Vulnerability assessment for European shrublands to climate change

Claus Beier
Risoe National Laboratory
Frederiksborgvej 399, DK-4000 Roskilde, Denmark. Email: claus.beier@risoe.dk

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Claus Beier  
Riso National Laboratory  
Frederiksborgvej 399, DK-4000 Roskilde, Denmark. Email: claus.beier@risoe.dk

Manipulator  
Years of experience in ecosystem manipulation studies at the field scale (acid rain, nutrients, climate change) and plot scale modelling

Biogeochemist  
Nutrients, C, N

Coordinator of CLIMOOR, VULCAN, EPRECOT, NitroEurope experiments  
+ New Danish CLIMAITE
Why?
Shrublands often vulnerable ecosystems
Climate change affects key biological processes, ecosystem functioning and ecosystem services
Manipulations often needed to know what happens

Conceptual problem
Involves at least CO$_2$, temp. and water = 3 factors
Experimentally challenging

What?
Climate change effects on key processes = services
Biogeochemistry, biodiversity and ecosystem/land protection
Future trends
Manipulation examples
Climate impacts on ecosystem processes and services

- **PLANT**: Plant chemistry, Nutrient storage, Root growth, Plant species change, Phenology, Fauna & Herbivory
- **SOIL**: C & N mineralisation, Nutrient cycling, Litterfall & decay, C storage, Mykhoriza, Soil fauna
- **Biogeochemistry**: Experimental work
- **Biodiversity**: Water quality, Biodiversity
- **Climate feedback**: Climate, Canopy Reflectance, Ecosystem CO2
- **Climate impacts on ecosystem processes and services**: Water quality, Plant chemistry, Nutrient storage, Root growth, Plant species change, Phenology, Fauna & Herbivory, Soil fertility, C & N mineralisation, Nutrient cycling, Litterfall & decay, C storage, Mykhoriza, Soil fauna, Drinking water
Ecological response to change in drivers over time

There may be several ways to get to the goal - important!!

Model testing
Biogeochemistry
N-balance
Possible biogeochemical effects of climate change

Elevated CO2
Elevated temperature

- decomposition of organic matter
- release of nitrogen
- acidification of soil and water
- fertilisation of soils, surface waters and coastal marine areas

emission of greenhouse gases
plant growth

Biology
Field scale manipulation of temperature and CO$_2$ in Norwegian forest ecosystem

KIM catchment
560 PPM CO$_2$
+ 3-5 °C air temperature (3.7)

Increased nitrogen mineralisation because of warming

Climate change has the potential to affect drinking water and surface waters

Ecosystem switches from N sink to N source
- biogeochemistry IS affected

Vulnerability assessment of shrubland ecosystems in Europe under climatic changes

A joint European research project funded by EU

Field scale warming and drying of heathland

Co-ordinator:
Claus Beier, RISØ National Laboratory, Denmark
Partners

Risoe National Laboratory – RISOE – Denmark – Claus Beier

Danish Forest and Landscape Research Institute – DFLRI – Denmark – Inger Kappel Schmidt

University of Amsterdam – UVA - the Netherlands – Albert Tietema

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Hungarian Academy of Sciences – IEB - Hungary – Edith Kovacs Lang

University of Wales – UWB – UK – Gareth Edward Jones

Natural History Museum – NATMUS - Denmark – Henning Pedersen
Precipitation

Temperature

United Kingdom

Italy

The Netherlands

Denmark

Spain

Hungary

Gradients
Gradients and treatments

**Nitrogen deposition**
- **N-dep (kg/ha/yr)**
  - Data points for UK, NL, DK, SP

**Growing degree days**
- **GDD per year**
  - Data points for UK, NL, DK, SP

Legend:
- Nitrogen deposition
- Treatment
- GDD
Drinking water quality in shrublands

Shrublands are generally “clean” – except at high inputs (here NL)

European drinking water limit
Interaction between N deposition and climate

Leaching response depend on N status (e.g. N deposition)

Climate change has the potential to affect drinking water and surface waters - but the effects depend on the nitrogen status (nitrogen saturated sites most likely to leach)

and nitrogen may limit growth response to climate change
Biogeochemistry
Other nutrients may determine the response to climate
Phosphorus limits plant growth response to climate in many areas (here NL) - progressive nutrient limitation (nitrogen often mentioned)

Nutrients may limit growth response to climate change

Progressive Nutrient Limitation (PNL)
Biology
Biodiversity
Effects on plant growth

Change in annual growth of single species

Species specific responses to warming - implications for biodiversity

Spain

-30 -25 -20 -15 -10 -5 0 5 10 15

Warming change (% of control)

Species 1
Species 2
Species specific and season specific growth response

Stem longitudinal increment growth (cm)

Annual

Erica multiflora

Globularia alypum

2002 2003

Species specific and season specific growth response
Warming by 1 deg. increases *Calluna* cover whilst *Empetrum* declines.

