How to estimate N and P losses from forestry in northern Sweden

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Text edited by
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Report from a workshop
at the Royal Swedish Academy of Agriculture and Forestry
14 March 2006

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Preface

The scientific workshop: *How to estimate N and P losses from forestry in northern Sweden*, was held in March 2006 by The Royal Swedish Academy of Agriculture and Forestry (KSLA) in cooperation with the SMED-consortium (IVL, SCB, SLU and SMHI). SMED is contracted by the Swedish Environmental Protection Agency to estimate and apportion sources of terrestrial nitrogen (N) and phosphorus (P) loadings to the sea. The aim of the workshop was to support SMED and others with guidance and suggestions on how to improve earlier estimates of N and P losses from forest land in northern Sweden associated with silvicultural practices. Eva Ring from Skogforsk, Mike Starr from Helsinki University and Ahti Lepistö from the Finnish Environmental Institute presented valuable summaries of the state of the art regarding these issues.

At the workshop, Olle Westling, from IVL, characteristically played a leading and inspiring role in the discussions. His long and broad experience and scientific knowledge were of great value at the workshop. In the summer of 2006, in a tragic accident, Olle was lost on a glacier in Sarek, northern Sweden. The participants of the workshop would therefore like to dedicate this report to his memory. As a colleague and friend, Olle will be sorely missed by all of us.

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Estimation of leaching of nitrogen and phosphorus from forestry in northern Sweden

EVA RING, SKOGFORSK

Introduction

Since approximately half the land area of Sweden is productive forest land (Swedish Forest Agency, 2005), forest management regimes could have a significant impact on the total export of elements from the land to surrounding coastal waters. However, little is known about the effects of forestry operations on water chemistry and runoff. Most of the relevant studies that have been performed were carried out in the 1970s and 1980s in the southern part of Sweden, but forest management practices have changed considerably since then. Thus, we lack data from sites in northern Sweden, which have been managed according to current practices (Löfgren and Brandt, 2005). In the present paper, I suggest some potential methodological improvements to the estimation of N (nitrogen) and P (phosphorus) leaching from forests in northern Sweden based on current knowledge and a preliminary evaluation of data from eight soil-solution experiments.

Extent of forestry operations

In the National Statistics on Swedish forestry (Swedish Forest Agency, 2005), Sweden is divided into four main areas, with northern Norrland (the counties Norrbotten and Västerbotten) and southern Norrland (the counties Jämtland, Västernorrland and Gävleborg) constituting the northern half of Sweden. Henceforth, 'northern Sweden' will refer to northern and southern Norrland.

The total area of productive forest land in northern Sweden amounts to 12.6 million hectares (Swedish Forest Agency, 2005). Currently around 89,000 hectares are finally felled annually and 84,000 hectares are subjected to mechanical site preparation. In addition, around 200 hectares are protectively ditched and, in 2003, 11,900 hectares were fertilised with nitrogen (Swedish Forest Agency, 2005). Thus, final felling and site preparation are annually performed on about 0.7% of the productive forest land in this part of the country.

Leaching

The amounts of an element that are leached can be calculated using the following simple equation:

Leaching = concentration × duration × runoff × area (1)

See below for discussion of circumstances affecting the variables in the equation.

Seasonal dynamics

Forestry statistics are produced on an annual basis, therefore, the minimum time resolution for calculating regional or national leaching rates is one year. However, different forestry operations are performed in different seasons. Final felling is carried out throughout the year, while site preparation can only be performed in the period without ground frost, i.e. from spring until autumn. Nitrogen fertilisation should preferably be performed between May and September (Jacobson et al., 2005), not on frozen ground, thawing ground or ground that is covered by snow (Swedish Forest Agency, SKSFS 1991:2). Protective ditching may be carried out between site preparation and planting. The environmental effects of different forestry operations might be affected by seasonal dynamics in runoff and temperature. However, the uncertainties related to seasonal dynamics are probably minor compared to other sources of uncertainty, such as the effects of management practices on sites with differing fertility.

Concentration and duration

The effects of different forestry operations on N leaching generally show a distinct temporal pattern. The N leaching related to final felling, site preparation and protective ditching derives from hydrological and biological processes, whereas the effects of nitrogen fertilisation originate from the application of an easily soluble fertiliser.

Figure 1. Location of Skogforsk soil-solution experiments, which include harvested control plots. The Garsås experiment was established by Stora Corporate Research AB.

Effects of forestry on P leaching have received little attention in Sweden.

Final felling and site preparation

N leaching

The productivity of the boreal forest is limited by the amount of available N (Tamm, 1991), resulting in a low background leaching of N. Hence, the forest land acts as a sink for N during most of the rotation periods of boreal forest stands. At final felling, however, a period with elevated N leaching is initiated as a result of increased runoff and increased availability of soil N (*cf.* Ring, 2001). Shortly afterwards, the effects of site preparation interact with the effects of final felling. Until the vegetation is re-established, the clear-cut forest land acts as a source of N.

Wiklander (1983) suggested that the rate of N leaching after final felling is related to the site quality in an analysis based on groundwater samples from clear cuts. I have used soil-solution data from untreated control plots on mineral soil, which have been clear cut by conventional methods and/or by whole-tree harvesting, to analyse the post-felling effects on the concentrations of inorganic N (mainly nitrate-N).

The control plots are part of eight field experiments which have been established mainly by Skogforsk over a 20-year period to study the effects of wood-ash application on clear cuttings, whole-tree harvesting, the long-term effects of forest fertilisation, site preparation and prescribed burning (Ring, 1996; Ring et al., 1999, 2001, 2003; unpublished data). The experiments include two to four control plots and are located in the southern half of Sweden (figure 1). On each study plot, one to five suction cups were installed at approximately 50 cm soil depth (30-40 cm depth at Mangskog). The concentrations of ammonium and nitrate in the soil solutions collected in these experiments provide indications of rates at which they are leached to groundwater in recharge areas. Such data may reveal important mechanisms of nitrate leaching. So far, however, we have not been able to relate leaching to groundwater with leaching from the catchment area accurately. Half of the sites had site qualities between 3.1 and 7.0 m^3 ha^{-1} yr^{-1} and the remaining four sites had site qualities between 8.4 and 12.6 m^3 ha^{-1} yr^{-1}.

The data from each of the eight experiments were collected in unique circumstances in terms of the weather, sampling intervals, number of samplings and amount of logging residues left on site. Moreover, the dates of final felling and the first recording of elevated nitrate-N concentrations are somewhat uncertain. Despite the merged data set, which includes the data from all eight experiments, being affected in an unknown manner by these variables, some patterns in changes of N concentrations were detected.

The concentrations of ammonium-N were generally much lower than the concentrations of nitrate-N, and elevations in ammonium-N due to clear cutting had shorter durations than those of nitrate-N. The concentrations of both ammonium-N and nitrate-N were highest at the sites with the highest site quality (8.4-12.6 m^3 ha^{-1} yr^{-1}). Detectable increases in nitrate-N following clear felling lasted approximately five years at all sites. The lag period (*cf.* Vitousek et al., 1979) from final felling until the concentration of nitrate-N started to rise was less than one year at the sites with the highest site quality (8.4-12.6 m^3 ha^{-1} yr^{-1}), but five years at the site with the lowest site quality (3.1 m^3 ha^{-1} yr^{-1}).

A preliminary statistical evaluation suggests that the mean soil-solution concentration of nitrate-N was linearly related to the C/N-ratio and the site-quality class (table 1). The mean concentration of nitrate-N for the period with elevated nitrate-N concentrations (>0.02 mg N l^{-1}) in the clear cuts was assumed to represent the effect of conventional final felling, i.e. when the logging residues are left on site. The duration of the elevation in the nitrate-N concentration due to final felling was defined accordingly (the period with nitrate-N>0.02 mg l^{-1}). The lag period is the period between final felling and the date of the first recorded elevation in the nitrate-N concentration (>0.02 mg N l^{-1}).

When calculating the nitrate leaching from final felling, the temporal development of the nitrate concentration and runoff must be accounted for, including the lag period and the duration period. Two examples of how this can be done are presented in figure 2.

The results from the soil-solution experiments suggest that the calculations should also include:

- Separation of leaching from conventionally harvested areas and that from whole-tree

Relationship	n	Slope	*p*-value	R^2
$C_{nitrate}$ =f (C/N in humus)	9	-0.13	0.030	0.51
$C_{nitrate}$ =f (site quality)	13	0.24	0.089	0.24
$C_{nitrate}$ =f (lag period)	13	-0.57	0.086	0.24
$C_{nitrate}$ =f (duration)	12	-0.51	0.13	0.22

Table 1. The mean concentration of nitrate-N ($C_{nitrate}$) in the soil solution during the post-felling period with elevated nitrate concentrations (duration) as a linear function of the C/N-ratio in the humus layer, the site quality, the lag period and the duration of the nitrate-N elevation. The data originate from conventionally clear-cut control plots in up to eight field experiments. "n" is the number of control plots used.

