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Effects of forestry ditch cleaning and supplementary ditching on water quality

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The effects of ditch cleaning and additional ditching of forest land were studied at a site in central Finland. The results from the two first years demonstrate that the influence of these measures on water quality is very similar to that of new forest ditching, i.e. the increases in total solids, total phosphorus, total nitrogen, pH and buffering capacity are of the same order of magnitude. On the other hand, the amount of ammonia increased more than in most new ditchings in Finland. Nitrate nitrogen load increased due to the high cocentrations during the snow melt in April–May 1994 and the variability in iron and manganese cocentrations were more pronounced. The amount of total solids deposited on artificial surfaces (plastic plates) in the brook Ruununsuonoja increased four-fold, mineral solids five-fold and organic solids 3.5-fold after ditching. The most striking changes in the microalgal flora in the first year after ditching of the Ruununsuo drainage area were the decline in the mainly acidophilic diatoms of the family *Eunotia* and in the green algae and the increase in family *Euglenophyceae* and the diatom genera *Nitzschia* and *Tabellaria*, mainly due to the increase in pH, nutrient status and organic matter in the brook.

Introduction

The hydrological and biological effects of forestry in Finland have been widely studied within the Finnish Nurmes project which was started in 1978 in north Karelia, Finland (Ahtiainen 1988, 1990, Holopainen *et al*. 1988, Huttunen *et al*. 1988, Seuna 1988, Holopainen and Huttunen 1998). In addition, Kenttämies (1981), and Kenttämies and Laine (1984) have dealt with the effects of forest ditching and Sallantaus (1986, 1988) with those of peat mining and forestry. In Sweden, this subject has been studied by e.g. Bergqvist *et al*. (1984) and Lundin (1988). Along with this present work, Ahti *et al*. (1995) studied water loading in connection with the cleaning of ditches and E. Ahti, S. Joensuu and M. Vuollekoski (unpubl.) the effectiveness of sedimentation basins for removing solids and nutrients from water originating from ditched forestry areas. The papers by Seuna (1981, 1982, 1988) are concerned with the hydrological effects of forest drainage. The present paper presents results of a project studying the loading and biological effects caused by ditch cleaning

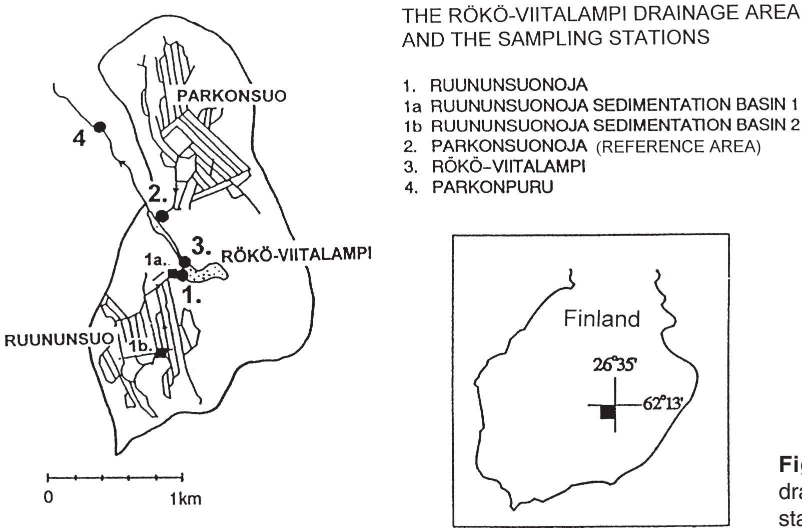

Fig. 1. The Rökö-Viitalampi drainage area and the sampling stations.

and the additional ditching of forest land focused on in Kangasniemi, in the north-western part of the province of Mikkeli Finland.

