AAAS Symposium
CO_2 Fertilization: Boon or Bust?

Dynamic Responses of Forest Trees to CO_2 Fertilization: *Will the Stimulation Persist?*

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The boon vs. bust polarity applies especially to trees and forests

Boon….

"In fact, if the air's CO_2 content were ever to double or triple, the productivity of the planet's trees may possibly rise severalfold"

S.B. Idso & B.A. Kimball, 1993, *Global Biogeochemical Cycles* 7: 537

or Bust…

"The projected climatic changes will destroy forests over large areas"

G.M. Woodwell, 1986 *Amicus Journal* Fall: 8

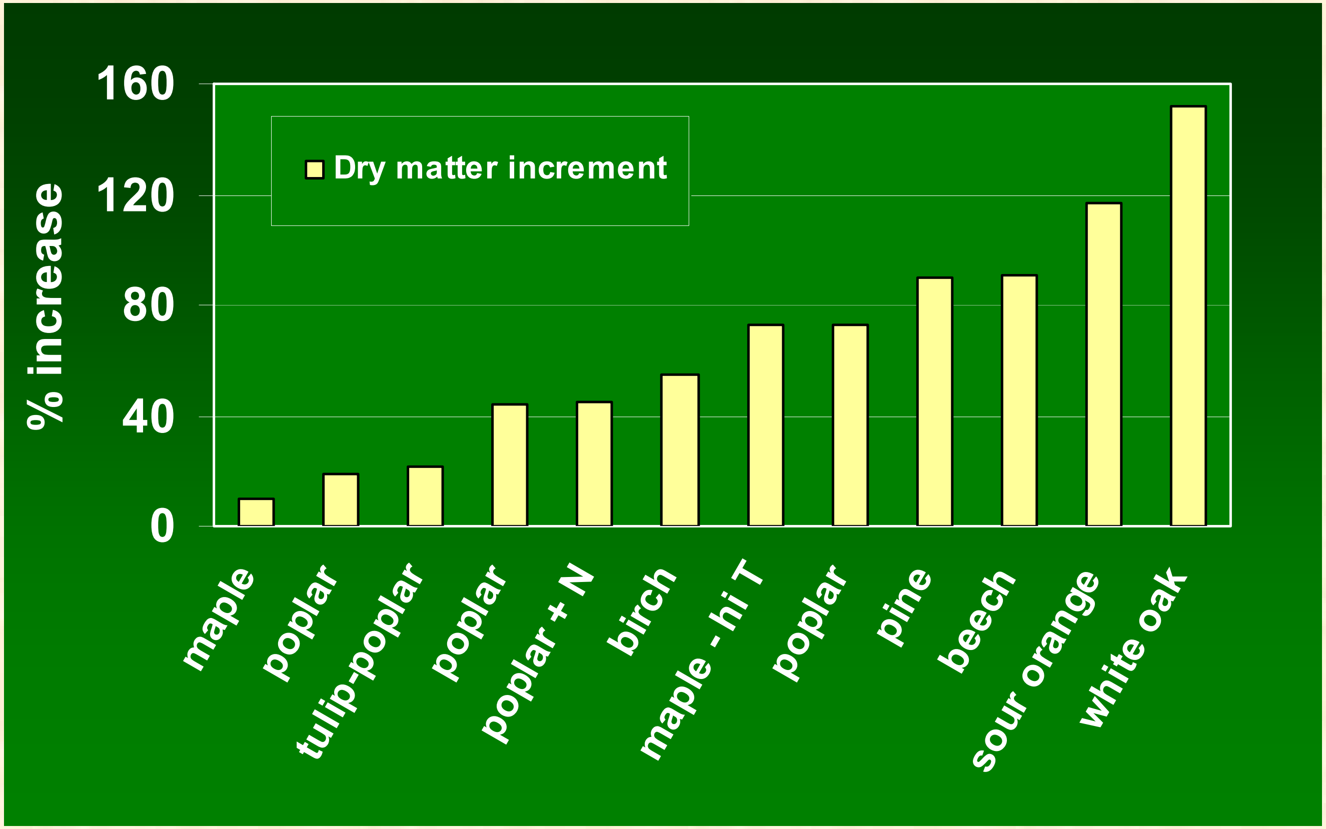
CO_2 fertilization of forests is important in global carbon analyses

The large size and long life of trees preclude direct assessment of CO_2 fertilization of intact, mature forests

Extrapolation of experimental results from young trees and seedlings led to "boon or bust" interpretations

