LEACHING OF NITROGEN FROM UPLAND FOREST-REGENERATION SITES INTO WETLAND AREAS

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The concentration of nitrate and ammonium nitrogen in the groundwater was investigated one year before, and during seventeen years after, clear-cutting at the Pahalouhi experimental site at Kivesvaara, located in the middle-boreal coniferous forest zone in Finland (64°28 'N, 27°33 'E). The effect of natural regeneration of Norway spruce *(Picea abies)* and Scots pine *(Pinus sylvestris)* has been investigated at the same experimental site since 2002, when the Pahalouhi experimental field was supplemented with the inclusion of natural regeneration. All the treatments caused a rise in nitrate nitrogen concentrations, but leaching during the first two years from natural regeneration was clearly less compared with that observed following clear-cutting and planting. Having been initially virtually zero, the concentrations of' nitrate nitrogen continued to rise for 5-7 years, reaching 500-700 µg/l at their highest, after which they began to fall. The concentrations were still high seventeen years after clear-cutting, which constituted a situation not observed earlier. Compared with nitrate, there was no corresponding ammonium nitrogen leaching.

1. Introduction

The effect of forest regeneration on watercourses depends on the regeneration method used. Clear-cutting and site preparation cause the greatest changes in site conditions and to the environment. The oldest research carried out within the boreal coniferous forest zone on the leaching of nutrients into watercourses was conducted in Sweden in the early 1970s [1], [2]. In Finland, the effect of clear-cutting and site preparation on the

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quality of surface runoff has been monitored since 1974 [3] and on the leaching of nutrients from entire catchment areas since 1983 [4]. The leaching of nutrients into the groundwater after forest regeneration has been monitored since 1986 [5].

In several studies, nutrient leaching into surface waters has been found to be a few years in duration. Long-term monitoring has revealed that after regeneration cutting, nitrate nitrogen is leached into the groundwater for more than 12 years [5]. Also, the timing of maximum leaching of nutrients into the groundwater following cutting takes place a few years later compared with leaching into surface water.

The main principle is for forestry practitioners to try to ensure that potential harm caused by forestry to watercourses and the aquatic organisms be minimised. This can be achieved in two basically different ways: by using sufficiently wide uncut buffer zones or slightly thinned buffer zones, or by stopping leached nutrients and solid Matter by means of overland-flow fields before they actually enter water systems [6]. Compared with surface runoff, the leaching of nutrients into the groundwater is more difficult In prevent. Within the clearcut area itself it seems to last for a long time [5], which is why it is important to study the effects of different regeneration methods on groundwater quality.

The aim of this study is to investigate the effects of natural regeneration of Scots pine *(Pinus sylvestris)* and Norway spruce *(Picea abies)* on the leaching of nitrogen into the groundwater during the first few years after cutting. The results arc compared with long-term monitoring information collected from the same research area. The new information can be utilized when developing ecologically sustainable forest management methods as well as when taking action to protect drinking water stored in large aquifers.

2. **Material and methods**

The experimental area. Pahalouhi, located at 64°28'N. 27°33'E is representative of the prevailing conditions in the middle-boreal coniferous forest zone. The site type is dryish upland. The total amount of logs and pulpwood harvested was 141 m^3/ha. of which Scots pine *(Pinus sylvestris)* made up 51%, Norway spruce *(Picea abies)* 46% and birch *(Betula pendul,. Betula pubescens)* 3%. The cutting was carried out in 1986 using a harvester. Monitoring the quality of the groundwater was commenced the year before cutting in 1985. The plots were planted with Scots pine *(Pinus* sylvestris) making use of manually made scalps in the spring of 1987. The soil ranged from sand to sandy till.

A total of 24 groundwater wells were set up within the Pahalouhi experimental area. They consisted of plastic piping varying from 4-6 m in length with perforations in the lowermost 1.5 m and a plug seal the bottom. Four treatment areas were established initially: clear-cutting with cutting waste not collected, clear-cutting with cutting waste collected, ploughed treatment, and an uncut control. In 2001, the Pahalouhi experiment was extended to include natural regeneration by using shelter-wood cutting of spruce in part of the old control area and seed-tree cutting in the area adjacent to the old clear-cutting in 1986. These areas had 11 new wells set up in the autumn of 2001. The amount of shelter-wood was 300 stems per ha while seed-trees numbered 50 sterns per ha. The shelter-wood area was not treated with site preparation to assist the emergence of seedlings while the seed-tree area was harrowed; these methods are in current use in Finnish forestry. The new groundwater wells were set up within these areas in 2001.

Water samples were taken annually from each well once a month from May to October. A low-pressure pump was used to sample the groundwater. Chemical analyses were carried out at the Muhos Research Station following standard methods. This paper presents the results for nitrate nitrogen concentration measurements in the clear-cutting and control areas over the period 1985-2003 and in the natural regeneration areas for the first two years.

