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Lake Trummen restoration project

III. Zooplankton, macrobenthos and fish

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With 5 figures and 3 tables in the text

Introduction

Lake Trummen is a small, shallow lake ($S = 1.0\ km^2$, $z_m = 2.2$ m) situated in an oligotrophic area in southern Sweden. Severely polluted, the lake did not recover after the diversion of sewage in 1958. Nutrient release from the top sediment layer was the main cause of a troublesome bloom of blue-green algae lasting from June to October. In 1970 and 1971 the macrophyte vegetation was removed and the nutrient rich sediment pumped up on land. Restoration principles and methods have been described earlier by BJÖRK (1972). A description of water and sediment chemistry is presented by BENGTSSON et al. (1975) and the bacteria, phytoplankton and phytoplankton production are described by CRONBERG et al. (1975).

The objective of the investigations has been to follow changes in species composition, abundance and biomass of the zooplankton, macrobenthos and fish communities following the restoration of Lake Trummen and to compare these changes with other components of the ecosystem. As a great deal of the collected material is still unprepared, the results given here must be restricted to changes in abundance and considered preliminary.

Methods

Zooplankton. During 1968 samples were taken with a water sampler at two levels in Lake Trummen at 3—5 week intervals, generally at 3 stations. However, the population fluctuations were rapid and the horizontal distribution uneven. In order to obtain more representative material, samples from 1969 onwards were taken at 1—2 week intervals using plexiglass tubes (length 2.0—2.5 m, diameter 40—44 mm). At 20 evenly distributed, pelagic sites, the water column from surface to bottom was sampled and the samples mixed together. A water volume of about 30 liters was obtained from which subsamples (0.5—10 liters) were taken out, filtered and counted in an inverted microscope.

Macrobenthos. Up to 1971 great interest was paid to the vertical distribution of the macrobenthos in the sediment, and for this purpose a special sampler (DIGERFELDT & LETTEVALL 1969) was used. Two to three samples of 250 cm² were taken at each site of investigation. Since 1972, a core sampler (BERGGREN 1972) with an opening of 95 cm² has been used. To get more representative collections, 5 samples have been taken from each station. In the sieving procedure a mesh with an aperture of 0.4 mm has been used. Several sites have been investigated in the lake. The results from the central sampling station are presented in Fig. 3.

Fish. The test-fishing was carried out with gillnets of the survey-link-type made of twined nylon. The survey-link consists of ten nets with different mesh sizes, each net being 7 × 1.5 m. The mesh sizes used were 9, 12, 14, 16, 18.5, 25, 30, 33, 38 and 46 mm from knot to knot. The test-fishing proceeded for 24 hours beginning at about 9 a.m.

Total length and body weight were recorded immediately after collection, and the stomach or the entire intestine was preserved in ethanol for future studies. The contents of the intestines were determined on 9 occasions in 1968—69 and on 5 occasions in 1972.

Results

Zooplankton

During the period studied before restoration (1968—69) the zooplankton community was numerically dominated by rotifers in spring and rotifers plus cladocerans in summer, both groups occurring in very high numbers. Twelve species of rotifers were common, the most abundant being *Brachionus angularis, Filinia longiseta, Keratella cochlearis,* and *Anuraeopsis fissa.* The total numbers of rotifers in summer varied from about 1,000 up to 20,000 ind/l.

The development of cladocerans began in the beginning of June, and the four species *Bosmina longirostris, Chydorus sphaericus, Daphnia cucullata* and *D. longispina* were abundant to the end of October (Fig. 1). The peak in 1968 consisted mainly of *B. longirostris* and that in 1969 of *C. sphaericus.*

