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OBSERVATIONS ON THE RECOVERY PROCESS IN A LAKE WHICH HAD EARLIER RECEIVED WASTE WATER FROM AN ORE-DRESSING PLANT

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Observations on the recovery process in a lake which had earlier received waste water from an ore-dressing plant

by
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A question, on which interest is currently focussing in the problem-complex of industrial pollution, is what happens to a recipient for industrial waste water if the industry closes down or improves its waste water plant so that the addition of polluted water appreciably diminishes.

The question is of very great importance for the standpoint to be adopted with reference to measures for the restoration of polluted lakes. In those cases in which a recipient cannot, within a reasonable time, purify itself to the point at which its water can be used for the different purposes that may be considered desirable, it may be necessary to take steps to restore the lake.

One of the lakes that has been investigated in order to study the recovery process is Lake Bålsjön in Central Sweden. The area of Bålsjön is 0,30 km^2 and the mean and maximum depths are 5 and 11 meters respectively. The catchment area is rather small, only 5,5 km^2 and consists mostly of marshes. Up to the autumn of 1967 Lake Bålsjön was receiving the waste water from a dressing plant for magnetite and hematite. The dressing plant operated with gravity and wet-magnetic concentration and had therefore to use large quantities of water. As the smallest particles were very hard to separate off with the methods used, they followed with the water through the dressing plant.

The waste water was pumped to a banked-in area for sedimentation (fig. 1). From here the still turbid water was conducted via a settling dam to Bålsjön. This made the water in Bålsjön so turbid that the Secchi disk transparency was reduced to only a few centimeters. Owing to this turbidity light could not penetrate to any appreciable depth, but was reflected or absorbed in the topmost layer of water. In Bålsjön there was constant sedimentation of the fine-grained particles. This meant that any organic substance eventually formed in or added to the lake was immediately embedded in the sediment, which made Bålsjön a very sterile milieu for many organisms.

Before the plant closed down Bålsjön and a similar lake used as a control lake had been investigated for a couple of years, so that there was a comparative material when it came to a study of the recovery of the lake. In order to be able to give a clear picture of the recovery it may be as well to give an account of the situation prevailing before the plant was closed down.

Quality of the water when the dressing plant was operating

Chemico-physical conditions

Turbidity, colour and Secchi disk transparency

The most striking effect of the discharge from the dressing plant was the marked turbidity of the recipient. The hemitate sludge that was not utilized imparted a distinct reddish colour to Bålsjön. Through the discharge this colouring was much intensified. The control lake had a colour value of about 30 mg Pt/l, while values as high as 650 mg Pt/l were measured in Bålsjön.

Owing to the turbidity the Secchi disk transparency was reduced to only a few centimeters.

pH and conductivity

The waste water had a pH between 8.2 and 8.3 in the sedimentation basins. In Bålsjön, after dilution, the pH was between 7.8 and 8.1 in the spring and summer samples respectively. Owing to the abundance of unbound ions in the waste water the specific conductivity was considerably increased. The value in Bålsjön was about seven times that in the control lake.

Iron-content

On account of the waste sludge the iron-content in the water was for the most part very high, as the iron-content in the particles was about 15 per cent. The highest content measured in Bålsjön was 10 mg Fe/l, which coincided with a markedly reddish colouring and turbidity. Analysis of the filtered and unfiltered samples showed that most of the iron occurred as suspended material. A not inconsiderable part, however, occurred in such a form that it passed a fine filter paper.

Content of oxygen

The oxygen-content was always high in Bålsjön, showing values of about 90 per cent saturation. The waste from the dressing plant thus did not affect the oxygen-content negatively.

Consumption of permanganate

The consumption of potassium permanganate in the water was determined. The result showed that very small amounts of organic chemically oxidizable substance existed in the water. The values measured were about half of those for the control lake, or 10 mg $KMnO_4$/l.

Biological conditions

The Bålsjön lake bed consisted of an extremely fine-grained red sediment. This is unsuitable as a substrate for more or less sessile living lake-bed organisms. Bålsjön was therefore characterized by the absence of such species as well as the greater part of the submerged plants. In the sample taken from the lake bed only a few odd specimens were found of Chaoborus, which swims freely in the water near the bed, and of crustaceans of copepod type. In the northern part of the lake there were indications of organic flocculi, and in connection with these a few protozoons, Flagellata and diatoms like e.g. Synedra.

Owing to the marked turbidity in Bålsjön the light could not penetrate to any appreciable depth, so that autotrophic organisms were able to exist only in a very thin surface layer. This implied a marked diminution of the lake's total production.

This meagre production was especially noticeable in the result of the zooplankton counts, where no individuals at all were found. In the lake, small specimens of pike (Esox lucius) roach (Rutilus rutilus), perch (Perca fluviatilis) and fresh-water crayfish (Potamobius astacus) were found.

The recovery process in Bålsjön after the closing down of the dressing plant in November 1967

Changes in the physic-chemical factors

Turbidity, colour, iron-content and Secchi disk transparency

When the discharge of waste water stopped, the particles existing in the water settled. This resulted in reduced turbidity from 1200 to 400 ZP-units (fig.2) and increased Secchi disk transparency to over two meters (fig.3). The lake, which had earlier had a marked red colouring, began to assume a considerably more normal hue. This is seen in the result of the colour measurements (fig.4), which shows that the colour-values in Bålsjön are beginning more and more to agree with those in the control lake.

In connection with the sedimentation of the suspended particles the iron-content was of course reduced to a range of values corresponding with that in the control lake (fig.5).

The variations now occurring in turbidity and in the Secchi disk transparency are due to the addition of particles from the surrounding embankment of waste. After the spring flood or after heavy rainfall this addition is noticed as a transient red colouring of Bålsjön.

pH and conductivity

A certain reduction of pH is observable in the spring samples, while the values in the autumn even show an increase. This may be interpreted to mean that the concentration of the pH-increasing substances has been reduced, which leads in turn to a reduction of pH. Furthermore, the primary production has increased, which gives increased pH during the production period.

The big difference earlier noted in the specific conductivity in Bålsjön and the control lake respectively begins gradually to become less (fig.6). The slowness of this lessening is due to the very slight water turnover in the lake.

Oxygen-content and consumption of permanganate

After the closing down of the dressing plant the values for the oxygen-content are still high. In some samples of water from the bottom of the lake, however, an oxygen deficit down to 17 per cent saturation was observable. This can indicate that organic substance had been added or formed in the lake in such quantities as to have an effect on the oxygen economy in the lake.

