Global Change: How Will the Mojave Desert Respond?

Stanley D. Smith

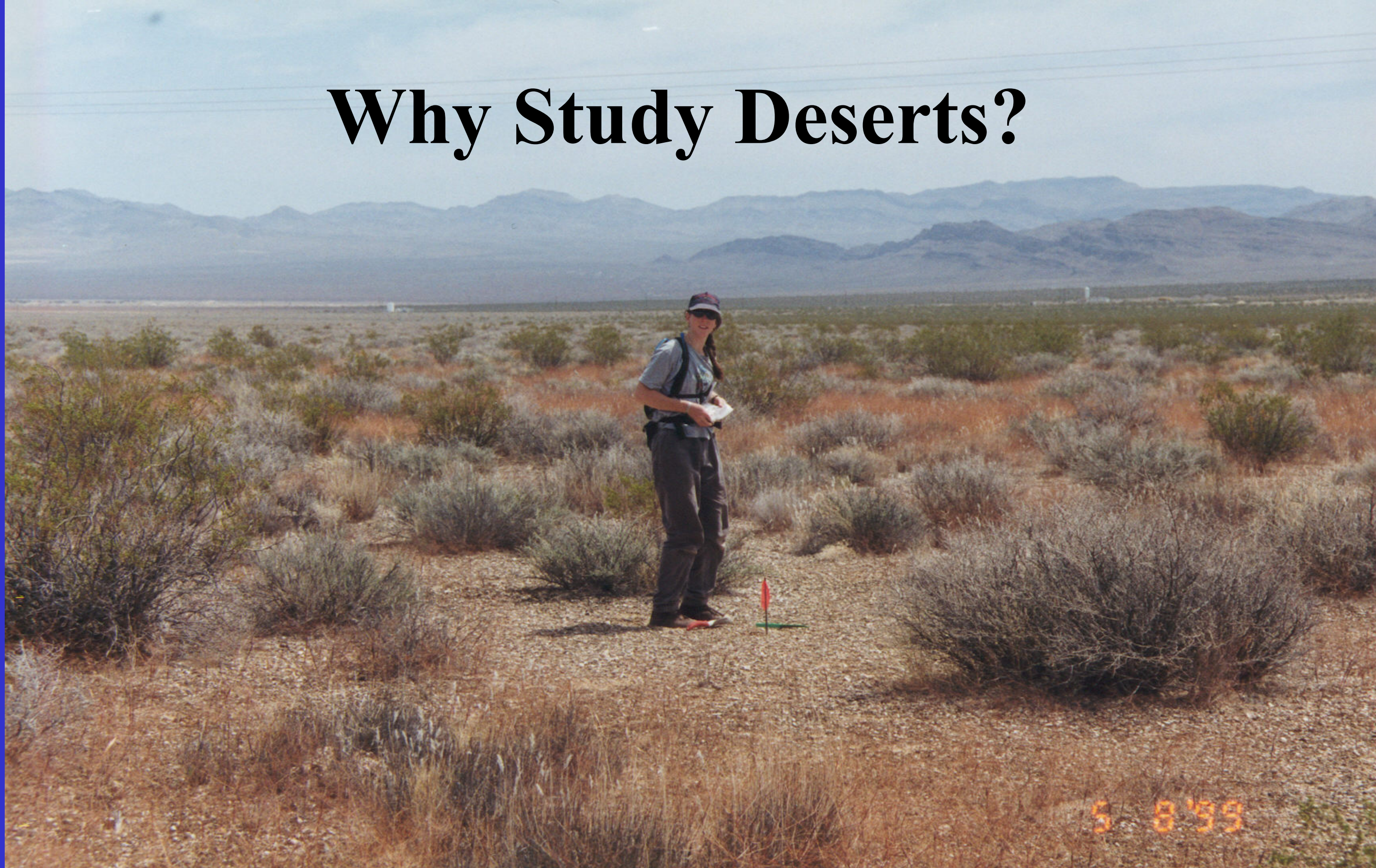
Department of Biological Sciences

University of Nevada, Las Vegas

Why Study Global Change?

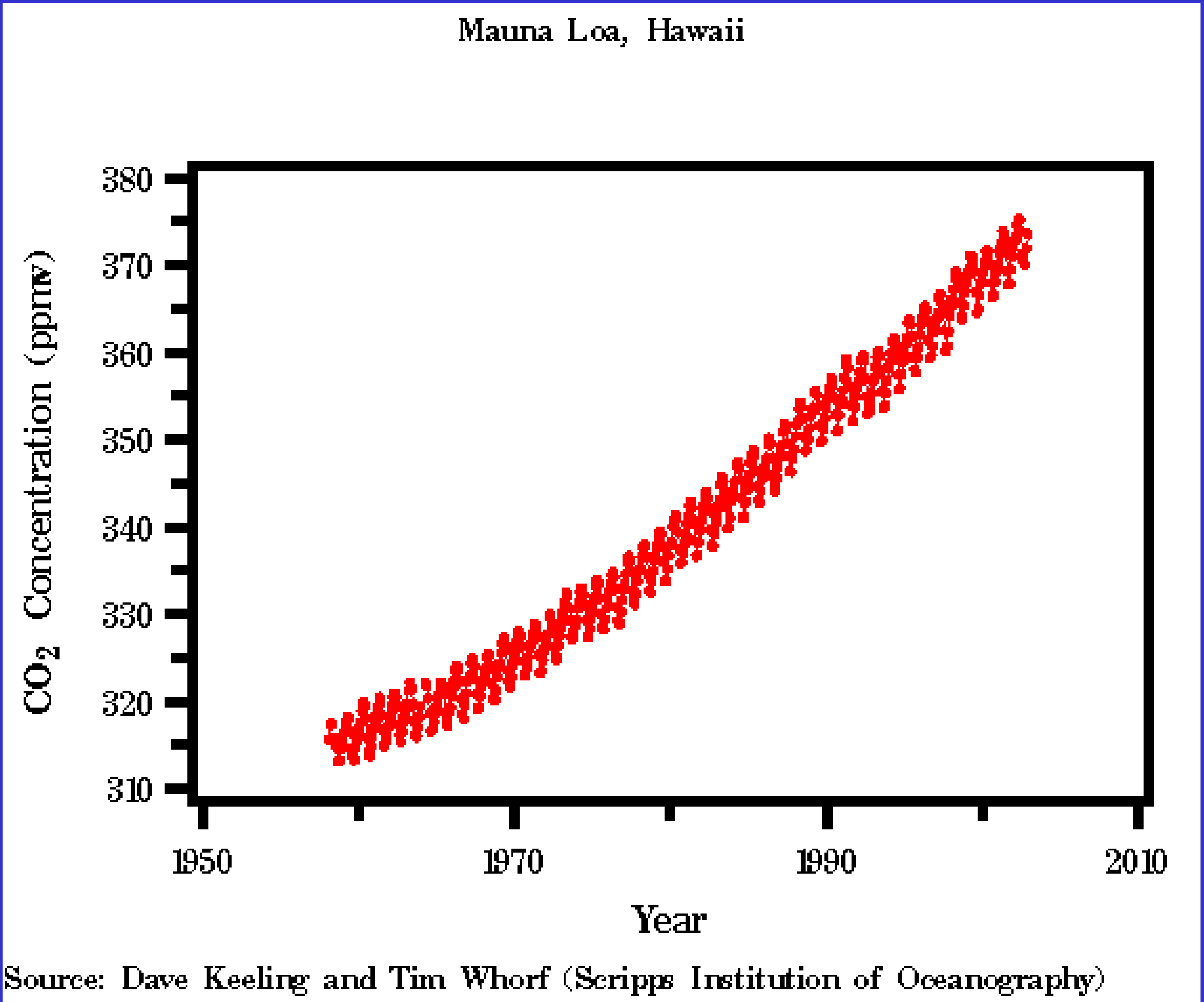
- **Atmospheric CO_2 concentration has risen 50% since the 1800's and will double from today's level by the end of this Century**
- **Scientists now agree that increasing CO_2 and other greenhouse gases are causing global warming**
- **Changing precipitation regimes, nitrogen deposition, land disturbance and invasive species are also critical changes that will affect the Mojave Desert**

Why Study Deserts?

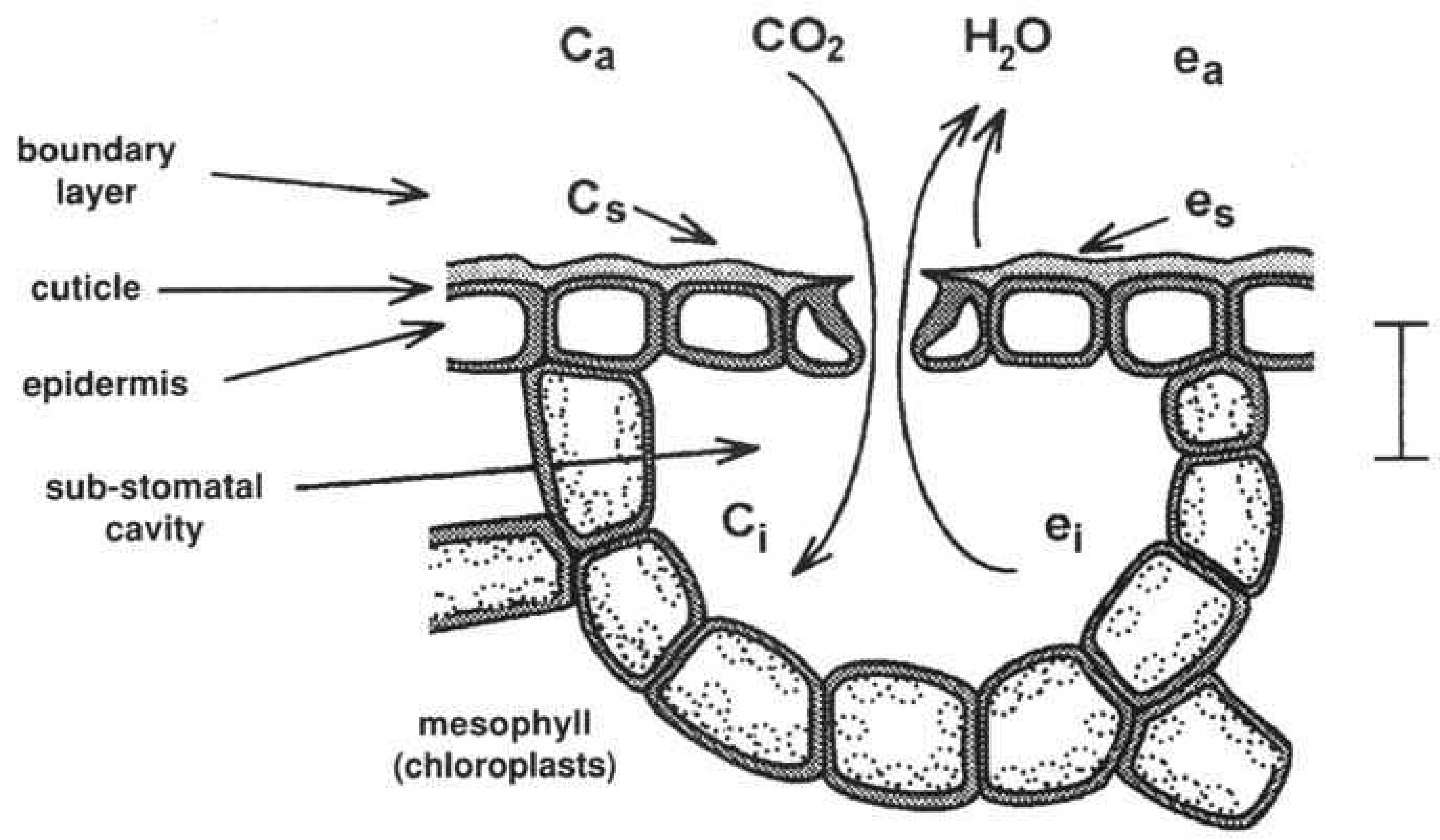


- Arid and semi-arid regions constitute ~40% of the earth's terrestrial surface
- Extreme environments, and particularly deserts, are predicted to show the greatest responses to rising atmospheric CO_2 and concomitant global change factors

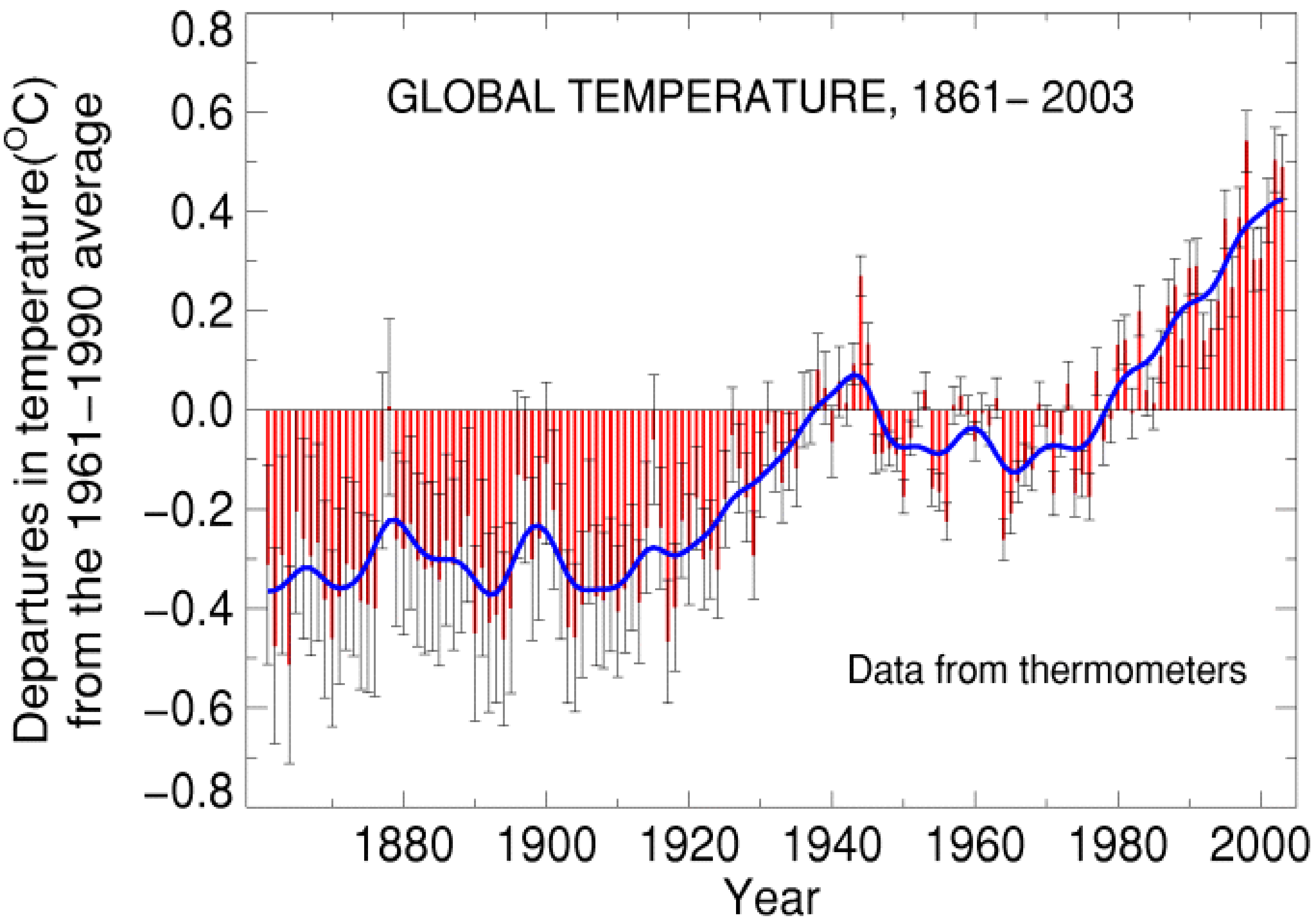
Mauna Loa: Atmospheric CO_2 Concentration