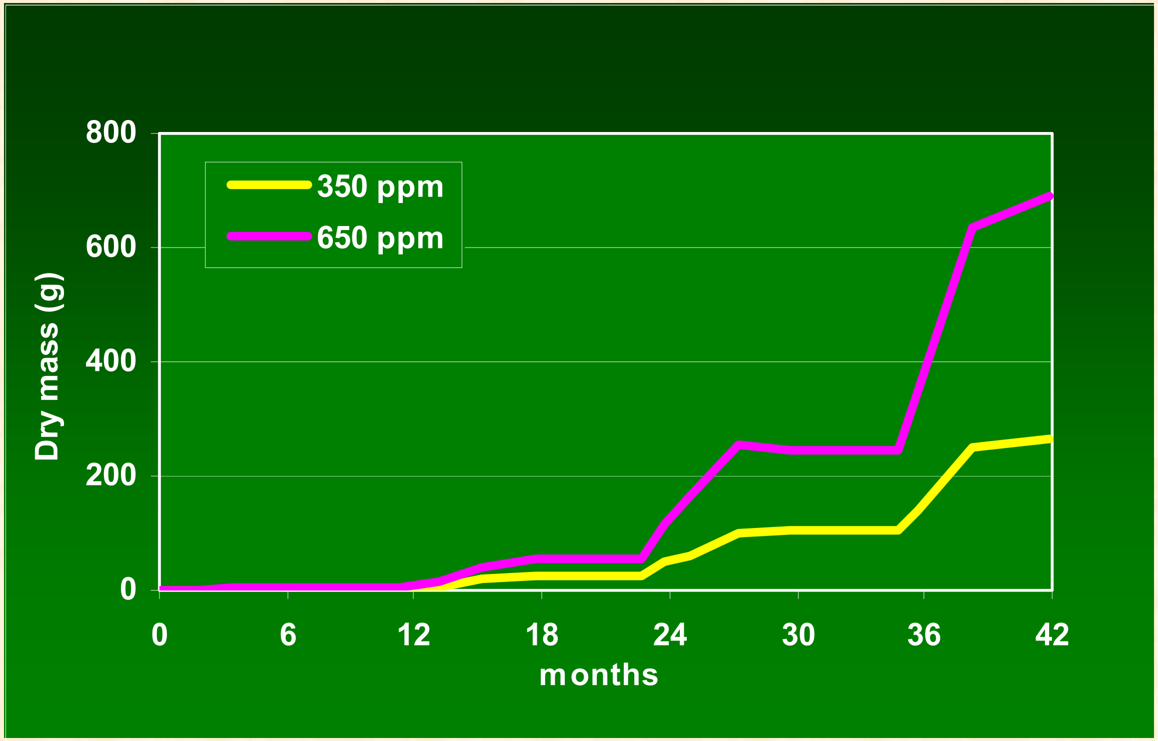
Current free-air CO_2 enrichment (FACE) studies help to resolve some of the uncertainty

Growth of young trees can increase dramatically in elevated CO_2



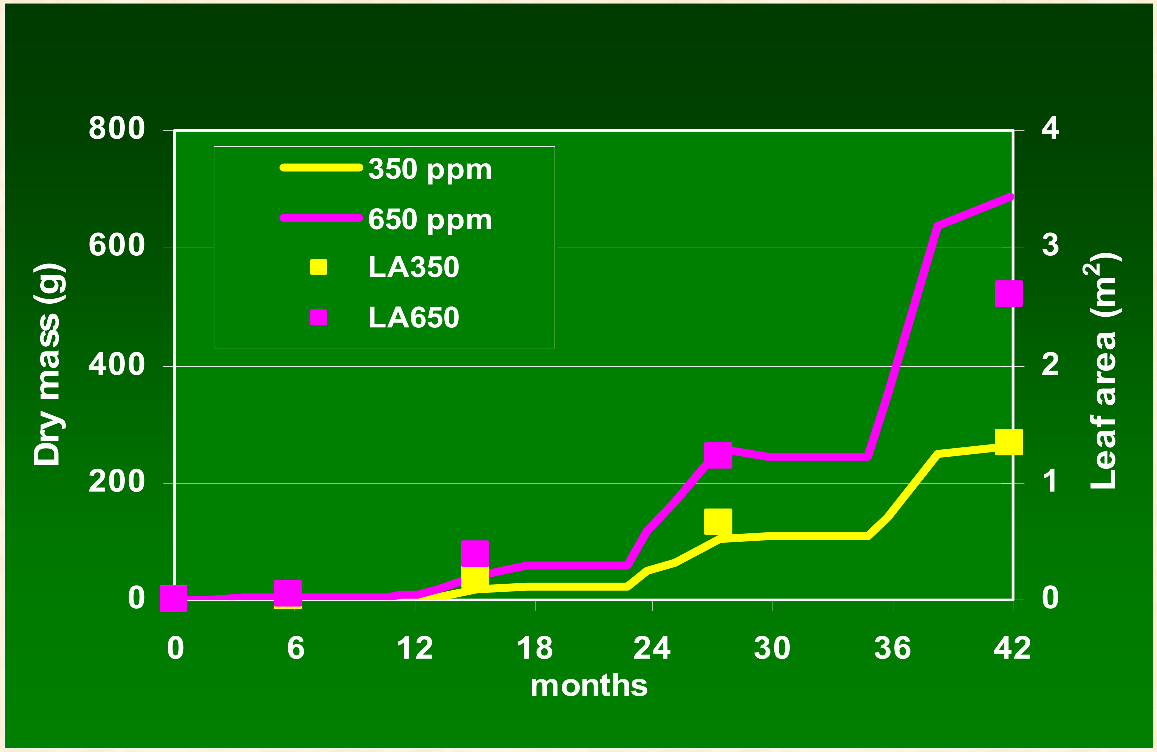
- Differences in response are not easily explained by species, growing conditions, or experimental approach
- Must account for plant developmental patterns