Materials and methods

The Rökö-Viitalampi drainage area includes two smaller drainage areas which had been ditched in 1964–1965. Those ditches were cleaned and additional ditching performed in the Ruununsuo area in 1992 while the other area, Parkonsuo, was left undisturbed as a control. All the sampling stations in both of the areas were monitored in an untouched state for nearly four years from 1988 onwards, before the ditch cleaning and additional ditching in the Ruununsuo drainage area was carried out. Water samples were taken manually weekly in April–June, twice a month in September–November and monthly during the winter and the midsummer period. Flow rates were measured using V-notch Thomson weirs equipped with a graphic water level recorder that allowed continuous measurement. All water quality parameters were measured and analysed by standard methods used at the National Board of Waters (Vesihallitus 1981, 1984). The leaching was calculated using monthly runoffs and flow-weighted monthly averages. The loads were calculated for the period between April and October each year. Some 2 800 m of ditches were cleaned and 12 000 m of new ditches were dug in July 1992 leading to a total ditched area of 68 ha. Two small sedimentation basins were constructed to the Ruununsuo brook (Fig. 1), the effective volume of the upper basin (1b) being 100 m^3 and that of the lower one (1a) about 110 m^3. The drainage area of Rökö-Viitalampi amounts to about 3 km^2, the Ruununsuo basin accounting for 1 km^2 and Parkonsuo about 0.5 km^2. The dominant tree species in both areas is the Scots pine (*Pinus silvestris*). The soil of the whole Rökö-Viitalampi area consists of peat and sandy till overlying metabasalt, greystone and amphibolite. The forest types represented are of pine bog and fresh and fairly dry heath forest (Table 1).

Table 1. The Ruununsuo and Parkonsuo areas: Forest and mire type.

	Ruununsuo	Parkonsuo (Reference area)
Fresh heath (Myrtillus type)	41%	30%
Dry heath (Vaccinum type	9%	13%
Dry transitional pine bog	30%	5%
Fairly dry **tr**. pine bog	11%	52%
Wasteland	10%	–

The Ruununsuo drainage area was partly fertilized with PK (11 ha) and NPK (23 ha) fertilizers in 1972. The Parkonsuo control area was not fertilized but some other parts of the Rökö-Viitalampi (32.5 ha) also received PK fertilizer in 1972. Small parts of the Rökö-Viitalampi drainage area were felled in 1990–1994.

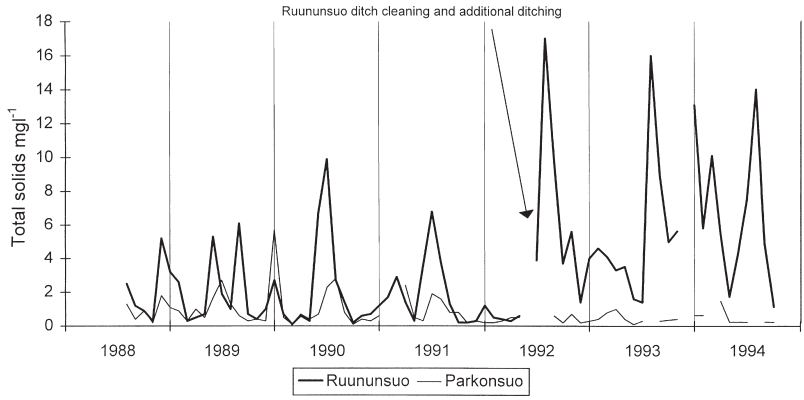

Fig. 2. Monthly mean concentrations of total solids in the brook Ruununsuonoja before and after ditch cleaning and additional ditching as compared with Parkonsuonoja (reference area).

The periphyton incubation was carried out on artificial substrates comprising polycarbonate plastic plates (100 × 150 × 2) mm fastened horizontally on one edge onto stands made of bricks. The water current speed was chosen to vary on a scale between about 6 to 20 cm^{-1} at all stations. The locations selected for incubation were the same as those used for measuring water quality. After a three week incubation period the plastic plates were taken away and packed in plastic bags in a dark and cool place for transport to the laboratory. The plates were refrigerated and analyzed by scraping the material from the surface into a known amount of water (Eloranta and Kunnas 1976, 1979, Weitzel 1979, Heinonen 1981, 1984). Chlorophyll *a*, total organic and inorganic solids were analysed according to standard methods (Vesihallitus 1981, 1984). Primary production and dark fixation were determined according to the Finnish SFS standard 3049 and alkaline metals, alkaline earth metals and heavy metals were analysed by the ICP-MS and ICP-AES techniques in the laboratory of the Geological Survey of Finland in Helsinki. Climatic conditions varied greatly in the period 1988-1994 with both warm and cold winters and both rainy and dry summers. Annual mean precipitation during the monitoring period (August 1988–July 1992) was 692 mm (622–810 mm) and during the research period (August 1992–September 1994) 682 mm (599–770 mm). Both periods included low and high spring, summer and autumn precipitation periods. Thus the two periods were fairly comparable in terms of meteorological conditions.

