MERCURY CONCENTRATIONS IN NORTHERN PIKE, ESOX LUCIUS L., IN SMALL LAKES OF EVO AREA, SOUTHERN FINLAND

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ABSTRACT. We measured Hg concentrations in northern pike (Esox lucius) from 17 small lakes in Evo forest area, Lammi, southern Finland. The mean Hg concentration in muscle tissue of a 1 kg pike ranged from 0.15 to 1.36 $\mu g\ g^{-1}$ (ww) in the lakes. There was a trend towards higher concentrations in acidic and humic lakes than in circumneutral and clear-water lakes. The Hg content of pike from successive lakes of a lake chain was similar, whereas there were clear differences in the Hg concentrations among seepage lakes and the uppermost lakes of other lake chains. The latter was probably due to special characteristics of the lakes: in one lake pike was the only fish species, two of the lakes were regulated by beaver, and one lake was a groundwater or spring lake. Our observations indicate that Hg concentrations in pike can vary considerably from lake to lake in a small geographical area and that the variation among lakes in the accumulation of Hg in fish largely depends on lake characteristics and on the diet of pike.

1. Introduction

The accumulation of Hg in fish in Finland has been studied for more than 20 yr. In the late 1960's, concentrations as high as 5 to 6 $\mu g\ g^{-1}$ in fish were recorded due to industrial pollution (Häsänen and Sjöblom, 1968). Since then, these high Hg concentrations have decreased due to a ban on the use of Hg compounds as a slimecide in the pulp and paper industry (Nuorteva et al., 1979; Lodenius, 1991). More recently, attention has been paid to increased concentrations of Hg of fish in newly constructed reservoirs (Lodenius et al., 1983; Mannio et al., 1986) and in lakes that have received no known direct Hg discharge (Verta et al., 1986; Metsälä and Rask, 1989; Verta, 1990a). Sediment studies have shown that increased concentrations of heavy metals in remote lakes are largely due to atmospheric deposition (Tolonen and Jaakkola, 1983; Verta et al. 1989). For Hg in the surface sediments, the proportion from atmospheric deposition has been estimated to be 70 to 89 % in southern and central Finland (Verta et al., 1989).

In Evo forest area, Lammi, southern Finland, the mean estimated Hg concentrations for 1-kg northern pike were 0.76 and 1.07 $\mu g\ g^{-1}$ in two highly humic lakes (Verta, 1990a). In the Evo area, there are many small lakes of different characteristics,

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encompassing an acidity gradient from 4.5 to 7 and a color gradient from 10 to >300 mg Pt L^{-1} (Rask et al., 1985; Arvola et al., 1990). There are both drainage lakes and seepage lakes with catchment sizes ranging from a few to several hundred hectares. Because such properties, among many others, can affect the accumulation of Hg in fish, we selected a set of lakes of different types to assess the variation in Hg concentrations of pike within and among lakes of a restricted geographical area.

2. Materials and methods

Northern pike for the Hg analyses were collected from 17 lakes and ponds of different size and water properties (Table I), located within an area of about 50 km^2 (Figure 1). They were selected so that 8 lakes formed a chain of successive lakes whereas the rest were seepage lakes or headwaters of lake chains. The fish were captured during 1982–1984 (75% in 1983) by different means including wire traps, gill nets, and angling. Some of the fish were from sampling done by the Evo State Fisheries and Aquaculture Research Station of the Finnish Game and Fisheries Research Institute. We analyzed from 6 to 24 pike from each lake; the total number analyzed was 223.

Samples were taken from dorsal axial muscle of pike and frozed until analyzed in the Department of Environmental Conservation of the University of Helsinki. The Hg concentration was determined as total Hg from HNO_3–H_2SO_4 (1:4) digestion using cold vapor atomic absorption spectrophotometry (Armstrong and Uthe, 1971) and a Perkin Elmer Coleman MAS–50 analyzer. The values are given as $\mu g\ g^{-1}$ of fresh muscle tissue (wet weight). Because it is seldom possible to obtain five to ten 1–kg pikes in the smallest lakes, we analyzed fish of different size (6 to 97 cm, 1 to 6100 g). The age of the pike was determined from cleithrum. To estimate the Hg concentration in 1–kg pike for each lake, we made a length correction to total length of 54 cm assuming a linear relation between the Hg concentration and the length of fish.

