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The effect of low pH on perch, Perca fluviatilis L. III. The perch population in a small, acidic, extremely humic forest lake

Martti Rask

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Lake Karhujärvi, a small, extremely humic forest lake has a perch population of 200 individuals. The growth and the composition of the diet resemble those in other, less acid lakes in the same area. The reproduction of the perch failed in the springs of 1980–1982 as a result of high mortality of roe caused by low pH. The fertilization of most eggs may have been inhibited by decreased activity of the sperm cells, but even fertilized eggs showed high mortality. In spring 1981, many adult fish died, probably due to the low pH and high aluminium concentration of the water.

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1. Introduction

Acidification can affect fish populations by lowering the number of fish species in the lakes (Harvey 1975), inhibiting the reproduction (Beamish et al. 1975), causing mass mortality of the fish (Leivestad & Muniz 1976) and food deficiency (Borgstrøm et al. 1976), and increasing the solubility of compounds toxic to fish (Schindler et al. 1980).

In this study, the reproduction, growth and food of a perch population from a small, extremely humic forest lake was studied with special reference to acid conditions in the lake.

2. The lake

Lake Karhujärvi is situated in Evo, Lammi, southern Finland. It is an extremely humic forest lake with a surface area of 0.8 ha and a maximum depth of 8 m (Fig. 1). In summer the lake is clearly stratified. The epilimnion is 3-4 m thick and gets warm during the summer. The hypolimnion is cold and has no oxygen, except during the spring and autumn circulations, which did not occur regularly in 1980-1982. Lake Karhujärvi is the most acidic lake in the Evo region. There was no pH minimum during the thaw, which is otherwise often observed in acidifying waters (Haapala et al. 1975, Dickson 1980), but the pH range was narrow (4.2-4.4) from April to September.

The pH of 60 lakes has been measured in Evo since 1979 and Lake Karhujärvi is the only one with a pH value continuously below 5.0. The reason is probably the ditching of the marshy

Table 1. Physicochemical properties of water in Lake Karhujärvi during the 1981 growing season. The measurements were made weekly, excluding cations, which were analysed once a month. Sampling depth 1 m.

	May	June	July	August	September
Temperature °C	7.9	11.7-14.0	15.9-18.1	13.7-17.3	9.4-12.9
Oxygen (mg/l)	10.6	7.8-9.4	6.8-7.9	6.6-7.4	6.9-7.8
pH	4.4	4.4	4.4	4.3	4.3
Alkalinity (meq/l)	-0.03	-0.04	-0.03	-0.04	-0.04
Cond. (μS/cm 20°C)	46	41	42	44	43
Colour (mg Pt/l)	200	200	270	340	400
Tot. P (μg/l)	180	150	140	140	130
Tot. N (μg/l)	570	490	550	670	630
SO_4 (mg/l)	7	7	7	6	7
Na (mg/l)	1.2	1.0	1.0	1.0	1.0
K (mg/l)	0.9	0.4	0.3	0.2	0.2
Ca (mg/l)	3.0	2.9	2.9	2.9	3.0
Mg (mg/l)	1.0	0.8	0.8	0.8	0.8
Mn (mg/l)	0.02	0.01	0.01	0.01	0.01
Fe (mg/l)	0.2	0.2		0.2	0.3
Al (μg/)	200	210		300	300

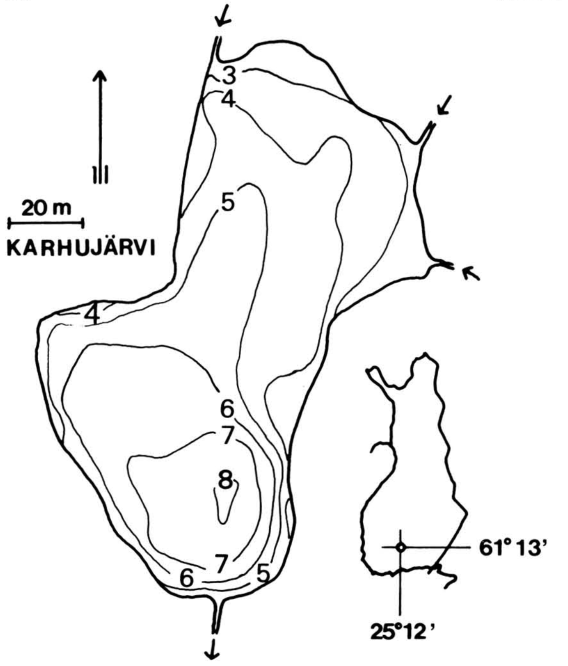

Fig. 1. Lake Karhujärvi and its location.

