# A modelling perspective for framing thoughts on vegetation dynamics

Stephen Roxburgh
School of Biological, Earth and Environmental Sciences, UNSW; Bushfire CRC; ENSIS, Canberra

Geoff Cary, Ian Davies, Rob de Ligt
The Fenner School School of Environment and Society, The Australian National University

UNSW
THE UNIVERSITY OF NEW SOUTH WALES

bushfire CRC



## Overview

- Dynamic Global Vegetation Models (DGVM's)
- The LPJ (Lund-Potsdam-Jena) & ED (Ecosystem Demography) models
- LPJ results for Australia
- Key questions/issues for modelling vegetation dynamics in Australian ecosystems






# DGVM's – LPJ Plant Functional Types (PFT's)

PFT bioclimatic limits defining broad-scale vegetation distribution

**Table 2** PFT Bioclimatic limits: $T_{c,min}$ = minimum coldest-month temperature for survival; $T_{c,max}$ = maximum coldest-month temperature for establishment; $GDD_{min}$ = minimum degree-day sum (5 °C base) for establishment; $T_{w-c,min}$ = minimum warmest minus coldest month temperature range

| PFT | $T_{c,min}$ (°C) | $T_{c,max}$ (°C) | $GDD_{min}$ (°C) | $T_{w-c,min}$ (°C) |
|---|---|---|---|---|
| Tropical broad-leaved evergreen | 15.5 | – | – | – |
| Tropical broad-leaved raingreen | 15.5 | – | – | – |
| Temperate needle-leaved evergreen | −2.0 | 22.0 | 900 | – |
| Temperate broad-leaved evergreen | 3.0 | 18.8 | 1200 | – |
| Temperate broad-leaved summergreen | −17.0 | 15.5 | 1200 | – |
| Boreal needle-leaved evergreen | −32.5 | −2.0 | 600 | – |
| Boreal needle-leaved summergreen | – | −2.0 | 350 | 43 |
| Boreal broad-leaved summergreen | – | −2.0 | 350 | – |
| Temperate herbaceous (TeH) | – | 15.5 | – | – |
| Tropical herbaceous (TrH) | 15.5 | – | – | – |

Sitch, S. *et al.* (2003). *Global Change Biology* 9: 161-185.

# DGVM’s - LPJ

## Inputs

Climate data

(Temp. Precip. $CO_2$, Wet days, Cloud)

Position data

(Latitude, Soil type) …

(When coupled to GCM)

## Outputs

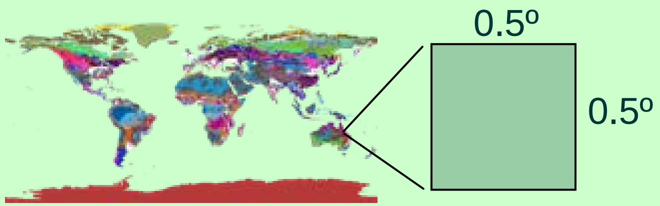
Vegetation/Soil

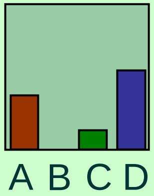
(PFT’s, Cover, LAI, Biomass C, Soil C, NPP, **NBP**, …)

Hydrology

(Evapo-transpiration, Soil water, Runoff) …

## LPJ




What PFT’s can establish + survive in this gridcell?

*Determined by PFT bioclimatic limits*

# DGVM’s – Gap model approaches (e.g. ED, SEIB-DGVM)

## Inputs

### Climate data

(Temp. Precip. $CO_2$, Cloud, Humidity,…)

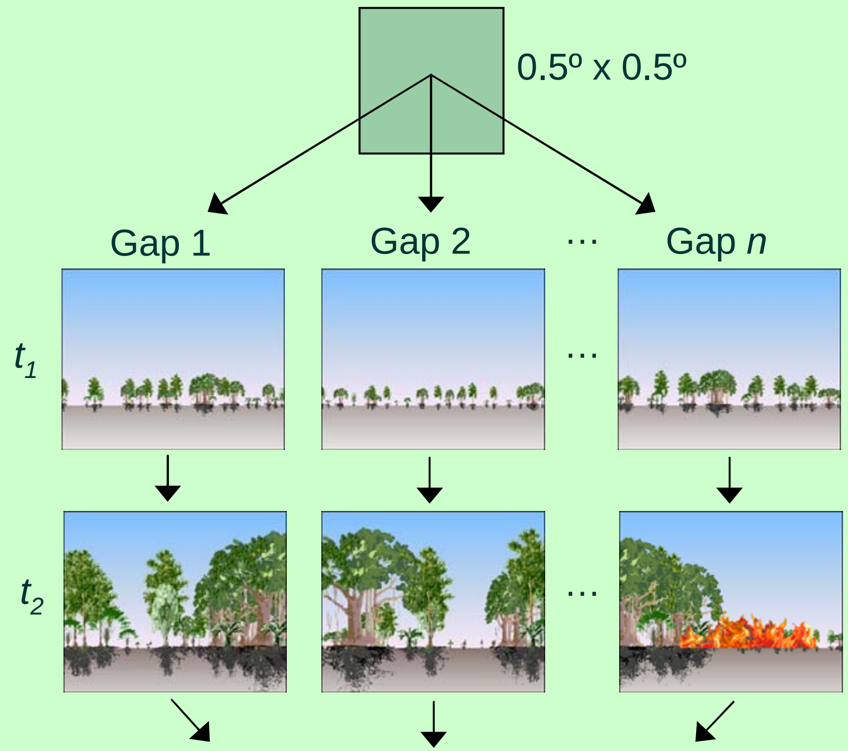
### Position data

(Latitude, Elevation, Soil type) …

## Global application of individual-based forest gap models

(a) For each gridcell run *n* replicate forest gap models from $t_1$ to $t_2$, inclusive of PFT neighbourhood competition, fire, windthrow, clearing…

