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Changes in leaching patterns of nitrogen and phosphorus after artificial drainage of a boreal forest — a paired catchment study in Lappajärvi, western Finland

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The effect of ditching of boreal (Finnish) peat-rich forest land on leaching patterns of phosphorus and nitrogen was assessed using a paired catchment approach (response stream + control stream) for a 4 + 1 year study period. After the ditching operations, the leaching of the organic nitrogen (TON) decreases, while that of the inorganic nitrogen (ammonium and nitrate) and phosphorus (total reactive P and total non-reactive P) increases. The TON does not decrease as much as TOC does, indicating that the pool of organic material being leached after the ditching is enriched in nitrogen. The increased leaching of ammonium and nitrate after ditching is related most likely to ammonification and nitrification processes in peat biomass after the release of excess surface water. The behaviour of P is complex. The data indicate that the major controls of the determined P fractions are the Fe redox chemistry and the behaviour of Fe hydroxides.

Introduction

In northern Europe, boreal forests export large amounts of nitrogen and phosphorus, although the highest concentrations still exist in runoff from the agricultural land (Pitkänen 1986, Rekolainen 1989, Vuorenmaa *et al.* 2002, Wiklander *et al.* 1991, Jacks *et al.* 1994, Forsius *et al.* 1997, Stålnacke *et al.* 1999). While in this part of Europe there is a general decrease in the N and P depositions from south to north (Kortelainen and Saukkonen 1998), there is no latitude-related trend in the amounts of these nutrients in runoff from forested catchments (Lepistö *et al.* 1995, Kortelainen *et al.* 1997, Kortelainen and Saukkonen 1998). This is explained by the overall high capacity of the forested catchments to retain the deposited N (Lepistö *et al.* 1995, Dise *et al.* 1998, Åström *et al.* 2002), and the large number of other local controls, of which several are anthropogenic and thus of particular environmental concern. Such controls include: (1) clear felling which increases the NO_3^- and PO_4^{3-} leaching at least in the short term prior to extensive biological regeneration (Wiklander *et al.* 1991, Lepistö *et al.* 1995, Kubin 1998, Nieminen 1998, Ahtiainen and Huttunen 1999, Vuorenmaa *et al.* 2002), (2) soil scarification which may increase at least the P leaching (Rask *et al.* 1998), (3) fertilisation which increases the leaching of

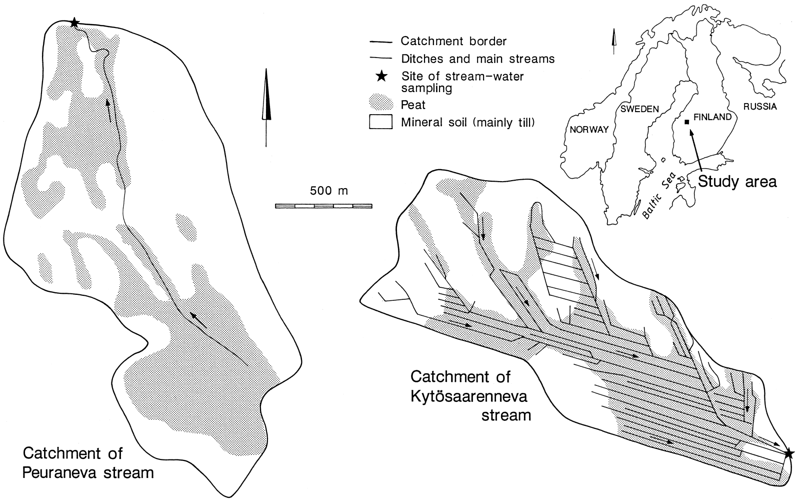


Fig. 1. The study areas. The 30-year-old ditches in the Peuraneva catchment are mostly filled with sediments and overgrown and therefore not included in the map.

the applied nutrients (Moldan and Wright 1998, Hagedorn *et al.* 2001, Joensuu *et al.* 2001a and references therein, Vuorenmaa *et al.* 2002), (4) previous land use and N additions (Andersson *et al.* 2002), and (5) drainage activities, which are generally followed by an increase in runoff pH (Heikurainen *et al.* 1978, Ramberg 1981, Lundin 1988, Lundin and Bergqvist 1990, Ahtiainen 1991, Tossavainen 1991, Ahti *et al.* 1995, Manninen 1998, Prevost *et al.* 1999, Åström *et al.* 2001a, 2001b, Joensuu *et al.* 2001b) and which will affect, in largely uncharacterised ways, the behaviour of inherent and anthropogenically introduced N and P loads.

