Experimental Effects of Tropospheric Ozone on Carbon Sequestration in Poplars

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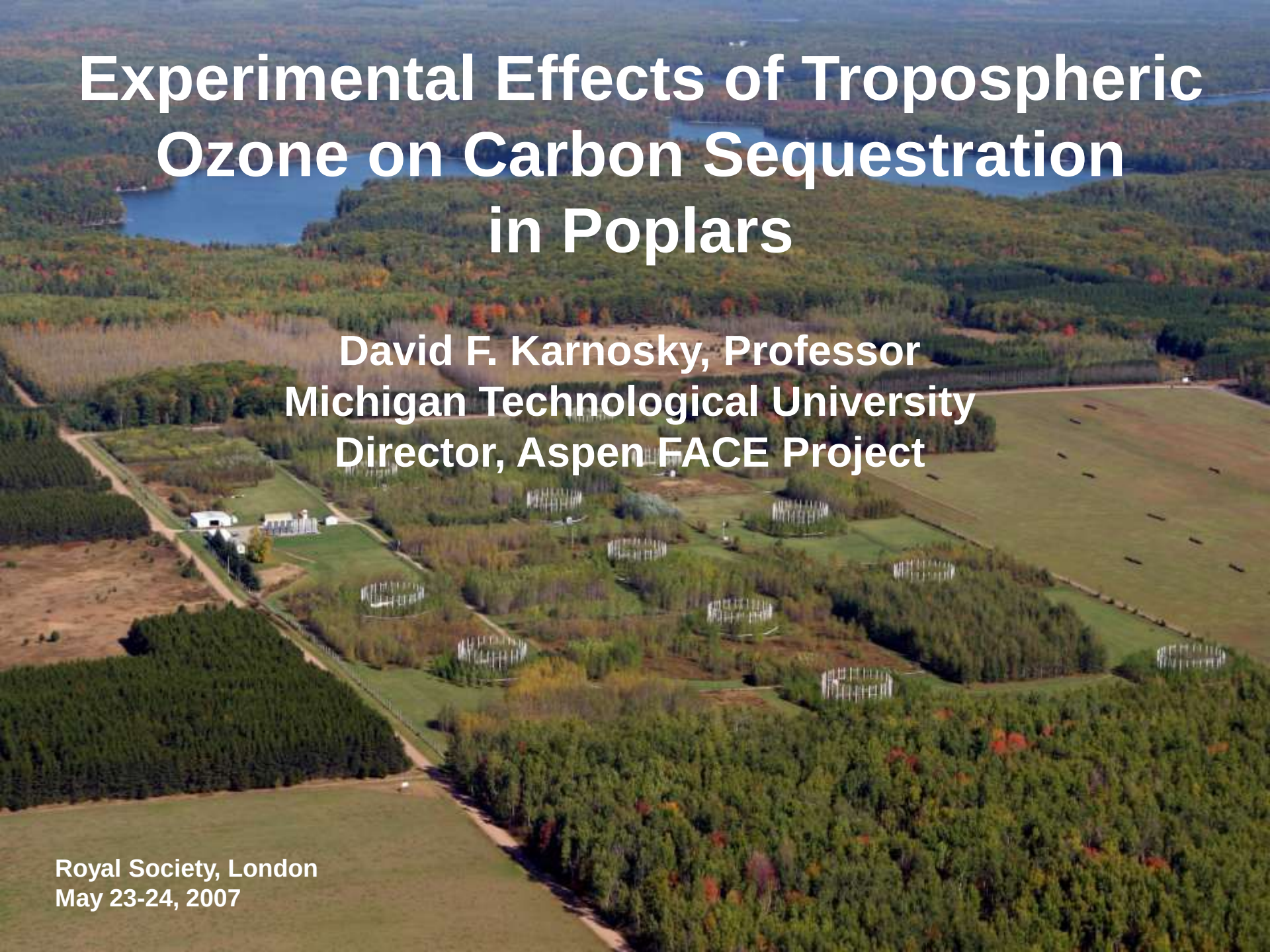


Royal Society, London
May 23-24, 2007

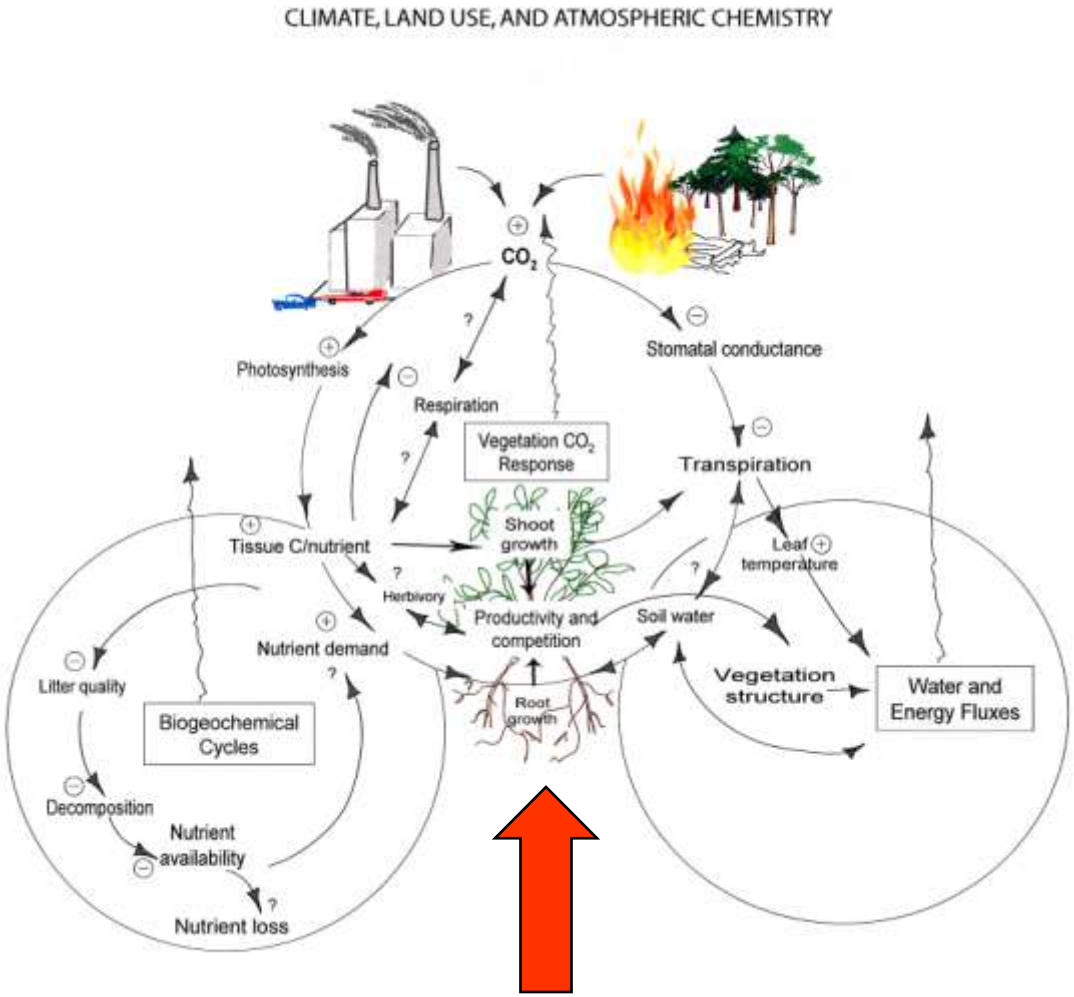
Key Climate Change and Air Pollution Drivers

Climate Change

- Temperature
- Drought
- [CO_2] ←
- methane

Air Pollutants

- [O_3] ←
- N deposition
- particulate matter



Over large portions of the Earth's forests, e[O_3] is a co-occurring stress.

What is C Sequestration?

Carbon sequestration is the uptake and storage of carbon (European Environmental Agency, 2006).

Carbon sequestration is the process through which agricultural and forestry practices remove carbon dioxide (CO_2) from the atmosphere (US EPA, 2006).

Carbon sequestration is the removal and storage of carbon from the atmosphere in carbon sinks (such as oceans, forests or soils) through physical or biological processes, such as photosynthesis (Green Facts, 2006).

How Do We Estimate the Impacts of e[CO_2] and e[O_3] on Carbon Sequestration?

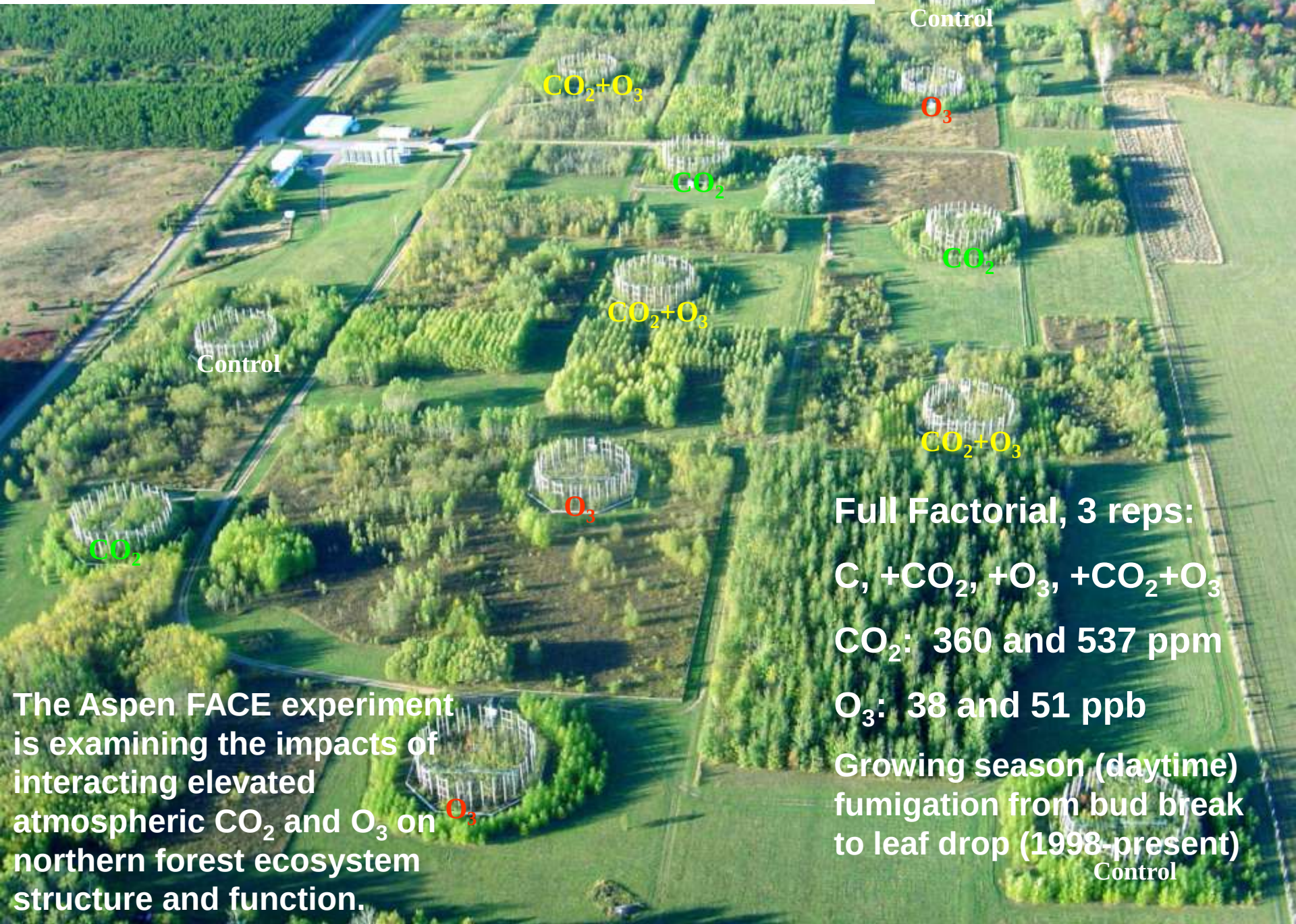
Experimentally

- Free-air Enrichment (FACE) facilities with long-term exposures of forest stands to e[CO_2] and/or e[O_3] (*i.e.*, King *et al*. 2005. New Phytol. 168:623-636).

