Global Climate Change: Potential Effects on Ecosystems in the Great Basin and Mojave

Stanley D. Smith

University of Nevada, Las Vegas

(stan.smith@unlv.edu)

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 temperatures to rise**

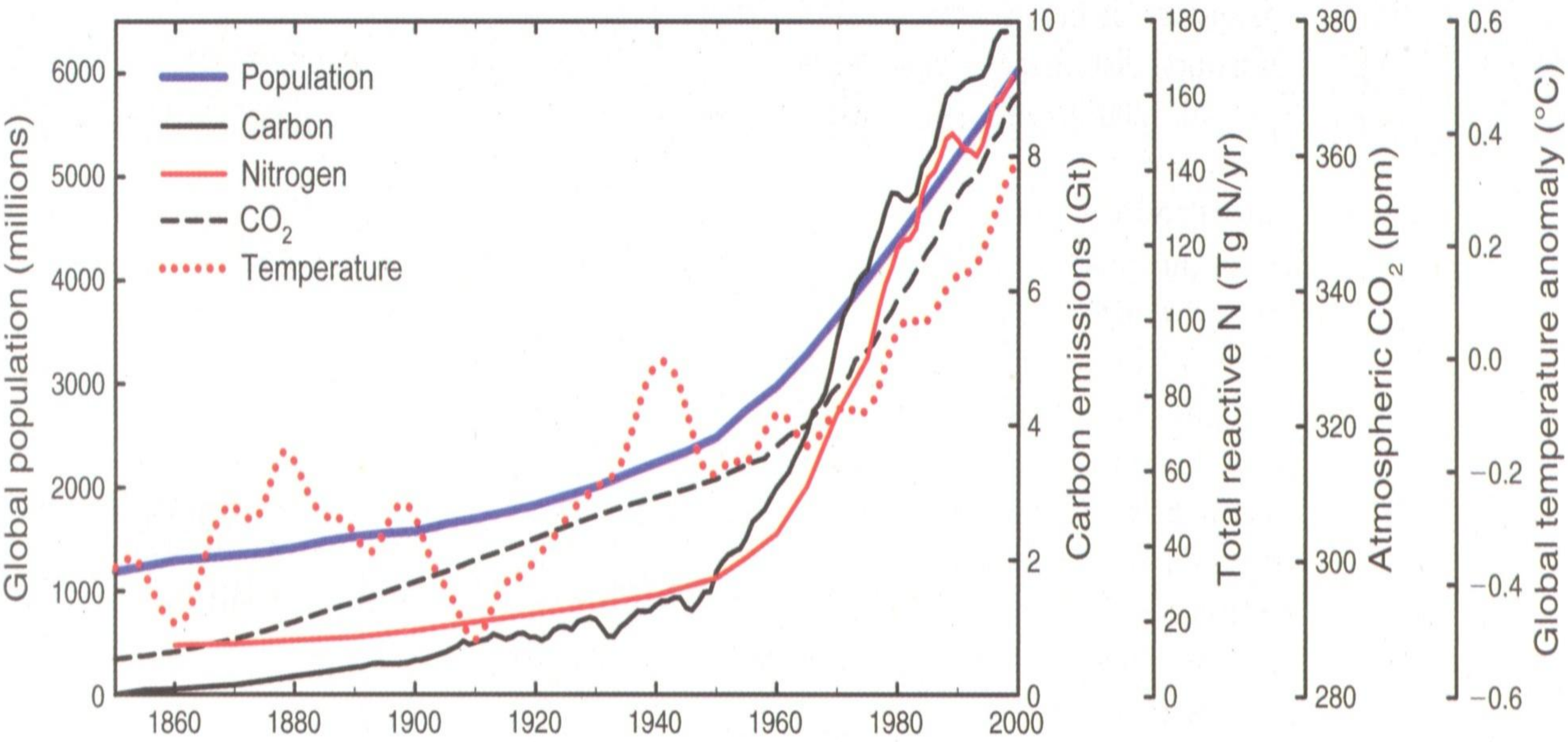
- **Changing precipitation regimes, nitrogen deposition, land disturbance and invasive species are also critical changes that will affect western desert regions**

The Past: Vegetation Development over the Last 20,000 Years in the Intermountain Region

(Spaulding and Graumlich 1986, Smith et al. 1997)

Region	Time Period (kypb)	Vegetation
Great Basin	Late Wisconsin (~ 20)	Conifer forest
	Early Holocene (~ 10)	PJ woodland
	Mid Holocene (~ 4-6)	Woodland-Steppe
	Late Holocene (< 4)	Steppe grassland (+ salt desert scrub)
Mojave	Late Wisconsin (~ 20)	Woodland-Grassland
	Early Holocene (~ 10)	PJ & Shrubland
	Mid Holocene (~ 4-6)	Desert scrub
	Late Holocene (< 4)	Desert scrub