The consumption of permanganate has increased to such an extent in Bålsjön that it now coincides with that in the control lake (fig.7), which implies that the quantity of organic substances in the water has increased. This increase is an indication that the primary production in the lake has increased, or that permanganate-consuming substance has been added to the lake.

Nitrogen and phosphorus

Nitrogen and phosphorus show higher values as in the control lake. There has not yet, however, been any change in the values.

Changes in the biological conditions

Phytoplankton

After the disappearance of the turbidity the occurrence of phytoplankton has markedly increased (fig.8). This applies especially to the diatoms, where during the autumn and winter Cyclotella comensis and to a certain extent also Synedra acus show high values for the number of individuals (in November 1969, for instance, there were 3 million Cyclotella per liter). In the spring and summer the Chrysomonad Rhodomonas lacustris and the earlier completely absent Dinobryon divergens occur in considerable quantities.

Apart from this increased number of individuals also the number of species or more properly genera of especially the larger group Chlorophyta have increased (fig.9). Newly added species are e.g. Elakatothrix gelatinosa and Gloeocystis sp. The new species in Bålsjön are as yet of very slight importance for the total production of the lake. From the general picture of plankton it emerges that there are a relatively large number of individuals belonging to a small number of species (fig.10); this gives the picture of an extreme milieu. However, the increasing number is an indication that the milieu is becoming less extreme.

If we compare the composition of species in Bålsjön with that in the control lake (fig.11) we find a considerably greater variety in the latter, with a larger number of larger groups represented.

Zooplankton

Two years after the closing down of the dressing plant Bålsjön shows a zooplankton composition almost identical with that in the control lake. The differences occurring refer exclusively to the number of individuals. Thus the number of Ciliata in the control lake is about 10 times greater that that in Bålsjön, and other zooplankton are 5 times more numerous. Although Bålsjön still shows a paucity in the number of individuals as compared with the control lake, the zooplankton existing there today imply a marked increase compared with the earlier total absence of these organisms.

Among the zooplankton occurring today the predominant species are the rotifers Polyarthra spp. Gastropus stylifer and Keratella cochlearis. Other zooplankton species of e.g. Cladocera and Copepoda occur in Bålsjön only as isolated individuals.

Lake-bed fauna

When the rain of particles over the sediment surface stopped, the fauna normally living on the lake-bed could once more start colonizing the bed. During the investigations carried out the year after the closing down of the dressing plant it was possible to observe only very slight changes. One only found scattered specimens of Ephemeridae and Chironomidae in the lake-bed samples taken.

It was not until one year later, during the summer and autumn of 1969, that it was possible to observe that a community of organisms was in process of being built up. Ephemeridae are now of general occurrence. It is, however, only Ephemera vulgata that occurs, and this gives an impression of the instability of the system.

The groups of lake-bed organisms most commonly occurring in Bålsjön two years after the closing down of the dressing plant are Chironomidae and Ceratopogonidae. Of the Chironomidae, Chironomus plumosus is abundantly represented, but large numbers of organisms from the sub-family Tanypodinae also occur. Of the Ceratopogonidae, Palpomyia is the animal occurring most generally in the whole system even if a smaller number of Chaoborus also occur. It is possible to find a greater density of organisms if one goes to the northern part of the lake. This is the part furthest away from the region where the waste was introduced into Bålsjön, so it thus got the least sedimentation of particles over the sediment surface. It is also possible to find a considerably more modified community of organisms in the discharge canal in the south end of the lake. Here the water has little depth and the surrounding reeds contribute organic material which promotes the colonization of the lake-bed organisms. Apart from the already mentioned organisms one can find in this canal Herpobdella, Asellus and large quantities of mites.

Owing to the small amount of organic material on the bottom the lake-bed organisms have very poor protection against predacity. This predacity must certainly be a strong reducing factor as regards these organisms. Analysis of the gastric contents in fish from Bålsjön also shows the organisms mentioned in the foregoing.

Other changes

Apart from the changes mentioned in the community of organisms it is possible to make a number of studies through visual examination of the lake. These changes are very difficult to assess quantitatively, and the observations thus made must, accordingly, be very subjective.

On the lake shores one can see great swarms of the ostracod Notodromas monacha. This organism commonly occurs in stagnant little lakes during the summer. It is, however, extremely unusual to find such mass development as it was here a matter of.

At the edge of the shore at the populations of Phragmites that exist it was possible to observe large shoals of one-year-old perch and a large number of pike. Such shoals often occurred near shoals of Notodeomas, which indicates that the ostracod may be an object of nourishment for the small fry among the fish.

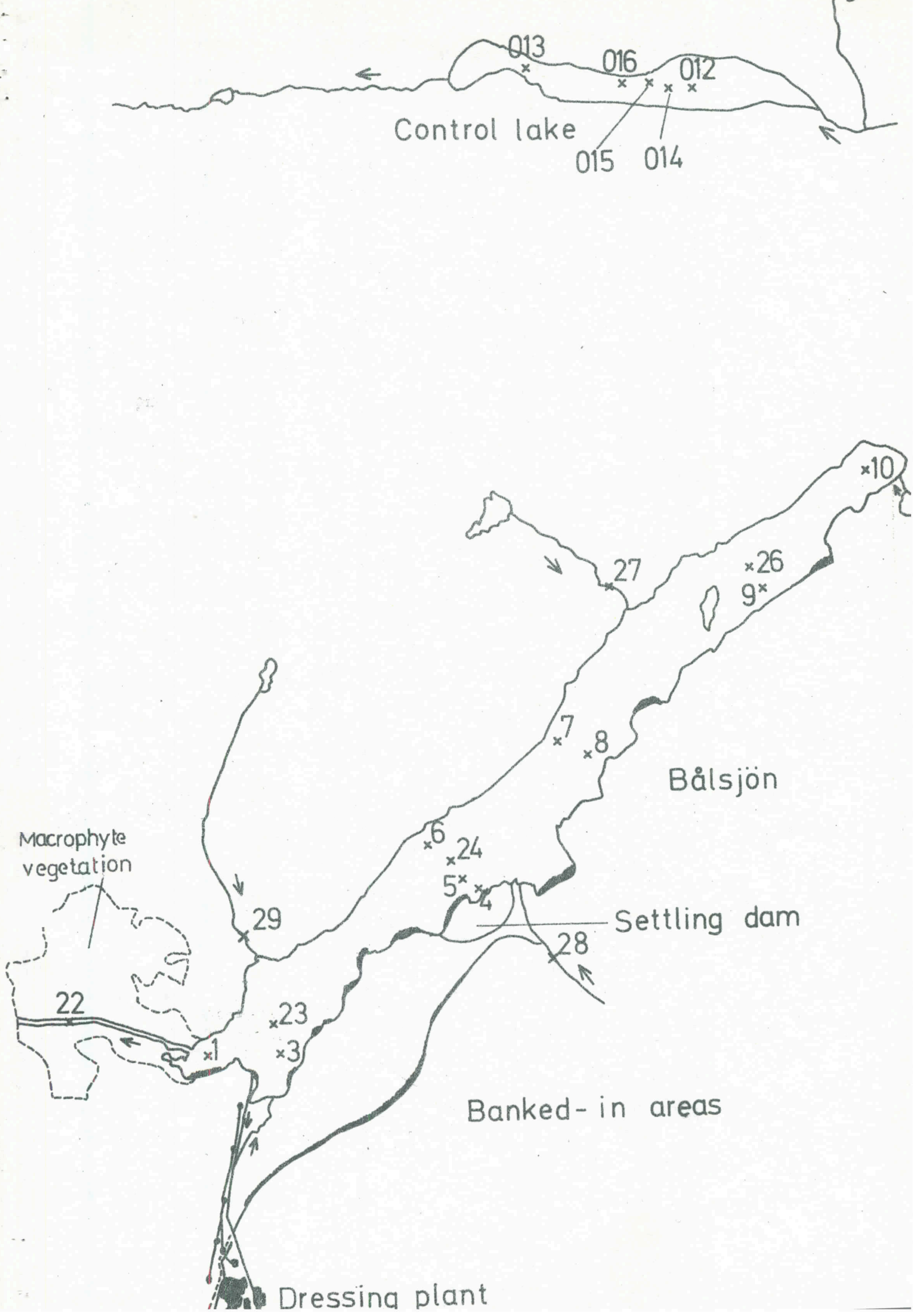
The first traces of Periphyton begin to appear on the lake-bed. These are the thread-formed algae Zygnema and Spirogyra which have began to spread to the regions where the light was earlier too weak for these autotrophic algae.

