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Recent Increase in Mercury Sedimentation in a Forest Lake Attributable to Peatland Drainage

Heikki Simola¹ and Martin Lodenius²

¹Univ. Joensuu, Karelian Institute, Section of Ecology, P.O. Box 111, SF-80101 Joensuu, Finland and ²Univ. Helsinki, Department of Environmental Science, SF-00710, Helsinki 71, Finland

Observations of elevated mercury levels in the aquatic environment in the northern hemisphere have recently evoked much attention (e.g. KOIRTYOHANN et al. 1974, SHERBIN 1979, Anon. 1982). Long-range transport of atmospheric pollutants, acid precipitation and drainage measures have been mentioned as possible reasons. In many cases high Hg levels seem to occur consequent to extensive peatland drainage undertakings, but lack of appropriate monitoring data has prevented the verification of causality in this relation.

In order to gain information about the natural background levels and about the recent history of mercury in our waters, we determined mercury profiles in two lakes in which annually laminated sediment is deposited, and which differ from each other with respect to the history of land use in their drainage areas. Annual sediment laminations or varves allow a precise dating of the studied sequence, and their existence indicates undisturbed recording of the history of the environment.

MATERIALS AND METHODS

Study sites

Lake Polvijärvi is situated in the commune of Juuka in North Karelia and Lake Pääjärvi in the communes of Lammi and Koski in the province of Häme in South Finland. The lakes and their drainage areas are characterised in Table 1.

The proportion of cultivated land around L. Pääjärvi is fairly well representative for the whole southern Finland. The drainage basin of L. Polvijärvi, with its high percentage of peatland, should be typical for the poorly drained and scarcely populated water divide zones of the Finnish Lake District.

Bedrock in the drainage area of L. Pääjärvi is mainly gneisses and granite. In the vicinity of the lake areas of granodiorite and amphibolite occur. Precambrian gneisses, striped with amphibolite zones, also prevail in the drainage area of L. Polvijärvi, but some metamorphosed sedimentary rocks (quartzite scists, calc silicates, limestone and mica gneiss) occur in its southern part.

Table 1. Characteristics of the Lakes Pääjärvi and Polvijärvi and their drainage areas.

	PÄÄJÄRVI	POLVIJÄRVI
position	61°04'N, 25°08'E	63°09'N, 28°58'E
elevation, m a.s.l.	103	170
area, km ²	13.42	1.83
max. depth, m	87	35
mean depth, m	14.4	5.1
volume, 10 ⁶ m ³	205.7	9.3
theor. retention time, d	1200	170
drainage area, km ²	244	65
of which: other lakes	7.2 %	9.2 %
peatland	10.6 %	34.6 %
arable fields	18.3 %	2.0 %

The laminated sediment of Lake Polvijärvi incorporates a history of rapid eutrophication of the lake during the 1970's, which evidently is due to extensive peatland drainage and fertilization in its drainage area (SIMOLA submitted). Nearly 80 % of the 22.5 km² peatland area has been drained for forestry since the year 1960, and 10.8 km² of ditched peatlands were fertilized with phosphorus-potassium fertilizer in 1971.

The ecosystem of Lake Pääjärvi has been extensively studied during the past decade (e.g. RUUHIJÄRVI 1974, SARVALA et al. 1981). The lake is considered to be near its natural oligotrophic state still, although signs of moderate eutrophication, mainly due to agricultural effluents, are apparent in its shallow bays.

Sampling

Two sediment cores were taken at each lake: one with the in situ -freezer of HUTTUNEN & MERILÄINEN (1978) and the other with a Kajak-type gravity corer. The Kajak cores were sliced from the sediment-water contact downwards for determination of the profiles of water content, dry matter and organic matter. Chronology for these profiles (in calendar years prior to the sampling date) was established through the sediment laminations, that were analyzed in the frozen cores (Fig.1.).

Lake Polvijärvi was sampled in May 1981. The Kajak core was sliced into 10 successive subsamples, varying between 0.9 and 2.6 cm in thickness (the accurate height of each slice was determined by dividing its fresh volume with the core cross-section; 43.0 cm²).

