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Long-term effects of maintaining ditch networks on runoff water quality

Kunnostusojituksen pitkän ajan vaikutus valumaveden ominaisuuksiin

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The effects of ditch network maintenance on runoff water quality was studied at 23 sites in different parts of Finland. The study included a calibration period of 1–3 years before maintaining the ditches and six years after. No observations were made during winter. After ditch maintenance, which involves either cleaning of old ditches and/or digging of complementary new ditches, the concentrations of suspended solids in runoff water increased immediately. At sites where the ditches cut into fine-textured subsoil, runoff continued to have increased suspended solids concentrations throughout the whole six-year period. However, if the bottom of the ditches consisted of coarse mineral subsoil or peat, the annual mean concentration of suspended solids returned to pre-treatment levels in 5–6 years. Concentrations of mineral nitrogen, especially NH_4-N, increased while the concentration of organic nitrogen decreased after ditch network maintenance. These changes persisted for the whole six-year period. The overall effect of these changes resulted in a slight lowering of total dissolved nitrogen concentrations. With the exception of a few sites, runoff water pH increased after ditch maintenance and remained high during the 6-year period. Concentrations of DOC decreased at all sites after ditch maintenance and was still at a low level after six years. Concentrations of base cations (Ca, Mg, K, Na) increased significantly after ditch maintenance and were still high after six years. High concentrations of Al and Fe immediately after the digging operations were observed in a few sites. Concentration of total dissolved P did not change much and tended to decrease rather than increase.

Key words: ditch maintenance, peatland, runoff quality

INTRODUCTION

Some 6% of the total phosphorus (P) load and 5% of the nitrogen (N) load to the water courses are estimated to be caused by forestry in Finland (Ympäristöministeriö 1998). The major part of this loading results from peatland drainage and site preparations in connection with forest regeneration, which make the soil susceptible to erosion (Maa- ja metsätalousministeriö 1987, Kenttämies & Saukkonen 1996).

Most of the research into the environmental effects of peatland drainage in the 1970's and 80's focused on hydrology (Heikurainen et al. 1978, Seuna 1982, Ahti 1987). The study of the effects of forestry on stream water quality started with the Nurmes project in 1978, in which the loading of headwater streams as a result of forest drainage was studied (Ahtiainen 1988, 1990, Ahtiainen & Huttunen 1995, 1999a). By continuing the monitoring of runoff water quality in the Nurmes basins until today, valuable information on the long-term effects of cuttings and first ditching has been obtained (Ahtiainen & Huttunen 1999a and b, Kenttämies & Vilhunen 1999, Alatalo 1999). Even if forest drainage has not been as extensive in Sweden as in Finland, the environmental effects of forest drainage have been studied for almost as long (Bergqvist et al. 1984, Lundin 1982, 1984, 1992, and 1996).

About 18% of the Finnish forest area consists of drained wetlands, i.e. peatlands and paludified mineral soil sites which have been drained for forestry by open ditches (Finnish Statistical… 1999). After a change in the Forest Improvement Act in 1987 (Yksityismetsätalouden säädökset 1987), the maintenance of the forest ditch networks increased considerably. In the 1990's, about 75 000 hectares of ditch networks were annually maintained, either through the cleaning of old ditches and/or by digging complementary new ditches between the old ones. According to the National Forestry Program accepted by the Finnish government in 1999, the area of ditch network maintenance should increase to 110 000 hectares annually by the year 2010 (Maa- ja metsätalousministeriö 1999). This program includes an assessment of the environmental impacts of ditch network maintenance (Hilden et al. 1999). However, the environmental effects of ditch network maintenance have not been subject to much research so far.

The first study to investigate the effects of ditch maintenance on runoff started in northern Ostrobothnia in 1983 (Ahti et al. 1995a). After a calibration period of six years, runoff and water quality were monitored for five years after ditch cleaning in two small catchments. Kortelainen et al. (1997, 1998, 1999) has compared the water quality from forested catchments dominated by peatlands with upland catchments by using long-term data from a series of catchments described by Seuna (1983). Lahermo et al. (1996) published maps on the water quality of small streams in Finland and also tried to find connections between basin characteristics and runoff water quality.

In this study, the effects of ditch maintenance on runoff water quality during six years after treatment are reported. The study is based the set of catchments described by Ahti et al. (1995b, 1999) and Joensuu et al. (1999a, 1999b). The magnitude and duration of the changes in runoff water quality are related to basin characteristics. The most important water quality parameters from the viewpoint of water protection, i.e. nitrogen (N), dissolved organic carbon (DOC), suspended solid material (SS), phosphorus (P), iron (Fe), aluminium (Al), and pH are concentrated on.

