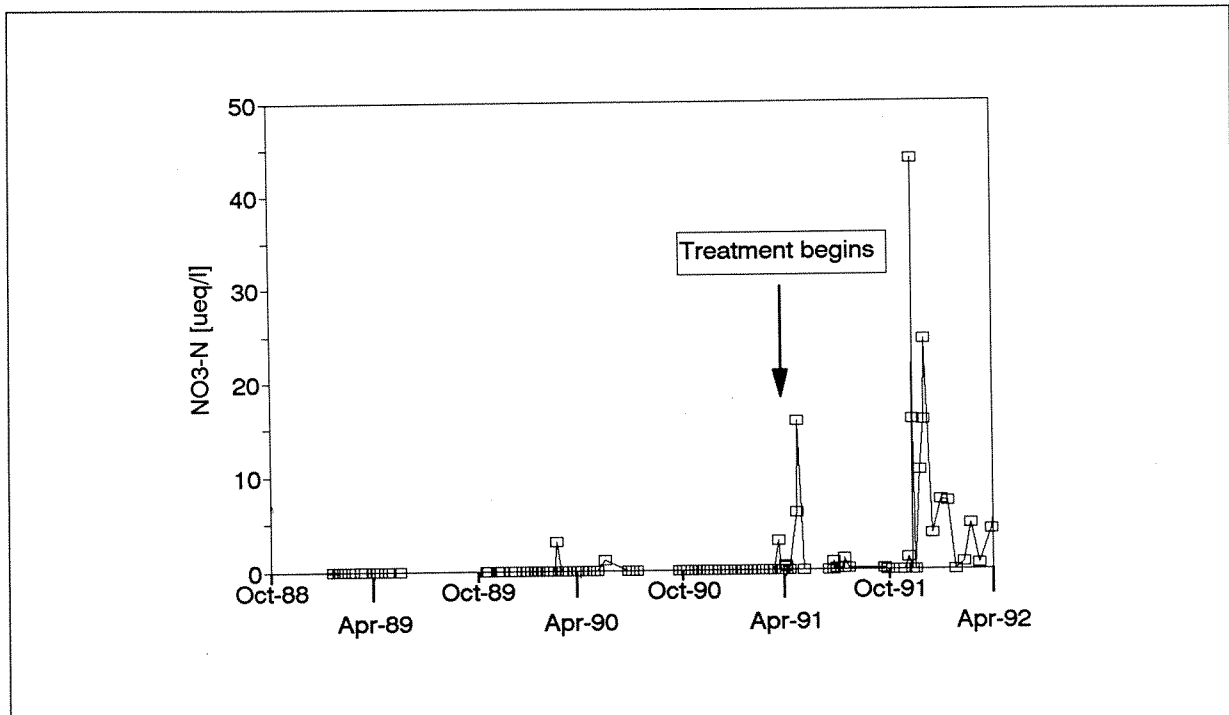


# NITREX

## Gårdsjön

Status report for 1991-1992;  
the first year of treatment



Report no 3/93 from NITREX Gårdsjön



# NIVA - REPORT

Norwegian Institute for Water Research



NIVA

Report No.:	Sub-No.:
Serial No.:	Limited distrib.:
2915	

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<b>Report Title:</b> Gårdsjön Status Report for 1991-1992: The First Year of Treatment	<b>Date:</b> Printed: NIVA 1993
	<b>Topic group:</b> Acid precipitation
<b>Author(s):</b> Richard F. Wright Ingvar Anderson Tor Erik Brandrud Nancy B. Dise Anna Clemensson-Lindell Hans Hultberg Magne Huse	<b>Geographical area:</b> Sweden
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<b>Contractor:</b> NMF/NAVF/SNV	<b>Contractors ref. (or NTFN-No.):</b>
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<b>Abstract:</b> Nitrogen addition weekly to the catchment G2 at Gårdsjön began April 1991. During the first year of treatment a total of 230 meq/m <sup>2</sup> yr NH <sub>4</sub> NO <sub>3</sub> was added in 33 mm of water plus the 90 meq/m <sup>2</sup> /yr deposited in 631 mm throughfall. Runoff contained significantly higher concentrations of NO <sub>3</sub> (but not NH <sub>4</sub> ) beginning in November 1991. No response was seen during the growing season. None of the other components and processes (soil solution, mineralization, fine-roots, mycorrhiza, and vegetation) studied as part of NITREX showed significant response during the first year of treatment.
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4 keywords, Norwegian

1. Nitrogen
2. Forsuring
3. Vannkjemi
4. Jord

4 keywords, English

1. Nitrogen
2. Acidification
3. Water chemistry
4. Soil

Project leader

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For the Administration

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ISBN-82-577-2271-5

# NITREX project - Gårdsjön

## Status report for 1991-92: the first year of treatment

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## SUMMARY

Nitrogen addition weekly to the catchment G2 at Gårdsjön began April 1991. During the first year of treatment a total of 230 meq/m<sup>2</sup>/yr (32.2 kgN/ha/yr) of nitrogen was added as NH<sub>4</sub>NO<sub>3</sub> in 33 mm of water. This is in addition to the 90 meq/m<sup>2</sup>/yr (12.6 kgN/ha/yr) deposited in 631 mm of throughfall during this same period. Runoff contained significantly higher concentrations of NO<sub>3</sub> (but not NH<sub>4</sub>) beginning in November 1991. No response was seen during the growing season.

None of the other components and processes (soil solution, mineralization, fine-roots, mycorrhiza, and vegetation) studied as part of NITREX showed significant response during the first year of treatment. Overall the results from the first year of treatment at Gårdsjön NITREX fit the general pattern reported from other NITREX experiments in Europe and the USA in which runoff responds rapidly whereas vegetation responds more slowly. With continued treatment we expect that nitrate losses will increase during the winter months, that nitrate will begin to be lost during the growing season as well, and that the various processes and components of the forest ecosystem will respond to the nitrogen additions.

## NORSK SAMMENDRAG

Ukentlige tilførsler av nitrogen til nedbørfeltet G2 på Gårdsjön begynte april 1992. I løpet av det første års behandling har totalt 230 meq/m<sup>2</sup>/år (32.2 kgN/ha/år) blitt sprøytet ut som NH<sub>4</sub>NO<sub>3</sub> i 33 mm vann. Dette kommer i tillegg til 90 meq/m<sup>2</sup>/år (12.6 kgN/ha/år) deponert i 631 mm kronedrypp i den samme perioden. Avrenningsvann hadde signifikante høye konsentrasjoner av NO<sub>3</sub> (men ikke NH<sub>4</sub>) fra november 1991. Ingen respons ble observert gjennom vekstsesongen.

Ingen av de andre komponenter og prosesser (jordvann, mineralisering, fin-rottene, mykorrhiza, og vegetasjon), studert som deler av NITREX, viste signifikant respons det første år. Resultatene fra NITREX Gårdsjön det første året passer godt med resultatene fra tilsvarende NITREX eksperimenter i Europa og USA. Endret tilførsel av nitrogen påvirker først avrenningen, senere de andre komponentene. Behandlingen ved NITREX Gårdsjön fortsetter. Vi venter at avrenning vil inneholde stadig økende konsentrasjoner av nitrat i vinter månedene, at nitrat vil begynne å lekke ut også i vekstsesongen, og at flere prosesser og komponenter i dette skogsøkosystem vil bli påvirket.

## ACKNOWLEDGEMENTS

In 1991-92 NITREX-Gårdsjön received financial support from the Norwegian National Committee for Environmental Research (NMF/NAVF), the Swedish Environmental Protection Agency (SNV), the Commission of the European Communities (CEC-STEP program) and from internal funds from the Norwegian Forest Research Institute (NISK), the Norwegian Institute for Water Research (NIVA), and the Swedish Environmental Research Institute (IVL). We thank our co-workers at our institutes for able and enthusiastic assistance with the field, laboratory and office work and our colleagues from other institutes participating in the NITREX experiment and other research projects at Gårdsjön for professional assistance and advice.

## 1. INTRODUCTION

NITREX (Nitrogen Saturation Experiments) is an international, interdisciplinary research project focused on the impact of nitrogen on forest ecosystems (Dise and Wright 1992a). The project addresses the role of nitrate and ammonium in acidification of soil and water by adding or removing nitrogen to precipitation falling on headwater catchments and forest stands. A total of 11 experiments are conducted at 7 sites in Europe spanning the gradient in nitrogen deposition from  $<5 \text{ kg N ha}^{-1} \text{ yr}^{-1}$  in Norway to  $>50 \text{ kg N ha}^{-1} \text{ yr}^{-1}$  in the Netherlands (Figure 1.1).

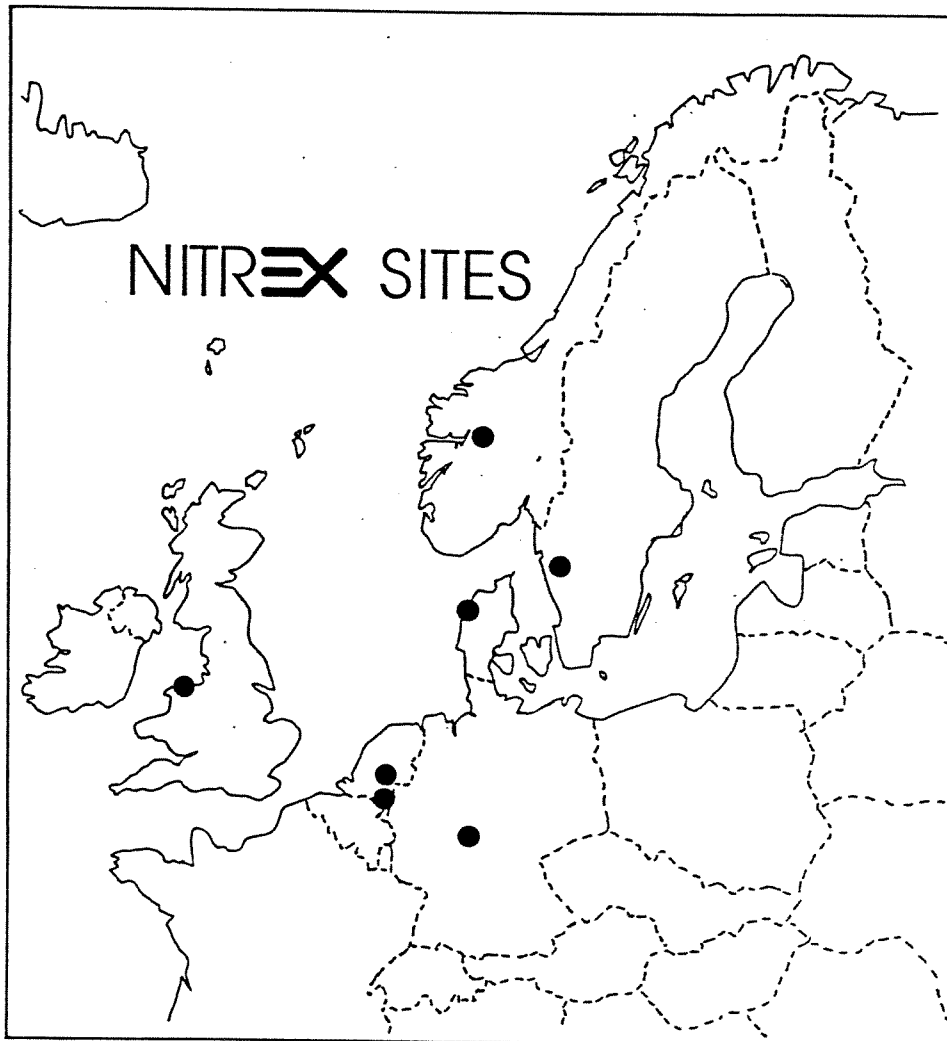


Figure 1.1. Map of Europe showing location of NITREX sites.

One of these NITREX sites is located at Gårdsjön, on the Swedish west coast. At the Gårdsjön site, nitrogen deposition is experimentally increased to an entire forested catchment. Here the objectives are to determine the potential for nitrogen saturation, estimate the role of nitrogen in ecosystem acidification, and determine the fate of added nitrogen and the source of nitrogen in runoff.

The Gårdsjön NITREX study began in late 1988. The site chosen for the nitrogen addition experiment is catchment G2. The adjacent catchment G1 was chosen at the same time for a pollution exclusion experiment (by means of roof beneath the canopy). The NITREX and roof experiment make use of a common untreated reference catchment F1. At both G2 and G1 sampling of throughfall and runoff at the site began in December 1988. Tensiometers were installed in the summer of 1989. Weirs, equipment for continuous gauging of runoff, and lysimeters were brought into operation in early 1990. Vegetation and soil analyses (including mineralization studies) also began in early 1990, and the first in-growth cores were implanted. The mycorrhizal fungi were first investigated in late summer 1990, and fish toxicity experiments began in early 1991. Treatment commenced April 1991. Wright et al. (1991) give a status report of Gårdsjön-NITREX for the years 1988-1990. Dise and Wright (1992b) report results from the pre-treatment year April 1990-March 1991. Here we report the results from the NITREX catchment G2 for period April 1991-March 1992, the first year of nitrogen addition.

## 2. SITE DESCRIPTION

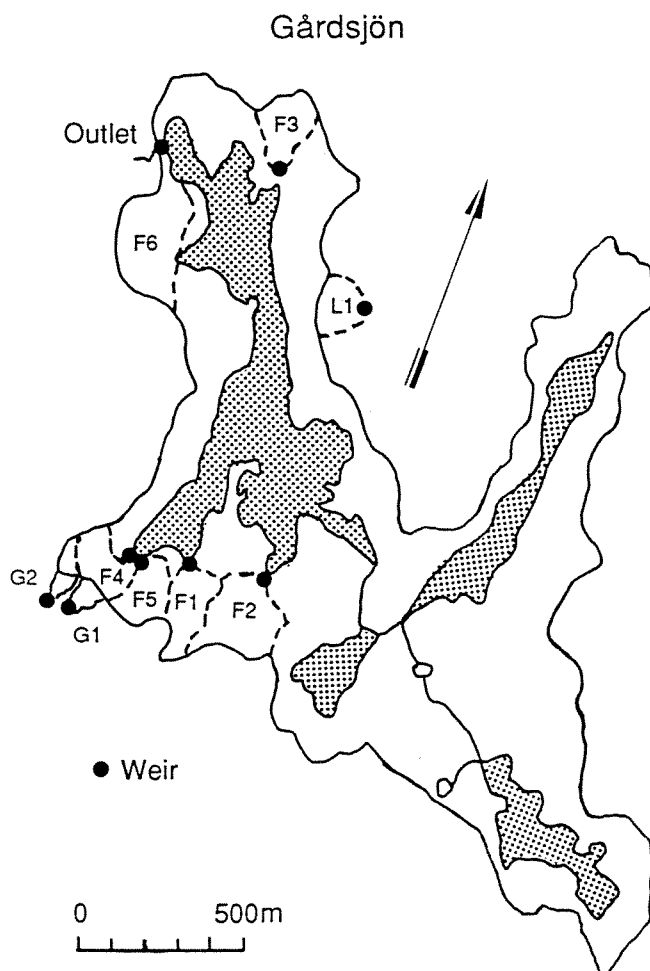
### 2.1. Gårdsjön, general

The lake Gårdsjön research area (58° 04' N, 12° 01' E) has been the focus of acidification research since the 1960's (Hultberg and Grennfelt 1986, Andersson and Olsson 1985). The entire drainage basin encompasses 2.11 km<sup>2</sup> (5 lakes) and sits 14 km from the west coast of Sweden (Figure 2.1), a region receiving moderately high deposition of both sulphate and nitrogen. Soils and waters here are chronically acidified (Hultberg and Grennfelt 1986) although most of the incoming nitrogen is still retained by the terrestrial ecosystems.

The Gårdsjön region has a humid maritime climate, with 1100 mm mean annual precipitation and a mean temperature of 6.4°C. Winters are mild (mean January temperature -2.4 °C), and summers are fairly cool (mean July temperature 15.6 °C). The 5-lake basin ranges from 113 to 170 meters above sea level. The topography is rough, with steep valleys and frequent bedrock outcrops. Geology is characteristic of acidified regions of the Swedish west coast and southern Norway, with granitic and gneissic bedrock overlain by thin patchy podzolic and peaty soils. The soils are developed from glacial till predominantly of local origin and of the same or similar lithology. Gårdsjön contains a mixed-age coniferous forest dominated by Norway spruce (*Picea abies*) >110 years of age; Scots pine (*Pinus sylvestris*) occurs in dry areas (Olsson et al. 1985). The area has supported a low level of grazing and selective forest cutting for centuries; current active land use is restricted to forestry.

