Biodiversity responses to past changes in climate

Guy F Midgley

SANBI
Climate change is nothing new (Milankovitch theory)
We live in an unusual, stable climate

We live on a predominantly cool-adapted planet!
How do we know all this?
Ice cores can tell us about prehistoric climate conditions.
Highly variable Northern Hemisphere temperatures reconstructed from low- and high-resolution proxy data

Anders Moberg¹, Dmitry M. Sonechkin², Karin Holmgren³, Nina M. Datsenko² & Wibjörn Karlén³

[Graphs and maps showing temperature anomalies and reconstructions over time.]
Measurements of global CO$^2$ levels from Mauna Kea Observatory in Hawaii have been increasing steadily since recording began in the 1950s.

Analysis of ice cores shows that current CO$^2$ levels are significantly higher than at any time in the past 450 000 years, and should be doubled by the middle of this century.

It is clear that this effect is anthropogenic (caused by human activity).
How might these changes have affected biodiversity?
Global features, Last Glacial Maximum (21-18 kbp)

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Historic pollen distributions

21.5 ka, 17 ka, 11.5 ka, 7 ka, Modern (0.5 ka)

A. Spruce Pollen

B. Oak Pollen

- 5-20%
- 20-40%
- >40%
- Laurentide Ice Sheet

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Current biodiversity reveals the imprint of these changes

Climate reconstruction – Temperature

General Circulation Model (CCM0)

- 6 kBP: + 0.05°C
- 12 kBP: - 1.82°C
- 18 kBP: - 3.67°C
Climate reconstruction – Rainfall

(a) N–S displacement

Tyson (1999)
Climate space modeling, bioclimatic modeling, niche modelling

Species/biome distribution

Maximum temperature

34° 36°

Max temp envelope

# records

Maximum temperature

34° 36°
Fynbos bioclimatic envelope

Correctly modelled = 0.76

MAR, Tmin, WB, %Win rain
Succulent Karoo bioclimatic envelope

Correctly modelled = 0.75

- Model Correct
- Model Errors
The succulent Karoo biome advanced as temperature increased.
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Pollen evidence?

Shi et al (1998)

------------- traces of both groups -------------

Restionaceae
Ericaceae

Time (kya)
Centres of endemism and stable climate

From Lovegrove (1993)

18 k BP
Karoo plants evolved incredibly fast.

Unmatched tempo of evolution in Southern African semi-desert ice plants

C. Klak\textsuperscript{1}, G. Reeves\textsuperscript{2} & T. Hedderson\textsuperscript{1}

\textsuperscript{1}Bolus Herbarium, Department of Botany, University of Cape Town, 7701 Rondebosch, South Africa
\textsuperscript{2}Leslie Hill Molecular Systematics Laboratory, Kirstenbosch Research Centre, National Botanical Institute Cape Town, Private Bag X7, 7735 Claremont, South Africa
Recent diversity is huge

letters to nature

NB: this dendrogram describes only the evolution of Ruschias, not all mesems.
What about CO$_2$ and other effects?
Savannas: CO2 and fire
Factors of a mechanistic model

- Climate
- CO₂
- PHYSIOLOGY
- BIOPHYSICS
- WATER & NUTRIENT FLUXES
- Soil
- DISTURBANCE
- PLANT STRUCTURE & PHENOLOGY
- VEGETATION DYNAMICS
DVM – dynamic vegetation model

Cover 1995
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Sheffield DGVM

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<th>ha</th>
<th>C3</th>
<th>C4</th>
<th>EvB1</th>
<th>EvN1</th>
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<td>10.7</td>
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Sheffield DGVM (Woodward)

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Climate

CO$_2$, N

Physiology

Biophysics

Water & Nutrient Fluxes

Plant Structure & Phenology

Vegetation Dynamics

Soil

The role of fire in Savanna ecosystems

Fire on

Fire off!
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Global distribution of fire in 1998

mapped by ATSR-2 World Fire Atlas (European Space Agency)
CO₂ crisis for C₃, woody plants
Low CO$_2$ limits tree growth relatively more than herbaceous plant growth
Under a fire regime, woody plants over a certain height may survive burning.
Simulated effects of CO$_2$ on stem height (Mesic savanna)

Bond & Midgley 2001, Global Change Biology
Implications and tests

- Past contraction of woody elements with low CO$_2$ (180ppm) – paleoecological record
- Bush encroachment since the pre-industrial, and into the future – empirical experiments
Modelled tree cover response to CO₂
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Empirical experiments

Barney Kgope NBI
Low \( \text{CO}_2 \) discriminates against woody plants.

Acacia karroo

550 ppm  180 ppm
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High CO₂ boosts productivity
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CO₂ level controls carbon investment in defenses

Thorn length

Foliar [tannin]

Response ratio (370 ppm)

[CO₂] ppm
Plant response

- Trees have increased in grasslands worldwide.
- Open savanna, S. Africa, 1955
- Same place, 1998
Conclusions

- Climate and CO$_2$ has changed in the past – sometimes rapidly!
- However, for the past 2 million years change has been fairly strictly bounded
- Species have tended to migrate to track past changes, there is occasional evidence of *in situ* adaptation/speciation – not relevant in a conservation context
- It’s not only climate, but CO$_2$ and fire (and other changes) that can affect biodiversity – management matters
- We need to view all biological response models with skepticism, taking into account the assumptions and uncertainties
Check your understanding of Chapter 4

PASS MARK 80%

Please do not proceed further until you have PASSED

Chapter 4: test yourself
I hope that found chapter 4 informative, and that you enjoy chapter 5.