MATERIAL AND METHODS

Study areas

Runoff from 23 catchment areas was monitored in 1990–1998, 1–2 years before and 6 years after ditch network maintenance (Fig 1, Table 1). The catchments were selected in 1995 from the 37 catchments used by Ahti et al. (1995b) and Joensuu et al. (1999a) for studying the effects of sedimentation ponds on the retention of suspended solids after ditch network maintenance. The selection of the 23 catchments was based on geographic distribution and subsoil texture.

The maintenance operations were performed in 1991–1993 according to the original planning performed by the local forestry centres. In addition to the data from the calibration period, data from control catchments were used when estimating the changes in water quality.

The selected catchments varied in area between 26 and 217 ha (Table 1), with a mean of 71 ha. On average, 34 ha in each catchment were subject to ditch maintenance, corresponding to 8.5 km (2.5–14.4 km) of ditches. The catchments included on average 24 ha of upland mineral soil sites and 13 ha of peatlands which were either pristine or left outside the maintenance operation. Most of the ditch maintenance involved cleaning of old ditches; 1.8–18.4 km per catchment. On average, 3 km of complementary new ditches were dug per catchment. The mean ditch density after maintenance was 250 m ha^{-1}.

The tree stands and the site types were characterised by applying the TASO forestry planning system (Kinnunen & Ärölä 1993). The volume of tree stands averaged across all catchments was 65 $m^3 ha^{-1}$ (variation range 15–190 $m^3 ha^{-1}$). The corresponding characteristic for the peatland forest stands only was 58 $m^3 ha^{-1}$.

The soil characteristics of the ditch maintenance areas were inventoried systematically along the ditches in 1994. At a minimum of 50 sampling points per site, the depths of the ditch and the peat layer were measured, and additionally subsoil texture, peat type and peat decomposition (von Post) were subjectively determined for the different soil layers visible in the ditch profile. Soil characteristics for the bottom layer of the ditches, i.e. the part of the ditch which is most closely in contact with runoff water, are given in Table 1.

Water sampling

Runoff water sampling was started during the snowmelt period in spring and continued once a week until the freezing period in late autumn. No water samples were taken during winter. The total number of water samples was 3867 (between 108 and 244 samples per catchment). The samples were taken directly into 500 ml polyethene bottles from flowing water in the middle of the main ditch. The samples were sent to the Central Laboratory of the Finnish Forest Research Institute (FFRI), and were stored for analysis at 5 °C.

Electric conductivity and pH were determined using the standard methods of FFRI (Jarva & Tervahauta 1993). The samples were filtered and the fibre glass filters (pore size 1.2 µm) were weighed for suspended solids after drying at 60 °C (Joensuu *et al.* 1999a). Concentrations of total dissolved phosphorus, sodium, potassium, magnesium, calcium, aluminium and iron were determined from the filtrates using a plasma emission spectrophotometer (ICP/AES, ARL 3580). Total dissolved nitrogen (N_{tot}), ammonium (NH_4), and nitrate (NO_3) were determined spectrophotometrically with a Tecaton FIA-analyser. The concentration of dissolved organic matter was determined as $KMnO_4$-consumption in 1990–91 and as dissolved organic carbon (DOC) with a Shimadzu carbon analyser from 1992 onwards. For 750 samples, the determination was done by

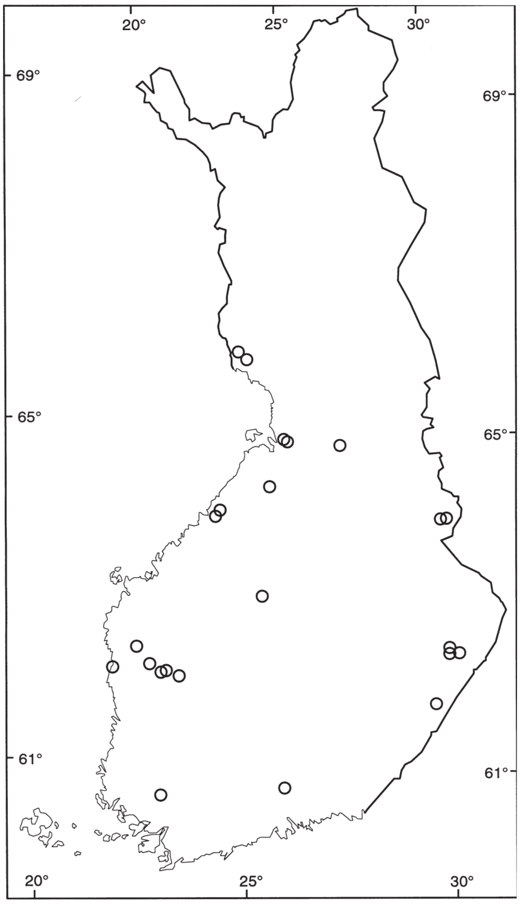

Fig. 1. Location of catchment sites

Kuva 1. Tutkimusalueiden sijainti

both methods and the values of $KMnO_4$-consumption were converted to DOC by using the following equation (Joensuu et al. 2001):

$$C_{DOC} = 0.164\ C_{KMnO4} + 3.2 \quad (1)$$
$$(r^2 = 0.978)$$

The catchment characteristics and runoff water quality are described by using basic statistics: distributions, means, medians, and standard errors. The duration of the effects as well as the relationships between water quality and basin characteristics were examined using the Mann-Whitney U-test, which is suitable for skewed distributions, and correlation (Pearson) and regression (SYSTAT 1996) statistics.