(b) Combine the *n* model outputs to derive a gridcell-level estimate of vegetation state at time $t_2$




Combine results across all *n* gaps

## Outputs

### Vegetation/Soil

(PFT’s, Cover, LAI, Biomass C, Soil C, NPP, **NBP**, …)

### Hydrology

(Evapo-transpiration, Soil water, Runoff) …

bushfire CRC



## LPJ - Versions

- LPJ v 1.3.

  Last version to be coded in Fortran; includes the improved hydrology of Gerten *et al*. (2004). Potential veg.

- LPJ-GUESS (LPJ v 2.*)

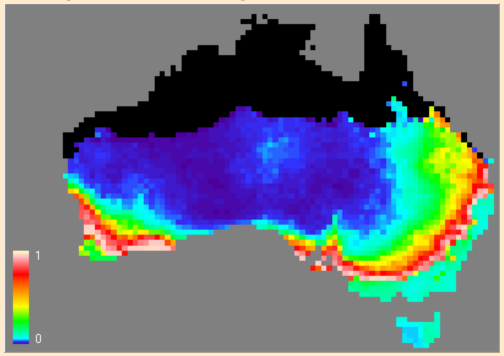
  Species/stand level implementation, coded in C++.

- LPJ v 3.* (includes LPJml - managed land)

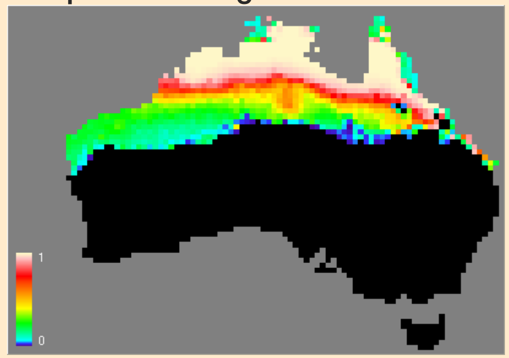
  Consolidated, reformatted + updated LPJ, coded in C.