3. Results

3.1. CLEAR-CUTTING AND PLANTING

Nitrate nitrogen concentrations at the site were initially 30-50 μg/l and they continued to rise for 4-5 years following clear-cutting, reaching their peak of over 500 μg/l in 1990 (Figure 1). The concentrations were still above the initial level for more than seventeen years after cutting. Contrary to nitrate nitrogen behaviour, the results for ammonium nitrogen do not indicate a corresponding increase as a result of this or any other treatment.

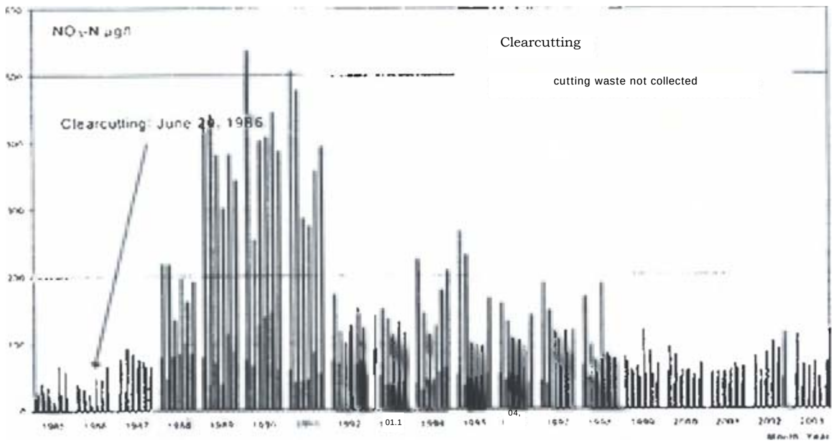

Figure 1. The effects of clear cutting and planting on the leaching of nitrate nitrogen into the groundwater in 1986-2003. Dark areas represent values from the control area. Each year samples were collected once monthly from May to December.

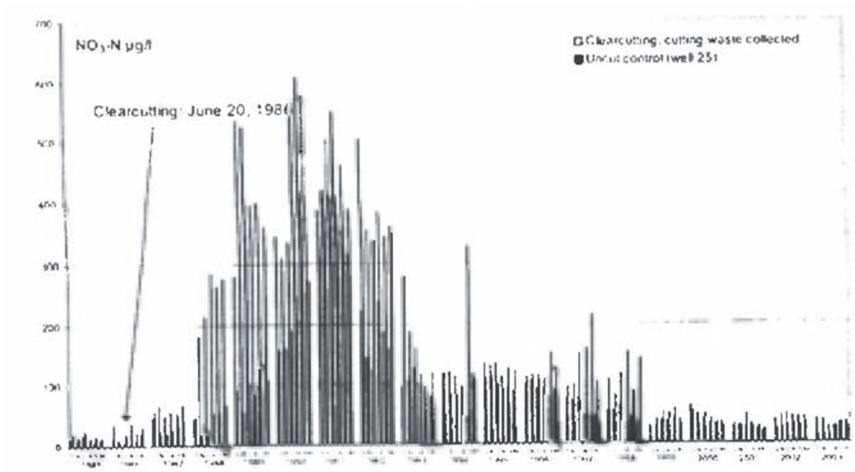

Figure 2. Nitrate nitrogen flow in the groundwater.

The slope of the site was lightly inclined towards this well, which makes it possible to follow the movement of nutrients. The results (Figure 2.) show that nitrate nitrogen is moving towards the wetlands further down,

3.3. NATURAL REGENERATION OF SPRUCE

Shelter-wood cutting was done in the late autumn of 2001. The results from the first two years indicate that leaching increased during the second year (Figure 3), but not as much as after clear-cutting (Figure 1) during the corresponding time. In the first year, there was a statistically significant difference *(p* 0.014) between shelter-wood cutting and the uncut control, but not in the second year (*p* 0.79).

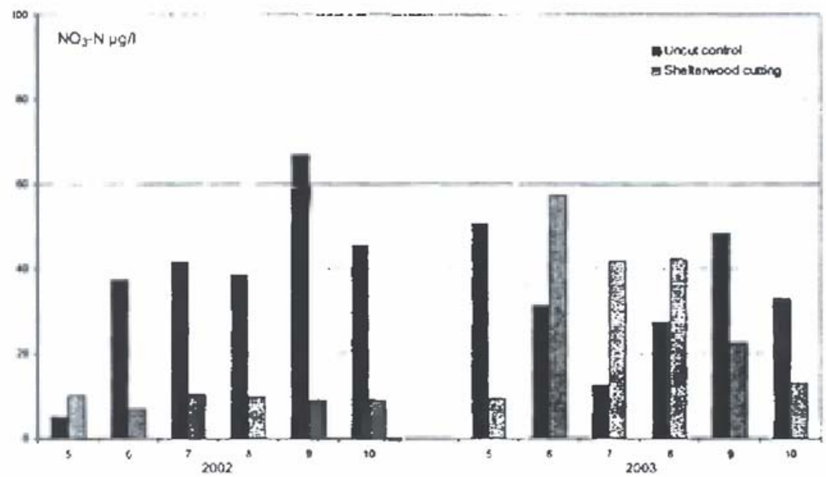

Figure 3. Nitrate nitrogen concentrations in the groundwater during the first two years after shelterwood cutting of Norway spruce.

