Challenges and opportunities in assessment of forest response to elevated atmospheric CO_2

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Why do we care about forest response to elevated CO_2?

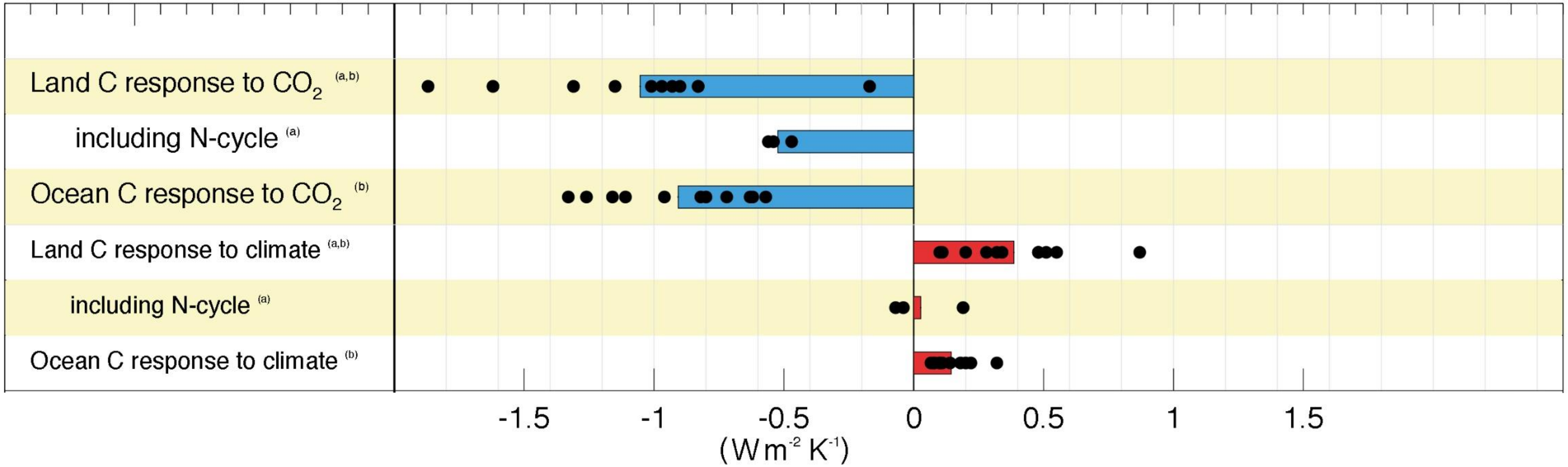
"It's good to know about trees. Just remember nobody ever made any big money knowing about trees."

CO_2 fertilization and climate change

The response of the terrestrial biome – especially forests – to increasing atmospheric CO_2 concentration provides a critical feedback to the rate of increase of atmospheric CO_2 and, therefore, to the trajectory of climate change.

From IPCC AR5:
"Elevated atmospheric CO_2 concentrations lead to higher leaf photosynthesis and reduced canopy transpiration, which in turn lead to increased plant water use efficiency and reduced fluxes of surface latent heat. The increase in leaf photosynthesis with rising CO_2, the so-called CO_2 fertilisation effect, plays a dominant role in terrestrial biogeochemical models to explain the global land carbon sink (Sitch et al., 2008), yet **it is one of most unconstrained process in those models**."

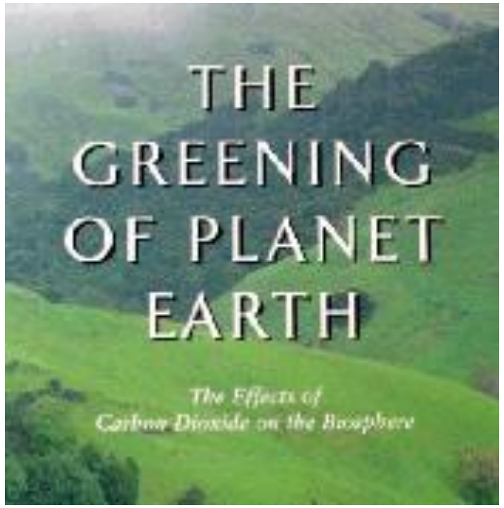
Biogeochemical feedbacks in climate change models



Challenge #1

If the direct effects of elevated CO_2 on plant growth are largely positive, does our research give ammunition for climate change deniers?

