Forest Sensitivity to Elevated Atmospheric CO_2 and its Relevance to Carbon Management

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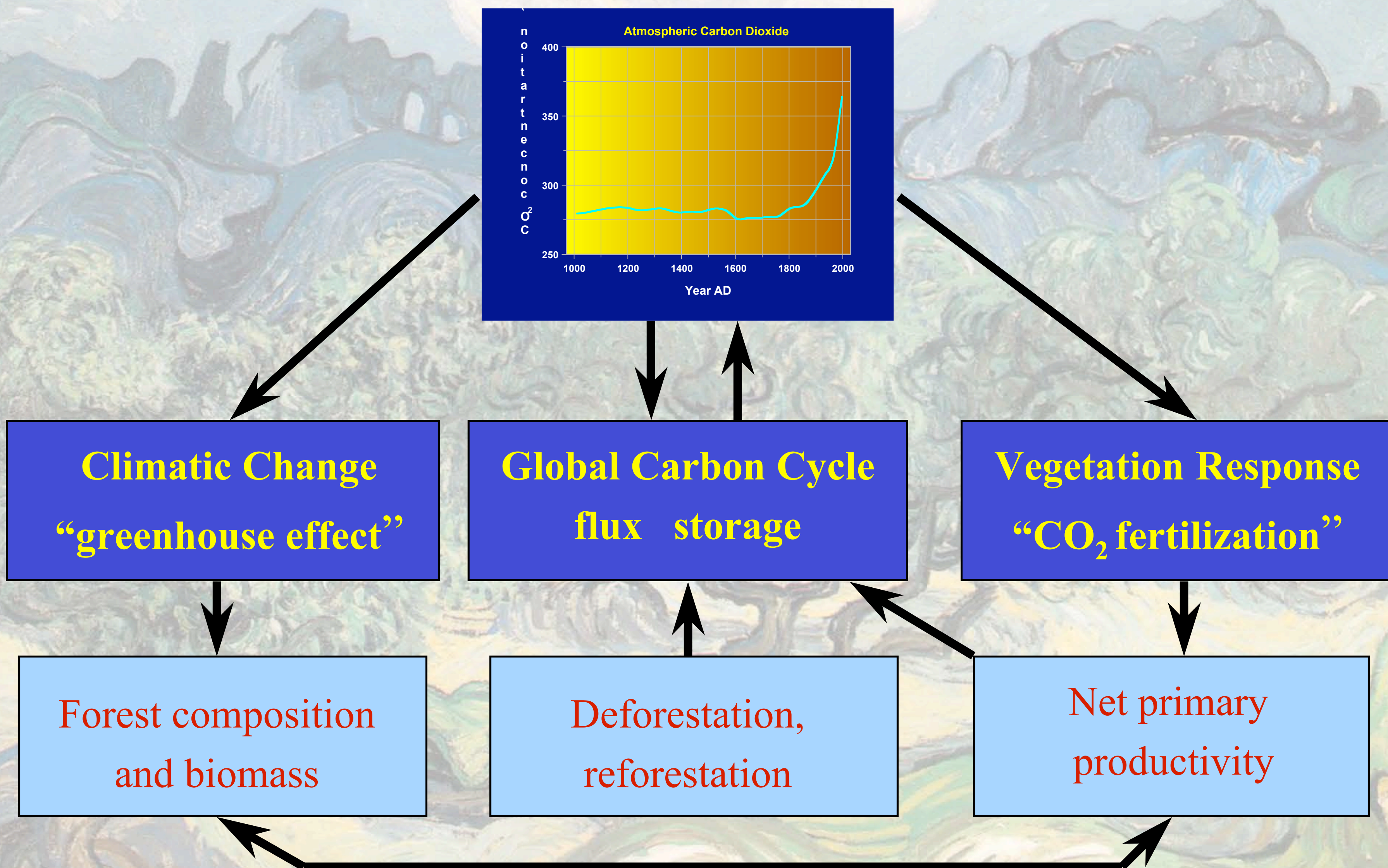
Trees that are planted today will be growing in a higher CO_2 concentration tomorrow

Forests play an important role in the global C cycle

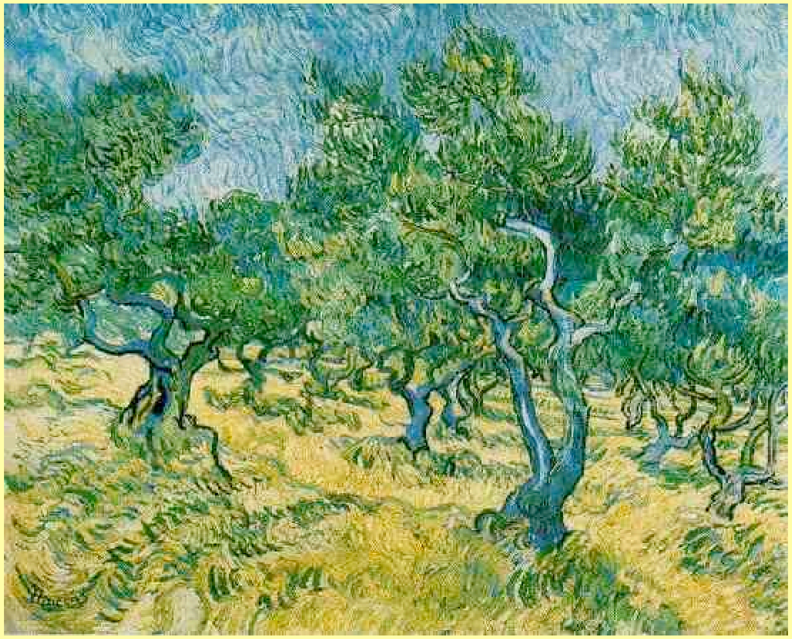
Increased rate of CO_2 uptake as atmospheric [CO_2] rises could slow the rate of [CO_2] increase

Forestry Issues with Rising Atmospheric CO_2



We cannot make reliable predictions concerning the global effects of increasing CO_2 concentration until we have information based on long-term measurements of plant growth from experiments in which high CO_2 concentration is combined with water and nitrogen stress on a wide range of species.

- Paul Kramer, 1981



The initial effect of elevated CO_2 will be to increase NPP in most plant communities... A critical question is the extent to which the increase in NPP will lead to a substantial increase in plant biomass. Alternatively, increased NPP could simply increase the rate of turnover of leaves or roots without changing plant biomass.

- Boyd Strain & Fakhri Bazzaz, 1983

Alternative Research Questions

Will increased [CO_2] boost profits on tree farms?

What trees should be planted to take advantage of rising [CO_2]?

Will trees prevent global warming?

Can high CO_2 be used to sequester more C in trees?

Role of Trees in Curbing Greenhouse Gases Is Challenged

Two new studies challenge the idea that planting forests could be an effective way to absorb emissions of carbon dioxide, heat-trapping gas that many scientists believe is causing global warming.