Modelling

- Ozone dose metrics regression analyses (Percy *et al*. 2007. Environ. Pollut. 147:554-566).
- Global biogeochemical models (*i.e.*, Felzer *et al*. 2005. Climatic Change 73:345-373).

Experimental Approach: The Aspen FACE User Facility



Full Factorial, 3 reps:

C, +CO_2, +O_3, +CO_2+O_3

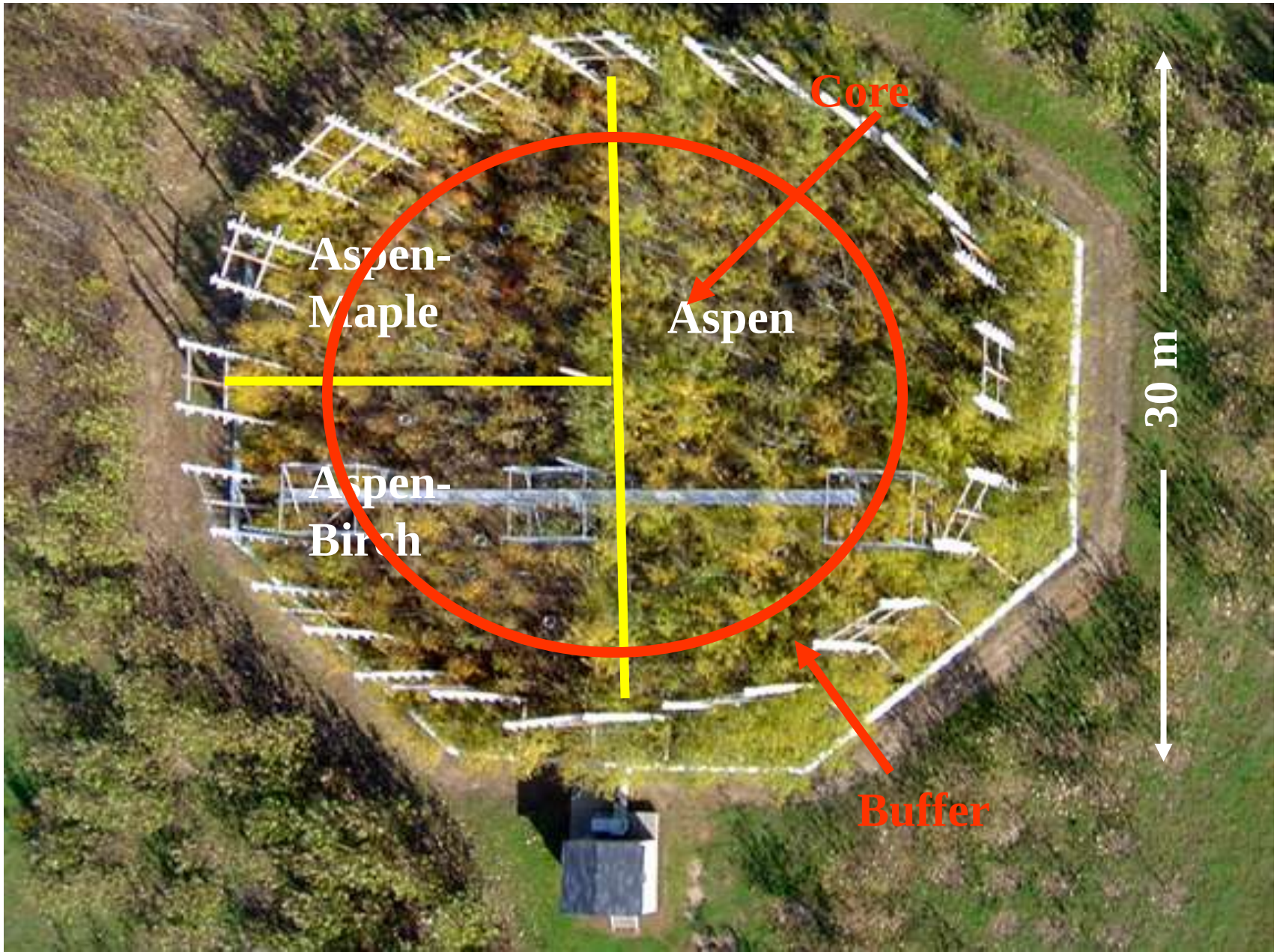
CO_2: 360 and 537 ppm

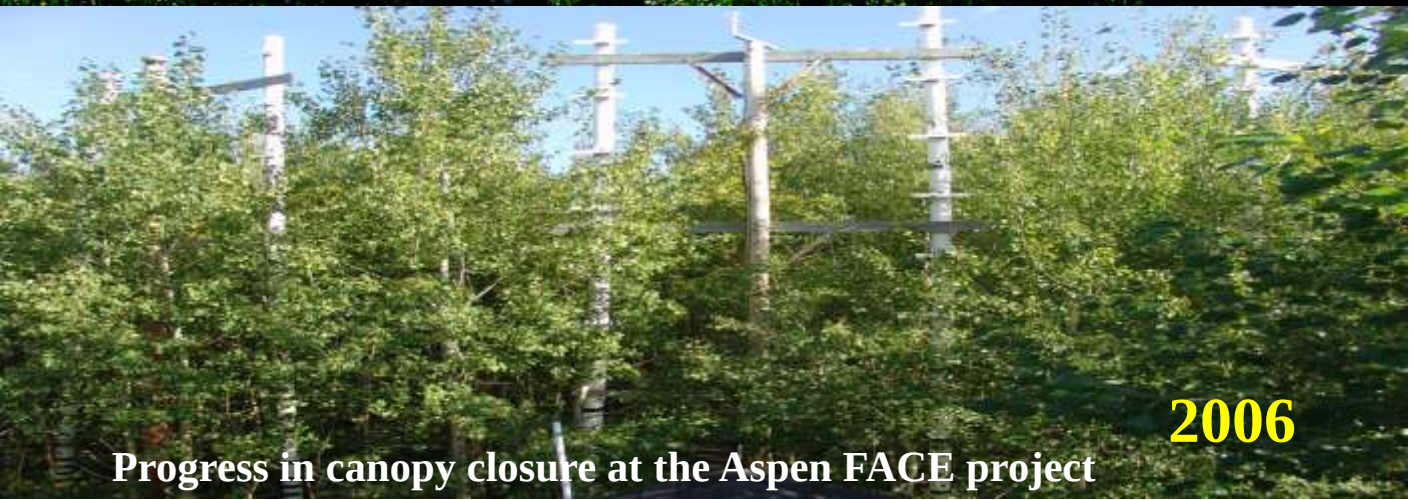
O_3: 38 and 51 ppb

Growing season (daytime) fumigation from bud break to leaf drop (1998-present)

The Aspen FACE experiment is examining the impacts of interacting elevated atmospheric CO_2 and O_3 on northern forest ecosystem structure and function.

Global Climate Change Research: The Aspen FACE User Facility

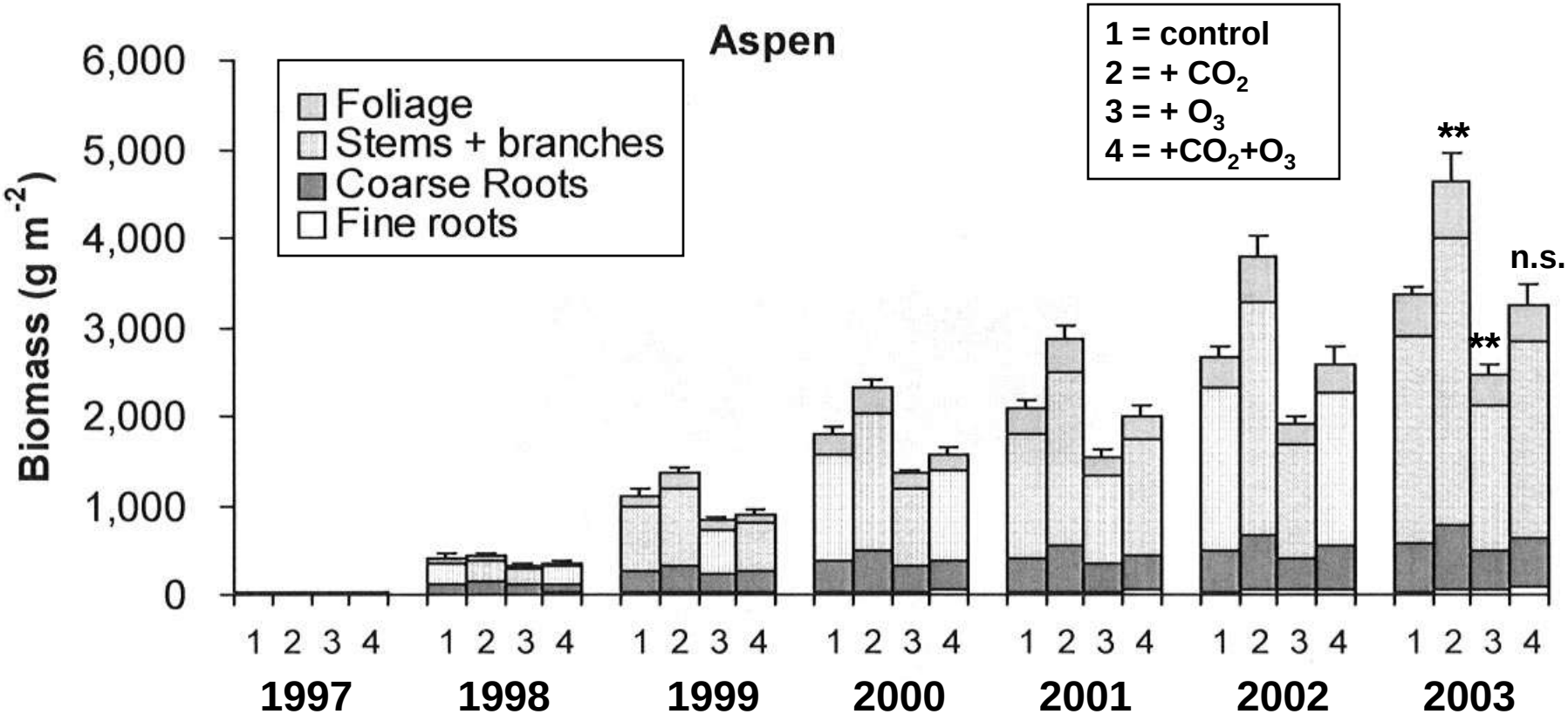




Progress in canopy closure at the Aspen FACE project

Aspen FACE Ring 1.4
(CO_2+O_3)

