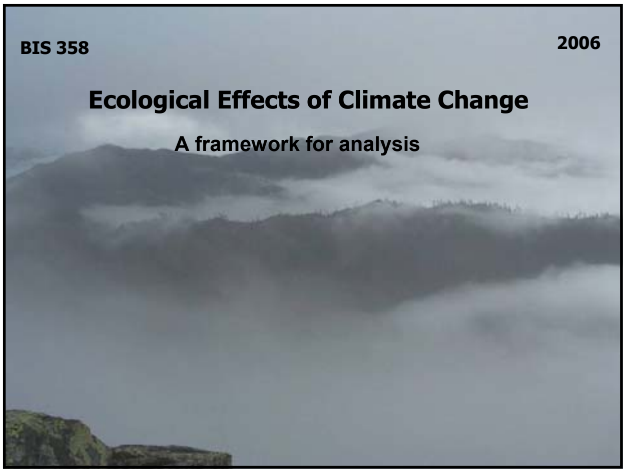


OVERVIEW

A Framework for Understanding Impacts & Responses

I. Responses of Individuals

II. Responses of Individuals & Populations

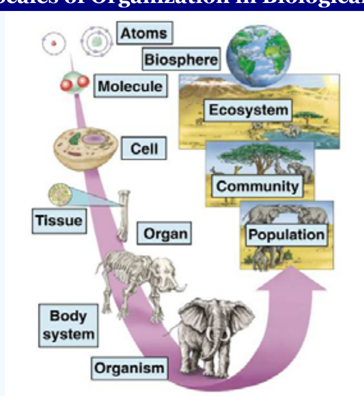
III. Responses of Communities

IV. Responses of Ecosystems

V. Time Scales of Ecological Response

VI. Ecosystem Feedbacks on Climate Change

Spatial Scales of Organization in Biological Systems



from Raven & Berg (2004)

Biological levels of organization for our analysis

Individual:

Population:

Community:

Ecosystem:

Landscape:

Framework of Climate Change Impact & Response

ENVIRONMENTAL CHANGES

Climate Change

Temperature Change | Precipitation Change | Change in other environ factors & interactions

IMPACTS

Organisms: | Populations:

Ecosystems: | Communities:

SHORT-TERM RESPONSES

Acclimation

Adjust physiology | Develop new relationships | Change behavior | Change timing

Acclimation:

Framework of Climate Change Impact & Response

ENVIRONMENTAL CHANGES

Climate Change

Temperature Change | Precipitation Change | Change in other environ factors & interactions

IMPACTS

Organisms: growth, survival, reproduction | **Populations:** range, abundance

Ecosystems: cycles, complex impacts | **Communities:** composition, interactions, change

SHORT-TERM RESPONSES

Acclimation | Movement | Call your congressman

LONG -TERM RESPONSES

Adaptation examples:

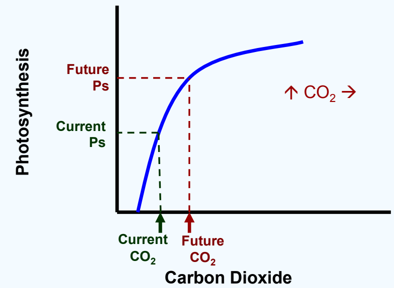
Range Shift | Adaptation

Adaptation:

I. Response of Individual Organisms to Climate Change

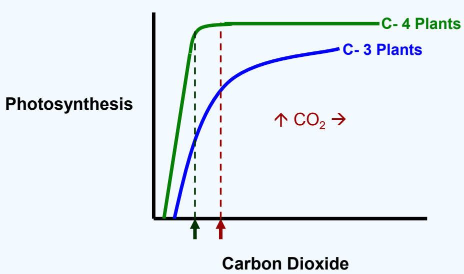
I. Response of Individual Organisms to Climate Change

1. Climate changes affect how organisms function: plant growth



I. Response of Individual Organisms to Climate Change

1. Climate changes affect how organisms function: plant growth



I. Response of Individual Organisms to Climate Change

1. Climate changes affect how organisms function: plant growth

Experiments to see how ↑CO_2 affects plants: adding CO_2 in Open Top Chambers

I. Response of Individual Organisms to Climate Change

1. Climate changes affect how organisms function: plant growth

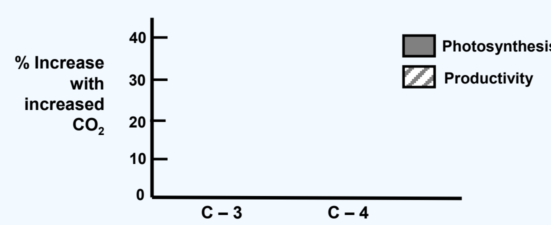
Experiments to see how ↑CO_2 affects plants: Adding CO_2 in FACE* Experiments

* Free Air CO_2 Enrichment

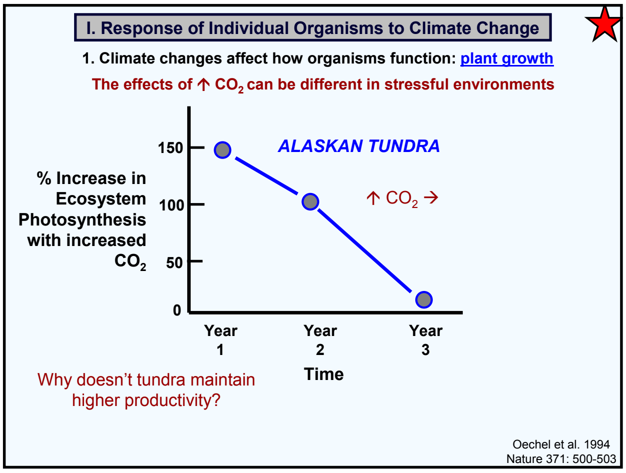
I. Response of Individual Organisms to Climate Change

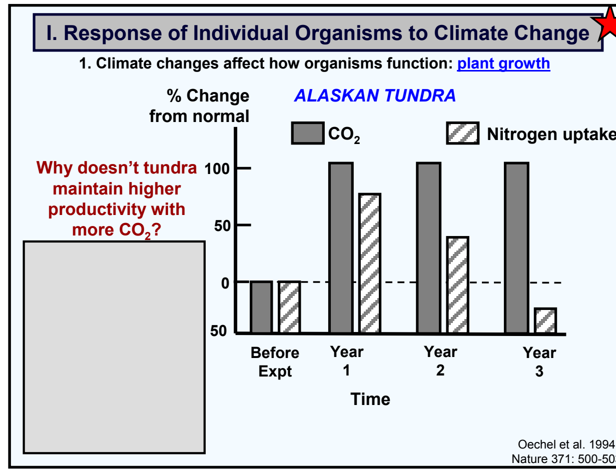
1. Climate changes affect how organisms function: plant growth