Smaller experimental sub-catchments within the whole catchment were identified for detailed

hydrochemical study in the mid 1980's (Figure 2.1). Whole-system manipulation experiments in these catchments have included liming, clearcutting, and sulphur addition (Hultberg and Grennfelt 1986). These experiments and the long record of background data (control catchment F1 monitored since 1979) provide an extensive base for the NITREX experiment. Nitrogen addition (NITREX) and nitrogen exclusion (roofed catchment) are the most recent manipulation experiments at Gårdsjön.



**Figure 2.1. Experimental sub-catchments within the Lake Gårdsjön basin used for large-scale manipulations. F1 is control (since 1979). The NITREX catchment (G2) and adjacent roofed catchment (G1) lie just outside Gårdsjön's catchment. Details on manipulations in remaining sub-catchments may be found in Hultberg and Grennfelt (1986).**



## 2.2. NITREX site

The Gårdsjön NITREX site (G2) is a 0.52 ha headwater catchment adjoining the Gårdsjön drainage basin (Figs. 2.1). Like the surrounding area, it is forested with Norway spruce and some Scots pine, with slight to moderate defoliation and needle discoloration (damage classes 1 and 2). Ground vegetation roughly segregates with the topography of the catchment: it is dominated by mosses (Dicranum majusm., Leucobryum glaucum (Hedw.)), and the grass Deschampsia flexuosa (L.) in the upper catchment, Vaccinium myrtillus (L.)/Vaccinium vitis-idea (L.) in drier outcrops, Sphagnum (predominantly (Sphagnum girgensohnii (L.)) in the wetter lower parts of the catchment, and Calluna vulgaris (L.) among the most exposed ridges. Many of the NITREX investigations in Gårdsjön compare the first three subgroups. Soils are predominantly acidic silty and sandy loams (Orthic Humic Podzols, Orthic Ferro-Humic Podzols, Gleyed Humo-Ferric Podzols, and Typic Folisols (Canada Soil Survey Committee 1978)), drier in the upper catchment and more peaty in the lower part. The depth of the soil varies between 0 and >100 cm, with a mean depth of 38 cm. Boulder outcrops are common, and soil cover is especially thin in the western and northern part of the catchment.

Equipment installed in G2 include throughfall collectors, groundwater tubes, weir at outlet, temperature probes, tensiometers, tension lysimeters (PRENART type), permanent plots for vegetation and mineralization studies, permanent transects for mycorrhize sampling, and permanent plots for fine root studies (Figure 2.2).

In G2 ammonium nitrate is added to augment the natural N deposition. Nitrogen is added as ammonium nitrate to deionized water and distributed above the ground vegetation with a sprinkler system in a 5x5 meter grid over the entire catchment. Treatment is weekly, with 115 mgN L<sup>-1</sup> added as NH<sub>4</sub>NO<sub>3</sub> to a volume of about 5% of the amount of natural throughfall measured the previous 7 days. The vegetation is wetted with about 0.2 mm deionized water prior to and following each treatment. By adding small portions of extra nitrogen in rain each week rather than a large single dose (as in fertilization experiments) we simulate increased atmospheric deposition of N. Treatment began on 1 April 1991.

## 2.3 Nitrogen Removal in G1 (Roof Project)

G2 lies adjacent to a similar catchment G1 (Figure 2.1) which is covered by a transparent roof beneath the canopy. The G1 Roof project investigates the processes of catchment recovery from pollution by removing sulphur and nitrogen from the input deposition. Incoming throughfall is intercepted by the roof and channeled from the catchment. For each precipitation event an equivalent amount of water is pumped from Lake Gårdsjön, ion-exchanged, resupplied with seasalt ions at assumed pre-industrial concentrations, and sprinkled below the roof. Treatment at G1 began at the same time as G2, in April 1991. Both catchments drain away from the lake. The removal experiment at G1 is funded independently of NITREX, but runs in parallel and with many of the same procedures and personnel.

## 2.4 Reference Catchment F1

F1 catchment is used as a untreated reference for the manipulations in the G2 and G1 catchments. Discharge of chemical composition of runoff at F1 have been monitored since 1979.

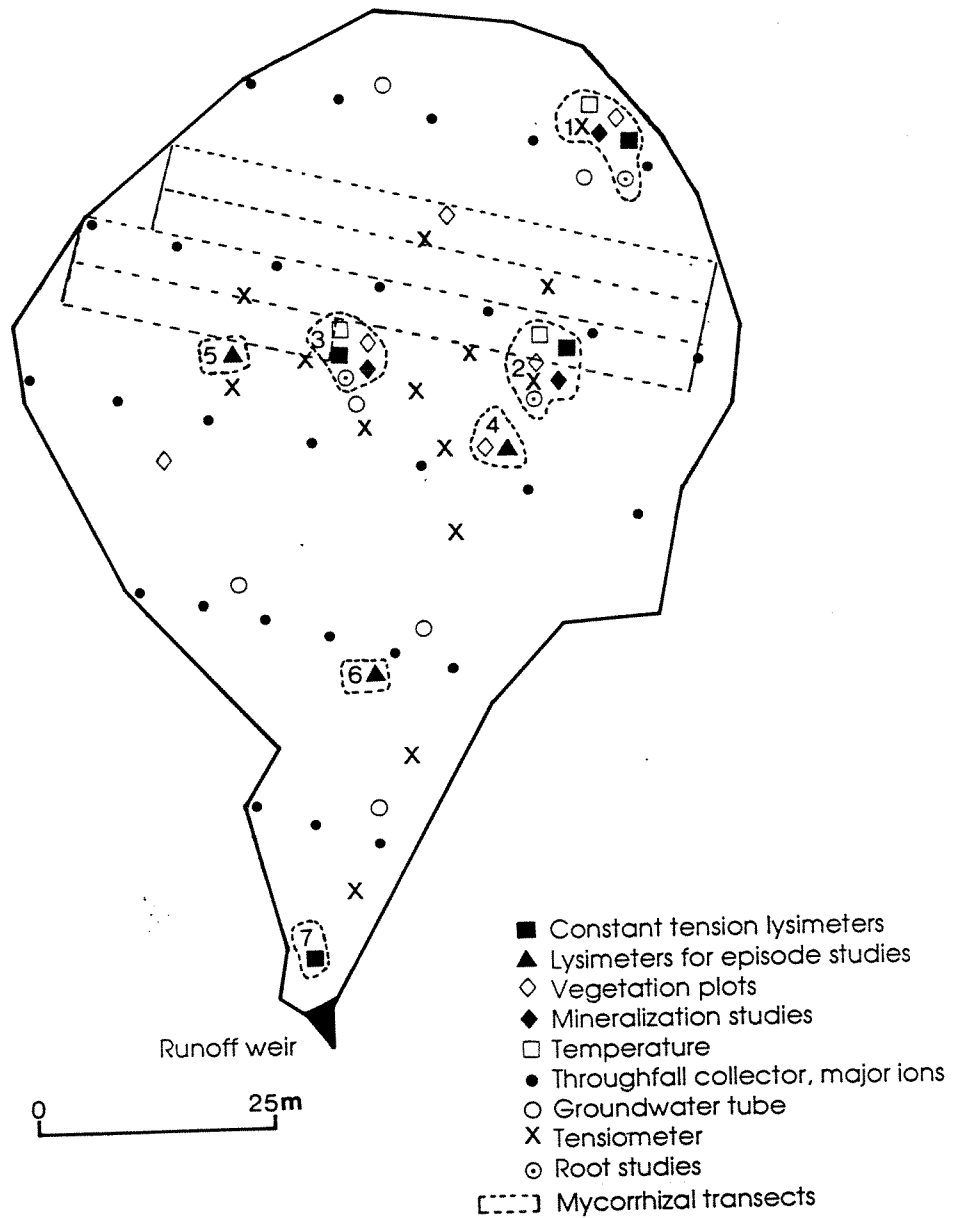


Figure 2.2 Map of the NITREX catchment G2 at Gårdsjön showing location of vegetation plots, lysimeters, tensiometers, throughfall collectors, mineralization studies, mycorrhiza transects, and groundwater wells.

### 3. INPUTS AND OUTPUTS: CONCENTRATIONS AND FLUXES

I. Andersson, N.B. Dise, H. Hultberg, F. Moldan, U. Nyström, G. Rudi, and R.F. Wright

Determination of ecosystem input-output budgets is a central objective to NITREX-Gårdsjön. Nitrogen saturation is defined in terms of changes in output of nitrogen at the ecosystem scale. The whole-catchment nitrogen addition at Gårdsjön G2 is aimed at evoking changes in nitrogen contents in runoff.

#### 3.1. Installations and Monitoring

Bulk deposition: Open-field precipitation is monitored at four stations: at the outlet of lake Gårdsjön (tipping bucket), at 0.5 km north of the outlet (SMHI standard gauge), at F1 (tipping bucket), and at G1 (tipping bucket). A meteorological station provides data on wind speed and direction, air temperature, relative humidity and solar radiation. Air and soil temperature and relative humidity are also measured at F1 and G1. Data are transferred to IVL by telephone and modem. Bulk precipitation is collected for chemical analysis on a monthly basis, twice-monthly for pH, NH<sub>4</sub> and color in the summer. Samples are analyzed at IVL for pH, conductivity, color, Ca, Na, K, Mg, Mn, SO<sub>4</sub>, Cl, NH<sub>4</sub>, NO<sub>3</sub>, and DOC, and at the Limnological Institute of the University of Uppsala for Kjeldahl-N and total-P. These chemical parameters are also measured in throughfall, stemflow, groundwater (with the addition of Al and Fe), and runoff (with the addition of Al and Fe). Standard methods are used for all chemical analyses. pH is determined potentiometrically, cations by atomic adsorption spectroscopy, anions by ion chromatography, and NH<sub>4</sub> colorimetrically. DOC is measured as CO<sub>2</sub> by infra-red spectrophotometry following oxidation by persulphate. Aluminum species are determined colorimetrically with (organic) or without (total reactive) cation exchange.

Throughfall: A total of 28 throughfall collection sites are arranged in 5 rows across G2 catchment and 15 sites in 2 rows across F1 catchment. Throughfall collected on the roof at G1 is gauged by weir and water level recorder. Each site contains a pair of plastic funnels in the summer or a single bucket in the winter. Throughfall was initially collected and analyzed every month (except for fortnightly analysis of pH, NH<sub>4</sub> and color), but was changed to fortnightly beginning in January 1992, and monthly again in October 1992.

Groundwater: Groundwater is sampled from wells 8-12 times per year and analyzed for the same constituents as runoff.

Runoff: Runoff is sampled proportional to flow with samples taken every 1 mm of runoff and mixed for monthly analysis. In addition episode studies are made. Discharge from G2 is measured by automatic filling and emptying of tanks. F1 is gauged by weir and level recorder with data transferred by telephone to IVL.

### 3.2. Results 1991-92

The first year of treatment (April 1991- March 1992) was remarkably similar both hydrologically and chemically to the 2-year pre-treatment period April 1989 - March 1991 for which complete data are available (Dise and Wright 1992b) (Figures 3.1 - 3.11). For most chemical components fluxes and weighted-average concentrations in bulk precipitation, throughfall and runoff were similar in the first year of treatment and the pre-treatment period (Tables 3.1 and 3.2).

Discharge during the first year of treatment (5 April 1991 - 7 April 1992) was 484 and 446 mm at F1 and G2, respectively (Table 3.1), approximately equal to annual discharge during the 2-year pre-treatment period, but somewhat less than the 13-year average runoff at F1 of 586 mm yr<sup>-1</sup>. The seasonal pattern of precipitation and runoff was also similar to the pre-treatment period with wet winter half-year and generally dry summer half-year, with the notable exception of heavy rainstorms and runoff in late June 1991 (Figure 3.1). The added 33 mm water to G2 did not affect discharge volume at G2. The amount sprinkled per event (0.2 to 3.6 mm) was insufficient to percolate to groundwater and thus discharge showed no response to the additions.

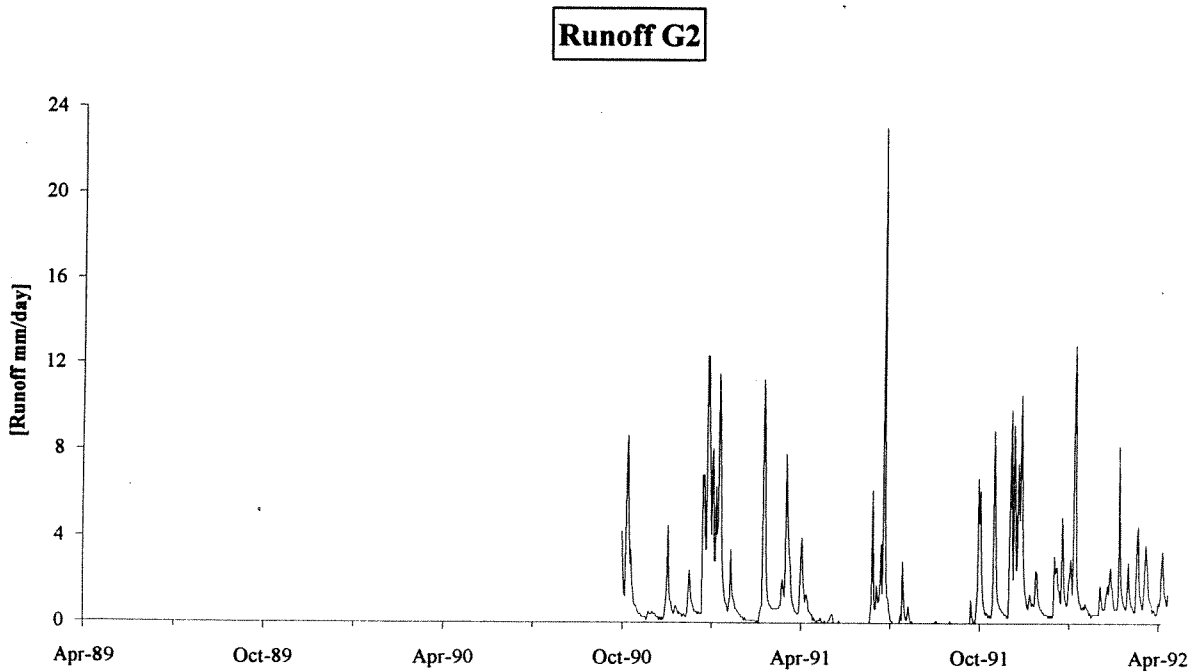


Figure 3.1. Mean daily discharge at F1 (reference) and G2 (NITREX) for the period April 1989 - March 1991 (2 years pre-treatment) and April 1991-March 1992 (the first year of treatment).

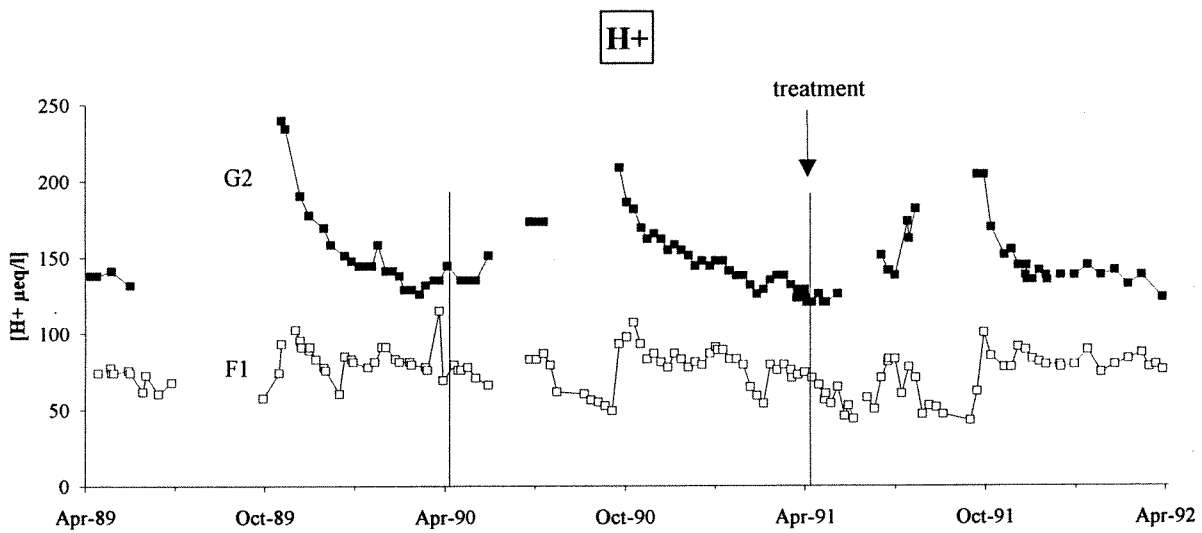


Figure 3.2.  $H^+$  concentrations ( $\mu\text{eq/l}$ ) measured in runoff at F1 (reference) and G2 (NITREX) for the period April 1989 - March 1991 (2 years pre-treatment) and April 1991-March 1992 (the first year of treatment).

