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The growth of perch, *Perca fluviatilis* L., in small Finnish lakes at different stages of acidification

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The growth of perch (*Perca fluviatilis* L.) was studied in 16 oligotrophic lakes at different stages of acidification. The lakes were divided into three groups according to their pH: I Very acid lakes (6 lakes, pH < 5), II Moderately acid lakes (5 lakes, 5 ≤ pH < 6) and III Circumneutral lakes (5 lakes, pH ≥ 6).

Perch was the only fish species caught from most of the very acid and moderately acid lakes. The mean weights of the perch were higher and numbers/catch smaller in very acid lakes than in other lakes. The perch grew faster in very acid lakes than in two other acidity groups, where the growth rates did not differ from each other. The most probable reason for the rapid growth in the most acid lakes was increased availability of food due to thinning of the perch populations as a consequence of acid induced reproduction failures. An exception was Lake Hauklampi (pH 4.8), where the perch did not grow as fast as in the other very acid lakes. This may have been due to the stress attributable to a high total aluminium content in the water (400 µg/l).

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1. Introduction

In southern Finland acidification has been observed especially in small oligotrophic lakes and ponds with small drainage areas (Pätilä 1982, Tolonen & Jaakkola 1983, Kämäri 1985, Tulonen 1985, Tolonen et al. 1986). Ecological changes, such as a decreasing number of species and an increasing number of individuals of some acid tolerant species, are typical to acidified lakes (Kenttämies et al. 1985).

The growth rate of fish exposed to acid water has been shown to be reduced in experiments with Salmonidae (Edwards & Hjeldnes 1977, Kwain & Rose 1985). In acidified lakes, however, the growth of the fish has in some cases accelerated due to the increased availability of food in the sparse fish populations (Almer 1972, Hultberg 1985). The sparsity of the populations is caused by disturbances in reproduction and mass deaths of the fish (Almer 1972, Almer & Hanson 1980, Rosseland et al. 1980, Hultberg 1985).

The purpose of this work was to clarify the connections between the growth rate of perch (*Perca fluviatilis* L.) and the state of acidification in small lakes in southern Finland. To achieve this end the growth of the perch was studied in 16 lakes at different stages of acidification.

2. Material and methods

2.1. The lakes studied

The lakes studied (Table 1) are all situated in areas dominated by coniferous forests with scots pine (*Pinus sylvestris*) and Norwegian spruce (*Picea abies*). The drainage

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Table 1. The study lakes.

Lake	Commune	Location	Area (ha)	Drainage area (ha)
Munajärvi	Tenhola	2-666970-46118	9	64
Saaren Musta	Vihti	2-669256-53378	6	26
Pieni Lehmä-lampi	Vihti	2-669286-53292	2	40
Iso Majas-lampi	Espoo	2-668990-53300	6	17
Orajärvi	Espoo	2-668852-53265	22	45
Hauklampi	Espoo	2-668962-53385	3	19
Häkläjärvi	Espoo	2-668712-53654	7	42
Mäkilampi	Ylämaa	3-673661-54831	12	24
Hirvilampi	Ylämaa	3-673314-55031	6	28
Vuorilampi	Ylämaa	3-673604-55029	3	25
Valkjärvi	Ylämaa	3-673739-56160	29	82
Kattilajärvi	Espoo	2-668794-53424	33	160
Vitsjön (Spj.)	Tenhola	2-665032-46196	29	58
Kotilampi	Ylämaa	3-673550-55111	5	113
Valkea Musta-järvi	Lammi	2-679050-56025	14	41
Iso Mustajärvi	Lammi	2-678950-55990	3	11

areas of the lakes are small and their shores consist mostly of forest, bedrock, or of peatland dominated by Sphagnum moss. The macrophytic vegetation in most lakes consists of species like *Isoetes sp.*, *Lobelia dortmanna*, *Nuphar lutea* or *Nymphaea sp.* In the littoral of Kotilampi, Vitsjön, Vuorilampi, and Iso Mustajärvi there are stands of sedges (*Carex sp.*). Common reed (*Phragmites communis*) can be found in patches in the most neutral lakes. Some occasional fishing has been practiced in the lakes. In the most acid lakes fishing by the local people has met with little success in recent years.

The lakes were divided into three groups according to their pH: I Very acid lakes (pH < 5), II Moderately acid lakes (5 ≤ pH < 6), and III Circumneutral lakes (pH ≥ 6).

