Berkeley connect
Environment

Sign up now for Berkeley Connect - Environment (ESPM 98/198) and…

-> experience Berkeley excellence with a small college feel
-> connect with peers interested in environmental issues
-> be supported by a graduate student mentor
-> receive career guidance
-> interact informally with faculty
-> eat great food

ESPM 98/198 is a 1-unit evening class to support undergraduates. There are no papers, exams or outside reading. Spaces are limited, so sign up now on TeleBears! For more information visit us at: http://www.berkeleyconnect.berkeley.edu/departments/espm

Ecosystems and Environmental Change, Part 1

Dennis Baldocchi
Ecosystem Sciences Division/ESPM
University of California, Berkeley

4/23/2014 ESPM 111 Ecosystem Ecology

The world about us is changing, in terms of temperature, CO_2, land use, N deposition, species loss, changing rain and weather patterns, extreme events, etc. This lecture and the next deal with how ecosystems are coping with a changing world.

Outline

- Background
- Methods
- Warming
- CO_2
- Rainfall
- Other
  - Ozone
  - N Deposition
  - Solar Dimming
  - Evaporation

ESPM 111 Ecosystem Ecology

We cover background to the problem, how change is studied at the ecosystem scale and look at results

Anthropocene Era

(coined by Paul Crutzen, Nobel Laureate)

- Tenfold change in Human Growth, to over 7 billion, over the industrial period
- Human activity will release, in a few generations, the fossil fuels that have been sequestered over +100 millions of years
  - Concentrations of trace gases (CO_2, CH_4) are exceeding historic values over the past 1 million years
- > 50% of land surface and use has been modified by mankind.
- More N is fixed Synthetically than Naturally
- > 50% of accessible fresh water is being depleted
- ~ 20% Marine fisheries are over exploited
- Extinction rates of species have accelerated
  - We're experiencing the 6th Great Extinction Period over Earth's History, the 1st caused internally.
- Land Use Change and Extinction Opens Niches for Invasive Species

http://www.igbp.kva.se//uploads/ESO_IGBP4.pdf

ESPM 111 Ecosystem Ecology

For context, we are entering a new geological era, the Anthopocene. What is this and what does it mean to ecosystems?

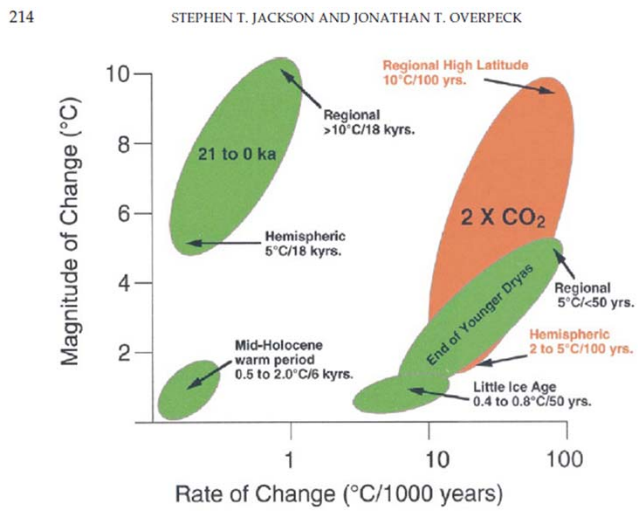
Attributes of Global Environmental Change

- It is More than just Climate Change
  - Land use change, elevated CO2, N Deposition, Species extinctions, etc
- Change is Fast
- Change is Multi-Factorial (CO_2, N, ppt, T, O_3, age, invasive species, disturbance)
- Change is Non-Linear, Hysteretic
- Change is Conditional on Antecedent Conditions
  - Down-regulation

ESPM 111 Ecosystem Ecology

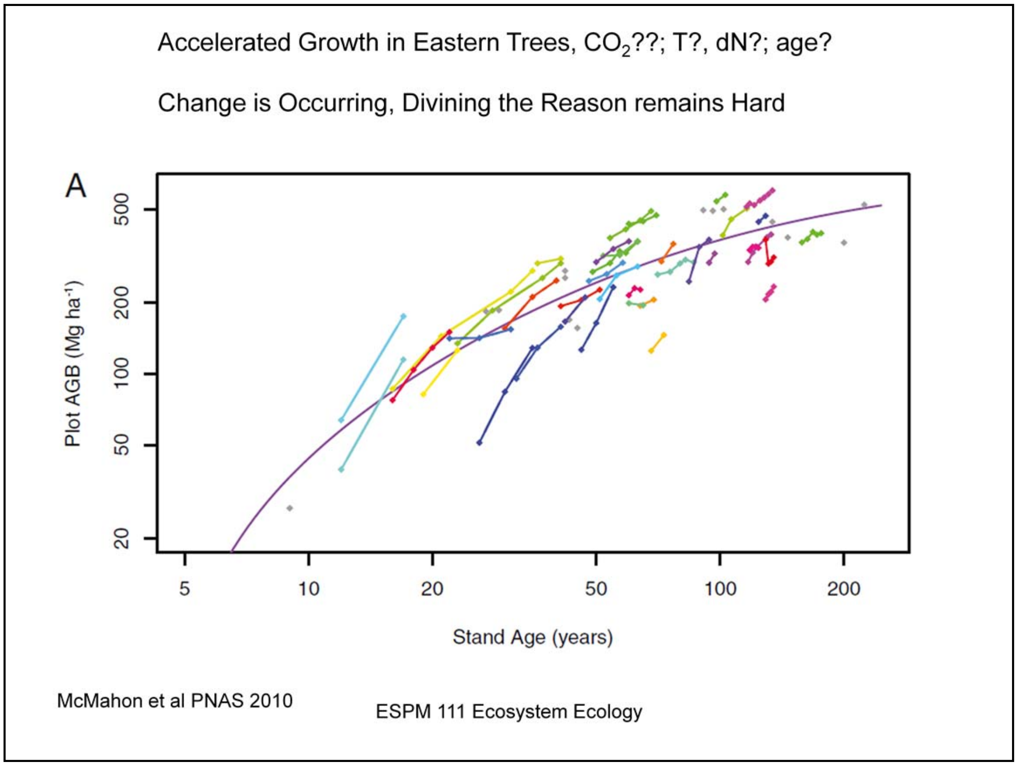
Many of the lessons and lectures so far are poising us to deal with a new world, how to study it and how to interpret it.

Change that is Occurring is Fast and Large



ESPM 111 Ecosystem Ecology

This graph reinforces the point that current changes in temperature and CO2 are different from what ecosystems experienced in the past in terms of rate and magnitude. During the last ice age the change in temperature was Large, but the change occurred slowly. And there was ecological shake out, vast northward movement of forests, loss of megafauna (wooly mammoth, saber tooth tiger, etc)



This paper is showing that above ground biomass of forests in the east are increasing. But why? Is it age, a CO2, temperature or N deposition effect? How do we separate these causes and effects from data? We do have to separate ecological age effects from observed trends when attributing other factors. Residual analysis is important. So here we see the theoretical line of changing above ground biomass with age and super imposed are vectors measuring change at give plots along this chrono sequence. Many of the vectors have slopes steeper than the age effect.

Difficulty of Extracting Cause/Effect Information from Time Series

Table 1. Hypotheses to explain accelerated recent growth of forest stands

Hypothesis	Description
Increased temperature	Higher temperatures over the growing season (or growing degree day sums) can increase metabolic rates and therefore, lead to more rapid carbon sequestration.
Increased growing season	Longer growing seasons (especially earlier springs) has been observed in many systems. A longer growing season would allow stands earlier leaf-flush and therefore, increased carbon sequestration.
Increased CO_2	Higher atmospheric CO_2 can increase photosynthesis and lead to higher biomass accumulation.
Nutrient fertilization	Nitrogen and phosphorus fertilization from agricultural and urban runoff can increase tree growth. Atmospheric deposition of nitrogen has increased in urban and industrial regions in the United States in recent decades and could lead to soil fertilization as well.
Community composition	Some pioneer species tend to grow faster than others, especially sweet gum (*Liriodendron styraciflua*) and tulip poplar (*Liquidambar tulipifera*). An influx of these species into a plot or a preponderance of fast-growing species recently becoming dominant could lead to an increase in biomass accumulation.
Demographic stochasticity	Although a stand may follow the ensemble biomass-accumulation pattern, random deaths of large trees can lower the stand biomass, and rapid regeneration will quickly increase the biomass as if the plot were, through a death, moved to a younger state.

McMahon et al 2010 PNAS

ESPM 111 Ecosystem Ecology

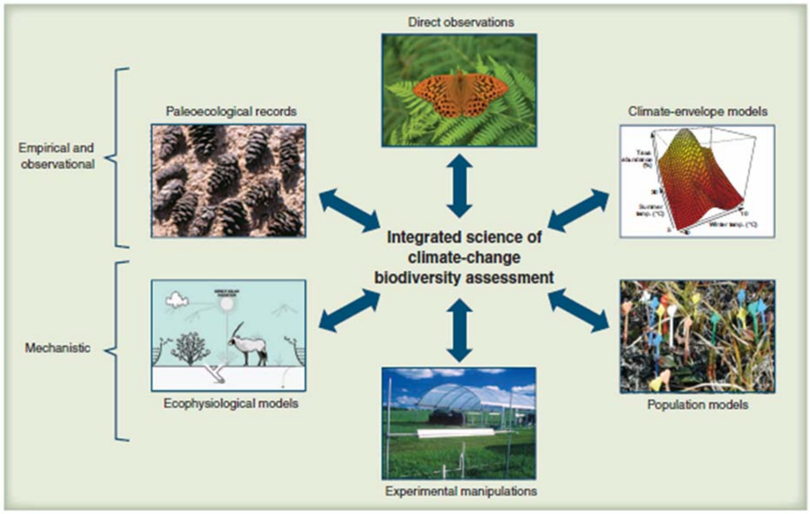
The authors do not conclude which factors are causing the change, but lean towards the combination of temperature, CO2 and longer growing seasons. Water deficits are not an issue in the east, so warmer temperature can be viewed as a positive factor

Responses to Environmental Change: Ecological Lessons your Mom, or Snarky Brother, may have taught you

- Tolerance
  - ‘Put up or shut up’
- Avoidance
  - ‘Get out of the sun or you’ll get a sun burn’; ‘If its too hot in the Kitchen, get out’
- Acclimation
  - ‘When the going gets tough, the tough get going’
- Adaptation
  - ‘put on your sunscreen, so you won’t get skin cancer’
- Dispersion/Movement/Migration
  - ‘Get the hell out of Dodge’
- Extinction
  - ‘Congratulations, you’ve won the Darwin Award’

Plants don’t move fast or far in short terms, hence they have to deal with what they got. What are the options.