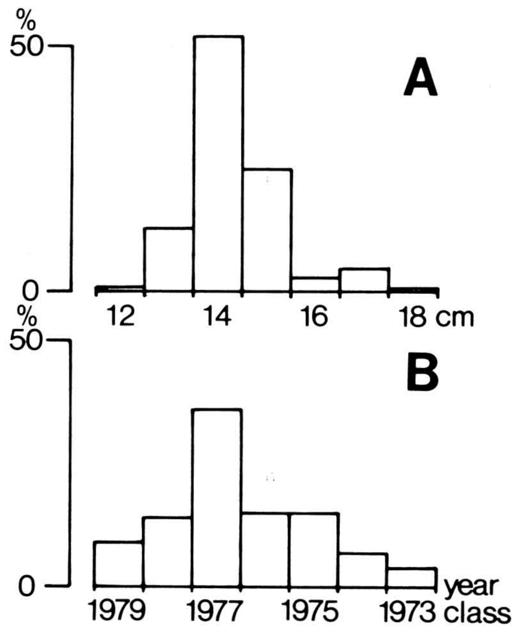

Fig. 2. (A) The length distribution and (B) the year class distribution of perch in Lake Karhujärvi.

part of the drainage area of the lake during the last decade. The quality of water in Lake Karhujärvi (Table 1), excluding pH, alkalinity and total phosphorus (mostly DIP) was about the same as reported from other lakes in Evo (Meriläinen & Paasivirta 1979, Arvola 1983). The high concentration of phosphorus was probably a consequence of forest fertilization of the area during the last decade.

The primary rock of the drainage area (23 ha) is veined gneiss covered with glacial moraine soil. The dominant vegetation is spruce forest and marshy vegetation with scotch pine. The whole shoreline of the lake is surrounded by *Sphagnum* vegetation with marshy grasses and dwarf shrubs, so the mineral soil does not reach the shore.

There are no macrophytic water plants in the lake. Small flagellated algae are the dominant phytoplankton, in particular *Cryptomonas ovata* (Arvola, unpubl.). *Ceriodaphnia quadrangula* is the most common pelagial zooplankton and *Polyphemus pediculus* is the most common among the littoral species. *Asellus aquaticus,* Odonata larvae and Trichoptera larvae are common in the benthos.

3. Material and methods

The size of the perch population in Lake Karhujärvi was estimated in spring 1982 by mark and recapture (Robson & Regier 1971). The left pectoral fin was cut and the length of marked individuals was measured for length distribution. Fish were caught in traps with a mesh size of 1 cm. To estimate the reproductive success of perch under the acid conditions in the lake, batches of roe were collected in the springs of 1980-1982 and reared in the laboratory. The differences in mortality of perch eggs from Lake Karhujärvi and a control lake were tested using a binomial *t*-test for comparison of two experimental percentages (Mäkinen 1974).

The samples for determining the age, growth and food of the perch were collected monthly during the ice-free period in 1981 (n=38) and 1982 (n=62). Age (according to Tesch 1971) and growth (according to LeCren 1947) were determined from the opercular bone. The differences in growth between sexes and year classes were tested using Student's *t*-test. The relative condition was calculated as monthly means of the condition factor, $K = w/l^3$ (w = weight, l = length of a fish), of different length groups (1 cm intervals). The June value was chosen as 0 level and percentage exceptions from this in July and August showed the development of condition during the later growing season. The production and biomass of the perch were estimated from population size, fish size distribution, and growth rate. In food analyses a volumetric points method (Windell 1971) was used with a scale of 0-24 points for the fullness of the stomach.

4. Results

4.1. Population

Mark and recapture in spring 1982 gave a population estimate of 190 ± 35 (95 % conf. limits). The population density was 230 individuals per hectare. This is less than in small, humic, forest lakes in general; 490 and 1020 (Tikka & Paasivirta 1979), 530 and 1750 (Rask 1983a), and 2500-3000 individuals per hectare (Alm 1946). In the larger dystrophic Lake Suomunjärvi the density of the perch population is 250 individuals per hectare (Viljanen 1978). The reason for the low population number of perch in Lake Karhujärvi is at least partly the result of death of the fish in spring 1981. Soon after the thaw 25 dead perch were found, the length range of which was 13-15 cm. This was probably only a small part of all the dead fishes, which means that there was a considerable decrease in the population. The dominant length group in 1982 was 14.0-14.9 cm and the dominant year class was 1977 (Fig. 2). The length distribution resembled those reported by Sumari (1971) from small forest lakes. The majority of the fishes were males, the sex ratio of collected samples (n=100) was 3:1.

Although perch is one of the fish species most tolerant to acidification, the populations are affected at a pH less than 5.0 (Almer 1972). Losses of perch populations due to acidification in Norway have been reported by Rosseland et al. (1980).

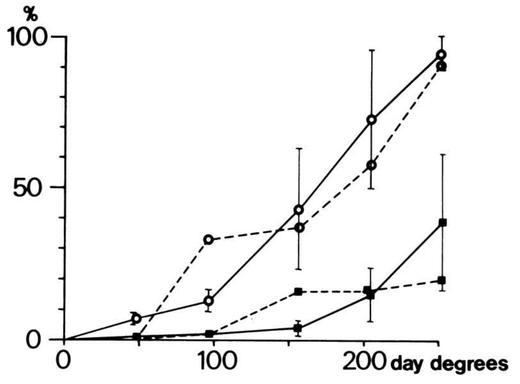

Fig. 3. The mortality (%) of fertilized eggs of perch from Lake Karhujärvi (circles, n=580) and L. Nimetön (squares, n=380) at pH 4.5 in 1980. Dotted line: pH 6.9 (n=60 and 150). Vertical bars = *SE*.