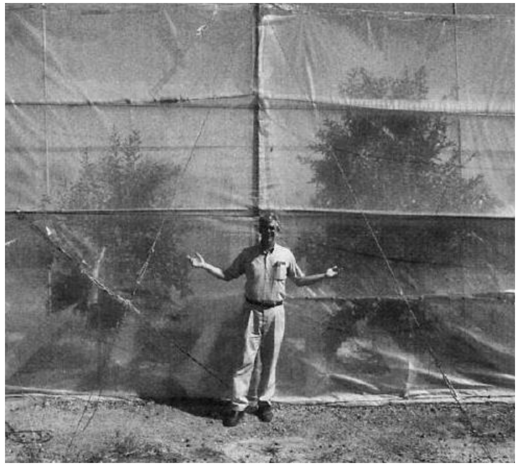
Meet the CO_2-Praising Physicist Behind the Latest Trump Climate Push



See for Yourself

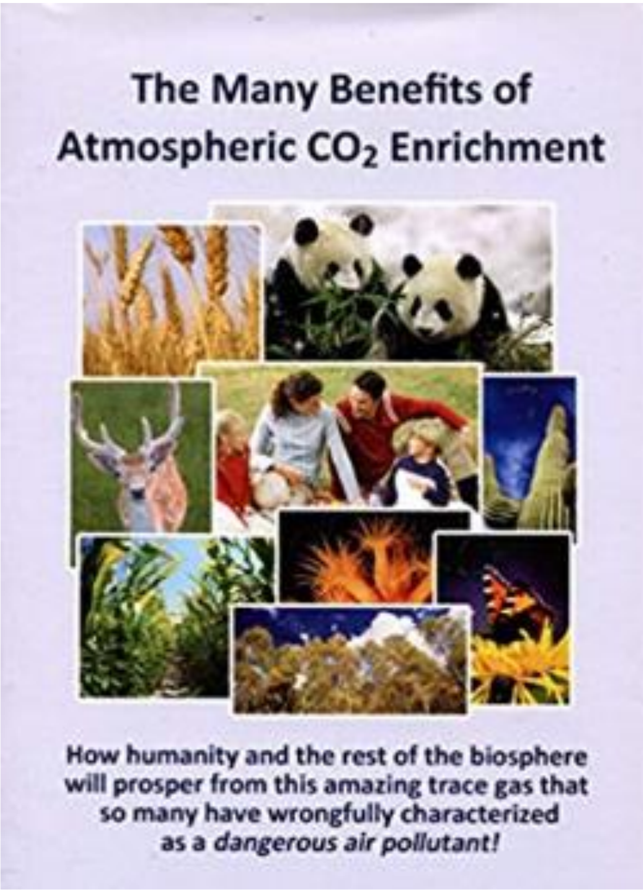
CO2 COALITION
CO2Coalition.org

Director of the CO_2 Coalition, Dr. William Happer, Professor Emeritus in the Department of Physics at Princeton University, a former senior director on the National Security Council, and perhaps the only scientist to brief President Trump on climate change research.



Sherwood Idso and his sour orange trees

"Were the CO_2 concentration of the atmosphere to double, the growth rates of Earth's trees would triple."



"I believe that more CO_2 is good for the world, that the world has been in a CO_2 famine for many tens of millions of years and that one or two thousand ppm would be ideal for the biosphere."

Opportunity

Provide accurate and relevant data to climate models and policymakers

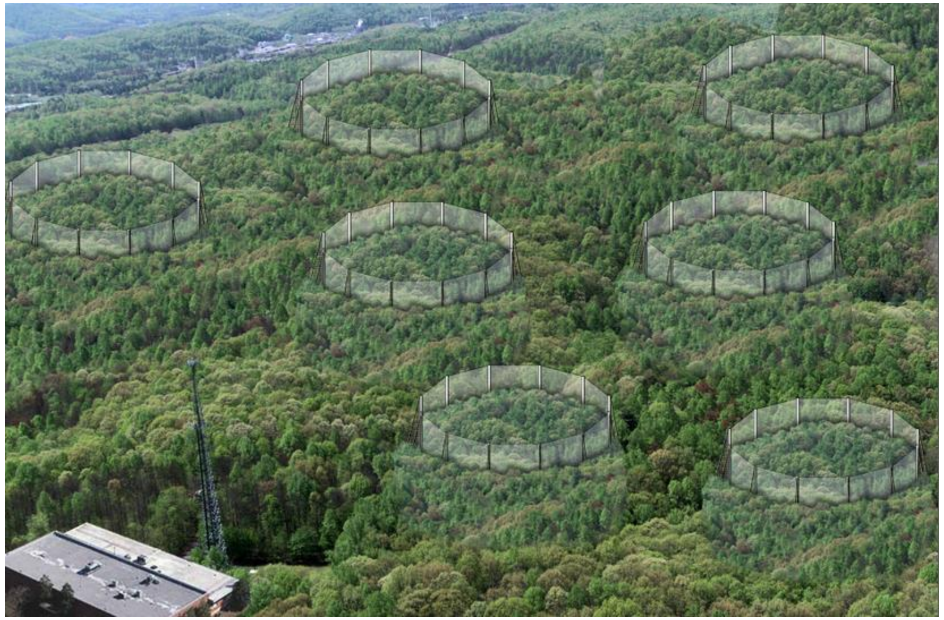
Challenge #2

Trees are *BIG*…

…and they live a *LONG TIME*

Big

- Large and expensive experimental facilities needed
- Difficult to access the canopy
- Large plot sizes needed to incorporate heterogeneity and diversity
- Scaling of processes to whole tree and whole ecosystem is critical challenge