Water properties of the lakes were analyzed in the Lammi Biological Station, University of Helsinki, mostly according to Finnish standard methods for water analysis (SFS–standards). Alkalinity was determined using the Gran titration method (Mackereth et al., 1978). Color was measured from filtered samples with a Hitachi spectrophotometer and total organic carbon by high temperature combustion, according to Salonen (1979).

3. Results

The estimated Hg concentration in 1–kg pike varied from 0.15 to 1.36 ug g^{-1} in the 17 lakes (Table II). There was a general trend towards higher pike Hg concentrations in acidic and humic lakes than in circumneutral and clear lakes (Figure 2). However, variation among lakes was great and no significant correlations were found between Hg in 1–kg pike and the lake properties given in Table I if all lakes were included. In the lake chain (lakes 1 to 8) the Hg concentrations of 1–kg pike were similar in lakes 1 to 7 but lower in lake 8 (Figure 3) indicating that the variations in pike Hg was greatest in the other lakes studied.

Within individual lakes the Hg concentration depended on the size and age of pike (Figure 4). The lowest concentrations in individual fish were below 0.1 ug g^{-1}, and they

TABLE I. Surface area (ha), maximum depth (m), size of the catchment (ha), pH, alkalinity (mmol L^{-1}), conductivity (μS cm^{-1}), Color (mg Pt L^{-1}) and concentration of total organic carbon (TOC, mg L^{-1}) in the studied lakes. Water samples were taken 31.5.1983.

Lake	Area	Depth	Catchm.	pH	Alk.	Cond.	Color	TOC
1.	0.4	11	37	6.2	0.08	34	230	20
2.	1.0	2	37	5.7	0.08	34	215	17
3.	12.1	14	57	6.4	0.08	32	100	9
4.	15.0	13	115	6.2	0.09	31	155	20
5.	16.6	12	154	6.1	0.08	34	165	14
6.	13.2	13	99	6.3	0.09	34	160	13
7.	14.4	10	112	6.5	0.12	36	155	12
8.	45.0	12	1010	6.5	0.11	37	120	11
9.	0.7	7	19	5.3	0.02	18	75	8
10.	2.3	8	906	6.0	0.08	44	170	14
11.	1.6	8	21	6.6	0.18	48	85	7
12.	4.2	8	17	4.9	-0.01	18	15	3
13.	3.9	12	53	6.1	0.08	33	205	16
14.	0.3	4	7	5.5	0.07	37	320	21
15.	0.9	8	23	6.6	0.22	51	13	6
16.	5.0	6	70	4.9	-0.02	34	175	14
17.	13.9	10	41	6.4	0.06	23	40	5

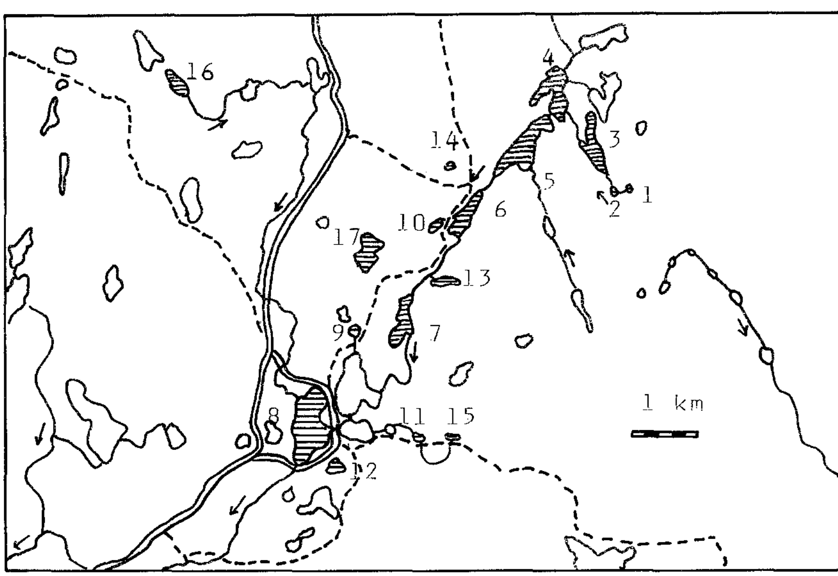


Figure 1. Map showing part of the Evo State Forest area. The numbers of the study lakes correspond to those in Tables I and II.

