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Changes in mineral element concentrations in peat soils drained for forestry in Finland

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Abstract

The concentrations of Ca, Mg, K, Fe, Mn, Al, Cu, Zn, Mo, Pb, Cr and Cd were determined for surface peat samples for 80 sites on both undrained and drained pine mires. The oldest areas had been drained 55 years earlier. Though the gravimetric concentrations of many elements tend to decrease with increasing drainage age, the stores in the 0-50 cm peat layer do not change much along the drainage age gradient. This is possible because compaction of peat takes place after drainage, and, consequently, the 0-50 cm layer in the drained plots includes peat that was below the 50 cm limit before the sites were drained. The fact that elements are removed from soil by uptake of tree stands and leaching is thus indicated by the decreasing, or unchanging, gravimetric concentrations only. *Key words: drainage, heavy metals, nutrients, pine mires*

INTRODUCTION

In the early phases of mire formation, plants have several sources of nutrients: the mineral soil below, ground water flowing from the surrounding upland areas, the decomposing organic remains forming the still thin peat layer, and atmospheric deposition. As the peat layer grows thicker, the root contacts with the mineral soil and ground water become weaker, and the vegetation becomes ever more dependent on the two last-mentioned sources. Some of the nutrients in dead decomposing plant material are cycled between the living vegetation and the aerated surface peat, but more and more are buried out of reach in the increasing bulk of peat. Various aspects of the biogeochemistry of undrained mires have been studied by e.g. Mattson & Koutler-Andersson (1954), Malmer (1962), Damman (1978, 1986), Hemond (1980), Damman et al. (1992), Verry & Urban (1992).

Drainage for forestry and the consequent water level drawdown causes many changes in the site properties from the plants' point of view, as outlined by, e.g., Laiho & Laine (1994). The oxidation/reduction conditions change (Lähde 1969), and the increased aeration of the surface peat allows for an accelerated rate of nutrient mineralisation (e.g. Lieffers 1988, Freeman et al. 1993). The subsidence of the mire surface brings new nutrient reserves from deeper peat layers back to where they can be reached by plant roots (Laiho & Laine 1994). On the other hand, leaching of many elements increases, at least temporarily, with the increased runoff after drainage

(Ahtiainen 1988, Lundin 1988, Sallantaus 1992), and in deep peat, all groundwater contact is usually cut off by the ditches.

Tree stand growth increases after drainage, because of an increased oxygen supply for roots in the aerated surface peat (Boggie 1977). The increasing tree biomass accumulates nutrients taken up from the soil. Calculations based on static physical post-drainage rooting zone volume have produced results that indicate that nutrient, especially K stores will be depleted in many site types as early as at the end of first or during the second tree stand rotation (Kaunisto & Paavilainen 1988, Finér 1989). Long-term studies on the actual changes in post-drainage nutrient stores have, however, not been done.

The aim of the present study is to examine how drainage for forestry affects the stores of mineral elements in surface peat of a selection of mire site types most commonly drained in Finland. Phosphorus has already been dealt with in an earlier paper (Laiho & Laine 1994) together with N.

MATERIAL AND METHODS

The selection of the material and the sampling procedure are described in detail in Laiho & Laine (1994), and are thus only briefly summarised here.

The studied mires are located in central Finland in a region between 61°35'-62°05'N and 23°50'-24°55'E. The elevation of the sites varies between 105 and 170 m a.s.l. The mean annual temperature of the region is 3 °C and that of July 16 °C. The mean annual temperature sum (accumulated mean daily temperatures $\geq$ 5 °C) varies between 1150 and 1250 d.d. The annual precipitation is about 650 mm, of which nearly 240 mm is snowfall**.**

Altogether, measurements were made at 80 sample plots on sites, both undrained and drained, which belong to following mire site types in the Finnish classification system (Cajander 1913, see Laine et al. 1986 for current terminology): 1) herb-rich sedge birch-pine fen (RhSR), 2) tall-sedge pine fen (VSR), 3) cottongrass-sedge pine fen (TSR), 4) low-sedge *Sphagnum papillosum* pine fen (LkR) and 5) cottongrass pine bog (TR). Short site type descriptions are also given in Laiho & Laine (1994). In addition to the material in Laiho & Laine (1994), two new sample plots were measured, one on an undrained herb-rich sedge birch-pine fen and one an undrained tall-sedge pine fen.

When selecting the sites, special attention was paid to their comparability, especially in the case of drained sites, where the vegetation differs significantly from that of the same site types in their natural condition (Laine 1989, Laine et al. 1995).