Long life

- System turnover times much greater than duration of any experiment
- Do responses change with succession? With tree age?
- Important to incorporate environmental fluctuations and rare events
- Possible CO_2 effects on forest community composition

Opportunity

FACE experiments should be optimized to provide critical data for models, which are the only way we can address large-scale issues

Model-data interactions identify where new measurements are needed

Green boxes: **processes for which FACE data allowed discrimination among model assumptions**

Red boxes: **FACE data identified missing or wrong assumptions**

Orange boxes: **additional data are needed to discriminate among model assumptions**

Most models treated LMA as a constant

Models need drought effect on both g_s and A

Models disagreed on fraction of rainfall intercepted and canopy gas exchange when wet

A/g_s should be proportional to C_a

Models assumed different values for the ratio of light- or CO_2-limited photosynthesis

Models overestimated the extent of stoichiometric acclimation

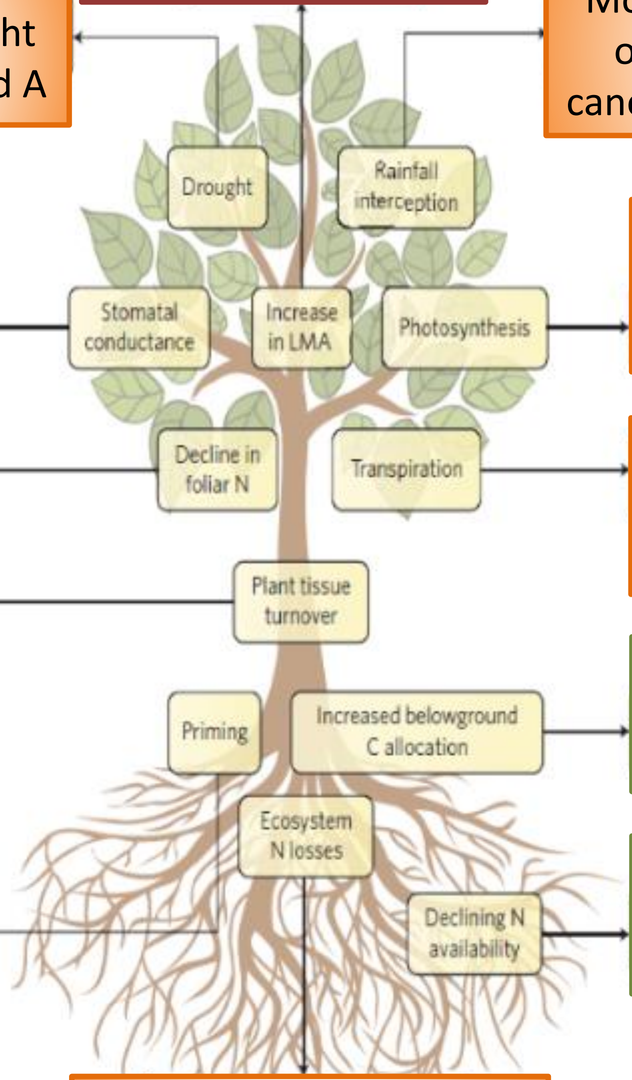
Model sensitivity of canopy transpiration to stomatal conductance varied

Large uncertainty in model parameter values for wood turnover

Models with dynamic allocation performed best

Models underestimate N uptake

Models should allow flexibility in C and N coupling



Models need constrained estimates of N losses with eCO_2

Medlyn *et al*. (2014). *Nature Climate Change 5: 528-534.*

Challenge #3

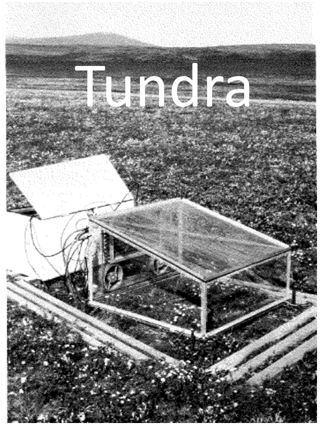
No one site or experiment can answer all of the questions or provide all of the needed model input

Opportunity

Joining the community of science and participating in cross-site syntheses and modeling projects enhances the value of all of our research

“At minimum, these experiments should be undertaken in each of the world’s six major biomes…”

Hal Mooney, 1991



Cross-site questions

1) **Mature forests**
   Is the response observed in previous FACE experiments in aggrading or disturbed systems only an accelerated approach to a new equilibrium that is the same in ambient and elevated CO_2?

2) **Nutrient limitation**
   Will nutrient limitation, particularly phosphorus, preclude response to elevated CO_2?

