Assessing the sensitivity of grassland ecosystems to climate change

KONZA PRAIRIE BIOLOGICAL STATION

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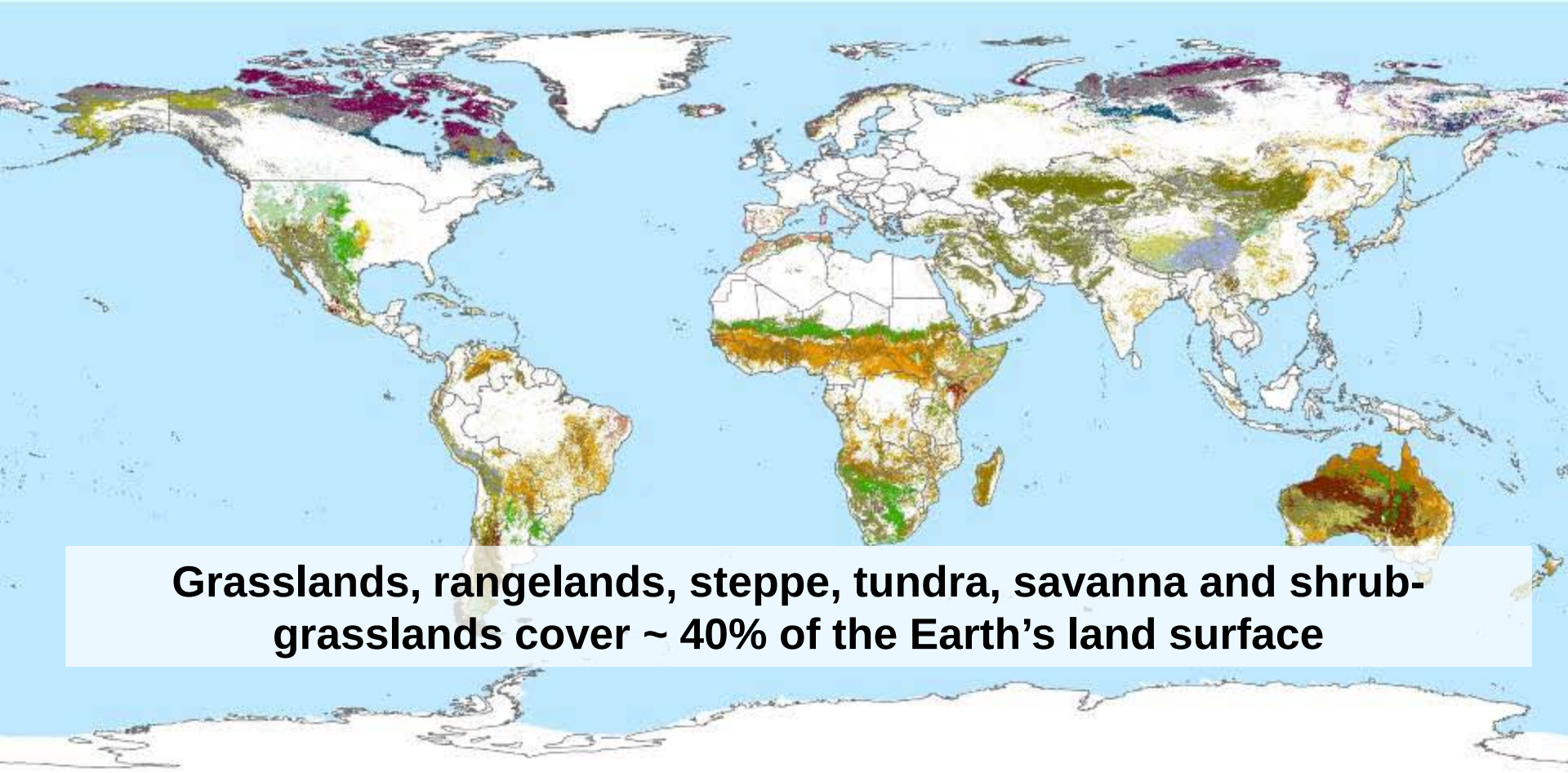
LTER

NRI

The Nature Conservancy® Saving the Last Great Places

Setting the stage…



Grasslands, rangelands, steppe, tundra, savanna and shrub-grasslands cover ~ 40% of the Earth's land surface

1992 AVHRR-NDVI Composite Data
Olson Global Ecosystems Classification

- Low Sparse Grassland
- Tall Grasses and Shrubs
- Upland Tundra
- Irrigated Grassland
- Semi-Desert
- Shrub Evergreen
- Shrub Deciduous
- Cool Grasses and Shrubs
- Hot and Mild Grasses and Shrubs
- Cold Grassland
- Savanna
- Mire/Bog/Fen
- Marsh Wetland
- Mediterranean Scrub
- Dry Woody Scrub
- Semi-Desert Shrubs
- Semi-Desert Sage
- Barren Tundra
- Succulent and Thorn Scrub
- Heath Scrub
- Woody Savanna

T. Riley and J.A. Klein

N W E S

0 1,500 3,000 4,500 6,000 Kilometers

1-Kilometer Resolution

Grasslands provide important ecosystem services:

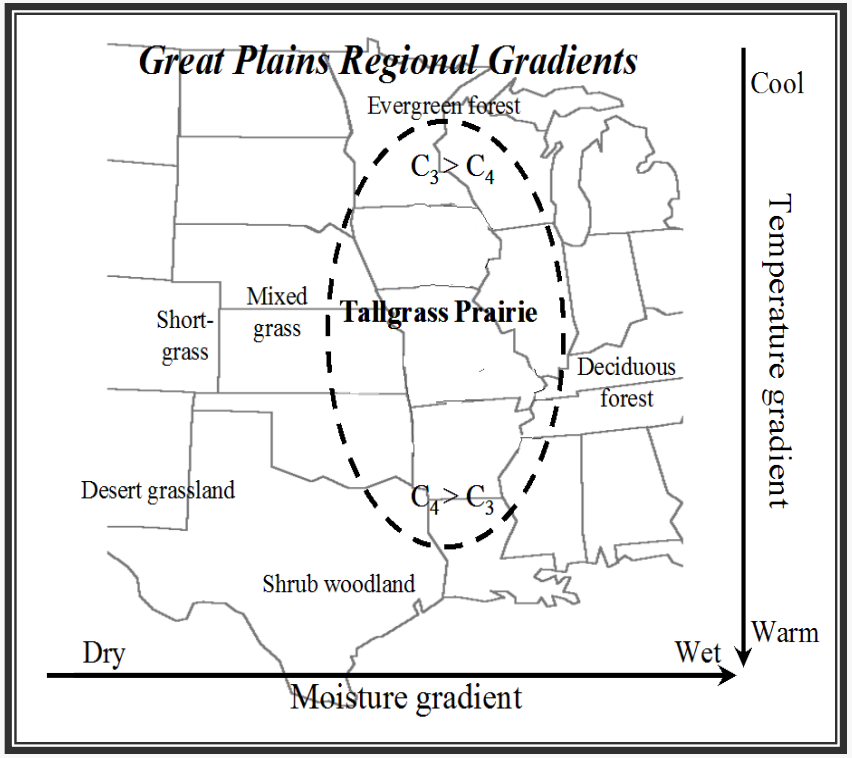
- Forage for domestic livestock
- Habitat for native ungulates

- Habitat for grassland plants/animals
- Migratory birds – breeding/forage

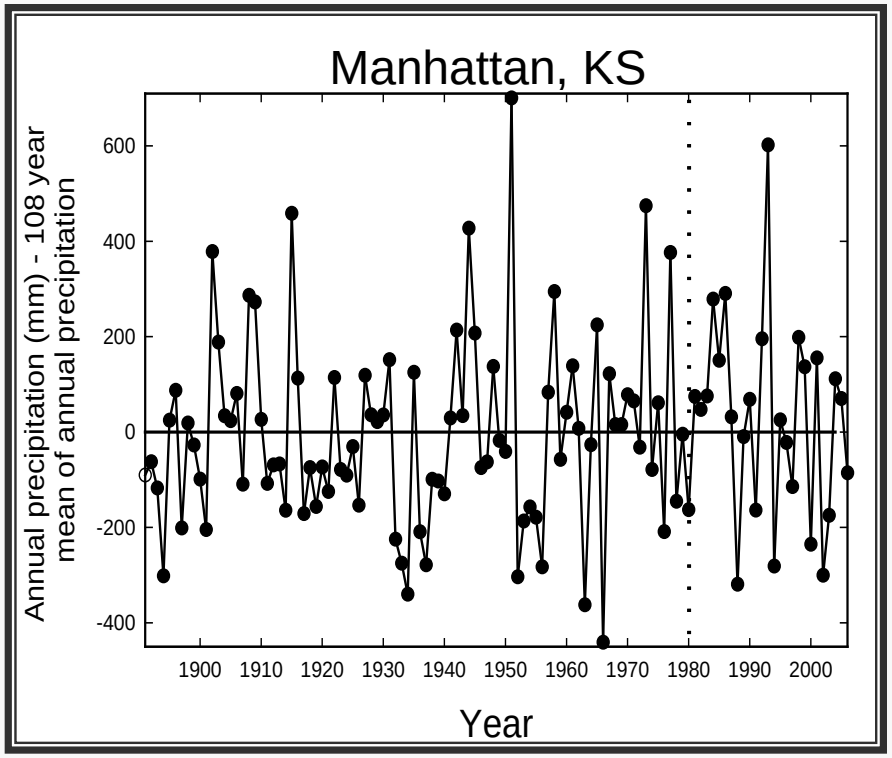
- Soil erosion control
- Carbon sequestration

