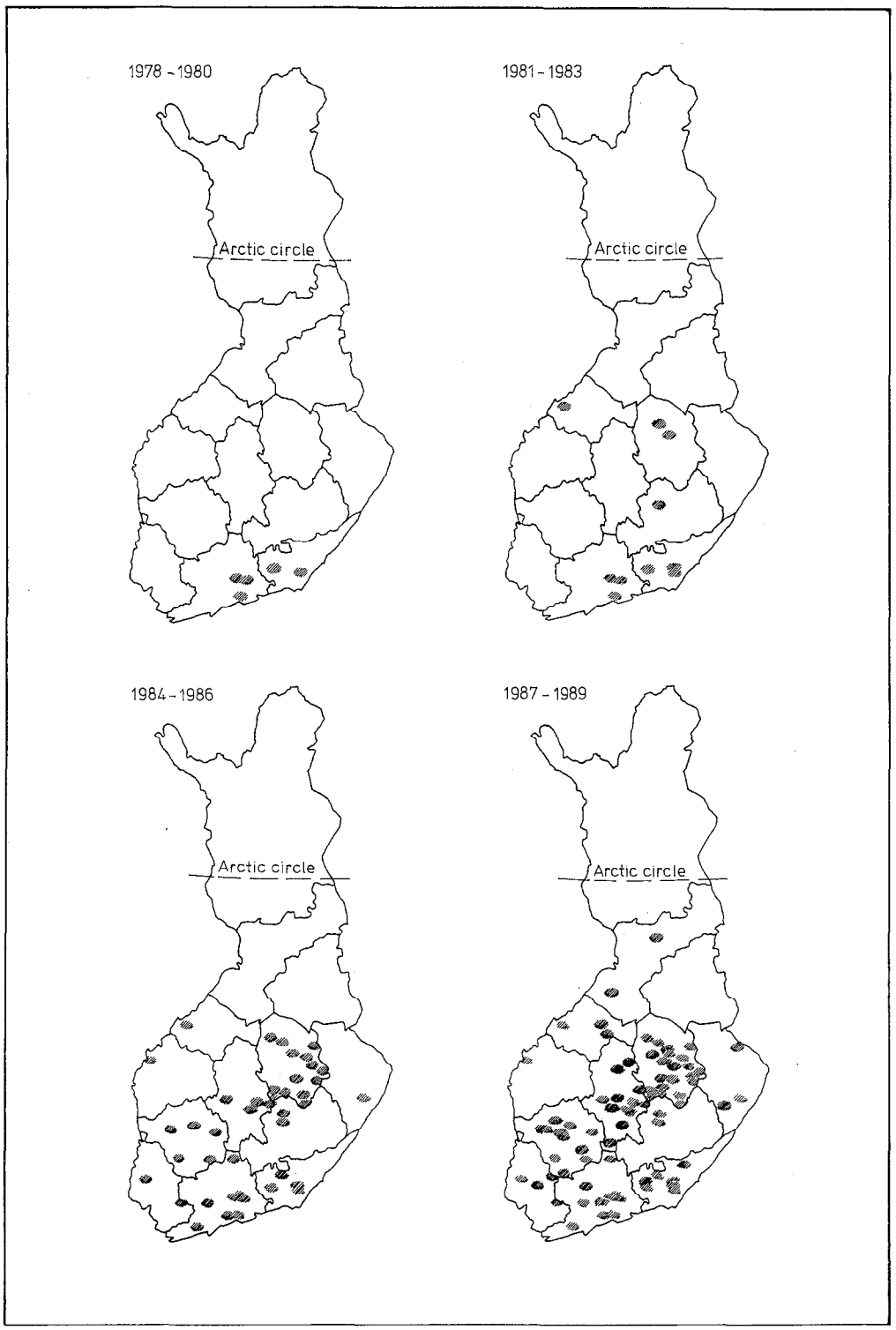

Fig. 1. The qualitative samples containing *Gonyostomum semen* taken by authorities or private individuals in Finland in 1978–1989 because of a nuisance to swimmers.

in 1982 was insufficient to be tested alone. The results from 1982 and 1986 were not treated together in order to avoid possible cumulative distortion.

Stepwise discriminant analysis by backward elimination was applied to the material of 1986 in order to select a subset of given variables. The lakes tested were simply grouped according to absence (group 1) or presence (group 2) of *G. semen* in the samples. This subset of variables was used in discriminant analysis to test its discrimination power.

Correlations between the number of cells and the studied variables were calculated. The SAS statistical program package was utilized in all calculations (SAS Institute Inc., 1989).