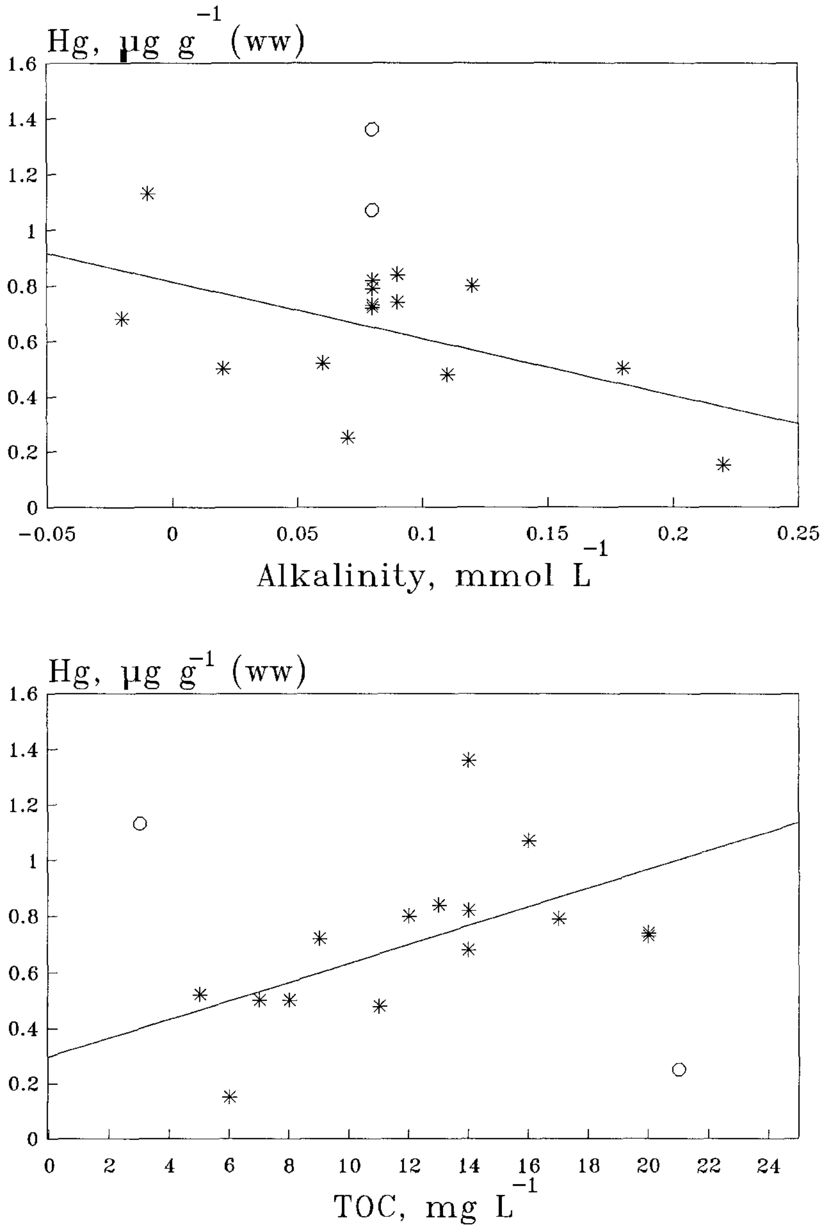


Figure 2. The estimated Hg concentration of 1–kg pike in relation to lake alkalinity (top) and TOC in the water (bottom). If two lakes regulated by beaver dams (lakes 10 and 13, circles) were excluded, the correlation between pike mercury and alkalinity was significant ($r = 0.52$, $p < 0.05$). The correlation between pike mercury and TOC ($r = 0.57$, $p < 0.05$) was significant if an acidified lake (12, circle) and a humic lake with pike as the only fish species (14, circle) were excluded.