White oak growth dynamics



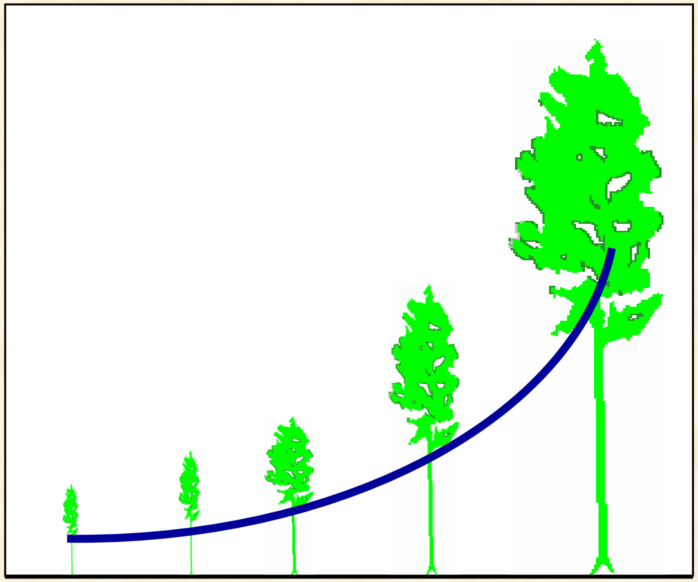
- The response to CO_2 started when the trees were young seedlings
- The difference in size increased with time

Leaf area control of growth

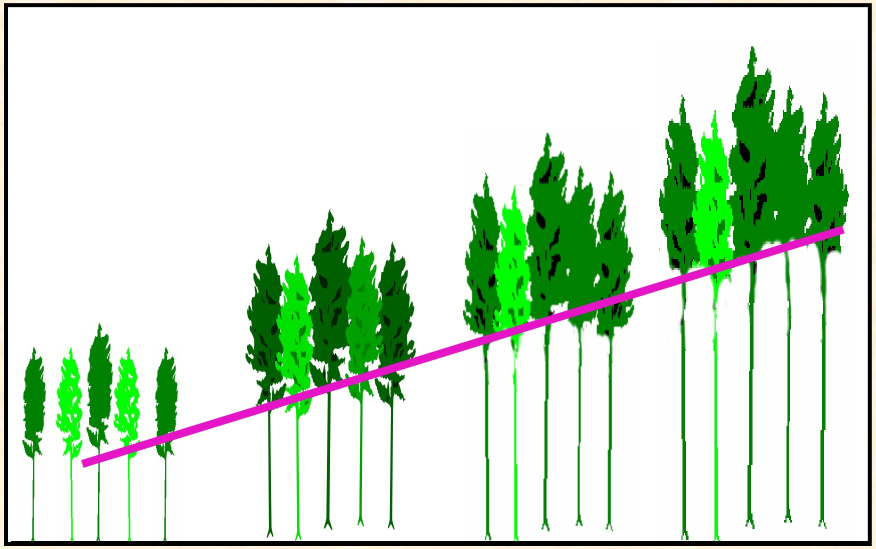


- Larger trees have more leaf area
- More leaf area permits faster growth
- Small effects of elevated CO_2 are magnified over time

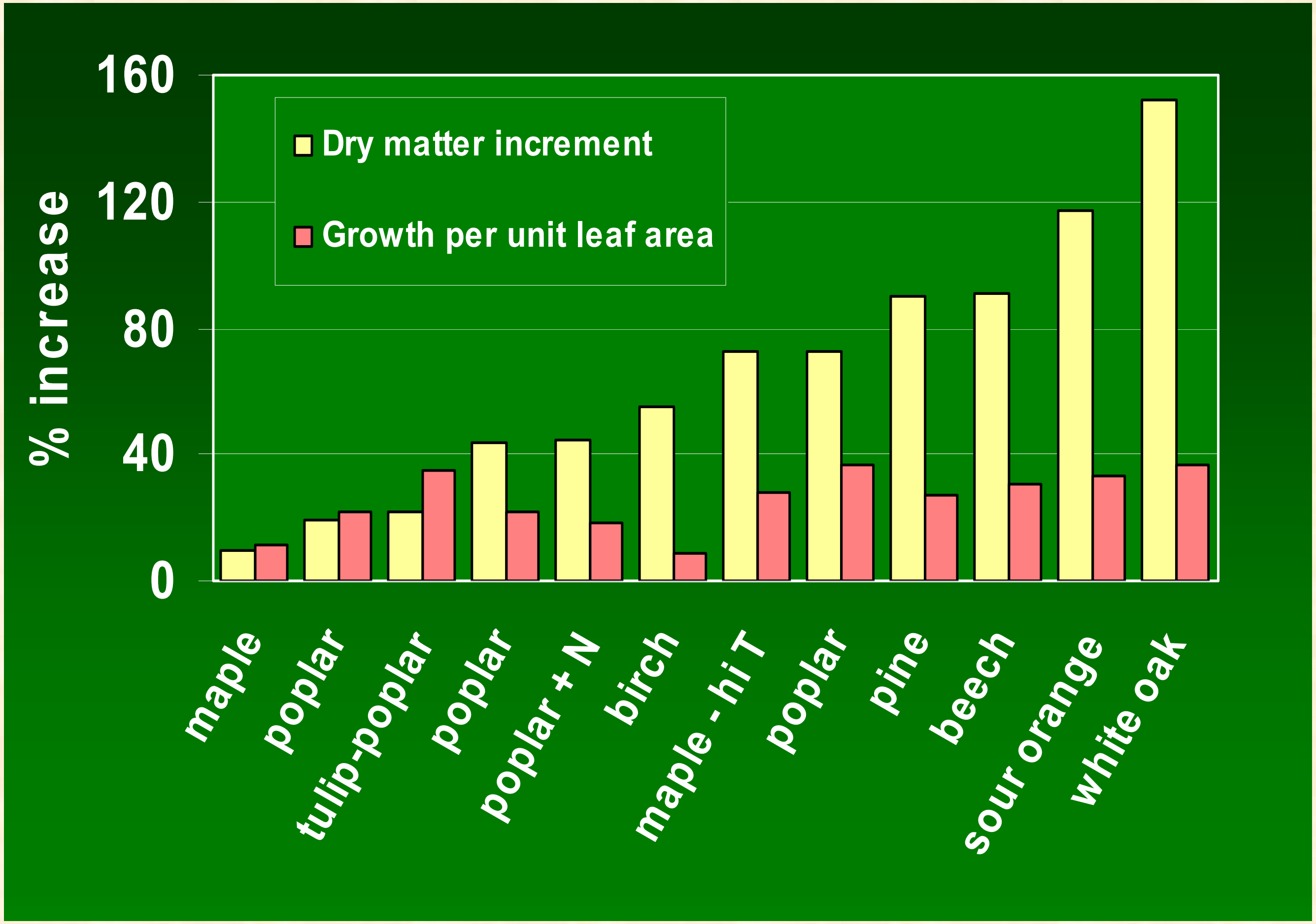
Isolated trees exhibit exponential growth



