The effects of climate change on vegetation

Václav Treml

Department of Physical Geography and Geoecology
treml@natur.cuni.cz
Assessing species vulnerability to climate change
Michela Pacifici et al.

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Increasing forest disturbances in Europe and their impact on carbon storage
Rupert Seidl1,*, Mart-Jan Schelhaas2, Werner Rammer1, and Pieter Johannes Verkerk3


European phenological response to climate change matches the warming pattern
ANNETTE MENZEL*, TIM H. SPARKS†, NICOLE ESTRELLA*, ELISABETH KOCH‡,

LETTER
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Declining global warming effects on the phenology of spring leaf unfolding
Yongshuo H. Fu1,2, Hongfang Zhao1, Shilong Piao1,3,4, Marc Peaucelle5, Shushi Peng1,2, Guiyun Zhou4, Philippe Claessens5-7, Mengtian Huang1, Annette Menzel1, Josep Penuelas5,9,10, Yang Song1, Yann Vitasse12,13,14, Zhenzhong Zeng1 & Ivan A. Janssens2
Recent climatic trends (Central Europe)
Climatic projections

Absolute Change in Moisture Index (Precipitation-PET) (mm/yr)

Change (mm/yr)
- < -500
- -499 - 400
- 400 - 300
- 300 - 0
- 0 - 100
- 100 - 200
- 200 - 300
- 300 - 400
- 400 - 500
- > 500

STD DEV
- High: 356.994
- Low: 0

Precipitation-PET

Duration of drought days

Annual Maximum Continuous Dry Days (CDD) Mean 1961-1990

Change in Mean Duration of Annual Maximum Continuous Dry Days (CDD) 2070-2099
Species vulnerability to climate change

**Exposure** – degree of climatic variation

**Sensitivity** – Changes in species range, population change, change in probability of extinction

Concentration of vulnerable species
Climate influence on plants
1) Photosynthesis and 2) growth

PHOTOSYNTHESIS

- Solar Energy
- CO₂ Absorption
- Release of Oxygen
- Absorption of water and mineral salts

[Graph showing treeline and timberline over years 2010, 2011, and 2012]
Climate change and vegetation

- Increasing temperature (growth, photosynthesis)
- Increasing drought stress (growth, photosynthesis)
- Increasing CO$_2$ concentration (photosynthesis)
- (increasing nitrogen deposition) (growth)
**CO₂ and forests**

**FOREST CARBON CYCLE**

In 1990-2005, Europe’s 1.5 million square kilometres of forests absorbed about 100 teragrams of carbon more each year than they released, or 10% of the region’s fossil-fuel emissions. Carbon is absorbed by growing trees and is released during decomposition and burning. Wood products act as a temporary carbon sink, and can substitute for fossil fuels.

**GLOBAL LAND SINK**

The quantity of carbon absorbed by trees and other types of vegetation per hectare of land has risen in the past 50 years as anthropogenic carbon dioxide and nitrogen emissions have grown. This is despite the world’s forest area falling by around 2% since 1990.
Trends in tree biomass (Central Europe)

Overall increase in tree size
Increasing water-use efficiency due to CO$_2$
Changes in growth-climate responses

A Temperature
B Precipitation
C Vapor pressure deficit
D SPEI
Projected changes in climatic variable driving growth
Changing growth
Plant phenology

Growing season length
*Phenological gardens*
Germany +6.6 days (1951-1996)
Switzerland +13.3 days (1951-2000)
Japan +12 days (1953-2000)

*NDVI*
Eurasia +18 days (1981-1999)
North America +12 days (1981-1999)
Growing season in treeline Norway spruce
Shifting species ranges

- Expansion of drought-adapted species (*Quercus ilex*) at the expense of *Fagus sylvatica* in NE Spain (trailing edge of *F. sylvatica* distribution);

- Expansion of *F. sylvatica* at the expense of the heathlands (*Calluna vulgaris*) leading edge of species distribution.
Biotoc inertia & climatic velocity
Climatic limits of temperate trees

Growing season length vs. freezing resistance
Northern limits of distribution of broadleaf trees

Fagus

Acer
Disturbances
Changing frequency of disturbances
Severity and size of disturbances

Max. Severity (%)

1s  10s  100s  1000s+
Max. Size (ha)

Alps
Apennines
Balkan Peninsula / Bulgaria
Bohemian Forest
Carpathian
Dinaric
N. Fennoscandian (birch)
N. Fennoscandian (conifer)

Wind  Insect  Fire  Avalanche
Example: Growth-climate response of Norway spruce in CZ
Example: Growth-climate response of Norway spruce in CZ
Example: treelines
Treeline terminology

ULCF

Alpine treeline

Tree species line

treeline ecotone
Why are treelines formed?

Because of decreasing temperatures along elevation gradients.

**Hypotheses focusing on tree growth**

- Source-limited growth
  - Insufficient amount of assimilates, nutrients
- Sink-limited growth
  - Inability to invest carbon and nutrients into new tissues

**Hypotheses focusing population dynamics**

- Seed production/viability
- Seedling establishment
- Seedling survival

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Christian Körner

*A re-assessment of high elevation treeline positions and their explanation*
Treelines are advancing upwards and polewards in consequence of warming.

Consequences for
- Surface albedo
- Species distribution
However, there are also stable treelines
(~ 46 % according to Harsch et al. 2009 in Ecology Letters)

Why?
• Not all treelines are probably exclusively temperature-limited
Treeline form reflects prevailing limiting mechanism of tree occurrence in cold environment. *(Harsch and Bader 2011, Glob. Ecol. Biogeogr.)*

**Diffuse** treeline – temperature limited growth  
**Abrupt** treeline – establishment limit (seedling mortality)  
**Krummholz** treeline – high biomass loss
Krummholz
Niwot ridge - south
Diffuse Rollins pass
Abrupt
Berthoud pass
Upward shift of treeline in Europe (1950s-2010)

![Graph showing the relationship between upward shift in m yr⁻¹ and temperature increase with an $R^2 = 0.453$]
Land-use change and temperature increase

Tree establishment and land-use

![Box plots showing recruitment residuals at different land-use stages: Absent, Abandon, In use at Timberline, Treeline, and Outpost treeline.]
Take-home messages

- Plants are increasing their productivity in response to CO$_2$ and warming;
- Plant growth is increasingly limited by drought (however WUE helps);
- Spring phenology is earlier;
- Plants are changing their distribution, however there are differences between leading and trailing edges; biotic inertia matters;
- The frequency of disturbances is increasing (facilitate species shifts);
- Cold-adapted plant communities response relatively most sensitively.