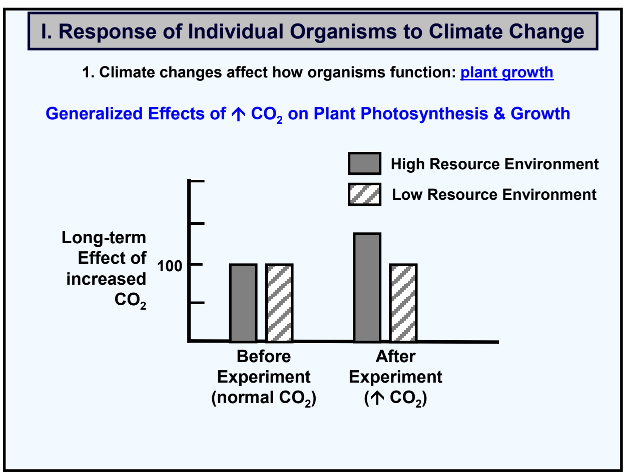
2005 Review of 120 published studies over 20 years

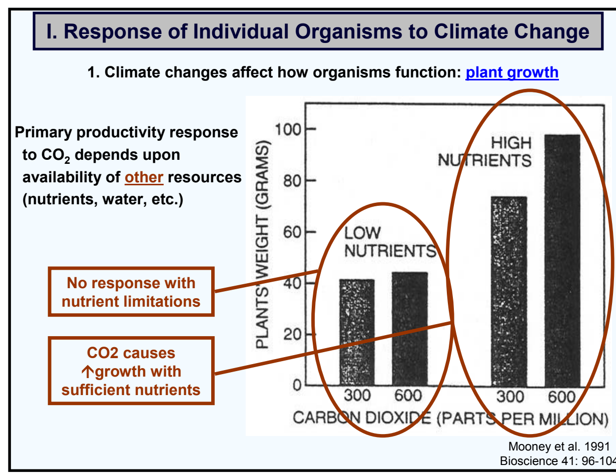


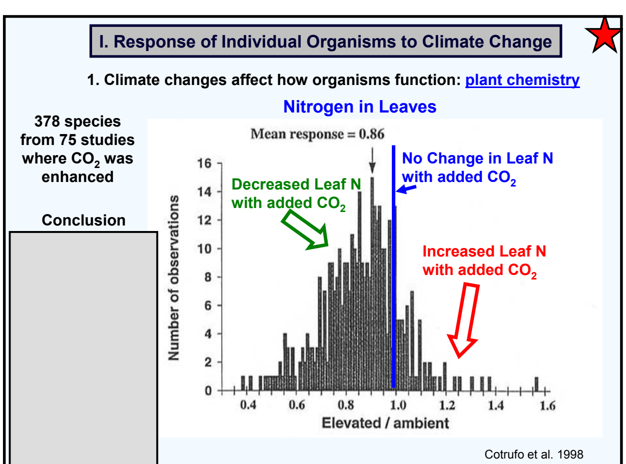
Ainsworth & Long 2005
New Phytologist 165: 351-372

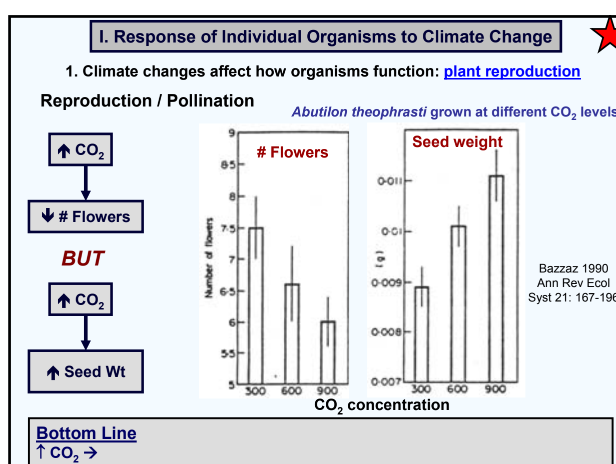

I. Response of Individual Organisms to Climate Change
1. Climate changes affect how organisms function: plant growth
The effects of ↑ CO_2 can be different in stressful environments
ALASKAN TUNDRA
% Increase in Ecosystem Photosynthesis with increased CO_2
150
100
50
0
↑ CO_2 →
Year 1
Year 2
Year 3
Time
Why doesn't tundra maintain higher productivity?
Oechel et al. 1994
Nature 371: 500-503


I. Response of Individual Organisms to Climate Change
1. Climate changes affect how organisms function: plant growth
% Change from normal
ALASKAN TUNDRA
CO_2
Nitrogen uptake
Why doesn't tundra maintain higher productivity with more CO_2?
100
50
0
50
Before Expt
Year 1
Year 2
Year 3
Time
Oechel et al. 1994
Nature 371: 500-503


I. Response of Individual Organisms to Climate Change
1. Climate changes affect how organisms function: plant growth
Generalized Effects of ↑ CO_2 on Plant Photosynthesis & Growth
High Resource Environment
Low Resource Environment
Long-term Effect of increased CO_2
100
Before Experiment (normal CO_2)
After Experiment (↑ CO_2)

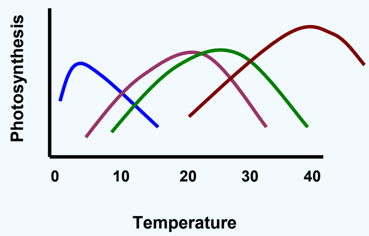

I. Response of Individual Organisms to Climate Change
1. Climate changes affect how organisms function: plant growth
Primary productivity response to CO_2 depends upon availability of other resources (nutrients, water, etc.)
No response with nutrient limitations
CO2 causes ↑growth with sufficient nutrients
PLANTS' WEIGHT (GRAMS)
100
80
60
40
20
0
LOW NUTRIENTS
HIGH NUTRIENTS
300
600
300
600
CARBON DIOXIDE (PARTS PER MILLION)
Mooney et al. 1991
Bioscience 41: 96-104


I. Response of Individual Organisms to Climate Change
1. Climate changes affect how organisms function: plant chemistry
Nitrogen in Leaves
378 species from 75 studies where CO_2 was enhanced
Conclusion
Mean response = 0.86
No Change in Leaf N with added CO_2
Decreased Leaf N with added CO_2
Increased Leaf N with added CO_2
Number of observations
16
14
12
10
8
6
4
2
0
0.4
0.6
0.8
1.0
1.2
1.4
1.6
Elevated / ambient
Cotrufo et al. 1998
Global Change Biol 4: 43-54


I. Response of Individual Organisms to Climate Change
1. Climate changes affect how organisms function: plant reproduction
Reproduction / Pollination
Abutilon theophrasti grown at different CO_2 levels
↑ CO_2
↓ # Flowers
BUT
↑ CO_2
↑ Seed Wt
Flowers
Seed weight
300
600
900
300
600
900
CO_2 concentration
Bazzaz 1990
Ann Rev Ecol Syst 21: 167-196
Bottom Line
↑ CO_2 →