The statistical significances of the changes in water quality at all the sampling stations were tested with the Mann-Whitney *U*-test taking as the grouping variable the time periods before and after ditching.

Results

Total solids

The clearest changes in water quality after ditch cleaning and additional ditching in the Ruununsuo area occurred in the forest brook Ruununsuonoja and the forest lake Rökö-Viitalampi. The concentration of total solids before these measures was 1.4 mg l^{-1} in Ruununsuonoja and 0.8 mg l^{-1} in the reference area Parkonsuonoja, values comparable to those of 0.7 to 2.1 mg l^{-1} recorded for areas in a natural state (Ahtiainen 1988, 1990). A twenty-fold increase was observed in Ruununsuonoja immediately after ditching, however, and values remained at an average level of 5.5 mg l^{-1} for the next two years. This concentration is about four times higher than the reference demonstrating a statistically significant change (Fig. 2, Table 2). The increase in the leaching of total solids was similar (Table 3). Total solids concentration in the Parkonsuonoja control area was on the average 0.4 mg l^{-1}, i.e. lower than the concentrations observed during the calibration period. The 4–6-fold increase in loading with total solids, corresponds to the levels found earlier in Finland (Kenttämies 1981, Seuna 1982, Ahtiainen 1988, 1990) although the absolute concentrations are quite low. The increase in total solids in Rökö-Viitalampi and Parkonpuru was lower, about 40% of the values during the calibration period.

Phosphorus and nitrogen

The mean total phosphorus content in both of the brooks was higher during the calibration period (Ruununsuonoja 43 µgPl^{-1} and Parkonsuonoja 37 µgPl^{-1}, median values) than is generally found in areas in a natural state, 13–35 µg l^{-1} (Kenttämies 1981, Sallantaus 1986, Rekolainen 1980, Ahtiainen 1990) (Fig. 3). Total phosphorus increased 1.3 fold and the total phosphorus and inorganic orthophosphate phosphorus load about two-fold in Ruununsuonoja after ditch cleaning and additional ditching (Table 3) being a statistically significant rise (Table 2).

The mean total phosphorus concentration in Ruununsuonoja after ditching was 46 µg l^{-1}, about the same as before the measures while at the same time the phosphorus content in Parkonsuonoja control area fell by 16% (also taken into account in the calculation).

Leaching of phosphorus varies greatly in the cases studied previously but the mean rise after new ditching was approximately 1.5–2-fold (Kenttämies 1981, Bergqvist *et al*. 1984, Sallantaus 1986, Ahtiainen 1990). Inorganic orthophosphate accounted for 50% of total phosphorus in Ruununsuonoja before ditching and 30% during the following two years. Filterable dissolved phosphorus was 70% of total phosphorus before ditching and 59% after ditching but this ratio for orthophosphate was 70% both before and after ditching. Thus the ditching procedures mainly increased the amount of phosphorus bound in total solids.

Total nitrogen concentration rose steeply immediately after ditching but quickly fell again and was during the following two years on the average 1 100 µg l^{-1}, clearly higher than the mean concentration before ditching, 720 µg l^{-1} (Fig. 4), a result which is statistically significant (Table 2). The leaching of nitrogen in Ruununsuonoja increased

Table 2. Statistical significances of the changes in water quality at the four sampling stations after ditch cleaning and supplementary forest ditching in the Ruununsuo drainage area. The significances of the changes in the factors before and after ditching are presented in the following table where: *** = $p < 0.001$, ** = $p < 0.01$, * = $p < 0.05$ and ° = $0.05 < p < 0.1$. The signs in parentheses denote negative change (values were lower during the measuring period than during the calibration period).

	Ruununsuonoja	Parkonsuonoja	Rökö-Viitalampi	Parkonpuru
Turbidity	***		*	°
Total solids	***	(*)	*	°
Electrical conductivity	***			
Gran-alkalinity/acidity	***		***	*
pH	***	(°)	**	°
Water colour				
COD_{MN}	**			
Total nitrogen	***	**	**	**
Nitrite nitrogen			(*)	
Nitrate nitrogen	(***)	(***)	(°)	(**)
Ammonium nitrogen	***	(**)		
Total phosphorus		(**)		
Phosphate phosphorus	(**)	(***)	(**)	(**)
Soluble total phosphorus	(**)	(***)	(*)	(*)
Sol. phosphate phosph.	(***)	(***)	(*)	(**)
Iron	***			
Manganese	***		*	*
Potassium	***	(***)		
Calsium	***		°	°
Magnesium	***		°	°
Sodium	**	(°)		
Silica		(°)		
Aluminium	*	*	°	
Copper	***			
Zink	*			**