In the cores of sediment collected in Bålsjön in 1969 it was possible to find traces of organic material. This was composed of detritus and vegetable fiber that was presumably only partly produced in the lake and had otherwise come from the soil surrounding the lake. Besides this material there were also shells and remains of diatoms and crustacea.

This study of lake-recovery has now reached one of the most interesting stages. The first part of the recovery referred chiefly to the physico-chemical factors and was a relatively simple process which was mainly a question of sedimentation rates. The most important question for this process in the near future is how rapidly the embankments of waste along the shores can be bound by vegetation. This is important for the prevention of inorganic material being washed out into the lake by rain and melt water.

The second stage, which refers chiefly to the building up of a balanced biosystem, is a good deal more difficult to foretell. The results hitherto obtained show that the number of species in the system is on the increase. They also show that certain species very easily begin to become predominant with a mass development. This is presumably a tendency that will continue until an organic layer has been formed above the inorganic sediment. This organic layer i s essential to give the different organisms protection against predacity. When they have this protection the fluctuations due to this predacity will be reduced.

Fig. 1


013
016
012
Control lake
015
014
10
26
27
9
7
8
Bålsjön
Macrophyte vegetation
6
24
5
4
29
Settling dam
28
22
23
1
3
Banked-in areas
Dressing plant

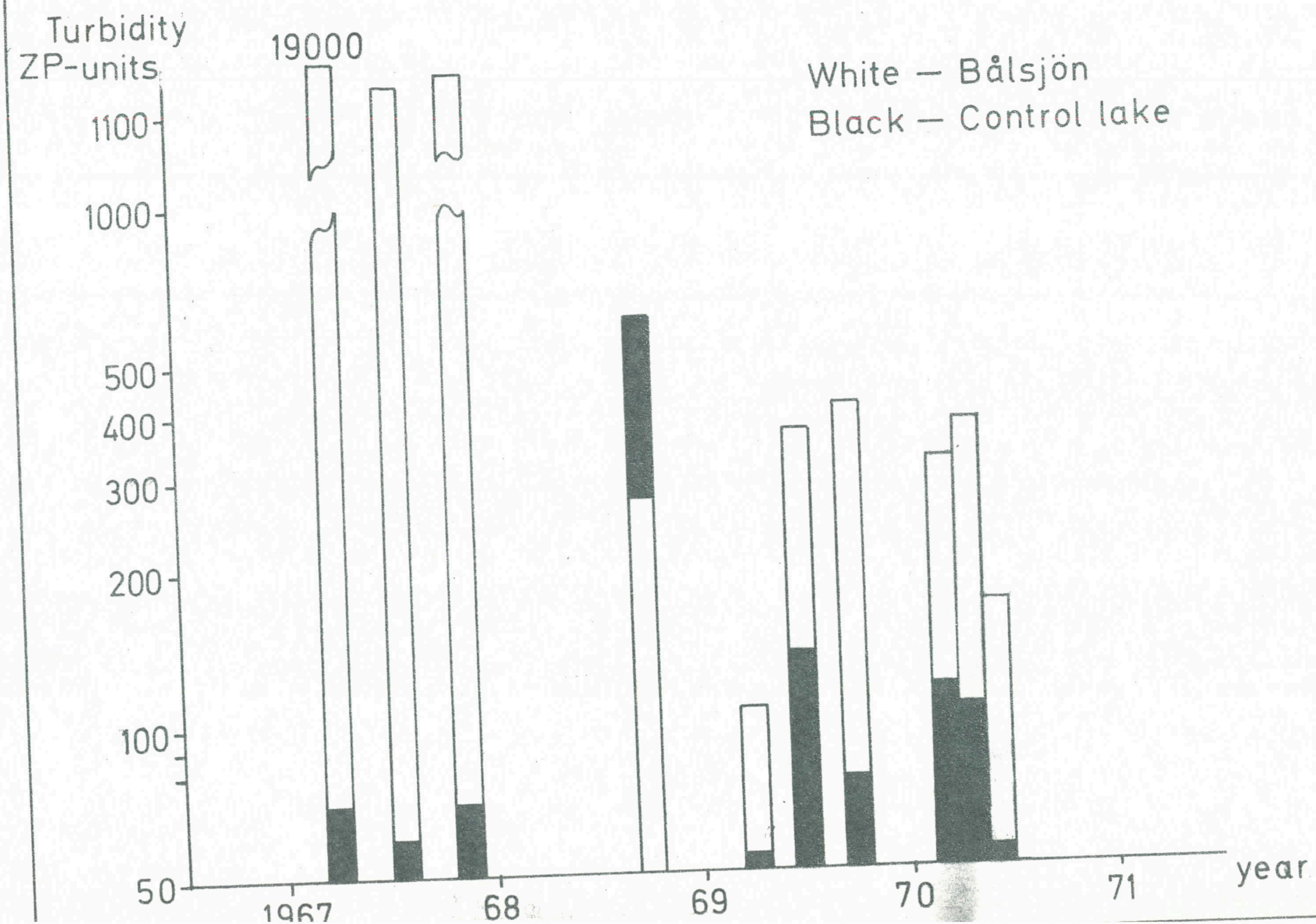

Turbidity
ZP-units
19000
White — Bålsjön
Black — Control lake
1100
1000
500
400
300
200
100
50
1967
68
69
70
71
year