Ways to Study Ecological Change



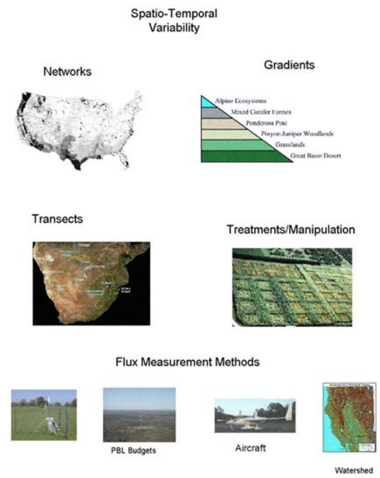
Dawson et al 2011 Science

ESPM 111 Ecosystem Ecology

Observations, models, manipulative studies are among the arrows in our quiver to study ecological change. We can look at past records via pollen and spores in lake sediments, tree rings and stable isotope records. Gradient studies provide a natural laboratory.

Experimental Manipulation & Methods

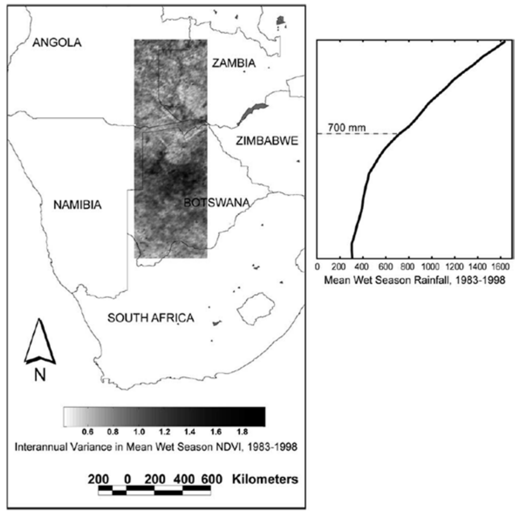
- Long-Term Monitoring Networks and Natural Experiments
- Transects/Gradients
- Open-Top Chambers
- Free-Air Exposure (FACE)
- Heating
- Exclusion/Addition
  - Rain, fertilizer



ESPM 111 Ecosystem Ecology

List of methods used. We will go into greater detail.

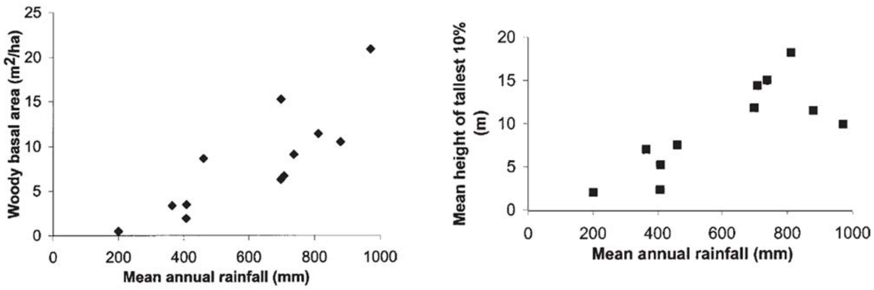
Kalahari Transect:
Uniform Soils, North-South
Precipitation Gradient



ESPM 111 Ecosystem Ecology

Natural gradients are great, if one can avoid artifacts by different soils, for example. The Kalahari transect is unique due to its uniform sands and strong precipitation gradient. One can study the ‘equilibrium’ response, operating on short to long time scales, of ecosystem-atmosphere interactions to rain, in terms of the physiological response, the type of plants and the leaf area index that is established.

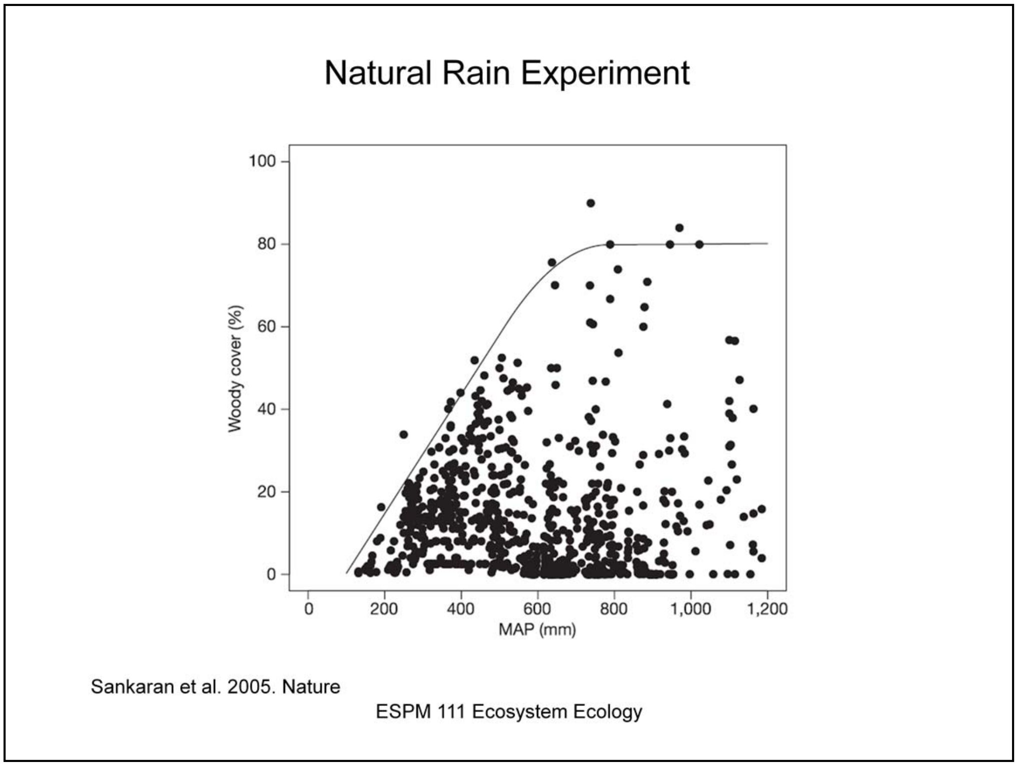
Kalahari Transect



Scholes et al 2002 J Veg Sci

ESPM 111 Ecosystem Ecology

Woody basal area and tree height are positively correlated with annual rain fall



Rain yields a boundary line analysis on percent of woody cover. Of course other limiting factors cause a deviation from the upper boundary line.

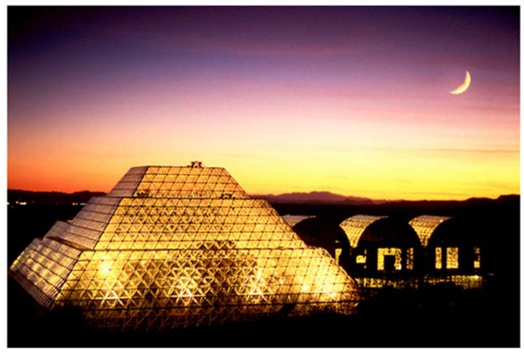
Open Top Chamber

Elevated CO_2 and O_3, warming

One can enclose plants and alter their conditions. This approach is more artificial, has artifacts (due to the age and stature of the plant and the conditions of the chamber, and can be only short term, due to funding and interest

Eco-cosms

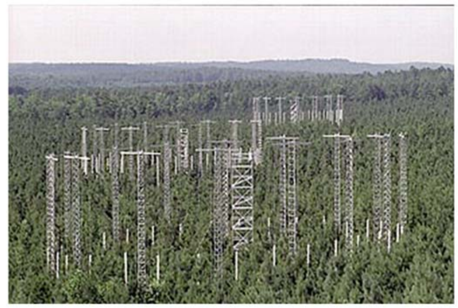
Biosphere II



ESPM 111 Ecosystem Ecology

Small ecosystems have been established at various institutes. On one hand, one can control the environment in a prescribed manner, and possibly well. But what is an ecosystem? What needs to be in it in terms of plants, species, soils and the modulation of conditions.

Free-Air Carbon Exposure (FACE)

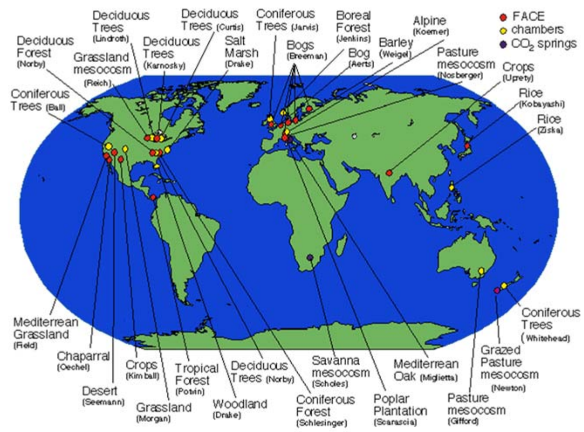


ESPM 111 Ecosystem Ecology

Free air exposure systems attempt to let plants grow under natural conditions and just goose the CO_2 by venting it upwind. The approach is very expensive as most CO_2 diffuses away, and large sources are needed to maintain elevated levels near the plant.

Questions arise to which CO_2 concentrations to choose? What about replications? How big should the plots be? Can they be sub sampled regularly?

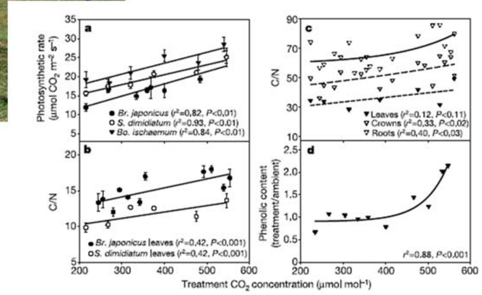
Elevated CO_2 Studies



ESPM 111 Ecosystem Ecology

FACE is popular, used world wide over crops, forests, plantations, wetlands, grasslands, deserts, etc, etc

CO_2 Tunnel, Temple, TX and Duke



Gill et al Nature, 2002

ESPM 111 Ecosystem Ecology

Clever method to impose a natural CO2 gradient as air moves through the tunnel with a continual carbon sink.