Table 1. Some basin characteristics. [1]Soil texture and type at bottom of new or maintained ditches, in km of ditch. Fine = mineral soil dominated by clay and/or fine loam, medium = mineral soil dominated by coarse loam and/or silt, coarse = mineral soil dominated by sand and/or gravel.

Taulukko 1. Valuma-alueiden ominaisuuksia. [1]Kivennäismaalajiteluokkien ja turpeen osuus kunnostusojien pohjassa, km ojaa. Hieno= saven tai henon hiesun vallitsema kivennäismaa, keskikarkea = karkean hiesun tai hiedan vallitsema kivennäismaa, karkea = hiekan tai soran vallitsema kivennäismaa.

Catchment *Valuma-alue*	Location *Sijainti*	Total area *Val.al. pinta-ala* ha	Treated area *Kunn.oj. ala* ha	Fertile peatlands *Reheviä soita* %	Poor peatlands *Karuja soita* %	[1]Bottom Soil texture and type — *Pohjamaan tyyppi*: Fine *Hieno*	Medium *Keskik.*	Coarse *Karkea*	Peat *Turve*	Total *Yht.*
						km of ditch — *km ojaa*				
Pöytyä	60°42’N, 22°49’E	33.3	13.9	60.0	0.0	3.92	0.00	0.28	0.00	4.2
Karvia	62°10’N, 22°39’E	31.3	29.2	0.0	100.0	0.00	3.75	0.85	0.00	4.6
Karvia	62°11’N, 22°46’E	79.0	17.4	0.0	100.0	0.00	11.08	3.12	0.00	14.2
Kihniö	62°08’N, 23°07’E	42.9	19.5	2.0	98.0	0.00	0.00	0.00	3.97	4.0
Orimattila	60°51’N, 25°51’E	75.2	35.7	14.3	85.7	2.05	0.00	0.00	6.38	8.4
Pyhäselkä	62°28’N, 30°04’E	24.8	24.8	0.0	61.5	0.00	0.79	0.00	1.71	2.5
Pyhäselkä	62°29’N, 30°04’E	59.8	25.8	35.0	5.0	0.00	1.96	0.00	1.54	3.5
Kiihtelysvaara	62°25’N, 30°18’E	100.2	25.3	12.0	62.0	0.00	0.47	2.24	3.19	5.9
Punkaharju	61°59’N, 29°40’E	64.1	24.4	12.2	68.3	0.00	0.31	1.38	4.61	6.3
Kinnula	63°22’N, 25°12’E	217.0	22.6	22.1	17.3	1.45	0.26	0.00	4.88	6.6
Isojoki	62°11’N, 21°53’E	48.8	14.9	0.0	61.4	0.29	3.05	0.57	0.19	4.1
Kauhajoki	62°26’N, 21°59’E	87.6	51.2	0.0	77.8	0.00	0.00	7.60	1.20	8.8
Kauhajoki	62°15’N, 22°20’E	89.1	69.3	0.0	20.9	0.00	13.51	3.47	2.32	19.3
Kannus	64°03’N, 23°58’E	26.2	15.5	9.1	40.9	2.36	0.16	0.31	2.67	5.5
Kalajoki	64°07’N, 23°58’E	97.0	83.1	41.7	0.0	0.28	2.17	8.11	3.24	13.8
Kuhmo	64°01’N, 30°09’E	63.4	22.9	21.6	41.2	0.00	0.79	0.00	5.91	6.7
Kuhmo	64°01’N, 29°59’E	119.9	45.1	0.0	78.4	0.00	2.35	0.00	8.55	10.9
Vihanti	64°25’N, 25°18’E	38.0	29.8	17.0	38.3	0.14	0.00	2.44	3.93	6.5
Oulu	64°57’N, 25°46’E	147.8	33.7	36.9	2.9	0.90	0.36	1.62	5.92	8.8
Oulu	64°59’N, 25°40’E	122.6	57.7	0.0	9.8	0.00	0.55	12.63	0.83	14.0
Utajärvi	64°55’N, 27°15’E	48.6	45.7	4.0	26.0	1.44	12.38	0.58	0.00	14.4
Keminmaa	65°55’N, 24°55’E	146.0	54.6	80.0	0.0	0.00	1.25	5.00	6.25	12.5
Tornio	66°00’N, 24°17’E	30.0	23.4	94.0	0.0	0.00	2.21	0.14	4.55	6.9

RESULTS

Nitrogen

The mean annual concentration of N_{tot} during the calibration period was 0.78 mg l^{-1}. After ditch network maintenance the annual N_{tot} concentrations varied between 0.59 and 0.67 mg l^{-1}. The basin mean varied from 0.32 to 1.30 before and from 0.31 to 1.16 after the treatment. The slight decrease in N_{tot}-concentration found during the first three years (Ahti et al. 1999) was still seen in the sixth year after the maintenance (Fig. 2).