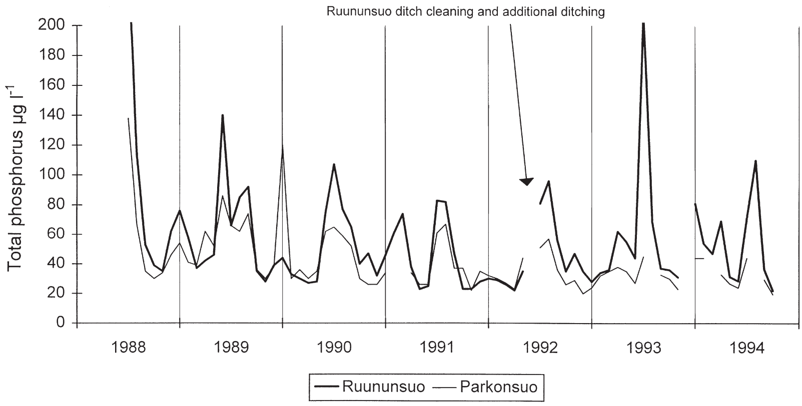

Fig. 3. Monthly mean concentrations of total phosphorus in the brook Ruununsuonoja before and after ditch cleaning and additional ditching as compared with Parkonsuonoja (reference area).

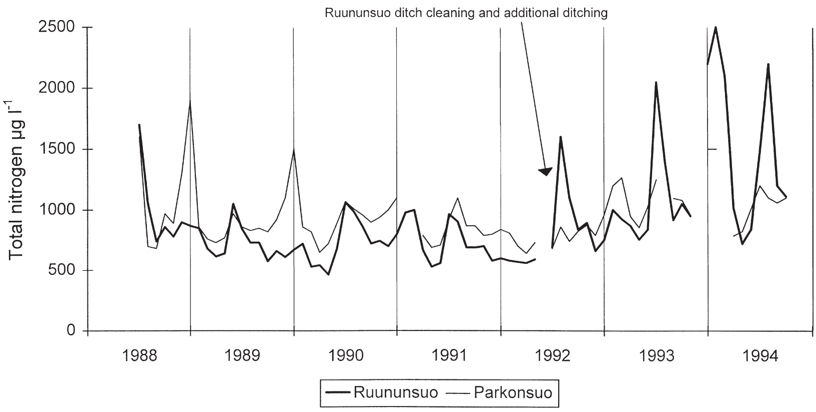

Fig. 4. Monthly mean concentrations of total nitrogen in the brook Ruununsuonoja before and after ditch cleaning and additional ditching as compared with Parkonsuonoja (reference area).

30% after ditching (Table 3).

Inorganic nitrogen as a portion of the total nitrogen rose about two-fold in Ruununsuonoja after ditching, from 12% to 23%, mainly on account of an over four-fold increase in ammonium, from around 60 µg l^{-1} to 283 µg l^{-1}. The highest concentrations of nitrate nitrogen in the Ruununsuo basin were obtained during the spring high water season in 1994, about four times higher than in the control area.

Buffering capacity and pH

The arithmetic mean of the pH in Ruununsuonoja rose to 5.7, and remained 0.8–0.9 units higher than before ditching for the next two years (Fig. 5), being a statistically significant change (Table 2). The pH in the Parkonsuonoja reference area remained at the same level as before ditching.

The buffering capacity of the water (Gran-alkalinity/acidity) was low in both of the brooks, with large annual fluctuations. Values during the calibration period were close to zero in Ruununsuonoja and negative (acidity) in Parkonsuonoja. Alkalinity rose from 0 to 0.2 mmol l^{-1} in Ruununsuonoja after ditching and compared to levels in Parkosuonoja over 0.15 mmol l^{-1}. This level was the same over the subsequent two years (Fig. 6, Table 2).

Table 3. Leaching of various substances in Ruununsuonoja before and after ditching in kg ha^{-1}.