NPP Estimation



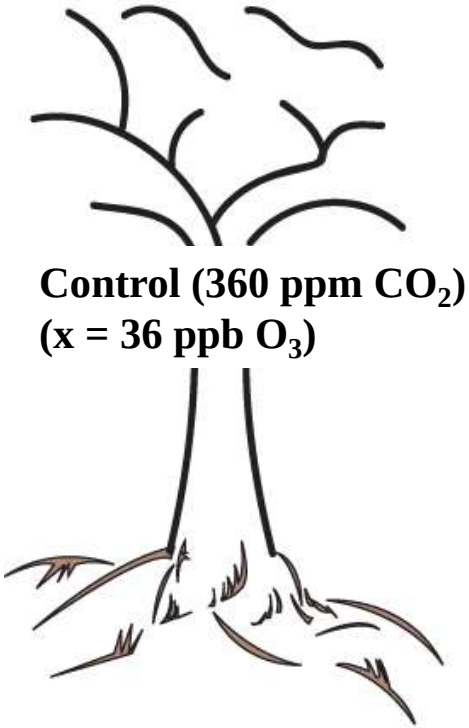
King *et al*. 2005. *New Phytol*. 168:623-636

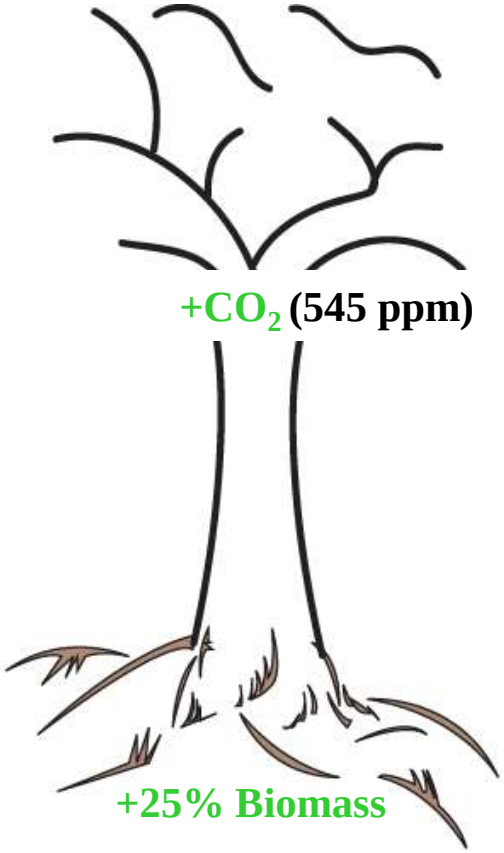
The Aspen FACE Project Carbon Gain (Relative to Controls) After 7 years

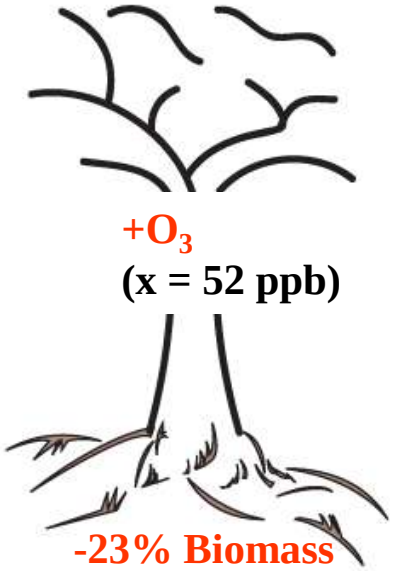
	Aspen Community	Aspen-Birch Community
CO_2	+25%	+45%
O_3	-23%	-13%
CO_2+O_3	-8%	+8%

King *et al*. 2005. *New Phytol*. 168:623-636

Components of Aspen Productivity (NPP)





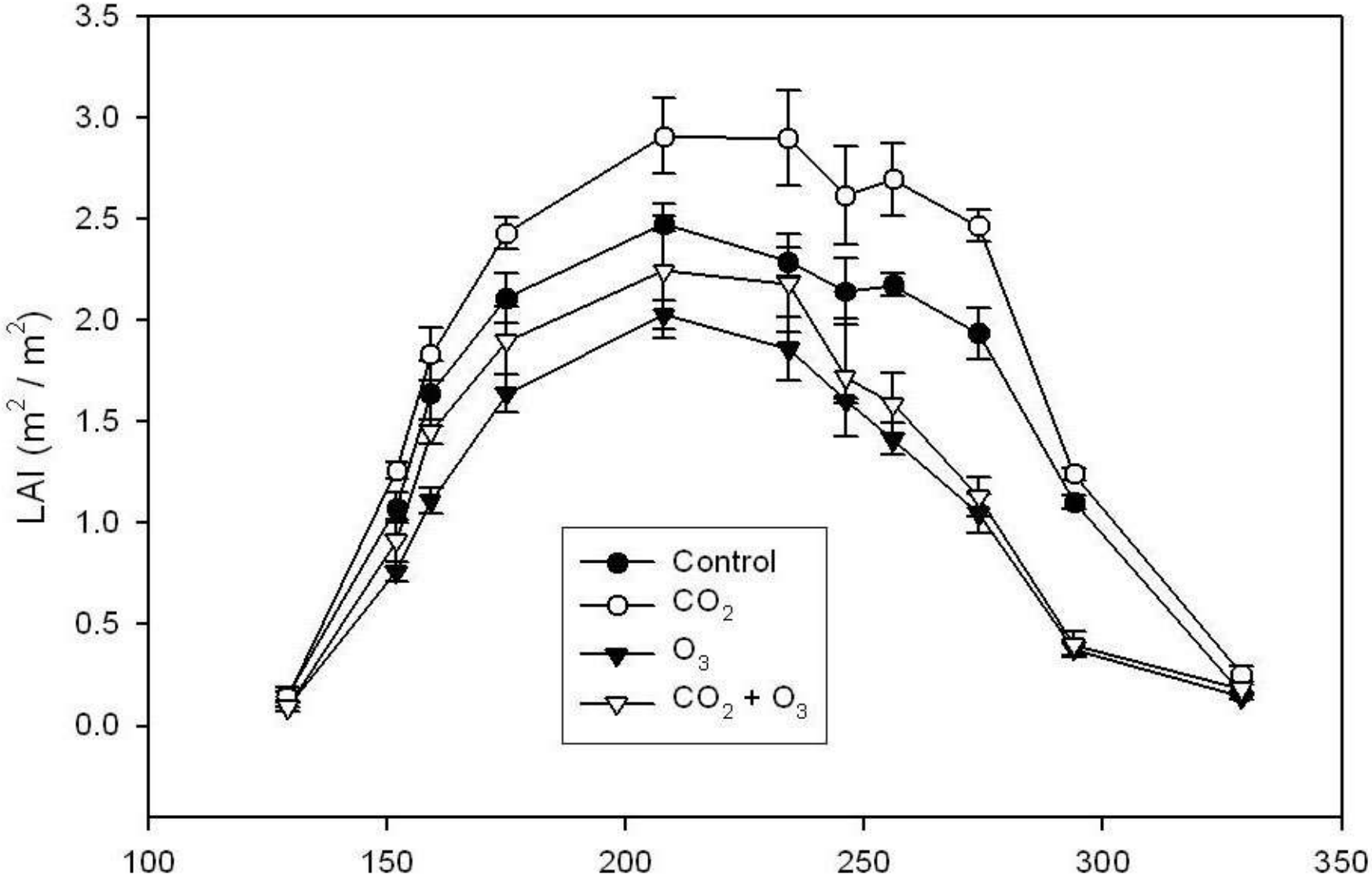


NPP estimates for aspen from King *et al*. 2005. New Phytol. 165:623-636.

↑ LAI
↑ Leaf duration
↑ Leaf size
↑ Ps
↓ Water stress

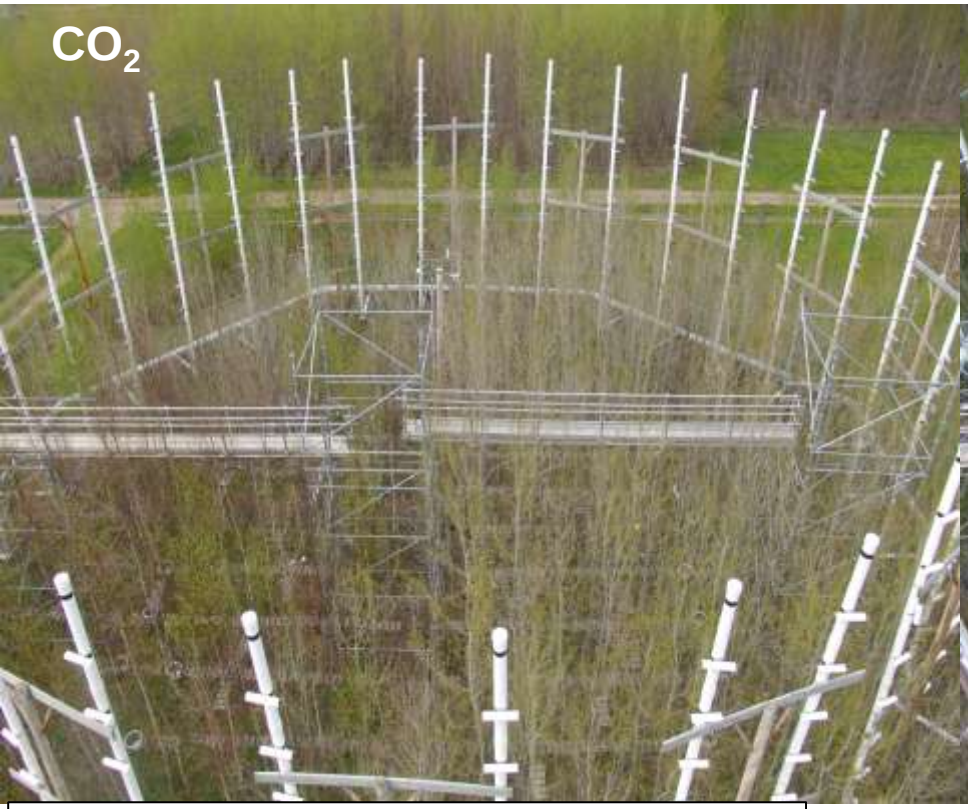
↓ LAI
↓ Leaf duration
↓ Leaf size
↓ Ps
↑ Pests
↑ Water stress
↑ Antioxidant gene expression

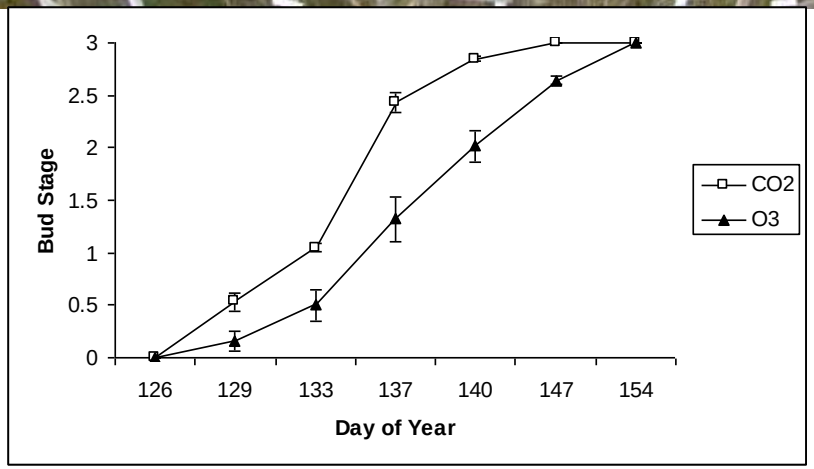
Effects of Elevated CO_2 and/or O_3 on LAI of Aggrading Aspen Stands



From: Karnosky *et al.* 2005. Plant Cell Environ. 28:965-981.