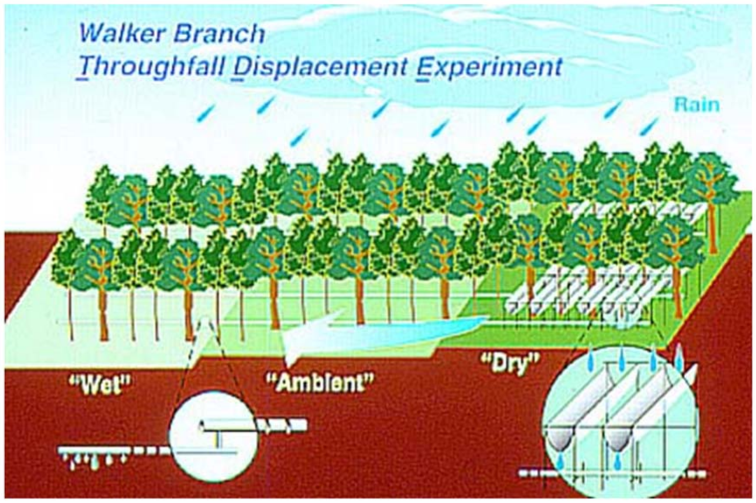
CO_2 Exposure Methods: Pros and Cons

- Pots
  - Seedlings or saplings, not representative of mature trees
  - Plants become root-bound
  - No Ecosystem interactions or competition
- Chambers and Soil monoliths
  - Artificial light, humidity and temperature levels in the chambers
  - No ecosystem processes
  - Limited to low stature plants
- Free-Air Carbon Exposure Studies (FACE)
  - Field conditions
  - Plants compete for light, water and soil resources
  - Expensive, much CO2 is Advected Away.
  - Control at set point varies by +/- 10 to 20%
  - Expensive to Replicate
  - Can't sample vegetation of Treatments periodically without destroying treatment

ESPM 111 Ecosystem Ecology

Explicit list of pros and cons. I don't advocate we should not attempt to use these methods, but be careful on how we interpret the data.

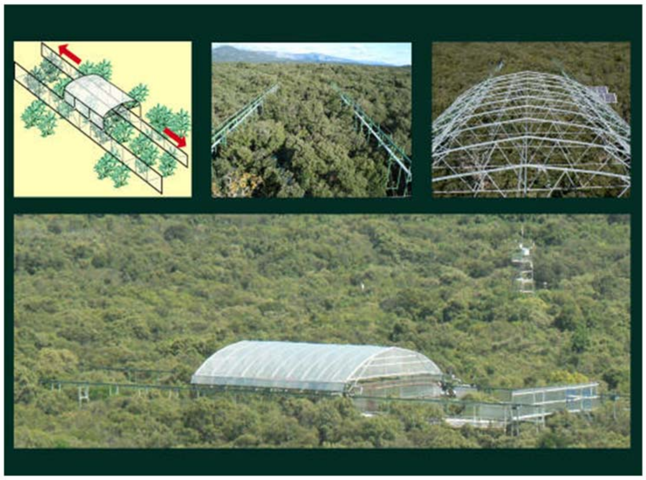
Rainfall Addition/Subtraction



ESPM 111 Ecosystem Ecology

Rainfall can be added and subtracted. Large scale field manipulations studies suffer many of the slings and arrows launched at FACE studies.

Mobile Rain Shelter, Puechabon, FR



Laurent Misson +

ESPM 111 Ecosystem Ecology

Colleagues in France developed a mobile rain shelter. Quite an engineering feat as this is the land of the Mistral, where 100 km/hr winds were common. Replication remains a concern.

Rain Exclusion, Amazon

ESPM 111 Ecosystem Ecology

Another example of rain exclusion in the tropics

Rain Addition/Exclusion Pros/Cons

- Rainfall effects are non-linear
  - Need 3+ treatments to characterize Non-linearity and know where the breakpoints are.
- Method is expensive and difficult to replicate
- Timing of rainfall may be as important as amounts added/subtracted
- Need Long term studies to sort out the short (physiological) and long term (lai, species, rooting depth) effects

ESPM 111 Ecosystem Ecology

Pros and cons

Ecosystem Warming Experiment, V1

Infrared Lamps Mimic CO_2 IR Forcing

ESPM 111 Ecosystem Ecology

Warming experiments have received much discussion on whether to expose plants to an elevated temperature or an elevated infrared flux density that mimics CO2 greenhouse effect. John Harte has favored the elevated IR effect, in the Colorado Mountains and this has been copied by many.

Warming Has different effects during summer and Winter

ESPM 111 Ecosystem Ecology

Rocky Mountain Biological Lab, photo of Saleska. Warming in the mountains affects not only plants during the growing season but snow, snow cover and its water input

Ecosystem Warming Experiment, V1a

Yiqi Luo, Univ OK

ESPM 111 Ecosystem Ecology

Visual difference of plants under the heating lamps, during the wetter period.

Passive Nighttime Warming System

Josep Peñuelas, Barcelona

ESPM 111 Ecosystem Ecology

A cost effective and less energy intensive way to warm ecosystems is with a passive shield at night, reducing long wave energy loss to the sky

Tree Warming Expt, v2

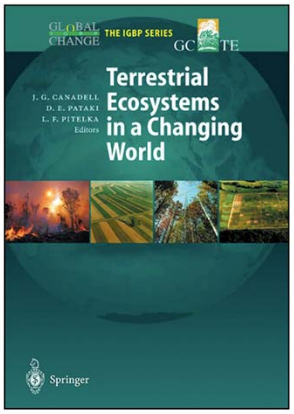
Air Conditioning Warms Air Temperature

The more elaborate is to just air condition the system

Warming Experiment: Pros and Cons

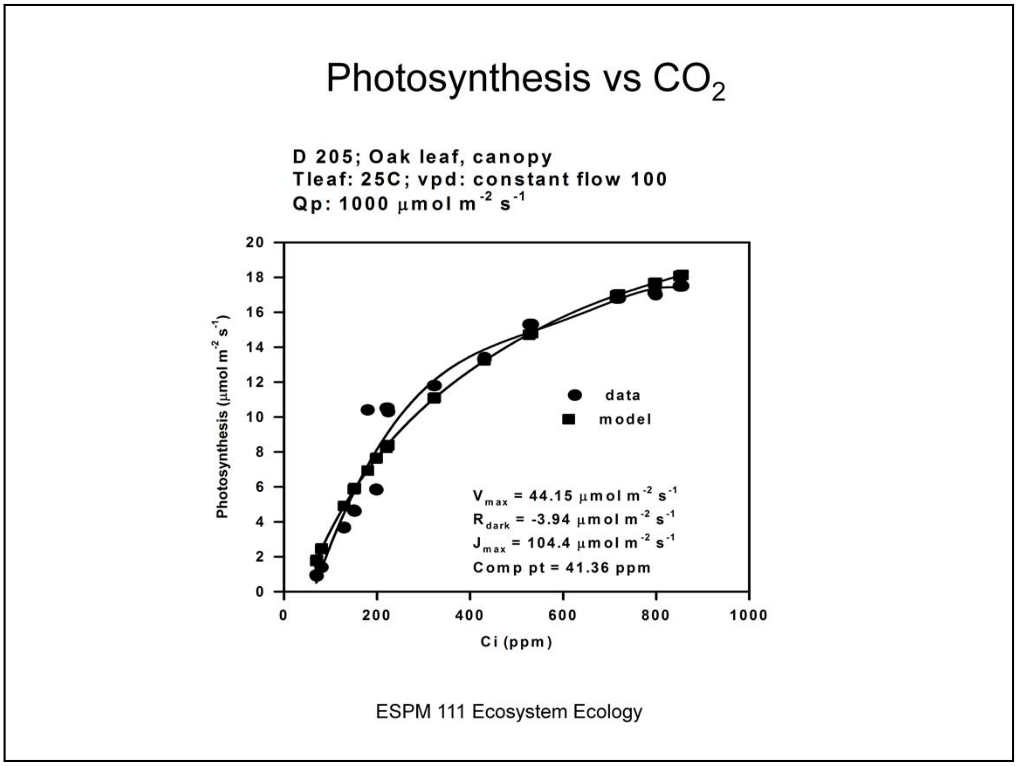
- Alter Radiation
  - Infrared lamps mimic predicted change in CO_2 forcing
  - Lets plants adjust surface energy balance (eg albedo, surface resistance, leaf temperature)
- Alter Temperature
  - Imposes a prescribed temperature differential
  - Air temperature is not the same as surface temperature
- Big Electricity Bills $$$ Warming the system
- Winter Effects differ from Summer Effects
- Co-Variation with Temperature and Water Balance

Results from Global Change Experiments



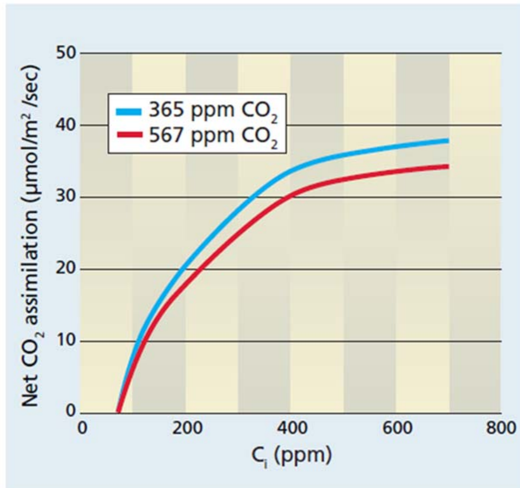
ESPM 111 Ecosystem Ecology

Two excellent resources on global change ecology



Physiologically CO2 can be viewed as good for plants. More CO2 more photosynthesis. The questions arise on how to sustain this and is it sustainable for natural ecosystems where light, water and nutrients may become limiting as plants grow bigger and bigger.

Down-Regulation of Photosynthesis based on CO_2 Growth Environment

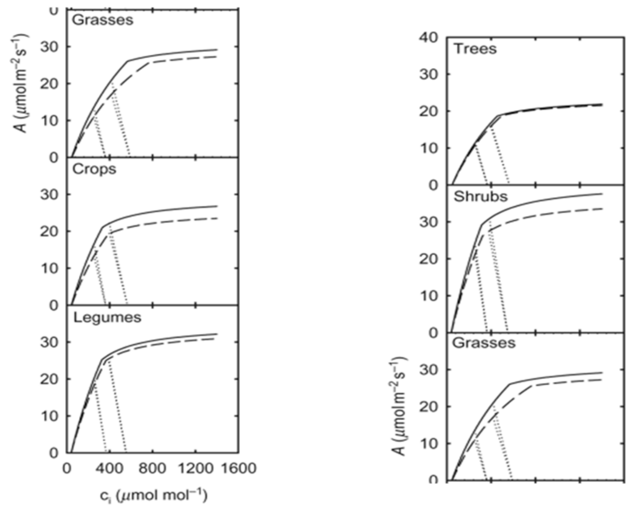


Ainsworth and Rogers 2007, PCE; adapted from Bloom, 2009 Cal Ag

ESPM 111 Ecosystem Ecology

One of the more important scale emergent facts is a down regulation in the response of photosynthesis with CO2, with growth environment. Plants grown under higher CO2 levels reach a lower maximum photosynthetic rate at high CO2.