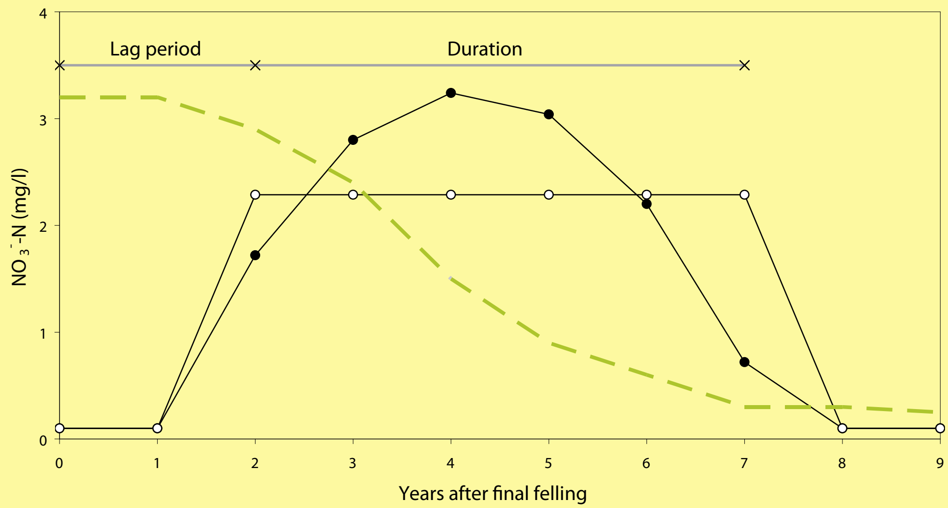

Figure 2. Illustration of how changes in the soil-solution nitrate-N concentration over time after final felling in northern Sweden may be expressed: (i) by a polynomial equation for the duration considered (●) or, (ii) as a mean concentration during that period (o). The broken line shows a potential effect of final felling on runoff based on the assumption that the effects are greatest initially and decline as the recolonisation of the clear cut proceeds. The scales on both axis are arbitrary.

harvested areas (the nitrate concentrations after whole tree-harvesting might be expressed as a fraction of the concentrations after conventional harvesting).

• Spatial stratification of the total harvested area on mineral soil based on the C/N-ratio in the humus layer and/or the site-quality class (currently under investigation by L. Högbom and E. Ring, focussing on northern Sweden. In addition, the content of ^{15}N in *Deschampsia flexuosa* will be tested as a potential indicator of nitrate leaching).

• The effect of site preparation (data from one field experiment in northern Sweden show reduced nitrate concentrations in site-prepared areas. Högbom and Ring will investigate this further).

• Conversion of the leaching rate to groundwaters to the leaching rate from the catchments.

The conversion of the leaching rate to groundwaters (according to soil-solution experiments) to the leaching rate from the catchments is crucial. Currently we do not know how this conversion should be done. Important chemical and hydrological processes taking place in the near-stream discharge areas are not normally accounted for in soil-solution experiments. In the Sniptjärn catchment in Hälsingland, the nitrate leaching was elevated for eight years after final felling and leaching of organic N was elevated for 16 years (K. Rosén, pers. comm., 2006). The initial leaching of organic N after final felling was also found to be quantitatively important in two other Swedish studies (Grip, 1982; Lundin, 1999). Increased leaching of organic N after final felling may result from enlarged near-stream discharge areas. Final felling on drained peatlands may increase leaching and/or the concentrations of total N and inorganic N (Ahtiainen, 1992; Lundin, 1999; Nieminen, 2004).

P leaching

Phosphorous may be leached either dissolved in water (mainly bound to humus) or bound to particles. Increased groundwater levels after final felling, causing enlarged discharge areas and increased leaching of organic matter, may thus increase leaching of P. Final felling, site preparation, ditching and ditch cleaning are forestry operations which sometimes increase the erosion to water, and hence, the transport of particulate P, especially in soils rich in P. Increased leaching of P, particularly organic P, after final felling has been found in Kloten in Västmanland (Grip, 1982), and in Sniptjärn in Hälsingland (Uggla and Westling, 2003). Varying effects of final felling on the leaching of P or concentrations of P from drained peatlands have been reported (Ahtiainen, 1992; Lundin, 1999; Nieminen, 2004).

Forest fertilisation with N

N fertilisation has no effect on phosphate-P in the soil solution (Ring et al., 2006), but it does affect N leaching. An easily soluble fertiliser is applied, so N leaching after forest fertilisation is influenced by the weather following application. Forest fertilisation at typical rates (about 150 kg N per hectare) may initially result in high concentrations of inorganic N in soil water and stream water (figure 3) (Nohrstedt and Westling, 1995). Unfertilised buffer zones may effectively reduce the initial rise in the inorganic N concentration recorded in stream water (Nohrstedt and Ring, 1991).

N leaching rates after forest fertilisation can be estimated in catchment studies, soil-solution experiments or isotope tracer experiments. Based on catchment studies, Nohrstedt and Westling (1995) concluded that leaching

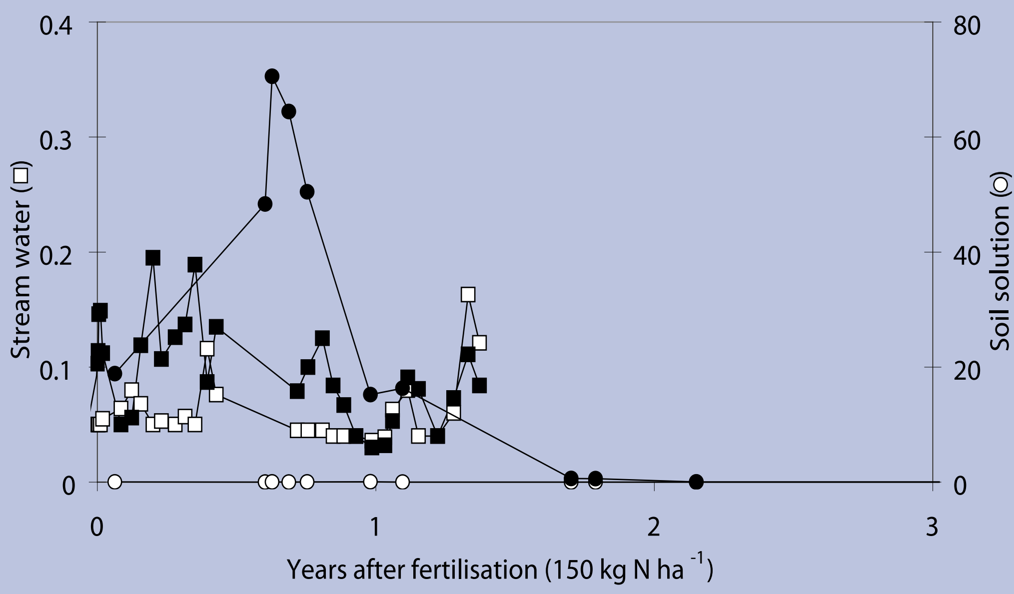

Figure 3. Concentration of inorganic N (mg l^{-1}) after forest fertilisation with N in the deep soil solution (circles) and in stream water (squares). The soil-solution study was performed in Västmanland and the stream study in Hälsingland (Nohrstedt and Ring, 1991; Ring et al., 2006). Open symbols = control, filled symbols = N-fertilised.

of inorganic N due to fertilisation generally accounts for less than 5% of the fertiliser dose, but a value of 25% has been reported. Moreover, concentration of inorganic N generally returns to control levels within two years. In a 50-year old *Pinus sylvestris* stand in south-central Sweden, Melin and Nômmik (1988) applied labelled ammonium nitrate at 150 kg N per hectare. Two growing seasons after the application, they recovered about 90% of the labelled fertiliser N in the vegetation and soil. Most of the unrecovered N was assumed to have leached from the system, amounting to about 10% of the fertiliser dose. I suggest therefore that estimates of regional N leaching resulting from forest fertilisation should be based on a constant percentage of the applied fertiliser dose, for instance 5-10 %, amounting to 7.5 to 15 kg of inorganic N per hectare. The majority of the leaching probably takes place in the first year after fertilisation. Hence, the duration of the leaching in Equation 1 may be set to one year.

Ditch cleaning and protective ditching

The effects of ditch network maintenance on runoff chemistry have been studied in 40 catchments with peatland forests located in southern and central Finland (Joensuu et al., 2002). No major changes were found in the concentrations of total dissolved N and P. However, high P concentrations were occasionally observed immediately after the digging operations. The concentrations of inorganic N, especially ammonium-N, increased significantly while organic N concentrations decreased. I suggest that the contribution from ditch cleaning and protective ditching to the regional N and P leaching should be disregarded, since these operations currently affect a very small area in northern Sweden and the study by Joensuu et al. (2002) found insignificant effects on the concentrations of total dissolved N and P. However, if the areas subjected to ditch cleaning and protective ditching increase dramatically in the future, we must improve our knowledge on the effects of these practices in northern Sweden.

Runoff

The forestry operations discussed here all affect runoff in some respect. Hence, runoff data obtained by national monitoring must be adjusted to improve the estimated contribution from forestry. Pronounced increases in runoff often occur after final felling, resulting from a decrease in evapotranspiration due to the tree harvest (Bosch and Hewlett, 1982; Grip, 1987). Forest fertilisation with N increases the leaf area index, which increases evapotranspiration and hence decreases percolation (Berdén et al., 1997; Alavi, 2002). Neither the effects of forest fertilisation on runoff nor the hydrological effects of site preparation appear to have been studied at a catchment scale. Ditch cleaning probably recreates the hydrological conditions originally created by ditching. Since final felling significantly affects runoff and is practised over a large area annually, I suggest that the leaching calculations for final felling alone should include correction factors for the increase in runoff. It seems reasonable to assume that the increase in runoff will decline over time since clear cuts are progressively re-colonised by ground vegetation and seedlings.

