Vegetation Dynamics and Climate Change
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Biomass and soil carbon: Major research needs for the coming decade

Roger M. Gifford, CSIRO Plant Industry, Canberra

John Raison, ENSIS, Canberra

Miko U. Kirschbaum, Landcare Research, New Zealand

Biomass and soil carbon

Our proposed nine priority areas of research identified for the decade are:

Net primary productivity (NPP)

1) Reducing uncertainty in Australian baseline net primary productivity
2) Understanding the temperature-dependence of NPP

Elevated [CO_2]

3) *Are C-stocks in natural ecosystems increasing under increasing [CO_2] ?*
4) Coupling the C cycle with the N & P cycles

Soil carbon dynamics

5) Long term temperature response of SOM decomposition
6) Fraction of above ground litter taken into soil - mechanisms
7) Formation and fate of black carbon (char)
8) Understanding and modeling SOC-saturation to additional inputs

Disturbance

9) Quantify & model recovery of the C-cycle of native vegetation to disturbances induced by climate change and management.

Priority 1: **Reducing uncertainty in Australian baseline net primary productivity**

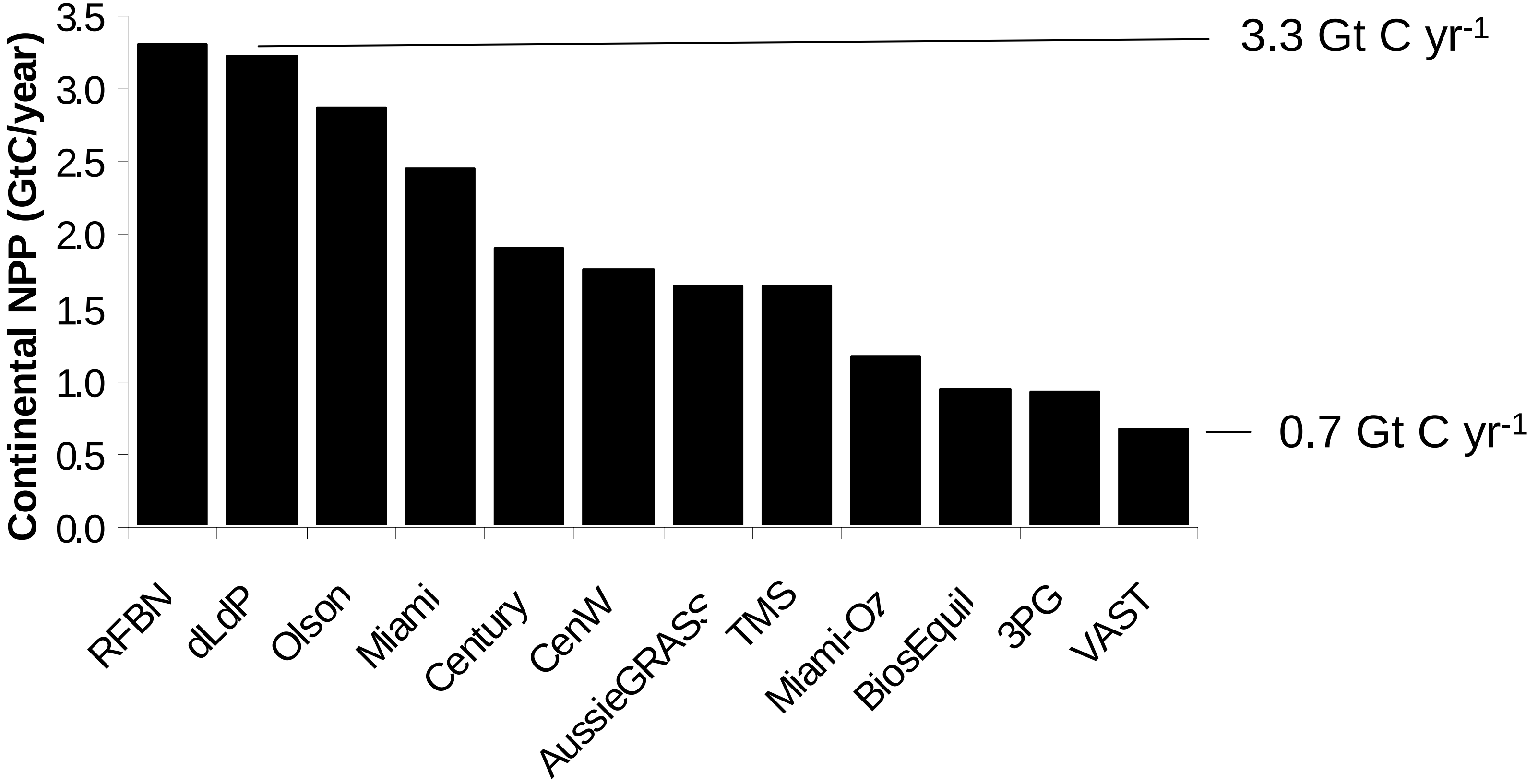
To be useful in ecosystem dynamics and coupling to GCMs, terrestrial carbon cycle models must work at the level of detail of:

- fixing carbon dioxide into vegetation (ie NPP)
- losing carbon via decomposition (heterotrophic respiration).

How well do we know baseline Australian NPP?

Comparison of 12 models of long term average NPP for Australia

(Roxburgh SH et al. (2004) A critical overview of model estimates of net primary productivity for the Australian continent. *Functional Plant Biology* 31:1043-1055)