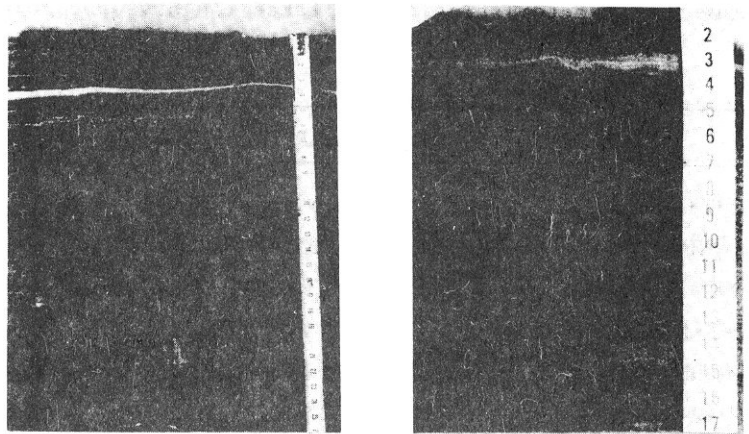


Figure 1. Laminated sediment of L. Polvijärvi (left) and L. Pääjärvi (right). The annual character of the laminations has been verified microscopically by SIMOLA (submitted) and SIMOLA & UIMONEN-SIMOLA (1983). ^{210}Pb -dating has further confirmed the annuality of the laminations of L. Pääjärvi (APPLEBY et al. 1979). The recent eutrophication of L. Polvijärvi is reflected in the sediment as an abrupt increase in the thickness of the laminations (above 5 cm depth).

The lower end of this profile is at 17.5 cm and according to laminae counting the core represents the period 1864-1981. Subsamples for Hg determination were taken of these slices after they had been dried to constant weight in $+50^{\circ}\text{C}$.

The samples of Lake Pääjärvi were taken at 55 m water depth in October 1979. The Kajak core (0-21 cm) was dissected into 0.5 cm thick slices, of which fresh weight, dry weight and loss-on-ignition were determined. Mercury concentrations were determined in 16 successive subsamples of the frozen core that were cut along the yearly boundaries. This sample sequence spanned the period 1873-1979 (a 3 cm thick turbid layer below the 1908 laminations was omitted from the chronology and from the samples). The dry matter and mercury quantities in the subsamples were transformed into fluxes through matching them with corresponding levels in the fresh and dry weight profiles of the Kajak core.

Mercury concentration were determined using cold vapour AAS after a wet combustion according to KIVALO et al. (1974) but using 10 ml of acids for each sample.

RESULTS

L. Polvijärvi

At the lower part of the profile analyzed in Lake Polvijärvi (1864-1920 according to varve chronology), Hg concentration is