3) **Temperature interactions**
   Experiments needed outside of the temperate zone

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Viewpoints | Free Access |

Model–data synthesis for the next generation of forest free-air CO_2 enrichment (FACE) experiments

Richard J. Norby, Martin G. De Kauwe, Tomas F. Domingues, Remko A. Duursma, David S. Ellsworth, Daniel S. Goll, David M. Lapola, Kristina A. Luus, A. Rob MacKenzie, Belinda E. Medlyn, Ryan Pavlick, Anja Rammig, Benjamin Smith, Rick Thomas, Kirsten Thonicke, Anthony P. Walker, Xiaojuan Yang, Sönke Zaehle ... See fewer authors

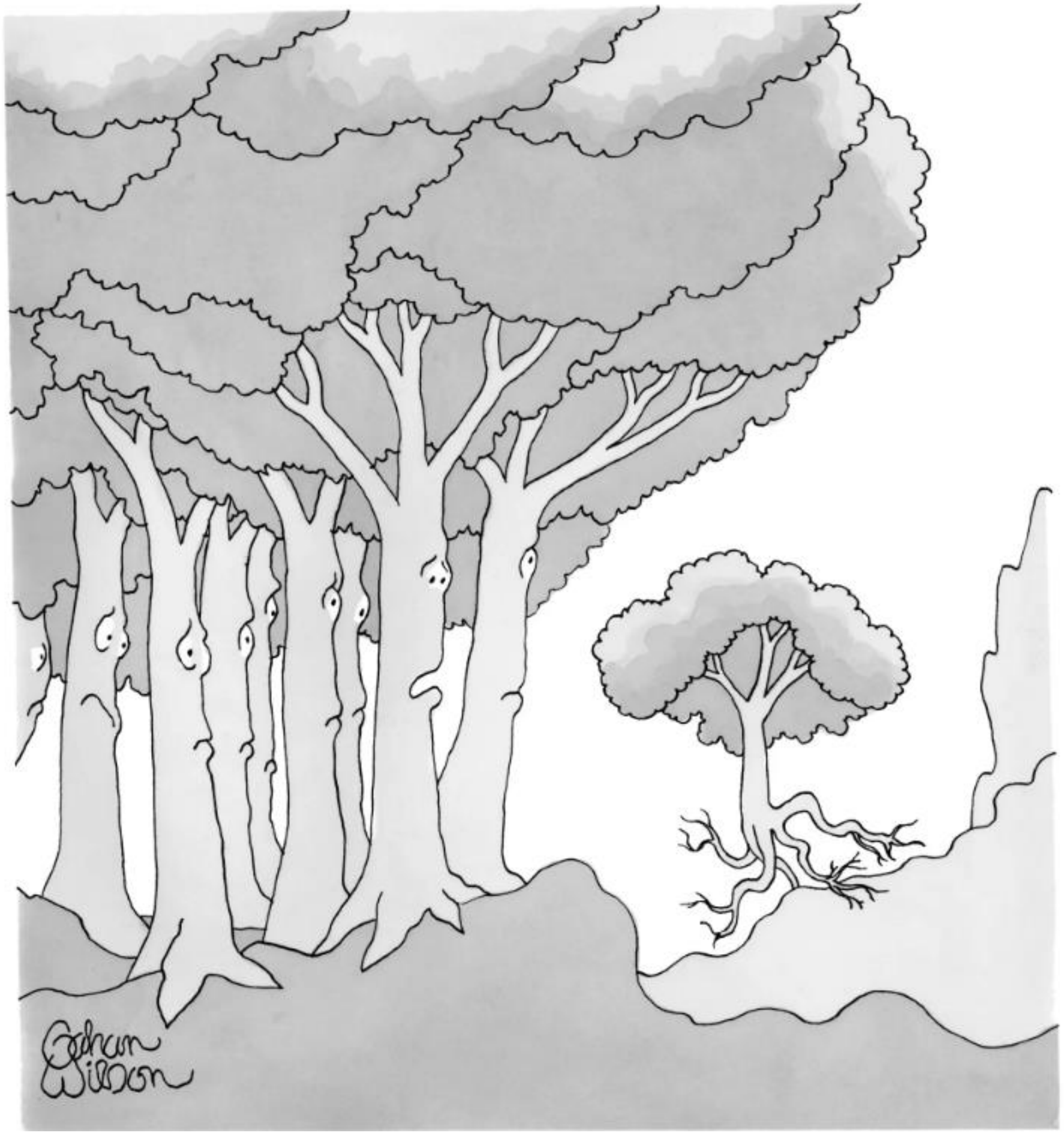
First published: 06 August 2015 | https://doi.org/10.1111/nph.13593 | Citations: 67

4) **Water stress**
   To take advantage of unpredictable extreme weather events, it is important to have continuous measurements of plant and soil water relations

5) **Biodiversity**
   How does elevated CO_2 alter biodiversity? How does biodiversity influence response to elevated CO_2?