Down-Regulation of A-Ci Occurs across many Plant Groups



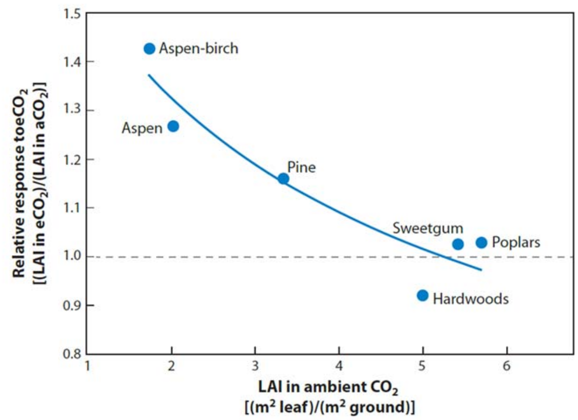
Ainsworth and Rogers, 2007, PCE

ESPM 111 Ecosystem Ecology

This effect is wide spread.

Check table 1 for Vcmax and compute A-Ci curves and redraw, dashed elevated co2 ~ 560 ppm, solid ambient co2 ~ 365 ppm

LAI Increases with Elevated CO2 only if the Canopy is Not Closed

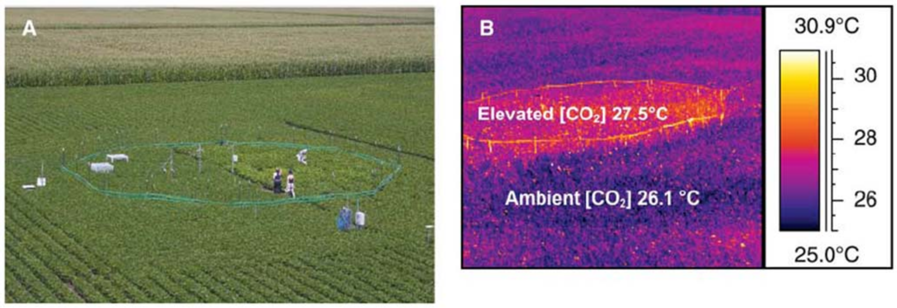


Norby and Zak, 2011 Annual Reviews Ecology Systematics

ESPM 111 Ecosystem Ecology

Good example of the role of light limitation on not fostering additional increments of leaf area once the canopy closes with an LAI of about 6, which intercepts over 95% of incident sunlight

CO_2 and Crop Temperature:
Induced Stomatal Closure Increases Surface Temperature



Long et al., 2006 Science

ESPM 111 Ecosystem Ecology

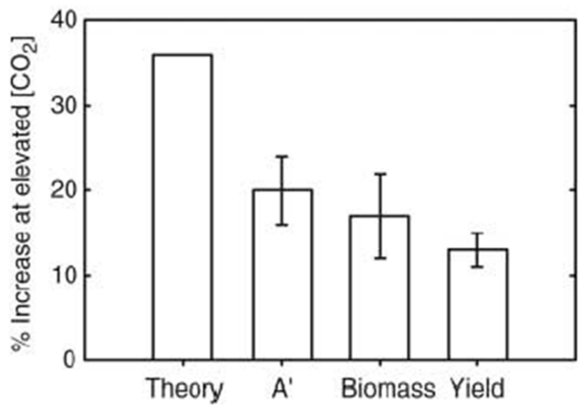
High CO2 causes stomatal closure, which will reduce transpirational cooling and warm the leaves of the plants more. Here is data from the soybean studies of Steve Long in Illinois. IR camera shows the warmer soybeans.

Elevated CO_2

- *'… the rate of CO_2 uptake per unit leaf area is a rather unreliable predictor of plant growth and the cascade of follow –up ecosystem processes'*
  - Korner et al 2007 GTCE

Effect of Elevated CO_2 Diminishes as One Follows the Carbon Cycle Cascade:

Atheory > Ameasured > Biomass > Yield



Long et al 2006 Science

ESPM 111 Ecosystem Ecology

Relation between elevated CO2 on theoretical and measured increase in photosynthesis and how this carbon is used to produce biomass and yield. Each step has a smaller incremental increase, though all are positive and greater than 10%

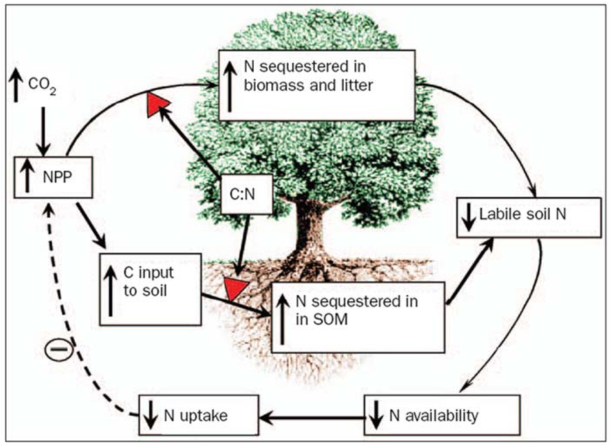
Elevated CO_2: Direct and Indirect Effects

- Fast-scale, Physiological
  - Photosynthesis, ++
  - Stomatal conductance, -
  - Transpiration, +/-
- Slower scale, Ecological/Biogeochemical
  - Growth, +
    - Bigger plants grow faster, 'compound interest effect'
  - Below ground allocation and Resource Acquisition, +
  - Mineralization, -
    - Down-regulation in Photosynthesis
  - Respiration, +
  - Water Balance
    - Water Use Efficiency increases with stomatal closure
- Slowest scale, Community Dynamics
  - Species change and competition
  - Vulnerability to Disturbance

ESPM 111 Ecosystem Ecology

We have to think about fast and slow responses, what they affect and how they interact and sum to affect the net ecosystem response

C-N Interactions and Feedbacks



Luo et al. 2004 Bioscience

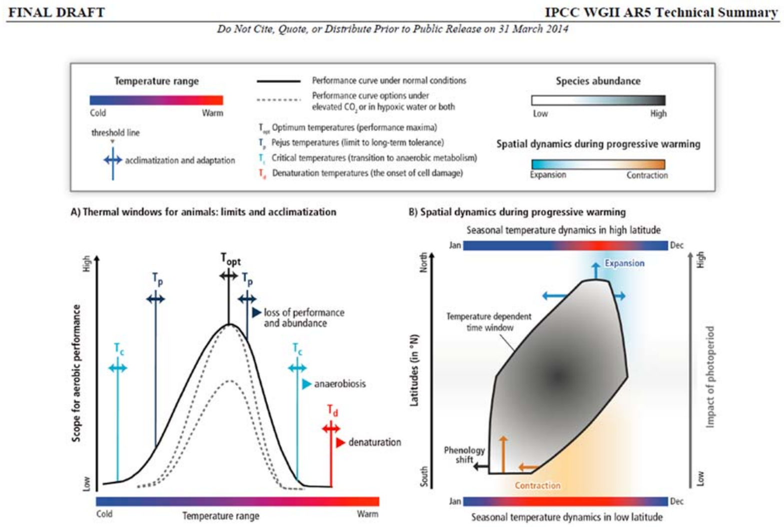
ESPM 111 Ecosystem Ecology

This feedback chart shows some of the processes that are amplified or reduced with a perturbation of CO2. More CO2 increases photosynthesis, leads to more growth and N sequestration. If C:N increases, N is diluted in the litter quality, which can reduce the amount of labile N for the next go round of the cycle, leading to a down regulation of photosynthesis.

Elevated CO_2, Facts and Myths

- Enhances Photosynthesis
  - Down-Regulation in Ps from Nutrient Limitations
- Reduces Stomatal Closure
  - Direct Effect
    - Reduces Transpiration and Increases WUE
  - In Direct Effect and Positive Feedback
    - Elevated Leaf Temperature, augments Transpiration
- Greater Growth and Leaf Area
  - Bigger plants grow faster. +; effect saturates at high LAI
  - Bigger plants transpire more
  - Soil moisture pool depleted faster: -
- Herbivore Interactions
  - Insects eat more foliage to compensate for lower N quality of leaves

Effects of Temperature are + and -

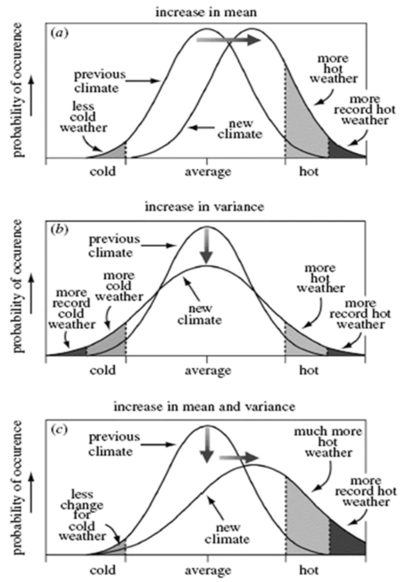


ESPM 111 Ecosystem Ecology

The effects of temperature are conditional, as the biological response is highly non linear

IPCC AR5 working group 2 report

Mean Temperature is not the only relevant biological temperature

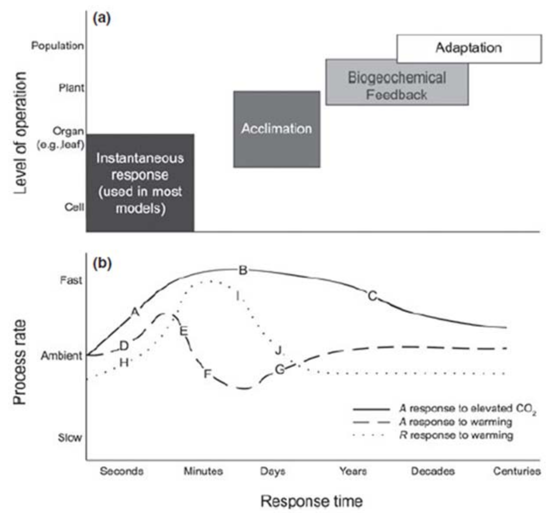


Porter and Semenov

ESPM 111 Ecosystem Ecology

The effect of temperature is complicated, as there are many temperatures of biological interest, average, minimum, maximum, range, extremes