# LPJ results - Average PFT Cover (1901-2000)

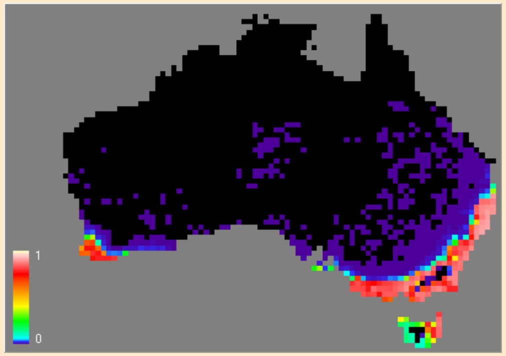
C3 perennial grass



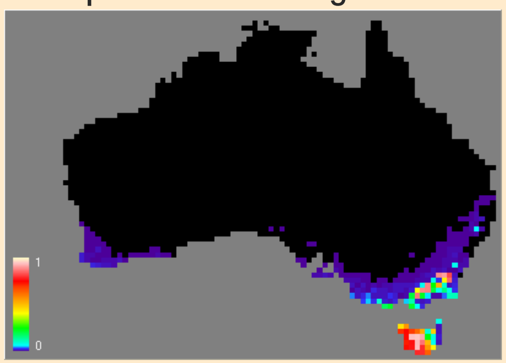

C4 perennial grass



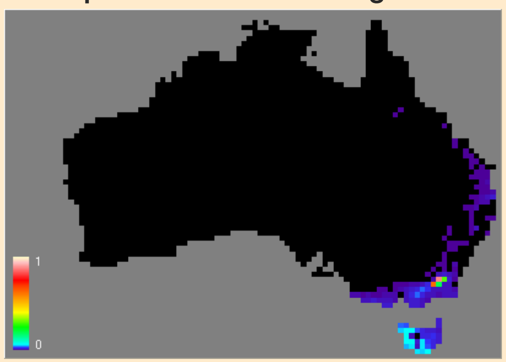

Temp. broad evergreen



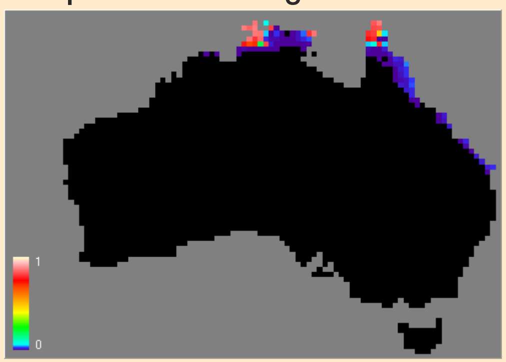

Temp. needle evergreen



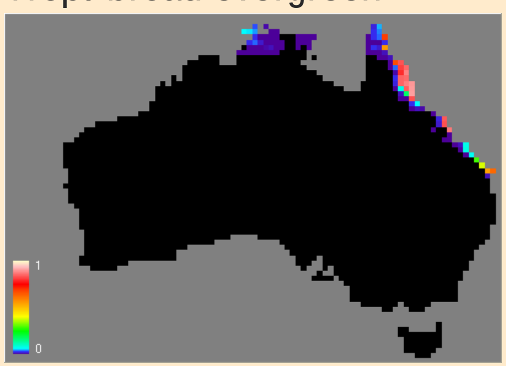

Temp. broad summergreen

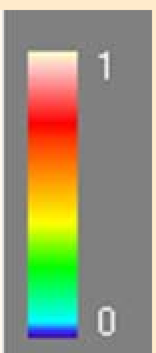



Trop. broad raingreen



