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Natural and land-use induced load of acidity, metals, humus and suspended matter in Lestijoki, a river in western Finland

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Lestijoki, a river in western Finland, runs through areas with abundant peatlands and acid sulphate (AS) soils, which cause water quality problems. A natural population of sea trout (*Salmo trutta* m. *trutta* (L.)) and other valuable species still exist in the river, but the declining water quality is a serious threat to their survival. The AS soils and the peatlands cause a natural high load of acidity, metals, humus and suspended matter. This load is enhanced by human activities such as agriculture and draining, being 2–5 times higher than in Fennoscandian streams in general. During high flow, the load reaches levels deleterious for many species. The results of several large water quality surveys and routine monitoring show that low pH in Lestijoki (min. 4.9) and the feeder streams (min. 4.4), together with high metal contents (e.g., max. Fe 7.3 and 5.8 mg l^{-1}, respectively) and high amounts of humic and suspended matter, occasionally cause conditions where reproduction failures of fish occur. The acidity and metal load from subsurface drained AS soils is especially deleterious for the biological conditions in the main stream.

Introduction

Atmospheric deposition and industrial point sources are generally considered to be the main causes for increased loads of acidity and metals on surface waters. However, under some exceptional conditions the diffuse load from natural sources can be the main reason for elevated acidity and metal contents. In western Finland, areas with abundant fine-grained clay/silt sediments rich in sulphides, and areas with large peatlands release large amounts of acidity, metals, humic and suspended matter to the surface waters (Laine *et al*. 1992, Palko 1994, Åström and Björklund 1996). The load from the sediments is natural and continuous because of isostatic land uplift, and it

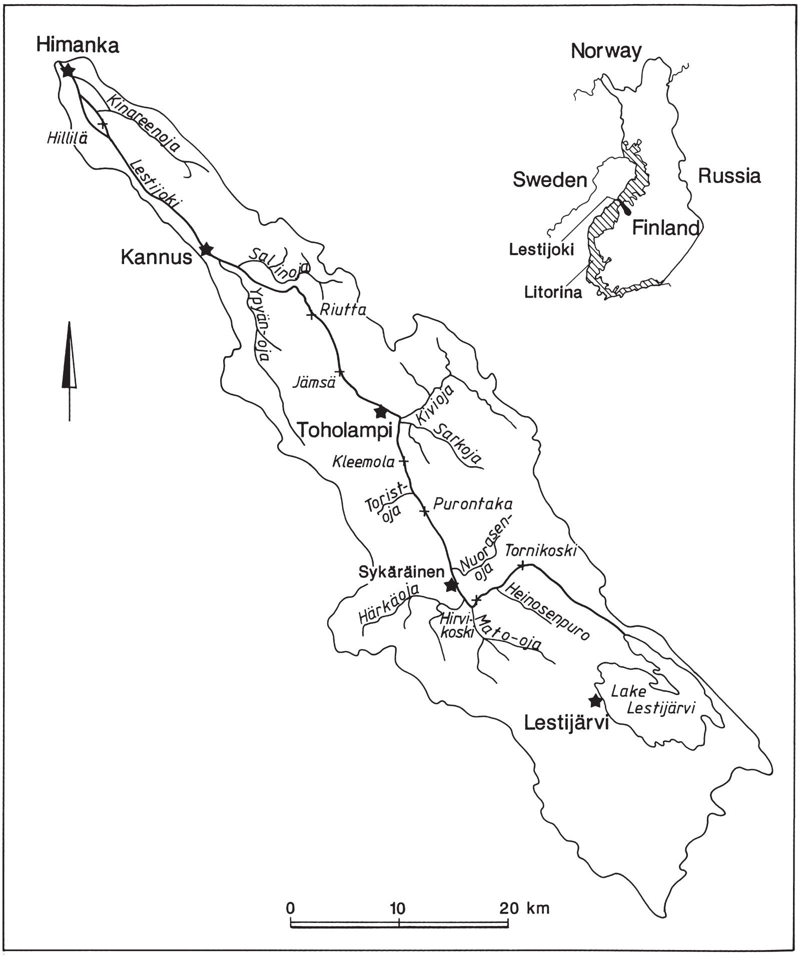

Fig. 1. The Lestijoki catchment with feeder streams.

is enhanced by human activities like intense farming and large-scale drainage operations. In Finland, peatlands are often efficiently drained, which increases the load of humic acids, metals and solids (Laine *et al.* 1992). The combined effect of these loads is a deterioration of the biological systems in the watercourses. Deleterious impacts on fisheries are of special concern, because the changes in water quality disturb fish metabolism, reproduction and growth, and they can even cause occasional fish deaths (Hudd *et al.* 1984, 1994, Vuori 1995).

The sulphide sediments along the coast of Finland release much more acidity into the soil and waters than acid atmospheric deposition (Palko and Weppling 1994), which has been one of the most debated environmental subjects during the last decades. The ecotoxicological effects of natural soil-related loads on flora and fauna in the waters have gained attention only in the last few years (Hudd *et al.* 1984, Brown and Saddler 1989, Björklund 1994, Kjellman *et al.* 1994, Vuori 1995).

The declining water quality is a serious threat to the survival of several fish species, and to the success of restoration efforts. Water protection was earlier largely concentrated on reducing nutrients and point sources. Research in some rivers along the coast of western Finland has, however, shown that it is not only the nutrients, but also the diffuse load of acidity, metals, humus and suspended matter, which cause damage to the fauna, e.g., mass fish kills, escape reactions and reproduction failures (Hudd *et al.* 1994, Kjellman *et al.* 1994, Vuori 1995, Myllynen *et al.* 1997). For example, the catches of lamprey (Lampetra fluviatilis (L.)) decreased 80% during the last two decades in Perhonjoki, a river about 30 km southwest of Lestijoki, (Myllynen *et al.* 1997), and the recruitment of burbot (*Lota lota* (L.)) in the estuary of Kyrönjoki, a river 140 km southwest of Lestijoki, decreased to 27%–53% of the normal one due to acidification (Kjellman *et al*. 1994). The present work was done in order to localise and identify the types of load from different source areas in the catchment of Lestijoki, and on the basis of the results suggest restoration methods to improve the water quality.