Budbreak of Aspen and Birch is Enhanced under Elevated CO_2 and Delayed under Elevated O_3





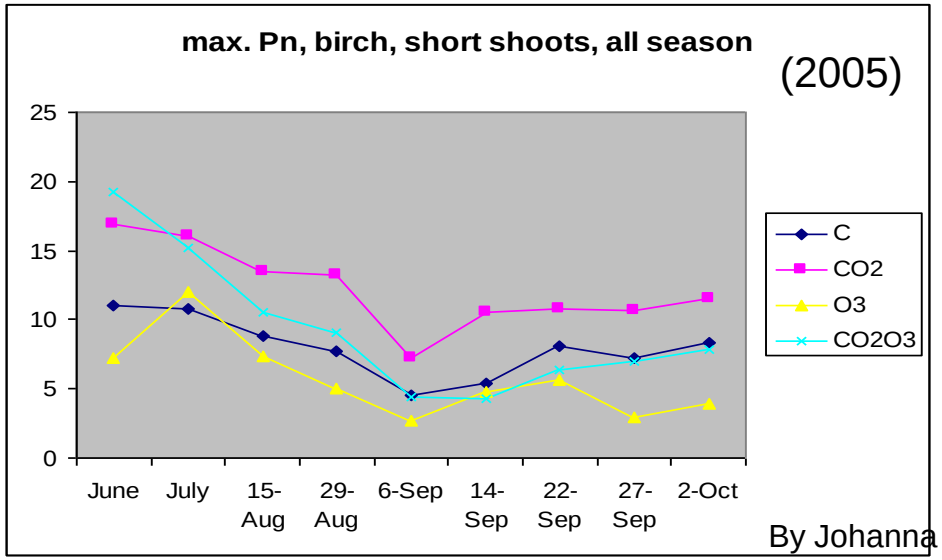
Rep 1 (5/10/05)

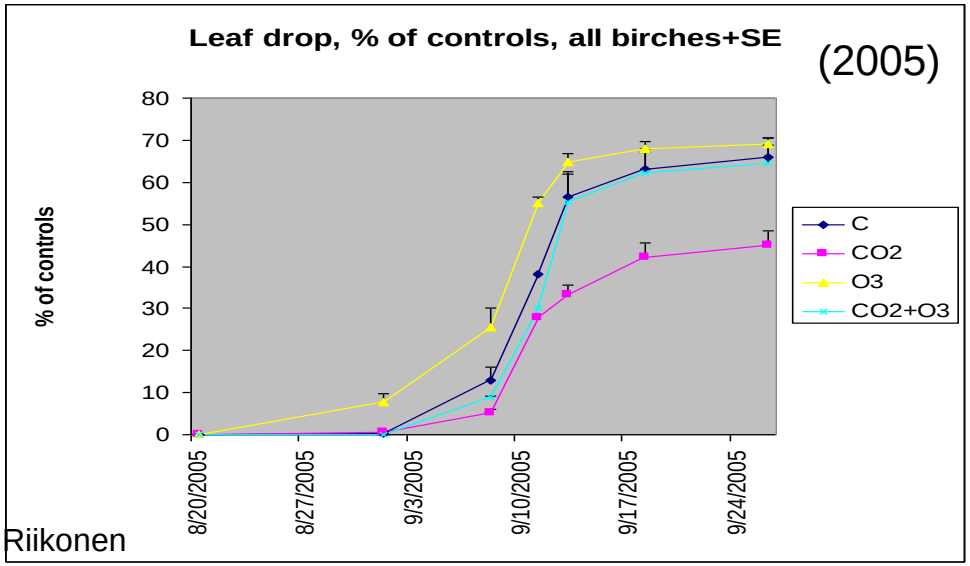
Bud Stages

0 1 2 3

Photos (9/21/05)

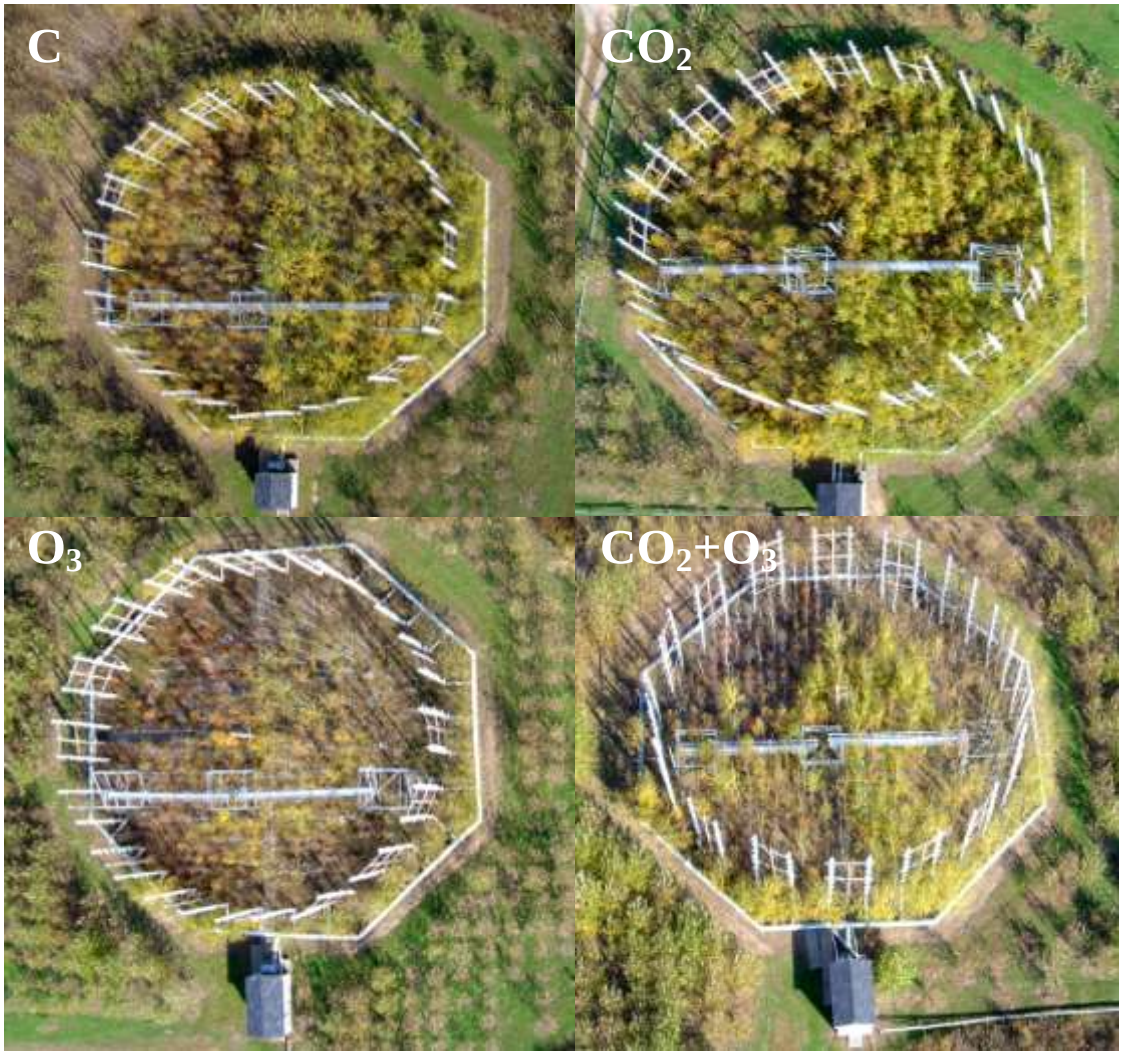
Decreased Late-season Sink Strength by O_3 (Regardless of CO_2 Treatment)





By Johanna Riikonen

Effects of Elevated CO_2 and/or O_3 on Autumnal Foliar Senescence

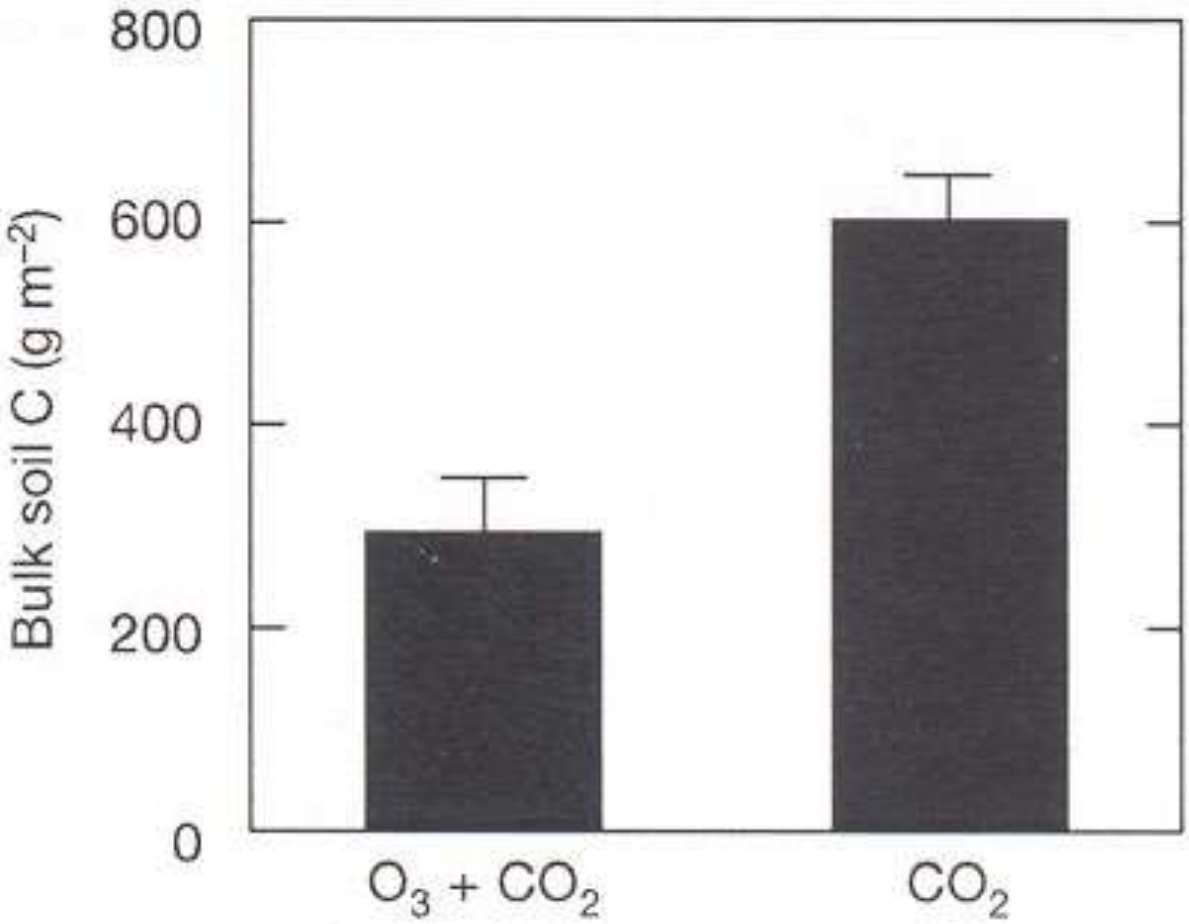


Photos from Rep 3 (10/10/04)