Exponential cannot be sustained in a forest stand



Growth per unit leaf area



Growth per unit leaf area is expressed as annual aboveground woody increment divided by leaf area

•Response is uniform across species and conditions: 29% increase at ~650 ppm CO_2

Expressing annual growth per unit leaf area adjusts for exponential growth pattern and provides a rational basis for extrapolation

- Growth per unit leaf area separates the functional response from the structural response
- Corresponds with global vegetation models and remote sensing: NPP = *f*(APAR, LUE)
- *Hypothesis*: growth per unit leaf area in fully developed forest stands remains enhanced in elevated CO_2 after stand leaf area reaches a maximum

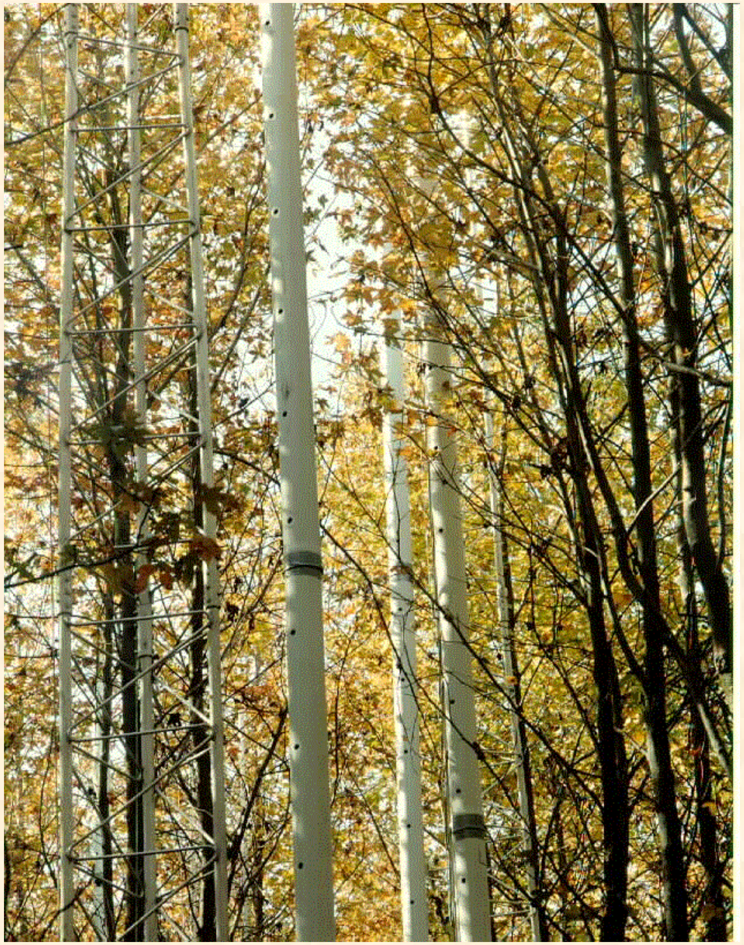
Oak Ridge Experiment on CO_2 Enrichment of Sweetgum