Description of the Lestijoki catchment

Lestijoki is situated in the central part of western Finland (Fig. 1). The upper parts of the river run through forests and peatlands, while the middle and downstream parts are bordered by fine-grained clay/silt sediments, which are cultivated to a large extent. The river is one out of seven, where a natural population of sea trout (*Salmo trutta* m. *trutta* (L.)) still exists in Finland (Koljonen and Kallio-Nyberg 1991).

Lestijoki starts from Lestijärvi, a lake 110 km upstream from the coast of the Gulf of Bothnia and 140 m above sea level (Fig. 1). The whole catchment is 1 409 km^2 in size. The mean water flow is 11.5 $m^3 s^{-1}$, and 6.3% of the catchment consists of lakes. The ground is normally covered with snow from December to the end of April, when the spring high water flow occurs. Normally, there is also an autumn high water flow in October–November due to increased precipitation during this period. The annual precipitation is about 500 mm (Vesihallitus 1977). Population density is low and there are no large industries within the catchment.

The relief in western Finland is very low due to an old and deeply eroded bedrock surface and thick sediments filling the depressions. Most of the area was covered by glacial till after the last deglaciation about 9 000 years ago. In some parts of the catchment, eskers and drumlins occur. Fine-grained clay/silt sediments occur along the river valley from Tornikoski, 70 km upstream down to the coast. Especially downstream in Himanka and the western parts of Kannus they cover large areas. They were deposited after the deglaciation during the Ancylus, Litorina and Postlitorina stages of the Baltic Sea. Due to the postglacial isostatic land uplift these fine-grained sediments are now situated above sea level. The upper layers of the sulphide-bearing Litorina sediments at the lower reaches of the river (in Himanka and parts of Kannus) have gradually risen above the water table and have subsequently been oxidised to form so called acid sulphate (AS) soils. The fine-grained sediments are in many places covered by a 0.5–4 m thick layer of fine alluvial sand. Due to the low topography, large areas are covered by peat layers of various thickness, especially in the upper parts of the catchment (Okko 1949, Kujansuu and Niemelä 1984).

The bedrock consists mainly of granitoids and migmatitic, often mica-rich gneisses, with narrow zones of metavolcanic (felsic to mafic) and metasedimentary rocks. Intercalations of black schists occur in some places, and small intrusions of diorite, gabbro and peridotite are quite common (Luukkonen and Lukkarinen 1985).

Sampling and analysis

Several sampling programs in Lestijoki and its catchment have focussed on water chemistry in different types of drains/ditches and feeder streams, as well as in the main stream. This study compiles the results from sampling performed at over 100 sites on two occasions in the beginning of May and June 1995, and on one occasion at partly different sites in autumn 1995. Additional results from the main stream and the feeder streams at five occasions in autumn 1985 and spring 1986 (M. Kalliolinna, unpubl.), and from a comparison between waters from natural and drained peatlands (Laine *et al*. 1992) are included.

Acidity, alkalinity, pH, electric conductivity (EC), colour, coarse suspended matter (> 1 mm) and turbidity were analysed immediately after sampling in the laboratory of the Central Ostrobothnia Regional Environmental Centre. Metals were analysed in unfiltered acidified samples with a graphite furnace AAS (Al, Cu, Cd, Pb, Ca, Mg, Na and K), flame AAS (Zn), and a spectrophotometer (Fe and Mn). The main nutrients N_{Tot} and P_{Tot} were analysed spectrophotometrically. All the analyses were performed according to the prevailing standards of the National Board of Waters and Environment (SFS standards 3005, 3017, 3018, 3021-3024, 3026, 3028, 3031, 3033, 3037, 3047, 5074, 5502).

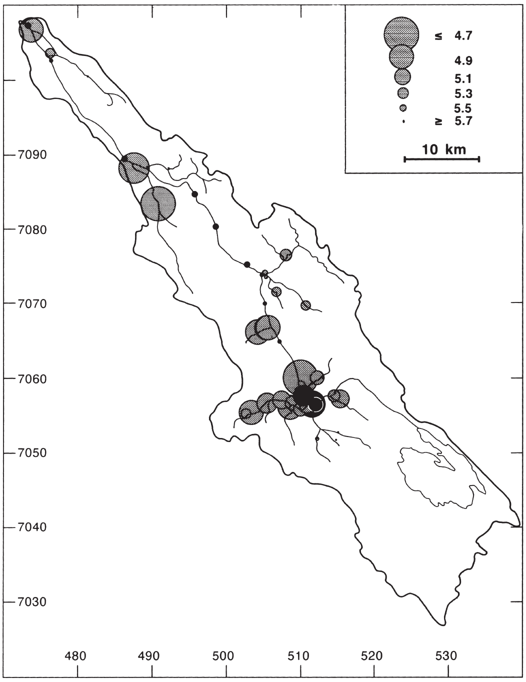

Fig. 2. pH at 15 sites in Lestijoki and at 31 sites in feeder streams in spring 1986 (data from M. Kalliolinna, unpubl.).