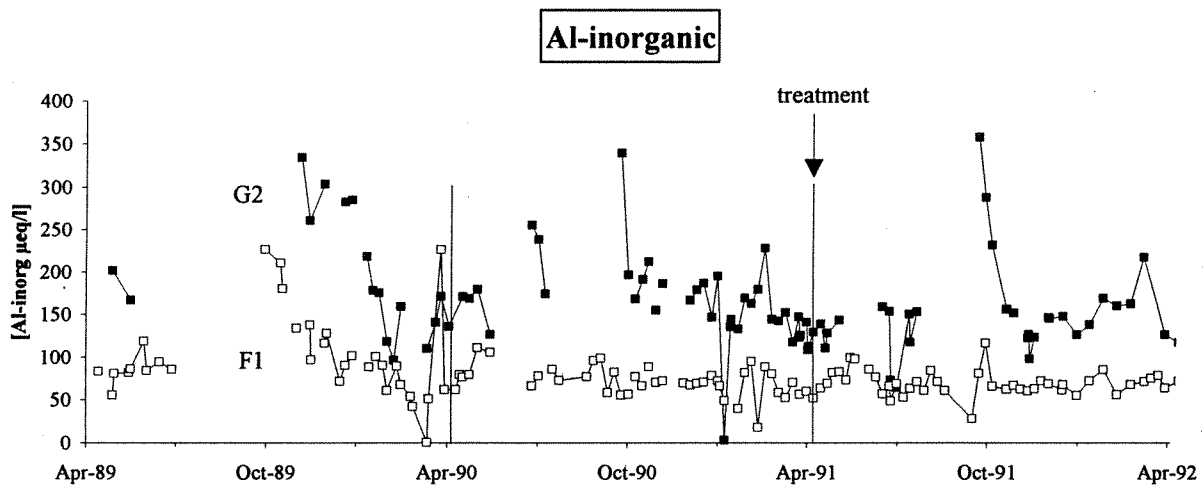


Figure 3.3. Inorganic Al concentrations ( $\mu\text{eq/l}$ ) measured in runoff at F1 (reference) and G2 (NITREX) for the period April 1989 - March 1991 (2 years pre-treatment) and April 1991-March 1992 (the first year of treatment).

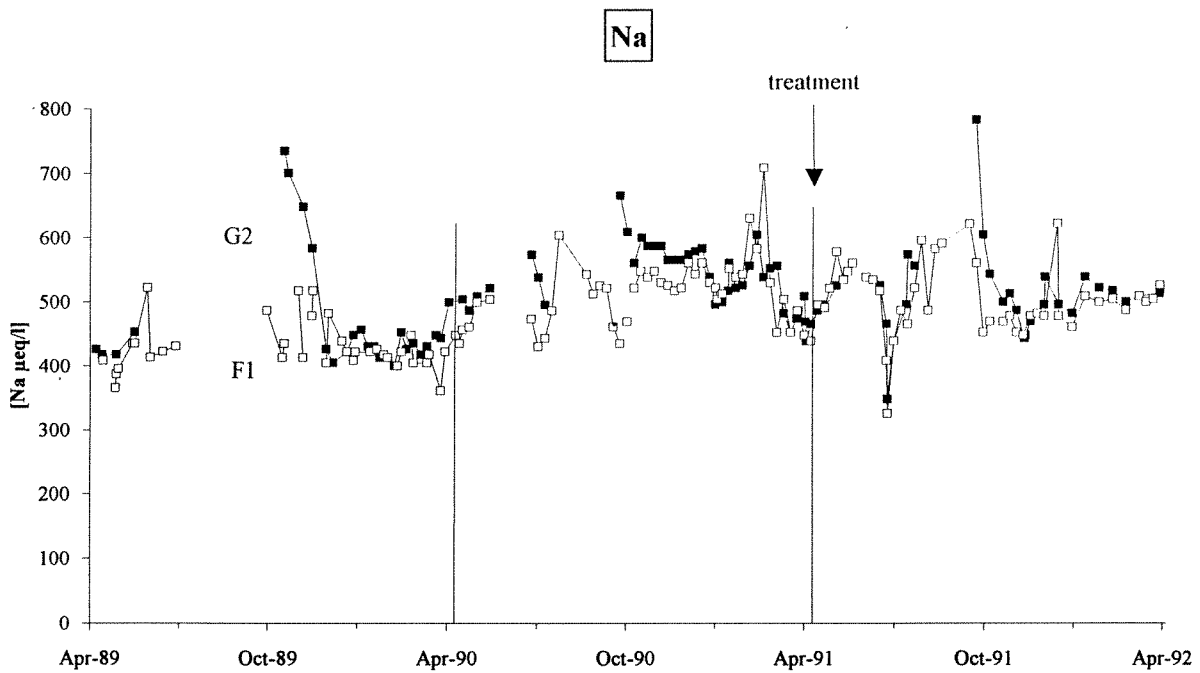


Figure 3.4. Na concentrations ( $\mu\text{eq/l}$ ) measured in runoff at F1 (reference) and G2 (NITREX) for the period April 1989 - March 1991 (2 years pre-treatment) and April 1991-March 1992 (the first year of treatment).

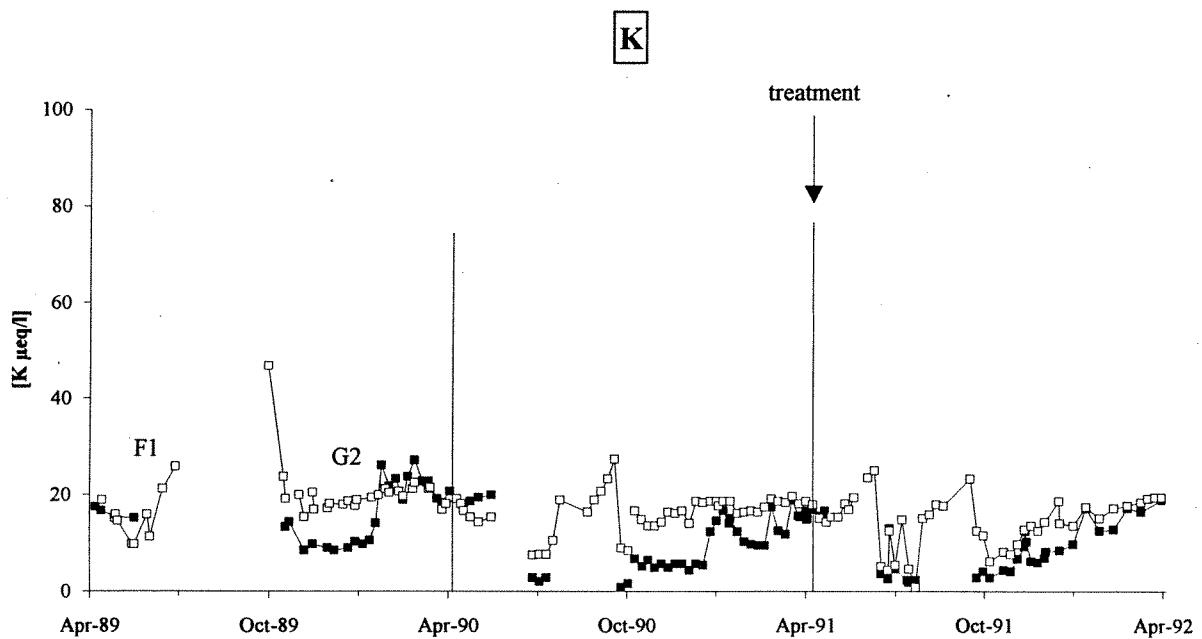


Figure 3.5. K concentrations ( $\mu\text{eq/l}$ ) measured in runoff at F1 (reference) and G2 (NITREX) for the period April 1989 - March 1991 (2 years pre-treatment) and April 1991-March 1992 (the first year of treatment).

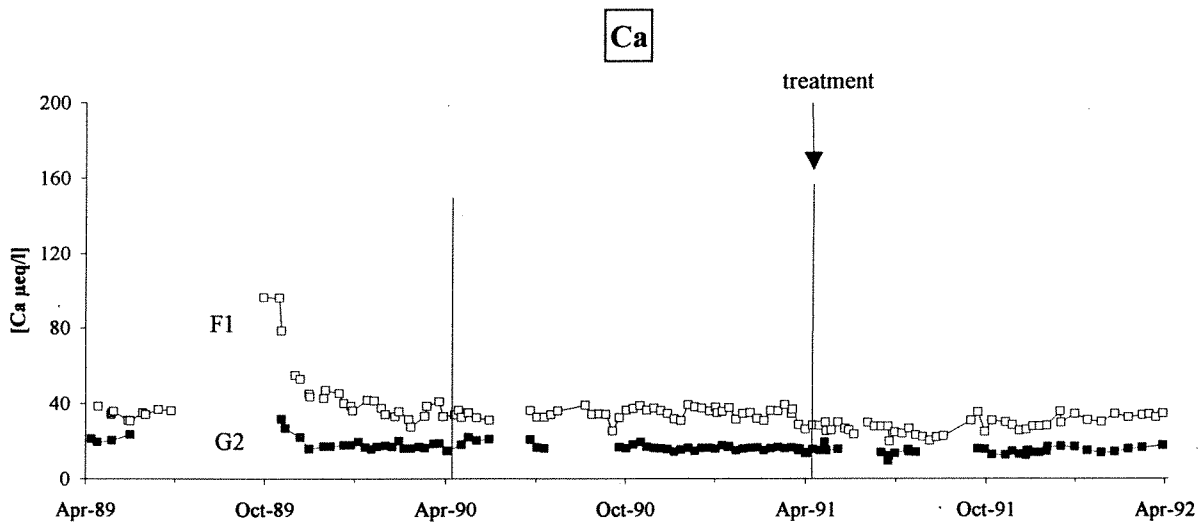


Figure 3.6. Ca concentrations ( $\mu\text{eq/l}$ ) measured in runoff at F1 (reference) and G2 (NITREX) for the period April 1989 - March 1991 (2 years pre-treatment) and April 1991-March 1992 (the first year of treatment).

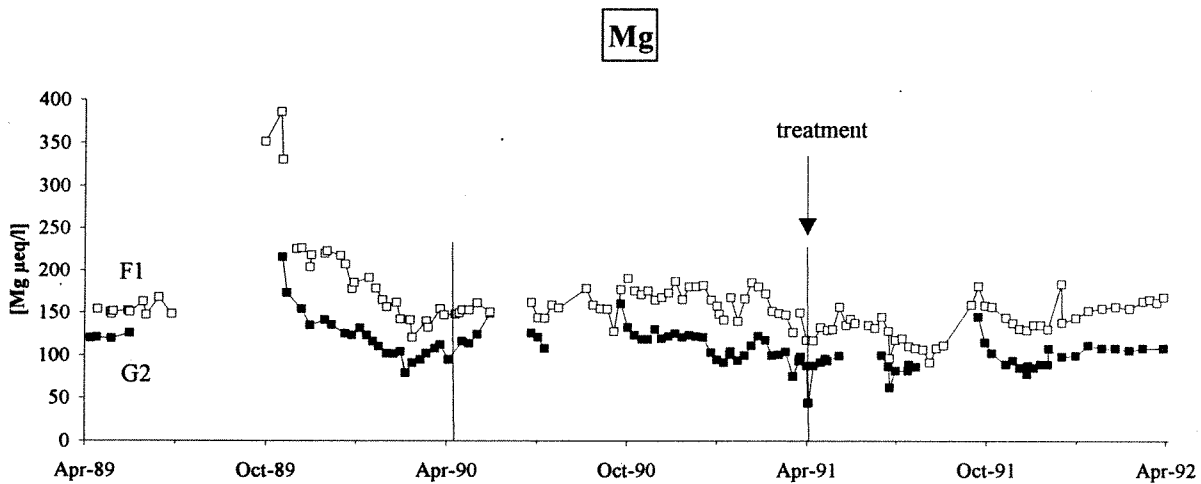


Figure 3.7. Mg concentrations ( $\mu\text{eq/l}$ ) measured in runoff at F1 (reference) and G2 (NITREX) for the period April 1989 - March 1991 (2 years pre-treatment) and April 1991-March 1992 (the first year of treatment).

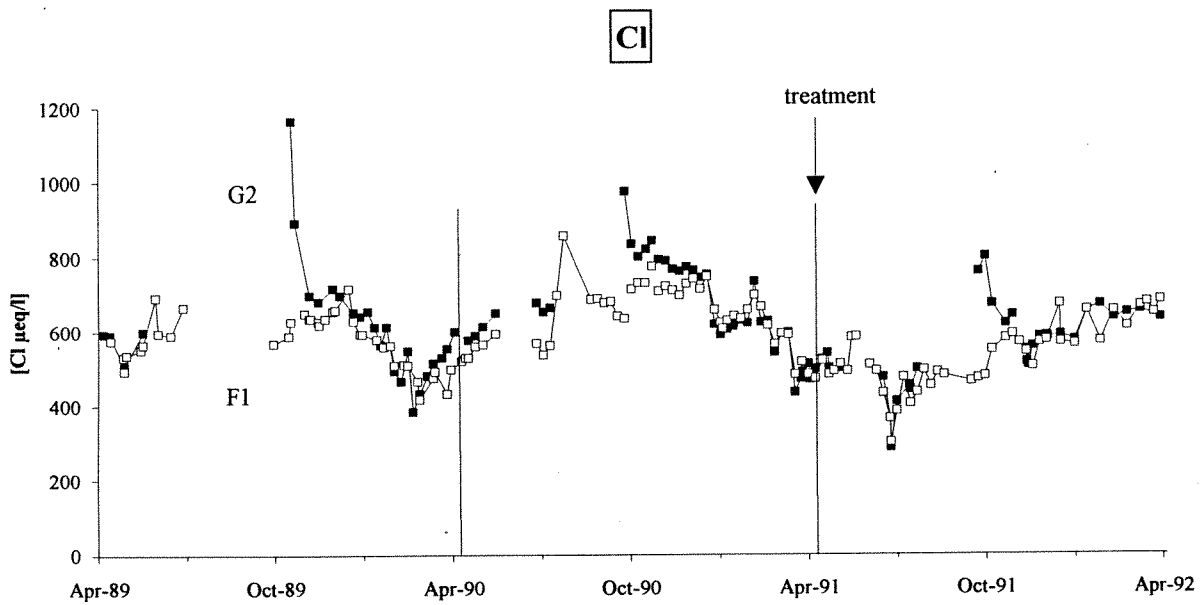


Figure 3.8. Cl concentrations ( $\mu\text{eq/l}$ ) measured in runoff at F1 (reference) and G2 (NITREX) for the period April 1989 - March 1991 (2 years pre-treatment) and April 1991-March 1992 (the first year of treatment).