Area

'Area' refers to the area affected by a certain forestry operation. A prerequisite when using the total affected area in leaching calculations is that the leaching should be unrelated to site characteristics such as fertility, soil type and geology. The soil data provided by the Swedish University of Agricultural Sciences (MarkInfo, http://www-markinfo.slu.se/) and the Geological Survey of Sweden (http://www.sgu.se) allow more detailed divisions of the affected area.

Conclusions

Attempts to accurately calculate N leaching rates from forest based on the extent of different forestry operations, should concentrate on the contribution from final felling and site preparation. Preliminary data from soil-solution experiments suggest that the calculations may be improved if the harvested area on mineral soil is stratified by site-specific parameters like the C/N-ratio in the humus layer or the site-quality class. However, the hydrological effects of final felling, especially enlarged near-stream discharge areas, may affect the subsequent leaching to surface water in unknown ways. Estimates of the N leaching resulting from forest fertilisation may be based on a constant percentage of the applied fertiliser doses, for instance 5-10 %, amounting to 7.5 to 15 kg of inorganic N per hectare. Leaching is assumed to take place during the year of fertilisation. The contribution from ditch cleaning and protective ditching to the regional N and P leaching may be disregarded, since these operations currently affect a very small area in northern Sweden and the reported effects of ditch cleaning on the concentrations of total dissolved N and P seem to be minor.

In this paper I have suggested ways of improving calculations of N and P leaching caused by different forestry operations. However, our knowledge of the effects of forestry on N and P leaching is still insufficient to provide major improvements in these calculations. Important issues that remain to be addressed include the following:

- How should post-felling effects on runoff and concentrations of N and P be expressed for mineral soils and peatlands?
- How does site preparation affect leaching of N and P?
- Can soil-solution data be utilised for calculating regional N and P leaching?

References

Ahtiainen, M. 1992 The effects of forest clear-cutting and scarification on the water quality of small brooks. *Hydrobiologia* **243/244**: 465-473.

Alavi, G. 2002. The impact of soil moisture on stem growth of spruce forest during a 22-year period. *Forest Ecology and Management* **166**: 17-33.

Berdén, M., Nilsson, S.I., and Nyman, P. 1997. Ion leaching before and after clear-cutting in a Norway spruce stand - effects of long-term application of ammonium nitrate and superphosphate. *Water, Air, and Soil Pollution* **93**: 1-26.

Bosch, J.M., and Hewlett, J.D. 1982. A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. *Journal of Hydrology* **55**: 3-23.

Grip, H. 1982. Water chemistry and runoff in forest streams at Kloten. UNGI *Report* no. 58, Department of Physical Geography, Uppsala University, Uppsala. 144 pp.

Grip, H. 1987. Avrinningsförändringar efter kalavverkning. *Sveriges Skogsvårdsförbunds Tidskrift* **2/87**: 43-49.

Jacobson, S., Pettersson, F., Högbom, L. and Sikström, U. 2005. Skogsgödsling – en handledning från Skogforsk. *Handledning*, Skogforsk, Uppsala. 55 pp.

Joensuu, S., Ahti, E., and Vuollekoski, M. 2002. Effects of ditch network maintenance on the chemistry of run-off water from peatland forests. *Scandinavian Journal of Forest Research* **17**: 238-247.

Lundin, L. 1999. Effects on hydrology and surface water chemistry of regeneration cuttings in peatland forests. *International Peat Journal* **9**: 118-126.

Löfgren, S. and Brandt, M. 2005. Kväve och fosfor i skogsmark, fjäll och myr i norra Sverige. *Report Series SMED and SMED&SLU* no. 14 (http://www.smed.se), SMHI, Norrköping. 36 pp.

Melin, J. and Nômmik, H. 1988. Fertilizer nitrogen distribution in a *Pinus sylvestris/Picea abies* ecosystem, Central Sweden. *Scandinavian Journal of Forest Research* **3**: 3-15.

Nieminen, M. 2004. Export of dissolved organic carbon, nitrogen and phosphorus following clear-cutting of three Norway spruce forests growing on drained peatlands in southern Finland. *Silva Fennic*a **38**: 123-132.

Nohrstedt, H.-Ö. and Ring, E. 1991. Brookwater chemistry and leakage after a calcium ammonium nitrate fertilization by tractor (In Swedish with English summary). *Report* no. 20, The Institute for Forest Improvement, Uppsala. 20 pp.

Nohrstedt, H.-Ö. and Westling, O. 1995. Miljökons ekvensbeskrivning av STORA SKOGs gödslingsprogram, Del 1 faktaunderlag (In Swedish). *Report* B1218, IVL Swedish Environmental Research Institute, Aneboda. 90 pp.

Ring, E. 1996. Effects of previous N fertilizations on soil-water pH and N concentrations after clear-felling and soil scarification at a *Pinus sylvestris* site. *Scandinavian Journal of Forest Research* **11**: 7-16.

Ring, E. 2001. Nitrogen in soil water at five nitrogen-enriched forest sites in Sweden. *Acta Universitatis Agriculturae Sueciae* Agraria 267, 36 pp.

Ring, E., Bergholm, J., Olsson, B.A., and Jansson, G. 2003. Urea fertilizations of a Norway spruce stand: effects on nitrogen in soil water and field-layer vegetation after final felling. *Canadian Journal of Forest Research* **33**: 375-384.

Ring, E., Högbom, L., and Nohrstedt, H.-Ö. 2001. Effects of brash removal after clear felling on soil and soil-solution chemistry and field-layer biomass in an experimental nitrogen gradient. In Optimizing nitrogen management in food and energy production and environmental protection: Proceedings of the 2nd International Nitrogen Conference on Science and Policy. *TheScientificWorld 1*.

Ring, E., Jacobson, J., and Nohrstedt, H.-Ö. 2006. Soil-solution chemistry in a coniferous stand after adding wood ash and nitrogen. *Canadian Journal of Forest Research* **36**: 153-163.

Ring, E., Lövgren, L., Nohrstedt, H.-Ö., and Jansson, G. 1999. Ash fertilization in a clearcut and in a Scots pine stand in central Sweden - Effects on soil-water and soil chemistry coupled to laboratory leachings of six ash products. *SkogForsk Report* no. 2, Skogforsk, Uppsala. 51 pp.

Swedish Forest Agency, 2005. Swedish Statistical Yearbook of Forestry 2005. (http://www.svo.se).

Tamm, C.O. 1991. Nitrogen in terrestrial ecosystems: Questions of productivity, vegetational changes, and ecosystem stability. *Ecological Studies* 81, 115 pp.

Uggla, E. and Westling, O. 2003. Utlakning av fosfor från brukad skogsmark. *IVL Rapport* B1549, IVL Swedish Environmental Research Institute Ltd., Stockholm. 20 pp.

Vitousek, P.M., Gosz, J.R., Grier, C.C., Melillo, J.M., Reiners, W.A. and Todd, R.L. 1979. Nitrate losses from disturbed ecosystems; Interregional comparative studies show mechanisms underlying forest ecosystem response to disturbance. *Science* **204**: 469-474.

Wiklander, G. 1983. Loss of nitrogen by leaching from fertile forest soils in southern Sweden (In Swedish with English summary). *Journal of the Royal Swedish Academy of Agriculture and Forestry* **122**: 311-317.

Nitrogen and phosphorus leakage from Finnish forestry - results from experimental studies

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Introduction – the Finnish experience

Leaching losses of nitrogen (N) and phosphorus (P) from forest soils represents both a loss of important nutrients from the site and a source of eutrophifying nutrients to recipient surface waters (and ultimately the Baltic). Normally, N and P are both tightly circulated in boreal coniferous forest-soil systems, and levels of leaching per unit area are generally low, at least compared to agriculture. In a study by Mattsson et al. (2003), annual leaching losses of N and P from unmanaged, forested Finnish catchments averaged 140 kg km^{-2} and 5.4 kg km^{-2} respectively, with individual catchment values ranging form 77 to 230 kg km^{-2} for N and from 2.1 to 18 kg km^{-2} for P. Disturbance of the forest-soil system through management practices, however, tends to result in leakage and increased leaching of N and P.

Annual N and P leaching from catchments (stream water export loads) subject to forestry management (varying amounts of peatland ditching, clear cutting, scarification and fertilisation) averaged 183 and 10 kg km^{-2}, respectively (Kortelainen and Saukkonen 1998). But the management needed to be rather intensive before clear long-term impacts were shown. Since forestry practices in Finland have tended to become lighter and more environmentally-friendly, the leakage of N and P from soil can be expected to be less intense nowadays than in the past.