To standardise hydrological conditions, the sample plots (10 x 30 m) were placed along contour ditches with the longer side of the plot being parallel to the ditch. Three series of undisturbed peat samples were taken from four depths: 0-10, 10-20, 25-35, and 50-60 cm. Zero-level was taken as the upper level of the rooting zone, which often corresponds to the lower level of the living moss layer.

The peat samples were dried at 105 °C, weighed for bulk density calculations, and ground to pass through a 2 mm sieve. Roots with diameter $\geq$ 1 cm, if present, were removed before grinding. For each sample plot, the samples from all three sample points representing the same depths were combined and mixed thoroughly. Element concentrations were measured on an ICP-analyser (ARL 358) after HNO_3-H_2SO_4-$HClO_4$ digestion in 200 °C (see Allen 1974).

The Pb concentrations obtained for some samples were disregarded because a very high Pb concentration was inexplicably found in the blank sample used to control that particular sample set.

Nutrient stores for the 0-50 cm surface peat layer were calculated as weighted means of the sampled layers. The depth of the peat layer represented by each peat sample was used as the weight (sampling did not cover the whole 0-50 cm layer).

Because the number of plots representing some original site types was too small, the plots were grouped into two site type groups. The "meso-oligotrophic" site type group consists of RhSR and VSR site types, which are closely related to each other in terms of vegetation and peat composition (sedge peat). The "oligo-ombrotrophic" site type group consists of more nutrient-poor site types: TSR, LkR and TR (*Sphagnum*-peat). According to time passed since drainage, the material was divided into four "drainage age" classes: undrained plots, plots drained 1 - 20 years, 21 - 40 years, and 41 - 55 years before sampling.

To illustrate the trends in the measured parameters after drainage, we used a robust locally weighted regression for smoothing scatter plots (Cleveland 1979, Wilkinson 1989).

RESULTS

Almost all of the mineral elements studied are found in larger quantities in the surface peat on the meso-oligotrophic, clearly minerotrophic, sites (Figs. 1 - 4). Only K and Pb occur in similar amounts on both site type groups, and there is more Zn on oligo-ombrotrophic than on meso-oligotrophic sites.

The variation in the stores of the studied elements in peat is large (Table 1, Figs. 1 - 4). In general, the stores do not change much along the drainage age gradient. Only the amounts of Ca and Fe seem to have decreased on meso-oligotrophic sites with increasing drainage age. On oligo-ombrotrophic sites, the amount of Mg decreased and that of Al increased, especially in the layer below 20 cm. Also the amount of K seems to slightly increase on oligo-ombrotrophic sites with increasing drainage age.

The amounts of heavy metals in peat (Figs. 3, 4) are too small to allow any conclusions concerning their relationship to the drainage age.

The average gravimetric concentrations of K, Ca, Mg and Mn tend to decrease towards the oldest drainage age class, especially on the meso-oligotrophic sites (Table 1). Concentrations of Al and heavy metals do not show a clear trend along the drainage age gradient.

DISCUSSION

The study is based on an assumption that drained sites belonging to the same original site type were similar before drainage and have developed in a similar manner after drainage. The validity of the approach has been discussed by Laiho & Laine (1994). It should be borne in mind that our data cannot be used to make any conclusions about actual changes taking place on individual sites, they only show an average trend within a relatively large material.

The stores of the studied elements in a 50 cm surface peat layer seem to remain rather constant after drainage. This observation may seem rather surprising at first, as we know, that after drainage of forested peatlands, an increasing amount of mineral elements is bound by the tree stands, and that the leaching of most elements increases at least in the beginning of the drainage succession.

The studied elements most readily taken up by trees are Ca, K and Mg. We estimated the amounts of these elements bound by the tree stands on our sample plots, using concentration values due to Paavilainen (1980) for ombrotrophic sites and those of Finér (1989) for meso-oligotrophic site types (see Laiho & Laine 1994). According to our estimates, the tree stands on the oldest drained meso-oligotrophic sites had bound, on average, approximately 200 kg ha^{-1} Ca, 90 kg ha^{-1} K and 40 kg ha^{-1} Mg in their above-ground biomass after drainage. The corresponding figures for oligo-ombrotrophic sites were 120, 70 and 30 kg ha^{-1}, respectively. The amount of K in the oldest tree stands is approximately the same as the amount in the surface peat, whereas the amounts of Ca and Mg found in the tree stands are ca. 20 % of the remaining stores in the surface peat.

