Ten-year record of forest response to elevated CO_2 provides evidence for declining NPP and growth

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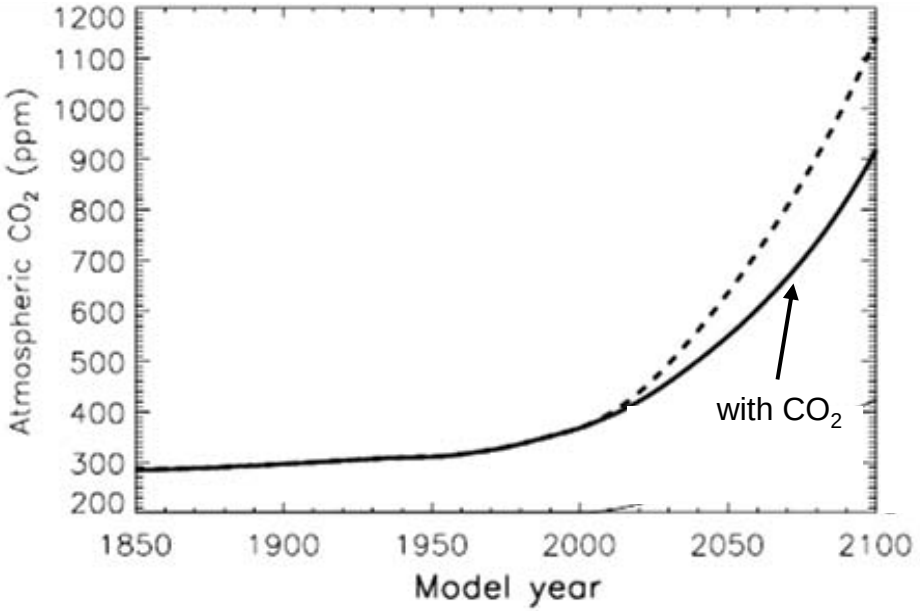
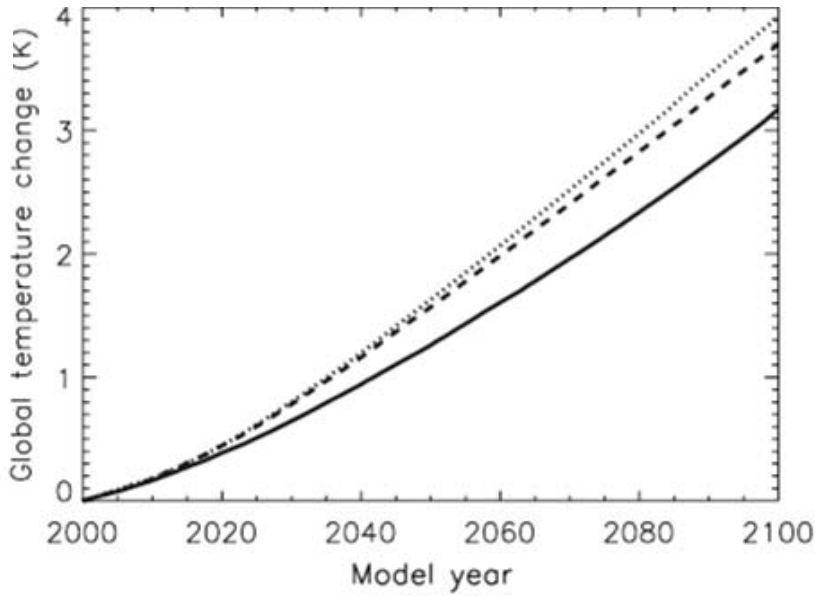
Global models indicate that CO_2 fertilization slows the rate of increase in atmospheric CO_2 …



… and reduces the global temperature increase



FACE experiments provide the only long-term data to guide how CO_2 fertilization is represented in models

HD Matthews. 2007. *Global Change Biology* 13, 1068–1078.