Why?

- *Empetrum* declines with winter warming.
Leaf unfolding advanced under warming
– species specific response

Vegetative growing phenology

Control vs warming

Growing branches (%)

Erca multiflora

Globularia alypum

Leaf unfolding advanced under warming – species specific response
Biological effects – why does species change

Change in phenology in Denmark – grasses
Seasonality changes – spring starts earlier

Mean leaf length/shoot (mm)

- con
- drought
- heat

Apr | May | Jun | Jul | Aug | Sep
Climate change has the potential to affect phenology (timing)
- different species respond differently
- potential mechanism for species change
- poorly understood and not included in models

Advanced leaf unfolding by warming
- may be an advantage for some plants
Warming has the potential to affect herbivory – often species specific attacks = different species affected differently.

Herbivory - responds to warming
Climate change has the potential to affect recruitment of new species – implications for biodiversity.

Loss of species in Spain with (warming) and drought

Species change - biodiversity
C-balance
C-balance and climate change

Atmospheric CO$_2$

Soil resp

Biomass uptake

Which one is most reactive to climate change??
Carbon loss

Soil resp
- we expect soils and plants to be sensitive to warming – most in North
- and soils to be more sensitive than plants – especially at colder climates
Increased carbon loss at northern sites, reduced loss in southern sites

Climate change has the potential to affect carbon loss – but the response is not equally strong at all climates.
Theoretical sensitivity of soil respiration to warming confirmed across Vulcan sites

\[ R^2 = 0.6675 \]

Q_{10} of control plots vs. Mean annual air temperature (deg. C)
Climate change has the potential to affect carbon loss – but the response is not equally strong at all climates.
15% loss in the amount of carbon in the top soil in Denmark … and this is with only moderate climate treatments.
Drought increases soil C loss in Wales over **ALL** the years
..and causes a long term change in the capacity of soil to hold water (Wales and NL)

Drought has the potential to affect carbon loss – general reduction except at wet sites - it has the capacity to change soil structure.
Carbon gain

Biomass uptake
RESULTS

Total aboveground biomass (1998-2000)

Warming Change (% of control)

Drought Change (% of control)

Wales  Netherlands  Catalonia

Wales  Netherlands  Catalonia

↑ 1°C -> ↑ 15% biomass production in warming plots in Wales
↓ 22% -> ↓ 14% biomass production in drought plots in Garraf
Carbon gain

Long term gradient – what if species change?
Short term experiment – what if species change?
Soil respiration and plant growth - relationship to temperature

Warming has the potential to increase growth
– mainly at colder sites (on the short term)
– response stronger than expected

- we still do not know which C process is the strongest

Opposite to expectations - asynchrony
Biological effects

Reduced plant cover in southern countries will increase erosion risk. Warming and drought has the potential to reduce plant cover at warm sites, increased risk for soil erosion in Spain.
Relatively more dead plants (HU)
more fuel - increased fire risk

Drought has the potential to increase dead
plant material fraction
– increased risk for fires
Vulnerable Mediterranean regions
Recurrence of fire – 1975-1995 (>30ha)

Recurrència d’incendis >30 ha
1975-1995
Break?
Vulnerability assessment – interactions with other factors
Before heather beetle attack

After heather beetle attack

Ecosystem disturbances

Ecosystem disturbance =

Heather beetle infestation 1999 - 2000 + complete harvest September 2000

Complete harvest of all aboveground vegetation to promote regrowth of Calluna
Effect on mineralisation

Net N-mineralisation - Mols

Beetles stimulate mineralisation

Warming/grazing stimulates mineralisation
Effects on soil solution

Warming (& beetles) stimulates leaching in O-layer

Beetles & cutting cause leaching

Warming induced plant growth increase retention
Retention of nitrogen in the soil at Mols - 1999 & 2000

Beetles induce short term high loss
12 Million in Wales

Sheep numbers in Wales 1867-1990

And double the weight
• 1 sheep hoof = pressure of tractor
• Implications for soil-plant water relations?
• And carbon?....15% reduction in soil carbon across the UK; Bellamy et al. 2005, Nature
• Management, climate change or perhaps a combination?
Interaction between grazing and summer drought

- Look at the interactive effects of summer drought and different grazing pressures.