Results

According to the qualitative results *Gonyostomum semen* occurs throughout southern and central Finland almost up to the Arctic circle in the north (Fig. 1).

In the quantitative samples of 1982 *G. semen* was present in 11 lakes in central Finland (Fig. 2a). In 1986 the alga was found in 42 lakes in an area extending somewhat further north

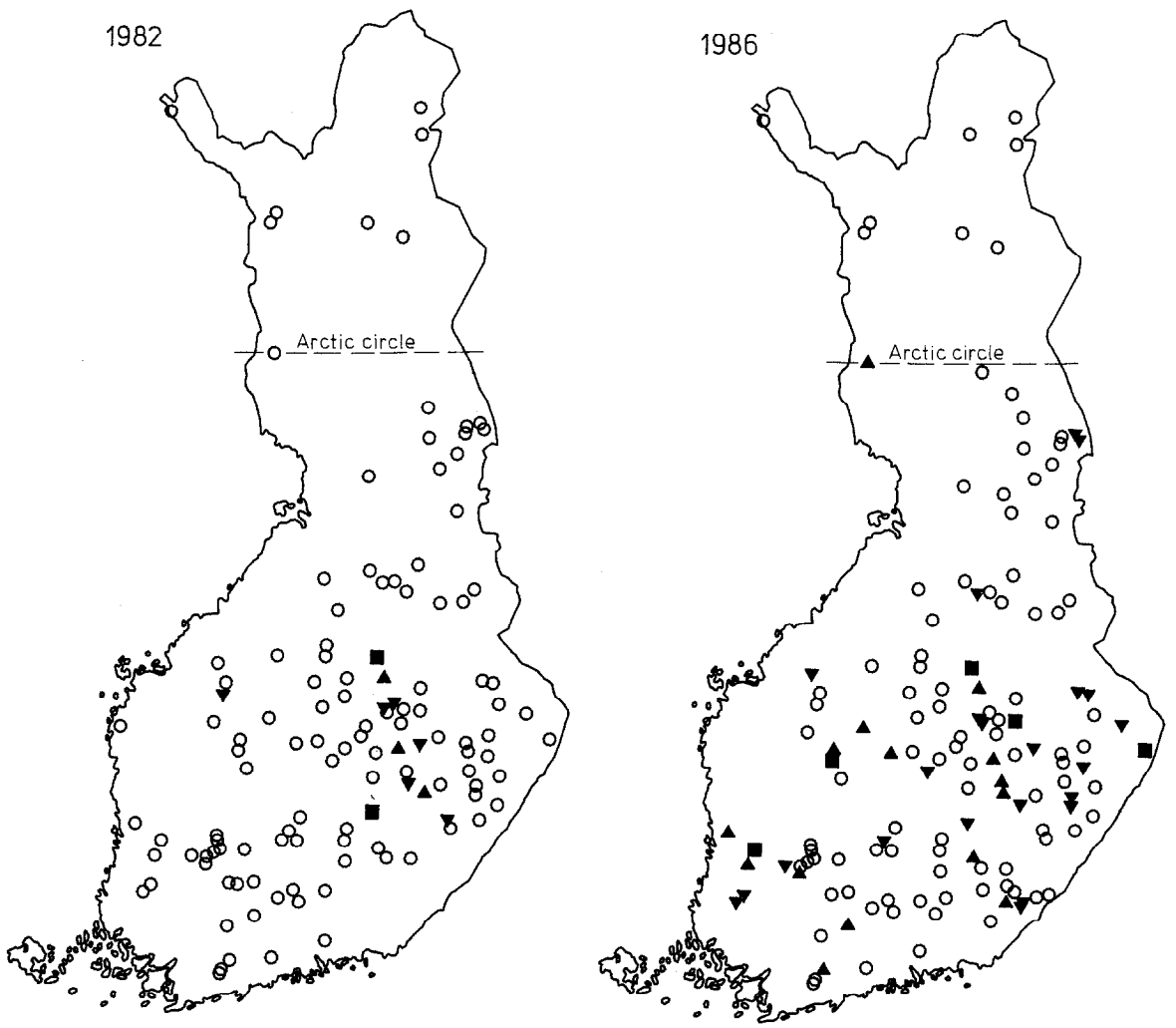

Fig. 2. The studied monitoring samples in 1982 and 1986. Legends: ○, no *Gonyostomum* found; ▼, <1000 cells l^{-1}; ▲, 1000–10000 cells l^{-1}; ■, >10000 cells l^{-1}.