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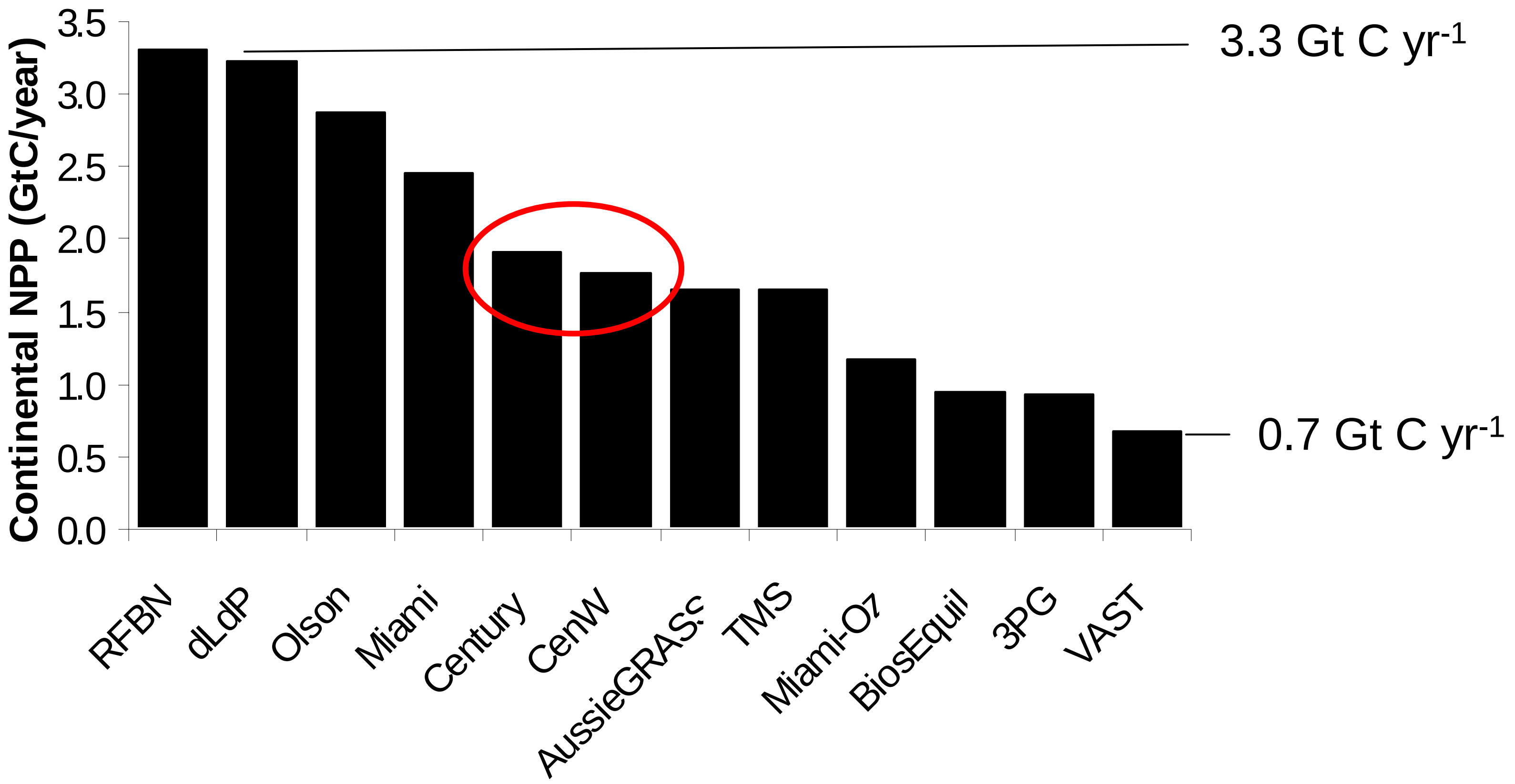
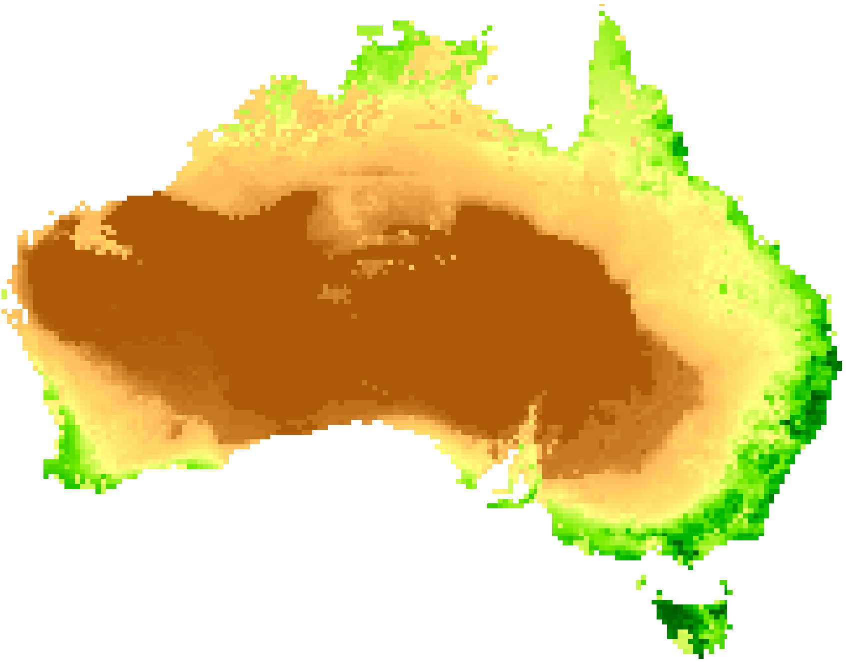
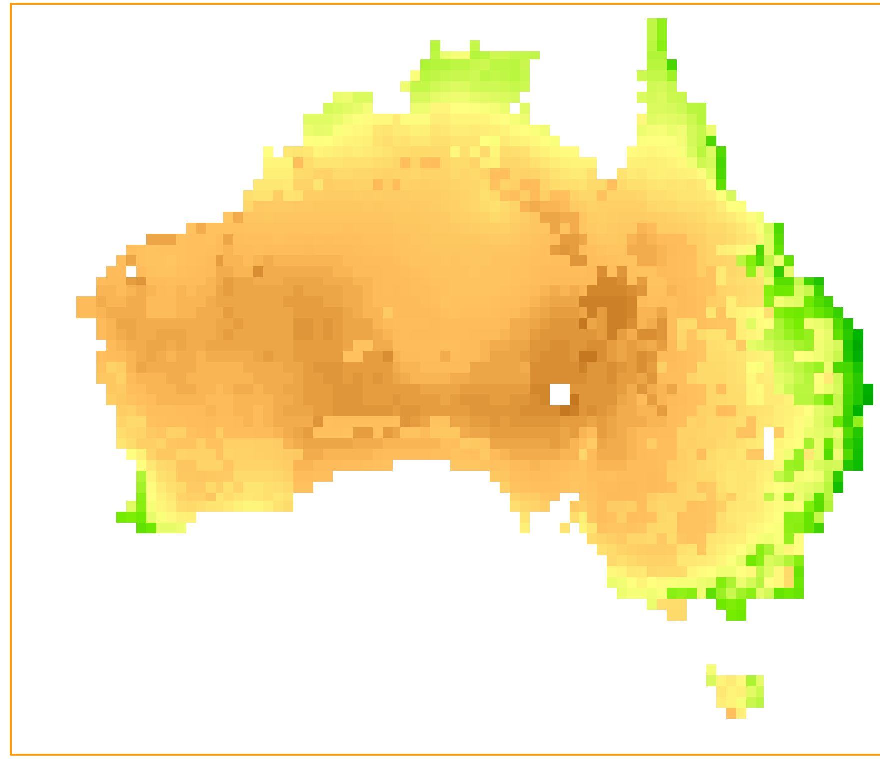