Gas Exchange through Plant Stomata

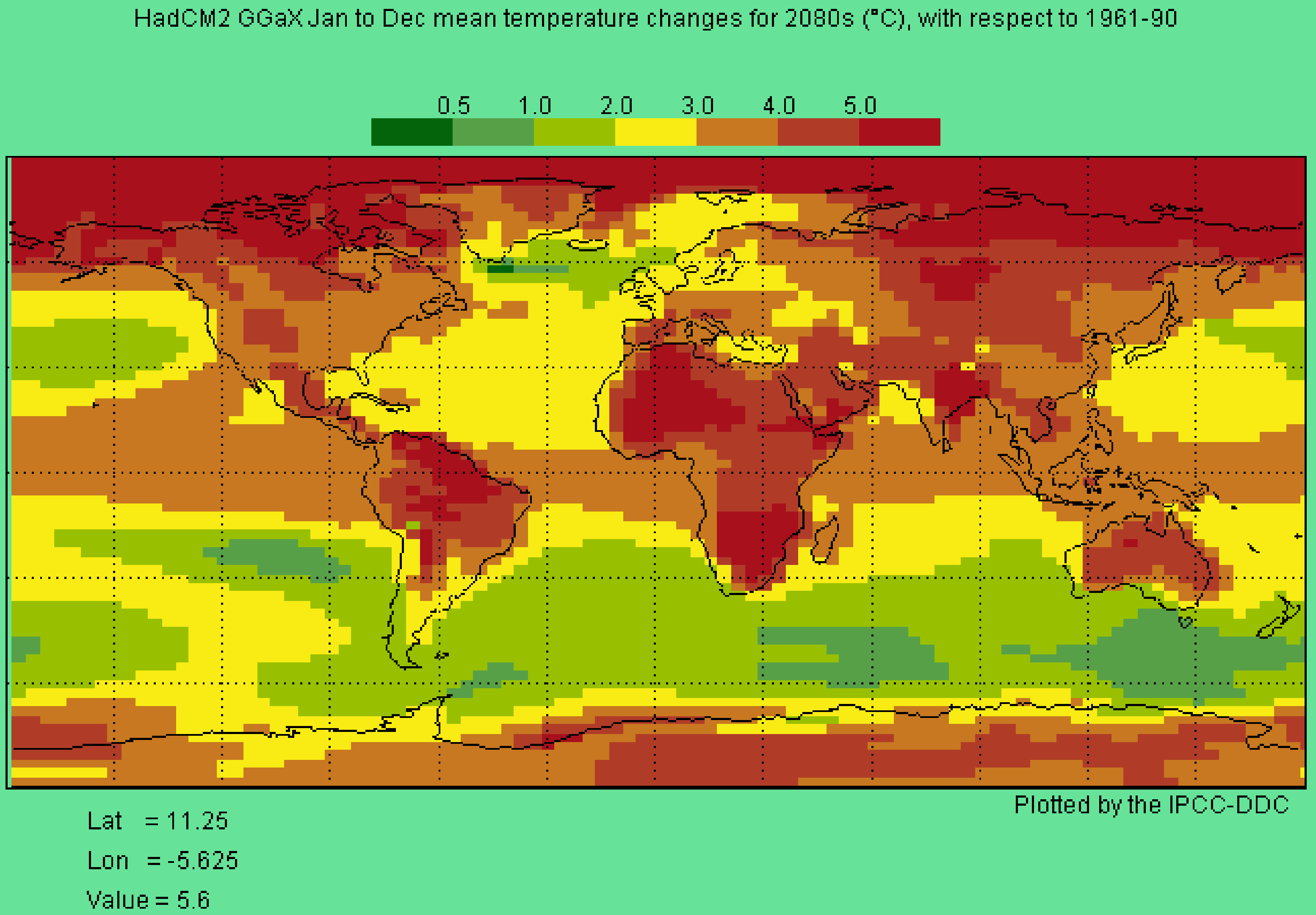


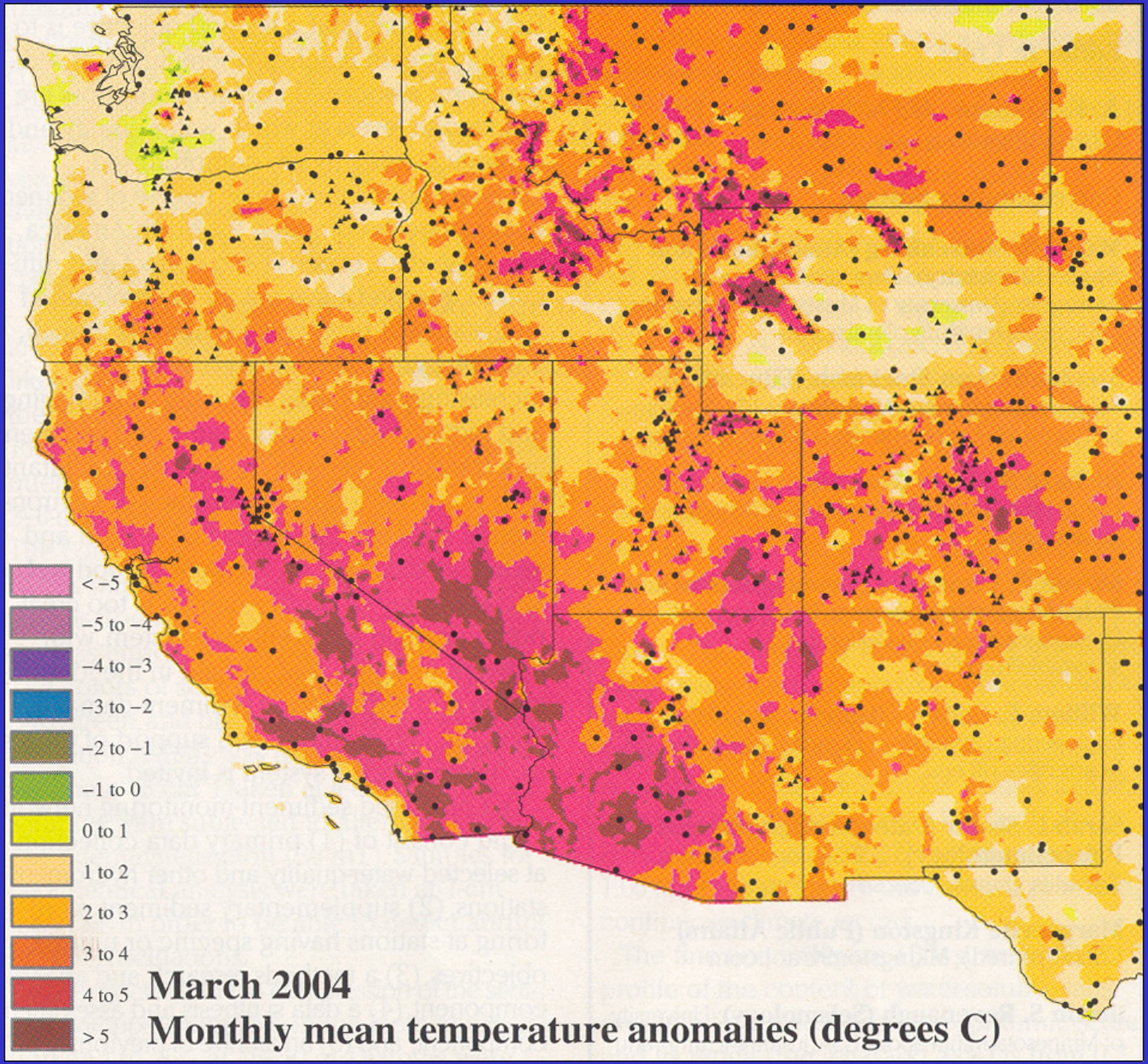
Water-Use Efficiency = CO_2 uptake / H_2O loss



GLOBAL TEMPERATURE, 1861– 2003
Departures in temperature(^{O}C) from the 1961–1990 average
0.8
0.6
0.4
0.2
0.0
–0.2
–0.4
–0.6
–0.8
1880
1900
1920
1940
1960
1980
2000
Year
Data from thermometers

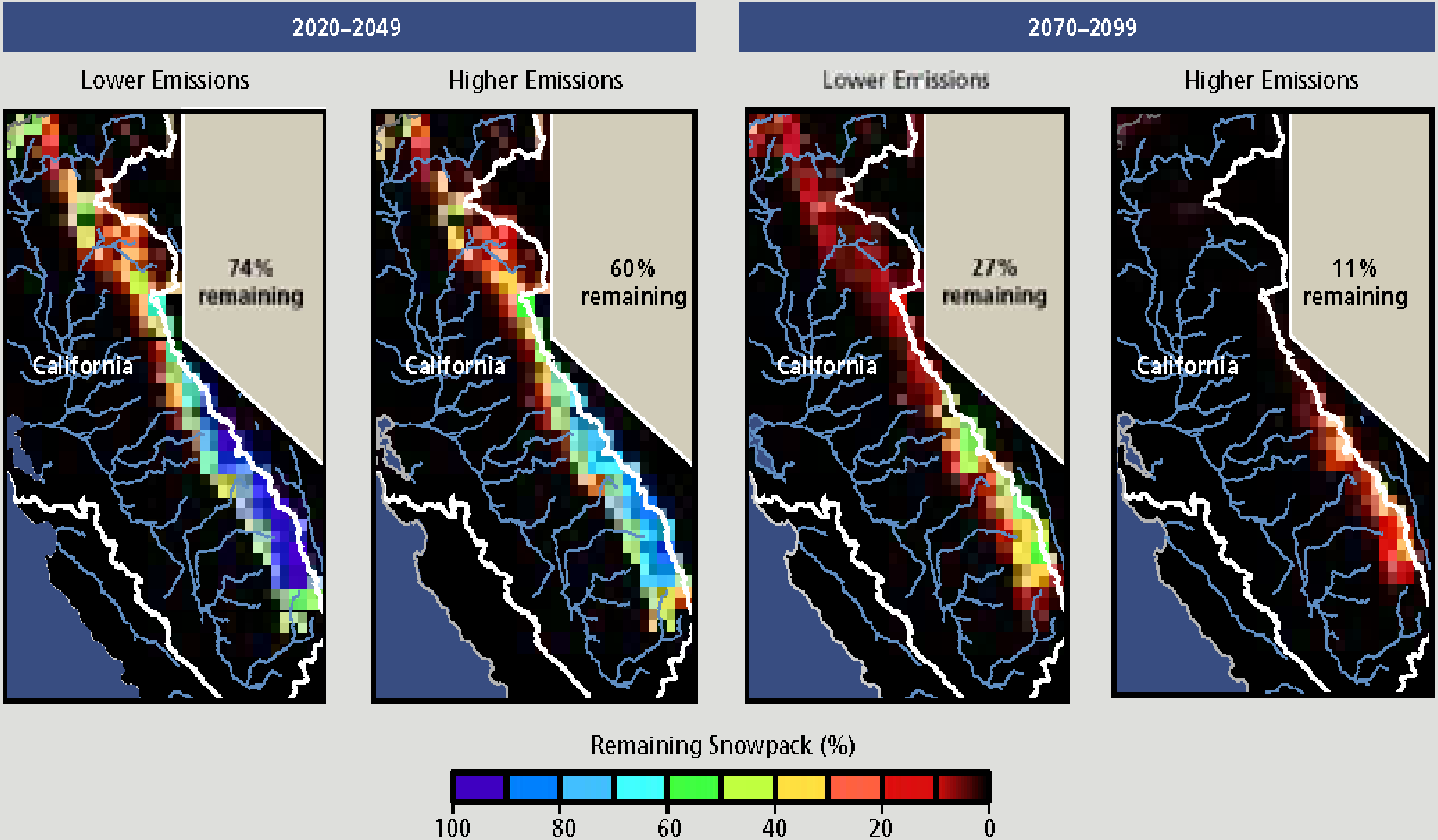
GCM-predicted winter temperatures in the 2080's





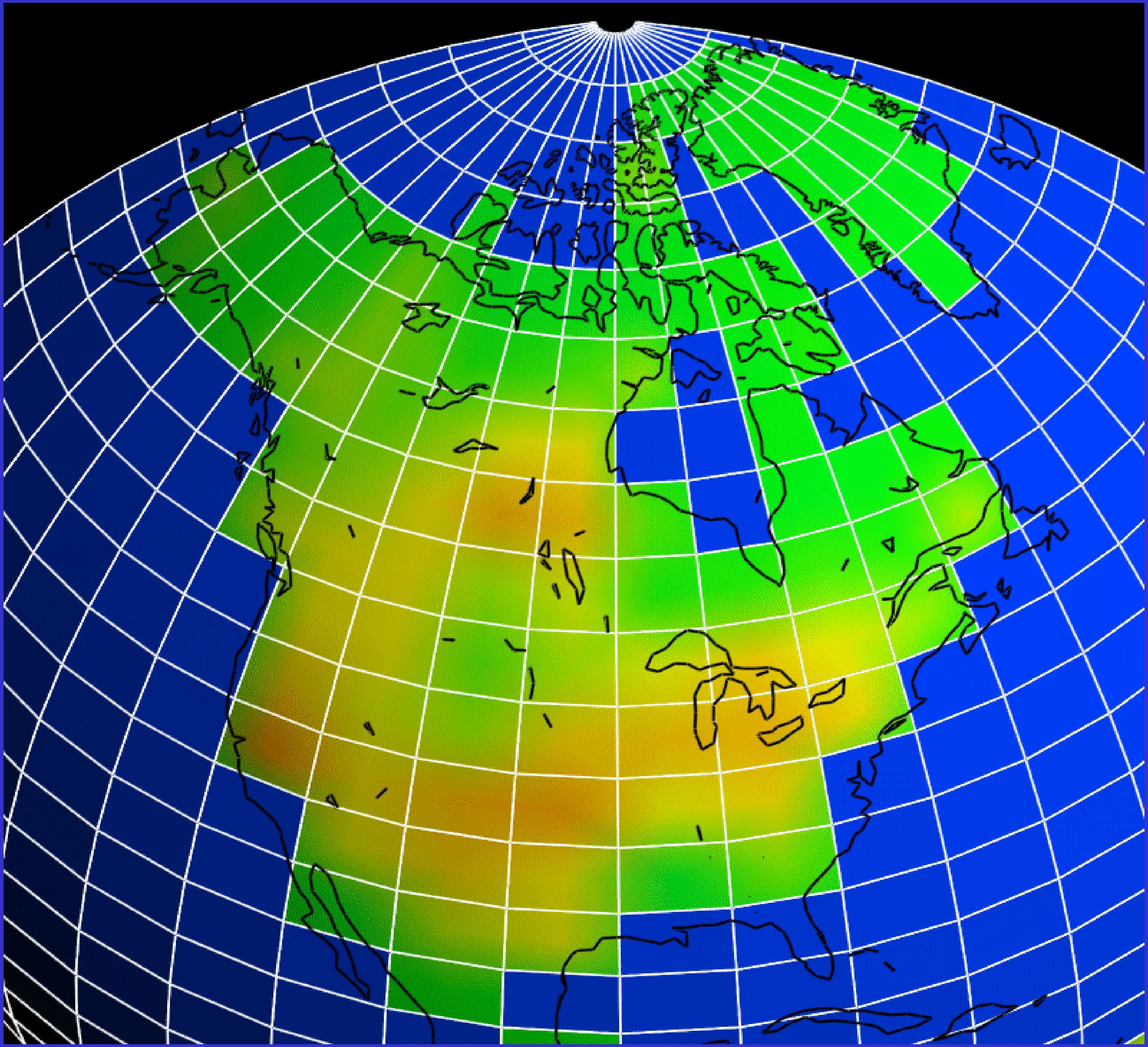
EOS 85:385 (2004)

Sierra Nevada Snowpack Projections Based on Different Emissions/Warming Scenarios