	Before	After
Total solids	4.1	15.5
Chemical oxygen demand (COD mn)	119.9	111.9
Total phosphorus	0.08	0.15
Phosphate phosphorus	0.028	0.105
Total nitrogen	1.56	2.04
Nitrate nitrogen	0.044	0.208
Ammonia	0.09	0.60
Iron	4.7	8.4
Manganese	0.13	0.18

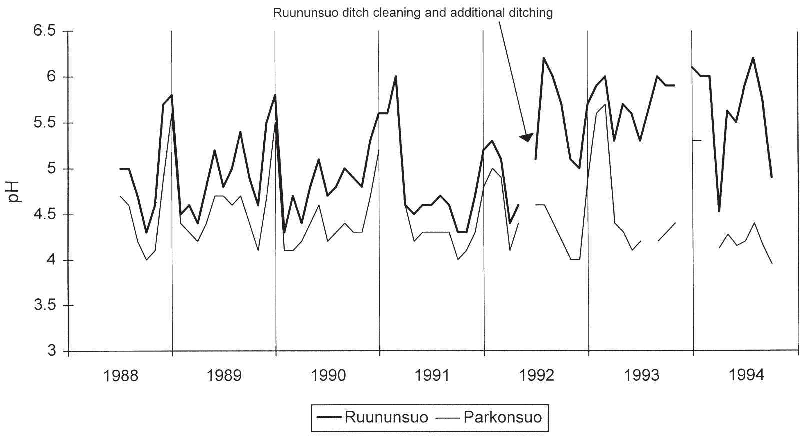

Fig. 5. Monthly mean pH in the brook Ruununsuonoja before and after ditch cleaning and additional ditching as compared with Parkonsuonoja (reference area).

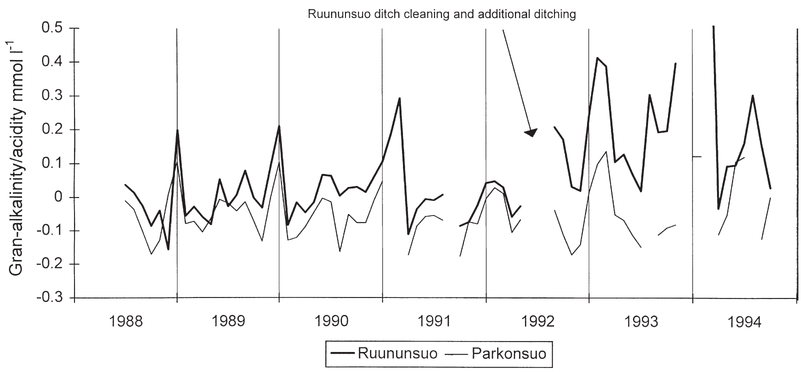

Fig. 6. Monthly mean Gran-alkalinity/acidity in the brook Ruununsuonoja before and after ditch cleaning and additional ditching as compared with Parkonsuonoja (reference area).

Heavy metals and base cations

The iron concentration in the water of Ruununsuonoja rose from around 2 300 μg l^{-1} to 4 500 μg l^{-1} in the two-year period after ditching while manganese rose from 68 μg l^{-1} to 135 μg l^{-1}. Both results are statistically significant (Table 2). The leaching of iron correspondingly increased 1.7-fold and that of manganese 1.4-fold (Table 3). Meanwhile concentrations in the Parkonsuonoja control area were about 10% lower than during the calibration period. The change in iron content varied in previous studies and often failed to be statistically significant (Hynninen and Sepponen 1983, Bergqvist 1984, Ahtiainen 1990). The values obtained for base cations(K, Na, Mg, Ca), and the heavy metal copper (Cu) rose by the following percentage: potassium about 30%, sodium < 20%, calcium and magnesium about 50% and copper 50%. Aluminium and zinc rose about 10%, but the silica concentration did not change. The mean concentrations in Ruununsuonoja before ditching were: K 0.7 mg l^{-1}, Na 1.7 mg l^{-1}, Mg 0.8 mg l^{-1}, Ca 2.8 mg l^{-1}, Cu 1.1 μg l^{-1}, Zn 4 μg l^{-1}, Al 400 μg l^{-1}, SiO_2 7 mg l^{-1}, and the changes in K, Ca, Mg and Cu after ditching were statistically significant, those in Na significant and those in Al and Zn fairly significant (Table 2). No clear changes in concentrations could be seen at the sampling stations at Rökö-Viitalampi and Parkonpuru.