4.2. Reproduction

The year class distribution of perch in Lake Karhujärvi shows that in 1979 some reproduction was successfull. In May 1980 the fertilized roe of three females was reared in the laboratory. The mortality of the eggs was over 90 % at pH 4.5 and at control pH (6.9), too (Fig. 3). The egg mortality in comparison to that of perch from a control lake, Lake Nimetön, was higher from the beginning of the experiment (P<0.001). The hatchability of fertilized perch eggs is usually 85.0-99.5 % (Nyberg 1976).

In May 1981 the batches of roe of 20 females were collected. Nearly all of the eggs were dead and the few live ones soon died in the laboratory at pH 6.4 while fertilized perch eggs from other forest lakes showed a mortality less than 1 % in the same water. In both years the eggs had developed 2-3 days after fertilization in the lake before transferal to the laboratory.

In May 1982 batches of roe from two females were collected soon after spawning (not more than 20 hours). These eggs also showed an abnormally high mortality (Table 2) while the control eggs from another forest lake had a mortality of 2 % in water at pH 6.4. According to these observations it seems that the reproduction of perch has failed in the last three years in Lake Karhujärvi. However, in 1981 fertilized perch eggs from other forest lakes were reared in Lake Karhujärvi. They were placed in the lake in netted polypropylene boxes 15 day degrees after spawning and their hatching percentage was 72 % (Rask 1983b).

Table 2. The mortality (%) in different pH of perch eggs from two females from Lake Karhujärvi.

	n	Date (May 1982) 12	13	14	15	16
Day degrees		6	15	26	38	51
pH 4.3						
Female I	259	6	28	60	68	80
Female II	180	9	43	49	55	78
pH 6.4						
Female I	300	5	35	50	80	90
Female II	350	10	52	61	72	88

4.3. Growth

The growth of perch in Lake Karhujärvi is slow (Fig. 4). According to the growth classification of Tesch (1955) and Valle (1944) it is very poor. However, in comparison to other perch populations of small forest lakes in Evo it is normal

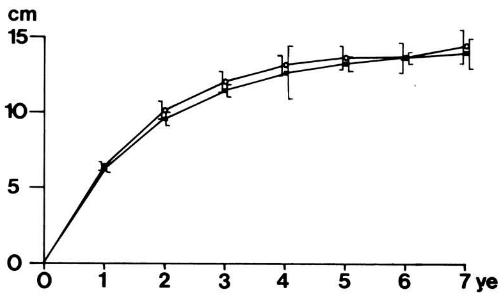

Fig. 4. The growth of perch in Lake Karhujärvi, females (circles, n=25) and males (dots, n=75) separately. Vertical bars indicate 95 % confidence limits.

Table 3. The growth (cm) of perch in some forest lakes in Evo region (L. Nimetön and L. Horkkajärvi, Rask 1983a; L. Haukilampi and L. Iso Mustajärvi, Tikka & Paasivirta 1979).

Age (years):	1	2	3	4	5	6	7	8
Karhujärvi	6.4	9.7	11.6	12.8	13.3	13.7	14.1	
Nimetön	5.7	9.8	12.5	15.2	16.7	17.8		
Horkkajärvi	6.3	9.0	10.2	11.1	11.7	12.6	13.3	14.2
Haukilampi	5.4	7.6	9.5	11.0	12.0	13.2	13.7	
Iso-Mustajärvi	6.6	9.5	11.1	12.4	13.4	14.6	15.9	16.5

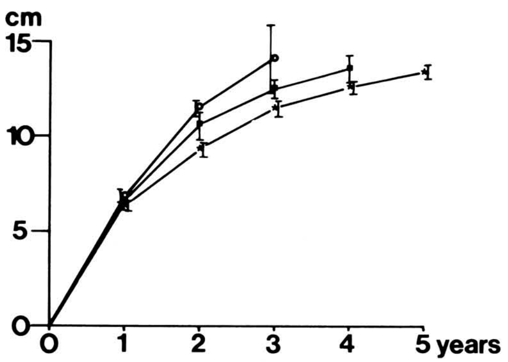

Fig. 5. The growth of perch from year classes 1979 (circles, $n=9$), 1978 (dots, $n=14$) and the mean growth of year classes 1973-1977 (crosses, $n=77$). Vertical bars indicate 95 % confidence limits.

