eclaire

Effects of climate change on air pollution impacts and response strategies for European ecosystems

SEVENTH FRAMEWORK PROGRAMME

# C3 Ecological processes and thresholds Overview of activities and key messages, 2015


**Gina Mills*, Lisa Emberson, Elena Paoletti, Chris Evans, Ed Rowe, Viki Bermejo, Sue Owen**

**and many others**

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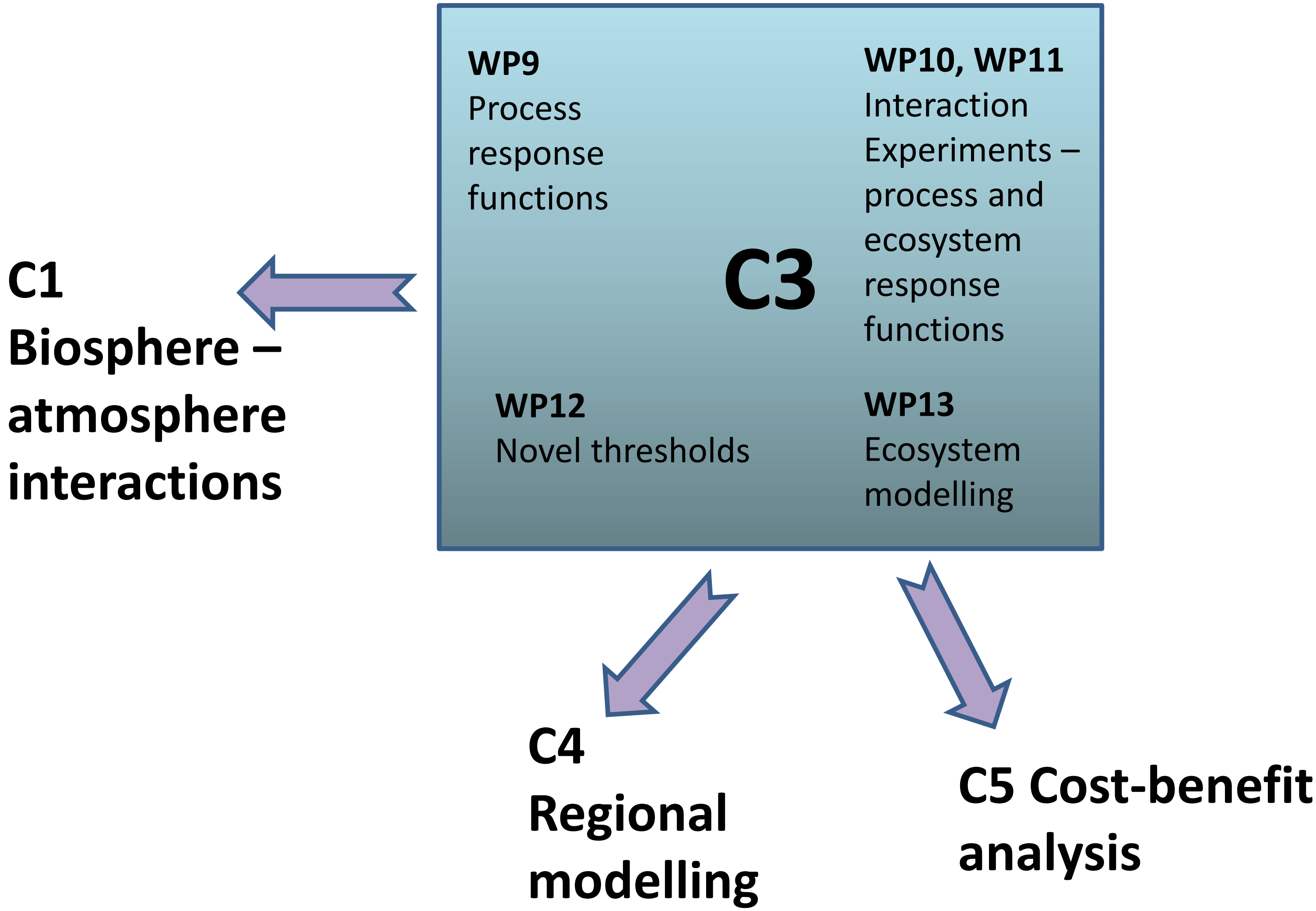
# C3 Overview: Content

- **Introduction – focus on interactions**
- **C3 key messages***
  KM 1 – 4: $O_3$ and N interactions
  KM 5: Aerosols
  KM 6 – 8: Air pollution and climate change interactions
- **Remaining work**

**** themes, exact wording to be discussed at this meeting***


WP9
Process response functions
WP10, WP11
Interaction Experiments – process and ecosystem response functions
C3
WP12
Novel thresholds
WP13
Ecosystem modelling
C1
Biosphere – atmosphere interactions
C4
Regional modelling
C5 Cost-benefit analysis

# Ozone and N interactions

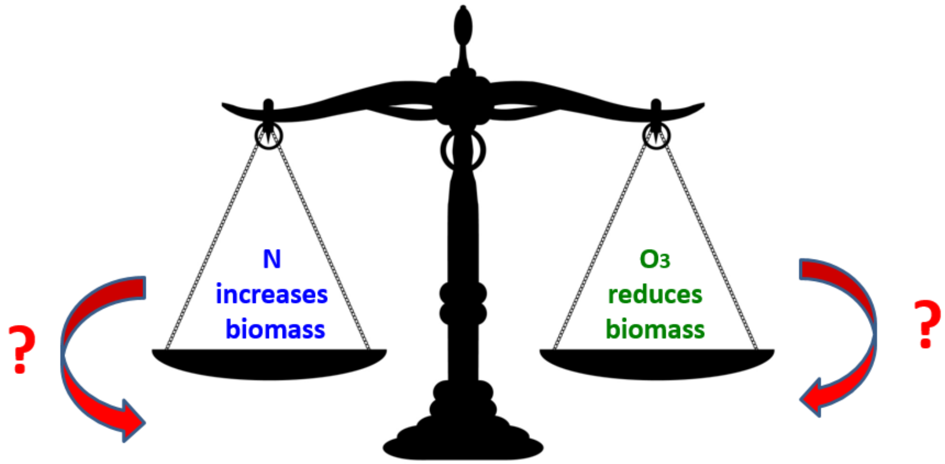
## Typical N deposition effects, confirmed in WPs 9 – 11

- Stimulation of photosynthesis and stomatal conductance
- Stimulation of growth
- Change in biodiversity in favour of grasses

+

## Typical ozone effects, confirmed in WPs 9 - 11

- Decrease in photosynthesis
- Decreased growth, especially roots
- Earlier and enhanced senescence

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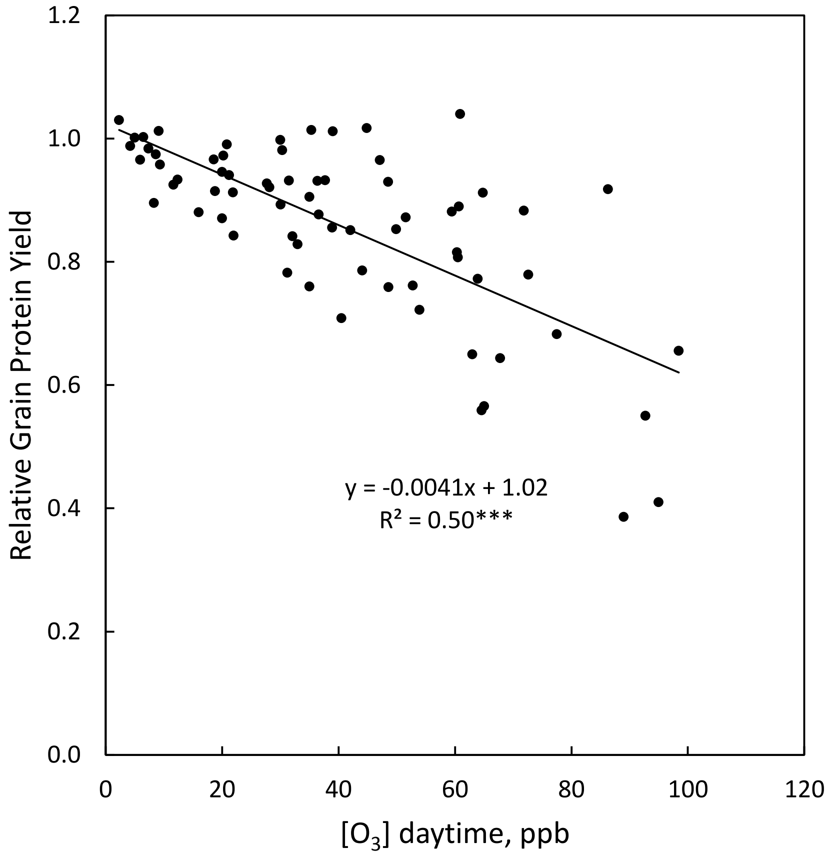
# C3 Key message 1

$O_3$ alters N cycling

# KM1a: Ozone reduces nitrogen use efficiency in crops



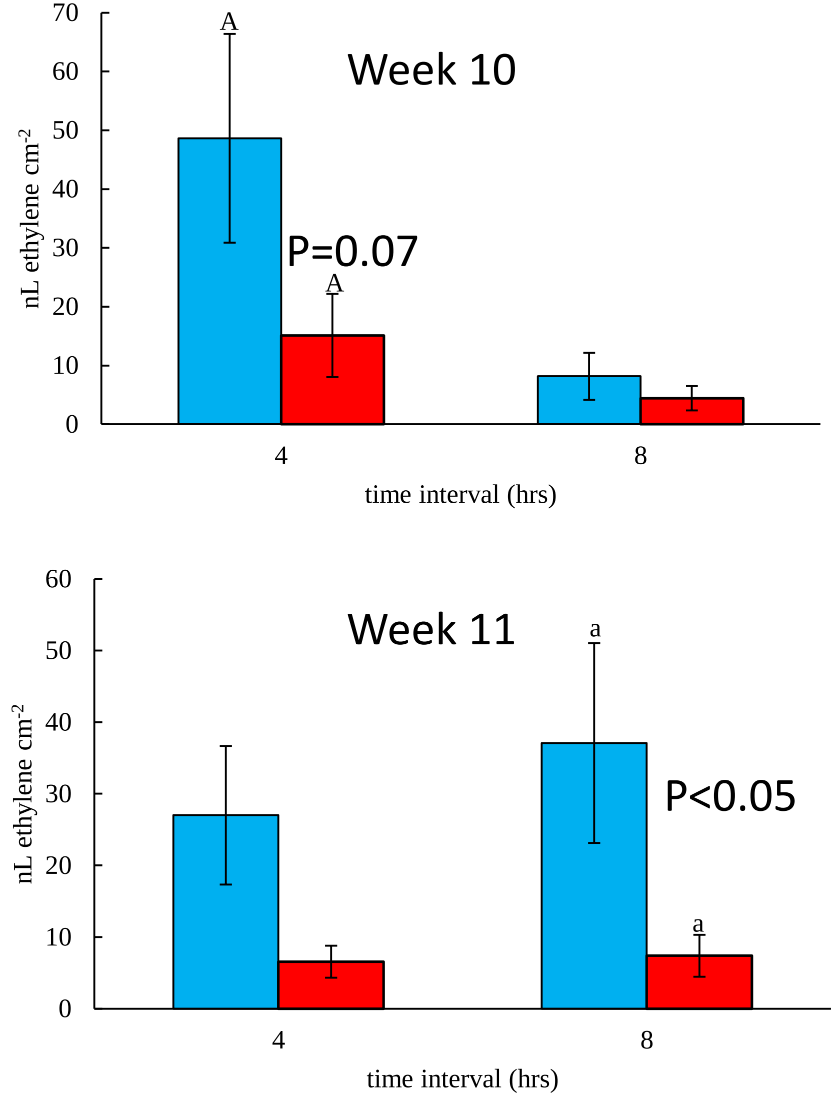

Hakan Pleijel et al.

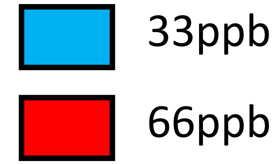
- Grain protein yield strongly negatively affected by $O_3$ – affects fertilizer efficiency

Broberg, M.C., Feng, Z., Xin, Y. & Pleijel, H. (2015). Ozone effects on wheat grain quality – a summary. *Environmental Pollution* 197, 203-213.

# KM1b: Ozone reduces biological N fixation

Acetylene reduction assays were used (cv 'Crusader')




Amount of ethylene evolved is proxy for nodule activity

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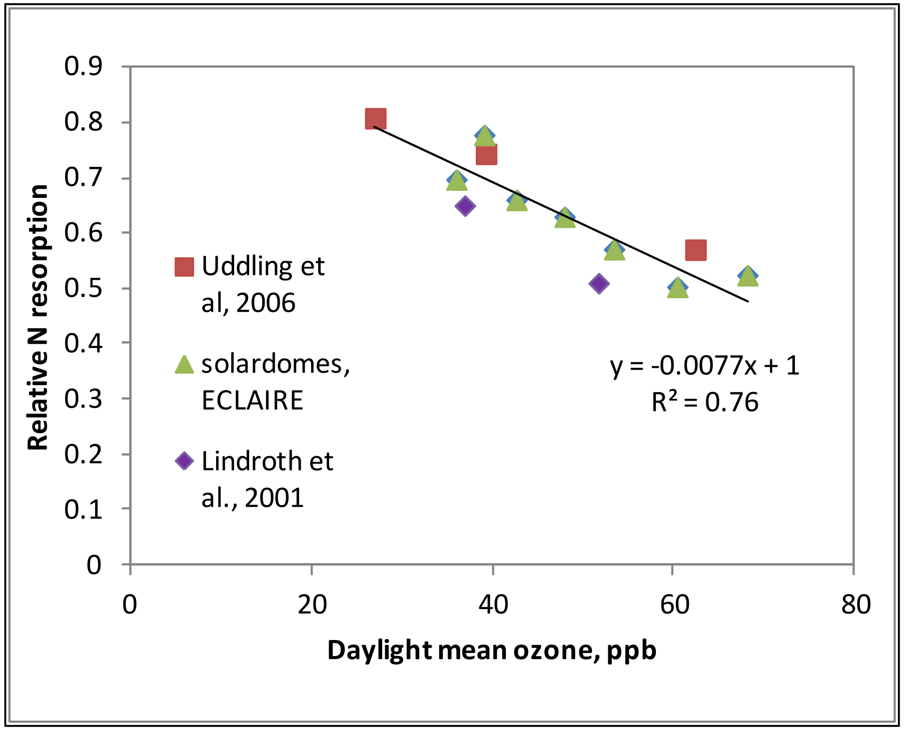
*Hewitt et al. (2014), Environmental Pollution*

# KM1c: $O_3$ changes litter quality




- At higher ozone concentrations, less of the leaf N is transported back into the tree before the leaves fall
- Implications for soil processes

**Resorption of N from leaves prior to leaf fall**
**Combined data set (ECLAIRE data mining)**

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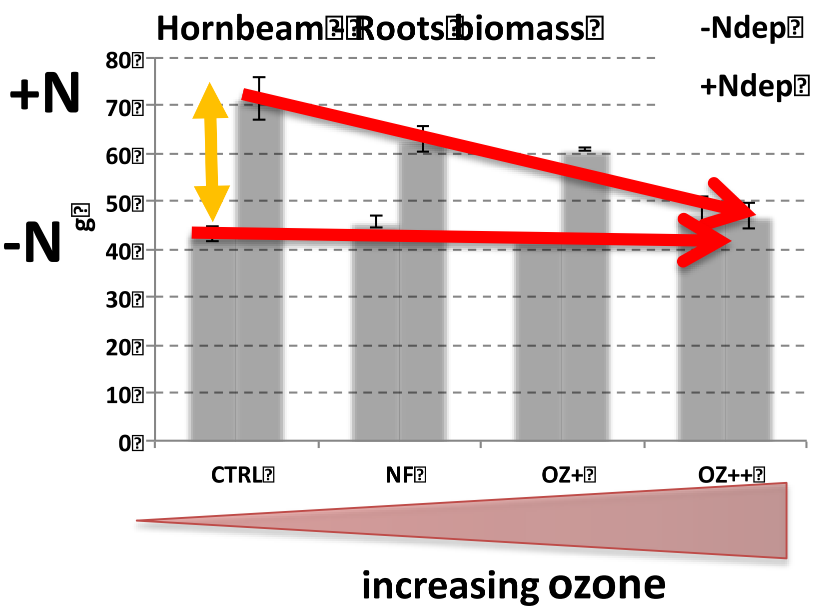
*Karlsson, Hayes, et al. ECLAIRE, unpublished*