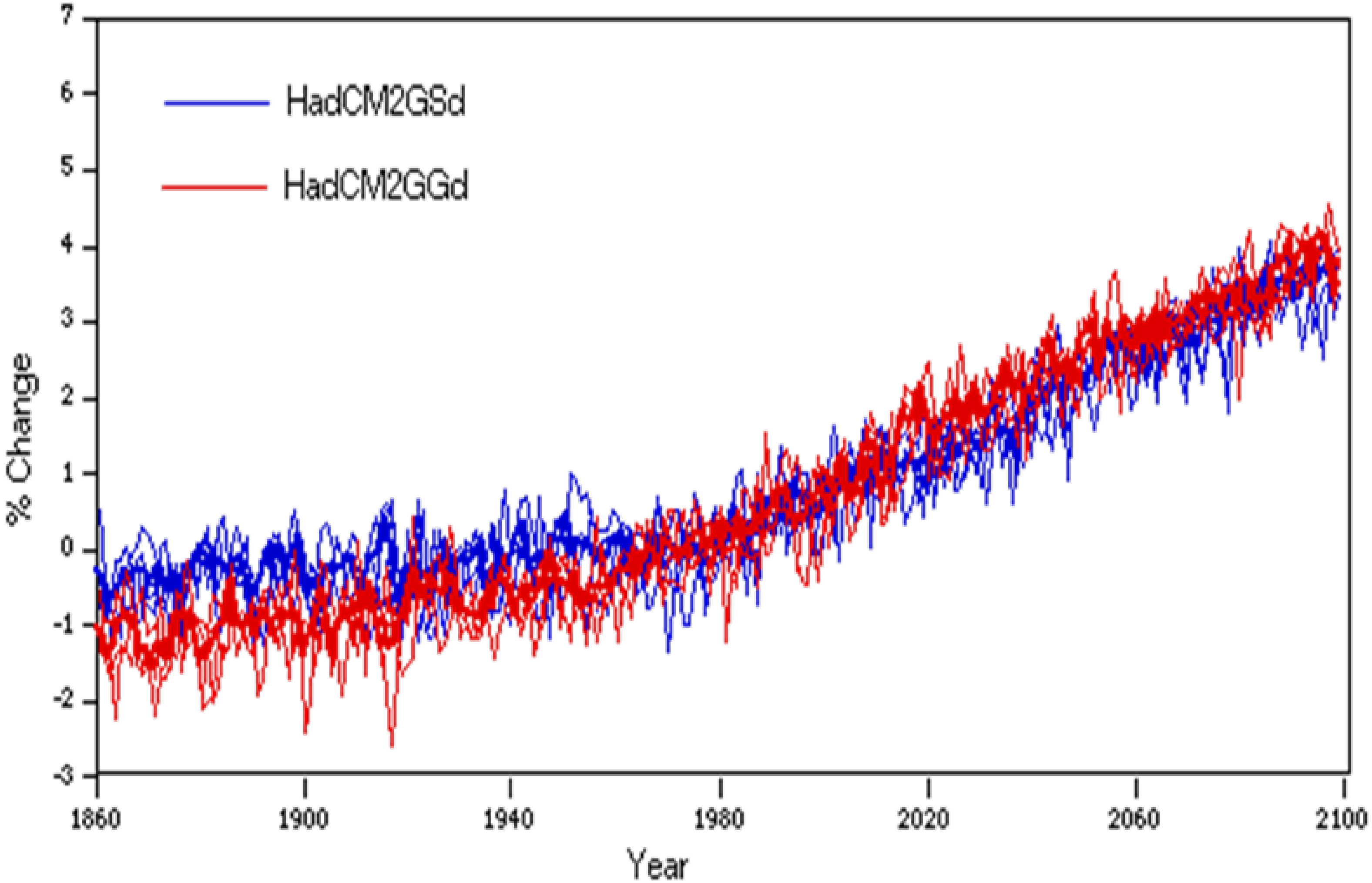


Hayhoe, Cayan, Field et al. (2004) PNAS 101:12422-12427

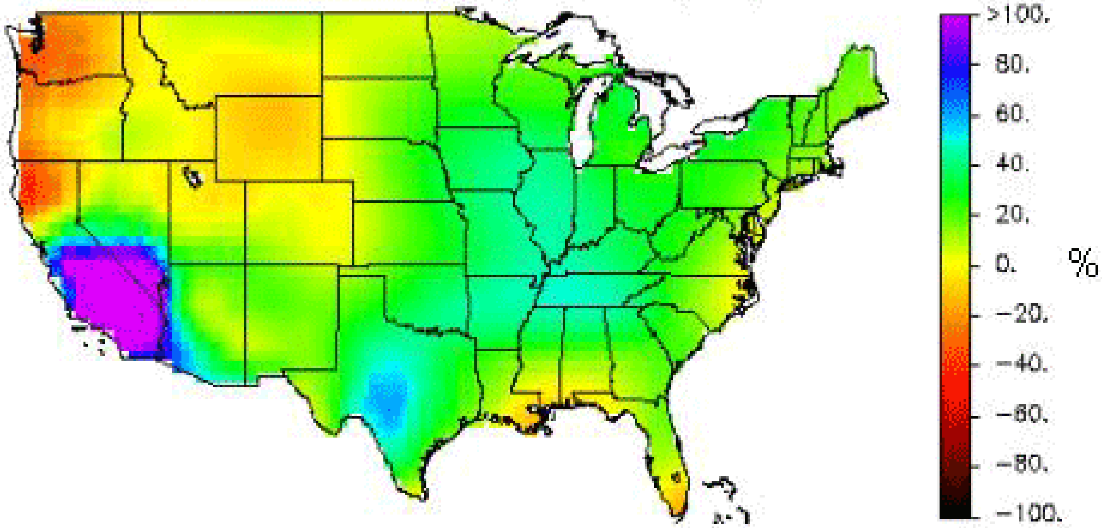
Predicted Soil Moisture in Late 21st Century



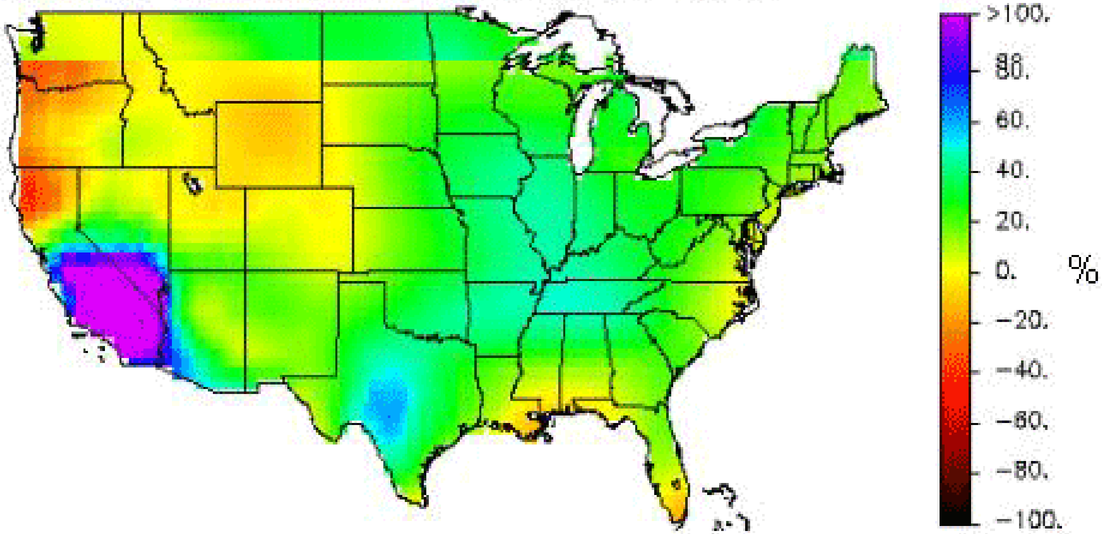
Past and Future Predicted Global Precipitation (Hadley GCM)



HadCM2 % Trend in Precipitation (JJA)



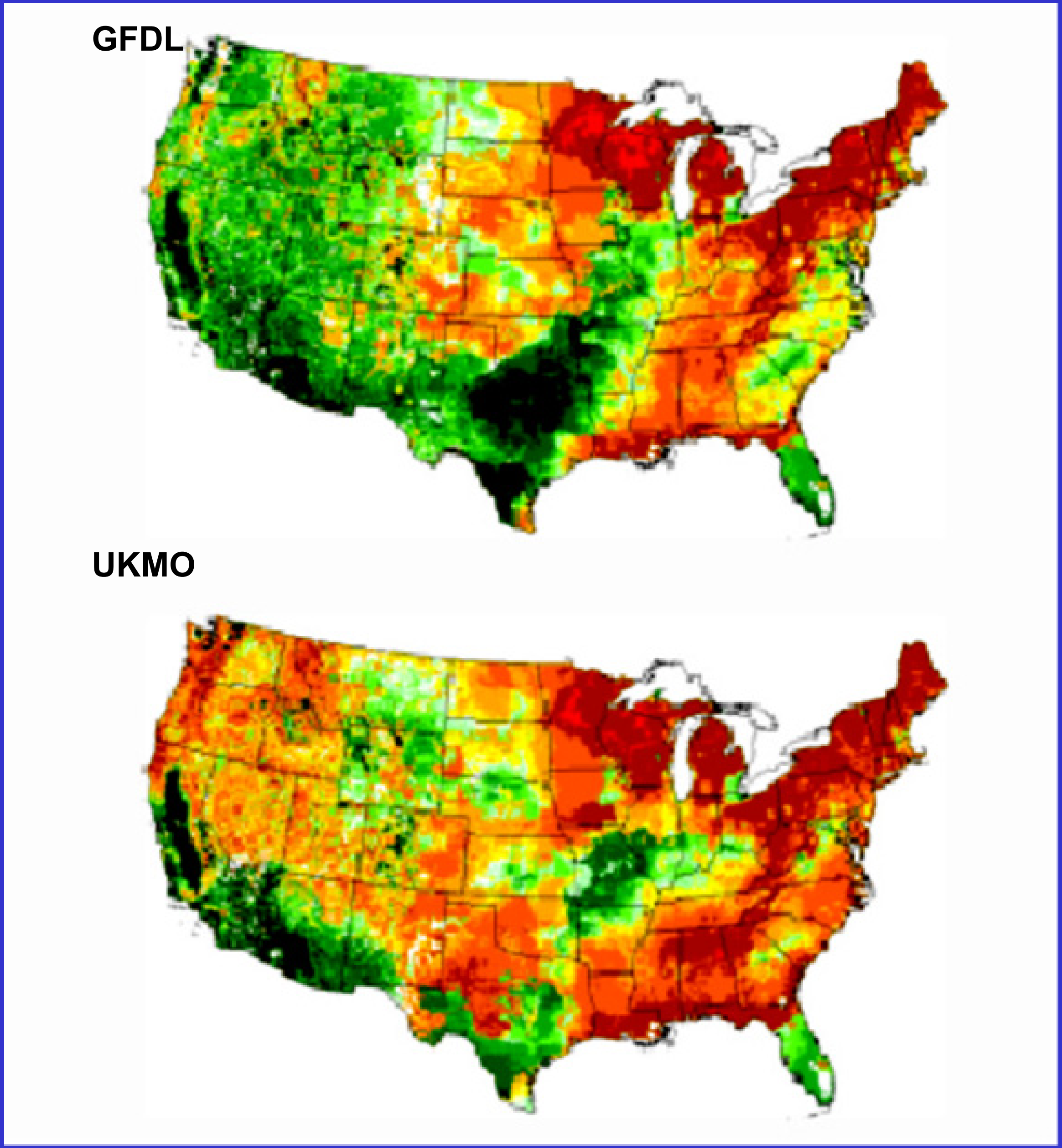
HadCM2 % Trend in Precipitation (DJF)



Increase in Vegetation Density

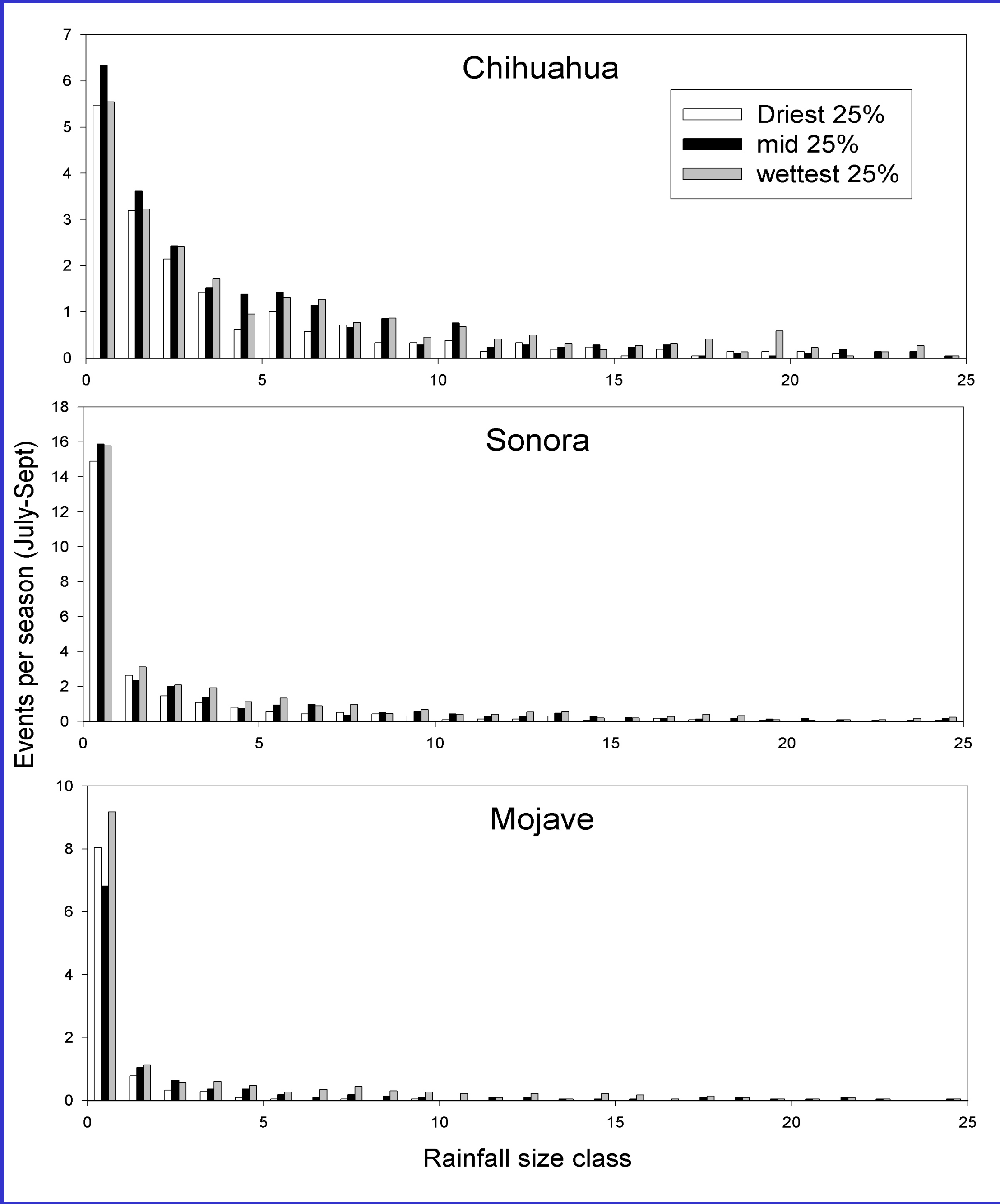
>200%
100 - 200%
50 - 100%
25 - 50%
10 - 25%
1 - 10%
No Change
1 - 10%
10 - 25%
25 - 50%
50 - 75%
75 - 100%
100%

Decrease in Vegetation Density



(From: Our Changing Planet, 1997)

Size-Frequency of Summer Rainfall Events in the SW Deserts



Huxman et al. (2004)