Fertiliser, which was identified as the major P source in Kortelainen and Saukkonen's study, is now little used in forestry, and site preparation has clearly moved away from heavy and deep ploughing practices to light scarification and to smaller areas being treated at any one time. However, the practice of whole-tree harvesting, which may be expected to cause considerably more disturbance than the more traditional stem wood-only harvesting practice, has increased recently. The intensity of both N and P leaching is generally related to the proportion of peatland (and thus ditches) in the catchment. Whilst the ditching of pristine peatlands has now all but ceased, ditch cleaning and maintenance is set to increase substantially in the near future (Joensuu 2002). Fortunately though, concentrations of dissolved N and P have been shown to be little affected by ditch maintenance (Joensuu et al. 2002). Increased loads of suspended solids in the first few years after ditch maintenance, however, may result in increased loads of particulate N and P.

These Finnish studies also show that concentrations of N and P in runoff from both unmanaged and managed catchments tend to be dominated by organic forms, and for concentrations to decrease northwards (reflecting the effects of decreasing temperature and an increasing proportion of peatland). However, as runoff increases northwards, differences in export loads between southern and northern Finland are not obvious.

Results from The VALU project

Since 1991 we have been carrying out a paired-catchment study to determine the effects of harvesting and site preparation practice on the cycling, leaching and export of nutrients to recipient surface waters in eastern Finland (Finér et al. 1997). Here, we report on the results from the most intensively studied of the paired-catchments: Kangasvaara and Kangaslampi (figure 1).

The location of the catchments (63º 51' N, 28º 58' E) is considerably further north than studies carried out in Sweden, and thus offers a useful insight into what may occur in northern Sweden.

The treated catchment, Kangasvaara, is 59 ha in area, of which 9% is peatland. The harvested stands were old-growth, uneven aged (average age 140 yr, max 170 yr) and mixed, with Norway spruce dominating, and having a stem volume of 275 m^3 ha^{-1}. The (Cajanderian) site type is *Vaccinium-Myrtillus*, VMT, i.e., relatively moist and fertile. The soil is a haplic podzol developed on sandy till material (<2 % clay; 28 % vol. stone content) and having mor humus layer averaging 3 cm in thickness.

Harvesting (conventional stem-only) was carried out in during September-October 1996, and involved 5 upland compartments at 'final cutting stage' totalling an area of 19.4 ha (30% of catchment area). As is now standard practice, no cutting was carried out adjacent to the stream. Site preparation with a disc plough mounted on the back of forest tractor was carried out in September 1998. The plough produces two shallow furrows (width c. 50 cm, depth 5-15 cm) with a low ridge on the outer side and separated by an undisturbed strip

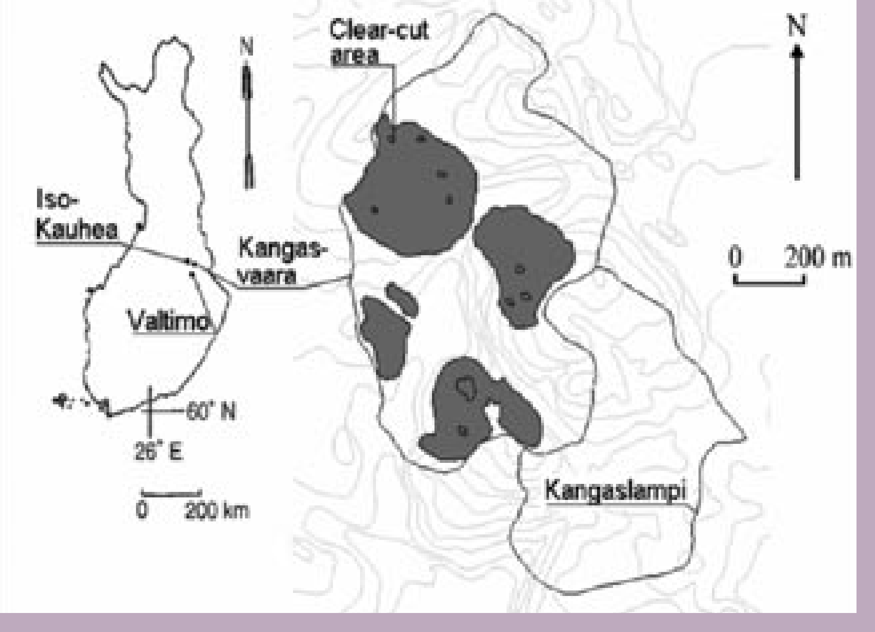

Figure 1. In Finland paired-catchment studies have been carried out in Kangasvaara and Kangaslampi to determine the effects of harvesting and site preparation practice on the cycling, leaching and export of nutrients to recipient surface waters.

(1 m width). Planting with 1-year-old Scots pine transplants was done in June 1999.

Soil water from below the humus layer, the E-horizon and the B-horizon (35 cm depth) at intensively monitored plots has been sampled weekly during the snow-free period (April-October) with gravity-type lysimeters (Finér et al. 1997, Piirainen et al. 2002, 2004 and 2006).

Before harvesting, annual leaching losses of dissolved N from below the B-horizon averaged (1993-1996) 0.1 kg ha^{-1} and that of P, 0.01 kg ha^{-1}. After harvesting, the leaching of N had increased to an average (1997-1999) of 0.2 kg ha^{-1}, which was due to an increase in both inorganic (nitrate and ammonium) and organic N (Piirainen et al. 2002 and 2004). PO_4-P accounted for >70% of total P in the leachate. The average annual leaching of P remained unchanged after harvesting.

Ploughing resulted in increased leaching of both N and P, the increase being particularly associated with the ridges. Taking into account the proportion of land occupied by ridges, furrows and undisturbed land, the leaching of N from below the B-horizon averaged 2.58 kg ha^{-1} and that of PO4-P, 0.09 kg ha^{-1} of clear-cut and prepared area over the five years following ploughing (Piirainen et al. 2006). The results suggest that ploughing had a stronger effect on leaching form the soil than did harvesting alone.

Runoff from the catchment integrates the leaching from upland harvested and unharvested areas of the catchment as well as the leaching from the lower lying riparian area, dominated by peatland. Over the 3 years following harvesting, annual runoff export loads of N from the Kangasvaara catchment increased by an average of 0.34 kg $ha^{-1}$of clear-cut, and that of P by 0.001 kg ha^{-1} of clear-cut (Ahtiainen & Huttunen 1999, Ahtiainen et al. 2003). After site preparation, the annual runoff export loads increased further; that of N reaching 0.58 and that of P reaching 0.006 kg ha^{-1} of clear-cut over the first 3 years following ploughing.

Concluding remarks

On the basis of Finnish studies, which would correspond to northern Sweden, it can be speculated that N and P losses from forestry in northern Sweden have been overestimated in previous calculations. The impacts of forestry in northern Sweden compared to those observed in southern Sweden are probably less intense (lower concentrations), but increases in runoff may offset lower concentrations resulting in no clear significant differences in export loads. Organic forms of dissolved N and P will be at least as important as inorganic forms, and the greater coverage of peatlands will play a significant factor in leaching losses. Particulate (suspended loads) losses of N and P should not be overlooked.

References

Ahtiainen, M. & Huttunen, P. 1999. Long-term effects of forestry management on water quality and loading in brooks. Boreal Environment Research 4: 101-114.

Ahtiainen, M., Finér, L., Haapanen, M., Kenttämies, K., Mattsson, T. & Rämö, A. 2003. Näkyvätkö hakkuun ja maanmuokkauksen vaikutukset valumaveden laadussa – tehoavatko ympäristönsuojeluohjeet? In: Finér, L., Laurén, A. & Karvinen, L. (eds.) Ajankohtaista metsätalouden ympäristökuormituksesta – tutkimustietoa ja työkaluja –seminaari Kolin Luontokeskus Ukko 23.9.2002. Metsäntutkimuslaitoksen tiedonantoja/Finnish Forest Research Institute, Research Papers 886: 25-34. (in Finnish)

Finér, L., Ahtiainen, M., Mannerkoski, H., Möttönen, V., Piirainen, S., Seuna, P. & Starr, M. 1997. Effects of harvesting and scarification on water and nutrient fluxes. A description of catchments and methods, and results from the pretreatment calibration period. Finnish Forest Research Institute, Research Papers 648. 38 pp.

Joensuu, S. 2002. Effects of ditch network maintenance and sedimentation ponds on export loads of suspended solids and nutrients from peatland forests. Finnish Forest Research Institute, Research Papers 648.

Joensuu, S., Ahti, E. & Vuollekoski, M. 2002. Effects of ditch maintenance on the chemistry of run-off water from peatlands forests. Scand. J. For. Res. 17: 238-247.

Piirainen, S., Finér, L., Mannerkoski, H. & Starr, M. 2002. Effects of forest clear-cutting on the carbon and nitrogen fluxes through podzolic soil horizons. Plant and Soil 239(2): 301-311.

Piirainen, S., Finér, L., Mannerkoski, H. & Starr, M. 2004. Effects of forest clear-cutting on the sulphur, phosphorus and base cations fluxes through podzolic soil horizons. Biogeochemistry 69(3):405-424.

Piirainen, S., Finér, L., Mannerkoski, H. & Starr, M. 2006. Carbon, nitrogen and phosphorus leaching after site preparation at a boreal forest clear-cut area. (Submitted manuscript).

Methods for estimating excess nitrogen and phosphorus leakage from forestry in Finland

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Introduction

There is a restricted amount of knowledge of how different forestry treatments quantitatively and spatially affect nutrient losses from soils to surface water. Both new empirical studies of forest treatments, and new more advanced methods to extrapolate results in large scales are needed. The methods should yield estimates relevant to improve scientific knowledge of forestry impacts, relevant for international reporting, relevant for assessing national environmental goals restricting eutrophication, and relevant for the EU Water Framework Directive.