This paper is concerned primarily with the impact of ditch cleaning plus supplementary ditching (second-time ditching) on N and P dynamics and export in boreal (Finnish) forests. The topic is highly relevant since (1) the response of N and P to forest-drainage operations are not well understood and, (2) the second time ditching is becoming increasingly important in order to maintain the drainage efficiency of the old forest ditches (covering 54 000 km^2 in Finland only; Sevola 1998) and thereby maintain the volume growth of the drained stands (Lauhanen and Ahti 2001). The experimental design consisted of two ‘paired catchment studies’ conducted over several (4–5) years. In previous papers, we report the results of major variables (pH, TOC, Fe, etc.) in Lappajärvi (Åström *et al.* 2001a) and Kronoby (Åström *et al.* 2001b) and of N and P in Kronoby (Åström *et al.* 2002). In this final paper, we present the results of N and P in Lappajärvi (Kytösaarenneva and Peuraneva streams), compare the results with those of Åström *et al.* (2002) in particular, and draw some overall conclusions for the whole project.

Catchment description

The Kytösaarenneva and Peuraneva catchments are small (1.6 km^2 and 2.1 km^2 respectively; Fig. 1) and drained by intermittent streams. In both catchments, the Proterozoic schist and gneiss dominated bedrock is overlain by glacial till which, in turn, is covered to a large extent by a peat layer with an average thickness of approximately 50 cm (Fig. 1). The catchments have flat topography and are covered with paludified forests (pine mire/pine bog) dominated by *Pinus sylvestris, Betula* sp. and *Picea abies*). The trees have an average age of 50–70 years. There are no records of fertiliser application in these catchments over the last few decades.

Both catchments were drained by ditching in 1963–1965 to release the excess surface water and thereby improve the conditions for the tree stand in the areas. Since the time of the initial drainage, however, the ditches have lost their capacity to efficiently transport water because of sedimentation and overgrowth. Whereas the Peuraneva catchment has not been ditched a second time (therefore, it constitutes the ‘control’), the Kytösaarenneva catchment was reditched in January–March 1995 (halfway through the sampling period), when a total of 17 472 m of old ditches were cleaned and a total of 14 373 m of new ditches (supplementary ditching) were dug in the peatland within the catchment (Fig. 1). In general, the ditches penetrate the upper peat cover and the underlying till. Hence, organic (peat) as well as mineral-soil layers are exposed on the ditch slopes. In the discussions below, ‘ditching’ refers to the ditch cleaning plus supplementary ditching made in 1995 and not to the first-time ditching made in 1963–1965.

The annual climatic and hydrological cycles in the area are characterized by four distinct seasons. The summer (June–August) is characterised by a mean temperature of ca. 15 °C, high biological activity, and mainly baseflow conditions. During the autumn months (September–November), there is a gradual decrease in temperatures from ca. 15 °C to ca. 0 °C, a corresponding decrease in biological activity and evapotranspiration, and high-flow events of variable duration. The winter (December–March) is characterised by freezing temperatures and a snow cover ranging in maximum thickness from approximately 20 cm to 100 cm. In early spring (April) the snow cover melts resulting in strong peaks in the hydrograph, while not until late spring (May) is the ground completely defrosted. The mean annual temperature and precipitation in the area is ca. 4 °C and ca. 500 mm (ca. 30% as snow) respectively. The growing season is 160–180 days.

Methods

Stream water

Water samples in the Kytösaarenneva and Peuraneva streams were collected from the nappe (the sheet of water that flows over the crest of the V-notched weir which was installed in each stream; Reuna 1984) weekly to once every 2 weeks from spring (March–May) to autumn (November) over 4 consecutive years (1993–1996) and, in addition, in 2000. The spring sampling was started at the time when water flow was detectable, except in 1994 when the discharge peak during the snow melting in April was missed due to nonpassable forest roads at that time. During dry periods, i.e. when the water level in the pond upstream of the weir was below the crest of the V-notched weir (no detectable streamflow), water samples were not collected. The annual sampling was terminated prior to the build-up of ice and snow in the catchments.

All the chemical analyses were done on unfiltered samples, with standard methods at the Chemical Laboratories of the West Finland and the Middle Ostrobothnia Environment Centres. Total reactive phosphorus (TRP) was determined with the acidic molybdenum-blue method and consists, in unknown proportions, of free orthophosphate, phosphate displaced from acid labile inorganic colloids/particles, and phosphate released by the hydrolysis of acid labile phosphate esters (Turtola 1996, Haygarth *et al.* 1997 and references therein, Baldwin 1998, Zhang and Oldham 2001). Total P (TP) was determined using an acidic persulphate digestion followed by the molybdenum blue reaction. Total non-reactive phosphorus (TNP) was calculated as follows: TNP = TP – TRP. The TNP pool is likely to consist of poorly hydrolysable phosphate esters and inorganic compounds such as polyphosphates (Baldwin 1998, Benitez-Nelson 2000 and references therein, Shand *et al.* 2000). Ammonium was determined using hypochlorite and phenol to produce indophenol. Any NO_3^- in the samples was converted to NO_2^-, which was further converted to the required azo dye. While the ratio of NO_3^- to NO_2^- in the samples is unknown, the recorded values are reported as NO_3^- because this species is in general by far the more common of the two. Total N (TN) was determined using an alkaline persulphate digestion followed by conversion of NO_3^- to NO_2^-, which was further converted to the required azo dye. Total organic N (TON) was calculated as follows: TON = TN – inorganic N (NH_4^+ + NO_3^-). For all the measurements, standards and duplicates were included at a frequency of approximately every five samples in order to monitor the analytical quality. Other stream variables discussed in this paper are presented by Åström *et al.* (2001a).

