The sensitivity of vegetation and soil processes to drought and warming and the consequences for C sequestration

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Short and long term effects of climate change

• Short term direct effects:
  – ANPP and SR

• Longer term indirect effects, asymmetry and ‘carry-over’ effects due to:
  – Response time of pool longer than length of event
  – Ecological changes due to change in plant and soil community
  – Lack of rewetting due to precipitation patterns and runoff due to a change in soil physical properties
Pre-disposing and modulating factors?

- Ambient climate (i.e. current limiting factors)
- Vegetation characteristics
  - Stability vs dynamic
  - Pre-conditioning or exacerbating events (e.g. insect infestation)
  - Plant functional types or strategies
- Soil characteristics which affect onset and modulation
  - Soil parameters which affect plant available water
  - Soil functional types or strategies
What are the conclusions of past syntheses?

Rustad et al. 2001; Walter et al. 2002; Knapp et al. 2008; Wu et al. 2011 etc:

• C fluxes
  – Reduction in precipitation reduces ANPP and biomass by ca. 20-30%
  – Warming increases biomass and TNPP by ca. 20-30%

• Pre-disposing or interfering factors
  – No effect of experimental approach or length of experiment
  – Variable effect of ambient climate/limiting factors
  – Physiological traits indicates predictive direction of change for ca. 80% of species
  – No other consistent factors identified

But few experiments > 5 years long
The Increase network

- 7-12 year long experiments = long term indirect effects
- Use a common approach so reduces interference from methodology
- Modest treatments (we didn’t want to kill anything immediately)
  - -20% rainfall during main growing season
  - +0.5 –to 1 °C
- Contrasting sites

www.increase-infrastructure.eu
The experimental design

-- 20 m² plots
-- 3 replicates for each treatment
-- since 1998/2001 to 2012
Climatic range of the site network

(Penuelas et al. 2007)
Our questions

• Are soil or plant biota more sensitive to climate change in the long term?

• What are short and long term implications for C sequestration?

• Can this be predicted from ambient climate?

• Are there other pre-disposing or interfering factors which influence outcome?
Hypotheses

Warming

Greater sensitivity of decomposition relative to plant production in northern latitudes (Kirshbaum 1995)
Hypotheses

Warming
Greater sensitivity of decomposition relative to plant production in northern latitudes (Kirshbaum 1995)

Net C loss
Decomposition
Plant production

Temperature
Cold Hot

Drought
Greater relative sensitivity of ANPP relative to decomposition in more arid climates (Ågren et al. 1996)

Net C loss
Decomposition

Aridity index
Wet Dry
Measurements

- **Biomass**
  - Annual pin pointing

- **Litterfall**
  - Litterpots or from sensing material

\[
\text{ANPP} = \Delta \text{ above-ground biomass + litterfall}
\]

- **Soil respiration**
  - IRGA
Response after 7-12 years

Xeric sites; Hungary and Italy
Xeric (Hungary and Italy)

**Hungary: Biomass**

**Hungary: Litter**

**Hungary: Soil respiration**

<table>
<thead>
<tr>
<th>Change relative to control</th>
<th>Drought</th>
<th>Warming</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass</td>
<td>-28%</td>
<td>+18%</td>
</tr>
<tr>
<td>ANPP</td>
<td>-34%</td>
<td>+32%</td>
</tr>
<tr>
<td>SR</td>
<td>+2%</td>
<td>+5%</td>
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</tbody>
</table>

ANPP more responsive than soil respiration
Equal sensitivity to drought and warming
Acclimation or carry-over effects?

Treatment effect relative to control over time

**Hungary: ANPP**

- $y = -7.3091x + 14683$
- $R^2 = 0.38169$

**Hungary: Soil respiration**

- $y = -1.176x + 2365.3$
- $R^2 = 0.60684$

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Response after 7-12 years

Mesic site; Netherlands
Mesic (Netherlands)

Change relative to control

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<tbody>
<tr>
<td>Biomass</td>
<td>-21%</td>
<td>+13%</td>
</tr>
<tr>
<td>ANPP</td>
<td>-15%</td>
<td>-7%</td>
</tr>
<tr>
<td>SR</td>
<td>-22%</td>
<td>+6%</td>
</tr>
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Vegetation and soil respond in parallel
More responsive to drought
Acclimation / carry over effect only observed in soils

Treatment effect relative to control over time

**NL: ANPP**

- **D-C**
- **W-C**

**NL: SR**

- **D-C**
- **W-C**

R² = 0.51158

R² = 0.78711
Response after 7-12 years

Mesic site + pests; Denmark
Calluna Dieback Due To Heather Beetle (DK)
Mesic + pest (Denmark)

Vegetation and soil respond in parallel (as in NL)
More responsive to drought (as in NL)
Drought exacerbated by pest outbreak (x2 NL)
Acclimation / carry over effects differ between vegetation and soil

Treatment effect relative to control over time

DKs: ANPP

DK: SR
Response after 7-12 years

Hydric site; UK
Hydric (UK)

**UK: Biomass**

**UK: Litter**

**UK: SR**

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<th>Warming</th>
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<tbody>
<tr>
<td>Biomass</td>
<td>+9%</td>
<td>-1%</td>
</tr>
<tr>
<td>ANPP</td>
<td>-11%</td>
<td>-3%</td>
</tr>
<tr>
<td>SR</td>
<td>+9%</td>
<td>+8%</td>
</tr>
</tbody>
</table>

Vegetation and soil respond in opposite directions
Responsive to both drought and warming
Ongoing positive carry-over in soil responses

Treatment effect relative to control over time

UK: ANPP

UK
Analysis cross-sites

Does the aridity index or MAT provide any predictive power?
ANPP response is well predicted by aridity index.
SR is not; response appears to be decoupled from ANPP
ANPP response to warming is related to MAT

Change in ANPP in response to warming along a MAT gradient
SR responds in opposite direction

Change in ANPP and SR in response to warming along a MAT gradient
Conclusions

• Drought
  • Drought reduced ANPP by 11-47% with greatest sensitivity in most xeric sites but had maximum effect on SR in sites mid-range of aridity gradient (-22 - +9%)
  • Loss of carbon will be greatest at the extremes of aridity gradient

• Warming
  • Warming increased ANPP by 0 – 32% with greatest sensitivity in warmer sites but had most effect on SR in colder sites (-2 - +8%).
  • More carbon stored in warmer sites and less in colder

• Vegetation and soil responses to climate treatments are decoupled in their responses and this is increasing over time due to carry-over effects

• Why? Direct change in soil communities and soil structure is at least one explanation
Thanks to the many funders over the years – EU and national

Questions?
Revisiting hypotheses

Greater relative sensitivity of decomposition to ANPP in response to warming in northern latitudes (Kirshbaum 1995)

Decomposition is more sensitive than ANPP in northern sites but unexpectedly large positive effect of warming on ANPP in southern sites

Greater relative sensitivity of ANPP to decomposition to drought in drier climates (Ågren et al. 1996)

Yes