Paleolimnological (diatom analysis) and chemical (conductivity–alkalinity-method) studies have indicated that the pH of the very acid lakes Munajärvi, Pieni Lehmälampi, Iso Majaslampi, Orajärvi, and Hauklampi began to decrease during the 1950s or 1960s (Tolonen & Jaakkola 1983, Kämäri 1985, Tulonen 1985, Tolonen et al. 1986). Roach (*Rutilus rutilus* L.) disappeared or became rare in Pieni Lehmälampi as early as the 1940s (source: local inhabitants). Saaren Musta is a head water lake situated in the same upland area as the nearby acidified lakes, Pieni Lehmälampi and Vaakkoi. Its paleolimnological history has not been studied. According to local informants the last observations of pike (*Esox lucius* L.) were made in the 1950s, and perch have gradually decreased in number, their population being small since the early 1970s at least.

On paleolimnological grounds the acidification of the moderately acid lakes Häkläjärvi, Mäkilampi, Hirvilampi, Vuorilampi, and Valkjärvi began to take place in the 1960s or 1970s (Tolonen & Jaakkola 1983, Liukkonen 1985, Tolonen et al. 1986). Roach, now rare in Vuorilampi, was still common in the lake in the 1960s (source: local inhabitants). Lakes Kattilajärvi and Vitsjön, although found to be acidified (Liukkonen 1985, Tolonen et al. 1986), were classified as circumneutral lakes because their pH-values were > 6 during the captures. In lakes Kotilampi, Valkea Mustajärvi, and Iso Mustajärvi no evidence of acidification has been found.

Data on the water chemistry of the lakes is based on analyses made during the summer of 1985 (Fig. 1). The water samples were taken from a depth of 20 cm. The values for the pH, alkalinity (Metrohm 605 pH-meter), conductivity (Radiometer CDM2), colour (Hellige Neo-comparator), and Ca-content were determined according to SFS-standards. In addition, the total aluminium content (atomic absorption spectrophotometer) of 12 lakes was analysed in April, and Iso Mustajärvi in September 1986.

2.2. The captures

Fifteen lakes were test fished with a series of eight 1,8 × 30 m gill nets (mesh sizes 12, 15, 20, 25, 30, 35, 45, and 60 mm from knot to knot). Fish < 9,5 cm (age group 0+, and partly 1+ and 2+) were thus excluded. The nets were kept at depths of from 2–4 m for 18 to 24 hours, with alternation of large and small mesh sizes of net. Two of the largest lakes in the study, Valkeajärvi and Kattilajärvi, were fished five times, the other lakes being fished only once to avoid changing or destroying their fish populations. Valkea Mustajärvi was fished using steel mesh traps (1 cm square mesh) capable of catching perch > 8,5 cm. The total length and weight of the perch were measured and growth was back-calculated from opercular bones using Monastyrsky's procedure (Bagenal & Tesch 1978). It was not possible to reliably determine the value of the regression coefficient for allometric growth for each population on its own because of the small numbers of perch present. For this reason in most lakes an average calculated from all the lakes (0.88) was used. This is similar to the values used by Le Cren (1958) in Lake Windermere (0.876) and Kokko (1980) in Lievestuoreenjärvi (0.879). In the catches of three lakes there were enough different size classes for the coefficient calculated separately from each lake to be used (Valkjärvi 0.87, Orajärvi and Kattilajärvi 0.82). The growth of perch from different Valkjärvi catches were also calculated separately, in order to gain an impression of the reliability of growth figures obtained from single catches. Because of the small fish samples and nonsignificant differences in back-calculated growth between the sexes in the catches (t-test), the sexes were treated together in the study.

The annual mean growths and lengths of perch were compared, using Student's t-test, in lakes where perch growth was closest to the average of each acidity group (pH < 5, 5 ≤ pH < 6, pH ≥ 6). The relationships between the growth of the perch and the relationships between the number of fish/capture (all fish species) and water pH, alkalinity and total aluminium content were examined using Spearman's correlation test, which was also used when testing the relationship between mean weight of the perch and total aluminium in the water. The mean weights of the perch in different acidity groups were compared using the Mann-Whitney U-test.

Table 2. Catches (number of fish and weight in grams) from 15 lakes (perch, *Perca fluviatilis* (L.); ruff, *Acerina cernua* (L.); pikeperch, *Stizostedion lucioperca* (L.); pike, *Esox lucius* (L.); whitefish, *Coregonus pallasi* (Valenciennes); roach, *Rutilus rutilus* (L.); bream, *Abramis brama* (L.); and rudd, *Scardinius erythrophthalmus* (L.)). The values for Valkjärvi and Kattilajärvi are averages of five captures. + = average catch < 1 individual/capture (lakes fished five times).

