Anthropocene:
Biosphere and Environmental Change

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The Anthropocene is a new term coined to represent the phase of the Holocene, the most recent geological epoch, that reflects the impact of humans on earth and their impact on the climate, surface and atmosphere.

There is more to the biosphere response to environmental change than a warmer world. Also changing are such factors as CO2, nitrogen loading, land use change, biodiversity, etc

# Outline

- Background
- Global Change and:
- CO2
- Warming
- Precipitation
- Ozone and Air Pollution
- Nitrogen
- Land Use Change
- Biodiversity



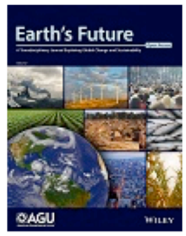
Here are the key topics we will cover today

## Anthropocene Era
(Overarching findings)

- Tenfold change in Human Growth, to near 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 1/2 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.

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

**Resources:**
**Journals and International Programs**


GLOBAL IGBP CHANGE International Geosphere-Biosphere Programme

http://www.igbp.net/

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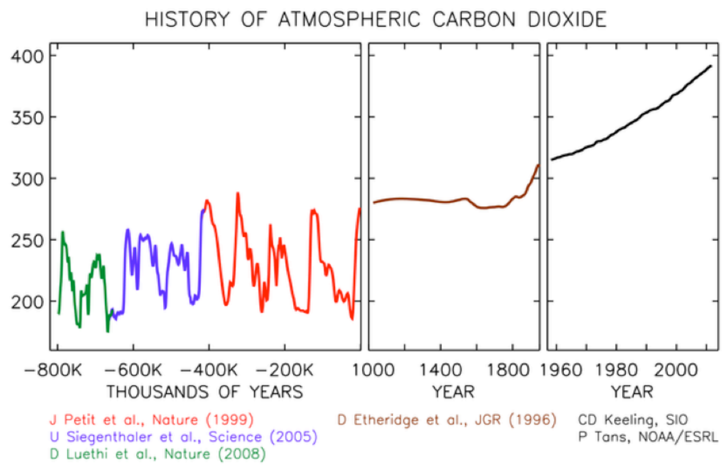
Key journals include Global Change Biology and a new journal on the Earth's Future. International programs linked to the International Geosphere-Biosphere Program are vast repositories of reports and meetings.

When Did the Anthropocene Start?
Conventional Wisdom:
Late 1700s, Dawn of the Industrial Revolution




Courtesy of Pieter Tans, NOAA

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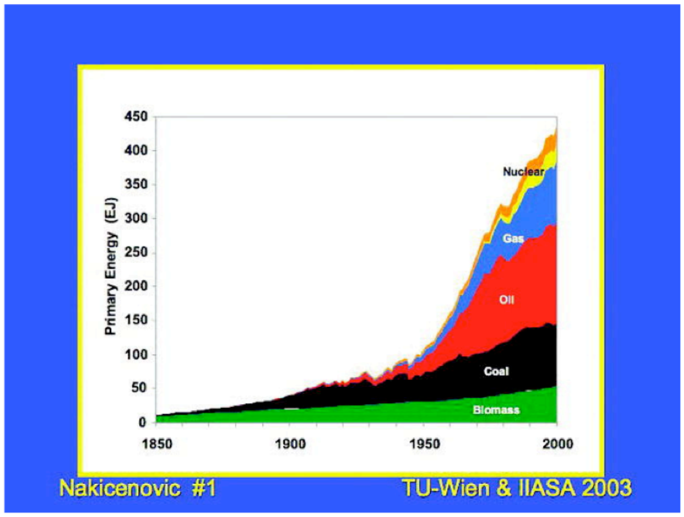
This figure re-emphasizes the dramatic change in the $CO_2$ concentrations before the development of civilization, changes after civilization and the industrial revolution until today's hyper fossil fuel hungry world. It is information like this that helps us define the start of the Anthropocene. According to this figure there is a prominent bump in $CO_2$ at about 1800, when there was great growth in industrialization, advent of the steam engine, etc

## Why Did the Anthropocene Start?




Steffen et al 2008 Ambio

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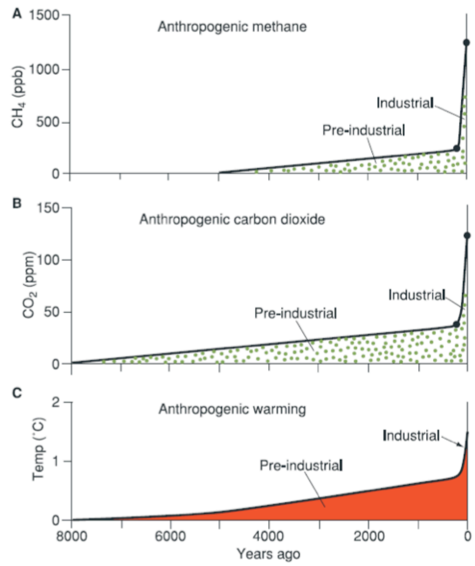
Some argue the Anthropocene may have started at the dawn of industrialization, after 1800. Independent of data on CO2 increase in the atmosphere we can look at data on energy consumption,its growth and dependence on fossil fuels. Clearly dependence on coal exploded after 1850. Dependence on oil started in 1900 with the age of the automobile. Transport networks for gas started after WWII, as does nuclear energy.

## When Did the Anthropocene Start?

Alternate Hypothesis: Dawn of Civilization




William Ruddiman
2007 Rev Geophysics

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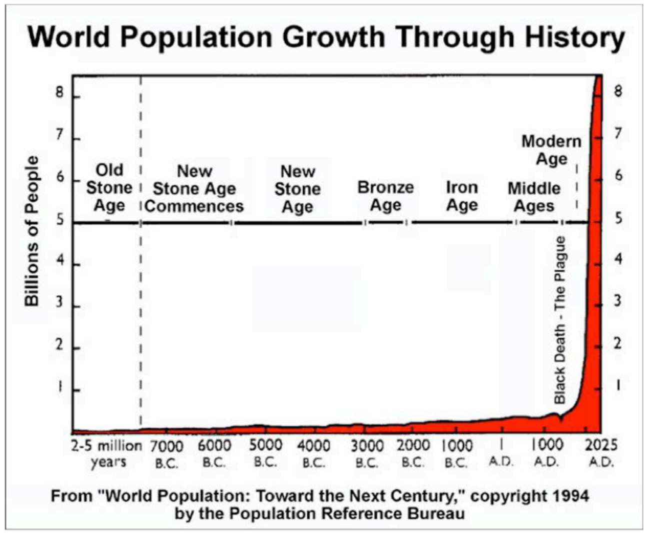
William Ruddiman advances the idea that the Anthropocene started at the dawn of agriculture as there is a signal of increasing methane from wide spread rice production in Asia and an increase in CO2 from deforestation in Europe to support expanding agriculture

Critique:
Were there Enough People to Make a Dent?
Ice Core Record indicates the next Ice Age is >10000 years into the future

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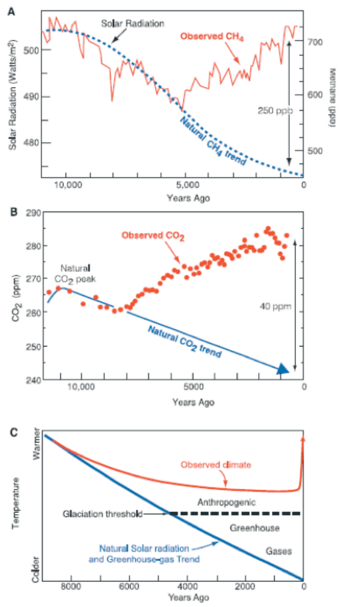
The big question is how well did the early populations of humans change the C balance of the atmosphere through deforestation and plowing lands in the 5000 years prior to 0 AD? Ruddiman's hypothesis remains contentious, with data and arguments supporting parts and refuting parts.

One argument is whether there were enough people, living in a fairly pristine world to alter the composition of the atmosphere to a great enough degree.

Arguments For and Against an Early Anthropocene




Rice Cultivation in Asia
Increased Methane Production

Deforestation increased CO2,
but it only accounts for 25% of
CO2 released

The inferred Decline in Solar Radiation
and lack of change in 13C are
Points made by Geologists,

Ruddiman, 2007 Rev Geophysics

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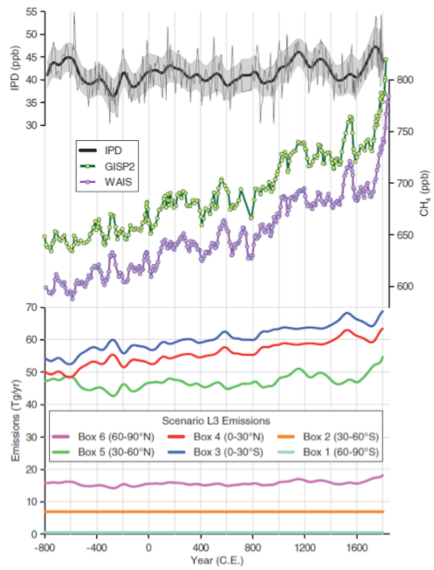
Ruddiman argues that the orbital mechanics would have caused a decline in solar radiation and advance the next ice age, which did not occur due to the increases in CH4 and CO2. He claims growing rice cultivation in Asia was responsible for much of the rise in methane. His claims of extensive deforestation seem not to release enough carbon dioxide as he claims. Geologists also argue that this rise in methane and carbon dioxide did not reverse an imminent ice age because it should be about 16000 years into the future based on analogs from past ice core records.And Wally Broecker criticizes Ruddiman's hypothesis because the record shows that the stable isotope 13C did not change. If there were massive emissions of CO2 in to the atmosphere from deforestation the delta 13C record would be more negative; Broecker aruges convincingly that the dip in the CO2 record about 8000 years ago reflects the regrowth of forests following the last glaciation.