**Key message 2**

Growth stimulating effects of N are lost at higher $O_3$

# KM2a: effects on oak and hornbeam root biomass

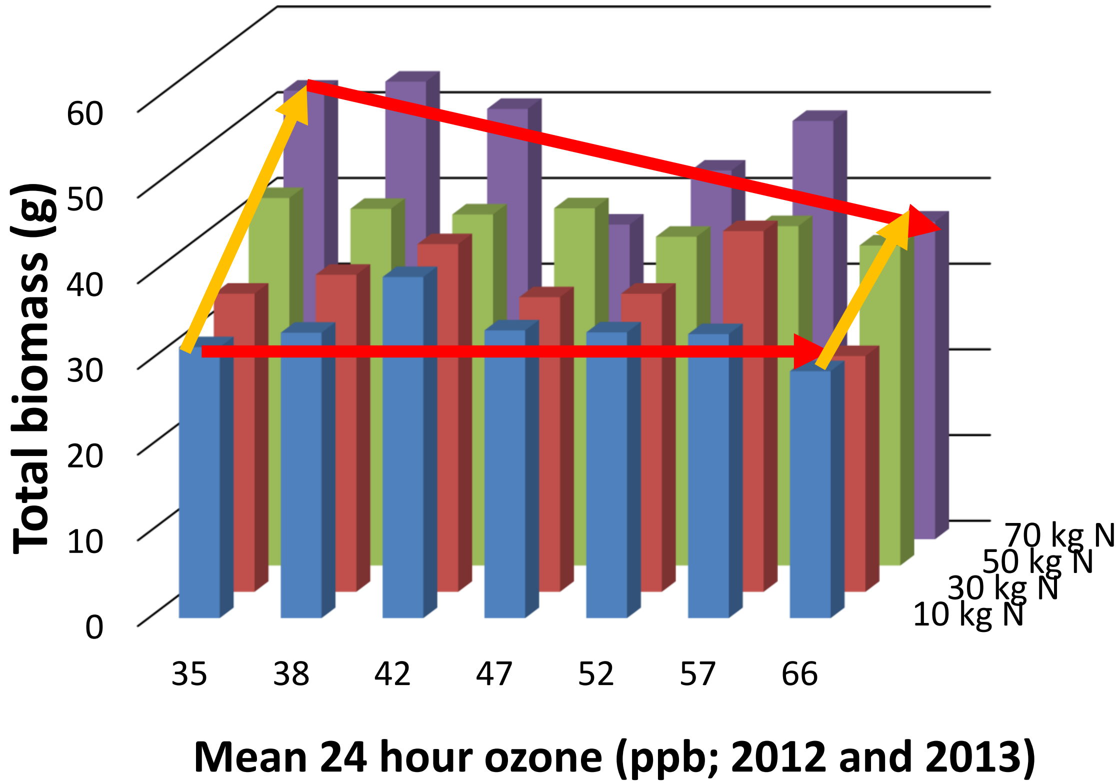
*Gerosa G., Marzuoli R., Monga R., Finco A., UNICATT, Italy*




After two years of treatments:

- **Nitrogen** (70 kg ha-1 y-1) caused positive effects on both species. Hornbeam showed a greater stimulation than oak.
- **Nitrogen** increased hornbeam susceptibility to ozone, while it remained unaltered in oak

# KM2b: effects on silver birch root biomass




- 2 year exposure of silver birch to 7 x $O_3$ and 4 x N
- At high ozone concentrations the stimulating effect of N was much reduced

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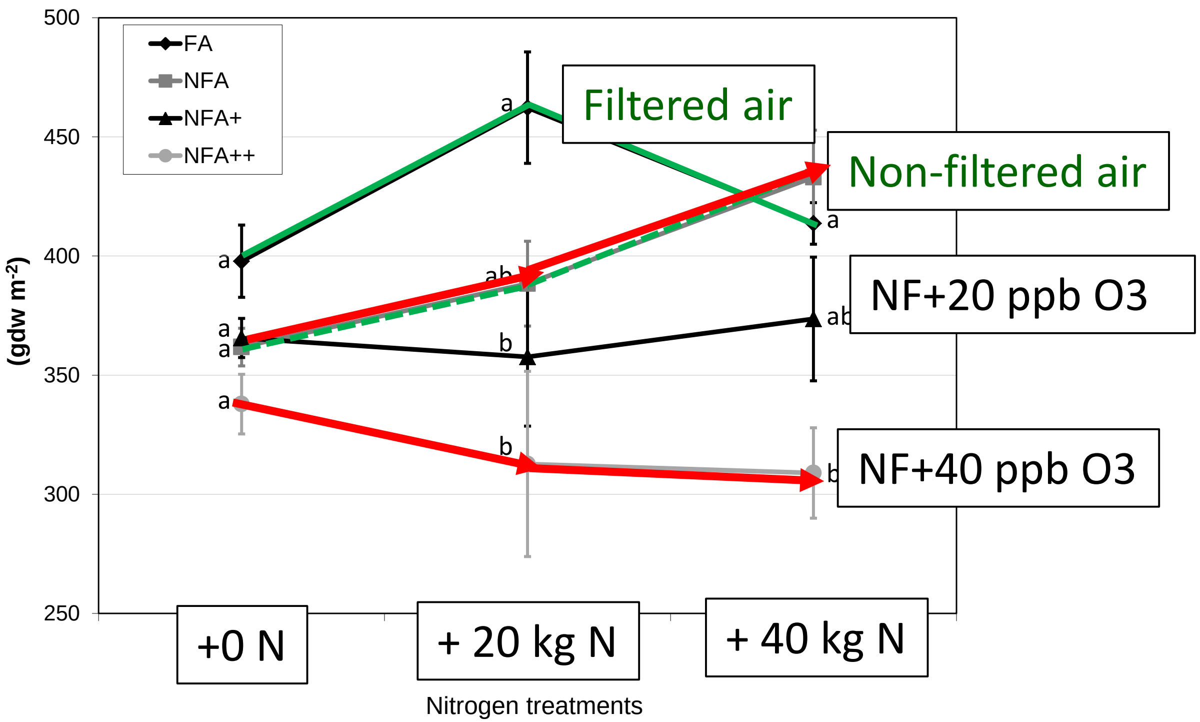
# KM2c: effects on Mediterranean annual pasture




Calvete Sogo et al 2014. Atmos. Environ. 94, 1-10

YIELD /CANOPY SCALE:

- ✓ $O_3$ limited the fertilization effect of the soil N availability,
- ✓ Higher N could compensate $O_3$ effects on yield only when concentrations were moderate, but not under high $O_3$ levels

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**Key message 3**

The direction of the $O_3$-N interaction is *largely* driven by effects on photosynthesis

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# KM3a: Enhanced N increases $g_{max}$

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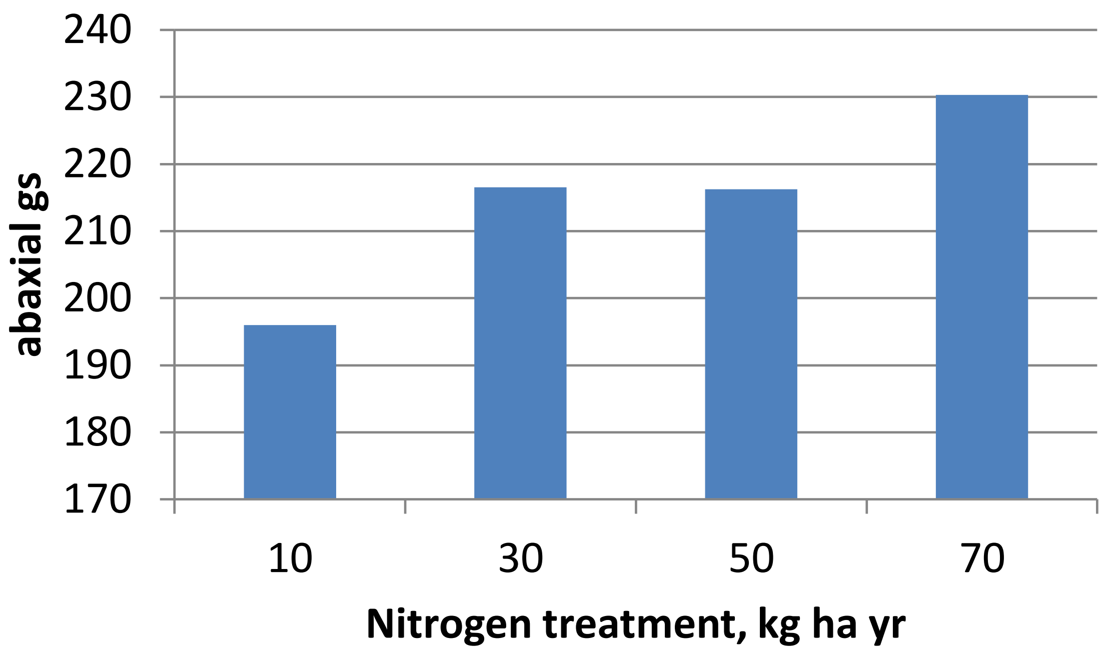
**Solardomes experiment**




- Maximum Stomatal conductance increased with increasing N in silver birch

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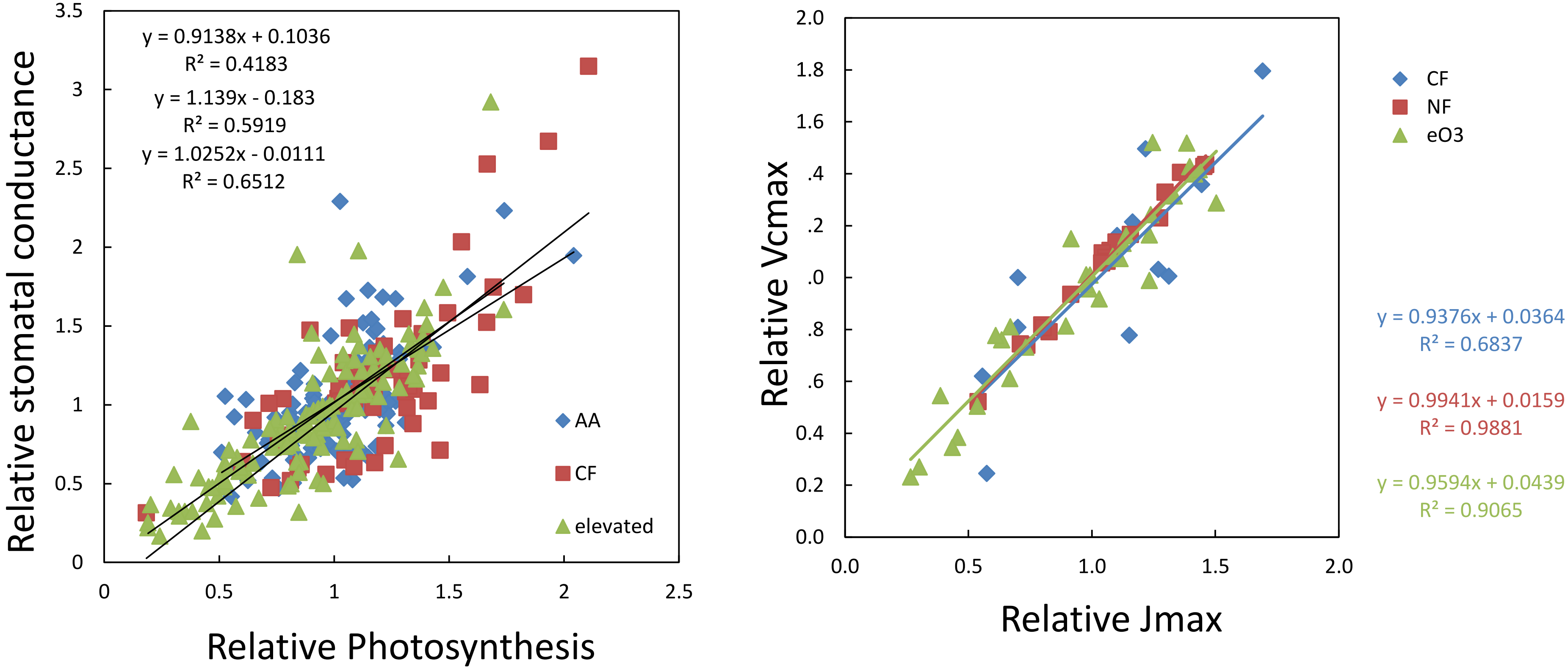
# KM3b: Stable relationships for photosynthesis components

## Wheat




Broberg, M.C., Feng, Z., Pleijel, H. et al in progress

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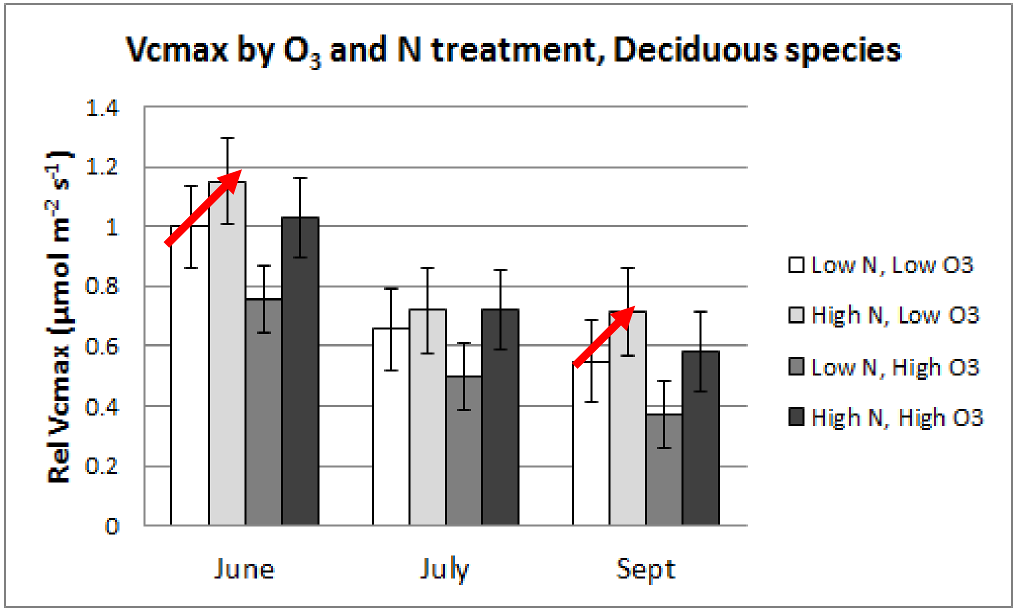
Vcmax =maximum rate of carboxylation
Jmax = the maximum rate of electron transport

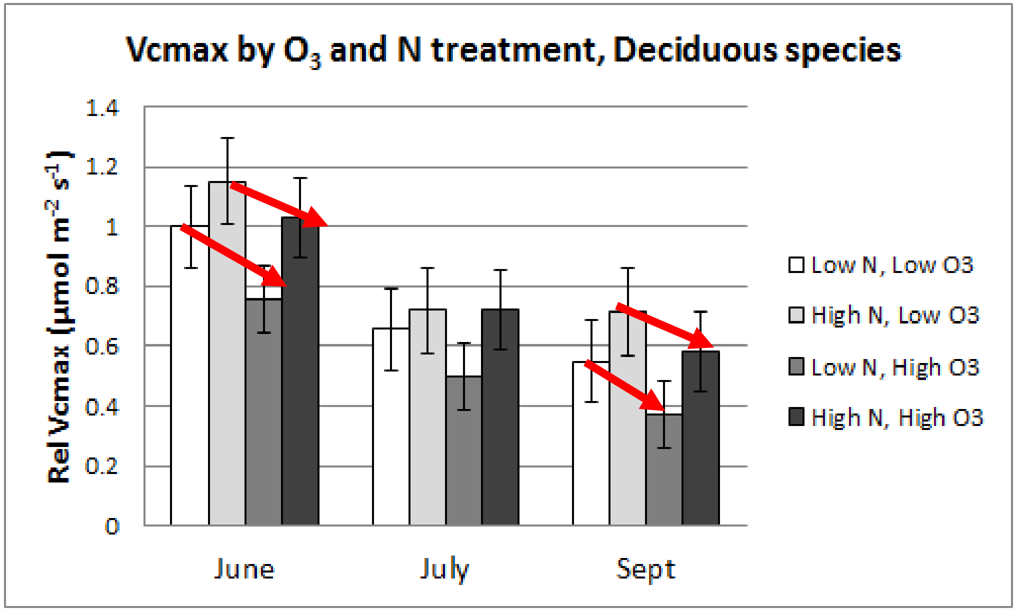
# KM3c: Measured combined effects on $V_{c\ max}$