Lake	Perch		Ruff		Pikeperch	Pike		Whitefish		Roach		Bream		Rudd
	n	weight	*n*	weight		*n*	weight	*n*	weight	*n*	weight	*n*	weight	
Munajärvi	4	1758				1	442							
Saaren Musta	46	5556												
Pieni Lehmälampi	121	12151												
Iso Majaslampi	1	583												
Orajärvi	98	31809												
Hauklampi	28	3878												
Häkläjärvi	25	1160												
Mäkilampi	867	18052												
Hirvilampi	197	4174												
Vuorilampi	210	4474				1	494			1	20			
Valkjärvi	152	4068	58	483	+	+		1	539					
Kattilajärvi	271	4986	9	106		2	1678			86	3798			+
Vitsjön	175	5008	38	313						144	11017			
Kotilampi	20	363				2	1344			128	3147	13	2295	
Iso Mustajärvi	166	1918						27	3976	506	10590			

3. Results

3.1. The captures

A positive correlation was observed between the number of fish/capture (all fish species, Table 2) and both pH (Spearman's correlation test, $t = 3.747$, $df = 13$, $P < 0.01$) and alkalinity ($t = 3.765$, $df = 10$, $P < 0.01$) of the water. The number of fish/capture also correlated with the aluminium content of the water (negative correlation, $t = -2.636$, $df = 8$, $P < 0.05$).

Perch was the only species of fish caught from five of the very acid lakes and three of the moderately acid lakes. In other lakes there were 2 to 5 species. The mean number of species was 2.2 in moderately acid lakes and 3.8 in circumneutral lakes (Table 2). Roach, *Rutilus rutilus* L., was more common than perch in the two most neutral lakes.

There were either few, or no, perch shorter than 16 cm in the catches from the very acid lakes (excluding Orajärvi) and moderately acid Häkläjärvi. In the other moderately acid lakes and the circumneutral lakes the majority of the perch in the catches were 9 to 15 cm in length (Fig. 1).

The mean weights of the perch in very acid lakes were higher than in two other acidity groups (Fig. 1, Mann-Whitney *U*-test, $U = 0$, $P < 0{,}05$). No differences were found in the weights of perch between moderately acid and circumneutral lakes. The total aluminium content of the water and the mean weight of the perch did not correlate with each other.

3.2. Growth

The growth of perch was faster in the lakes of pH < 5 than in the other lakes (Figs. 2A and 4), being similar to the growth of perch living in the pelagic zone of large lakes (Fig. 2B). In the circumneutral lakes growth rate varied more than in the moderately acid lakes. A negative correlation was found between annual length increment and pH, being most distinct in the second summer (Fig. 3).

The comparison of growth rates between the populations closest to the mean growth of their acidity group showed that the perch in the very acid lakes Orajärvi and Pieni Lehmälampi grew significantly faster during growing periods I to IV than the perch in moderately acid Mäkilampi and circumneutral Valkea Mustajärvi (Student's *t*-test, $P < 0.001$ in most cases). The growth rates in the two latter lakes did not differ from each other. After the fourth summer the perch in Orajärvi continued to grow quickly, but in