--New York Times, 24 May 2001

Trees Aren't a 'Magic Answer' on Warming

Studies suggest forests won't soak up excess CO_2.

--New York Times, 2 June 1992

Mature Forests Not Necessarily CO_2 Sinks

Madison, Wisconsin – Some scientists and policy-makers claim forests can absorb enough carbon dioxide to cut the risk of further global warming. But at least some forests may not be up to the job.

--ScienceNow, 10 August 2001

We know how trees respond to elevated CO_2

- Elevated CO_2 stimulates photosynthesis and photosynthetic enhancement is sustained in the field
- Trees in elevated CO_2 are bigger at the end of the experiment
- N concentrations are reduced
- No large changes in structure
- Stomatal responses are inconsistent

Response of tree productivity is likely to be less for mature trees in a closed forest

How can data from relatively short-term experiments be used to address the long-term responses of a forest?

Hypotheses for new experiments

- Maximum stand leaf area will increase with increasing CO_2
- Growth per unit leaf area will increase after canopy closure
- Fine root standing crop will not change but turnover will increase
- Downregulation of growth will occur through N cycle
- Stand water use will be decoupled from effects on stomata

Oak Ridge Experiment on CO_2 Enrichment of Sweetgum

Goal

- To understand how the eastern deciduous forest will be affected by CO_2 enrichment of the atmosphere, and what are the feedbacks from the forest to the atmosphere.
- This goal will be approached by measuring the integrated response of an intact forest ecosystem, with a focus on stand-level mechanisms.

CO_2 Enrichment of a Deciduous Forest: The Oak Ridge Sweetgum Experiment

- ***Liquidambar styraciflua*** **plantation started in 1988**
- **2 elevated, 3 control plots (2 with blowers)**

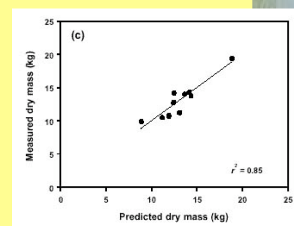
- **Each plot is 25 m diameter (20 m diameter inside buffer)**
- **Full year of pre-treatment measurement in 1997**
- **CO_2 exposure (560 ppm) started spring, 1998**
- **Exposure is 24 hours per day, April through October**
- **Brookhaven exposure system**

Oak Ridge Experiment on CO_2 Enrichment of Sweetgum

Calculation of NPP

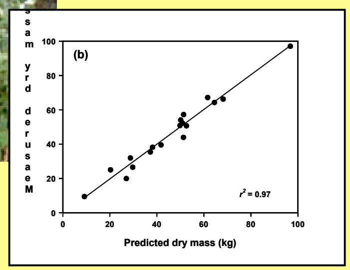
Coarse root

Allometry: DM = f(BA)



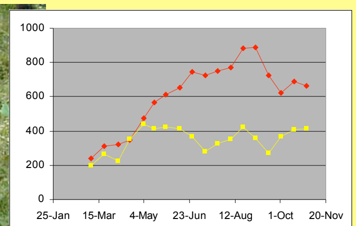
Stem

Allometry : DM = f(BA, H, taper, density)