TABLE II. The mean Hg concentration (μg g^{-1}, ww) of 1–kg pike in the studied lakes, range of measured Hg concentrtions, number of analyzed fish (N), and length range and weight range of examined fish in each lake.

Lake	Hg	Range	N	Length(cm)	Weight(g)
1.	0.70	0.02-0.68	21	6.2-50.5	2-750
2.	0.79	0.44-0.96	21	19.5-66.0	50-2500
3.	0.72	0.51-1.50	13	45.0-97.0	525-6100
4.	0.74	0.50-1.53	10	41.0-96.5	390-5350
5.	0.82	0.30-0.92	10	24.5-49.5	63-775
6.	0.84	0.46-1.60	15	31.5-84.5	170-3500
7.	0.80	0.48-1.10	12	31.0-81.0	150-3070
8	0.48	0.21-0.62	14	28.3-65.0	70-1530
9.	0.50	0.31-0.53	7	13.0-61.0	10-1100
10.	1.36	0.85-2.10	13	32.5-91.0	210-4600
11.	0.50	0.19-0.58	11	20.1-69.0	50-1340
12.	1.13	0.30-1.40	21	15.5-70.6	18-2200
13.	1.07	0.13-1.39	24	6.0-70.3	1-2070
14.	0.25	0.11-0.40	6	13.4-55.0	13-1130
15.	0.15	0.05-0.18	12	18.8-41.0	33-830
16.	0.68	0.45-0.82	7	22.5-45.0	60-550
17.	0.52	0.14-0.35	6	24.0-37.0	100-270

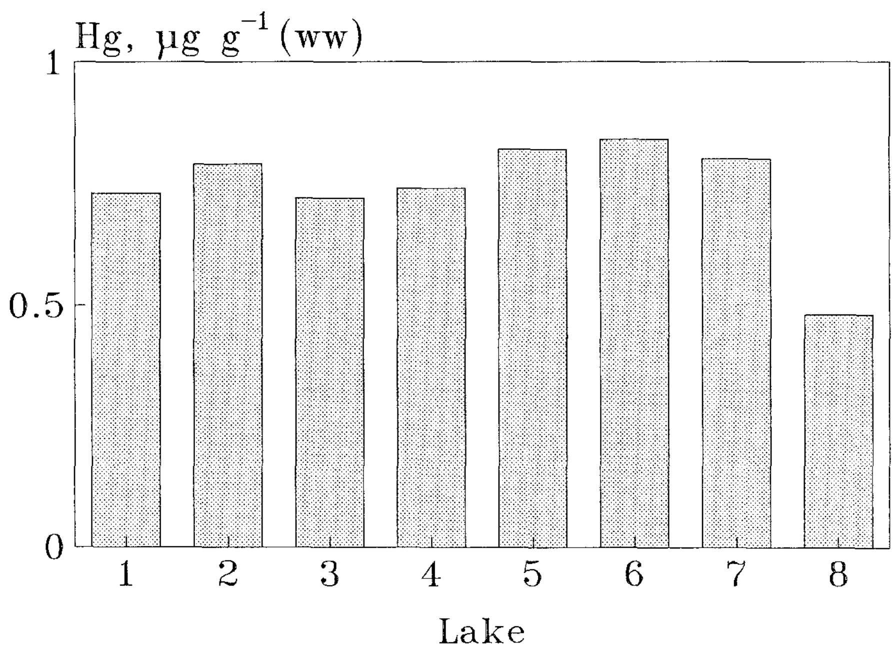


Figure 3. The Hg concentrations of 1–kg pike in the chain of lakes 1 to 8.