Increased leaf abscission under elevated O_3, regardless of CO_2 treatment

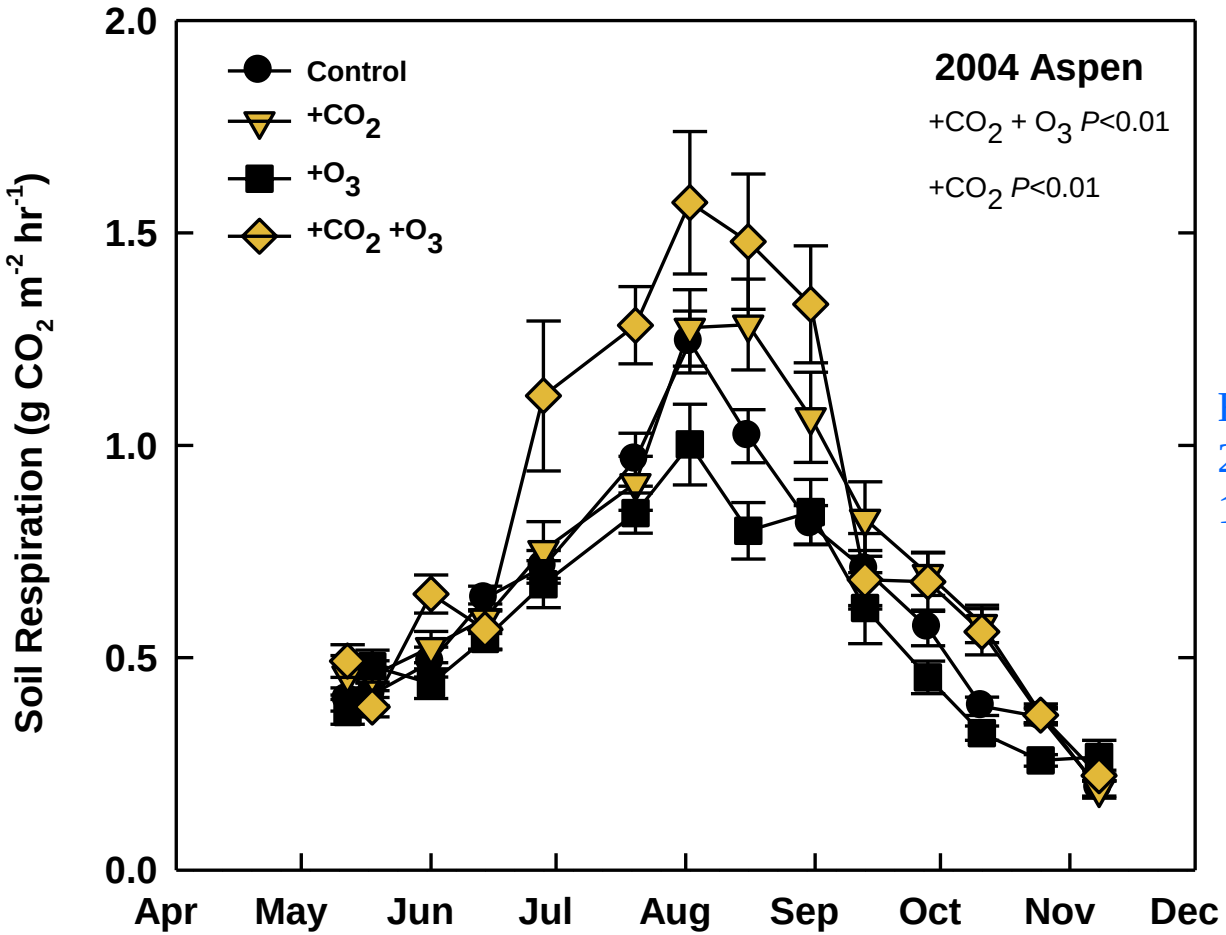
From: Karnosky *et al*. 2005. Plant Cell Environ. 28:965-981.

Does Ozone Affect Soil Carbon Formation Buildup?



From Loya *et al*. 2003. Nature 425:705-707.

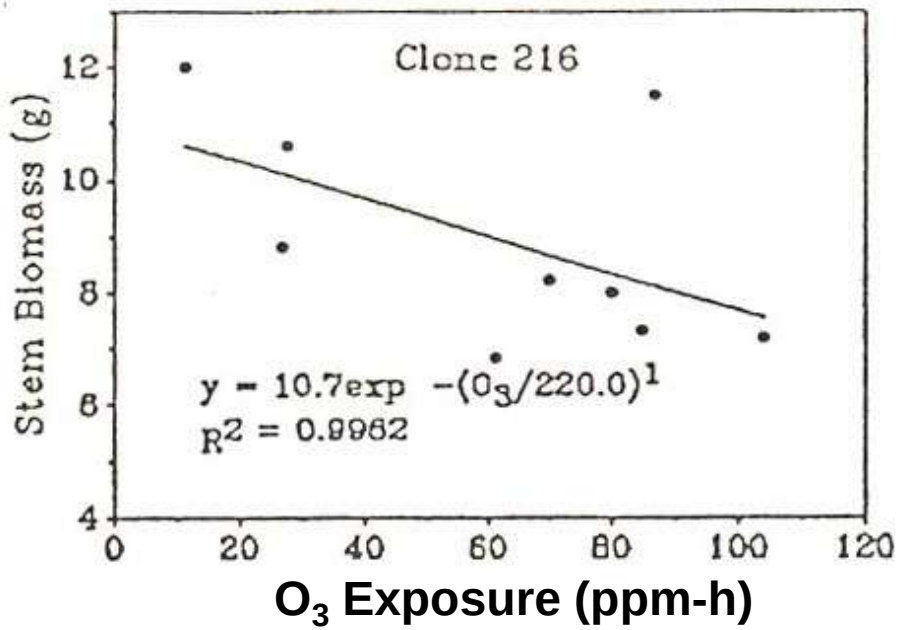
Is Any of the Extra "C" Sequestered in the Soil?

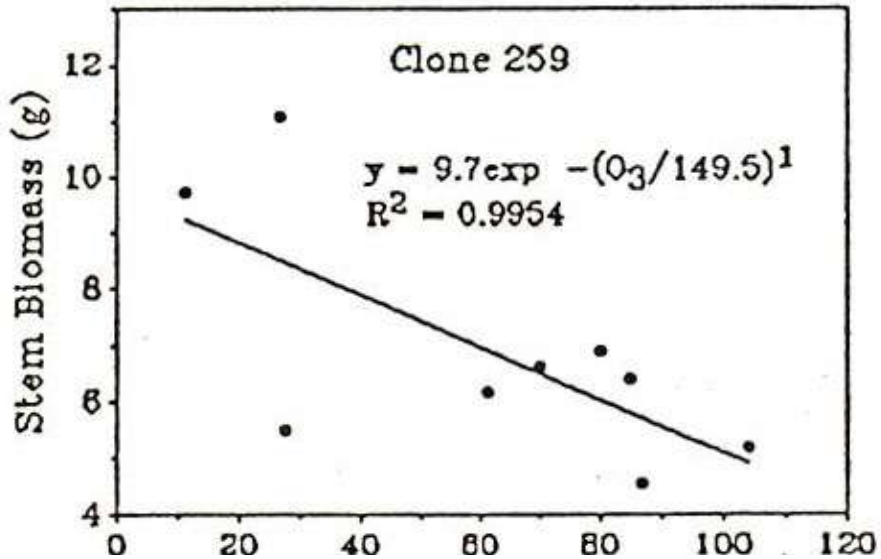


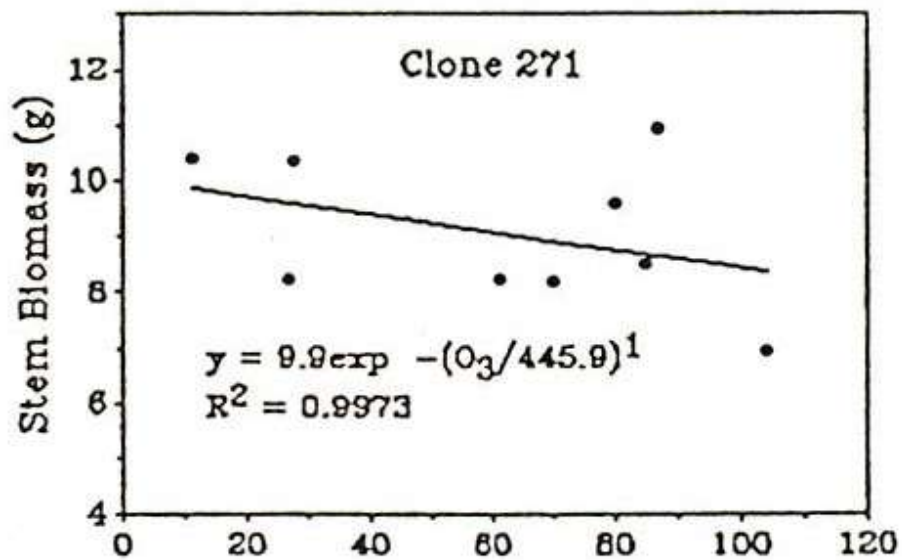
From Pregitzer *et al*. 2006. Oecologia 148:503-516.

- **Elevated O_3 in combination with elevated CO_2 causes accelerated soil respiration**

What is the Shape of a Typical O_3 Response Curve for Aspen?