New Evidence that Rice Ag may have increased Methane 2800 years ago

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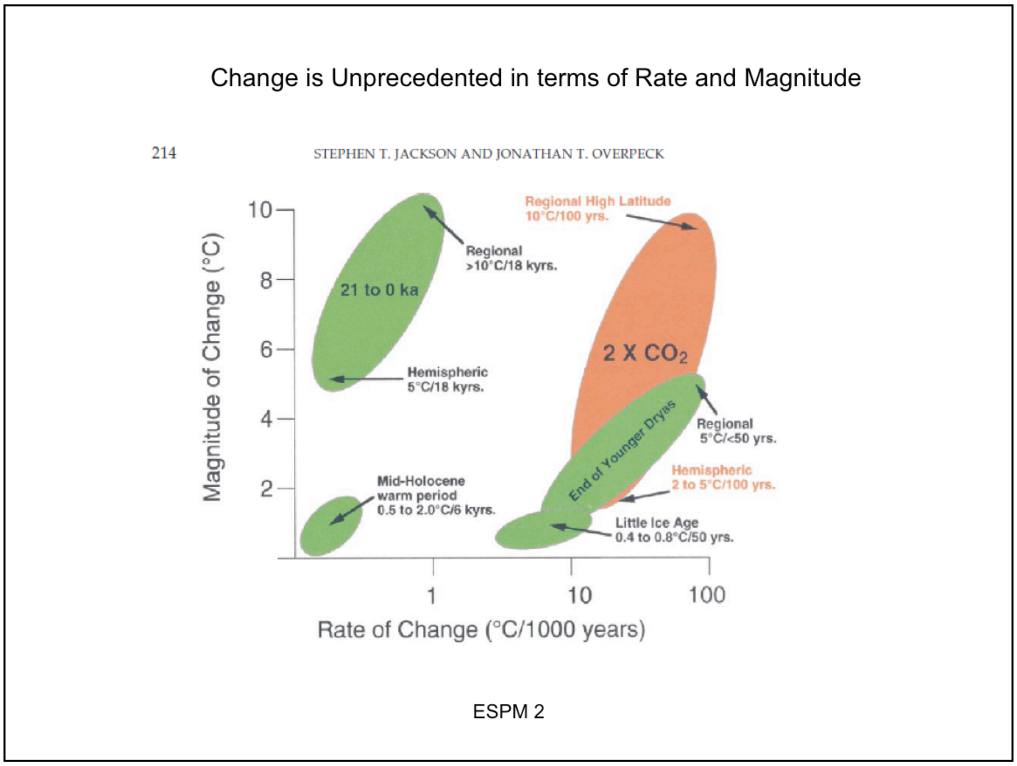
New data in Science, 2013 by Mitchell et al looked at methane in ice cores in the northern and southern hemispheres. Since most people and early rice ag would have been in Asia in the north, one would expect methane to be greater there. Indeed this is what they find.




Whether the Anthropocene started 8000 or 200 years ago, may be beside the point of the current conditions we face today and how we will respond to them.

We are concerned about environmental change due to its rate of change and magnitude, both are unprecedented in the geological record over which our species and our inter-dependent biosphere have evolved.  So with rapid change, surprises are and can be expected. Remember the Earth System is a complex system.  It is robust for small perturbations but is vulnerable to regime shifts with large and persistent perturbations.  Since more and more people rely on the services of the biosphere, we should invoke the ‘precautionary principle’, like the Hippocratic Oath given to medical doctors to ‘do no harm’.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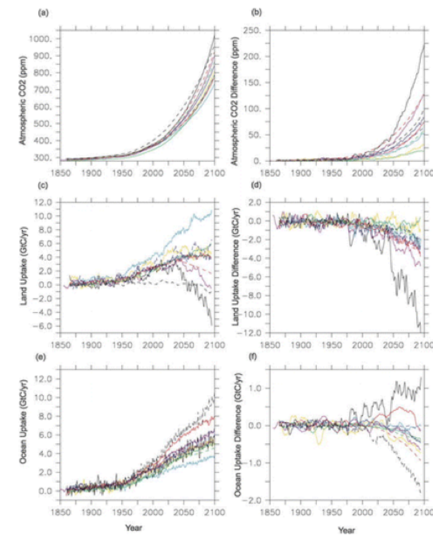
In this section we will discuss how ecosystems respond to changing $CO_2$



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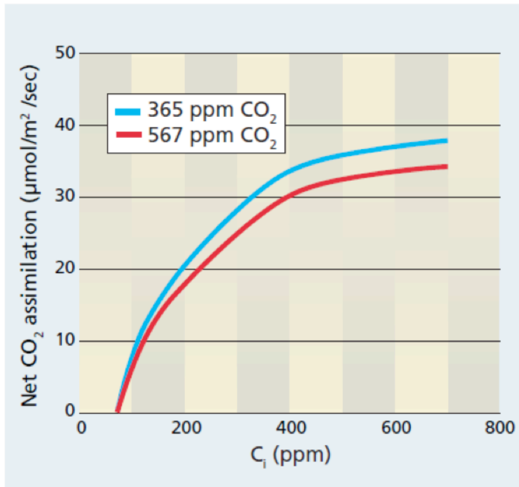
There are major uncertainties in feedbacks with carbon cycle and climate.
Friedlingstein et al 2006 J Climate


Abstract

Eleven coupled climate–carbon cycle models used a common protocol to study the coupling between climate change and the carbon cycle. The models were forced by historical emissions and the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) A2 anthropogenic emissions of $CO_2$ for the 1850–2100 time period. For each model, two simulations were performed in order to isolate the impact of climate change on the land and ocean carbon cycle, and therefore the climate feedback on the atmospheric $CO_2$ concentration growth rate. There was unanimous agreement among the models that future climate change will reduce the efficiency of the earth system to absorb the anthropogenic carbon perturbation. A larger fraction of anthropogenic $CO_2$ will stay airborne if climate change is accounted for. By the end of the twenty-first century, this additional $CO_2$ varied between 20 and 200 ppm for the two extreme models, the majority of the models lying between 50 and 100 ppm. The higher $CO_2$ levels led to an additional climate warming ranging between 0.1° and 1.5°C.

All models simulated a negative sensitivity for both the land and the ocean carbon cycle to future climate. However, there was still a large uncertainty on the

While Photosynthesis Increases with CO2




Down-Regulation of Photosynthesis Occurs, based on $CO_2$ Growth Environment

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

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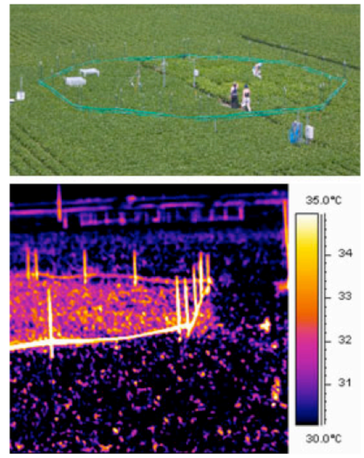
Yet studies show the response of leaf photosynthesis to elevated CO2 is plastic and depends upon the conditions to which the plant was grown. Plants grown in elevated CO2 experience an Down Regulation in their photosynthetic response to changing CO2.

At former student gave me a good analogy for down regulation. Think about making cookies with 100 g of flour and 10 grams of sugar. This is case 1, where flour is like CO2 and sugar is like nitrogen. now try and make cookies with 200 g of flour and 10 g of sugar. You will make more cookies but they wont be as good and tastey and you may even sell fewer because the quality is lower. This is an analogy to plants in a high co2 world.

## Free-Air $CO_2$ Enrichment Studies

Duke Forest

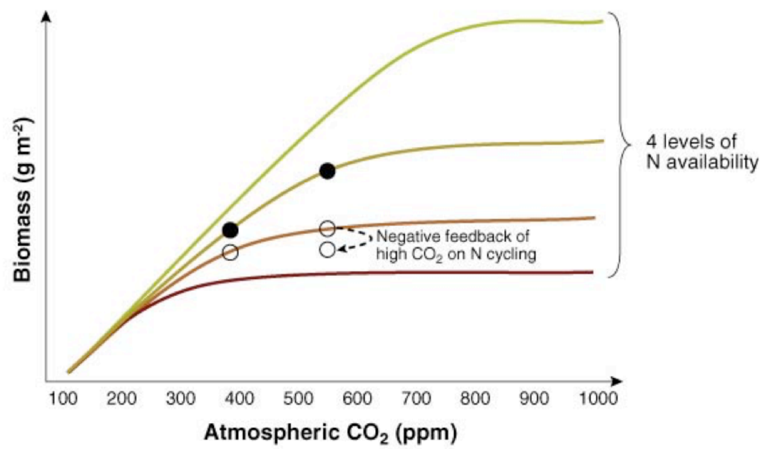



Soybeans, Illinois



Early studies were done in pots or enclosed chambers. These manipulations caused artifacts like binding the roots, heating the air, changing the light quality and short-circuiting the long term nutrient feedbacks on growth and CO2 response. By the 1990s, FACE, Free-Air CO2 enrichment studies were developed. These studies fumigated a region of a plant canopy with high levels of CO2 depending on wind direction and wind speed.