Fig. 2

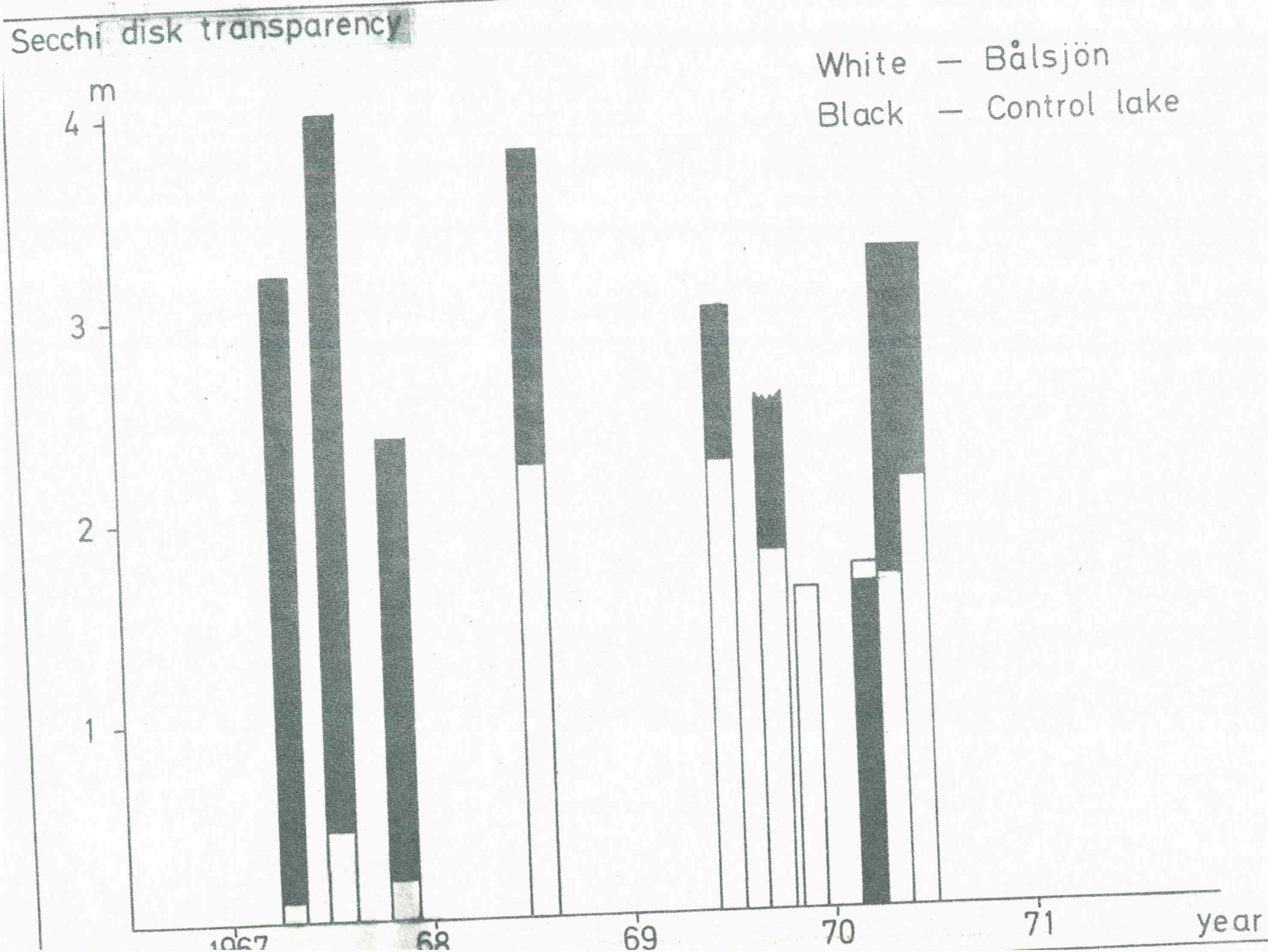

Secchi disk transparency
m
4
3
2
1
White — Bålsjön
Black — Control lake
1967
68
69
70
71
year

