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RESPONSES OF AN OMBROTROPHIC BOG ECOSYSTEM TO AMMONIA OXIDISED ENHANCED DEPOSITION, AND REDUCED N

Lucy Sheppard & Ian Leith et al

CEH Edinburgh

Transitional raised / blanket bog (280 m asl)- Scottish Borders NVC M19
Calluna-Eriophorum

950-1100 mm rainfall y^{-1}.

8.5 -10.5 kg N ha^{-1} y^{-1}

Funded by **GANE**, Defra and CEH

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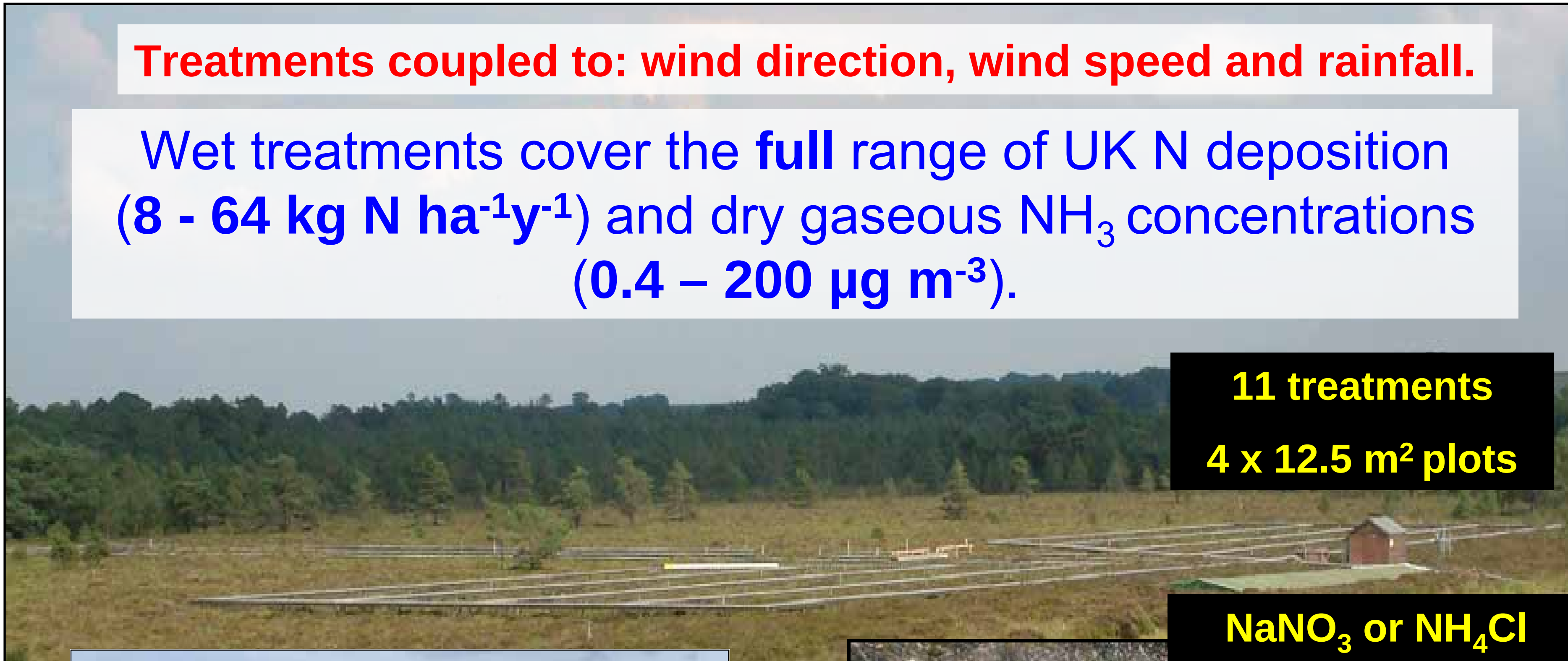
Whim Moss: Automated N manipulation system



Treatments coupled to: wind direction, wind speed and rainfall.

Wet treatments cover the **full** range of UK N deposition (**8 - 64 kg N ha^{-1}y^{-1}**) and dry gaseous NH_3 concentrations (**0.4 – 200 µg m^{-3}**).

11 treatments

4 x 12.5 m^2 plots

NH_3 3-14% y^{-1}

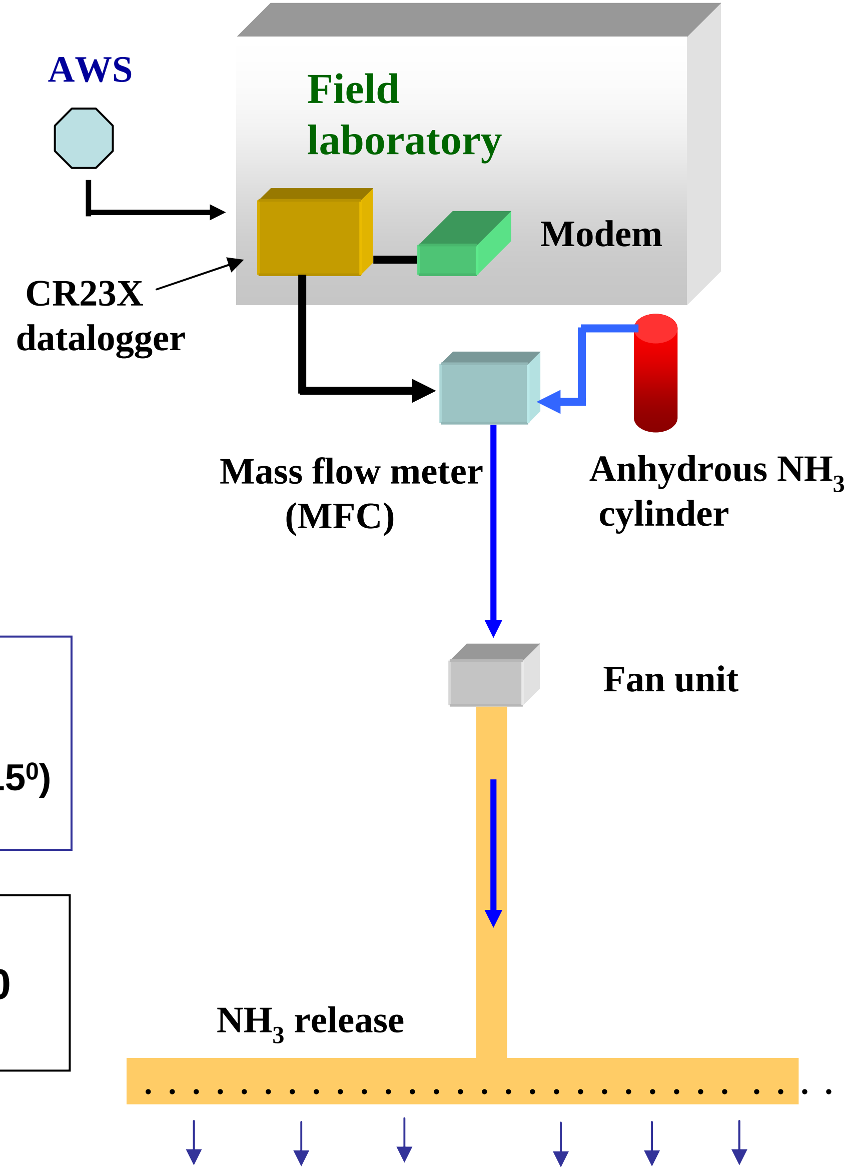
$NaNO_3$ or NH_4Cl

+/- K_2HPO_4

0.57- 4 mM

120 ‘rain’ events y^{-1}

Whim Moss NH_3 Field Fumigation System



AWS

Wind speed (>2.5 m s^{-1})

Wind direction (180^0 – 215^0)

Ammonia release simulating a 100,000 bird poultry unit

Data:

1 minute average:

Wind speed
Wind direction
Mist allowed
MFC output

15 minute average:

Above +
Air temperature
Relative humidity
Net radiation
Rainfall
Soil temperature (10 cm)
Soil temperature (20 cm)
Leaf wetness sensor
Water table depth

WET TREATMENTS

oxidised vs reduced N

Treatment	N form	P & K added	Wet N depn. kg N ha^{-1} y^{-1}	Number of replicate plots
CONTROL		No	8	4
NIT 16	$NaNO_3$	No	Ambient + 8	4
NIT 32	$NaNO_3$	No	Ambient + 24	4
NIT 64	$NaNO_3$	No	Ambient + 56	4
AMM 16	NH_4Cl	No	Ambient + 8	4
AMM 32	NH_4Cl	No	Ambient + 24	4
AMM 64	NH_4Cl	No	Ambient + 56	4
NIT+PK 16	$NaNO_3$	Yes	Ambient + 8	4
NIT+PK 64	$NaNO_3$	Yes	Ambient + 56	4
AMM+PK 16	NH_4Cl	Yes	Ambient + 8	4
AMM+PK 64	NH_4Cl	Yes	Ambient + 56	4