LAKE POLVIJÄRVI

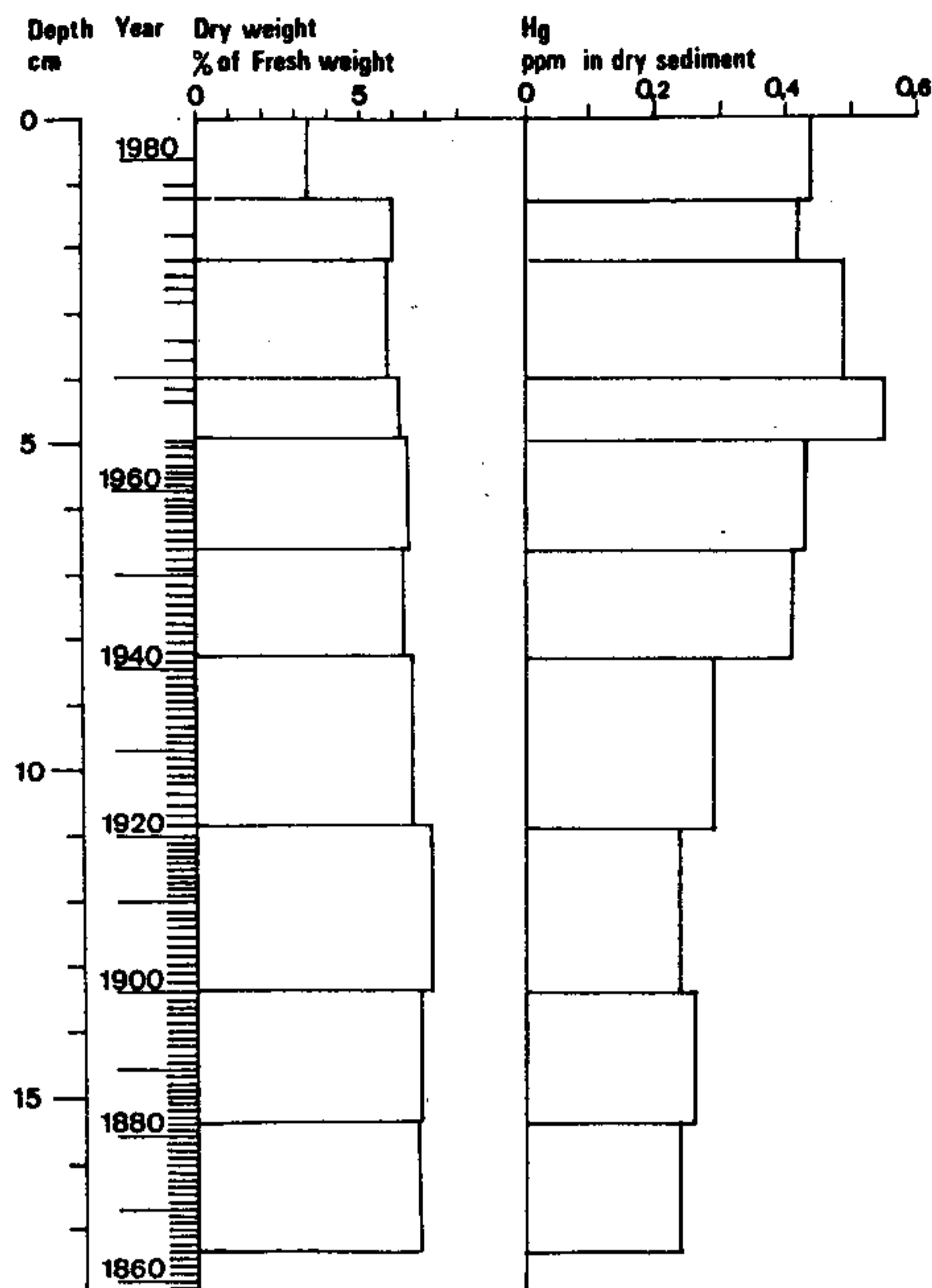


Figure 2. Dry weight and mercury profiles in the surface sediment at 35 m depth in L. Polvijärvi. Chronology according to sediment varves.

rather steadily $0.25 \mu\text{g g}^{-1}$ (ppm) in dry sediment. From this background value the concentration rises to an about doubled level in the samples representing the period 1967-1975 (Fig.2.). In the two uppermost slices (1976-1980), the concentration is only slightly lowered.

The gradual increase in the Hg concentration is superimposed with a rapid increase of the sediment accumulation rate that started in the late 1960's. For this reason, the flux of Hg into the sediment in the period 1967-1977 has been about five times higher than that at the end of the 19th century (Fig.3.).

The first rise in the concentration and in the accumulation rate of mercury is apparent in the slice representing the period 1942-1952. Tentatively, we relate this increase with the clearance of some small fields on the NW shore of the lake (partly on mineral slopes, partly on peatland) that took place during this period (mr. A. Nykänen, pers. comm.).

The recently increased sedimentation of Hg seems to have occurred in close correlation with the progress of the drainage undertakings (Fig.3.). Mobilization of soil mercury seems, indeed, the most plausible explanation for the observed increase, as industrial or agricultural emissions should not have been of any significance in the area.