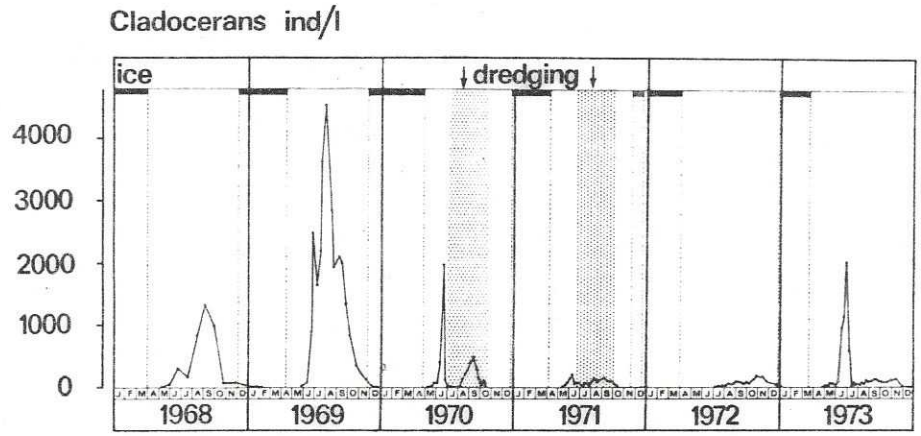

Fig. 1. Abundance of Cladocera in Lake Trummen 1968—1973.

The copepods — represented mainly by *Cyclops strenuus* and *Mesocyclops leuckarti* — were most numerous in summer and autumn, with the total number of adults plus copepodites varying normally between 50 and 300 ind/l. It is notable that no calanoid copepod was observed.

The restoration period (1970—71) was characterized by a striking decrease in the abundance of the cladocerans (Fig. 1). In particular, the numbers of *Chydorus sphaericus, Daphnia cucullata* and *D. longispina* decreased drastically. The only exception was the peak in June, 1970, when these three species were abundant during a short period. These populations, however, disappeared just before the restoration work started. The development of zooplankton in summer, 1970, was in many ways atypical, probably affected by changes in predation due to a large-scale fish kill in the oxygen-free lake in winter 1970.

While the cladocerans were reduced, some rotifer species seemed to have been favoured by the prevailing conditions during restoration. The most abundant species were *Keratella cochlearis* (max. value 13,000 ind/l) and *Anuraeopsis fissa* (max. value 8,600 ind/l), and the highest number obtained for all rotifers together was 28,000 ind/l.

During the years after the restoration (1972—73) the abundance of cladocerans was still at a relatively low level (Fig. 1), and the abundance during summer (June—September) was only about 15 % of that in 1968—69. The only deviation was a short rise in June, 1973, in the number of *Bosmina longirostris* which was well correlated with a rise in aerobic, heterotrophic bacteria (CRONBERG et al. 1975). The abundance of rotifers decreased after restoration and the total number during summer was about half that before restoration.

The least affected group was the copepods as only as slight decrease has been observed. Some individuals of *Eudiaptomus* sp. (copepodit stage) appeared in 1973, the first observation of a calanoid copepod in Lake Trummen.

The only period when an increase in the zooplankton population after restoration has been observed is in winter when better oxygen conditions have made it possible for the genera *Keratella* and *Polyarthra* to survive in higher numbers than before restoration.

The most striking effect of the restoration on the zooplankton community is the decline in the number of most species. The changes in abundance of species characteristic for Lake Trummen are summarized in Tab. 1. The numerical proportions among most species are largely unchanged. One of the few exceptions, illustrated in Fig. 2, indicates that *Keratella cochlearis* has replaced *K. quadrata*. The only species which seems to have disappeared is *Brachionus budapestinensis*. A few observations of *Kellicottia longispina* and *Eudiaptomus* sp. (copepodit stage) — both absent before restoration — have been made.

Tab. 1. Principal changes in characteristic zooplankton species following the restoration of Lake Trummen.

Brachionus calyciflorus	— —	*Filinia longiseta*	—
Brachionus angularis	— —	*Daphnia longispina*	— —
Keratella cochlearis	+	*Daphnia cucullata*	— —
Keratella quadrata	— —	*Bosmina longirostris*	—
Anuraeopsis fissa	— —	*Chydorus sphaericus*	— —
Trichocerca pusilla	— —		

— decrease — — large decrease + increase.

The decrease in abundance of rotifers and cladocerans is directly correlated with a decrease in production and biomass of phytoplankton (CRONBERG et al. 1975). The similarity in the decrease of blue-green algae and of *Bosmina longirostis, Daphnia cucullata, D. longispina* and some rotifers, is conspicuous and interesting as these algae (especially *Microcystis)* are considered to be of low food value for zooplankton (SOROKIN 1968; EDMONDSON 1974). The blue-green algae have probably been utilized after decomposition as discussed by GLIWICZ & HILLBRICHT-ILKOWSKA (1972) as typical for eutrophic waters.