NH_3 Sampling

Samplers at 0.1, 0.5 & 1.0 m above vegetation

- NB Ammonia network monitoring occurs at 1.5 m

Alpha sampler

Timing and duration of NH_3 release recorded

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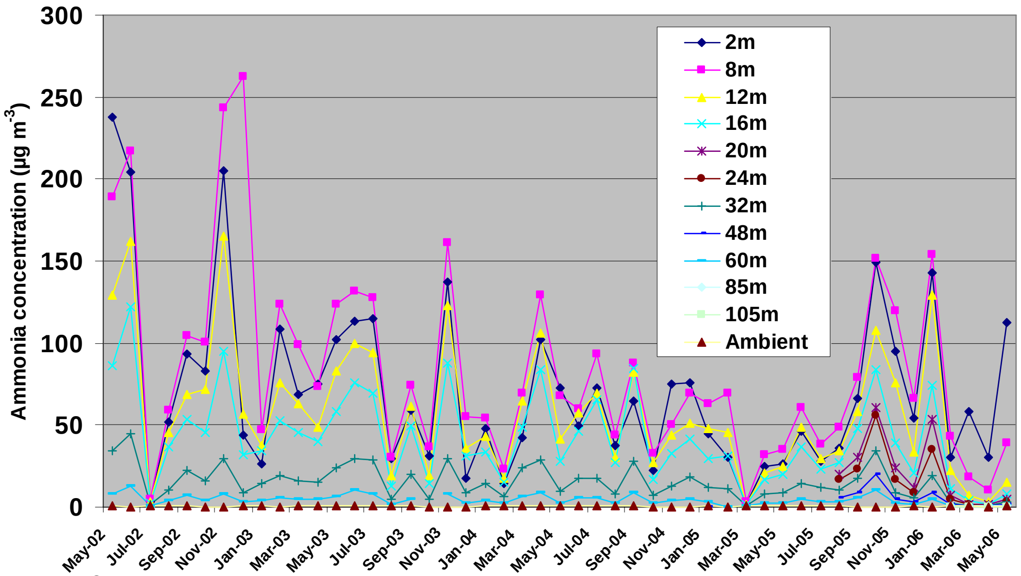
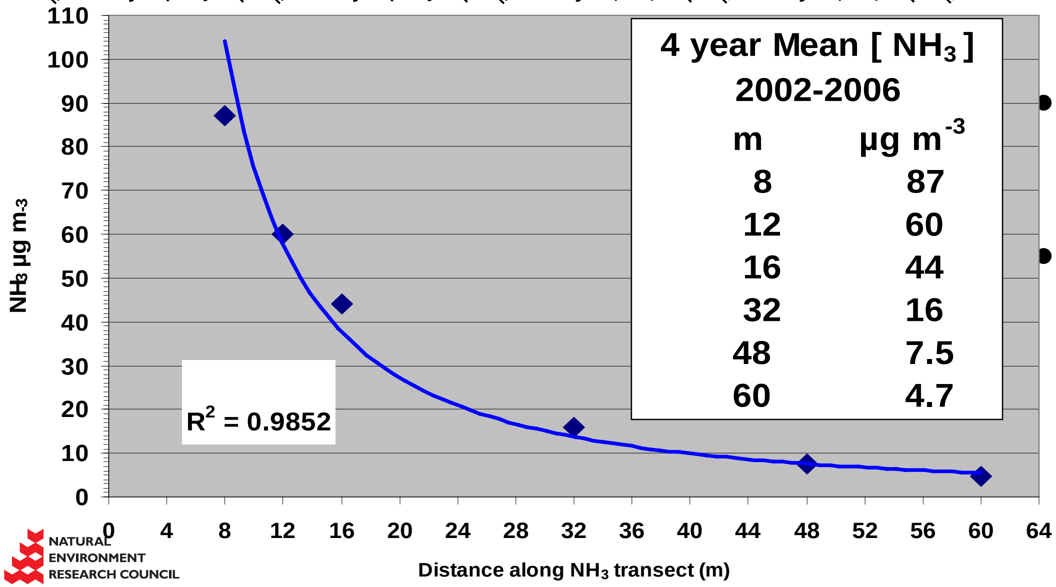
Mean monthly ammonia concentrations at 0.1m since 2002





m	µg m^{-3}
8	87
12	60
16	44
32	16
48	7.5
60	4.7

- Ammonia exposure ranges from **1 – 14 %** of each month.
- Actual [NH_3]'s range from **6 – 1600 µg m^{-3}.**
- Exponential decline in [NH_3] along transect.
- Ambient [NH_3] ~ 0.3 – 0.6 µg m^{-3}.
- Maximum [NH_3] 8m from source.

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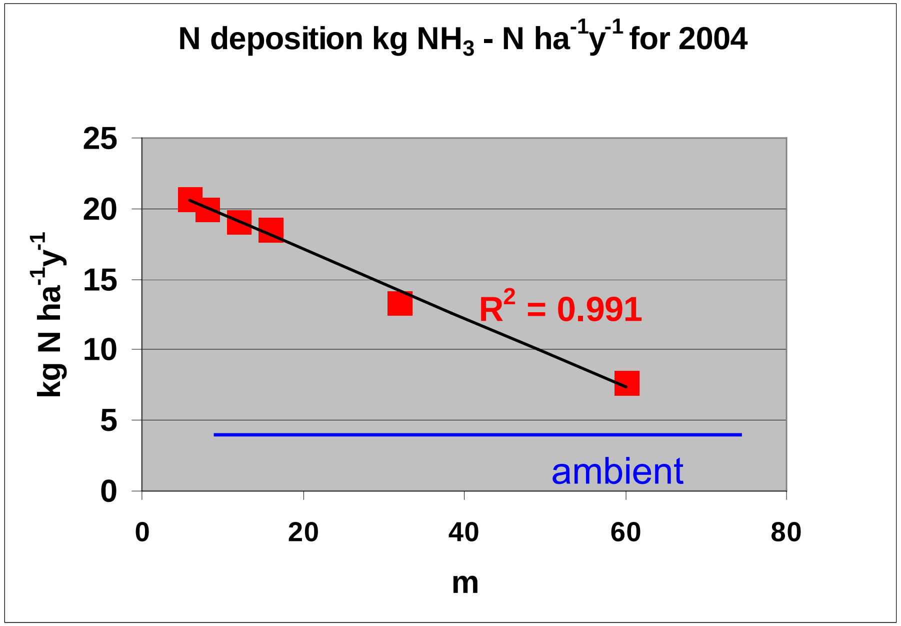
N deposition from released ammonia in 2004 - calculated for a mixed *Calluna* community

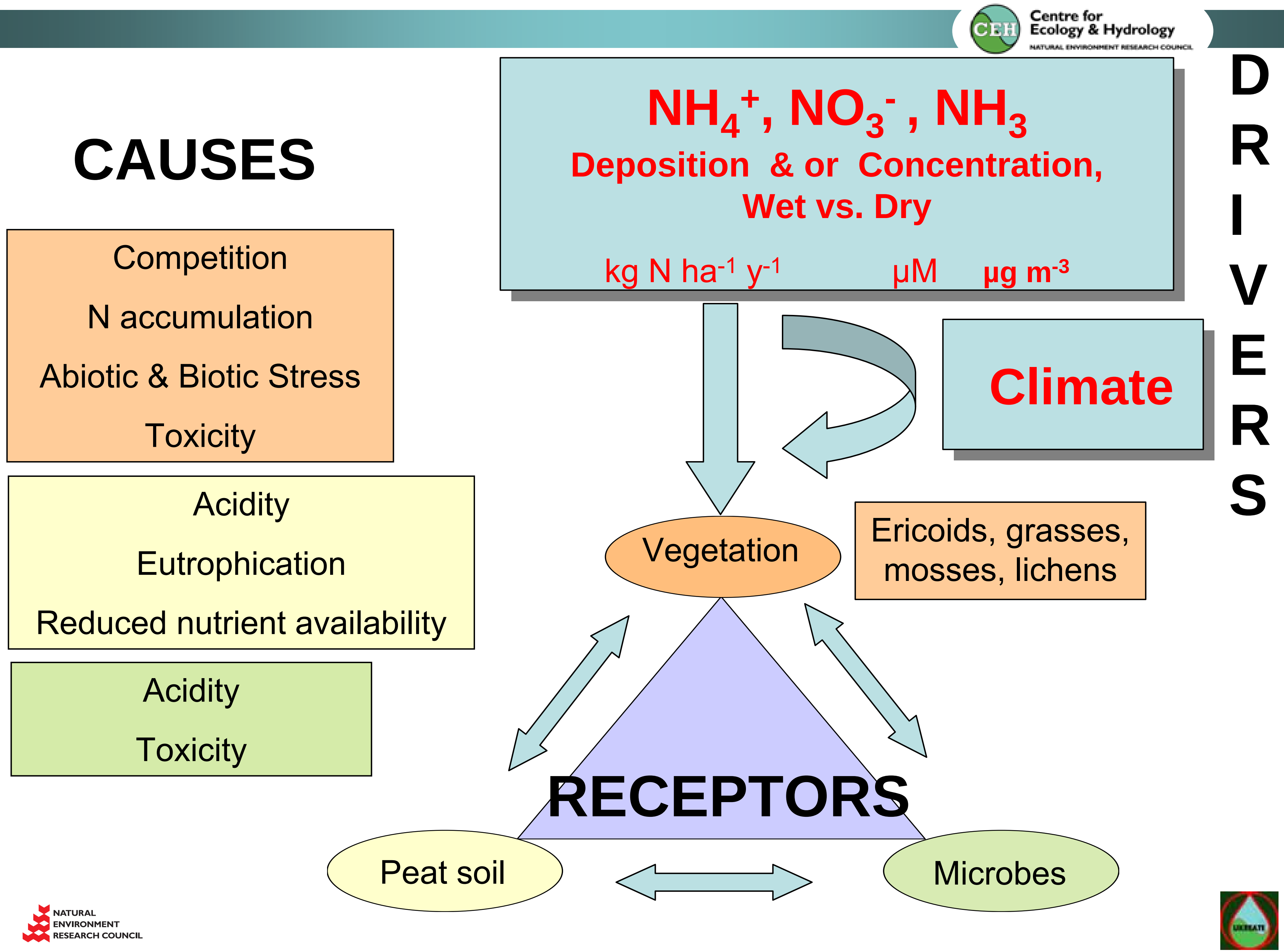


- Calculation based on an R_c for moorland vegetation (Jones 2006), $[NH_3]$ at 0.1m, stomatal opening (day, night) and windspeed.
- R_c varies with species:

  Calluna >>>*Eriophorum*
  > *Cladonia* = *Sphagnum*.
- *Sphagnum* and *Cladonia* are 'sinks' for ammonia and probably receive a lot more N than shown here.
- N deposition is relatively modest, max N dose < 30 kg N ha^{-1} y^{-1} falling 5 kg every 20 m.