LAKE POLVIJÄRVI

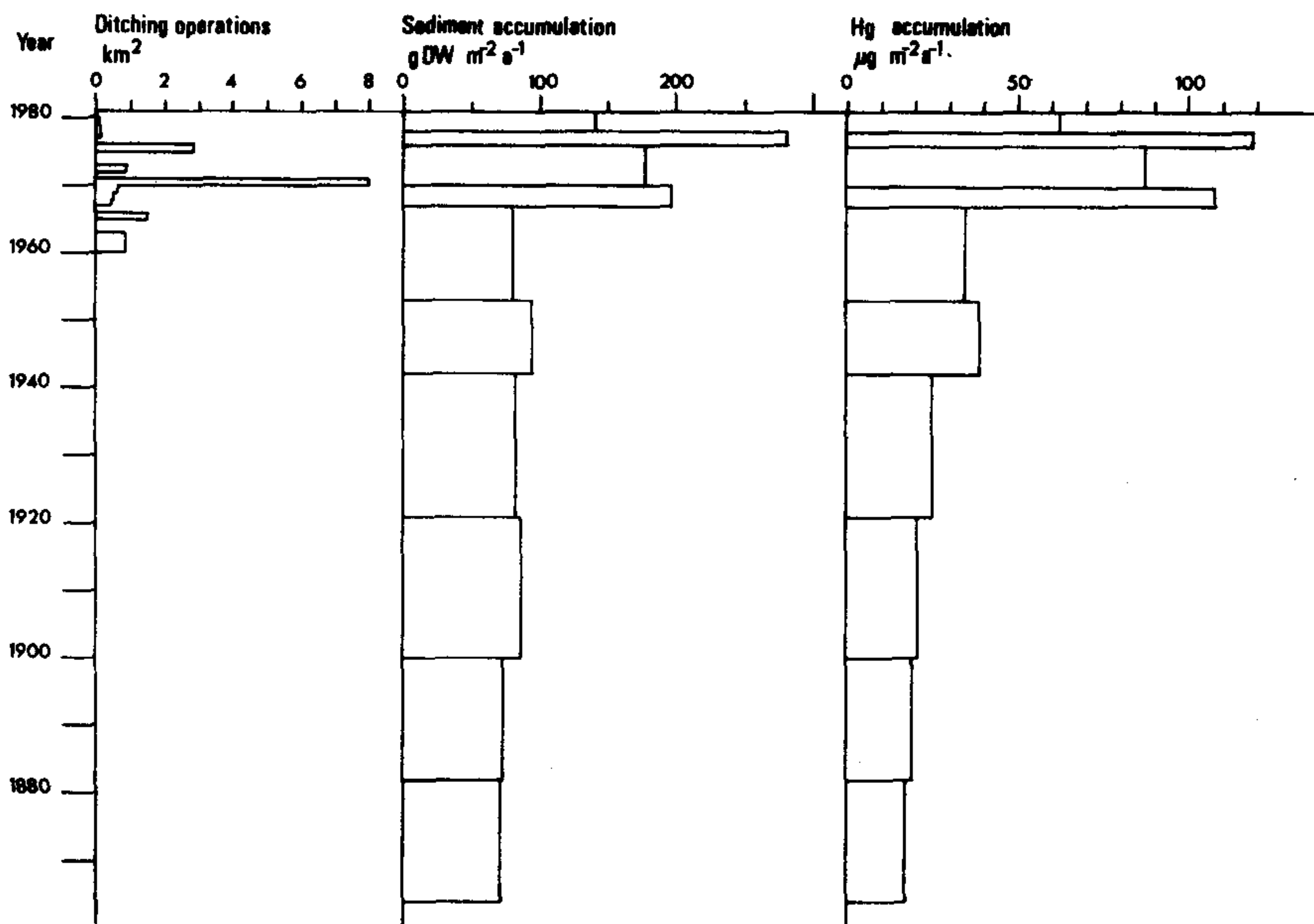


Figure 3. Ditchings of virgin peatlands in the drainage area and accumulation of sediment dry matter and mercury in L. Polvijärvi