I. Response of Individual Organisms to Climate Change

1. Climate changes affect how organisms function: Effects of temperature



I. Response of Individual Organisms to Climate Change

1. Climate changes affect how organisms function: temperature effects

Various Effects of Temperature on Organism Function

PLANTS

Physiology
- Photosynthesis
- Respiration
- Ionic Balance
- Thermal stress

Water Balance
- Water loss
- Water uptake

Resource Investments
Energy partitioning in
- Growth
- Reproduction
- Survival

Growth & Development
- Plant form / architecture
- Senescence

ANIMALS

Physiology
- Respiration
- Ionic Balance
- Thermal stress

Water Balance
- Water loss
- Water uptake

Resource Investments
Energy partitioning in
- Growth
- Reproduction
- Survival

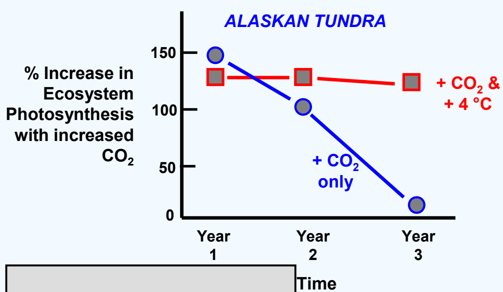
Behavior
- Food gathering
- Mating
- Predator avoidance

Growth & Development
- Body form

Examples – not a comprehensive list

I. Response of Individual Organisms to Climate Change

1. Climate changes affect how organisms function: complex additive effects of CO_2 AND temperature



Oechel et al. 1994
Nature 371: 500-503

I. Response of Individual Organisms to Climate Change

1. Climate changes affect how organisms function: interactive effects

Some possible effects of ↑ Temperature & ↑ CO_2

PLANTS

Physiology
- ↑ Photosynthesis
- ↑ Thermal stress (esp seedlings)

Water Balance
- ↑ Water stress
  - ✓ ↑ soil water evaporation
  - ✓ ↑ transpiration (?)

Survival
- ↑ Survival in cold environments
- ↓ Survival in warm, dry environments

ANIMALS: I'll leave it to you to come up with some examples here

I. Response of Individual Organisms to Climate Change

2. Climate changes affect the TIMING of organisms' function

PLANTS: Onset of seasonal activity
- Flowering
- Leaf production
- Leaf fall

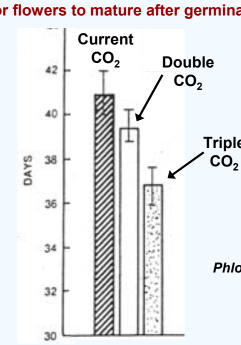
I. Response of Individual Organisms to Climate Change

2. Climate changes affect the TIMING of organisms' function

Reproduction / Pollination — Effects on the time it takes flowers to mature

Days for flowers to mature after germination

↑ CO_2 → ↓ Days for flowers to mature



Lesson:

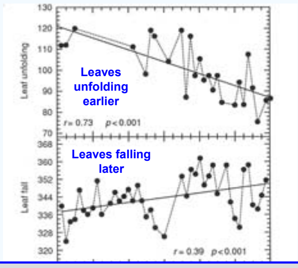
Phlox drummondii

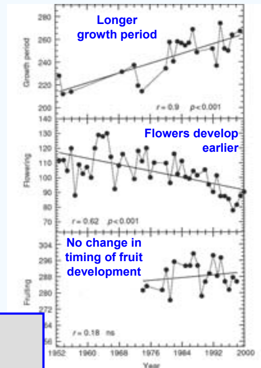
Garbutt & Bazzaz 1984
New Phytol 98: 433-446

I. Response of Individual Organisms to Climate Change

2. Climate changes affect the TIMING of organisms' function

Apple Trees in NE Spain (1952 – 2000)
Avg annual temperature ↑ 1.4 °C





Lesson:

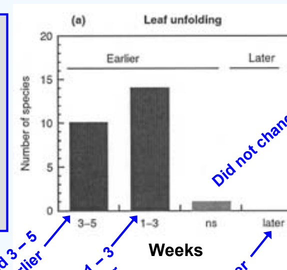
Penuelas et al. 2002
Global Change Biol 8: 531-544

I. Response of Individual Organisms to Climate Change

2. Climate changes affect the TIMING of organisms' function

24 – 57 plant species in NE Spain (1952 – 2000)
Avg annual temperature ↑ 1.4 °C

Lesson:



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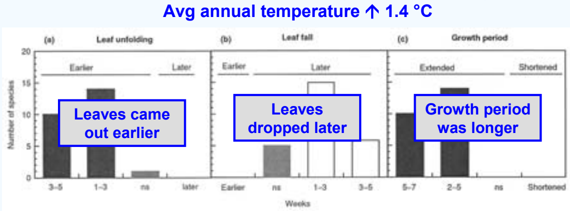


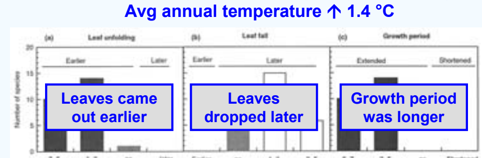
Lesson: timing of plant activities changed along with recent temperature changes: ↑ °C → ↑ growing period

Penuelas et al. 2002
Global Change Biol 8: 531-544

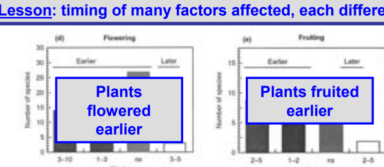
I. Response of Individual Organisms to Climate Change

2. Climate changes affect the TIMING of organisms' function

24 – 57 plant species in NE Spain (1952 – 2000)
Avg annual temperature ↑ 1.4 °C



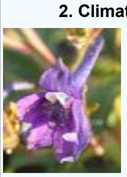
Lesson: timing of many factors affected, each differently



Penuelas et al. 2002
Global Change Biol 8: 531-544

I. Response of Individual Organisms to Climate Change

2. Climate changes affect the TIMING of organisms' function



Date of first spring flowering studied in 395 Plant Species in Britain 1990s compared to 1954 - 1989

385 Species: flowered earlier in 1990s by an average of 4.5 days
16% flowered more than 15 days earlier

10 Species: flowered later

Lesson: timing of plant activities changed recently:

Fitter & Fitter 2002
Science 296: 1689-1691

I. Response of Individual Organisms to Climate Change

2. Climate changes affect the TIMING of organisms' function

Other Examples of Timing Shifts

Northern hemisphere temperate growing season

Satellite data for 45 – 70 °N for 1982 – 1990:
- Earlier start by 8 days
- Delayed end by 4 days

Myneni et al. 1997
Nature 386: 698

Aphid development

3 – 6 day advance of aphid development over past 25 years in UK

Penuelas & Filella 2001
Science 294: 793-795

Migratory bird timing

Migratory bird (20 species) arrival & departure in Oxfordshire, UK has shifted by 8 days over past 30 years

Cotton 2003

I. Response of Individual Organisms to Climate Change

2. Climate changes affect the TIMING of organisms' function

A "META-ANALYSIS"
Timing of activity over periods from 16 - 132 years analyzed for 677 species (plants & animals)

Timing shifts detected included:

- Timing of frog breeding
- Timing of bird nesting
- Arrival of migrant birds & butterflies
- Timing of flowering
- Timing of bud burst

_____ % showed timing shift in the direction expected from measured changes in climate (warming)

For 172 species average advance of spring activity was 2.3 days / decade

Lesson:

Parmesan & Yohe 2003
Nature 421: 37-42

I. Response of Individual Organisms to Climate Change

2. Climate changes affect the TIMING of organisms' function

Larger Implications of Phenological Changes in NE Spain

Global Warming (1950 – 2000)

Change in Plant Phenology
- Leaf Fall 1-2 wk delay
- Leaf Birth 1-4 wk sooner
- Flowering 1wk sooner
- Growing Season 3 wks longer

Change in Animal Phenology
- Appearance & Activity 1-2 wk sooner
- Spring Migration 1-2 wk sooner
- Fall Migration 1-2 wk delay
- Breeding Season 1 - 2 wks longer

Adapted from: Penuelas & Filella 2001 Science 294: 793-795

II. Response of Individuals & Populations to Climate Change

II. Response of Individuals & Populations to Climate Change

1. Climate changes affect the movement of individuals & range of populations

META-ANALYSIS
Geographical ranges over periods from 17 – 1,000 years analyzed for 434 species (plants & animals)

______ showed range shift in the direction expected from measured changes in climate

For 99 species of birds, butterflies & alpine plants:

- average northward range shift was 6.1 km (4 miles) per decade
- average upward shift was 6 m (20 ft) per decade

Maximum range shifts over past 40 years:

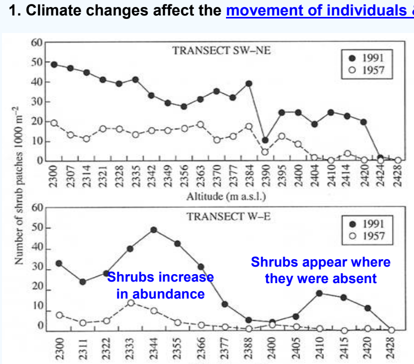
- 200 km (butterflies)
- 1,000 km (marine copepods)

Lesson:

Parmesan & Yohe 2003
Nature 421: 37-42

II. Response of Individuals & Populations to Climate Change

1. Climate changes affect the movement of individuals & range of populations



Shrub species extending their range upward over 34 years of warming in Spain's central mountains

Sanz-Elorza et al. (2003)
Ann. Bot. 92: 273-280

II. Response of Individuals & Populations to Climate Change

1. Climate changes affect the movement of individuals & range of populations

Table adapted from your reading: Glan-Reto et al. 2002; Nature 416: 389-395

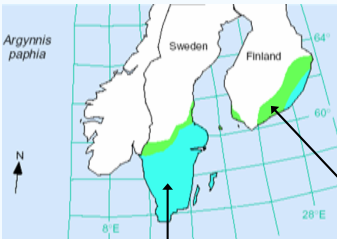
Species	Location	Range Shift	Climate Link
Treeline	Europe, NZ	Moving upward	Warming
Arctic shrubs	Alaska	Expansion into grass tundra	Warming
Alpine plants	Austria	Moving up 1 - 4 m / decade	Warming
Marine invertebrates, fish, plankton	Calif; N Atlantic	Increased abundance of warm water species	Warmer ocean temps
Butterflies	North America & Europe	Range shifts north up to 200 km / 27 years for 39 species	Warming
Birds	Britain	18.9 km shift north over 20 years	Warmer winters
Red fox	Canada	Expansion of range north	Warming

II. Response of Individuals & Populations to Climate Change

1. Climate changes affect the movement of individuals & range of populations

Study examples

Silver-washed Fritillary: <u>Northern range boundary extended</u>



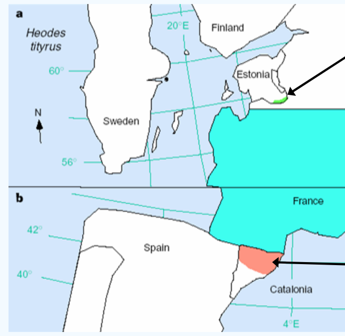
Parmesan et al. 1999
Nature 399: 579-583

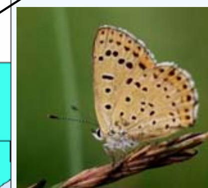
II. Response of Individuals & Populations to Climate Change

1. Climate changes affect the movement of individuals & range of populations

Study examples

Sooty Copper butterfly: <u>northern range extended AND southern range contracted</u>

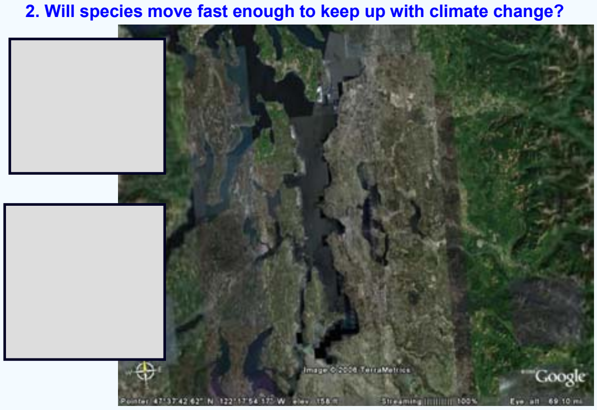




Parmesan et al. 1999
Nature 399: 579-583

II. Response of Individuals & Populations to Climate Change

2. Will species move fast enough to keep up with climate change?



II. Response of Individuals & Populations to Climate Change

2. Will species move fast enough to keep up with climate change?

How fast do they likely need to move?

2.0 to 5.0 °C temperature rise in next 50 years =

- Moving **UP** __________ feet (300 – 600 ft / decade)
- Moving **NORTH** __________ miles (25 – 60 miles/ decade)

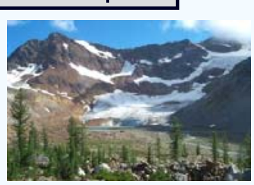
II. Response of Individuals & Populations to Climate Change

2. Will species move fast enough to keep up with climate change?

How fast have species moved in the past?

2 – 125 miles / century typical latitude movement of trees from last post-glacial

(compare to prediction of need to move 125 – 300 miles / 50 years)



Rate of alpine plant extension upward in Austrian Alps over past 70 years:

~ half as fast (1 – 4 m up / decade) as warming over that time

Grabherr et al. 1994
Nature 369: 448

II. Response of Individuals & Populations to Climate Change

2. Will species move fast enough to keep up with climate change?

How fast have species moved in the past?

<u>Northward expansion of birch in Europe as glaciers retreated</u>

- <u>Northern Europe</u>: post glacial temperatures rose ~ 1 °C / century according to migration of water beetles
- Arrival of birch lagged at least 500 years behind when it was warm enough for birch growth – they couldn't get there fast enough

Pennington 1986
Vegetatio 67: 105-118

II. Response of Individuals & Populations to Climate Change

2. Will species move fast enough to keep up with climate change?

How fast have species moved in the past?

Northward expansion of forests in North America as glaciers retreated

- Spruce forests migrated from central US after glacial retreat at rapid rate of ______________________
  - compared to predicted need for ________________ with future climate change

- Deciduous tree species moved at about 15 – 40% of the rate of spruce

Brubaker 1988

II. Response of Individuals & Populations to Climate Change

2. Will species move fast enough to keep up with climate change?

How fast have species moved in the past?