The main reason as to why the samples were analysed unfiltered is that a large majority of the watercourses in western central Finland commonly carries low amounts of suspended material (< 10 mg l^{-1}) and that, as a consequence, most of the stream-monitoring programmes are based on unfiltered samples. The main disadvantages of not having the samples filtered are: (1) there is no information on the distribution of nutrients in various size fractions, and (2) the amount, size and quality of the particulate material will affect the results. The advantages of using unfiltered samples are: (1) there is no artificial cut-off of colloids/particles at a predetermined filter pore size, and (2) filtering (0.45 μm) can have a large and selective effect on molybdate reactive P which is often taken as being potentially bioavailable (Shand *et al.* 2000).

Glacial till

Samples of glacial till were collected in a uniform pattern (Swan and Sandilands 1995: p. 13) at 29 sites in the Kytösaarenneva catchment and 23 sites in the Peuraneva catchment. In the laboratory, the samples were dried in an oven (at ca. 70 °C) and sieved to < 0.06 mm. Half a gram of this fraction was analysed for P concentrations by ICP-AES after partial dissolution in 3 ml 3:1:2 $HCl:HNO_3:H_2O$ (dilute aqua regia) for one hour at 95 °C and dilution to 10 ml with water. It is expected that approximately 90% of the P in the samples were extracted with this reagent (Koljonen 1992).

Results and discussion

The P concentration in the fine fraction of till in the Kytösaarenneva catchment (median: 0.059%; average: 0.062%) and the Peuraneva catchment (median: 0.058%; average: 0.056%) were similar and on the same level as that in the corresponding fraction in till collected throughout the whole country (average: 0.07%: Koljonen 1992). Thus, the hydrochemical data presented below are not affected by spatial variations or anomalous levels of P concentrations in the underlying geological materials.

Organic nitrogen

In the Peuraneva (control) stream, the annual arithmetic mean of the TON concentrations varied little over the period 1993–1996 (55–62 μM) but was clearly elevated in 2000 (100 μM). This difference was not reflected in the flow weighted means (Fig. 2e), because all the elevated TON values in 2000 occured when the flow was particularly low (Fig. 2a). There was a strong relationship between TON and TOC (Fig. 2c), and the median TOC/TON ratios both in 1993–1994 (51) and 1995–2000 (52) are in line with results reported by other researchers (Kortelainen *et al.* 1997, Joensuu *et al.* 2001a).

In the Kytösaarenneva (response) stream, the TOC concentrations decreased after the ditching. This is discussed in detail by Åström *et al.* (2001a) and indicated in Fig. 2d. Also the TON concentrations (both flow weighted and arithmetic means) decreased, but not to the same extent as those of TOC (Fig. 2b, d, e). After the ditching, the median TOC/TON ratio was lowered (47 as compared with 60 before the ditching), and there was a weakening of the relationship between these two variables (Fig. 2d). Hence, while the leaching of organic C clearly decreased after the ditching operations, there was only a minor corresponding decrease in the leaching of TON.

The reason as to why the TON concentrations did not decrease after the ditching to the same extent as those of TOC may be an analytical bias. Because the TON concentrations were determined colorimetrically (all organic N is detected) and the TOC concentrations instrumentally (while results are reported as TOC, organic particles might have settled to the bottom of the sample tubes and thus not been detected in the analyses), organic-rich particles in the stream, delivered from dried peat and/of formed in-stream by flocculation of humic molecules, will cause a drop in the TOC/TON ratio. However, if there was an abundance of organic particles in the water, the TON values would have increased and not, as they did, decreased. Therefore, this possible bias is unlikely to be large and significant. A possible natural explanation is that after the ditching, the released organic substances are enriched in N. This may