The climates of US grasslands are characterized by…

…strong regional precipitation and temperature gradients

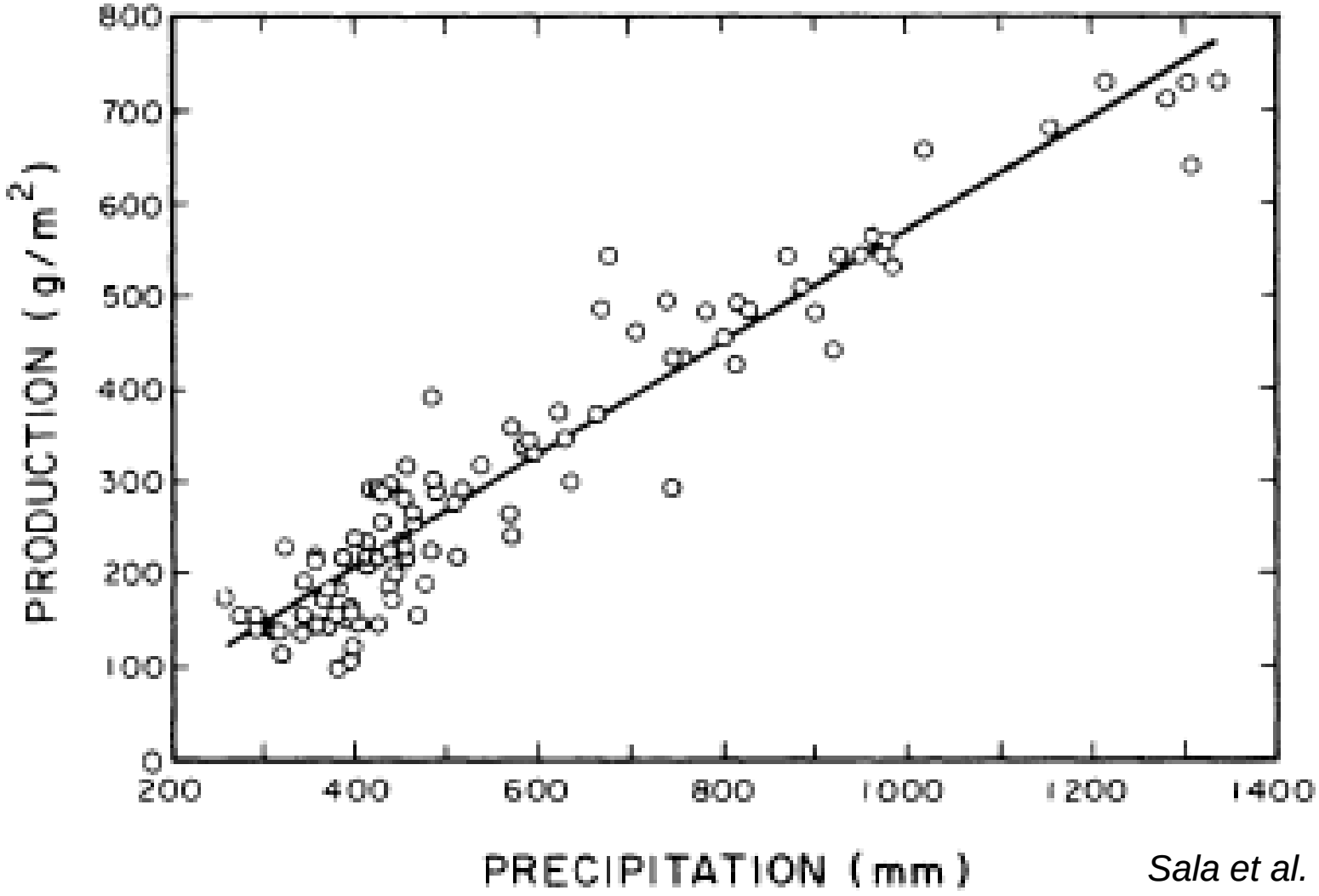


…and high interannual rainfall variability



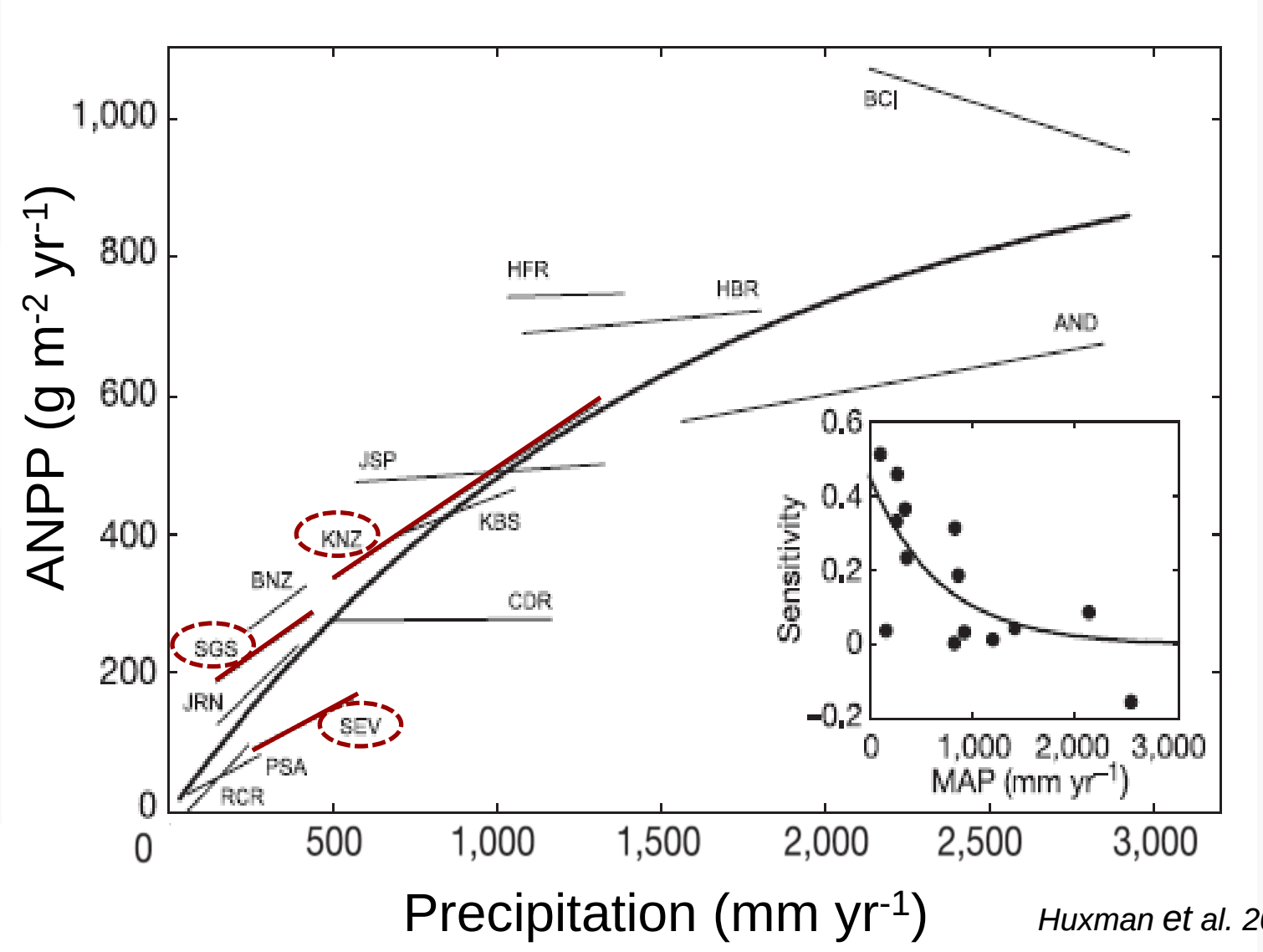
Regional precipitation gradients drive patterns of plant productivity *across* sites

Precipitation vs. productivity across the Central US



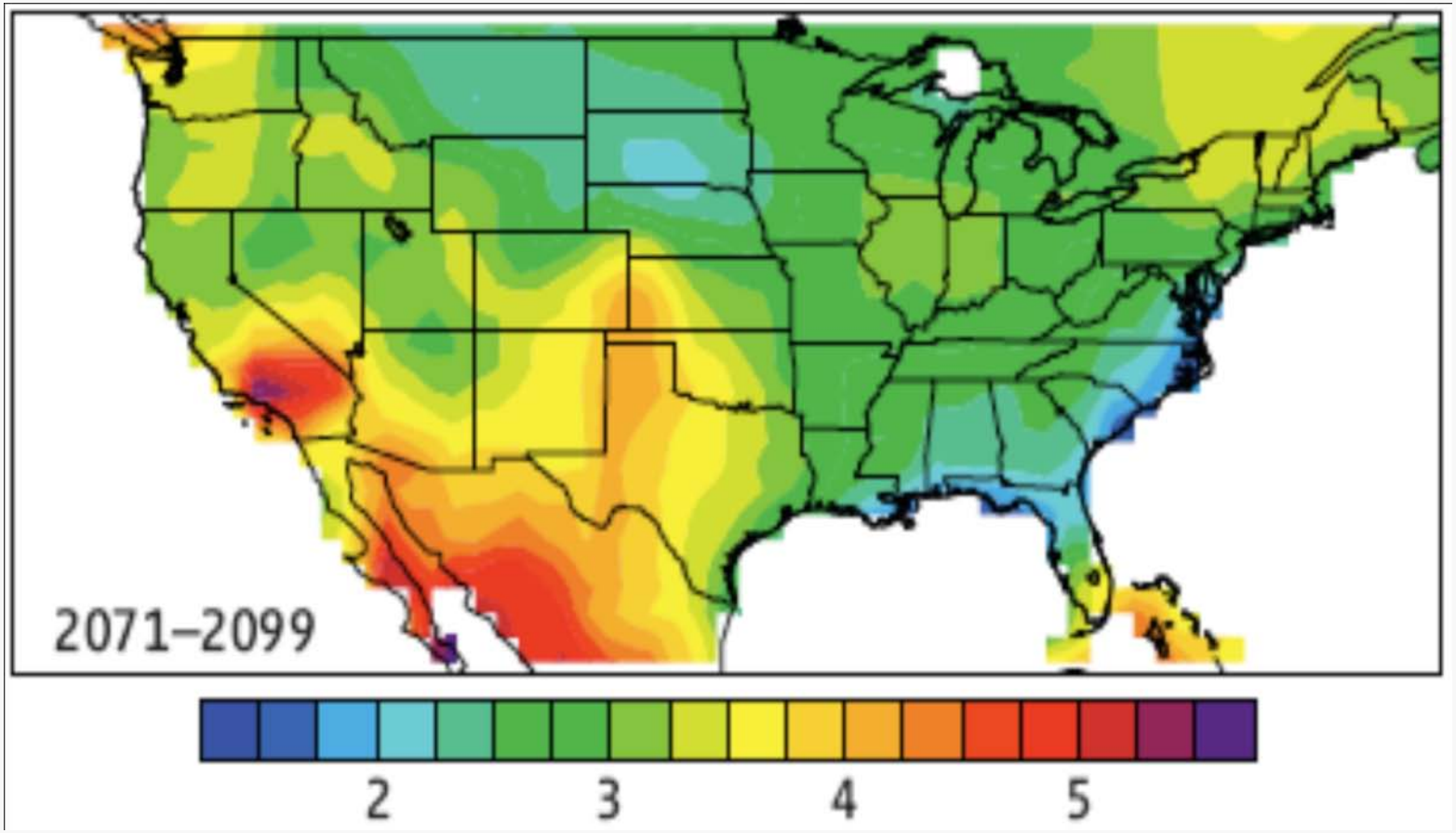
Sala et al. 1988

Grassland productivity is also highly sensitive to interannual variability in rainfall *within* sites



Huxman et al. 2004

Climate change “hot spots” based on predicted changes in temperature, precipitation and climate variability

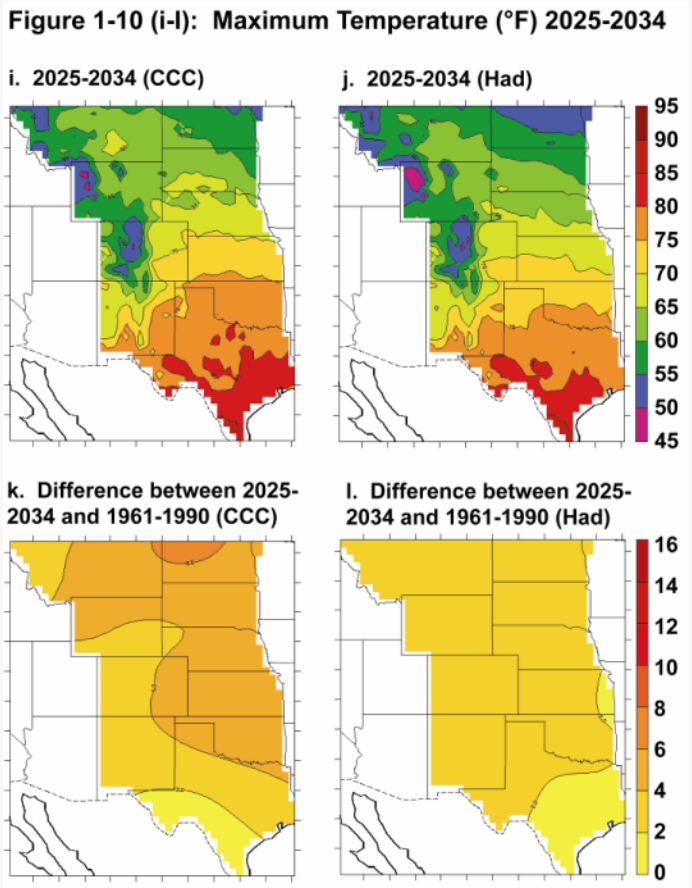


In the continental US, the greatest responsiveness is predicted to occur in the southern Plains and arid southwest