L. Pääjärvi

Mercury concentrations in the samples of L. Pääjärvi are between 0.032 and $0.088 \mu\text{g g}^{-1}$ in dry sediment, or much lower than in L. Polvijärvi. However, due to considerably higher accumulation rate of the (more minerogenic) sediment, the sedimentary flux of Hg in L. Pääjärvi is of the same magnitude as it was in L. Polvijärvi prior to the recent increase (Fig.4.). There is no clear trend in the Hg accumulation profile in L. Pääjärvi; part of the variation between successive samples seems merely to reflect lack of precision in the sediment accumulation rate determination.

In 1960 the water level of L. Pääjärvi was lowered by about 1 m, which, together with the drainage of peatlands, seems to have caused increased mineral sedimentation in the profundal area during the 1960's. Mercury does not seem to have been excessively mobilised during this period.

DISCUSSION

The mercury content of Finnish soil and peat is around $0.1 \mu\text{g g}^{-1}$ (dry weight) (BYSIEK et al. 1972, SOVERI 1977). In soils the mercury is to a great extent bound to the organic matter, especially at low pH-values. At changing conditions the organic

LAKE PÄÄJÄRVI

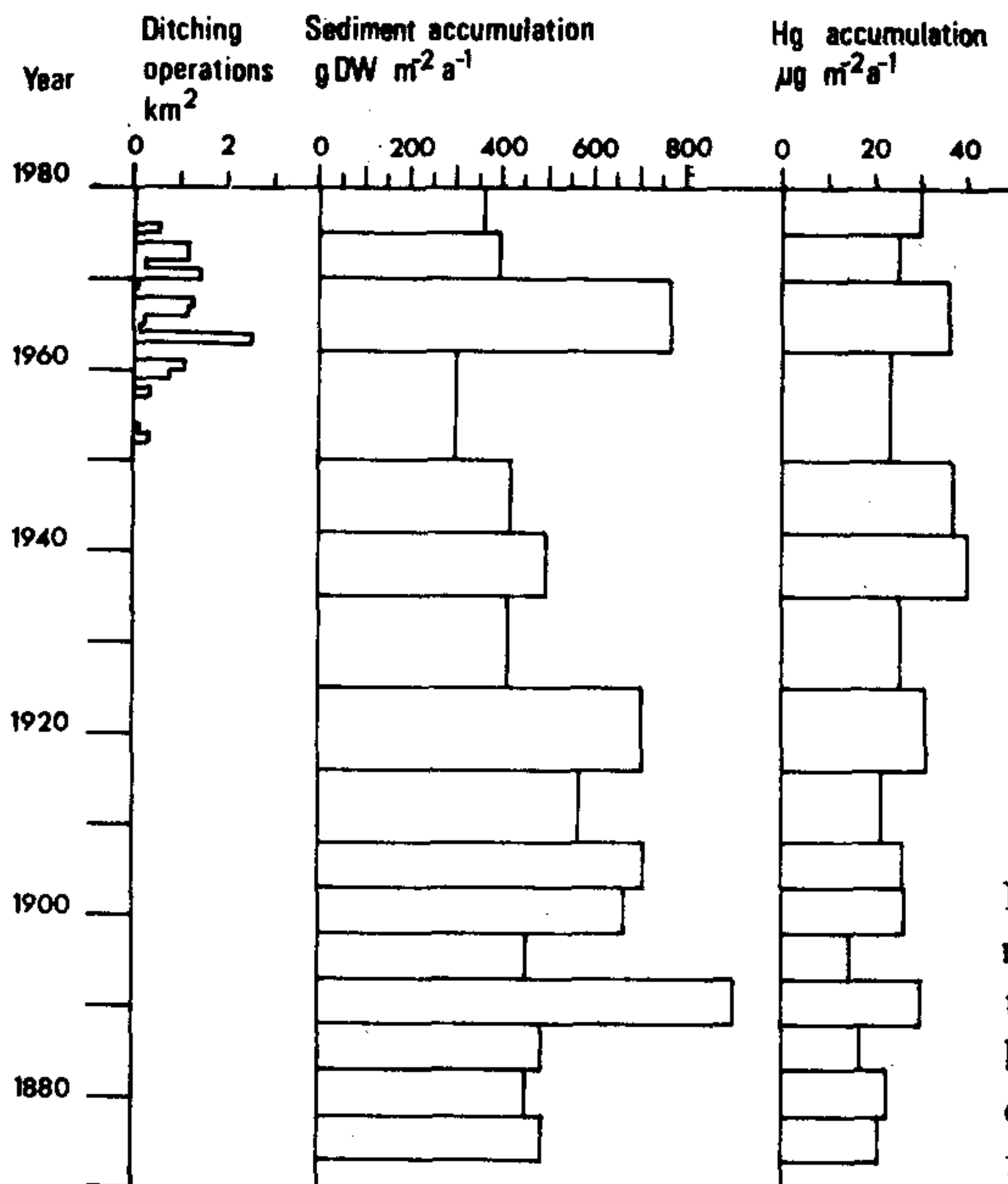


Figure 4. History of dry matter and mercury sedimentation in L. Pääjärvi as dated by sediment varves. Peatland drainage operations are also indicated.

components including the complexed mercury may pass into solution (ANDERSSON 1979).

Mercury may be released from the soil and accumulated in aquatic food-chains after the construction of man-made lakes (e.g. ABERNATHY & CUMBIE 1977, VERTA 1981, LODENIUS et al. 1982). Mercury forms readily complexes with humic substances (STROHAL & HULJEV 1971, MILLER 1975, BENES et al. 1976) and the fulvic acids have been shown to increase the solubility of mercury (SCHNITZER & KERNDORFF 1981). It has also been shown that the mercuric ion (Hg^{2+}) in sediments may be reduced to elemental mercury (Hg^0) in the presence of humic acid and thus released back into the water phase (ALBERTS et al. 1974, MILLER 1975). Much less mercury was by this way released by whole sediments than by purified humic acids (MILLER 1975) indicating the essential role of humic substances in the movements of mercury between water and sediments. Fulvic acids may also promote the methylation of mercury in soils (ROGERS 1977).