Communities have not moved as assemblages, indicating species were not tracking geographic shifts in climate (they could not keep up)

Brubaker 1988

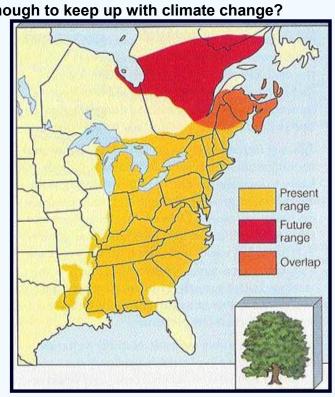
II. Response of Individuals & Populations to Climate Change

2. Will species move fast enough to keep up with climate change?

Shift in range of appropriate habitat for beech with warming by 2050

Likely loss of all but the most northern populations due to

- inability of populations further south to disperse north fast enough
- more limited final range of appropriate habitat



Raven & Berg 2004

II. Response of Individuals & Populations to Climate Change

2. Will species move fast enough to keep up with climate change?

Bottom Lines

Past natural dispersal rates for plants are inadequate to keep up with expected future rates of climate change. Modern barriers make it less likely. Even if plants could move fast enough, what about:

Animals can generally disperse much faster, but will they?

- Will barriers restrict their movement?
- Will their habitat be there?

II. Response of Individuals & Populations to Climate Change

3. Species at greatest risk

Species most at risk:

III. Response of Biological Communities to Climate Change

III. Response of Biological Communities to Climate Change

1. Climate changes affect SPECIES INTERACTIONS

Characterizing interactions between species

Ecological Interaction	Effect on Species 1	Effect on Species 2
Mutualism (pollination, dispersal)		
Competition		
Herbivory		
Predation		

III. Response of Biological Communities to Climate Change

2. Climate changes affect species interactions: MUTUALISMS

Reproduction / Pollination

↑ CO2

↑ °C → ↑ Rate of flower maturation

↑ °C → Δ Timing of pollinator appearance

→ Δ Coordination of pollinator appearance with flower maturation

↓

↓ Plant reproductive success

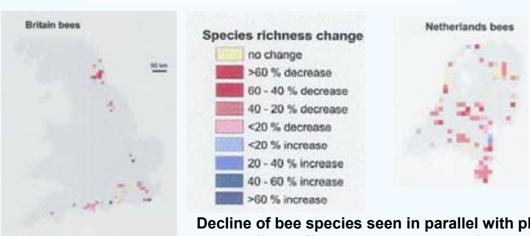
III. Response of Biological Communities to Climate Change

2. Climate changes affect species interactions: MUTUALISMS

Parallel Declines in Pollinators and Insect-Pollinated Plants in Britain and the Netherlands

Science (2006)

J. C. Biesmeijer, S. P. M. Roberts, M. Reemer, R. Ohlemüller, M. Edwards, T. Peeters, A. P. Schaffers, S. G. Potts, R. Kleukers, C. D. Thomas, J. Settele, W. E. Kunin

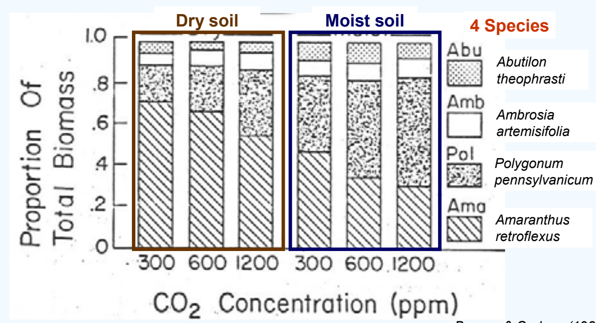


Decline of bee species seen in parallel with plants used as pollen sources over past 25 years

III. Response of Biological Communities to Climate Change

3. Climate changes affect species interactions: COMPETITION

Competition in mid west prairie "community" changes with CO_2



Bazzaz & Carlson (1984)

III. Response of Biological Communities to Climate Change

3. Climate changes & interactions: COMPETITION & COMMUNITY COMPOSITION

The balance of plant growth forms in a subalpine meadow shifts with warming

FORBS

GRASSES

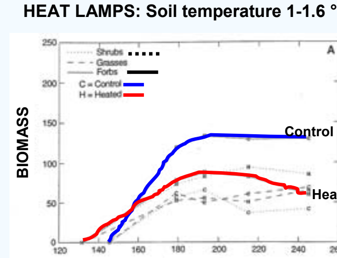
SHRUBS

Harte, J & R Shaw. 1995. Shifting dominance within a montane vegetation community: results of a climate-warming experiment. Science 267: 876-880.

III. Response of Biological Communities to Climate Change

3. Climate changes & interactions: COMPETITION & COMMUNITY COMPOSITION

HEAT LAMPS: Soil temperature 1-1.6 °C higher in heated plots



FORB RESPONSE:

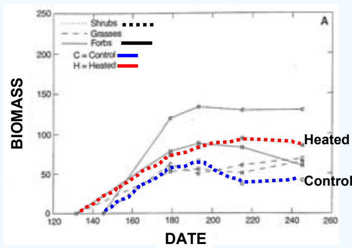
-
-

Harte & Shaw 1995
Science 267: 876-880

III. Response of Biological Communities to Climate Change

3. Climate changes & interactions: COMPETITION & COMMUNITY COMPOSITION

HEAT LAMPS: Soil temperature 1-1.6 °C higher in heated plots



SHRUB RESPONSE:

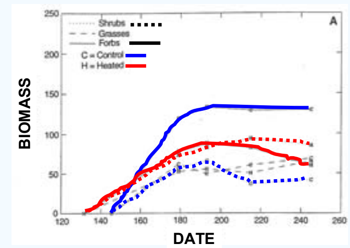
-
-

Harte & Shaw 1995
Science 267: 876-880

III. Response of Biological Communities to Climate Change

3. Climate changes & interactions: COMPETITION & COMMUNITY COMPOSITION

HEAT LAMPS: Soil temperature 1-1.6 °C higher in heated plots



FORB RESPONSE:

- ↓ biomass

SHRUB RESPONSE:

- ↑ biomass

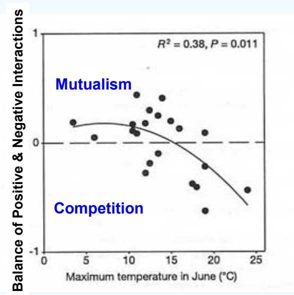
Competition response:

Also ↓ soil H_2O 15-20%
↑ growing season by 1 month

Harte & Shaw 1995
Science 267: 876-880

III. Response of Biological Communities to Climate Change

3. Climate changes affect species interactions: Competition & Mutualism



Warmer conditions favors competition over mutualism in alpine plant communities

22 alpine sites around the world

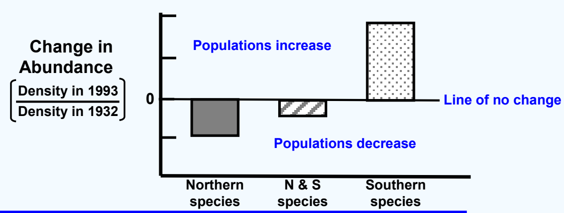
Callaway et al. 2002
Nature 417: 844-848

