

Effects of clear-cutting and site preparation on water quality from a drained Scots pine mire in southern Finland

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Nieminen, M. 2003: Effects of clear-cutting and site preparation on water quality from a drained Scots pine mire in southern Finland. *Boreal Env. Res.* 8: 53–59. ISSN 1239-6095

Ditch outflow from four treatment areas on a drained Scots pine mire was sampled for one year before and four years after clear-cutting and different site preparation operations. Ditch-mounding, or excavation of 40–60 cm deep ditches at spacings of 12–15 m in connection with mounding, is currently considered the most reliable site preparation method for drained peatlands in Finland. High leaching rates of suspended solids were detected from the ditch-mounding area, where the ditches reached down into the mineral soil below peat layer. In contrast to clear-cutting + mounding (without ditches) and clear-cutting alone, cutting and ditch-mounding also increased the leaching of ammonium and nitrate. Phosphorus concentrations in ditch outflow following clear-cutting and site preparation increased from areas where peat contents of phosphorus sorbing minerals (aluminium and iron) were low. The study demonstrated that clear-cutting and site preparation can significantly impair water quality from drained low productive pine mires.

Introduction

The area of peatlands in Finland totals about 10 million ha, which corresponds to one-third of the total land area. About half of this area has been drained for forestry purposes. Forest drainage activity was particularly high during 1960–1980, when the annually drained area exceeded 100 000 ha (Yearbook... 1981). The volume of the growing stock of drained peatland forests is now 307 million m³, accounting for about 16% of the total stock of all Finnish forests (Tomppo 1998). The rate of forest clear-cutting on drained

peatlands will undergo a rapid increase in the future, when a large number of these forests approach their regeneration age. Among the forests to be regenerated, low to medium productive Scots pine mires are the most numerous (Tomppo 1998).

Water quality effects of clear-cutting mineral soil forests have long been of concern (Bormann *et al.* 1968, Verry 1972, Wiklander 1981, Grip 1982, Martin *et al.* 1985, McClurkin *et al.* 1985, Martin and Harr 1988, Tiedemann *et al.* 1988, Kubin 1995). The effects on water quality of clear-cutting undrained peatland stands have

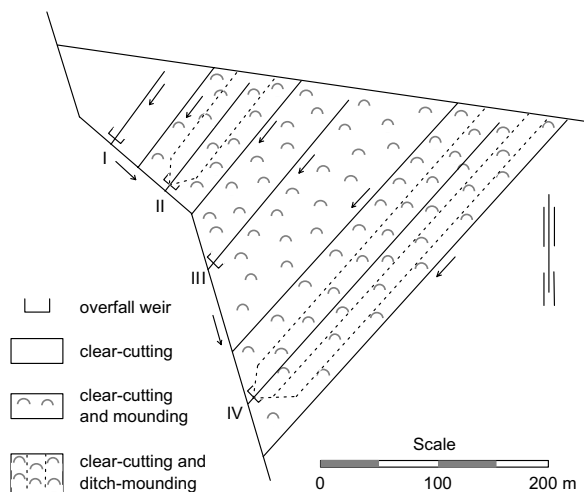


Fig. 1. The experimental layout at Vilppula. Treatment areas I–IV.

also received attention (Knighton and Stiegler 1980, Ahtiainen 1988). More recently, leaching of nutrients following clear-cutting of drained, highly productive Norway spruce mires has been studied (Lundin 1998, Nieminen 1998). However, results concerning clear-cutting of drained, low productive Scots pine mires have not been published.

Outflows of most nutrients following clear-cutting are likely to be less from nutrient poor pine mires than from highly productive spruce mires. This is because of lower nutrient contents in peat from nutrient poor pine mires (Kaunisto and Paavilainen 1988). Less logging residues are also left on site after conventional (stem-only) clear-cutting on low productive pine mires. Furthermore, the rate of mineralization of nutrients from peat and logging residues may be low for nutrient poor mires. However, the outflow of phosphorus can be high from nutrient poor mires. This is due to the very low phosphorus adsorption capacity of such sites (Cuttle 1983, Nieminen and Jarva 1996). Thus, if phosphorus supply exceeds plant demand after clear-cutting, the loss of phosphorus to water courses from nutrient poor mires may be expected to increase.

