Trees, fires and elephants
applying ecological theory to science-society issues in southern Africa

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Wooded lands in Africa

65% of Africa consists of savannas and woodlands
13% consists of forests
Fundamental question:

What controls the growth rate of trees in savannas?

- Moisture?
- Nutrient supply?
- Competition with other trees?
- Competition with grasses?
- Temperature?
The Shackleton dataset

Tree growth measured every year for 6 years in 50 sites throughout the Savanna biome in South Africa
Finding an upper envelop to tree biomass

A predictive model

\[
\frac{\Omega}{T_0 - T} = \frac{T_{\text{max}} - T}{T_{\text{max}}} 0.19 e^{-0.2\sqrt{x}} T
\]

Where

- \( T \) = tree basal area (m\(^2\)/ha)
- \( T_{\text{max}} \) = maximum \( T \) for a given site, predicted from MAP
- \( \sqrt{x} \) = mean stem diameter, (cm)
Model validation

\[ y = 0.9998x \]
\[ R^2 = 0.6487 \]
Application #1
The African Fuelwood Crisis

- The majority of people in Africa use wood or charcoal as their primary energy source
- Experts have for several decades predicted the imminent exhaustion of the supply
A wood supply-and-demand model

Annual growth

Stock of trees → Firewood

kiln → Charcoal

Transport cost → Rural demand

→ Urban demand
Fuelwood supply less demand

Is there a woodfuel crisis?

- There are local shortages, but no regional crisis
  
  Wood production >> wood use

- Wood use tends to be self-limiting due to the high transport costs

- A regional-scale model, driven with local-scale data, was able to identify the hotspots of unsustainable use correctly
Application #2
The carbon balance of Namibia

- As a signatory to the UN Framework Convention on Climate Change, Namibia needed to report its greenhouse gas emissions
- The emissions are small in global terms
- A ‘sink term’ due to bush encroachment was uncertain and potentially large
How bush encroachment sucks up carbon

![Graph showing carbon density over time]

- **Bush encroachment begins**
- **Total amount of carbon taken up**
- **Still encroached, but further carbon uptake now zero**

- **Carbon density (gC/m²)**
- **Time (years)**

0 50
Encroachment has occurred over nearly 400 00 km$^2$ (half of Namibia)
Findings

- 620 million tonnes of carbon have been taken up by bush encroachment in Namibia over the past 50 years
- ~45 Tg CO$_2$/y
- Namibian industrial, transport and agricultural emissions are about 5 TgCO$_2$eq/y
- Namibia has a large net uptake of greenhouse gases!
Application #3

Elephant numbers and conservation

- Elephant populations in Botswana, Zimbabwe, Namibia and South Africa are growing at 6-8% per year and have reached 250 000
- This is associated with radical transformation of woodlands, which may threaten other species
- Will the elephant populations stabilise at an acceptable level, or will they need to be culled?
Elephants will eliminate mature trees
(Tree growth rate 3%/y, elephant growth 6%/y)

Caughley, G 1976 The Elephant problem - an alternate hypothesis E Afr Wild J 14, 265-283
Stable limit cycle with coppice

coppice growth 19%/y, elephant growth 6%/y
Insights so far

- Realistic parameter values do not permit an elephant-mature woodland coexistence
- Coppicing species can coexist with elephants in a stable limit cycle with a 200 year period
A more realistic model

- **big trees**
- **coppice**
- **elephants**
- **browsers**
- **grazers**
- **grass**
- **(fire)**

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Application #4
Climate change and the Kruger Park

- The lowveld is predicted to become warmer, drier and higher in CO₂ by the end of this century
- Will this lead to a change in habitat suitability and wildlife carrying capacity?
Basic savanna system model

- Fire freq
- CO₂
- Rainfall
- Temperature
- Tree ht & BA
- Tree prodn
- Sour grass
- Sweet grass
- Sand %
- Fire intens
- Elephants
- Browsers
- Mixed
- Coarse graz
- Fine grazers
- Carnivore
Skukuza flux tower

Monthly Composite of Diurnal Fluxes for 2004

- CO₂ flux [mg m⁻² s⁻¹]
- Water flux [W m⁻²]
- Sensible Heat flux [W m⁻²]

Dates: Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec
Effect of CO₂ on NEP

\[ F(\text{CO}_2) = 1 + \beta \ln(\frac{[\text{CO}_2]}{[\text{CO}_{2\text{ref}}]}) \]

\[ \beta \approx 0.4 \text{ for trees, } 0.2 \text{ for grass} \]

\[ [\text{CO}_{2\text{ref}}] = 360 \text{ ppm} \]
Effects of temperature on NEP

\[ f(T) = e^{c\left(1-\frac{(b-T)}{(b-a)}\right)^d} \frac{(b-T)}{(b-a)^c} \]

- \( a \) = position of optimum \( \sim 28^\circ C \) for trees, \( \sim 33^\circ C \) for grasses
- \( b \) = temperature below which no growth occurs \( \sim 5^\circ C \) trees, \( 10^\circ C \) grass
- \( c \) = steepness of curve below optimum \( \sim 3 \)
- \( d \) = steepness of curve above optimum \( \sim 7 \)
Projected impacts
A2 scenario, Hadley GCM

[Graphs showing projected impacts over time for different categories, including basal area, grass production, tree height, herbivores, and various browsing types.]
Conclusions

• Water and temperature effects can overwhelm the CO$_2$ effect
• Substantial changes in herbivore stocking rate are possible in the future
• The outcome of climate-change induced habitat change depends on how fires and elephants are managed
New directions
Predicting tree and grass phenology
What makes trees and grasses go green?

Archibald, S and R Scholes (submitted) Global Change Biology
Summary

By paying attention to a few fundamental questions in savanna ecology over a period of a decade, we have been able to shed light on several issues of social, economic and political importance.
The End