Fine root

Minirhizotrons and in-growth cores



Leaf

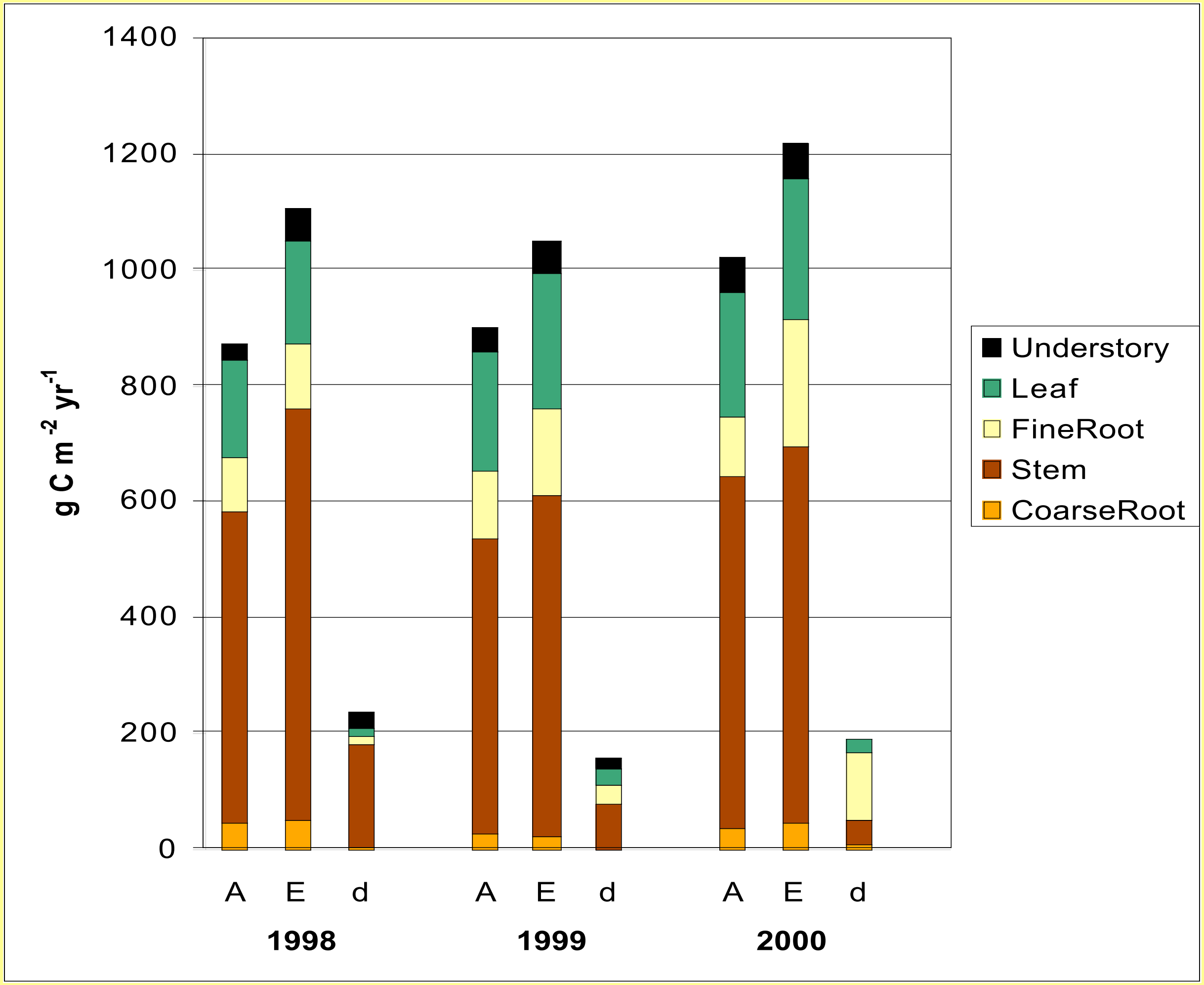
Litter traps

Understory

Harvest

Oak Ridge Experiment on CO_2 Enrichment of Sweetgum

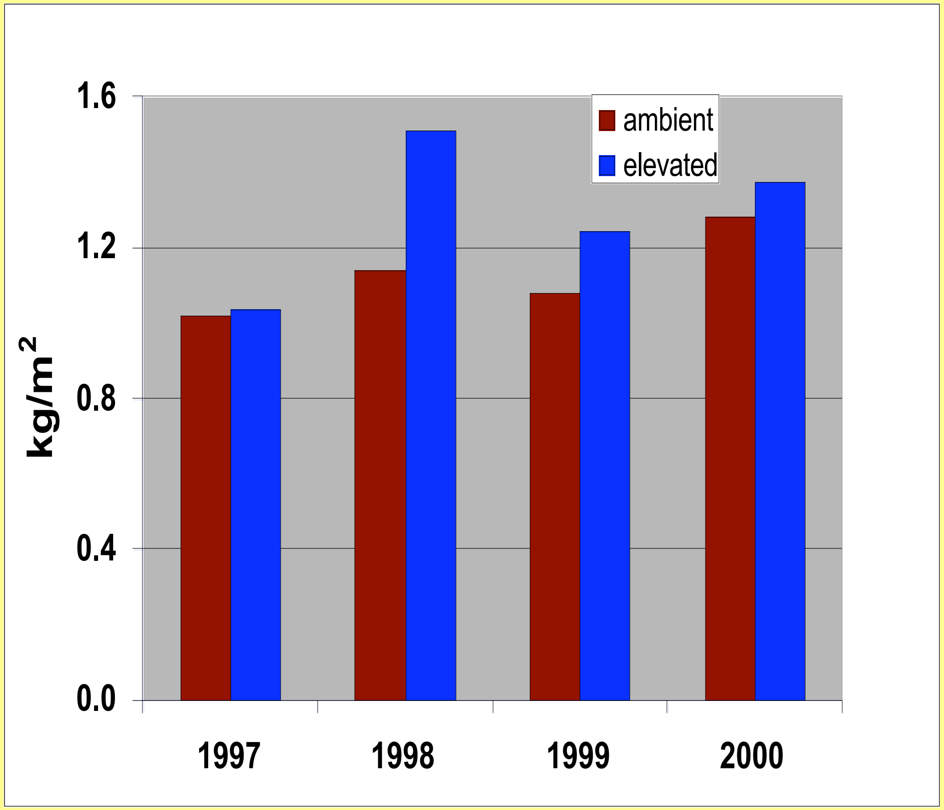
Net Primary Productivity



- CO_2 effect on NPP was: 27% in 1998, 17% in 1999, 19% in 2000.
- GPP was 27% higher in elevated CO_2.
- Allocation of the extra C changed from stem to fine root.

Oak Ridge Experiment on CO_2 Enrichment of Sweetgum

Aboveground Woody Increment



- No difference in growth prior to treatment (1997).
- CO_2 significantly increased growth in 1st year of treatment (35%), but not in 2nd (15%) or 3rd (7%).
- The CO_2 effect on stem growth also has disappeared in the Duke prototype FACE ring.

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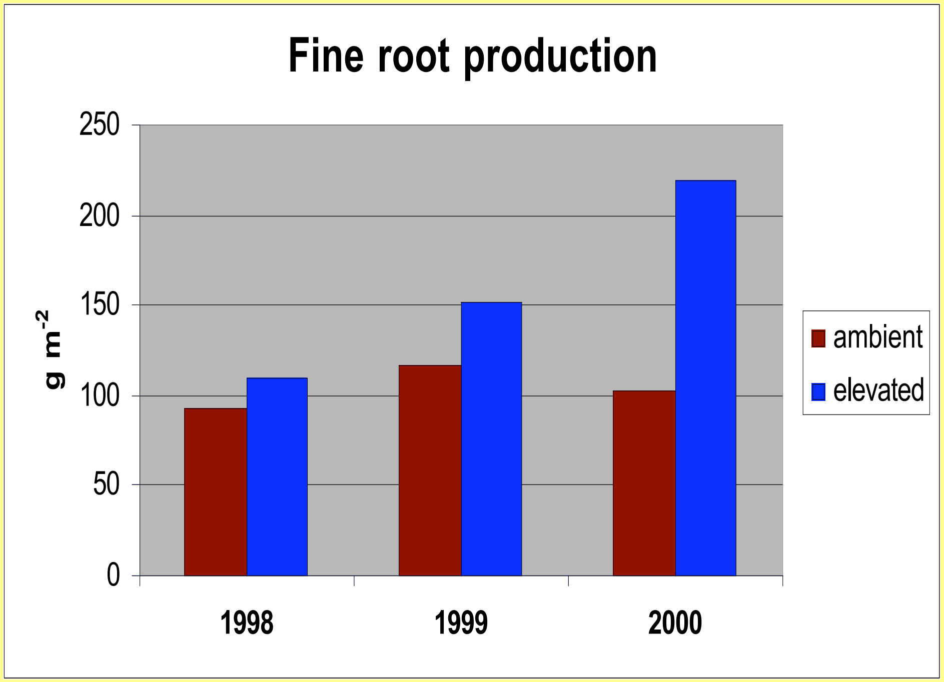
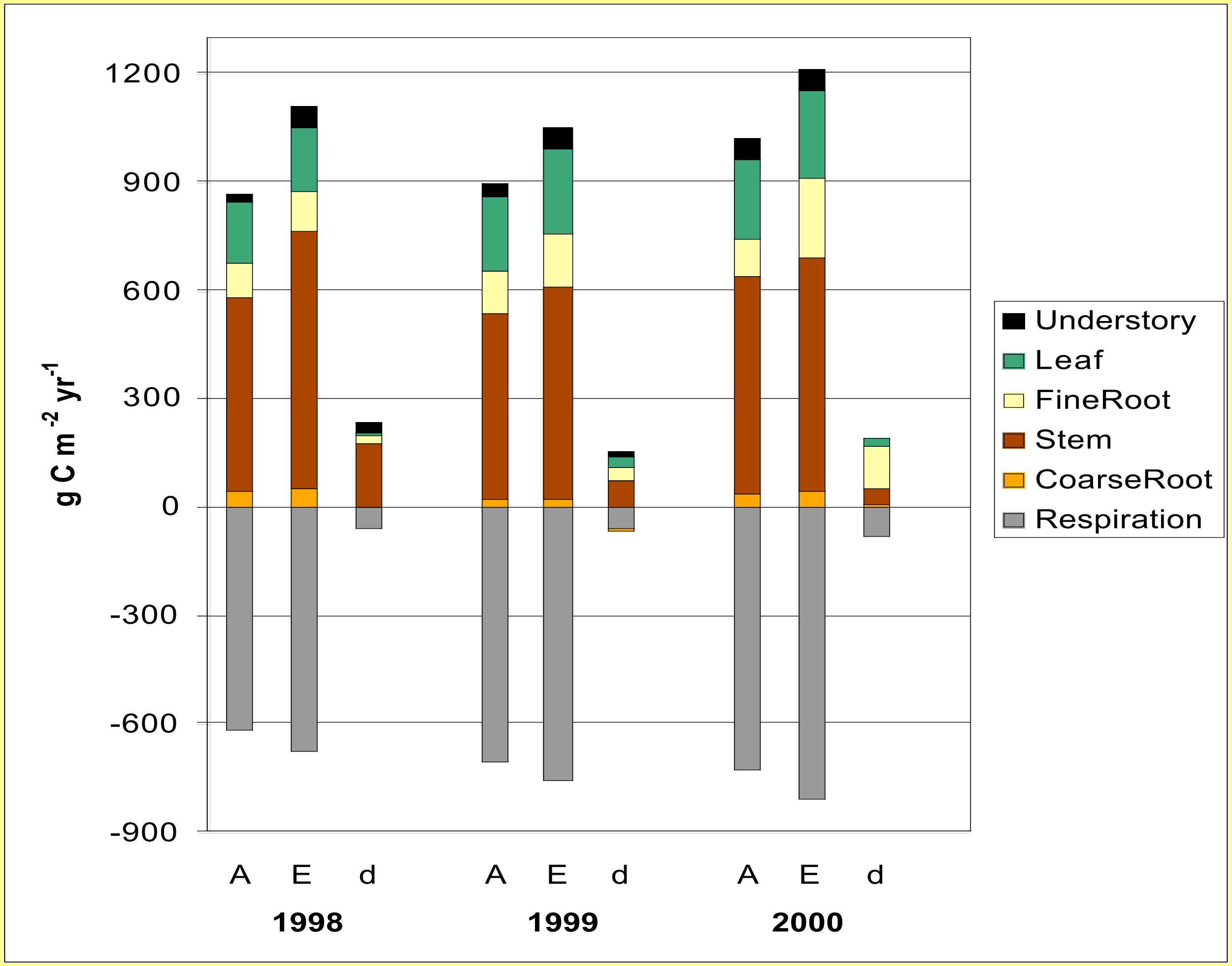
Fine Root Productivity