Compared with mineral soil sites, more intensive site preparation methods are generally used to regenerate wet peatland forests. Ditch-mounding is currently considered the most reliable site preparation method for drained peatland sites in Finland. It is done in such a way that the

excavator digs shallow ditches (40–60 cm deep) at 12–15 m spacings and creates small mounds from the soil removed from ditches. Outflow of nutrients, and especially particulate matter, may largely depend upon the extent to which the soil has been damaged by these ditches. High leaching rates of particulate matter may be expected from areas where the ditches reach down into the fine-textured mineral soil below the peat layer (Joensuu *et al.* 1999).

To provide information on water quality effects, the ditch outflow from a drained, low productive Scots pine mire was monitored for one year before and four years after clear-cutting and different site preparation operations. This paper describes the resulting effects on the leaching of suspended solids, nitrogen, and phosphorus.

Material and methods

Study site and treatments

The study was carried out in Vilppula, south-central Finland (62°04'N, 24°34'E). The long-term (1960–1990) mean annual precipitation in the Vilppula region is 600 mm. Mean annual temperature is +3.4 °C, with means of –8.4 °C in February and +16.8 °C in July. The average duration of the growing season, defined as the number of days with a mean temperature > +5 °C, is 164 d.

The study site covered an area of about 7 ha (Fig. 1). The site was drained already in 1909, but the present ditch network originates from 1951. The elevation varies from 116 to 120 m a.s.l., and the average slope is 1.7%. The peat layer at the site is 0.3–1.0 m thick and consists of highly decomposed *Sphagnum* peat with remnants of wood and *Eriophorum vaginatum*. The peat layer is underlain by clay.

In 1993 four small treatment areas were designed by building V-notched overfall weirs in the middle ditch of each area (Fig. 1). The areas are described in Table 1. According to the classification of drained peatlands used in Finland (Heikurainen and Pakarinen 1982), all four areas had reached the final stage of drainage succession. At this stage the ground vegetation and the tree stand resemble the corresponding fertility levels on mineral soils. On the basis of peat analysis,

area IV was more fertile than the other areas. Especially the peat concentrations of N, P, Fe, and Al were higher in area IV. The higher stand volume in area IV also indicated higher fertility. Scots pine (*Pinus sylvestris* L.) was the only tree species in areas I, II, and III. In area IV, about 90% of the stand volume was Scots pine, the remainder being Norway spruce (*Picea abies* Karst.).

The areas were clear-cut in January 1995 using conventional stem-only harvesting in which only boles down to a diameter limit of 7 cm were removed. The ground was frozen and covered by a thick snow layer during cuttings. Thus, there was no damage to the soil caused by the heavy harvesting machinery. Four months after clear-cutting in May 1995, two of the four treatment areas (II and IV) were ditch-mounded, the third area (III) was mounded without ditches, and the fourth (I) was left intact (Fig. 1). The two ditch-mounding areas differed in that the ditches were dug down into the mineral subsoil in the very shallow-peat area IV, but were entirely left in the peat layer in the area II.

samples were taken from the overflow of the weir in the middle ditch of each area. All the samples were analysed at the Finnish Forest Research Institute according to procedures described by Jarva and Tervahauta (1993). The samples were first filtered through 1.0 μm glass fibre filters (Schleicher & Schull Rundfilter 589³). The filters were then dried at 60 °C and weighed to determine the amount of suspended solids (SPS). The filtrates were analysed for total dissolved N (N_{tot}) and $\text{NH}_4^+\text{-N}$ by flow injection analysis and for $\text{NO}_3^-\text{-N}$ and $\text{PO}_4^{3-}\text{-P}$ by ion chromatography. Total dissolved P (P_{tot}) was analysed by inductively coupled plasma emission spectrometry (ICP/AES, ARL 3580). Dissolved organic N (N_{org}) was calculated as the difference between N_{tot} and inorganic nitrogen, and organic P (P_{org}) as the difference between P_{tot} and $\text{PO}_4^{3-}\text{-P}$.