Artificial surfaces

Total solids increased almost four-fold ($p < 0.001$) in Ruununsuonoja during the two-year period after ditching, mineral solids five-fold ($p < 0.001$) and organic solids 3.5-fold ($p < 0.001$). Total solids on artificial surfaces in the control brook Parkonsuonoja decreased by about 50% relative to the calibration period ($p < 0.05$). This decline was mainly caused by a decrease in inorganic solids ($p < 0.01$). In Rökö-Viitalampi the recipient forest lake, total solids on the artificial substrates decreased by about 50% ($p < 0.01$) after ditching and inorganic solids by about 70% ($p < 0.001$) and a decrease was also discernible in Parkonpuru (the outflow from Rökö-Viitalampi). In Rökö-Vitalampi this effect was probably due to the intensive grazing of zooplankton.

During the calibration period 1989–1991 the algal biomass on the artificial surfaces in May–June at all the brook stations was composed of single-celled members of the family *Pleurococcus* and rod-shaped green algae of the families *Mougeotia*, *Cladophora* and *Ulothrix*, especially in Rökö-Viitalampi, while indifferent and acidophilic diatoms (*see* Meriläinen 1967, Huttunen and Turkia 1990) such as *Eunotia praerupta*, *E. pectinalis*, *E. valida*, *E. lunaris, E. rhomboidea* and *Tabellaria flocculosa* and to a certain extent *T. binalis*, *T. quadriseptata*, *Pinnularia gibba* and *P. subcapitata* dominated the algal flora during the summer months at all stations. In the first year after ditching of the Ruununsuo drainage area the most significant changes in the algal flora were a decline in the mainly acidophilic diatoms of the family *Eunotia* and in green algae and an increase in *Euglenophyta*, *Nitzschia* and *T. flocculosa*. The changes were probably due to the increases in pH, nutrients and organic matter in Ruununsuonoja after ditching.

Primary production

^{14}C-primary production measured in Ruununsuonoja (*in vitro*) after ditching increased 1.7-fold (median values) and the chlorophyll *a* content about two-fold compared with the levels before ditching. Due to the high variance, the results are not statistically significant. CO_2 dark fixation varied in general between 1 and 6 mg C m^{-3} d^{-1} during the calibration period with the exception of Parkonsuonoja, where it varied between 6 and 12 mg C m^{-3} d^{-1}. The CO_2 dark fixation level showed no significant alterations in Ruununsuonoja, Rökö-Viitalampi or Parkonpuru after ditching but decreased by 50% in Parkonsuonoja, the control area along with a decrease of about 40%, in primary production. Autotrophy predominated in both of the brooks, in Ruununsuonoja and in Parkonsuonoja control area before and after ditching. In the Nurmes study (first forestry ditching), primary production increased three-fold on average over a period of two years after ditching and algal biomass four-fold. CO_2 dark fixation increased noticeably only two years after ditching (Holopainen *et al* 1988, Huttunen *et al*. 1988, Holopainen and Huttunen 1998).

Other findings

The rise in runoff in Ruununsuonoja during the first year after ditching was about 15% relative to the runoff recorded in Parkonsuonoja, the control area. By the second year 1994 it was practically the same as before ditching. The sedimentation basin 1a (Fig. 1) showed no clear effect on removing solids and nutrients from the water. The only positive effect can be seen just after ditching when the effectiveness of sedimentation basin 1a in removing total solids was 20% and 17% for total P. There was no clear reduction in any of the other parameters measured.

Discussion

Climatic conditions varied greatly both during the calibration period and during the monitoring period both having rainy and dry summer, autumn and spring periods. Thus conditions during the calibration and monitoring periods were well comparable.

Water sampling techniques may affect the final results. The leaching of suspended solids for example is only a rough estimate as there was no continuous sampling procedure available for measuring total solids, and this also applies to the nutrient measurements (Sallantaus 1986). On the other hand, almost all the analyses showed a clear correlation between the values for Parkonsuonoja (reference area) and Ruununsuonoja before forest ditching. The correlation decreased markedly over the two-year period after ditch cleaning and additional ditching.

The results for the first two years after supplementary forest ditching show that the influence of this measure on water quality is very similar to that of initial forest ditching, as the rises in total solids, total phosphorus, total nitrogen, pH and buffering capacity are close to those typical of new forest ditching areas (Ahtiainen 1988, 1990, Seuna 1988, Bergqvist *et al*. 1984, Lundin 1988,

M. Ahtiainen and P. Huttunen unpubl.). On the other hand, ditch network maintenance in the Ruununsuonoja drainage basin consisted to quite a large extent of totally new ditches.