Biodiversity

How can we test whether elevated CO_2 affects biodiversity and species composition?



"Very few leave the grove!"

Eos Earth & Space Science News

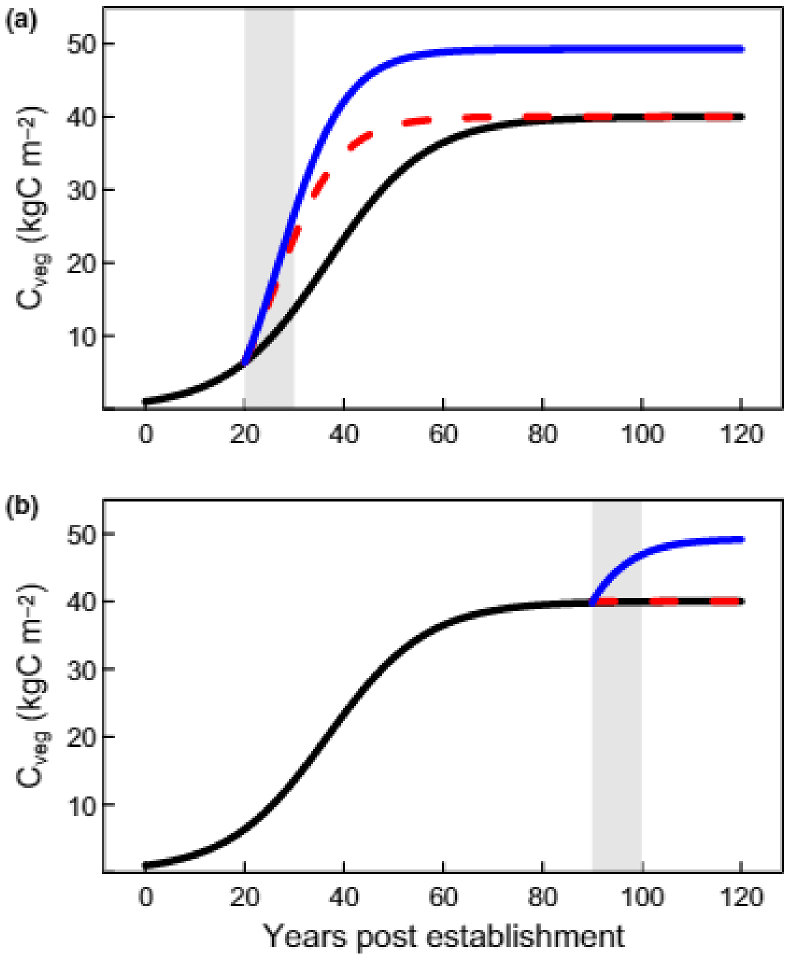
Forests Respond to Volcanic Emissions

Researchers propose using volcanoes to study forests and forests to study volcanoes.

The forested slopes of Turrialba, a volcano in Costa Rica, were monitored for volcanic carbon dioxide emissions.

Petersen, K. S. (2020), Forests respond to volcanic emissions, Eos, 101, https://doi.org/10.1029/2020EO138654. Published on 15 January 2020.

Mature Forests



Opportunity: A response in an aggrading forest cannot predict a new equilibrium, but a response in a mature forest can

Challenge: Requires full accounting of stand-level biomass

Opportunity: Test model assumptions about increased allocation to reproductive structures and the effects of elevated CO_2 on fecundity

Challenge: Must separate acorns from leaf litter

Data on net primary production and its distribution among different components (leaf, wood, fine roots) is key to these assessments!

Net primary production is a key response

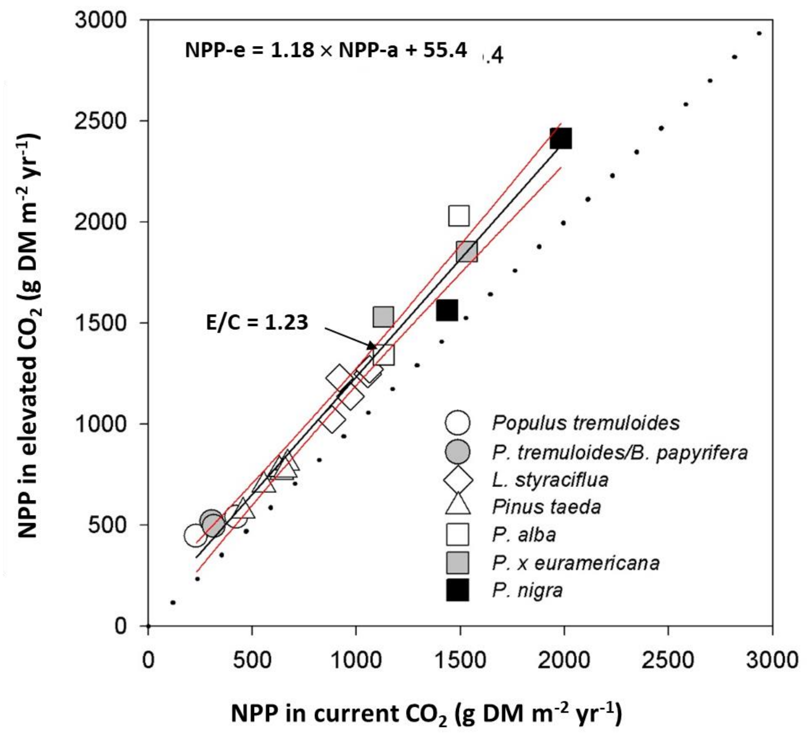
Basis for comparison across sites and a benchmark for models