The Response of Biomass to Changing CO2 depends on Nutrient Status




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

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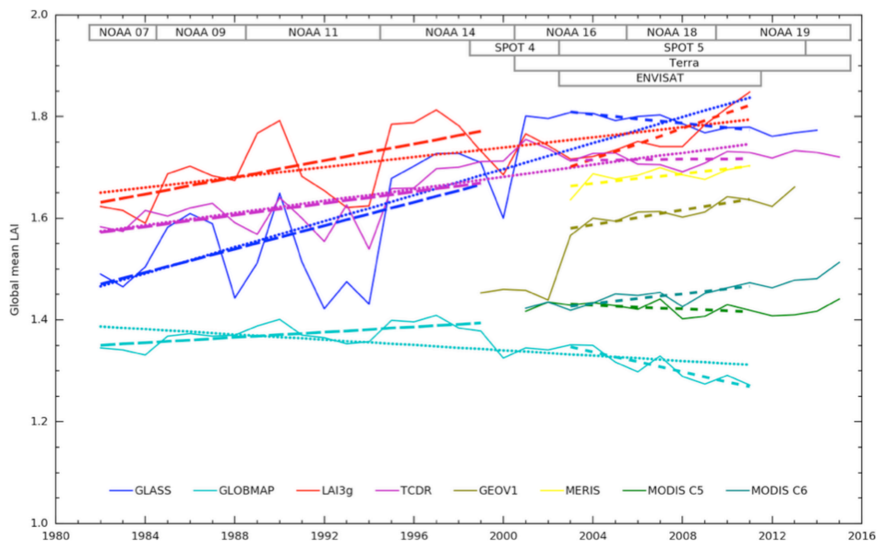
The response to elevated CO2 depends upon nitrogen levels. At low N, a 50% change in CO2 may have a small effect on biomass and it may force a negative feedback by sequestering precious N into the increment of biomass.

**Inconsistencies of interannual variability and trends in long-term satellite leaf area index products**




**Global Change Biology**
6 JUL 2017 DOI: 10.1111/gcb.13787
http://onlinelibrary.wiley.com/doi/10.1111/gcb.13787/full#gcb13787-fig-0001

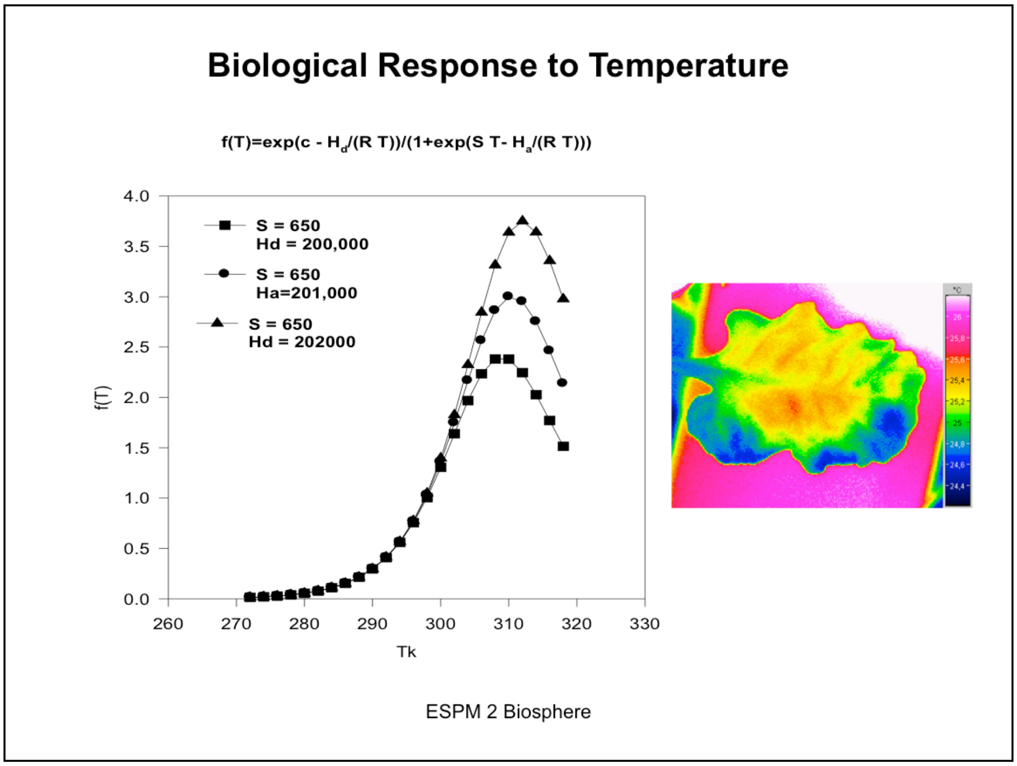
Global mean LAI (solid curves) and linear trends during 1982–2011 (dotted lines), 1982–1999 (long dashed lines), and 2003–2011 (short dashed lines) for different LAI products. Trend values are listed in Table . Lifespans of different satellite platforms are also illustrated

## 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
  - InDirect Effect and Positive Feedback
    - Elevated Leaf Temperature, augments Transpiration
- Greater Growth and Leaf Area
  - Bigger plants grow faster. +
  - Bigger plants transpire more
  - Soil moisture pool depleted faster: -
- Herbivore Interactions
  - Insects eat more foliage to compensate for lower N quality of leaves

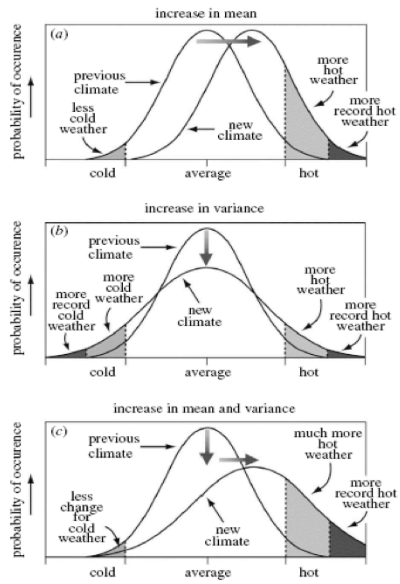
# Elevated $CO_2$:
# Direct and Indirect Effects

- 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




Biology responses to temperature in a non-linear manner. The response is exponential in the range between 0 and 30C. At higher temperatures, enzyme denaturation can occur, which leads to an inhibition and decline of temperature dependent functions

Mean Temperature is not the only relevant biological temperature




Porter and Semenov

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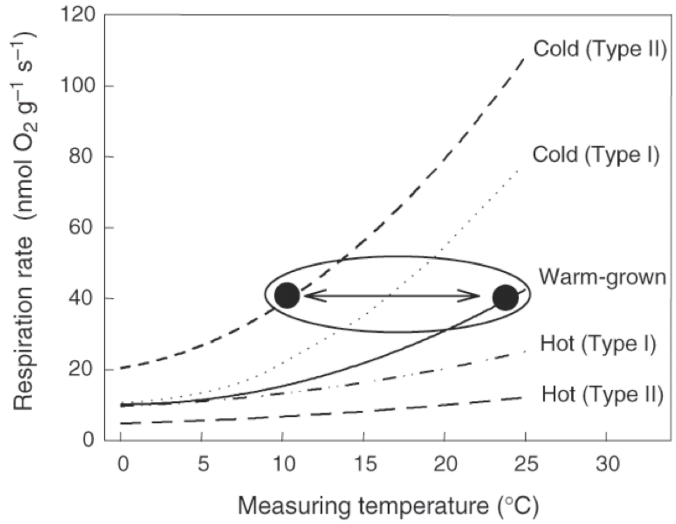
There are many biologically relevant temperatures and knowing the projections and distributions of these temperatures is critical towards understanding how biological systems will respond to warming per se. It gets back to the conditional response of the non-linear function. A warming from 20 to 30 C may have a negligible change on the previous function. An increase from 10 to 20 C, may double rates, and an increase from 30 to 40 may halve rates.

Figure from Porter and Semenov 2005 Phil Trans Roy Soc, B

Respiration Acclimation with Temperature




Atkin et al 2005 Functional Plant Biology

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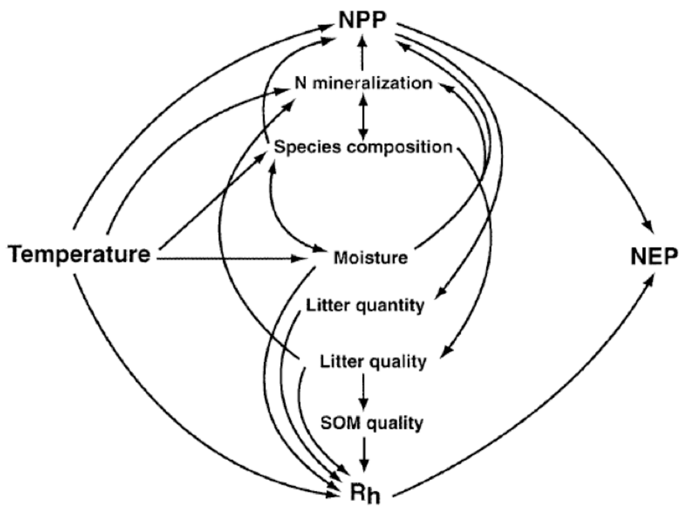
Temperature responses of metabolic processes, like respiration, can be plastic. The can yield acclimation responses. The curve is steeper for cold adapted plants than for warm adapted plants. Atkin et al 2005 Functional Plant Biol