III. Response of Biological Communities to Climate Change

3. Climate changes affect interactions: COMPETITION & COMMUNITY COMPOSITION

Change in a CA Rocky Intertidal Marine Invertebrate Community from 1932 to 1993

Water temperature changes: ↑ Mean annual of 0.75 °C
↑ Mean summer maxima of 2.2 °C



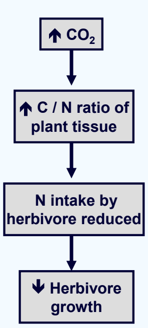
Lesson:

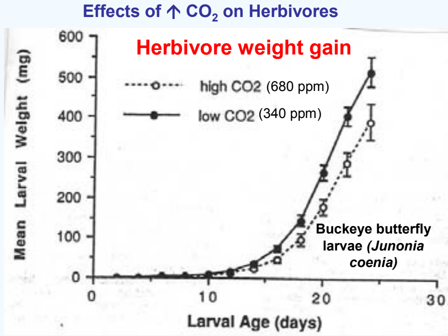
Barry et al. 1995
Science 267: 672-675

III. Response of Biological Communities to Climate Change

4. Climate changes affect species interactions: HERBIVORY

Effects of ↑ CO_2 on Herbivores





Bazzaz (1990)

III. Response of Biological Communities to Climate Change

4. Climate changes affect species interactions: HERBIVORY

Evidence for climate – herbivore & pathogen link was discussed in "Lessons from the Past" lecture

III. Response of Biological Communities to Climate Change

4. Climate changes affect species interactions: HERBIVORY

Herbivory / Pathogens

- ↑ CO_2 → ↑ Ps → ↑ C available for defensive compounds
- Δ CO_2 / °C → Δ range of herbivores / pathogens

Balsam wooly aphids are devastating herbivores for subalpine fir (*Abies lasiocarpa*)

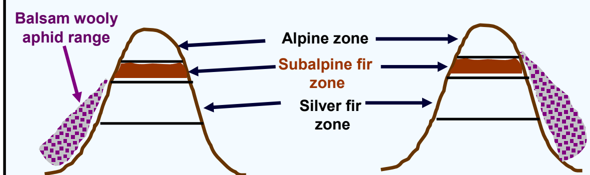
III. Response of Biological Communities to Climate Change

4. Climate changes affect species interactions: HERBIVORY

Balsam wooly aphids are devastating herbivores for subalpine fir (*Abies lasiocarpa*)

Climate:

Climate:



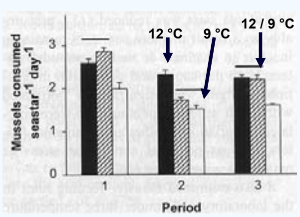
III. Response of Biological Communities to Climate Change

5. Climate changes affect species interactions: *PREDATION*

Predation

- Δ °C → ______________________

Sanford, E. 1999. Regulation of keystone predation by small changes in ocean temperature. Science 283: 2095-2097.



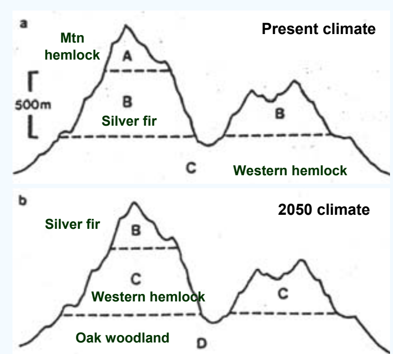
III. Response of Biological Communities to Climate Change

6. Overall scenarios of community change

Simple models of community change

Present day forest zones

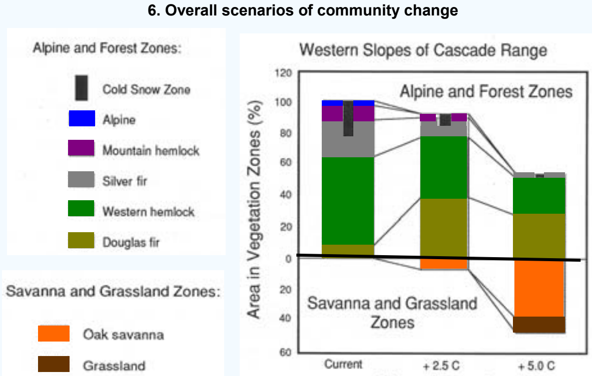
General upward shift in forest zones



Franklin et al. 1991 NW Environ Journal 7: 233-254

III. Response of Biological Communities to Climate Change

6. Overall scenarios of community change

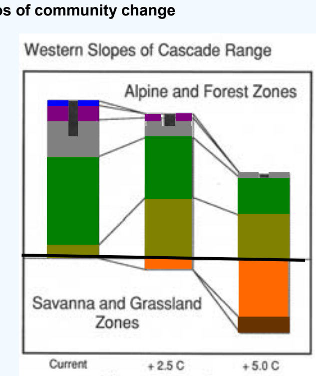


Franklin et al. 1991 NW Environ Journal 7: 233-254

III. Response of Biological Communities to Climate Change

6. Overall scenarios of community change

Some Key Responses

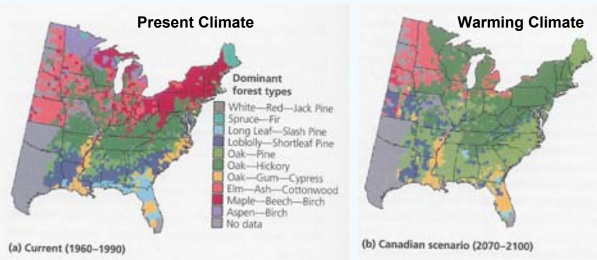


Franklin et al. 1991 NW Environ Journal 7: 233-254

III. Response of Biological Communities to Climate Change

6. Overall scenarios of community change

Modeling of eastern hardwood forest response to warming



Brennan & Withgott (2004)

IV. Response of Ecosystem Characteristics to Climate Change

IV. Response of Ecosystem Characteristics to Climate Change

1. Response of disturbances: FIRE

Evidence for climate – fire link was discussed in "Lessons from the Past" lecture

IV. Response of Ecosystem Characteristics to Climate Change

1. Response of disturbances: FIRE

- ↓ Summer Rainfall → ↑ fire frequency
- ↑ CO_2 / °C → ↑ fire frequency

Natural fire frequencies:
- West-side fir / hemlock forests: 200 - 500 years
- East-side pine forests: 20 - 50 yrs

Most carbon in our forests is stored in wood (much of it dead). Fires release that carbon to the air → positive feedback.

- Other factors possibly altered that affect fire
  - ✓ Humidity
  - ✓ Wind
  - ✓ Plant chemistry
  - ✓ Decomposition (fuel buildup)
  - ✓ Plant morphology (fire ladders)

IV. Response of Ecosystem Characteristics to Climate Change

2. Response of disturbances: WIND

- Regional differences in warming → Δ air pressure differentials → Δ winds & atmospheric circulation
- ↑ Ocean surface °C → ↑ hurricane frequency

IV. Response of Ecosystem Characteristics to Climate Change

2. Response of disturbances: WIND – the hurricane controversy

Pielke, RA et al. 2005. Hurricanes and global warming.