A FACE experiment in a deciduous forest

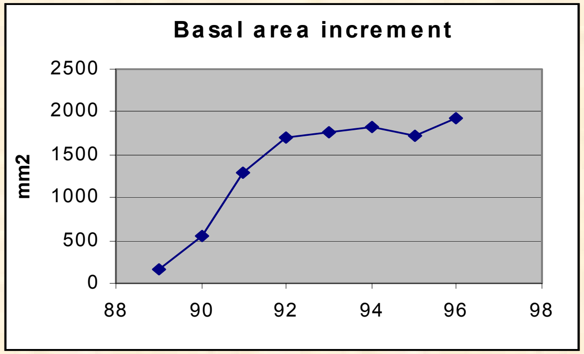
Goal

- **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**

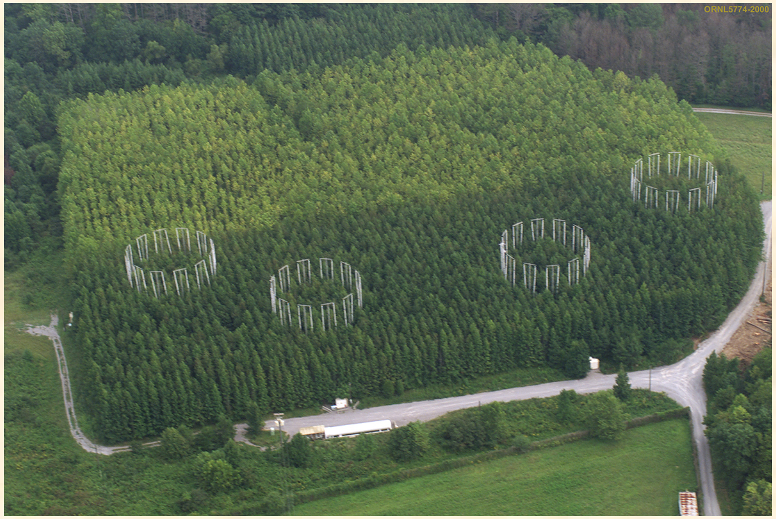
Essential features



- *Liquidambar styraciflua* monoculture plantation started in 1988
- the closed canopy constrains growth responses
- full occupancy of the soil by the root system constrains the nutrient cycle
- tree growth is in a linear phase



Experimental design

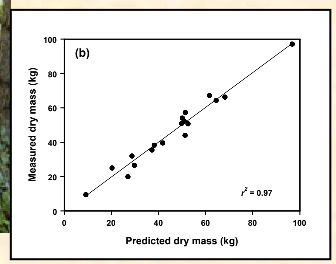


- 2 elevated, 3 control plots (2 with blowers)
- Each plot is 25 m diameter (20 m diameter inside buffer) with ~90 trees
- Full year of pre-treatment measurement in 1997
- CO_2 exposure (550 ppm) started spring, 1998
- Exposure is from sunrise to sunset, April through October
- Brookhaven exposure system

Calculation of NPP

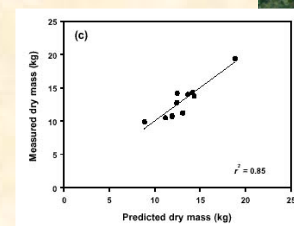
Stem

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



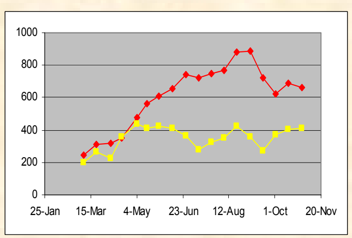
Coarse root

Allometry: DM = f(BA)