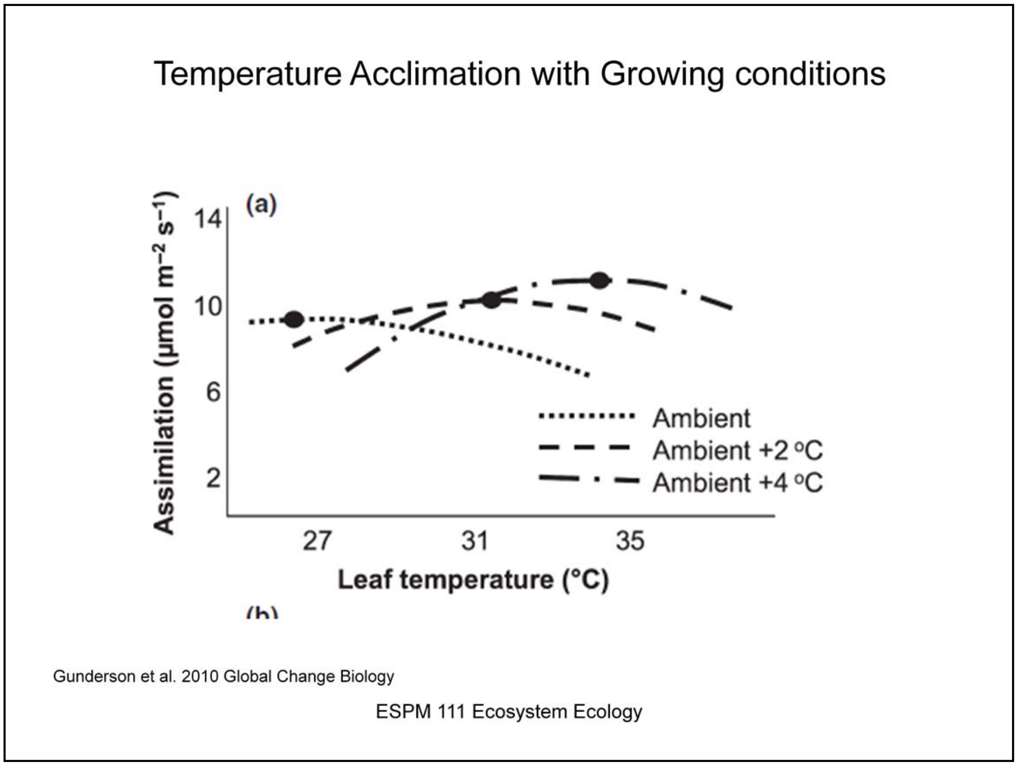
Role of Temperature Acclimation and Adaptation



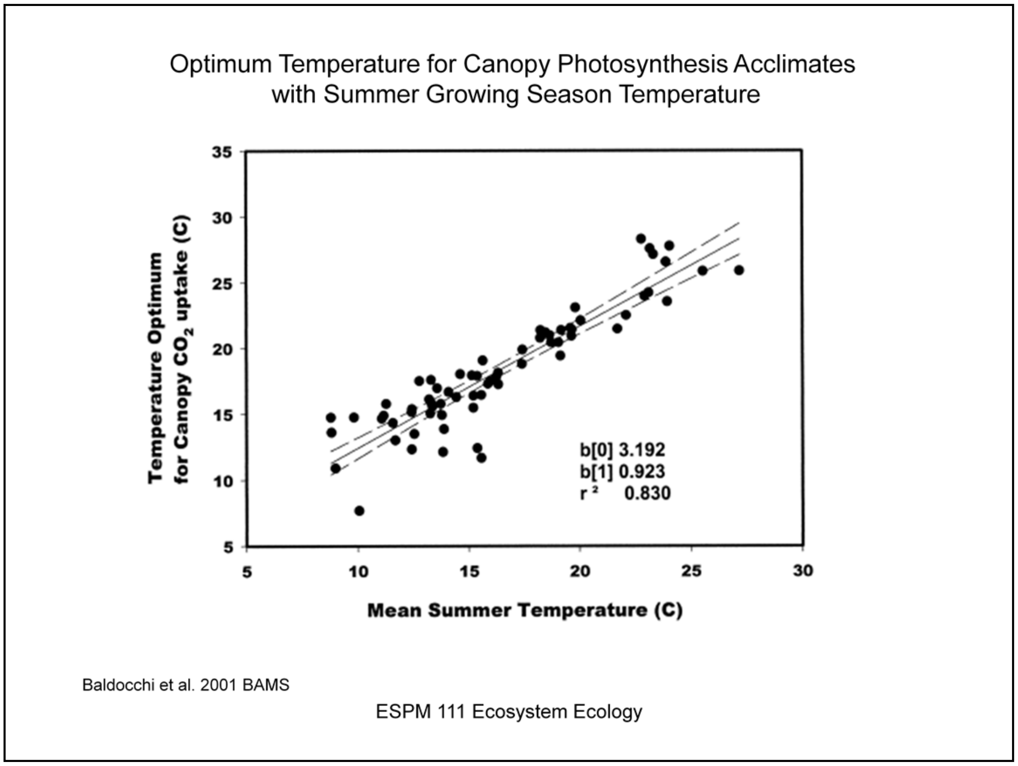
Smith and Dukes 2012 GCB

ESPM 111 Ecosystem Ecology

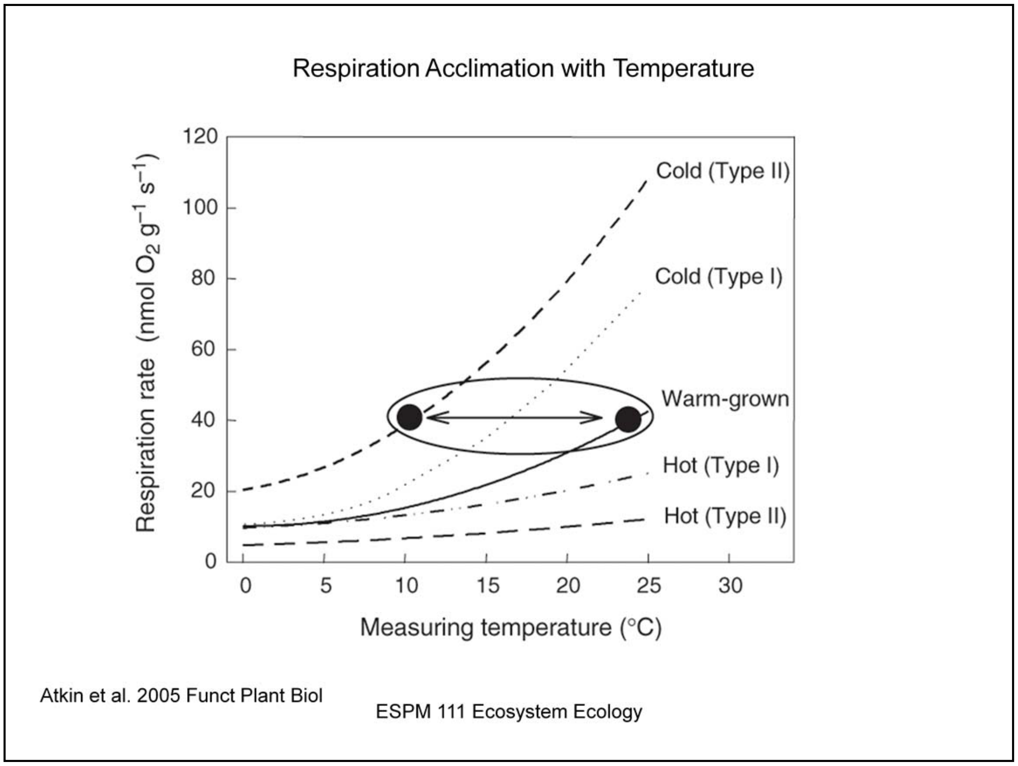
Temperature effects and responses occur on short and long time scales, including direct physiological responses, acclimation, feedbacks and adaptation



The physiological temperature response to photosynthesis is non linear with a broad optimum, but the optimum acclimates and shifts with growing temperature. Yet, another scale emergent property

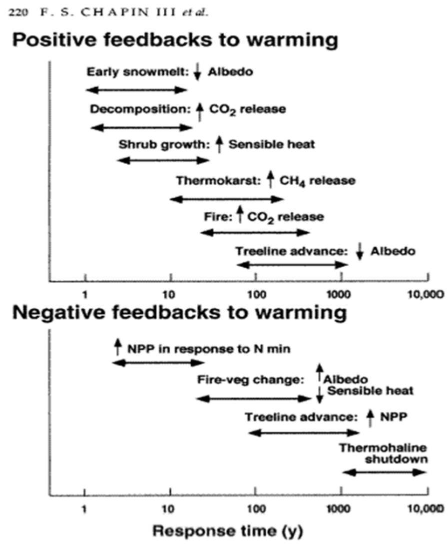


Data from the fluxnet project indicating that ecosystem response of carbon assimilation to temperature acclimates with growing season temperature.



Respiration-temperature response, too is a function of growth conditoins.
Atkin et al 2005 Functional Plant Biol

Direct and Indirect Effects of Temperature



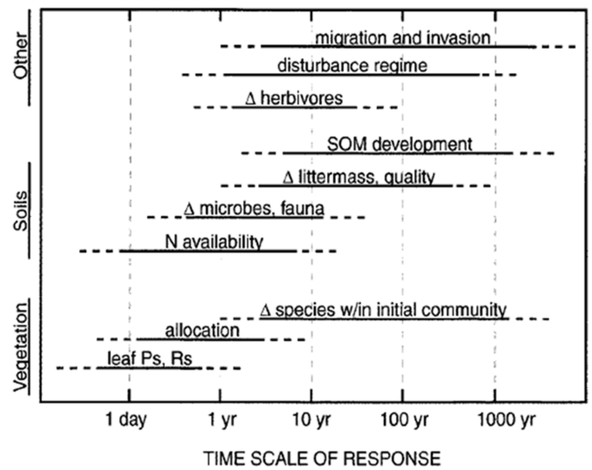
Missing are Insect and pest infestations; drought, accelerated mortality

ESPM 111 Ecosystem Ecology

Examples of biogeochemical feedbacks, fire, growth, species migration, etc With temperature and ecosystems there are many direct and Indirect effects to consider that have negative and positive feedbacks. What is missing on this figure?