3.4. NATURAL REGENERATION OF SCOTS PINE

Following seed-tree cutting, the regeneration area was divided into two one with and the other without site preparation. A small area with one well was left in the uncut state (Figure 1). There were statistically significant differences *(p 0.00)* between all treatments in both years (Figure 4). The highest concentrations were observed in the harrowed plots and the lowest values in the uncut area. A gradual increase towards the autumn was noted. The results clearly show that natural regeneration increased nitrate leaching into the groundwater, especially with site preparation included, but once again the values were far lower than after clear-cutting (Figure 1) within the corresponding period of time. In the clear-cutting area, the maximum concentrations during the second year were between 100-200 µg/l while in the area involving natural regeneration they all were clearly below 100 µg/l with and without site preparation.

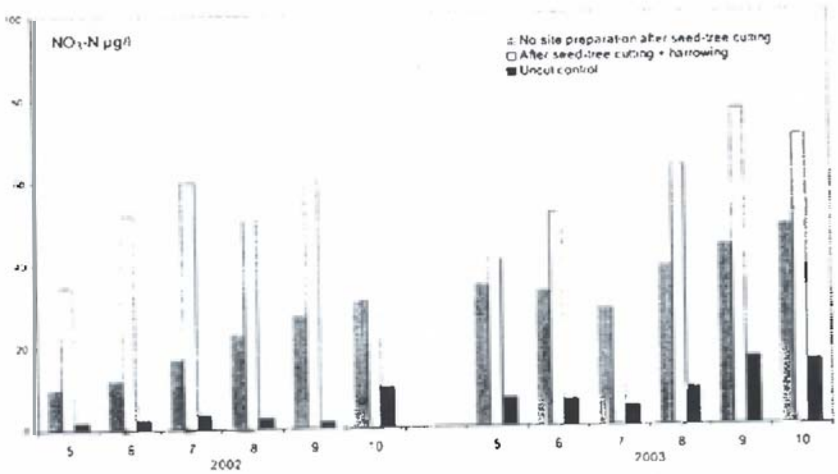

Figure 4. Nitrate Nitrogen concentrations in the groundwater during the first two years after seed tree cutting of Scots Pine.

4. Discussion

The Muhos Research Station of the Finnish Forest Research Institute has established several experimental fields at Kivesvaara, northern Finland, dedicated to forest regeneration and its environmental effects [3], [5], [7], [8]. The research data collected in this study comprises some of Finland's oldest and most extensive monitoring data on the leaching of nutrients into surface waters and groundwater as caused by forest regeneration when applying clear-cutting. No site preparation was used in the clear-cutting area.

The effects of clear-cutting on nitrate nitrogen concentrations in surface water have been shown to last only a fcw years [1], [3], [4], but the longterm property of increasing groundwater concentrations, which have persisted much longer than 10 years. have not been reported in earlier studies

[2], [9]. Clear-cutting increases the input of precipitation, but in northern areas this cannot be the main reason for the higher values. The greater part of the increased concentrations is due to the decomposition of cutting waste and humus, but the reasons for long-lasting leaching need further investigation. There was no increase in ammonium concentrations, as was also observed in boreal areas by Rusanen et al. [9].

Nitrate nitrogen seems to be the foremost nutrient leached into the groundwater as a consequence of forestry operations. The impacts of forest regeneration on aquatic ecosystems can be prevented quite effectively as regards surface waters, but preventing the impacts on groundwater is far more difficult. As our knowledge in this matter based on experimental research was formerly lacking, it is not possible to go into any detail concerning preventative methods. An essential aspect would appear to be that the biological cycling of nutrients on regeneration sites should continue to function so as to minimise leaching of nutrients [10].

The fresh results provided by this study indicate that natural regeneration causes less nitrogen leaching than clear-cutting. The results represent, however, a very brief period of time, and we do not know the long-term effects as yet. However, in order that we might take good care of the forest environment and apply ecologically sustainable forestry, it is worth recommending that natural regeneration be used whenever it is economically feasible. This complies also with the environmental guidelines set for forestry. As an aspect of environmentally sound silviculture, special attention has been given to the effects on watercourses and the protection of water ecosystems. The central objective of watercourse protection guidelines is to preserve the waters in good condition and protect the biodiversity of aquatic and adjacent ecosystems.

5. Acknowledgement

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