Before treatment, catchment mean concentration of NH_4–N varied between 0.001 and 0.142, and after ditch maintenance between 0.004 and 0.405 mg l^{-1}.

Mean NO_3-N concentrations were lover for the treatment sites compared to the control sites during the pre-treatment period and the difference was significant (Fig. 2). The effect of ditch maintenance on NO_3 concentrations was therefore difficult to ascertain.

Mean annual concentrations of mineral nitrogen (NO_3-N + NH_4-N) generally remained at a raised level in the treatment catchments during the whole six-year period compared to the control catchments. The catchment mean annual N_{min} concentration varied between 0.15 and 0.19 mg l^{-1} after the treatments, and between 0.05 and 0.08 mg l^{-1} in the control sites. The concentration of organic nitrogen (N_{tot}–N_{min}) decreased significantly after ditch network maintenance and remained low during the whole six-year period (Fig 2).

Phosphorus

During the pre-treatment period, catchment mean annual concentrations of dissolved total phosphorus varied between 0.027 and 0.458 mg l^{-1}. In the post-treatment period, the corresponding variation was from 0.031 to 0.143 mg l^{-1}. The distinct decrease in the maximum value was due to usually high concentrations before maintenance at one site, Ruskeesuo, and the marked decrease after treatment.

In the first year of the post-treatment period, P concentrations tended to increase in the runoff water from both treated and control sites. In the control sites this increase exceeded the corresponding increase in the treated sites (Ahti et al. 1999). During the five last years of the post-treatment period, P concentrations were lower than during the calibration period. Phosphorus concentrations in the control sites were also lover during the treatment period than in the calibration period and, consequently, concentrations from the control and treatment sites did not show any statistically significant difference. In the sixth year of the post-treatment period, P concentrations from the treatment sites were, however, lower than in the control areas and the difference was significant ($p<0.01$) (Fig. 2).

During the pre-treatment period, the monthly concentrations of total dissolved phosphorus were positively correlated with organic nitrogen and DOC concentrations (Table 2). In the post-treatment period, the P concentrations were also positively correlated with the concentrations of sodium, potassium, magnesium, aluminium and iron.

Suspended solids

Mean annual concentrations of suspended solids increased considerably after ditch maintenance. The increase was most conspicuous in the first year after maintenance, particularly in the following spring (Joensuu et al. 1999a, Ahti et al. 1999), but could still be clearly seen in the sixth year after treatment (Fig. 2).

The type of subsoil explained 62% of the variation in the concentration of suspended solids (Joensuu et al. 1999a):

$$C_{ss}=-11.2 + 19.6L_{ft} + 7.52L_{mt} + 3.82L_{ct} + 1.49L_p \quad (2)$$
$$(r^2 = 0.62, F = 9.84, p<0.001)$$

where C_{ss} = concentration of suspended solids, mg l^{-1}, L_{ft} = total length of the ditches dug into fine-textured subsoil within each catchment, km ($p<0.01$), L_{mt} = total length of the ditches dug into medium-textured subsoil, km ($p<0.001$), L_{ct} = total length of the ditches dug into coarse-textured subsoil, km ($p<0.05$) and L_p = total length of the ditches dug into deep peat, km.