Non-parametric Kruskal-Wallis test with multiple comparisons was used to calculate statistical differences in element concentrations in ditch outflow between different years. The tests were made using the BMDP (1990) software package.

Sampling and analyses

Ditch water samples were taken in each treatment area once a week over the period 1994–1998. The

Results

The leaching of SPS increased after clear-cutting and site preparation only from area IV (Fig. 2).

Table 1. Background information about treatment areas.

	Area			
	I	II	III	IV
Site type ¹⁾	Vatkg	Vatkg	Vatkg	Ptkg
Peat depth (m)	0.5–1.0	0.5–1.0	0.5–1.0	< 0.5
Stand volume ($\text{m}^3 \text{ha}^{-1}$)	132	101	157	191
Peat (0–10 cm)				
N_{tot} (%)	1.08	1.13	1.19	1.52
P_{tot} (mg kg^{-1})	699	718	668	863
K_{tot} (mg kg^{-1})	552	454	415	519
Ca_{tot} (mg kg^{-1})	3139	3474	3112	3285
Fe_{tot} (mg kg^{-1})	996	945	1101	3285
Al_{tot} (mg kg^{-1})	629	847	861	1307

¹⁾ *Ledum–Empetrum* type (Vatkg) has developed after drainage from peatlands of poor fertility. With the exception of *Rubus chamaemorus*, most herbs are not present in any significant quantities. These sites are characterized by abundant occurrence of the dwarf-shrubs typically associated with pine bogs. *Vaccinium vitis-idaea* type (Ptkg) has developed from somewhat more fertile sites than *Ledum–Empetrum* type. The field layer is usually dominated by *Vaccinium myrtillus* and *V. Vitis-idaea*. The occurrence of dwarf-shrubs characteristic of pine bogs is quite limited (Heikurainen and Pakarinen 1982).