CenW (1.76 Gt C yr^{-1})

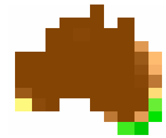
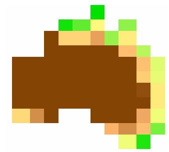
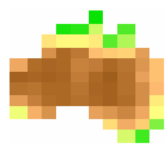
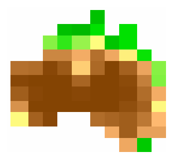
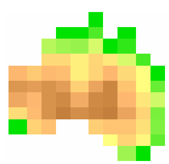


Century (1.92 Gt C yr^{-1})



Models that yield similar continental totals can do so via substantially different distributions of NPP around the country.

International DGVM results for Australia

Model	Mean Global NPP (GtC/yr)	Mean Australian NPP (GtC/yr)	Spatial distribution
Hybrid	49.1	0.38	
Triffid	51.5	1.19	
SDGVM	50.3	1.39	
LPJ	60.1	1.71	
IBIS	59.9	1.78	
VECODE	61.4	2.85	

Legend (gC/m^2/yr) 

Global DGVMs also yielded very different continental average NPP and spatial distribution of NPP.

re 4

Conclusion:

- Continental NPP estimates varied by an order of magnitude.
- The continental distribution of modeled NPP varied greatly.

However:

- The models varied as to whether they were modelling actual vegetation or notional pre-European vegetation.

- The environmental data inputs varied.

Further steps:

- Need tighter specification of NPP model objectives and inputs (esp. rainfall).

- In the longer term there must be a concerted stratified effort to ground-truth annual NPP around the country for model improvement.

- This needs to be by direct ecosystem measurements augmented with satellite monitoring and, where suitable, eddy flux measurements.

- Incorporating long-term ecosystem manipulation experiments in some of the NPP study sites would be valuable (eg water, N, P, CO_2 treatments).

- A key Australian question is why above-ground NPP of evergreen forests is lower than for N-hemisphere forests at the same rainfall.

Priority 2: **Understanding the temperature-dependence of NPP**

To model the interactive effects of global warming on vegetation, it is necessary to understand how warming affects NPP.

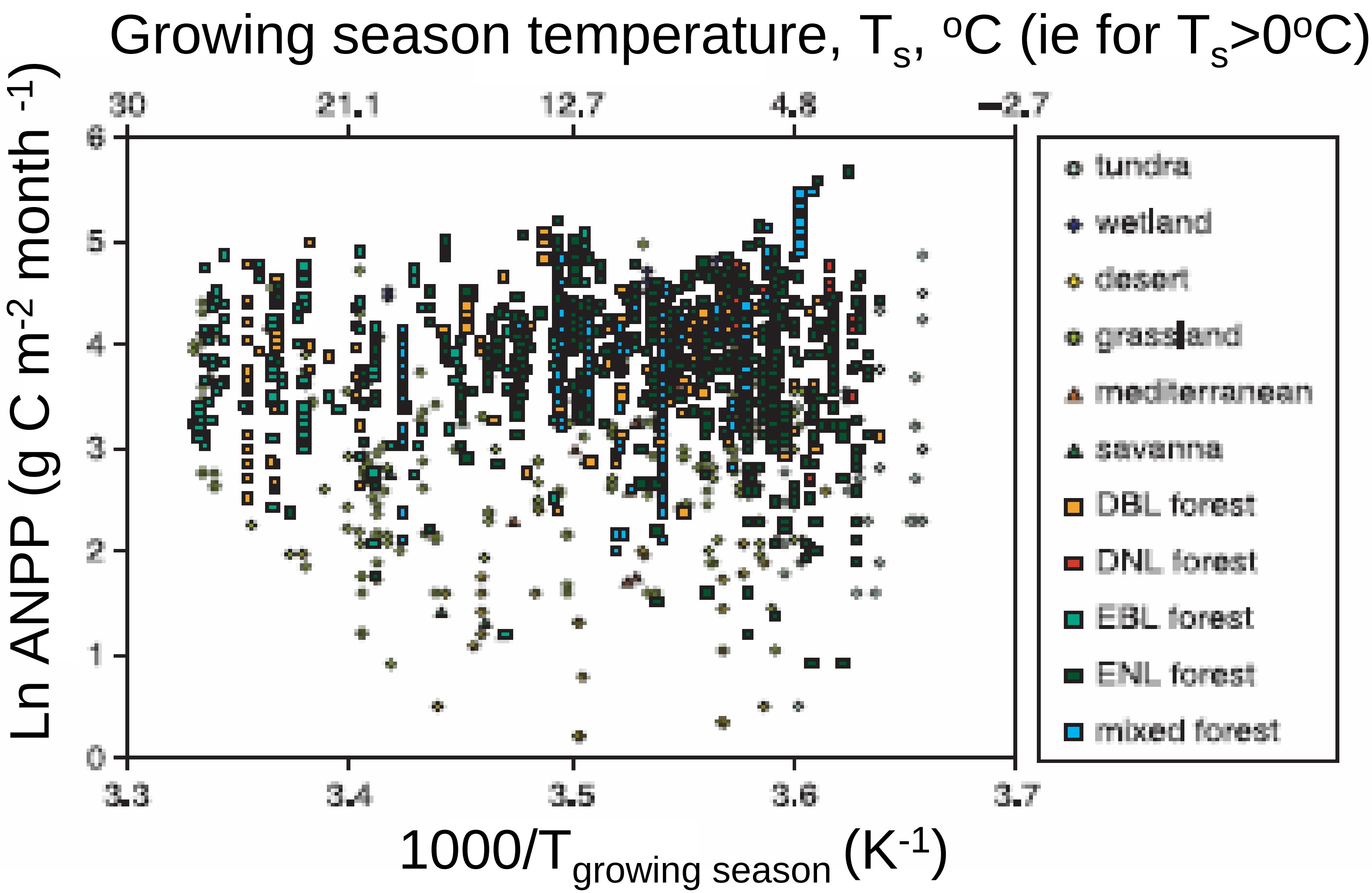
We must learn to distinguish:

- short term responses of growth to temperature
  from
  physiologically acclimated responses.