In Finland, forests cover over 80% of the total land area, of which forested peatlands cover one third. Over half of these peatlands have been drained for forestry using open ditches to lower the water table in order to ensure successful establishment of trees on peat soils. The contribution of forestry as a nutrient source to waters increases towards eastern and northern Finland. For example, in the northern Oulujoki river basin, forestry and agriculture contribute equally to the total N export: approximately 16% each (Lepistö et al., 2001). Forest management practices such as clear-cutting may alter the N cycle by decreased plant uptake, enhanced mineralisation, altered accumulation rate of inorganic nitrogen in the soil, nitrate leaching and increased denitrification (e.g. Wiklander et al., 1991). These practices may alter the P cycle e.g. by increased erosion forces, by decreased plant uptake, by changes in soil temperature, or by anaerobic conditions as a consequence of rising groundwater table. The nutrient losses may be high and the increased leaching may in some cases continue up to 10-15 years after the disturbance (Ahtiainen and Huttunen, 1999). However, data on large-scale impacts of forest management practices are needed before any clear effect on spatial variability of nutrient export can be identified (Lepistö et al., 1995; Kortelainen and Saukkonen, 1998). Concerning forestry, random mosaic of treatment areas is typical, with highly varying impact periods, therefore scale issues are very important. At large spatial scales, the use of satellite imagery for detecting forest changes has attracted increasing attention, and methods to control the quality of continuously updated forest information by remote sensing have been proposed, e.g. (Varjo, 1997).

Examples of approaches for modelling N transport and retention in large scales include HBV-N, which is based on hydrological HBV model linked to the process-based SOIL-N model and with input data handled in GIS (Arheimer and Brandt, 1998). The second approach for nutrient modelling, the export coefficient modelling approach typically utilises all major land use classes based on remote sensing, including forestry, other GIS data sets and export coefficient data from empirical studies. The approach is simple and logical and the limited input requirements make the approach useful for catchment assessments and for national scales (Johnes, 1996; Johnes and Butterfield, 2002). Examples include Moneris for simulating nutrient emissions (Behrendt et al., 2002), PolFlow which simulates the transport of nutrients as a function of soil, lithology and runoff characteristics (De Wit, 2001) and N_EXRET (Lepistö et al., 2001) for simulating N export from different sources and N retention in lakes and peatlands, and for simulating P export in regional scale (Markkanen et al., 2001).

In catchments and river-dominated basins, advanced process-based, semi-distributed, dynamic nutrient models such as INCA (Whitehead et al., 1998; Wade et al., 2002) can be applied over a wide range of spatial and temporal scales, utilising e.g. forest cut area data based on remote sensing, and available data on N transformation processes in cut areas (Rankinen et al, 2002; 2004). However, the model is currently unsuitable for complex waterways with large lakes, or for large, national scales.

Possible methods for estimating nutrient losses from forestry

Detailed paired-catchment experiments. The effects of forestry treatments on nutrient losses have usually been studied using paired-catchment experiments: comparing first - during calibration period - a treatment catchment with a reference natural-state catchment. After the forestry treatment, its impact can be quantified (e.g. Ahtiainen and Huttunen, 1999).

Excess nutrient export due forestry can be roughly estimated by comparing average of managed catchment nutrient export values with those of natural-state catchments, using long-term data, and as many catchments as possible. These estimates give us an idea of the excess leaching due forestry in regional scale, and prevent us to extrapolate the 'outlier' export values to large scales.

N/P export from forestry is defined as excess export (over natural background N/P export) from the forests attributable to management practices such as drainage and cuttings. Background N/P export is defined as all 'natural' N export, both from forests on mineral and organic soils and from peatlands, which are close-to-pristine conditions.

Export coefficient models such as N_EXRET (Lepistö et al., 2001) are useful tools in large scales. To test reliable utilisation at the regional scale, the forestry export coefficients measured elsewhere can be evaluated in a 'test' catchment. One example of this approach is the Myllypuro catchment, where a model for temporal variability of N export was used. The model overestimated slightly the total N export, but provided a reasonable representation of the annual N dynamics and the response to two major forest treatments; drainage in 1973 and clearcut in 1980-1982 (Lepistö & Kenttämies 1998; Lepistö et al. 2001).

The export-coefficient model N_EXRET briefly

Model overview

The total N export to a water body at any point along its length can be calculated as the sum of the nitrogen outputs from each source in the river basin using N_EXRET model. A full description of this raster-based GIS model is given in Lepistö et al. (2001). Briefly, the modelling can be done in three steps. First, N export from soil to water is estimated by each land use class within each 1 km * 1 km grid, using the export co-efficients for each land-use class. Second, the total terrestrial nitrogen export (N_{ex}) to a watercourse is calculated by summing the N exports of the grids (N_{ex_grid}) within the river basin concerned. Third, mass balances for the river basins are calculated, including diffuse and point sources and retention. Retention in peatlands and in lakes are assumed to be stable within a river basin, directly related to their areas, and estimated by retention parameters.

GIS-based land use data and export coefficients as model input

Spatial data is typically obtained from satellite image-based land cover and forest classification data (e.g. Vuorela, 1997), including major land use classes such as agricultural land, mineral soil forests, different types of peatlands, recent and older cut areas, plantations, peat harvesting areas and built-up areas. Export coefficients should be based on empirical studies from the geographical and climatic region concerned. Their widespread application is always a problem due to spatial and temporal heterogeneity of the studied ecosystems. Examples of the regionally used export coefficients in Finland are given by Lepistö et al. (2001), Markkanen et al. (2001) and Lepistö et al. (2006).

Nitrogen export from forestry and background in Finland

Nitrogen input from major diffuse and point sources and its retention in all the major river basins in Finland were quantified recently. A spatial N export and retention model N_EXRET was applied in the national scale, and specifically to 30 river basins (range 357-49500 km^2) which together cover 60% of the country. The total estimated input for the whole country, 119 000 tonnes N a^{-1}, was based on N export from different land use types, together with N deposition and point sources (Lepistö et al., 2006).

Nitrogen export from forestry is difficult to separate from background N export from semi-natural forests. The nutrient export from forestry, defined here as 'excess N export', occurs typically in the same areas as background export but is based on a mosaic of numerous forest treatment areas, where the time-period of the impact varies from site to site. Although the uncertainties are high, an attempt was made to separate between these two sources, utilising satellite-image based forest cut area information and up-to-date data of export coefficients for different land-use types (Lepistö et al, 2006).

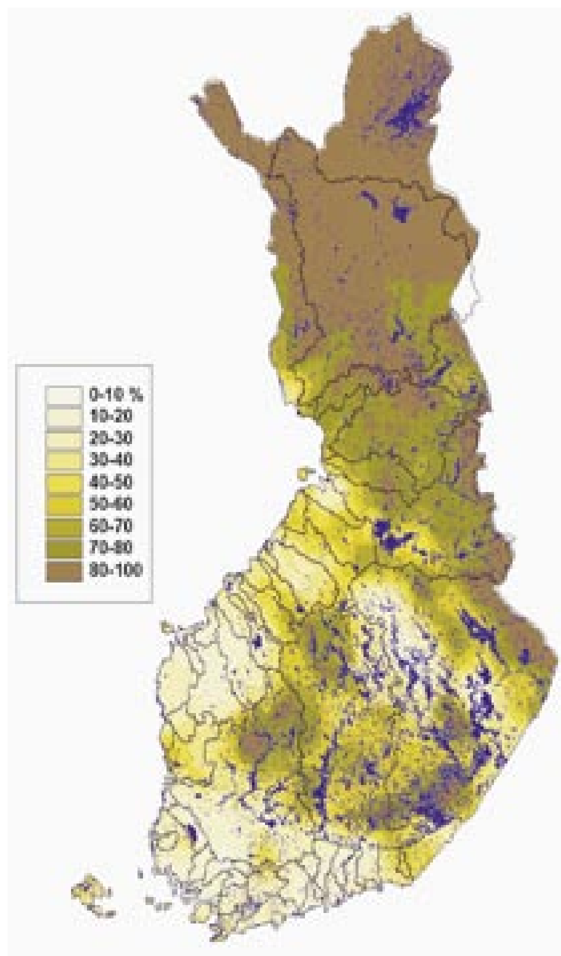

Figure 1. Contribution (%) of the diffuse source N export from background and forestry in Finland (Lepistö et al, 2006).

Forestry contributes on average 9% of the total export, with dominance towards eastern and northern parts of the country: from 2-15% in the southern-mid-western Finland basins to 10-30% in the large northern basins. Background N export in the northern basins may contribute from 40 to 90% of the total export (figure 1). The contribution of forestry is estimated to be 11 000 tonnes N a^{-1} and that of background export 32 000 tonnes N a^{-1}. The combined export was 43 000 tonnes N a^{-1} and the excess export due to forestry was 34% of background N export (Lepistö et al, 2006). This means that in large forested areas, forest management contributes N excess export of the same order as that measured in small forest catchments representative of semi-natural forest. Kortelainen and Saukkonen (1998) give a mean N export of 1.90 kg $ha^{-1}a^{-1}$ for 22 small catchments with numerous small-scale forest management practices from the 1960s until the early 1990s, representing forestry in Finland. This export is on average 0.55 kg $ha^{-1}a^{-1}$ (40%) higher than the mean N export of 1.35 kg $ha^{-1}a^{-1}$ in 42 small catchments with semi-natural forest (Mattsson et al., 2003; Kortelainen et al., 2006).