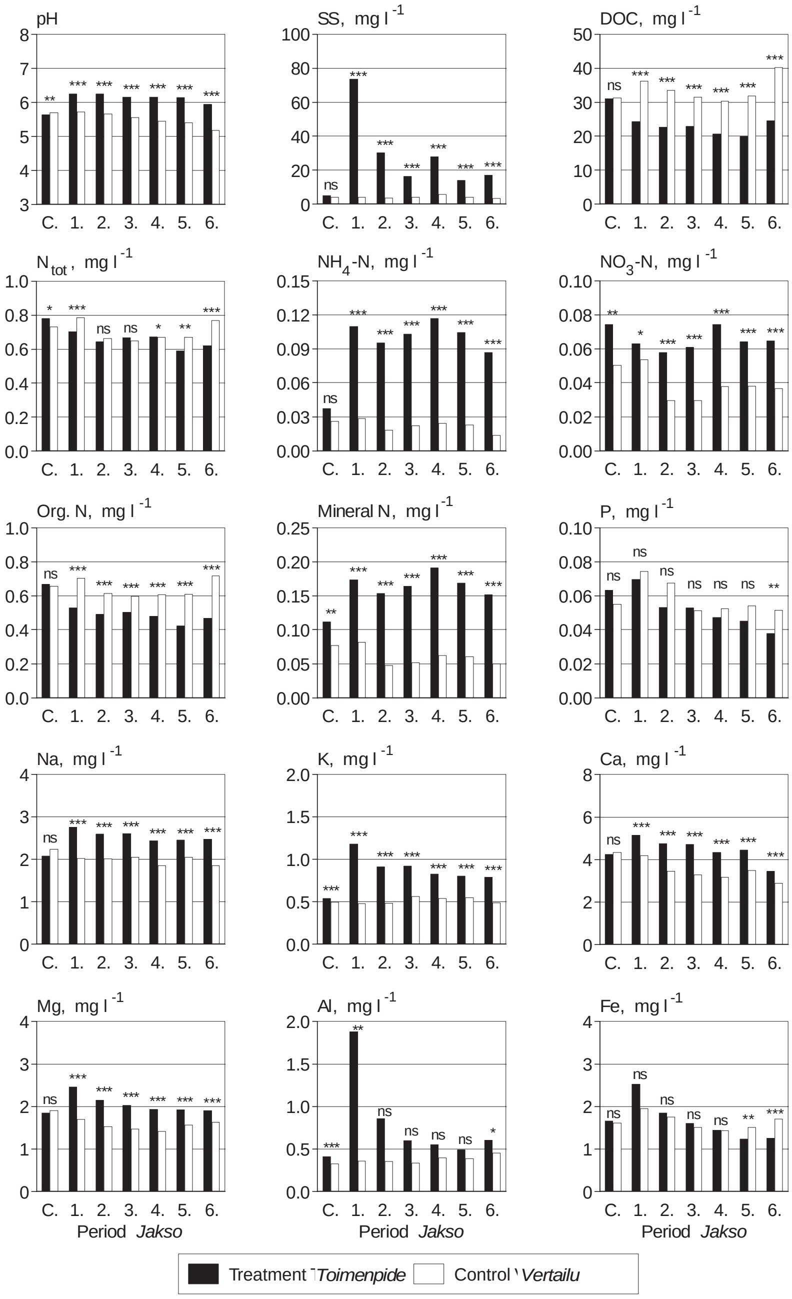

Fig. 2. Mean pH, electric conducitivity (EC) and concentrations of suspended solids (SS), DOC, N_{tot}, NH_4-N, NO_3-N, organic N, mineral N, total dissolved P, Na, K, Ca, Mg, Al and Fe in treated areas and control areas before ditch network maintenance and in six years after it. Significant differences between control and treatment (Mann-Whitney U-test): ns = nonsignificant, * = $p< 0.05$, ** = $p < 0.01$, *** = $p < 0.001$. C.= calibration period, 1.–6. = years after treatment.

*Kuva 2. pH:n ja sähkönjohtavuuden (EC) sekä kiintoaine- (SS), N_{tot}-, NH_4-N-, NO_3-N-, orgaanisen typen, mineraalitypen, P-, Na-, K-, Ca-, Mg-, Al- ja Fe-pitoisuuksien keskiarvot vertailualueilla ja toimenpidealueilla ennen kunnostusojitusta ja kuutena vuotena kunnostusojituksen jälkeen. Vertailu- ja toimenpidealueiden merkitsevät erot: ns = ei merkitsevä * = p<0.05, ** = p<0.01, *** = p<0.001. C. = kalibrointijakso, 1.–6. = kunnostusojituksen jälkeiset vuodet.*

DOC and pH

Pre-treatment mean annual DOC concentrations were 31.0 mg l^{-1} and 23.3 mg l^{-1} during the 6-year post-treatment period. Catchment mean values varied between 12.0 and 50.2 mg l^{-1} before ditch network maintenance and between 11.2 and 58.0 mg l^{-1} afterwards. During the calibration period, DOC concentrations from the treatment and control sites did not differ from each other. Post-treatment mean annual concentrations of DOC were lower for the treatment sites (Fig. 2) and the difference was significant ($p<0.001$).

During the pre-treatment period, DOC concentrations correlated positively with organic nitrogen, iron and phosphorus, and negatively with pH. After ditch maintenance DOC concentrations were still correlated with organic nitrogen, phosphorus and pH, but not with iron (Table 2).