AIMS

- Separate the effects of reduced (agricultural sources) versus oxidised (combustion, transport) N.
- Mimic real world treatment scenarios with respect to timing, frequency and concentration.
- Determine if NH_3 is more damaging to an acid organic ecosystem than NH_4^+, for both above and below ground responses.
- Evaluate critical N loads and levels for an ombrotrophic bog ecosystem.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CAUSES
Competition
N accumulation
Abiotic & Biotic Stress
Toxicity
Acidity
Eutrophication
Reduced nutrient availability
Acidity
Toxicity
NH_4^+, NO_3^- , NH_3
Deposition & or Concentration,
Wet vs. Dry
kg N ha^{-1} y^{-1}
μM
μg m^{-3}
Climate
DRIVERS
Vegetation
Ericoids, grasses, mosses, lichens
RECEPTORS
Peat soil
Microbes
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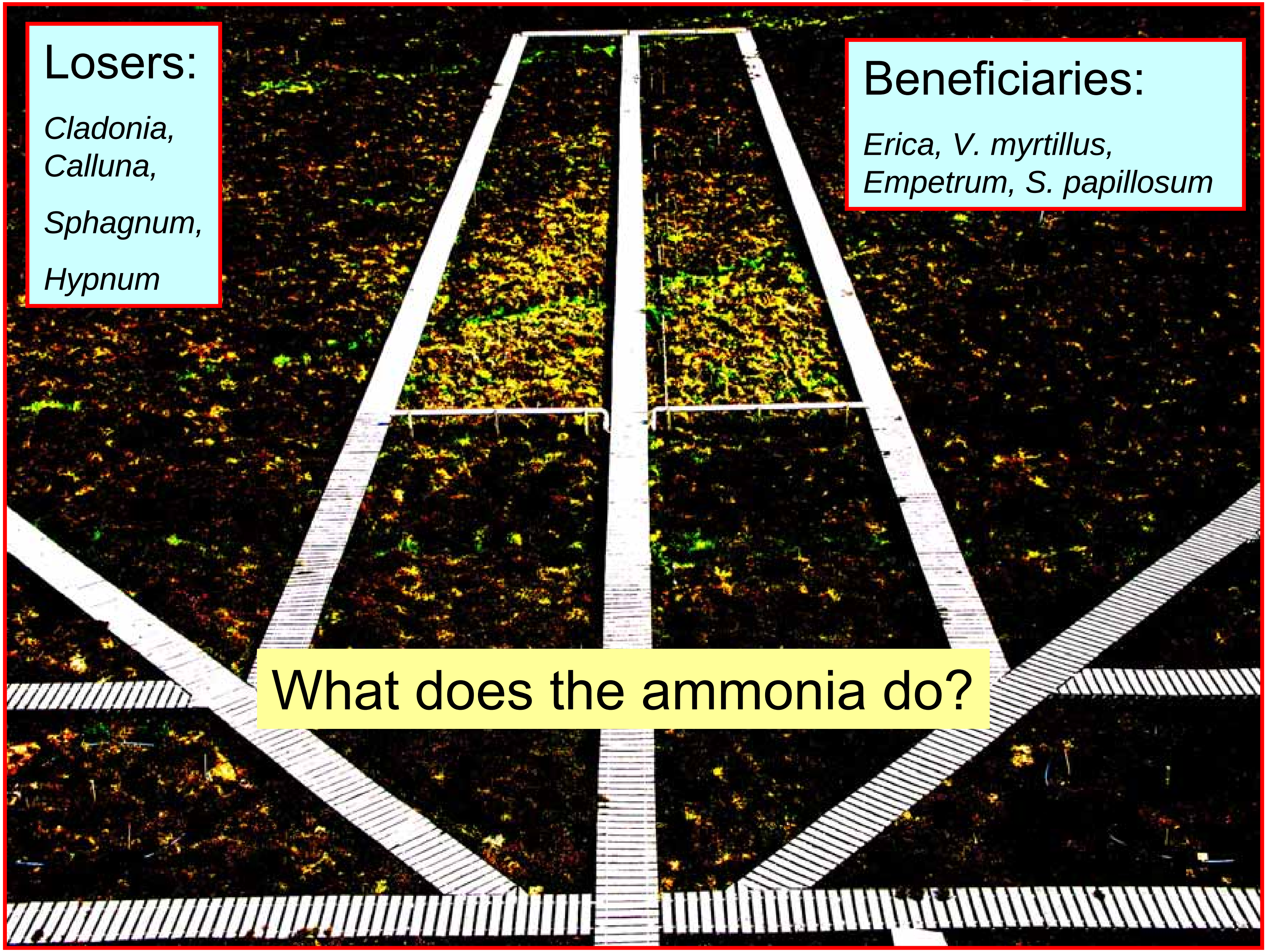


Losers:

Cladonia,
Calluna,

Sphagnum,

Hypnum

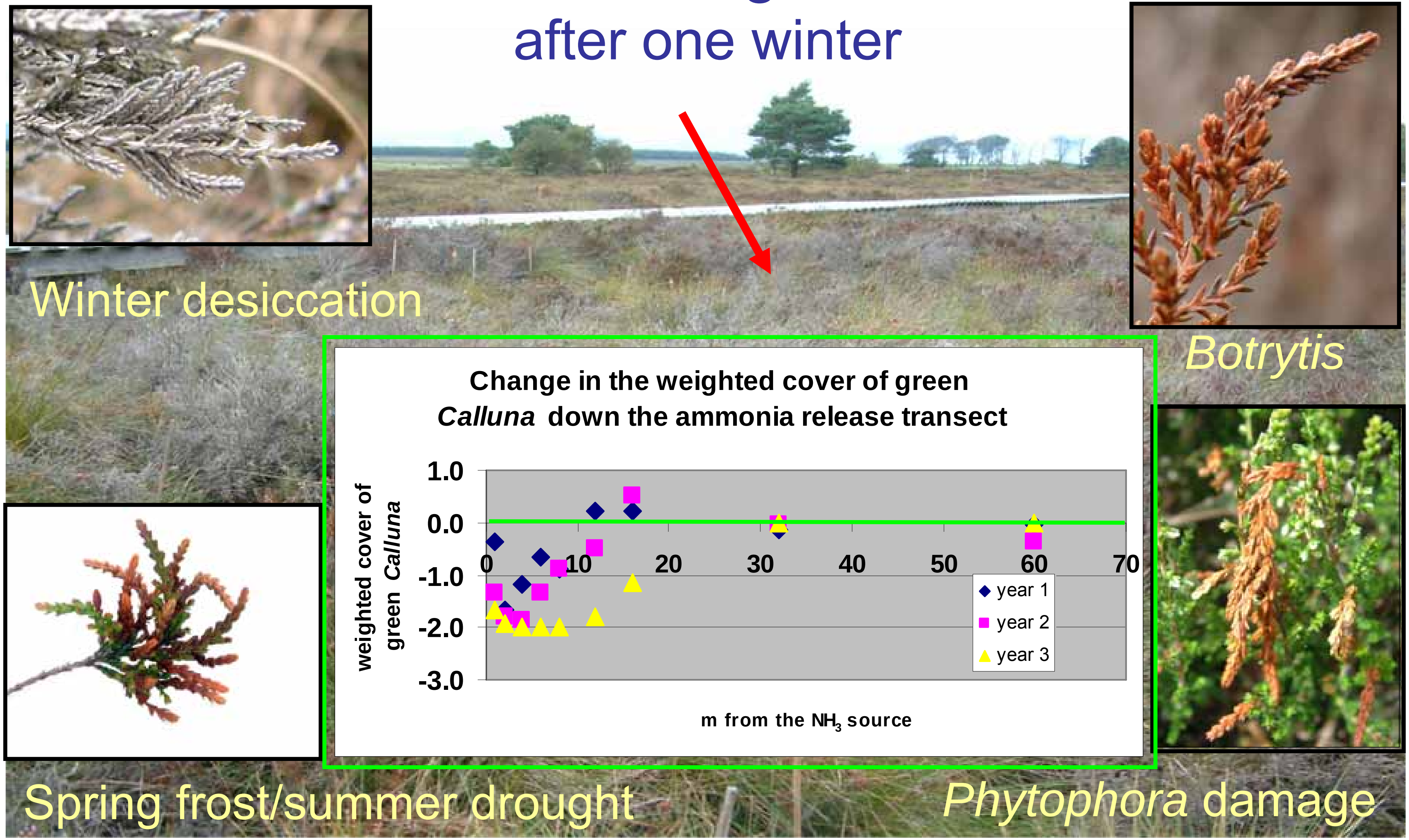
Beneficiaries:

Erica, V. myrtillus,
Empetrum, S. papillosum

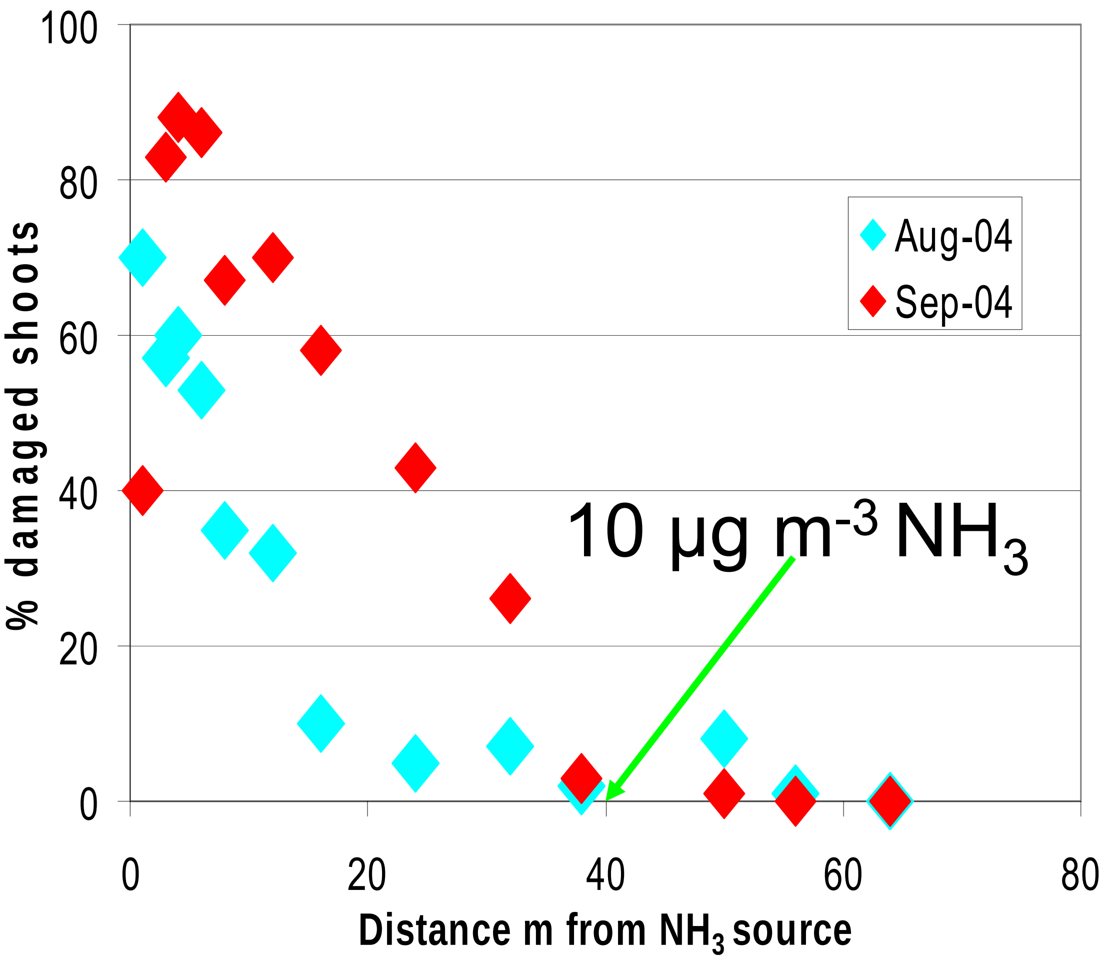
What does the ammonia do?

Ammonia damage to *Calluna*

after one winter



Proportion of damaged young *Calluna* shoots, Autumn 2004



- May be linked to Botrytis fungus
- Not found on wet N plots ★
- Level of damage increased with time
- pH effect on leaf surface?