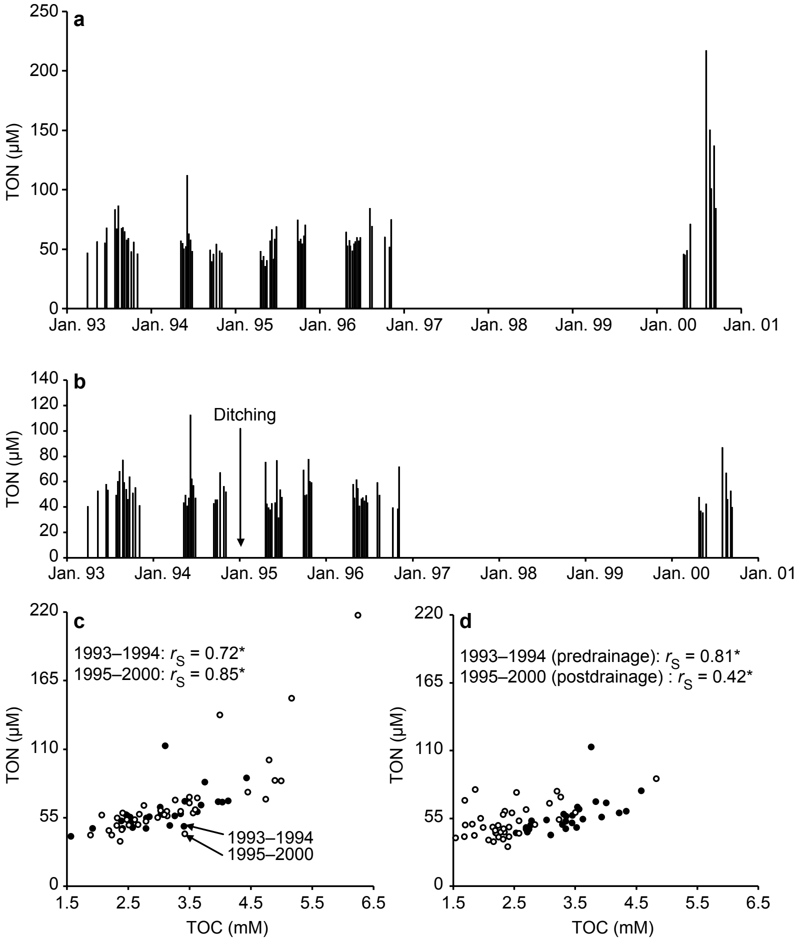


Fig. 2. Total organic nitrogen in the studied streams: — **a**: Peuraneva (control) stream; — **b**: Kytösaarenneva (response) stream; — **c**: Peuraneva (control) stream; — **d**: Kytösaarenneva (response) stream. Significant Spearman's rank correlation coefficients ($p < 0.05$) are indicated with asterisks (*).

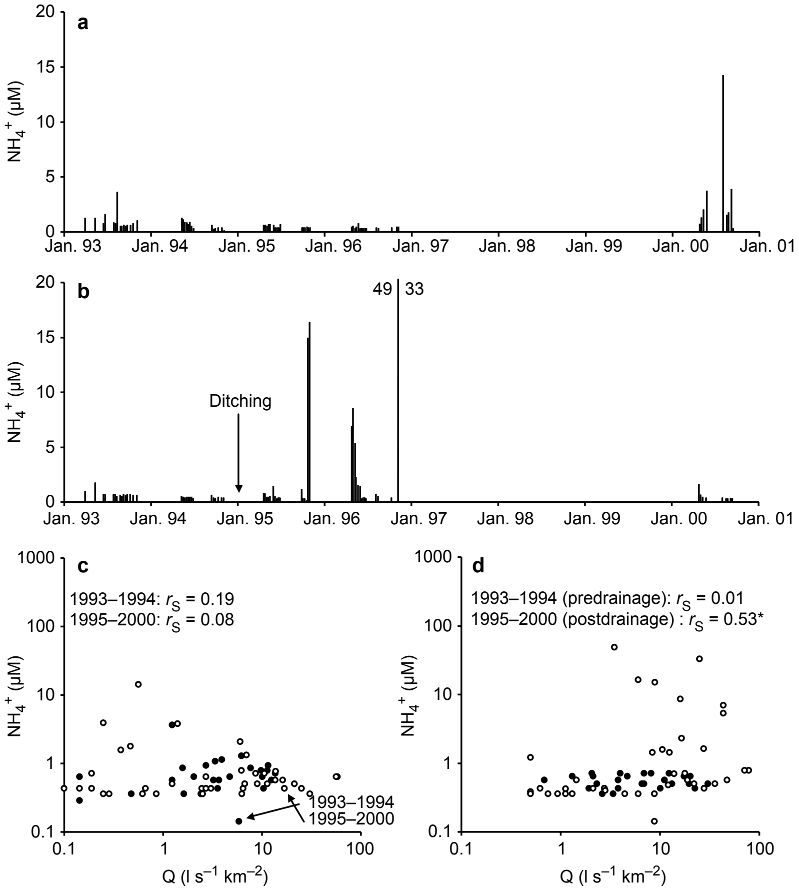
e	Peuraneva (control) stream					Kytösaarenneva (response) stream				
	1993	1994	1995	1996	2000	1993	1994	1995	1996	2000
TON (µM) arithmetic mean	62	56	55	61	100	56	55	54	50	51
TON (µM) flow weighted mean	64	67	48	63	54	61	68	57	57	44

be expected, because after the ditching, the water is forced to move in deeper soil horizons where the TOC/TON ratio of the dissolved organic matter has been shown to be lower than in near-surface horizons (Fölster 2000). Elsewhere in similar catchments, ditching operations have either not affected the stream-water TON concentrations (Andersson and Lepistö 2000, Åström *et al.* 2002), or have resulted in a decrease (Lundin and Bergqvist 1990, Joensuu *et al.* 2001b) or increase (Lepistö *et al.* 1995) in such concentrations.