"**CONCLUSIONS. To summarize, claims of linkages between global warming and hurricane impacts are premature for three reasons**. First, no connection has been established between greenhouse gas emissions and the observed behavior of hurricanes (Houghton et al. 2001; Walsh 2004). Emanuel (2005) is suggestive of such a connection, but is by no means definitive. In the future, such a connection may be established [e.g., in the case of the observations of Emanuel (2005) or the projections of Knutson and Tuleya (2004)] or made in the context of other metrics of tropical cyclone intensity and duration that remain to be closely examined. Second, the peer-reviewed literature reflects that a scientific consensus exists that any future changes in hurricane intensities will likely be small in the context of observed variability (Knutson and Tuleya 2004; Henderson-Sellers et al. 1998), while the scientific problem of tropical cyclogenesis is so far from being solved that little can be said about possible changes in frequency. And third, under the assumptions of the IPCC, expected future damages to society of its projected changes in the behavior of hurricanes are dwarfed by the influence of its own projections of growing wealth and population (Pielke et al. 2000).

While future research or experience may yet overturn these conclusions, the state of the peer-reviewed knowledge today is such that there are good reasons to expect that any conclusive connection between global warming and hurricanes or their impacts will not be made in the near term."

Pielke et al. 2005
Bull Am Meteor Soc 86:1571-1575

IV. Response of Ecosystem Characteristics to Climate Change

2. Response of disturbances: WIND – the hurricane controversy

Anthes et al. 2006. Hurricanes and global warming: potential links and consequences.

"**These climate changes may well be changing the properties of tropical cyclones, yet the potential relationships between climate change and tropical cyclones and the consequences for humans have been downplayed or dismissed by a number of recent articles**… For example, the recent article with the all encompassing title "Hurricanes and global warming" by Pielke et al. (2005) raises several important points, yet it is incomplete and misleading because it 1) omits any mention of several of the most important aspects of the potential relationships between hurricanes and global warming, including rainfall, sea level, and storm surge; 2) leaves the impression that there is no significant connection between recent climate change caused by human activities and hurricane characteristics and impacts; and 3) does not take full account of the significance of recently identified trends and variations in tropical storms in causing impacts as compared to increasing societal vulnerability."

Anthes et al. 2006
Bull Amer Meteor Soc 87: 623-628

IV. Response of Ecosystem Characteristics to Climate Change

2. Response of disturbances: WIND – the hurricane controversy

Anthes et al. 2006. Hurricanes and global warming: potential links and consequences.

"**CONCLUDING REMARKS.** Because of natural variability, no one event or a single season like 2005 can be attributed solely to changes in climate. However, it is equally inappropriate to declare or imply that the current observed global changes and seasons with storms of unusually high frequency or intensity are not related to global warming and that there will not be a significant change in climate in the future. It should be recognized that the issue is not black or white, but rather that global warming has a pervasive influence on ocean SST and heat content, atmospheric temperature, water vapor, and atmospheric and oceanic general circulation patterns, all of which affect tropical cyclones in complex, not yet fully understood ways. However, while there are obvious large and natural oscillations, in our view the growing body of evidence suggests a direct and growing trend in several important aspects of tropical cyclones, such as intensity, rainfall, and sea level, all of which can be attributed to global warming. Aspects of the association between global warming and tropical cyclones and other extreme atmospheric events are uncertain, in part because climate change is continuous, yet irregular. However, in a warmer, moister world with higher SSTs, higher sea level, altered atmospheric and oceanic circulations, and increased societal vulnerability, it would be surprising if there were no significant changes in tropical cyclone characteristics and their impacts on society."

Anthes et al. 2006
Bull Amer Meteor Soc 87: 623-628

IV. Response of Ecosystem Characteristics to Climate Change

3. Response of nutrient cycling

Nutrient Cycling – Microorganisms

↑ CO_2 & °C & Δ H_2O

Δ Plant photosynthesis

Δ C available for root exudates

Δ Soil microbe populations / function

Δ Nutrient Cycling: such as mineralization, denitrification, etc.

Bottom Line

IV. Response of Ecosystem Characteristics to Climate Change

3. Response of nutrient cycling

Nutrient Cycling – Plant litter chemistry

↑ CO_2 & °C

Δ Litter chemistry of existing species

Δ Species mix (and thus litter chemistry of community)

Δ Litter chemistry of community

Δ Decomposability of litter

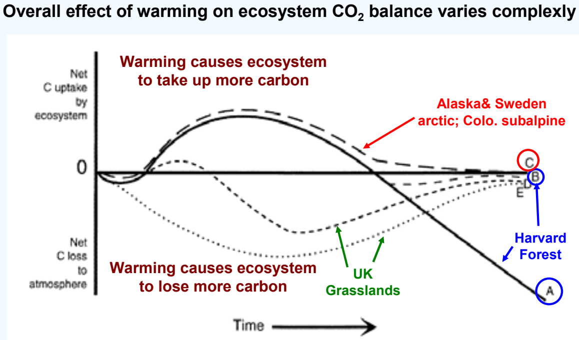
Δ Microbe function (e.g., mineralization)

Bottom Line:

IV. Response of Ecosystem Characteristics to Climate Change

4. Response of carbon cycling

Overall effect of warming on ecosystem CO_2 balance varies complexly



Shaver et al. 2000
Bioscience 50: 871-882

IV. Response of Ecosystem Characteristics to Climate Change

5. Response of trophic relations: altering complex chains of relationships

BERING SEA ECOSYSTEM

20th Century Conditions

Extensive Sea Ice
⇩
Algae grow under ice in early spring
⇩
Zooplankton limited by cool temps
⇩
Algae die and fall to bottom; eaten by crabs, bottom fish, worms, clams, amphipods
⇩
Walruses, grey whales feed on clams, amphipods

Current *warmer* Conditions

Sea Ice melts earlier
⇩
Algae bloom later in spring
⇩
Zooplankton bloom at same time and consume much algae before it falls to bottom
⇩
Benthic (bottom) ecosystem suffers

Pelagic fish favored: pollock, cod
Predators of these fish also favored: sea lions, killer whales

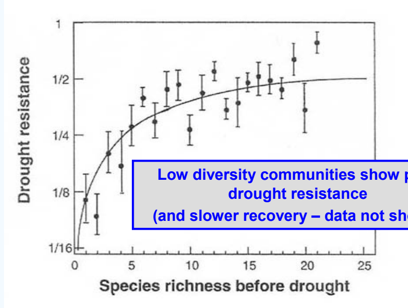
Wespestad et al. 2000
J Marine Sci 57:272-278