- physiologically acclimated responses to temperature
  from
  genetically adapted ecosystem responses.

- partially acclimated/adapted responses
  from
  fully genetically-adapted community responses.

Aboveground biome-NPP is insensitive to mean growing-season temperature (>0°C)



Kerkhoff AJ et al (2005) *Global Ecol and Biogeog. 14:585-598*

Priority 2 cont'd: Understanding the temperature-dependence of NPP

Kerkhoff et al (2005) conclude that:

1) When the temperature is above freezing, adapted ecosystem NPP is independent of temperature.

and they proposed from their analysis that:

2) This counterintuitive result is because the reduction in photosynthetic capacity with decreasing temperature is counteracted by:

"*the precipitous non-intuitive increase in N-productivity with decreasing temperature and its correlation with phytomass P-concentration*".

Further steps: We are far from clear about how to model annual adapted-NPP change with increasing temperature. It needs a concerted international field research effort.

Priority 3: **Are C-stocks in natural ecosystems increasing under increasing atmospheric [CO_2]?**

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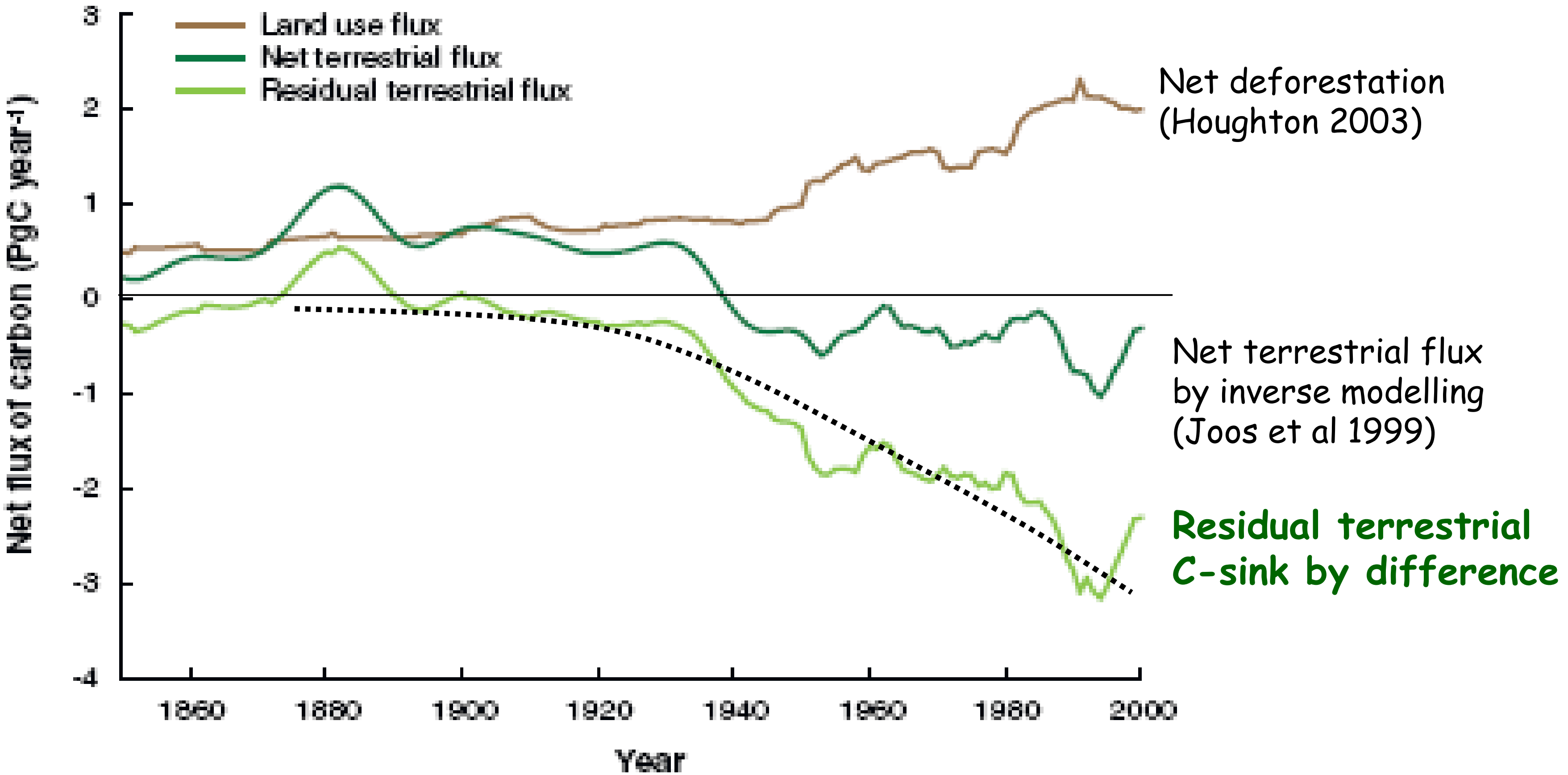
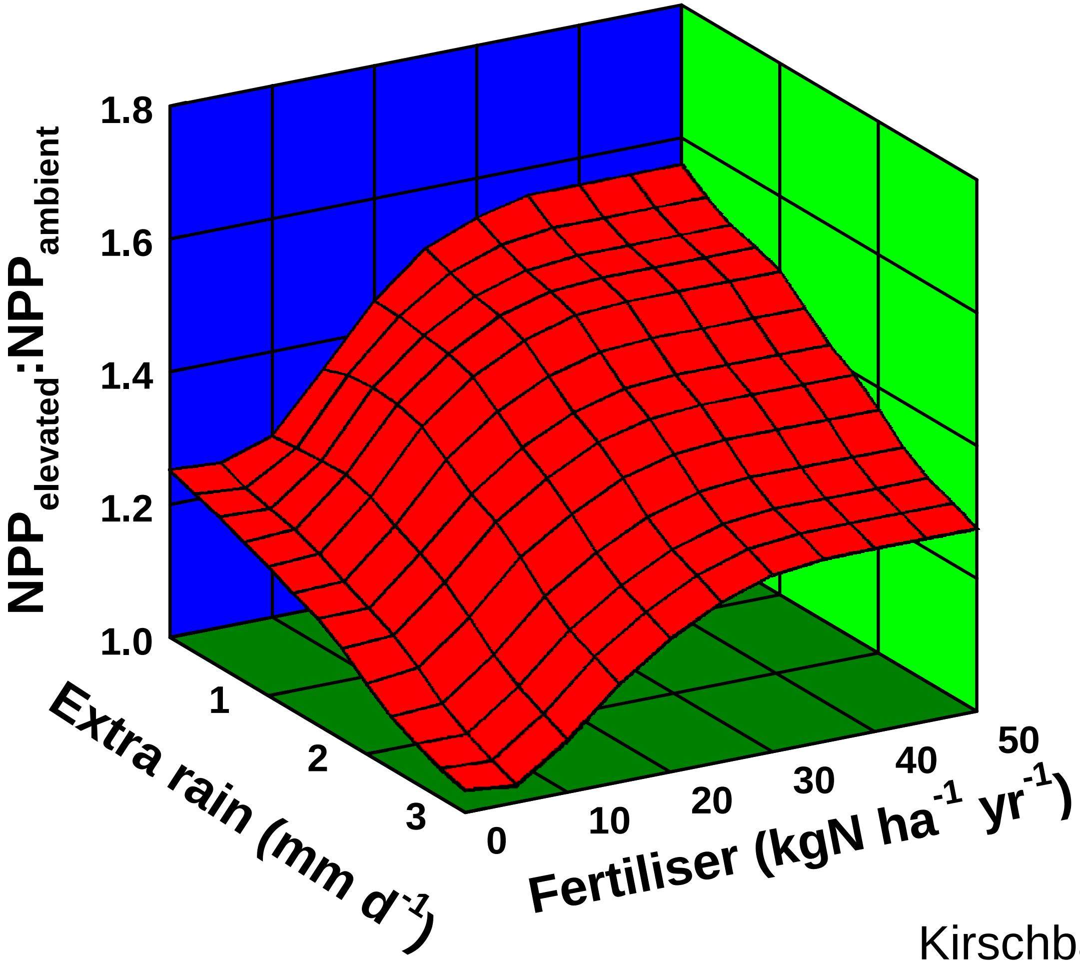