Ammonium

In the Peuraneva (control) stream, the NH_4^+ concentrations were overall low, except for a few samples in 2000 (Fig. 3a). The annual flow-weighted and arithmetic means were close to or smaller than 1 μM, except in 2000 when they increased to some extent (Fig. 3e). The NH_4^+ concentrations and flow were uncorrelated (Fig. 3c).

In the Kytösaarenneva (response) stream prior to ditching (1993–1994), the NH_4^+ concentrations were, like in the control stream,



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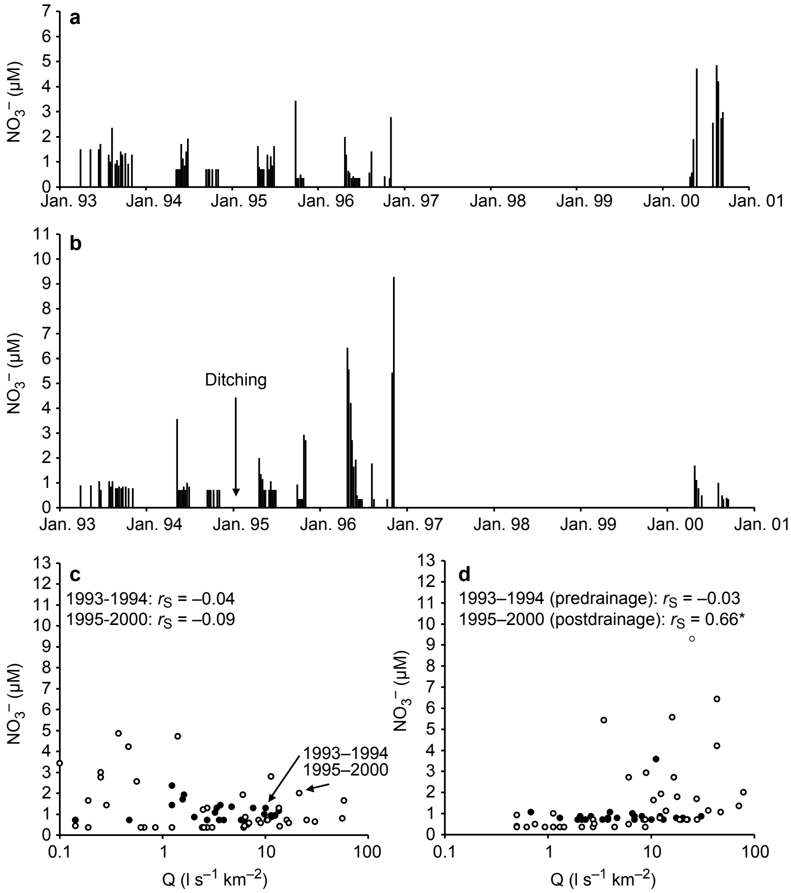
	Peuraneva (control) stream					Kytösaarenneva (response) stream				
	1993	1994	1995	1996	2000	1993	1994	1995	1996	2000
NH_4^+ (µM) arithmetic mean	1.1	0.6	0.5	0.4	3.3	0.8	0.5	2.5	7.4	0.6
NH_4^+ (µM) flow weighted mean	0.8	0.7	0.6	0.5	1.6	0.7	0.5	1.3	8.5	1.0

Fig. 3. Ammonium in the studied streams: — **a**: Peuraneva (control) stream; — **b**: Kytösaarenneva (response) stream; — **c**: Peuraneva (control) stream; — **d**: Kytösaarenneva (response) stream. Significant Spearman's rank correlation coefficients ($p < 0.05$) are indicated with asterisks (*).

low (Fig. 3b) and uncorrelated with the flow (Fig. 3d). After the ditching, however, the NH_4^+ concentrations were clearly elevated on several occasions: at intermediate flow in the latter half of October 1995, at high flow in April 1996, at low flow in October 1996, and at the flow peak in November 1996 (Fig. 3b). The overall result was an increase in the Spearman's rank correlation coefficient between the flow and NH_4^+ concentrations (Fig. 3d) and an increase in the flow-weighted mean values in all years after ditching, and in the arithmetic mean values in the first two years after the ditching (Fig. 3e). The most likely reason for these patterns is an increased postdrainage NH_4^+ availability in the soil, related to ammonification of peat biomass after the release of excess surface water (Lepistö *et al.* 1995, Arheimer *et al.* 1996). Elevated NH_4^+ fluxes are commonly (Lepistö *et al.* 1995, Manninen 1998, Prevost *et al.* 1999, Joensuu *et al.* 2001b, Åström *et al.* 2002) but not exclusively observed (Lundin and Bergqvist 1990) after artificial drainage of boreal forest land.