- **Delay in fine root response may be related to accumulation of CHO in coarse roots.**
- **Fine roots C turns over faster than wood C through soil processes.**
- **Analyze soil heterotrophic respiration:**
  - **- integrate CO_2 efflux**
  - **- subtract root respiration**
  - **- add litter decomposition**

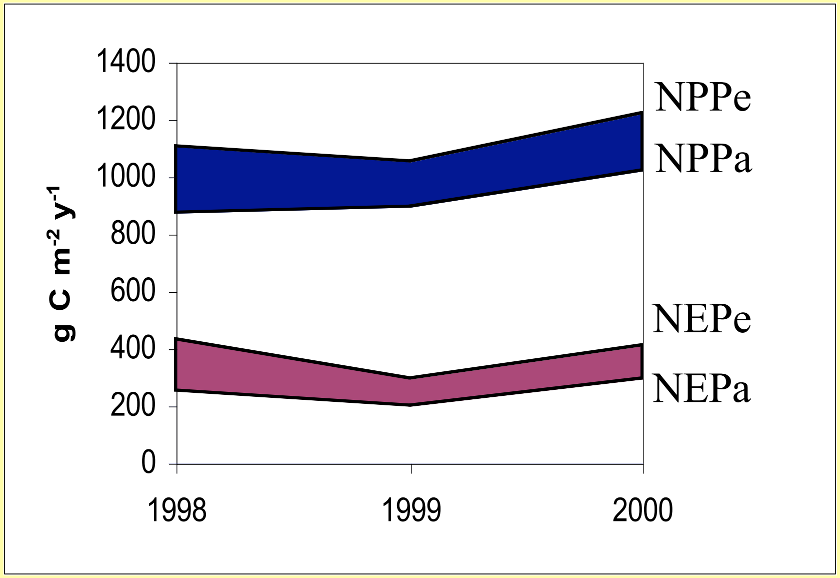
Oak Ridge Experiment on CO_2 Enrichment of Sweetgum

Net Ecosystem Productivity

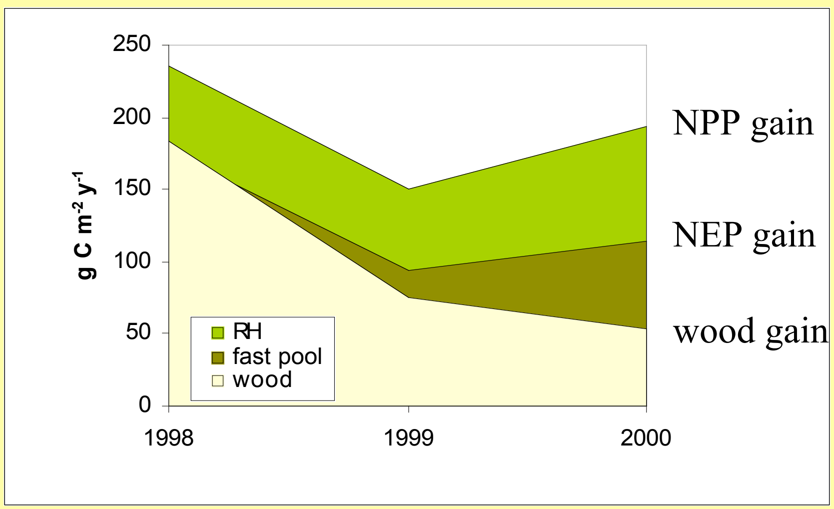


- NEP was positive each year.
- CO_2 effect on heterotrophic respiration was less than effect on NPP.