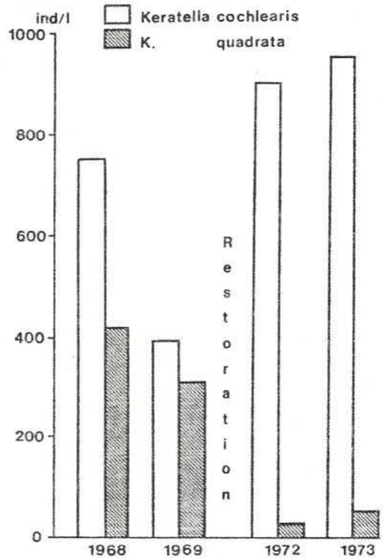

Fig. 2. Changes in abundance of *Keratella cochlearis* and *K. quadrata*. Mean values for the summer period (June—September).

A good positive relationship has been recorded for the decrease of *Microcystis aeruginosa* and *Chydorus sphaericus*. Appearance of *C. sphaericus* in large numbers in plankton is characteristic of strongly enriched waters (Brooks 1969). The numerical decrease of *C. sphaericus* is thus a good indication that the trophic state of Lake Trummen has changed to less eutrophic conditions.

Macrobenthos

During the heavily polluted stage in the history of Lake Trummen, the bottom fauna was relatively low in abundance and comprised of only a few species, demonstrated as early as 1945 by Brundin (1949) concerning the chironomids.

Before restoration the mud dwelling fauna was dominated by the two groups Oligochaeta and Chironomidae (mainly *Chironomus plumosus*). Even *Chaoborus flavicans* occurred in low numbers. During 1969 the abundance of the total macrobentic fauna fluctuated between 1,000 and 2,000 ind/m^2 (Fig. 3). The year after, however, was characterized by a marked rise in the numbers of tubificids, but even the chironomids increased in abundance.

The peak in abundance for the five years of investigation was reached in August, 1971, when about 80,000 ind/m^2 were found, with the tubificids still in outstanding dominance. During 1972 and 1973 a certain stabilization of the fauna ensued, with the number of tubificids at about 10,000 ind/m^2, and a mean density of chironomid larvae of about 1,500 ind/m^2. The phantom midge (*Chaoborus flavicans*) has increased in number considerably following a collapse during the dredging. However, there was no decrease in the abundance of chironomids as reported by Carlander et al. (1963).

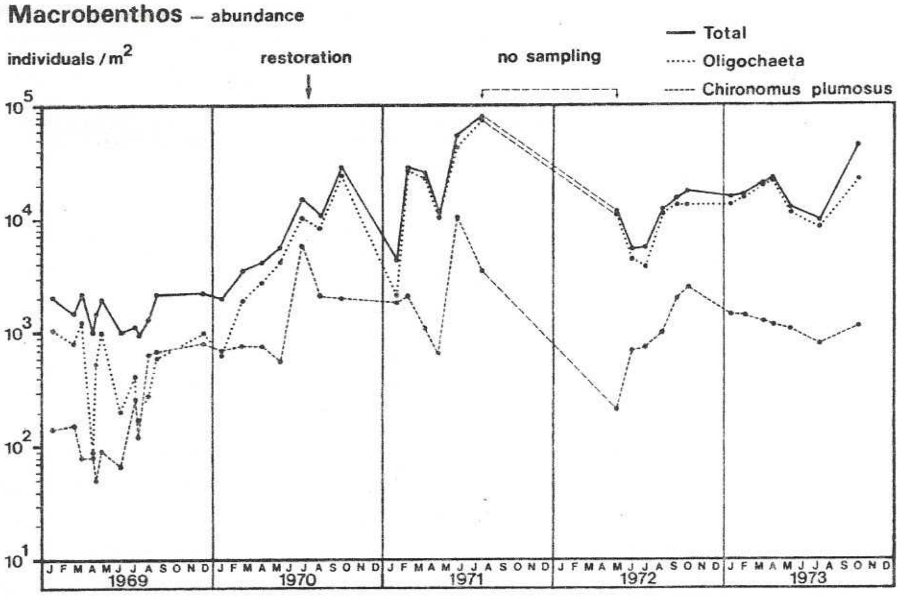

Fig. 3. Abundance of macrobenthos in Lake Trummen 1969—1973.

The most striking qualitative change in the benthos was the appearance of *Anodonta cygnea* in even the deepest parts of the lake (about 2.5 m) where small individuals of this species now can be found.