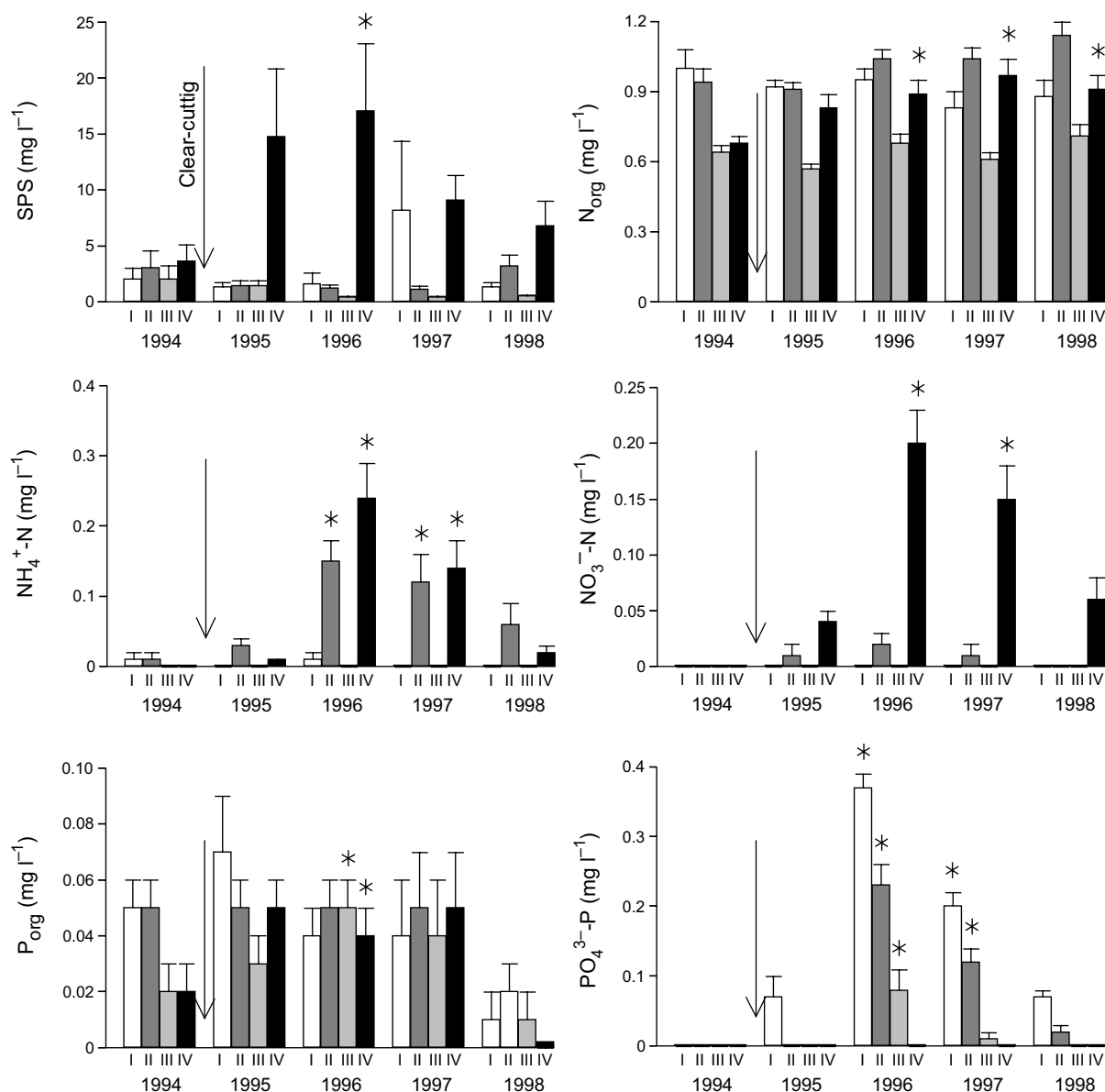


Fig. 2. Mean annual concentrations of SPS, nitrogen, and phosphorus in ditch outflow from treatment areas I, II, III, and IV over the period 1994–1998. Lines in the bars indicate standard error of mean. An asterisk indicates a statistical difference ($p < 0.05$) from the samples collected during the pre-cut period in 1994.

High loads were observed immediately after site preparation in 1995 and during snow-melt in 1996 (Fig. 3). However, SPS concentrations in 1997–1998 no longer differed from those before clear-cutting and site preparation.

Also increased leaching of N_{org} only occurred at area IV. The mean annual concentrations in ditch outflow in 1995–1998 were 22%–42% higher than before clear-cutting and site preparation in 1994. The concentrations of NH₄⁺-N and NO₃⁻-N in ditch outflow following clear-cutting and site preparation increased from areas II and

IV (Figs. 2, 4 and 5). The concentrations of inorganic nitrogen were particularly high during the second and the third year after clear-cutting and site preparation. The increase in NO₃⁻-N concentrations at area II was not significant ($p > 0.05$) however.

Concentrations of P_{org} from areas III and IV were significantly higher in 1996 than before clear-cutting and site preparation in 1994. Concentrations of PO₄³⁻-P following clear-cutting and site preparation increased from areas I, II, and III although concentrations from area III

were only high during the second year after treatment (Figs. 2 and 6). Very high $\text{PO}_4^{3-}\text{-P}$ concentrations were observed also during the third year after treatment from areas I and II.