Oak Ridge Experiment on CO_2 Enrichment of Sweetgum

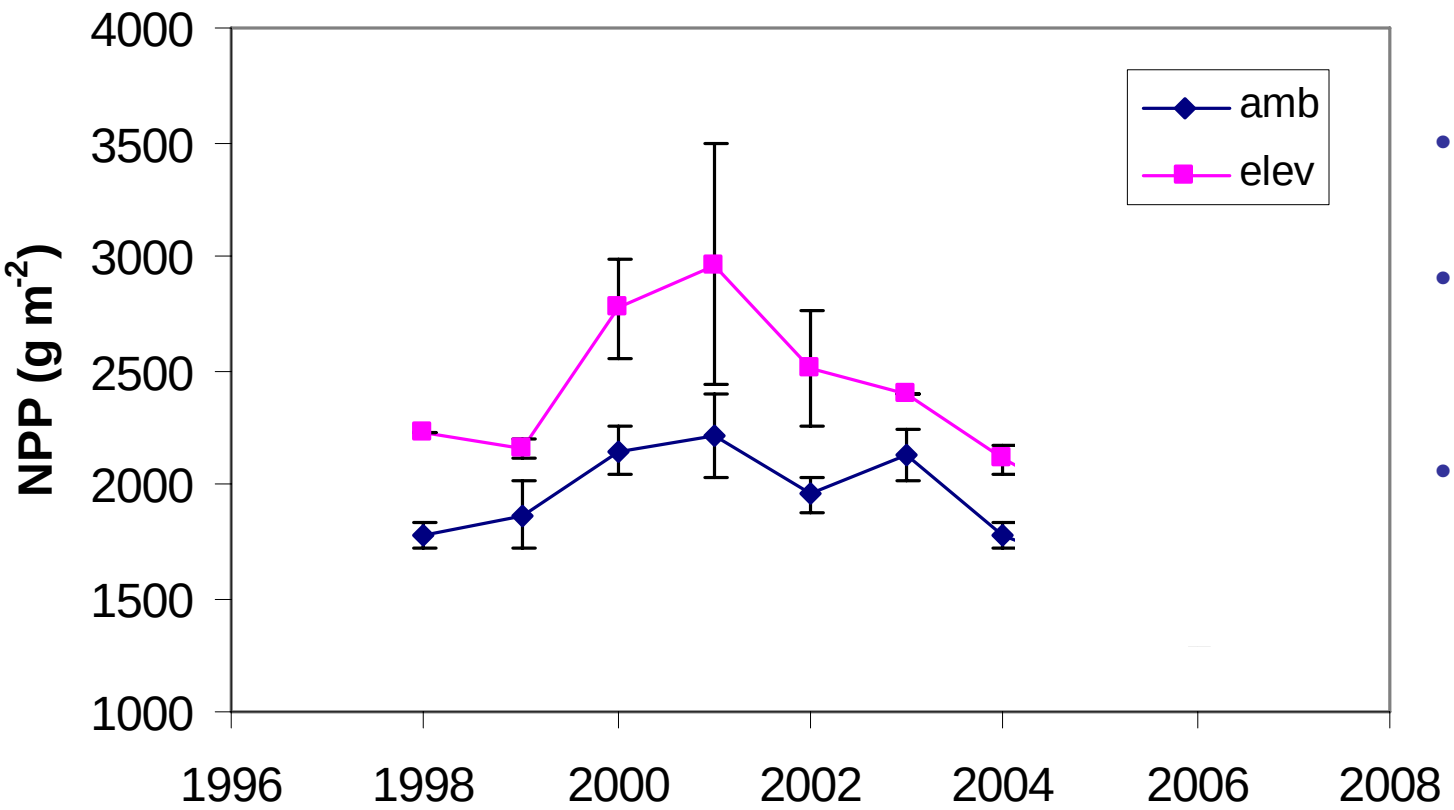
A FACE experiment in a deciduous forest

- ***Liquidambar styraciflua* plantation started in 1988**
- **Closed-canopy stand, linear growth rate**
- **2 elevated, 3 control plots (25 m diameter)**
- **CO_2 exposure (545 ppm) started in 1998**

NPP = stem + coarse root increments + leaf litter + fine-root production

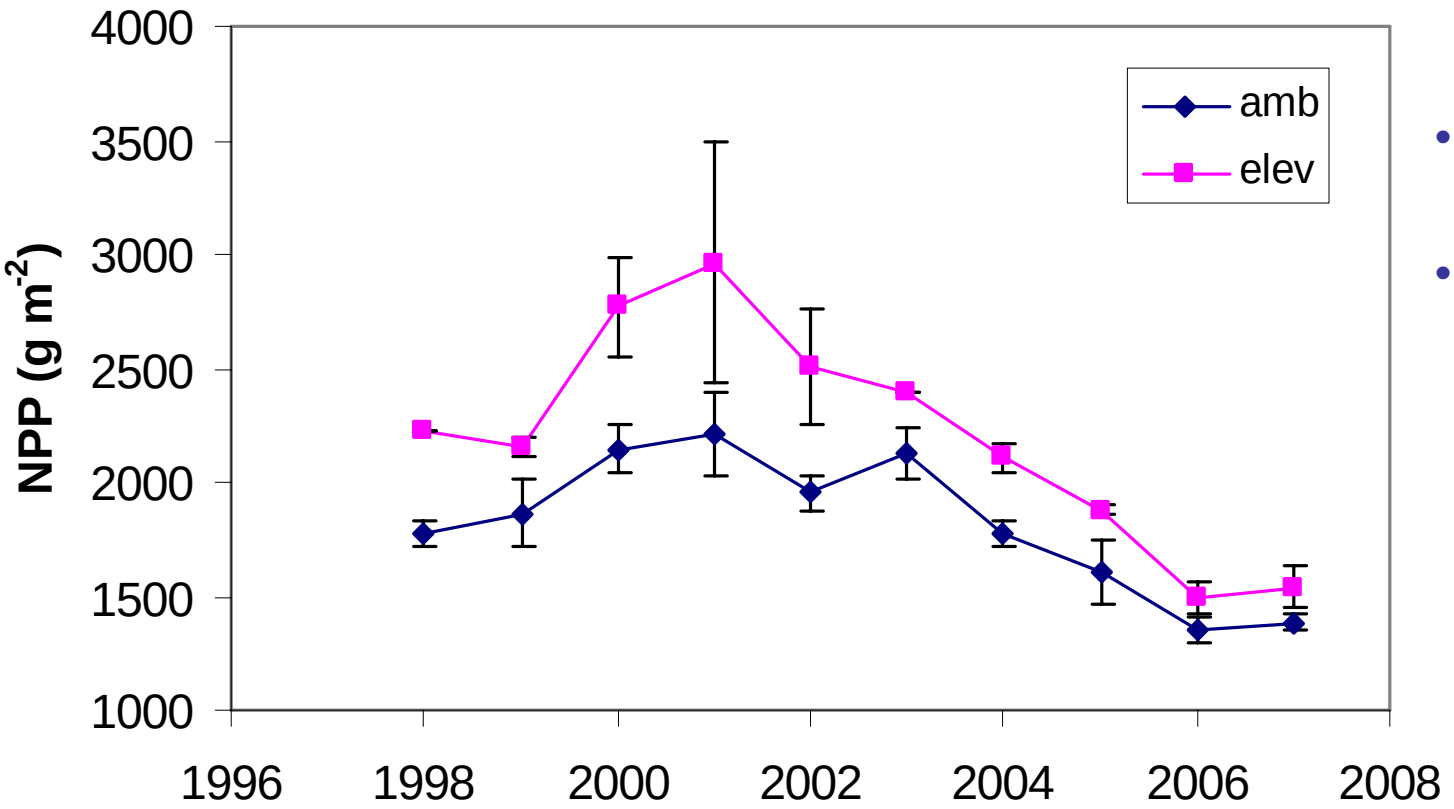
N uptake = N content in these components