Many Coupled Feedbacks with Warming




Shaver et al 2000 Bioscience

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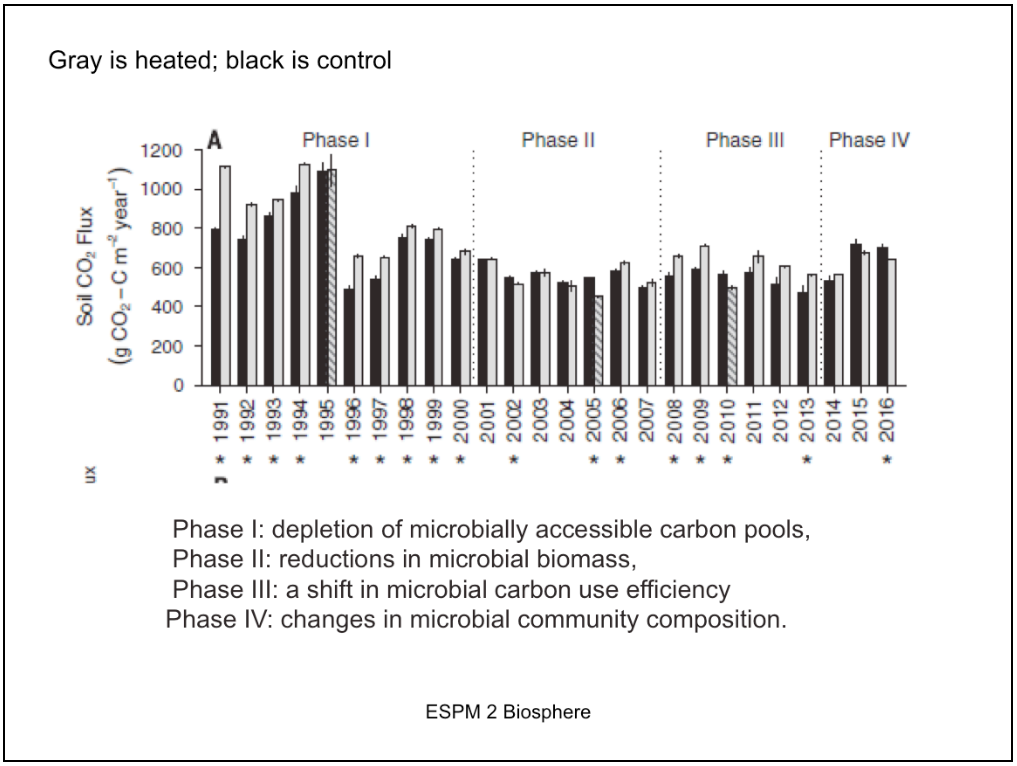
Warmer temperatures turn the wheel of the biogeochemical cycles faster, up to a point. Warmer temperatures can enhance decomposition and photosynthesis, releasing nutrients through mineralization that act as positive feedbacks. But warmer temperatures can evaporate water more, which can inhibit decomposition and the release of nutrients




Melillo Science 2017. Control is black bar, grey heated

In a 26-year soil warming experiment in a mid-latitude hardwood forest, we documented changes in soil carbon cycling to investigate the potential consequences for the climate system.

We found that soil warming results in a four-phase pattern of soil organic matter

decay and carbon dioxide fluxes to the atmosphere, with phases of substantial soil carbon loss alternating with phases of no detectable loss. Several factors combine to affect the timing, magnitude, and thermal acclimation of soil carbon loss. These include depletion of

microbially accessible carbon pools, reductions in microbial biomass, a shift in microbial

carbon use efficiency, and changes in microbial community composition. Our results support

projections of a long-term, self-reinforcing carbon feedback from mid-latitude forests to the

climate system as the world warms.

# Precipitation

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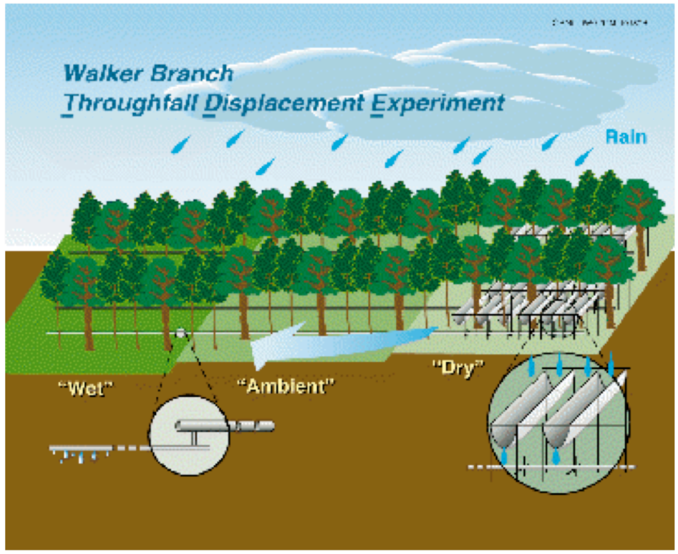
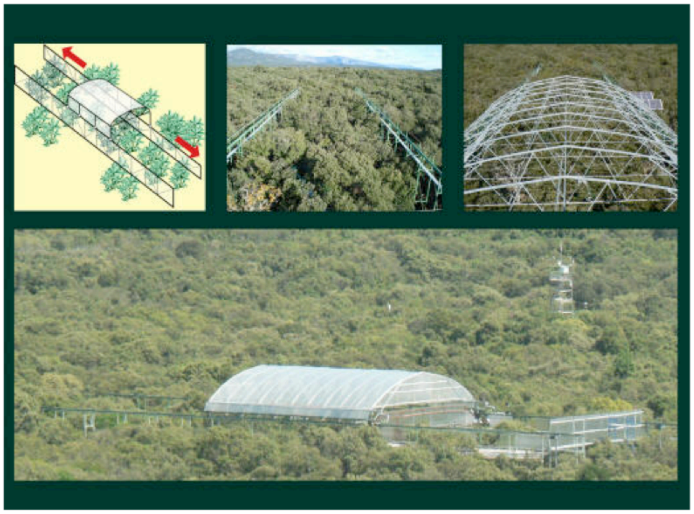
## Rainfall Manipulation Experiments






In Oak Ridge, troughs were put under the forest to collect throughfall. This water was then moved to another portion of the forest and used to irrigate it. This approach gave the experiment an ambient, wet and dry treatment

Rain Exclusion System



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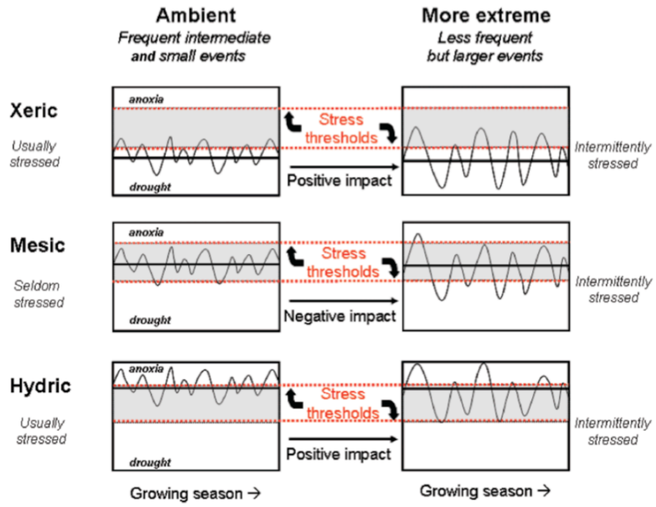
In France, they developed a movable rain shelter that would cover a portion of the oak forest before ensuing rains.

It also Depends on Rainfall Frequency, Intensity and Ecosystem




Knapp et al 2008 Bioscience

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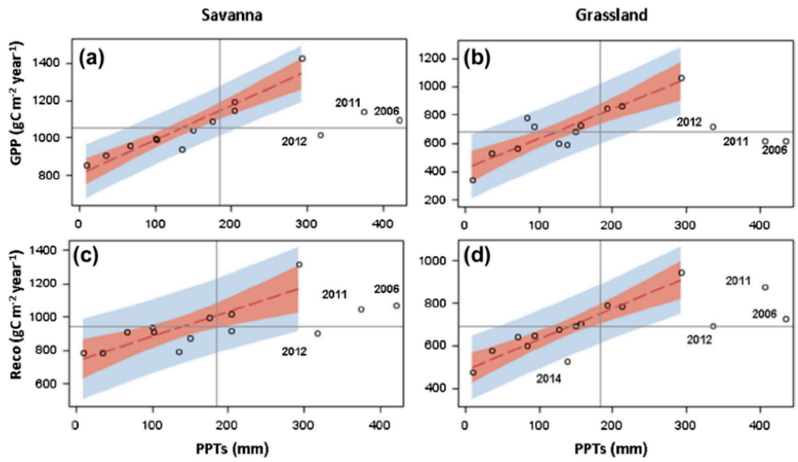
The response to more or less rain is very complicated, non-linear and dependent on antecedent conditions. How an ecosystem response to precipitation depends on when it rains, how much it rains, and how often it rains. Many small but frequent rains may keep the soil profile wet and alleviate physiological stress. Infrequent but large rain events cause a feast and famine approach. While the numerical sum of rain may be indeed great, long periods of low rainfall can induce physiological stress.

A warmer world may be wetter, but rains may be more intense and less frequent in mesic systems

Ecosystem Metabolism Depends on Spring Rain




Ma et al 2016 AgForMet

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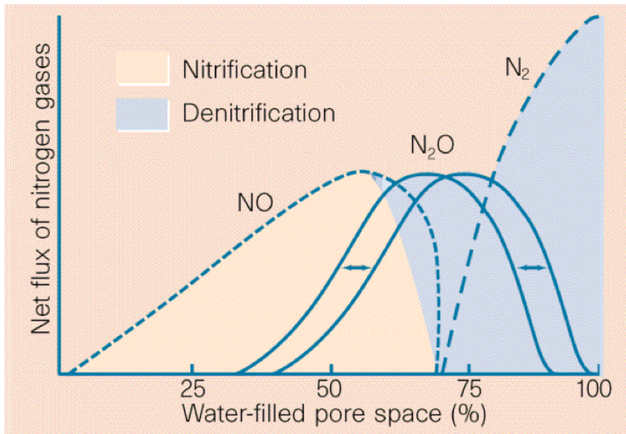
We study how ecosystems respond to rain using natural experiments in highly variable environments like the Mediterranean climate of Europe and California. My group, and confirmed by colleagues in France and Portugal, find that annual sums of ecosystem photosynthesis and respiration are tightly coupled not with annual rainfall but with rainfall during the active growing season in spring. So one has to be careful relating annual sums of precipitation with biological and ecological processes. Surplus rain in the winter may run off and not be available to summer growth and productivity.