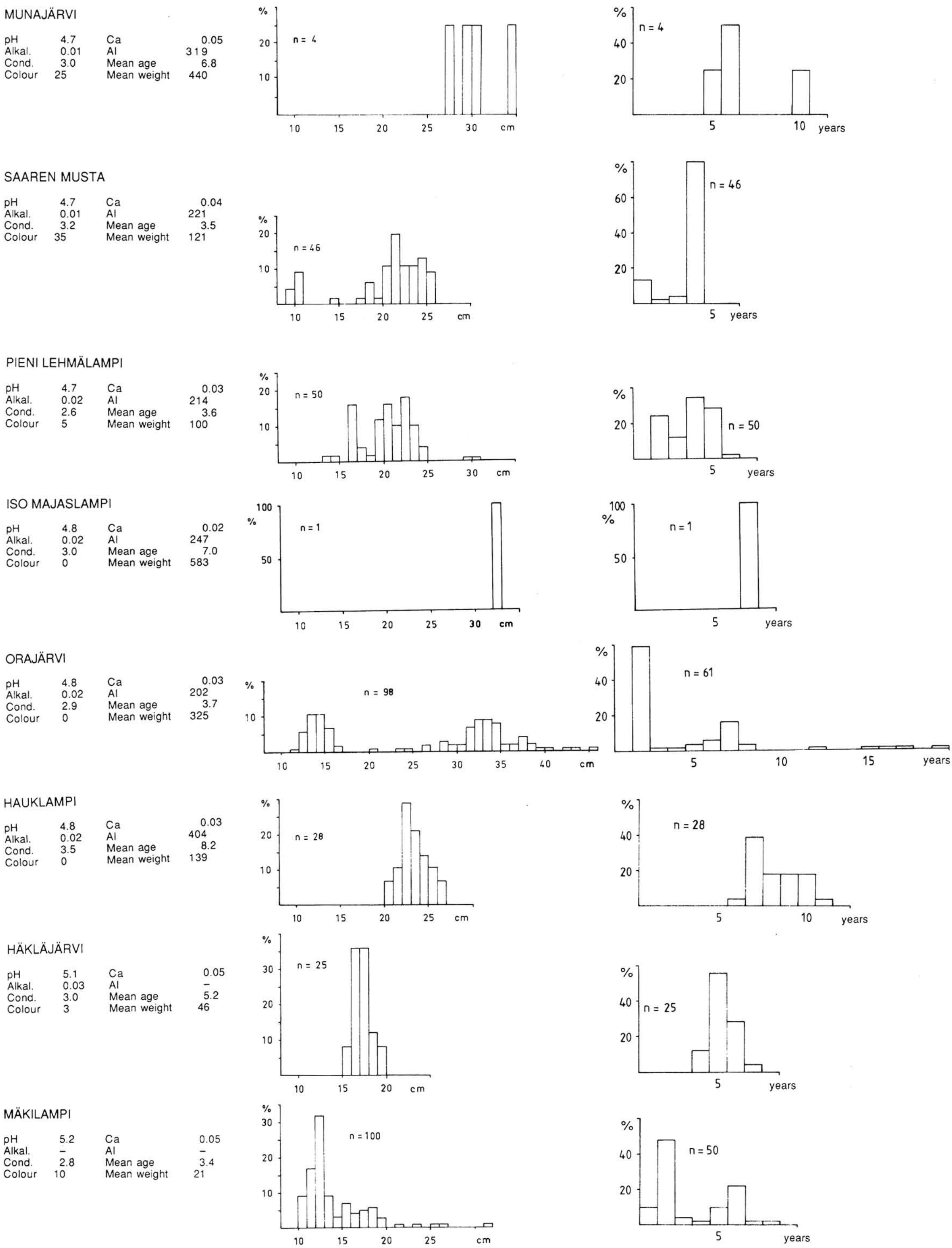
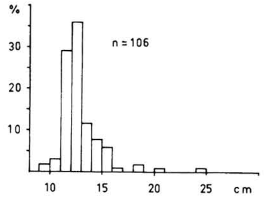
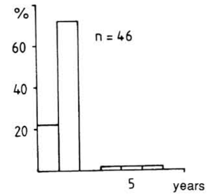


Fig. 1. Length and age distributions, mean age (years) and mean weight (g) of the perch in the catches and pH, alkalinity (mmol/l), conductivity (mS/m), colour (mg Pt/l), calcium (mmol/l) and total aluminium (µg/l) concentrations in the water.

HIRVILAMPI

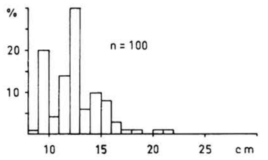
pH	5.3	Ca	0.05
Alkal.	–	Al	–
Cond.	3.2	Mean age	2.0
Colour	5	Mean weight	21

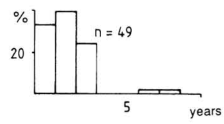




VUORILAMPI

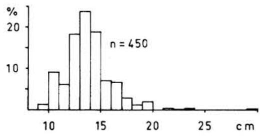
pH	5.6	Ca	0.05
Alkal.	–	Al	348
Cond.	3.4	Mean age	2.1
Colour	5	Mean weight	21

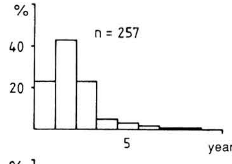




VALKJÄRVI

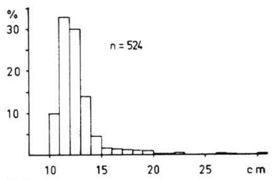
pH	5.8	Ca	0.05
Alkal.	0.04	Al	79
Cond.	2.5	Mean age	2.3
Colour	15	Mean weight	27