Concluding remarks

On a wide spatial scale, there are many uncertainties which produce variability in both measured and modelled N export values: limited frequency of sampling, land use class interpretation and estimation of export coefficients and their accuracy when applied across regions.

There is a very high variability of nutrient leaching, both between forestry catchments and natural-state catchments. Concerning natural N leaching, there is a clear difference in mineral soils in southern vs. northern Finland. Average excess N (40%) and P fluxes (90%) are considerable, and impacts may be long lasting (in some cases up to 10-15 years).

Regional scale modelling is a useful tool, but uncertainties are high: concerning both the export coefficients, GIS land-use data, and retention model parameters. Export coefficient models such as N_EXRET can be used for spatial assessment of nutrient sources and retention in large river basins, bearing in mind the uncertainties involved. In modelling, sensitivity analysis needs to be done, different combinations of parameters may give same results. Detailed assessment and scenario work needs process-based models. More long-term empirical studies of forestry impacts on nutrient fluxes are clearly needed, together with further development of extrapolation and modelling methodologies.

References

Ahtiainen M, Huttunen P. 1999. Long-term effects of forestry managements on water quality and loading in brooks. *Boreal Environ. Res.* 4: 101-114.

Arheimer B, Brandt, M. 1998. Modelling nitrogen transport and retention in the catchments of southern Sweden. Ambio 27: 471-480.

Behrendt H, Kornmilch M, Opitz D, Schmoll O, Scholz G. 2002. Estimation of the nutrient inputs into river systems – experiences from German rivers. *Regional Environmental Changes* 3: 107-117.

De Wit MJM. 2001. Nutrient fluxes at the river basins scale. I: The PolFlow model. *Hydrol Process* 15: 743-759.

Johnes PJ. 1996. Evaluation and management of the impact of land use change on the nitrogen and phosphorus load delivered to surface waters: the export coefficient modelling approach. *J Hydrol* 183: 323-349.

Johnes PJ, Butterfield D. 2002. Landscape, regional and global estimates of nitrogen flux from land to sea: Errors and uncertainties. *Biogeochemistry* 57/58: 429-476.

Kortelainen P, Saukkonen S. 1998. Leaching of nutrients, organic carbon and iron from Finnish forestry land. *Water Air Soil Pollut* 105: 239-250.

Kortelainen, P., Mattsson, T., Finer, L., Ahtiainen, M., Saukkonen, S. & Sallantaus, T. 2006.Controls on the export of C, N, P and Fe from undisturbed boreal catchments, Finland. *Aquatic Sciences* 68:453-468.

Lepistö A, Andersson L, Arheimer B, Sundblad K. 1995. Influence of catchment characteristics, forestry activities and deposition on nitrogen export from small forested catchments. *Water Air Soil Pollut* 84: 81-102.

Lepistö, A. & Kenttämies, K. 1998. Towards the use of satellite-based forest change data in large-scale N leaching models - testing and modeling in a catchment scale. The Nordic Coordinating Committee for Hydrology (KOHYNO), Helsinki. NHP Report 44:210-224.

Lepistö, A., Kenttämies, K. & Rekolainen, S. 2001. Modeling combined effects of forestry, agriculture and deposition on nitrogen export in a northern river basin in Finland. *Ambio* 30(6): 338-348.

Lepistö, A., Granlund, K., Kortelainen, P. & Räike, A. 2006. Nitrogen in river basins: sources, retention in the surface waters and peatlands, and fluxes to estuaries in Finland. *Science of the Total Environment* 365:238-259.

Markkanen, S-L, Markkanen, S.-L., Lepistö, A., Granberg, K., Huttunen, M., Kenttämies, K., Rankinen, K. & Virtanen, K. 2001. Kainuun vesistöjen ravinnekuormitus. Suomen ympäristö 509. (in Finnish)

Mattsson, T., Finér, L., Kortelainen, P. & Sallantaus, T. 2003. Brook water quality and background leaching from unmanaged forested catchments in Finland. *Water, Air & Soil Pollution* 147: 275-297.

Rankinen K, Lepistö A, Granlund K. 2004. Integrated nitrogen and flow modelling (INCA) in a boreal river basin dominated by forestry: Scenarios of environmental change. *Water Air Soil Pollut, Focus* 4: 161-174.

Rankinen, K., Lepistö, A. & Granlund, K. 2002. Hydrological application of the INCA model with varying spatial resolution and nitrogen dynamics in a northern river basin. *Hydrology and Earth System Sciences* 6: 339-350.

Varjo J. 1997. Change detection and controlling forest information using multi-temporal Landsat TM imagery. *Acta Forest. Fenn*. 258. 64 pp.

Vuorela A. 1997. Satellite image based land cover and forest classification of Finland. Reports of the Finnish Geodetic Institute Nr 97, pp. 42-52.

Wade AJ, Durand P, Beaujouan V, Wessels WW, Raat KJ, Whitehead PG, Butterfield D, Rankinen K, Lepistö A. 2002. A nitrogen model for European ecosystems: INCA, new model structure and equations. *Hydrol Earth Syst Sci* 6: 559-582.

Whitehead PG, Wilson EJ, Butterfield D. 1998. A semi-distributed Integrated Nitrogen model for multiple source assessment in Catchments (INCA): Part I - model structure and process equations. *Sci Tot Environ* 210/211: 547-558.

Wiklander G, Nordlander G, Andersson R. 1991. Leaching of nitrogen from a forest catchment at Söderåsen in Southern Sweden. *Water Air Soil Pollut* 55: 263-282.

Recent publications in Finland, related to forestry and/or natural leaching:

Regional scale N modelling:

Lepistö, A., Kenttämies, K. & Rekolainen, S. 2001. Modeling combined effects of forestry, agriculture and deposition on nitrogen export in a northern river basin in Finland. *Ambio* 30(6): 338-348.

Modelling of P and N in Kainuu region:

Markkanen, S-L, Markkanen, S.-L., Lepistö, A., Granberg, K., Huttunen, M., Kenttämies, K., Rankinen, K. & Virtanen, K. 2001. Kainuun vesistöjen ravinnekuormitus. Suomen ympäristö 509. (in Finnish)

Monitoring in small catchments in Finland:

Vuorenmaa, J., Rekolainen, S., Lepistö, A., Kenttämies, K. & Kauppila, P. 2002. Losses of nitrogen and phosphorus from agricultural and forest areas in Finland during the 1980s and 1990s. *Environmental Monitoring and Assessment* 76: 213-248.

Leaching from small forestry catchments:

Kortelainen, P. & Saukkonen, S. 1998. Leaching of nutrients, organic carbon and iron from Finnish forestry land. *Water, Air, Soil Pollut* 105: 239-250.

Leaching from natural-state catchments:

Mattsson, T., Finér, L., Kortelainen, P. & Sallantaus, T. 2003. Brook water quality and background leaching from unmanaged forested catchments in Finland. *Water, Air & Soil Pollutio*n 147: 275-297.

Kortelainen, P., Mattsson, T., Finer, L., Ahtiainen, M., Saukkonen, S. & Sallantaus, T. 2006. Controls on the export of C, N, P and Fe from undisturbed boreal catchments, Finland. Aquatic Sciences 68:453-468.

N fluxes and retention in national scale (including forestry and background):

Lepistö, A., Granlund, K., Kortelainen, P. & Räike, A. 2006. Nitrogen in river basins: sources, retention in the surface waters and peatlands, and fluxes to estuaries in Finland. *Science of the Total Environment* 365:238-259.

Recent national MeSuVe project of nutrient loading from forestry:

Kenttämies, K. & Mattsson, T. (eds.). 2006. Metsätaloudenvesistökuormitus. Finnish Environment, SY816 (in Finnish with English abstract).

Conclusions from the workshop

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Background and aim

There is a restricted amount of scientific knowledge on how different forestry measures quantitatively affect the nitrogen (N) and phosphorus (P) losses from soils to surface waters in northern Sweden. The information is based on a limited number of studies performed during the 1970s and 1980s (Löfgren & Olofsson 2002). During this period silvicultural measures e.g. clear felling, fertilisation and drainage were performed with fewer considerations for the environment than is generally the case today. Furthermore, the study catchments were located in the southern half of Sweden, implying large uncertainties when applied to the northern boreal region (Löfgren & Olofsson op. cit.). To our knowledge, no catchment studies on the effects of forestry practices on the N and P leakage to surface waters have been performed north of the River Ljungan. Hence, it is uncertain whether the older results are representative of modern forest management in northern Sweden.

In the international reporting to HELCOM (PLC4), Sweden estimated that 50% of the net N loading to the Bothnian Bay and Bothnian Sea originated from forested land, and that clear-felling caused 20% of the anthropogenic N loading (Brandt & Ejhed 2002). It was concluded, however, that the N leakage from clear-felled areas was overestimated due to errors in the estimates of the clear-felled area and the duration of the enhanced N leaching, among other sources of uncertainty. Additionally, a recent assessment indicates that the N concentrations used in the N source apportionment model were too high, both for growing forests and for clear-felled areas (Löfgren & Brandt 2005). Hence, it is most probable that the N-loading from growing forests and forestry practices was tangibly overestimated in the PLC4. A similar problem could be assumed for P (op.cit.).