Houghton RA (2007) Balancing the global carbon budget.
Annual Review of Earth and Planetary Science 35:313-347

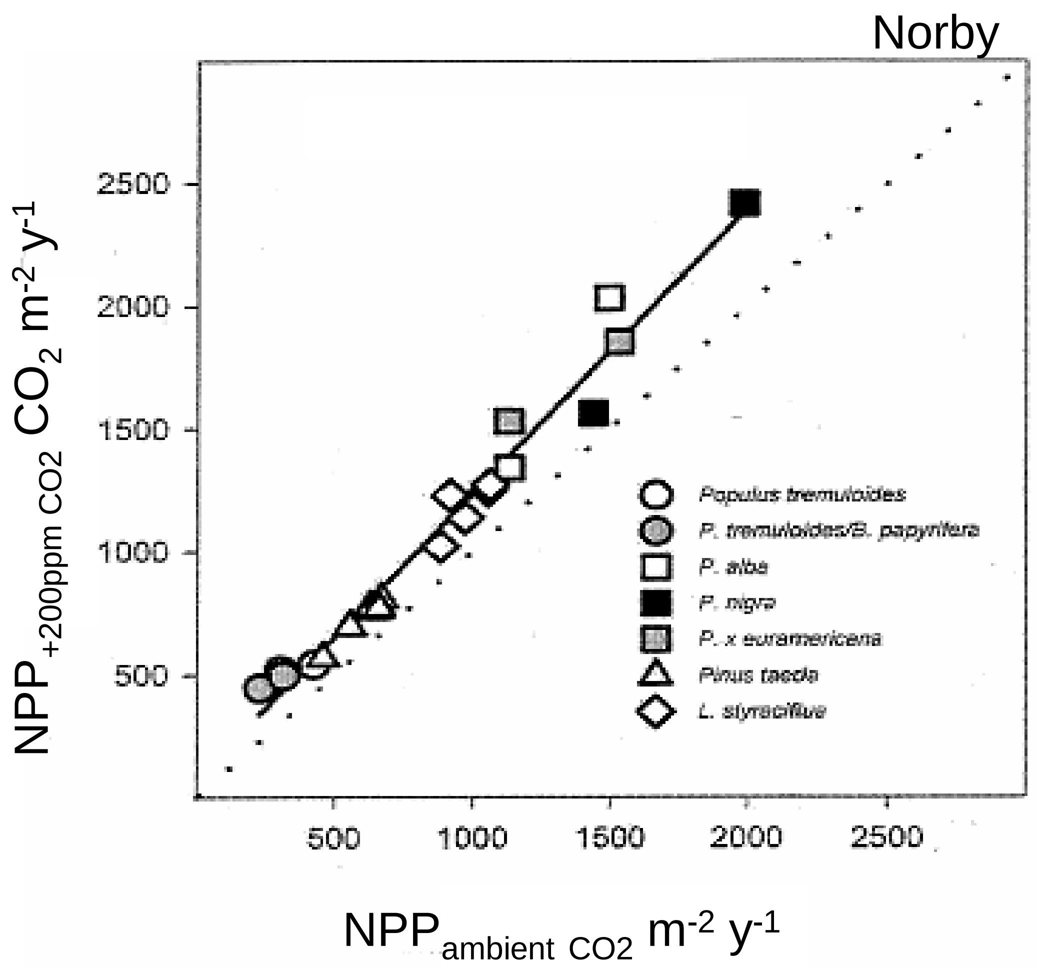
Priority 3**(cont’d)**: **Are natural ecosystems increasing C-stocks under elevated [CO2]?**

- **What is causing the progressive increase in the “residual terrestrial C-sink”?**
- **To what degree is the increasing CO_2 concentration contributing to it?**
- **When will the residual sink saturate or become a source?**