If Total Summer

Rainfall Increases,

We Will See

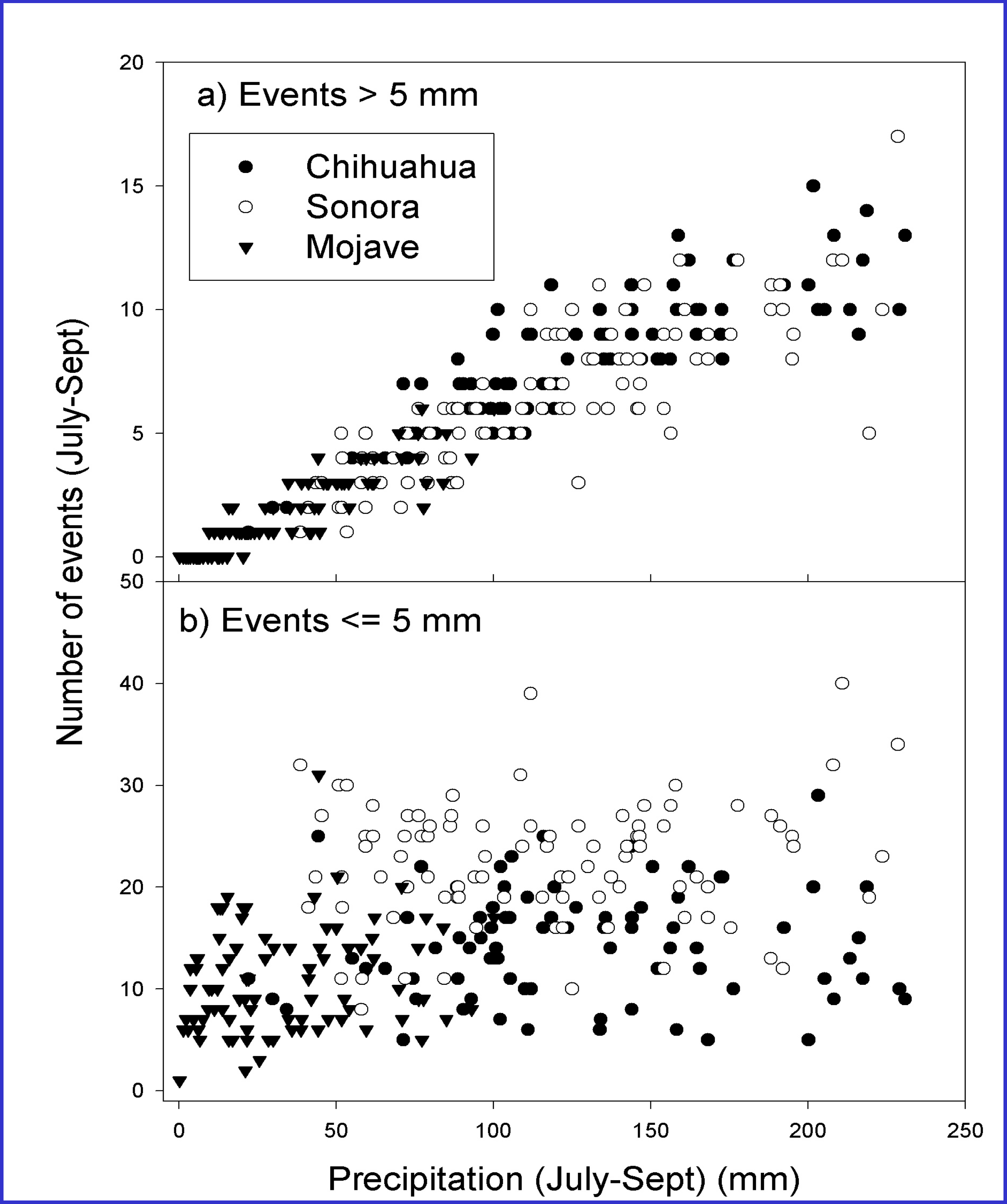
Disproportionately

More Large

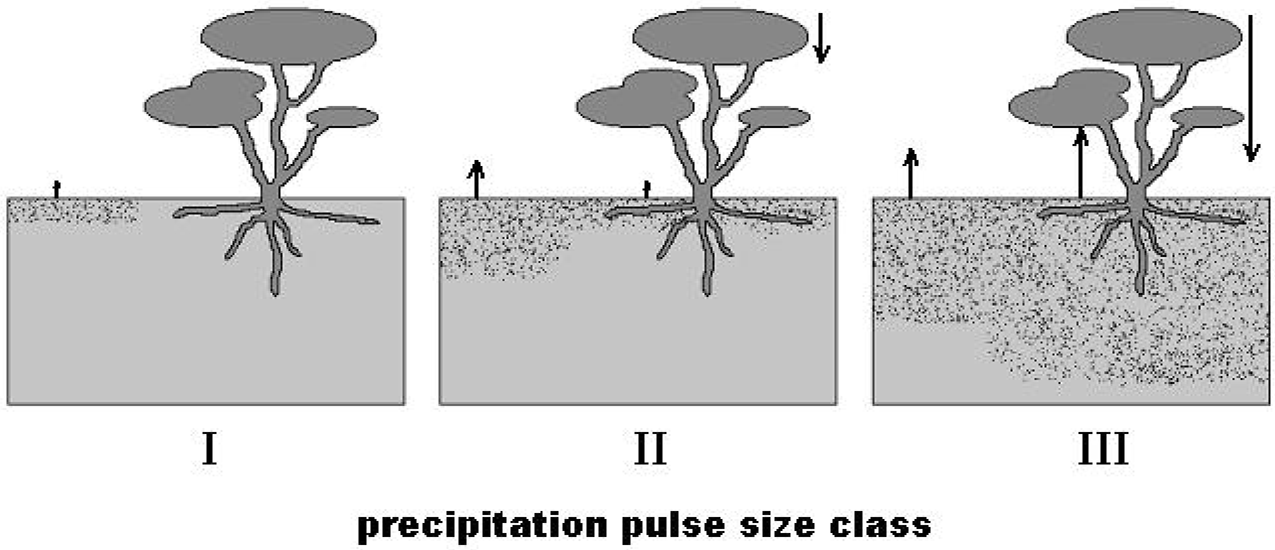
(> 5 mm)

Rainfall Events

Huxman et al. (2004)

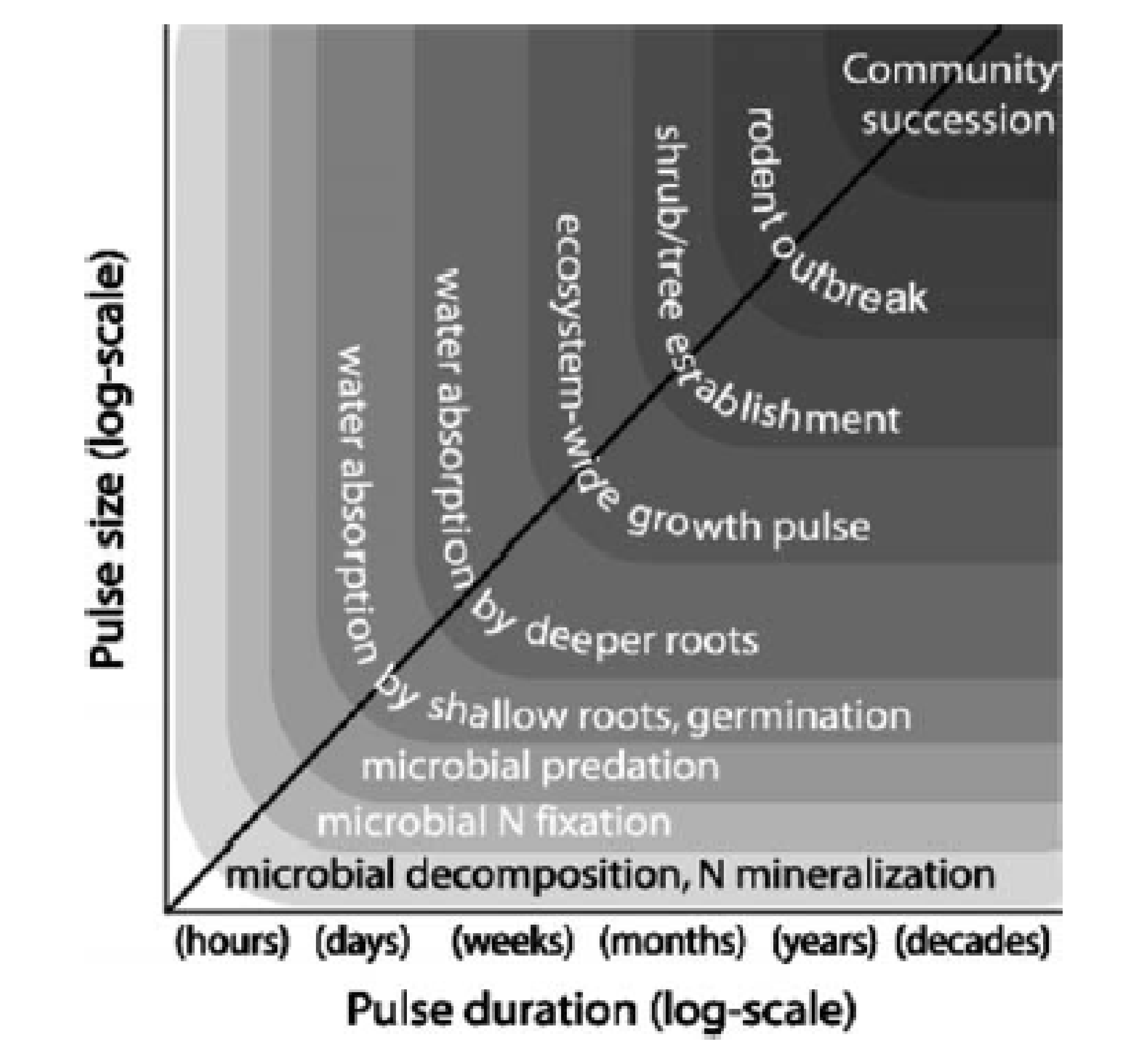


Differential Use of Large and Small Summer Rainfall Events



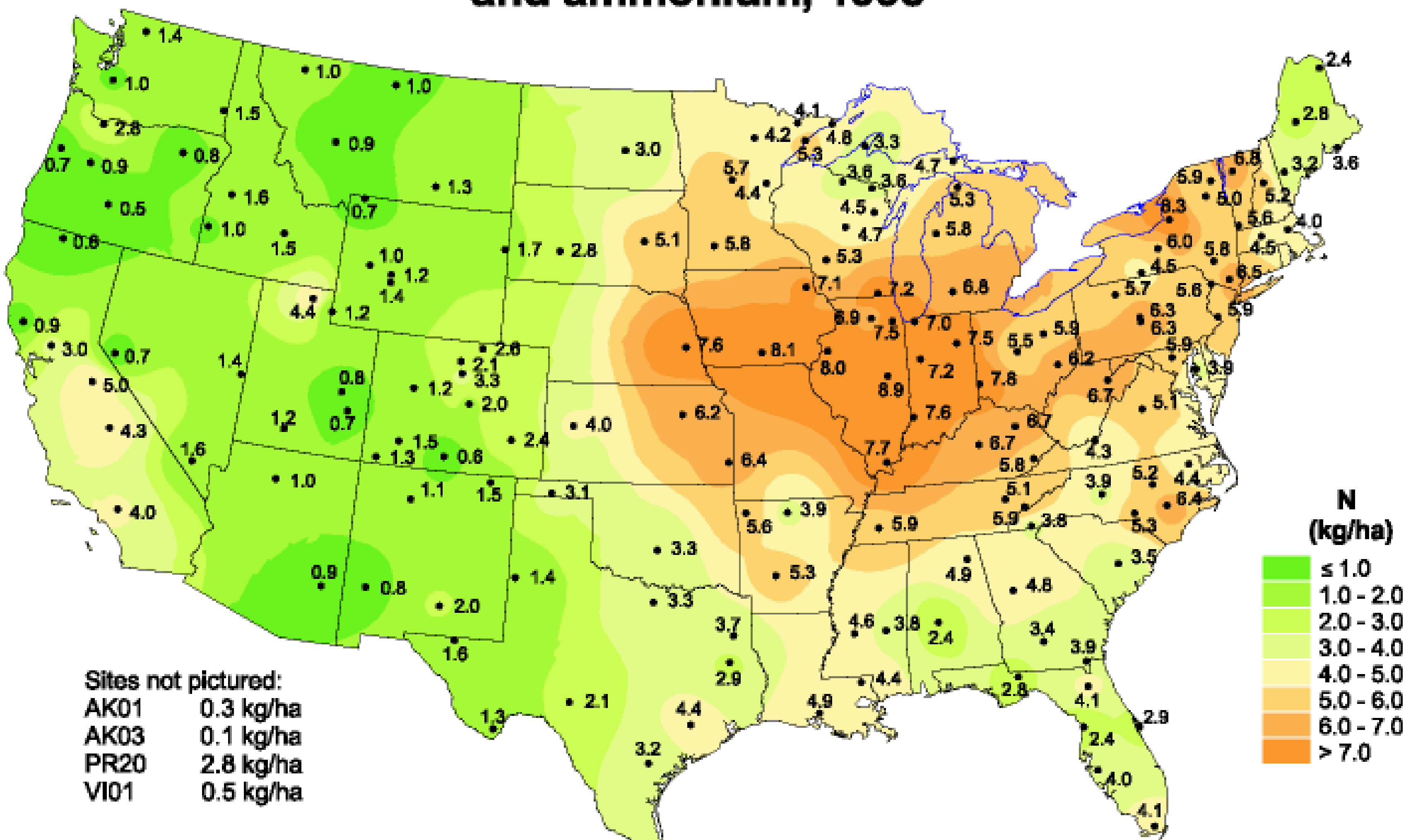
Huxman et al. (2004)

Potential Ecosystem Change with Changing Precipitation Regime



from Schwinning et al. (2004)

Estimated inorganic nitrogen deposition from nitrate and ammonium, 1998



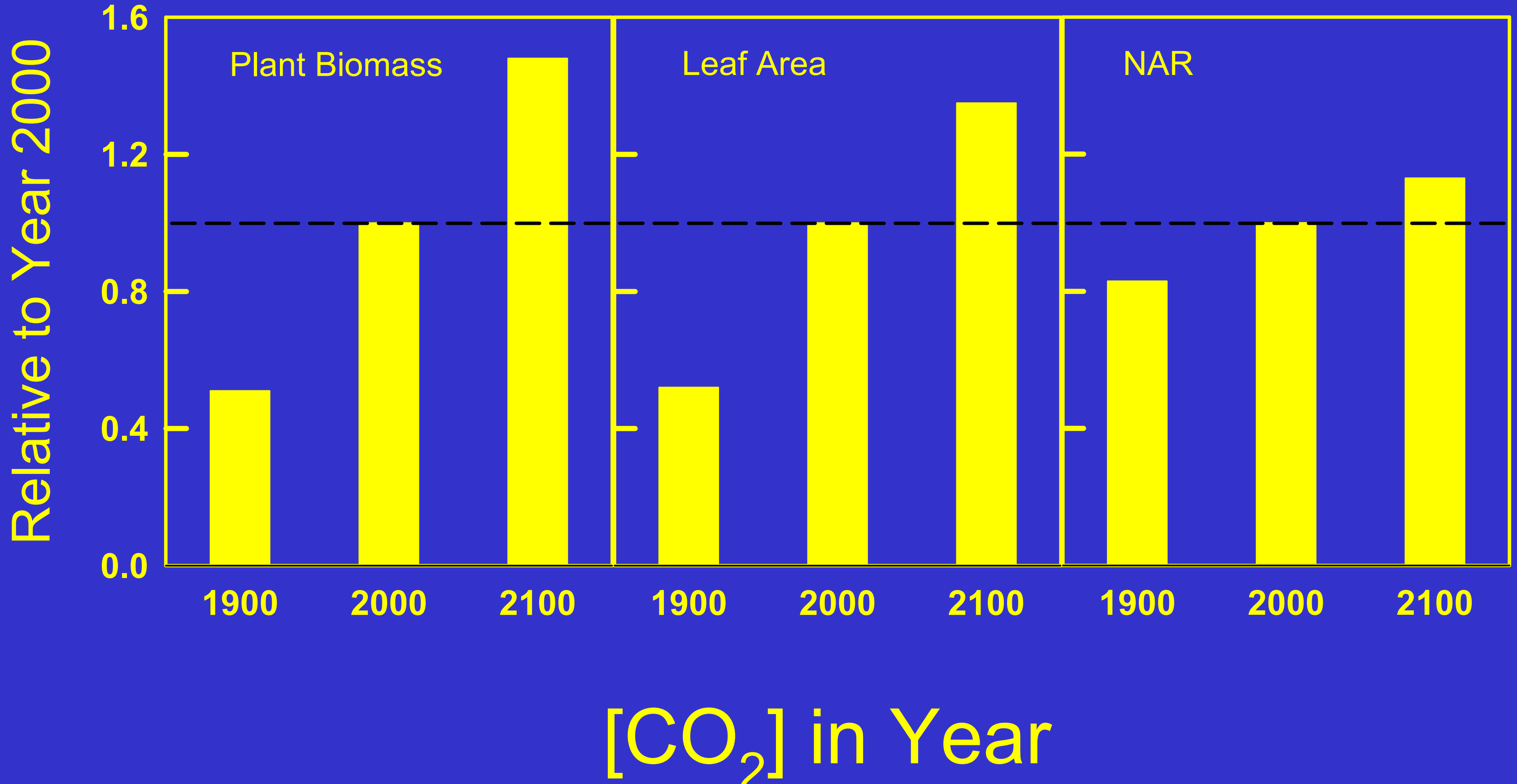
National Atmospheric Deposition Program/National Trends Network
http://nadp.sws.uiuc.edu