Differences in pH between the treatment sites (mean 5.63) and control sites (mean 5.69) was small during the pre-treatment period (Fig. 2). Immediately after ditch maintenance, however, the mean pH value increased by 0.6 pH units. In the sixth year after ditch maintenance, pH continued to be 0.3 units higher than during the pre-

Table 2. Pearson correlation coefficients between monthly values of some water quality parameters before (a; n=225) and after (b; n=942) ditch network maintenance. SS = suspended solids, EC = electric conductivity. Statistically significant values ($p<0.05$) are given in boldface.

Taulukko 2. Eräiden vedenlaatumuuttujien kuukausikeskiarvojen väliset Pearsonin korrelaatiokertoimet ennen (a) kunnostusojitusta ja sen jälkeen (b). SS = kiintoaine, EC = sähkönjohtavuus. Merkitsevät erot ($p < 0.05$) lihavoidulla tekstillä.

a)	Ntot	NH_4-N	NO_3-N	Org. N	Min..N	DOC	C/N	SS	EC	pH	Na	K	Ca	Mg	Al	Fe
Ntot	1.000															
NH_4-N	**0.473**	1.000														
NO_3-N	**0.415**	0.036	1.000													
Org. N	**0.891**	**0.286**	0.017	1.000												
Min. N	**0.585**	**0.518**	**0.874**	0.154	1.000											
DOC	**0.642**	0.196	-0.181	**0.815**	-0.059	1.000										
C/N	**-0.450**	-0.177	-0.201	**-0.404**	**-0.258**	0.103	1.000									
SS	**0.445**	**0.562**	0.100	**0.341**	**0.359**	0.111	**-0.363**	1.000								
EC	**0.491**	0.147	**0.258**	**0.434**	**0.293**	**0.248**	**-0.317**	0.191	1.000							
pH	0.202	0.196	**0.315**	0.043	**0.365**	**-0.335**	**-0.495**	**0.440**	**0.373**	1.000						
Na	**0.443**	**0.379**	**0.301**	**0.293**	**0.442**	-0.018	**-0.459**	**0.493**	**0.439**	**0.685**	1.000					
K	**0.339**	0.106	**0.360**	0.212	**0.359**	-0.116	**-0.376**	0.216	0.156	**0.406**	**0.540**	1.000				
Ca	**0.491**	0.119	**0.373**	**0.387**	**0.377**	0.034	**-0.484**	**0.292**	**0.701**	**0.685**	**0.494**	**0.404**	1.000			
Mg	**0.472**	0.119	**0.353**	**0.374**	**0.360**	0.021	**-0.481**	**0.339**	**0.699**	**0.701**	**0.556**	**0.416**	**0.972**	1.000		
Al	-0.208	**-0.262**	-0.191	-0.091	**-0.291**	0.082	**0.256**	-0.157	**-0.263**	**-0.602**	**-0.395**	-0.215	**-0.459**	**-0.371**	1.000	
Fe	**0.574**	**0.649**	-0.034	**0.539**	**0.287**	**0.395**	**-0.285**	**0.510**	0.161	**0.246**	**0.350**	0.105	**0.267**	**0.261**	-0.157	1.000
P	**0.395**	0.099	-0.018	**0.464**	0.033	**0.442**	-0.110	0.136	**0.292**	-0.111	0.027	0.098	0.097	0.084	0.025	0.180

b)	Ntot	NH_4-N	NO_3-N	Org. N	Min..N	DOC	C/N	SS	EC	pH	Na	K	Ca	Mg	Al	Fe
Ntot	1.000															
NH_4-N	**0.605**	1.000														
NO_3-N	**0.423**	**0.200**	1.000													
Org. N	**0.755**	0.068	-0.037	1.000												
Min. N	**0.680**	**0.848**	**0.686**	0.033	1.000											
DOC	**0.535**	-0.040	**-0.159**	**0.832**	-0.115	1.000										
C/N	**-0.138**	-0.043	0.024	**-0.168**	-0.022	**0.140**	1.000									
SS	0.006	0.009	0.025	-0.011	0.021	-0.081	-0.047	1.000								
EC	**0.244**	0.106	**0.255**	**0.142**	**0.214**	0.012	**-0.163**	-0.074	1.000							
pH	-0.015	**0.160**	**0.182**	**-0.213**	**0.215**	**-0.481**	**-0.248**	0.002	**0.414**	1.000						
Na	**0.300**	**0.241**	**0.232**	**0.143**	**0.299**	**-0.125**	**-0.234**	0.047	**0.499**	**0.598**	1.000					
K	**0.152**	0.043	**0.247**	0.060	**0.164**	**-0.131**	**-0.178**	**0.323**	**0.239**	**0.237**	**0.479**	1.000				
Ca	**0.161**	0.085	**0.205**	0.067	**0.170**	-0.065	**-0.152**	-0.059	**0.889**	**0.473**	**0.441**	**0.225**	1.000			
Mg	**0.188**	0.033	**0.281**	0.100	**0.174**	-0.080	**-0.198**	0.043	**0.873**	**0.538**	**0.530**	**0.464**	**0.896**	1.000		
Al	0.020	-0.096	**0.128**	0.029	-0.003	-0.055	-0.082	**0.381**	-0.048	-0.019	**0.204**	**0.895**	-0.051	**0.221**	1.000	
Fe	**0.285**	**0.143**	**0.208**	**0.195**	**0.217**	0.033	**-0.126**	**0.353**	0.089	**0.183**	**0.451**	**0.891**	0.083	**0.321**	**0.890**	1.000
P	0.351	-0.042	0.029	**0.493**	-0.016	**0.353**	**-0.120**	**0.217**	**0.144**	0.017	**0.361**	**0.568**	0.107	**0.232**	**0.524**	**0.637**