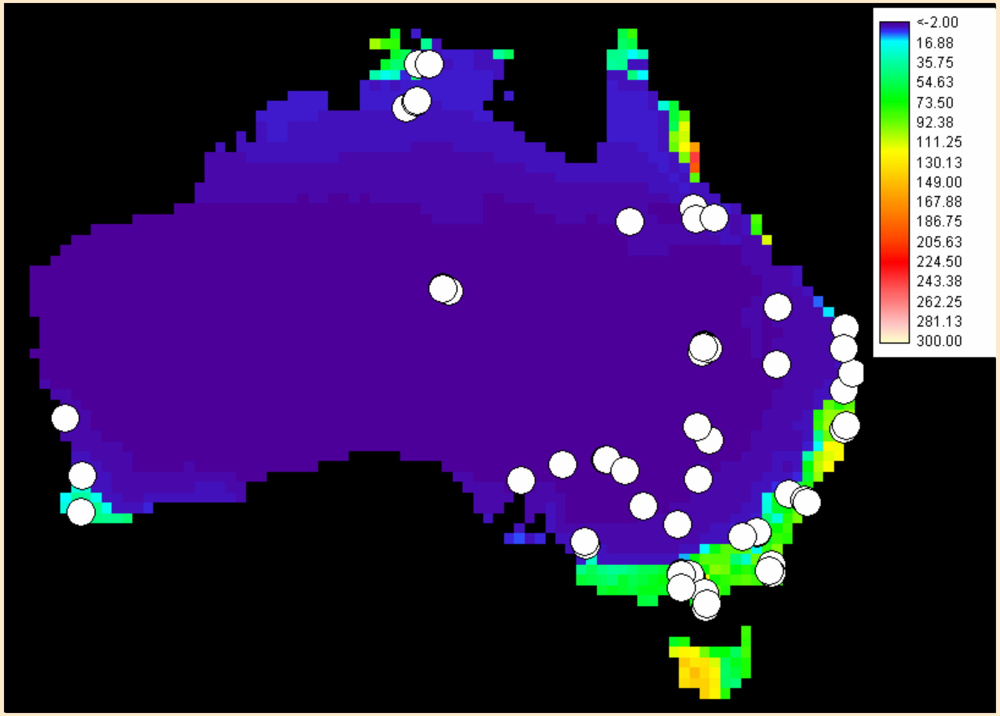

Trop. broad evergreen

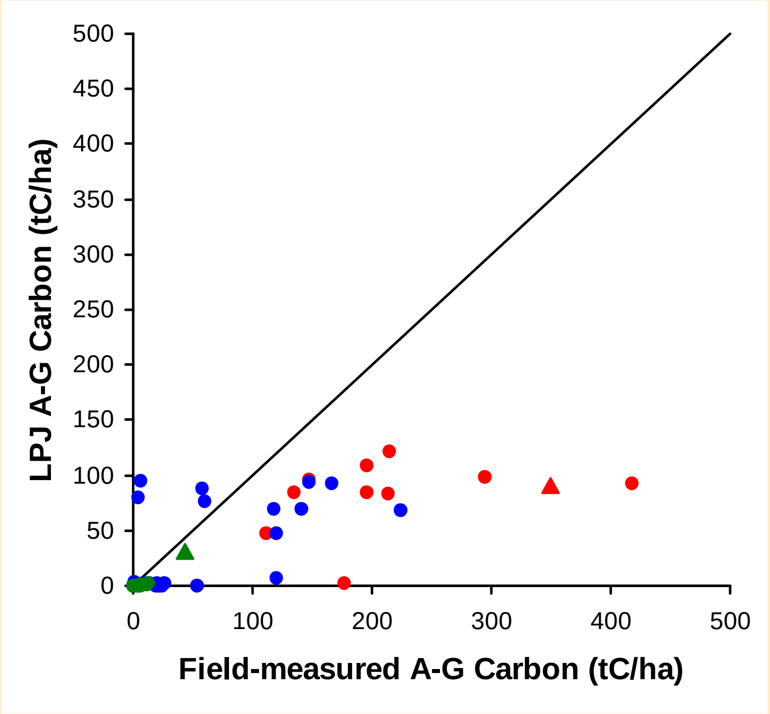


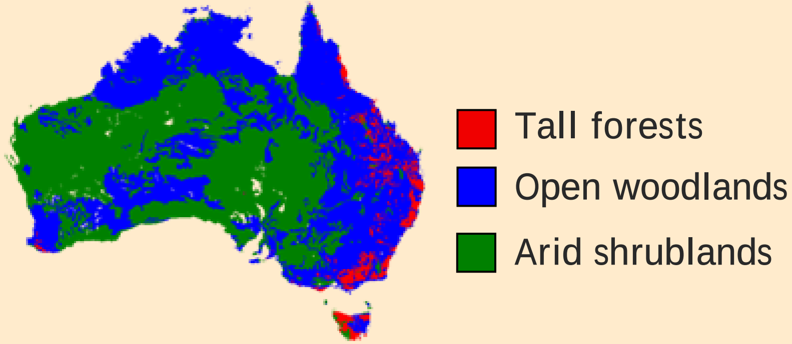



# LPJ results – Above-Ground Vegetation Carbon

## ... vs. field measurements



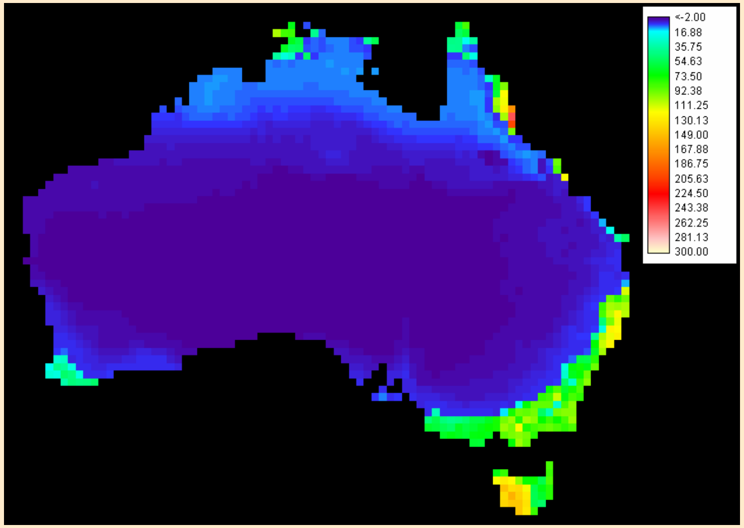



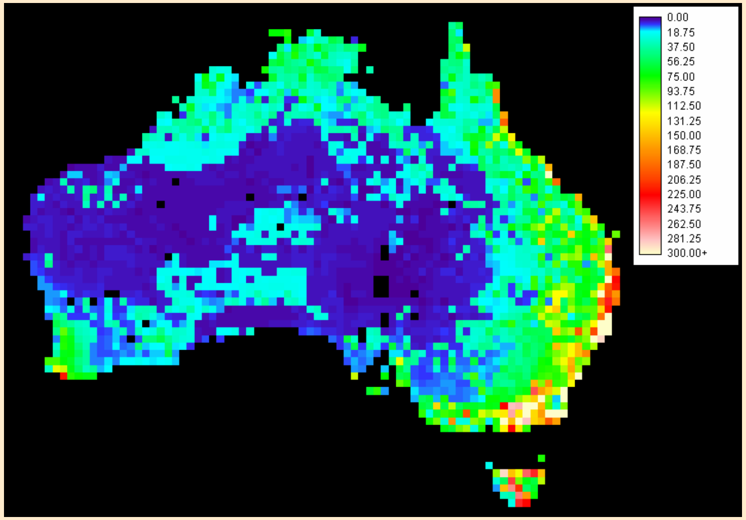

Barrett (2001). VAST calibration dataset, ORNL

# LPJ Results - Total Vegetation Carbon

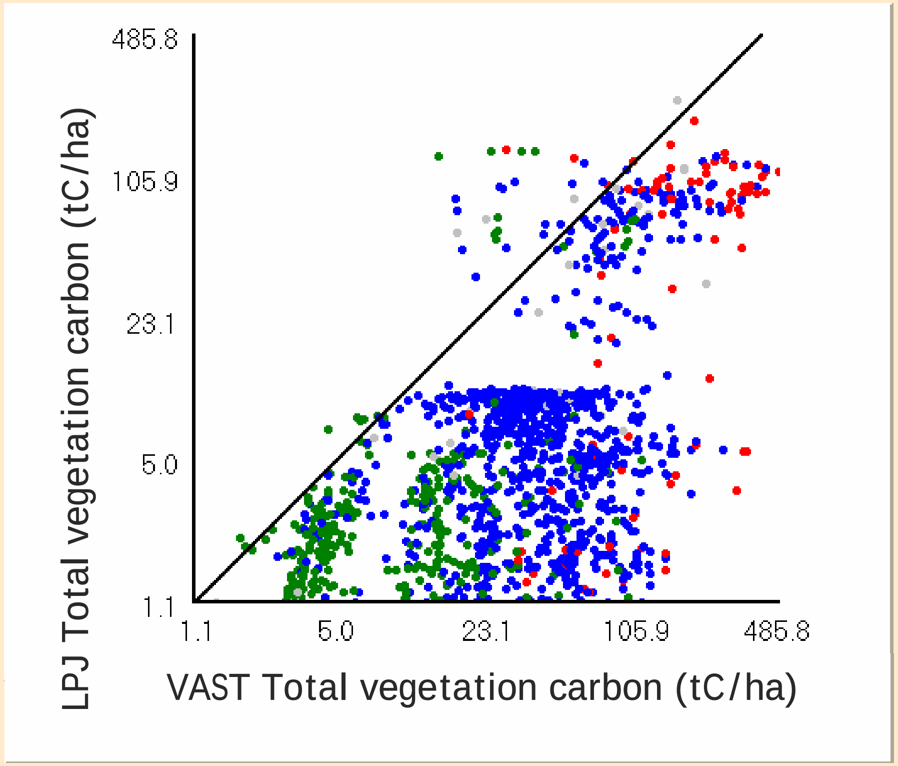
LPJ Total vegetation carbon (tC/ha)