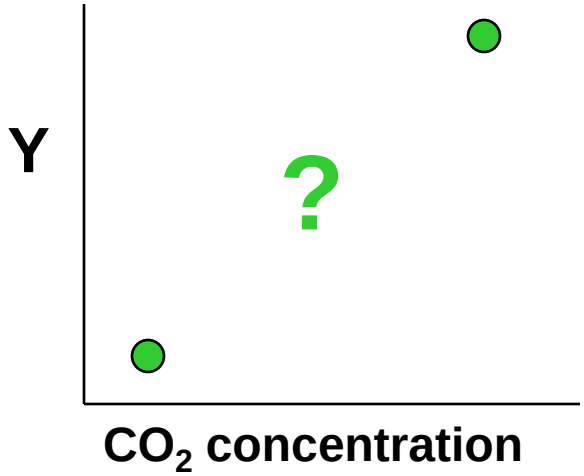


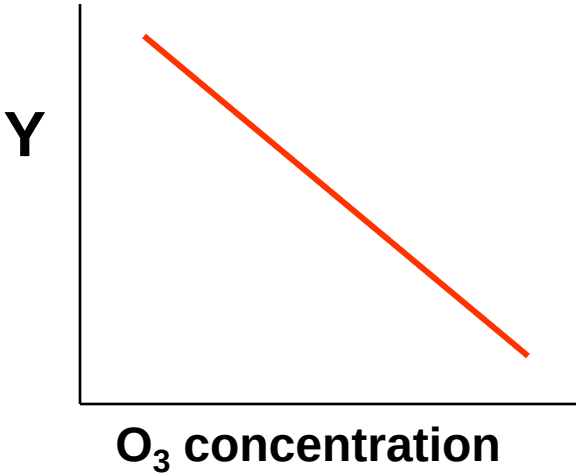


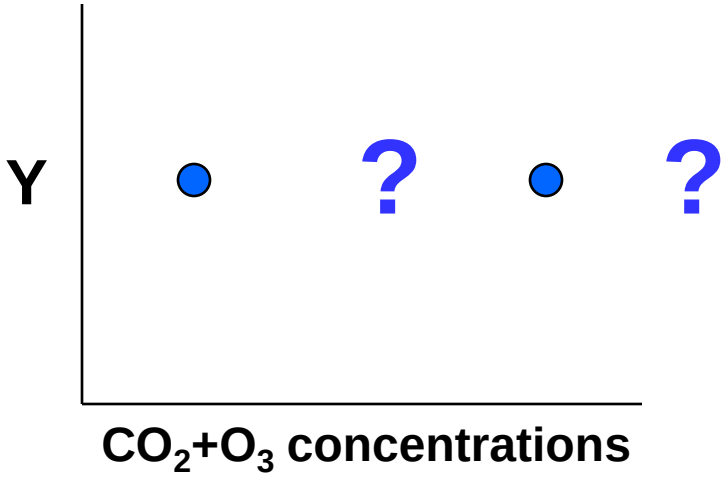


- **The response curve from 10-100 ppmh O_3 appears to be linear but is highly variable by genotype (Karnosky *et al*. 1996. Can. J. For. Res. 26:23-37).**

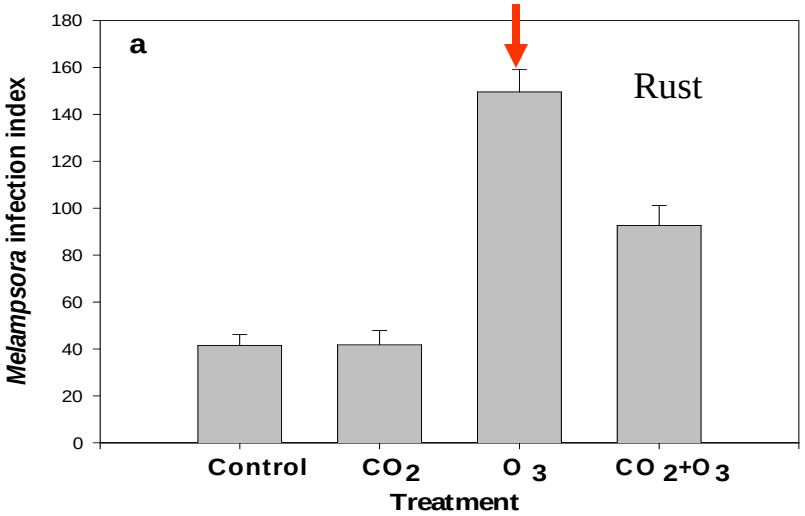
What is the Shape of the CO_2/O_3 Response Curve in Aspen?

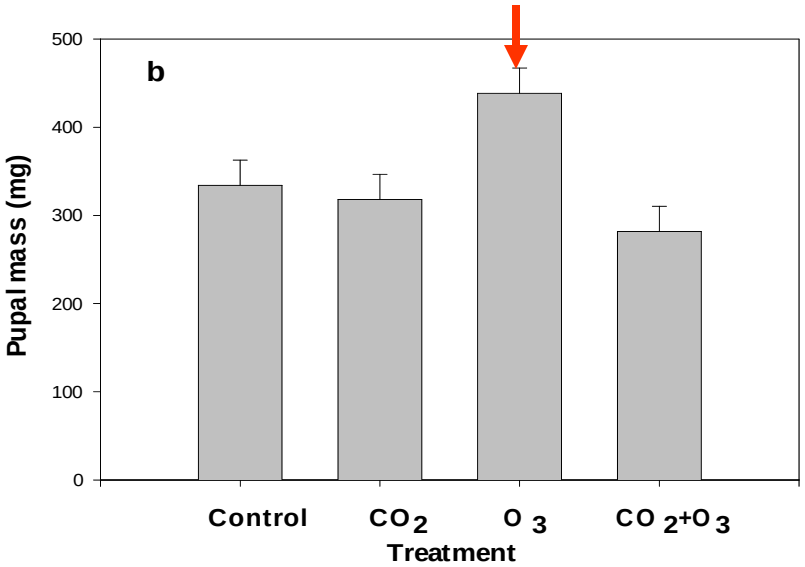






Indirect Effects of O_3 on Poplars That Can Affect Carbon Acquisition: e[O_3] Alters Response to Important Forest Pests





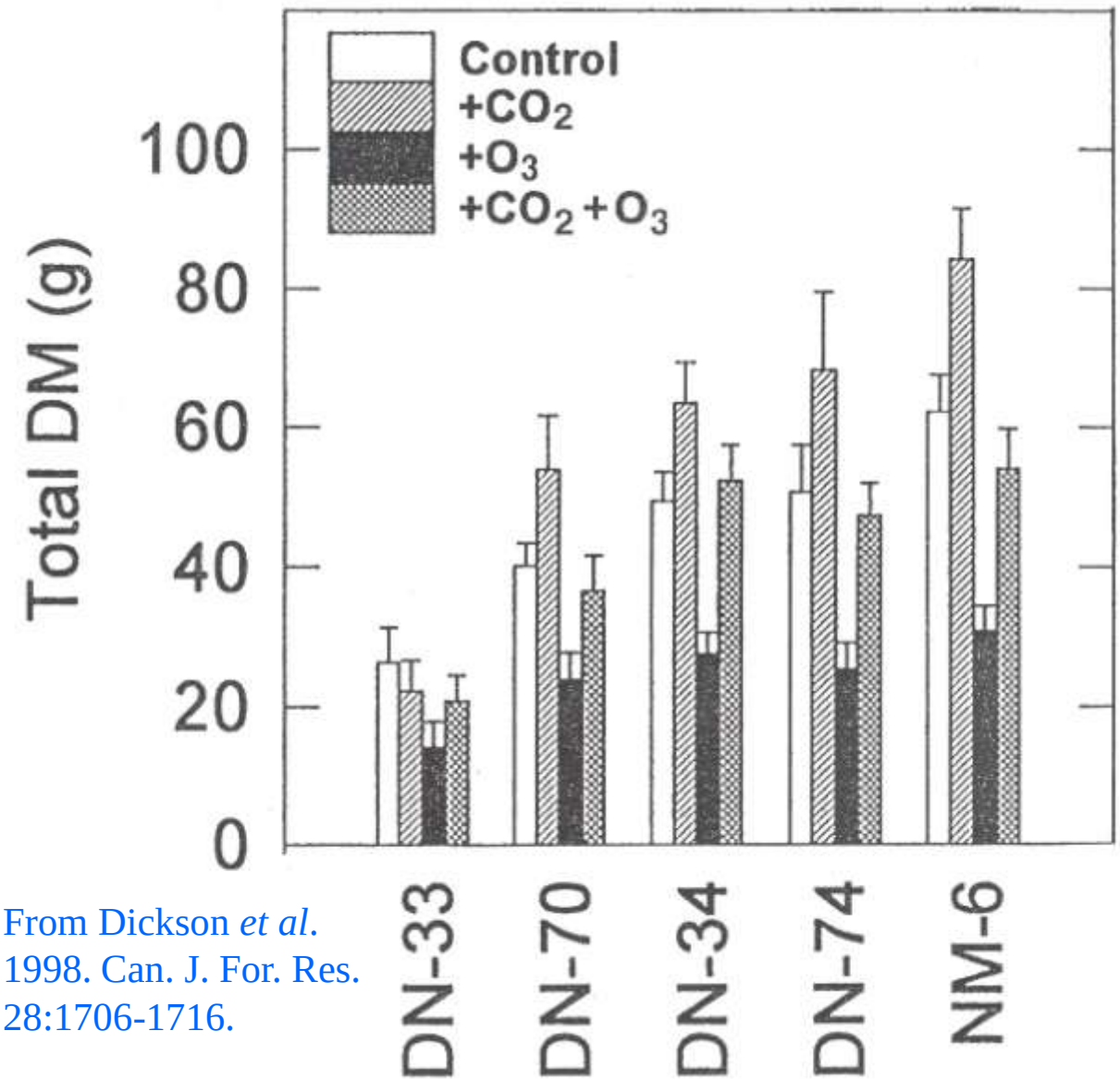
Other Experimental Results with Aspen and Ozone

- **Ambient O_3 in southern New York was shown in OTC experiments (filtered air vs. non-filtered air) to reduce total biomass by 12-24% for aspen clones grown in the ground (Wang *et al.* 1986. Can. J. For. Res. 16:47-55).**

- **Single season square-wave and episodic O_3 exposures in the range of 50-90 ppmh decreased biomass of three aspen clones and a population of seedlings by 23-45% in OTC experiments with plants grown in the ground (Karnosky *et al.* 1996. Can. J. For. Res. 26:23-37).**

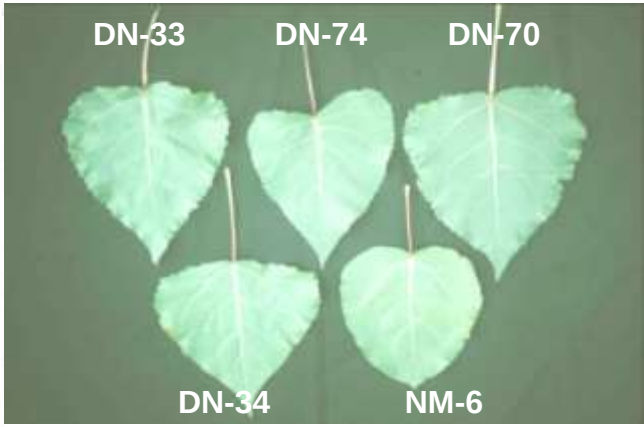
- **Twice ambient O_3 in a clean-air northern Michigan site decreased aspen root dry weight by up to 45% in a single-season OTC study with potted plants (Coleman *et al*. 1996. Tree Physiology 16:145-152).**

How do Hybrid Poplars Compare in O_3 Responsiveness?