We had been reporting that NPP showed a consistent response to elevated CO_2



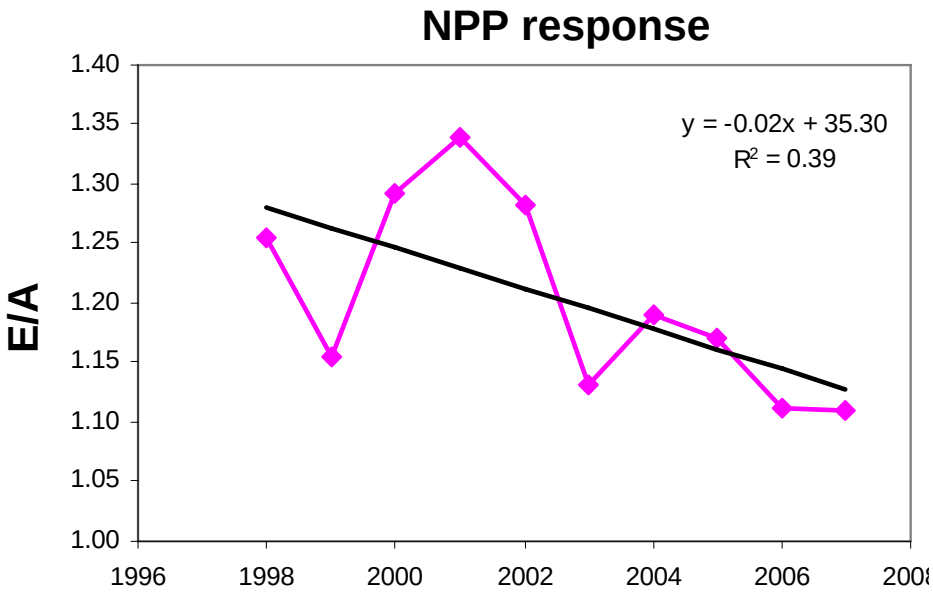
- **Average increase 23%**
- **Most of the increase was in fine-roots**
- **Part of forest FACE synthesis**

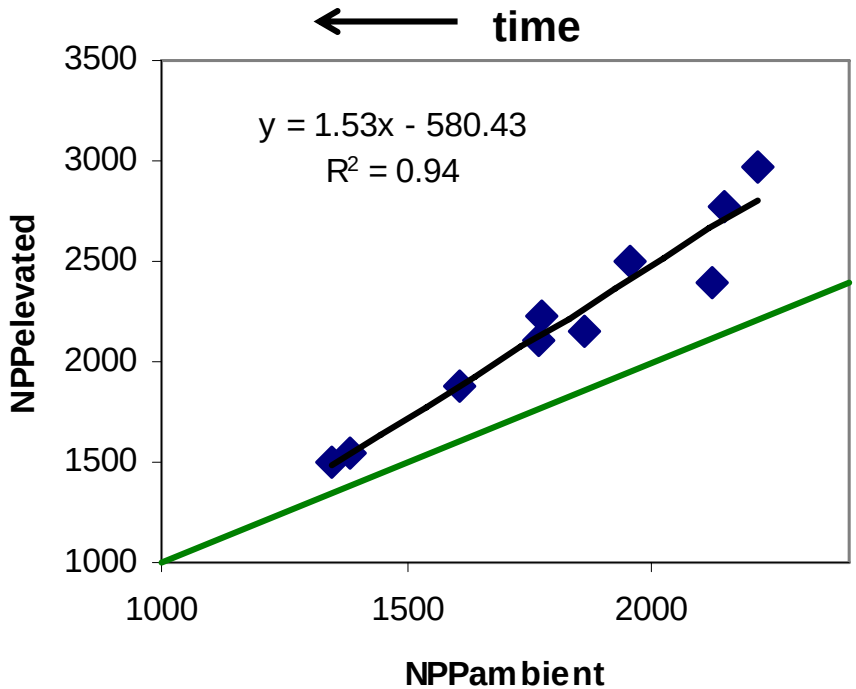
We now see that NPP has been declining in both ambient and elevated CO_2



- Decline leveling off in 2007?
- Relative response to eCO_2 declining since 2004

… and the response of NPP to elevated CO_2 has been declining





Can we explain these responses?

- Why is NPP declining in ambient CO_2?
- Why is response to eCO_2 declining?
- What do we project for the future?

C^4MIP models used in IPCC 4^{th} assessment report matched (on average) FACE results

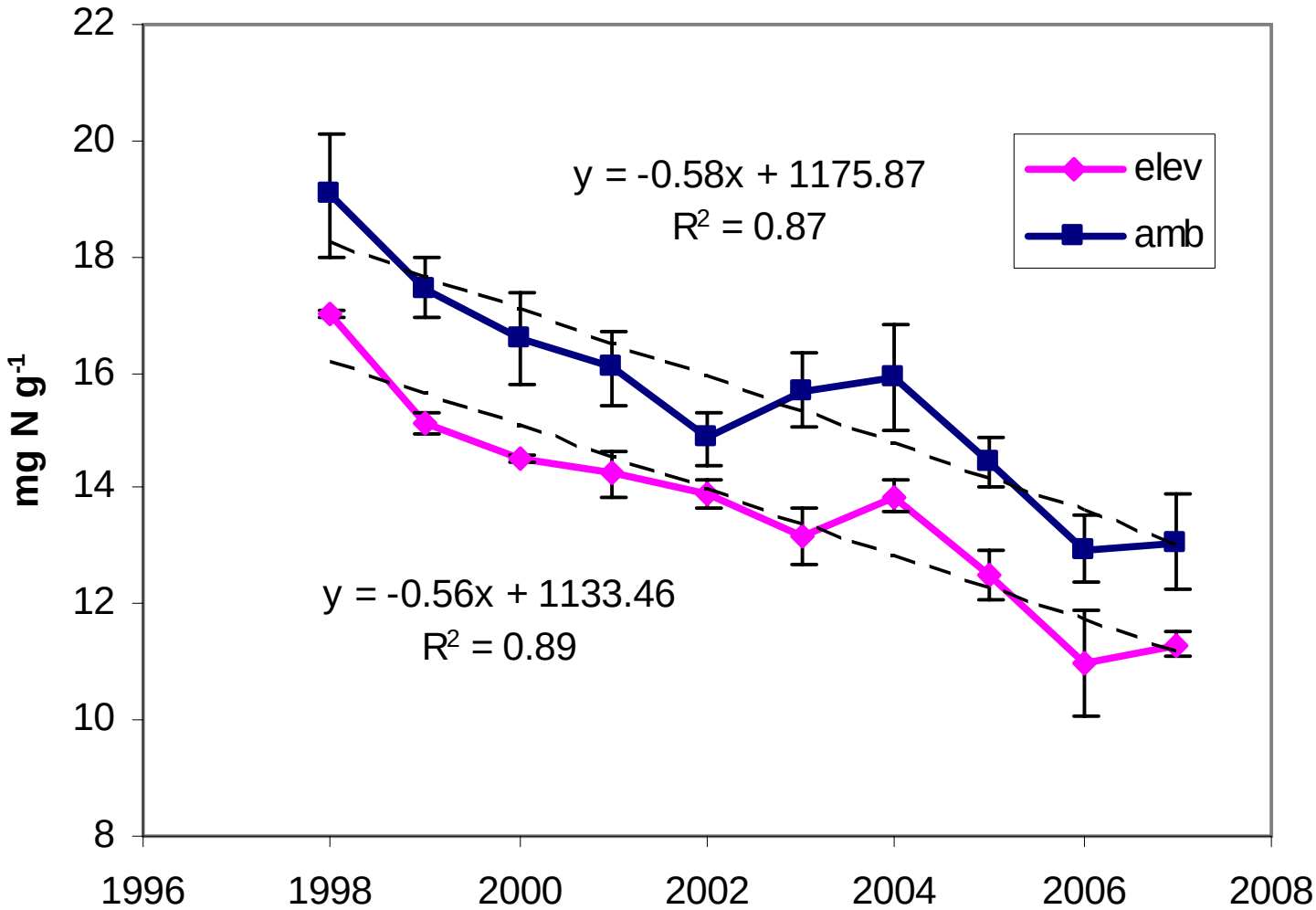
Both the models and experiments do not represent long-term N feedback