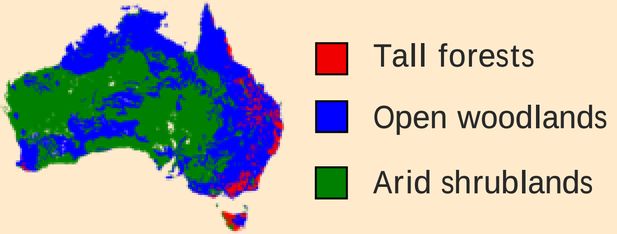



VAST Total vegetation carbon (tC/ha)




## ... vs. VAST model

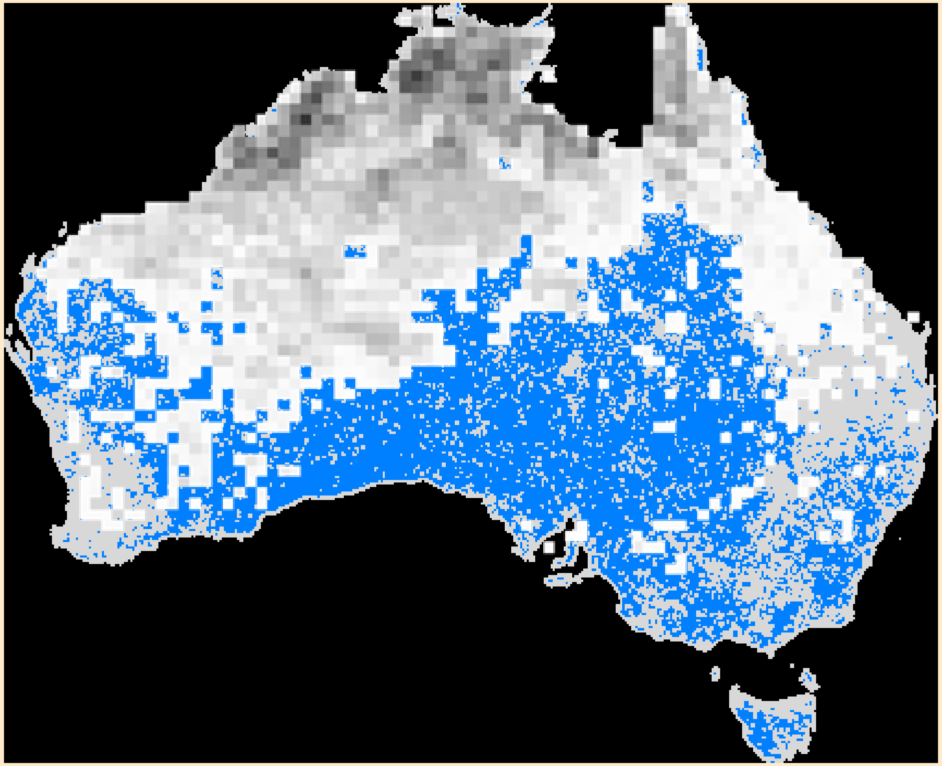



Barrett (2002). *Global Biogeochemical Cycles* 16: 1108.

# LPJ Results - Fire, 1998-2000

Combined fire scar + fire hotspot observations (DOLA)



LPJ

=  + 

scar hotspot

# 10 key issues/questions for modelling vegetation dynamics in Australian ecosystems

## → 1. Purpose of the model

In developing any research agenda you need to be clear about the goals. Different objectives will require different approaches, spanning a range of spatial & temporal scales.

Dynamic vegetation modelling for:

- Global climate modelling
- Biodiversity/habitat conservation
- Natural Resource Management
- Production forestry / timber yield
- Carbon sequestration
- Wildfire risk / fuel management
- ...

# 10 key issues/questions for modelling vegetation dynamics in Australian ecosystems

## → 2. Scale of application & data requirements

Scaling vegetation dynamics from local (**D**ynamic **L**andscape **V**egetation **M**odel), continental (**D**ynamic **C**ontinental **V**egetation **M**odel) to global (**DGVM**) is clearly a challenge. What data do we need for calibration + validation?

- DGVM's operate at spatial scales that limit their utility at local/management scales (50km x 50km & above).
- Can we adapt the DGVM framework to improve local-to-regional modelling of vegetation for environmental management? (finer-scaled PFT classifications? Finer spatial resolution?)
- What local/regional processes need to be incorporated into current DGVM's to improve their behaviour (watershed? firespread?)
- What data do we need to calibrate and validate our models? (remote sensing technologies? Existing infrastructure – e.g. NCAS)

# 10 key issues/questions for modelling vegetation dynamics in Australian ecosystems

## → 3. Capturing variability / scaling.

Most current approaches focus on ‘average’ descriptions of vegetation. E.g. ‘average’ or ‘typical’ parameter values are used to define generalised PFT’s. However, vegetation dynamics are inherently variable & nonlinear, and scaling correctly across time and space demands knowledge of parameter variances and covariances, in addition to the averages.