Try insect infestations, drought

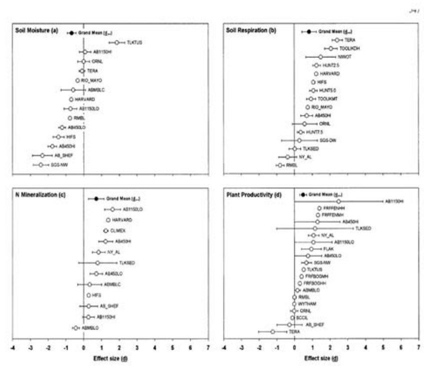
Warming and Ecosystems



Shaver et al 2000 Bioscience

Meta Analysis of Warming Studies

- Soil Respiration increased by 20% with 0.3 to 6 C warming
- Net N mineralization increased by 46%
- Plant Productivity increased by 19%



$$d = \frac{\overline{X_{\exp t}} - \overline{X_{control}}}{std\ dev}$$

Rustad et al. 2001 Oecologia

ESPM 111 Ecosystem Ecology

Soil warming experiments have been conducted and analyzed with meta analysis.

Duration of Heat Stress and Mortality

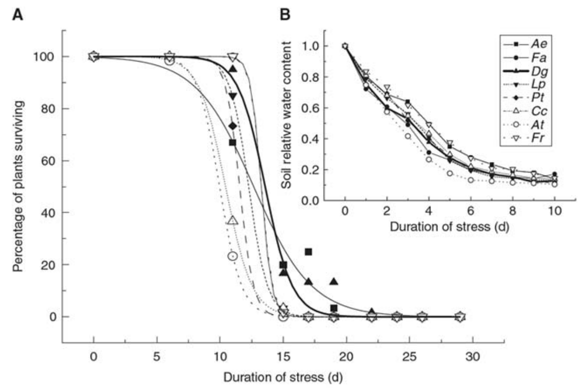


Fig. 1. (A) Species-survival percentage measured after different exposure times to a simulated heat wave. Data are fitted with dose–response curves: $y = A/[1 + 10^{(\log x_0 - x)p}]$. Each symbol is based on 60 plants in two containers. Note that the *Fa* and *Fr* curves overlap. (B) Decrease of soil relative water content during the first 10 days of exposure to the heat wave. Data are means of nine containers. Species codes: *Ae*, *Arrhenatherum elatius*; *At*, *Agrostis tenuis*; *Cc*, *Cynosurus cristatus*; *Dg*, *Dactylis glomerata*; *Fa*, *Festuca arundinacea*; *Fr*, *Festuca rubra*; *Lp*, *Lolium perenne*; *Pt*, *Poa trivialis*.

Milbau et al 2005 Physiologia Plantarum

Duration of heat stress is important, too

Long Term Warming Experiment

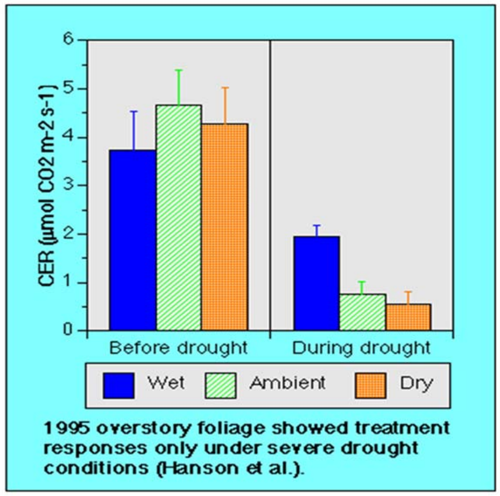
- Harte investigated carbon-cycle responses to climate changes by combining results from a controlled 15-year ecosystem warming experiment in montane grassland with observational data from before and during the recent drought.
- They found that both experimental warming and real-world drought induced substantial soil carbon loss in the study system, and that the same mechanism, a drying-induced shift in plant species composition and an associated decline in community productivity, provides a common explanation for these declines in soil carbon. warming expt

Harte et al 2006 ERL

Rainfall Exclusion or Addition

- Studies and Results are Conditional
  - Treatment addition/removal
  - Climate Zone
  - Research Results seem Difficult to Publish

In Temperate Zones, Wet years are WET, so reduction in ppt has little effect

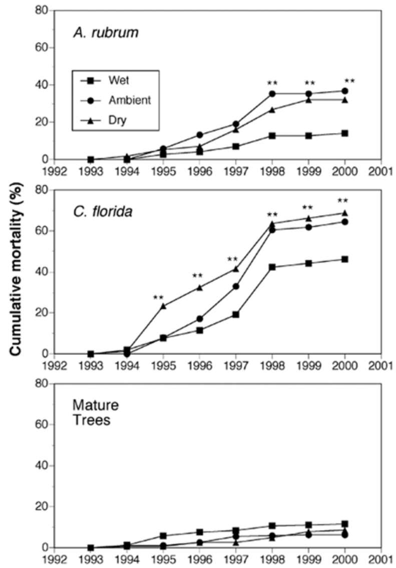


In Temperate Zones, Dry years are DRY so a reduction is observed in all Treatments

ESPM 111 Ecosystem Ecology

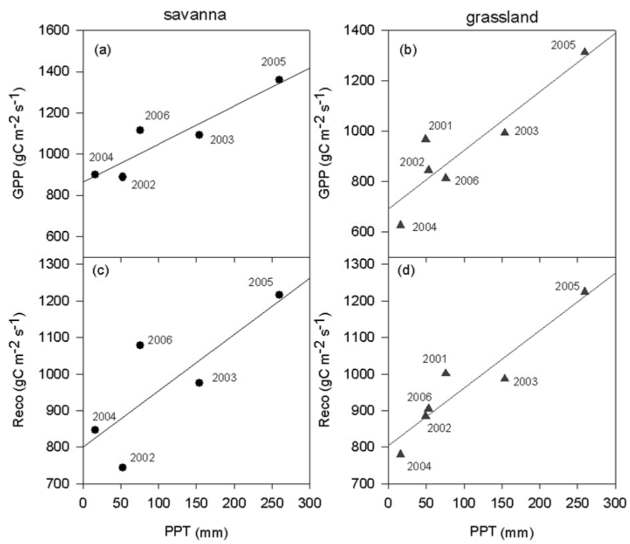
Rain manipulation studies in eastern deciduous forests have been difficult to maintain treatments; an example why I like natural experiments, natural gradients and work in California with our predictable and repeatable drought.

Mortality is Increased with Long-Term Rain Treatments



Hanson et al. ORNL

Carbon Fluxes of CA (Mediterranean) ecosystems respond best to rain during the Growing Season

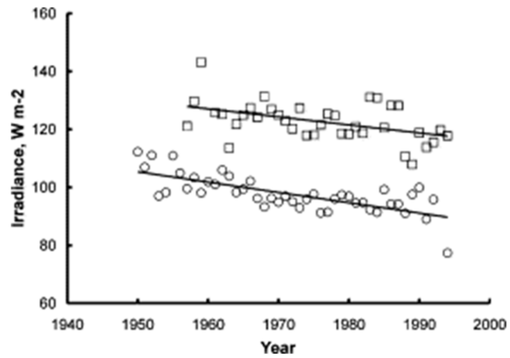


Ma et al. 2007 AgForest Met

ESPM 111 Ecosystem Ecology

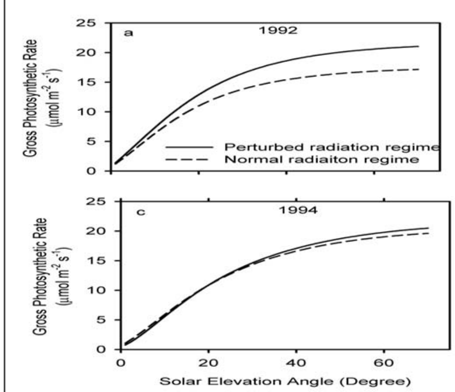
Here are data from our field sites in the Sierra foothills. We find that rain during the spring growing season best describes year to year changes in GPP and Reco

Pollution and Dimming of Solar Radiation



Stanhill and Cohen, 2001

Impact of Dust on GPP



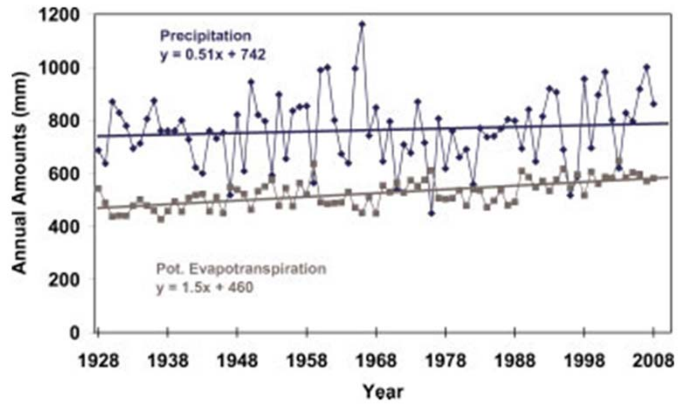
Gu et al., Science, 2003

Evaporation and Climate Change

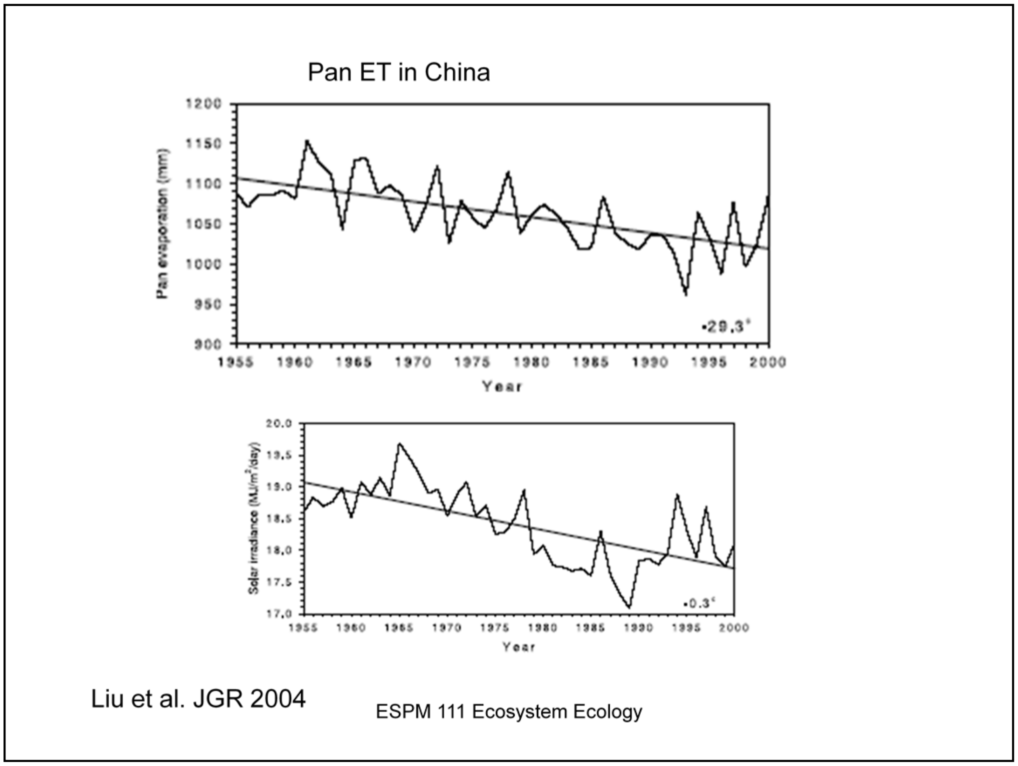
- In Principle, Global Warming Should
  – Accelerate and Water Cycle
  – Increase Evaporation
  – Increase Cloud Cover
  – Increase Precipitation
  – Reduce Solar Radiation
    - Negative feedback on Evaporation