Possible Impacts of Global Change Elements on the Prevalence of Invasive Species

Element of Global Change	Prevalence of Invaders
Increased [CO_2]	+/–
Climate Change	+
Increased N Deposition	+
Altered Disturbance Regimes	+
Increased Habitat Fragmentation	+

Dukes & Mooney (1999)
Trends Ecol & Evol **14:135-139**

Relative Growth of Six Invasive Species at [CO2] in 1900, 2000 and 2100



Ziska (2000)

Production of *Centaurea solstitialis* (yellow starthistle) at elevated [CO_2] in monoculture and polyculture

	Percent Increase (~2X [CO_2])	
	Aboveground Biomass	**Reproductive Biomass**
Centaurea **in monoculture**	+ 70%	+ 91%
Centaurea **in polyculture**	+ 69%	+ 47%
Total polyculture	+ 28%	

Dukes (2002)
Plant Ecology **160:225-234**

Effects of Elevated CO_2 (2X Ambient) on Dry Weight of Four Great Basin Grasses

Species (Functional Type)	Biomass (g $plant^{-1}$) Seedling	Mature
Bromus tectorum (C_3 invasive annual)	+ 93%	+ 54%
Agropyron smithii (C_3 rhizomatous grass)	+ 47%	+ 31%
Oryzopsis hymenoides (C_3 bunchgrass)	—	+ 10%
Eragrostis orcuttiana (C_4 weedy annual)	+ 38%	+ 51%

Smith, Strain & Sharkey (1987)
Functional Ecology **1:139-143**

The Nevada Desert Research Center

NDRC: Principal Investigators

Plant Gas Exchange	Stan Smith & David Barker, UNLV
Aboveground Production	Stan Smith & Beth Newingham, UNLV
Belowground Processes	Bob Nowak (UNR) & Paul Verburg (DRI)
Water Balance	Bob Nowak (UNR) & Michael Young (DRI)
Nutrient Dynamics	Dave Evans, Washington St.
Biological Soil Crusts	Jayne Belnap, USGS-Moab Lloyd Stark & Stan Smith, UNLV
Microbial Community	Eduardo Robleto, UNLV
Landscape Gas Exchange	Jay Arnone, DRI (CO_2) Travis Huxman, Univ. Arizona (CO_2) Jed Sparks, Cornell (NO_x)
Remote Sensing	Lynn Fenstermaker, DRI John Gamon, Cal. State LA Susan Ustin, UC-Davis
Ecosystem Modeling	Jim Reynolds, Duke Univ. Paul Kemp, Univ. of San Diego

*NDFF Experimental design

Nevada Desert FACE Facility
- Mojave Desert
- elevation: ~970 m
- annual precip: ~140 mm
- max temp: ~ 45 C (Jul-Aug)
- min temp: ~ -10 C (Dec-Jan)

Control
- ~365 µmol mol^{-1}

FACE
- set point: 550 µmol mol^{-1}
- start date: April 28, 1997
- 24 h d^{-1} 365 d yr^{-1}
- conditional shutdowns: high wind & cold temperature

Jordan et al. (1999) GCB


NON-POTABLE WATER
LIQUID
CARBON DIOXIDE

Oblique aerial view of Ring 3; an elevated CO_2 treatment plot

Walkway: Preserve Biological Soil Crust N_2 Fixation


SMITH

Variables Measured at NDFF

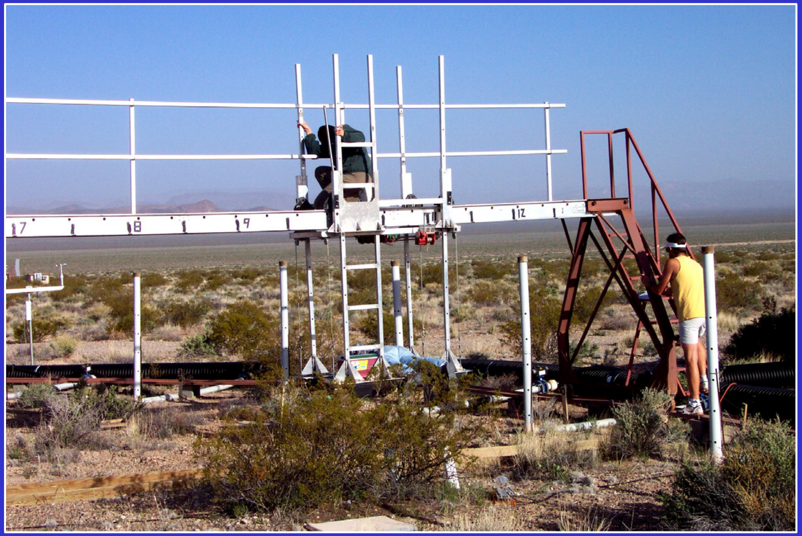
Physiology
- Leaf gas exchange
- Root physiology

Aboveground production
- Biomass
- Litter
- Carbon pools/fluxes
- Nitrogen pools/fluxes

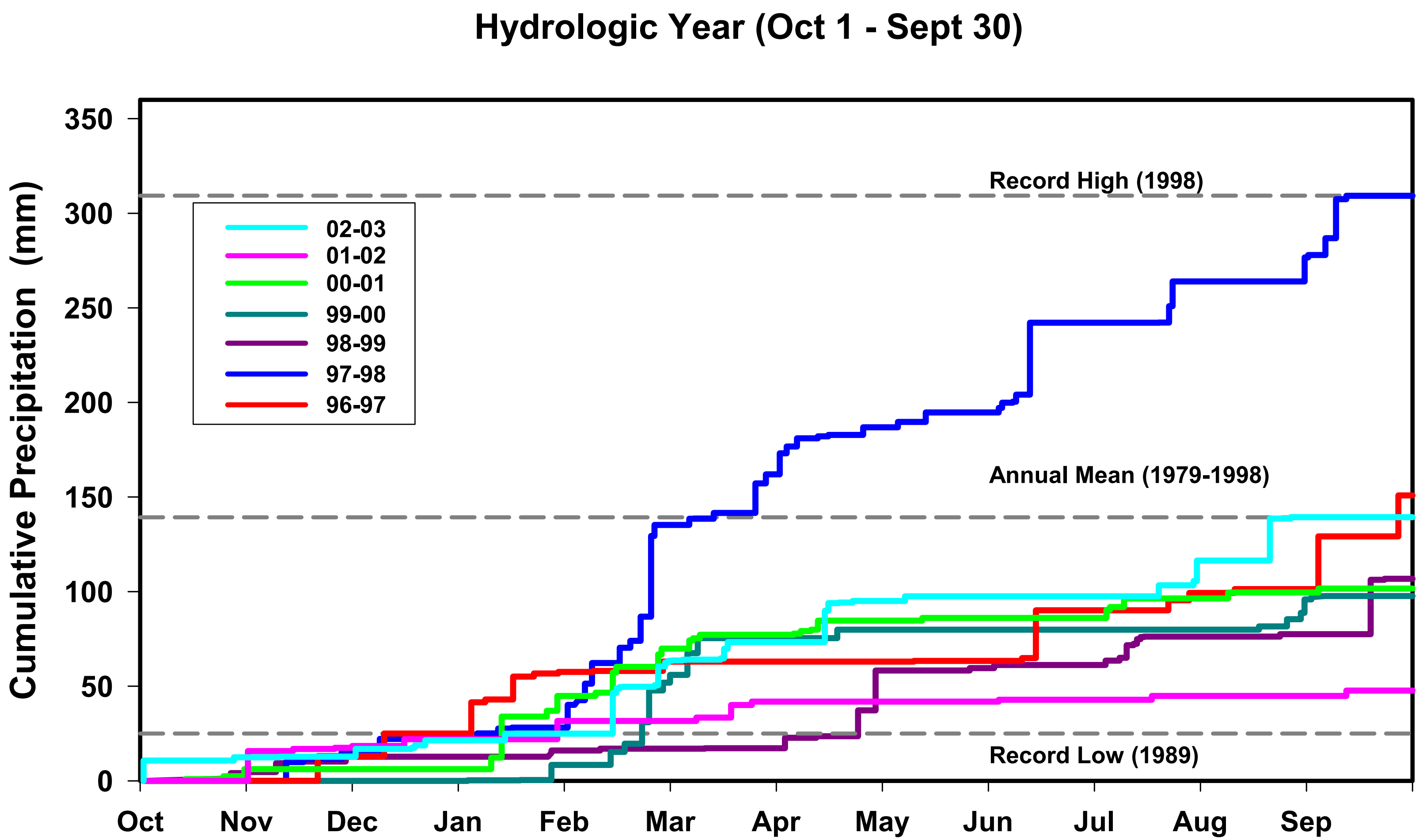
Belowground production
- Root
- Microbial
- Carbon pools/fluxes
- Nitrogen pools/fluxes

Soil water content

Biodiversity
- Plants
- Insects

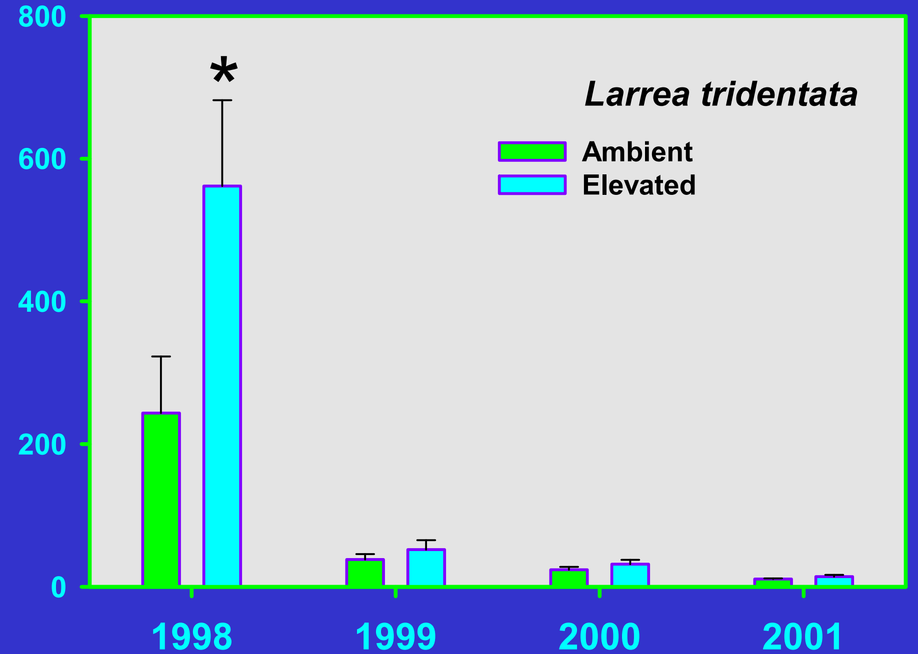


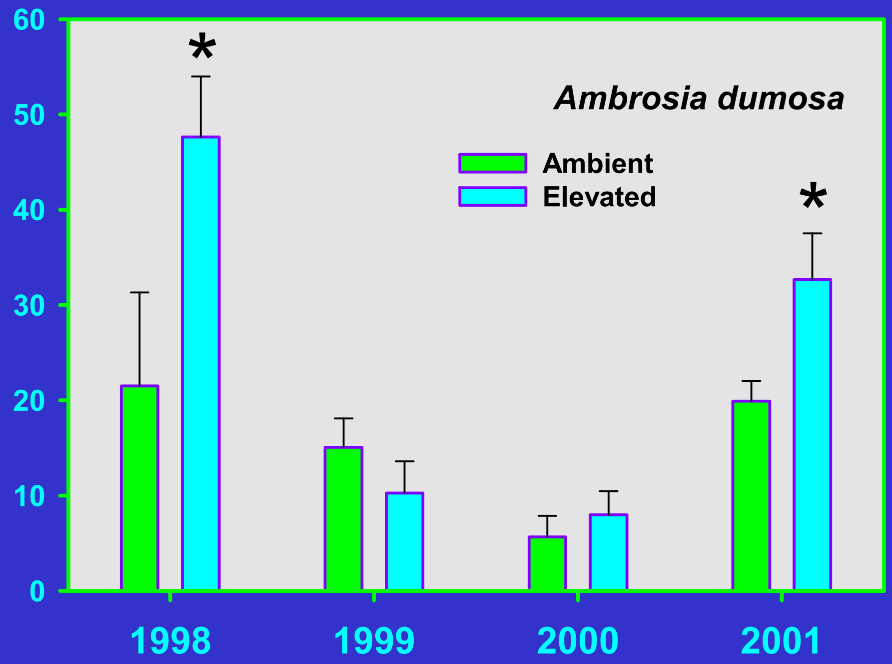
Precipitation at the NDFF 1996-2003

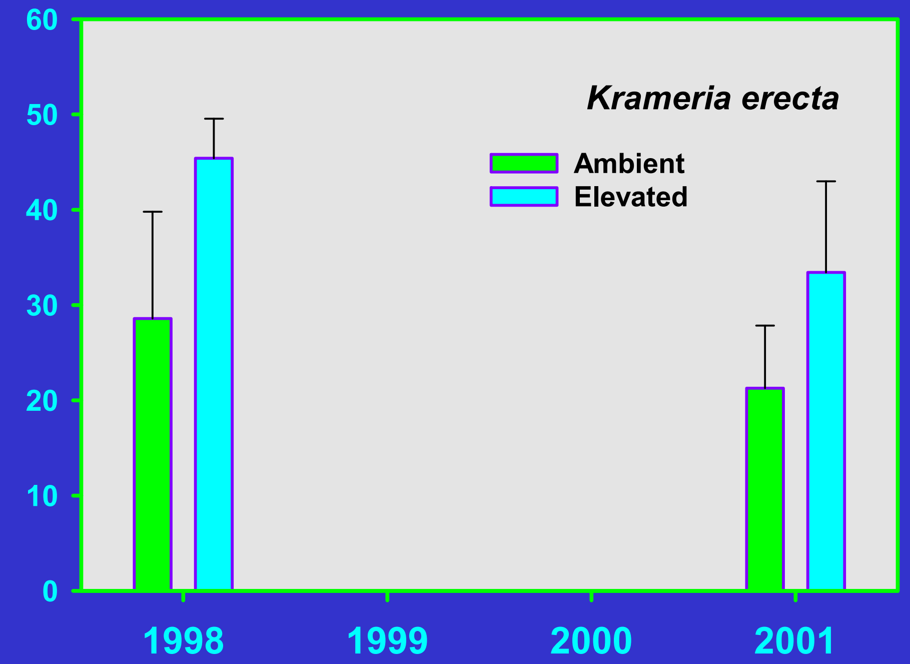


NDFF
1998 - 2001

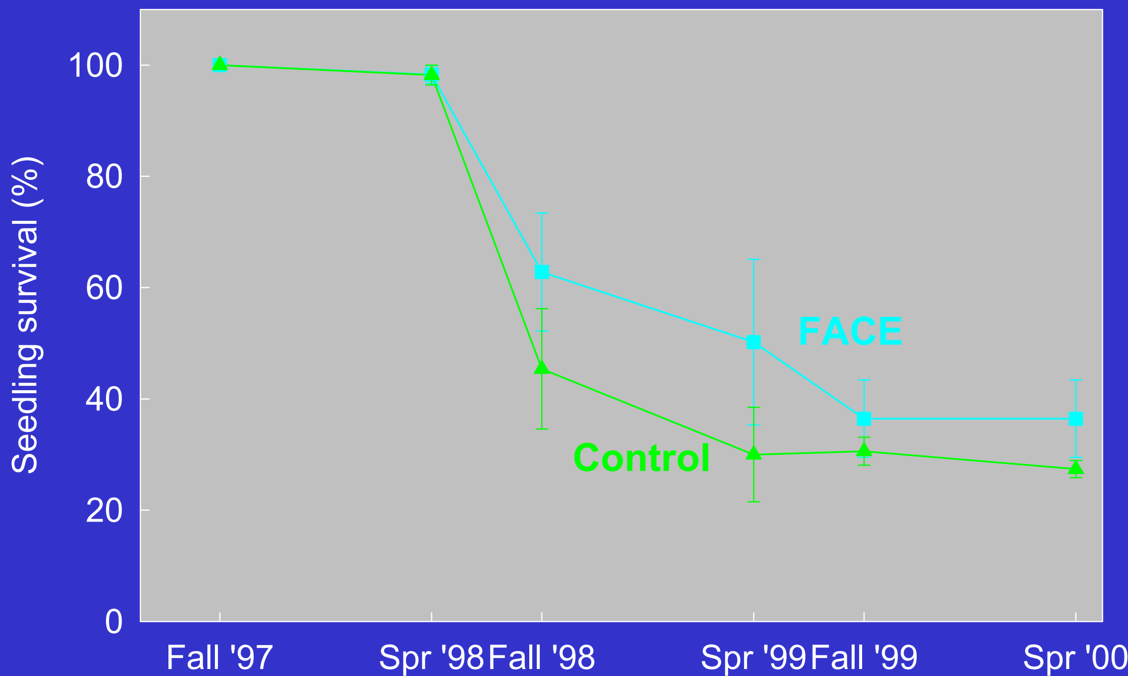
Cumulative Shoot Biomass (mg)