Fig. 3

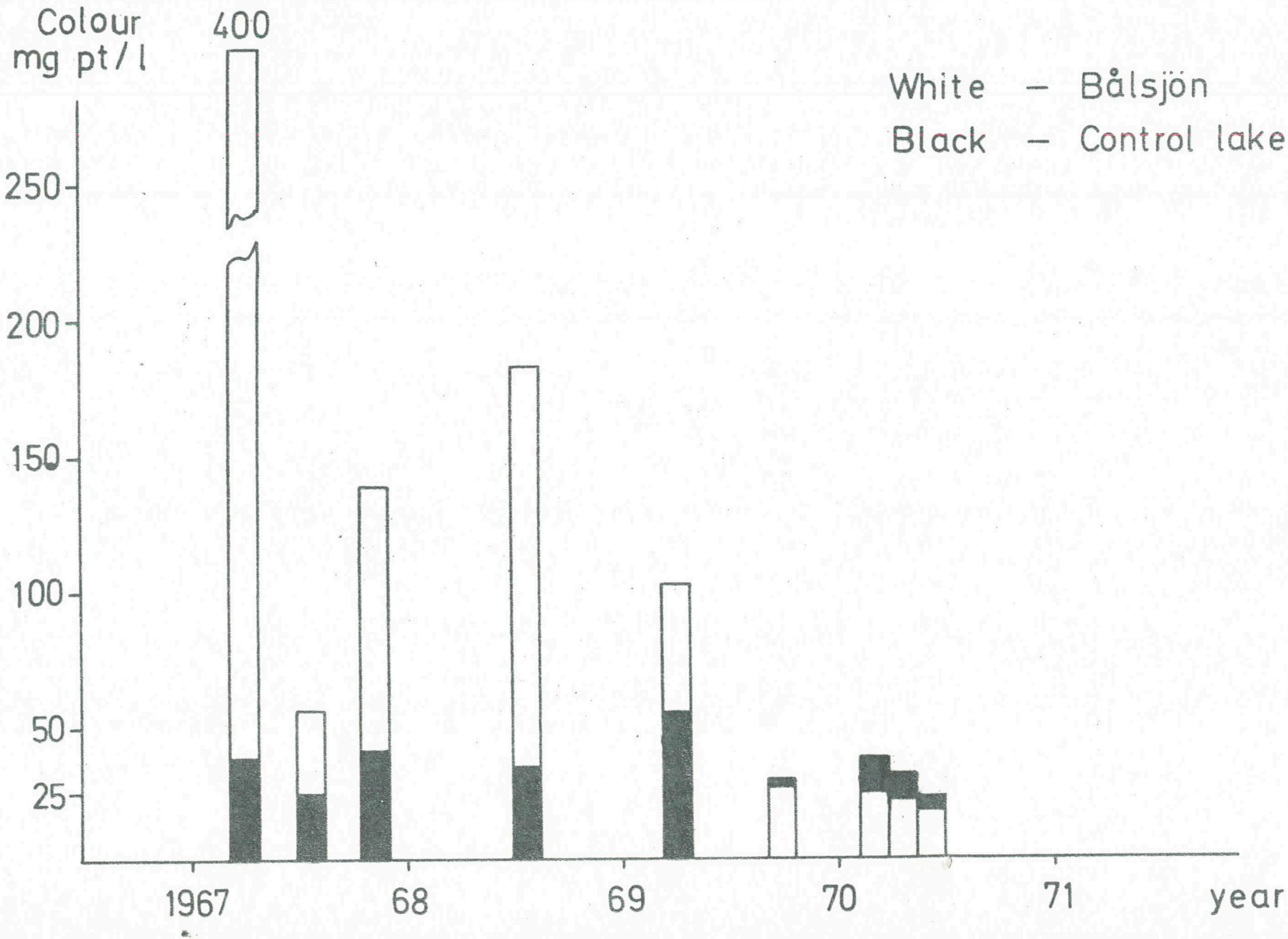

Colour
mg pt/l
400
250
200
150
100
50
25
White – Bålsjön
Black – Control lake
1967
68
69
70
71
year

Fig. 4

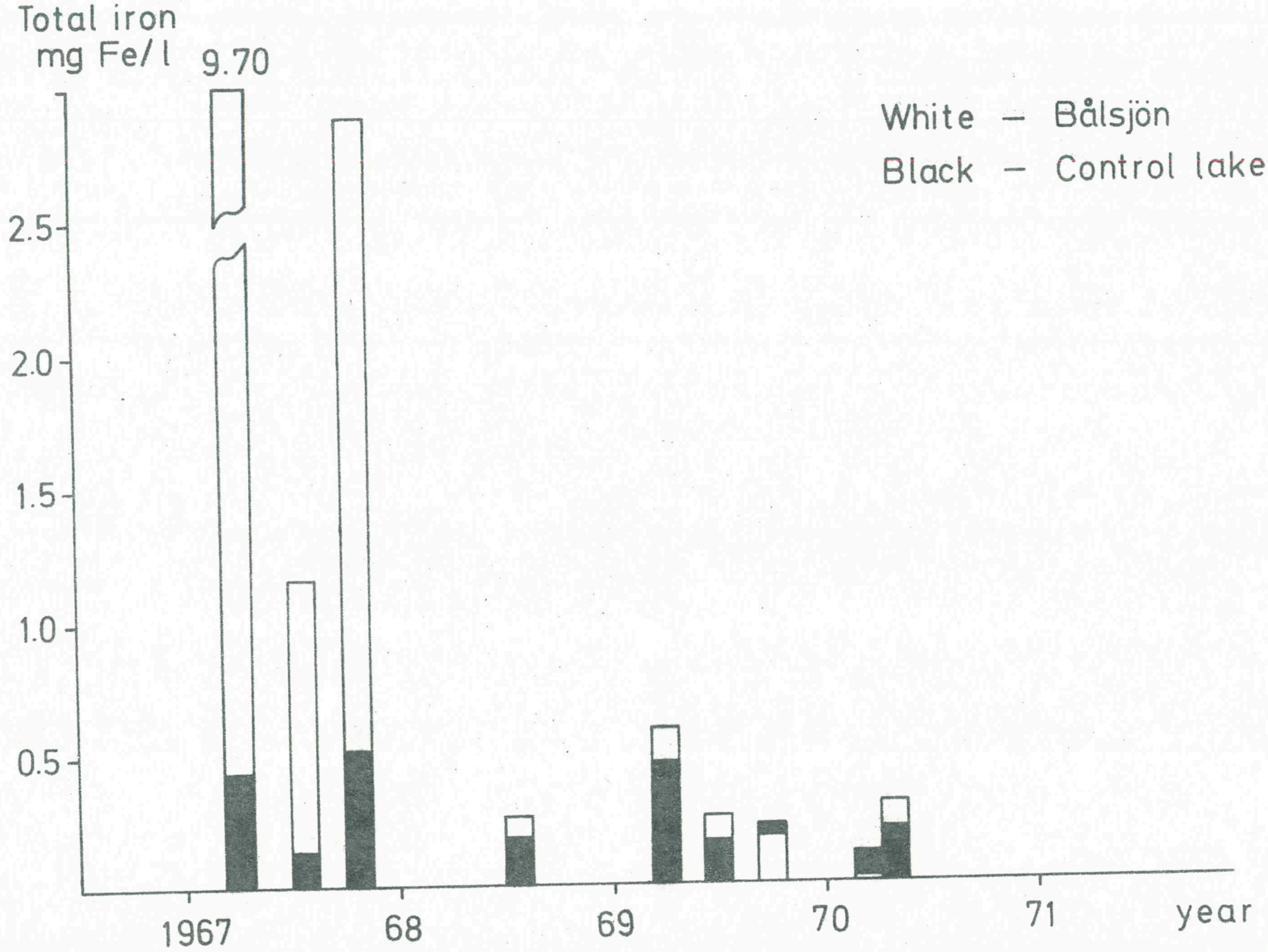
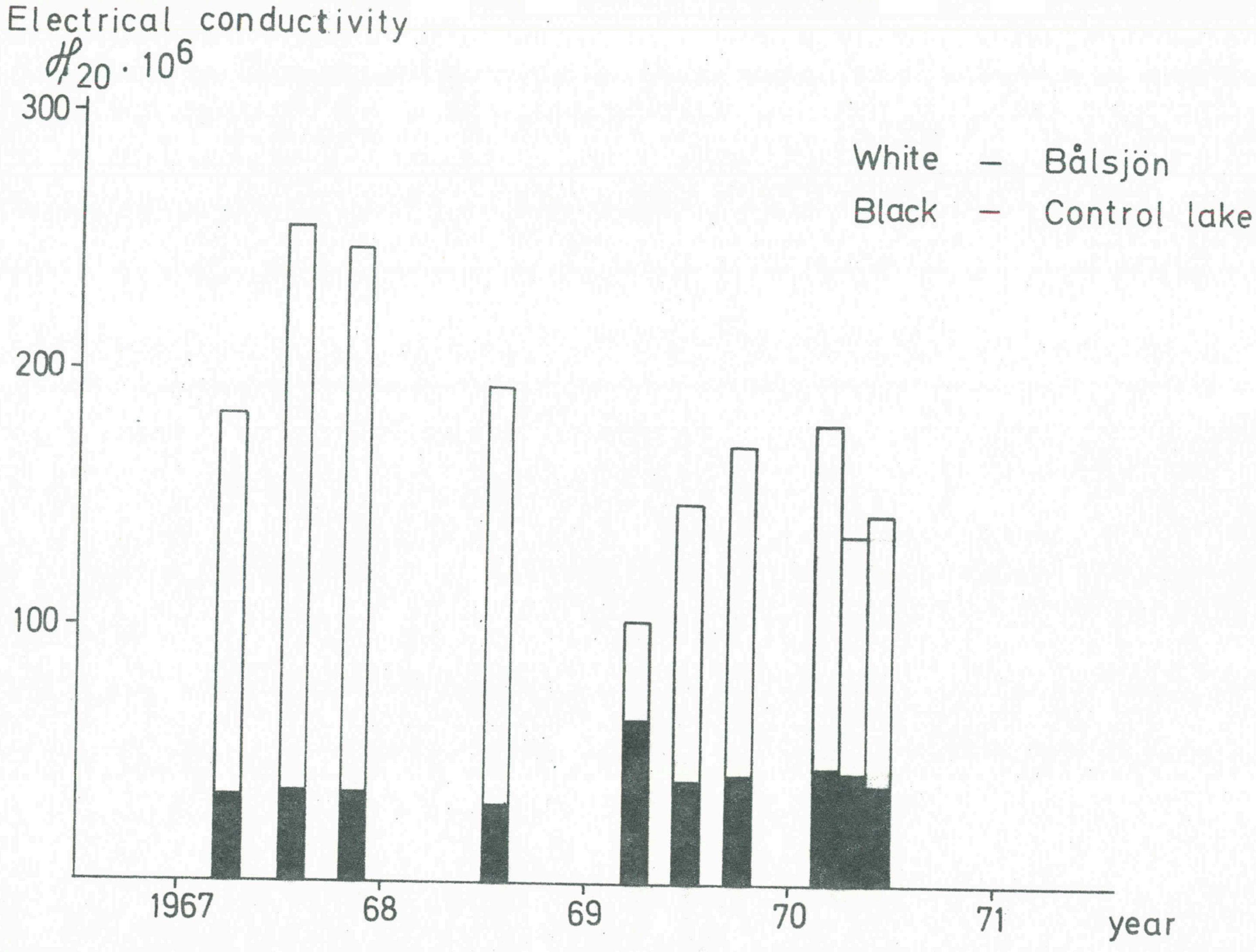