- ❑ Increasing N increased $V_{c\ max}$

- Data from CEH Bangor and UNICATT, Italy
- Silver birch and hornbeam
- 10 and 70 kg N/ha/yr and 35 and 70 ppb $O_3$ as a 24 hour mean

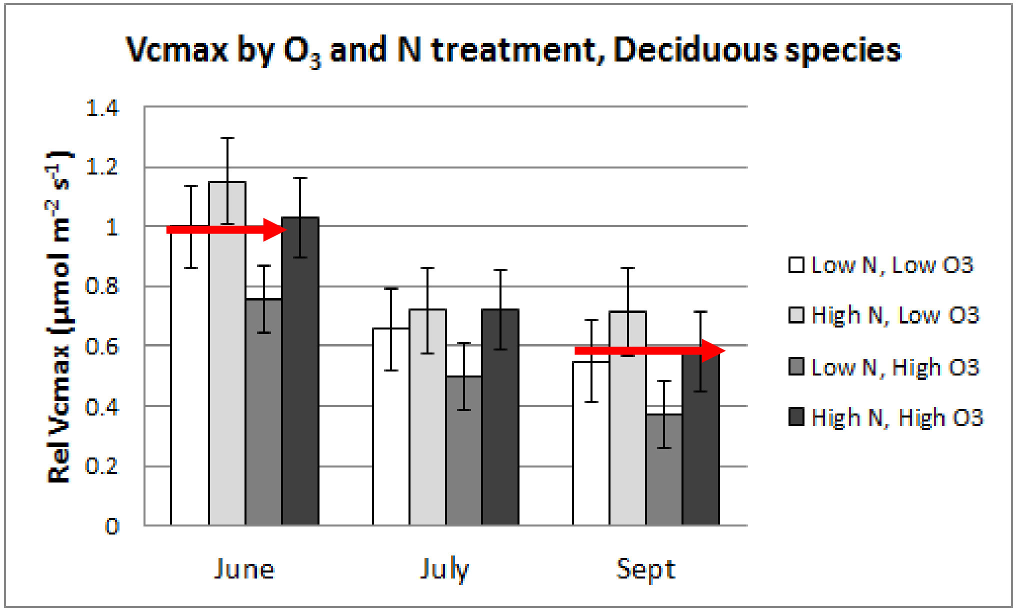
# KM3c: Measured combined effects on $V_{c\ max}$




- ❑ Increasing N increased $V_{c\ max}$
- ❑ Increasing $O_3$ decreased $V_{c\ max}$

- Data from CEH Bangor and UNICATT, Italy
- Silver birch and hornbeam
- 10 and 70 kg N/ha/yr and 35 and 70 ppb $O_3$ as a 24 hour mean

# KM3c: Measured combined effects on $V_{c\ max}$




- Data from CEH Bangor and UNICATT, Italy
- Silver birch and hornbeam
- 10 and 70 kg N/ha/yr and 35 and 70 ppb $O_3$ as a 24 hour mean

- ❑ Increasing N increased $V_{c\ max}$
- ❑ Increasing $O_3$ decreased $V_{c\ max}$
- ❑ Together, $V_{c\ max}$ was the same as in the low N/low $O_3$ treatment

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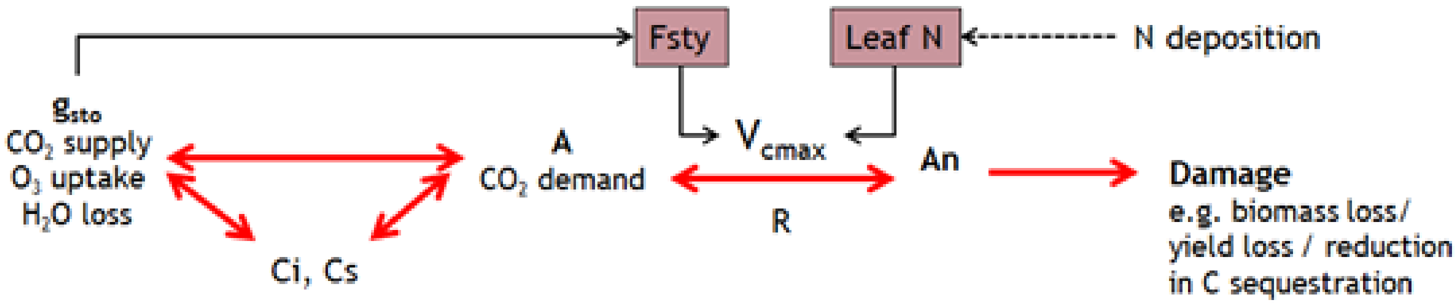
# KM3d: New development of the $DO_3SE$ model, combined effects of $O_3$ and N




- The $DO_3SE$ model has been developed to incorporate a coupled net Photosynthesis-stomatal conductance (An-gsto) model
- Leaf Nitrogen (through Vcmax) is central to determining net Photosynthesis (An), gtso and hence $O_3$ uptake.
- By understanding the role that leaf N plays in altering $O_3$ uptake we can assess the influence combinations of leaf N and $O_3$ would have on DRRs
- This assumes uptake is the sole mechanism by which leaf N alters $O_3$ sensitivity.

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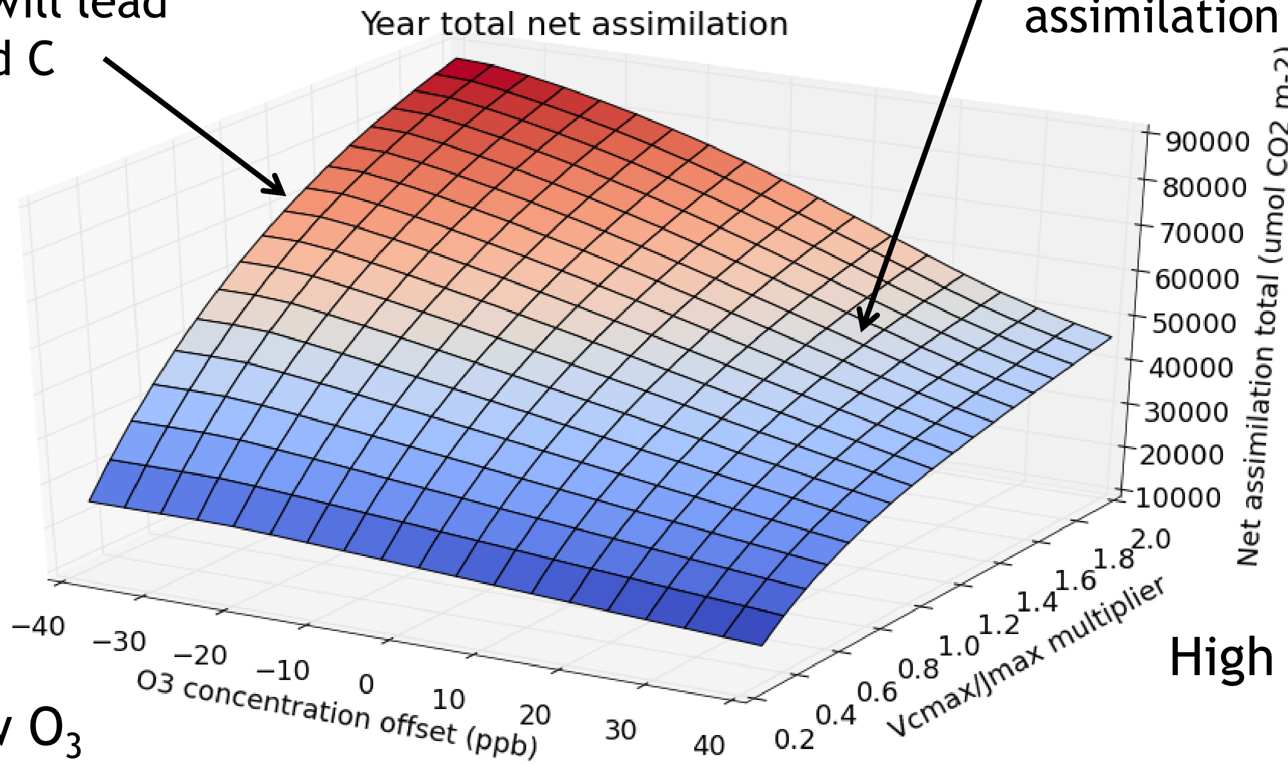
## Key message 4

The combined effects of $O_3$ and N on ecosystems cannot be predicted by the sum of the two effects

# KM4a: DO3SE-C modelling of combined effects on seasonal assimilation

Under low $O_3$ concentrations, increasing N will lead to a increased C assimilation

High $O_3$ concentrations negate the positive influence of N on C assimilation




Low $O_3$

High $O_3$

High N

Low N

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'ECLAIRE final meeting'
1-4 Sept 2015; Edinburgh

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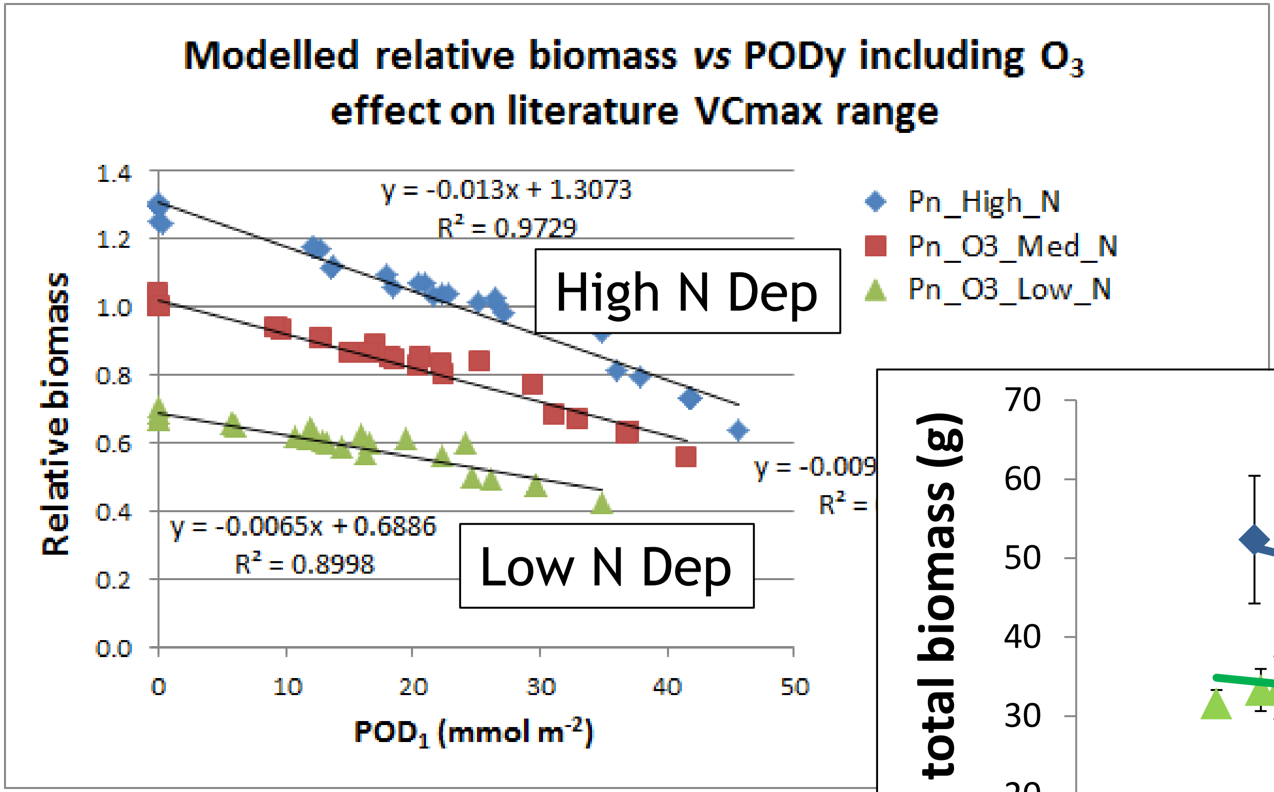
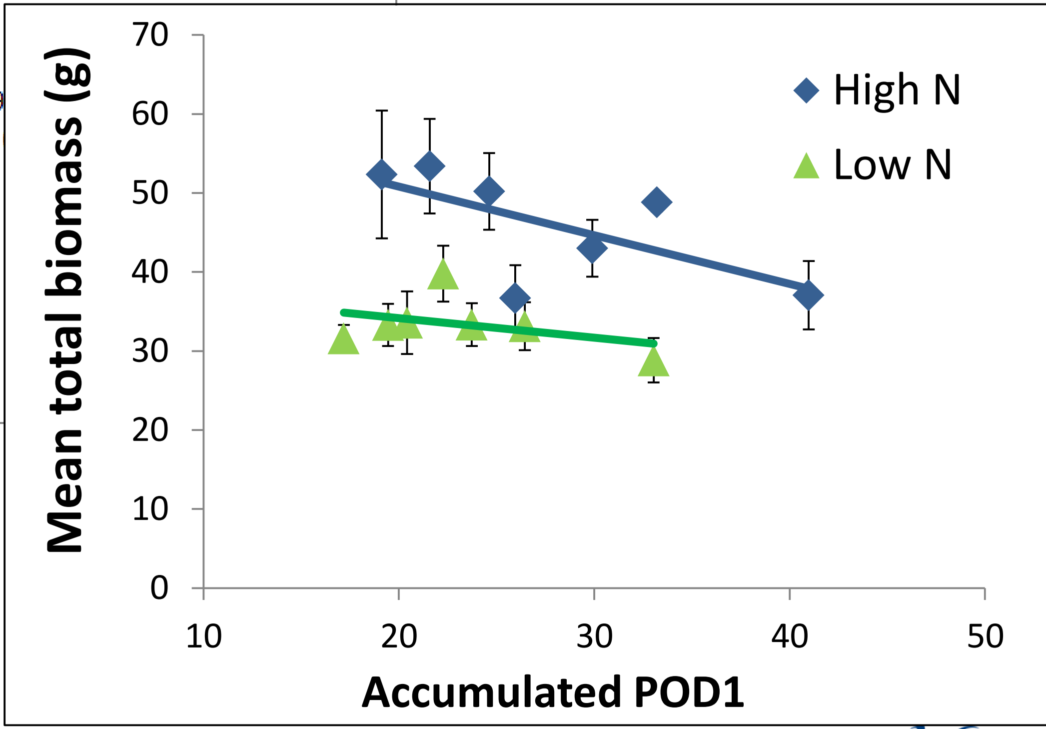
# KM4b: e.g. New DRRs for low, medium and high N loads



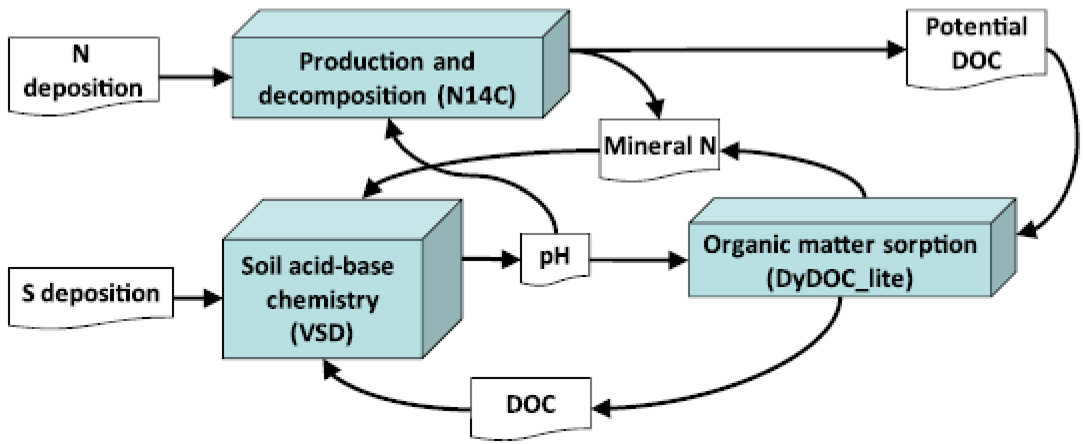

**Data from solardomes**




- High leaf N increases ozone uptake but this in turn can increase damage causing a more sensitive response

# KM4c: $O_3$ and N in the MADOC Model

E.C. Rowe et al. / Environmental Pollution 184 (2014) 271–282




- Accounts for the flows of carbon and other elements through vegetation and soil, simulating the effects of long-term trends of large-scale ecosystem drivers

- Processes include acid-base exchange, the contribution of dissolved organic acids, and effects of ozone and nitrogen availability on plant growth and litterfall.