Dynamics of Carbon Storage

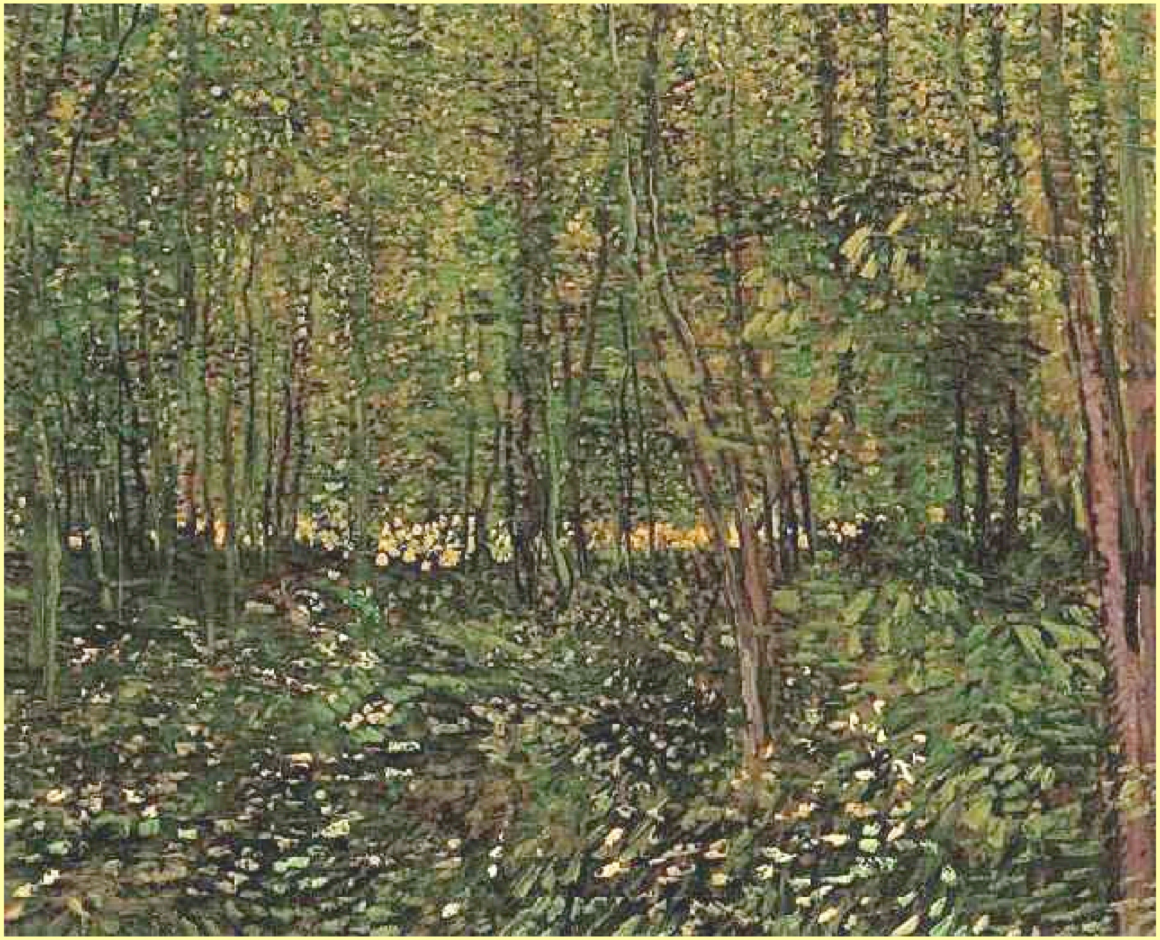


Short-term C sequestration (NEP) was enhanced by CO_2 enrichment

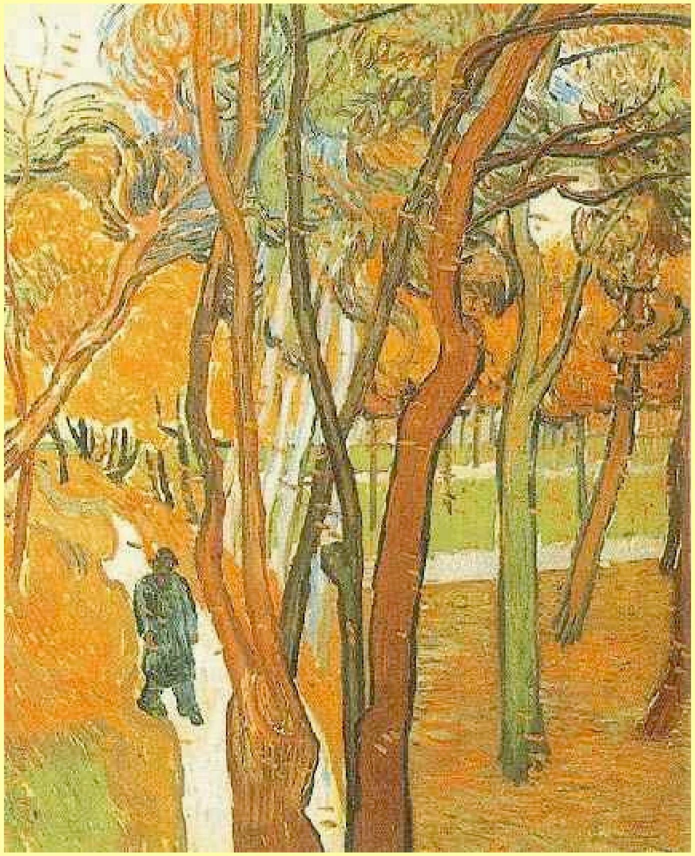


With an increasing fraction of the additional C storage allocated to short-term pools rather than to wood, the gains are likely to be short-lived

Additional carbon entering the soil through root systems has the potential to add to long-lived soil organic matter pools, but most analyses suggest this is unlikely.



Regardless of the fate of the extra C taken up in the Oak Ridge and Duke FACE experiments, both of these rapidly-growing tree plantations are sequestering substantial amounts of C under current conditions.



Interactions between CO_2 and Water

Elevated CO_2 often reduces stomatal conductance and leaf-level transpiration and increases water-use efficiency

Common assumption is that this will confer increased drought resistance, but evidence generally is lacking

CO_2 effects on leaf-level transpiration are mitigated as the scale increases to a whole canopy, stand, and region

Interactions between CO_2 and Warming

Temperature affects all biological processes

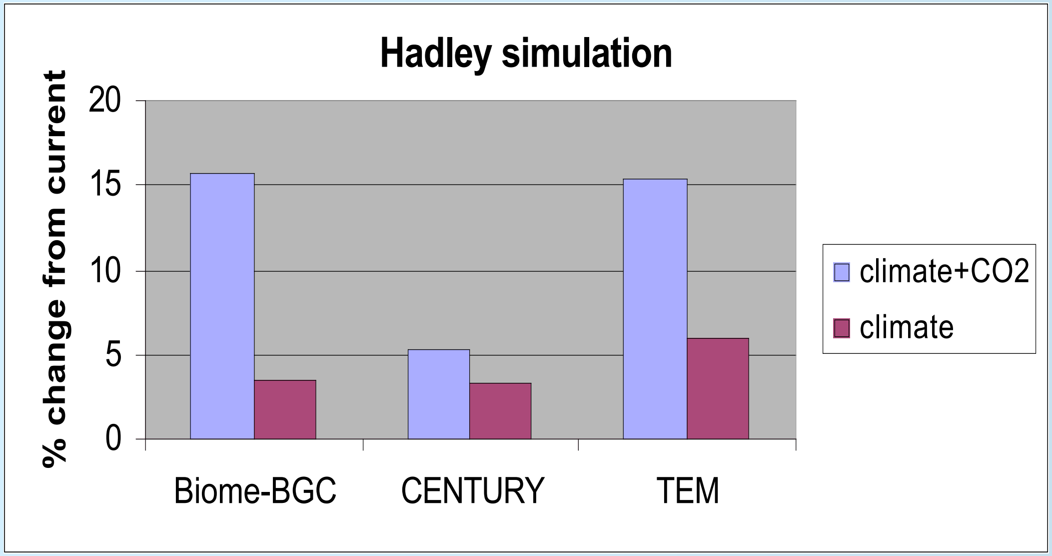
Effects are non-linear, time-dependent, and highly dependent on initial conditions