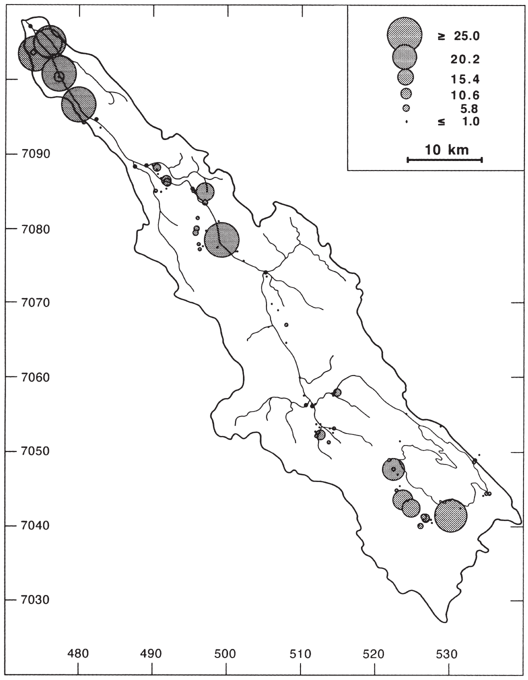

Fig. 3. Contents of Fe (mg l^{-1}) in Lestijoki, feeder streams and different kinds of drains/ditches in the beginning of May and June 1995.

AS soils in the study area were mapped using a field method developed and described by Palko *et al.* (1988). Soil profiles were drilled down to a depth of two meters with a through-flow auger and soil pH was measured directly from the auger in 10 cm intervals. AS soils were identified by the existence of a transition layer with pH < 5.

Types and sources of load

The types and sources of load are different in different parts of the basin according to variations in soil type and land-use practices. Although pH is low (about 4.5) in some ditches from peat lands around Lestijärvi (Fig. 2), and Fe is high in some subsurface drains south of the lake (Fig. 3), there are neither severe water quality problems in the lake nor in the streams discharging to the lake. The same is also true for the uppermost 20 km of Lestijoki downstream from the lake, where the river runs through unpopulated forests and peatlands with no fine-grained sediments and no farming. However, starting from Tornikoski (Fig. 1) the water quality declines rapidly (Fig. 2) (Jokela 1988, M. Kalliolinna, unpubl.). This is a flat area with cultivated peatlands underlain by layers of clay/silt sediments close to the river, and with peatlands and forests further away. Two of the major feeder streams, Mato-oja and Härkäoja (Fig. 1), join the main stream in this area. Further downstream large areas are covered by cultivated, and in many places sulphide-bearing, clay/silt sediments. For these reasons this study concentrated on the part of the catchment situated between Tornikoski and the outlet at the coast in Himanka.

The results for different types of waters sampled during spring 1995 are listed in Table 1. The pH in feeder streams and drains/ditches was lower, and contents of havy metals and nutrients higher than in the main stream. The water from subsurface drains had higher concentrations of Fe and Al, and several times higher EC and heavy metals contents, except Pb, than the other types of water.

Acidity and pH

In many of the feeder streams, pH often decreased to values between 4.5 and 5.0. In the main stream, pH sank below 5.0 during high flow in the surroundings of Sykäräinen (downstream from the outlet of Mato-oja and Härkäoja; Fig. 2). Near the mouth of the river, a minimum pH measured in monitoring 1962–1986 was 4.9 (Jokela 1988).

Humic substances lower pH of river water. Thus, pH < 5 is a natural phenomenon in Finnish rivers draining peatlands (Pettersson 1992, Kortelainen 1993). This is probably the case in Sykäräinen, where draining of peatlands in the upper parts of the tributary and the use of peatlands for farming purposes downstream, cause increased leaching of humic substances. The waters in this area had high colour values due to humic compounds. The pH in feeder streams draining peatlands downstream from Sykäräinen was also below 5.

pH between Sykäräinen and Kannus was lower on the SW side of the river than on the NE side (Fig. 2). In autumn 1995, the feeder streams on the NE side of the river had pH 6.4 (mean for 11 sites), while those on the SW side had pH 5.4 (mean for 10 sites). The higher pH on the NE side was at least partly due to geological features, reflected as higher contents of Ca, Mg and P in till in this area (Fig. 4). Laine *et al*. (1992) studied runoff waters from drained and natural peatlands in the catchments of Ypyänjoki on the SW side and Kivioja on the NE side of Lestijoki. The results of their study showed the same trend as observed here: median pH is 4.9 in the former and 5.7 in the latter. There were no significant differences between drained or natural peatlands (Laine *et al*. 1992), at least not when measured a few years after draining (Simonsson 1987).

The water from agricultural surface drains at Sykäräinen had lower pH (6.0, $n = 5$) than further downstream at Toholampi (6.5), probably due to larger portions of peat at Sykäräinen. At Kannus pH was 5.9 ($n = 7$) for this type of drains. The surface drains in the cultivated clay/silt soils in Himanka had distinctly lower pH, with a mean of 5.25 ($n = 5$) and a minimum of 4.25.

Median pH for 93 water samples from subsurface drains was 5.54, which was slightly higher than for the feeder streams (Table 1). There were, however, considerable differences for different

Table 1. Medians for physical parameters and chemical elements along the main stream, in feeder-streams and in different types of ditches in the Lestijoki catchment in the beginning of May and June 1995. n = number of samples, na = not analysed

	Main stream ($n = 9$)	Feeder streams ($n = 20$)	Forest/peat ditches ($n = 42$)	Agric. surface drains ($n = 16$)	Subsurface drains ($n = 93$)
pH	5.83	5.28	5.35	6.30	5.54
Acidity (mmol l^{-1})	na	0.23	0.29	0.29	2.74
EC (mS m^{-1})	2.91	3.36	3.33	6.71	27.28
Turbidity (FTU)	2.4	4.8	4.8	6.4	5.5
Colour (Pt mg l^{-1})	230	274	240	160	80
Fe (µg l^{-1})	1 038	1 482	1 428	1 401	1 797
Mn (µg l^{-1})	61	78	69	127	366
Al (µg l^{-1})	480	680	925	760	800
Cu (µg l^{-1})	0.6	1.3	1.3	3.5	4.5
Zn (µg l^{-1})	1.0	3.5	1.0	2.5	10.0
Pb (µg l^{-1})	na	0.1	0.3	0.3	0.1
Cd (µg l^{-1})	0.04	0.02	0.01	0.01	0.15
Ca (mg l^{-1})	4.8	2.4	2.0	5.0	17.1
Mg (mg l^{-1})	1.6	1.1	1.1	2.8	8.2
Na (mg l^{-1})	2.4	1.4	1.6	2.8	6.4
K (mg l^{-1})	3.2	0.5	0.5	1.7	5.2
N_{Tot} (µg l^{-1})	639	772	706	1 018	4 271
P_{Tot} (µg l^{-1})	31	37	32	89	75