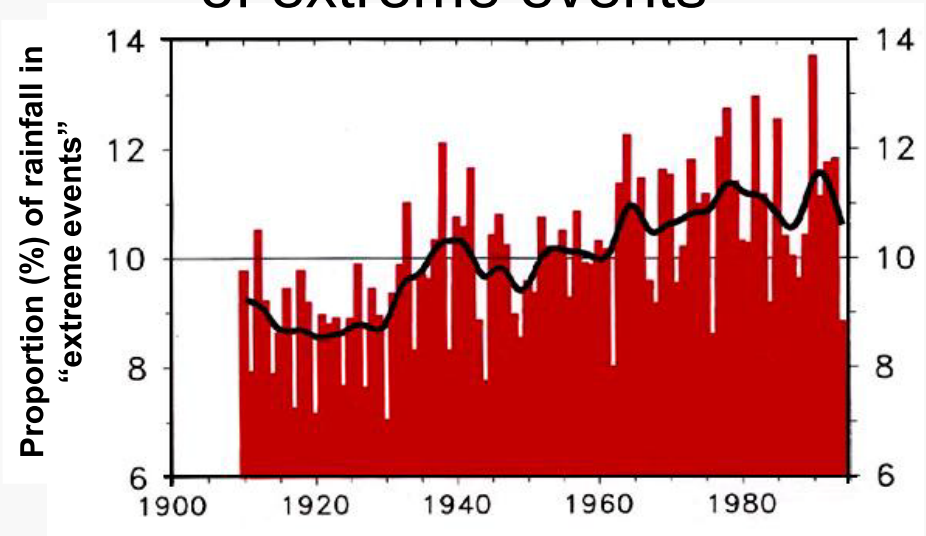
Diffenbaugh et al. 2008

Two important climate change predictions for the US Central Plains…

1. Max and min temps are expected to increase



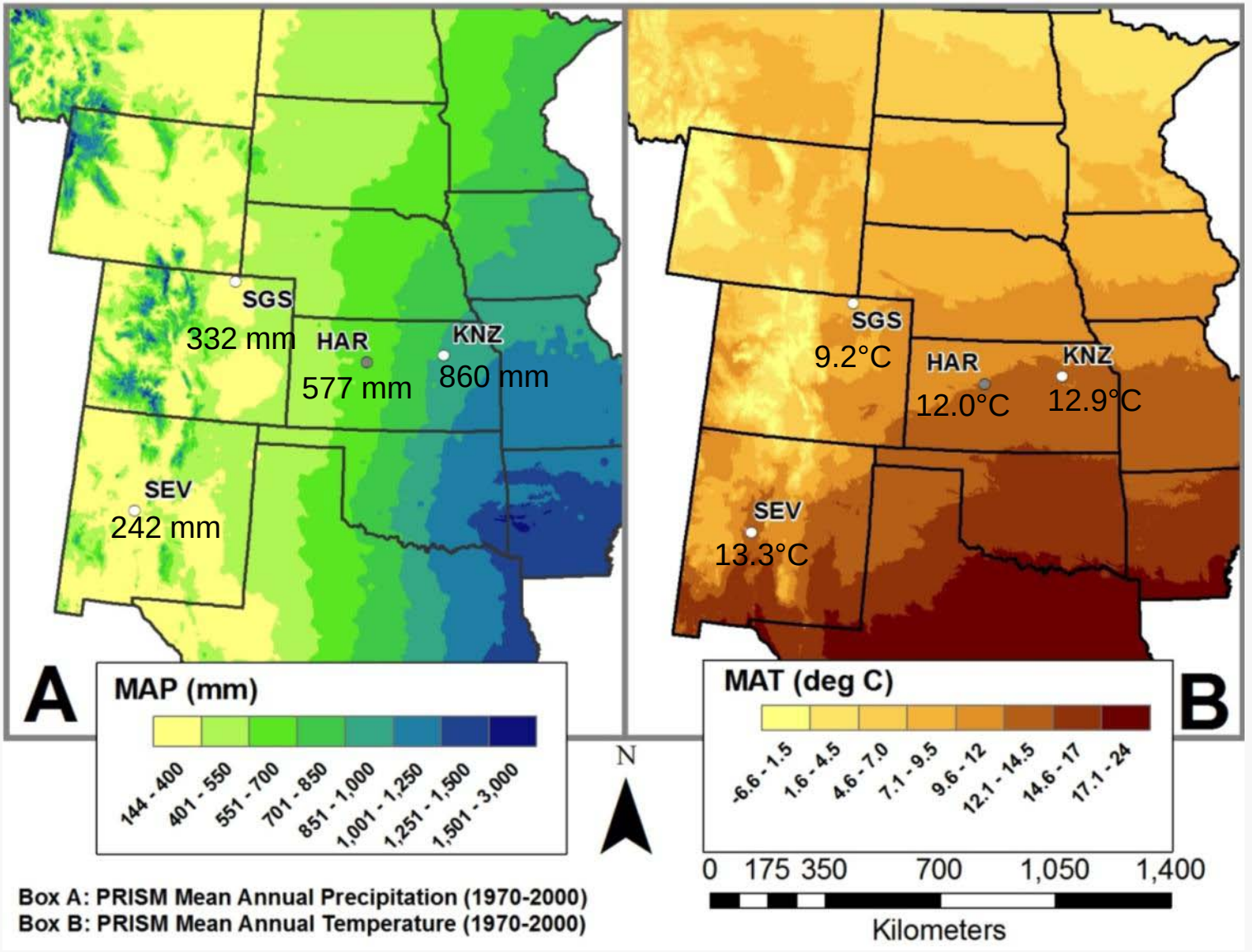
2. Increased rainfall variability and frequency of extreme events



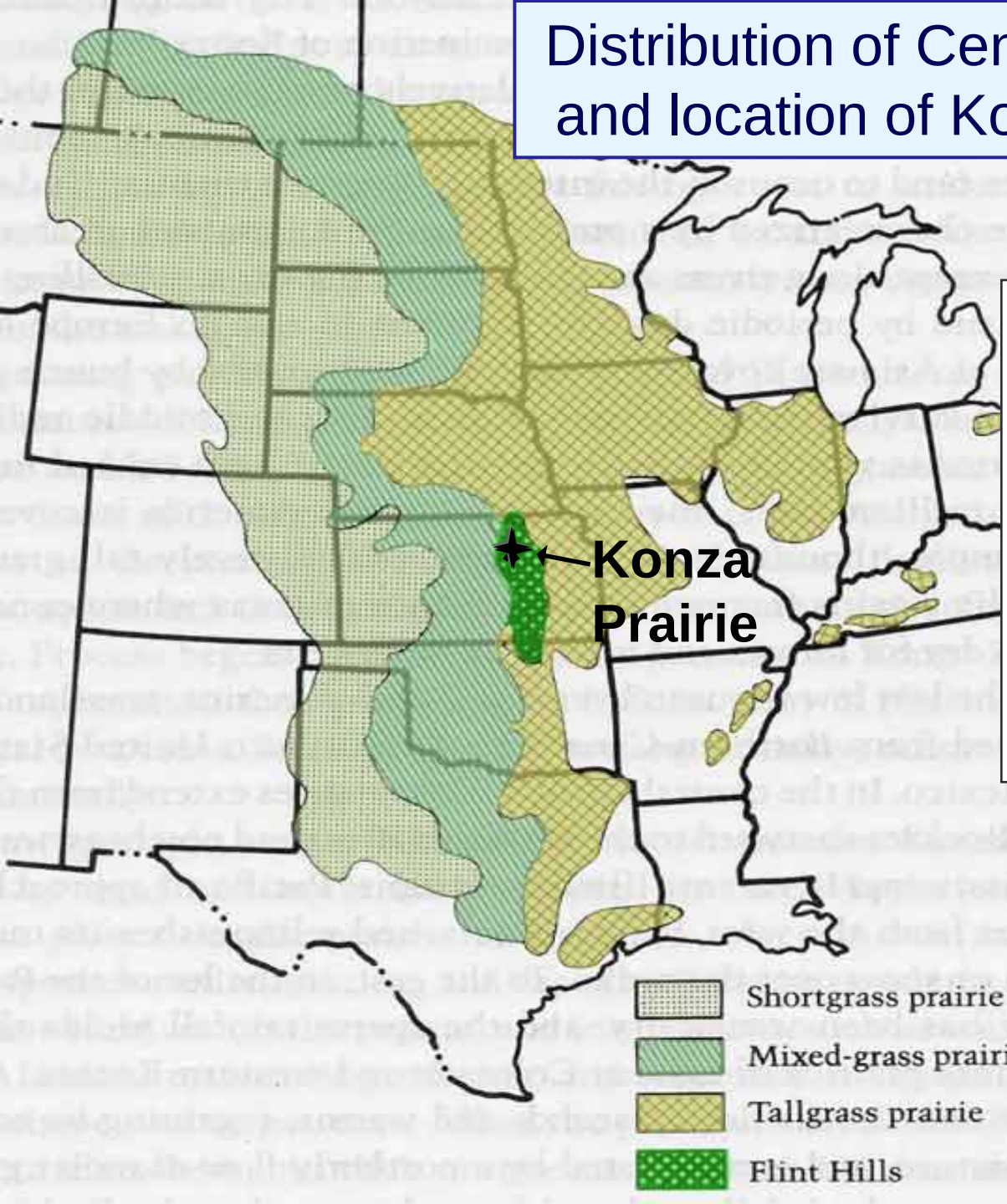
Proportion of total rainfall in the US from large (>5 cm) rainfall events

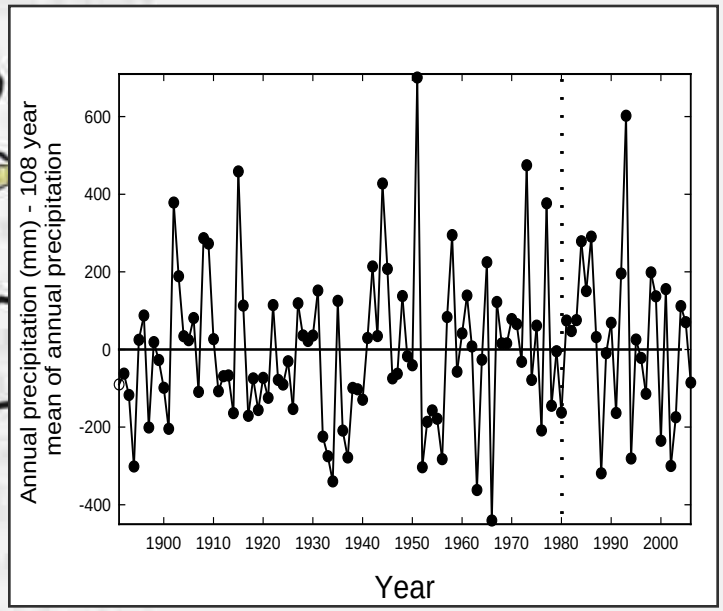
Evidence of increasing frequency of large rainfall events in many regions

Climate change research at three LTER sites that vary in mean annual precipitation and temperature…



Distribution of Central Plains grasslands and location of Konza Prairie LTER site





Mean ppt = 835 mm/yr

Highly productive tallgrass prairie, but water limitations are still important

Two critical climate change questions:

To what extent will increased *precipitation variability* alter ecosystem processes (e.g., ANPP, soil respiration) in “mesic” grasslands?