Fine root

Minirhizotrons and in-growth cores



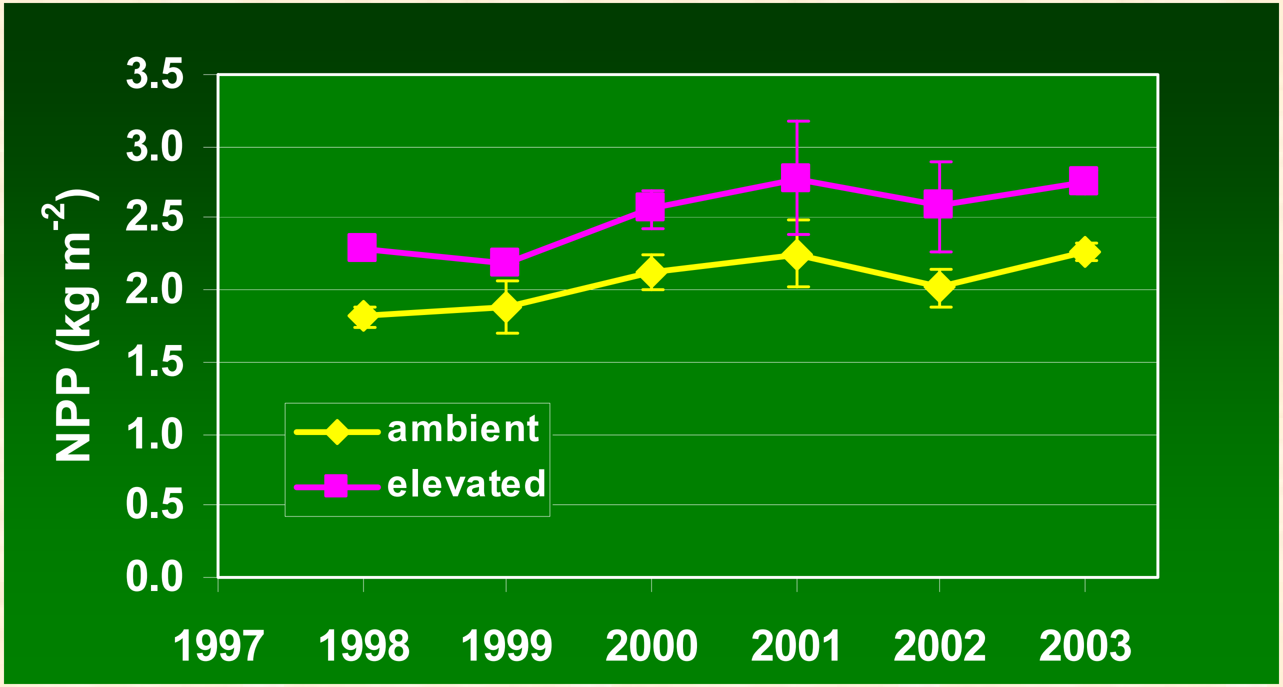
Leaf

Litter traps

Understory

Harvest

Net primary productivity



CO_2 has consistently stimulated NPP

Average increase is 23% (16-38%)

LAI (~6) has not been increasing with time or CO_2

NPP can be separated into structural and functional components

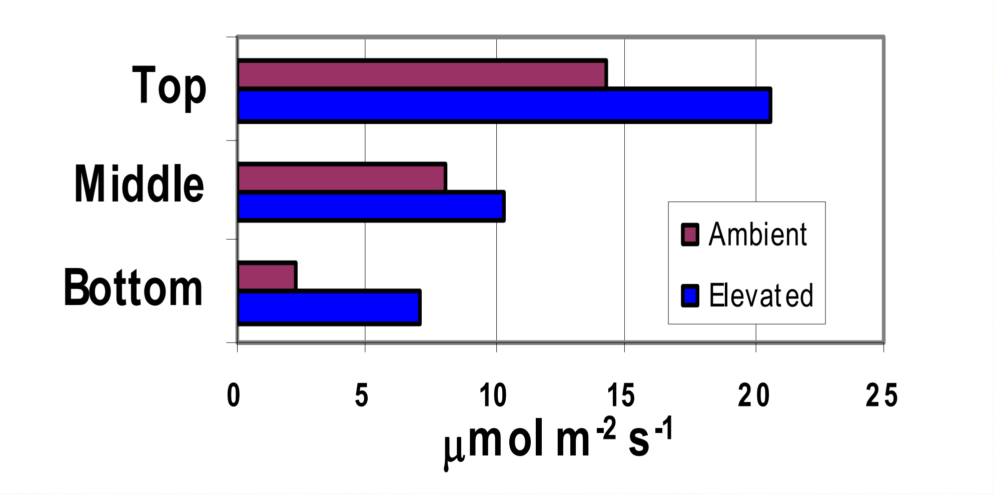
1999-2002

	LAI (m^2 m^{-2})	APAR (MJ m^{-2} y^{-1})	LUE (g MJ^{-1})	NPP (g m^{-2} y^{-1})
ambient	5.66	1225	1.71	2070
elevated	5.93	1226	2.11	2561
E/A	1.05	1.00	1.24	1.24

- Leaf area and APAR were not altered by elevated CO_2
- Increase in NPP is attributable to increased light-use efficiency
- CO_2 effect on LUE is similar to canopy productivity index