The low abundance (1,000—2,000 ind/m^2) of the total macrobenthos community in the hypereutrophic Lake Trummen was of the same order of magnitude as in oligotrophic lakes in the same region. The extreme environmental conditions prevailing in the lake before restoration may have limited the macrobenthos to a great extent. The oxygen content of the nearbottom water often reached zero not only during the ice-cover periods but also during calm weather conditions in summer. Even the high pH values in summer and late summer, when pH often exceeded 10, might have been of importance to some species.

As can be seen from the results available up to now, the main impact upon macrobenthos by the dredging was an increase in the abundance of the tubificids, mainly *Tubifex tubifex* var. *ignotus, Limnodrilus hoffmeisteri* and to some extent *Potamothrix hammoniensis* (Milbrink pers. comm.) and chironomids (mainly *Chironomus plumosus*). The large increase in the number of oligochaetes in 1970—71 may partly be the result of decreased predation following the fish kill during winter 1970, discussed below.

Surprisingly, the dredging in July, 1970, did not result in any profound decrease in the number of benthos as a whole. Regarding the chironomids, this might be due to the well known mobility of the larvae, especially those of *Procladius* sp. Furthermore, the dominating species *Chironomus plumosus* swarms during the whole summer, and newly hatched larvae might soon have colonized the dredged areas.

Fish

Before the restoration (1969) the biomass of the fish community — as indicated by the catches (Tab. 2) — was very large. The fish fauna consisted mainly of roach *(Rutilus rutilus)*, bream *(Abramis brama)*, silver bream *(Blicca bjoerkna)*, pike *(Esox lucius)*, perch *(Perca fluviatilis)* and eel *(Anguilla anguilla)* (Fig. 4, Tab. 2), with rather large populations of tench *(Tinca tinca)* and rudd *(Scardinius erythrophthalmus)* found in the vegetation. A comparison between the catches in the central lake and at the edges of the reed belts *(Phragmites communis* and *Equisetum fluviatile)* indicated that roach, silver bream, rudd and tench were the species most favoured by the expanding vegetation (Tab. 2); but the high trophic state also favoured the bream, pike and perch. The bleak *(Alburnus alburnus)*, gudgeon *(Gobio gobio)* and ruffe *(Acerina cernua)*, however, were nearly extinguished in 1969, and finally disappeared after the fish kill 1970.

Tab. 2. Catches (kg) per survey-link · 24 hours in Lake Trummen and Lake Hinnasjön (mean values for July—October).

	Trummen littoral	Trummen central lake						Hinnasjön
	1969	1969	1970	1971	1972	1973	1974	1971
pike	1.4	3.1	0.8	2.7	2.0	1.5	1.4	0.2
perch	0.5	0.5	0.9	2.1	1.3	0.5	0.7	0.3
bream	0.7	1.6	0.6	0.8	0.9	0.8	1.4	0.5
silver bream	2.6	1.0	0.1	0.2	0.2	0.1	0.1	0.0
roach	1.9	1.0	4.4	5.0	1.4	0.6	2.1	0.4
rudd	0.2	—	—	—	—	—	—	0.0
tench	0.3	—	0.3	0.6	—	—	—	—
Total	7.6	7.2	7.1	11.4	5.8	3.5	5.7	1.4

The hard winter (1970) — immediately before the restoration — also reduced the populations of all other species. This effect was, however, not detectable in the catches, except for bream and silver bream because of the restoration work in the reed belts, which forced the fish out into the central lake. According to Tab. 2 this effect should be most pronounced for roach and silver bream, but the catches after the fish kill indicate that a large part of the perch population also occurred within the reed belts.

With these disturbing facts in mind, Fig. 4 and 5 show that almost all the bream and silver bream were killed during the winter 1970, and only some older specimens survived. All young roaches (year classes 0+ and I+) were also killed, while no effect (because of the restoration work) was measurable on the populations of pike and perch. The rudd and especially the tench probably left the restored kart of Lake Trummen for the unrestored bay Skirviken. This was not, however, the case with the other species.