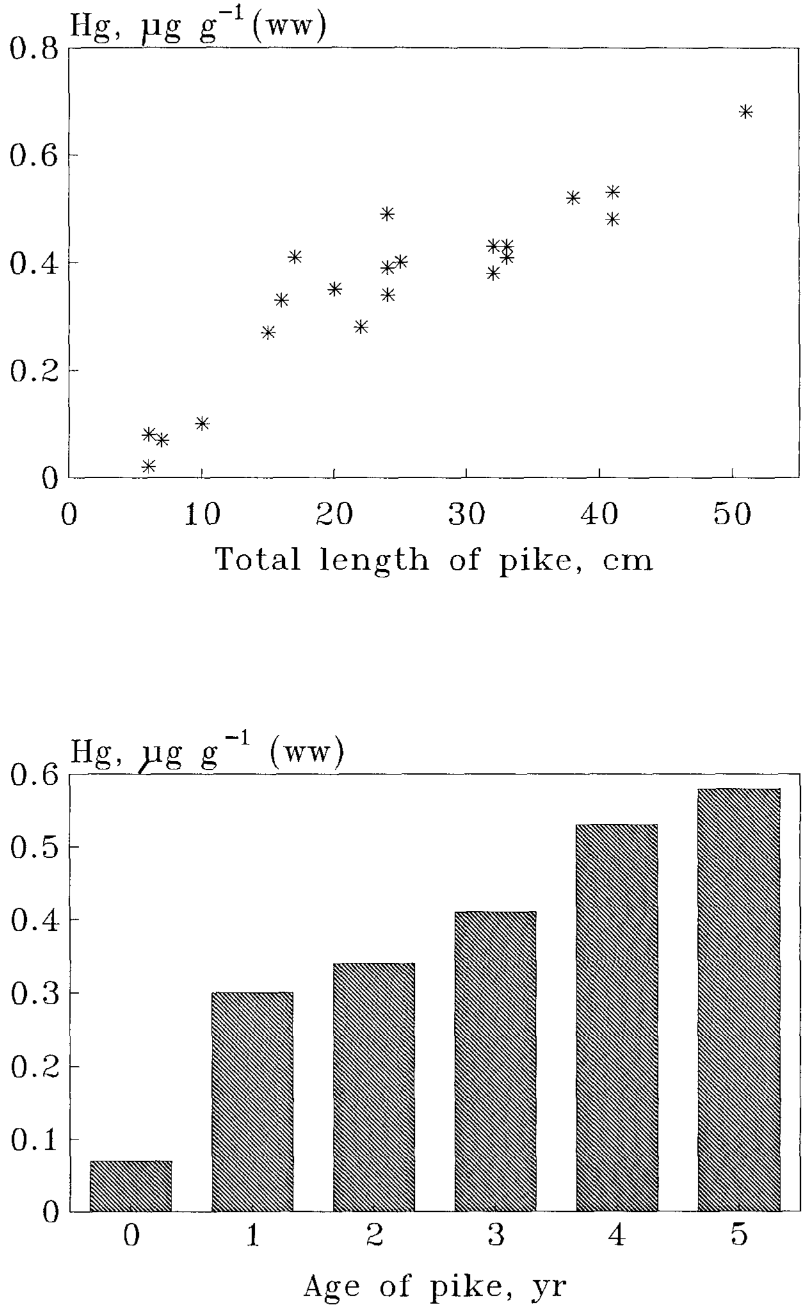


Figure 4. The Hg concentration of northern pike in L. Nimetön (lake 1) in relation to total length (top, $r = 0.92$, $p < 0.001$) and age (bottom, $r = 0.93$, $p < 0.001$) of the fish.

were recorded in pikes of <10 cm in L. Nimetön (lake 1) and in 20 to 30 cm long, 2 to 3 year old pikes of L. Syrjänalunen (lake 15, Figure 5). The highest Hg concentration, 2.1 $\mu g\ g^{-1}$, was in a large pike (91 cm, 4.6 kg) from L. Haukilampi (lake 10), the lake also having the highest concentration in 1–kg pike. Concentrations exceeding 1 $\mu g\ g^{-1}$ were found in fish from 7 lakes, mostly from pikes greater than 1 kg in weight but sometimes also from much smaller pike: in L. Majajärvi (lake 13) three pikes, 0.2–0.3 kg in weight and 36 to 38 cm in length, had Hg concentrations of 1.1 to 1.2 $\mu g\ g^{-1}$ (Figure 5). The variation in Hg concentrations of fish of a certain size class was at the highest in L. Iso Valkjärvi (lake 12) where values of 0.18 to 0.97 $\mu g\ g^{-1}$ were recorded from 20 to 30 cm pike (Figure 5). The variation was much less in the lakes having low concentrations, such as L. Syrjänalunen (lake 15) and L. Mekkojärvi (lake 14).