Cladonia portentosa NH_3 Transect

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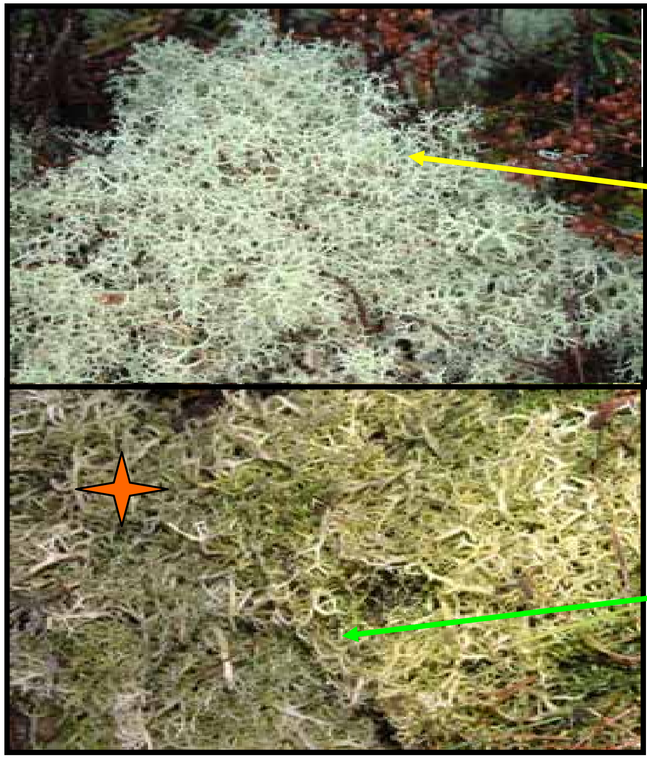
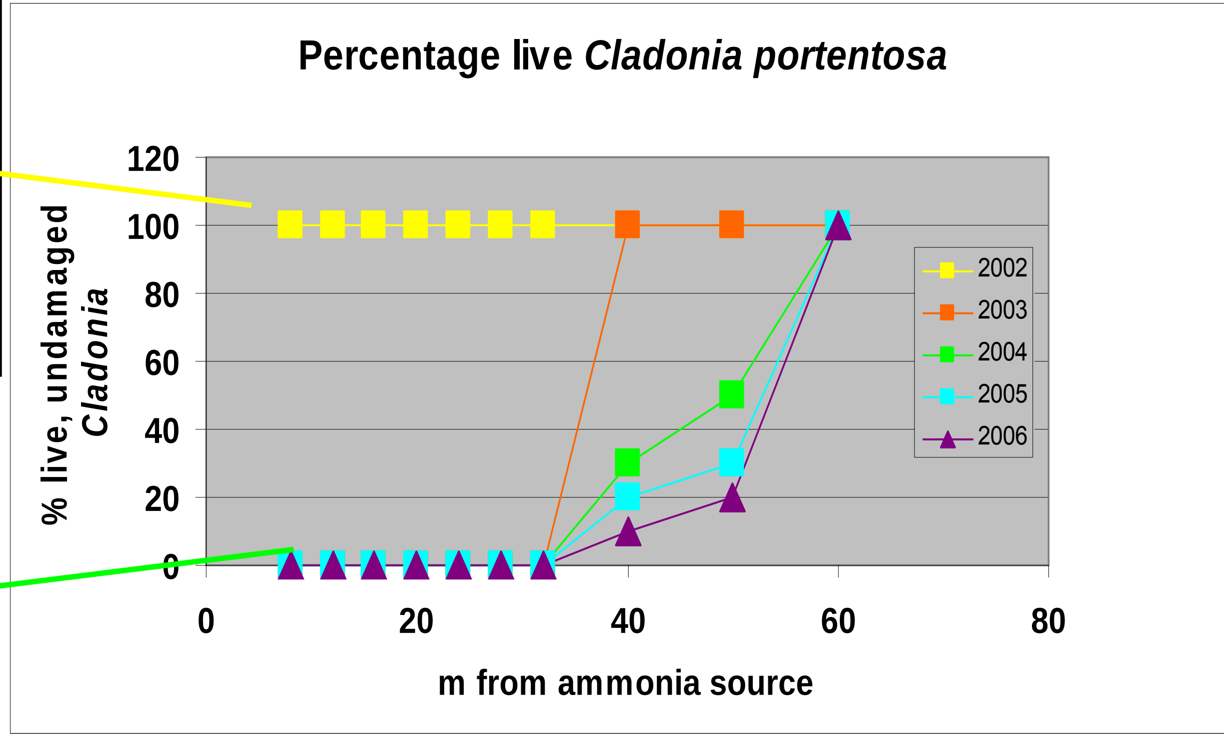
Pre-treatment March 2002

May 2002

November 2002

February 2003

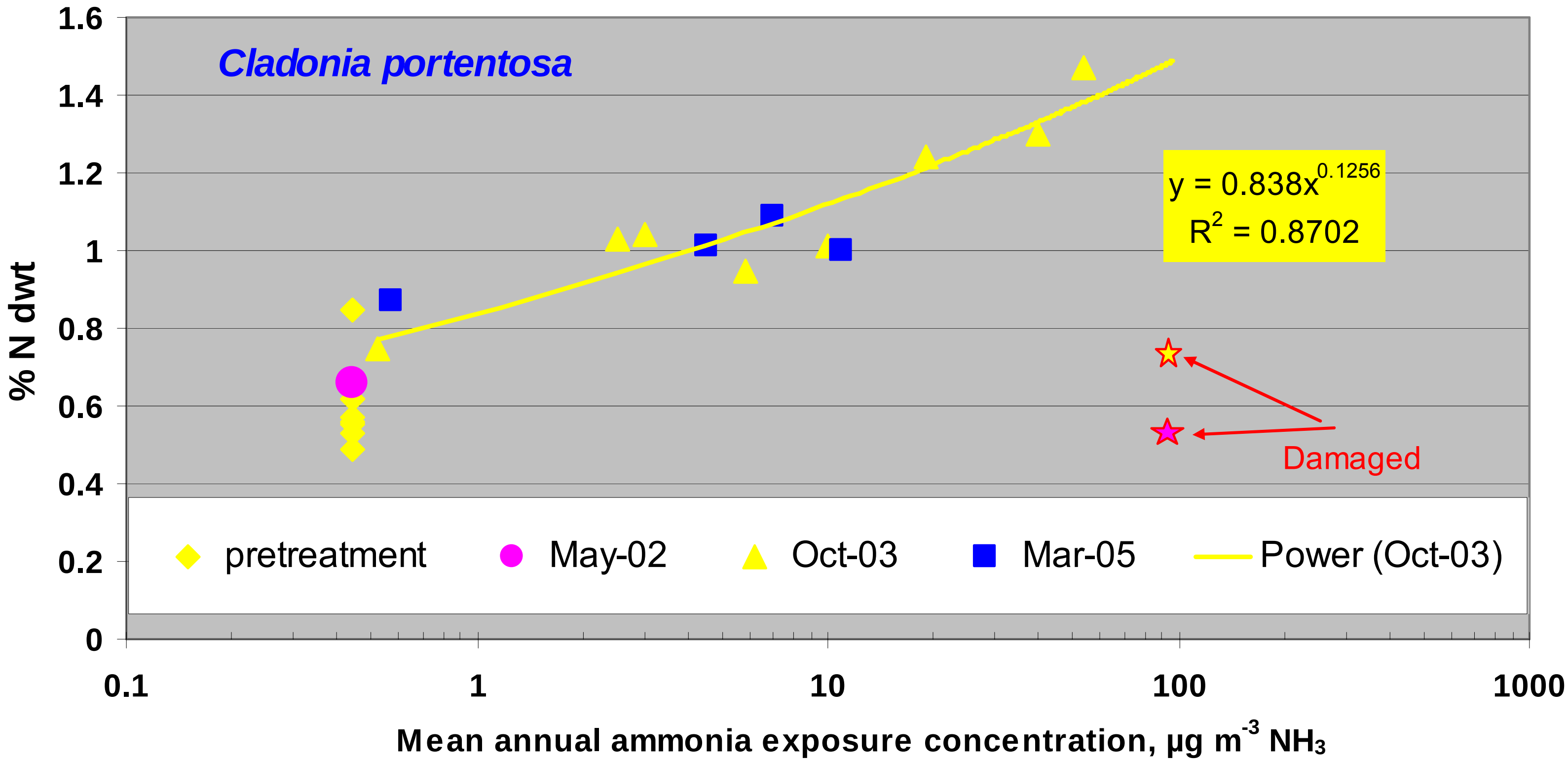




Cladonia portentosa was irreversibly damaged within 3 months at 8m. NH_3 damage includes: destruction of usnic acid – bleaching, reduction in photosystem II efficiency, loss of membrane integrity and K leakage.

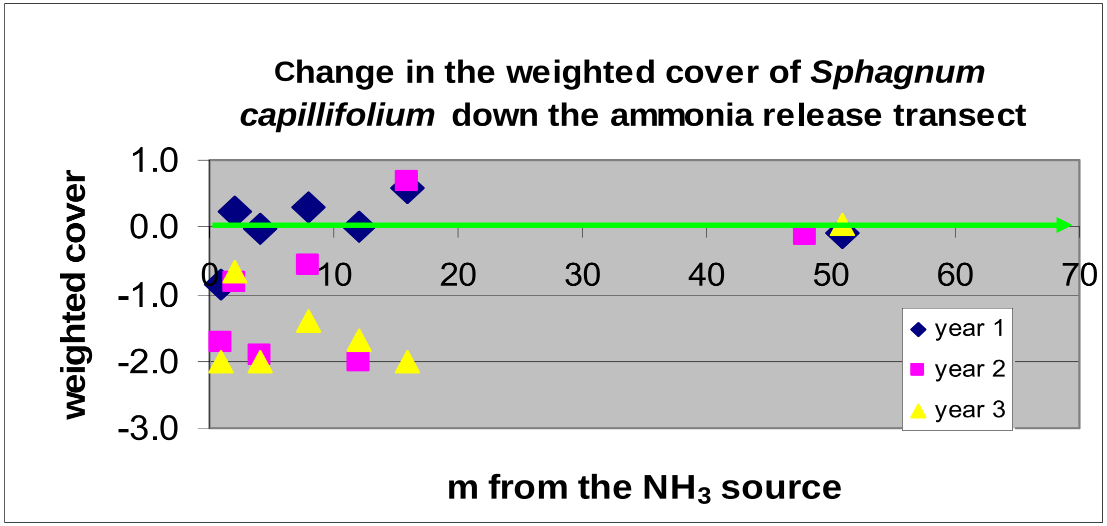
The algal greening and bleaching have also been found in the wet plots, treated with high N, 3 years on.