Nitrogen Losses and Soil Moisture

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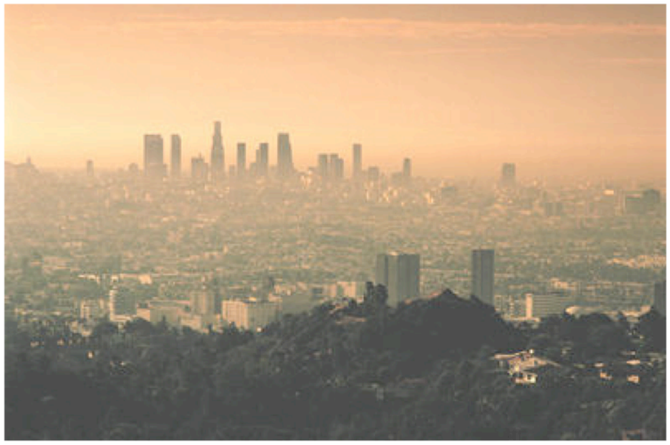
Losses of various nitrogen compounds are highly non-linear with soil moisture, too. Too little or too much moisture can have inhibition effects

# Effects of Drought

- Short-Term
  - Physiological Stress (stomatal closure, reduction in photosynthesis and transpiration
  - Soil Water Deficits inhibit Microbial processes like decomposition and respiration
- Long-Term
  - Reduction in Growth, Hydraulic Cavitation, Mortality, Change in Community Composition and Dynamics, Predisposition to Disease and Pests

## Ozone and Air Pollution



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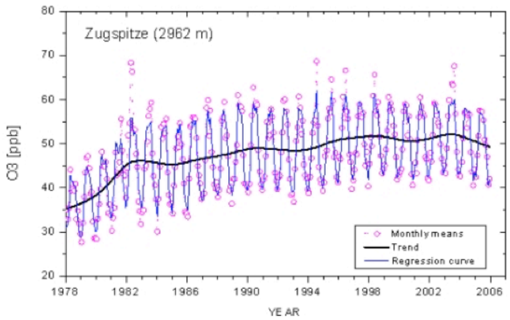
We live in a world bathed in ozone, produced by photochemical processes between nitrogen oxides, NOx, and volatile organic carbon compounds, VOcs. Ozone is phytotoxic, so it is bound to have effects on the underlying biosphere

# Ozone, Past and Present

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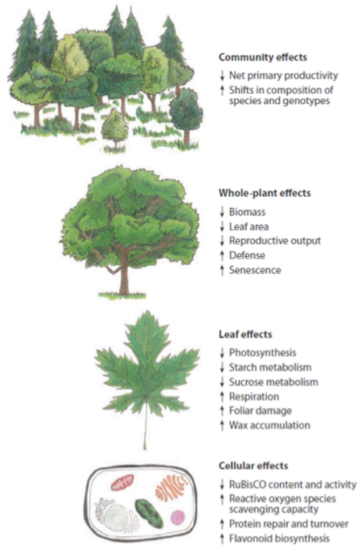
Ozone levels have risen, even in pristine areas like Zugspitze in Germany at nearly 3000 m.

## Effects of Elevated Ozone on Life




Ainsworth et al 2012 Ann Rev Plant Biology

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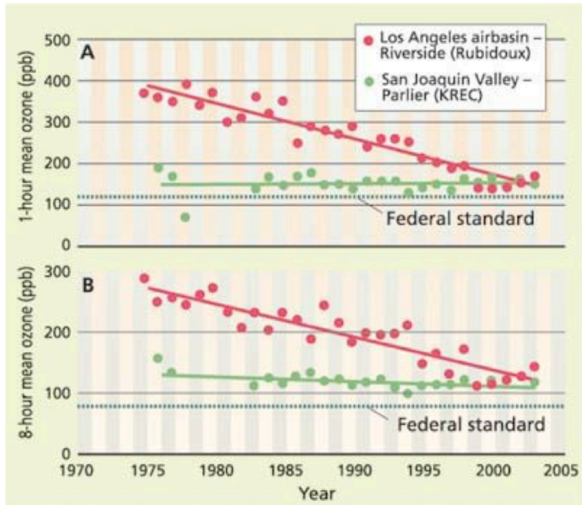
Ozone has deleterious effects on plants that start at the cellular level and are manifested at the leaf, plant and community levels. Ozone causes damage which increases the cost of protein repair and turnover

Ozone in California




Grantz and Shrestha 2005 Cal Ag

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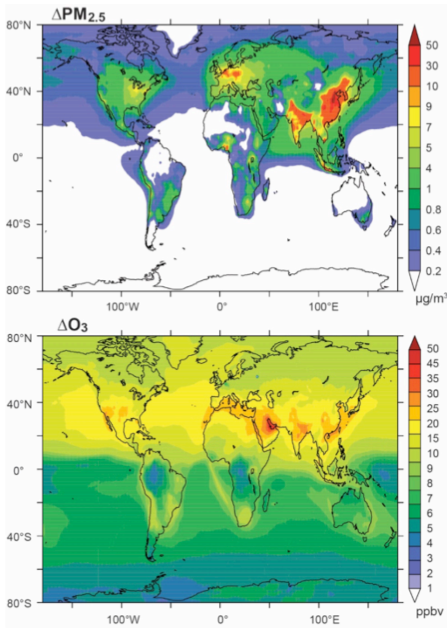
Ozone in California far exceeded federal standards, and air quality is improving, especially in soCal. Ozone remains high in the ag valley and can lead to crop losses on the order of 5 to 30%. Considering agriculture is a multi-billion dollar industry and many crops are only produced in California the impact is especially noteworthy.

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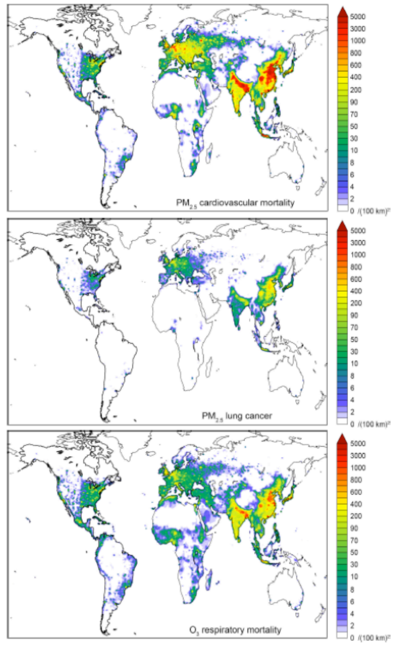
Lelieveld et al 2013 ACP

Mortality with Air Pollution

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Lelieveld et al 2013 ACP

# Ozone-$CO_2$ Interactions

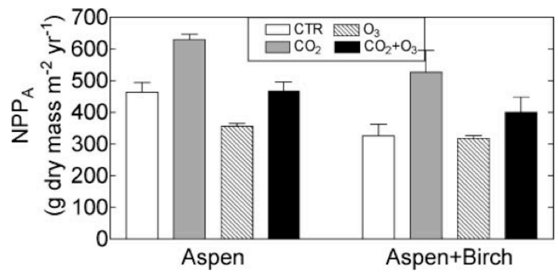


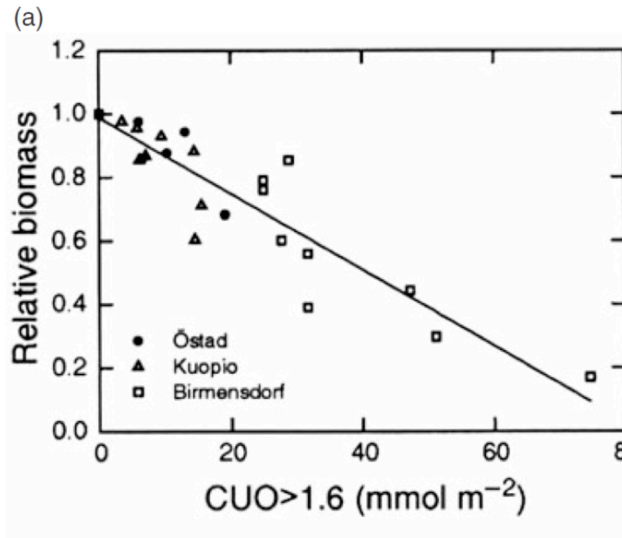

**Figure 14** Comparison of $NPP_A$ for mixed trembling aspen and birch trees grown in ambient or control atmospheric $CO_2$ concentration (CTR), enriched $CO_2$, elevated ozone, and ozone + enriched $CO_2$ FACE rings. (Data were generously provided by E. Kruger, University of Wisconsin.)

Gower, 2003, Ann Rev Environ Res



Elevated CO2 closes the stomata, so the combined effect of high CO2 and ozone is less than the negative effect of ozone alone. This stresses that we need to assess the cumulative uptake of ozone to a plant, not just its exposure

Ozone Damage Depends on the Flux to the Leaf,
the Cumulative Uptake of Ozone (CUO), not Dose-Exposure




Ashmore, 2005 PCE

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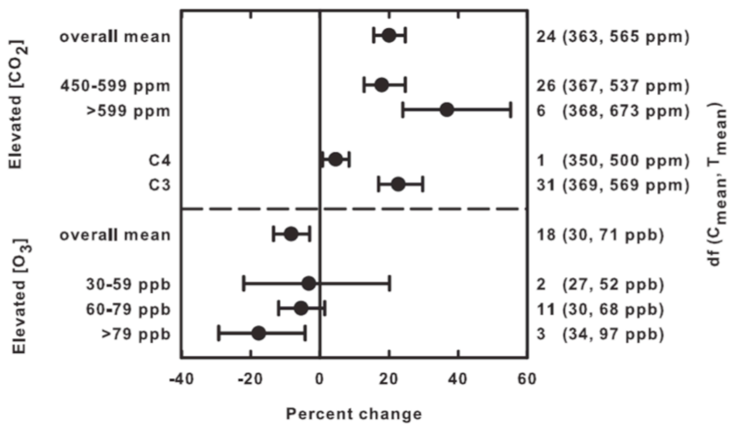
Many of the early studies on ozone damage were based on exposure, hours of ozone at some level. But ozone uptake is mediated through the stomata. If the stomata are closed the plant will not take up ozone, even if the exposure is high. In recent years, practitioners have started to appreciate the flux effect on ozone response to plants. Key point of this figure is how data from many independent studies become aligned when the effects are measured in terms of cumulative ozone uptake.