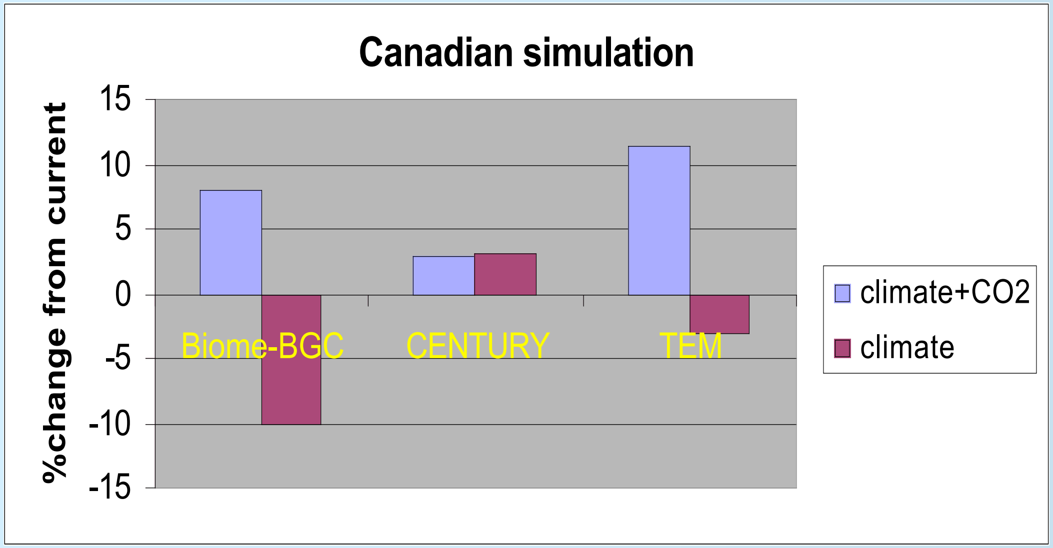
Warming can stimulate productivity through increased photosynthesis and longer growing season

Warming can decrease productivity through increased stress

Elevated CO_2 is likely to ameliorate negative effects of warming

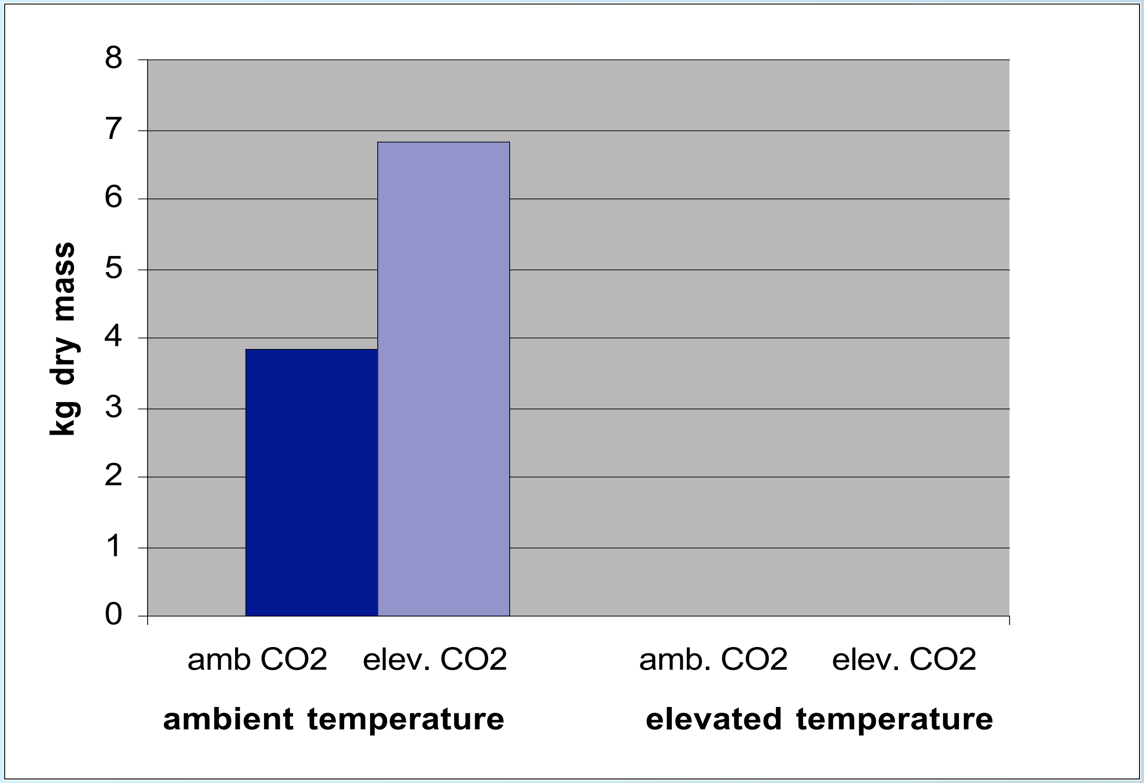
Prediction of NPP with Three Biogeochemical Models