80 year Trend in Evaporation

Wageningen, Netherlands



Jacobs et al 2009 Int J Climatology

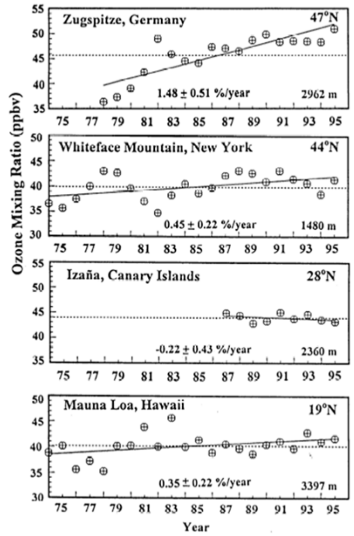


Pan evaporation may be decreasing. One would think that the hydrological cycle is accelerating and evaporation is increasing. But there is the pan paradox and actual and pan evaporation are complimentary.

Explanations

- Pan Evaporation paradox (Brusaert and Parlange, 1998)
  - Actual and pan evaporation exhibit complimentary behavior.
  - observation of decreased pan evaporation indicates that actual evaporation is increasing in semi-arid regions,
- global reduction in pan ET reflects the dimming of radiation due to aerosols
  - Roderick and Farquhar
  - Liu et al. JGR

Tropospheric Ozone Trends



Oltmans et al 1998 GRL

Ozone-CO_2 Interactions

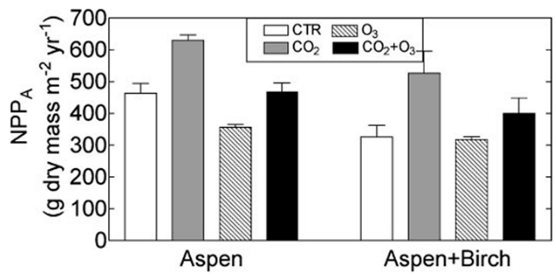


Figure 14 Comparison of NPP_A for mixed trembling aspen and birch trees grown in ambient or control atmospheric CO_2 concentration (CTR), enriched CO_2, elevated ozone, and ozone + enriched CO_2 FACE rings. (Data were generously provided by E. Kruger, University of Wisconsin.)

Gower, 2003, Ann Rev Environ Res

Ozone, N and forests

- Decreased visibility by sulphate particles
- Increased tropospheric Ozone
- Depletion of Cations in soil and mobilization of aluminum
- Tree dieback (spruce and maple, NE)
  - disruption of Ca nutrition and Al toxicity
  - Cold tolerance disrupted

Driscoll et al

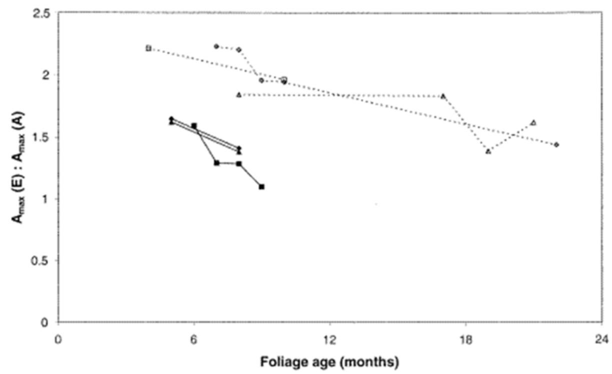
CO_2 Sink Saturation

CO2 fertilization on NPP	Sink
Nitrogen deposition fertilization on NPP	Sink
Air pollution effects on NPP	Reduced sink
T and ppt on NPP	Sink/reduced sink
T and ppt on Rhetero	source
Permafrost thawing	source
Shift in disturbance (fire, insects, disease)	Source/sink
Shift in vegetation	Sink/source
Afforestation/reforestation	sink
Forest regrowth, abandoned cropland	Sink/Reduced Sink with Age
Vegetation thickening and encroachment	Sink/Reduced Sink with Age
Soil erosion and burial	source./sink
Crop management	Source/sink
Deforestation	source
Peatland drainage	source

Canadell et al 2007 GTCE

Down Regulation of Photosynthesis:

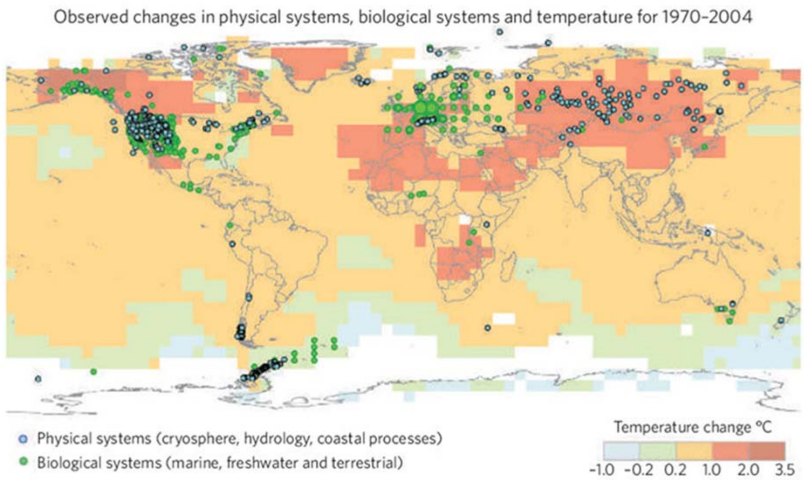
European Forests



Medlyn et al. 1999

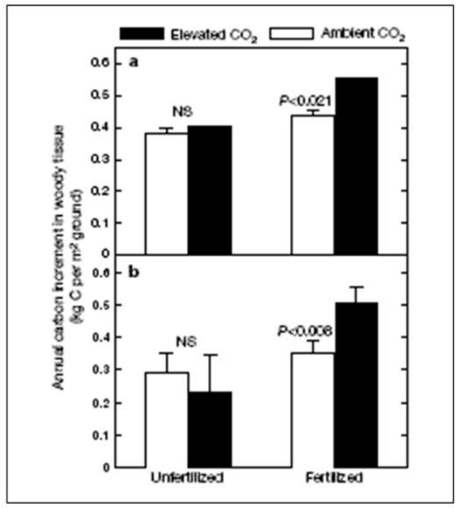
ESPM 111 Ecosystem Ecology

Norby


Observed changes in physical systems, biological systems and temperature for 1970–2004
Physical systems (cryosphere, hydrology, coastal processes)
Biological systems (marine, freshwater and terrestrial)
Temperature change °C
-1.0 -0.2 0.2 1.0 2.0 3.5

IPCC 2007

Soil Fertility Limits C sequestration at Duke Forest



Oren et al. 2001 Nature

ESPM 111 Ecosystem Ecology

CO_2 and N interactions

- Evidence from long-term field studies suggests that both progressive N limitation under *e*CO_2 and a significant interaction between CO_2 and plant available N supply that constrains NPP responses to *e*CO_2 are likely to be common, although not ubiquitous, in many natural and managed ecosystems.

- The combination of progressive N limitation and an interaction of CO_2 and plant available N supply will likely lead to smaller NPP enhancement under *e*CO2 than widely anticipated.

Reich et al. 2006 Ann Rev Ecol

Global Change and Ecosystem Issues

- Population Growth
- Climate Change
  - Rising CO2, Sea level rise, Global warming, changing ppt patterns (+/-)
- Stratospheric ozone depletion
  - uv effects, cancer, mutations
  - Good News, it is being Mended
- Land Use Change
  - Forest fires, biomass burning, conversion to agriculture
- Water Quality and Fresh Water Depletion
  - Ground water depletion, lake/sea depletion (e.g. Aral Sea)
- Air Pollution
  - Rising ozone and aerosols
    - Good News it is Improving
- Soils Degradation, Subsidence and Erosion
- Toxic chemicals and hazardous waste
- Loss of Biodiversity
- Nitrogen Loading on Ecosystems
  - Acid rain, eutrophication, hypoxia
- Marine Resources
  - Over-Fishing
    - Good News it is being Mended
  - Ocean Acidification and Coral Bleaching

CO_2 and Forest Photosynthesis

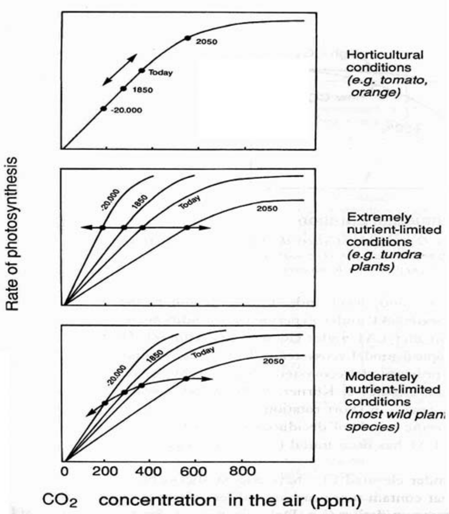
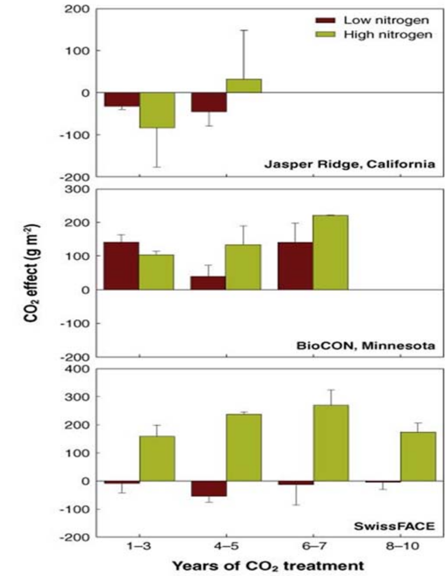