- How do we currently implement spatial and temporal scaling? (SEIB = brute force; ED = clever analytical approximations; LPJ = fudged through parameter tuning)
- How do we communicate the importance of measuring variance and covariance (as well as average) as the key ingredient to scaling nonlinear processes?

**Ruel, J.J & Ayres, M.P. 1999. Jensen’s inequality predicts effects of environmental variation.** *Trends in Ecology & Evolution* **14: 361-366**

# 10 key issues/questions for modelling vegetation dynamics in Australian ecosystems

## 4. Simplifying the Australian biota.

Plant Functional Types (PFT's) are the dominant paradigm for modelling large-scale dynamic vegetation patterns. Can we develop an optimal set of PFT's for modelling Australian vegetation? Would such a set be globally applicable? Do we need PFT's at all?

- Current DGVM's represent the distribution of vegetation in Australia poorly. Why?
- Do we need to re-define/extend current PFT descriptions? Do we need to develop some new ones?
- Do we need PFT's at all?

# 10 key issues/questions for modelling vegetation dynamics in Australian ecosystems

## → 5. Level of process description required.

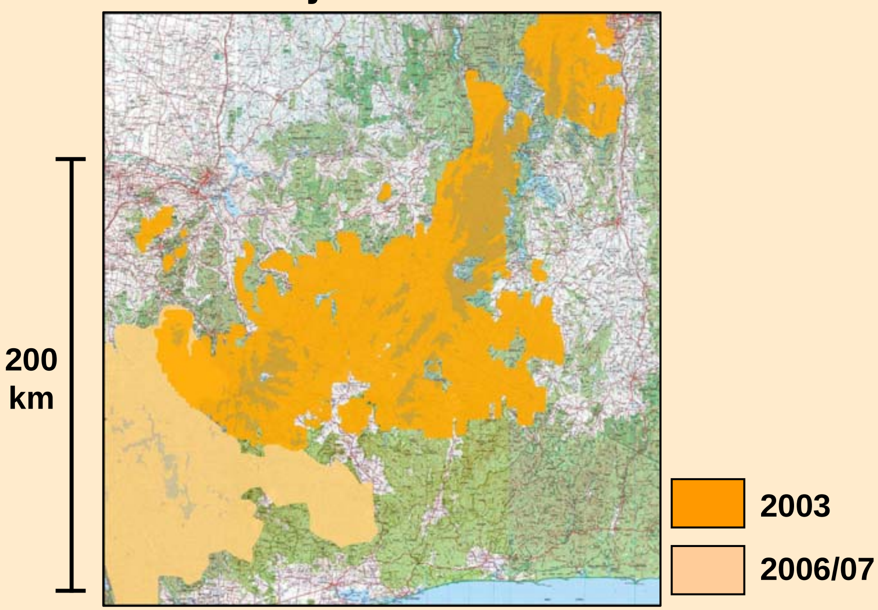
Empirical relationships based on current/past conditions may not remain valid under a changed climate. Predictive modelling therefore requires a certain level of process description.

- Some vegetation processes are currently well known and described (e.g. photosynthesis), others remain poorly known and/or empirical (e.g. photosynthate allocation, plant competition, succession).
- Some important processes have not received the attention they deserve: genetic variability and the capacity of vegetation to evolve; dispersal/migration rates.
- Some Australian-specific vegetation dynamics/processes demand attention (woodland thickening, fate of Alpine biota, …)

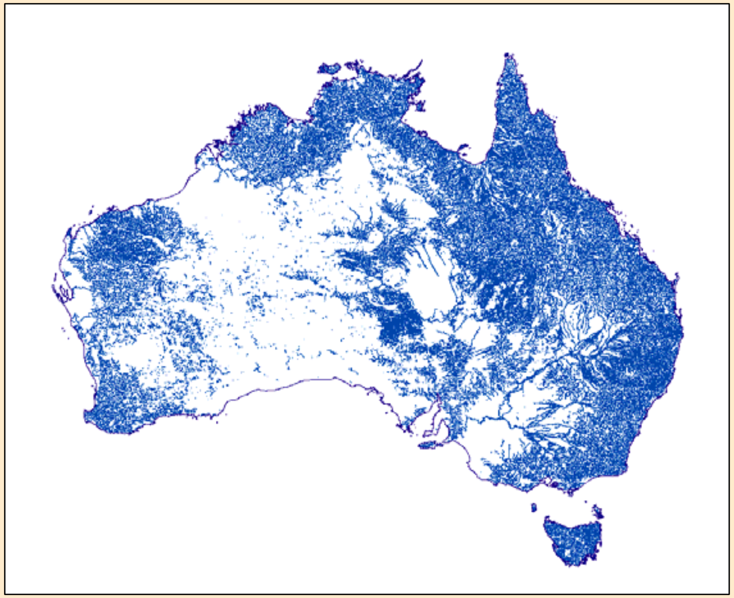
## → 6a. Spatially contagious processes – large scale.