"Forests and Climate Change: Forcings, Feedbacks, and the Climate Benefits of Forests"

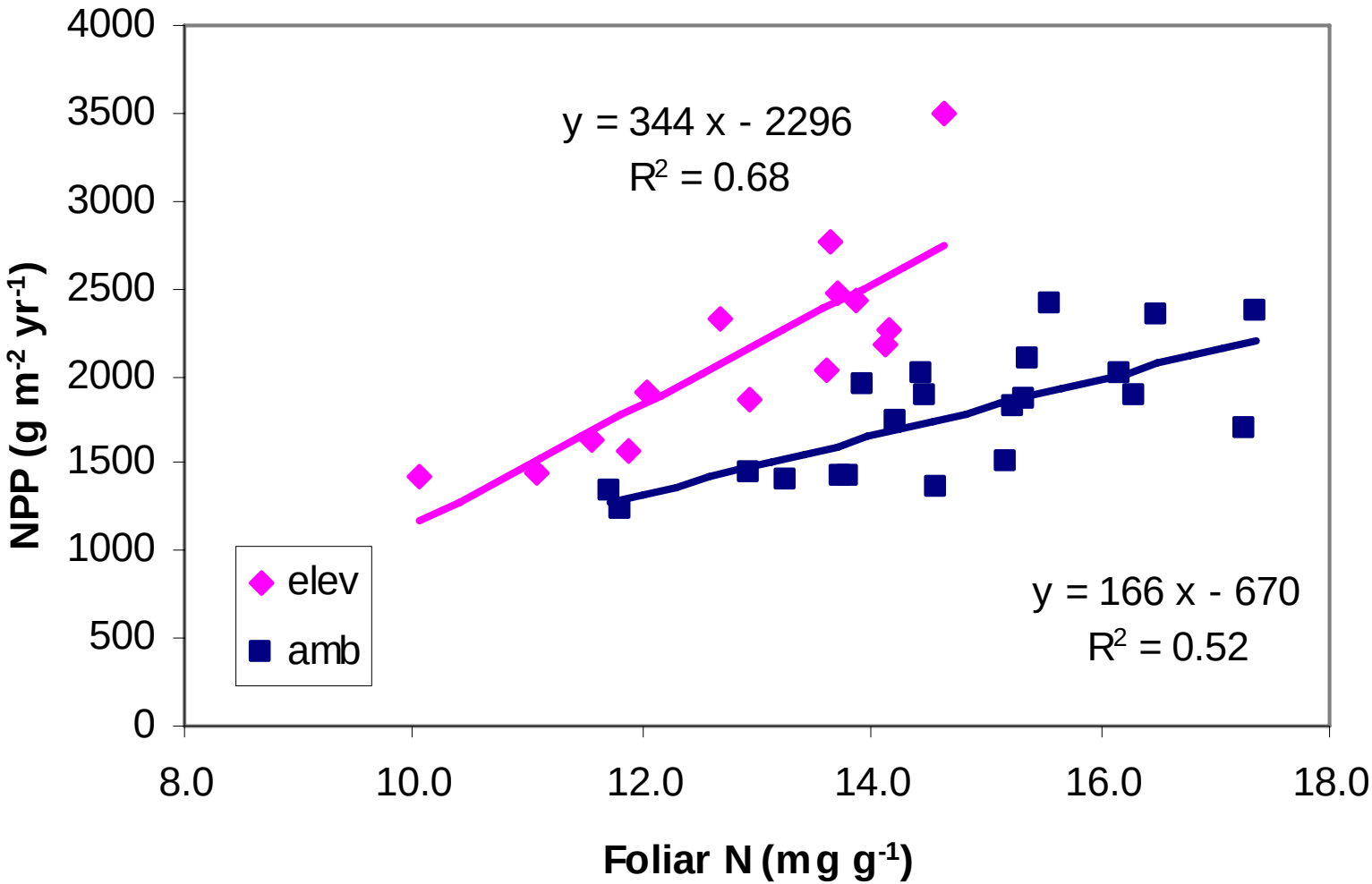
Free-air CO_2 studies in forests find that a ~50% increase in atmospheric CO_2 concentration sustained over several years enhances NPP by 23%, but the long-term outcome is unclear, especially when interactions with nitrogen availability are considered.

(Bonan, *Science*, 2008)

Foliar nitrogen concentration has been declining steadily



The decline in NPP response is probably related to declining N economy



Implication: **no NPP response to eCO_2 when [N] < 9 mg g^{-1}**

Can all these results be obtained from a simple model of carbon, water, and nitrogen economy?