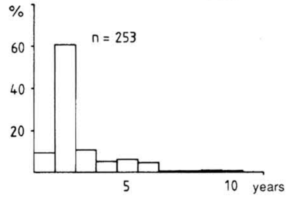




KATTILAJÄRVI

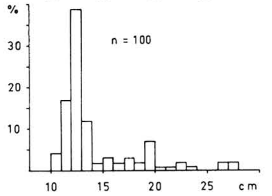
pH	6.1	Ca	0.06
Alkal.	0.05	Al	77
Cond.	3.5	Mean age	2.7
Colour	20	Mean weight	18

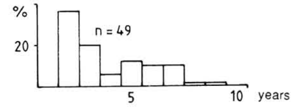




VITSJÖN

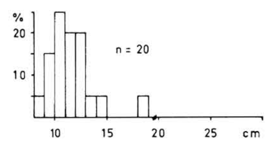
pH	6.4	Ca	0.06
Alkal.	0.06	Al	–
Cond.	4.0	Mean age	3.9
Colour	10	Mean weight	29

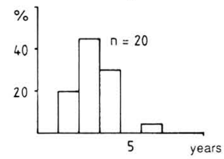




KOTILAMPI

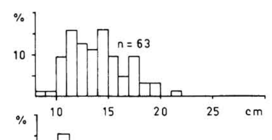
pH	6.7	Ca	0.10
Alkal.	0.13	Al	–
Cond.	4.1	Mean age	3.3
Colour	40	Mean weight	18

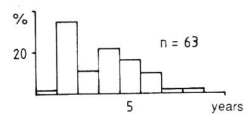




VALKEA MUSTAJÄRVI

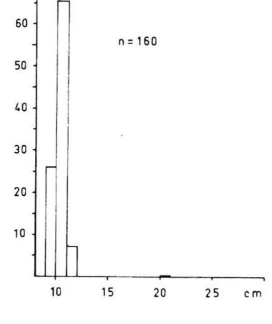
pH	6.9	Ca	–
Alkal.	0.05	Al	26
Cond.	2.3	Mean age	3.6
Colour	–	Mean weight	–





ISO MUSTAJÄRVI

pH	6.6	Ca	0.13
Alkal.	0.19	Al	17
Cond.	3.9	Mean age	–
Colour	100	Mean weight	12



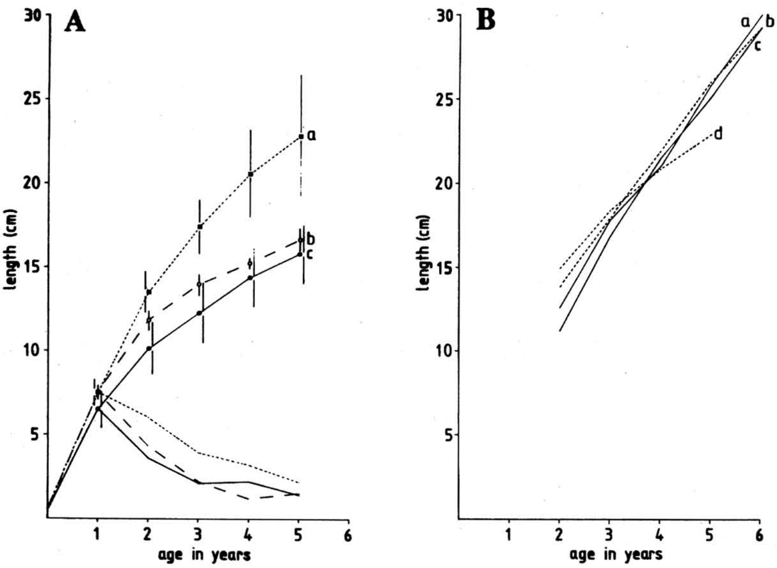


Fig. 2 (A). Average growth of the perch (mean lengths of different age groups, standard deviations of the mean lengths, and mean annual length increments) in the lakes of three acidity groups, pH < 5 (a), 5 ≤ pH < 6 (b) and pH > 6 (c). (B) Perch growth in the pelagic zones of two large lakes (continuous line), a) Ladozkoje Ozero and b) Tsudsko-Pskovskoje Ozero (Smirnov 1977), and in two lakes with pH < 5 (broken line), c) Orajärvi and d) Pieni Lehmälampi.