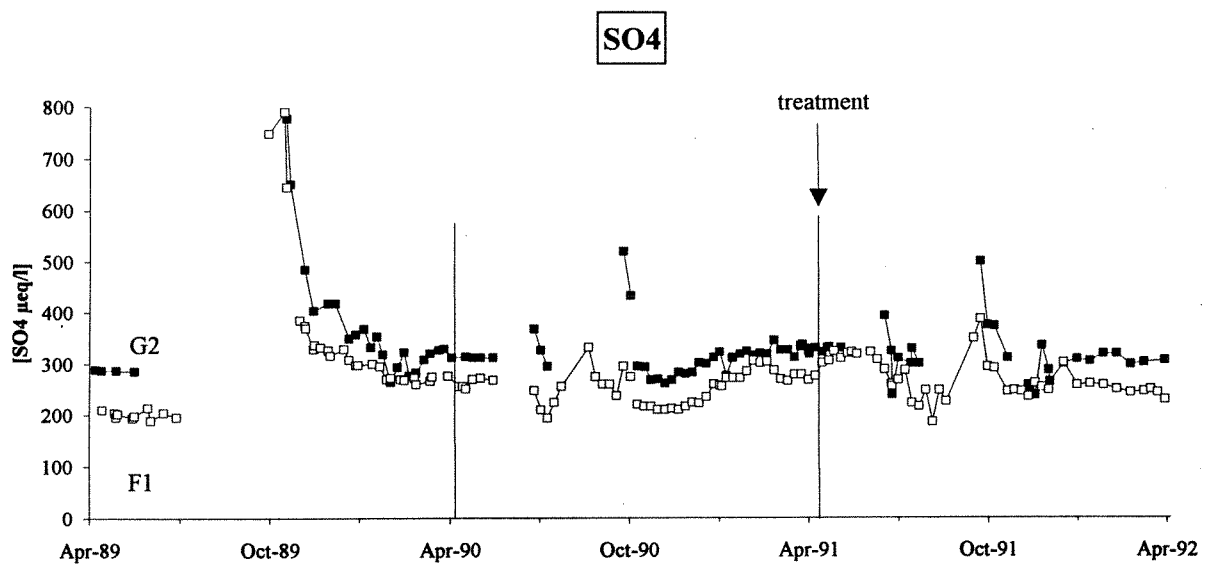
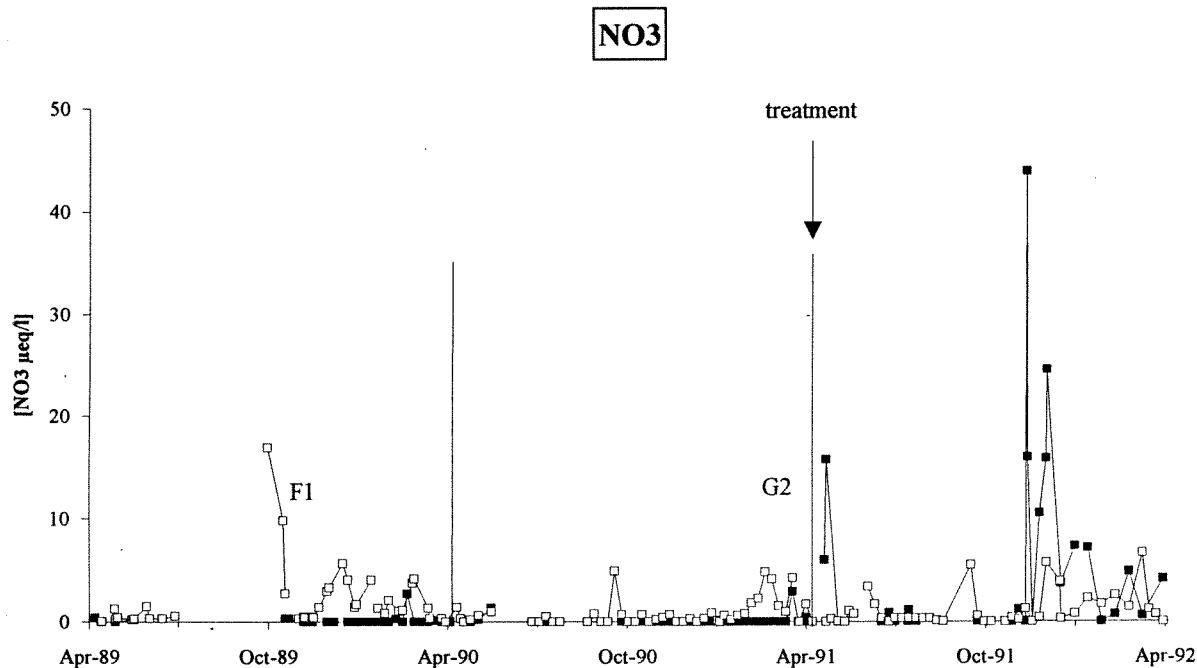


Figure 3.9.  $\text{SO}_4$  concentrations ( $\mu\text{eq/l}$ ) measured in runoff at F1 (reference) and G2 (NITREX) for the period April 1989 - March 1991 (2 years pre-treatment) and April 1991-March 1992 (the first year of treatment).

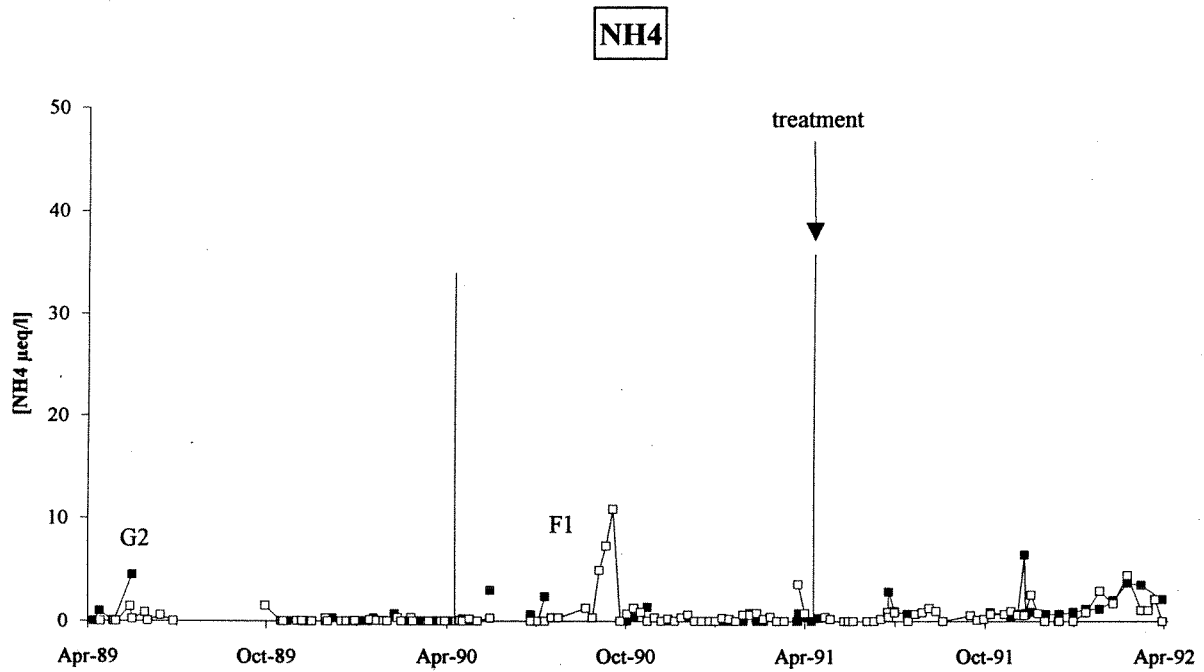


Nitrate is the notable exception. During the first year of treatment a total of  $14.5 \text{ kgN ha}^{-1}$  ( $36 \text{ meq/m}^2/\text{yr NH}_4$  and  $54 \text{ meq/m}^2/\text{yr NO}_3$ ) and was deposited in 631 mm throughfall (Table 3.1). To this we added a total of  $32.2 \text{ kgN ha}^{-1}$  ( $115 \text{ meq/m}^2/\text{yr}$  each of  $\text{NH}_4$  and  $\text{NO}_3$ ) in 33.3 mm water. Runoff contained elevated concentrations of nitrate during the first 2 weeks of treatment in April 1991, but then very low concentrations the rest of the spring, summer and early autumn (Fig. 3.10). The signal of nitrate leakage appeared in mid-November 1991 and continued much of the winter. Nitrogen results for the first year of treatment are discussed in Hultberg et al. (1993).



**Figure 3.10.  $\text{NO}_3$  concentrations ( $\mu\text{eq/l}$ ) measured in runoff at F1 (reference) and G2 (NITREX) for the period April 1989 - March 1991 (2 years pre-treatment) and April 1991-March 1992 (the first year of treatment).**

The elevated concentrations of nitrate in runoff cannot be explained as an artifact of the sprinkling method or due to lack of contact with the soil by, for example, macropore flow. The runoff samples are collected prior to the weekly application of N, the increased nitrate concentrations in runoff were not observed during the summer, and ammonium concentrations showed no response (Fig 3.11).



**Figure 3.11. NH<sub>4</sub> concentrations (µeq/l) measured in runoff at F1 (reference) and G2 (NITREX) for the period April 1989 - March 1991 (2 years pre-treatment) and April 1991-March 1992 (the first year of treatment).**

The nitrate lost from G2 is still only a tiny fraction of the input. The amount of nitrate lost relative to F1 (control catchment) was  $0.24 \text{ kg N ha}^{-1}$  from April 1991 to April 1992. Even in winter, 99% of the input N is still retained.

Table 3.1. Fluxes of major ions in bulk precipitation, throughfall (TF) and runoff (OUT) for the first year of treatment (April 1991 - March 1992) at the reference catchment F1 and the NITREX catchment G2 and at Gårdsjön. Organic anions (A<sup>-</sup>) are determined by difference from the ionic balance. SBC = sum of base cations (including NH<sub>4</sub>), SAA = sum of acid anions, ANC = acid neutralizing capacity (SBC-SAA). Units: meq m<sup>-2</sup> yr<sup>-1</sup>; Al-org mmol m<sup>-2</sup> yr<sup>-1</sup>.

Fluxes meq/m<sup>2</sup>/yr

	Bulk prep.	F1		G2			
		TF	OUT	TF	IN ADDED	TOTAL	OUT
H <sub>2</sub> O(mm)	1075	646	484	631	33	664	446
H <sup>+</sup>	45	51	39	51		51	64
Ca	10	50	28	40		40	13
Mg	20	73	68	58		58	42
Na	84	266	227	211		211	220
K	5	45	7	34		34	5
Al <sub>i</sub>			32				67
NH <sub>4</sub>	37	32	0	36	115	151	1
NO <sub>3</sub>	41	56	1	54	115	169	2
SO <sub>4</sub>	62	127	124	110		110	135
Cl	94	300	265	238		238	257
Fe			8				5
Mn	0	4	1	2		2	1
A <sup>-</sup>	6	34	10	26		26	18
SBC	157	466	330	378		378	280
SAA	197	483	390	402		402	394
ANC	-40	-17	-60	-24		-24	-113

Table 3.2. Volume-weighted average concentrations of major components in bulk precipitation, throughfall plus added (IN) and runoff (OUT) for the first year of treatment (April 1991 - March 1992) at the reference catchment F1 and the NITREX catchment G2 and at Gårdsjön. Organic anions (A<sup>-</sup>) are determined by difference from the ionic balance. SBC = sum of base cations (including NH<sub>4</sub>), SAA = sum of acid anions, ANC = acid neutralizing capacity (SBC-SAA). Units: meq m<sup>-2</sup> yr<sup>-1</sup>; Al-org mmol m<sup>-2</sup> yr<sup>-1</sup>.

Concentration µeq/l

	Bulk prep.	F1		G2	
		IN	OUT	IN	OUT
H <sub>2</sub> O(mm)	1075	646	484	664	446
H <sup>+</sup>	42	79	81	76	143
Ca	10	77	58	60	29
Mg	19	114	140	88	95
N	78	411	469	318	494
K	4	69	13	51	10
Al <sub>i</sub>			65		151
NH <sub>4</sub>	35	49	1	227	2
NO <sub>3</sub>	38	87	1	255	4
SO <sub>4</sub>	58	196	257	165	303
Cl	87	464	548	359	576
Fe			17		12
Mn	0	6	1	4	3
A <sup>-</sup>	5	52	21	40	40
SBC	146	721	681	570	629
SAA	183	748	806	606	883
ANC	-37	-27	-125	-36	-254

Visual inspection of the nitrate data in Figure 3.10 clearly indicates an increase in nitrate concentrations in runoff from G2 in response to treatment. The statistical significance of this response can be tested by means of a new technique called Random Intervention Analysis (RIA) (Carpenter et al. 1989). This technique uses paired samples from the treated catchment and reference catchment. First the mean difference in concentration between the pairs are calculated for the pre-treatment period (n=48) and the treatment period (n=31) (Fig. 3.12). Then the chronological order of the sample pairs is randomly mixed, and the mean difference of the first 48 pairs and the remaining 31 pairs recalculated. This procedure is repeated many times to generate a frequency distribution of mean differences. The actual observed mean difference is then compared to the frequency of randomly generated mean differences. For the nitrate concentrations in runoff at G2 vs F1, the measured mean difference between the pre-treatment period and the first year of treatment was 3.2  $\mu\text{eq/l}$ . Of 1000 randomly generated mean differences, the maximum obtained was 2.1  $\mu\text{eq/l}$  (Figure 3.13). Thus there is less than 1 in 1000 probability that the observed change in nitrate concentration at G2 relative to F1 is due to chance.

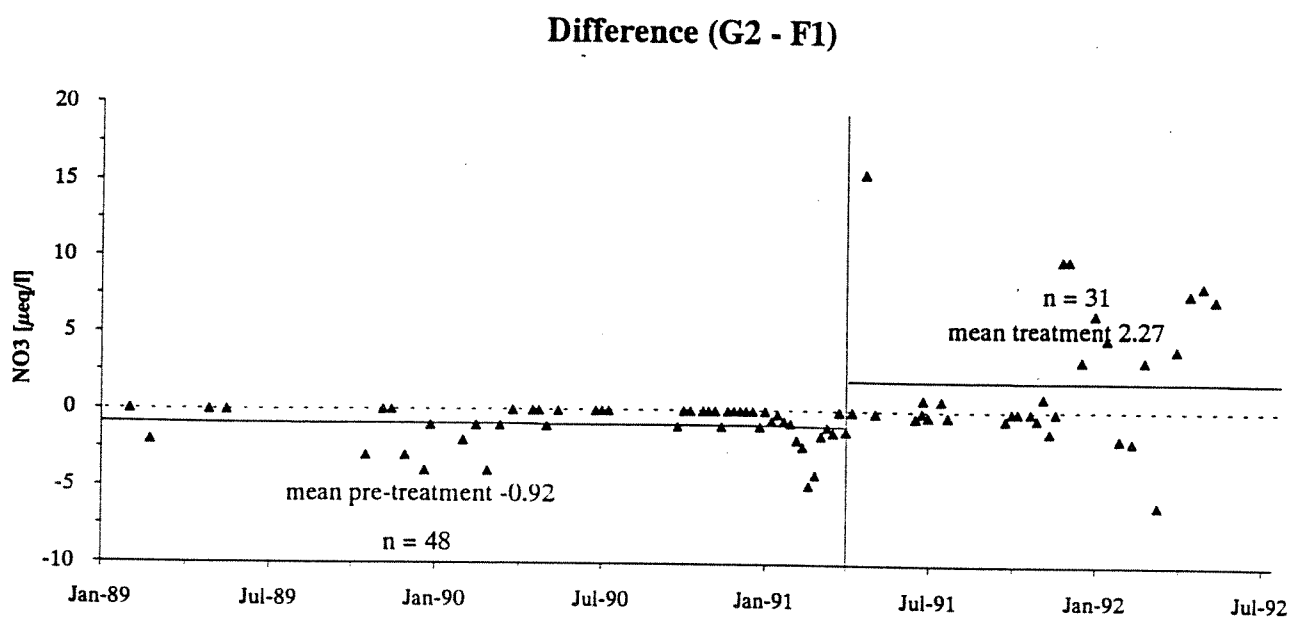
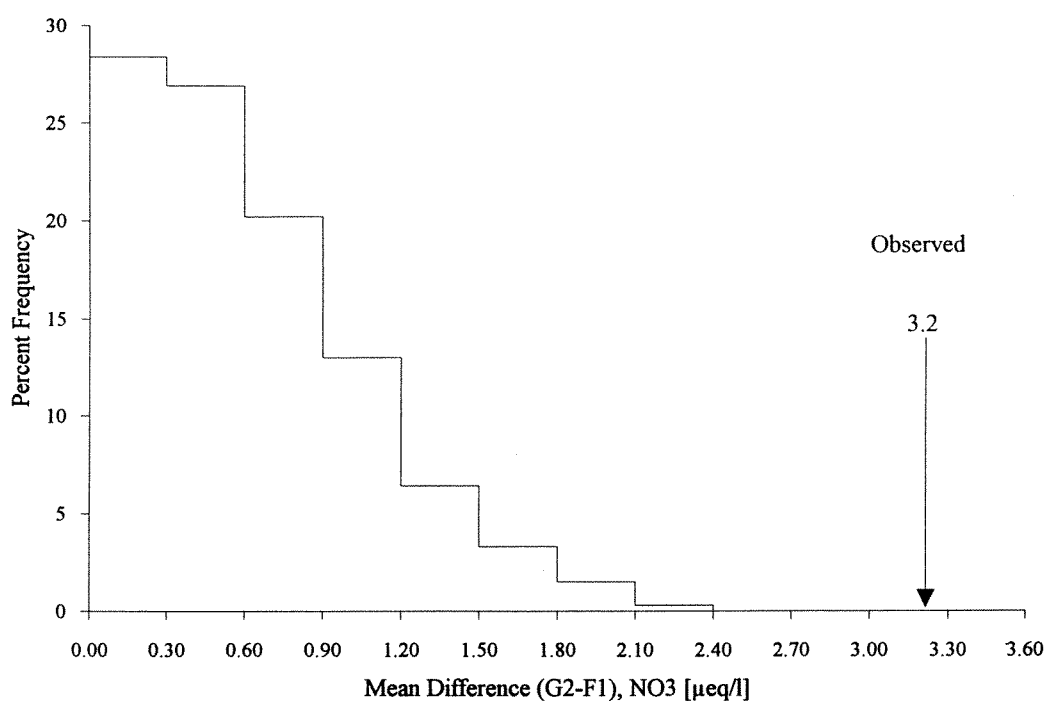


Fig. 3.12 Difference in nitrate concentrations in runoff at G2 less F1 for the pre-treatment period through April 1991 at the first year of treatment April 1991 - April 1992.