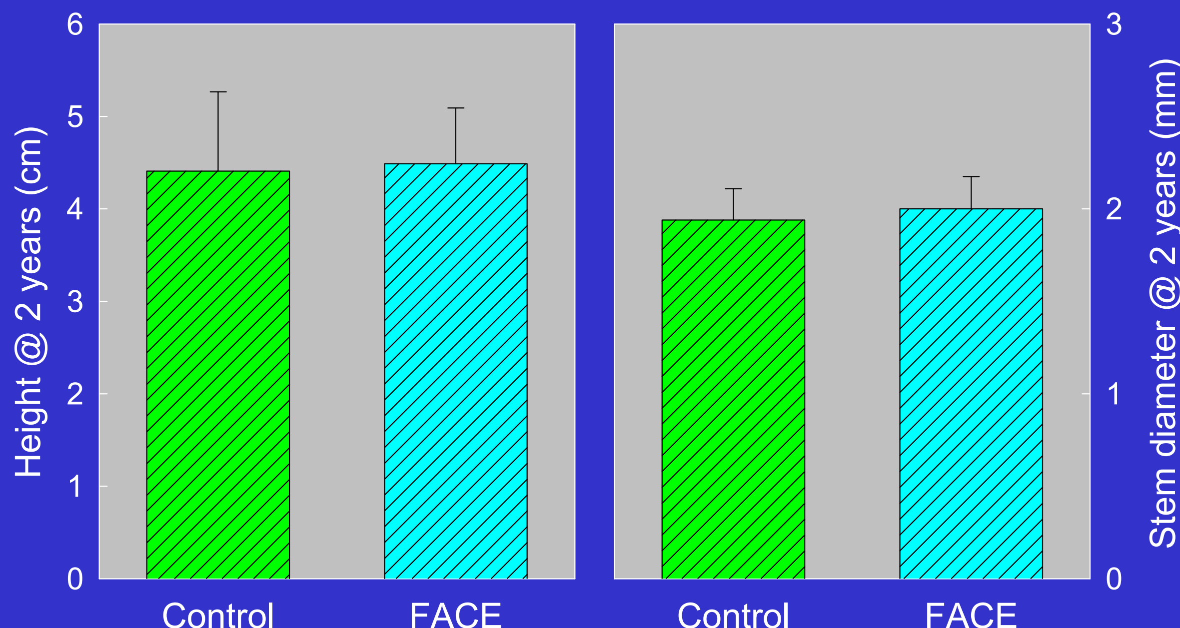




Larrea and *Ambrosia*

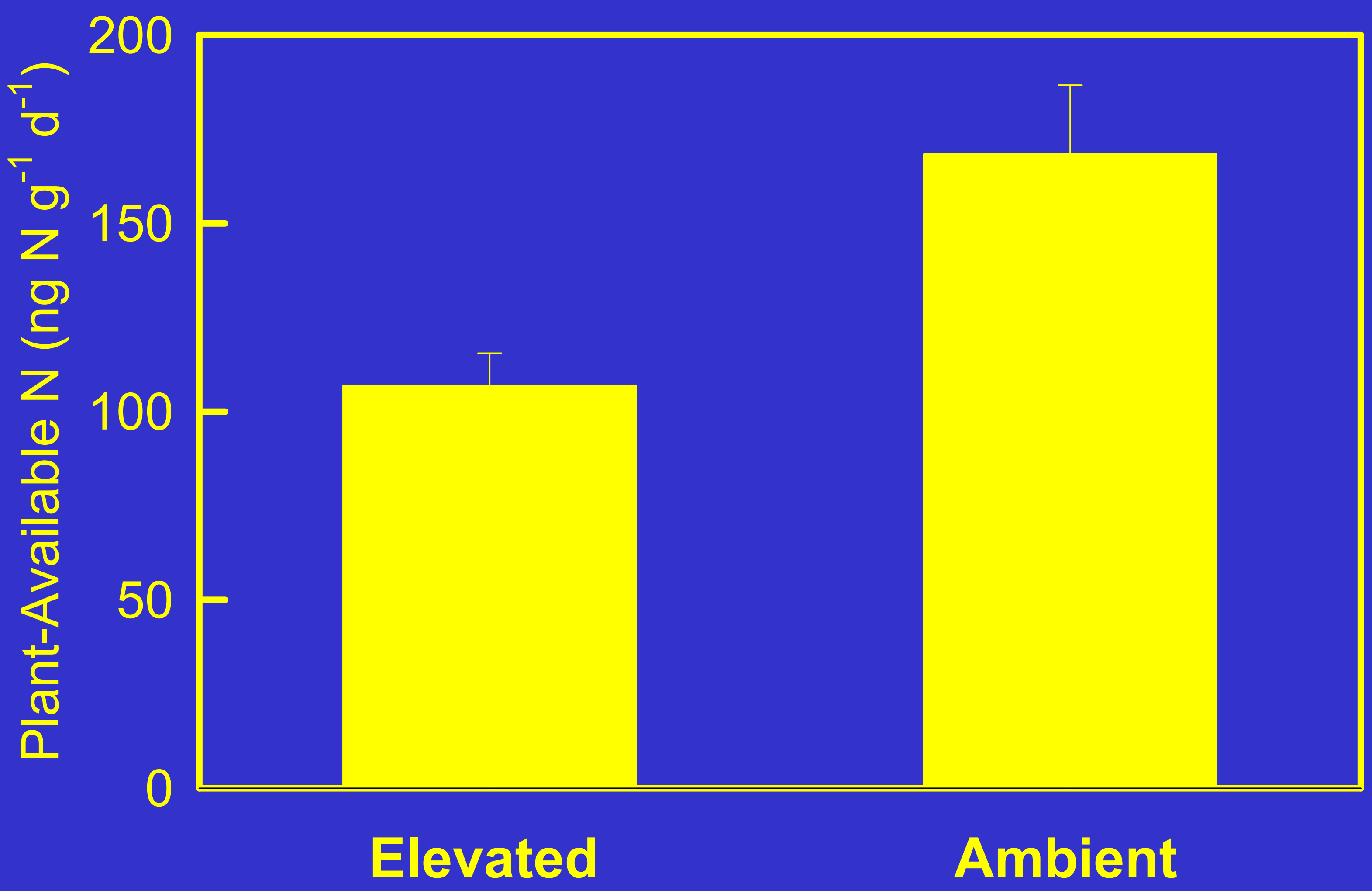


*Seedling recruitment

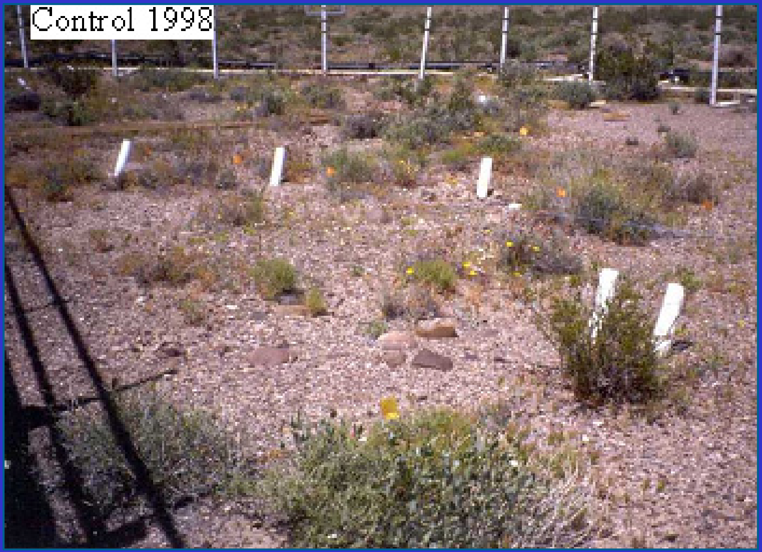


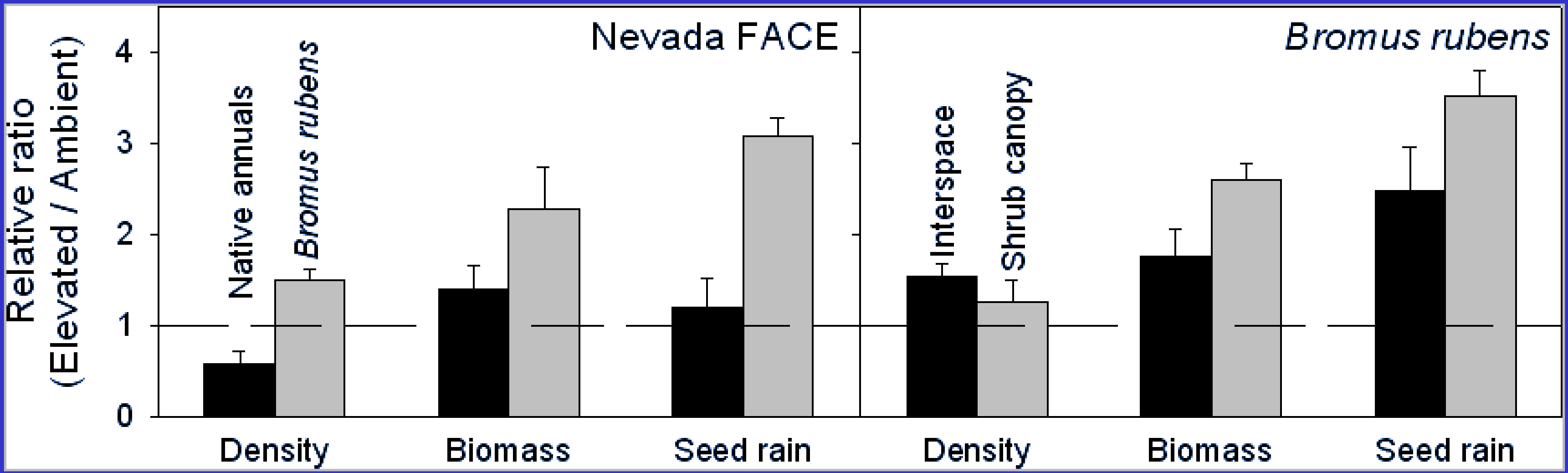
Housman et al. (2003)
Global Change Biology

Plant – available N



Productivity of Annuals: 1998





Smith et al. (2000) ***Nature*** **408:79-82.**

Why does *Bromus* Respond More to Elevated CO_2 Than Do Native Species?