treatment period (Fig. 2). Concurrent with these changes at the treated sites, the mean annual pH in the control sites decreased from 5.69 to 5.18.

Base cations

Concentrations of sodium, potassium, calcium and magnesium in runoff water were higher after ditch maintenance (Fig. 2). The differences between treatment and control sites were statistically significant ($p<0.001$) throughout the six-year post-treatment period, and the increase could still be clearly seen during the sixth year after treatment for all four base cations. The concentrations of all base cations correlated positively with each other and with the pH-values, both before and after treatment (Table 2).

After having been only slightly higher (0.54 mg l^{-1}) than in the control areas (0.49 mg l^{-1}) during the pre-treatment period, the mean annual concentration of K varied between 0.79 and 1.18 mg l^{-1} during the post-treatment period. The mean annual K concentration in the control sites during post-treatment period varied between 0.48 and 0.56 mg l^{-1}.

Iron and aluminium

The mean concentrations of Fe and Al showed elevated values after treatment especially the first year, but later the influence of ditch maintenance was less (Fig. 2). However, the median annual concentrations of Fe and Al in the treated sites did not increase after ditch maintenance. This was because the increases in Fe and especially Al concentrations were usually short-lived and occurred in only a few of the 23 sites. Such peak concentrations were particularly strong in the southernmost Pöytyä site, which was eutrophic and had a thin peat layer over a fine textured subsoil. The mean annual Al concentration of the first year after ditch maintenance at this site was 22.2 mg l^{-1} and that of Fe 15.6 mg l^{-1}, with individual samples during the digging operation exceeding 160 mg Al l^{-1} and 120 mg Fe l^{-1}. Elevated mean concentrations also occurred during the second, third and sixth year after treatment.

DISCUSSION

In earlier studies dealing with drainage of pristine peatlands, long-term changes in the concentration of suspended solids in runoff have been reported (Kenttämies 1987, Ahtiainen & Huttunen 1999a, Alatalo 1999). At a site studied by Manninen (1995, 1998, 1999), the effects of ditch maintenance could still be seen in the concentration of suspended solids 3–5 years after the digging operations.

The increased loads of phosphorus resulting from forest drainage have been connected with an increase in the load of suspended solids (Kenttämies 1980, 1981, Kenttämies & Vilhunen 1999, Ahtiainen & Huttunen 1999a and b). In our material the concentrations of total P, which does not include particulate phosphorus, were not substantially changed by ditch maintenance. Furthermore, P concentrations were only weakly correlated to subsoil texture, but were positively correlated to DOC concentrations. It can therefore be concluded that a great part of the dissolved P in our data is organic phosphorus.

The concentration of suspended solids increased conspicuously after ditch network maintenance. This change was most probably connected with a corresponding increase in the concentration of particulate P. However, as particulate P is largely unavailable for algae even in the runoff waters from agricultural soils (Ekholm 1998), it is probably much less available in forest waters which contain mineral particles originating from the unfertilised bottom surfaces of the ditches. Consequently, it might be more relevant to use total dissolved phosphorus to estimate the effects of ditch network maintenance.

Runoff waters from organic soils have been reported to contain more N than waters from mineral soils (Saukkonen & Kortelainen 1995, Kortelainen et al. 1997, Kortelainen & Saukkonen1998, Kortelainen et al. 1999). Ahtiainen & Huttunen (1999a) and Manninen (1999) both reported raised concentrations of total nitrogen after first ditching and ditch maintenance. However, in our study, there was a slight decrease in concentrations of total N, which persisted throughout the six-year observation period. In addition to the effect of different methods of chemical analysis being used between the studies, the discrepancy can be explained by natural variation (Joensuu et al. 2001).

Total N consists of organic and inorganic forms. In our data, organic N was the dominant form. However, the concentration of mineral nitrogen clearly increased after ditch maintenance while the concentrations of organic N decreased. The decrease in organic N was reflected in the clear decrease in DOC concentrations which they were strongly correlated to.