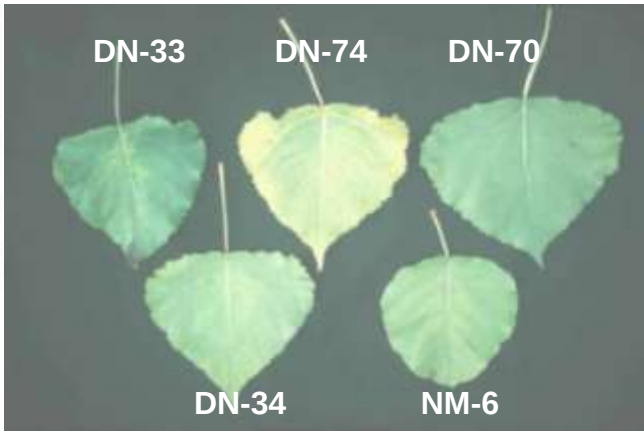


From Dickson *et al*. 1998. Can. J. For. Res. 28:1706-1716.

LPI 5 leaves



Control

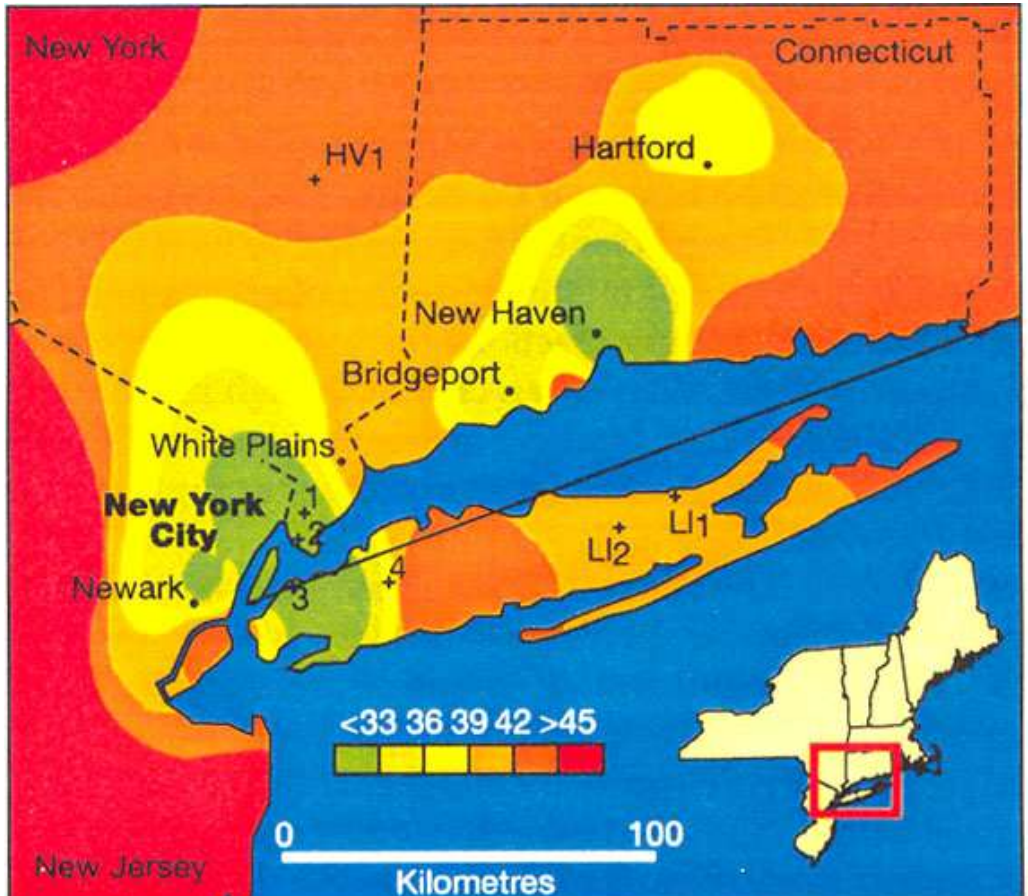


$+CO_2+O_3$

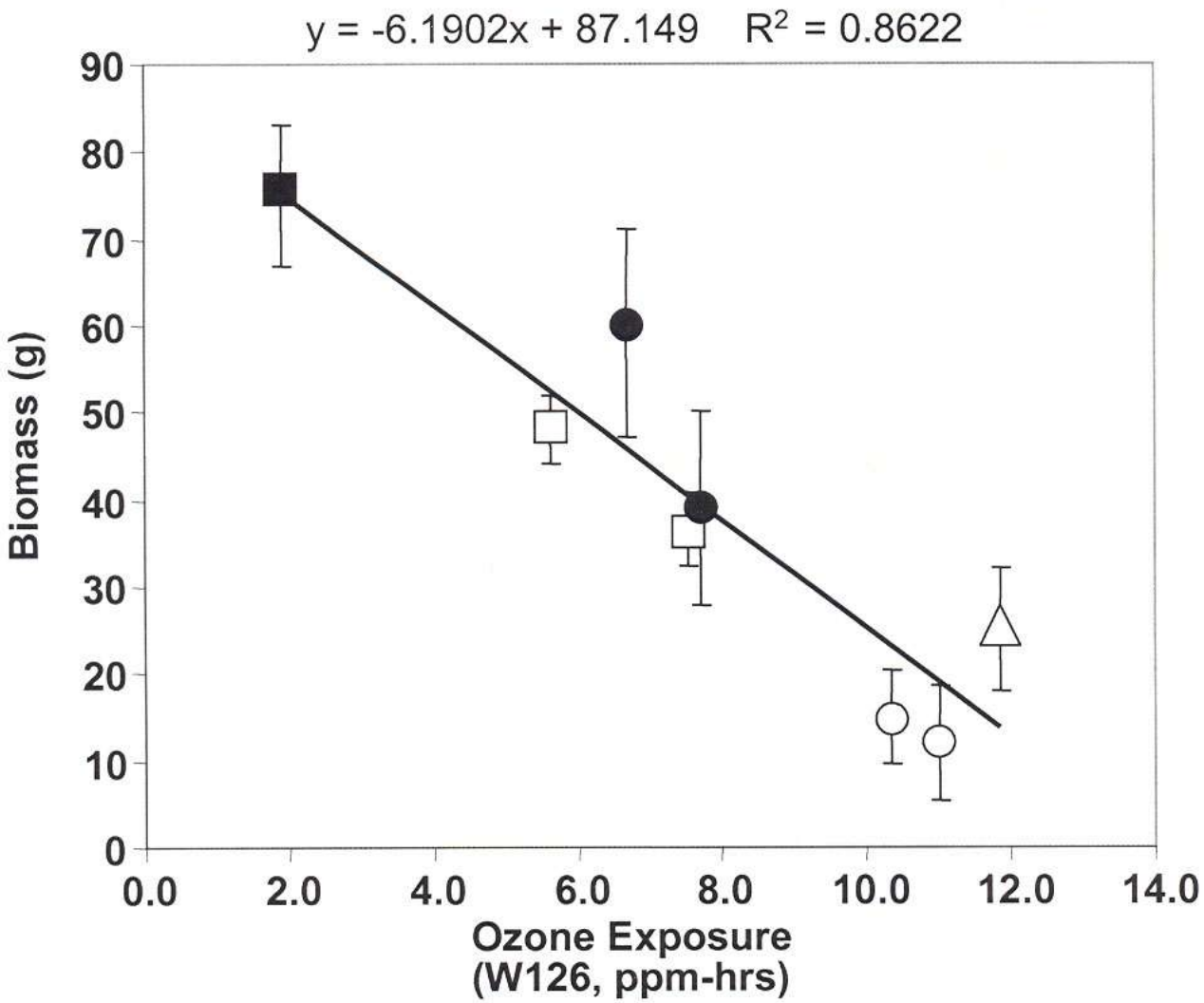
Other Evidence of Adverse O_3 Effects on Poplars Being Used in Carbon Sequestration Plantations

- **Season-long exposures to ambient O_3 in southern New York State caused a 19% reduction in aboveground biomass with hybrid poplar clone NE 388 grown in the ground (filtered vs. non-filtered air OTCs) (Wang *et al*. 1986. Environ. Sci. Technol. 20(11):1122-1125).**

- **Ambient O_3 in southern New York caused a 50% growth reduction in *Populus deltoides* growth in the ground (Gregg *et al*. 2003. Nature 424:183-187; Gregg *et al*. 2006. Ecol. Applic. 16:2368-2381).**