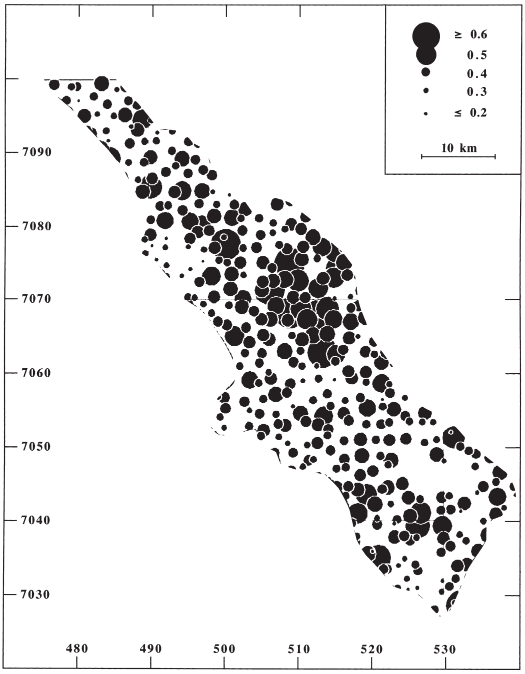

Fig. 4. Contents of Ca (%) in till in the Lestijoki catchment (Geological Survey of Finland 1987).

parts of the catchment. pH in the subsurface drains decreased rapidly downstream at Kannus (5.08) and Himanka (4.08), while the acidity and most metal contents increased strongly (Table 2). The results for the Kinareenoja feeder stream (4.45) at Himanka are also included in the table. This stream has a catchment of 60 km^2, and its lower reaches run mostly through cultivated clay/silt sediments. The composition of the water in Kinareenoja was closer to that of the subsurface drains in the same area than to that of the other feeder streams.

Soil profile studies showed that the sulphide-bearing clay/silt sediments deposited after the Pleistocene ice age are the ultimate cause of the low pH, high acidity and high metal contents in the downstream part of Lestijoki. This is explained by the postglacial history of the Baltic Sea, which can be divided into four stages: The Baltic Ice Lake, the Yoldia Sea (10200–9300 a B.P.), the Ancylus Lake (9300–7500 a B.P.) and the Litorina Sea (after 7500 a B.P.) (Winterhalter *et al.* 1981). The clay/silt sediments at Sykäräinen and Toholampi were deposited during the freshwater Ancylus

Table 2. Medians for the measured parameters in water from subsurface drains divided according to location within the catchment of the Lestijoki river and for the feeder stream Kinareenoja situated downstream in Himanka. The results represent two sampling events in the beginning of May and the beginning of June 1995. *n* = number of samples, na = not analysed.

	Lestijärvi (*n* = 24)	Toholampi (*n* = 29)	Kannus (*n* = 28)	Himanka (*n* = 12)	Kinareenoja (*n* = 2)
pH	5.72	5.68	5.08	4.08	4.45
Acidity (mmol l^{-1})	2.5	2.7	2.6	4.2	0.8
EC (m Sm^{-1})	21.8	24.0	33.1	99.8	30.5
Turbidity (FTU)	7.1	5.5	3.2	22.5	13.4
Colour (Pt mg l^{-1})	85	62	60	120	160
Fe (μg l^{-1})	2 305	1 118	1 038	20 237	2 507
Mn (μg l^{-1})	346	259	336	3 047	531
Al (μg l^{-1})	735	625	1 900	16 300	5 000
Cu (μg l^{-1})	3.4	4.4	5.6	30.0	7.3
Zn (μg l^{-1})	3.0	10.0	30.5	290.0	69.0
Pb (μg l^{-1})	0.1	0.1	0.1	0.1	0.1
Cd (μg l^{-1})	0.1	0.1	0.4	2.0	0.4
Ca (mg l^{-1})	16.5	17.3	22.2	71.5	15.3
Mg (mg l^{-1})	7.3	9.6	13.1	29.8	9.0
Na (mg l^{-1})	4.7	6.8	5.6	8.2	8.6
K (mg l^{-1})	4.1	5.6	5.7	18.5	4.4
N_{Tot} (μg l^{-1})	3 164	4 271	3 154	6 744	na
P_{Tot} (μg l^{-1})	181	80	45	47	na

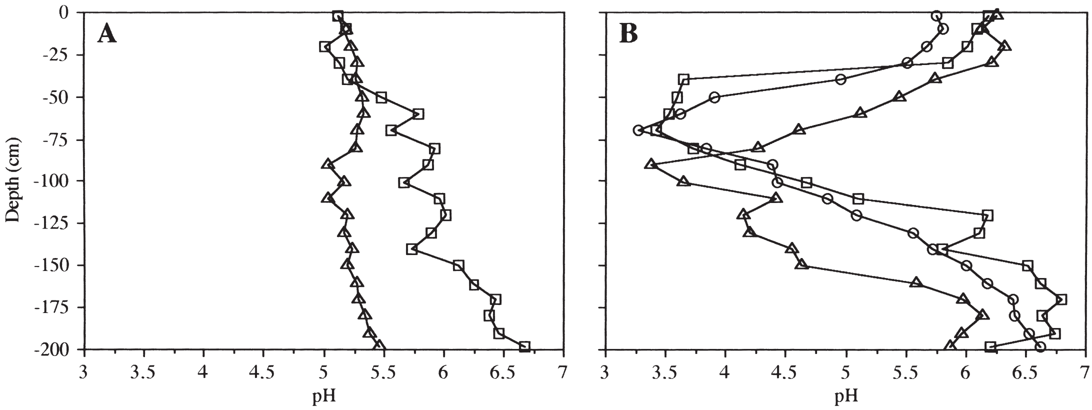

Fig. 5. (A) pH in two "normal" soil profiles, and (B) pH in three AS soil profiles at Himanka.