Table 2. Descriptive statistics of the observations of *G. semen* (cells l^{-1}) separately for the years 1982 and 1986. (N = number of observations, Std = standard deviation, Min = minimum, Max = maximum).

Year	N	Mean	Std	Median	Min	Max
1982	11	27900	84700	640	20	283000
1986	42	5960	14900	600	20	80000

(Fig. 2b). The northernmost observation was made from a lake close to the Arctic circle. In 1986 the cell number was lower than in 1982 in six lakes, although the difference was insignificant. The number of cells in the whole material was generally low, varying from 20 cells l^{-1} (one cell in a sedimented 50 ml water sample) to 283000 cells l^{-1} (Table 2).

Two class levels were recognized, lakes with or without *G. semen*. The discriminant analysis selected seven variables: total P, turbidity, pH, total N, colour, PO_4-P and NO_3-N, in this order (Table 3). The two groups studied were not well separated. Pure discriminant analysis was applied with these seven variables to determine how well they discriminate the studied lakes into the two groups. The prior probabilities of group membership were set proportional to the original group sizes. Only 29% of lakes classified originally to group 2 (with *G. semen*) remained in this group.

The descriptive statistics of the seven variables in the two studied groups are given in Tables 4 and 5. The water colour and concentrations of total P and total N were clearly higher in lakes with *G. semen* than in lakes without this alga. The concentration of PO_4-P, was also somewhat higher in lakes in which *G. semen* was recorded. By contrast, the median and mean values of pH were slightly lower in lakes with the alga (Tables 4 and 5).

Table 3. Stepwise discriminant analysis with backward elimination. The variables conforming to the criteria for inclusion in the model are presented (both the squared partial correlation and the significance level of an F-test are shown). There were two class levels, lakes with (22) or without (44) *Gonyostomum*. The significance level for inclusion of variables in the model was 0.15.

Variable	Partial R^2	F	Prob > F
Colour	0.080	5.07	0.028
NO_3-N	0.049	2.95	0.091
Total N	0.092	5.84	0.019
PO_4-P	0.049	2.97	0.090
Total P	0.179	12.67	0.001
pH	0.119	7.86	0.007
Turbidity	0.121	7.99	0.006

Wilks' Lambda = 0.657, Prob > F = 0.0007.
Average squared canonical correlation = 0.343.

A very significant correlation was observed between the density of the alga (ln, natural logarithm of cell number) and water colour ($r = 0.71$***) when a linear model was used. A simple non-linear model gave a rather better explanation of chlorophyll a($r_s = 0.73$***) and total P concentration ($r_s = 0.57$***) (Fig. 3). A great variance can be seen in all these variables.

When the abundance of the alga was plotted as a function of lake pH and water colour (Fig. 4), it was apparent that *G. semen* was favoured by a

Table 4. Descriptive statistics of variables in monitored lakes classified into group 1 (*Gonyostomum* absent) in 1986. Sampling depth was 1 m or 0–2 m (abbreviations as in Table 2).

Variable	N	Mean	Std	Median	Min	Max
Colour (mg l^{-1} Pt)	93	42	33	35	5	207
NO_3-N (μg l^{-1})	92	98	105	81	2	630
Total N (μg l^{-1})	94	520	324	441	142	2700
PO_4-P (μg l^{-1})	87	3	4	1	1	30
Total P (μg l^{-1})	95	18	18	12	4	104
pH	94	6.9	0.3	6.9	6.0	7.6
Turbidity (FTU)	90	1.7	4.4	0.7	0.1	33.0

Table 5. Descriptive statistics of variables in monitored lakes classified into group 2 (*Gonyostomum* present) in 1986. Sampling depth was 1 m or 0–2 m (abbreviations as in Table 2).

Variable	N	Mean	Std	Median	Min	Max
Colour (mg l^{-1} Pt)	37	61	36	55	12	149
NO_3-N ($\mu g\ l^{-1}$)	41	109	112	64	2	540
Total N ($\mu g\ l^{-1}$)	40	607	246	567	223	1300
PO_4-P ($\mu g\ l^{-1}$)	35	5	7	3	1	39
Total P ($\mu g\ l^{-1}$)	41	27.0	18.5	23.5	4.5	86.0
pH	37	6.8	0.3	6.8	6.2	7.5
Turbidity (FTU)	37	1.8	1.6	1.0	0.3	6.6

pH-range of 6.2–7.2 (Md pH 6.8) and high water colour.