8% reduction in Energy Conversion Efficiency of Yield due to elevated O3




Slattery et al 2012 J Expt Botany

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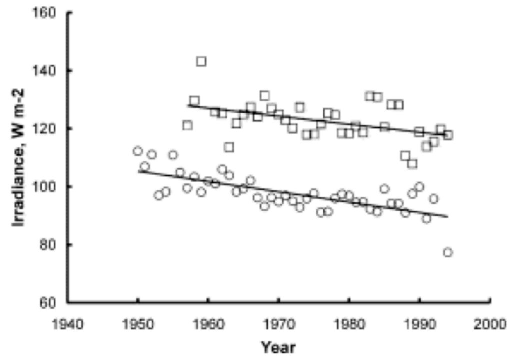
Meta analysis is a way of distilling data from a large number of diverse publications. This paper by Slattery et al finds ozone to have an 8% negative effect on the energy conversion efficiency of producing crop yield. The effects are greater with higher ozone levels.

Air Pollution and Dimming of Solar Radiation




Stanhill and Cohen, 2001, AgForMet

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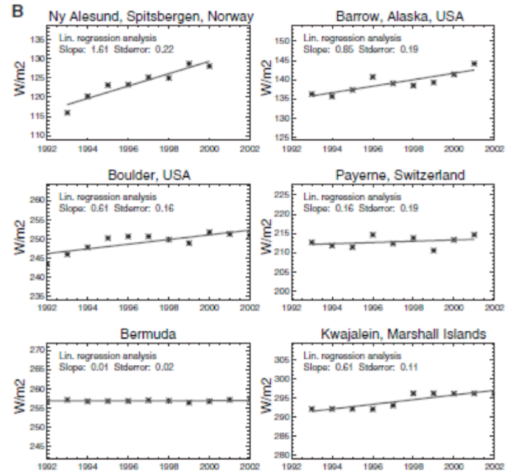
Through the 1950s and 2000 there was noticeable dimming of the sky due to air pollution

As We started to Mitigate Air Pollution in the 1990s,
Global Dimming is Reversing at Many Locales




Unintended Consequence---Contribute to Global Warming

Wild et al 2005 Science

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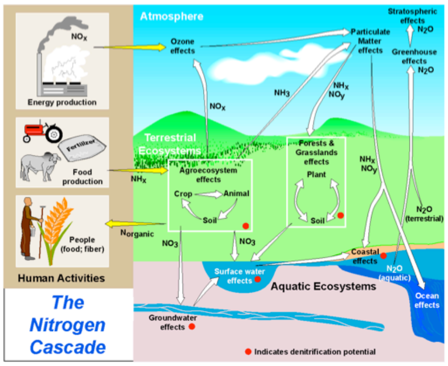
As we have started to mitigate air pollution, global dimming is reversing at many locales.  The unintended consequences is that dimming helped to minimize global warming, while the reverse in global dimming is putting more solar energy back to the landscape.

# Nitrogen Cascade




Nitrogen Cascade Mark Sutton

Nitrogen Cascade is associated with Energy and Food Production

It has Deleterious effects on Air, Water Bodies and Ecosystems , while a positive effect on food production

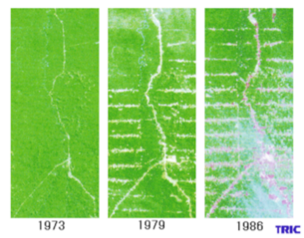
Human Related N Sources:
•Fossil Fuel Combustion: NOx
•Fertilization: $NH_3$, NOx, $N_2O$

Natural N Sources
•Lightning: NO
•Legumes and Rhizobium

# Land Use Change

# Disturbance and Land Use Change

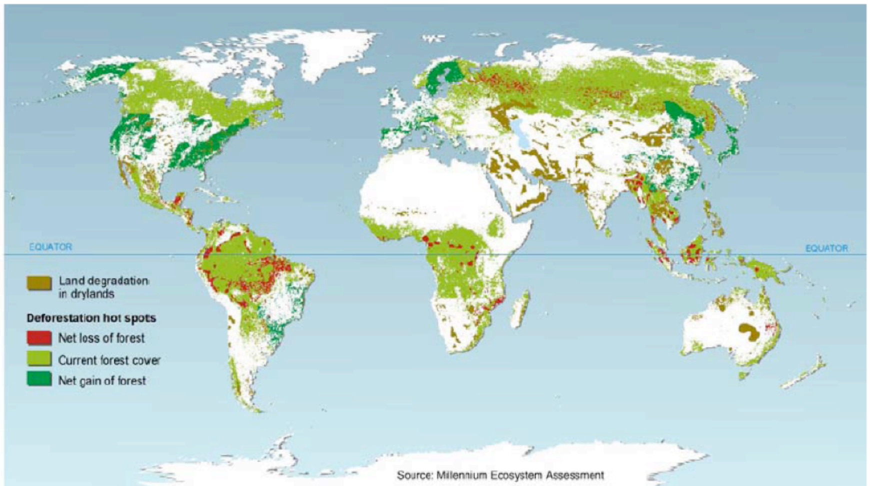
- Fires
- Deforestation/Logging
- Urbanization
- Desertification
- Woody Encroachment
- Afforestation/Reforestation
- Storms
- Invasive Species
- Soil Degradation




ESPM 111 Ecosystem Ecology

Humans are changing land use in many ways, directly and indirectly, positively and negatively

## Land Use Change

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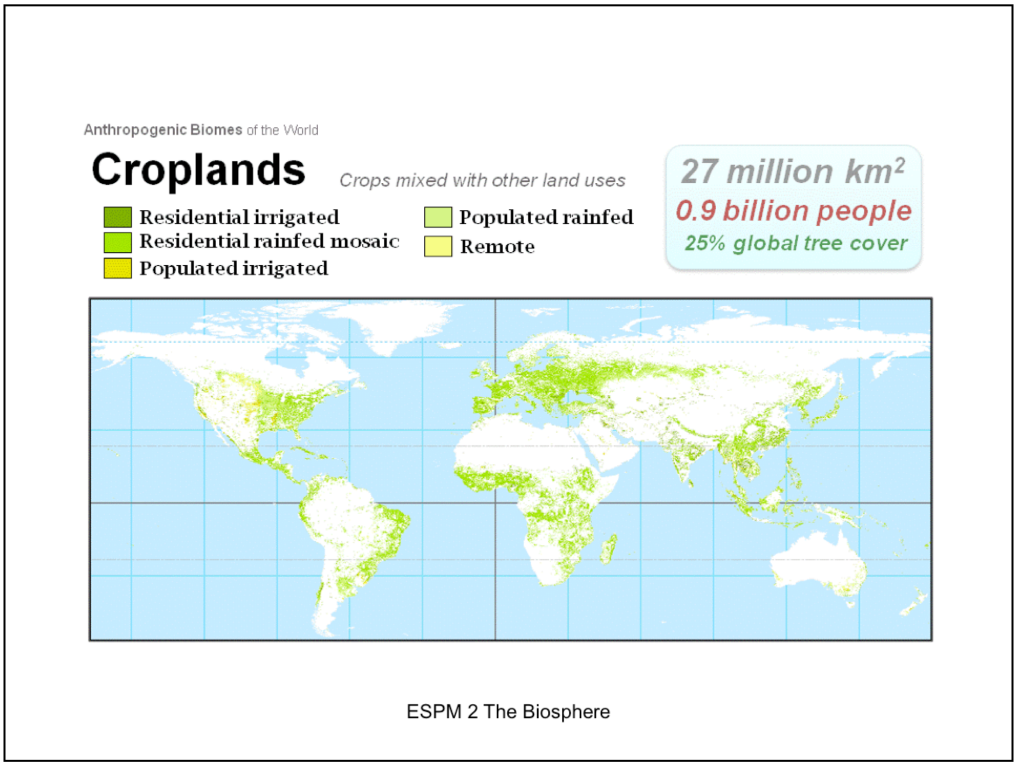
Here we see the global extent of land use change. In the northern latitudes there is actually a net gain of forest cover as farms have been abandoned and people have moved to the cities. In contrast there is a net loss of forests in the tropics due to increased pressure from burgeoning populations and policy decisions by local governments




Over 27 million square kilometers of land are devoted to croplands, nearly a billion people live on those lands.

For perspective the non-ice land area of the globe is over 100 million km2

# Agricultural Degrades Land

- Soil Erosion
  - reduced carbon content, tilth and water holding capacity
- Fertilizers
  - Runoff of nutrients leads to eutrophication of aquatic habitats
  - Pollutes ground water
  - Emission of greenhouse gases
- Pesticides/Herbicides
  - pollute groundwater
  - Reduces biodiversity and changes species composition
  - Cause bioaccumulation
- Irrigation
  - mines ground water, causes soil subsidence, causes salt accumulation, hard pans

## Fire

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While fire is natural and is started by lightening, humans have also used fire as a tool to clear land, thin forests, move wildlife.  Humans also start fires accidently and on purpose.