- It has been used to understand and explore the impacts of nitrogen and ozone pollution on plant productivity, carbon storage and water quality.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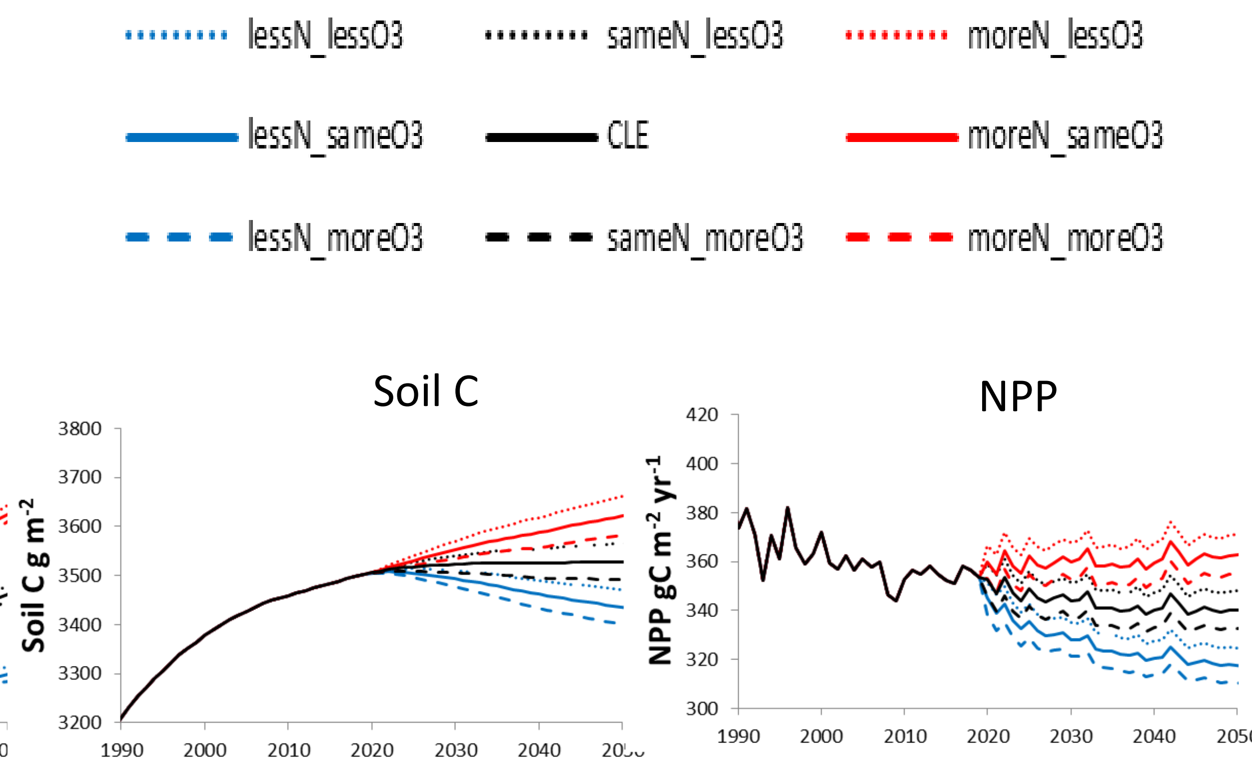
# KM4d: Combined effects on Coniferous forest




- ❑ Steady decline with CLE
- ❑ N effect dominates; small $O_3$ effects
- ❑ Ozone modifies effect of N
- ❑ Biggest decrease with less N and more $O_3$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**C3 Key message 5**
Aerosols damage stomatal functioning

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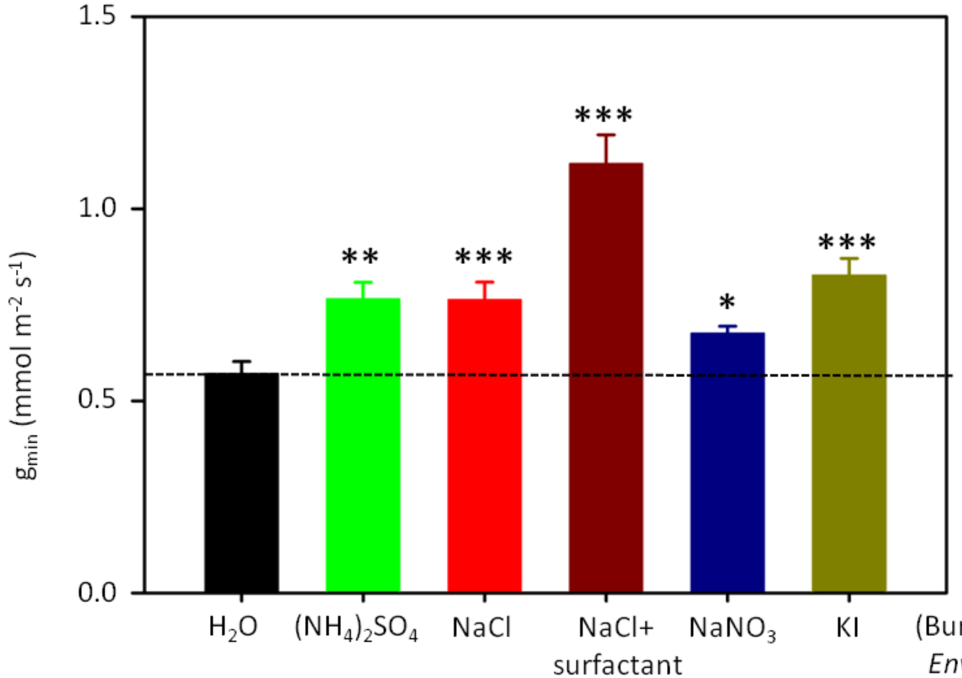
# KM5: Aerosol impacts on plant water relations

*Shyam Pariyar, Jürgen Burkhardt*




(Burkhardt & Pariyar, *Env. Poll.*, 2014)

- Epidermal minimum conductance ($g_{min}$) of pine needles increased after salt spray treatment
- elevated $g_{min}$ indicates reduced drought tolerance
- $g_{min}$ is possibly a useful threshold parameter for aerosol impacts on plants

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Component 3: Ecological response processes and thresholds

# C3 Key message 6

Climate change will modify stomatal uptake of ozone, thereby changing the magnitude of effect

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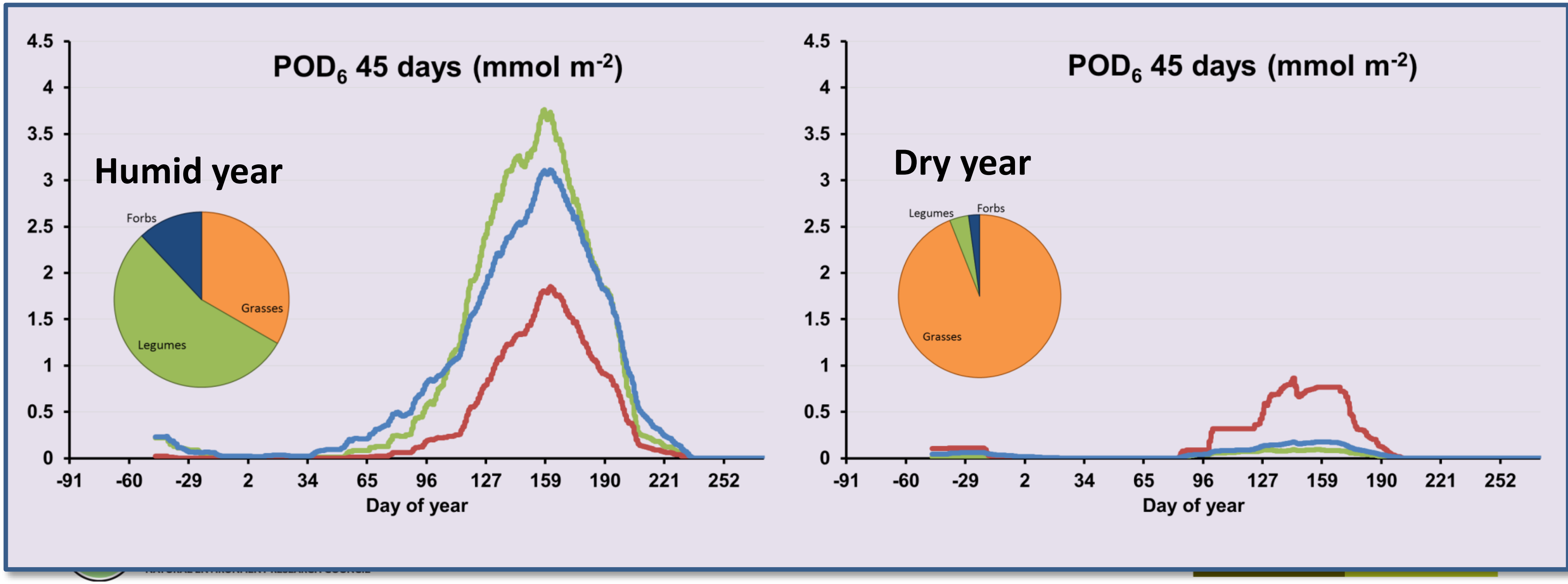
# KM6a: Ozone and climate/Annual pastures

Climatic conditions change annual pastures sensitivity to $O_3$

- Altering gas exchange rates; thus the ozone absorbed doses
- Changing growing seasons; thus the accumulated period for ozone absorbed doses
- Changing species composition with varying $O_3$ sensitivity (legumes generally more $O_3$ sensitive are less abundant on dry years)

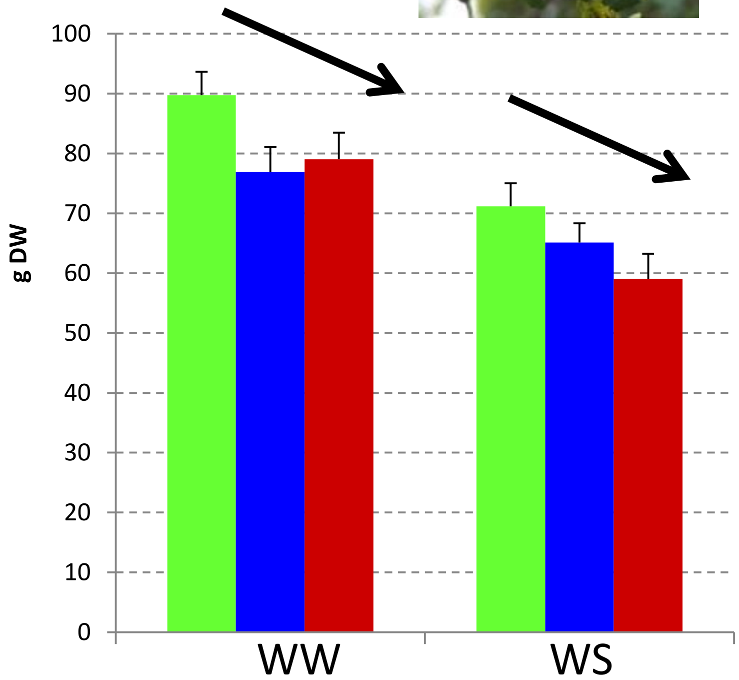
**Ozone absorbed doses (PODs)**




González-Fernández et al. CIEMAT In preparation

# KM6b: Ozone and climate/evergreen Med. trees

**Holm oak**




- Water stress (WS) does not protect perennial Med trees from $O_3$ effects on biomass (Alonso et al., 2014, *Plant Biol.)*
- Also seen in temperate grasslands, Wagg et al, 2014, Env. Poll.

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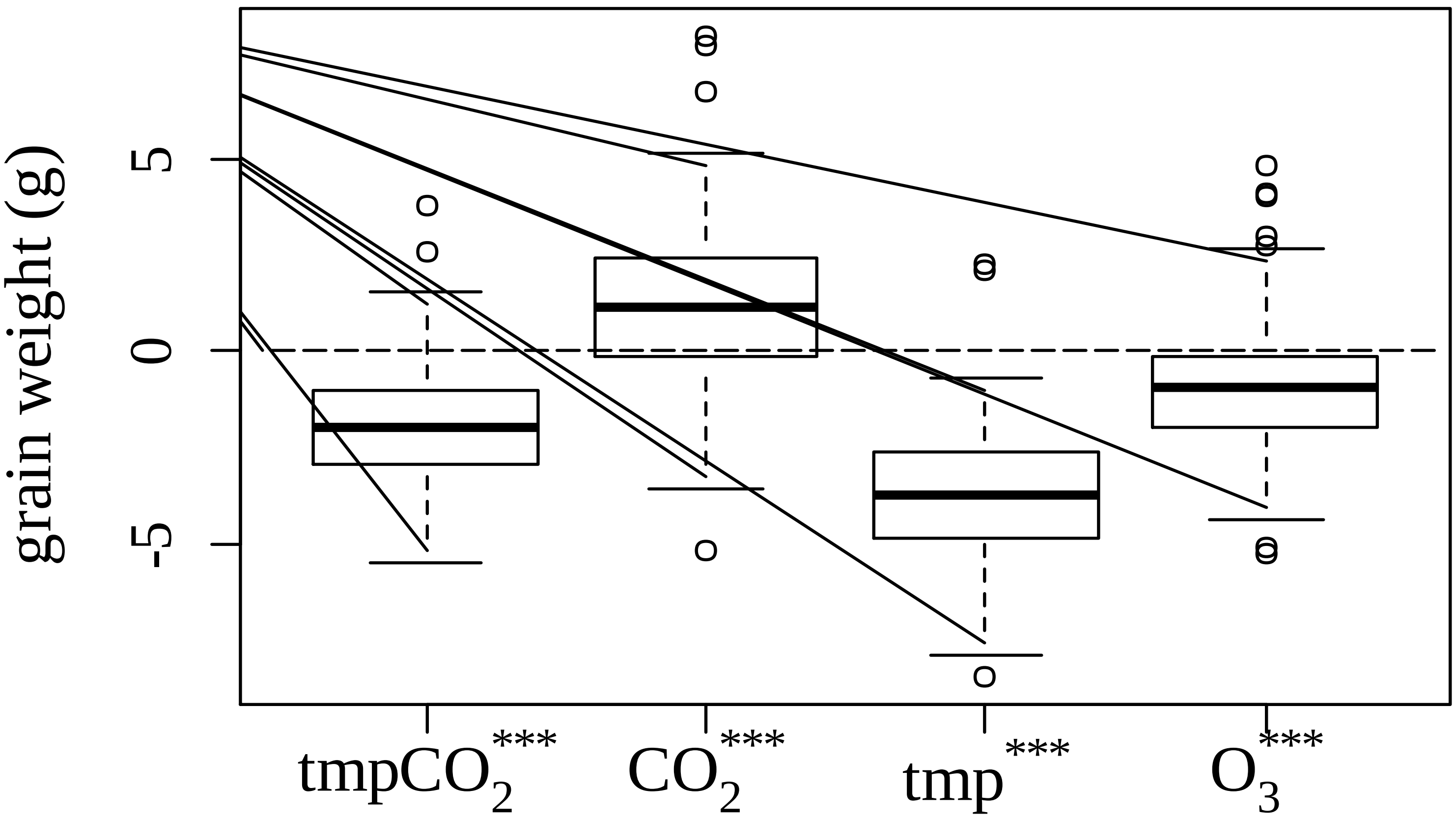
# KM6b: Screen of 138 barley accessions