Canberra, Australia



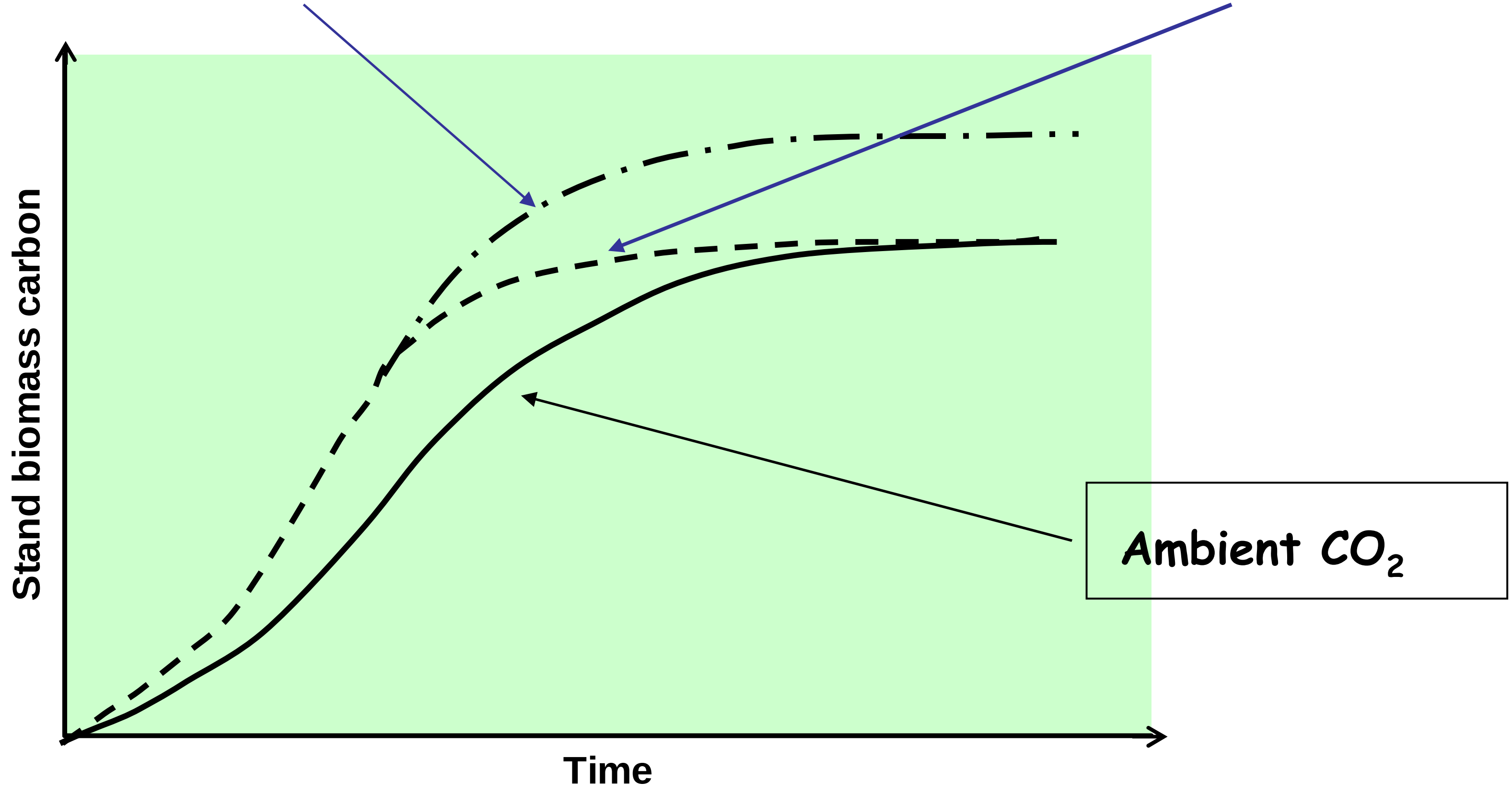
Kirschbaum, M. 2004



+ 20% response of ecosystem NPP

to a 200 ppm CO_2 enrichment over several years for all the plantation field FACE sites.

But, does elevated CO_2 cause a forest to grow faster to a **larger maximum biomass** or faster to **the same biomass**?



Further steps: Need long term (>10 yr) forest-FACE studies set in a forest modelling framework.

Priority 4: **Coupling the C cycle with the N & P cycles**

- As with the temperature response, to understand the CO_2 response of NPP and biomass, N & P feedbacks need to be taken into account.

- Need to evaluate the competing hypotheses for the nitrogen relationship to the CO_2 fertilising effect on climate change timescale, namely:

  the "**N-cycle tracks the C-cycle**" hypothesis (Gifford 1992)

  the "**Progressive N-limitation**" hypothesis (Luo 2004)

"N-cycle tracks the C-cycle"

- Depends on ecosystem N-fixation/retention being paced by the C:N ratio of the system.
  CO_2 fertilisation increases ecosystem C:N ratio.

- May also be dependent on the phosphorus availability.

Does the CO_2 response of plant growth and N-fixation disappear when phosphorus supply is low?

Results vary.....needs resolution.

Further steps: Long term forest-FACE studies should incorporate detailed N-cycle observations

Priority 5. **Long term temperature response of SOM decomposition**

A consensus has not yet been reached

Some authors of DGVMs are making much of the high temperature sensitivity of heterotrophic respiration found in short term laboratory studies, leading to a strong long term positive feedback onto global warming in the modelled global C-cycle.

Priority 5 (cont'd). **Long term temperature response of SOM decomposition rates**

But:

there are several reasons for caution about this:

- Decline of short term temperature sensitivity with increasing temperature
- Interrelation with soil water relations and other environmental constraints
- Instantaneous response vs long term response

  * the soil nutrient feedback link (esp. N-mineralisation)?

  * differential depletion of active, passive & recalcitrant pools?

  * temperature sensitivity of SOC protection mechanisms

  * soil microbial population adaptation to gradual warming?

Priority 5 (cont'd). **Long term temperature response of SOM decomposition rates**

Further steps:
Prior to establishment of further experiments, there needs to be a much more thorough analysis of the large amount of existing soil respiration & decomposition data to provide guidance for better experimental design.