Discussion

Many explanations have been suggested for the elevated abundance and distribution of *G. semen*; increased peat extraction (Manninen, 1987), organic load from fish farming and general eutrophication (Eloranta & Palomäki, 1986; Eloranta, 1991), and even acidic water conditions (Cronberg *et al.*, 1988). Nutrients, especially total phosphorus, favour the alga according to Rosén (1981), Cronberg *et al.* (1988) and Hongve *et al.* (1988). Its maxima occurs typically in late summer (Brettum, 1989; Eloranta & Järvinen, 1991).

The numbers of cells in the phytoplankton samples from the monitored lakes were with some exceptions rather low. The sampling depth (0–2 m) underestimated the number of cells. This alga generally migrates below the upper water layers, thus avoiding too intense illumination during day time (Cronberg *et al.*, 1988; Eloranta, 1991). It may be present in high densities in many lakes where it has not been recorded because of its very short stays in the euphotic zone (Cronberg *et al.*, 1988; Eloranta, 1991). On the other hand the cells observed in upper water layers may have been trapped by water currents (Eloranta & Järvinen, 1991) and thus the observed cell densities may not represent the real situation in the studied lakes.

In this study the water colour was found to be clearly correlated with the occurrence of *G. semen* in the monitored lakes, which according to Laaksonen (1972) are slightly brownish. The median colour of the lakes with *Gonoyostomum* was 55 mg Pt l^{-1}. According to Rosén (1981) the median colour in Swedish *Gonyostomum* lakes is 60 mg Pt l^{-1}. The alga is typically found in humic lakes with brown, even dark brown water (Rosén, 1981; Manninen, 1987; Brettum, 1989; Arvola *et al.*, 1990; Eloranta & Järvinen, 1991) and more rarely in waters with low colour levels as observed also by Manninen & Kivinen (1985). Total organic carbon (TOC) could be of interest, but unfortunately it was not included in the monitoring program of the studied lakes.

High nutrient levels, especially of phosphorus, appeared to favour the alga, as was also observed by Rosén (1981), Cronberg *et al.* (1988), Brettum (1989) and Eloranta (1991). Brettum (1989) observed that *G. semen* favours waters with N/P ratio in range 20–50, total P concentration 7–25 $\mu g\ l^{-1}$ and total N concentration 200–500 $\mu g\ l^{-1}$ concerning the whole growing season (May-October). In this study N/P ratio range was 10–60, but it was not significant discriminating factor. The annual means showed a wider ecological amplitude for the alga. *G. semen* obtains the necessary nutrients from the deeper water layers and is not dependent on the nutrient gradient in the upper epilimnion (Eloranta, 1991; Eloranta & Järvinen, 1991). According to Cronberg *et al.* (1988), the presence of *G. semen* also affects the concentration and the vertical distribution of nutrients.

Chlorophyll *a* was dependent on the cell density, as observed earlier by Manninen (1987) and

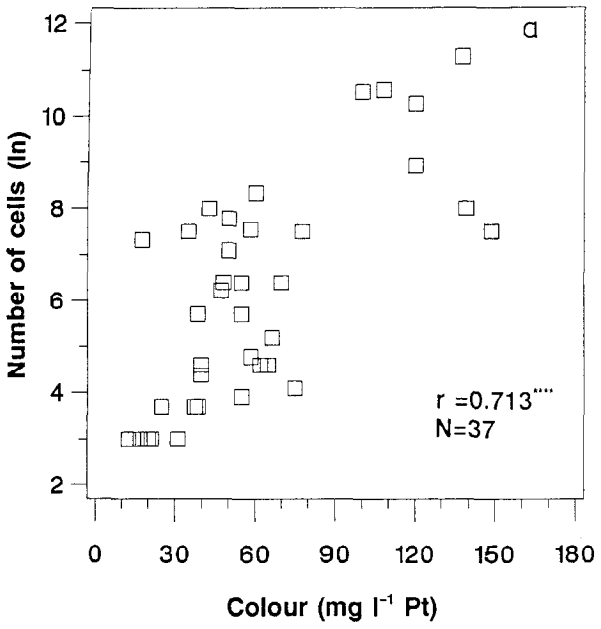

Fig. 3a.