Nitrate

In the Peuraneva (control) stream, the NO_3^- con-



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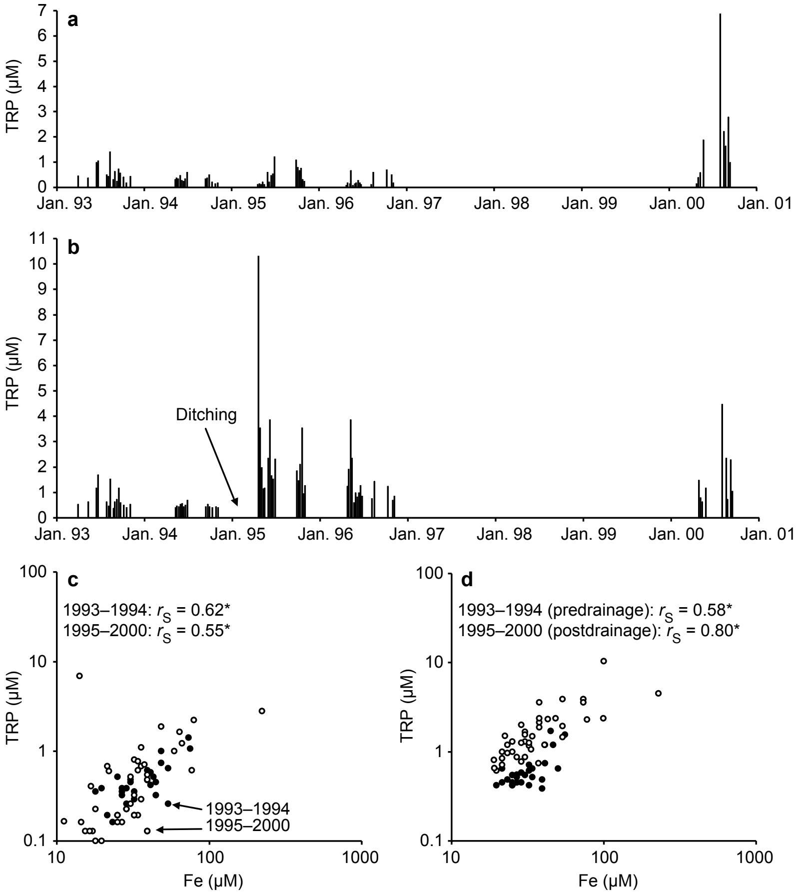
	Peuraneva (control) stream					Kytösaarenneva (response) stream				
	1993	1994	1995	1996	2000	1993	1994	1995	1996	2000
NO_3^- (µM) arithmetic mean	1.3	1.0	1.0	0.8	2.8	0.9	1.0	1.1	2.8	0.7
NO_3^- (µM) flow weighted mean	1.1	0.9	1.0	1.1	1.1	0.8	1.0	1.3	4.5	1.3

Fig. 4. Nitrate in the studied streams: — **a**: Peuraneva (control) stream; — **b**: Kytösaarenneva (response) stream; — **c**: Peuraneva (control) stream; — **d**: Kytösaarenneva (response) stream. Significant Spearman's rank correlation coefficients ($p < 0.05$) are indicated (*).

centrations were low throughout the study period (Fig. 4a). While the arithmetic mean increased to some extent in 2000, all the annual flow-weighted means are found within a narrow range, 0.9–1.1 μM (Fig. 4e). The NO_3^- concentrations and flow were uncorrelated (Fig. 4c).

In the Kytösaarenneva (response) stream over the predrainage period (1993–1994) the NO_3^- concentrations were, like in the control stream, low (Fig. 4b) and uncorrelated with the flow (Fig. 4d). In contrast, over the postdrainage period the NO_3^- concentrations were positively correlated with the flow (Fig. 4d), and in 1996 (second year after the ditching) they were elevated in several samples (Fig. 4b). Consequently, in each year after the ditching, the flow-weighted means of NO_3^- were higher than those over the two years prior to the ditching (Fig. 4e). This indicates a minor increase of the NO_3^- flux during the postdrainage period. A large increase would, however, not be expected, because while the increase in ditch density (ditching) is likely to increase the NO_3^- transport and leaching (Lepistö *et al.* 1995), the high TOC/TON ratio and high acidity of the forest floor/peat layers suppress nitrification processes (Ste-Marie and Paré



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	Peuraneva (control) stream					Kytösaarenneva (response) stream				
	1993	1994	1995	1996	2000	1993	1994	1995	1996	2000
TRP (µM) arithmetic mean	0.60	0.35	0.49	0.29	1.96	0.79	0.49	2.58	1.34	1.68
TRP (µM) flow weighted mean	0.44	0.28	0.21	0.19	0.59	0.51	0.49	4.32	1.78	1.21

Fig. 5. Total reactive phosphorus in the studied streams: — **a**: Peuraneva (control) stream; — **b**: Kytösaarenneva (response) stream; — **c**: Peuraneva (control) stream; — **d**: Kytösaarenneva (response) stream. Significant Spearman's rank correlation coefficients ($p < 0.05$) are indicated (*).

1999, Åström *et al.* 2002). This is also apparent in other similar catchments in where the NO_3^- concentrations either remained unchanged (Åström *et al.* 2002) or increased only slightly (Andersson and Lepistö 2000, Joensuu *et al.* 2001b) after the ditching.