The rise in iron and manganese content in the water was more evident than in the first ditchings in the Nurmes study (Ahtiainen 1990). A rise in iron content of over 2 mg l^{-1} can have significant ecological effects in a water environment. A rise in cation content after ditching is often connected with the depth of the ditch. If it is deep enough and reaches the mineral soil below the peat layer, element values will rise, with peaks observable during the low flow period in winter and late summer, when the proportion of groundwater in the runoff is greatest.

The positive correlation between alkaline earth metals (Ca, Mg) and pH/alkalinity is often strengthened in the runoff after forestry ditching, probably due to the increased proportion of groundwater in the outflow (Bergqvist *et al.* 1984, Ahtiainen 1990). Particularly a marked increase in cation concentrations can be associated with ditch cleaning where the ditches are dug deeper into the mineral soil under the peat, so that the amount of minerogenic groundwater in the runoff increases (Bergqvist *et al.* 1984, Lundin 1988).

The increased carbon dioxide concentration in the rain water in the upper soil layer causes minerals to leach from the top soil, and these are segregated into the illuvial zone in response to the pH neutralizing effect caused by the leaching reactions. Thus the groundwater from the deeper layers will have a higher base cation concentration than in the upper layers (Soveri 1985, Soveri and Ahlberg 1990). Sallantaus (1995) notes that the buffering capacity has not decreased in accordance with the mass balance equations in many ditched areas. The reason being that the water movement, having shifted to deeper peat layers, can release base cations and retain organic acids arising in the surface peat layers.

Forestry ditching in natural, untouched areas has been shown at first to lower the pH in some studies (Ahtiainen 1988, 1990) along with the lowering in the water level. Generally, however, the pH rises 0.2–1 units after ditching (Ramberg 1981, Hynninen and Sepponen 1983, Bergqvist *et al.* 1984, Kenttämies and Laine 1984, Sallantaus 1986, Ahtiainen 1988, 1990). The rise in buffering capacity after ditch cleaning and additional ditching is the most significant alteration in water quality observed here giving high capacity to neutralize the effects of acid precipitation over a period of several years.

The amount of ammonia increased more than previously seen in Finland (Ahtiainen 1988, 1990). Nitrate nitrogen loading increased due to the high values in April–May in spite of lower content in the water during the two years after ditching. The amount of solids deposited on artificial surfaces was well comparable to the values in water and may provide an easy method for monitoring the effectiveness of water protection methods in forestry.

The chlorophyll *a* content of the algae attached in the artificial surfaces before and after ditching showed no difference. This was probably due to the increased turbidity and solids content of the water which accumulated on the surfaces, although the variation between sampling periods was also great. The greatest changes in the algal flora in the first year after ditching of the Ruununsuo drainage area were the declines in the mainly acidophilic diatoms of the family *Eunotia* and in the green algae and increases in *Euglenophyta* and *Nitzschia*. These changes were caused mainly by the increases in pH, nutrient status and organic matter in brook Ruununsuonoja after ditching. The changes in algal species composition in Rökö-Viitalampi point to alterations in nutrient status. In Parkonsuonoja, the control area, the succession of algal species remained the same as during the calibration period. In the Nurmes study performed in north Karelia, Finland, the main factors affecting the algal flora were the increased amount of total phosphorus in the water in the first year after ditching and increased pH and ammonia in the following years and after that the decrease in nutrients and pH (Holopainen and Huttunen 1998).

In general, periphytic diatoms growing on solid substrata are sensitive indicators of water quality, especially of pH, but also of the organic content of the water. Acidophilic and acidobiontic taxa predominate in clear and brown-water lakes with zero or negative alkalinity, and water with positive alkalinity has higher proportions of neutriphilic and alkaliphilic taxa (Eloranta 1990). The present results are in good accordance with this observation.

The sedimentation basin showed no clear effect in removing solids or nutrients from the water. The only positive effect was just after ditching, when the reduction in total solids was about 20% and that in total phosphorus about 17% This was probably due to the ditching, which took place mainly on peatland, where the amount of more easily precipitated mineral solids is moderately low (Ministry of Agriculture and Forestry 1987, Ahti *et al.* 1995) and by the limited dimensions of the basin, which was little over 100 m^3 in size whereas the Finnish recommendation is 100–500 m^3 km^{-2}.

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