The significant increase in pH after ditch maintenance persisted throughout the six-year observation period. This change is probably related to the drop in the water table depth. After treatment some of ditch water is derived from deeper soil layers, which have higher pH and concentrations of exchangeable base cations. In the Docksmyren peatland area in Sweden, the pH of soil water was 0.5–1.0 units higher in deep peat layers than in surface peat, and correspondingly, the concentrations of the base cations were higher and the concentrations of organic N and DOC lower in deeper peat layers (Lundin 1996).

Most of the changes in runoff water quality caused by ditch network maintenance were still clearly to be seen six years after treatment. It is therefore important to continue monitoring in order to determine when the effects of ditch maintenance diminish to control levels.

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TIIVISTELMÄ

Kunnostusojituksen pitkän ajan vaikutus valumaveden ominaisuuksiin

Laajamittainen metsäojitusalueiden kunnostaminen alkoi Suomessa vuoden 1987 jälkeen. 1990-luvulla ojitusalueita kunnostettiin vuosittain keskimäärin 75 000 hehtaaria. Vuosina 2000–2010 toteutettavan Kansallisen metsäohjelman mukaan vuosittain tullaan kunnostamaan 110 000 hehtaaria ojitusalueita.

Tutkimuksessa tarkastellaan kunnostusojituksen vaikutusta valumaveden kiintoaine- ja ravinnepitoisuuksiin pitkällä aikavälillä kaivun jälkeen 23: lla eri puolilla Suomea (Kuva 1) sijaitsevilla käytännön kunnostusojitusalueilla. Havaintoaluejoukko on osa vuonna 1990 aloitettua Metsätalouden vesistöhaitat ja niiden torjunta (METVE) -projektiin liittyvää laskeutusaltaiden toimivuutta käsittelevää tutkimusalueverkkoa (Ahti et al. 1995b). Tämän tutkimuksen tarkastelujakso käsitti yhdestä kolmeen vuotta kestävän kalibrointivaiheen ja kunnostusojituksen jälkeisen kuuden vuoden veden laadun seurannan sulan maan kaudella.

Tutkimusaluepari muodostui toimenpidealueesta ja vertailualueesta, joilla tehtiin perustamisvaiheessa ojien kunnon kartoitus sekä puuston ja kasvupaikkojen inventointi. Kunnostusojituksen jälkeen tehdyssä ojakohtaisessa inventoinnissa mitattiin systemaattisella otannalla kunnostettujen ojien syvyydet sekä kartoitettiin silmävaraisesti ojaprofiilin kivennäismaa- ja turvelajit sekä mitattiin maalajien kerrospaksuudet ojaprofiilissa. Vesinäytteitä analysoitiin kaikkiaan 3867 kpl. Näytteet otettiin yleensä viikoittain ja kevättulvien aikana kaksi kertaa viikossa. Näytteenottokausi jatkui lumentuloon ja ojien jäätymiseen saakka.

Vesinäytteet suodatettiin lasikuitupaperisuodattimen läpi (huokoskoko 1,2 mm). Suodatetuista näytteistä määritettiin liuennut kokonaisfosfori, natrium, kalium, magnesium, kalsium, alumiini ja rauta ARL 3580 ICP plasma emissio spektrofotometrillä. Kokonais-, ammonium- ja nitraattityppi määritettiin spektrofotometrisesti Tecaton FIA-analysaattorilla. Veteen liuenneen orgaanisen aineksen pitoisuus määritettiin vuosina 1990–1991 kaliumpermanganaatin kulutuksena SFS 3036 menetelmällä ja vuoden 1992 alusta orgaanisen hiilen määränä (DOC) Shimazu-hiilianalysaattorilla. Kaliumpermanganaatin kulutuksena mitatut arvot muunnettiin liuenneen orgaanisen hiilen arvoiksi. Lisäksi näytteistä määritettiin pH-arvo ja sähkönjohtavuus.

Kunnostusojituksen jälkeen kiintoaineen, ammoniumtypen ja emäskationien pitoisuudet sekä valumaveden pH-arvo kasvoivat. Orgaanisen typen ja liuenneen orgaanisen hiilen pitoisuudet sen sijaan laskivat. Totaalitypen ja totaalifosforin pitoisuudet eivät oleellisesti muuttuneet kunnostusojituksen vaikutuksesta. Vaikutukset olivat yleensä pitkäaikaisia. Vielä kuuden vuoden kuluttua kunnostusojituksesta muutokset olivat selvästi havaittavissa. Korkeita rauta- ja alumiinipitoisuuden huippuja esiintyi muutamilla alueilla kaivun aikana ja välittömästi kunnostusojituksen jälkeen.

Valumaveden ominaisuuksien seurantaa tullaan jatkamaan yhdeksällä tämän tutkimuksen alueista. Tavoitteena on näillä alueilla vähintään 10 vuoden aikasarjat.

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