Sallantaus (1992) found a net loss of Ca, Mg and K with runoff water from drained mire catchments, whereas on the undrained parts of the same catchments, the inputs and outputs of these elements were more or less balanced. Magnesium and Ca were leached relatively more easily than K, which is retained effectively by the vegetation, as concluded by e.g. Laiho & Laine (1992). In our drained material, the ratio of K to Ca and Mg in peat is highest in the oldest drainage age class.

The removal of elements from peat can be seen as a decrease in the gravimetric concentrations of most elements after drainage (Table 1). If the gravimetric concentrations decrease but the volumetric ones remain the same, it means that compaction of peat must take place simultaneously. The bulk density values of peat, presented in an earlier paper (Laiho & Laine 1994), indeed increase after drainage. Thus the compaction of peat, which brings "new" peat material from below to the studied layer (always 50 cm), compensates for the losses of elements when a certain peat volume is observed. The amount of some elements may even increase, depending on the relation between the rates of peat compaction and element removal. The fact that elements are actually removed from peat, is thus shown as decreasing gravimetric concentrations only. The mechanism of peat compaction is discussed in more detail by Laiho & Laine (1994).

In addition to peat compaction, another factor compensating for the removal of elements from the surface peat, may be the ability of increased tree stand canopy biomass to capture dry deposition, which, as a process, is generally acknowledged but difficult to quantify (e.g. White & Turner 1970, Lindberg & Lovett 1985, Hicks et al. 1987).

The gravimetric concentrations of Al and some heavy metals remain, on an average, approximately the same after drainage. The same holds for Fe on oligo-ombrotrophic sites; on meso-oligotrophic sites the very large variation in the Fe concentration makes it difficult to draw any firm conclusions. This is partially explained by the fact that these elements are not actively taken up by the plants, as most of them are toxic. Information concerning their leaching rates from peatlands, and the effect of drainage, is scanty and partly contradictory (e.g. Ahtiainen 1990, Bergquist et al. 1984). As the concentrations of Al and Fe in our material do not increase even if the surface peat is compacted, it may be concluded that these elements are leached to some extent from the surface peat assuming that no significant amounts are bound into the tree stand biomass.

Our values for heavy metals, especially Cd, Cr, Mo and Pb, may be considered as being only indicative, showing the magnitude of their presence in peat. Their concentrations were close to the detection limits of the assay method used, and the quantitative effect of possible contamination of samples during sampling and further treatment could not be estimated.

Harvesting may considerably affect the nutrient capital of these ecosystems. Relatively large quantities of some cations, e.g. K, are removed in harvested stemwood (Kaunisto & Paavilainen 1988, Finér 1989), and whole-tree harvesting would further increase element losses. The leaching losses of most elements have been found to increase after harvesting as well (e.g. Ahtiainen 1988).

Earlier studies concerning nutrient stores on drained peatlands have been based on rather small data sets. The very large variation included in our material shows, that making comparisons within various small subsets could lead to very different conclusions about the post-drainage changes. On an average, however, it seems that the first post-drainage tree generation does not essentially deplete the nutrient supplies of surface peat in the studied site types.

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REFERENCES

Ahtiainen, M. 1988. Effects of clear-cutting and forestry drainage on water quality in the Nurmes-study. Proc. Int. Symp. on the Hydrology of Wetlands in Temperate and Cold Regions, Joensuu, Finland, 6-8 June. Publications of the Academy of Finland 4, pp. 206-219. ISSN 0358-9153; ISBN 951-715-215-9.

Ahtiainen, M. 1990. The effects of clear-cutting and forestry drainage on water quality of forest brooks. National Board of Waters and the Environment, Finland, Publications of the Water and Environment Administration, series A 45: 1-122. ISSN 0786-9592; ISBN 951-47-3631-1. (In Finnish with English summary.)

Allen, S.E. (Ed.) 1974. Chemical analysis of ecological materials. 565 pp. Blackwell Scientific Publications, Oxford. ISBN 0-632-00321-9.

Bergquist, B., Lundin, L. & Andersson, A. 1984. Hydrologiska och limnologiska konsekvenser av skogs- och myrdikning. Siksjöbäcksområdet. Summary: Effects of peatland drainage on hydrology and limnology. The basin Siksjöbäcken. Department of Limnology, Uppsala University, Research report 9: 1-27. (In Swedish with English summary.)

Boggie, R. 1977. Water-table depth and oxygen content of deep peat in relation to root growth of Pinus contorta. Plant and Soil 48:447-454.