Total iron
mg Fe/l
9.70
2.5
2.0
1.5
1.0
0.5
1967
68
69
70
71
year
White – Bålsjön
Black – Control lake

Fig.5



Electrical conductivity
$\varkappa_{20} \cdot 10^6$
300
200
100
White – Bålsjön
Black – Control lake
1967
68
69
70
71
year

Fig. 6

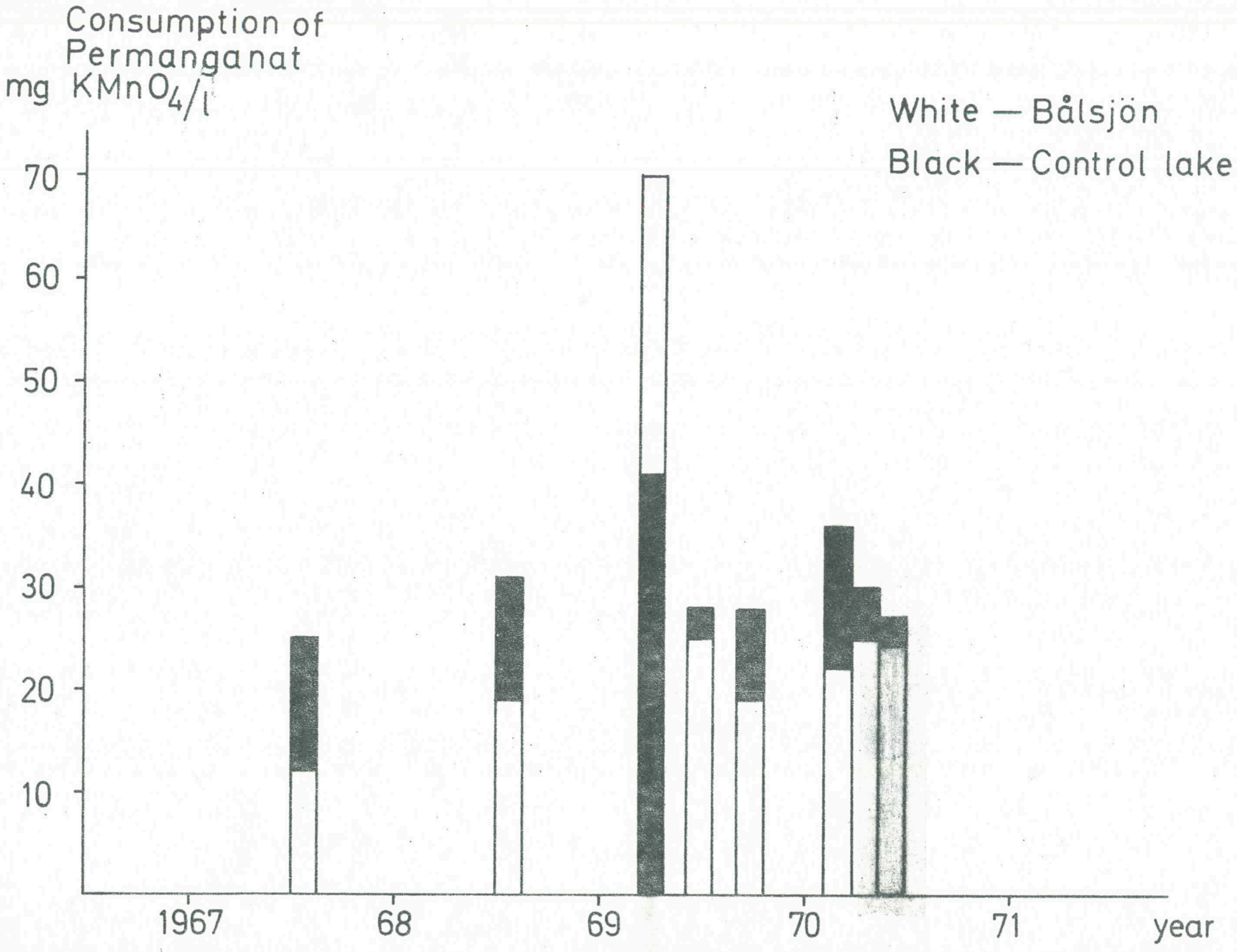

Consumption of
Permanganat
mg KMnO4/l
White — Bålsjön
Black — Control lake
70
60
50
40
30
20
10
1967
68
69
70
71
year