stage, while the clay/silt sediments downstream at Kannus and Himanka were deposited during the Litorina and Postlitorina stages (Okko 1949). During the latter periods the climate was warmer and the water brackish, which caused a dramatic increase in the production of organic matter. In many places a combination of excessive sulphates, a high content of organic matter and dissolved iron provided favourable conditions for iron sulphide formation in an anaerobic environment (Wiklander *et al.* 1950, Bloomfield 1972). Hydrotroilite is very likely the main active iron sulphide in Finnish sulphide soils. The different forms tend to be reduced into pyrite, but the transformation has probably not been complete. Thus, monosulphides and elemental sulphur are abundant in the sediments (Purokoski 1958, Palko 1994).

The clay sediments in the Lestijoki valley are on average 4–5 m thick, but they are mostly covered by 0.5–4.0 m alluvial sand or peat (Okko 1949). The clay is exposed on the shores of the river, in drains and wherever digging is done. The postglacial isostatic land uplift, which in this area is about 9 mm yr^{-1}, has lifted the clay layers above sea level. These natural processes lower the groundwater table and are enhanced by different drainage operations. In this situation the sulphides, which are stable only under reducing conditions, are oxidised and release acidity and metals. The oxidation takes place in several stages, involving both chemical and microbiological processes. The oxidation of pyrite can be summarised with the following four reactions (Stumm and Morgan 1981):

$$FeS_2(s) + 7/2O_2 + H_2O = Fe_2+ + 2SO_4^{2-} + 2H^+$$
$$Fe^{2+} + 1/4O_2 + H^+ = Fe_3+ + 1/2H_2O$$
$$Fe^{3+} + 3H_2O = Fe(OH)_3(s) + 3H^+$$
$$FeS_2(s) + 14Fe^{3+} = 15Fe^{2+} + 2SO_4^{2-} + 16H^+$$

In this way, the clay horizons above the groundwater table develop into acid sulphate (AS) soils. Soil sulphides are oxidised to sulphuric acid at a rate exceeding soil buffering and neutralising rates, thus causing environmental problems in affected farmlands and watercourses (Alasaarela 1982, Palko *et al.* 1988, Palko and Weppling 1994, Åström and Björklund 1996, Åström 1996). The sulphide oxidation process with subsequent release of acidity is clearly detectable in the AS soil profiles from Himanka (Fig. 5).

Aluminium tends to occupy most cation exchange sites in the acid soil, while base cations and surplus metal cations are subjected to leaching. An ionic composition dominated by acid metal cations balanced by sulphate is established in oxidised layers of the soil, which is rapidly reflected in the chemistry of both drainage waters and their recipients (Hartikainen and Yli-Halla 1986, Weppling 1993).

The severity of the acidity can be evaluated by the minimum pH of the soil profile and the thickness of the transition layer. In extreme cases, the minimum pH in the transition layer is below 3. At Himanka the lowest value measured was 2.68. Below this layer, oxidised conditions rapidly change into reduced conditions, while pH increases towards neutrality. In "normal" profiles, pH slowly increases with depth towards neutrality (Fig. 5).

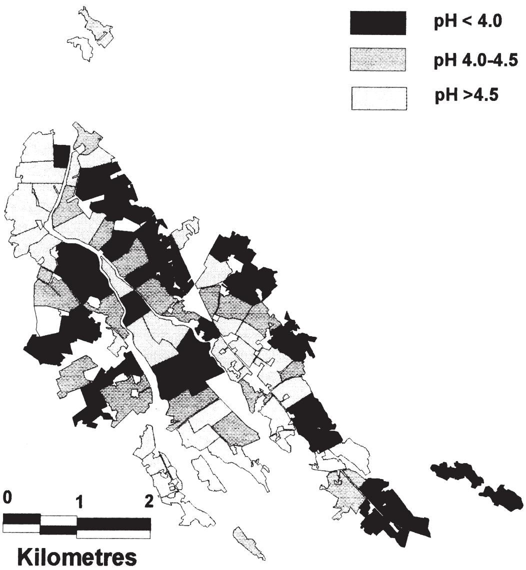

Fig. 6. Map showing subsoil pH minima of 93 soil profiles at Himanka.

AS soils are frequent in the Himanka-Kannus area, which is clearly reflected in the water chemistry of the subsurface drains as low pH and high metal contents (Table 2) and in pH measurements from soil profiles (Figs. 5 and 6). Åström and Björklund (1996) noticed that the electric conductivity and metal contents increased in rivers when the proportion of AS soils in the catchment increased. This is also seen in Lestijoki, where EC and the content of many metals increased 2–3 times from Tornikoski to the outlet at Himanka (Fig. 7).

Sources of metal load

The metal contents increased downstream in Lestijoki with the increase of AS soils and agriculture (Figs. 7 and 8), and the highest metal input was obtained through subsurface drains in AS soils. Subsurface drains draining AS soils in Himanka thus had several times higher metal contents than subsurface drains higher upstream in Kannus, Toholampi and Lestijärvi (Table 2 and Fig. 8). Particularly Fe, Al, Mn, Cu, Zn and Cd, but also Ca, Mg, Na, K, N_{Tot} and P_{Tot} reached several times higher concentrations in this type of water as compared to the other types (Tables 1 and 2). Of the analysed elements, Pb was the only exception having elevated contents in open ditches from forests/peatlands and cultivated land, which might indicate atmospheric deposition.

The maps in Fig. 8 show the situation in autumn 1995. There was no distinct high flow during that period, and due to hydrological reasons the contents were lower than during spring and "normal" autumn conditions. The spatial patterns were, however, the same.