The objective of this workshop was to suggest methods for estimating the N and P leakage on a regional scale to surface waters from different forestry measures in northern Sweden. The conclusions presented in this paper are based on current scientific knowledge, expert judgement and experiences from Finland. The methods should yield estimates relevant for international reporting (e.g. HELCOM PLC5), for assessing national environmental objectives (e.g. no eutrophication) and for characterisations of water bodies according to the EU Water Framework Directive.

Hopefully, the conclusions from the workshop can act as guidance on how to estimate regional N and P losses from forestry measures in northern Sweden. However, the complexity of N and P source apportionment models including supporting databases might induce the needs for model specific adjustments of the methods.

Participants and organisation

The workshop was initiated with three state-of-the-art presentations about results from central and northern Sweden and from Finland, which has comparable climate to central and northern Sweden, ecosystems and forestry practices. This was followed by discussions in two working groups on how to estimate the N and P leakage resulting from various forestry measures in northern Sweden. The participants in each working group are listed in table 1. The results from the two working groups were presented and discussed at a general assembly at the end of the workshop. The conclusions from those discussions are summarised in this report. The workshop participants have been given the opportunity to comment on a draft manuscript of this report. Hence, the conclusions should be considered as formulated in consensus among them who participated both days.

Important limitations for the discussions

The simulations of N and P losses from forestry measures for reporting to HELCOM PLC5 will be performed at catchment areas of 35-40 km^2 with the HBV-NP model by the SMED consortium (IVL, SCB, SLU and SMHI). Hence it was important for the workshop to take into account the limitations that this methodology creates. The list below shows some important issues, which were defined and distributed to the participants before the discussions started.

- The models for estimating leaching are in principal constructed as follows:
LEACHING = CONCENTRATION * DURATION * RUNOFF * AREA
- hence, it must be possible to get information about the spatial distribution and the area of each forestry measure,
- it must be possible to estimate the duration of the forestry measure effect,
- it must be possible to estimate the effects on concentrations and/or runoff by the forestry measure,
- the area affected by a forestry measure must be of significant importance.

Questions that were discussed

The questions below were distributed to the participants before the discussions started.

Which forestry measures do you consider important to quantify the excess N and P-losses from?

GROUP A	GROUP B
Eva Ring, Skogforsk (chair)	Harald Grip, SLU (chair)
Håkan Staaf, Naturvårdsverket	Ahti Lepistö, SYKE, Finland
Mike Starr, Helsinki University, Finland	Lars Högbom, Skogforsk
Olle Westling, IVL	Stefan Löfgren, SLU
Maja Brandt, SMHI	Göran Adelsköld, SLU
Karin von Arnold, Skogsstyrelsen	Gunnar Jacks, KTH
Ulf Sikström, Skogforsk	Per-Erik Mellander, Mitthögskolan
Ann-Catrin Norrström, KTH, (14th March)	Ulla Lundström, Mitthögskolan (14th March)
Börje Pettersson, Bergvik Skog AB, (14th March)	

Table 1. Participants in the group discussions at the workshop.

- Clear felling (with and without shelter wood)
- Site preparation (different methods)
- Drainage (including cleaning of old ditches and forest road constructions)
- Fertilisation (N and P and ash application)
- Thinning

If a forestry measure is considered important, how should it be estimated?

- What parameters (N-deposition, C/N-ratios in soil etc.) affect the concentrations?
- Do we have spatially distributed data on these parameters?
- Are both the inorganic and organic fractions affected? How are they affected?
- How could the duration be described?
- Is runoff affected? How is it affected?
- Suggest an algorithm to estimate it!

Suggest scientific studies necessary for improving the estimates of forestry impact on the N and P losses to surface waters. No limitations due to the PLC5 methodology.

'Background' losses - recommendations

Swedish studies of runoff in small streams draining managed and unmanaged forests show that there are almost no differences in concentrations and total losses of N and P as long as the managed forests are in the forested phase (Westling et al. 2001, Uggla & Westling 2003). The forested phase is defined as the whole rotation period excluding the clear-felled phase with elevated N and P concentrations. The N and P leakages from unmanaged forests in Finland were in the same range (Mattsson et al. 2003, Kortelainen et al. 2006). Hence, we suggest that the background losses of N and P should be based on recent observations in tree-covered areas. Methods to estimate N and P background concentrations from observed relationships with altitude have been developed for streams in northern Sweden (Löfgren & Brandt 2005).

It is not evident, however, that short-term excess N and P losses resulting from different forestry measures cause long-term net N and P losses compared to unmanaged forests. Hypothetical estimates, based on reasonable assumptions for a managed and an unmanaged forest in central Sweden, show that a slight N leakage increase from 1.5 to 2.25 kg N ha^{-1} y^{-1} due to reduced tree vitality in the unmanaged forest, is enough to compensate for the excess N leakage caused by clear-felling, protective drainage and N-fertilisation during two rotation periods (≈160 years, Löfgren & Olsson 1990). In Finland, however, during the last decades there has been an excess average N export of 0.55 kg N ha^{-1} y^{-1} from managed (1.90 kg ha^{-1} a^{-1}) compared to semi-natural forests (1.35 kg $ha^{-1}a^{-1}$, Lepistö, this volume). Due to insufficient data from Sweden, we are neither taking into account the hypothetical possibility of long-term lower nutrient losses from managed forests compared with background levels nor the opposite.

Excess losses due to forestry measures - recommendations

Final felling and site preparation

Final felling is annually performed on approximately 0.7% (84 000 hectare) of the productive forestland in northern Sweden (Ring, this volume). It enhances the losses of nitrate, organically bound nutrients (humus) and suspended solids, as well as the amount of runoff, causing excess nutrient exports to surface waters during many years. As already stated, both the amounts and the duration of excess losses of N and P to surface waters have been poorly investigated, resulting in large uncertainties in estimating the nutrient losses in northern Sweden.

In a report by Löfgren & Olsson (1990), summarising the state-of-the-art at that time, the leaching period for clear-felled areas in northern Sweden was set to 12 years for N and 3 years for P, with an average increase in the losses of the inorganic and organic N and P with a factor of 2. This factor was based on area losses, including effects on both concentrations and runoff. Long-lasting effects (10-15 years) have been observed in Finland as well (Ahtiainen and Huttunen 1999). Uggla & Westling (2003) came to a similar duration period for phosphorus when examining data from Hälsingland. For the PLC4 estimates, the duration periods suggested by Löfgren & Olsson (1990) were used, but for nitrogen, the factor was changed from 2 to 3 (based on the concentrations) and it was assumed that the entire increase occurred in the inorganic nitrogen fraction. Effects on runoff were neglected (Brandt & Ejhed 2002), which may be expected to increase after harvesting.

Assuming the surplus N is due to inorganic forms is in agreement with how N losses from clear-cut areas have been estimated in southern Sweden, where there is relatively high atmospheric N deposition loads (>8 kg N ha^{-1} yr^{-1}, Brandt & Ejhed op.cit.). The correlation used for estimating the clear-felling effects were, however, based on nitrate concentrations in soil water. It was assumed that higher concentrations in soil water compared with surface water would be compensated for by higher stream water discharge after harvest, not taken into account in the N export estimates (Löfgren & Westling 2002, Akselsson et al. 2004). It is well known, however, that the N fluxes in soil water can deviate markedly from that of stream water (Piirainen et al. 2002; Ring, this volume).

A difficulty arising when using excess N leaching periods of up to 12 years is the insufficient information on when and where clear felling have been performed. For the last five years, satellite images have been used by the Swedish Forestry Agency to estimate felling areas, but before then, estimates are poorer. Thus, for practical reasons, it would be wise to use 5 years for the whole of Sweden. From a theoretical point of view, however, this is not satisfactory for northern Sweden because of the probable long duration of excess loads of N, especially organically bound nitrogen. The results from catchment studies in Bergslagen and Hälsingland indicate losses of organically bound nitrogen as quantitatively the most important fraction (Grip 1982, Lundin 1999; Ring, this volume).

Finnish soil water studies indicate excess N and P leakage related to site preparation (Starr, this volume), while a Swedish study on a poor site in Härjedalen indicated reduced N losses (Ring, this volume). In agreement with normal forest management, site preparation and protective drainage have been performed in most of the catchments used for studying the losses of N and P. Hence, the effects of site preparation measures cannot be equivocally distinguished from the effect of final felling, and it is recommended that they be considered as included in the harvesting effect when calculating N and P loss estimates.

There are indications from southern Sweden that shelter wood with more than 100 stems ha^{-1} has the potential to reduce the N leaching (Örlander 2000). Buffer zones might be important as well, but due to lack of data regarding both area information and effect on leaching, it is not possible to estimate the effects of these measures.

Many European studies indicate a relation between the C/N ratio in the O-horizon and the nitrate losses from growing forests (Gundersen et al. 2006) as well as clear-cut areas (Ring, this volume). Such relationships could, in the future, be the basis for estimating typical concentrations in runoff from clear-cut areas, but at present such models are not available.