The effects of the fish kill, of course, reenforced the expected effects of the restoration, so it is still too early to say anything about the longterm reaction of the fish fauna to the restoration. After the restoration (and the fish kill) the total catches

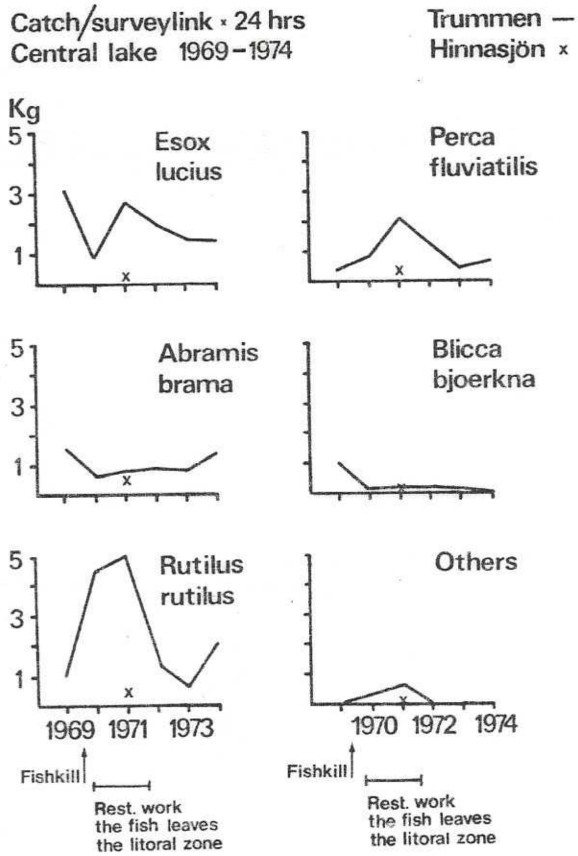

Fig. 4. Catches of fish in the central part of Lake Trummen 1969—1974 (mean values for July—October), and in the oligotrophic, reference Lake Hinnasjön 1971.

continued to decline until 1973, when the values were almost as low as in the oligotrophic reference Lake Hinnasjön (Fig. 4, Tab. 2). The preliminary data for 1974, however, indicate higher catches than 1973, and most of the populations of perch, bream and roach consist of fish younger than 4 years with specimens older than that very rare. One effect which seems definite is the sharp decline of the silver bream population.

Food choice of the fish fauna

Before the restoration chironomids occurred with about the same frequency in the stomachs troughout the year, while copepods dominated during spring and early summer, after which they were replaced by cladocerans (Tab. 3).

The small roach fed most frequently upon *Bosmina* and to a less degree upon Chydoridae. The older specimens turned to chironomids and to parts of macrophytes, but almost all bottom animals that occurred in the lake were also found in the intestines of the roaches.

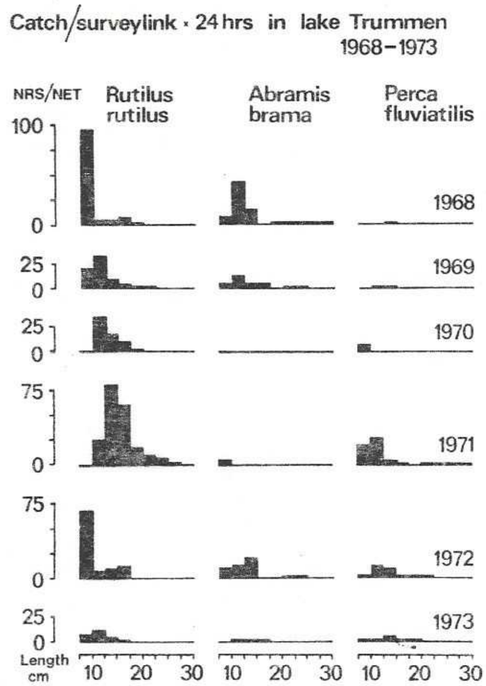

Fig. 5. Catch of roach *(Rutilus rutilus)*, bream *(Abramis brama)* and perch *(Perca fluviatilis)* distributed on different size classes. Mean values for July—October in Lake Trummen 1968—1973.

The small b r e a m fed almost exclusively on Chydoridae. When they grew larger they also included *Daphnia* and Copepoda in their diet, and the largest specimens fed almost entirely on *Daphnia* and to a smaller extent on Chironomidae. The zooplankton was thus of great importance for all age classes, which is often noticed in eutrophic lakes.

Small s i l v e r b r e a m s occurred very seldom in the catches, so little is known about their food choice. It seems, however, that they resembled the bream in their food habits, but with a greater tendency to prefer chironomids. The larger specimens (above 200 mm) were carnivores and yearlings of roach were the most important food item in their diet.