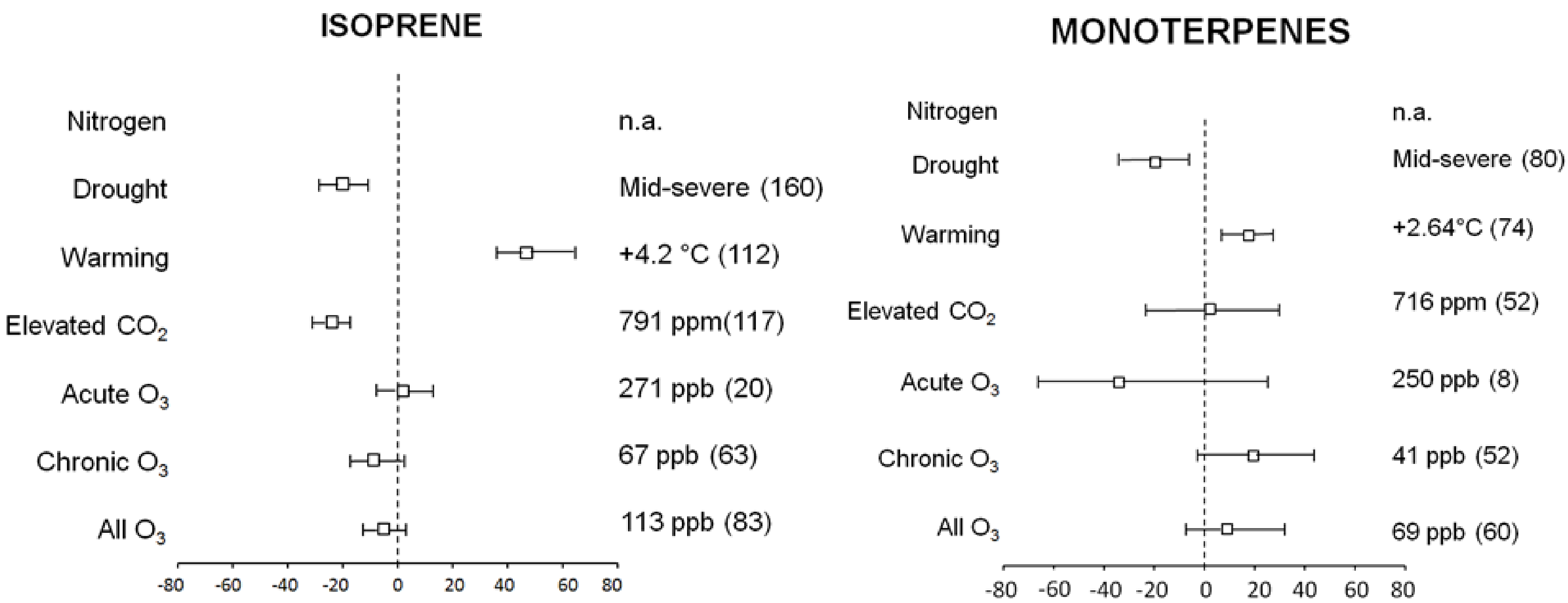

- Effects of climate change and ozone on barley, a moderately ozone-sensitive species, Ingvordsen et al. 2015, DTU

## C3 Key message 7

Climate change and ozone modify BVOC release from vegetation, with implications for air quality

# KM7a: meta-analysis of published data

- **Isoprenoids emission increases with increasing temperature, and decreases with increasing $CO_2$ and soil water stress.**




Percent change in isoprene and total monoterpenes emission under the effect of different climate change drivers . Symbols are bracketed by 95% bootstrapped confidence intervals. Mean level of stress and number of observations (in parenthesis) are also given.

Elena Paoletti CNR, Silvano Fares CREA

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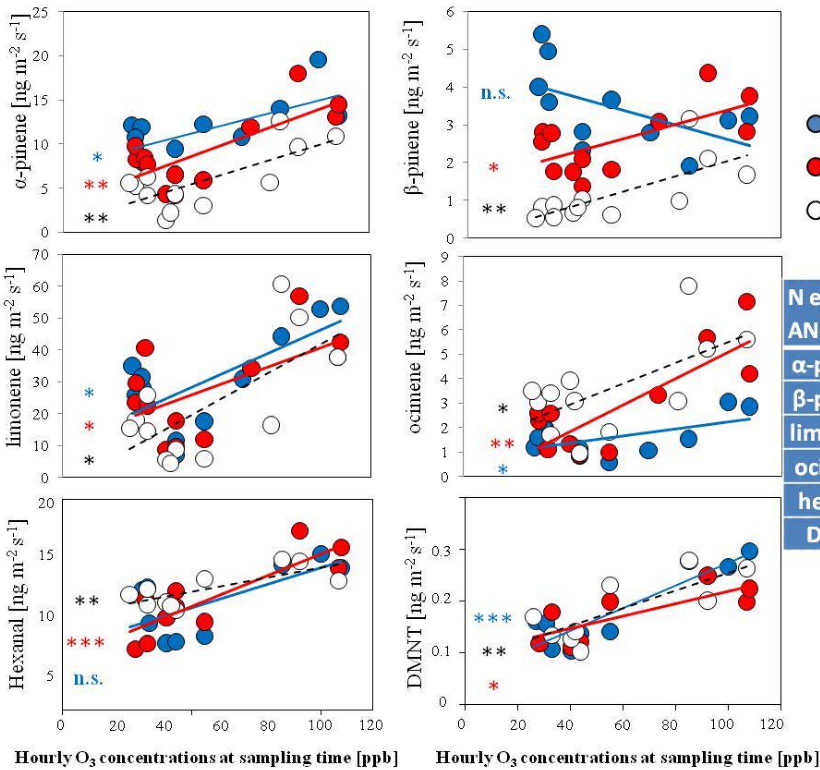
# KM 7c: Combined effects of O3 and N on BVOC emissions from silver birch




| N effect ANCOVA | slope | y-intercept |
|---|---|---|
| α-pinene | n.s. | ** ↓ |
| β-pinene | *** ↓ | |
| limonene | n.s. | n.s. |
| ocimene | n.s. | * ↑ |
| hexanal | * ↑ | |
| DMNT | n.s. | n.s. |

- **Ozone stimulated emission, while nitrogen effects are compound-specific (from stimulation to inhibition),** Carriero et al., Environmental Pollution, submitted

Effects of ozone (concentrations at the time of BVOC sampling) and nitrogen (weekly fertilization) on BVOC emission from silver birch saplings after two years of exposure

Guilia Carriero, Elena Paoletti CNR, Silvano Fares CREA, Felicity Hayes and Gina mills (CEH)

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## C3 key message 8

Combined effects of ozone, N and climate change can be predicted with C3 models … [message to be discussed further at this meeting]

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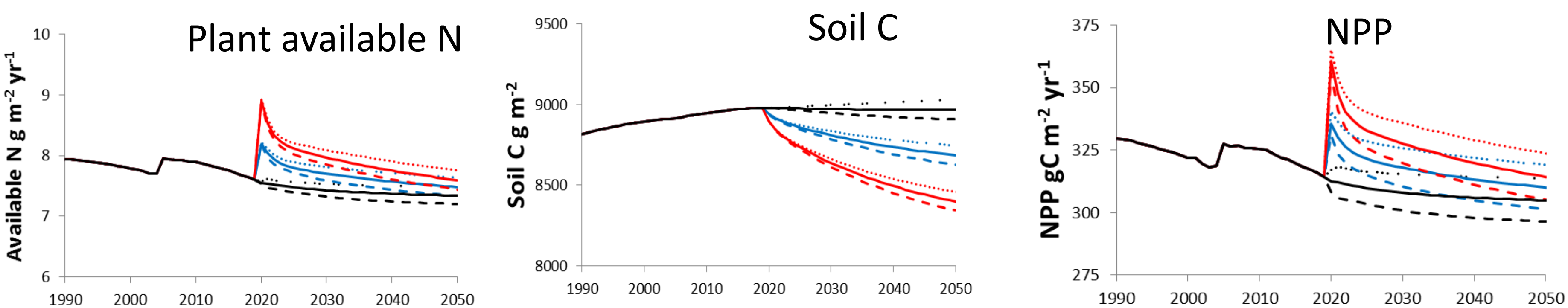
# KM8a: Combined O3 and temperature effects – Whim bog


- ❑ Increasing temperature increases available N, reduces soil C and increases NPP
- ❑ Reducing O3 by 20% enhanced stimulating effect of temperature on available N and NPP, but reduced temperature-induced losses in soil C
- ❑ Losses in soil C made worse in +2 and +4 °C under +20% $O_3$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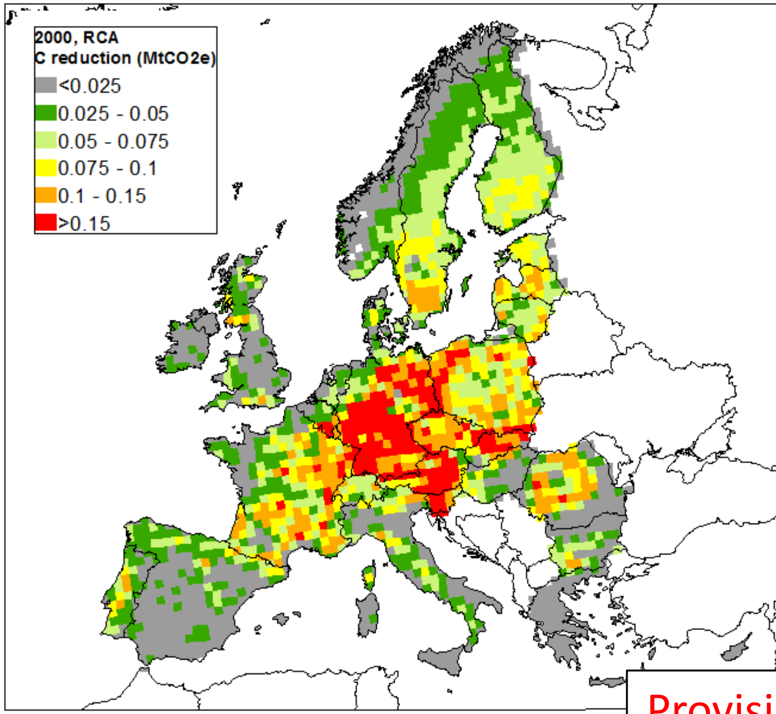
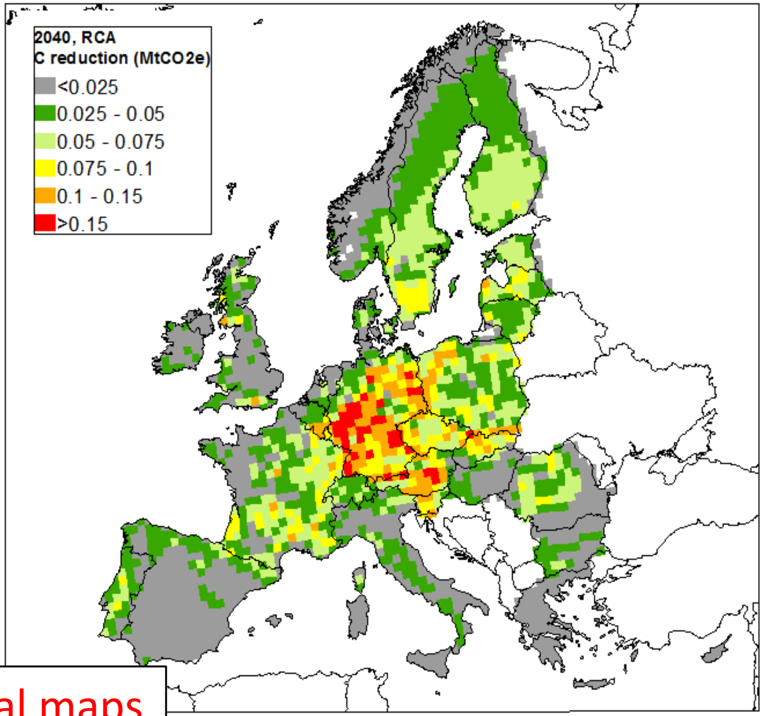
# K8b: Ozone impacts on C sequestration in trees

2000




2040




Provisional maps

- Response functions derived for $O_3$ effects on Net Annual Increment of tree species
- Maps generated for reduction in C sequestration in living biomass of trees due to ozone, relative to pre-industrial ozone

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Bűker, Briolat, Emberson, Harmens, Sharps, Mills, in progress

University of York

# C3 Tasks for this meeting

- Review key messages and responses to ECLAIRE questions
- Novel thresholds discussion
- Remaining work
- Plans for paper writing

# C3 Key messages (to date…)

1. $O_3$ alters N cycling
2. Growth stimulating effects of N are lost at higher $O_3$
3. The direction of the $O_3$-N interaction is driven by effects on photosynthesis
4. The combined effects of $O_3$ and N on ecosystems cannot be predicted by the sum of the two effects
5. Aerosols damage stomatal functioning
6. Climate change will modify stomatal uptake of ozone, thereby changing the magnitude of effect
7. Climate change and ozone modify BVOC release from vegetation, with implications for air quality
8. Combined effects of ozone, N and climate change can be predicted with C3 models …

SPARE SLIDES FOR DISCUSSION IN C3 MEETINGS

## C3 deliverables for this year

| | |
|---|---|
| D11.4 | Measurement and parameterization of the fraction of O3 that is taken up by leaves due to detoxification by constitutive BVOC, under associated environmental constraints and during leaf development |
| D12.3 | Delivery of novel thresholds for key dose-response relationships for use in regional scale modelling and mapping relevant for ecosystem service assessment |
| D12.4 | Final Report describing new dose-response relationships and novel thresholds |
| D13.4 | Report on assessment of the effects of combined air pollution and climate change scenarios on ecosystem C/GHG balance, soil quality and vegetation change at all experimental sites, based on integrated models |

# ECLAIRE questions

**Q1**: What are the expected impacts on ecosystems due to changing ozone and N-deposition under a range of climate change scenarios, taking into consideration the associated changes in atmospheric CO2, aerosol and acidification

**Q2:** Which of these effects off-set and which aggravate each other, and how do the mitigation and adaptation measures recommended under climate change relate to those currently being recommended to meet air pollution effects targets?

**Q3:** What are the relative effects of long-range global and continental atmospheric transport vs. regional and local transport on ecosystems in a changing climate

**Q4**: What is the relative contribution of a) climate dependence in biogenic emissions and deposition vs. b) climate dependence of ecosystem thresholds and responses in determining the overall effect of climate change on air pollution impacts?

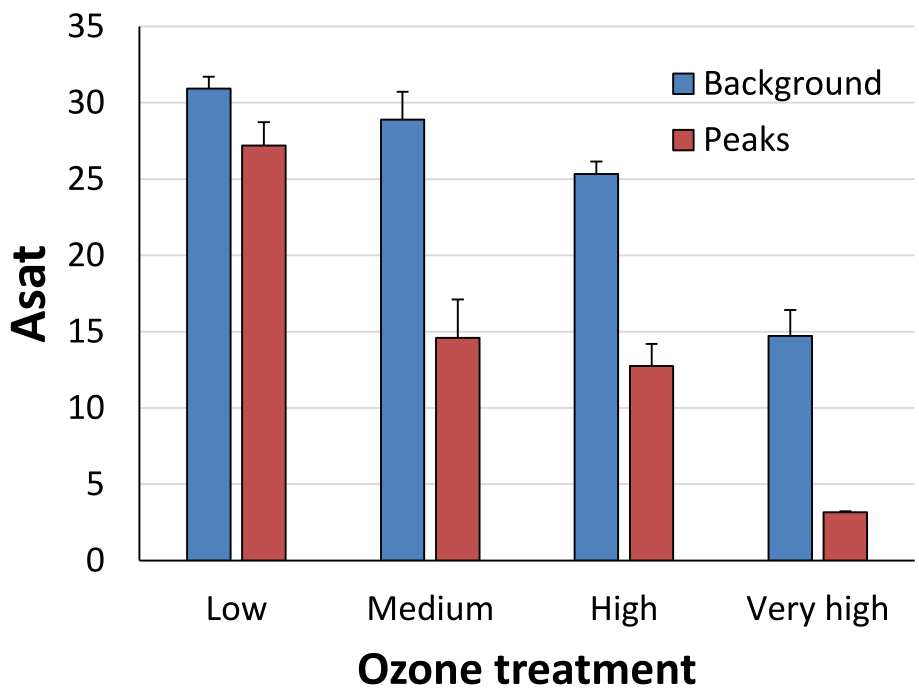
**Q5**: What are the best metrics to assess O3and N impacts on plants and soils, when considering interactions with CO2and climate, and the different effects of wet vs. dry deposition on physiological responses?