Fig. 7

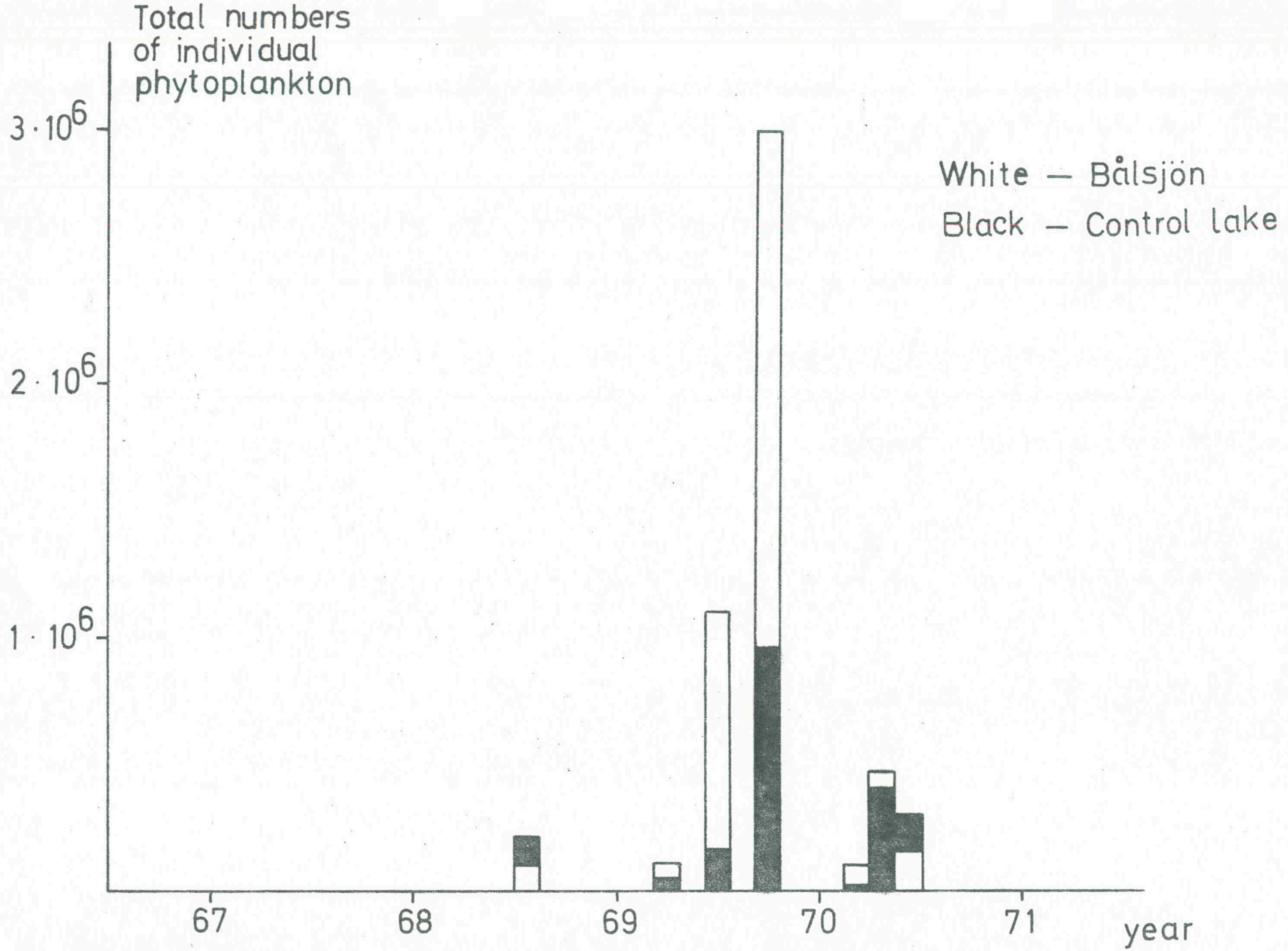

Total numbers
of individual
phytoplankton
3 · 10^6
2 · 10^6
1 · 10^6
67
68
69
70
71
year
White — Bålsjön
Black — Control lake