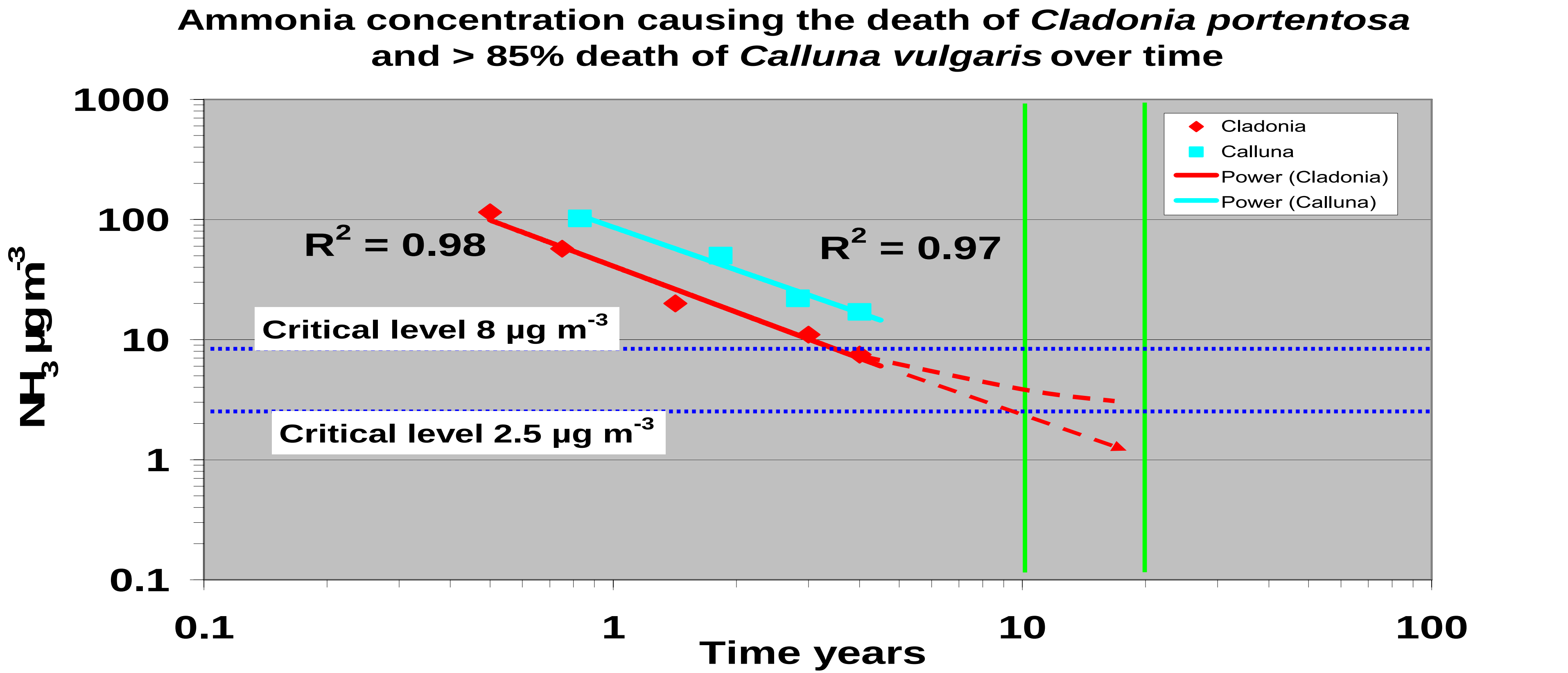
Cladonia portentosa - %N



- October 2003: Lichens barely sorediate, most apices were broken, > 85 % bleached at 16 m, >50 % bleached at 32 m.
- At some point, the damage affects the membranes so that %N values no longer correlate with ammonia concentrations. This may explain the lower % N in 2005. There were no thallii to sample at the higher [NH_3].

Damage to *Sphagnum capillifolium*



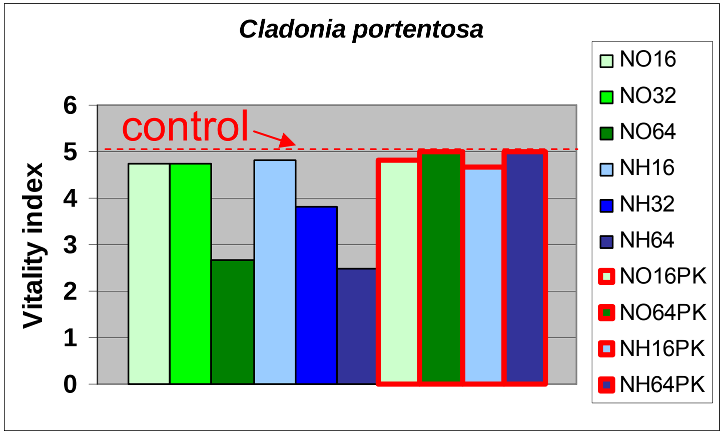


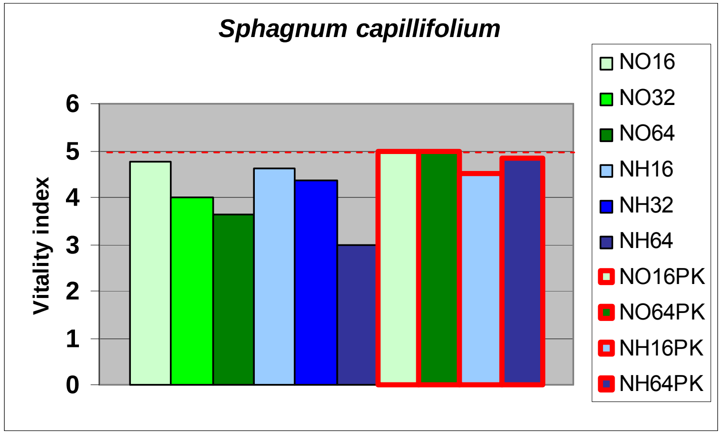
- Threshold [] for ammonia effects decreases with increasing length of exposure.
- Van der Eerden's 1991 annual CL of 8 µgm^{-3} provides inadequate protection for *Cladonia*.

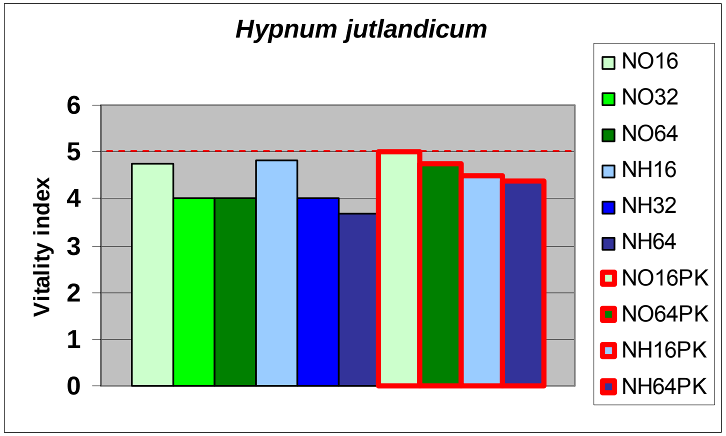
Effects of NH_3

- Effects of NH_3 gas on N sensitive species are more damaging than those of NH_4^+ or NO_3^- in precipitation (for a specified N dose ?). Intermittent high [NH_3], concealed by the long-term average [], are probably responsible.
- Negative effects of NH_3 gas are species specific.
- Critical Levels of NH_3 gas depend on accumulated exposure duration.
- *Hypnum* is recovering and new propagules of *Calluna* are recolonising the transect. Neither *Cladonia* nor *Sphagnum* appear to be recovering.


After 4 years **No** large scale visible damage on the wet N plots, *cf* the ammonia transect







Visible Damage by wet NH_4^+ or NO_3^- to vegetation in wet plots

- No large scale annihilation of vegetation RATHER some patchy damage, represented as a reduction in vitality index. Dose more important than form, reduced N slightly more damaging than oxidised N.
- PK additions mitigate damage.
- *Calluna* is NOT showing damage.
- *Hypnum* was also badly affected by NH_3.
- *Hypnum* is reviving under all N treatments.