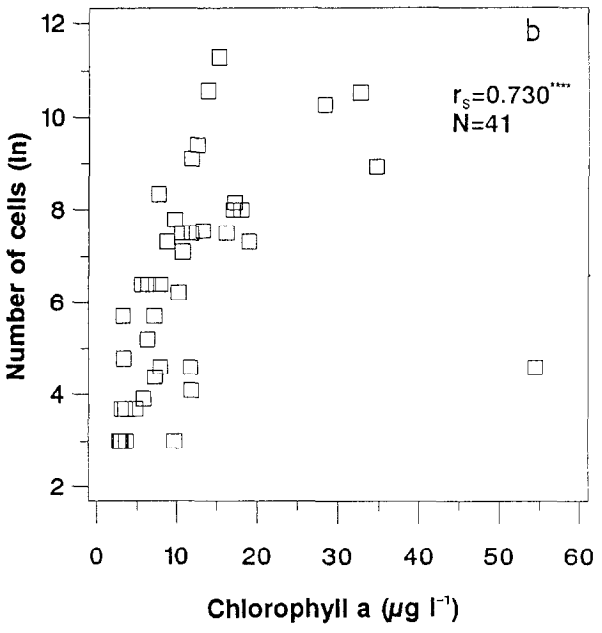

Fig. 3b.

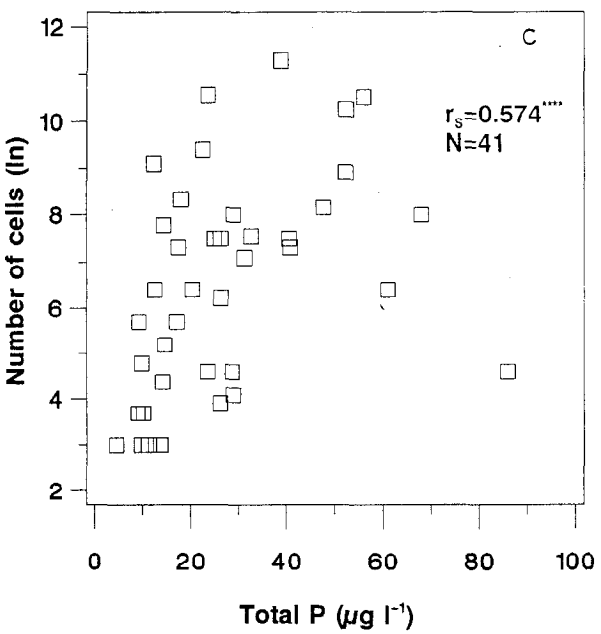

Fig. 3c.

Fig. 3. Observed relationships between logarithmic cell density of *G. semen* and (a) water colour, (b) chlorophyll *a*, (c) total P. *r* = Pearson's correlation coefficient, r_s = Spearman rank correlation coefficient. **** P = 0.0001. N = number of lakes.

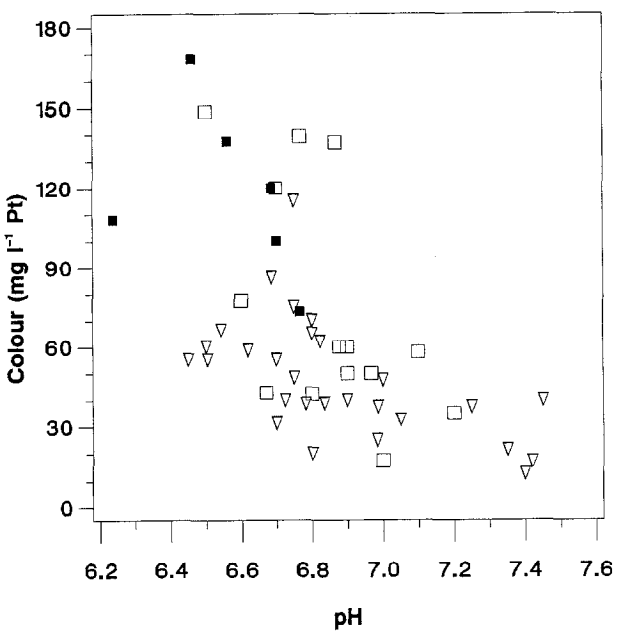

Fig. 4. Occurrence of *Gonyostomum semen* with relation to water colour and pH in the monitored lakes in July 1982 and 1986. Legends: ▽, <1000 cells l^{-1}; □, 1000–10000 cells l^{-1}; ■, >10000 cells l^{-1}.

Cronberg *et al.* (1988). *G. semen* has a rather high chlorophyll content because of its adaptation to low illumination (Eloranta, 1991).

Extreme pH values were not found in the studied material an the alga seemed to prefer slightly acidic to neutral conditions. The alga tol-

erates rather wide pH range (5–7.5) (Cronberg *et al.*, 1988; Eloranta & Järvinen, 1991; Brettum, 1992).

Gonyostomum semen occurs as far north as the Arctic circle in Finland (Figs 1 and 2), preferring dystrophic and eutrophic lakes designated by Järnefelt (1925) as mixotrophic.

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