**Q6:** Which mitigation/adaptation measures are required to reduce damage to “acceptable” levels to protect C stocks and ecosystem functioning? How do the emission abatement costs compare with the economic benefits of reduced damage

# Larger effect of peak than background ozone for wheat (Skyfall)

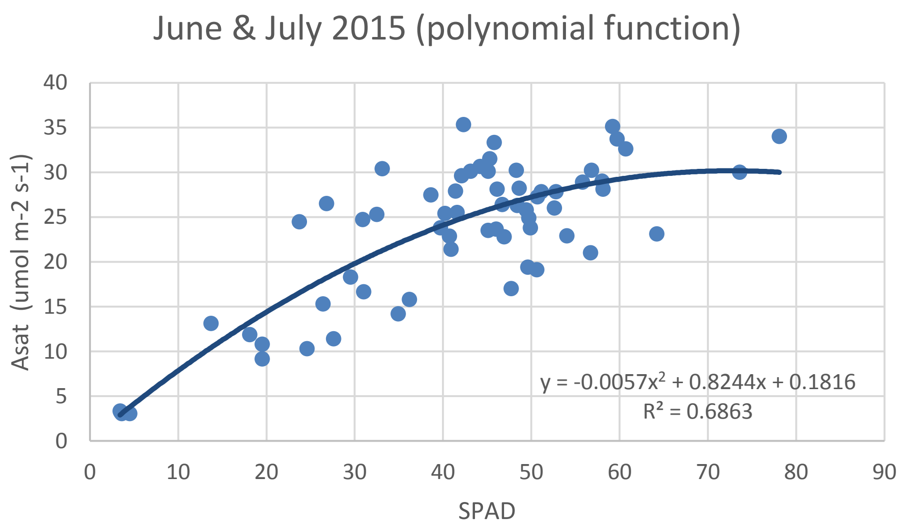
CEH Bangor – Harry Harmens, Felicity Hayes, Gina Mills

**Solardomes experiment**

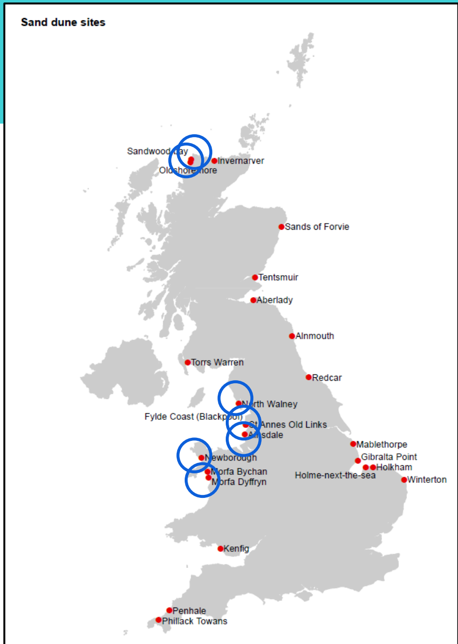


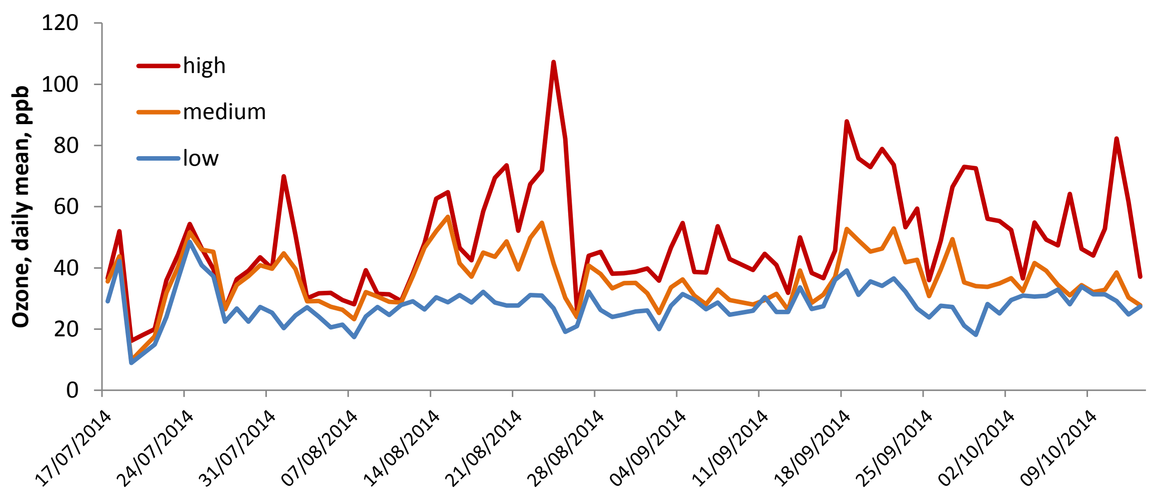

- Asat (light saturated photosynthesis) of wheat was reduced by ozone in late season (after flowering)
- The effect was larger for peaks of ozone exposure than for elevated background
- The response was partly explained by changes in chlorophyll content

# SPAD vs ASAT for wheat (Skyfall)



# CEH Bangor: O3 and N impacts on coastal grassland




| | |
|---|---|
| High | – 48 ppb |
| Medium | – 36 ppb |
| Low | – 28 ppb |

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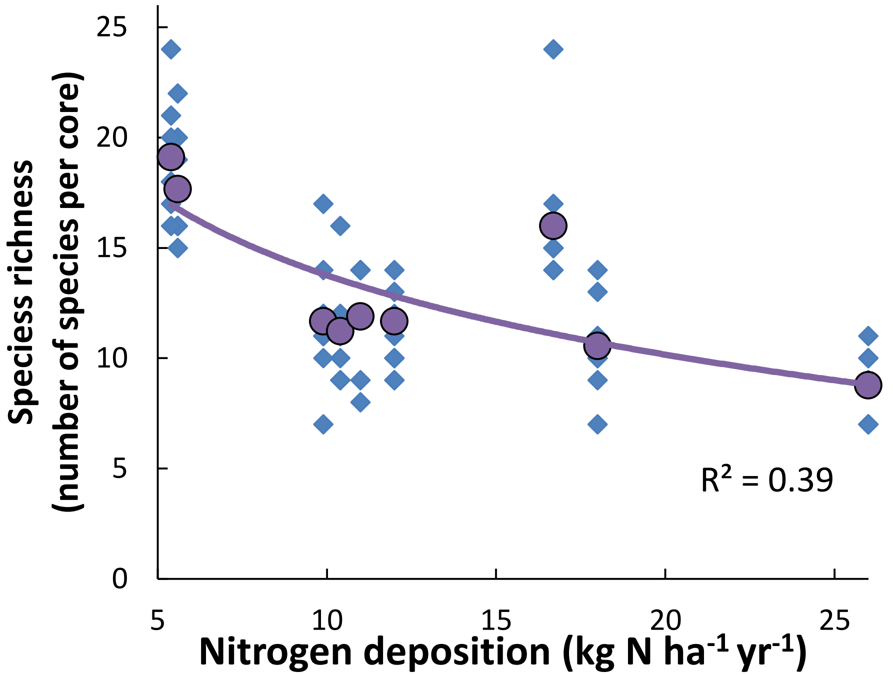
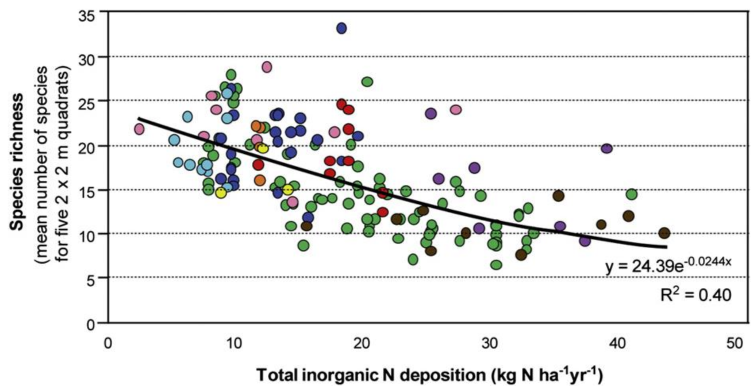
# Bangor FAZE: N effects on species richness of cores




*Stevens et al., 2010, Environmental Pollution*

- Across Europe species diversity of acid grasslands decreases with increasing N deposition

- ❑ Species richness decreased with increasing N
- ❑ Pattern (and values) matched well with previous data

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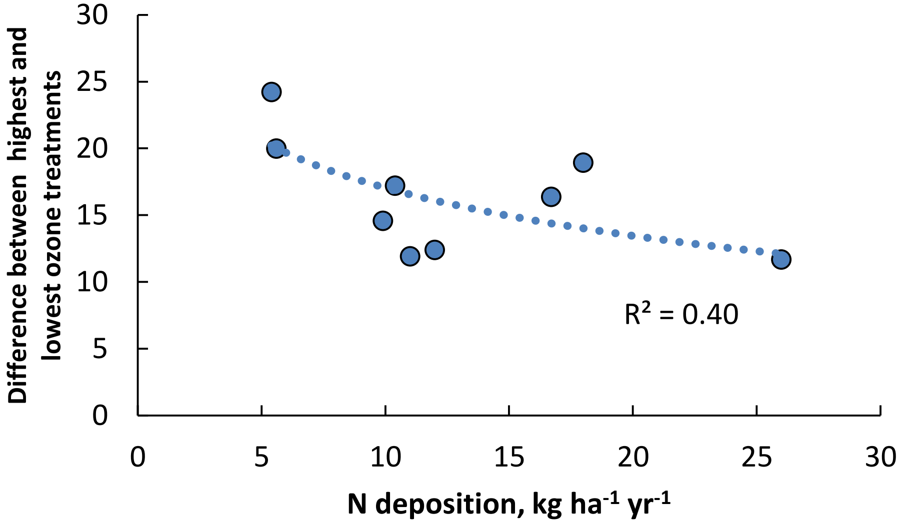
# Many species showed increased leaf injury/senescence

| |
|---|
| *Ruta graveolens* |
| *Avenula pubescens* |
| *Leontodon spp 1* |
| *Carex arenaria* |
| *Carex flacca* |
| *Hypericum perforatum* |
| *Achillea millefolium* |
| *Galium verum* |
| *Rumex spp* |
| *Luzula campestris* |
| *Leontodon spp 2* |
| *Plantago lanceolata* |
| *Trifolium repens* |
| *Dactylis glomerata* |
| *Senecio jacobaea* |
| *Ranunculus spp* |

- Per species, it is difficult to show whether N affects sensitivity to ozone, as not all species were found in all cores
- Based on mean per core (of the species that had injury/senesced leaves), high N cores were less sensitive
- But – N affected the species composition with a shift towards grasses!




**Highest - lowest ozone only**

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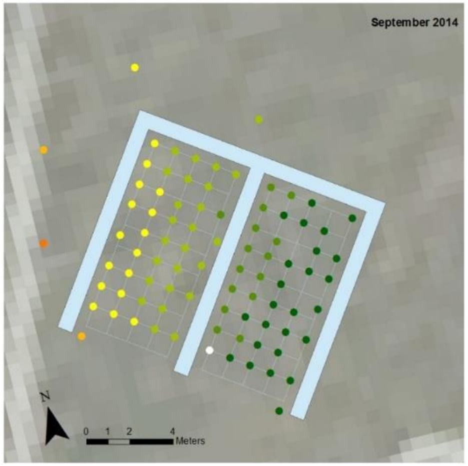
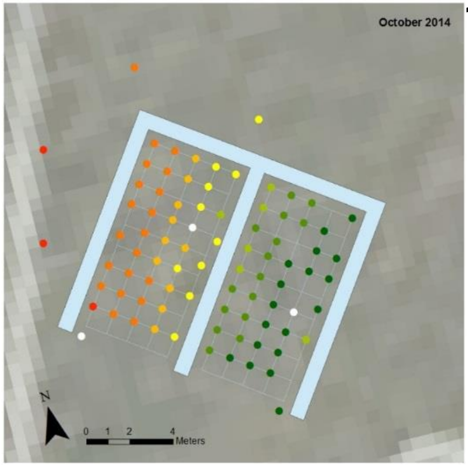
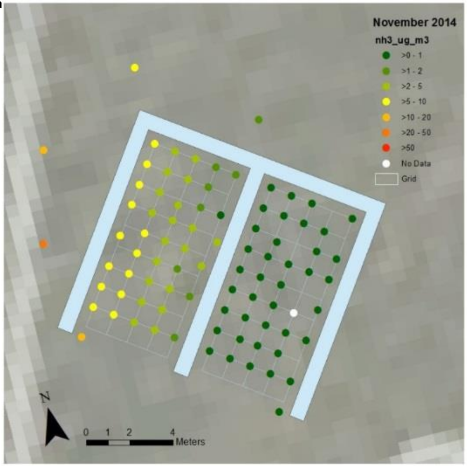
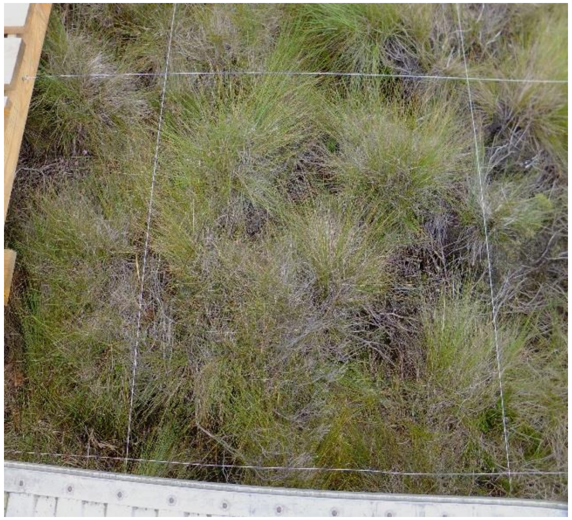
# Whim ozone transect, effect of $NH_3$ concentrations on vegetation




$NH_3$ concentrations high at left side and low at right side



High $NH_3$ concentrations

Effect on vegetation:

High $NH_3$ : mostly *Eriophorum vaginatum*

Low $NH_3$:  mostly *Calluna vulgaris* and *Sphagnum capilliopholium*

Low $NH_3$ concentrations

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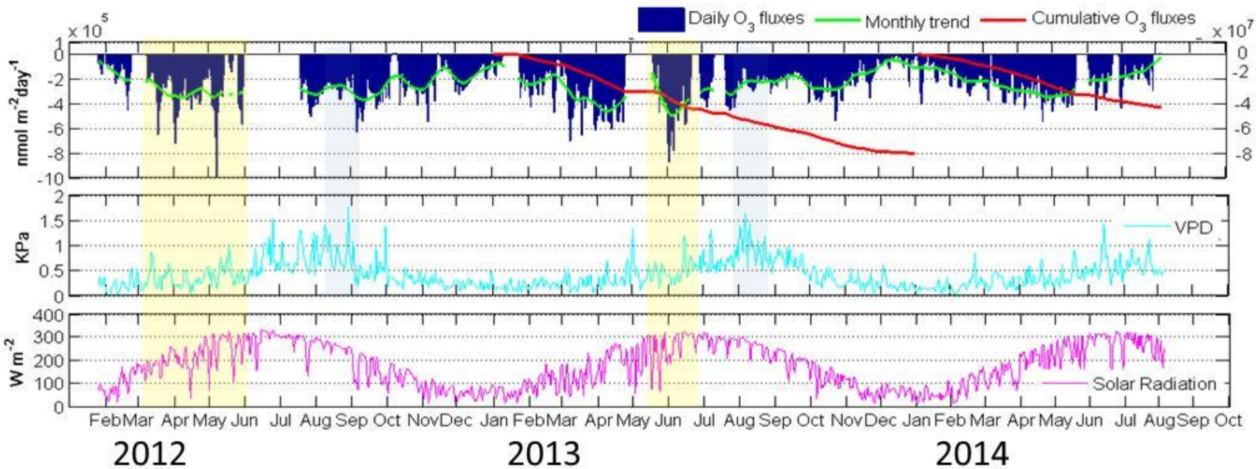
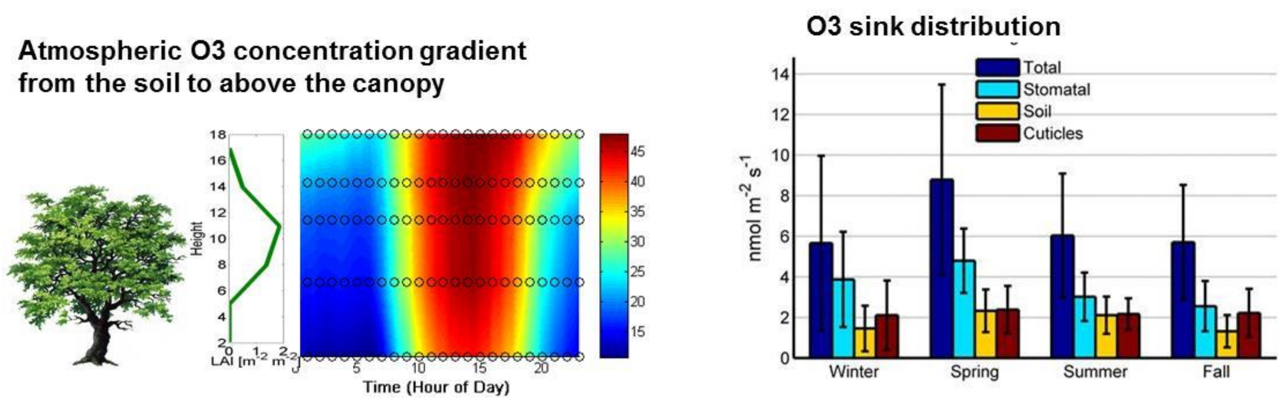