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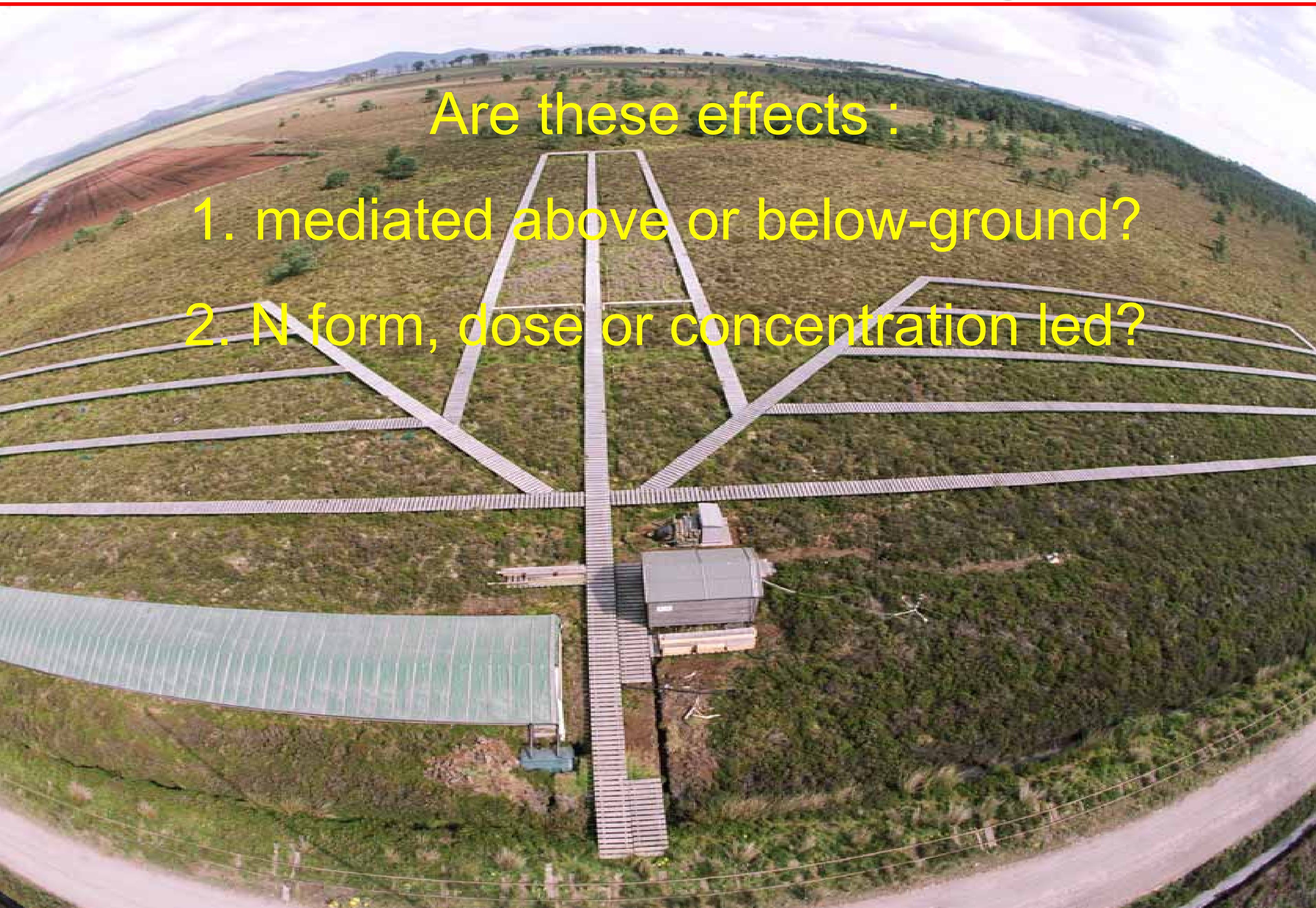
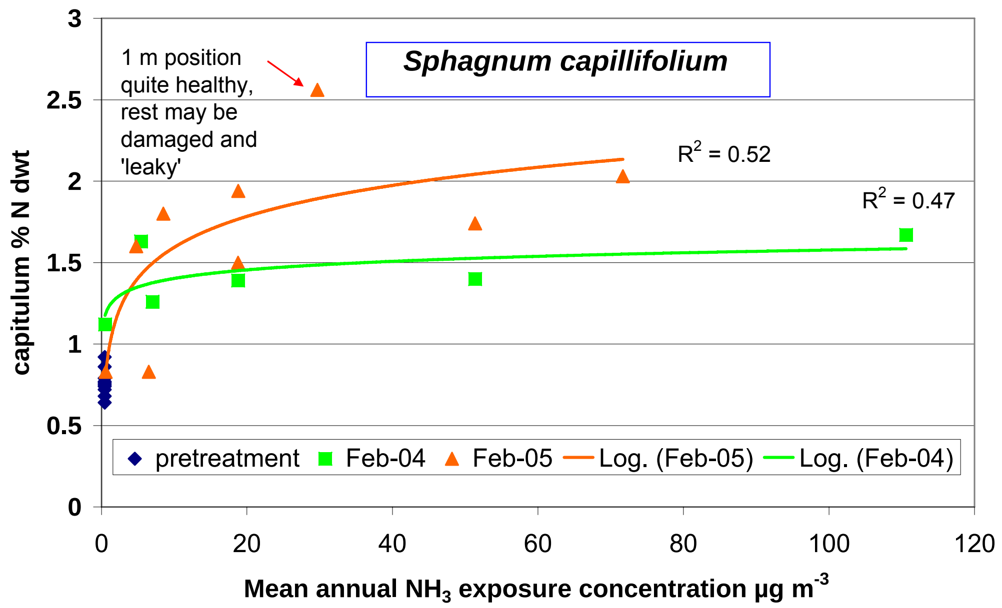
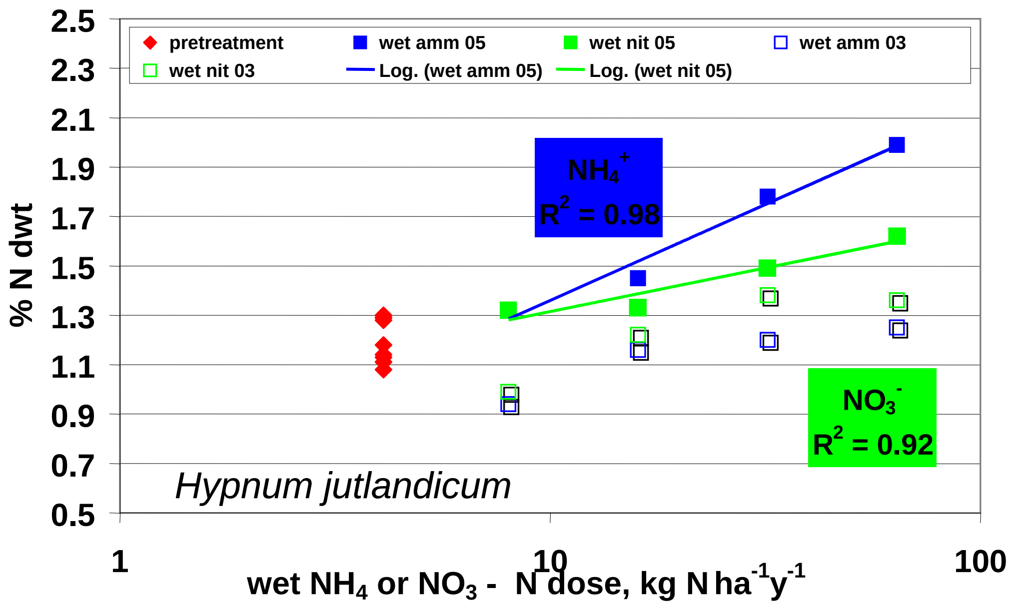
Are these effects :

1. mediated above or below-ground?

2. N form, dose or concentration led?



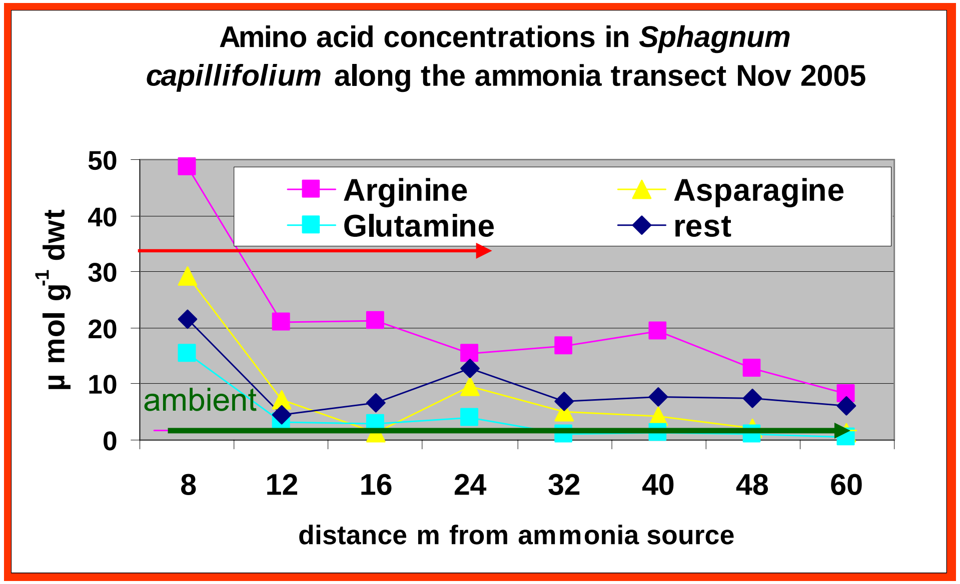


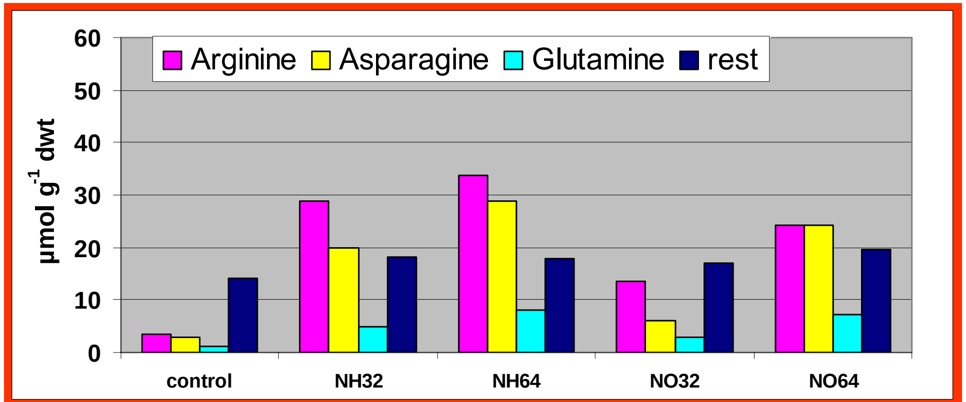


- Both *Sphagnum* and *Hypnum* take up and accumulate N from both dry and wet N.
- If plant material is damaged the foliar N status may not be indicative of N uptake.
- Indication of 'memory effects'.
- *Hypnum* preferentially takes up reduced N.

Amino acids in *Sphagnum capillifolium*, treated since summer 2002 with NH_3, NH_4^+ or NO_3^-

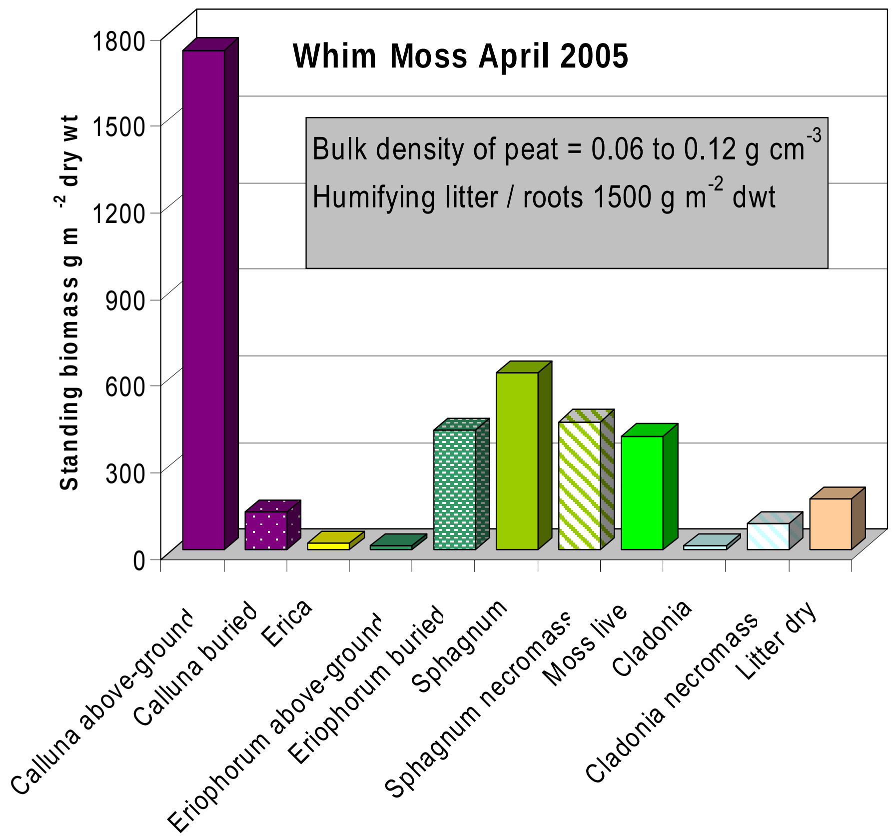
(de Lange & vanZetten unpub)





- All N forms significantly enhanced arginine relative to the control.
- Reduced N caused the greatest enhancement.
- Arginine concentrations were raised all along the NH_3 transect and for wet inputs.
- Wet N inputs significantly increased arginine at >32 kg N ha^{-1} y^{-1}, but the visible damage was restricted.
- In *Calluna* there was no clear N effect on amino acid concentration.