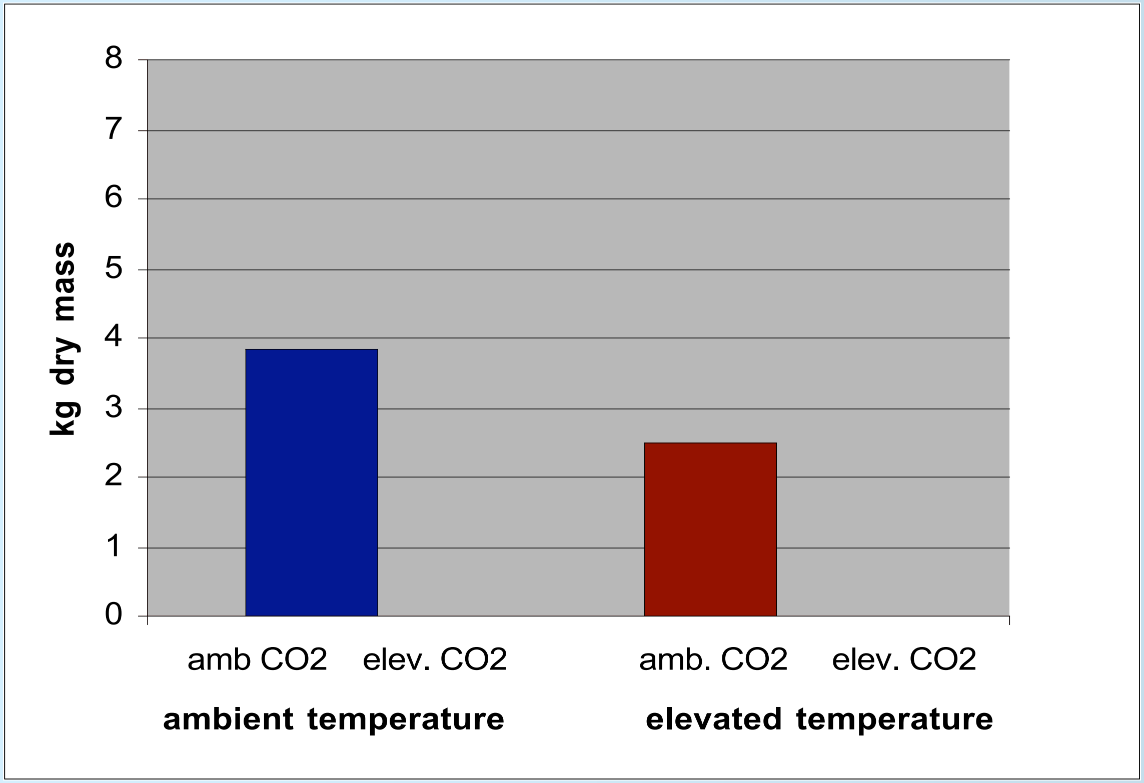
- Predictions are for 2025-2034 (425 ppmv CO_2)
- All three models predict increased NPP with climate change and increased CO_2 for both climate simulations
- Increases are smaller (or become decreases) when CO_2 is not included
- Increases are less with the Canadian climate simulation

CO_2 x Temperature Interactions



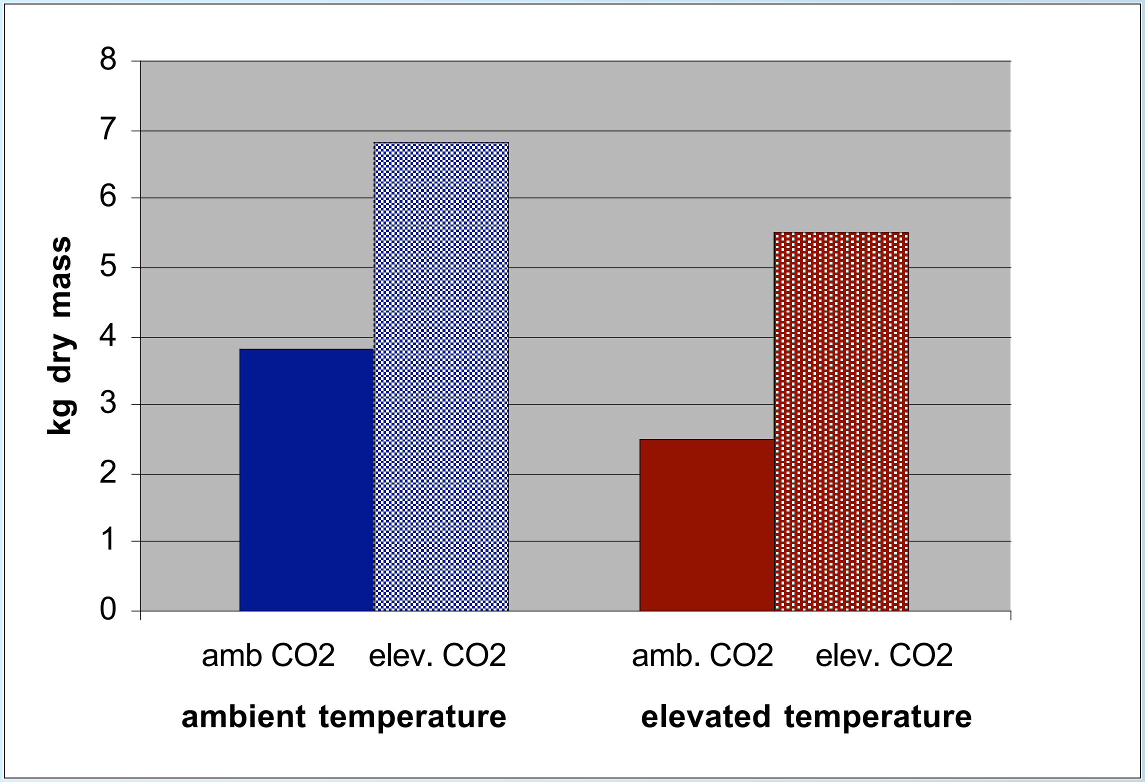
Elevated CO_2 increased growth of maples trees by 73%

CO_2 x Temperature Interactions



Elevated temperature reduced growth by 35% because of increased stress

CO_2 x Temperature Interactions



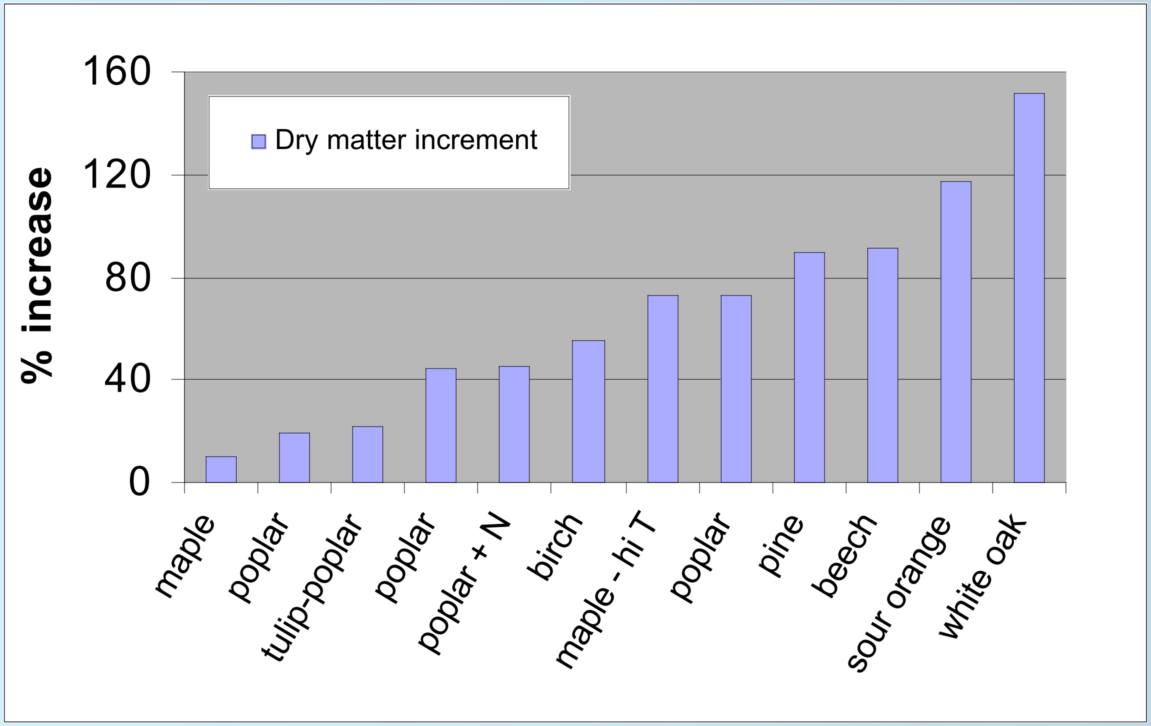
Positive effects of CO_2 and negative effects of temperature were additive