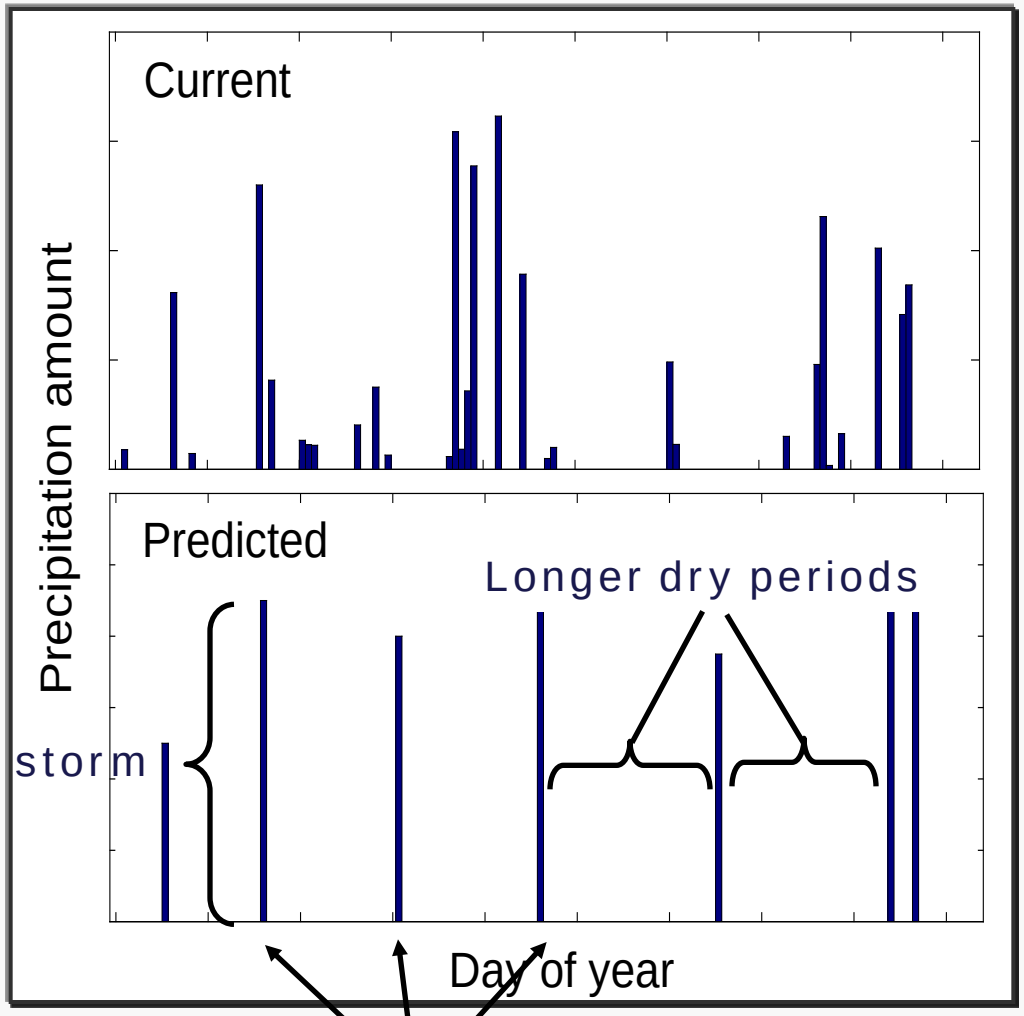
What are the likely impacts of *warmer temperatures* alone and when coupled with increases in precipitation variability?

The Rainfall Manipulation Plot (RaMP) Experiment

Address the impact of changes in ***size and timing*** of growing season rainfall events and ***elevated temperature***

- 12 **Ra**infall **M**anipulation **P**lot**s** (RaMPs) + non-sheltered controls
- Collect, store, and reapply natural rainfall on intact prairie plots
- Treatments include ambient and altered rainfall patterns since 1998
- Elevated temperature treatment added in 2003 (not covered here)

Target altered rainfall pattern: 50% longer inter-rainfall periods, larger individual rain events



<u>No</u> change in total growing season precipitation quantity

Key driver of responses: Soil moisture dynamics

Ambient ppt timing:

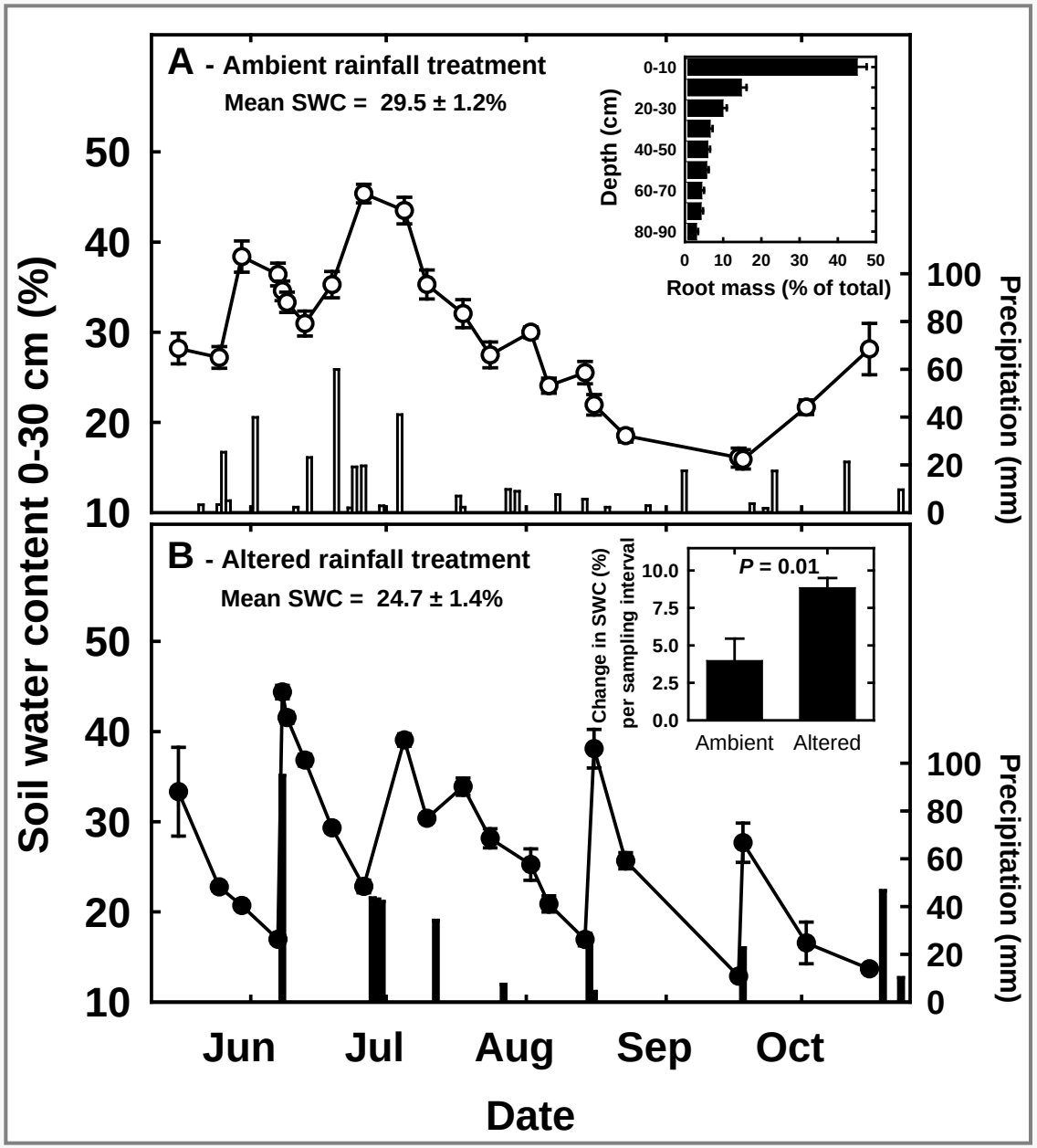
- "typical" seasonal pattern

Altered ppt timing:

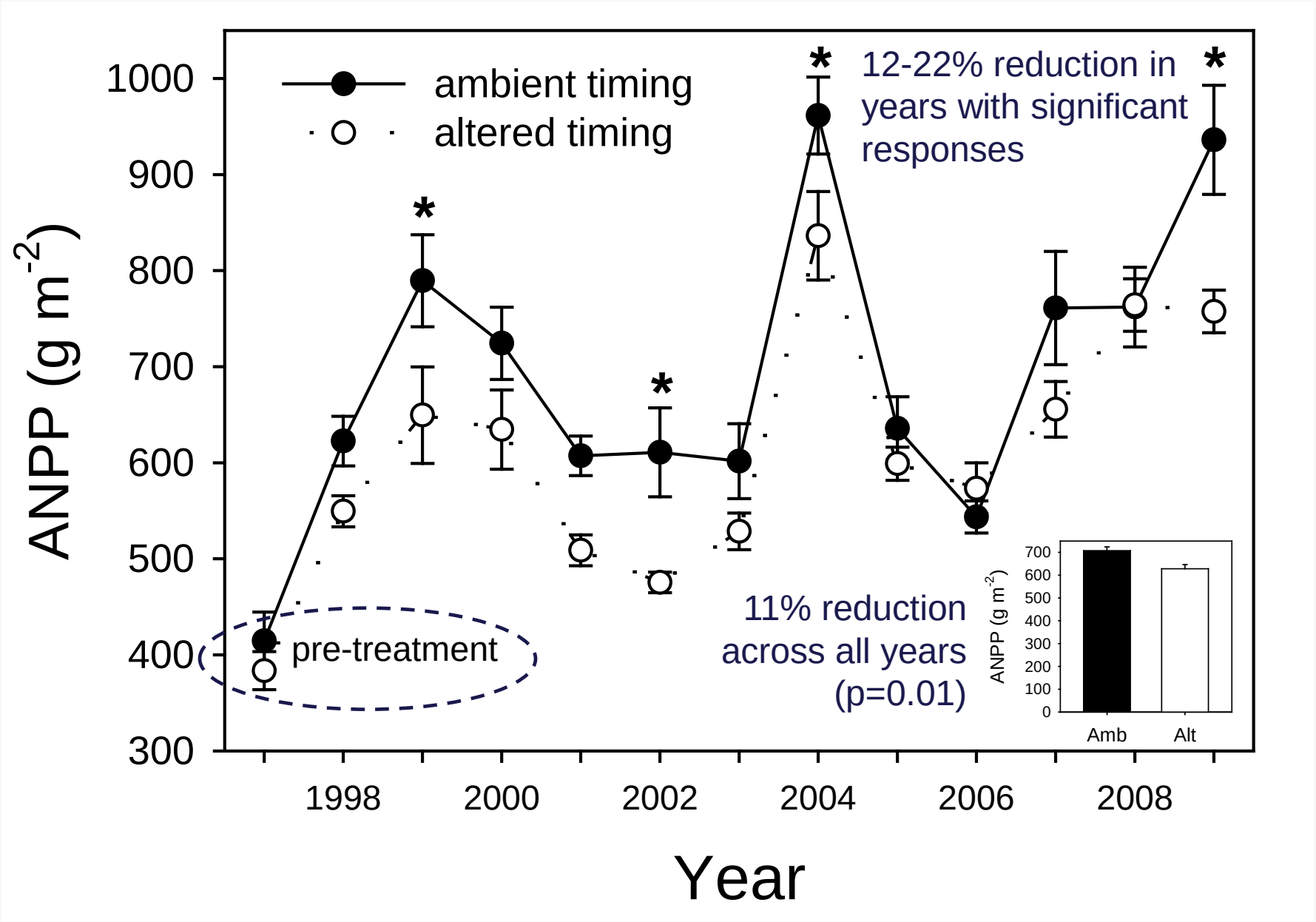
- more extreme wetting and drying cycles
- repeated soil water deficits