Cajander, A.K. 1913. Studien über die Moore Finnlands. Acta Forestalia Fennica 2(3): 1-208. (In German.)

Cleveland, W.S. 1979. Robust locally weighted regression and smoothing scatterplots. Journal of the American Statistical Association 74: 829-836.

Damman, A.W.H. 1978. Distribution and movement of elements in ombrotrophic peat bogs. Oikos 30: 480-495.

Damman, A.W.H. 1986. Hydrology, development, and biogeochemistry of ombrogenous peat bogs with special reference to nutrient relocation in a western Newfoundland bog. Canadian Journal of Botany 64: 384-394.

Damman, A.W.H., Tolonen, K. & Sallantaus, T. 1992. Element retention and removal in ombrotrophic peat of Häädetkeidas, a boreal Finnish peat bog. Suo 43(4-5): 137-145.

Finér, L. 1989. Biomass and nutrient cycle in fertilized and unfertilized pine, mixed birch and pine, and spruce stands on a drained mire. Acta Forestalia Fennica 208: 1-63.

Freeman, C., Lock, M.A. & Reynolds, B. 1993. Climatic change and the release of immobilized nutrients from Welsh riparian wetland soils. Ecological Engineering 2: 367-373.

Hemond, H. 1980. Biogeochemistry of Thoreau's bog, Concord, Massachusetts. Ecological Monographs 50: 507-526.

Hicks, B.B., Baldocchi, D.D., Meyers, T.P., Hosker Jr., R.P. & Matt, D.R. 1987. A preliminary multiple resistance routine for deriving dry deposition velocities from measured quantities. Water, Air, and Soil Pollution 36: 311-330.

Kaunisto, S. & Paavilainen, E. 1988. Nutrient stores in old drainage areas and growth of stands. Communicationes Instituti Forestalis Fenniae 145: 1-39.

Lähde, E. 1969. Biological activity in some natural and drained peat soils with special reference to oxidation-reduction conditions. Acta Forestalia Fennica 94: 1-69.

Laiho, R. & Laine, J. 1992. Potassium stores in peatlands drained for forestry. Proceedings of the 9th International Peat Congress, Uppsala, Sweden. Vol. 1, pp. 158-169. ISSN 0782-7784.

Laiho, R. & Laine, J. 1994. Nitrogen and phosphorus stores in peatlands drained for forestry in Finland. Scandinavian Journal of Forest Research 9:251-260.

Laine, J. 1989. Classification of peatlands drained for forestry. Suo 40: 37-51. (In Finnish with English summary).

Laine, J., Päivänen, J., Schneider, H. & Vasander, H. 1986. Site types at Lakkasuo mire complex. Field guide. Publications from the Department of Peatland Forestry, University of Helsinki 8, pp. 1-35.

Laine, J., Vasander, H. & Laiho, R. 1995. Long-term effects of water level drawdown on the vegetation of drained pine mires in southern Finland. Journal of Applied Ecology (Accepted).

Lieffers, V.J. 1988. *Sphagnum* and cellulose decomposition in drained and natural areas of an Alberta peatland. Can. J. Soil Sci. 68: 755-761.

Lindberg, S.E. & Lovett, G.M. 1985. Field measurements of particle dry deposition rates to foliage and inert surfaces in a forest canopy. Environ. Sci. Technol. 19: 238-244.

Lundin, L. 1988. Impacts of drainage for forestry on runoff and water chemistry. Proc. Int. Symp. on the Hydrology of Wetlands in Temperate and Cold Regions, Joensuu, Finland, 6-8 June. Publications of the Academy of Finland 4, pp. 197-205. ISSN 0358-9153; ISBN 951-715-215-9.

Malmer, N. 1962. Studies on mire vegetation in the Archaean area of southwestern Götaland (south Sweden) II. Distribution and seasonal variation in elementary constituents on some mire sites. Opera Botanica 7(2):1-67.

Mattson, S. & Koutler-Andersson, E. 1954. Geochemistry of a raised bog. Kungliga Lantbrukshögskolans Annaler 21: 321-366.

Paavilainen, E. 1980. Effect of fertilization on plant biomass and nutrient cycle on a drained dwarf shrub pine swamp. Communicationes Instituti Forestalis Fenniae 98: 1-71.

Sallantaus, T. 1992. Leaching in the material balance of peatlands - preliminary results. Suo 43: 253-258.

Verry, E.S. & Urban, N.R. 1992. Nutrient cycling at Marcell Bog, Minnesota. Suo 43: 147-153.