Discussion

Water quality effects of clear-cutting and site preparation were studied on a drained, nutrient poor Scots pine mire by sampling the outflow water from the middle ditches of four treatment areas (Fig. 1 and Table 1). Concentrations of SPS in ditch outflow following clear-cutting and site preparation increased significantly from area IV whereas no increases were detected from the other areas. Area IV was ditch-mounded in such a way that the ditches reached down into the fine-textured mineral soil below the peat layer. The enhanced leaching of SPS from this area is therefore not surprising. In a study by Joensuu *et al.* (1999), the total length of ditches dug down into fine-textured subsoil was the most important factor explaining the concentrations of SPS in ditch outflow. To reduce the leaching of SPS from clear-cut areas, site preparation methods other than ditch-mounding should be used where

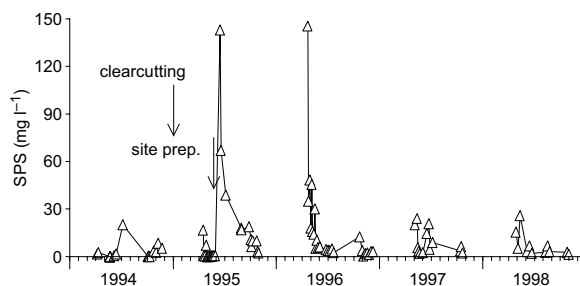


Fig. 3. Concentrations of SPS in ditch outflow from treatment area IV.

the ditches are likely to reach down into the fine-textured subsoil.

The concentrations of $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$ in outflow water increased from the two ditch-mounding areas (II and IV), whereas clear-cutting and clear-cutting+mounding (areas I and III) did not increase leaching. Increased leaching of $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$ from only the ditch-mounding areas indicates that ditching has a stronger impact on nitrogen than clear-cutting. This contrasts with Lundin's (1998) results from productive Norway spruce mires where clear-cutting increased the leaching of $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$ slightly more than clear-cutting+ditching. Compared with my previous results from productive

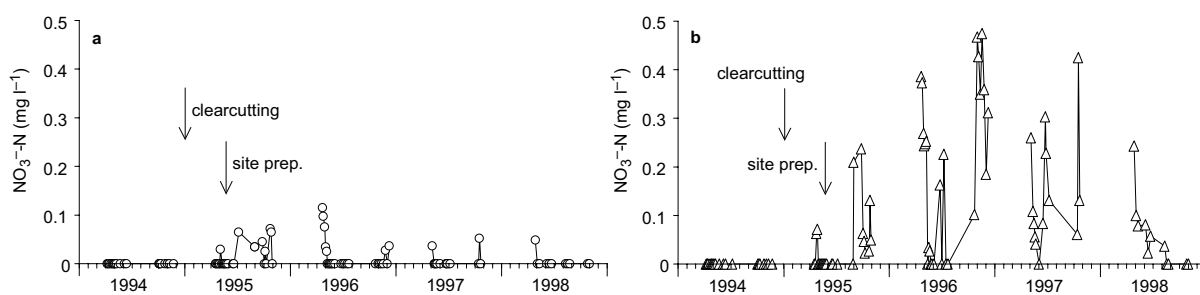


Fig. 4. Concentrations of $\text{NO}_3^-\text{-N}$ in ditch outflow from treatment areas (a) II and (b) IV.

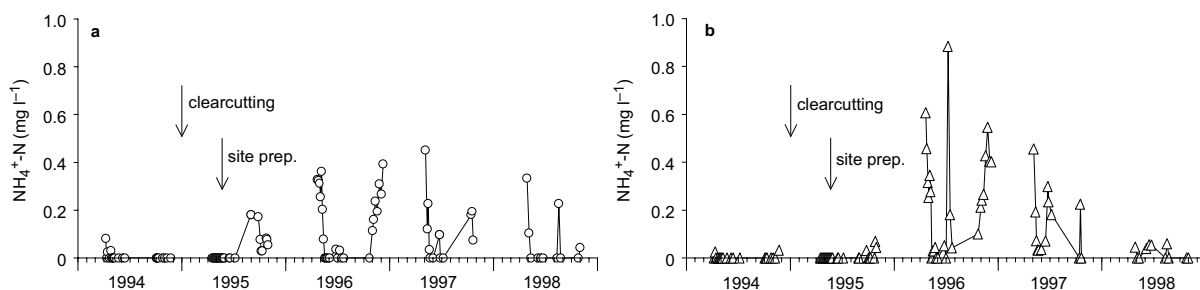


Fig. 5. Concentrations of $\text{NH}_4^+\text{-N}$ in ditch outflow from treatment areas (a) II and (b) IV.