$$NPP = LUE \times APAR$$

Light-use efficiency

Absorbed photosynthetically active radiation

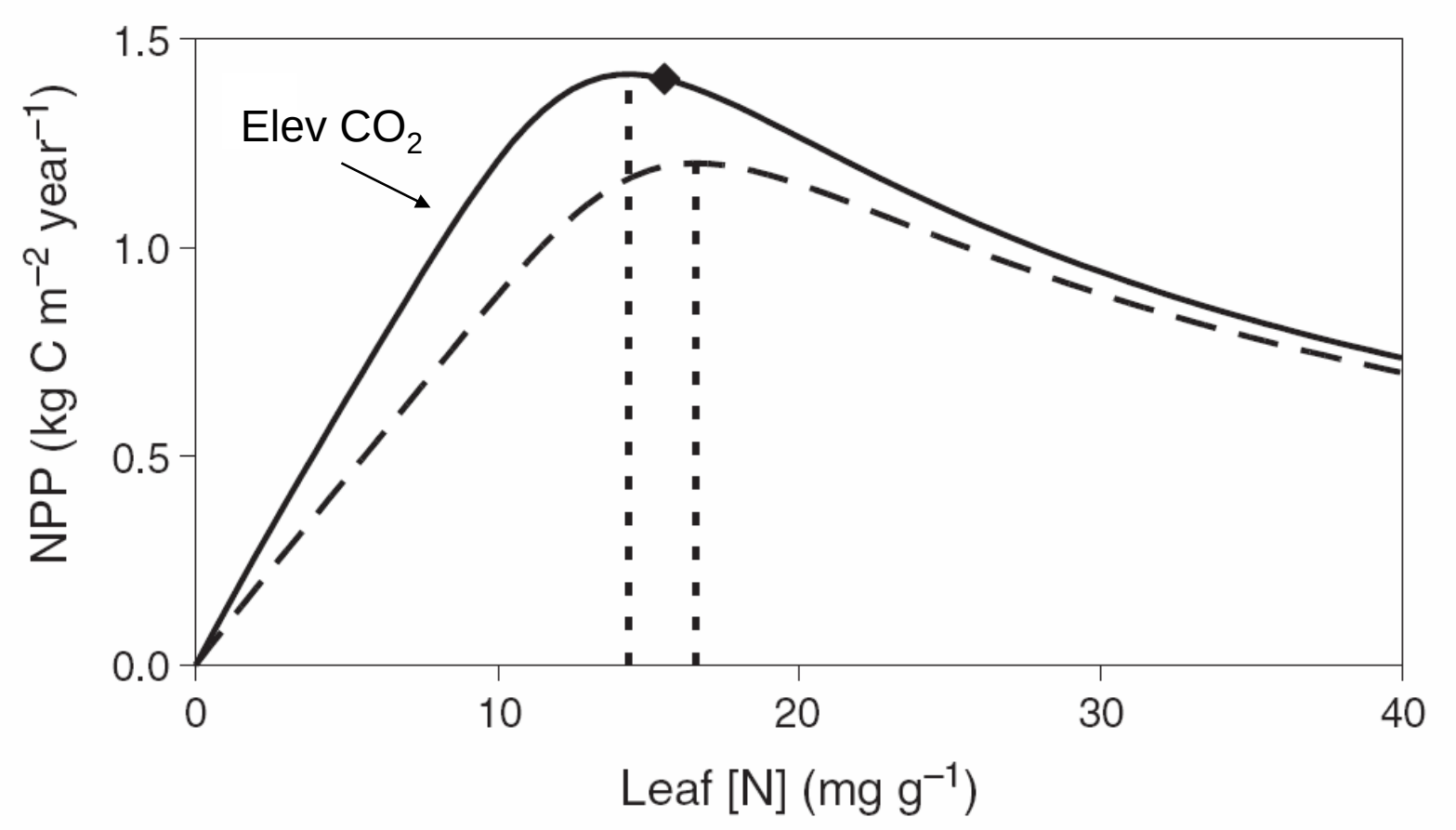
LUE is function of light-saturated photosynthetic rate (A_{max})

(Sands 1996, *Aust. J. Plant Physiol*)