***Figure 1.*** *Profiles of ozone fluxes, vapour pressure deficit and solar radiation over a Quercus ilex canopy*




•***Figure 2.*** *Daily and vertical profile of ozone concentrations across a Quercus ilex canopy*

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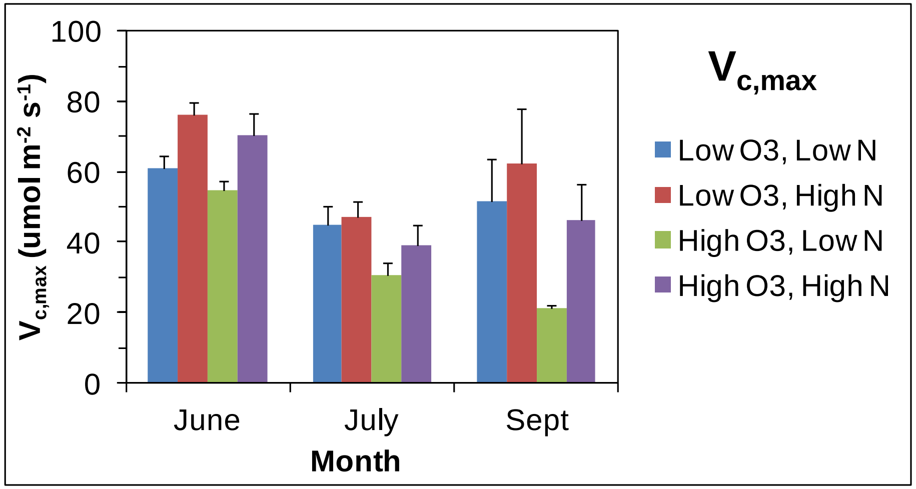
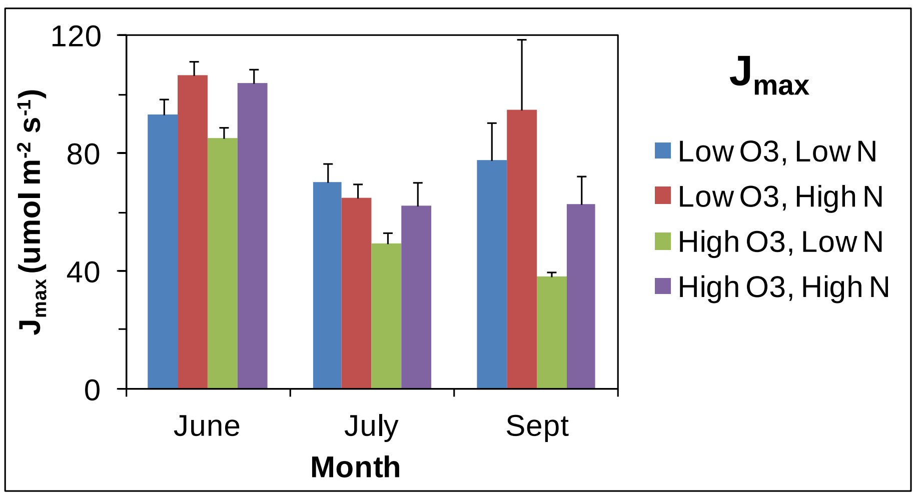
# Photosynthetic capacity silver birch




- ❑ High ozone reduced photosynthetic capacity, but only significantly at low N supply. This effect became more marked as the season progressed.
- ❑ Early in the season high N supply stimulated photosynthetic capacity.




$V_{c,max}$ = max. carboxylation rate allowed by Rubisco

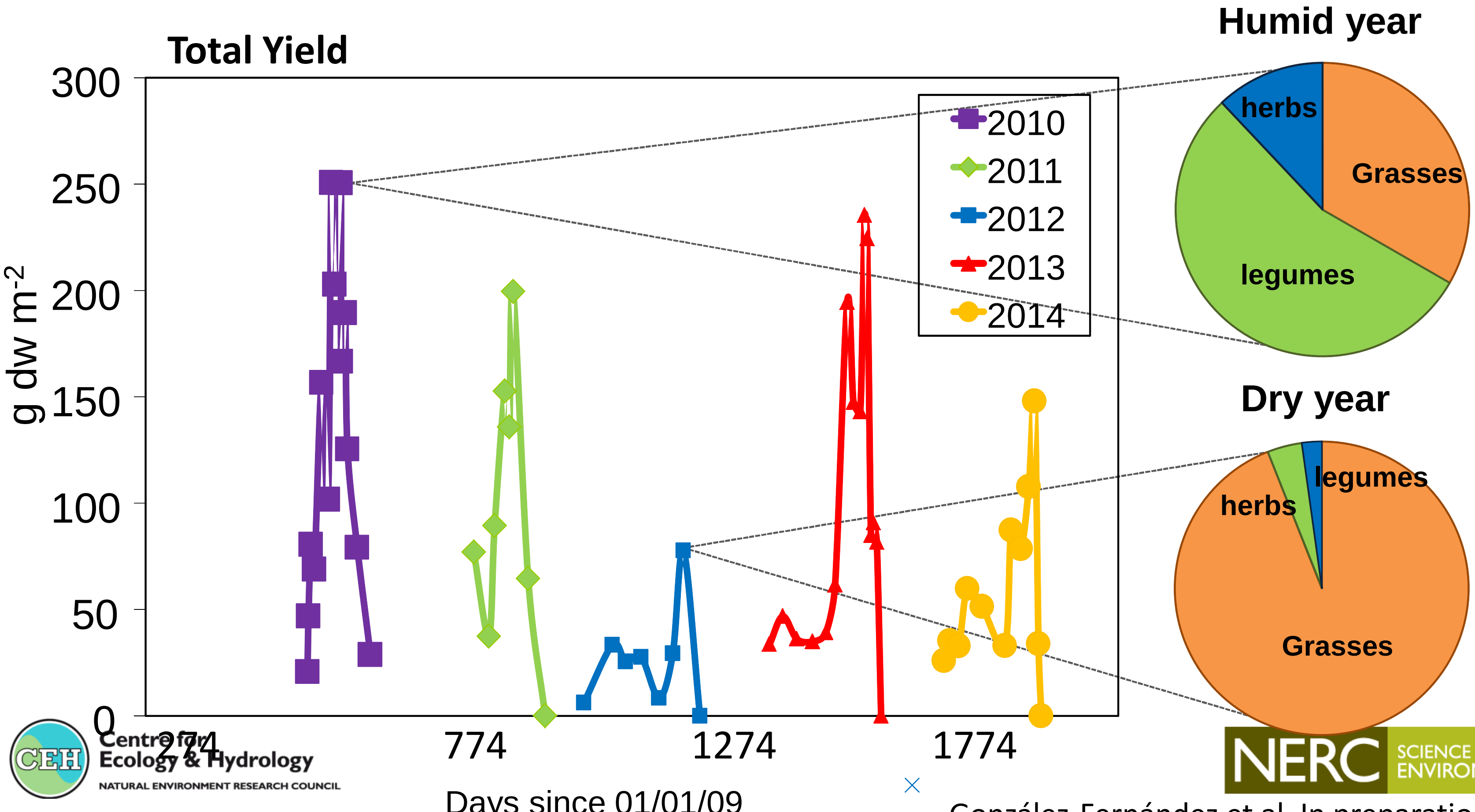
$J_{max}$ = max. rate of photosynthetic electron transport

# Climate/Annual pastures

climate

**FIELD STUDIES**

- ✓ High inter-annual variability on species structure and composition
- ✓ Soil moisture: key variable for growth and species structure/composition
- ✓ **Dry years: less yield and quality (less legumes)**

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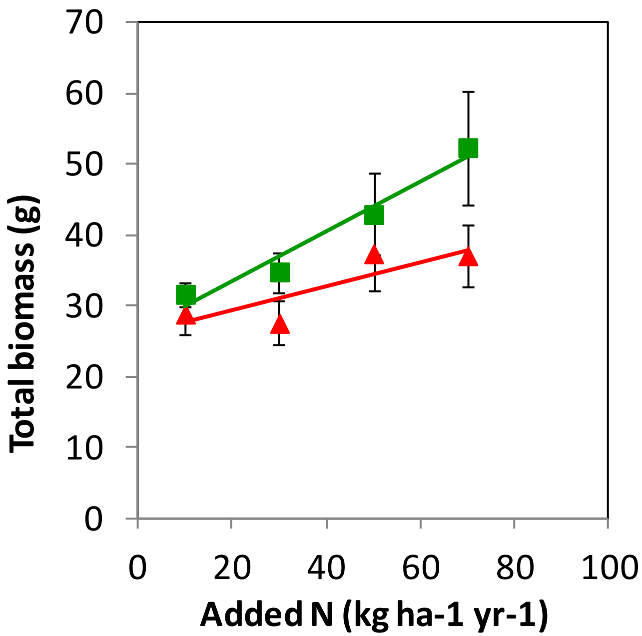
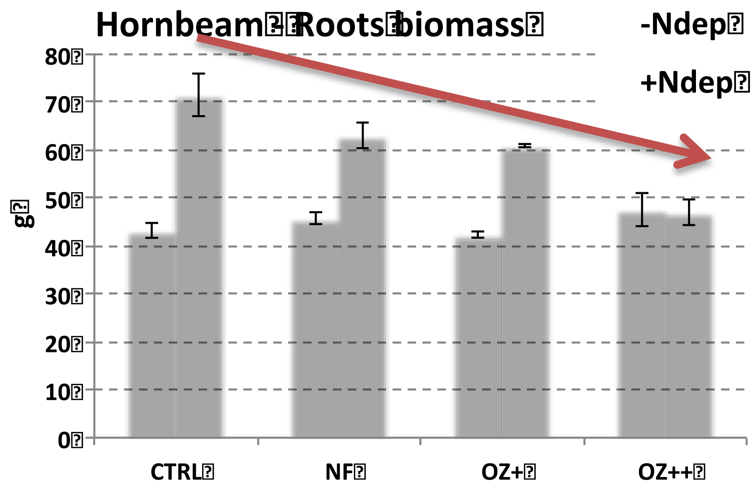
González-Fernández et al. In preparation

# KM2 example 1 : Deciduous tree species




- Silver birch, CEH expts

*Hayes et al., ECLAIRE, unpublished*




- Hornbeam, UNICATT expts

*Gerosa et al., ECLAIRE, unpublished*

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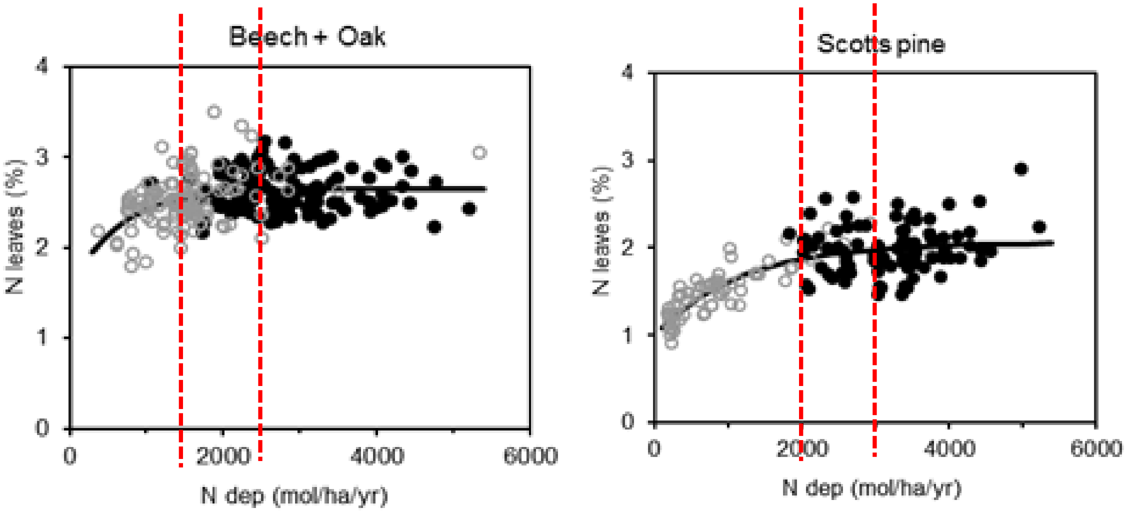
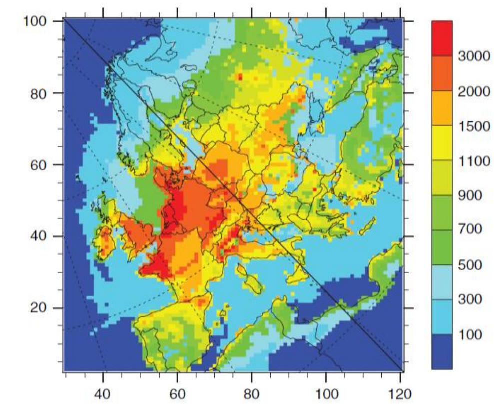
# Mapping $O_3$ and N risk across Europe – possible options

Relationship between N concentrations of N in leaves in beech+oak and Scots Pine from ICP forest plots. DeVries et al (2000).




+

Modelled N deposition (Simpson et al 2011)




…can be used to identify low, med and high leaf N regions across Europe

| | Coniferous (Norway spruce) | | | Deciduous (Beech/Birch) | | |
|---|---|---|---|---|---|---|
| | Low N | Med N | High N | Low N | Med N | High N |
| **N deposition (mol/ha/yr)** | < 2, 000 | 2, 000 – 3, 000 | > 3, 000 | < 1, 500 | 1, 500 – 2, 500 | > 2, 500 |
| **Vcmax (μmol/m$^2$/s)** | 30 | 45 | 60 | 35 | 55 | 75 |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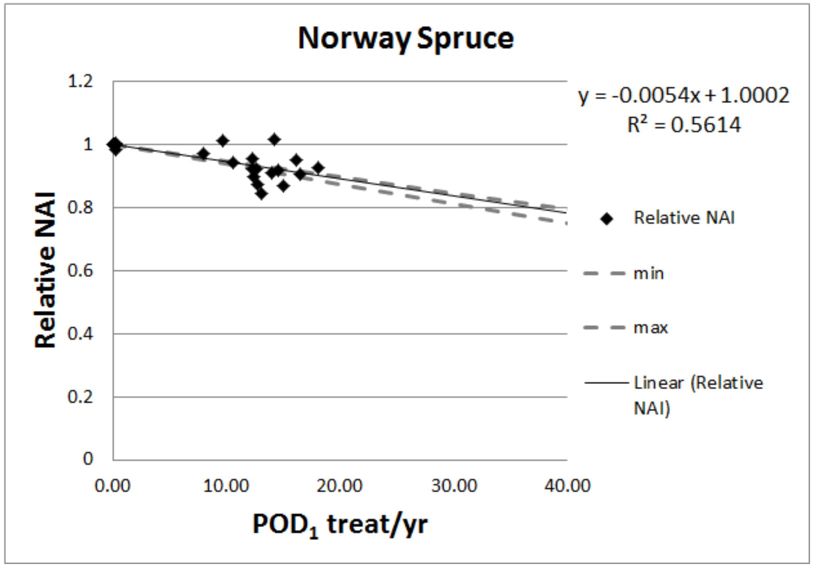
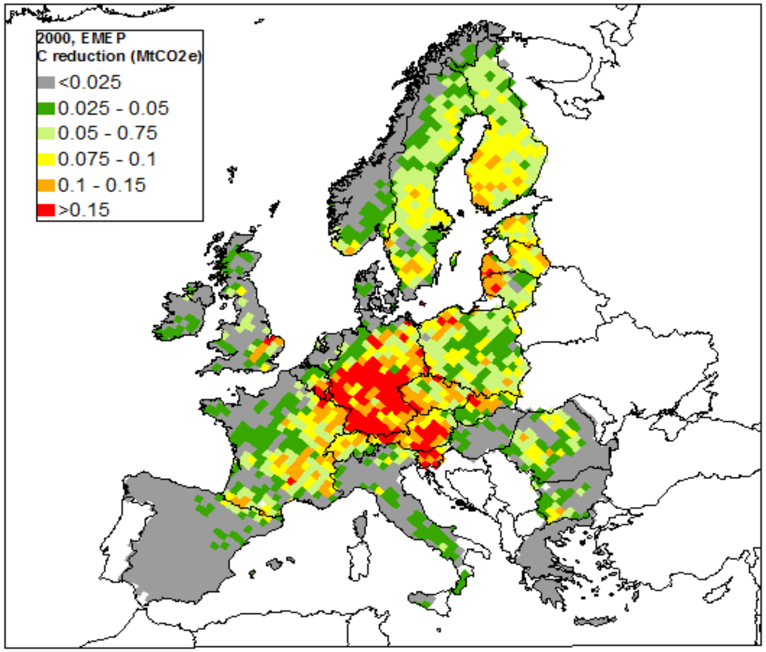
UNIVERSITY of York