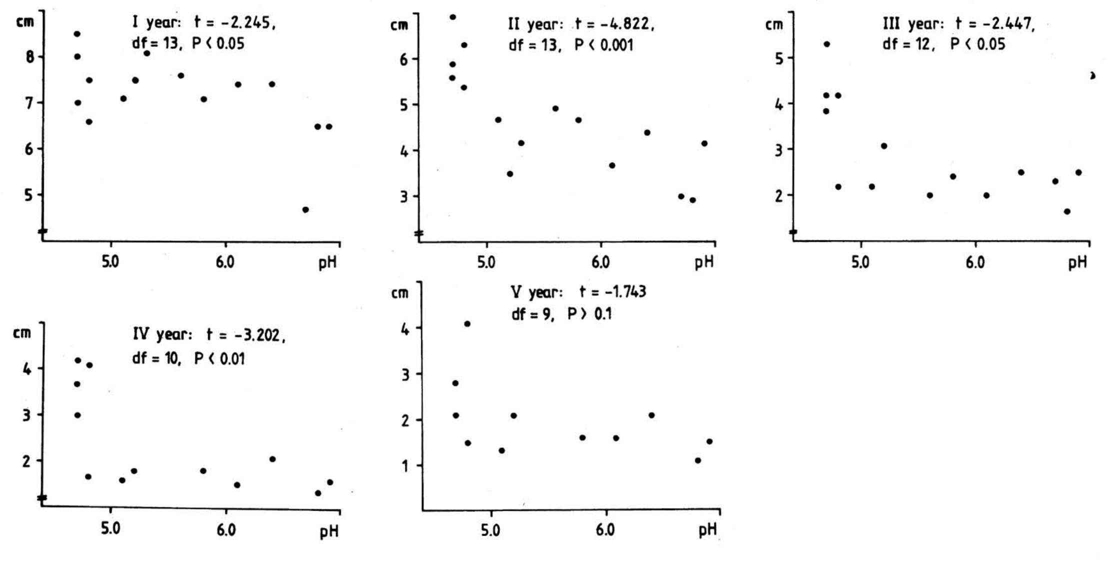


Fig. 3. Comparison of back-calculated average annual length increments of the perch (cm) and pH of the water (Spearman's correlation).

Pieni Lehmälampi the growth rate declined. During their fifth summer the perch in Pieni Lehmälampi did not grow more than the perch in Mäkilampi; nevertheless, the difference in perch growth between Pieni Lehmälampi and Valkea Mustajärvi was still significant ($P < 0.05$). The differences in back-calculated growth of perch in the five catches of Valkjärvi were nonsignificant.

The perch in very acid Hauklampi grew more slowly than the perch in other very acid lakes. Age determination was difficult because of many false annuli in their opercula (Fig. 4).

From 1980 onwards one of the four perch caught from Munajärvi began to grow faster than previously. The other perch (born in 1979 and 1980) also grew rapidly (Fig. 5). According to a local inhabitant, there

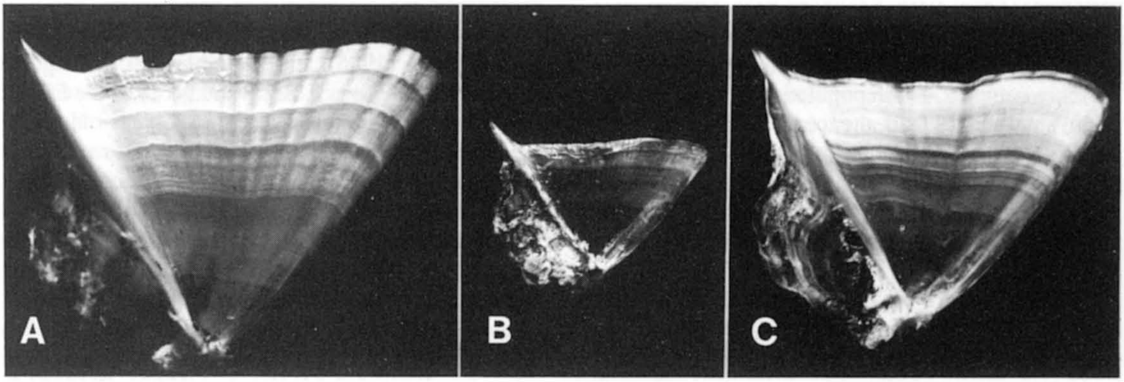


Fig. 4. The operculum of a perch caught from A) Munajärvi on 13 June 1985 (length 29.7 cm, weight 339 g, determined age 6), B) Mäkilampi on 4 July 1985 (length 15.7 cm, weight 35 g, determined age 5+), and C) Hauklampi on 6 June 1985 (length 23.9 cm, weight 145 g, determined age 7).