A_{max} depends on [CO_2], leaf N_{area} & stomatal conductance

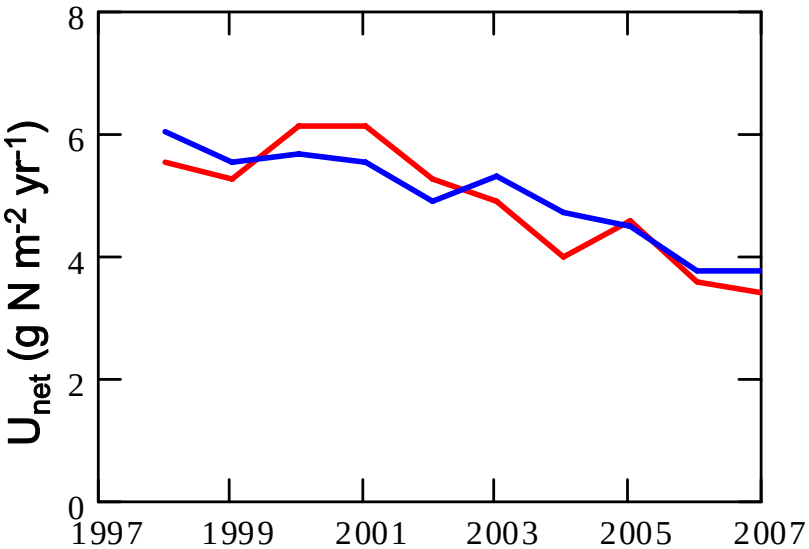
APAR is function of leaf-area index

Optimum leaf [N] shifts with eCO_2

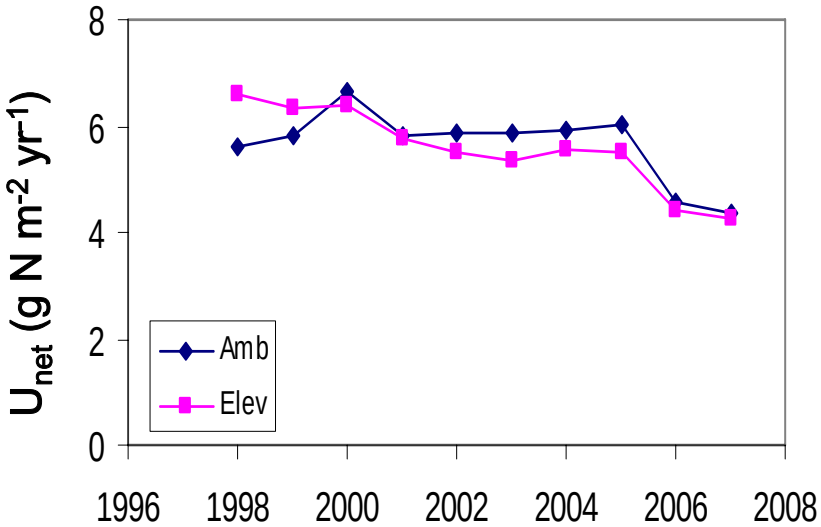


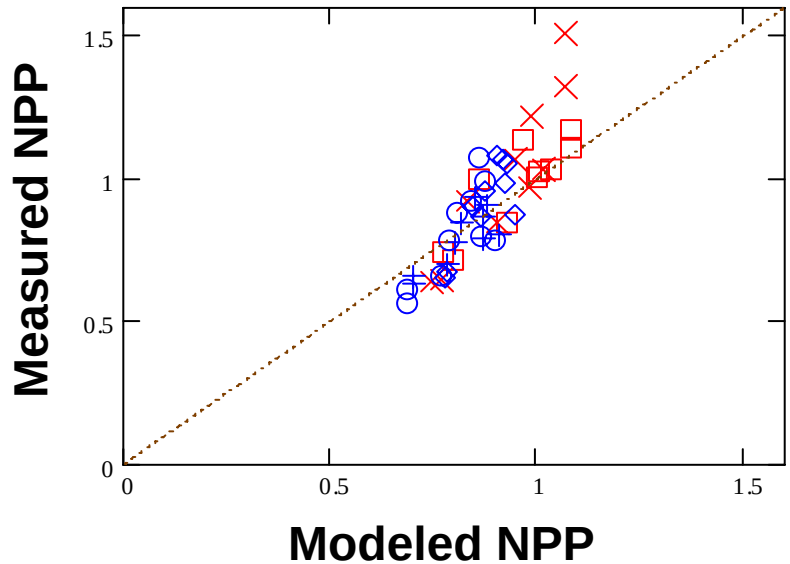
McMurtrie et al. *Functional Plant Biology* 35: 521-534.

Model can explain NPP based on N uptake to aboveground pools

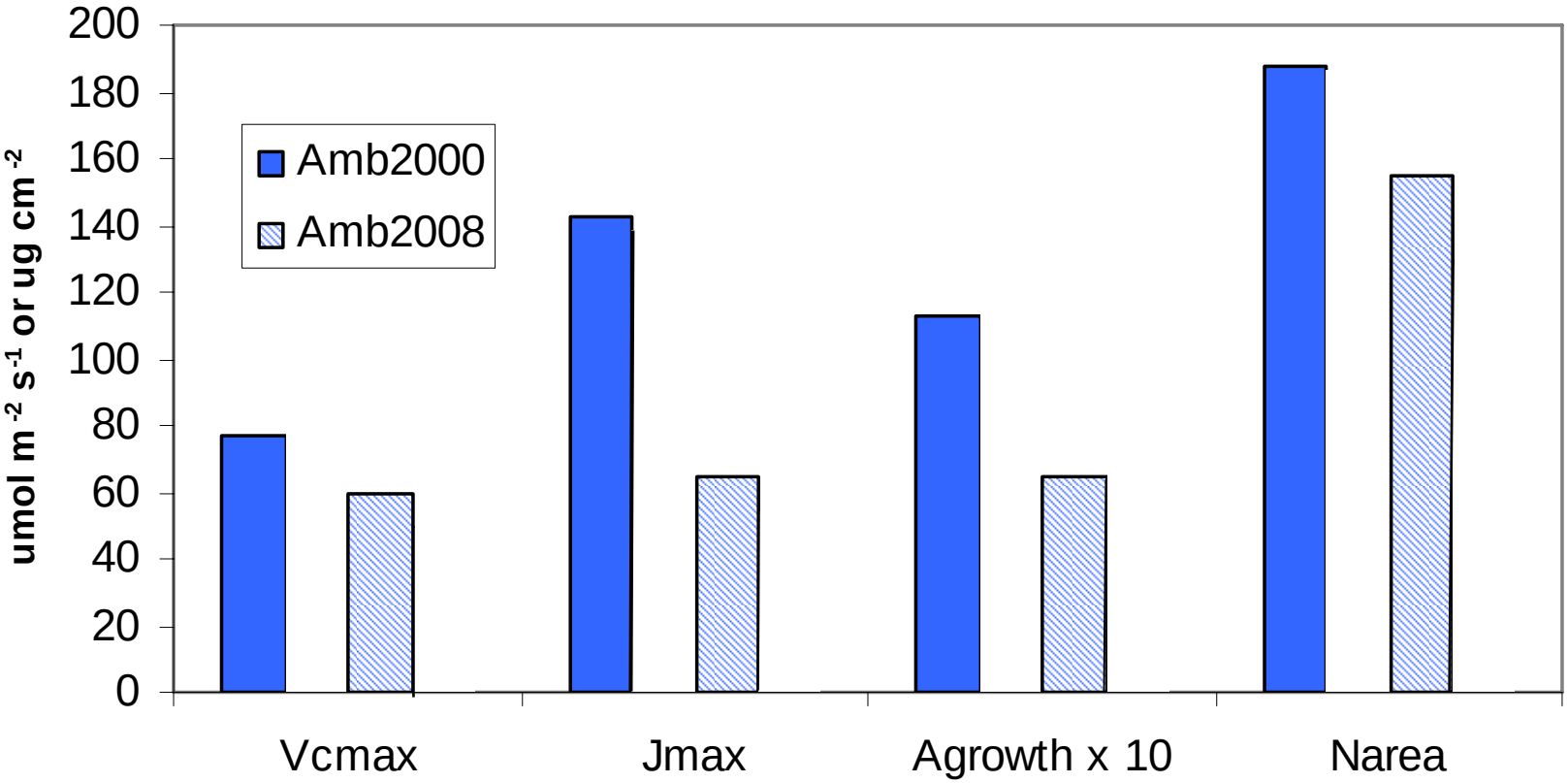


Model estimate of Unet based is best fit of model optimum to LAI , foliar [N], and NPP