Whim Moss Site Characteristics

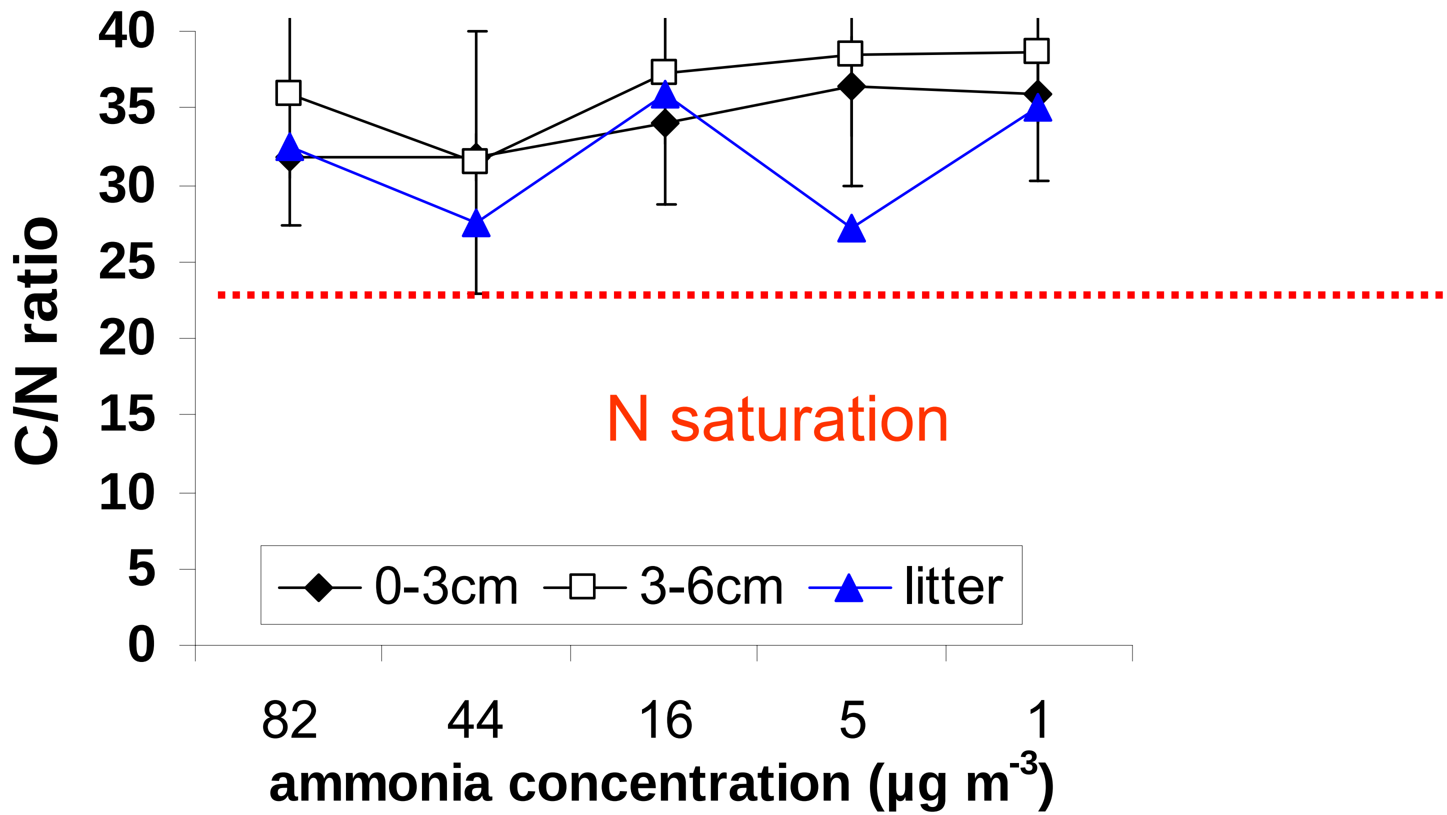


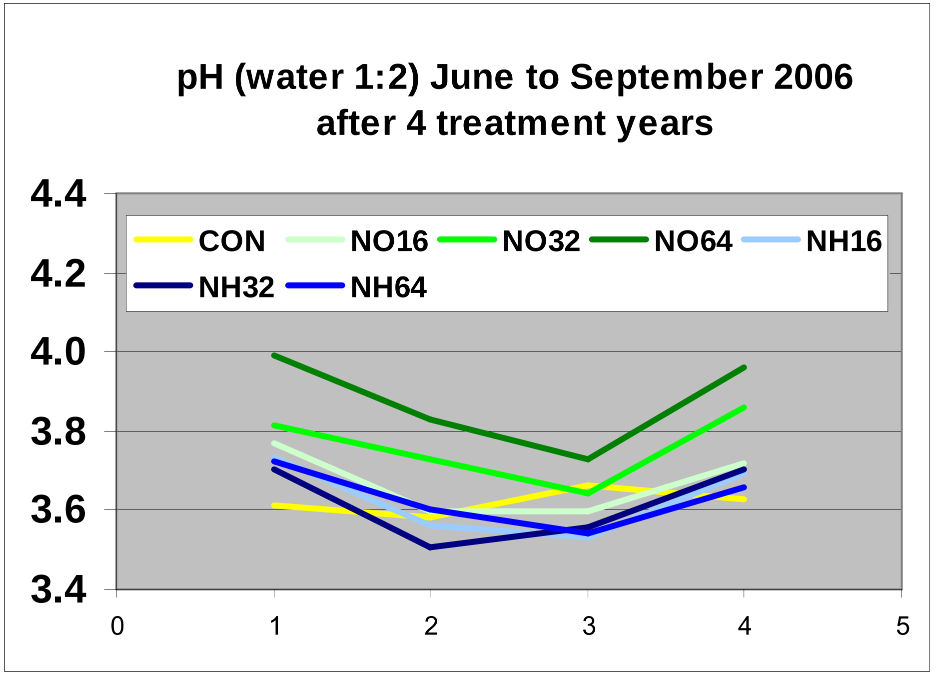
Above-ground biomass 3.5 kg m^2

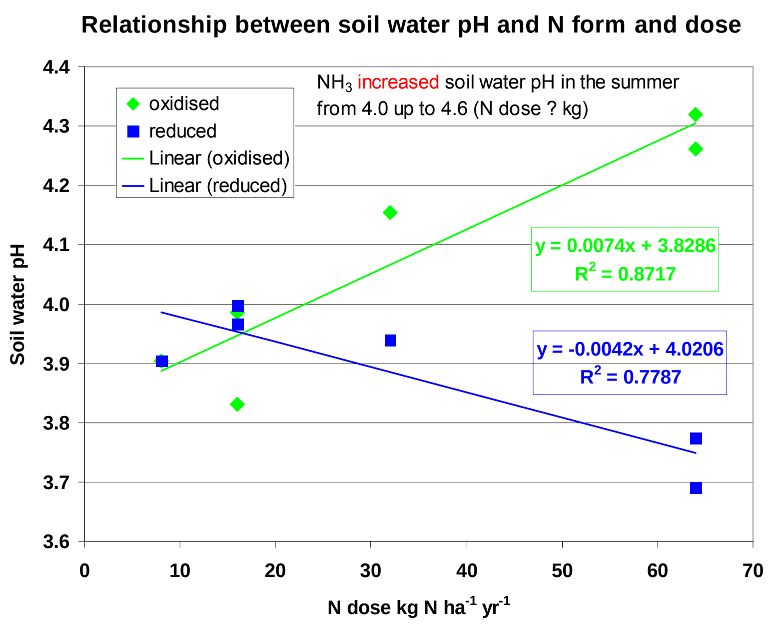
pH (water 1:5)	3.78
pH ($CaCl_2$)	2.89
Exchangeable acidity	1143 meq H kg^{-1}
% Base saturation	10
Al, Fe and Mn	Negligible
Available P	43 mg kg^{-1}
Available K	90 mg kg^{-1}
% C	51.6
% N	1.55
C:N	33.3

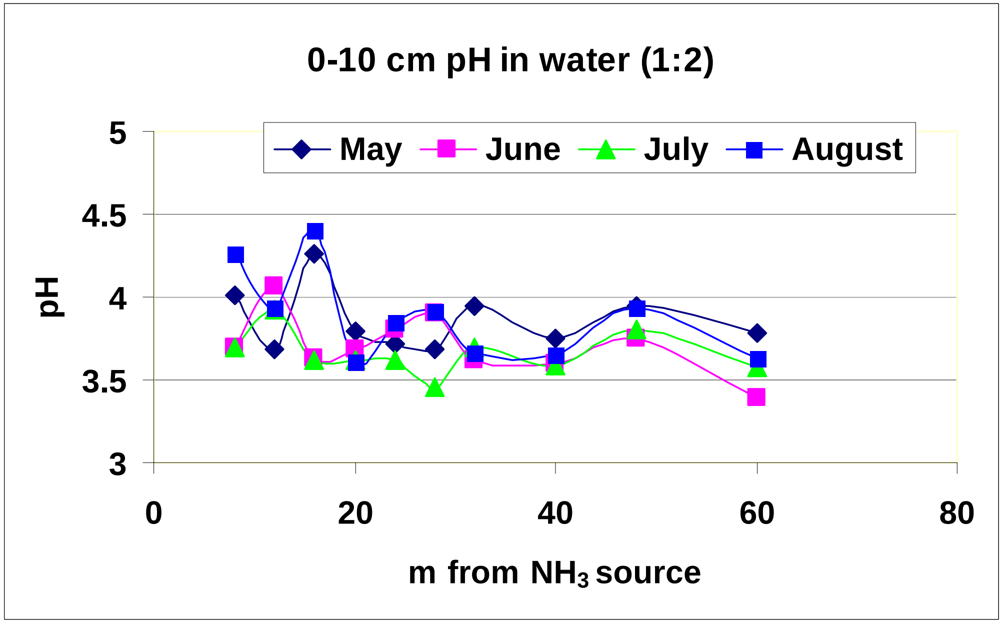
Change in the litter/peat C:N ratios -?

(Prendergast unpub)









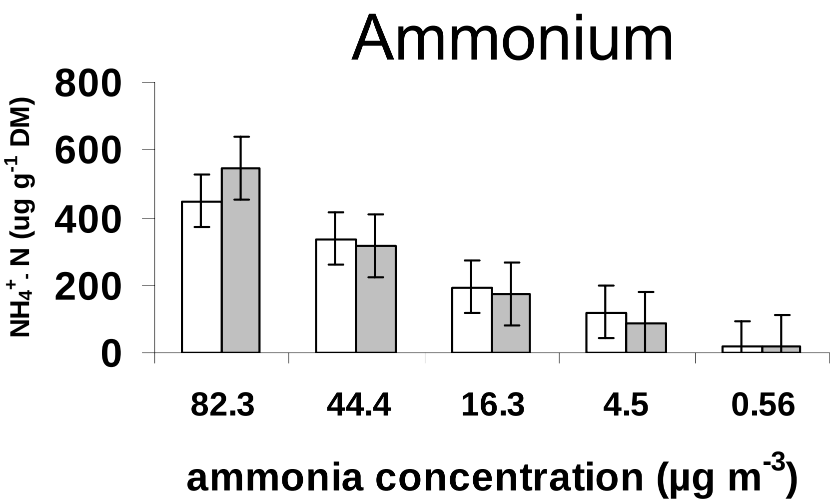
Significant effects on pH:

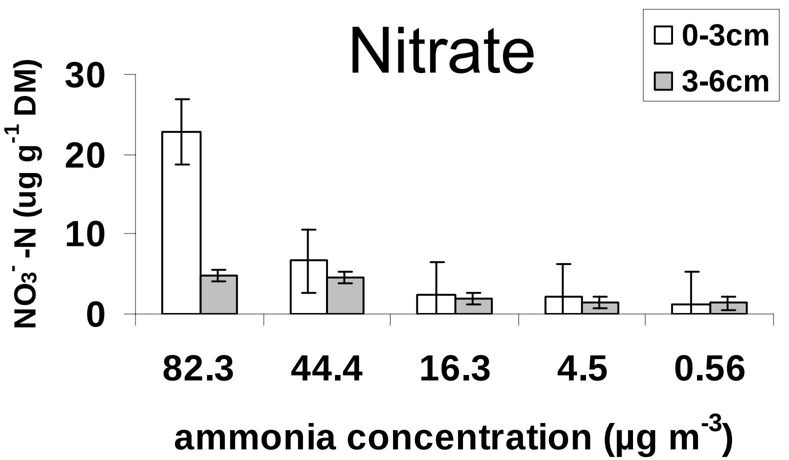
NH_3 increases

NO_3^- increases

NH_4^+ reduces pH

Effect of 3 years of NH_3 exposure on the amount of KCl extractable N (Prendergast unpub)





- KCl extractable NH_4^+ 20 fold higher than NO_3^-
- 90% of the variation explained by [NH_3].
- NO_3^- - N much higher in surface 0-3 cm suggesting some nitrification at the surface, at least in the summer.