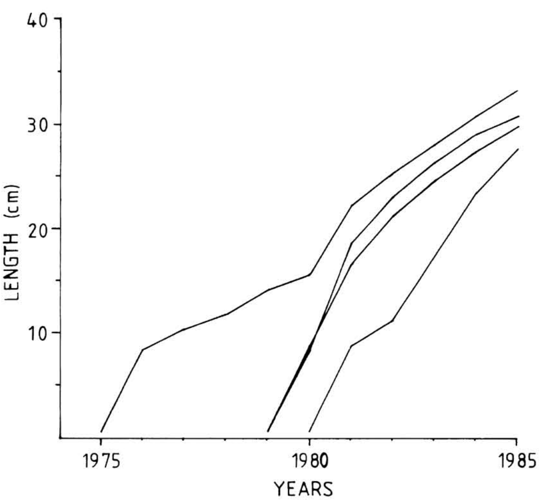


Fig. 5. Back-calculated growth of four perch caught in lake Munajärvi in 1985. A fish kill was observed in Munajärvi in the spring of 1980 or 1981.

was a mass death of perch in Munajärvi in the spring of 1980 or 1981. Since then he has not observed fish either visually (as was often the case previously) or through the agency of a wire trap and of angling.

3.3. Age composition

The year class born in 1983 (age 2+) was remarkably strong in most circumneutral and moderately acid lakes. In moderately acid Häkläjärvi the youngest individual caught was determined to be 4 years old, in very acid Munajärvi 5 years old, and in Hauklampi 6 years old. Perch less than 4 years old were scarce in Saaren Musta's catch. In Orajärvi's catch there were plenty of perch born in 1983. The perch born in 1979 to 1982 were few in number; however, the year class 1978 was abundant (Fig. 1).

The mean age of perch was 5 years in very acid lakes and 3 years in moderately acid and circumneutral lakes. The highest mean ages were observed in very acid lakes Hauklampi (8 years) and Munajärvi (7 years). The lowest mean age was exhibited in the catch from moderately acid Hirvilampi (2 years, Fig. 1).

4. Discussion

4.1. Growth of perch in different waters

The growth rate of perch is affected by the quantity of food available (Alm 1946, Le Cren 1958, Sumari 1971), the length of the growing season, and most likely by feeding habits as well. Although the length of the growing season is a considerable factor when comparing the growth rates of perch in different parts of the range of the species in Europe (Thorpe 1977), other factors are also important in small Finnish lakes (Sumari 1971). In small lakes and ponds, where perch is often the only fish species, populations are usually dense and the perch grow slowly due to poor nutrition. Their food consists mostly of planktonic crustaceans and benthic invertebrates (Alm 1946, Kjellberg 1971, Sumari 1971, Nyberg 1976, Rask 1983, 1986). In large lakes and in the brackish water of the Baltic Sea the environments are more complex. Perch populations are not as dense as in small lakes and the perch occupy different niches. The diet of some alters partly or entirely from invertebrates to fish, which speeds up their growth and is the most probable reason for the great differences in the growth rates of the perch in a lake (or the Baltic Sea). According to Smirnov (1977) there were great differences in the growth rates of perch caught from the littoral zones (slower growth) and the pelagic zones (faster growth) of the large lakes Ladozkoje Ozero and Tsudsko-Pskovskoje Ozero in the Soviet Union, near to the Gulf of Finland.

4.2. Preconditions for growth in acid waters

The growth of perch has in some cases been observed to speed up when the population has thinned due to increased fishing pressure or predation, or both (Le Cren 1958, Eshenroder 1977). The rapid growth has been possible because of increased numbers of invertebrates/fish and the easier change from invertebrate food to fish food.