5. Discussion

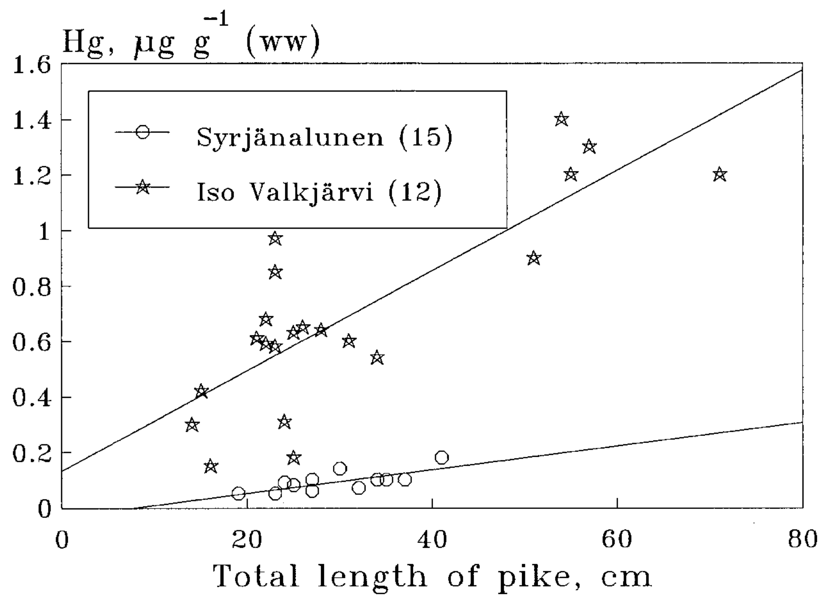
The Hg concentrations in the lakes of our study were generally high and exceeded the criterion for banning of fish sales (>1 $\mu g\ g^{-1}$) in three lakes (18%). The concentration used as a criterion for restricting human consumption of fish (>0.5 $\mu g\ g^{-1}$) was exceeded in 13 of the 17 lakes (76%).

The trend of increasing Hg concentrations in acidic and highly humic Finnish lakes is consistent with many other studies. The connection between increasing acidity and increasing fish Hg may be due to different combinations of several possible mechanisms, as reviewed by Richman et al. (1988) and Verta (1990a). The importance of humus in bioaccumulation of Hg is based on the complex formation between Hg and dissolved organic matter (Jackson et al., 1980). The importance of humic compounds as a source of energy in ecosystems of humic lakes (Salonen and Hammar, 1986) may increase the transfer of Hg in food chains. As in the case of acidity, humic substances may affect mercury bioaccumulation through several possible mechanisms (Verta, 1990a). The importance of allochthonous organic matter emphasizes the significance of catchment properties in bioaccumulation processes of aquatic ecosystems.

The low variability in the Hg concentrations of pike among 7 lakes of the 8–lake chain is probably a result of similar environments in the lakes: the lakes have similar water properties, are of similar size and depth, and have a catchment of similar types and size. The fish fauna is also similar in most of the chain lakes with pike, perch, Perca fluviatilis L., and roach, Rutilus rutilus L. being the most abundant species. In addition, the throughflow allows migration of fish among some of the lakes.

Most of the remaining lakes differed from the chain lakes. Two of the remaining lakes with TOC above 10 mg L^{-1} and mean Hg of pike exceeding 1 $\mu g\ g^{-1}$ were regulated by beavers (lakes 10 and 13, see Figure 2). The activity of beavers may cause circumstances somewhat comparable to those in reservoirs, where the fluctuation of water levels flushes the shores and increases the organic load and Hg in the system (Mannio et al., 1986). In addition, L. Haukilampi, which had the highest mean Hg concentration in pike, has a quite large catchment where forestry ditching has taken place.