Provides context for more specific measurements

- Relative importance of herbivore losses
- Calculation of carbon use efficiency when combined with sap flow data

Allocation – hard to model and important for C cycling

> "…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." BR Stain & FA Bazzaz, 1982



Challenge and opportunity:

Calculation of NPP requires collaboration, cooperation, integration, and careful attention to data quality – all good things!

NPP at BIFoR FACE

NPP = wood production + leaf production + reproductive output + fine-root production

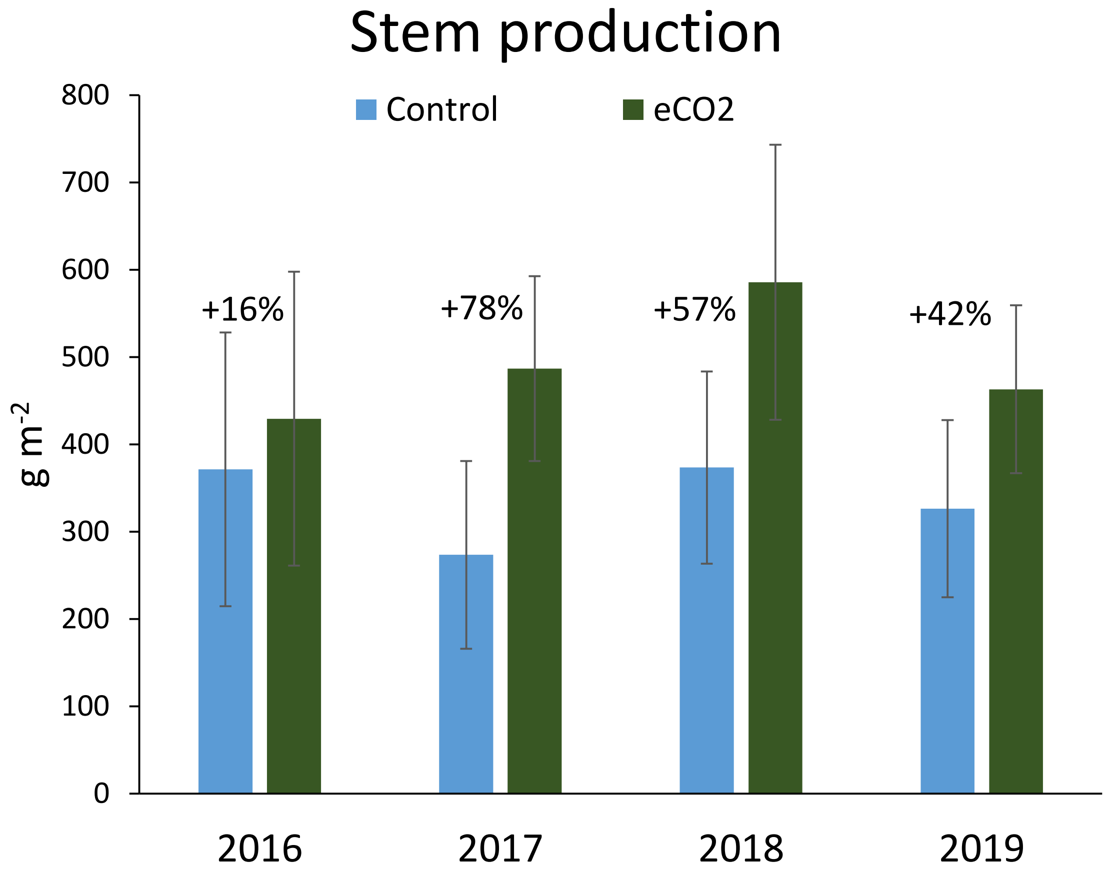
Wood production = annual increments of aboveground stem wood + coarse root, calculated from allometric equations and diameter data (data from Martha Crockatt and Earthwatch) using data just from trees within 12.5 m of plot center

Stem mass = $\exp(-2.9128 + 2.7442 \times \ln(D))$ for oak; similar equations for all others
Coarse root mass = $\exp(-2.863 + 2.208 \times \ln(D))$ for oak; similar equations for all others

Leaf mass = litter mass × 1.07. This currently includes flowers and fruit but does not include herbivory losses (data from Giulio Curioni)

Fine-root production – scale-up of minirhizotron assessment from root volume production to g/m^2 (data from Claire Ziegler)

Preliminary results. Do not cite.