Average soil water content:
- reduced by 15%

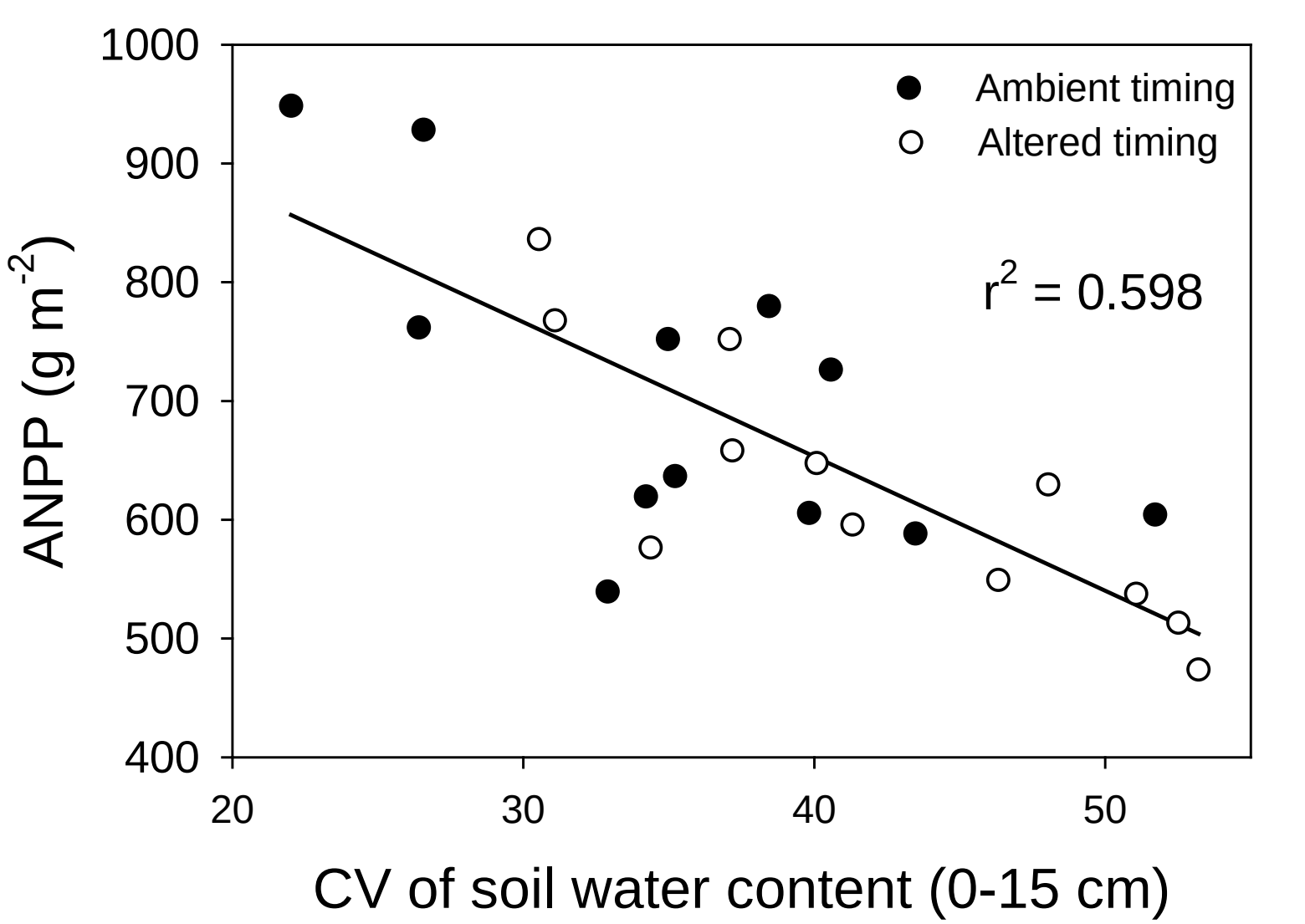
Variability in soil water content:
- CV increased by 18%



ANPP responses to altered rainfall timing



Greater variability in soil water content reduces productivity across all years and treatments

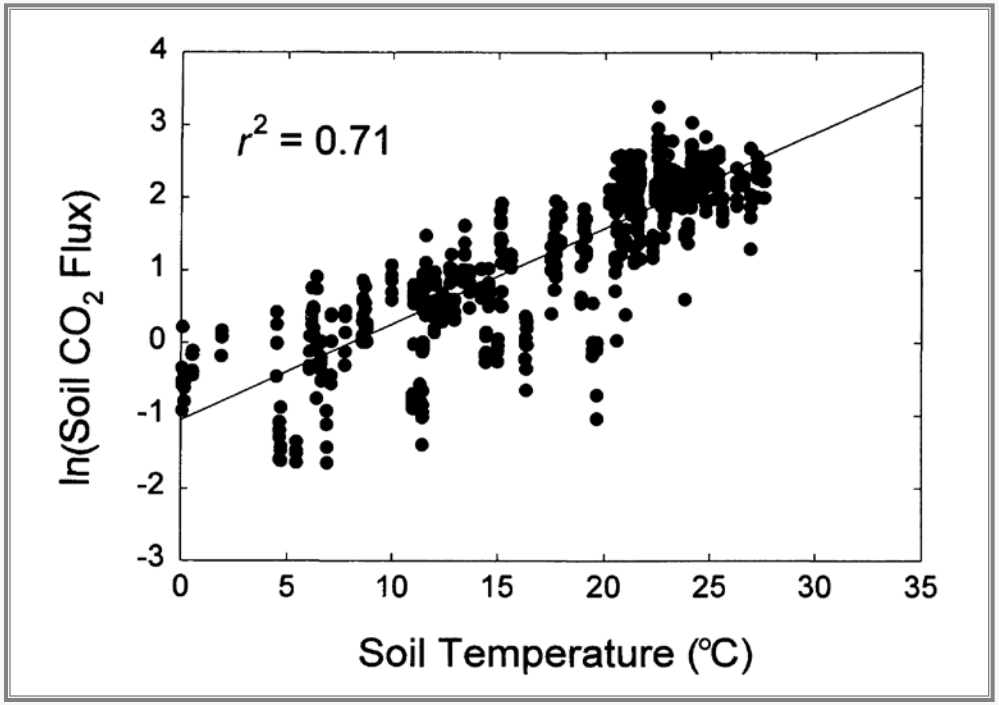


Grasses and forbs respond to different aspects of soil water dynamics

Response	Predictor variable	Partial r^2	Model r^2
Total ANPP	**CV SWC 15cm**	**0.598 (92%)**	**0.651**
	mean SWC 15cm	0.053	
Grass ANPP	**mean SWC 15cm**	**0.470 (70%)**	**0.676**
	mean SWC 30cm	0.103	
	CV SWC 30cm	0.103	
Forb ANPP	**mean SWC 30cm**	**0.375 (82%)**	**0.453**
	CV SWC 30cm	0.078	

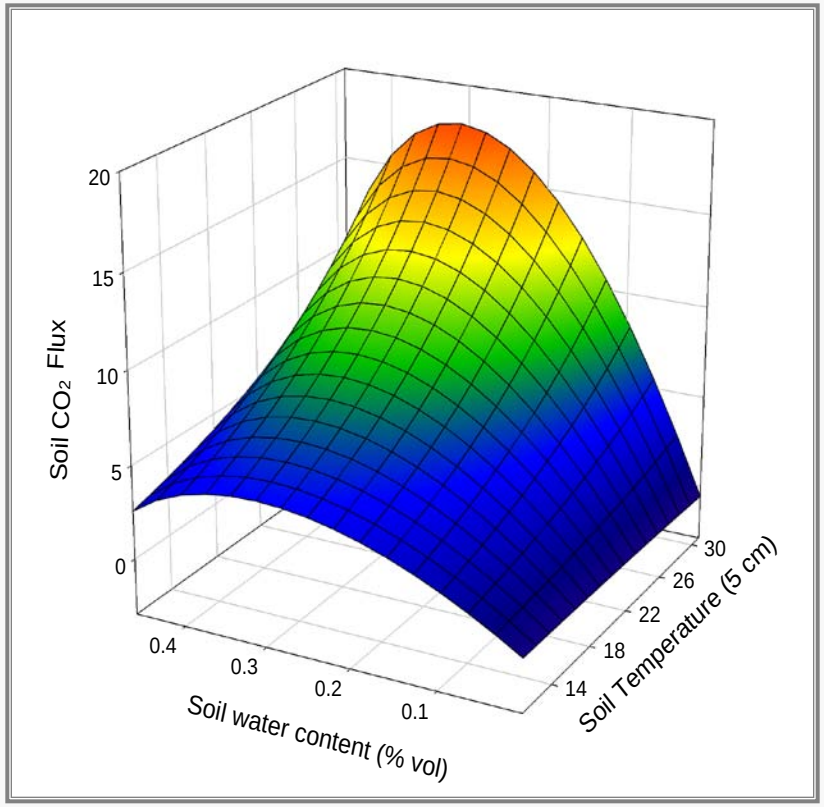
- Grasses more sensitive to mean surface SWC, while forbs respond more to deeper SWC
- Potential for long-term changes in community composition

Variation in temperature and soil water content also affects soil CO_2 flux in grasslands



Knapp et al. 1998

$$JCO_2 = (9.65 \times e^{0.068 \times Ts}) \times [2.12 \times (\theta v - \min \theta v) \times (\max \theta v - \theta v)^{1.46}]$$

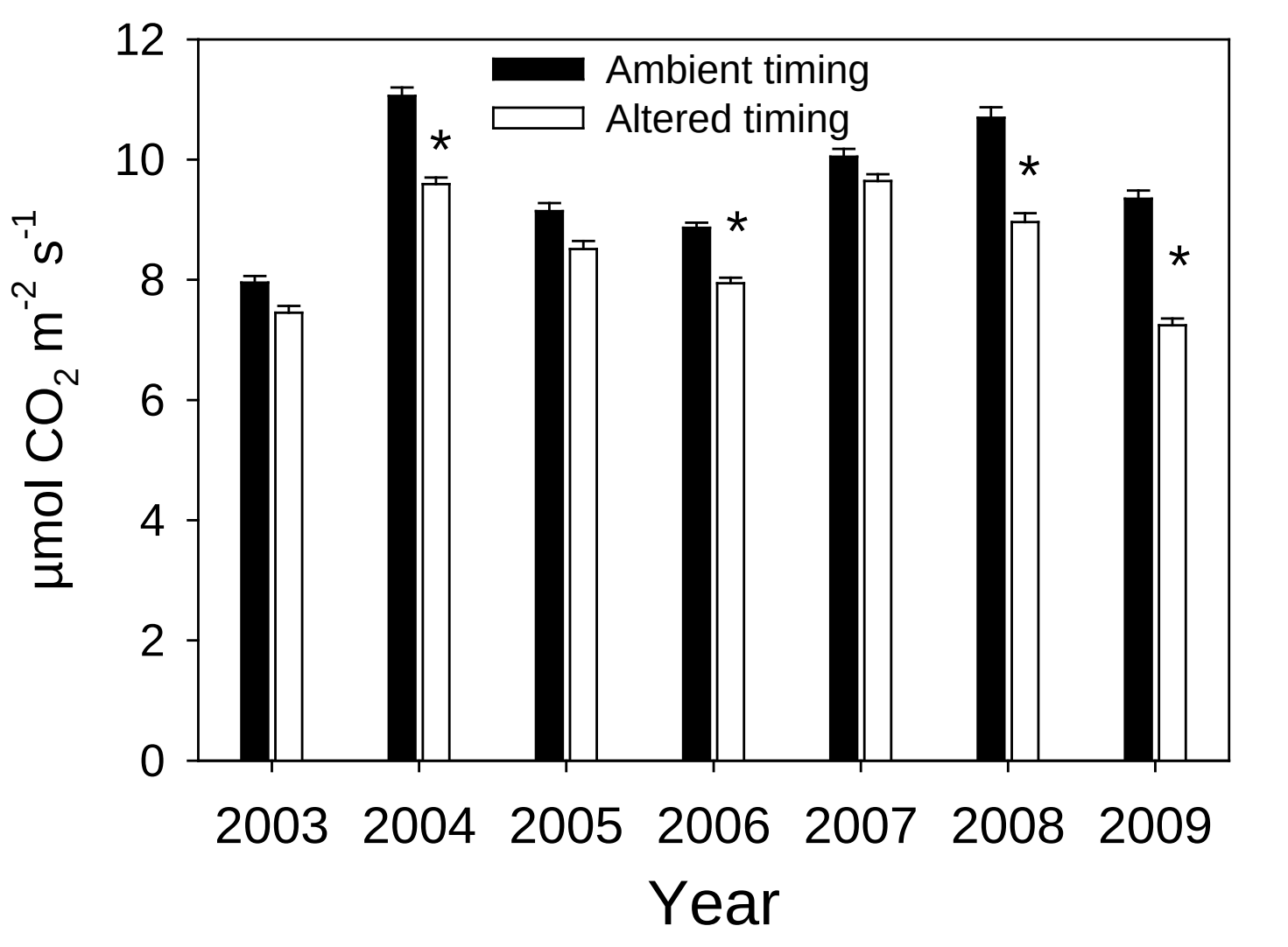


Harper et al. 2005

Response to changing rainfall patterns?