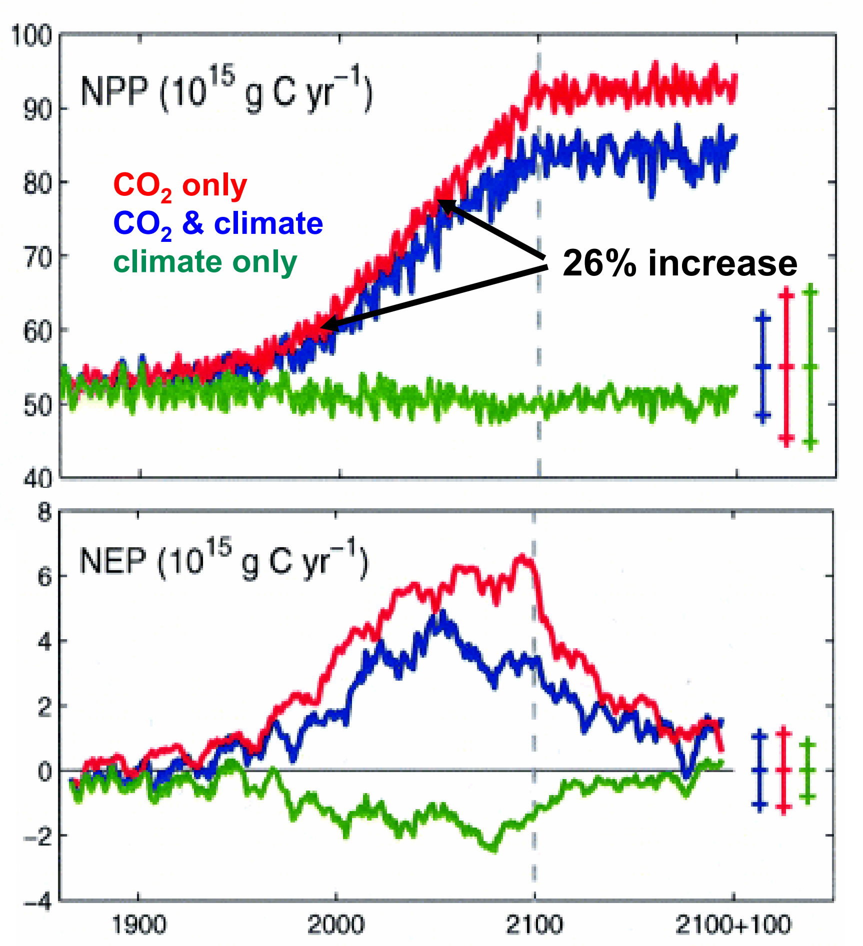
Photosynthesis

Photosynthesis under prevailing conditions relative to canopy position



- Photosynthetic rates at the top of the canopy were generally 30-70% higher in elevated CO_2
- Photosynthetic enhancement occurred at all canopy positions
- Foliar N concentration is lower, but photosynthetic N use efficiency is higher
- No evidence for down regulation or loss of response

The observed CO_2 fertilization response is consistent with global vegetation models



Cramer *et al.*, 2001, *Global Change Biology* 7: 357

- Six dynamic global vegetation models combined with IPCC CO_2 projection and Hadley climate simulation
- Global NPP increased 26% with CO_2 fertilization, consistent with the 23% increase in sweetgum NPP
- CO_2 fertilization allows for uptake of 35% of C emissions from 1991 to 2100, reduced to 23% when combined with climate change

NPP of this closed-canopy deciduous forest stand is enhanced by CO_2 fertilization

Will this response continue?

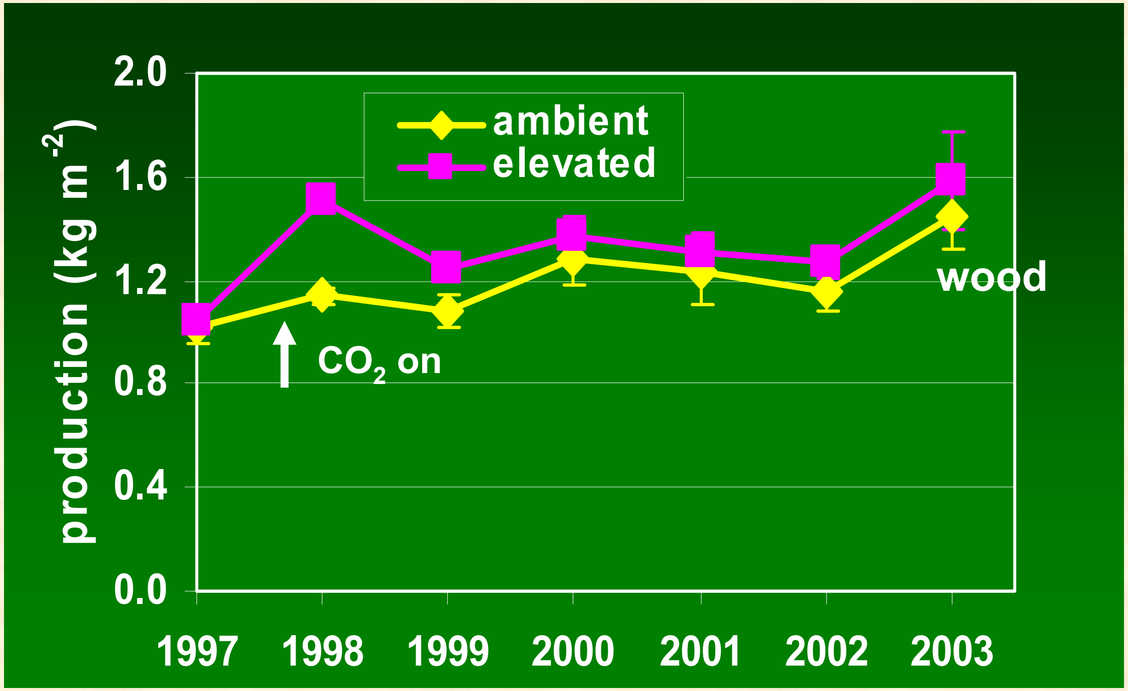
- **No evidence for photosynthetic downregulation**
- **N uptake is increased by elevated CO_2, avoiding N limitation**
- **No change in microbial N cycling**

After 6 years of treatment in this established forest stand, we see no evidence that the stimulation will not be sustained