Should the certainty of rising atmospheric CO_2 influence forest management decisions?

Plant most responsive species?

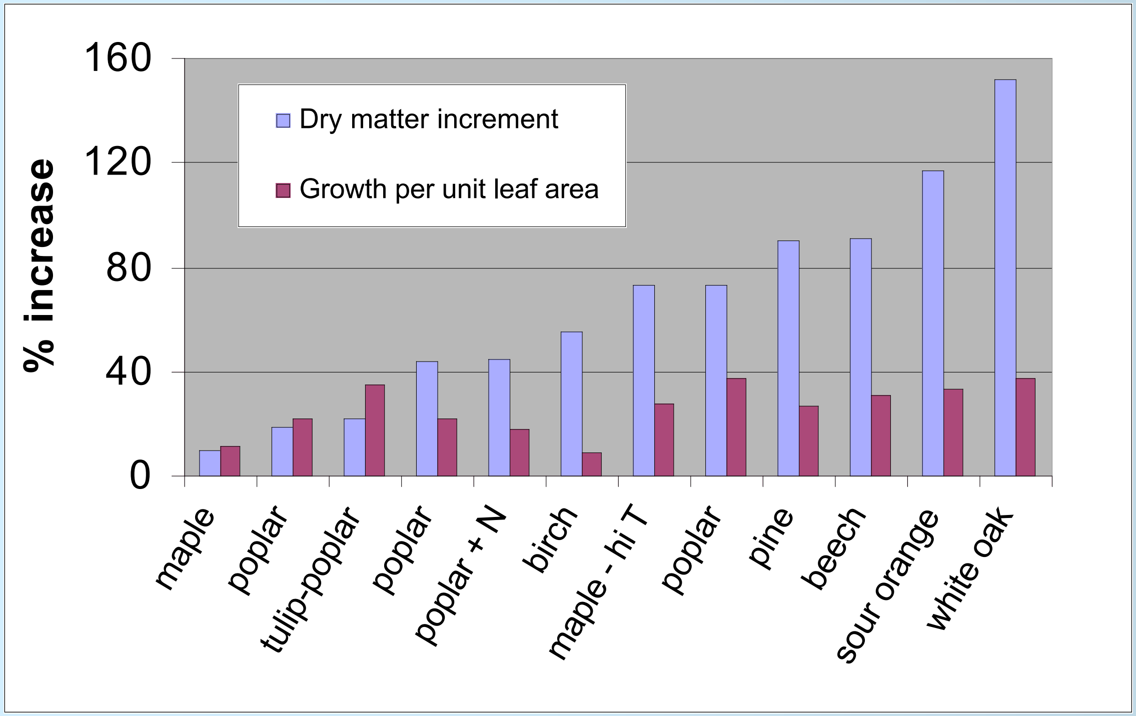
A factor in evaluation of sequestration projects?

Wide range in response to high CO_2?



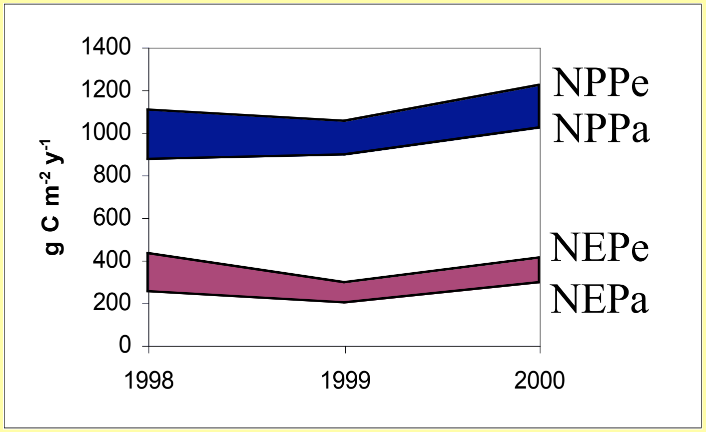
- Is variation due to species or experiment?
- Dry matter increase is confounded by increasing leaf area and exponential growth
- These results do not predict the response of a forest

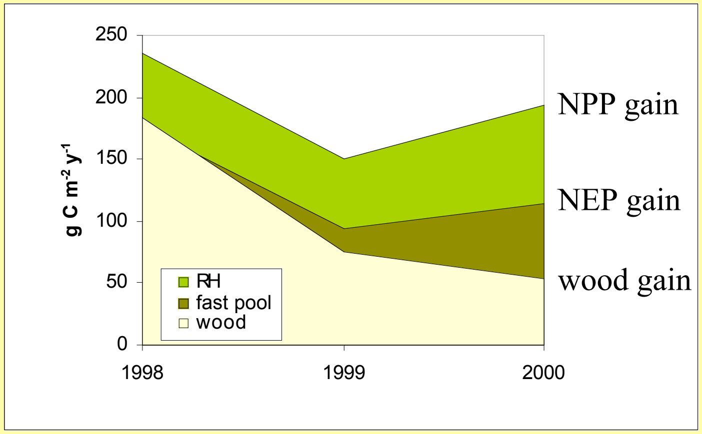
Species may be fundamentally similar



- Expressing annual growth per unit leaf area adjusts for exponential growth pattern
- Response is uniform across species and conditions: 29% increase at ~650 ppm CO_2
- Growth per unit leaf area separates the functional response from the structural response

CO_2 Effect on Sequestration is Relatively Small





CO_2 effect on NEP must be discounted somewhat because of lack of permanence and because increase in [CO_2] will be gradual

Any remaining effect is small compared to the substantial measurement errors

CO_2 fertilization need not be considered part of the evaluation of a C sequestration project

FACE experiments are a useful testbed for sequestration projects

Heavily instrumented tree plantations

Full C budgets

New instrumentation

Increasing focus on belowground C accounting

Acknowledgements

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Artwork provided by Vincent van Gogh (www.vangoghgallery.com)