White, E.J. & Turner, F. 1970. A method of estimating income of nutrients in a catch of airborne particles by a woodland canopy. Journal of Applied Ecology 7: 441-461.

Wilkinson, L. 1989. SYGRAPH: The system for graphics for the PC. SYSTAT Inc. Evanston IL. 980 pp. ISBN 0-928789-05-5.

Table 1. Mean values (± SD) of the gravimetric concentrations of some mineral elements in peat (0 - 50 cm layer). The values are given separately for site type groups, drainage age classes (years since drainage). The values in brackets show the number of sites for which Pb concentrations could be given.

	Years since drainage			
	0	1-20	21-40	41-55
Meso-oligotrophic sites				
K, mg g^{-1}	0.295±0087	0.202±0.050	0.199±0.038	0.193±0.041
Ca, mg g^{-1}	5.652±4.994	3.936±1.108	3.869±1.924	2.579±1.127
Mg, mg g^{-1}	0.531±0.270	0.603±0.282	0.487±0.331	0.413±0.145
Mn, mg g^{-1}	0.114±0.140	0.061±0.078	0.073±0.054	0.037±0.024
Fe, mg g^{-1}	8.569±6.517	3.118±2.002	6.362±2.644	2.845±1.920
Al, mg g^{-1}	1.982±1.239	2.225±0.680	1.665±0.758	1.998±0.857
Zn, mg g^{-1}	0.015±0.008	0.012±0.006	0.014±0.011	0.015±0.006
Cu, μg g^{-1}	7.330±7.103	7.555±2.379	3.973±2.319	5.949±2.282
Mo, μg g^{-1}	1.619±1.004	0.997±0.476	1.391±0.503	0.896±0.454
Cd, μg g^{-1}	0.643±0.478	0.290±0.170	0.365±0.107	0.339±0.104
Cr, μg g^{-1}	4.850±3.189	3.718±1.204	4.093±1.965	3.296±1.380
Pb, μg g^{-1}	6.260±2.701	3.640±1.611	3.986±1.592	4.757±1.773
n	5	13 (9)	12	14
Oligo-ombrotrophic sites				
K, mg g^{-1}	0.308±0036	0.215±0.032	0.253±0.100	0.211±0.040
Ca, mg g^{-1}	2.737±0.715	2.308±0.658	2.943±1.450	1.705±0.597
Mg, mg g^{-1}	0.620±0.166	0.478±0.164	0.506±0.161	0.293±0.101
Mn, mg g^{-1}	0.030±0.015	0.022±0.014	0.018±0.012	0.023±0.030
Fe, mg g^{-1}	1.213±0.433	1.268±0.597	1.113±0.509	1.259±1.063
Al, mg g^{-1}	0.673±0.315	1.171±0.585	0.633±0.196	1.466±0.446
Zn, mg g^{-1}	0.038±0.010	0.022±0.010	0.025±0.014	0.022±0.025
Cu, μg g^{-1}	3.070±0.829	3.610±1.106	2.692±0.672	4.639±1.555
Mo, μg g^{-1}	0.754±0.292	0.608±0.306	0.665±0.346	0.655±0.197
Cd, μg g^{-1}	0.438±0.186	0.293±0.182	0.397±0.080	0.301±0.082
Cr, μg g^{-1}	3.140±0.783	2.713±1.233	1.993±0.793	2.327±0.935
Pb, μg g^{-1}	9.559±3.327	7.195±2.106	7.771±3.513	5.553±2.706
n	6 (5)	11 (7)	8	11

LEGENDS FOR ILLUSTRATIONS:

Fig. 1. The stores of Ca, Mg, K, Fe, Mn and Al in the 0 - 50 cm peat layer of the meso-oligotrophic sites, as a function of drainage age. The lower, dashed, lines show the stores in the 0 - 20 cm peat layer.

Fig. 2. The stores of Ca, Mg, K, Fe, Mn and Al in the 0 - 50 cm peat layer of the oligo-ombrotrophic sites, as a function of drainage age. The lower, dashed, lines show the stores in the 0 - 20 cm peat layer.

Fig. 3. The stores of Cu, Zn, Mo, Pb, Cr and Cd in the 0 - 50 cm peat layer of the meso-oligotrophic sites, as a function of drainage age. The lower, dashed, lines show the stores in the 0 - 20 cm peat layer.

Fig. 4. The stores of Cu, Zn, Mo, Pb, Cr and Cd in the 0 - 50 cm peat layer of the oligo-ombrotrophic sites, as a function of drainage age. The lower, dashed, lines show the stores in the 0 - 20 cm peat layer.