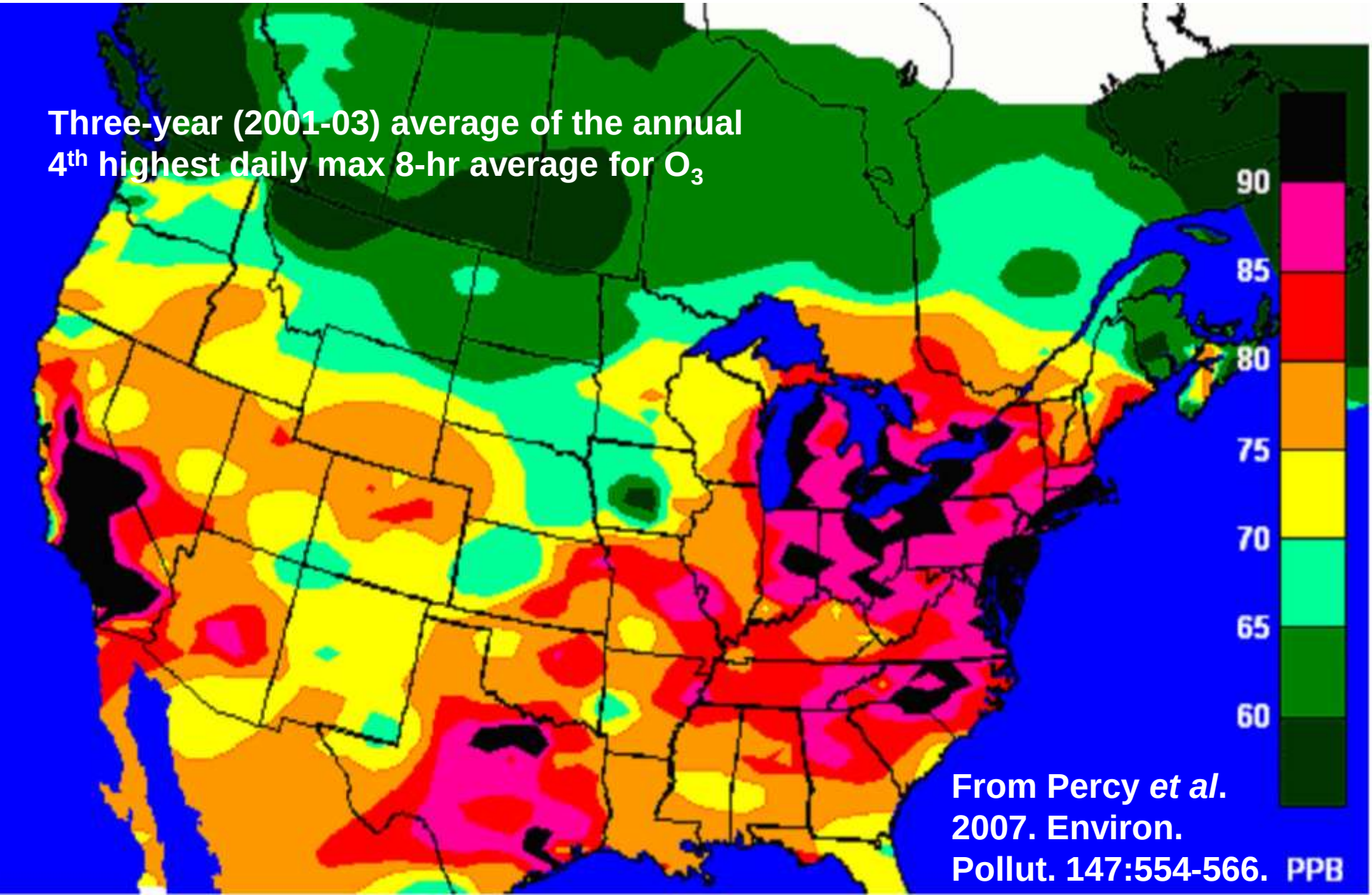


The O_3 Response Curve is Linear for *Populus deltoides*

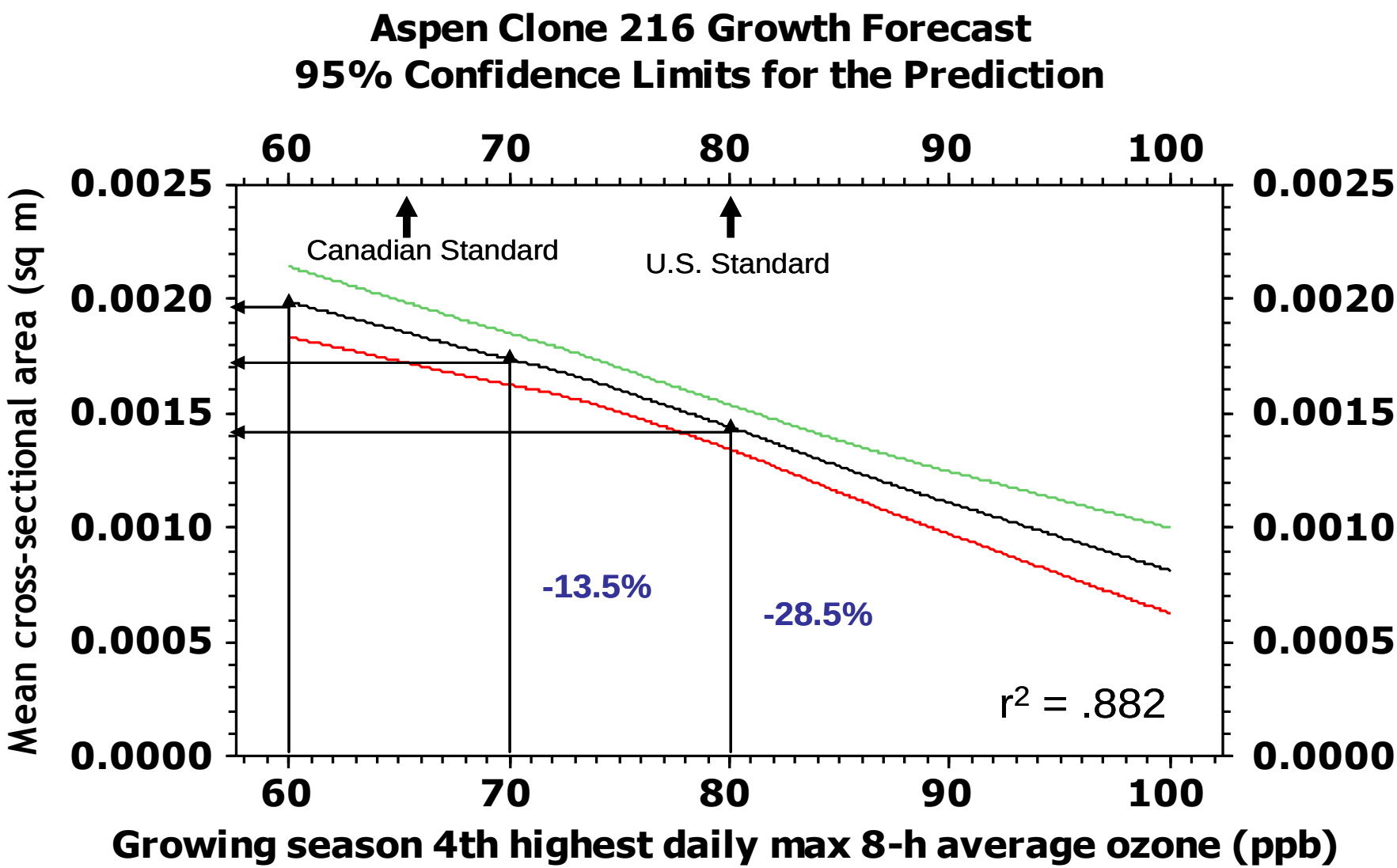


Modified from Gregg *et al*. 2003.

Modelling to Estimate the Impacts of Ozone on Carbon Sequestration: Ozone Dose Metrics



From Percy *et al*. 2007. Environ. Pollut. 147:554-566.

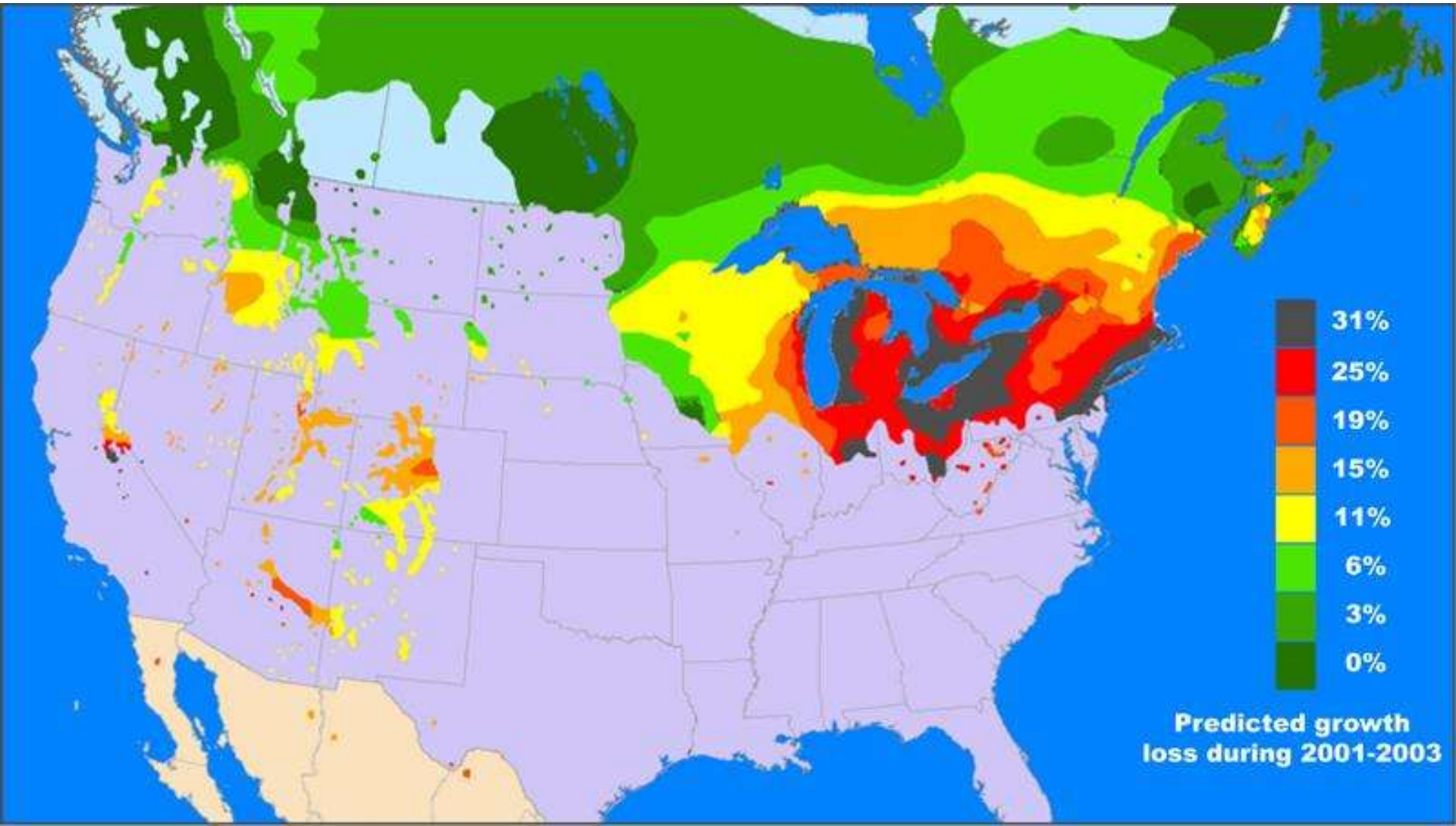


*Clone 216 mean annual cross-sectional area (m^2) = 0.00684 – 0.000031 4th highest O_3 – 0.00551 WS + 0.000003 GDD

From Percy *et al*. 2007. Elsevier Developments and Environmental Science (In Press)

Scaling Aspen FACE Results

Using multiple regression techniques and Aspen FACE responses to a range of the fourth highest daily maximum 8-hour O_3 concentrations, we estimated 2001-03 growth losses for trembling aspen in North America (Percy *et al*. 2007. Environ. Pollut. 147:554-566).



Summary: Impacts of e[CO_2] and e[O_3] on "C" sequestration

1) e[CO_2] is generally increasing the "C" sequestration capacity in stems, branches and coarse roots of young forests.

2) e[O_3] in hot spots is generally decreasing the "C" sequestration capacity of O_3 sensitive trees and will likely offset enhancement by e[CO_2].

3) More work is needed on long-term effects of the greenhouse gases, particularly with older trees in forests.

Research Needs

1) Little is known about the shape of the response curves for e[CO_2]+e[O_3].

2) Only a very small number of tree species have been adequately characterized for their responsiveness to either e[CO_2]+e[O_3] under forest conditions.

3) More work is needed with mature trees growing in forests.

4) Vast areas of developing countries (China and India) are facing rapidly rising O_3 concentrations with little information available on forest tree effects in these areas.

5) Ecosystem level responses to O_3 are largely unstudied (community dynamics, biogeochemical cycles, etc).

6) Few interactions with O_3 have been studied (warming, drought, CO_2, N, especially for ecosystem-level responses.

Acknowledgements

Aspen FACE Operators:
Wendy Jones
Scott Jacobson

Thank You

Aspen FACE web site: http://aspenface.mtu.edu

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