Most global/continental vegetation models do not allow energy and matter to pass from gridcell-to-gridcell, and assume that such dynamics are mostly within-gridcell phenomenon. In Australia there may be exceptions to this rule (e.g. continental-scale rainfall re-distribution, ‘megafire’).

**Recent major bushfires**




**Continental water courses**

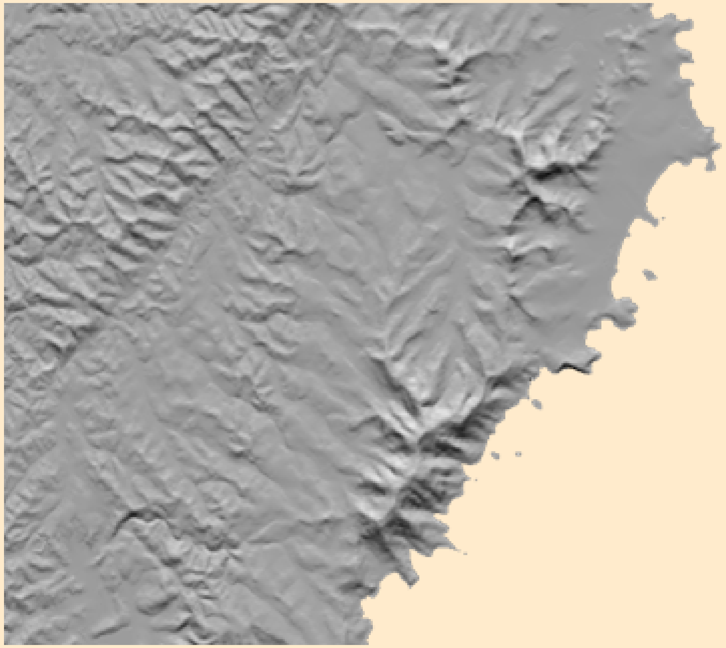


# 10 key issues/questions for modelling vegetation dynamics in Australian ecosystems

## 6b. Spatially contagious processes – fine scale.

At the landscape-scale horizontal fluxes (e.g. above and below-ground water movement), fire spread, and the redistribution of organisms (e.g. dispersal, invasion) are important processes. How do we capture these?

**Kioloa landscape, NSW**



*Angophora costata* **stand, Queensland**

# 10 key issues/questions for modelling vegetation dynamics in Australian ecosystems

## → 7. Fire.

The Australian landscape, the current distribution of its biota (and its evolution) are all dominated by the influence of fire. We need to get fire right!

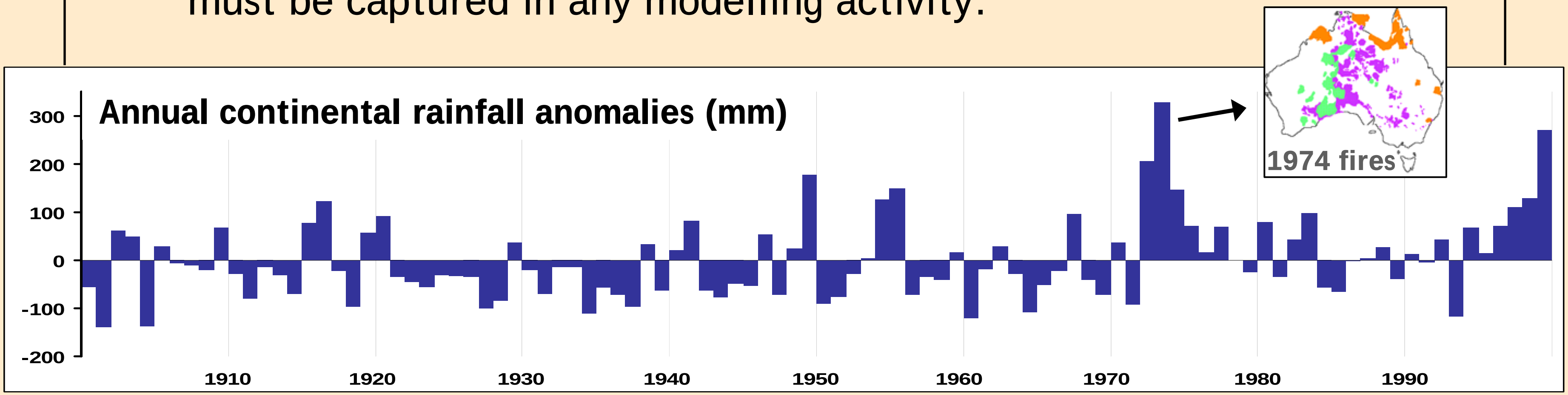
- Consequences of changed fire regimes under climate change?
- Impacts of fire on biota, both destructive (e.g. mortality) and positive (e.g.maintaining biological diversity).
- Separating natural and human-induced fires.
- Interactions with nutrient/water cycles.
- Fire as a determinant of past, present and future vegetation pattern.

# 10 key issues/questions for modelling vegetation dynamics in Australian ecosystems

## → 8. Water / Nutrient cycling.

Vegetation requires three basic resources: light, water, nutrients. Australian ecosystems are generally nutrient-deficient and water limited. There is also a strong influence of fire on water and nutrient cycling.