A possible reason for the unusually low Hg content in the pike of the most humic study lake (L. Mekkojärvi, lake 14) was the structure of the food chain in the lake: pike is the only species of fish in the lake. Thus, its diet differ from a typical pike diet (perch and roach) and is consisted largely from invertebrates that are not as effective in



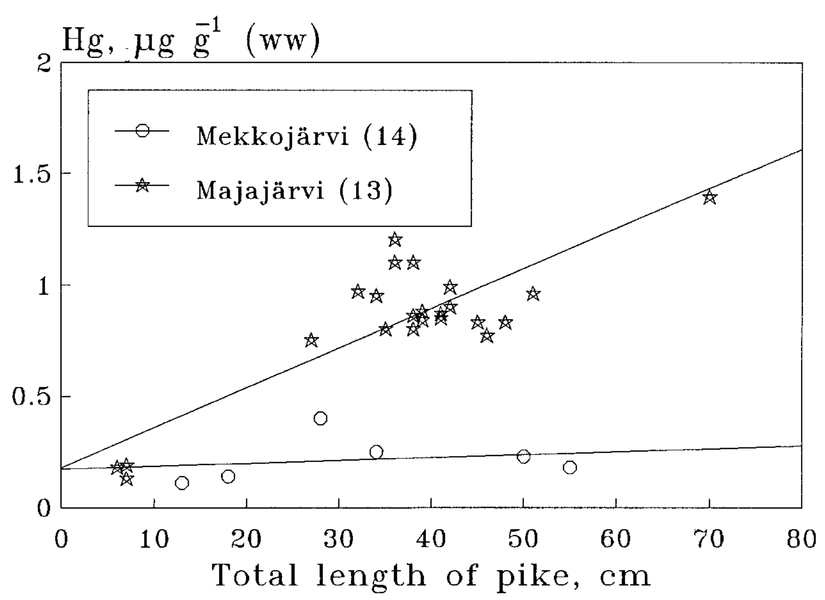


Figure 5. The Hg concentration in pike relative to total length in two clear-water lakes (top) and two humic lakes (bottom). Correlations were as follows: L. Syrjänalunen: $r = 0.87$, $p < 0.001$; L. Iso Valkjärvi: $r = 0.80$, $p < 0.001$; L. Mekkojärvi: $r = 0.21$, $p > 0.1$ and for L. Majajärvi: $r = 0.47$, $p < 0.05$.

bioaccumulating Hg as are the fishes.

Among the lakes of lower TOC concentrations the differences in pike Hg concentrations were also very clear. The low Hg concentrations in pike in L. Syrjänalunen (lake 15) have two possible explanations. Firstly, Syrjänalunen is a groundwater lake; it can be considered almost as a large spring. Thus, precipitation and surface runoff have probably a minor role as a source of water for this lake. Secondly, there are no perch in the lake and so roach is the main food item of pike. Because roach generally have lower Hg concentrations than perch (Metsälä, 1989; Verta, 1990b), the rate of accumulation of Hg in pike may be correspondingly lower. In contrast to L. Syrjänalunen, L. Iso Valkjärvi (lake 12) receives almost all of its incoming water from precipitation. This lake has recently acidified, which also may contribute the high Hg concentration of pike.

The structure and functioning of aquatic ecosystems, including their fish assemblages vary widely. Densities and biomasses of fish populations fluctuate causing differences in food availability and growth of the fish. These changes also affect the bioaccumulation of substances along food chains. Therefore, a Hg concentration recorded in one year from a sample of a few fish is not necessarily a precise estimate of the average concentration and cannot be considered valid over years. High variations within a lake as recorded in some lakes of this study still increase the uncertainty. Growth dilution, initiated by effective removal of fish, has been used as a remedial measure in lakes with high fish Hg concentrations (Göthberg, 1983; Verta, 1990b). It is a good example of the effects of changes in fish community on the accumulation of Hg in fish.

In conclusion, our observations showed that Hg concentrations in pike may vary widely in a small geographical area. This suggests that in addition to the amount of Hg precipitating in the catchments and the lakes, other factors also affect bioaccumulation. Differences in water properties, catchment properties, degree of acidity and structure of the food webs are emphasized as possible reasons for the different Hg concentrations of pike among the studied lakes.

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