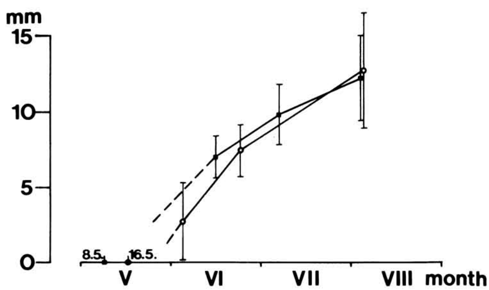

Fig. 6. The increase in length of perch during 1981 growing season (circles, $n=38$) and 1982 (dots, $n=62$). Vertical bars indicate 95 % confidence limits. Date of thaw in both years also given.

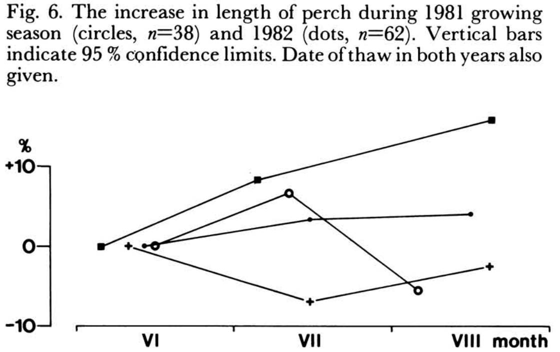

Fig. 7. The relative condition of perch in L. Karhujärvi (circles), in L. Tavilampi (squares), in L. Nimetön (crosses) and in L. Horkkajärvi (dots), $n=50$-100 fishes per lake.

(Table 3). The difference in growth between sexes was significant ($P<0.05$) only in age groups 2 and 3. It is clearer in populations with better growth (Goldspink & Goodwin 1979). The growth of year classes 1978 and 1979 was better than the mean growth of the year classes 1973-1977 ($P<0.001$) in all age groups (Fig. 5). False annual marks were common in the operculum of fishes from the year classes 1973-1977, but not in those from the last two year classes. The perch grew rather evenly during the growing seasons of 1981 and 1982 (Fig. 6). No decrease in growth during midsummer, as reported by Nyberg (1976), was observed.

The relative condition of fishes decreased clearly from July to August. The phenomenon was not present in other perch populations in Evo (Fig. 7). In Windermere (LeCren 1951) and Lake Pounui (Jellyman 1980) the relative condition of perch increased during the summer months.

The production of perch in Lake Karhujärvi was 2.4 kg/ha in 1982. The biomass was 8.5 kg/ha and the P/B ratio 0.3. The production was lower than in studies from Lake Kiutajärvi, Finland (Lind et al. 1974) and Lake Vitalampa and Lake Botjärn, Sweden (Nyberg 1976).

4.4. Food

The main food items of the perch in Lake Karhujärvi were *Asellus aquaticus*, Odonata larvae and Trichoptera larvae, which together formed 82 % of the diet (Fig. 8a). Asellus was most important in July, when adult individuals of 0.7-1.3 cm were still available to the perch. In August perch fed on smaller individuals of the new generation. The importance of *Asellus* in the diet of perch has also been reported from Lake Botjärn (Nyberg 1976) and Loch Leven (Thorpe 1974). Odonata larvae (from families Aeschnidae, Libellulidae and Coenagriidae) were most important in August. Trichoptera larvae, mostly Limnephilidae, were most important in June. In July the Trichoptera proportion consisted mostly of pupae, which were eaten especially by the fish of length group 16.0-18.0 cm (Fig. 8b). The monthly variations in the amounts of these food