**Figure 3.13. Results of randomized intervention analysis of nitrate concentrations in runoff at G2 (NITREX) and F1 (reference) catchments at Gårdsjön. Shown is the frequency distribution for 1000 randomly generated cases of mean difference for pre-treatment period (April 1989 - March 1991, n=48) and the first year of treatment (April 1991 - March 1992, n= 31). The actual observed mean difference of 3.2 µeq/l falls well beyond the tail and thus RIA indicates that this change is statistically significant at the  $p<0.001$  level.**

#### **4. SOILS AND SOIL SOLUTION**

O. Janne Kjønaas, Magne Huse and Arne O. Stuanes

##### **4.1. Soil chemical and physical characteristics**

The soils at G2 (NITREX) were mapped thoroughly in 1990. Soil samples were taken in a grid across the catchment every 5x10 m for the humus layer and every 10x10 m for the mineral soil. Samples were collected before the start of treatments and will be re-surveyed after treatments end. They allow quantification of the soil physical and chemical variability in the catchment, and will also be used to produce a soil map. In addition, the upper 13 cm of soil is analyzed for available NH<sub>4</sub> and NO<sub>3</sub> four times a year in 10 cores from each of the three different moisture regimes with different ground vegetation.

Samples are chemically analyzed for base cations, and N, (some samples also for organic C and S) using the methods described by Ogner et al. (1991). Exchangeable cations and other extractable elements (Al, Ca, K, Mg, Na, P, and S) are determined in 1 M  $\text{NH}_4\text{NO}_3$  extracts by ICP (inductively-coupled plasma emission spectroscopy). The cation exchange capacity (CEC) is defined as  $\text{CEC}_{\text{NH}_4\text{NO}_3} = \text{exchangeable acidity} + \text{Na}^+ + \text{K}^+ + \text{Mg}^{2+} + \text{Ca}^{2+} + \text{Mn}^{2+} + \text{NH}_4^+$ . The base saturation (BS) is defined as  $\text{BS}_{\text{NH}_4\text{NO}_3} = (\text{Na}^+ + \text{K}^+ + \text{Mg}^{2+} + \text{Ca}^{2+} + \text{NH}_4^+)/\text{CEC}_{\text{NH}_4\text{NO}_3} \times 100\%$ . The  $\text{NH}_4^+$  value is included in the calculations only if it is available from a separate extraction with 2 M KCl.

The soils in the NITREX catchment are classified as Orthic Humic Podzols, Orthic Ferro-Humic Podzols, Gleyed Humo-Ferric Podzols, and, at the shallow outcrops, Typic Folisols (Canada Soil Survey Committee 1978). The mineral components consist of moraine material that is influenced by water during the post-glacial isostatic rebound. This results in a soil texture gradient from loamy sand in the higher areas, sandy loam in the slopes to silty loam on the lower parts of the catchment.

The soil in the control catchment F1 is slightly more stony than the NITREX site G2, but the soil from the F1.1 profile is comparable to G2.1. The differences between soils of the nitrogen manipulation site and the control underscore the importance of comparing time trends in the two areas.

#### 4.2. Soil solution chemistry

In G2 90 teflon tension lysimeters (PRENART) are located in seven plots, four with constant suction and three for event sampling. Lysimeters are installed at 5, 10, 20, 40 and 70 cm depths, with 2-3 lysimeters at each depth connected to the same sampling bottle. Catchment F1 has two such lysimeter plots (same depths and frequency) corresponding to moisture regimes in G2. Both ceramic cups and teflon lysimeters are used in these plots. Water samples for chemical analysis are collected fortnightly. Volume is recorded when samples are collected. Samples are analyzed at NISK for the same constituents as bulk deposition (except for Kjeldahl-N), with the addition of alkalinity, total N, total S,  $\text{PO}_4$ , Al, Fe, Cu, Si and Zn (Ogner et al. 1991).

Volume-weighted mean values for some soil solution constituents over the period April 1990 - March 1992 (one year pre-treatment and one year treatment) are shown in Figures 4.1 - 4.5.

The nitrate concentration in the runoff from the NITREX catchment has increased slightly after the addition of nitrogen started. If the outflowing water represents the sampled soil water from the catchment a similar increase should be seen in the soil water. Soil water from comparable lysimeter sites in catchment G1 (Roof), G2, and F1 (Control) were compared. As a general statement we can say that no changes can be related to the nitrogen addition in the NITREX catchment. Included here are figures from 20 cm depth for pH,  $\text{NO}_3\text{-N}$ ,  $\text{NH}_4\text{-N}$ , Organic N, and  $\text{SO}_4\text{-S}$  (Figures 4.1, 4.2, 4.3, 4.4, and 4.5, respectively).

The pH of the soil water was quite similar in the three catchments (Figure 4.1). Very small changes have taken place during the two years of measurements. The nitrate concentrations were very low in G1 and G2, but in periods much higher in F1 (Figure 4.2). This was in accordance with the mineralization studies. As seen from Figure 4.3, the ammonium level was

also low and that is true for all three catchments. There was a sign of higher concentrations in the spring of 1992, but the concentration was not higher in the NITREX catchment. Also the concentrations of organic N in the three catchments were quite similar (Figure 4.4). There was a decreasing trend in all the catchments towards the spring of 1992 probably due to climatic conditions. However, there seem to be a decreasing trend in sulphate concentrations under the roof (G1) (Figure 4.5). A similar trend could not be seen in the other two catchments.

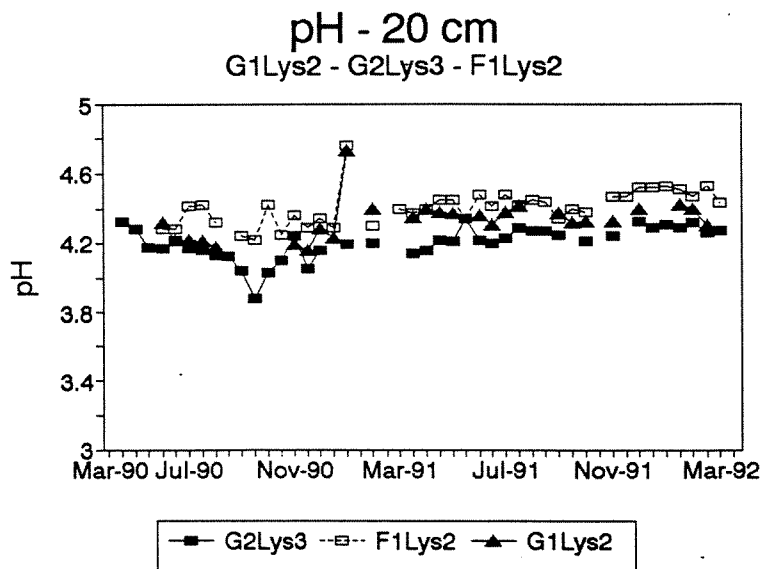


Figure 4.1 Soil water pH at 20 cm depth in comparable lysimeter sites in catchments G1, G2, and F1.

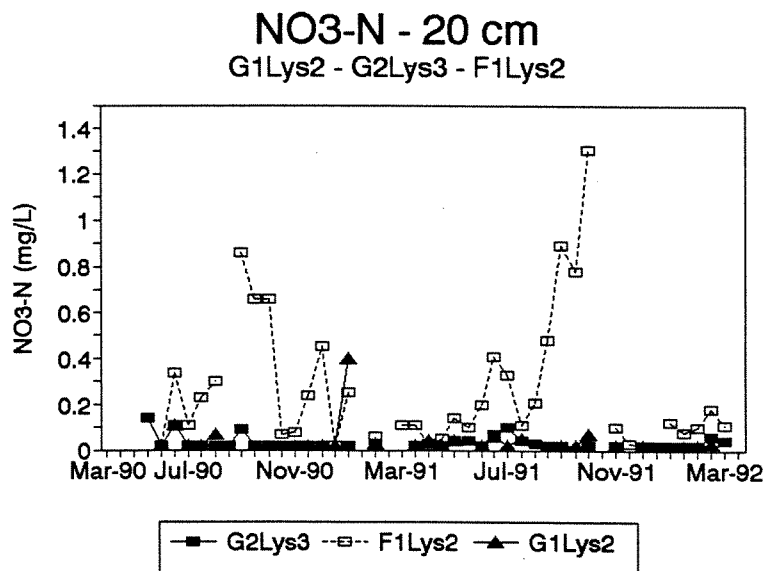


Figure 4.2 Soil water NO<sub>3</sub>-N at 20 cm depth in comparable lysimeter sites in catchments G1, G2, and F1.

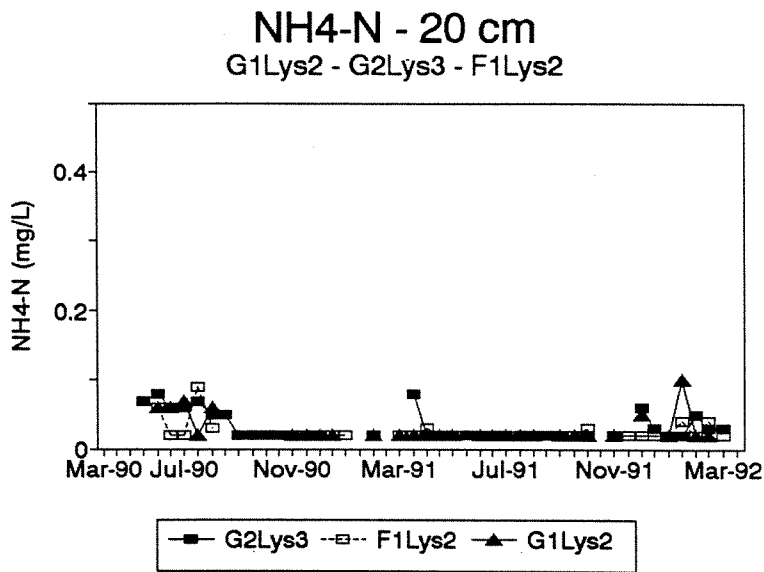


Figure 4.3 Soil water NH<sub>4</sub>-N at 20 cm depth in comparable lysimeter sites in catchments G1, G2, and F1.

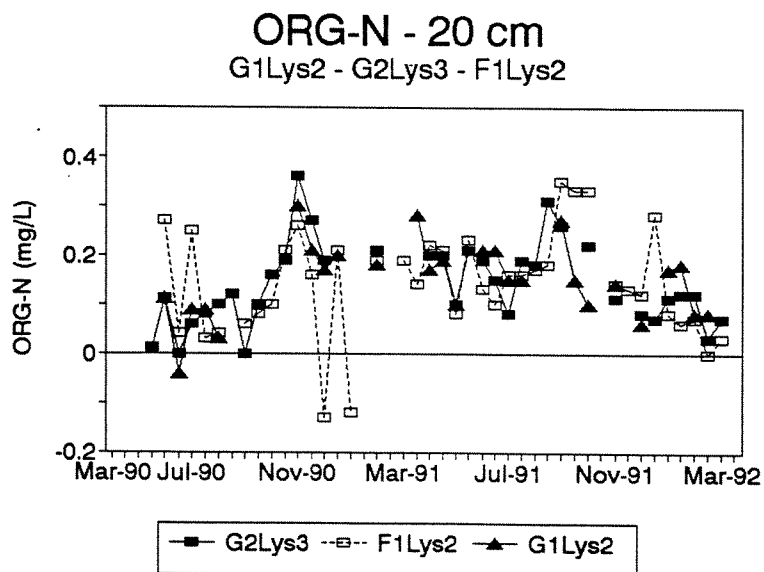


Figure 4.4 Soil water organic-N at 20 cm depth in comparable lysimeter sites in catchments G1, G2, and F1.



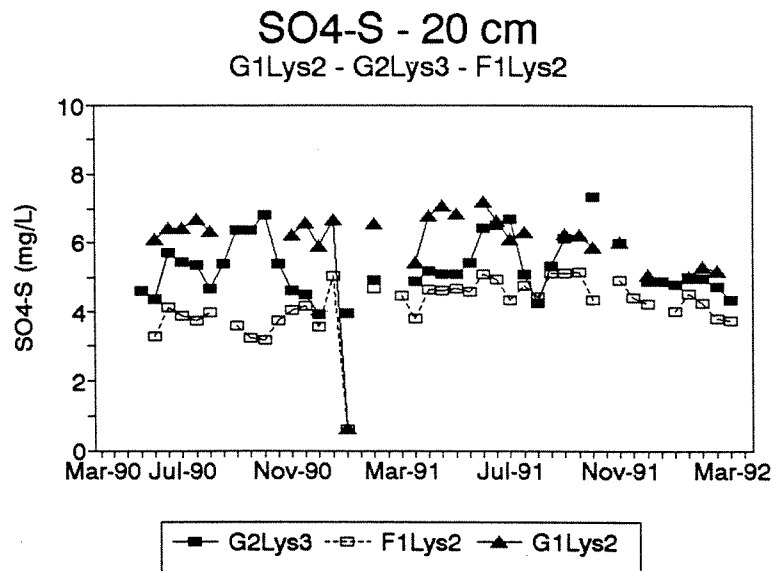


Figure 4.5 Soil water SO<sub>4</sub>-S at 20 cm depth in comparable lysimeter sites in catchments G1, G2, and F1.

## 5. SOIL MICROBIAL PROCESSES

O. Janne Kjønnaas

Gårdsjön-NITREX investigations include monitoring the rate and amount of microbiological conversion of organic-N to ammonium (mineralization), ammonium to nitrate (nitrification), and nitrate to atmospheric-N<sub>2</sub>O/N<sub>2</sub> (denitrification) using either soil core incubations or chamber techniques. These soil processes may be either disturbed by internal nitric acid production during dry periods (Ulrich 1983), or stimulated by the increased supply of available nitrogen. The studies at Gårdsjön compare rates of soil microbial transformations in similar soil moisture regimes in the NITREX (G2) and the Roof (G1) catchments with the common control (F1).

**Mineralization** capacity is studied in three soil moisture gradients with differing ground vegetation in G2, and single (medium dry) moisture regime in the control site (Vaccinium-dominated) and the Roof catchment (Dicranum-dominated). The incubation is made *in situ* with ion-exchange resin bags placed in the bottom of soil cores. To estimate the relative contributions of input- versus mineralized-nitrogen, resin bags are also placed on the surface adjacent to the soil cores. Soil cores are collected before each mineralization study to measure pre-incubation levels of NH<sub>4</sub>, NO<sub>3</sub> and total N.

Incubations are made over 2-month intervals in the spring-autumn (May-June, July-August, September-October) and over 5 months in the winter (November to May), with 10 replicate cores for each vegetation type. The cores are placed in a grid net, and vegetation in the grid is

recorded in detail. The holes from collected samples are re-filled with soil from similar vegetation types (gathered from outside the catchments) to minimize mineralization in the catchments due to disturbance. Soil temperature is measured adjacent to the mineralization plots at 5, 10, 20, 40 and 70 cm. The mineralization studies are carried out close to the lysimeter installations (downslope) to facilitate comparison of  $\text{NH}_4^+$  and  $\text{NO}_3^-$  levels in soil and soil solution.