For the purpose of reporting to PLC5 and due to lack of new data compared with those available in the early 1990's, we recommend that the excess nitrogen and phosphorus losses from clear-felled areas be estimated principally in agreement with the proposal by Löfgren & Olsson (1990) by multiplying the background concentration in growing forests with a constant, representing the average increase for the leaching period compared to background level. Even though the factor is multiplied with the concentration, it also takes into account effects on runoff. We also recommend that the excess nitrogen losses from clear-cut areas be added mainly to the organic fraction, which will be the case if the Löfgren & Olsson method is used.

Drainage, ditch maintenance and road construction

Nowadays, drainage, ditch maintenance and road constructions are performed on restricted areas compared to the practice in the 1970s. In the future, however, more large-scale ditch maintenance operations could be foreseen. Of the 1 million hectare drained, productive forestland in Sweden, approximately 0.2 million hectare have a need for ditch cleaning. Additionally, another 0.3 million hectare peat-covered land is drained but non-productive with respect to tree production (Hånell & Magnusson 2005). Studies from Sweden and Finland indicate increased N and P losses compared to background during up to 12 years after drainage (Ahtiainen & Huttunen 1999, Lundin 1999), while other Finnish studies indicate small or no effects of ditch maintenance (Joensuu et al. 2002). The effects of road constructions are poorly understood, but effects similar to drainage could be expected (Nisbet 2001). *For the purpose of reporting to PLC5 and due to the restricted area influenced by the measures, we suggest that losses of N and P deriving from drainage, ditch maintenance and road constructions are not taken into account in the nutrient source apportionments. However, the measures might have tangible local effects.*

Nitrogen fertilisation and wood-ash application

Nitrogen fertilisation is currently 120 to 150 kg N ha^{-1} and performed on approximately 18 000 hectare forestland per year in northern Sweden (Swedish Forest Agency 2006). Due to the large effect on forest production by N fertilisers and the increasing demand from the timber, pulp and energy sectors, a more widespread use could be foreseen in the future. Nitrogen fertilisation affects the N-losses in direct connection to the application. Most studies indicate a net loss to surface waters of less than 5% of the N dose, but much higher values have been reported (Nohrstedt & Westling 1995). There is no easily available digital information on where spatially the N fertilisation is performed. At present, ash fertilisation is not significant, neither regarding area of distribution nor its effect on N and P losses to surface waters in northern Sweden.

For the purpose of reporting to PLC5 and due to the restricted area influenced by N fertilisation, we suggest that it is handled similar to a point source on the main catchment level and that 5% of the annual N dose is assumed to reach surface waters. Ash fertilisation does not have to be considered.

Thinning

There is no information on N and P losses to surface waters in connection with thinning. Annually, large areas are affected by this measure, but the long-term effect is almost certainly insignificant or may even decrease the nutrient losses.

For the purpose of reporting to PLC5 and due to the insignificant effects on the N and P losses, we suggest that the effect of thinning is not considered.

Future studies - recommendations

Due to the extent of forestry on large areas in combination with scarce information on N and P losses and other water quality effects related to different forestry measures, there is an urgent need for complementary investigations. In 2004, Skogforsk and SLU initiated a catchment study on the effects of final felling and buffer strips in Västerbotten. However, large climatic and forest production gradients in northern Sweden imply that similar studies are needed in other areas as well in order to be able to accurately estimate N and P losses. To follow up and quantify these effects on a regional basis, there is a need for a combination of experiments, surveys and monitoring (c.f. Löfgren & Olofsson, 2002), as well as a development of modelling tools (Lepistö, this volume).

Issues of particular interest are forestry-induced processes influencing the mobilisation, transport and retention of N and P along the flow paths from soil water, to groundwater and stream water. Possible relationships between N leaching and C/N ratios in soils are of great interest, as well as processes affecting the N and P leaching phases after clear-cutting (conventional and whole tree harvesting), site preparation with different techniques, establishment of shelter wood and buffer zones, drainage work (ditching and ditch maintenance), and forest road constructions.

References

Ahtianen, M. & Huttunen, P. 1999. Long-term effects of forestry managements on water quality and loading in brooks. *Boreal Environ.* Res. 4:101-114.

Akselsson, C., Westling, O. & Örlander, G. 2004. Regional mapping of nitrogen leaching from clearcuts in southern Sweden. *For. Ecol. Manage.* 202:235-243.

Brandt, M. & Ejhed, H. 2002. TRK Transport – Retention – Källfördelning, Belastning på havet. *Naturvårdsverket rapport* 5247.

Grip, H. 1982. Water chemistry and runoff in forest streams at Kloten. *UNGI Report* no. 58, Department of Physical Geography, Uppsala University, Uppsala. 144 pp.

Gundersen, P., Schmidt, I.K., Raulund-Rasmussen, K. 2006. Leaching of nitrate from temperate forests – effects of air pollution and forest management. *Environ. Rev.* 14:1-57.

Hånell, B. & Magnusson, T. 2005. An evaluation of land suitability for forest fertilization with biofuel ash on organic soils in Sweden. *For. Ecol. Man.* 209:43-55.

Joensuu, S., Ahti, E., and Vuollekoski, M. 2002. Effects of ditch network maintenance on the chemistry of run-off water from peatland forests. *Scandinavian Journal of Forest Research* 17: 238-247.

Kortelainen, P., Mattsson, T., Finér, L., Ahtiainen, M., Saukkonen. S. & Sallantaus, T. 2006. Controls on the export of C, N, P and Fe from undisturbed boreal catchments, Finland. *Aquatic Sci.* 68:453-468, and available on line (http://www.springerlink.com/content/j44820381xw98377?p=e65e306f9b7447b58801e82b63da250e&pi=0).

Lepistö, A. 1996. Hydrological processes contributing to nitrogen leaching from forested catchments in Nordic conditions. *Monographs Bor. Env. Res.* no 1, 72 pp.

Lundin, L. 1999. Effects on hydrology and surface water chemistry of regeneration cuttings in peatland forests. *International Peat Journal* 9: 118-126.

Löfgren, S. & Brandt, M. 2005. Kväve och fosfor i skogsmark, fjäll och myr i norra Sverige. *SMED rapport* 14, 36 pp. In Swedish.

Löfgren, S & Olofsson, H. 2002. Övervakning av akvatiska system I brukad skog – nuvarande status och förslag till framtida program. *Inst. F. miljöanalys, SLU Rapport* 2002:20, 26 pp. In Swedish. English summary.

Löfgren, S. & Olsson, H. 1990. Tillförsel av kväve och fosfor till vattendrag i Sveriges inland. *Naturvårdsverket rapport* 3692, 100 pp. In Swedish. English summary.

Löfgren, S. & Westling, O. 2002. Model för att skatta kväveförluster från växande skog och hyggen i södra Sverige. *Inst. F. miljöanalys, SLU Rapport* 2002:1. 23 pp. In Swedish. English summary.

Mattsson, T., Finér, L., Kortelainen, P., Sallantaus, T. 2003. Brook water quality and background leaching from unmanaged forested catchments in Finland. *Wat. Air. Soil. Poll.* 147:275-297.

Nisbet, T. 2001. The role of forest management in controlling diffuse pollution in UK forestry. *For. Ecol. Man.* 143:215-226.

Nohrstedt, H-Ö. & Westling, O. 1995. Miljökonsekvensbeskrivning av STORA SKOGs gödslingsprogram, del 1 faktaunderlag, *IVL report* B1218, 90 pp. In Swedish.

Piirainen, S., Finér, L., Mannerkoski, H. & Starr, M. 2002. Effects of forest clear-cutting on the carbon and nitrogen fluxes through podzolic soil horizons. *Plant and Soil* 239(2):301-311.

Swedish Forest Agency. 2006. Swedish Statistical Yearbook of Forestry 2006. ISBN 91-88462-68-4

Uggla, E. & Westling, O. 2003. Utlakning av fosfor från brukad skogsmark. *IVL rapport* B1549, 21 pp. In Swedish.

Westling, O., Löfgren, S. & Akselsson, C. 2001. Arealförluster från skogliga avrinningsområden i Västra Götaland, *Skogsstyrelsen rapport* 2001:2, 78 pp. In Swedish.

Örlander, G. 2000. SUFOR, delprogram A: Skogsskötsel för uthålligt skogsbruk. En kortfattad sammanställning över programmets organisation, projektbeskrivning samt några aktuella resultat. *KSLA tidskrift* 139(6):13-19. In Swedish.

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Nr 2 How to estimate N and P losses from forestry in northern Sweden

There is a restricted amount of scientific knowledge on how different forestry measures quantitatively affect the nitrogen (N) and phosphorus (P) loss from soils to surface waters in northern Sweden. The information is based on a limited number of studies performed during the 1970s and 1980s. That is a period when silvicultural measures e.g. clear-felling, fertilisation and drainage were performed with less considerations for the environment than is generally the case today. Furthermore, the study catchments were located in the southern half of Sweden, implying large uncertainties when applied to the northern boreal region.

This report is from a workshop with the objective to suggest methods, based on sound scientific assumptions, for estimating the N and P leakage to surface waters from different forestry measures in northern Sweden. The methods should yield estimates relevant for international reporting (e.g. PLC5), for assessing national environmental goals (e.g. no eutrophication) and for characterisations of water objects according to the EU Water Framework Directive.

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