## Fire Frequency, Globally

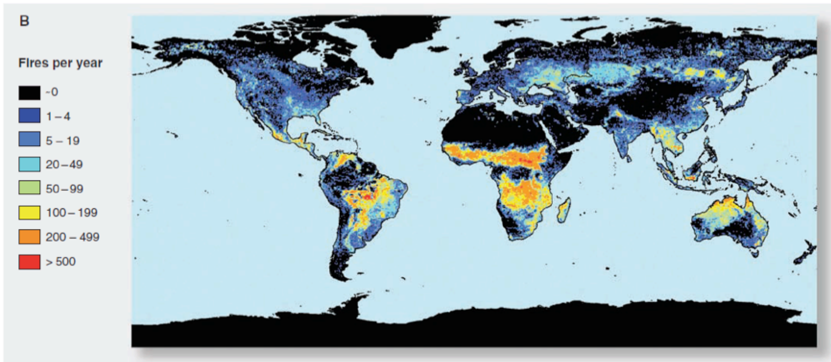


**Fig. 2.** Current pyrogeography on Earth, illustrated by (**A**) net primary productivity (NPP, g C $m^{-2}$ $year^{-1}$) (*40*) from 2001 to 2006, by 1° grid cells; and (**B**) annual average number of fires observed by satellite (*49*).

Bowman et al. 2009 Science

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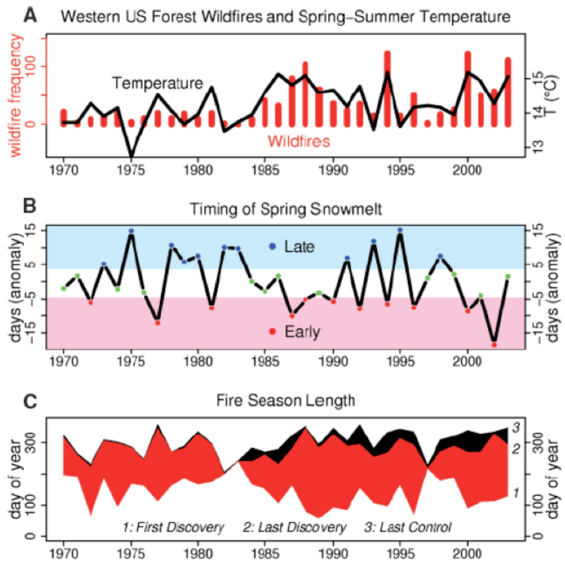
Fires are most frequent in the subtropics of Africa, South America and Australia. Big fires are a factor in the functioning of forests in the mountain West and in the boreal forests.




Wildfires in US Since 1980s

- Higher large-wildfire frequency
- Longer wildfire duration
- Longer Wildfire Seasons

Westerling et al 2006 Science

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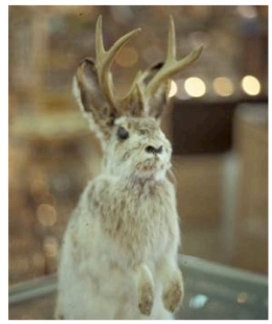
There is a connection between climate and fires.

# Extinction



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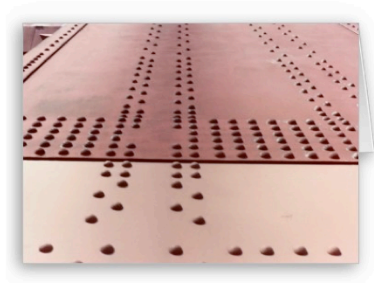
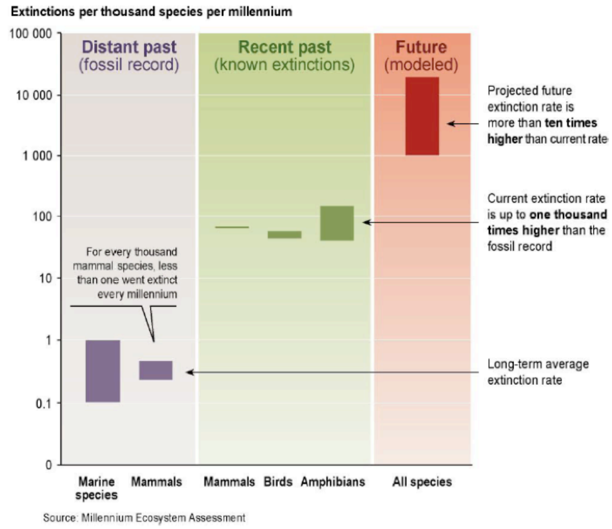
Which changes in the environment come extinction of species

Biodiversity Loss is like Losing Rivets on an Airplane.
Many are redundant, so you can afford to lose a few.
But you don't know Which ones and How many will
cause the System to Collapse



Hence, Many Environmental Scientists tend to invoke the 'Precautionary Principle'

Trends in Extinction

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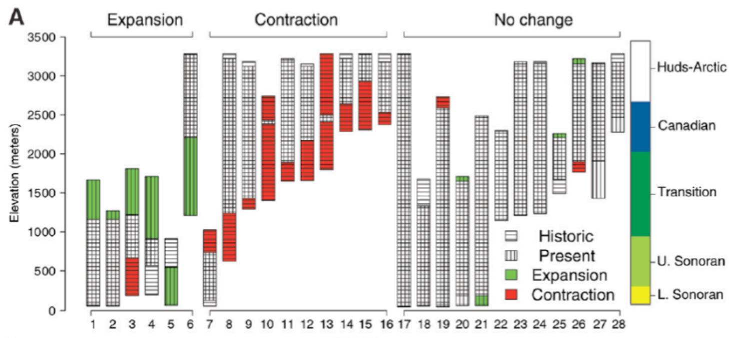
Recent extinction rates are elevated from historical norms.

Repeat of the Grinnell Survey across Yosemite found substantial (~500 meters upward changes in elevational limits for half of 28 species monitored, consistent with the observed ~3°C increase in minimum temperatures.




Moritz et al 2008 Science

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Repeating Grinnell's early–20th century survey across a 3000-meter-elevation gradient that spans Yosemite National Park, California, USA. Using

occupancy modeling to control for variation in detectability, Moritz et al found substantial (~500 meters on

average) upward changes in elevational limits for half of 28 species monitored, consistent with the

observed ~3°C increase in minimum temperatures. Formerly low-elevation species expanded their

ranges and high-elevation species contracted theirs, leading to changed community composition at

mid- and high elevations.

Rapid and Recent Melting of Himalaya Glaciers,
Source of Water for over 2 Billion People

1950s

Notice lake

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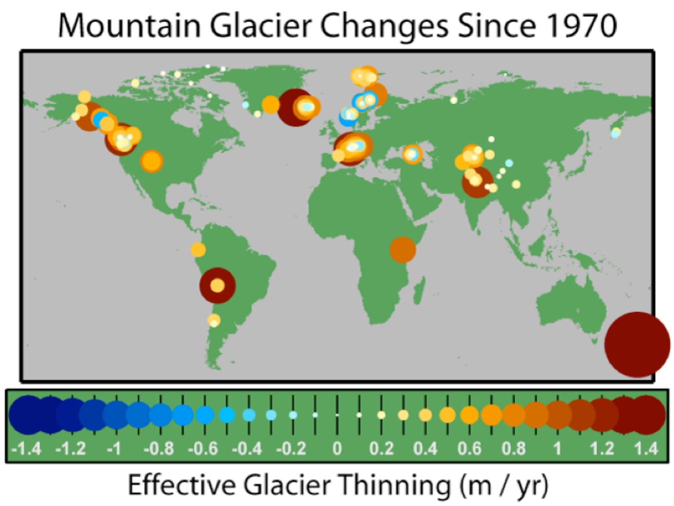
Oliver Schell's editorial NY Times




www.globalwarmingart.com

Over Exploitation of the Oceans

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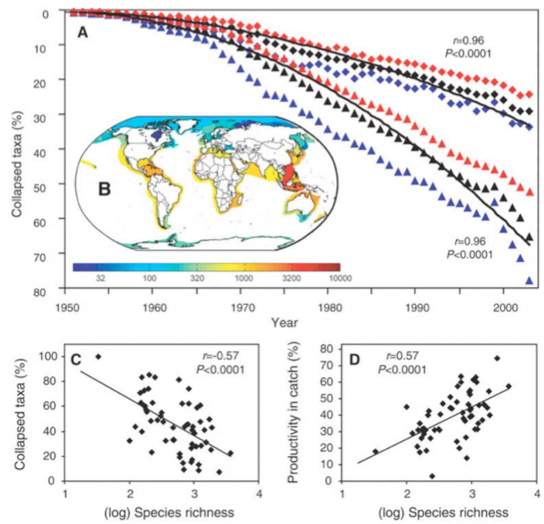
And if we arent exploiting the land enough, let’s go to the sea. Super trawlers and remote sensing have increased the intensity and extensiveness of catches, depleting many of the world’s fisheries

Trends in Fish Taxa




Worm et al. 2006 Science

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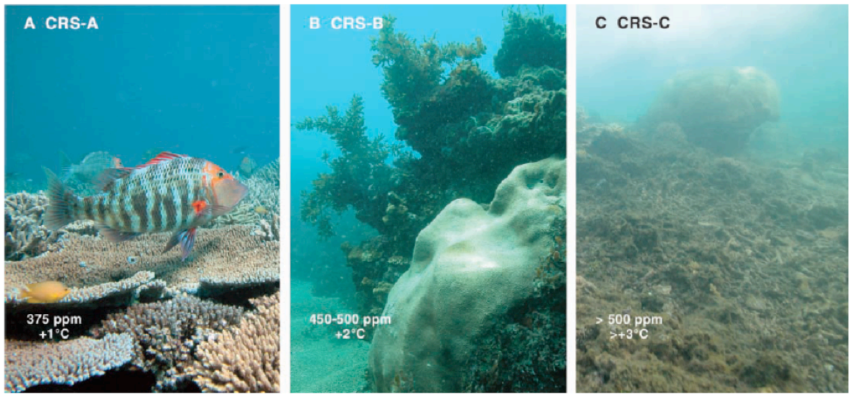
Over fishing..refer to seminar by Ray Hilborn..maximum sustainable yield reduces maximum population to about 30 to 40% of pre-fishing levels and it seems sustainable