In general there is no difference in mineralization between vegetation types in the NITREX catchment. No differences in mineralization appear between comparable vegetation types in the NITREX and the G1 catchments during the first year of nitrogen addition. The mineralization was much higher in the F1 catchment compared with the G1 and G2 catchments. The nitrogen added during the summer of 1991 has been incorporated into the microbial biomass, the soil, or consumed by the ground vegetation. The measured soil nitrate values were generally low and close to the detection limit. Values up to 15 mmol/kg soil were measured for ammonium in the LF-layers. These values decreased sharply with depth within the upper 13 cm of soil and very small amounts have been leached further down. The mineralization rate was higher in May/June 1991 than during July/August the same year most probably due to the moisture conditions.

**Denitrification** rates have been measured in G2 beginning in the spring of 1992 using a closed chamber technique, with three chambers placed in each moisture/vegetation regime. Measurements began in G1 and F1 in 1991 as part of a separate study conducted by IVL.

Potential **nitrification**, microbial biomass and the activity and density of nitrifying bacteria are measured at irregular intervals. Samples are analyzed by IVL, NISK and the Institute for Microbiology, NLH (The Norwegian Agricultural University). These process-oriented studies are all coordinated to facilitate comparison among results.

## 6. FINE-ROOT VITALITY AND DISTRIBUTION

Anna Clemensson-Lindell and Hans Persson

The aim of the present study is to investigate the effects of increased nitrogen deposition (the NITREX catchment G2), and decreased nitrogen and sulphur deposition (the roof catchment G1) respectively, on the distribution and development of fine roots of different vitality.

### 6.1. Materials and Methods

Sampling was performed by using soil cores and ingrowth cores (Vogt & Persson 1991). A number of 10-20 soil cores (4.5 cm in diameter, depth about 30 cm) were taken in each of two vegetation types (Vaccinium-dominated and moss-dominated, respectively) within each catchment. Roots were picked out from the soil and sorted into diameter classes: 0-1, 1-2 and 2-5 mm. The fine roots 0-1 mm were separated into 4 vitality classes, following certain morphological characteristics:

- Class 1: The roots are light, yellowish, often with a great amount of white root tips. The stele is elastic and white.
- Class 2: The roots are darker, more suberised and well-branched, with the main part of the root tips being active. The stele is white and elastic.
- Class 3: The roots are darkened. White root tips are often lacking. The stele is still elastic and light to slightly brown.
- Class 4: The roots in this class are normally referred to as dead. The stele is brownish and easily broken off. No elasticity remains.

The ingrowth cores, viz. a nylon net filled with perlite, were placed into the holes left from the core sampling. After two growing seasons they were resampled. The same root separation was carried out as with the soil cores.

The total amount of root tips and the active amount of root tips were counted on the fine roots. Three different types of mycorrhiza were also distinguished - Cenococcum, cottony mycelium and smooth, brown mycorrhiza.

## 6.2. Results and Conclusions

### Soil cores.

The fine-root distribution shows a similar pattern in the different catchments, with the more vital fine roots (vitality classes 1 and 2) in the upper part of the humus layer. In the mineral soil only fine roots of class 3 and 4 were found. All catchments show a decreased vitality from 1990 to 1991, with an increase of class 4 and a decrease of class 1, 2 and 3 (Fig. 6.1a and b). The deterioration in root vitality was reflected also in the amount of root tips, with the smooth, brown mycorrhiza showing the strongest decrease. The black Cenococcum showed no change at all (Fig. 6.2a-e).

### Ingrowth cores.

The main parts of the fine roots in the ingrowth cores were of vitality classes 3 and 4, both in the upper and the lower part of the core. The Vaccinium-dominated, dryer part of the roof-catchment showed a significantly lower total amount of fine roots in the ingrowth cores compared to the other sampling areas (Fig. 6.3a and b). The amount of root tips was about the same in all areas in all catchments, except for the Vaccinium-dominated area in the roof-catchment, which showed an extremely low amount of root tips (Fig. 6.4a and b).

From the results of the present investigation we conclude that:

- All areas show a deteriorated fine-root vitality between 1990 and 1991;
- Fine roots in the ingrowth cores are mainly of class 3 and 4, both in the upper and the lower part of the core, with 50% or more of class 4;
- The total amount of root tips and root tips infected by mycorrhiza also show a

decrease between 1990-1991, with the smooth, brown mycorrhiza and the cottony, yellow or white mycorrhiza being more sensitive than the black Cenococcum.

The variation between years is substantial, and several sampling occasions will be needed before changes in relation to the treatments can be distinguished.

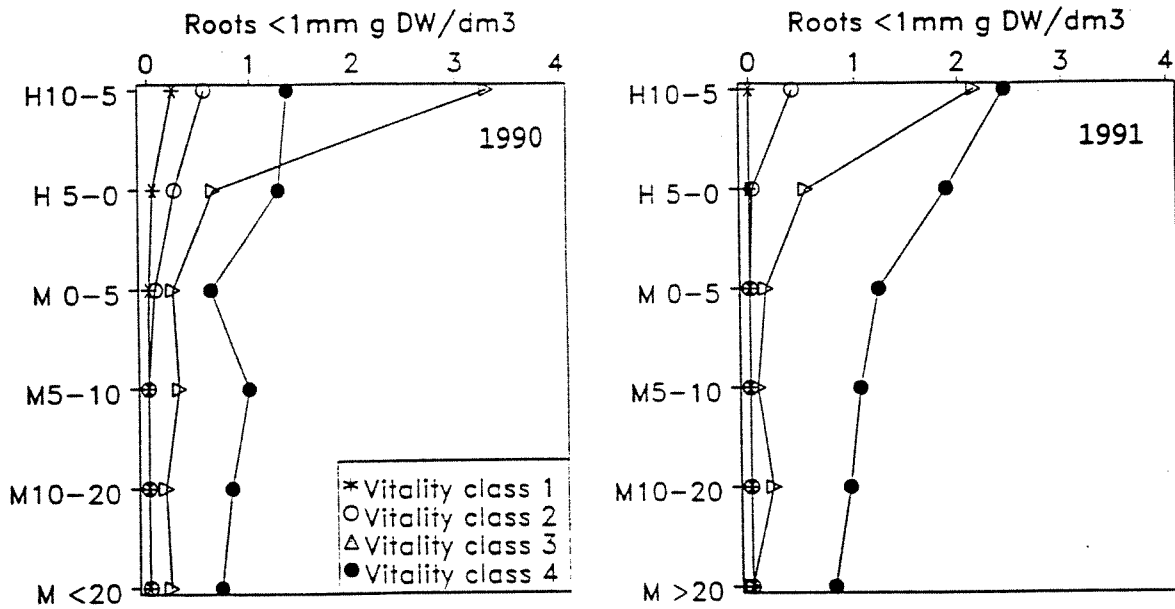


Fig. 6.1a and b. Fine-root distribution in soil cores sampled in October 1990 and 1991 respectively, in the moss-dominated part of the NITREX catchment (G2). H = organic soil layer; M = mineral soil layer. n = 6-10.

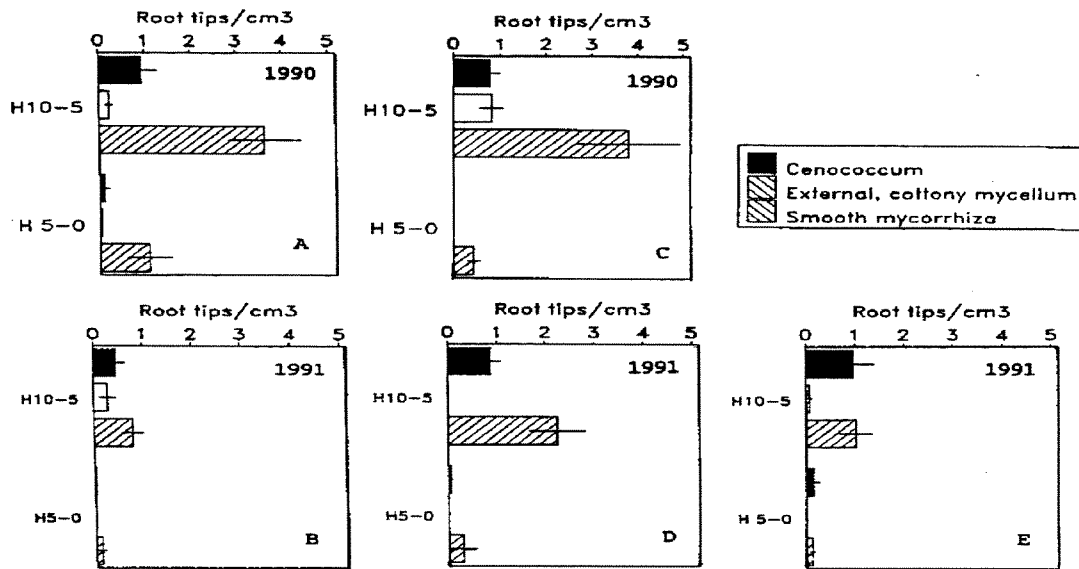


Fig. 6.2a and e. Number of root tips in the humus layer infected with three different types of mycorrhiza, for each catchment and vegetation type, 1990 and 1991 respectively. A+B) Roof area, Vaccinium-type; C+D) Control area, moss-type; E) N-area, moss-type. Results from soil core sampling. n=6-10. Depth in cm.

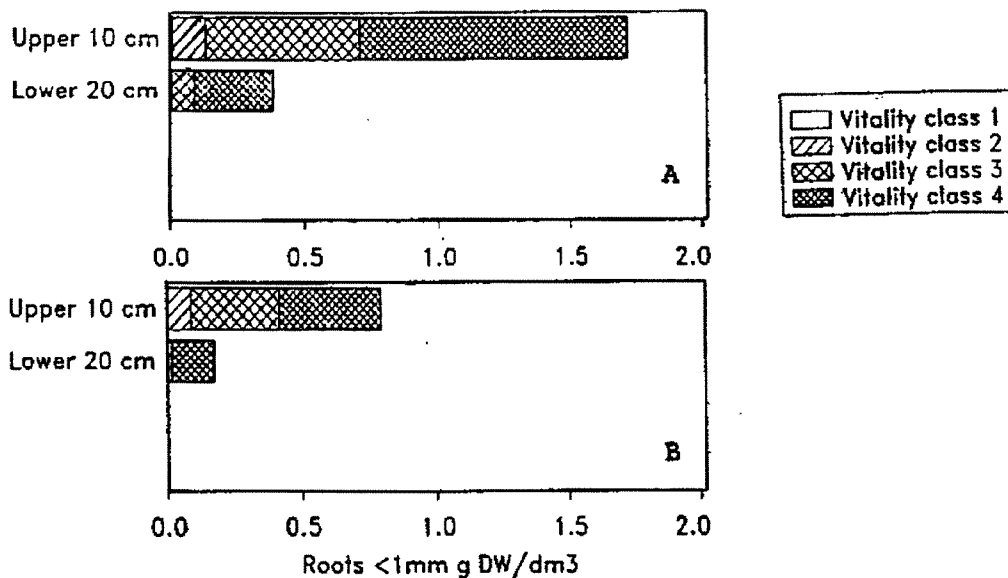
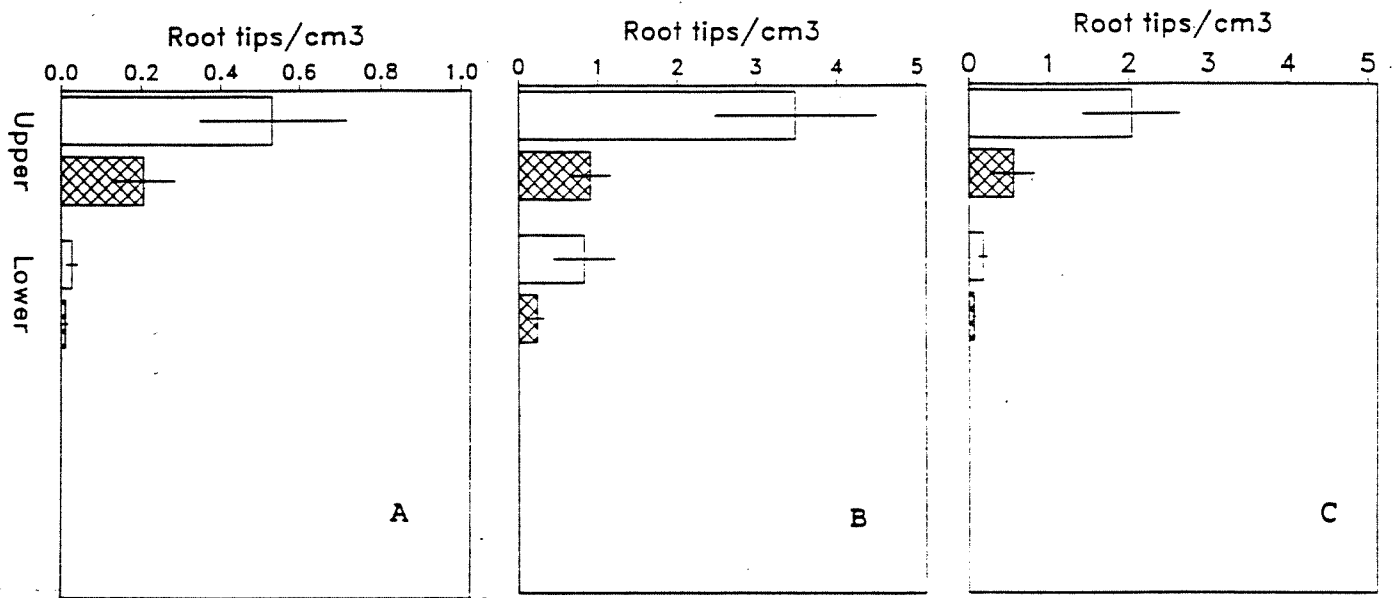


Fig. 6.3a and b. Fine-root distribution in ingrowth cores sampled in October 1991 in a) the moss-dominated part of the NITREX catchment (G2) and b) in the Vaccinium-dominated part of the roof catchment (G1). n = 7-10.



**Fig. 6.4a-c.** Number of root tips on fine roots from ingrowth cores in a) the *Vaccinium*-dominated part of the root-catchment (G1), b) the moss-dominated part in the control catchment (F1) and c) the moss-dominated part of the NITREX catchment (G2).  $n = 7-10$ .

## 7. THE ECTOMYCORRHIZAL FUNGI

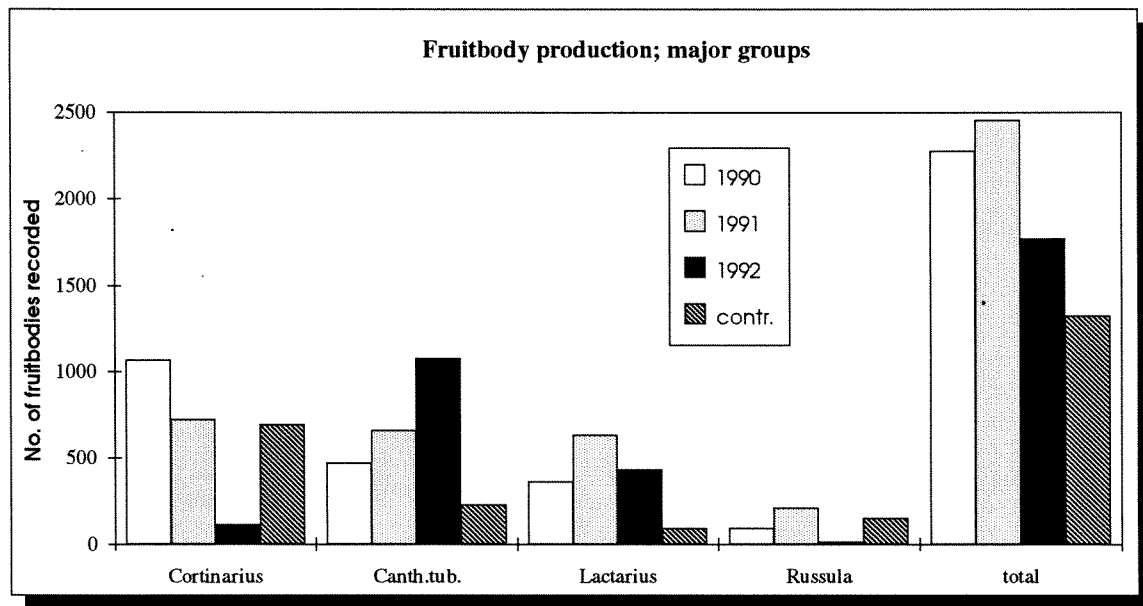
Tor Erik Brandrud

### 7.1 Introduction

The above-ground and below-ground ectomycorrhizal development have been studied at the NITREX site at Gårdsjön in 1990 (background data), 1991 and 1992. Both NITREX, roof and control catchment are included in the study from 1992, but the complete 1992 data are not yet available. Preliminary results from 1990 and 1991 are presented in the Gårdsjön status reports 1988-1990 (Wright et al. 1991) and 1990-1991 (Dise and Wright 1992b).