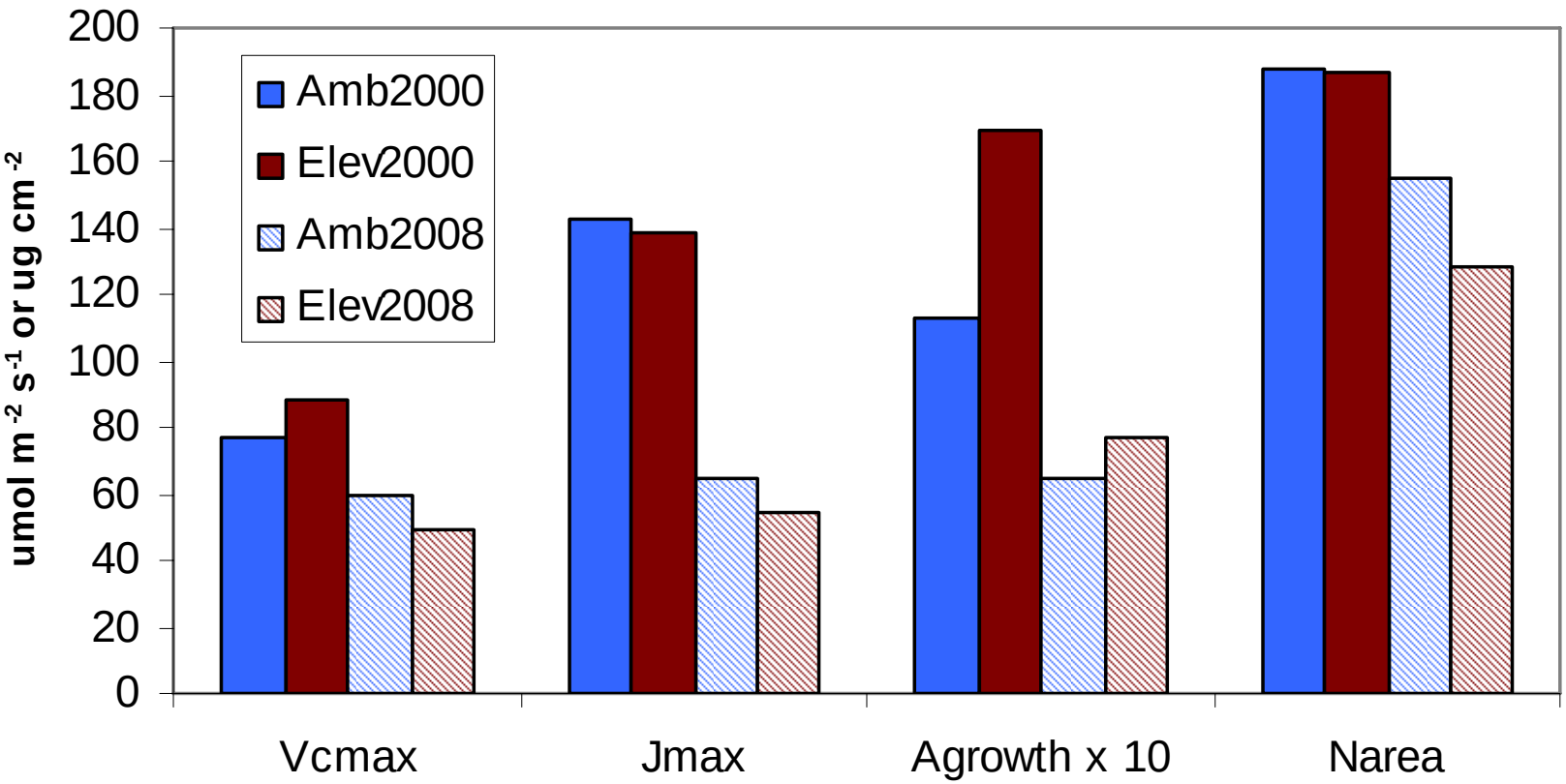


Photosynthesis is lower than in 2000 …



Sholtis et al., *New Phytologist*, 2004; Warren (unpublished)

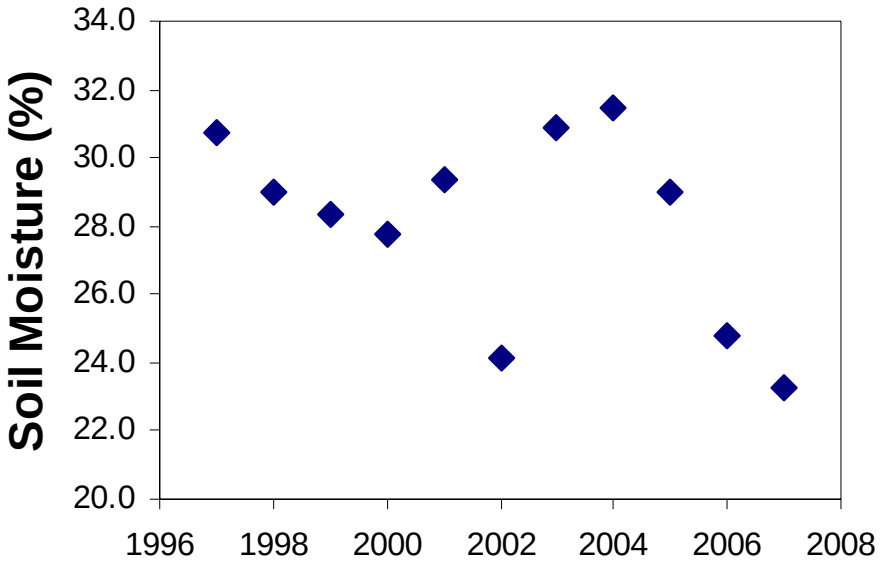
… and the response to eCO_2 is much less

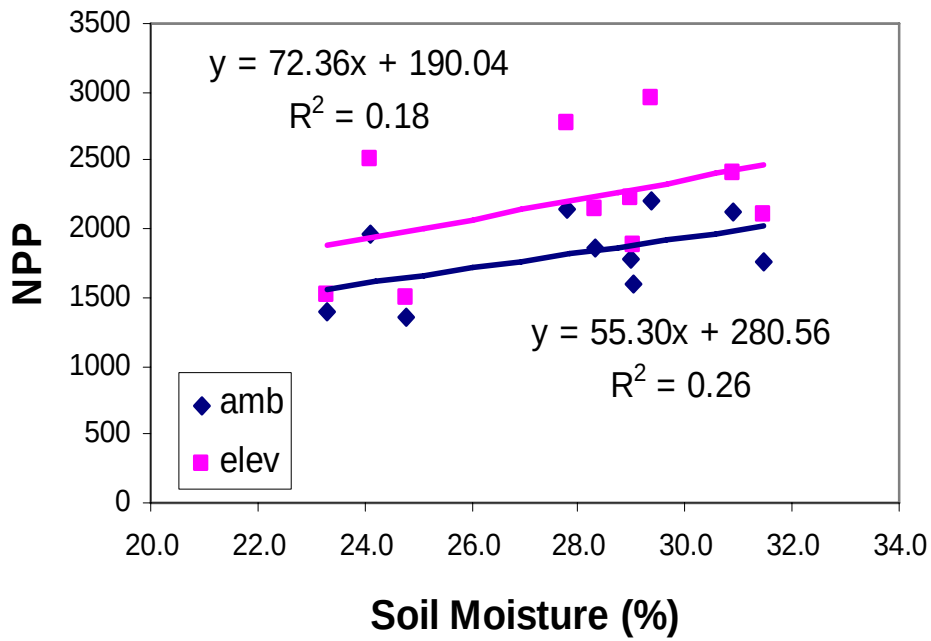


Sholtis et al., *New Phytologist*, 2004; Warren, (unpublished)

Can soil moisture explain the results?