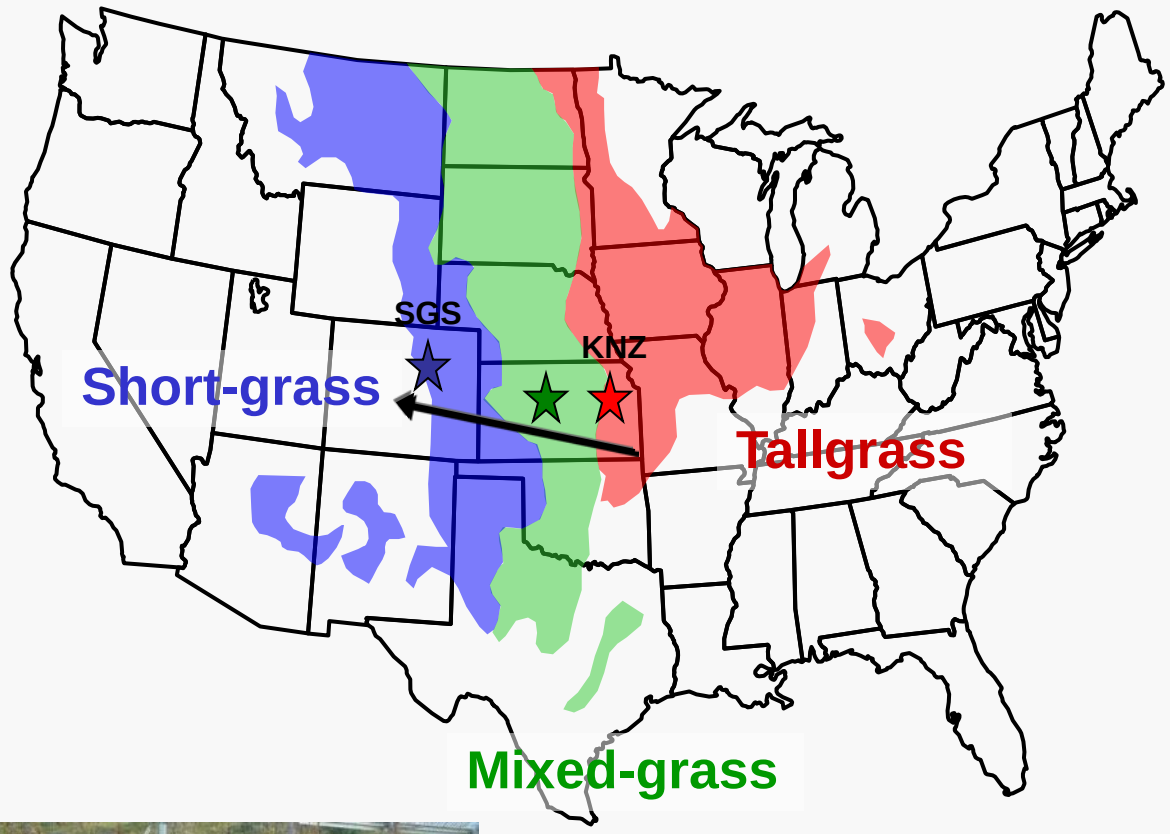
Altered rainfall timing reduced mean growing season CO_2 flux by 11% across all years

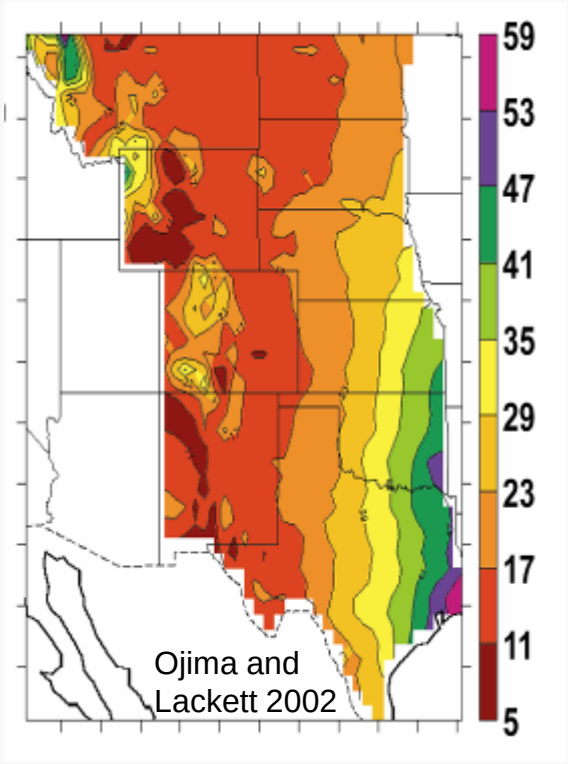
(consistent with results from 1998-2002; *Harper et al.* 2005)



Can we apply results from mesic grasslands to other climates and grasslands?

A regional assessment of climate change responses

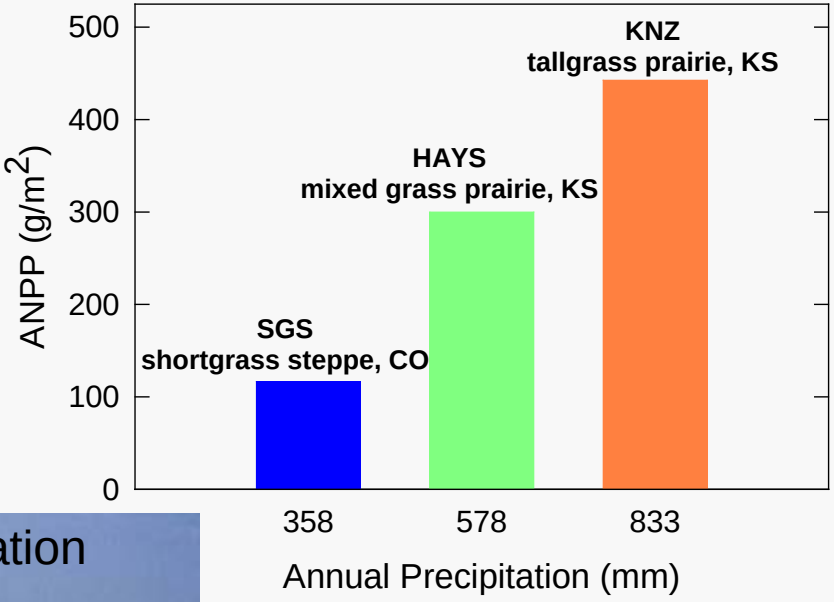




Precipitation gradient

Jana Heisler-White
Alan Knapp
John Blair
Gene Kelly
Keith Harmony

Heisler-White et al. 2009.
Global Change Biology 15:2894-2904.



Semi-arid grassland
Extreme rainfall events, long dry intervals = reduced ANPP?

Mesic grassland
Extreme rainfall events, long dry intervals = reduces ANPP

How will these different grasslands respond to the same experimental design and treatments?