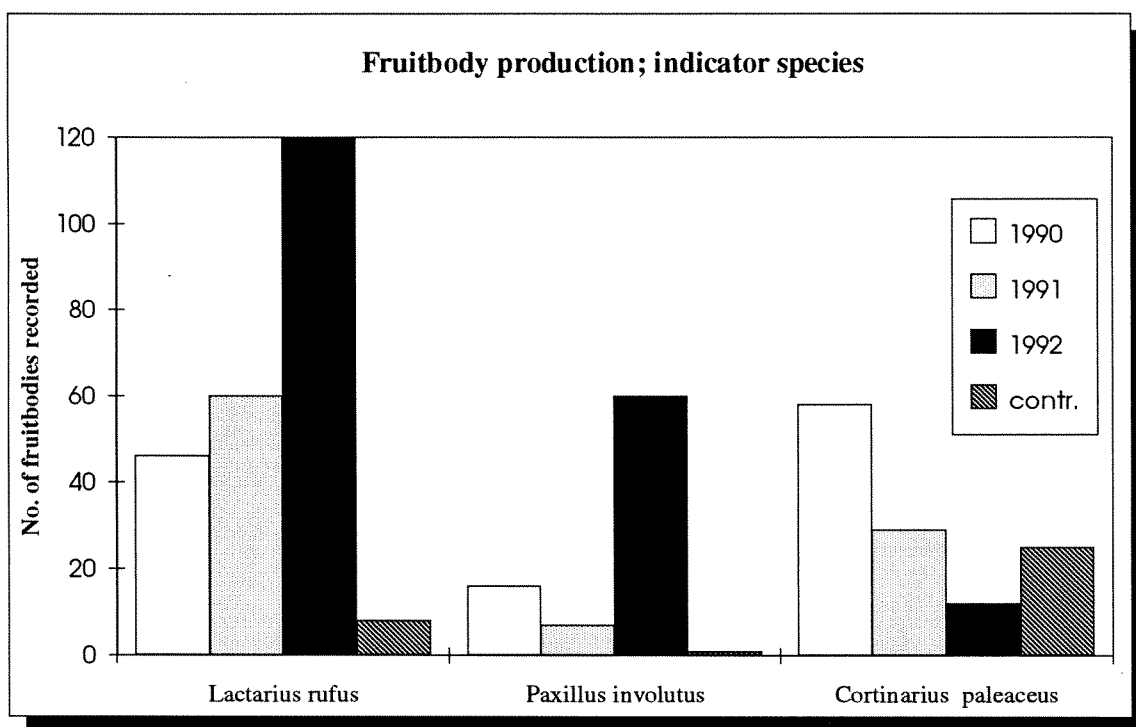
### 7.2 Results

Above-ground study: Both in 1990 and 1991 a fairly high - and quite similar - total production of fruitbodies was recorded (Fig. 7.1). However, the number of fruitbodies of *Cortinarius*, the dominant genus with external mycelium mycorrhiza decreased substantially in 1991, while the numbers for *Russula* (smooth mycorrhiza) increased. The species diversity (73 species) recorded is comparable to that of other south Scandinavian, oligotrophic, moderately polluted (mature, natural) forests.



**Fig. 7.1.** Fruitbody production of the four dominant mycorrhizal fungus genera in the NITREX site. (The genus *Cantharellus* is represented only by the dominant species *C. tubaeformis*.) The three first columns represent production in the NITREX site 1990 (before treatment) to 1992. The fourth column represents data from the control site 1992. Each column represents a transect plot area of 1300 m<sup>2</sup>.

In 1992 both the species diversity and the fruitbody production decreased for a number of genera, especially *Cortinarius*, which showed considerably lower numbers than in the control plot (Fig. 7.1). The genus *Lactarius*, on the other hand, showed a more or less unchanged production (compared to 1990). This was much higher than in the control. Some species such as *Cantharellus tubaeformis*, *Lactarius rufus*, *L. theiogalus* and *Paxillus involutus* showed increased productivity in 1992 (Fig. 7.2), and were more abundant in the NITREX site than in the control. The observed increase in fruitbody production of these four species was mainly limited to individuals/populations already recorded in 1990, and establishment of new individuals is probably not involved. The indicator value of these species is discussed below.

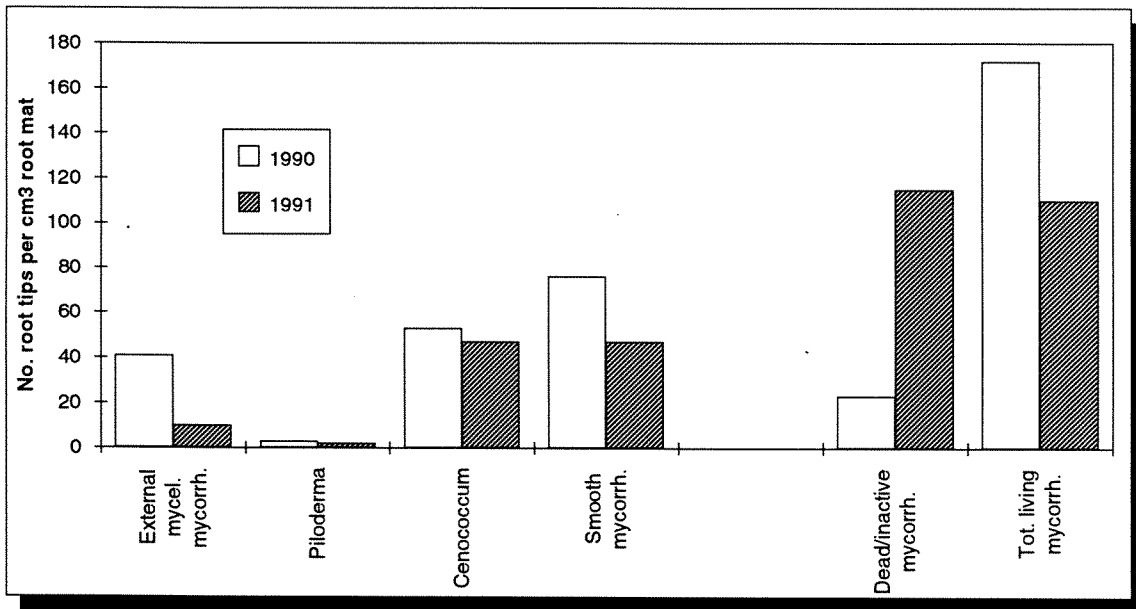


**Fig. 7.2.** Examples of species with a significantly increase in the NITREX site after 1.5 years of N-addition; the acidophilous-nitrophilous *Lactarius rufus* and *Paxillus involutus*, and the acidophilous N-sensitive *Cortinarius paleaceus*. The three first columns represent production in the NITREX site 1990 (before treatment) to 1992. The fourth column represents data from control site 1992. Each column represents a transect plot area of 1300m<sup>2</sup>.



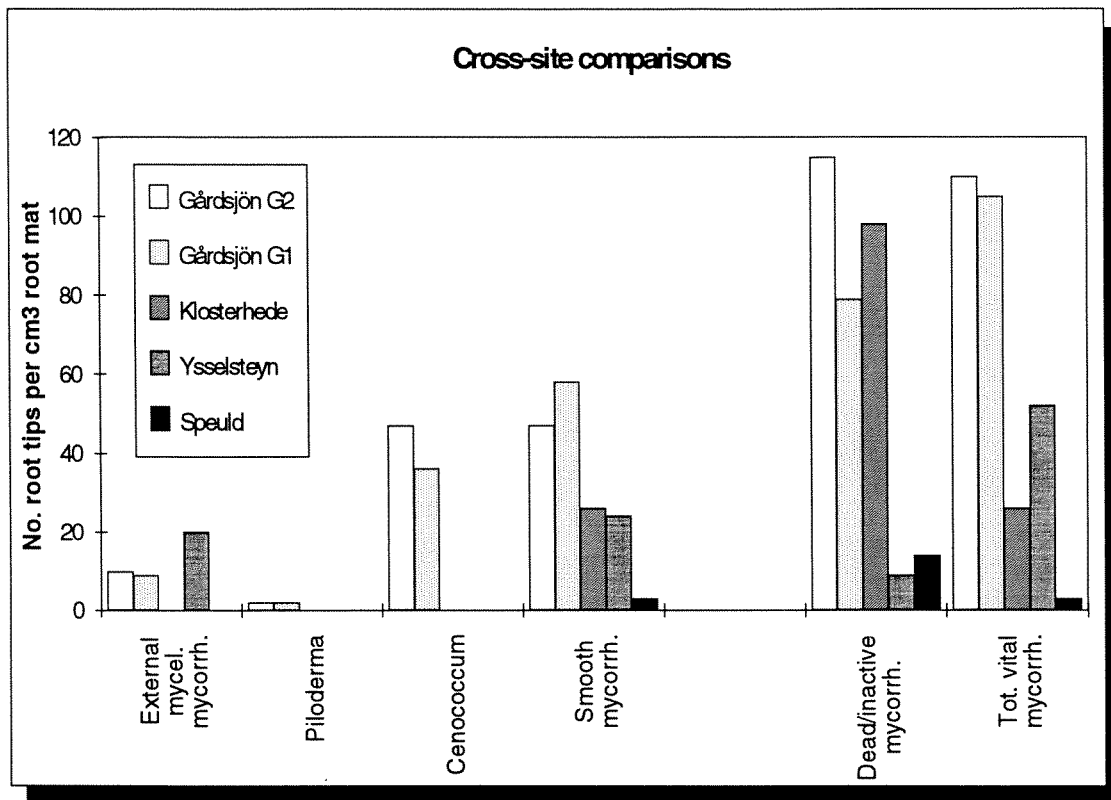
Below-ground study: The total number of living and vital mycorrhizal roots at the surface decreased by approximately 30% from 1990 to 1991 (Fig. 7.3), while the number of dead/inactive root tips increased drastically, indicating less vital conditions in 1991. Among the mycorrhizal morphotypes, the mycorrhizas with white, external mycelium were most severely affected, with a root tip density reduction of approximately 75%. So far, the 1992 results appear to resemble 1991 more than 1990.

A few 1991 samples taken from the roof catchment were in general very similar to the 1991 NITREX catchment samples, with low numbers of external mycelium mycorrhizas, and a comparatively high number of dead/inactive mycorrhizas, although not so high as in the NITREX site (Fig. 7.4).



**Figure 7.3. The below-ground mycorrhizal development in the NITREX catchment in 1990 and 1991. Samples taken from the surface root mat.**

Cross-site comparisons: From 1992, below-ground mycorrhizal sampling will be carried out in the NITREX sites at Gårdsjön, Klosterhede, Solling, Speuld and Ysselsteyn. A limited number of samples from the Dutch and Danish sites were taken in 1991, and a preliminary comparison to the two Gårdsjön catchments is given in Fig. 7.4. The differences between the sites was large, both quantitatively and qualitatively. Klosterhede, Ysselsteyn and especially Speuld showed poorly-developed mycorrhiza, with low numbers of vital mycorrhizal roots, and in the case of Klosterhede and Speuld, also a very low living/dead ratio. Generally, the diversity was very low in these sites, and *Piloderma* and *Cenococcum* was not found at all.



**Figure 7.4.** The below-ground mycorrhizal development in various NITREX sites; Gårdsjön (G1/roof and G2), Klosterhede (reference), Ysselsteyn (roof) and Speuld (roof). Samples taken from the surface root mat.

### 7.3 Discussion

The large changes in the below-ground mycorrhizal development from 1990 to 1991 are most probably due to climatic year-to-year variations, and not the nitrogen treatment. Such year-to-year variation is normal for fruitbody production, and is probably reflected also in the mycorrhizal root development. The main genera responsible for the white, external mycorrhiza had a poor fruitbody season all over southern and central Scandinavia in 1991.

The roof catchment also showed a fairly poorly-developed mycorrhiza in 1991, with a productivity comparable with that of the NITREX catchment. This indicates that the nitrogen treatment per September 1991 did not have any significant effect on the mycorrhizal development.

However, the changes in the fruitbody production from 1990/91 to 1992 are more difficult to explain by climate-dependent year-to-year variation, especially since the 1992 data deviate also from the control plot data. Moreover, some of the species showing an increase are typical indicator species for enhanced N-levels/N saturation. In particular *Paxillus involutus* and *Lactarius rufus* seem in general to respond to N-addition by a more or less rapid increase in fruitbody production (cf. eg. fertilization studies such as Ohenoja 1988), and must be regarded

as more or less nitrophilous. Generally, the genus *Lactarius* seems to be more tolerant to high N-inputs than most other genera of mycorrhizal macrofungi.

The very abundant and substantially increasing species *Cantharellus tubaeformis* is not reported as a rapidly increasing species in connection with other N-addition studies, but the species seems in general to be stress tolerant.

In most N-addition/fertilization studies only a few species (such as *Lactarius rufus* and *Paxillus involutus*) show an increase; the large majority of species show a negative response. The most vulnerable species may vary somewhat from study to study, but at the genus level, *Cortinarius* seems to be the most sensitive group. It seems therefore probable that the 1992 decrease in *Cortinarius* productivity (Fig. 7.1) relative to the fairly high production of the reference plot is due to the increased N-levels.

In conclusion, the increased fruitbody production of some nitrophilous mycorrhizal fungi, and (possibly) the decrease in some N-sensitive groups seems to be the first biological response to the N-addition, being apparent 1.5 years after start of treatment.

## **8. VEGETATION**

Per Holm Nygaard, Magne Huse and Arne O. Stuanes

### **8.1. Litterfall**

Disruption of the soil biota through acidification affects the amount and rate of litter decomposition, a process of central importance for the recycling of nutrients through the ecosystem.

Litter is sampled from collectors placed approximately 1 meter above the ground and sheltered from the nitrogen spraying. There are 23 collectors in G2 and 20 in G1 arranged in rows across the catchment parallel to the throughfall collectors (Fig. 2.2). In F1, five collectors are along each slope (east, west) and three are placed randomly in the more intensively studied area in the lower part of the catchment, and an additional 10 at regular intervals on each slope. The samples are bulked according to vegetation and soil type, dried, weighed and sorted ("needles" and "rest"). They are currently analyzed on a monthly basis but if variation is low, the frequency will be reduced to annual analysis.

### **8.2. Vegetation composition**

Community composition can affect the nitrogen cycle through the quality of litterfall: species which grow under high inputs of nitrogen produce labile litter which more easily decomposes than litter from plants grown under nitrogen deficient conditions. Thus, through decomposition, vegetation provides a positive feedback into the cycling of nitrogen (Pastor and Post 1986). Species changes may occur quickly in response to changes in deposition, they may lag the treatments by years (and lag the cessation of the treatments), or it is possible that no changes occur within the span of the experiments.

Vegetation analyses are carried out on 22 permanent 1 m<sup>2</sup> plots spanning the natural moisture gradient. Percent cover is recorded for all species in the plots. Each sample plot is divided into 25 sub-plots (total of 550) in which presence/absence of all species is recorded. The data are analyzed by the technique of detrended correspondence analysis (DCA) (Hill & Gaush 1980; ter Braak 1987).

Every third year the plots will be re-analyzed and photographed, and the dominant species will be chemically analyzed for major elements including nitrogen reductase activity and arginine content (Ogner et al. 1991).