- The availability of nutrients and water will change under a changed climate. Dynamic vegetation models need to link the growth of vegetation to the supply/demand dynamics of water and nutrients.
- Significant inter-annual and inter-seasonal variability in rainfall is a feature of the Australian climate. The impacts of this variability must be captured in any modelling activity.

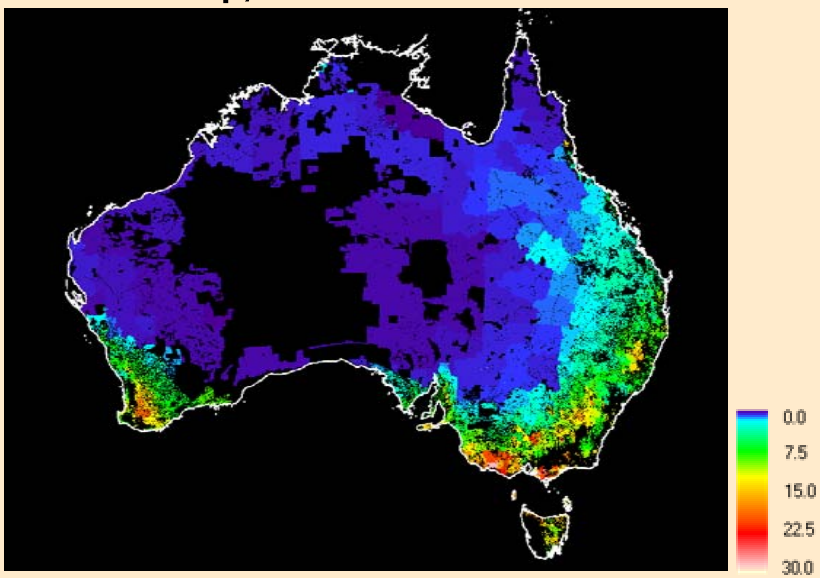


# 10 key issues/questions for modelling vegetation dynamics in Australian ecosystems

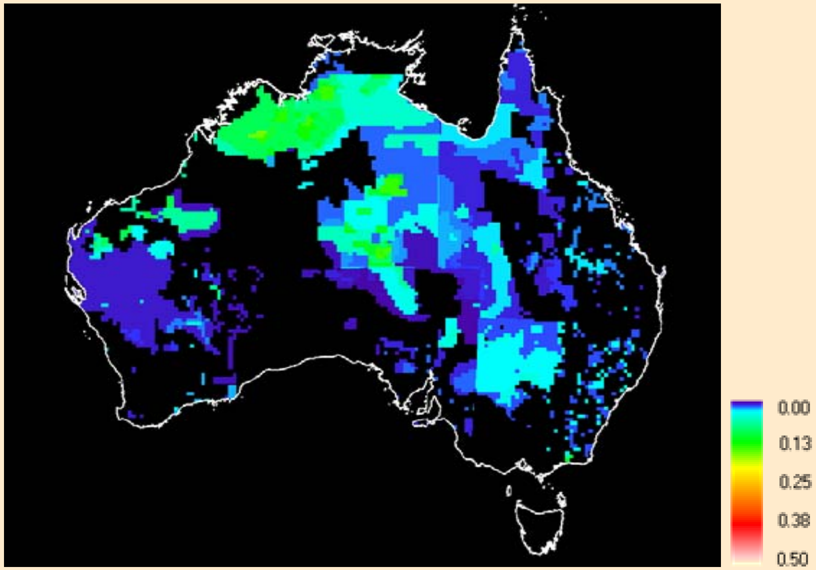
## 9. Herbivory.

Herbivores consume vegetation! 10%-20%(?) of global NPP is consumed by native, domestic, feral and insect herbivores.

**Cattle + sheep; DSE/ha**




**Horse + goat + camel + donkey; DSE/ha**




DSE = Dry Sheep Equivalent

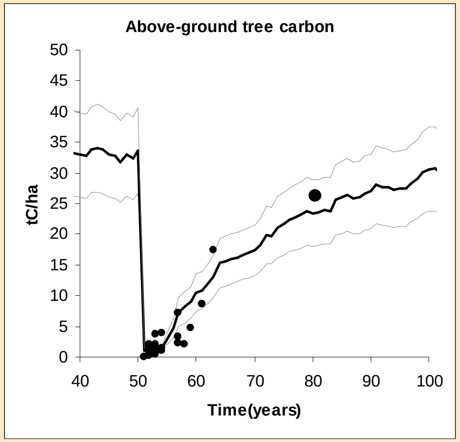
# 10 key issues/questions for modelling vegetation dynamics in Australian ecosystems

## → 10. Land management.

Most DGVM's start with the assumption of 'natural' or 'potential' vegetation. For real-life application the influence of land management must also be included

- Descriptive (e.g. using historical records) vs. predictive (e.g. human behaviour and land-use models)
- Requires an understanding of the impacts on water/nutrient cycles, carbon balance…
- Agricultural, rangeland management, native forest harvesting, plantation forestry

**Cotton plantation, NSW**




**Model-predicted + observed recovery of Poplar Box following chaining**

# 10 key issues/questions for modelling vegetation dynamics in Australian ecosystems

- What are the objectives?
- Scale of application & data requirements
- Capturing variability / scaling
- Level of process description required?
- Simplifying the Australian biota
- Spatially contagious processes
- Fire
- Water / Nutrient cycling
- Herbivory
- Land management