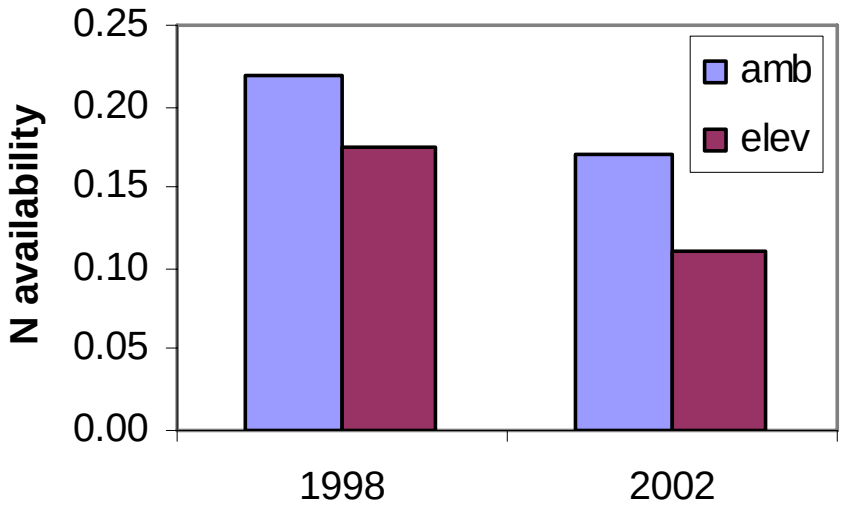
- Effects of drought in 2002 and 2007 were observed
- Relationships between NPP and growing season soil moisture are weak





Possible interactions between soil moisture and N availability?

Why is N uptake declining?



A different optimization model suggests N availability declined from year 1 to 5 and was lower in eCO_2

Franklin et al, *Global Change Biology*, in press

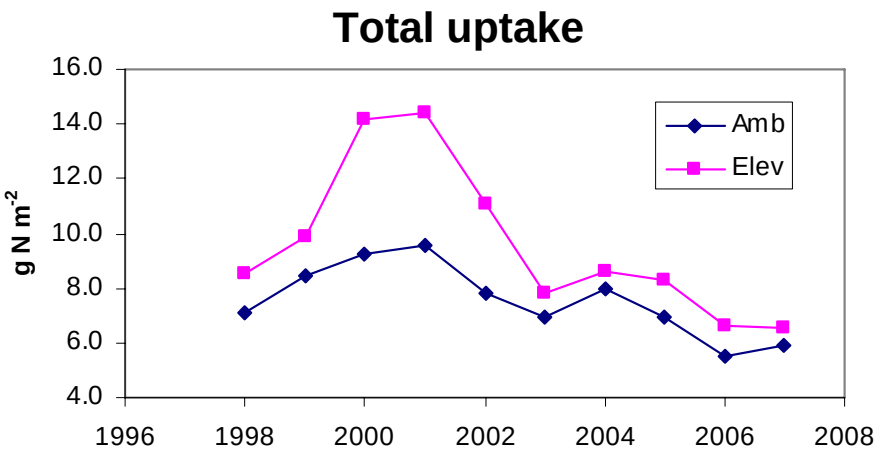
Here, N availability is a plant-centric term (g N g^{-1} root C)
How does this relate to a soil-based evaluation of N availability?

No CO_2 effect on N mineralization
Temporal trend is unresolved

Linking fine-root production, N uptake, and NPP

Franklin model predicts increased N demand for fine roots at the expense of wood and leaves as N availability declines

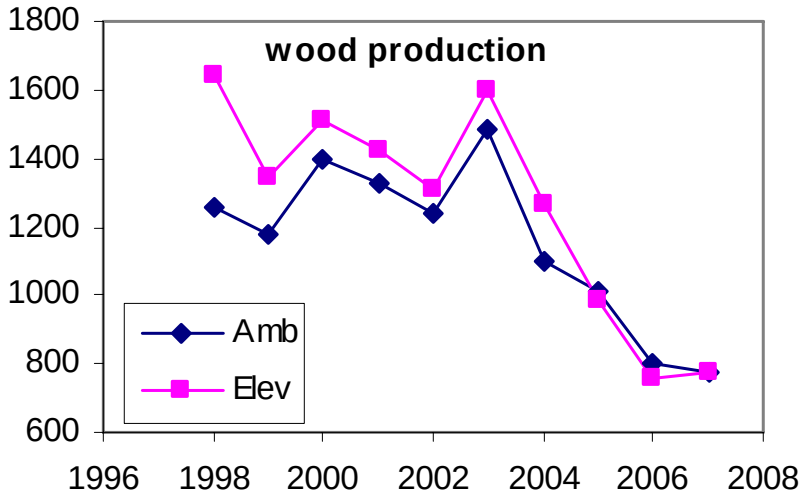
Our data also show increased N uptake to support fine-root production, but without benefit to wood production



We speculated on two potential outcomes of increased fine-root production

Hypothesis:

Increased fine-root production will eventually support greater N supply above ground and increased wood production



Hypothesis is not supported

Alternative Hypothesis:

Increased cycling of C and N from fine roots to soil might lead to sequestration in the soil and lower N availability to the trees

Conclusions and Continuing Questions

- **The NPP response to eCO_2 is declining as site or stand development factors cause NPP to decline**

- **The trends in NPP and NPP response are probably related to N economy**

  but this is not Progressive N Limitation

- **The important question now is whether the declining trends in NPP and [N] will continue, or have they reached relatively steady-state levels?**

- ***To make progress in linking experimental data and models, we need better understanding of plant-soil interactions***