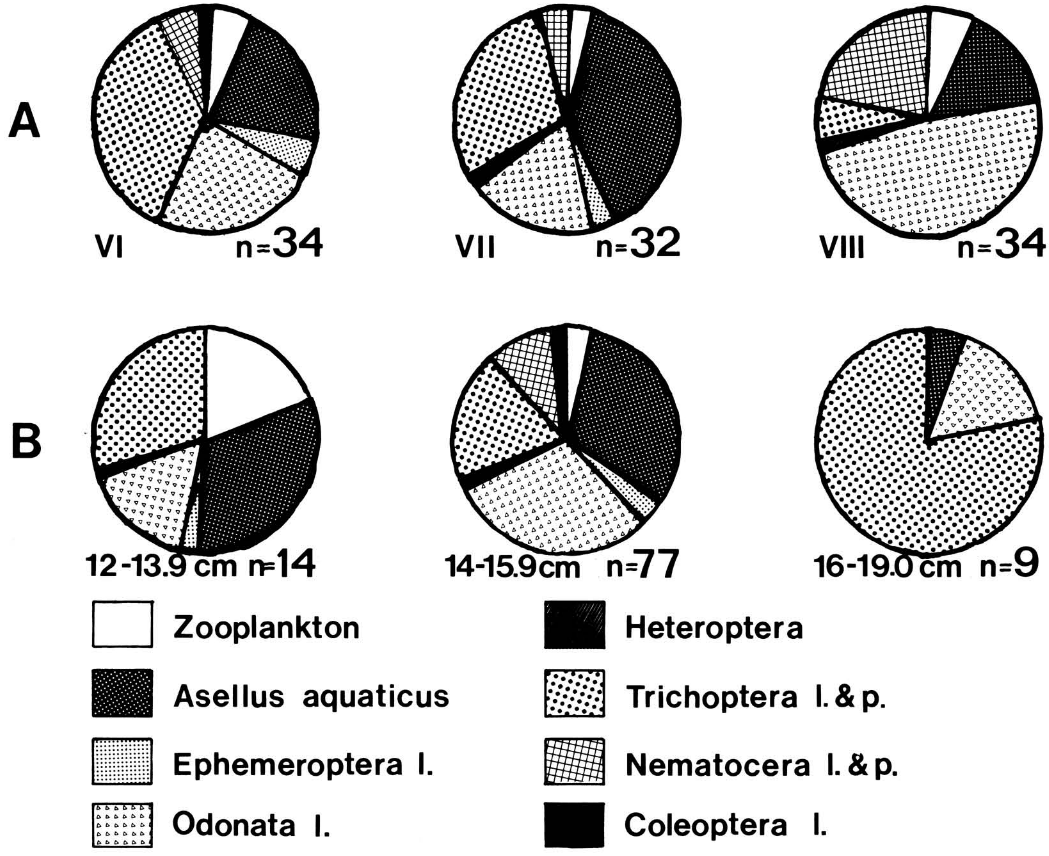

Fig. 8. The composition of the diet of perch (A) during summer months and (B) in different length groups in Lake Karhujärvi (% of fullness points).

items may be due to their different life cycles. *Asellus* is annual, as are Trichoptera larvae (Hickin 1967), but Odonata larvae are perennial (Corbet et al. 1960) and they are thus available to the fish throughout the growing season. The most important zooplankton species in the diet of perch was *Polyphemus pediculus*. Zooplankton was important only in the diet of the smallest fish (Fig. 8b). Nearly all Nematocera larvae eaten by perch were *Chaoborus* sp.

The amount of food in the stomachs varied during the summer. The mean fullness in June was 9.2/24 points (SD=7.5, n=34), in July 13.5 (SD=8.6, n=32), and in August 6.3 (SD=6.7, n=34). The size distribution of prey also varied: in June, food items $\geq$ 10 % of the length of the fish were eaten by 17.6 % of the fishes. In July and August the corresponding percentages were 15.6 and 5.9 %.

The comparison of diets of perch in some forest lakes in Evo (Table 4) shows considerable similarity: all important food items in Lake Karhujärvi were also important in one or more other lakes, the pH of which varied between 5.7 and 6.9.

Perch functions as an important converter of invertebrate food into a suitable form for ingestion by terminal fish predators (Thorpe 1977). In Lake Karhujärvi perch is the top predator, but it has no prey fish, which according to Deelder (1951) is the reason for their slow growth.

5. Discussion

5.1. Population

The population in the lake is now low, less than 200, and the fish is in danger of extinction. Thorpe (1977) gives as a summary of many studies a range

Table 4. The main food items (% of stomach contents) of perch in some forest lakes in Evo Region (L. Nimetön and L. Horkkajärvi, Rask 1983a; L. Iso Mustajärvi and L. Haukilampi, Meriläinen & Paasivirta 1979).

	Karhu-järvi	Nimetön	Horkka-järvi	Iso-Musta-järvi	Hauki-lampi
Zooplankton	4	14	31	8	20
Asellus aquaticus	30	9	23	1	4
Ephemeroptera l.	3	17	2	2	-
Odonata l.	27	17	7	32	-
Heteroptera	1	15	7	-	-
Sialis lutaria	-	-	1	3	24
Trichoptera l. & p.	25	6	13	3	32
Nematocera l. & p.	9	11	12	42	18
Others	1	11	4	9	2

of 20-41 % annual mortality for perch. With a mortality rate of this magnitude, the perch population of Lake Karhujärvi will soon decrease below 100 individuals and towards extinction if the reproductive failure continues. No immigration to the lake can occur because of the small outlet and wide difference in altitude between Lake Karhujärvi and the receiving lake.

The death of adult perch in the lake in spring 1981 may have been a consequence of the poor general condition of the fishes after winter, the energy demands due to spawning, the stress caused by the low pH and the high aluminium concentration of the water (200 μg/l), which is toxic to fish in combination with low pH (Dickson 1978). The toxic action of aluminium is a combined effect of impaired ion exchange and respiratory distress caused by mucus clogging the gills (Muniz & Leivestad 1980).

5.2. Reproduction

The reason for reproductive failures of fish in acid conditions may be decreased functioning of the gametes (EIFAC 1969), the failure of fertilized eggs to develop or hatch (Peterson et al. 1980), hatching of deformed fry (Runn et al. 1977) or cessation of spawning (Beamish & Harvey 1972).