Fig. 8

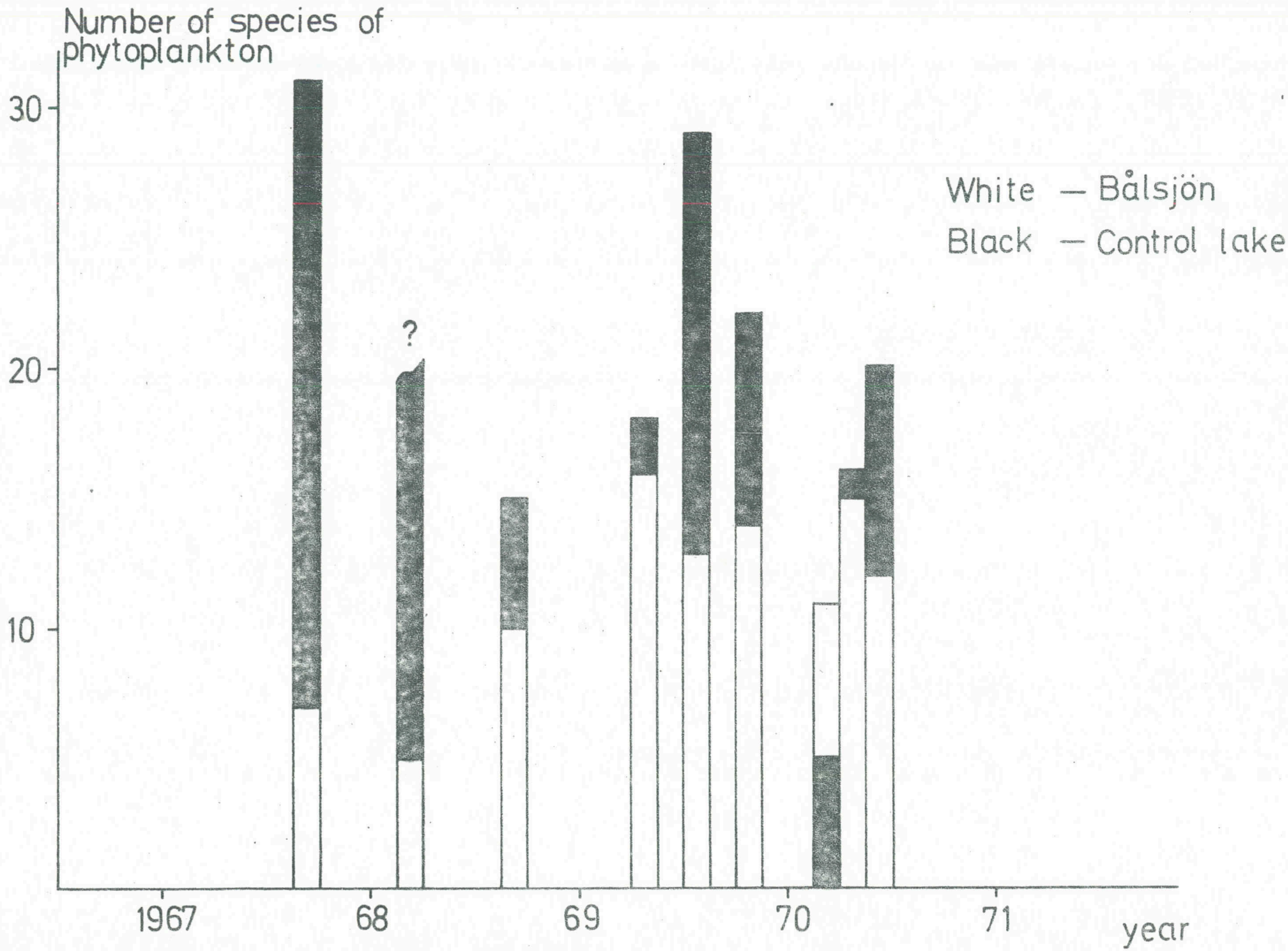
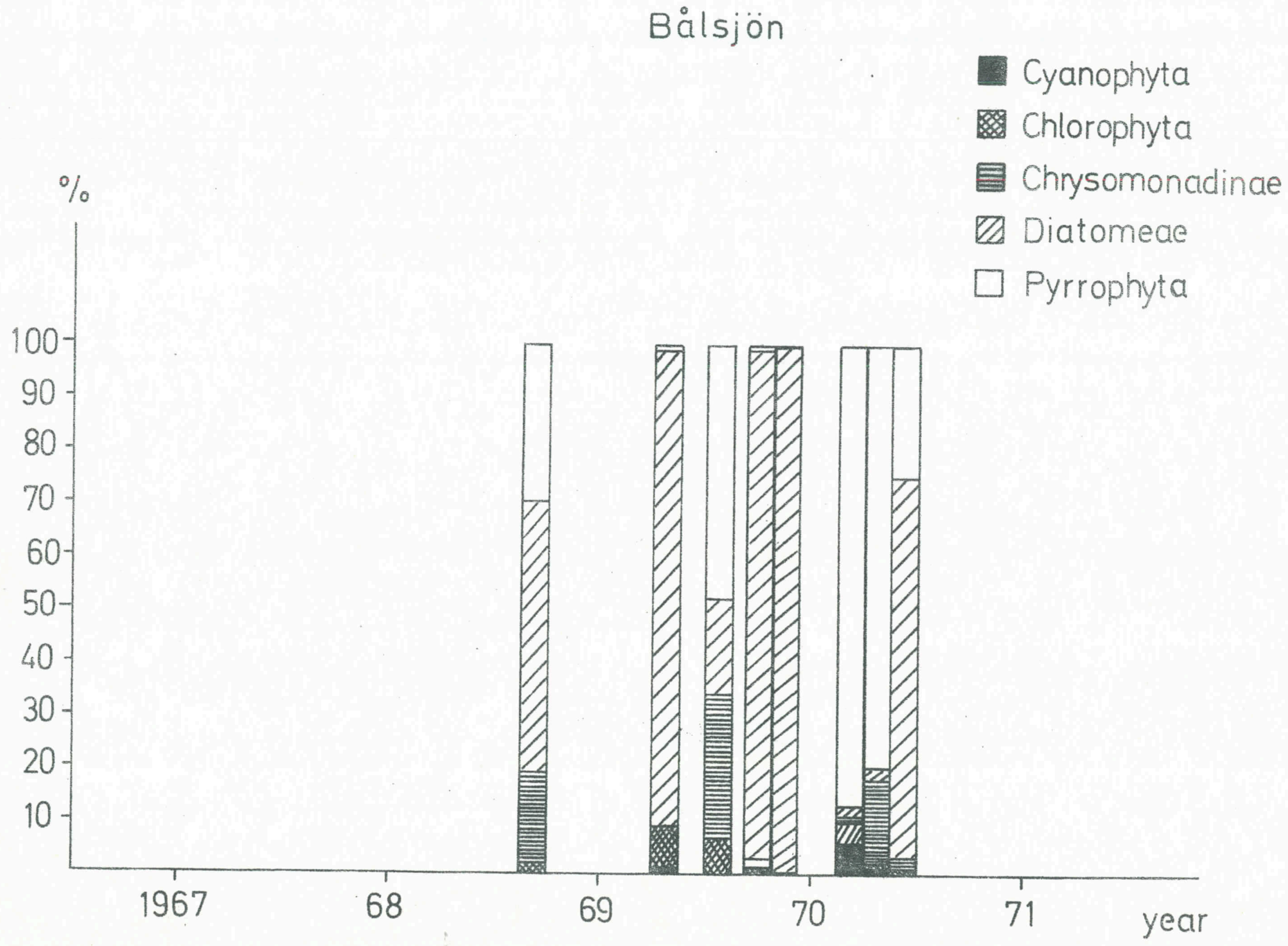

Number of species of phytoplankton
30
20
10
?
White — Bålsjön
Black — Control lake
1967
68
69
70
71
year

Fig. 9



Bålsjön
Cyanophyta
Chlorophyta
Chrysomonadinae
Diatomeae
Pyrrophyta
%
100
90
80
70
60
50
40
30
20
10
1967
68
69
70
71
year

Fig. 10