The background mercury levels in the sediments of the three largest Swedish lakes are 0.030, 0.040 and 0.095 $\mu\text{g g}^{-1}$ respectively (HÄKANSSON 1977). Also in Finland the background values are at the same level (SÄRKKÄ et al. 1978, HÄKKILÄ 1980, LODENIUS 1980). The mercury concentration in the sediment of Lake Pääjärvi is in good agreement with these. The higher base level concentration in sediment of Lake Polvijärvi (about 0.25 $\mu\text{g g}^{-1}$) is obviously consequent to the low mineral content. In fact, when calculated on the basis of sedimentary organic matter the concentrations appear equivalent: in L. Pääjärvi the range is 0.41 to 0.73 $\mu\text{g gOM}^{-1}$, and in L. Polvijärvi the pre-1920 concentration level is about 0.50 $\mu\text{g gOM}^{-1}$.

The anthropogenic emissions of mercury to the atmosphere seem to be much greater than the natural ones (LANTZY & MACKENZIE 1979) and an increasing deposition of this metal has been observed in Danish bogs since approximately 1850 (MADSEN 1981). As no clear increase in the mercury sedimentation was observed in Lake Pääjärvi and the elevated concentrations of Lake Polvijärvi were closely related to the drainage undertakings, the influence of atmospheric deposition must be considered negligible in these two lakes.

In Finland about 55 000 km² of peatland has already been drained, which corresponds to 16 % of the whole country. As a consequence of the abundance of peatlands the Finnish lakes are in general polyhumic (average 13 mg humic matter l⁻¹) and the artificial drainage of forests and bogs as well as the regulation of waters may strongly increase the organic matter content in the lake water (HEIKURAINEN et al. 1978, KENTTÄMIES 1980). This may be one explanation for the high mercury concentrations found in many unpolluted lakes.

ACKNOWLEDGEMENTS

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