## General Comments and Trends

- Overfishing is occurring, but not everywhere
- By fishing at maximum yield there will a reduction in carrying capacity, down to about 30-40% level..but it will be sustained and come at the cost of reducing a large number of taxa
- We can aim towards reaching ~80% of maximum yield with a less dire reduction in stocks and taxa

Ocean acidification and corals




Hoegh Guldberg science 2007

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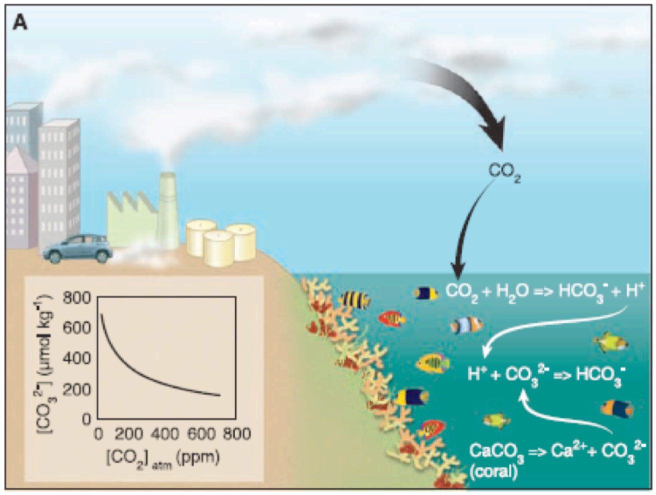
Ocean acidification and corals




Hoegh Guldberg science 2007

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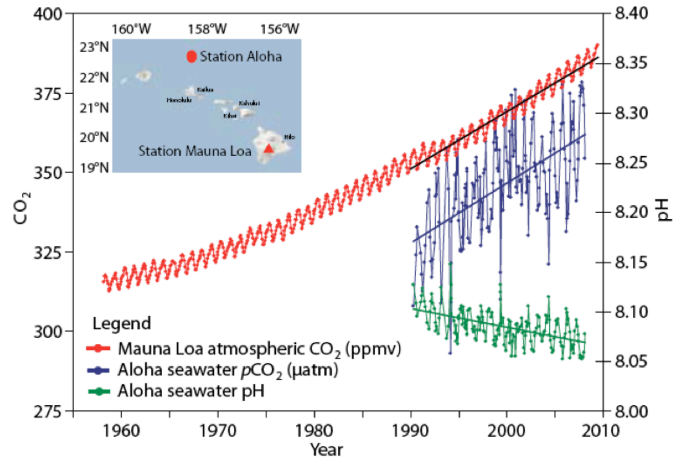
It is important to remember ocean acidification because if there are geoengineering solutions to the climate that don't reduce CO2 the oceans will continue to acidify and this affects marine life, especially shell fish and corals.

Trends in Ocean pH




Doney et al. 2009 Oceanography



Here is the most recent trend in ocean acidity.

## Anthropocene Era

(Overarching findings)

- Tenfold change in Human Growth, to near 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 1/2 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.

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

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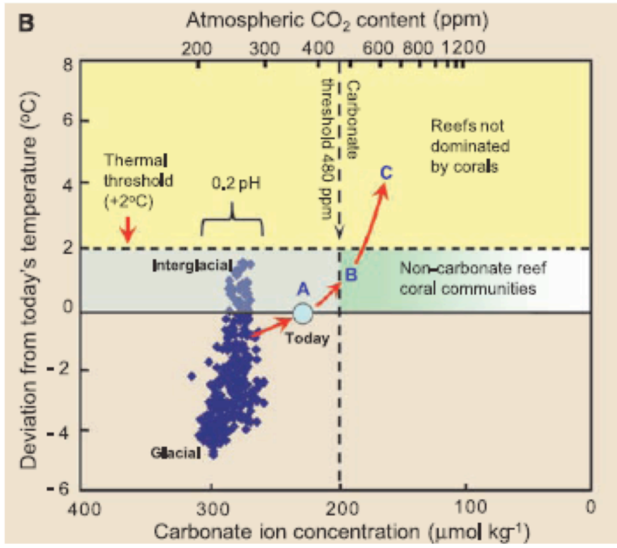


Hoegh Guldberg science 2007

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# $CO_2$ and Forest Photosynthesis

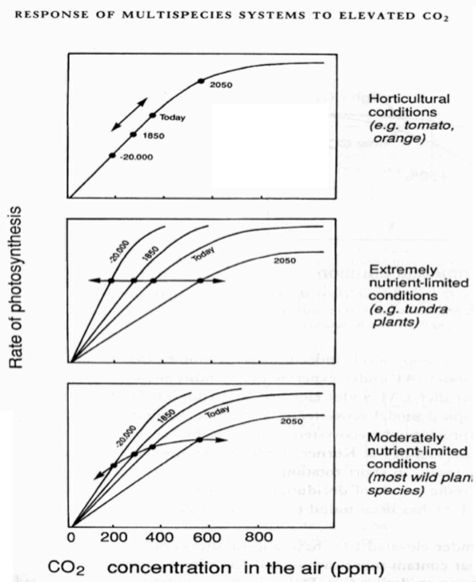
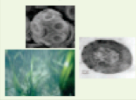



**Figure 3.2** *Photosynthetic adjustment to changing $CO_2$ concentration: a multitude of possible long-term responses.*



Korner, 1996

| Physiological response | Major group | Species studied | Response to increasing $CO_2$: a | b | c | d |
|---|---|---|---|---|---|---|
| **Calcification**  | Coccolithophores[1] | 4 | 2 | 1 | 1 | 1 |
| | Planktonic Foraminifera | 2 | 2 | – | – | – |
| | Molluscs | 4 | 4 | – | – | – |
| | Echinoderms[1] | 3 | 2 | 1 | – | – |
| | Tropical corals | 11 | 11 | – | – | – |
| | Coralline red algae | 1 | 1 | – | – | – |
| **Photosynthesis[2]**  | Coccolithophores[3] | 2 | – | 2 | 2 | – |
| | Prokaryotes | 2 | – | – | 1 | – |
| | Seagrasses | 5 | – | – | – | – |
| **Nitrogen Fixation**  | Cyanobacteria | 1 | – | 1 | – | – |
| **Reproduction**  | Molluscs | 4 | 4 | – | – | – |
| | Echinoderms | 1 | 1 | – | – | – |

1) Increased calcification had substantial physiological cost; 2) Strong interactive effects with nutrient and trace metal availability, light, and temperature; 3) Under nutrient replete conditions.

**Figure 4**

Doney et al 2009 Annual Rev Marine Sci

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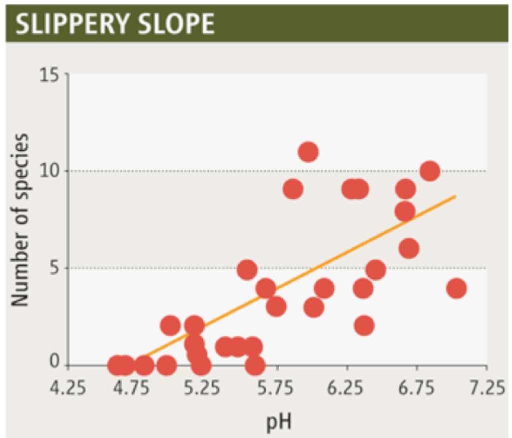
Biodiversity and Lake Acidity




Science, 2010

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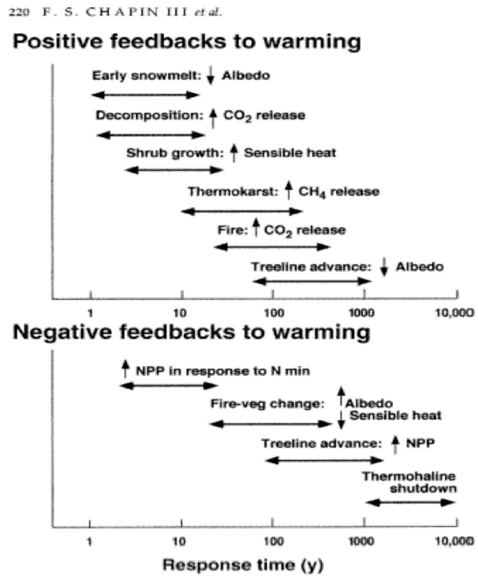
They reveal the often complex—and sometimes surprising—ways that acid rain has reshuffled aquatic food webs in sensitive waters. One trend is crystal clear, a team led by Nierzwicki-Bauer reported this past July in *Environmental Science & Technology*: More acid meant less biodiversity. The researchers came up with a grim rule of thumb: For every one-digit drop in pH (from 6 to 5, for instance, which represents a 10-fold increase in acidity), there were 2.5 fewer genera of bacteria, 1.43 fewer bacterial classes, and 3.97 fewer species of phytoplankton. A one-digit drop in pH also meant nearly two fewer crustacean species and about four fewer species of aquatic plants, rotifers, and fish. “Lots of studies had examined acid rain's impact at a chemical level,” says Nierzwicki-Bauer. “We tried to quantify how it changes the biota.”

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The effect of warming has positive and negative feedbacks on a suite of ecological processes, too. Some are fast and immediate. Others are slow to occur.

# CO2

- Response of leaves vs plants vs ecosystems to $CO_2$ are different
- Feedbacks with Nitrogen cycle lead to down regulation in $CO_2$ response of photosynthesis
- Plants can become root-bound in pots
- Overall, Growth is increased, but partly attributed to compound interest effect
- Stomatal Closure, with elevated $CO_2$, yields an increase in water use efficiency