Manipulated the distribution of growing season rainfall

frequent, small events vs. less frequent large events

equal rainfall amounts within each site

A = 12 events
B = 6 events
C = 4 events
Total = 191 mm

SGS

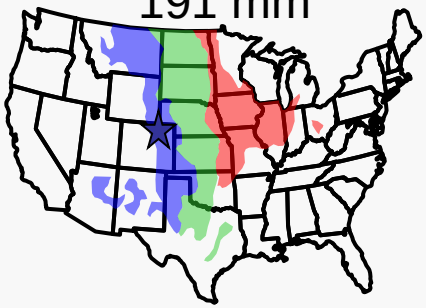
Semi-arid

A = 12 events
B = 6 events
C = 4 events
Total = 450 mm

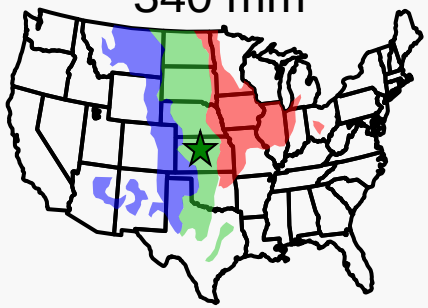
KNZ

Mesic

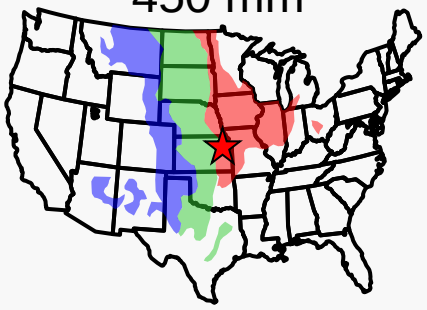
Semi-arid steppe
191 mm

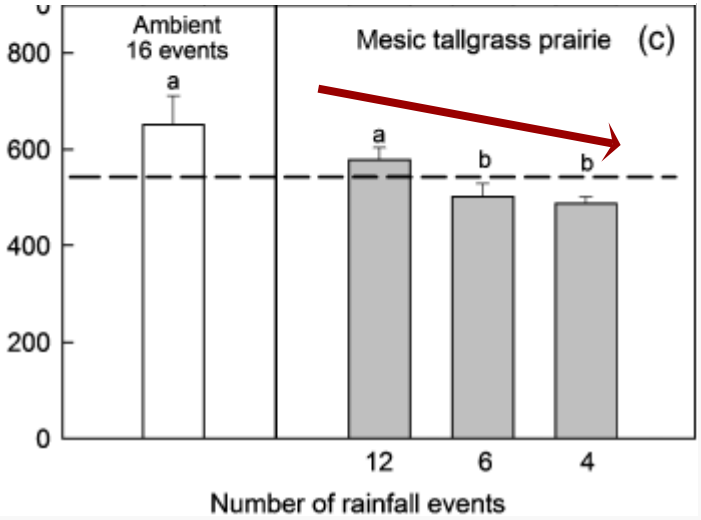


Mixed grass prairie
340 mm



Tallgrass prairie
450 mm





30% increase in ANPP with fewer large events

70% increase in ANPP with fewer large events

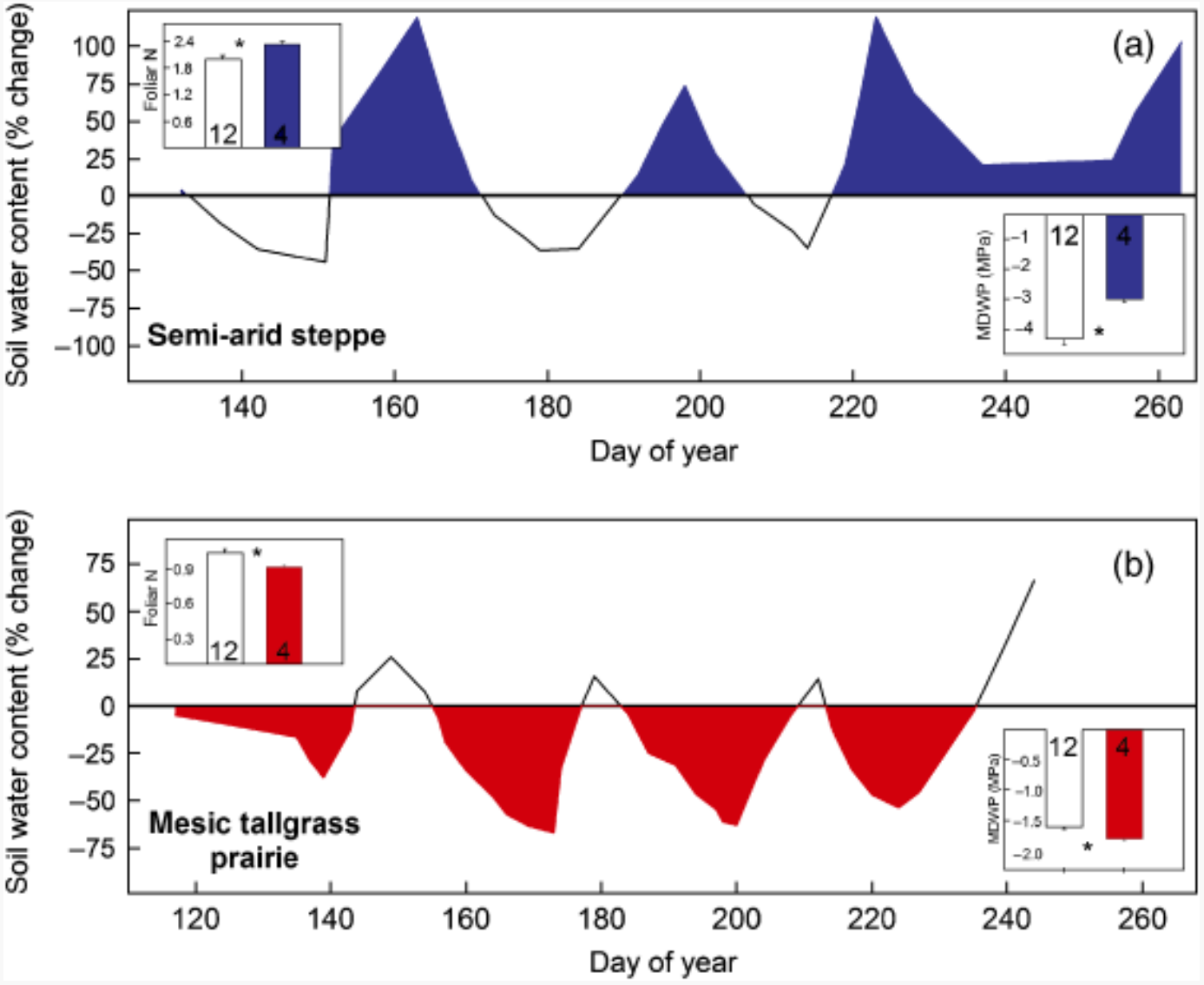
15% decrease in ANPP with fewer large events

Heisler-White et al. 2009

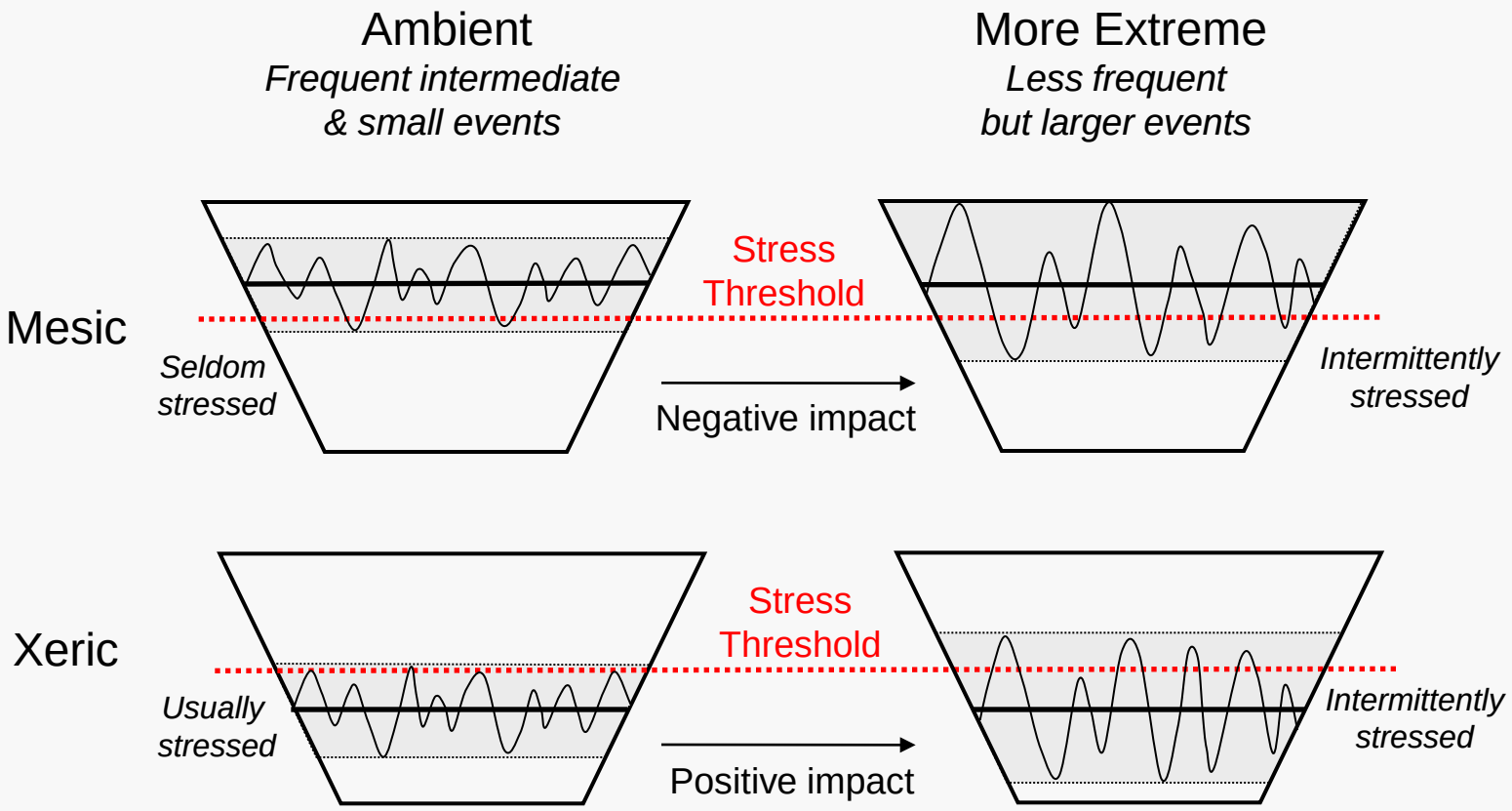
Divergent responses are linked to differential effects of extreme rainfall events on mean soil water content

↑ SWC by 19% in arid site

↓ SWC by 20% in mesic site



“Bucket model” of the response of soil moisture and ecosystems to more extreme precipitation regimes

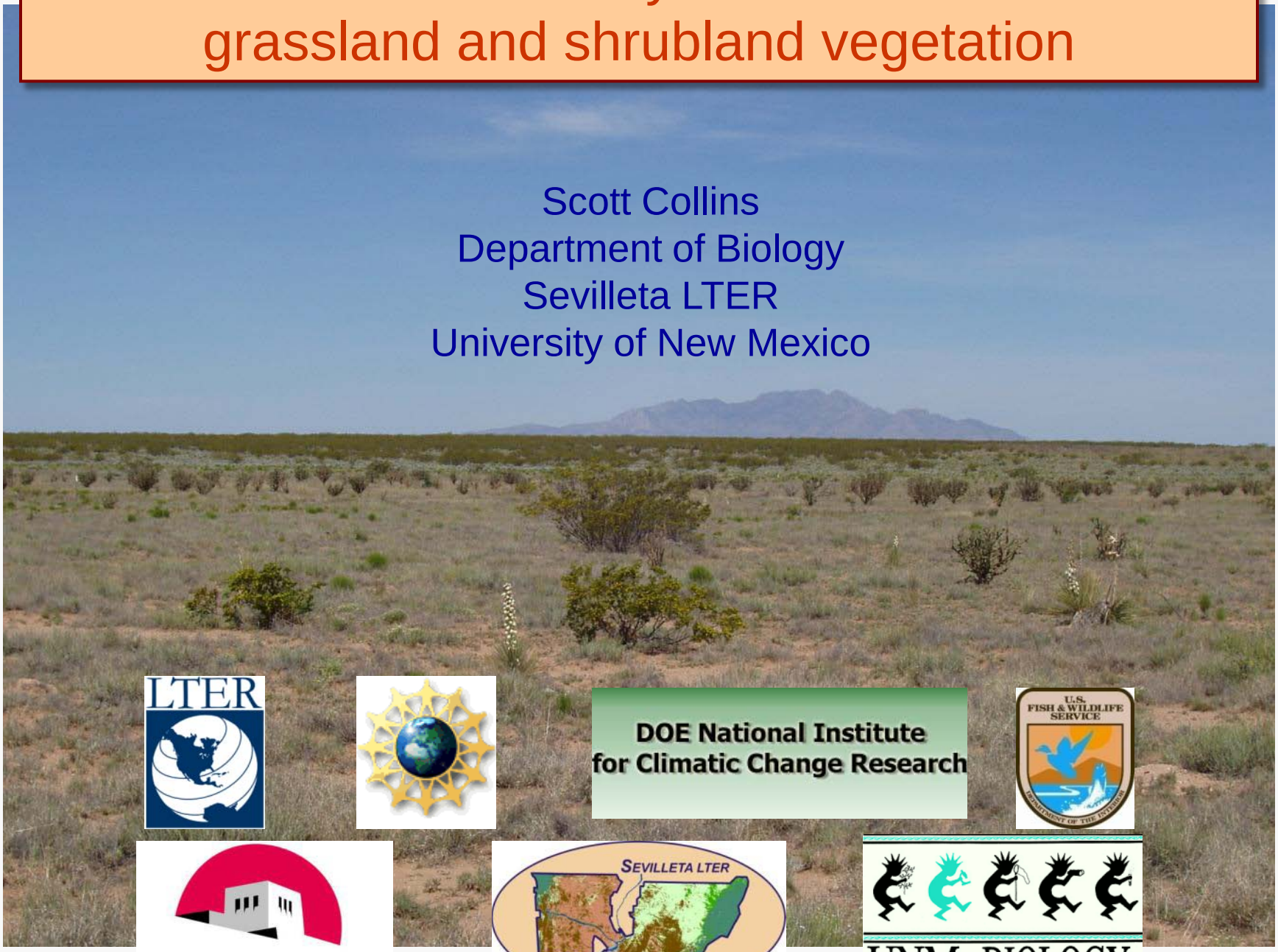


The Bucket model predicts that ANPP will increase in aridland ecosystems with an increase in precipitation variability