Total reactive phosphorus

In the Peuraneva (control) stream, the TRP concentrations were low except for few samples collected in 2000 (Fig. 5a), they correlated positively with the Fe concentrations (Fig. 5c), and they were negatively correlated with the flow resulting in higher arithmetic means than flow weighted annual means (Fig. 5e). The clearly elevated TRP concentrations in 2000 all occured when the flow was very low resulting in only a marginally elevated flow weighted value that year (Fig. 5e).

In the Kytösaarenneva (response) stream prior to ditching (1993–1994), the TRP concentrations were, like in the control stream, low (Fig. 5b), positively correlated with the Fe concentrations (Fig. 5d), and overall negatively correlated with flow (Fig. 5e). Over the two years immediately after ditching (1995–1996), the behaviour of TRP clearly changed: (1) the concentrations (in most samples) were considerably higher than those prior to ditching and than those in the control stream in the same years (Fig. 5a and b); (2) the correlation with Fe was strengthened despite the fact that the Fe concentrations were unchanged after ditching (Fig. 5d); and (3) the correlation with the flow was no longer negative ($r_S = 0.13, p > 0.1$) and there was a strong increase in the flow weighted annual values (Fig. 5e). Also in 2000 the TRP concentrations increased, but so did they in the control stream suggesting an explanation other than a ditching-related one.

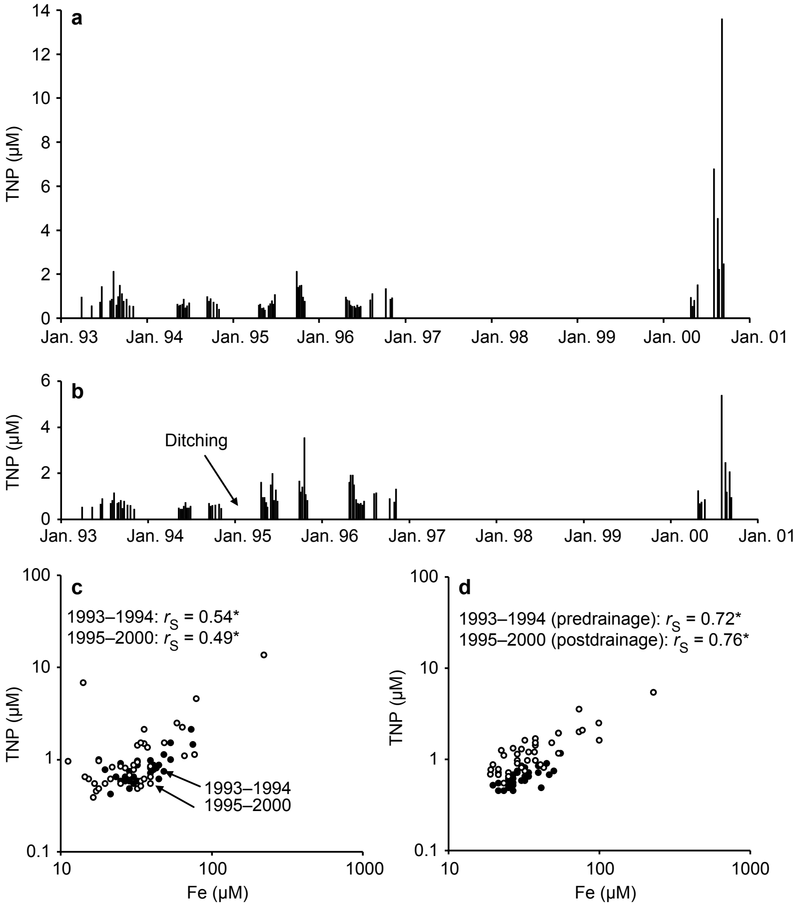
It is intriguing that in the postdrainage period the correlation between Fe and TRP was strengthened, despite discrepancies in concentrations changes (Fe unchanged and TRP increased after ditching). This would appear to reflect an increased binding capacity of suspended/colloidal Fe hydroxides in the postdrainage period. Such a mechanism is unlikely, however, since after ditching the pH of the stream waters increased by nearly a unit (on average from ca. 4.5 to ca. 5.5; Åström *et al.* 2001a) favouring desorption rather than additional sorption of TRP on hydroxides. Another possible explanation is related to the expected (however not measured) change in the oxidation state of Fe after the release of excess surface water. When additional O_2 is supplied, there will be oxidation in the soils of Fe(+II), with a low TRP binding capacity, to Fe(+III)-hydroxides that efficiently bind TRP (Fox 1989, Geelhoed *et al.* 1997, Mayer and Jarrell 2000, Ekholm and Krogerus 2003, Lehtoranta and Heiskanen 2003, Lehtoranta and Pitkänen 2003, Krogerus and Ekholm 2003) through adsorption and co-precipitation mechanisms (Mayer and Jarrell 1995). If the freshly precipitated Fe hydroxides are retained in the soil they will contain a sink of TRP, but if they are mobilised through colloidal transport, which can occur, they are turned into important carriers of TRP. While the concentration of suspended material, like that of TRP, increased in the stream after ditching (from < 1 mg l^{-1} to > 20 mg l^{-1}; Åström *et al.* 2001a), the weak correlation between these two variables over the postdrainage period ($r_S = 0.46$) indicates that eroded particles are not the major reason for the increased TRP flux.