The magnitude of the metal contents in waters from AS soils in Himanka appears in Table 3. The composition of water from subsurface drains, Kinareenoja and Lestijoki is compared with that of 1 165 head water streams in Finland (Lahermo *et al.* 1995), of 39 rivers and brooks along the western coast of Finland draining AS soils (Weppling 1993), and of four "normal" rivers of the same size as Lestijoki in Finland and Sweden. The cations in the head water streams were analysed in filtered samples, which may significantly lower the contents of Fe, Al and Pb due to complexation with suspended material (Edén and Björklund 1993).

Sources of humus and suspended matter

Organic compounds and suspended particles strongly affect the quality of running waters. They are abundant in the waters in the Lestijoki catchment. No analyses of organic matter are available in the studies described here, but Pettersson (1992) and Edén and Björklund (1993) showed that river waters in this region had the highest contents of organic material in Fennoscandia. According to C. Pettersson (unpubl.), the contents of TOC (Total Organic Carbon) were highest in Lestijoki (31 mg l^{-1}) when sampling 27 rivers along the west coast of Finland and the east coast of Sweden. TOC was 7–25 mg l^{-1} in the other rivers in Finland and 2–10 mg l^{-1} in the Swedish rivers. Pettersson (1992) estimated that 80% of the TOC in these waters consist of humic substances.

Colour is an approximate measure of the organic content of water. Table 1 shows that ditches from peatlands/forests and the feeder streams had much higher colour values than other types of drains or the main stream. In autumn 1995, the highest colour values were detected in feeder streams (425 mg Pt l^{-1}) and ditches from peatlands/forests (351

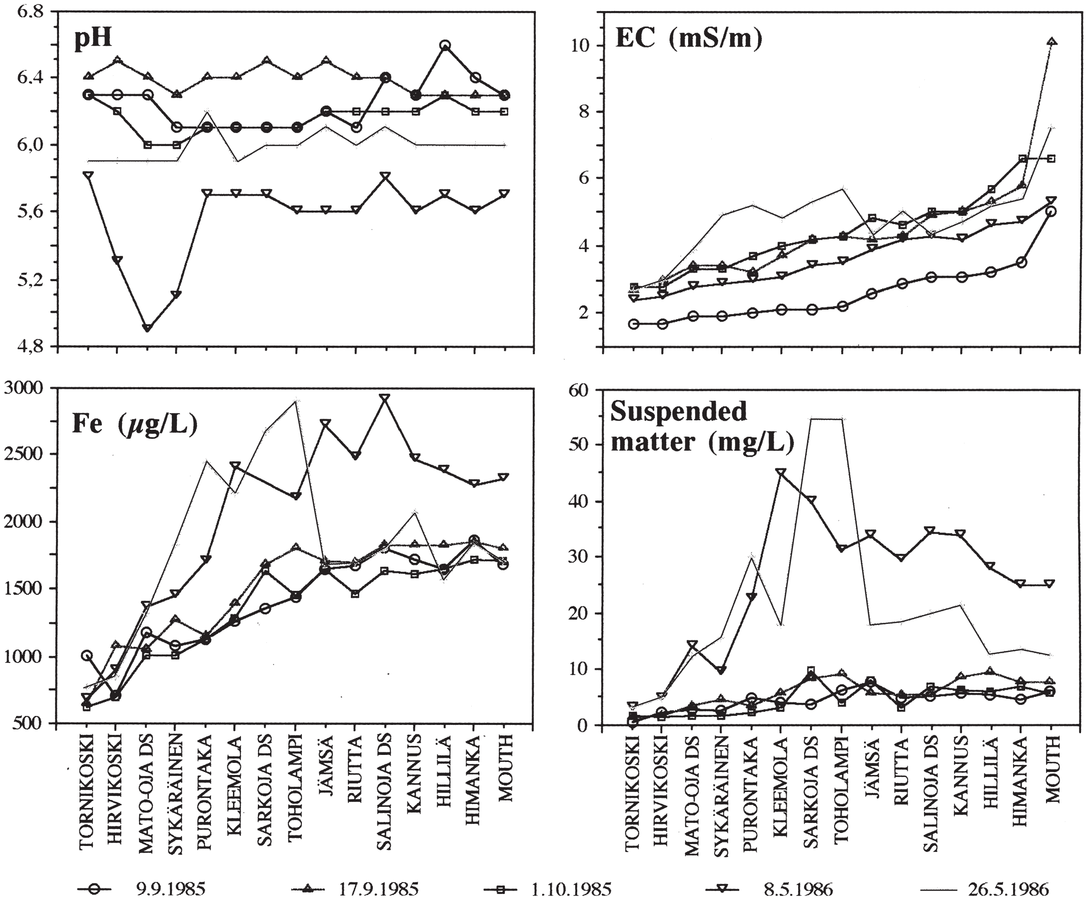

Fig. 7. Profiles of pH, EC, Fe and suspended matter along Lestijoki measured on five occasions in autumn 1985 and spring 1986 (data from M. Kalliolinna unpubl.).

mg Pt l^{-1}) on the SW side of the river. This was 5 times higher than the median for head water streams in Finland (Lahermo *et al.* 1995, Table 3). The surface drains in Sykäräinen and Toholampi had high colour values (> 320 mg Pt l^{-1}), reflecting agriculture on peatlands. The variation in colour along the main stream was quite small. However, the values were much higher than for average streams in Finland or Sweden (Table 3). The organic material, which predominantly consists of humic acids, lowers pH, increases the colour and binds metals. Peatlands and draining of them were the main sources for the organic material (Pettersson 1992, Kortelainen 1993, Myllynen *et al.* 1997).

The amount of suspended matter (>1 mm) was measured in 1985–1986 (M. Kalliolinna unpubl.) and in autumn 1995. In the main stream, high values were detected during high flow in spring in the same area as the highest contents of organic matter. Particles are washed out to the river from the drained and farmed peatlands and in Toholampi also because the river here runs in a deep valley with steep slopes. According to Simonsson (1987), 60%–80% of the suspended material in waters from newly drained peatlands consist of organic material. The waters with the highest contents of humus/suspended matter also have the highest contents of most metals, probably due to complexation.