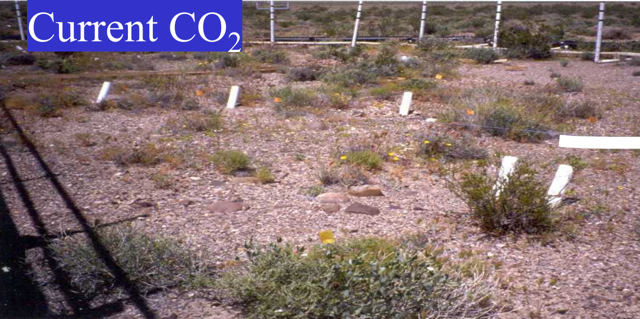
1. Accelerated phenology

2. Produces smaller, more numerous seeds

3. Lower construction cost


Current CO_2

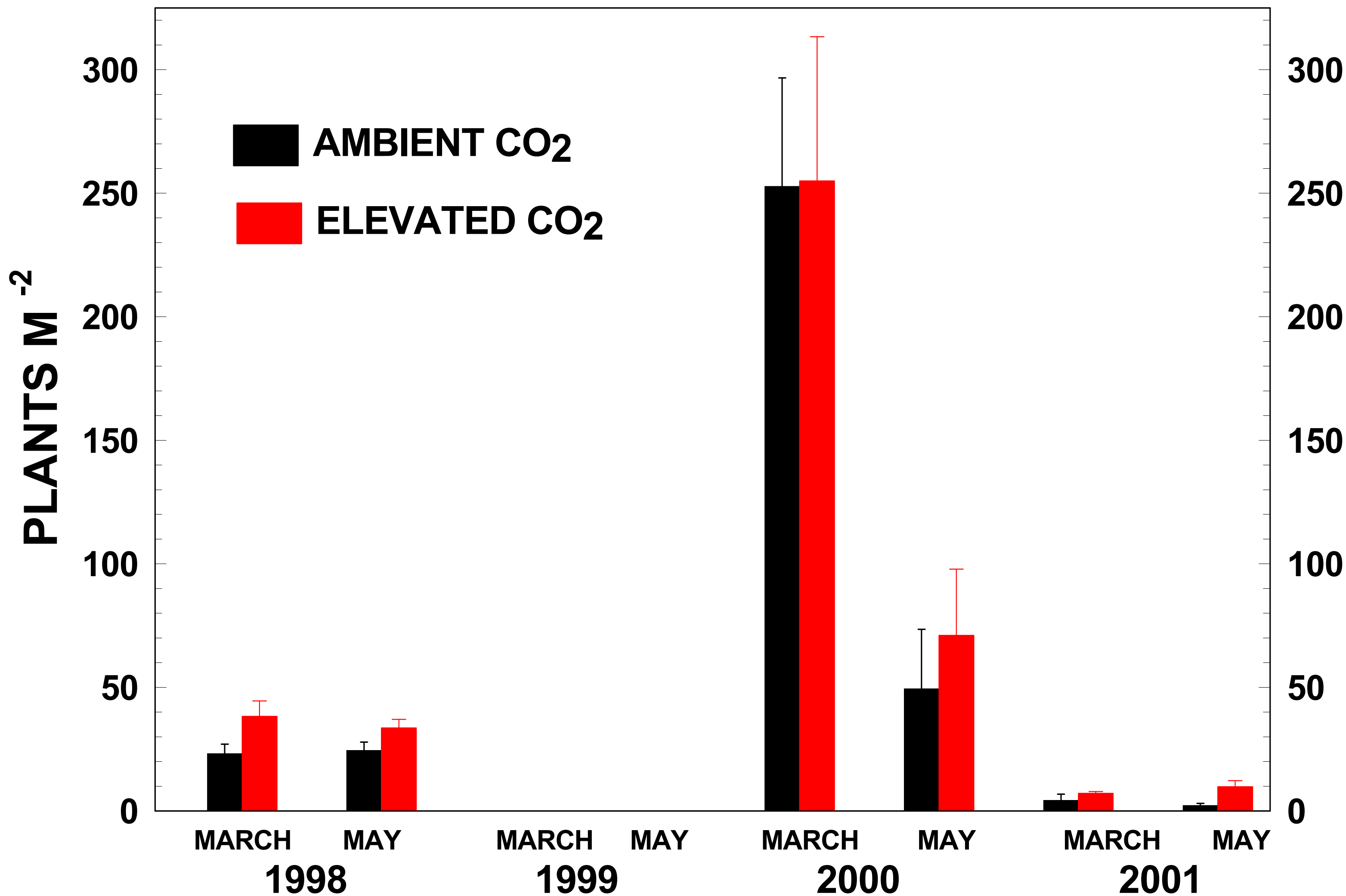

Elevated CO_2

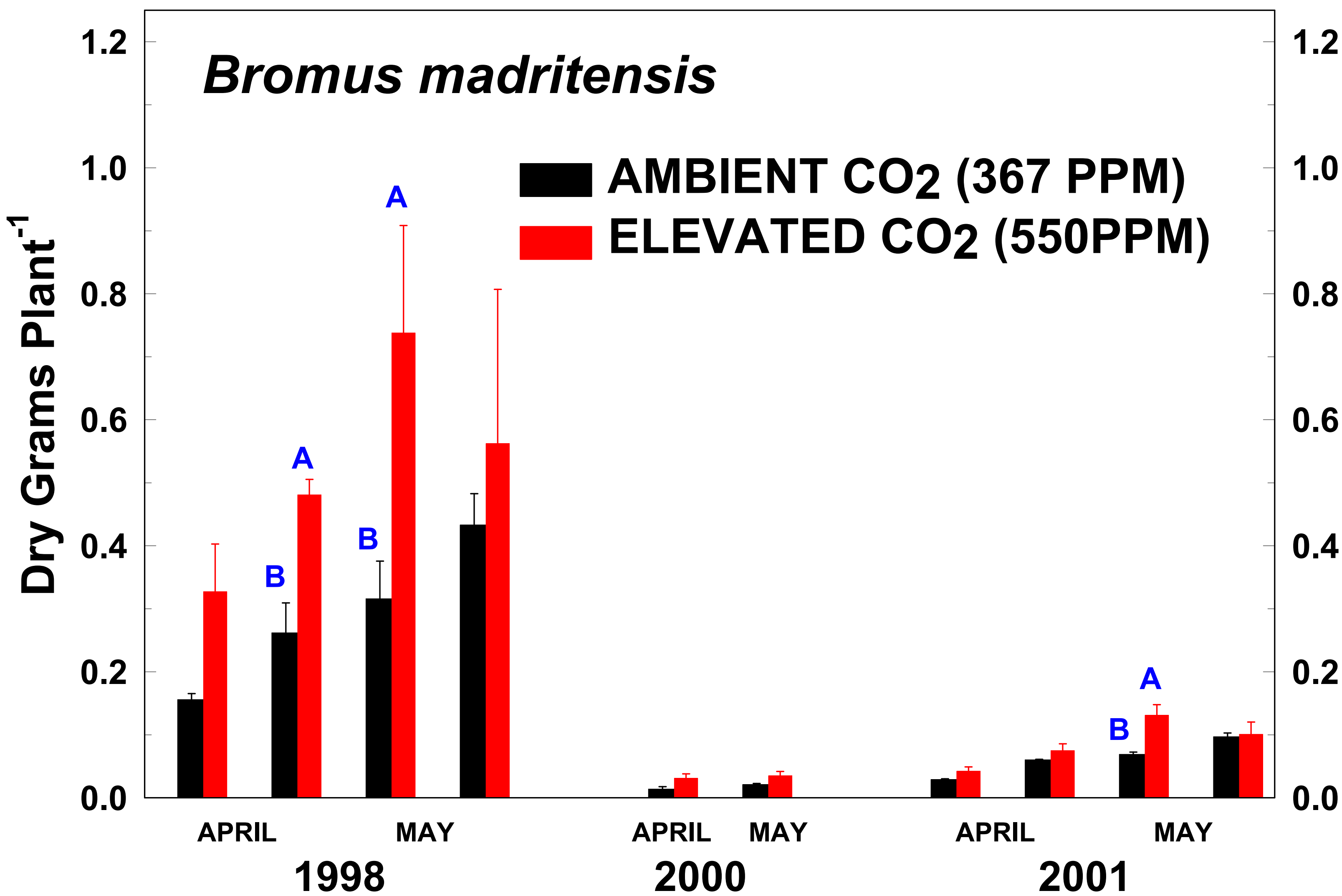


Community change

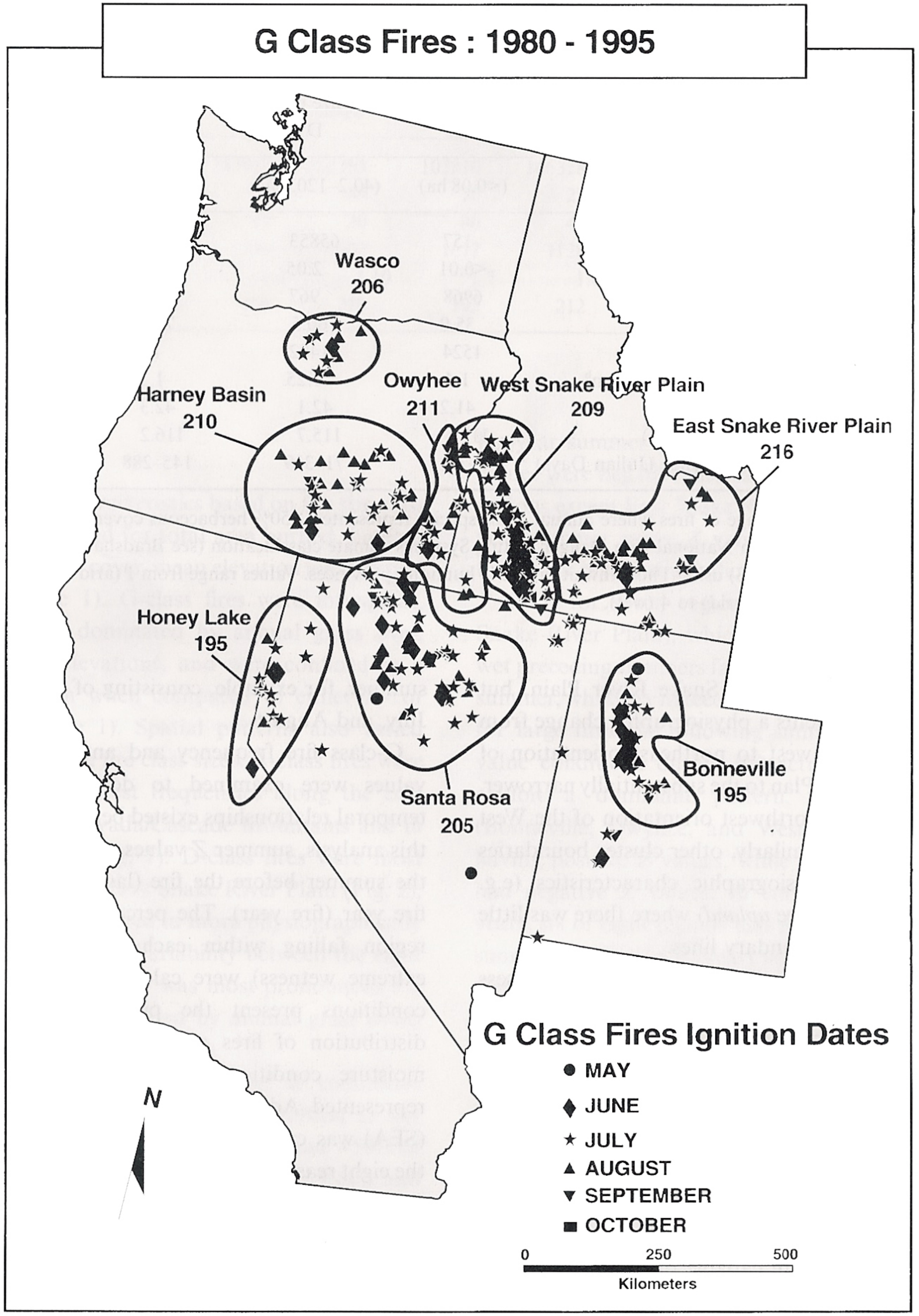
Photos by T. Huxman & T. Esque

Bromus madritensis ssp. *rubens*





Bromus madritensis
AMBIENT CO2 (367 PPM)
ELEVATED CO2 (550PPM)
Dry Grams Plant-1
1.2
1.0
0.8
0.6
0.4
0.2
0.0
A
B
A
B
B
A
APRIL
MAY
1998
APRIL
MAY
2000
APRIL
MAY
2001

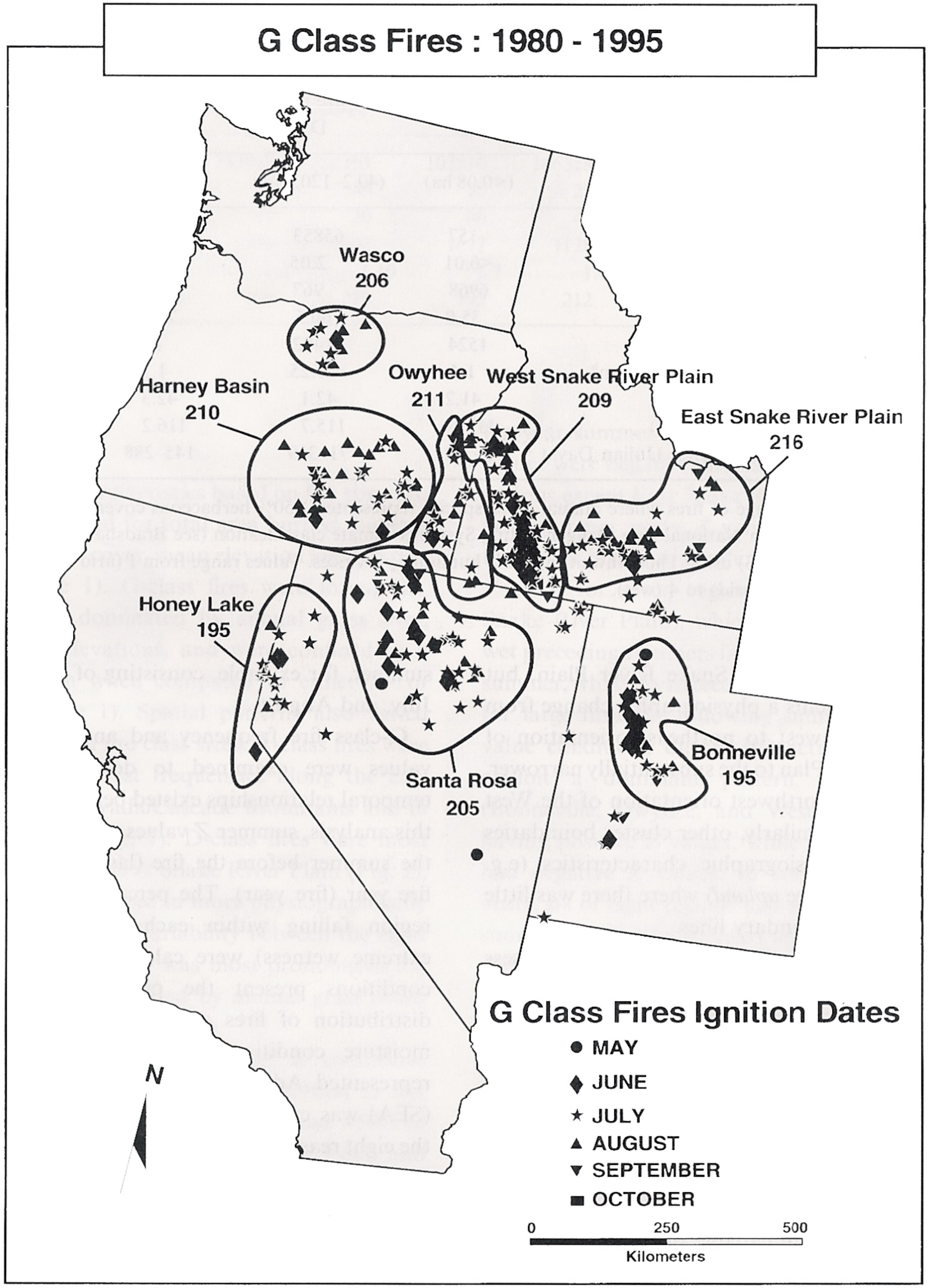


Class G Fires:

> 2,000 ha in Area

Knapp (1998)

Global Ecology & Biogeography Letters



Correlations with Annual Precipitation

Years with Fire

Previous Year	(+ +)
Current Year	(–)

Years w/o Fire

Previous Year	(–)
Current Year	(+)

The Mojave Global Change Facility

A complementary facility to the Nevada Desert FACE Facility (elevated CO_2 experiment) is investigating how GCM-predicted increases in summer precipitation, nitrogen deposition and crust disturbance may impact important ecosystem processes in deserts

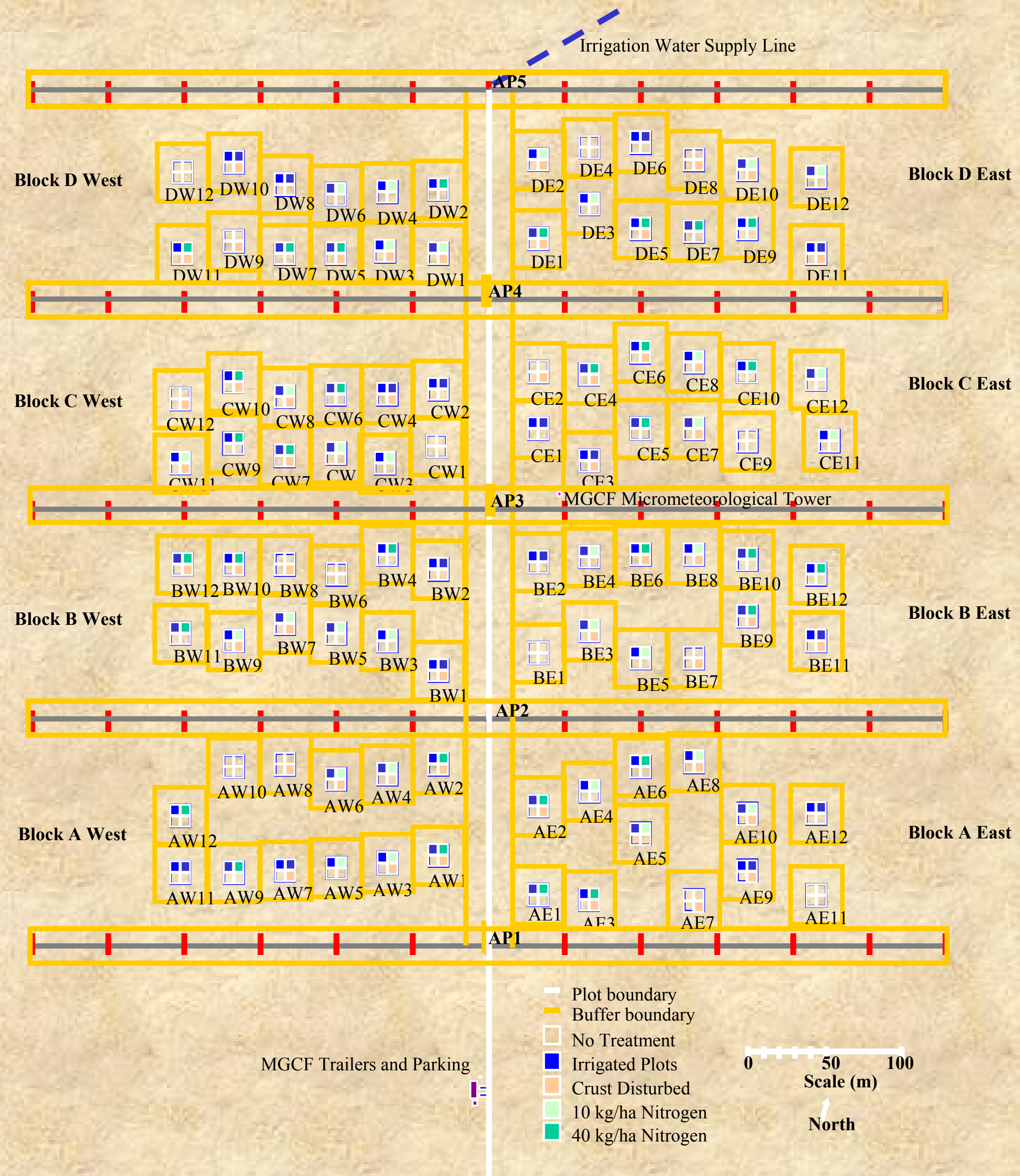
MGCF

Simulate predicted increases in:

- **summer precipitation**
- **nitrogen deposition**
- **crust disturbance**

96 plots (ea. 200 m²)

Results are integrated with NDFF data to predict how desert ecosystems will respond to global change

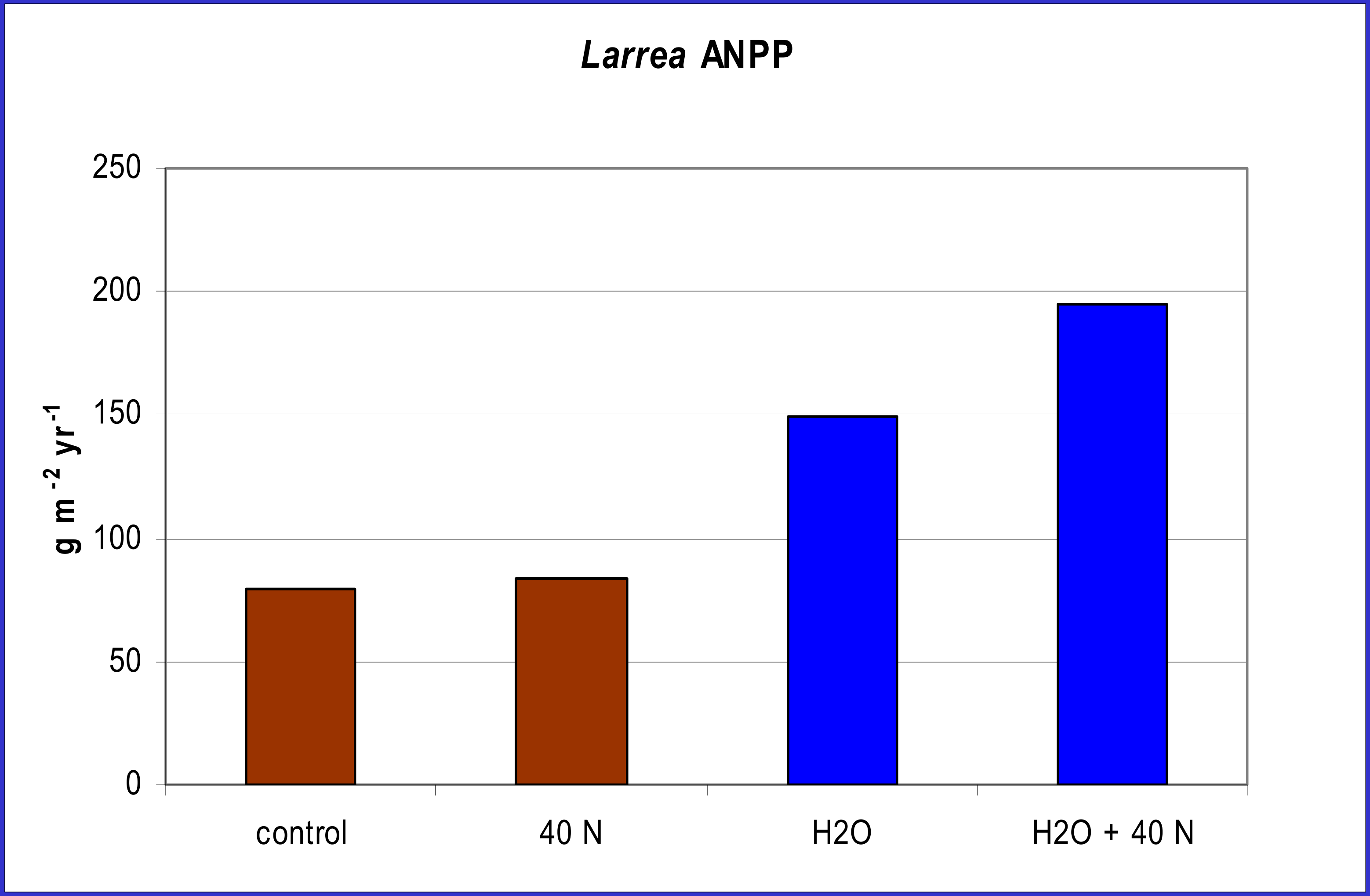


False color infrared image of MGCF from the Probe 1 hyperspectral sensor (5 meter spatial resolution 11/10/02).

MGCF Studies Initiated

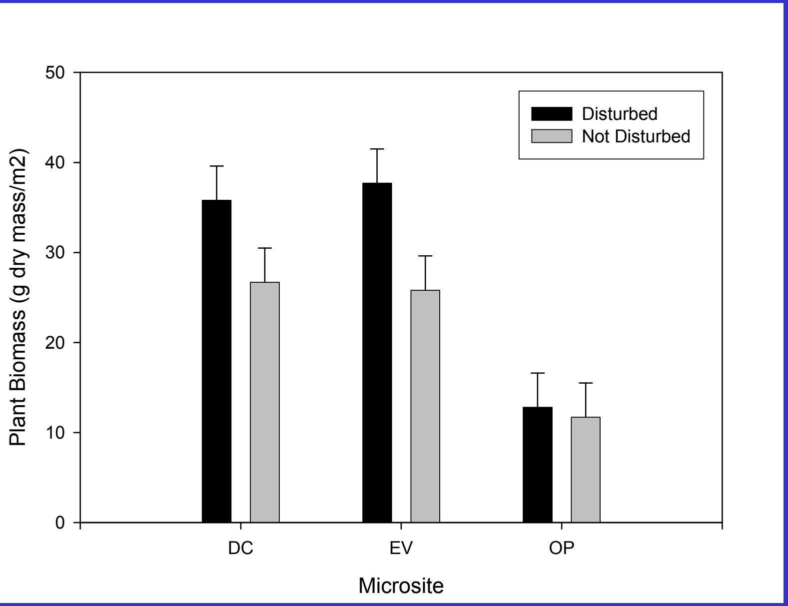
- Water uptake by roots
- Soil heterogeneity
- Nitrogen Mineralization
- Nitrogen Fixation
- Moss responses
- Soil carbon uptake and respiration
- Leaf/canopy level photosynthesis
- Primary productivity
- Soil moisture/temp differences
- Reflectance measurements
- Aerial photography

Initial Response of *Larrea* Production to Added Summer Rain and N-Deposition

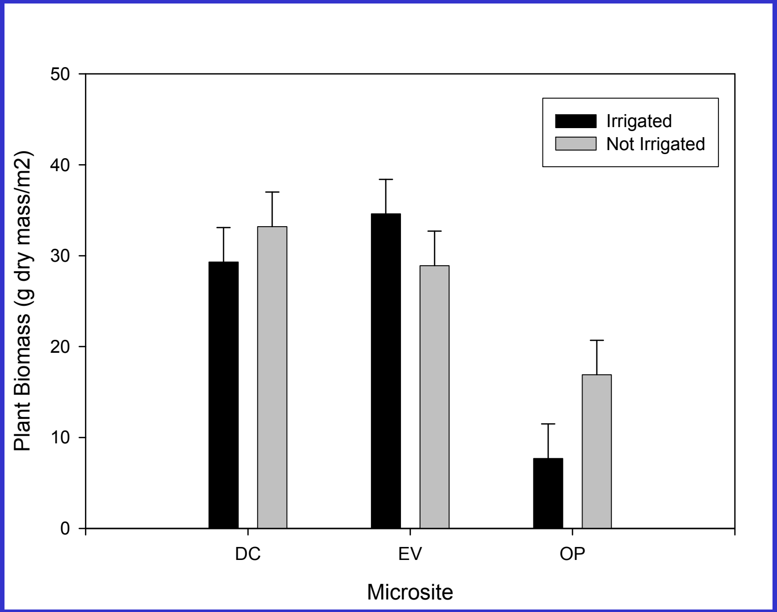


Annuals 2003

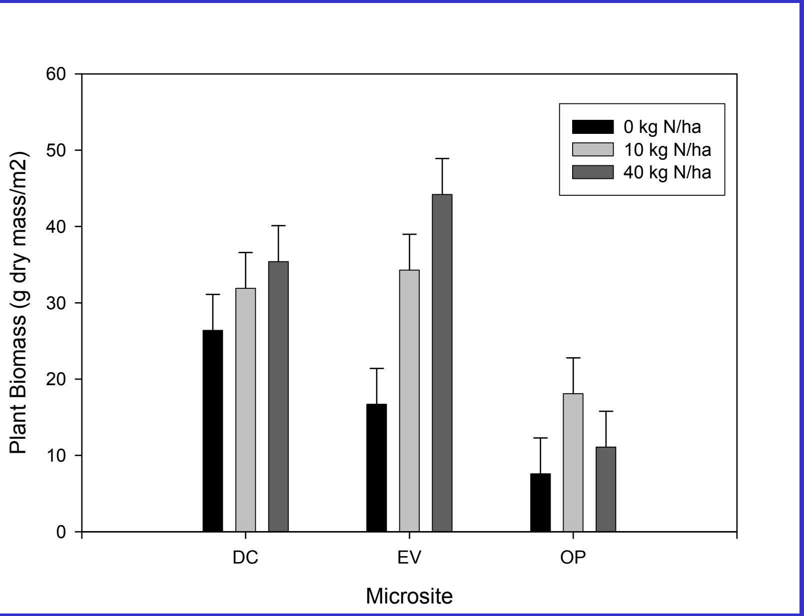
Disturbance



Irrigation

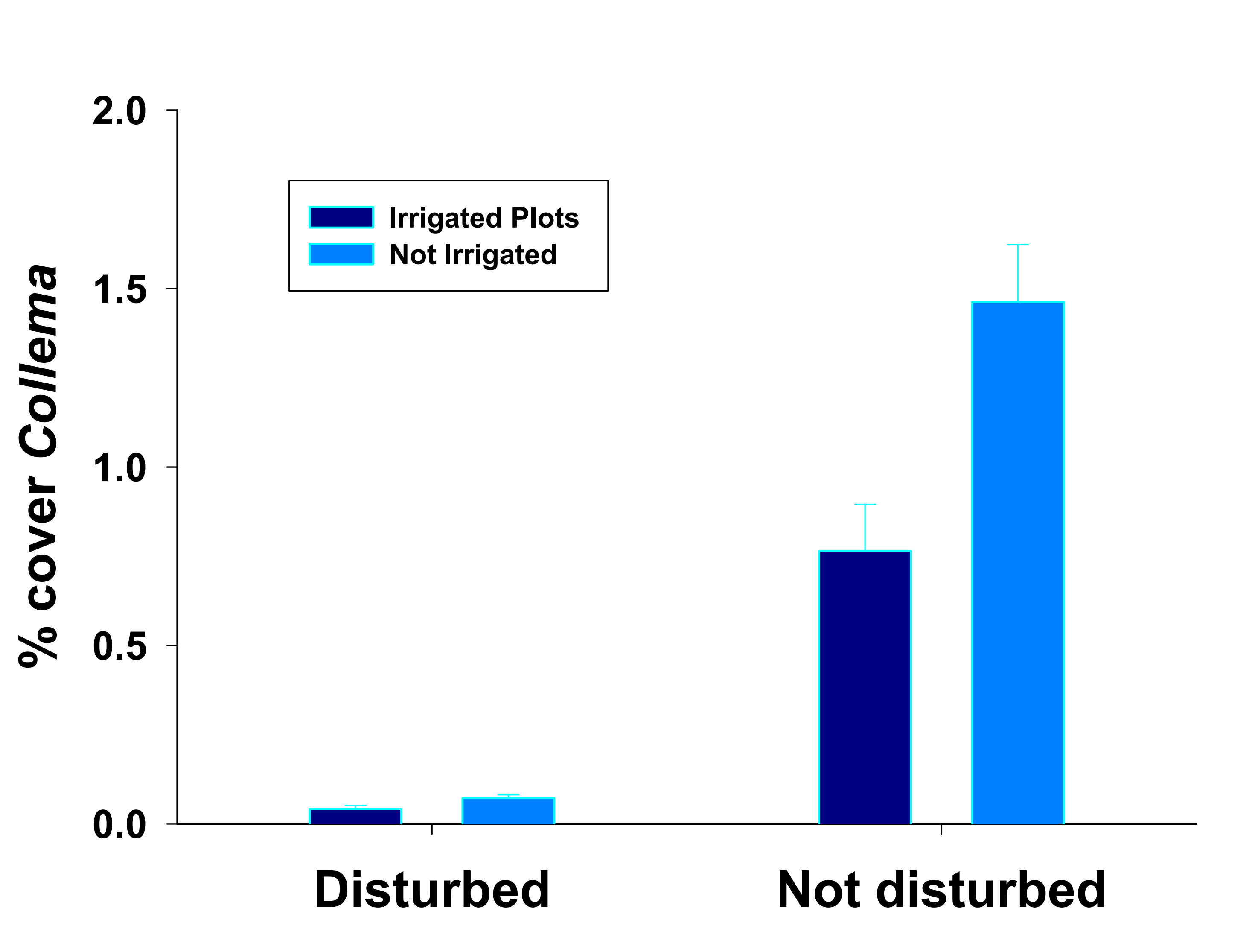


Fertilization



Biological Soil Crusts

Collema % cover: Irrigation & Disturbance



MGCF Hypotheses

- Increased nitrogen deposition will result in increases in photosynthesis and production, particularly in concert with increased rainfall.
- Disturbance of biological soil crusts will result in reduced production over time.
- Increased summer rainfall will result in increased production; growth forms such as evergreen shrubs and perennial grasses will increase more in production than drought-deciduous shrubs or spring annuals.

Higher Order Responses?

Ecological Effects of Global Change

External Variable	Internal Variables	New Regime
Elevated CO2	Greater plant production	More productive desert
	Increased invasion	Fire-controlled grassland
Higher Temperature	Species range shifts	Community disequilibrium
Altered Precipitation		
Wetter	Greater plant production	Semiarid ecosystem-type
Drier	Increased mortality	Species-poor system
Increased N-deposition	Greater plant production	More productive desert
	Increased invasion	Community shift to invasive

Global Change: How May it Affect Ecosystem Restoration?

- Uncertainty of future conditions (?)
- Shifting boundaries of reserves/corridors (-)
- Potential decoupling of mutualisms (-)
- Alleviation of environmental stress (+)
- Stimulation of invasive species (-)

Acknowledgements

NDRC Co P.I.'s: Bob Nowak, UNR
Jay Arnone, DRI
Lynn Fenstermaker, DRI

UNLV: Dene Charlet, David Barker,
Beth Newingham & Karen Nielsen

Colleagues: Many, but esp. Travis Huxman,
Dave Evans and Jayne Belnap

Funding: NSF (Ecosystems & EPSCoR)
DOE (PER, TCP & NIGEC)
Andrew W. Mellon Foundation

Why Study Deserts?

Deserts <u>are</u> quite responsive to elevated CO_2, altered precipitation, and N-deposition.

Potential responses to global change have important implications for land management.