After extensive ditching of a nearby similar catchment (Lodis stream), the concentrations and fluxes of TRP, in contrast, remained unchanged (Åström *et al.* 2002). In the Lodis stream, however, the mean annual TRP concentrations were high (1.1–3.7 μM and 1.9–3.3 μM respectively) and the median Fe/TRP ratio was low (28 for both periods) both in the predrainage (1993–1994) and postdrainage (1995–1996) period. In the Kytösaarenneva (response) stream after the ditching operations, the Fe-TRP hydrochemistry became similar to that in the Lodis stream, i.e. the annual average TRP concentrations were 1.21–4.32 μM and the Fe/TRP ratio was 24 (prior to ditching these figures were 0.49–0.79 μM and 53 respectively). The interpretation of this data is that in the Lodis-stream catchment already prior to ditching the conditions were favourable for Fe(+III) and TRP binding, while in the Kytösaarenneva-stream catchment such conditions were established only after the ditching. The data thus support the importance of Fe redox chemistry and Fe hydroxides on the TRP flux in the catchments.

Total non-reactive phosphorus

In the Peuraneva (control) stream, the TNP concentrations were low, except for a few samples in 2000 (Fig. 6a). Both in 1993–1994 and in 1995–2000 TNP correlated with Fe (Fig. 6c) and the flow ($r_S = -0.45$ and -0.53 respectively). Because of the overall negative correlation with the flow, in each year the flow-weighted mean TNP value was similar to or lower than the corresponding arithmetic mean value (Fig. 6e). The clearly elevated TNP concentrations in 2000 all occurred when the flow was very low which resulted in only a marginally elevated flow weighted value that year (Fig. 6e).

In the Kytösaarenneva (response) stream prior to ditching, the TNP concentrations were low (Fig. 6b) and they correlated strongly and positively with Fe (Fig. 6d) but not significantly ($p > 0.05$) with the flow ($r_S = 0.02$). After the ditching operations, the TNP concentration



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	Peuraneva (control) stream					Kytösaarenneva (response) stream				
	1993	1994	1995	1996	2000	1993	1994	1995	1996	2000
TNP (μM) arithmetic mean	0.97	0.69	0.92	0.77	3.72	0.71	0.58	1.32	1.11	1.74
TNP (μM) flow weighted mean	0.79	0.65	0.65	0.80	1.15	0.70	0.61	1.32	1.44	1.10

Fig. 6. Total non-reactive phosphorus in the studied streams: — **a**: Peuraneva (control) stream; — **b**: Kytösaarenneva (response) stream; — **c**: Peuraneva (control) stream; — **d**: Kytösaarenneva (response) stream. Significant Spearman's rank correlation coefficients ($p < 0.05$) are indicated (*).

increased on average by approximately 100% (Fig. 6e) and they were still strongly correlated with Fe, despite the fact that the concentrations of this metal did not increase after the ditching (Fig. 6d). Hence, there are many similarities in the response of TNP and TRP to the ditching operations. After similar ditching operations elsewhere, the leaching of total P increased most likely due to increased fluxes of particulate P (Lundin and Bergqvist 1990, Manninen 1998, Ahtiainen and Huttunen 1999), the leaching pattern of TNP remained unchanged (Åström *et al.* 2002), and the concentration of the P fraction passing 1.2 μm filters decreased (Joensuu *et al.* 2001b).

Conclusions

The hydrochemistry of runoff from boreal peat-rich forested catchments is influenced by a variety of natural and anthropogenic factors and is therefore complex. As a consequence, the hydrochemical effects following artificial drainage of such areas will vary from site to site and time to time. However, at sites where the bedrock and overburden is poor in sulphide minerals, limestone/dolomite and other easily weathered rocks (such as in the catchments included in this project), common effects are increased runoff pH, decreased fluxes of organic C, increased fluxes of NH_4^+, no change or a weak increase in the NO_3^- flux, and no change or a weak decrease in the TON flux. The effects on P are complex and not entirely understood. In addition to being associated with organic and inorganic particles, the P may, as indicated in the present data, be closely linked with the Fe redox chemistry and behaviour of Fe hydroxides, both of which are affected by ditching operations.

The paired catchment approach is a powerful tool in studying hydrochemical changes after activities such as forest-ditching operations. The results should, however, be interpreted with some caution since even in nearby seemingly similar catchments, the natural and postdrainage patterns of leaching and fluxes of various compounds may be quite different. In this project, the most complex patterns were displayed by TRP, which not only responded differently to ditching in different catchments, but also behaved differently from site to site under predrainage (natural) conditions.

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