- 12 large paddocks, 3 levels of grazing applied, drought shelters in each.
Threshold for net C fixation

\[ y = 0.0046x^2 - 0.3411x + 3.8801 \]
\[ R^2 = 0.6217 \]

\[ y = 0.0009x^2 - 0.0986x + 1.2693 \]
\[ R^2 = 0.6032 \]

\[ y = -0.0038x^2 + 0.2424x - 2.6088 \]
\[ R^2 = 0.6679 \]
Grazing x drought

- Grazing can:
  - reduce infiltration rates
  - decrease soil OM content
  - cause shallower root systems (in arid can lead to deep-rooting shrubs)
  - change vegetation structure

- Consequences for water:
  - reduces water stored in soil
  - reduces water holding capacity of soil
  - reduces access to water
  - change in rooting patterns, canopy structure etc
Effects of disturbance

- can cause significant increase in nitrogen mineralisation – bigger than warming
- periodically affect soil water quality (drinking water)
- reduced retention of nitrogen
- Change in soil structure, water holding capacity and plant growth conditions
- dramatic changes in ecosystem characteristics (new ecosystem type) – probably dependent on ecosystem status before disturbance

Interactions need to be taken into account
Climate change is a multifactor problem
All you have seen so far was based on single factor experiments
Next generation experiments
Multifactor experiment

CO2 (FACE) warming, water and N
at Jasper Ridge, US
Effects of elevated CO$_2$, temperature and altered precipitation – effects are not additive

Maybe because of soil-plant interactions – e.g. microbial removal of nutrients
A new Danish multifactor project

www.climaite.dk
CO₂, temperature and water manipulations

- Ambient CO₂
- 510 ppm CO₂
- +2 °C
- Summer drought
CO₂, temperature and drought

- Water exclusion (summer)
- Control
- "0"
- +/- H₂O
- +T

- Passive Night time warming

- CO₂ FACE
- Control
- CO₂
- +/- H₂O
- +T
- +/- H₂O

- CO₂
- +T

- CO₂
- +/- H₂O

- CO₂
NitroEurope

Interactions between C & N
Implications for greenhouse gas emission (CH4 & N2O)

14 super sites (gradient approach)
22 manipulation sites (”what if drivers change”)
3 level modelling
Shrublands ARE vulnerable to climate change – individual processes as well as general functioning and structure of drinking water, C balance, soil structure & fertility, fire risk & desertification, biodiversity.

Long term effects may not be like the short term effects.

Key uncertainty: potential change in species composition of new ecosystem = new processes.

Interactions can be quite strong and other factors may be just as important.
Very different risks identified for different countries and areas (urbanisation, abandonment etc)
In Spain, erosion the greatest concern for people

2 degree warmer
Spain
36 - 69 Euros/person/year
### Conclusions – climate change and service threats

#### Biogeochemistry
Climate change has the potential to affect drinking water and surface waters
- but the effects depend on the nitrogen status
- and nitrogen (nutrients in general) may limit growth response to climate change

#### Carbon storage
Warming has the potential to increase carbon loss from soil – most in cold sites and less in warm (maybe even negative)
Drought generally reduce C loss from soils, except at wet sites – but also interaction with plant growth
Warming has the potential to increase growth at colder sites on the short term – and response stronger than expected

#### Biology
Climate change has the potential to affect species composition – implications for biodiversity
(species and season specific responses – e.g. phenology, winter temperature, herbivory)

#### Soil structure – growth media
Warming has the potential to reduce plant cover at warm sites – increased risk for soil erosion
Drought has the capacity to change soil structure. + Interactions with disturbance and LU

#### Fire protection
Drought has the potential to increase dead plant material fraction – increased risk for fires
Experimental manipulations and climate change
Questions to the biodiversity community

Discussions

Getting from the plot to the landscape

Biodiversity – measurements and modelling – how do we include it?

Genetics and adaptation – is genetic diversity parallel to species diversity?

How do we compare climate and LUC? (and other drivers)
The end
N mineralisation is primarily controlled by soil moisture

Soil moisture content, %

Mineralisation, mgN kgC$^{-1}$ day$^{-1}$

ES, NL & DK, UK
This contrasts soil respiration - so an asymmetry in response of C and N cycles.