IV. Response of Ecosystem Characteristics to Climate Change

6. Response of species diversity & community stability

Response of species diversity to climate change varies tremendously

But where diversity may decline there are implications for ________________



Midwest grasslands

Chapin et al. 1998
Bioscience 48: 45-52

IV. Response of Ecosystem Characteristics to Climate Change

7. Ecosystem Response Models

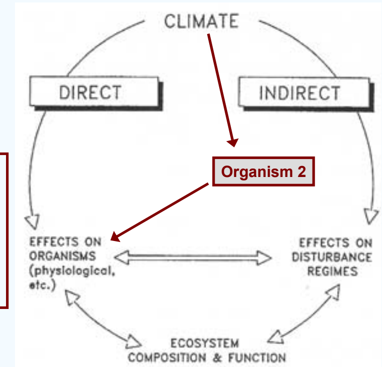
Franklin et al. (1991) Model

for

direct & **indirect**

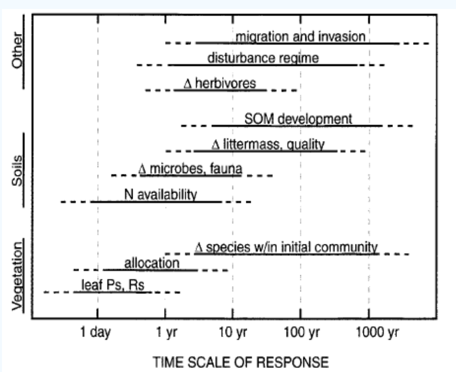
effects of climate change

Note: indirect effects are:



Franklin et al. 1991
NW Environ Journal 7: 233-254

V. Time Scales of Ecological Response to Climate Change

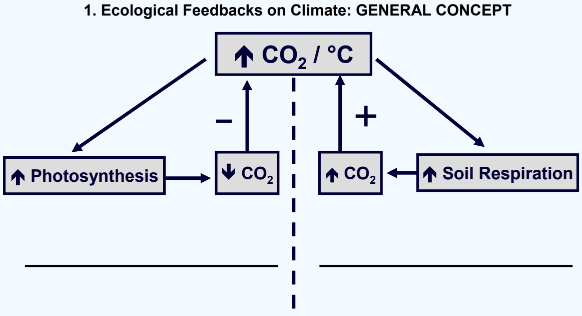


Shaver et al. 2000
Bioscience 50: 871-882

VI. Ecosystem Feedback Effects on Climate Change

VI. Ecosystem Feedback Effects on Climate Change

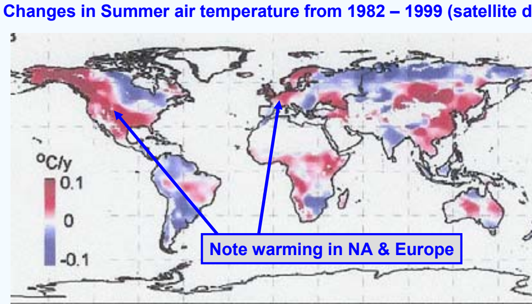
1. Ecological Feedbacks on Climate: GENERAL CONCEPT



VI. Ecosystem Feedback Effects on Climate Change

2. Ecological Feedbacks on Climate: PLANT PRODUCTIVITY (negative CO_2 feedback)

Changes in Summer air temperature from 1982 – 1999 (satellite data)

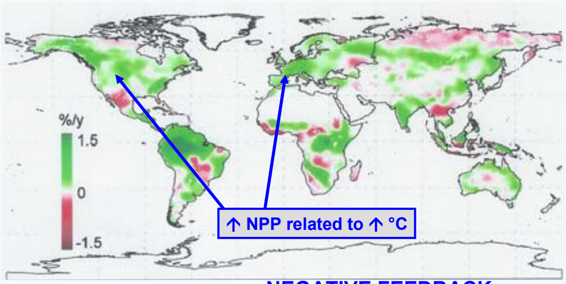


Nemani et al. 2003
Science 300: 1560-1563

VI. Ecosystem Feedback Effects on Climate Change

2. Ecological Feedbacks on Climate: PLANT PRODUCTIVITY (negative CO_2 feedback)

Changes in NPP from 1982 – 1999 (satellite data)

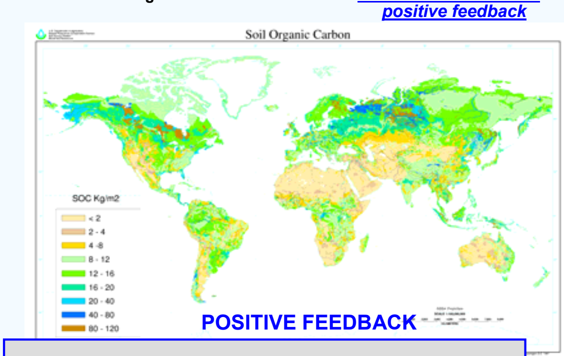


NEGATIVE FEEDBACK

Nemani et al. 2003
Science 300: 1560-1563

VI. Ecosystem Feedback Effects on Climate Change

2. Ecological Feedbacks on Climate: MELTING PERMAFROST
positive feedback



POSITIVE FEEDBACK

Map source: USDA

VI. Ecosystem Feedback Effects on Climate Change

2. Ecological Feedbacks on Climate: MELTING PERMAFROST
positive feedback

Methane bubbling from Siberian thaw lakes as a positive feedback to climate warming
K. M. Walter[1], S. A. Zimov[2], J. P. Chanton[3], D. Verbyla[4] & F. S. Chapin III[1]

Nature (2006)

- Magnitude of emissions measured increases estimates of methane emissions (a potent greenhouse gas) from arctic tundra 10 – 63 %
- Thawing permafrost along lake margins account for most of methane release
- 58% increase in regional area of thaw lakes from 1974 – 2000 parallels warming

Walter et al. 2006
Nature 443: 71-75

VI. Ecosystem Feedback Effects on Climate Change

2. Ecological Feedbacks on Climate: MELTING PERMAFROST
positive feedback

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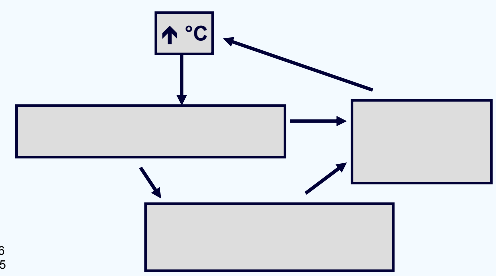
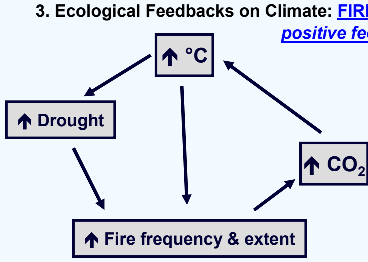


Walter et al. 2006
Nature 443: 71-75

VI. Ecosystem Feedback Effects on Climate Change

3. Ecological Feedbacks on Climate: FIRES
positive feedback



There are many complications to this simplistic picture – such as?

Framework of Climate Change Impact & Response

ENVIRONMENTAL CHANGES

Climate Change

Temperature Change | **Precipitation Change** | **Change in other environ factors & interactions**

IMPACTS

Organisms: growth, survival, reproduction | **Populations:** range, abundance

Ecosystems: cycles, complex impacts | **Communities:** composition, interactions, change

SHORT-TERM RESPONSES

Acclimation | **Movement** | **Call your congressman**

LONG -TERM RESPONSES

Range Shift | **Adaptation**