In Lake Karhujärvi spawning occurred in 1980-1982 but the hatchability of the eggs was low or zero. The reason seems to be a combination of the first two possibilities. Hudd (unpubl.) observed that the time of motile activity of perch sperm cells decreased sharply at pH 4.6-4.8. According to this observation the fertilization was more or less totally inhibited in 1981 and 1982 in Lake Karhujärvi. In spring 1980 at least some of the laid eggs were fertilized, but there was high mortality of the developing eggs in the rearing experiment with the fertilized eggs: the eggs probably suffered damage during the first few hours after fertilization or even earlier, during oogenesis, which is also a pH sensitive stage in fish egg development (Craig & Baksi 1977). The chorion of the egg is at first freely permeable to water and various molecules but hardens rapidly during the first few hours after fertilization (Lee & Gerking 1980). This explains the high hatchability (72 %) of the eggs fertilized in other lakes but reared in Lake Karhujärvi.

5.3. Growth

The differences in growth between year classes in fish populations may be due to changes in population density, amounts of suitable food, abiotic factors, etc. (Goldspink & Goodwin 1979, Hartmann 1975, LeCren 1958). Increased growth of perch (Mossberg & Nyberg 1976) and roach (Lessmark 1976) has been observed under acid conditions. The reason seems to be the absence of competition for food due to decreased species diversity of the fish and decreased fish populations in acid lakes. Edwards & Hjeldnes (1977) observed that rainbow trout and arctic char grew significantly more slowly at pH 4.8-5.0 than 5.5-6.2 in tank experiments. Beamish (1974) has recorded reduced growth at low pH in natural fish populations.

The growth rate of perch in Lake Karhujärvi is so similar to that in other small forest lakes in Evo that no direct effect of acid conditions on it can be seen. This is because several factors affect the growth. The increased growth of perch from year classes 1978 and 1979 might be due to the decrease in the population number caused by low pH. The reduced occurrence of false annual marks in the opercula of fishes from these year classes may indicate better growth conditions than earlier. However, the decrease in the relative condition during later summer shows that the fishes live under severe stress. It seems that the energy costs caused by living under acid conditions and the growth of gonads in late summer exceed the energy resources of the perch.

The reason for the low production in 1982 was the lower population in the lake. The absence of age classes 0+ and 1+ also affects the production. The proportion of age class 1+ can be more than 50 % of the total production of perch populations in small lakes (Lind et al. 1974). In practice, the biomass of the population decreased due to sampling.

5.4. Food

The composition of the food of perch may change with decreasing pH. Cyprinid fishes, which are important as sources of food for the perch, disappear and are replaced by invertebrates, first by *Asellus aquaticus* and when the acidification goes further on, by Corixa bugs (Almer et al. 1974). The importance of corixids as food for the perch in acid lakes is also reported by Andersson (1972). In Lake Karhujärvi corixids have no significance in the diet of the perch. All the important food items of the perch in Lake Karhujärvi can tolerate low pH. *Asellus'* lower limit of pH tolerance is 4.8 (Økland 1980), but here it seems to tolerate even more acid water. Odonata larvae and *Chaoborus* larvae are tolerant to low pH (Eriksson et al. 1980) and so are Trichoptera larvae (Raddum 1979). Because these food items are also important in the diet of perch in forest lakes with higher pH values, it is probable that no significant changes in the composition of the diet of adult perch have occurred due to acidification.

The absence of daphnid cladocers and cyclopoid copepods from the diet of perch is probably an effect of low pH. These groups are sensitive to low pH (Hobaek & Raddum 1980). In Lake Karhujärvi they were replaced by *Ceriodaphnia quadrangula,* which is tolerant to low pH (Carter 1971), and a littoral species *Polyphemus pediculus,* which also tolerates low pH (Sprules 1975).

Smaller fullness of stomach and smaller average size of prey in August may indicate poorer food conditions than in the early summer. The reason may be the different life cycles and the relative small number of species of benthic fauna in that kind of lake: there may be periods during the growing season when not enough food is available. This does not explain the decrease in the relative condition in comparison to other forest lakes in Evo, at least not totally, because the food conditions in other lakes may be similar to those in Lake Karhujärvi. According to Menshutkin & Zhakov (1964) starvation is an important factor in the population dynamics of 4–8 year old perch in lakes with no other species of fish.

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References

Alm, G. 1946: Reasons for the occurrence of stunted fish populations with special reference to the perch. — Rep. Inst. Freshw. Res. Drottningholm 25: 1-146.

Almer, B. 1972: Försurningens inverkan på fiskbestånd i västkustsjöar. — Information från Sötvattenslaboratoriet Drottningholm 12, 1972, 47 pp.

Almer, B., Dickson, W., Ekström, C. & Hörnström, E. 1974: Effects of acidification on Swedish lakes. — Ambio 3: 30-36.

Andersson, B. 1972: Abborrens näringsval i försurade västkustsjöar. — Information från Sötvattenslaboratoriet Drottningholm 17, 1972, 21 pp.

Arvola, L. 1983: Primary production and phytoplankton in two small, polyhumic forest lakes in S. Finland. — Hydrobiologia 101: 105-110.