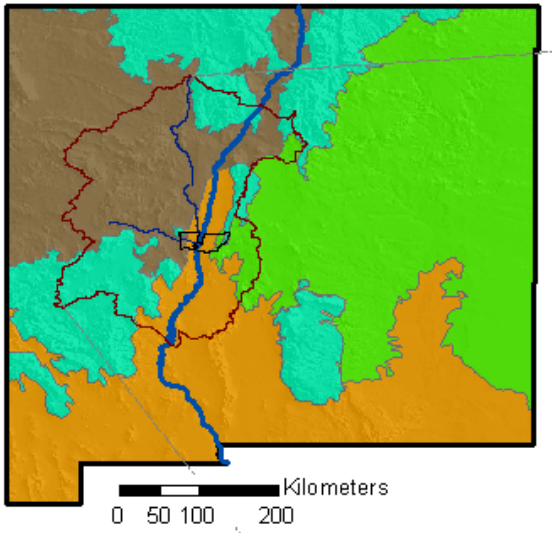
Knapp et al. 2008 BioScience

Effect of climate variability on Chihuahuan Desert grassland and shrubland vegetation

Scott Collins
Department of Biology
Sevilleta LTER
University of New Mexico



The Sevilleta LTER site



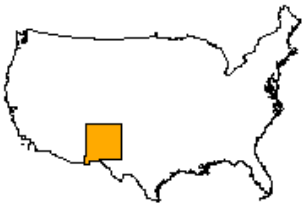
New Mexico Biomes:

- Chihuahuan Desert
- Great Plains Grassland
- Colorado Plateau Shrub-Steppe
- Conifer Woodland
- Rio Grande
- Rio Puerco & Rio Salado
- ET Flux Towers

Elevation

3715 m

1305 m



Cochiti Dam

Albuquerque

South Valley

Sevilleta N.W.R.

Bernardo

Rio Salado

San Acacia

Bosque del Apache

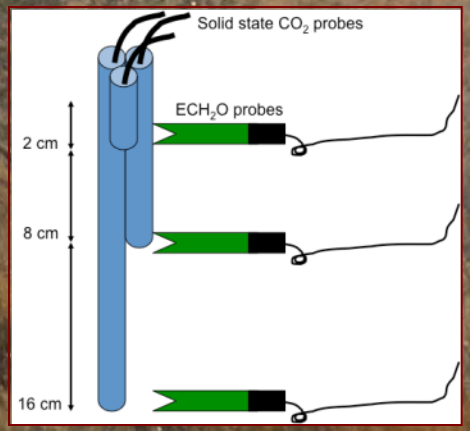
Elephant Butte Dam

Kilometers
0 25 50 100

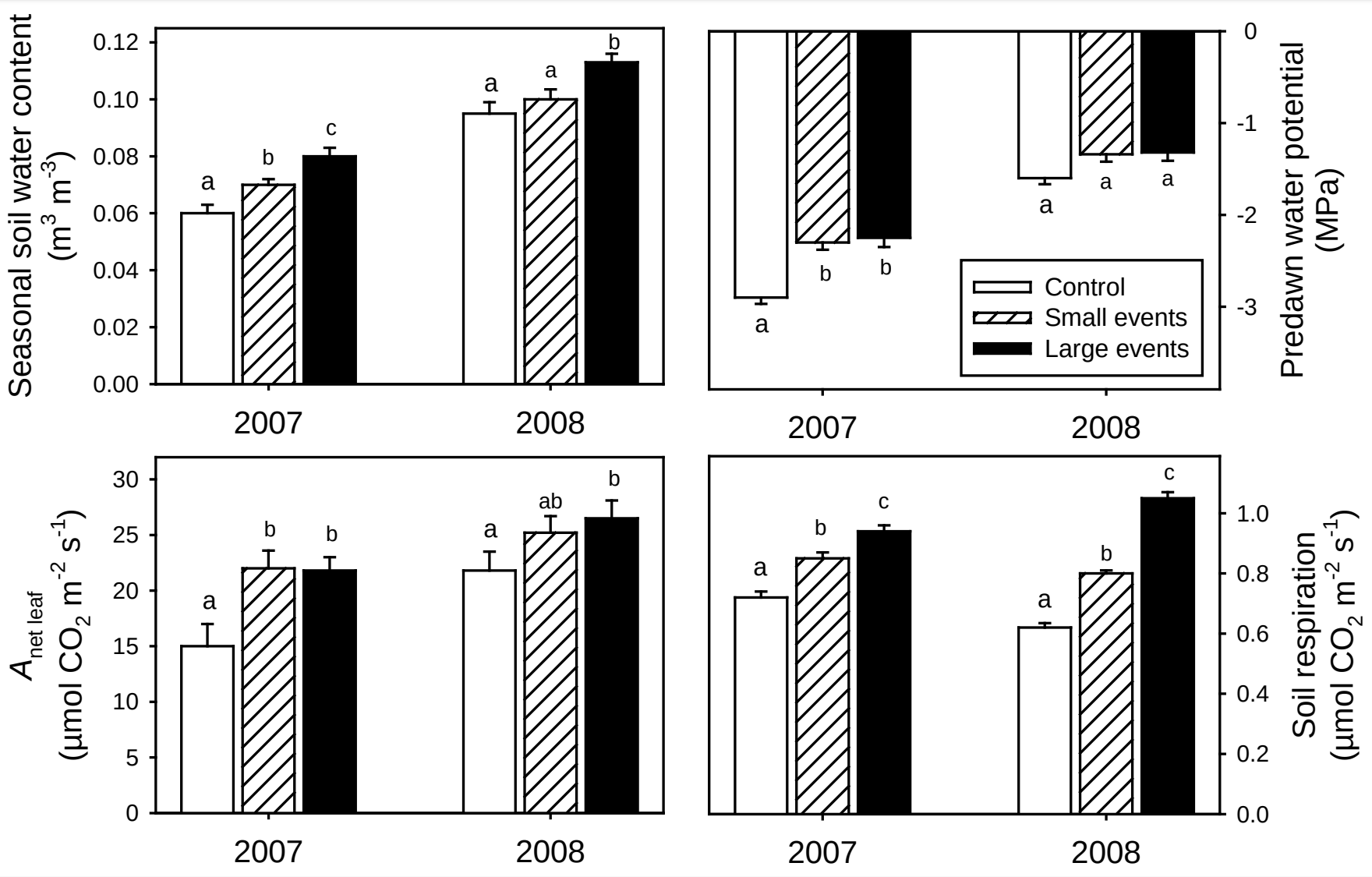
The Monsoon Rainfall Manipulation Experiment

During the summer monsoon July through September:
3 plots receive ambient rainfall
5 plots receive a 5mm rainfall (small) event every week
5 plots receive a 20 mm rainfall (large) event every month

Scott Collins
Michell Thomey
Rodrigo Vargas
Jennifer Johnson
Renee Brown
Don Natvig
Mike Friggens



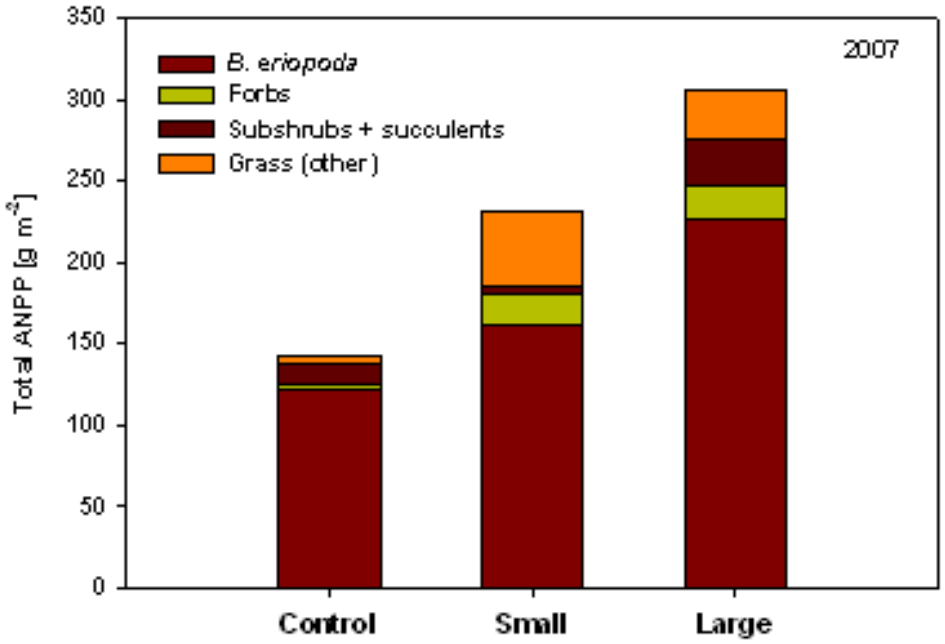
Seasonal average soil water content, predawn water potentials, leaf-level A_{net} and soil CO_2 flux were highest in plots receiving a few large events

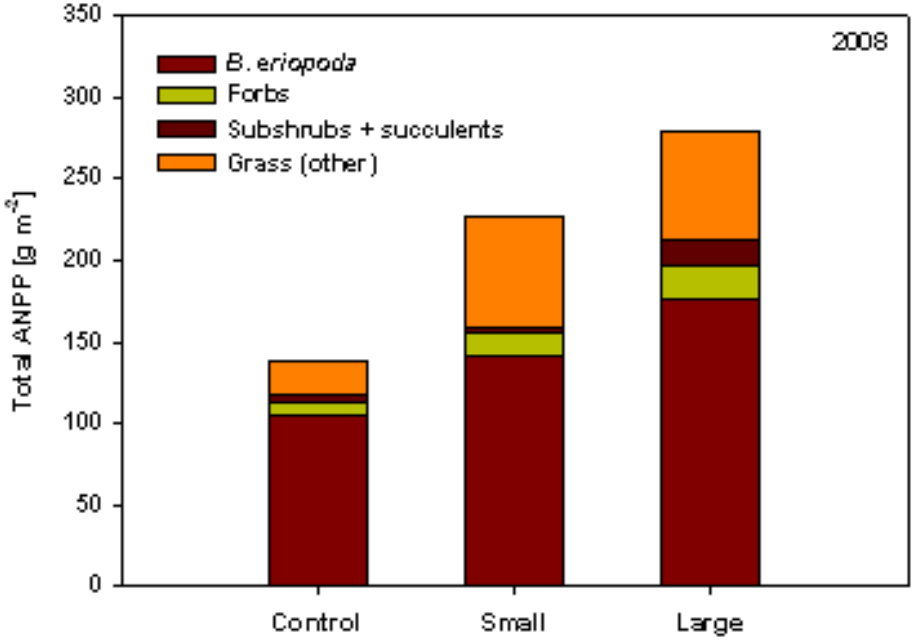


Responses similar to shortgrass steppe, but opposite mesic grasslands

Thomey et al. 2011 GCB

Total ANPP and ANPP of black grama were highest in plots receiving a few large events





- 25 – 40% greater ANPP of black grama with few large events compared to many small events
- similar trends for ANPP of all species combined

Thomey et al. 2011 GCB

Summary

- Both mesic and arid grasslands are sensitive to predicted changes in rainfall timing and event size
- Responses vary depending on grassland communities and ambient rainfall patterns (across grasslands and across years)
- Highlights the need for additional coordinated, long-term climate change experiments, using common protocols, across a broad range of grassland (and other ecosystem) types

Great Plains, US

Inner Mongolia, China