Consequences of the load

The composition of the water in Lestijoki was similar to that of the other streams in western Finland draining AS soils. Electric conductivity and

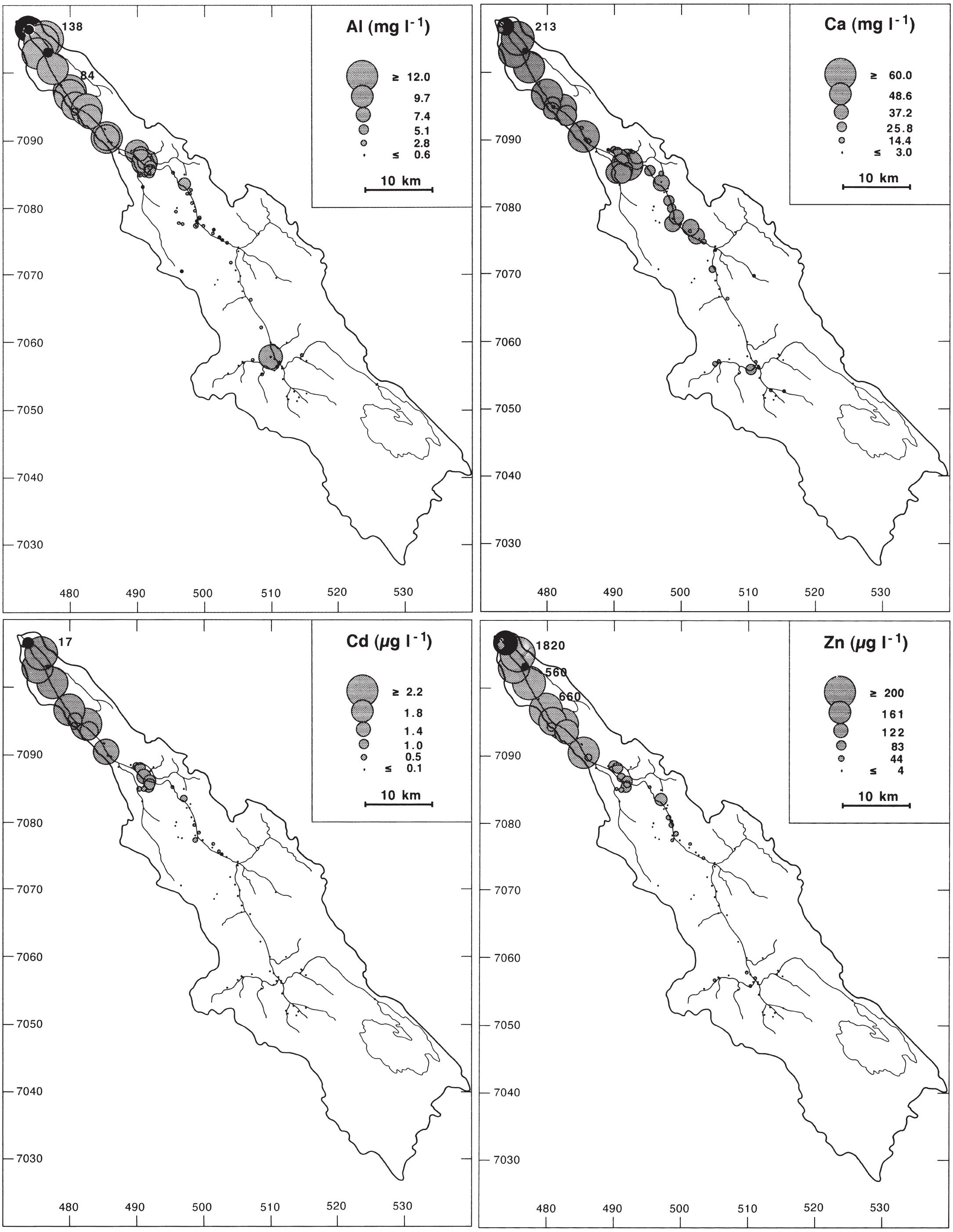

Fig. 8. Dot maps showing the contents of Al, Ca, Cd and Zn in autumn 1995 in water from Lestijoki, feeder streams and different kinds of drains/ditches.

metal contents increased rapidly downstream due to the increase of AS soils and agriculture (Figs. 7 and 8, Åström and Björklund 1996). Compared to "normal" streams in Finland and other parts of Fennoscandia, pH was much lower, while the contents of Fe, Al, Mn, Na, K, N_{Tot}, P_{Tot}, TOC and colour were 2–5 times higher, and the content of suspended matter even 20 times higher in Lestijoki (Table 3).

These circumstances, corresponding to those seen by Kjellman *et al*. (1994) and Myllynen *et al*. (1997), cause severe environmental problems, which at high runoff during snowmelt in spring, after rain periods in autumn, and also after occasional heavy rains in summer may cause reproduction failure and even mass kills of larvae and spawn in both the river and the estuary. The severity of the fluxes depend on the climatological conditions. The fluxes during spring flood are stronger after long, cold and snowrich winters with frozen ground and fast melting of snow and ground. The fluxes in summer or autumn are stronger if a long dry period is followed by sudden and heavy rains. The stronger the runoff, the higher the load of acidity, metals, humus and suspended matter.

According to experiments by Myllynen *et al.* (1997) larvae of lamprey start to die when pH in humic stream waters decreases below 5.0, and 100% have died when pH reaches 4.5. Increased Fe content (2 mg l^{-1}) will kill almost all larvae already at pH 5.0, while high Al contents have only small consequences, probably because Al is bound to the humic matter. Myllynen *et al*. (1997) also mixed acid (pH 4.7) and metal-rich drain water with stream water (pH 6.2). The eggs started to die when the ratio stream water:drain water was 3:1 and pH was 5.5. The water then had 2.7 mg l^{-1} of Fe and 1.3 mg l^{-1} of Al. In water from the drain alone less than 20% of the larvae survived longer than 72 hours.