Priority 6. **Fraction of above-ground litter taken into soil – mechanisms and quantification**

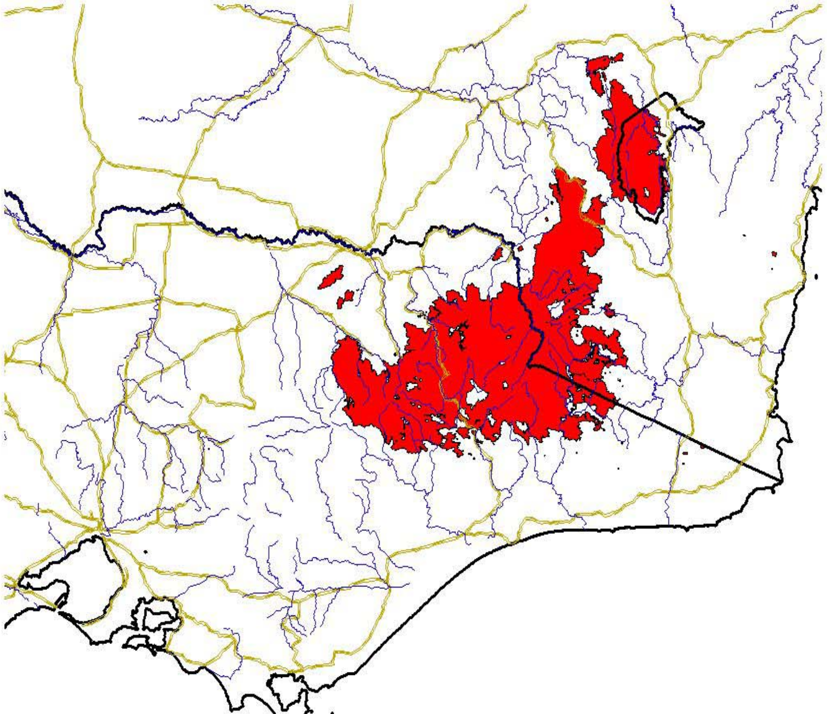
- The distinction between above- and below-ground decomposition seems to be a little-addressed subject in carbon cycle modelling.
- Above-ground and below-ground litter are subject to very different biotic and abiotic environments.

Further steps: Need much primary observational data to guide algorithm development differentiating between above- and below-ground decomposition.

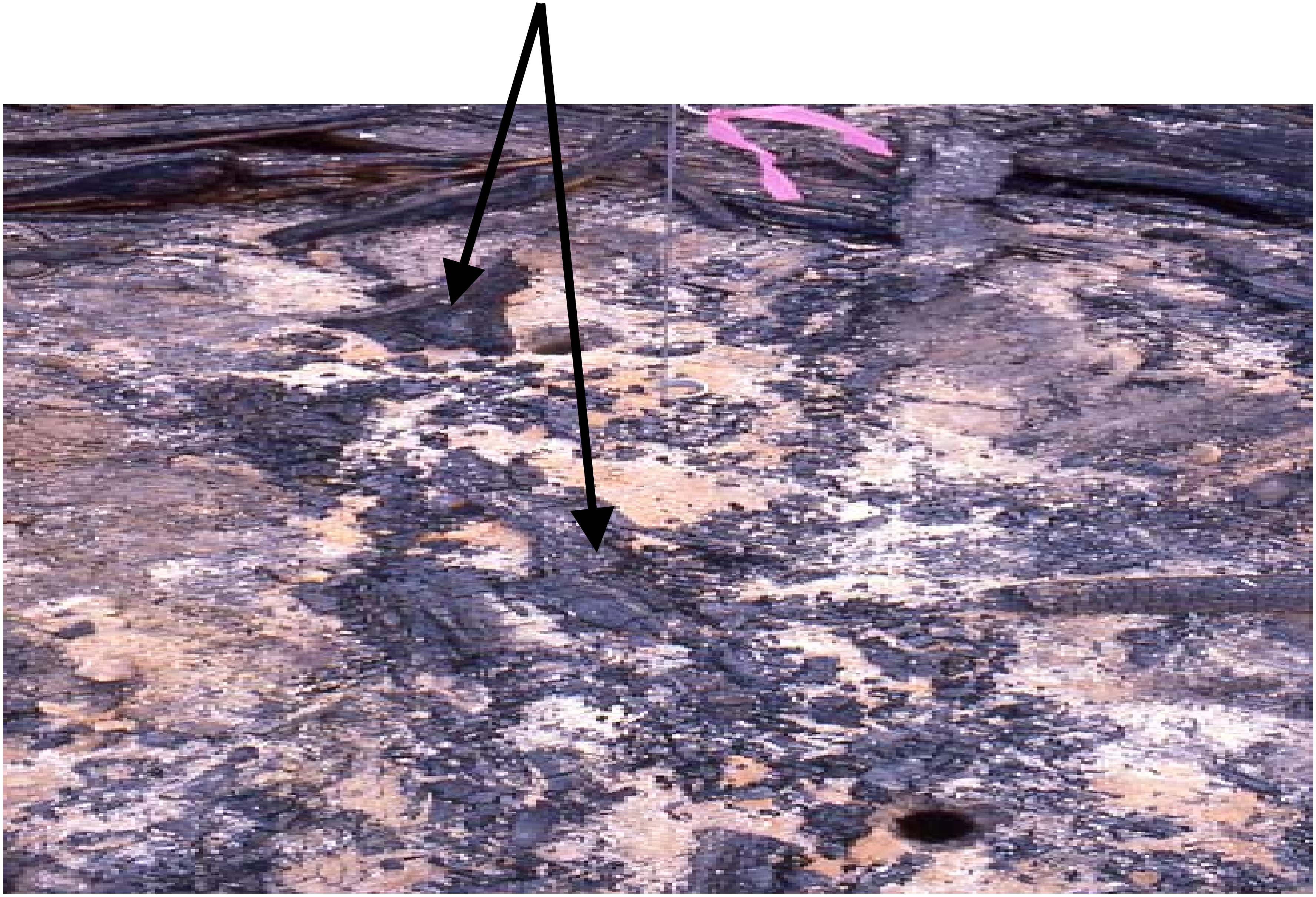
Priority 7. **Formation and fate of black carbon (char)**

- Char formation is highly episodic – temporally and spatially
- Forms the longest lived form of C in ecosystems
- Difficult to deal with in modelling

Fire Scar Area from Jan/Feb 2003 bushfires



Forest fire produces much lumpy char - charcoal



Grass fires produce microscopically fine black C, which will have very different functional and decomposition properties from lumpy charcoal

Char – key points

- Up to 10% (but often <3%) of carbon consumed by fire is converted to char
- For Australia, char formation is equivalent to ~6% annual net GHG emissions

Further steps.