Oaks account for >95% of plot-level dry matter increment

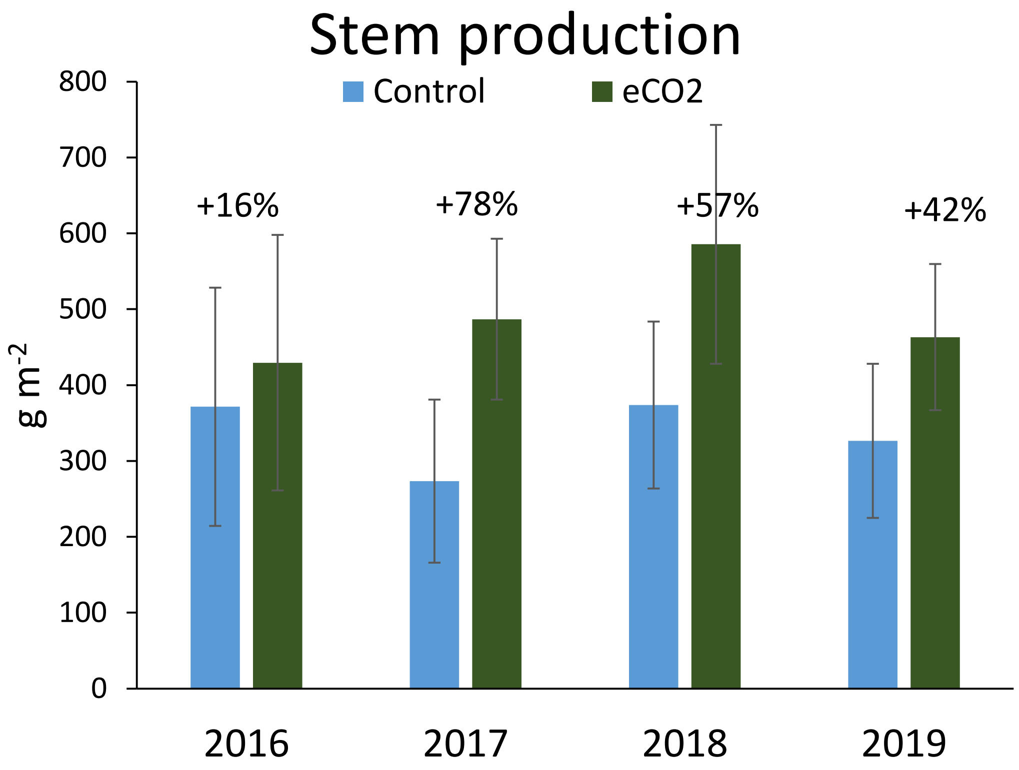
Plot 3 has much lower productivity despite similar standing biomass… *why?*

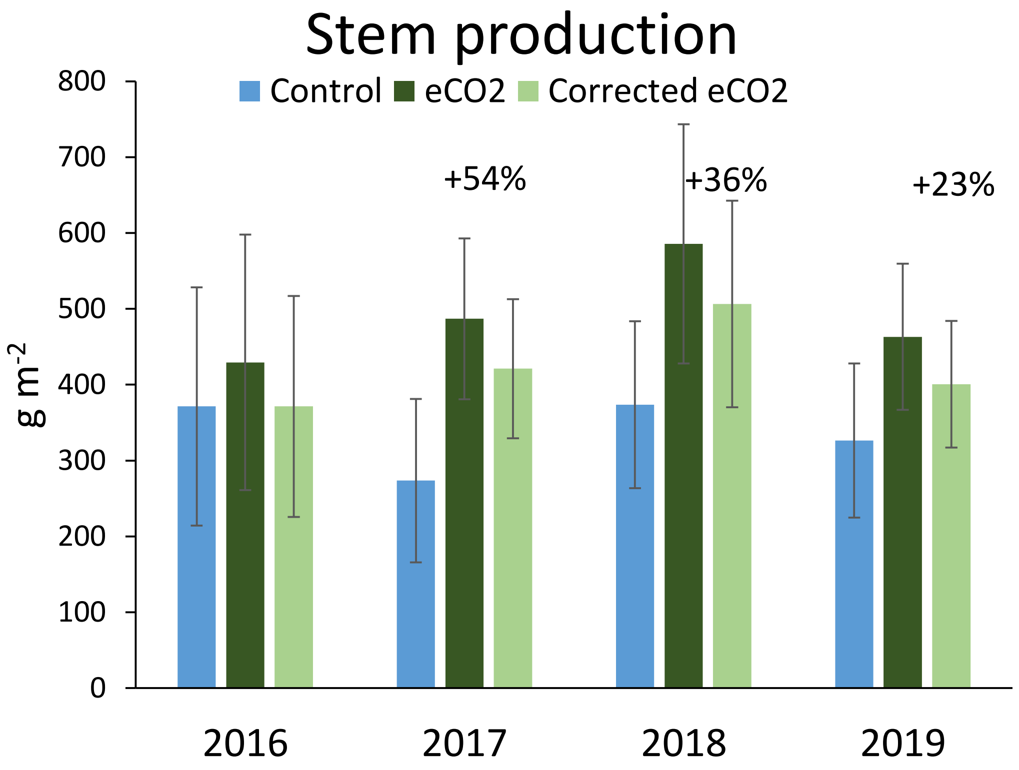
No treatment differences are close to statistical significance