Beamish, R. J. & Harvey, H. H. 1972: Acidification of the La Cloche mountain lakes, Ontario, and resulting fish mortalities. — J. Fish. Res. Board Can. 29: 1131-1143.

Beamish, R. J. 1974: Growth and survival of white sucker (Catostomus commersoni) in an acidified lake. — J. Fish. Res. Board Can. 31: 49-54.

Beamish, R. J., Lockhart, W. L., Van Loon, J. C. & Harvey H. H. 1975: Long-term acidification of a lake and resulting effects on fishes. — Ambio 4: 98-102.

Borgstrøm, R., Brittain, J. & Lillehammer, A. 1976: Evertebrater og surt vann. Oversikt over innsamlingslokaliteter. — SNSF-project, IR 21/76, 33 pp.

Carter, J. C. H. 1971: Distribution and abundance of planktonic Curstacea in ponds near Georgian Bay (Ontario, Canada) in relation to hydrography and water chemistry. — Arch. Hydrobiol. 68: 204-231.

Corbet, P. S., Longfield, C. & Moore, N. W. 1960: Dragonflies. — 260 pp. London.

Craig, G. R. & Baksi, W. F. 1977: The effects of depressed pH on flagfish production, growth and survival. — Water Res. 11: 621-626.

Deelder, C. L. 1951: A contribution to the knowledge of the stunted growth of perch (Perca fluviatilis L.) in Holland. — Hydrobiologia 3: 357-378.

Dickson, W. 1978: Some effects of the acidification of Swedish lakes. — Verh. Internat. Verein. Limnol. 20: 851-856.

Dickson, W. 1980: Properties of acidified waters. — In: Drabløs, D. & Tollan, A. (eds.), Ecological impact of acid precipitation: 75-83. SNSF-project, Oslo-Ås.

Edwards, D. J. & Hjeldnes, S. 1977: Growth and survival of salmonids in water of different pH. — SNSF-project, FR 10/77, 12 pp.

EIFAC 1969: Water quality criteria for European freshwater fish — extreme pH values and inland fisheries. — Water Res. 3: 593-611.

Eriksson, M. O. G., Henrikson, L., Nilsson, B.-I., Nyman, G., Oscarson, H. G. & Stenson, A. E. 1980: Predator-prey relations important for the biotic changes in acidified lakes. — Ambio 9: 248-249.