The small p e r c h between 70 and 100 mm fed on Chironomidae (mostly the pupae). At a length of about 125 mm they started eating small fish — perch as well as roach but never bream.

The p i k e preferred roach but perch and bream occurred occasionally in their stomachs.

After the restoration zooplankton disappeared almost entirely as a food item for the r o a c h and even the macrophytes were of less importance. The chironomids were now the most important food item, but with the absolute frequency unchanged compared to the results from 1968/69. There seemed therefore to be a shortage of food for the roaches after the restoration.

Daphnia, Bosmina and Copepoda had lost all importance as food items for the b r e a m. They were replaced in 1972 by *Chydorus* sp. and other chy-

Tab. 3. Food choice of the fish population in Lake Trummen before (1968 and 1969) and after (1972) the restoration. Mean values for the periods June 1968—November 1969 and May—October 1972, respectively.

Species Length, mm		Roach <100	Roach 100—150	Roach 150—200	Roach >200	Bream < 100	Bream 100—150	Bream 150—200	Bream >200	Perch < 100	Perch 100—150	Perch 150—200	Perch >200	
Daphnia	1968/69	9	24	3	—	1	34	290	715	—	—		—	nrs/fish
	1972	—	—	—	—	—	—	—	—	—	—	—	—	,,
Bosmina	1968/69	113	195	15	—	6	33	7	3	—	—		—	,,
	1972	—	64	—	—	—	—	—	—	—	—	—	—	,,
Chydorus	1968/69	20	54	2	4	52	559	365	45	—	—		—	,,
	1972	5	—	—	—	71	705	—	—	—	—	—	—	,,
Chydoridae, others	1968/69	5	3	41	—	71	48	4	10	—	—		—	,,
	1972	—	41	—	—	253	319	—	—	—	—	—	—	,,
Cyclopidae	1969/69	1	5	18	—	19	75	415	246	—	—		—	,,
	1972	—	—	—	—	—	1	—	—	—	—	—	—	,,
Zooplankton, total	1968/69	148	281	79	4	149	749	1081	1019	—	—		—	,,
	1972	5	105	—	—	324	1025	—	—	—	—	—	—	,,
Chironomidae	1968/69	0.1	0.4	1.6	6.5	0.1	1.3	4.3	15.9	—	—		—	,,
	1972	0.1	0.4	3.2	1.4	—	0.1	0.8	16.0	1.8	1.9	0.4	0.3	,,
Bottom-fauna, others	1968/69	—	—	0.3	2.3	—	0.1	0,4	6.3	—	1.3		0.1	,,
	1972	—	0.1	0.2	0.5	—	—	—	—	0.1	—	—	—	,,
Bottom-fauna, total	1968/69	0.1	0.4	1.9	8.8	0.1	1.4	4.7	22.2	—	1.3		0.1	,,
	1972	0.1	0.5	3.4	1.9	—	0.1	0.8	16.0	1.9	1.9	0.4	0.3	,,
Primary producers	1968/69	5	13	11	60	—	1	5	9	—	—		—	frequency
	1972	—	—	3	65	—	—	—	—	—	—	3	—	%
Fish	1968/69	—	—	1	17	—	—	—	—	—	60		60	,,
	1972	—	—	—	10	—	—	—	—	—	16	45	25	,,

doridae. These zooplankton occurred in the diet of the bream even before the restoration.

The small perch fed on chironomidae as before, and they still turned to a fish diet at a length of about 125 mm. The frequency of fish in their stomachs was, however, considerably lower in 1972 than in 1968/69 (20 % compared with 60 %).

It is obvious that *Daphnia, Bosmina* and cyclopidae have lost almost all importance to the fish because of the relatively low numbers in which they occur in the lake after the restoration. The bream — which is a bottom-feeder — then turned to small bottom-dwelling crustaceans, while the roach — in spite of a smaller population — could not find an alternative food item.

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Discussion

HORNE: What percentage of the fish habitat, reed beds etc. were removed along with dredging?

ANDERSON: About 90 % of the area with macrophyte vegetation was removed but there were still good possibilities for fish to spawn. Furthermore the vegetation in a bay of the lake, Skirviken, was left untouched.

MALUEG: Would you propose dredging of a eutrophic stratified lake as a lake restoration technique?

ANDERSSON: Yes, if the new bottom will provide good conditions with respect to nutrient exchange etc.