Figure 3.2 *Photosynthetic adjustment to changing CO_2 concentration: a multitude of possible long-term responses.*

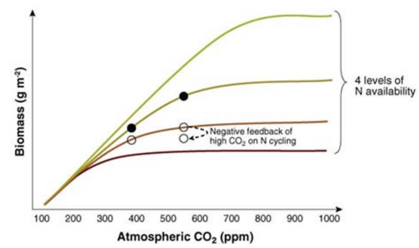
ESPM 111 Ecosystem Ecology

Korner, 1996

Effect of Duration of Study and N Load

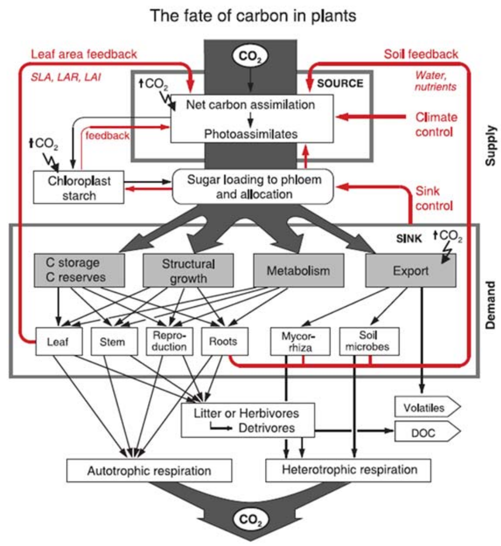


Reich PB, et al. 2006.
Annu. Rev. Ecol. Evol. Syst. 37:611–36

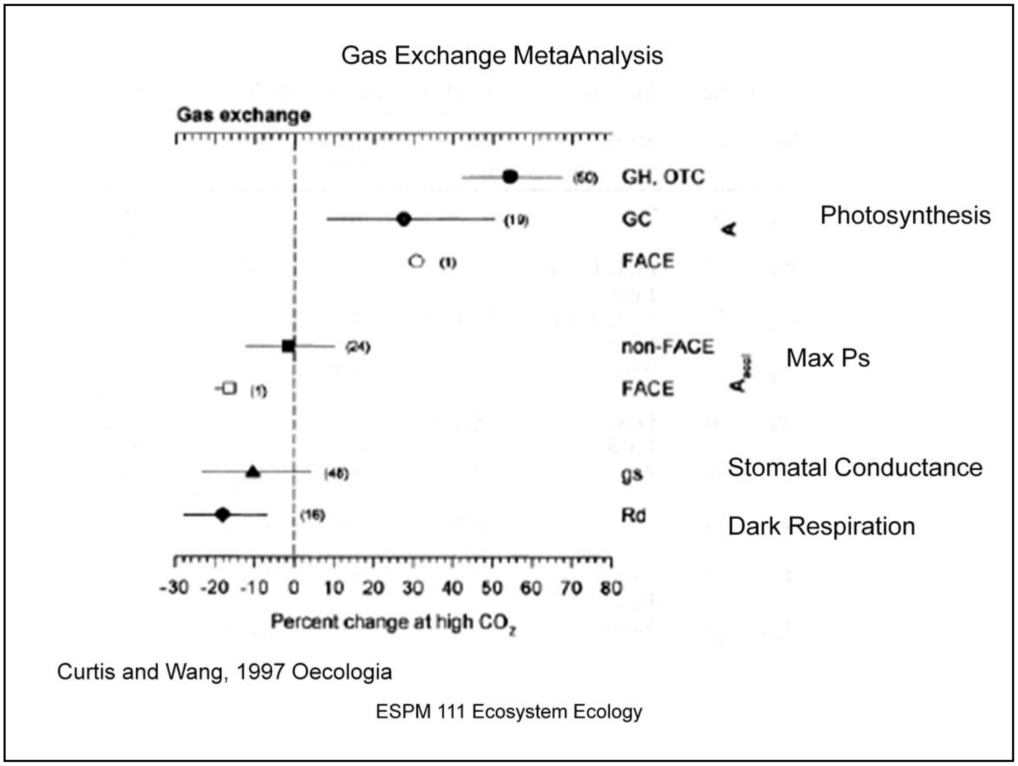


Reich PB, et al. 2006.
Annu. Rev. Ecol. Evol. Syst. 37:611–36

But ‘Everything is Connected’, W. Silver

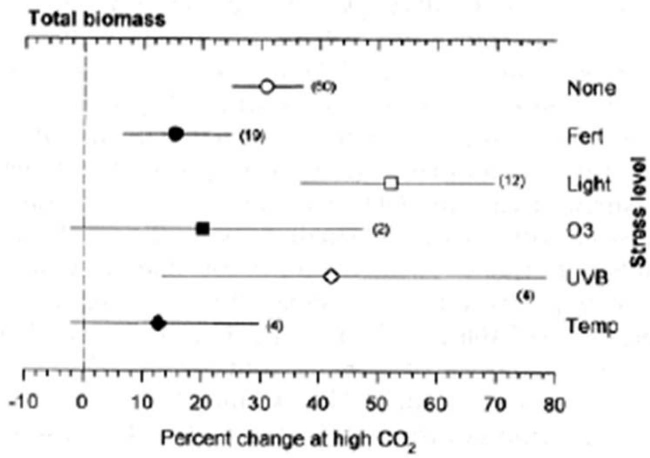


Korner, 2006 New Phytologist



Curtis meta analysis

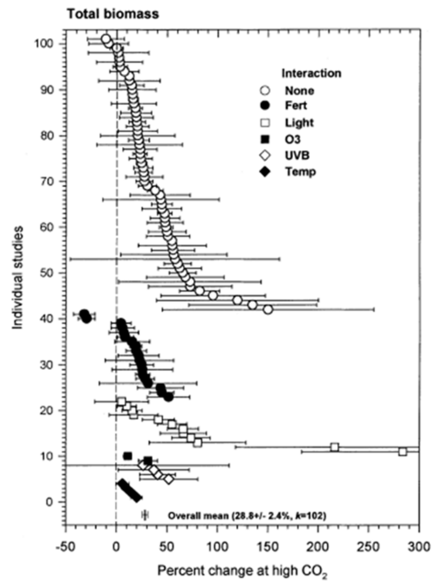
Biomass Meta Analysis



Curtis and Wang, 1997 Oecologia

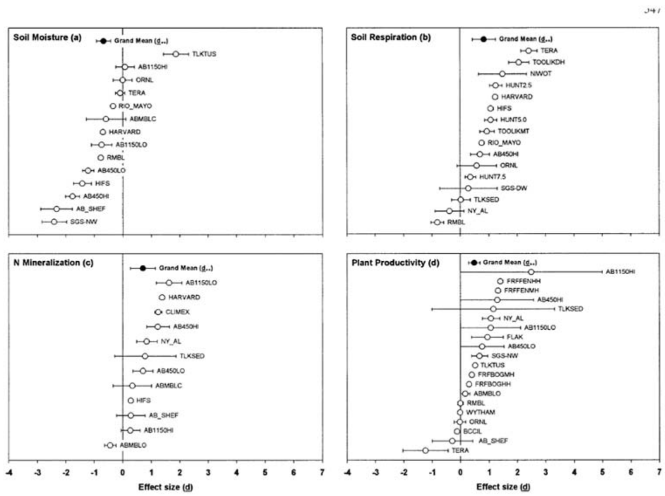
Curtis Meta analysis

MetaData Analysis



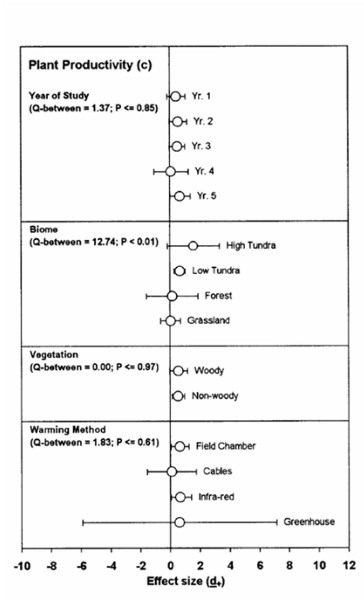
Curtis and Wang, 1997 Oecologia

- Meta Analysis of Warming Studies



$$d = \frac{\overline{X_{\exp t}} - \overline{X_{control}}}{std\ dev}$$

Rustad et al 2001, Oecologia Warming Meta analysis



Rustad et al 2001, Warming Meta analysis

ESPM 111 Ecosystem Ecology

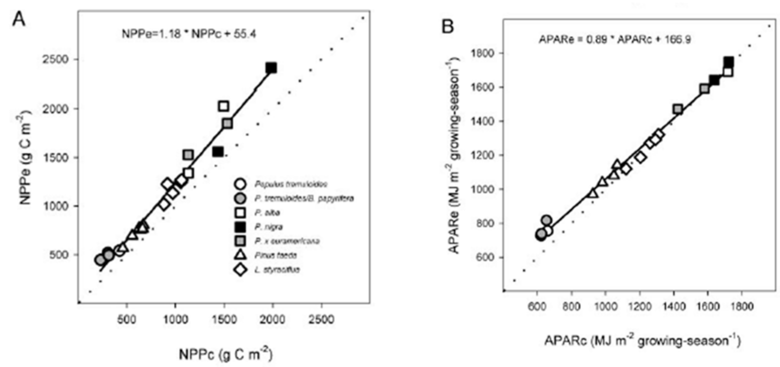
Meta Analysis

- Synthesis of
  - Treatments
  - Methods
  - Plant Functional Types
  - Physiological Processes
  - Duration

Summary of CO_2 MetaAnalysis

- Photosynthesis
  - +50% greenhouse, open-top chamber
  - +20-30%: FACE, growth chamber
- Stomatal Conductance
  - -10%
- Biomass
  - +28%

Forest Response to Elevated CO2 is Conserved over Range of NPP



Norby et al. 2006 PNAS