The results for Lestijoki obtained in the present survey 1995, by M. Kalliolinna (unpubl.) 1985–1986, and by monitoring 1962–1986 (Jokela 1988), indicate that conditions causing larvae and egg deaths and reproduction failure (Kjellman *et al*. 1994, Myllynen *et al*. 1997) occur frequently in both drains/ditches, small and big feeder streams (Table 3), and occasionally also in the main stream. Immediately upstream from Sykäräinen pH in the river is often below the critical value 5.0 during high flow. In Toholampi and Himanka, annual monitoring on several occasions shows a minimum pH of 4.9 at both sites, and a maximum Fe content of 3.4 and 7.3 mg l^{-1}, respectively. These conditions probably cause severe damages to the fish populations in the light of the experiments described above. Mass kills of fish exposed to water chemical conditions comparable to those described above were reported

Table 3. Median values for different parameters in waters from subsurface drains in AS soils in Himanka, from rivers and brooks draining AS soils in western Finland (Weppling 1993), from 1 165 headwater streams in Finland (Lahermo *et al.* 1995), mean for Kinareenoja, annual means for Lestijoki (measured 1995 in Himanka) and for four "normal" rivers in Finland (Simojoki and Suojoki; Finnish Board of Waters and the Environment) and Sweden (Moälven and Örekilsälven; National Swedish Environmental Protection Board). [1)] Not analysed in the Swedish rivers. *n* = number of samples.

	AS soils Himanka	Kinareenoja	AS soils W Finland	Headwater streams	Lestijoki	FIN + SWE (4 rivers)
pH	4.08	4.45	4.90	5.91	6.4	6.7
EC (mS m^{-1})	99.8	30.5	24.5	4.4	5.5	3.6
Colour (Pt mg l^{-1})	120	160	180	80	197	95[1)]
Fe (mg l^{-1})	20.2	2.5	3.2	0.68	2.67	1.02
Mn (µg l^{-1})	3047	531	600	29	83	45
Al (µg l^{-1})	16 300	5 000	2 900	95	1 017	180[1)]
Cu (µg l^{-1})	30.0	7.3	–	0.6	2.0	2.0
Zn (µg l^{-1})	290.0	69.0	–	3.6	7.6	12.0
Pb (µg l^{-1})	0.1	0.1	–	0.2	0.8	–
Cd (µg l^{-1})	2.0	0.4	–	0.01	0.03	–
Ca (mg l^{-1})	71.5	15.3	13.0	4.1	4.0	4.7
Mg (mg l^{-1})	29.8	9.0	7.8	1.4	1.6	1.5
Na (mg l^{-1})	8.2	8.6	–	2.1	2.7	1.6
K (mg l^{-1})	18.5	4.4	–	0.7	1.8	0.7
n	12	2	39	1 165	9	32

from the estuary of Kyrönjoki 140 km southwest of Lestijoki (Hudd *et al*. 1984).

Many rivers along the west coast of Finland have even bigger problems than Lestijoki during most of the year, and are considered ecologically destroyed (Rantala 1991). In order to improve the water quality, lowering of the water table in AS soils should be prohibited (Åström 1996), and draining of peatlands should be stopped. The runoff through existing ditches should be slowed down to reduce the fluxes of organic acids and suspended material. Appropriate mitigation methods, such as in-stream liming (Rantala 1991, Weppling 1993) and lime filter drainage (Weppling *et al*. 1995), should be applied in situations, where ecologically important watercourses are threathened by acidification.

There are approximately 336 000 ha of AS soils along the coast of Finland (Palko 1994), quite unevenly distributed. These soils form an everlasting problem for agriculture and environmental protection, because "new" AS soils are forming as long as the natural land uplift continues. The extent of AS soils was mapped in Himanka and draining was done in 1997 using lime filters, partly as a result of the present study and in co-operation between the local farmers, WWF in Finland, environmental and agricultural authorities. This type of drainage should lower the fluxes of acidity, nutrients and metals (Weppling *et al*. 1995). Lestijoki has small populations of some valuable species (e.g., sea trout and lamprey), which may still be saved by appropriate mitigative actions. The experiences from Lestijoki might help decisionmakers to start similar actions in other problematic river catchments.

Conclusions

The results of the present study in Lestijoki point out three problem areas. The AS soils in Himanka and the western parts of Kannus cause problems in form of low pH, high acidity and high metal contents in the watercourses. At Sykäräinen and on the SW side of the river between Sykäräinen and Kannus, drained and cultivated peatlands lower pH and increase the content of suspended matter and metals bound to it. In these areas the loads of acidity, metals, humus and suspended matter are several times higher than in Finnish and Fennoscandian rivers in general. During high flow in spring, autumn and after occasional heavy rains in the summer, the loads reach levels deleterious for many species living in the river.

Causes to the different types of load in Lestijoki and many other streams and rivers in western Finland are:

1. Sulphide-bearing clay/silt sediments, which change into AS soils due to natural land uplift enhanced by agricultural draining. The AS soils cause acidification and high metal contents of the waters.
2. Peatlands, which release high contents of organic acids, humus and suspended matter enhanced by abundant draining.

In order to improve the water quality, lowering of the water table in AS soils should be prohibited, draining of peatlands should be stopped, and runoff through existing ditches should be slowed down to reduce the fluxes. Appropriate mitigation methods, such as in-stream liming and lime filter drainage, should be applied where ecologically important watercourses are threathened by acidification.

The AS soils along the west coast of Finland form an everlasting problem for agriculture and environmental protection, because "new" AS soils are forming as long as the natural land uplift continues. In order to locate and quantify the total extent of AS soils, a thorough mapping should be conducted to reveal the areas, where steps should be taken to decrease the deterioration of the watercourses.

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