Long term studies required:

- rates of char formation under different burning conditions in important ecosystems.
- rates of decomposition & transport of char in contrasting environments in soils & sediments and with different char types.

Priority 8. **Understanding and modeling SOC-saturation to additional inputs**

There is much talk about saturation of organic matter in soil, above which further inputs of litter are "puffed off".

- Is it true?
- How does it come about?
- Is it important enough to be represented in DGVMs?
- If so, how should it be represented in models?

Priority 9. **Quantify & model recovery of the C-cycle of to disturbances induced by climate change and management.**

Management-induced disturbances

- LUC e.g. woody/non-woody conversions
- Changed systems e.g. new crops/rotations

Climate change-induced disturbance

- Direct e.g. temperature stress, drought, flood
- Indirect e.g. fire, pests/diseases

Areas of disturbance

- Fire in forests/grasslands (40-100 Mha/yr)
- Woody conversions (<0.5 Mha/yr)
- 'Intensive' agriculture (?% of 40 Mha/yr)
- Forest harvesting (~100,000 ha/yr)
- Drought/insect impacts in native vegetation (??)

Priority 9 (cont'd) . **Quantify & model recovery of C-cycle to disturbances induced by climate change and management.**

Further steps:

- Define a minimum set of important vegetation types/classes that can be used for specific purposes.

- Develop a capacity to model change by coupling 'ecological' models (describing the nature of the response) with biophysical models (defining the rate of the response).

Biomass and soil carbon

Priority ranking for 10 year research goal:

A) Those with Australia-specific focus

- Reducing uncertainty in Australian **baseline primary productivity**
- **Are C-stocks** in Australian natural ecosystems **increasing** under increasing [CO_2] ?
- **Quantify & model** recovery of C-cycle to **disturbances** induced by climate change and by management.
- **Formation and fate of black carbon** (char)

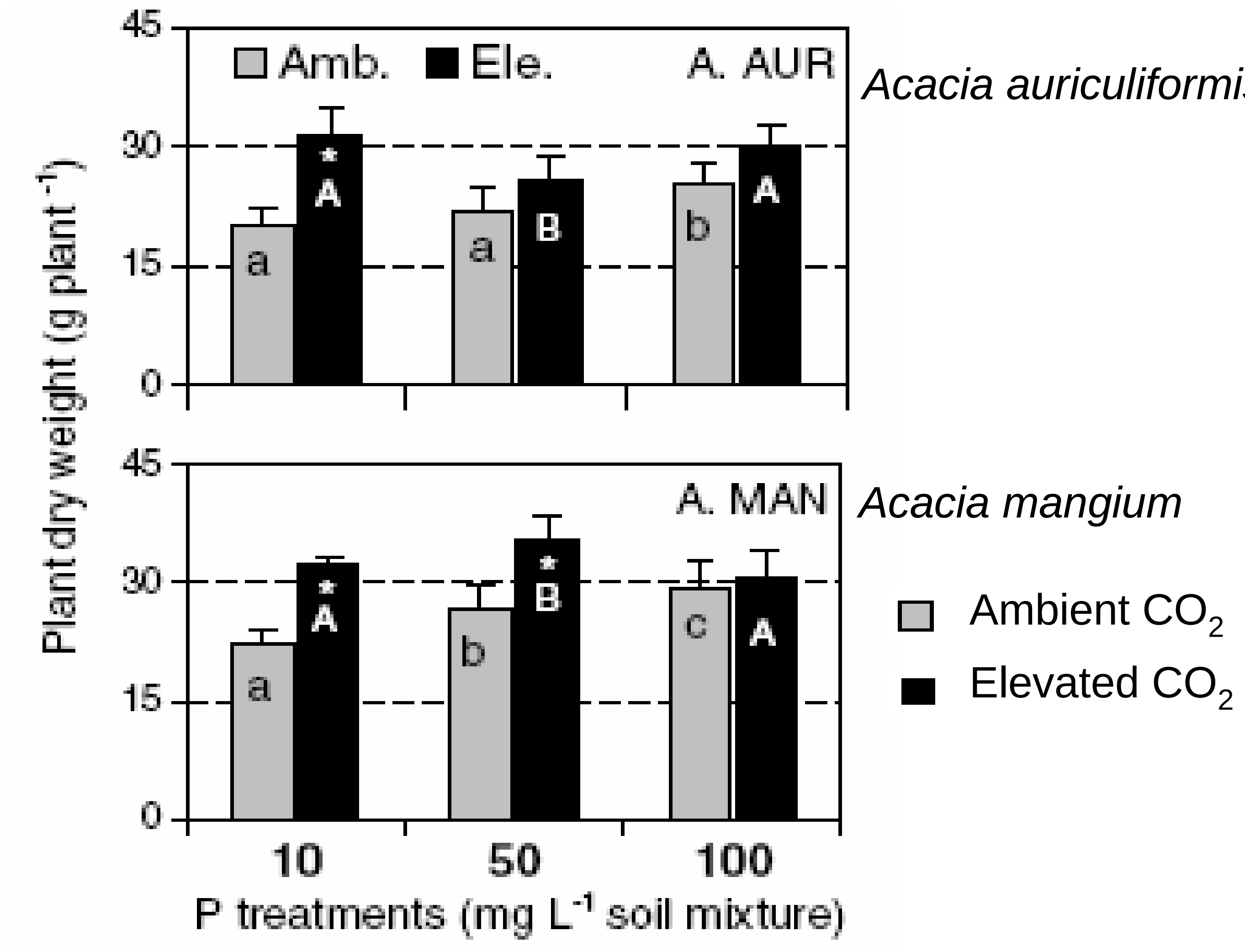
B) Generic issues that Australia can contribute to

- **Coupling** the C cycle with the **N & P cycles**
- **Temperature response of SOM decomposition** rates
- Understanding the **temperature-dependence of NPP**

C) Important areas of lesser imperative

- Fraction of above ground litter taken into soil - mechanisms
- Understanding and modeling SOC-saturation to additional inputs


Thank you



From Nguyen NT, Mohapatra PK, Jujita K (2006). Elevated CO_2 alleviates the effects of low P on the growth of N_2-fixing *Acacia auriculiformis* and *Acacia mangium. Plant and Soil* 285:369-379.