Goldspink, C. R. & Goodwin, D. 1979: A note on the age composition, growth rate and food of perch, Perca fluviatilis (L.), in four eutrophic lakes, England. — J. Fish Biol. 14: 489-505.
Haapala, H., Sepponen, P. & Meskus, F. 1975: Effect of spring floods on water acidity in the Kiiminkijoki area Finland. — Oikos 26: 26-31.
Hartman, J. 1975: Der Barsch (Perca fluviatilis) im eutrophierten Bodensee. — Arch. Hydrobiol. 76: 269-286.
Harvey, H. H. 1975: Fish populations in a large group of acid stressed lakes. — Verh. Internat. Verein. Limnol. 19: 2406-2417.
Hickin, N. E. 1967: Caddis larvae. — 476 pp. London
Hobaek, A. & Raddum, G. G. 1980: Zooplankton communties in acidified lakes in South Norway. — SNSF-project, IR 75/80, 132 pp.
Jellyman, D. J. 1980: Age, growth and reproduction of perch, Perca fluviatilis L., in Lake Pounui. — N. Z. J. Marine & Freshwater Res. 14: 391-400.
LeCren, E. D. 1947: The determination of the age and growth of the perch (Perca fluviatilis) from the opercular bone. — J. Anim. Ecol. 16: 188-204.
—»— 1951: The length-weight relationship and seasonal cycle in gonad weight and condition in the perch (Perca fluviatilis). — J. Anim. Ecol. 20: 200-219.
—»— 1958: Observations on the growth of perch (Perca fluviatilis, L.) over twenty-two years with special reference to the effects of temperature and changes in population density. — J. Anim. Ecol. 27: 287-334.
Lee, R. M. & Gerking, S. D. 1980: Sensitivity of fish eggs to acid stress. — Water Res. 14: 1679-1681.
Leivestad, H. & Muniz, I. P. 1976: Fish kill at low pH in a Norwegian river. — Nature 259: 391-392.
Lessmark, O. 1976: Försurningens inverkan på fiskfaunan i några småländska sjöar. — Information från Sötvattenslaboratoriet Drottningholm 7/1976, 25 pp.
Lind, E. A., Ellonen, T., Keränen, M. & Kukko, O. 1974: Population structure and production of the perch, Perca fluviatilis L., in Lake Kiutajärvi, NE-Finland. — Ichthyol. Fenn. Borealis 1974(3): 116-159.
Menshutkin, V. V. & Zhakov, L. A. 1964: Opyt matematicheskogo opredeleniya kharaktera dinamiki okunya v zadannykh ekologicheskikh usloviyakh. — In: Ozera karelskogo Peresheika: 140-155. Moscow-Leningrad.
Meriläinen, J. & Paasivirta, L. 1979: Food of perch (Perca fluviatilis L.) in two forest lakes at Evo, southern Finland. — NCE-symposium Ecology and fishery biology of small forest lakes. Jyväskylän Yliopiston Biologian laitoksen tiedonantoja 19: 87-94.
Mossberg, P. & Nyberg, P. 1976: Försurningseffekter på bottenfauna och fisk i Västra Skälsjön. — Information från Sötvattenslaboratoriet Drottningholm 9/1976, 23 pp.
Muniz, I. P. & Leivestad, H. 1980: Acidification — effects on freshwater fish. — In: Drabløs, D. & Tollan, A. (eds.), Ecological impact of acid precipitation: 84-92. SNSF-project, Oslo-Ås.
Mäkinen, Y. 1974: Statistics for biologists (in Finnish). — 306 pp. Turku.
Nyberg, P. 1976: Production and food consumption of perch in two Swedish forest lakes. — Scripta Limnologica Upsaliensia 421, Klotenprojektet Rap. 6: 1-97.
Økland, K. A. 1980: Ecology and distribution of Asellus aquaticus (L.) in Norway, including relation to acidification in lakes. — SNSF-project, IR 52/80, 70 pp.
Peterson, R. H., Daye, P. G. & Metcalfe, J. L. 1980: Inhibition of atlantic salmon (Salmo salar) hatching at low pH. — Can. J. Fish. Aquat. Sci. 37: 770-774.
Raddum, G. G. 1979: Virkninger av lav pH på insektlarver. — SNSF-project, IR 45/79, 58 pp.
Rask, M. 1983a: Differences in growth of perch (Perca fluviatilis L.) in two small forest lakes. — Hydrobiologia 101: 139-144.
—»— 1983b: The effect of low pH on perch, Perca fluviatilis L. I: Effects of low pH on the development of eggs of perch. — Ann. Zool. Fennici 20: 73-76.
Robson, D. S. & Regier, H. A. 1971: Estimation of population number and mortality rates. — In: Ricker, W. E. (ed.), Methods for assessment of fish production in fresh waters. IBP handbook 3: 131-165. Oxford/Edinburgh.
Rosseland, B. O., Sevalrud, I., Svalastog, D. & Muniz, I. P. 1980: Studies of freshwater fish populations — effects of acidification on reproduction, population sturcture, growth, and food selection: — In: Drabløs, D. & Tollan, A. (eds.), Ecological impact of acid precipitation: 336-337. SNSF-project, Oslo-Ås.
Runn, P., Johansson, N. & Milbrink, G. 1977: Some effects of low pH on hatchability of eggs of perch, Perca fluviatilis. — Zoon 5: 115-125.
Schindler, D. W., Hesslein, R. H., Wagemann, R. & Broecker, W. S. 1980: Effects of acidification on mobilization of heavy metals and radionuclides from the sediments of a freshwater lake. — Can. J. Fish. Aquat. Sci. 37: 373-377.
Sprules, W. G. 1975: Midsummer crustacean zooplankton communities in acid stressed lakes. — J. Fish. Res. Board Can. 32: 389-395.
Sumari, O. 1971: Structure of the perch populations of some ponds in Finland. — Ann. Zool. Fennici 8: 406-421.
Tesch, F. W. 1955: Das Wachstum des Barsches (Perca fluviatilis L.) in verschiedenen Gewässern. — Z. Fisch. 4: 321-420.
—»— 1971: Age and growth. — In: Ricker, W. E. (ed.), Methods for assesment of fish production in fresh waters. IBP handbook 3: 98-130. Oxford/Edinburgh.
Thorpe, J. E. 1974: Trout and perch populations at Loch Leven, Kinross. — Proc. R. Soc. Edinb. (B) 74: 295-313.
—»— 1977: Morphology, physiology, behaviour, and ecology of Perca fluviatilis L. and P. flavescens Mitchill. — J. Fish. Res. Board Can. 34: 1504-1514.
Tikka, J. & Paasivirta, L. 1979: Growth, population size and production of perch (Perca fluviatilis, L.) in two forest lakes at Evo, southern Finland. — NCE-symposium Ecology and fishery biology of small forest lakes. Jyväskylän Yliopiston Biologian laitoksen tiedonantoja 19: 95-100.
Valle, K. J. 1944: Tutkimuksia kalojen kasvusta eräissä Karjalan järvissä. — Ann. Soc. Zool. Vanamo 11: 1-65.
Viljanen, M. 1978: Population studies of vendace (Coregonus albula L.) and perch (Perca fluviatilis L.) in a mesohumic oligotrophic lake. — Verh. Internat. Verein. Limnol. 20: 2103-2110.
Windell, J. T. 1971: Food analysis and rate of digestion. — In: Ricker, W. E. (ed.), Methods for assessment of fish production in fresh waters. IBP-handbook 3: 215-226. Oxford/Edinburgh.

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