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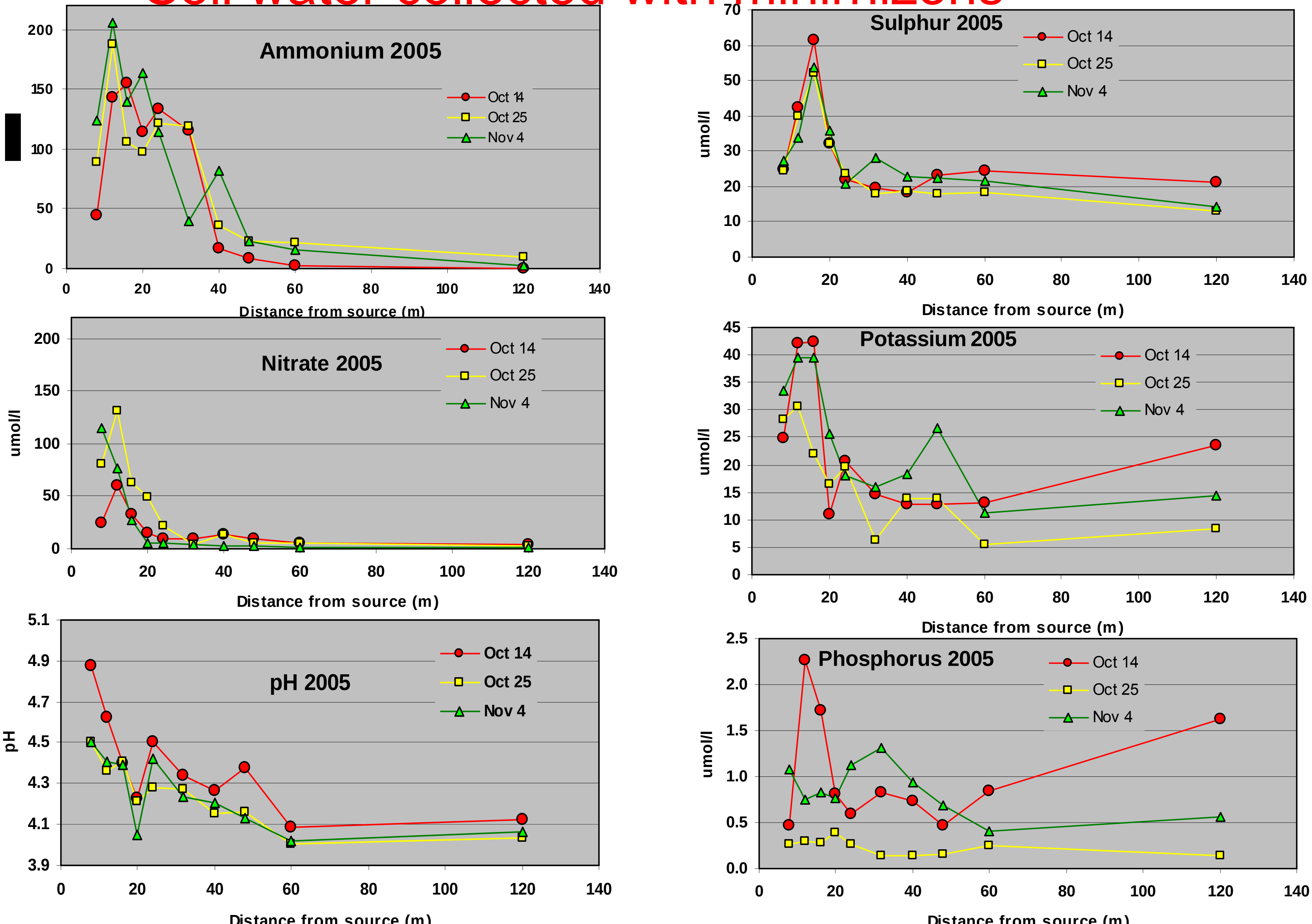
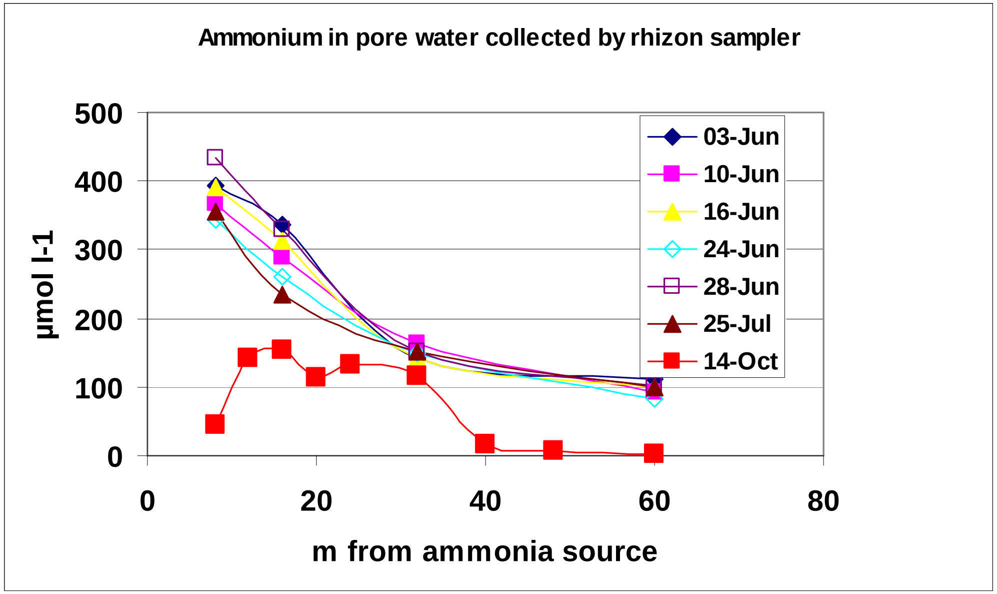
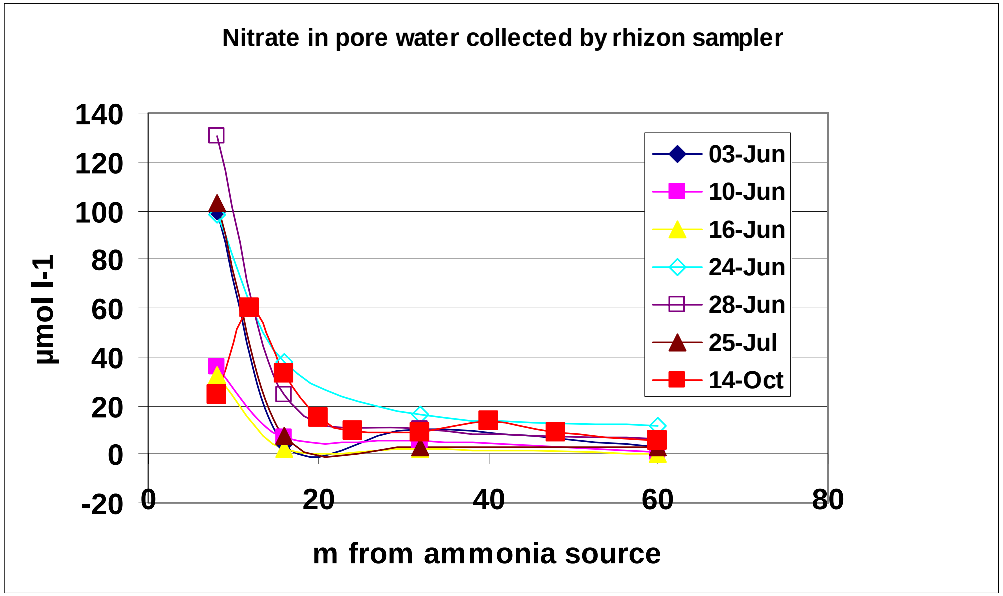
- Soil water collected with minirhizons







Pore water N in response to ammonia

- Large increases in pore water N (3 yrs fumigation).
- Lower [NH_4 – N] in autumn whereas [NO_3^- - N] more similar.
- Exponential decline in both reduced and oxidised N reflect [NH_3] rather than the linear N deposition.
- [NO_3^- - N] near source indicate nitrification in response to higher pH.

N effects on soil chemistry

- The N form has important implications for soil pH and processes that are pH dependent *eg.* nitrification.
- Total soil N (%N) has not yet responded significantly, but so far inputs represent < 10% of the N store.
- Inorganic N - pore water N and KCl extractable N have been significantly increased.
- Exponential decline in both reduced and oxidised N reflect $[NH_3]$ rather than the linear N deposition.

Effects of NH_3

- Effects of NH_3 gas on N sensitive species are more damaging than those of NH_4^+ or NO_3^- in precipitation, for a specified N dose. Intermittent high [NH_3], concealed by the long-term average, are probably responsible.
- Negative effects of NH_3 gas are species specific.
- Critical Levels of NH_3 gas depend on accumulated exposure duration.
- *Hypnum* is recovering and new propagules of *Calluna* are recolonising the transect. Neither *Cladonia* nor *Sphagnum* appear to be recovering.

Reduced vs Oxidised NH_4^+, NO_3^-

- The high frequency, low concentration, N deposition scenario suggests the **accumulated N dose** is the key driver for effects as plant tissues become N enriched. Significant changes in the physiology and biochemistry of the sensitive species were detected within one year of wet treatment at doses of ≥ 32 kg N ha^{-1} y^{-1} **irrespective of N form.**
- Visible effects above-ground were not related to N form.
- Amino acids increased most in response to reduced N**.**
- Species cover has taken longer to respond and damage is patchy.
- *Hypnum* is recovering but not *Cladonia in the wet plots*.