In acid waters like Munajärvi or Iso Majaslampi, where no fish were caught in a mark-recapture experiment carried out in the spring of 1986 (Lappalainen et al. 1988), there is no fish for the perch to feed regularly on. However, owing to little predation by sparse perch stocks, the individuals of acid tolerant invertebrate species can become remarkably abundant (Grahn et al. 1974, Mossberg & Nyberg 1979). Some of these species, which include water-boatmen (Corixidae), dragonfly nymphs (Odonata) and phantom midge nymphs (*Chaoborus obscuripes*), cannot sustain predation by fish in neutral waters, where the insects are either lacking or exist in small numbers (Grahn et al. 1974, Eriksson et al. 1980). A considerable abundance of invertebrates has also been observed in lakes from which the fish have been removed (Tuunainen 1970, Eriksson et al. 1980). The abundance of invertebrates/individual fish probably enables the few perch to grow fast in acid lakes, especially during the first years of their life (cf. Hultberg 1985). On the other hand, a great number of e.g. water-boatmen in the stomachs of the perch or in the open parts of the littoral zone may suggest that there are only a few fish left in the lake.

In very acid Pieni Lehmälampi reduced growth rate was observed at an age of 4 to 5 years. A similar decrease in the growth rate of perch of this age has been observed in acid lakes by Ryan & Harvey (1980) and Hultberg (1985). It is possible that feeding on small animals becomes disadvantageous to the fish as they grow. In Orajärvi, where 4- to 6-year-old perch grew faster than in the other very acid lakes and were comparable to the pelagic perch of Estonian and Karelian large lakes (Smirnov 1977), cannibalism may have occurred, because reproduction took place in the lake in 1983 at least. However, the perch in the catch did not have smaller perch in their stomachs; instead, they had eaten a lot of *Asellus aquaticus* L., which probably lives in Orajärvi close to its acidity tolerânce limit (cf. Andersson 1972, Økland & Økland 1980).

Rosseland et al. (1980) suggested that stress caused by acid water inhibited the growth of perch in Norwegian acid lakes, where the perch could have grown faster because of sparse populations and a probable excess of food. Similarly, the marking and recapturing work in 1986 showed that the population density of perch in Hauklampi was very low, about 6 individuals/ha (Lappalainen et al. 1988), but the growth of the perch was not distinctly faster than in less acid lakes with denser populations. Reduced growth rate in acid water has been demonstrated in experiments with Salmonidae (Edwards & Hjeldnes 1977, Rodgers 1984, Kwain & Rose 1985). Growth reductions have been accompanied by salt loss, an excess of H+-ions in the blood (McWilliams et al. 1980, Muniz & Leivestad 1980), and oxygen deficiency (Neville 1985), all of which are well-known responses of fish to acidity.

The toxicity of acid water is often increased by dissolved aluminium, the concentration of which usually increases in clear water during acidification (Dickson 1980, Driscoll 1980, Wright et al. 1980, Pätilä 1984). Inorganic aluminium is most toxic to fish at pH ≤ 5 (Muniz & Leivestad 1980, Overrein et al. 1980). In humic waters aluminium is mainly in an organic form, which is not as toxic as inorganic aluminium (Dickson 1978). An aluminium concentration of 100 to 200 μg/l is considered toxic in acid water (Dickson 1978, Baker & Schofield 1980, Leivestad et al. 1980, Muniz & Leivestad 1980, Overrein et al. 1980). In the spring of 1986, the total aluminium concentration in all the very acid study lakes exceeded 200 μg/l. The stress effects on perch growth in Hauklampi are contributed to, not only by a high aluminium concentration in the water (400 μg/l), but also by exceptional annuli in the operculars. Unusually low calcium contents in the bones of white suckers (*Catostomus commersoni* La., Fraser & Harvey 1982) and false annuli lacking $CaCO_3$ in the otoliths of brown trout (*Salmo trutta* L., Hultberg 1977) have been reported in fish living in acid waters.

Orajärvi and Pieni Lehmälampi are examples of lakes where capture might not have revealed anything exceptional, if the perch growth had not been so rapid. A mark-recapture done in Pieni Lehmälampi in the spring of 1986 showed that the density of the perch population was 262 individuals/ha. In the circumneutral control lake, Iso Mustajärvi, where roach is the dominating fish species, the density of the perch population was 1432 individuals/ha (Lappalainen et al. 1988). In Iso Majaslampi, Munajärvi, and Saaren Musta the small catches also suggested that the populations are sparse.

5. Conclusions

Since the reproduction of perch has failed in some of the very acid lakes, it seems that in most of these lakes feeding conditions, i.e. intra/interspecific competition, affect the growth of perch more than stress caused by acidity of the water. Only in extreme cases is the stress a considerable limiting factor. It can be predicted that the fish populations, at least in the very acid lakes of this study, are at risk and further losses of fish stocks will occur, if acidification continues.

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