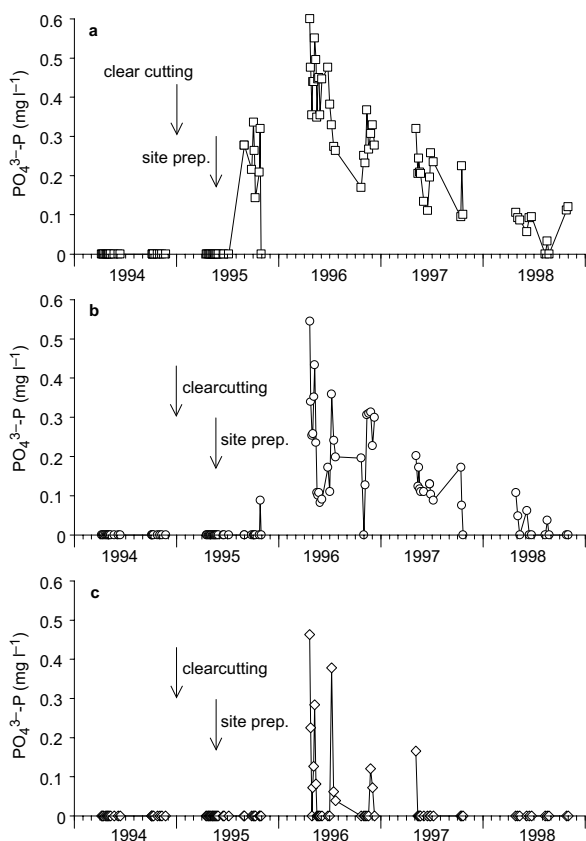


Fig. 6. Concentrations of $\text{PO}_4^{3-}\text{-P}$ in ditch outflow from treatment areas (a) I, (b) II, and (c) III.

spruce mires (Nieminen 1998), the changes in the leaching of N_{org} caused by clear-cutting in the present study were small.

Concentrations of $\text{PO}_4^{3-}\text{-P}$ in ditch outflow following clear-cutting and site preparation increased from areas I, II, and III. However, no changes in $\text{PO}_4^{3-}\text{-P}$ concentrations due to treatment were observed from area IV. The movement of P in mineral soils and Al and Fe rich peatlands is limited by their high PO_4 adsorption capacity (Cuttle 1983, Nieminen and Jarva 1996). Peat with low Al and Fe content such as occur in nutrient poor ombrotrophic mires have very low PO_4 adsorption capacities. The low Al and Fe content in the peat at areas I, II, and III (Table 1) are likely to mean low PO_4 adsorption capacities and thus explain the increased leaching of $\text{PO}_4^{3-}\text{-P}$ from these areas. Phosphate adsorption in area IV is probably higher than from the other areas, and this is why no changes in P leaching occurred. The results concerning P from this study are in accordance with previous

ones showing enhanced P leaching following P-fertilizer application on Al and Fe poor peatlands (Ahti 1983, Nieminen and Ahti 1993). The Al and Fe content of peat thus appears to be a very critical factor in controlling PO_4 leaching from drained peatland forests.

The study demonstrated that clear-cutting and site preparation can significantly impair water quality from drained pine mires of low productivity. This is the first time results for such mires have been reported. However, the study comprised only one experimental site. In future research, a number of sites with differing soil and stand properties and climatic conditions should be investigated. The present study also only investigated the changes in nutrient concentrations in ditch outflow; information about nutrient loads (kg ha^{-1}) would also be important for water quality planning and protection. Future research should therefore include data on water yield. Research examining the effects of alternative cutting treatments, such as whole-tree harvesting, on nutrient outflow would also be important.

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Received 1 April 2001, accepted 15 November 2002