# DO$_3$SE used to estimate O$_3$ damage on ecosystem services – C sequestration (living forest biomass)




Re-analysed existing dose-response relationships (DRRs) for forest trees for a new response parameter- Net Annual Increment (NAI)

The DRRs are used with European data to estimate changes in C stock comparing current with pre-industrial O$_3$ concentrations





**Lisa Emberson, Patrick Bűker, Alan Briolat**

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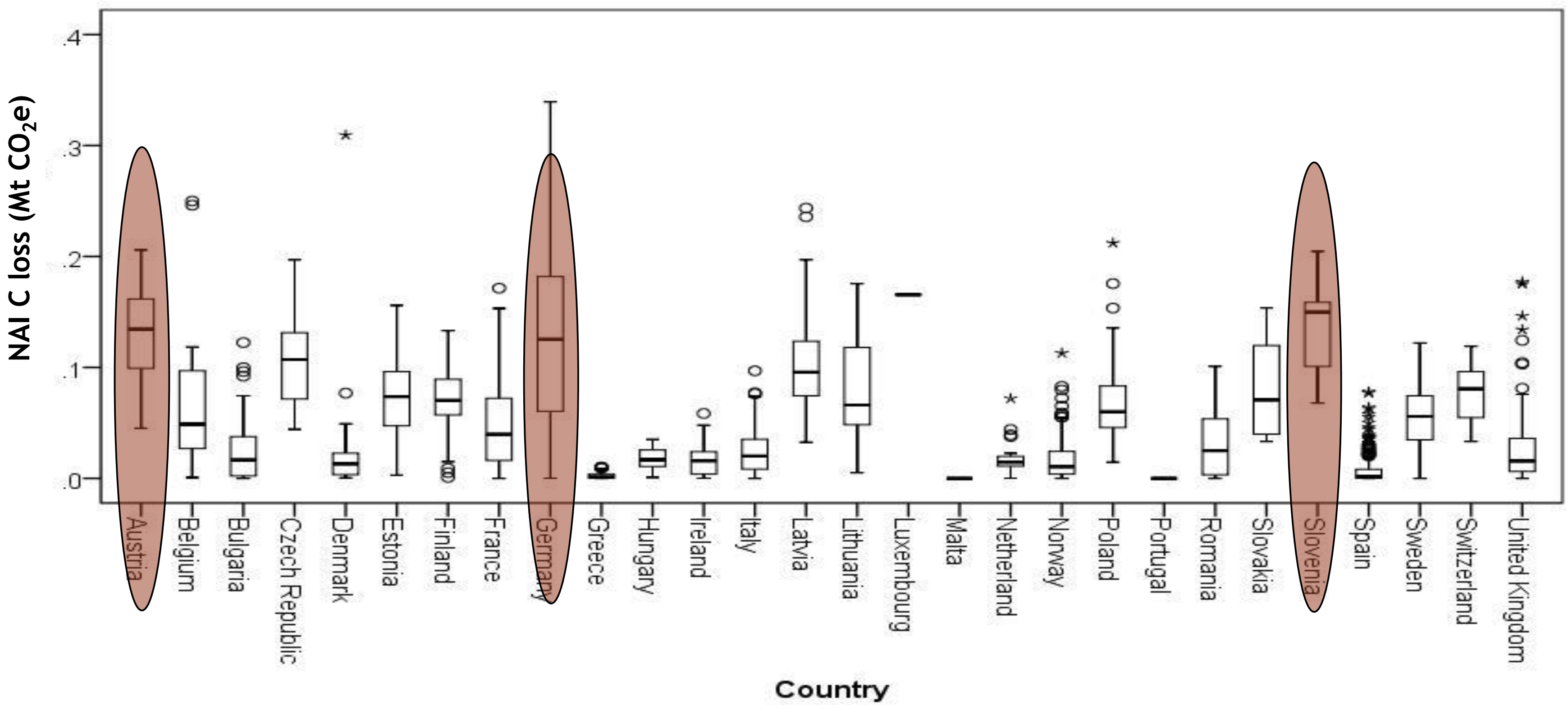
'ECLAIRE final meeting'
1-4 Sept 2015; Edinburgh

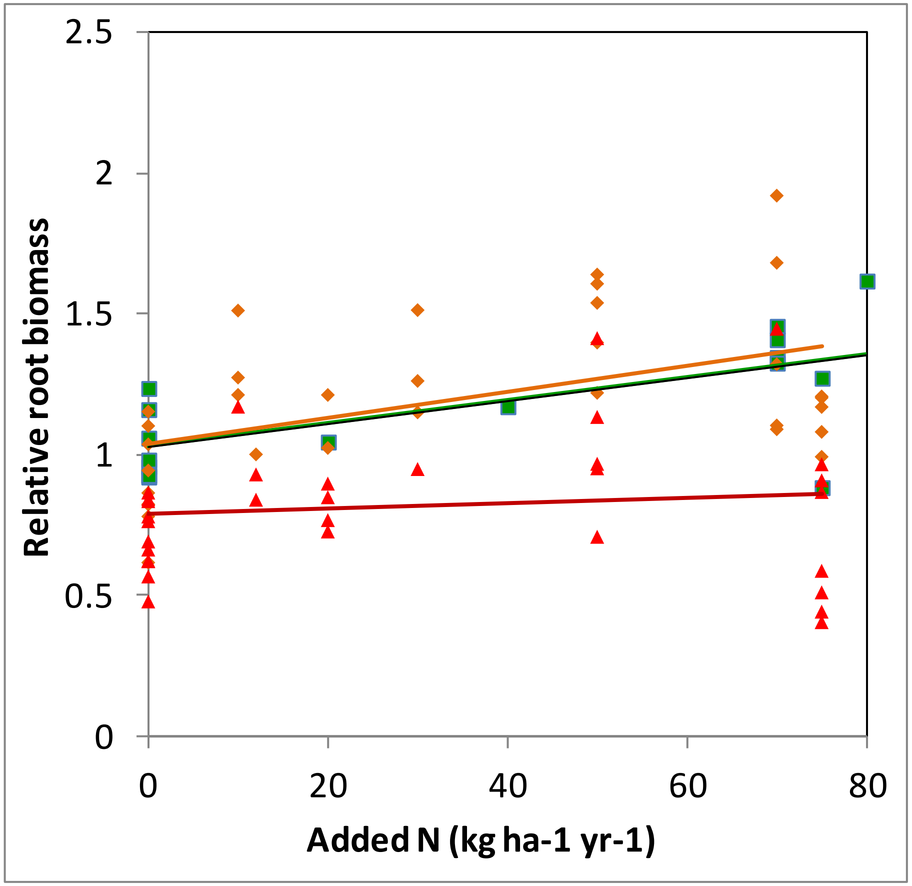
# Reduction in NAI ($NAI_{loss}$ ; Mt $CO_2$e) due to $O_3$ using 'detailed PFT' parameterisations




The countries most affected by $O_3$ (i.e. have greatest NAI C loss) are determined by their forest cover, size of NAI and PODy values


Lisa Emberson, Patrick Bűker, Alan Briolat

# KM2 e.g. Combined data from data mining and ECLAIRE experiments




## Root biomass

<u>Significance</u>

N effect: $p<0.01$

O3 effect: $p <0.01$

N x O3: ns ($p=0.16$)

Linear DR, $p <0.01$ for MFR and CLE; NoC ns

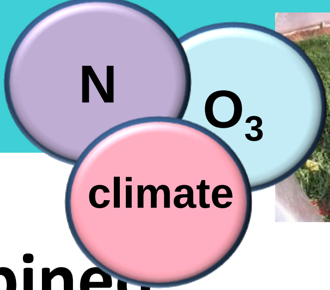
* Strong hint for loss of beneficial effect of N at high $O_3$

- < 35 ppb, "MFR"
- 40 – 55 ppb $O_3$, "CLE"
- 60 – 95 ppb, no $O_3$ controls ("NoC")

*Katrina Sharps, Gina Mills et al., CEH*

Data sources

| **Sources:** | **Species:** |
|---|---|
| Gerosa et al. (in prep) | *Quercus robur; Carpinus betulus* |
| Hayes et al. (in prep) | *Betula pendula* |
| Jones et al. 2010 | *Carex arenaria* |
| Thomas et al. 2005 | *Picea abies* |
| Watanabe et al. 2008 | *Castanopsis siebaldii* |
| Wyness et al. 2011 | *Ranunculis acris* |
| Yamaguchi et al. 2007 | *Fagus crenata* |

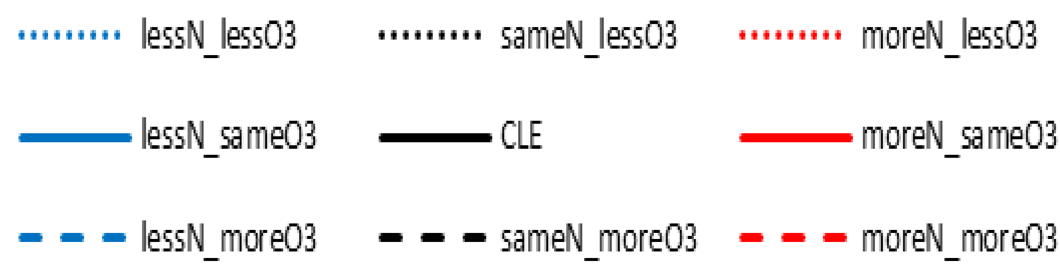


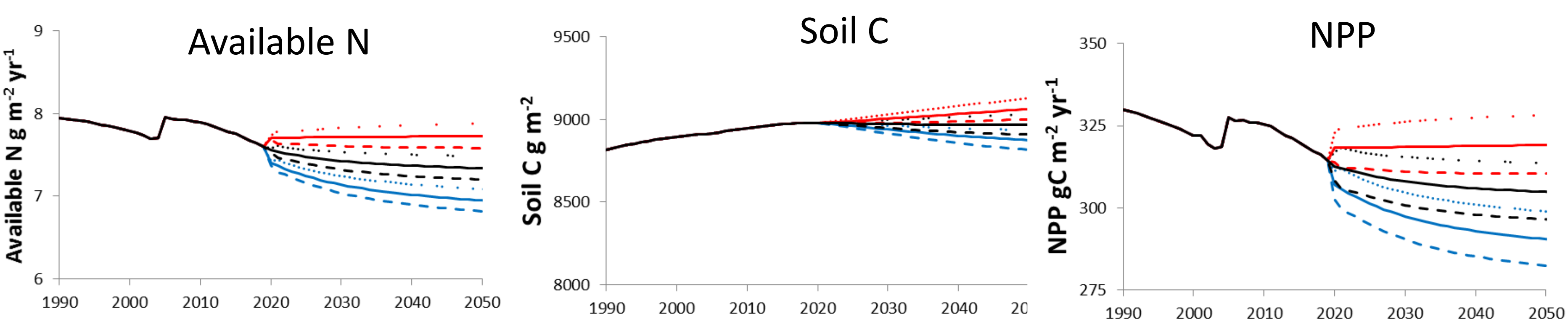
○ **How does climate change modify combined responses to O3 and N?**

**Example: Mediterranean annual pastures**

| Climate | $O_3$ effects | N effects |
|---|---|---|
| **HUMID year** (more clovers) | Higher $O_3$ flux<br>More $O_3$ sensitive spp | Less N-sensitive spp |
| **DRY year** (more grasses) | Lower $O_3$ flux<br>Less $O_3$ sensitive spp | More N-sensitive spp |

# KM4e: Combined effects – Whim bog


- More pronounced separation of $O_3$ effects on available N
- Beneficial effects of more N on NPP lost under +20% $O_3$
- Available N, soil C and NPP reduced the most under 20% less N and 20% more $O_3$

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Ed Rowe, Felicity Hayes, Chris Evans

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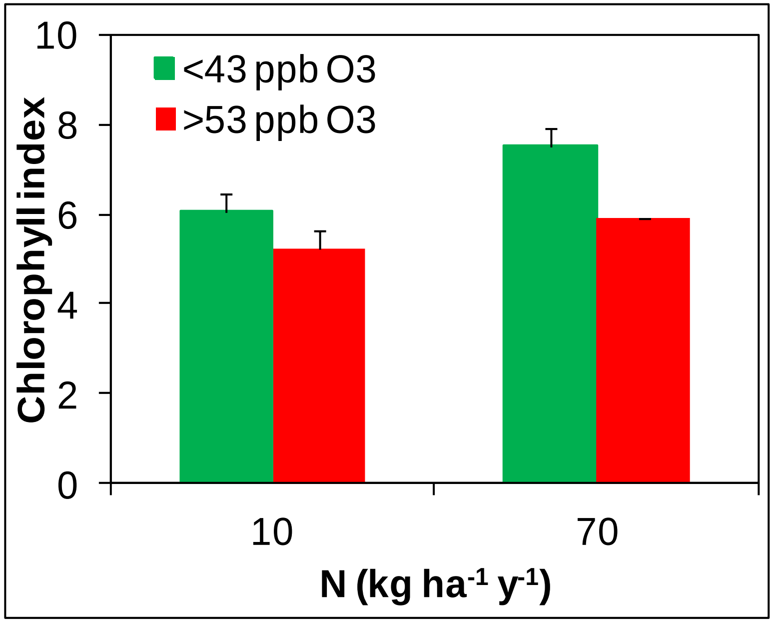
# KM1c: $O_3$ changes litter quality

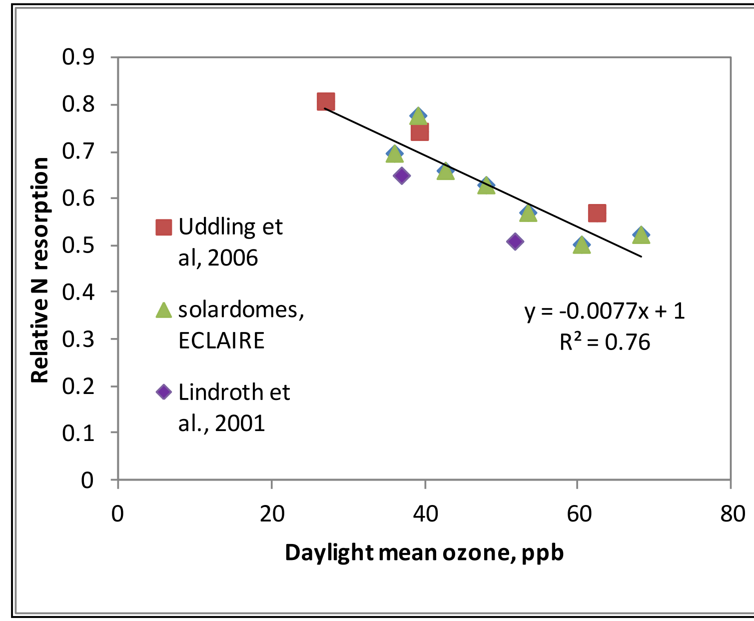
**Chlorophyll content of autumn leaves**




**Silver birch, CEH, September 2014**

- At low ozone, leaves are greener with the high N treatment
- Leaves are less green in higher O3, and there is no beneficial effect of added N

**Resorption of N from leaves prior to leaf fall**




**Combined data set (ECLAIRE data mining)**

- At higher ozone concentrations, less of the leaf N is transported back into the tree before the leaves fall
- Implications for soil processes

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*Hayes et al., ECLAIRE, unpublished*

*Karlsson, Hayes, et al. ECLAIRE, unpublished*