Treatment mans can be adjusted according to pre-treatment difference

EARTHWATCH INSTITUTE

Preliminary results. Do not cite.





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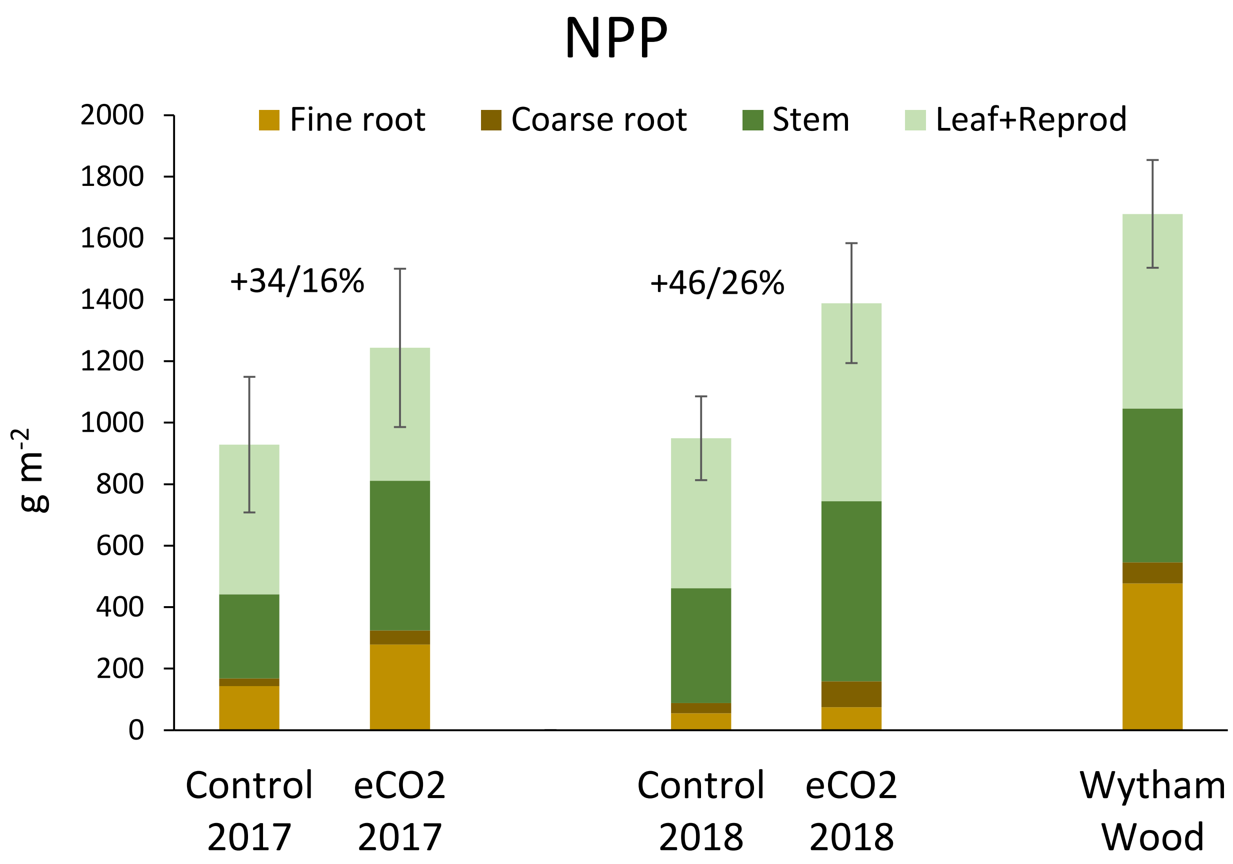

Apparent CO_2 effect on NPP, after correcting for pre-treatment difference in stem production, is consistent with other FACE experiments.

However, these differences are not statistically different

NPP is consistent with data from Whytham Woods, with the important exception of fine-root production

BIFoR FACE can play a significant role in advancing the assessment of CO_2 effects in forests, and thereby informing predictions of climate change impacts and the policy decisions that must be made.

All of the challenges ahead, both large and small, create new opportunities for creative research.

I look forward to working with all of you.

BIFOR