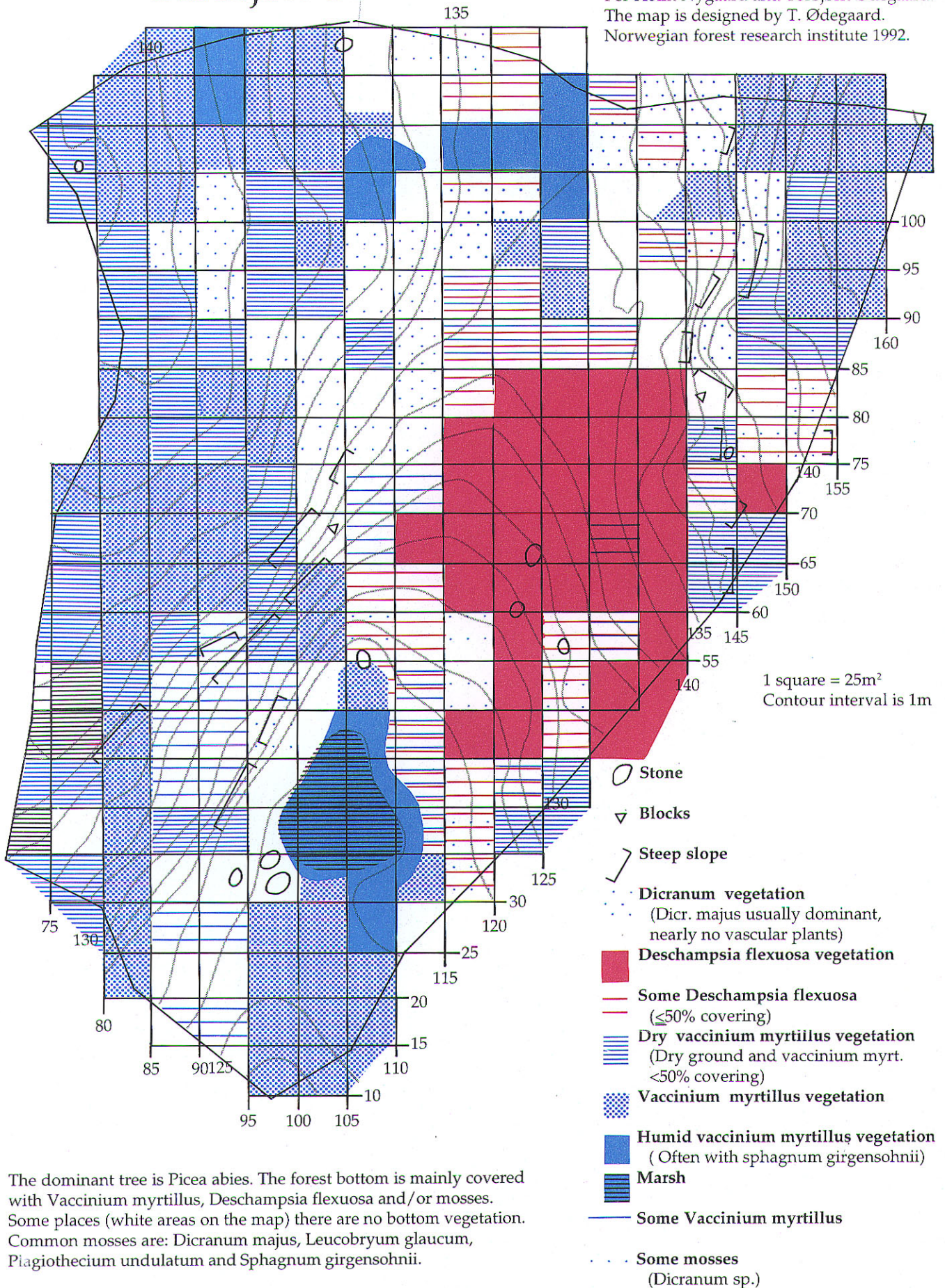
### 8.3. Vegetation map

In 1992 vegetation maps have been made for both G1 and G2 catchments at Gårdsjön (Figures 8.1 and 8.2). For every square (25m<sup>2</sup>) all the species have been recorded. The maps are based on the dominant species and the moisture condition in each square. The vegetation was subjectively classified into 6 types reflecting the main floristic and ecological variation in the catchment.

Vegetation type	Comments
1. <i>Cladonia (Cladina)</i>	Small patches dominated by lichens on drier locations
2. <i>Calluna vulgaris</i>	Drier rocky sites dominated by <i>Calluna vulgaris</i> .
3. <i>Dicranum</i>	Dry sites dominated by <i>Dicranum majus</i>
4. Dry <i>Vaccinium myrtillus</i>	Dry sites with <i>Vaccinium myrtillus</i>
5. <i>V. myrtillus</i>	Mesic sites dominated by <i>V. myrtillus</i> .
6. Humid <i>V. myrtillus</i>	Moist sites dominated by <i>V. myrtillus</i> and <i>Sphagnum girgensohni</i>

# Gårdsjön G1

The vegetation studies are done by Per Holm Nygaard and Torbjørn Ødegaard. The map is designed by T. Ødegaard. Norwegian forest research institute 1992.

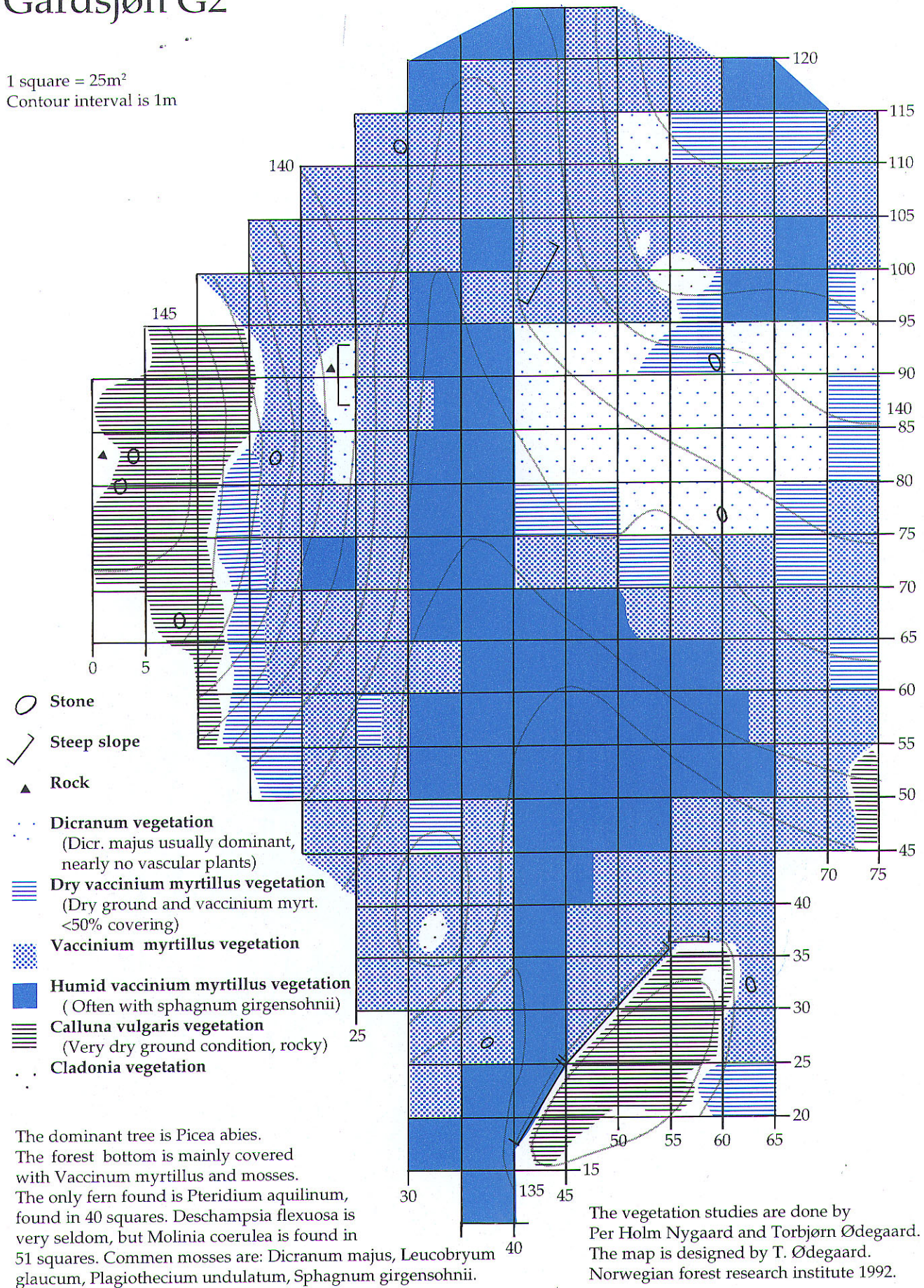


The dominant tree is *Picea abies*. The forest bottom is mainly covered with *Vaccinium myrtillus*, *Deschampsia flexuosa* and/or mosses. Some places (white areas on the map) there are no bottom vegetation. Common mosses are: *Dicranum majus*, *Leucobryum glaucum*, *Plagiothecium undulatum* and *Sphagnum girgensohnii*.

**Figure 8.1** Vegetation map of G1 catchment at Gårdsjön

# Gårdsjön G2

1 square = 25m<sup>2</sup>  
Contour interval is 1m



**Figure 8.2** Vegetation map of G2 catchment at Gårdsjön

#### 8.4. Trees

Overall health and growth of trees is monitored regularly. Trees are assigned into damage classes based on needle yellowing and crown density, and changes in the proportion of these classes over the course of the treatment are followed. This information on the resilience of the vegetation to pollution stress will be used to test forest decline and critical load models.

For calculating above-ground standing biomass, height and diameter at breast height (dbh) of all trees were measured in 1990 in G1 and G2 catchments and will be re-measured at the end of the experiment. Six Norway spruce in F1 were also measured. Standard forest decline parameters such as crown density and color were measured first in 1990 for 100 trees each in G1 and G2, and 10 trees in F1, and has been re-assessed every autumn.

The mean crown density of all monitored trees in 1990 in G1, G2, and F1 was 76%, 73%, and 83%, respectively. Only small changes were observed in the 1991 assessment (74%, 75%, and 70%, respectively). In G1 and F1 a slight decrease in crown density was observed. Also the discoloration increased slightly in foliage in these 2 catchments.

Foliage is collected once a year in the autumn from the 7th and 15th whorl from the top of the tree. The needles from each branch are sorted by age (current-year, previous-year, and remainder) and analyzed for total elements by simultaneous ICP technique (Ogner et al. 1991). Six spruce from each of the three soil moisture regimes in G2 and G1 are sampled together with six from one vegetation type (Vaccinium) in the more intensively-studied area of F1. Additionally, six pines were also sampled in G2 in 1991. Needles were collected in March 1990 and October 1991, and will be collected annually in October.

The first needle samples were taken in the spring of 1990 followed by a new sampling in the fall of 1991. There were no striking differences between these two samplings (Table 8.1). Very small changes were found for most of the nutrients. It was even a tendency to lower nitrogen values in the needles in the NITREX catchment (G2) in 1991. This decrease was larger for the G1 catchment. Taking the variation into consideration, the changes are small. The clearest differences were seen for calcium. For the current year needles the content in 1991 was about half of that in 1990. It is not clear if these differences are real or an effect of different sampling times within the year.

Table 8.1. Needle content in spring 1990 (S90) and fall 1991 (F91). Figures are means for all sampled trees in the different catchments.

		N	S	P	K	Mg	Ca	Zn
		----- mmol/kg -----					----- μmol/kg -----	
G1 Curr. yr.								
7th whorl	S90	1023	32	47	175	43	110	662
	F91	907	32	48	199	41	53	499
15th whorl	S90	934	30	44	161	49	110	728
	F91	889	31	47	206	42	58	535
G1 Prev. yr.								
7th whorl	S90	963	32	47	153	46	114	613
	F91	781	28	33	135	35	93	463
15th whorl	S90	887	31	41	146	48	123	722
	F91	792	28	35	143	40	107	540
G2 Curr. yr.								
7th whorl	S90	933	31	45	173	45	107	680
	F91	881	31	48	196	41	51	632
15th whorl	S90	842	29	40	154	50	117	784
	F91	849	30	44	199	43	61	662
G2 Prev. yr.								
7th whorl	S90	885	30	44	150	50	119	689
	F91	763	28	33	140	36	89	607
15th whorl	S90	815	28	37	149	50	123	806
	F91	770	27	32	140	41	111	714
F1 Curr. yr.								
7th whorl	S90	947	33	44	163	44	123	685
	F91	972	35	47	199	50	66	746
15th whorl	S90	855	29	36	131	51	147	807
	F91	966	34	44	203	49	74	720
F1 Prev. yr.								
7th whorl	S90	960	36	46	132	58	140	643
	F91	899	32	34	144	45	124	672
15th whorl	S90	839	29	35	130	50	152	775
	F91	897	30	32	144	49	144	690

## 9. <sup>15</sup>N TRACER STUDY

O. Janne Kjølne

The main objectives of the NITREX project are to measure the threshold for nitrogen saturation and nitrogen saturation reversibility. The large pools of nitrogen already present in the vegetation and forest floor makes changes due to experimental treatments difficult to detect. The use of the stable isotope <sup>15</sup>N is being used by many of the NITREX sites to overcome this problem (Kjølne et al. in press).



To enable the fate of one year's input to be followed, the  $^{15}\text{N}$  is to be applied over one full year. The path of  $^{15}\text{N}$  is followed into tree, soil and leachate, by sampling of the following pools: precipitation, throughfall, runoff, mineral soil, soil water, forest floor, litter roots needles, branches, ground vegetation, and the N fertilizer.

Application began in April 1992 and will end in April 1993. Nitrogen is added at an enrichment of 1500 ‰  $^{15}\text{N}$ .

## 10. DISCUSSION

The increased loss of nitrate during the winter months clearly indicates the onset of nitrogen saturation (defined as increased leaching; Aber *et al.* 1989). The nitrate lost from G2 is still only a tiny fraction of the input.  $^{15}\text{N}$  tracers are currently beginning applied to identify where the nitrogen is partitioned in the ecosystem.

Nitrogen saturation at forested ecosystems apparently proceeds in several stages (Stoddard, in press). Undisturbed systems generally only exhibit significant concentrations of nitrate in runoff in association with snowmelt. The first stage is manifested by significant nitrate export during the winter months, when the vegetation is dormant. Streams draining forested catchments at Hubbard Brook Experimental Forest, New Hampshire, USA, are apparently at this stage (Likens *et al.*, 1977). We have induced this first stage at Gårdsjön during the first year of nitrogen addition.

The second stage of nitrogen saturation is manifested by significant loss of nitrate also during the summer months, when the vegetation is active. This stage of nitrogen saturation was induced after 3 years of ammonium sulphate addition at  $25 \text{ kg N ha}^{-1} \text{ yr}^{-1}$  to a 30-ha forested catchment at Bear Brook, Maine, USA (Kahl *et al.*, in press).

Sulphur and nitrogen deposition at Gårdsjön is intermediate between areas in central Europe, where forest decline and increasing nitrate loss is common; and the pristine forests of northern Scandinavia. Our experiments indicate that the forests at Gårdsjön are apparently "poised" at or near the threshold for nitrogen saturation; additional nitrogen inputs lead to response in nitrate loss within one year. With continued treatment, we expect that nitrate losses during winter months will increase from G2, and that eventually the catchment's ability to retain N during the growing season will also be exceeded.

At the nitrogen addition experiment at Gårdsjön nitrate concentrations in runoff have begun to increase already the first winter of treatment. No trace of the added nitrogen to the NITREX catchment could be found in the tree needles or soil water. The mineralization rate was similar in the adjacent catchments G1 and G2. At Gårdsjön as in the Netherlands the vegetation exhibits no response as yet. Also during the first year of N addition neither the root nor mycorrhiza exhibit changes that can be related to treatment. Here the year-to-year variations are large and may mask response to treatment.

Overall the major trend seems to be that the output of nitrate at the various sites responds rapidly to changes in inputs, especially when the change moves the site across the "threshold" of 10-15 kgN/ha/yr. Vegetation, on the other hand, reacts much more slowly. These NITREX

results are compatible with other data from Europe and North America. Regional data from southern Sweden as well as other data from across northern Europe indicate a "threshold" of inorganic nitrogen deposition (throughfall) about 10-15 kgN/ha/yr above which nitrate appears in significant concentrations in the soil solution. The NITREX results fit this general picture.

Gårdsjön can be thought of as lying in time and space in a "transition zone" between the highly impacted acidified forest sites of central and eastern Europe, which have a long history of pollution stress and intensive management dating back for hundreds of years, and the relatively pristine Scandinavian sites which have, until fairly recently, escaped significant impact. By increasing nitrogen inputs at the low-deposition sites, and decreasing them at the high-deposition sites, the NITREX experiments are designed to move all the ecosystems across the "threshold" of nitrogen saturation. Because it lies between the two types, Gårdsjön is a vital link between them; here (as at Klosterhede), nitrogen is both increased and decreased. The clear break between the N-saturated and the N-unsaturated sites supports the hypothesis that nitrogen saturation may be both induced and reversed. The major unknown factor is time -- how fast will Gårdsjön respond to substantially changed nitrogen inputs? The continuing NITREX experiment at Gårdsjön aims to answer this question.

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ISBN 82-577-2271-5