Carbon allocation is a key issue

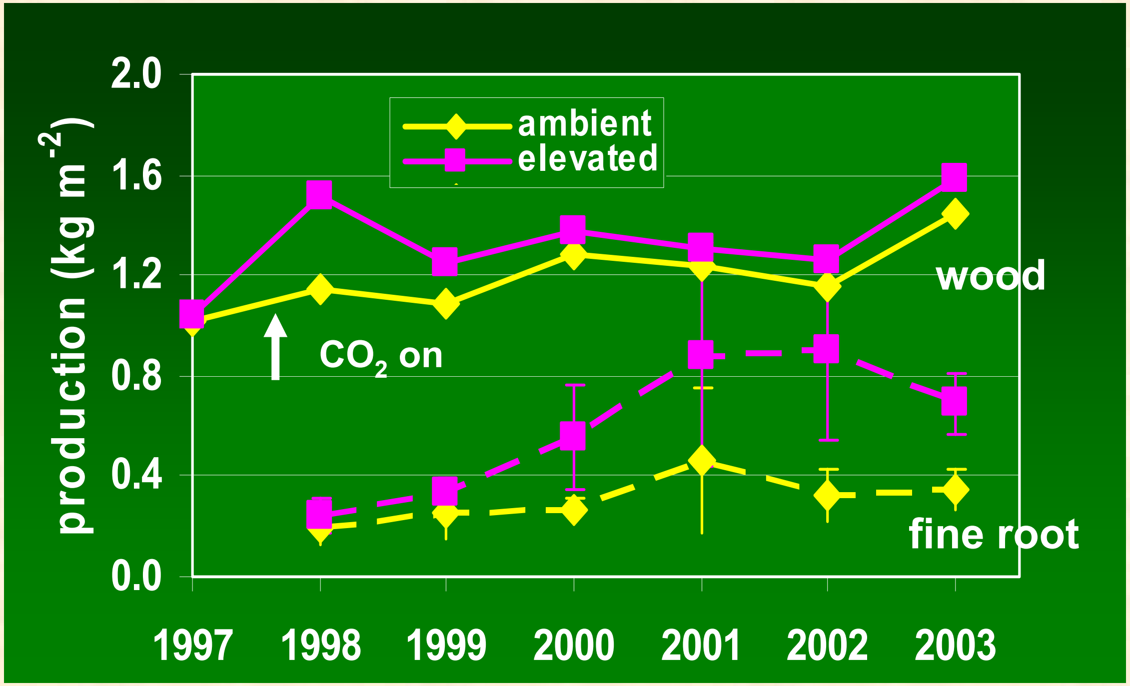
- The additional C is being allocated primarily to fine roots
- Patterns of C allocation have implications for C turnover and sequestration
- Belowground C allocation important for
  - detection of response
  - verification of C sequestration
  - integrated ecosystem response

Aboveground woody increment



- No difference in growth prior to treatment (1997)
- CO_2 significantly increased growth in 1st year of treatment (33%), but not in subsequent years (5-15%)
- NPP increase not recovered in wood

Fine root production



- The increase in NPP is recovered primarily in fine root production
- Annual fine root production has more than doubled since the 3rd year of treatment

Implications of carbon allocation to fine roots

- Increased access to soil N and water
- C allocated to short-lived tissue is not sequestered in biomass
- What is fate of C in dead fine roots?
  - a large fraction rapidly returns to the atmosphere
  - but CO_2 efflux from soil increased only occasionally in elevated CO_2
  - more C is accumulating in soil
  - time lags in response confound analysis

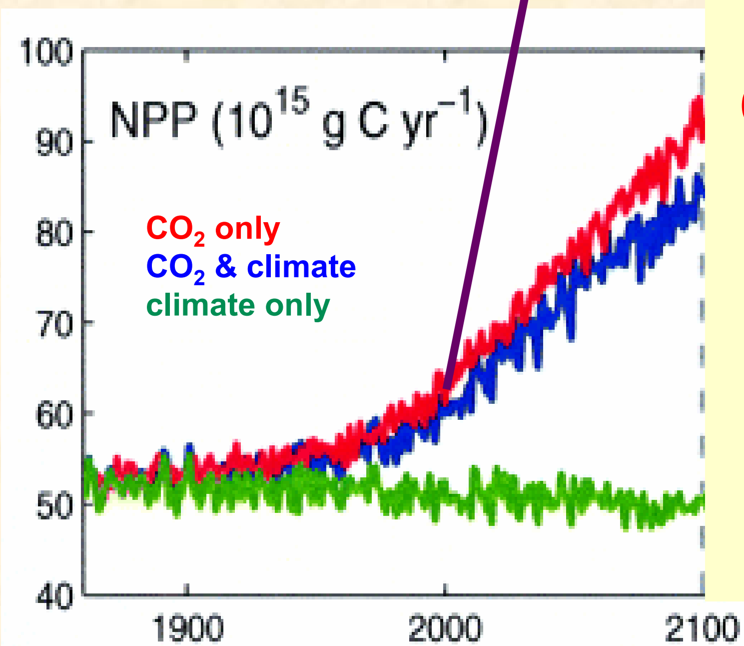
Will the stimulation persist?

- **NPP in this deciduous forest stand is higher in elevated CO_2, and the response has been sustained for 6 years**
- **The response is similar to that predicted from smaller-scale experiments**
- **There is no evidence to suggest the stimulation in NPP will not continue for the near future**
- **Increased NPP does not necessarily imply increased C sequestration**

CO_2 fertilization: Boon or Bust?

- No!
- Predictions of large, sustained growth responses that would eliminate concerns about climate change were never realistic, and are not supported by current experiments
- CO_2 fertilization is a reality, and it should be included in carbon cycle models and ecosystem analysis

Boon!



Optimistic

Realistic

?

Bust