The Anthropocene



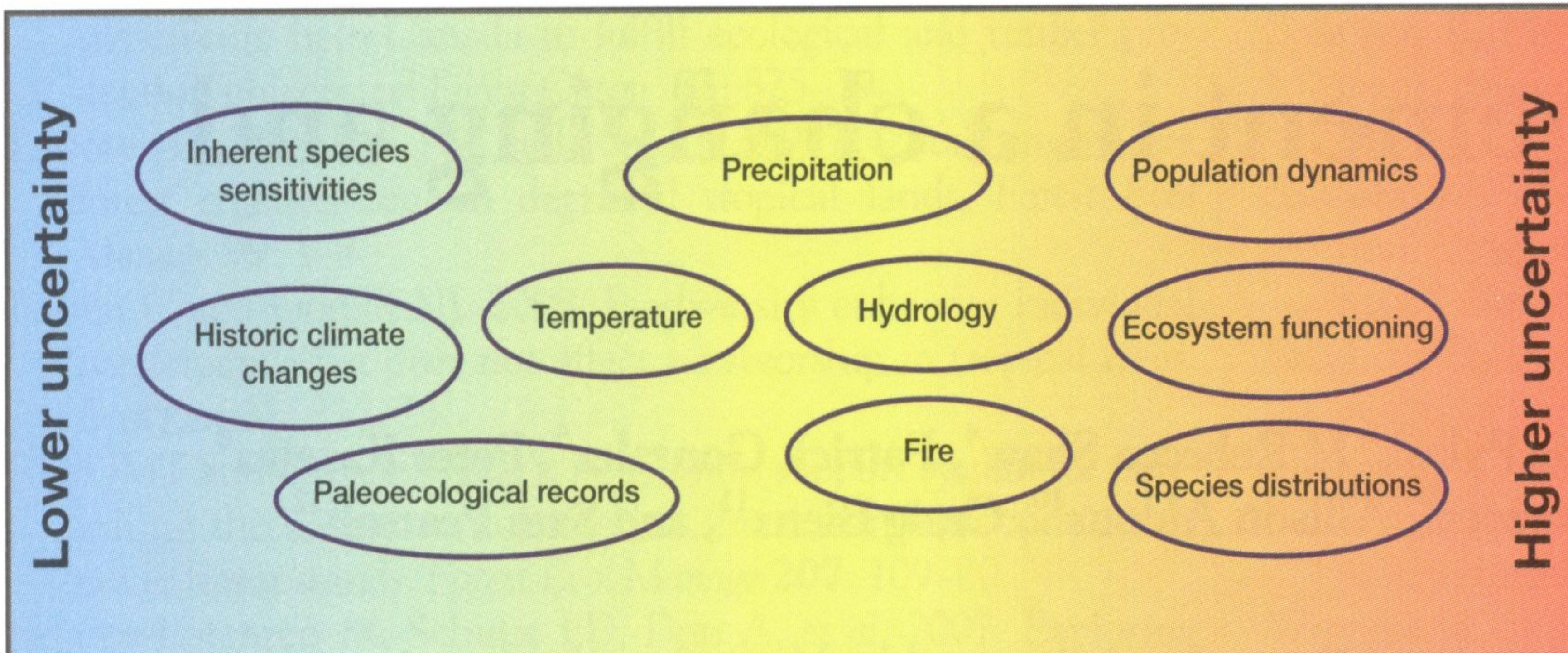
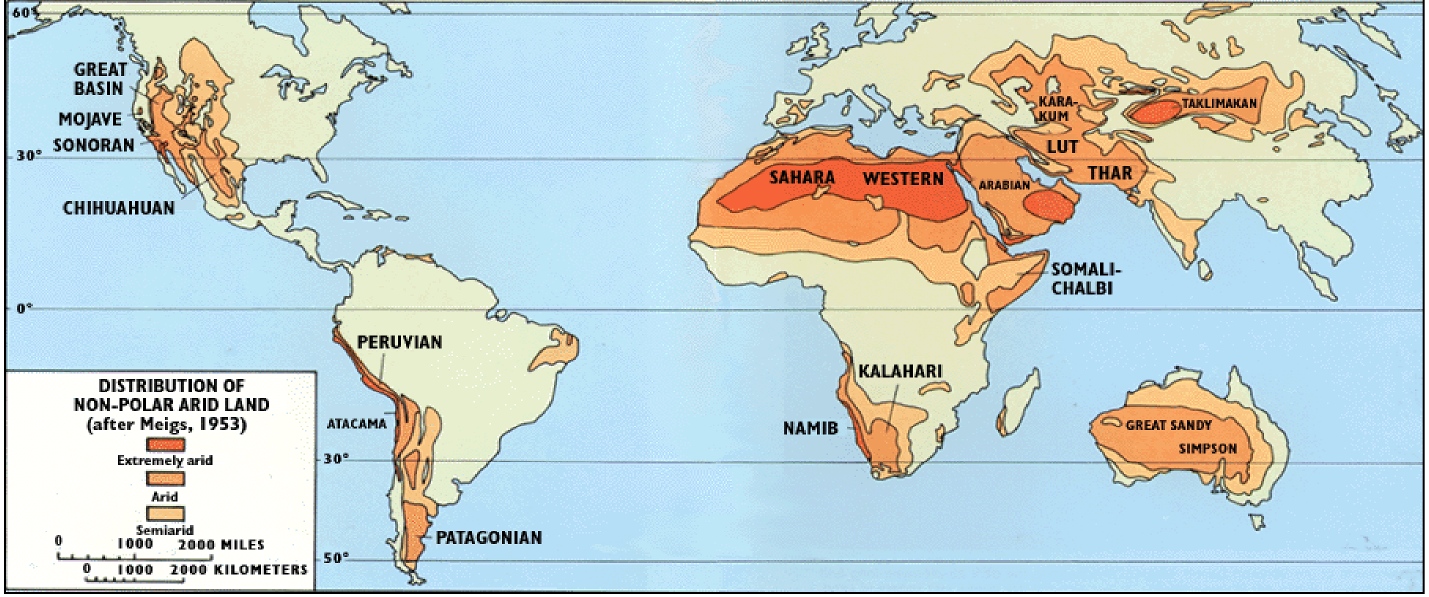


Figure 1. *Information used to develop management strategies for addressing climate change across a range of levels of uncertainty. The level of uncertainty assigned to each of the general types of information is necessarily subjective. Particular datasets in these general categories may be associated with more or less uncertainty than the levels depicted here.*

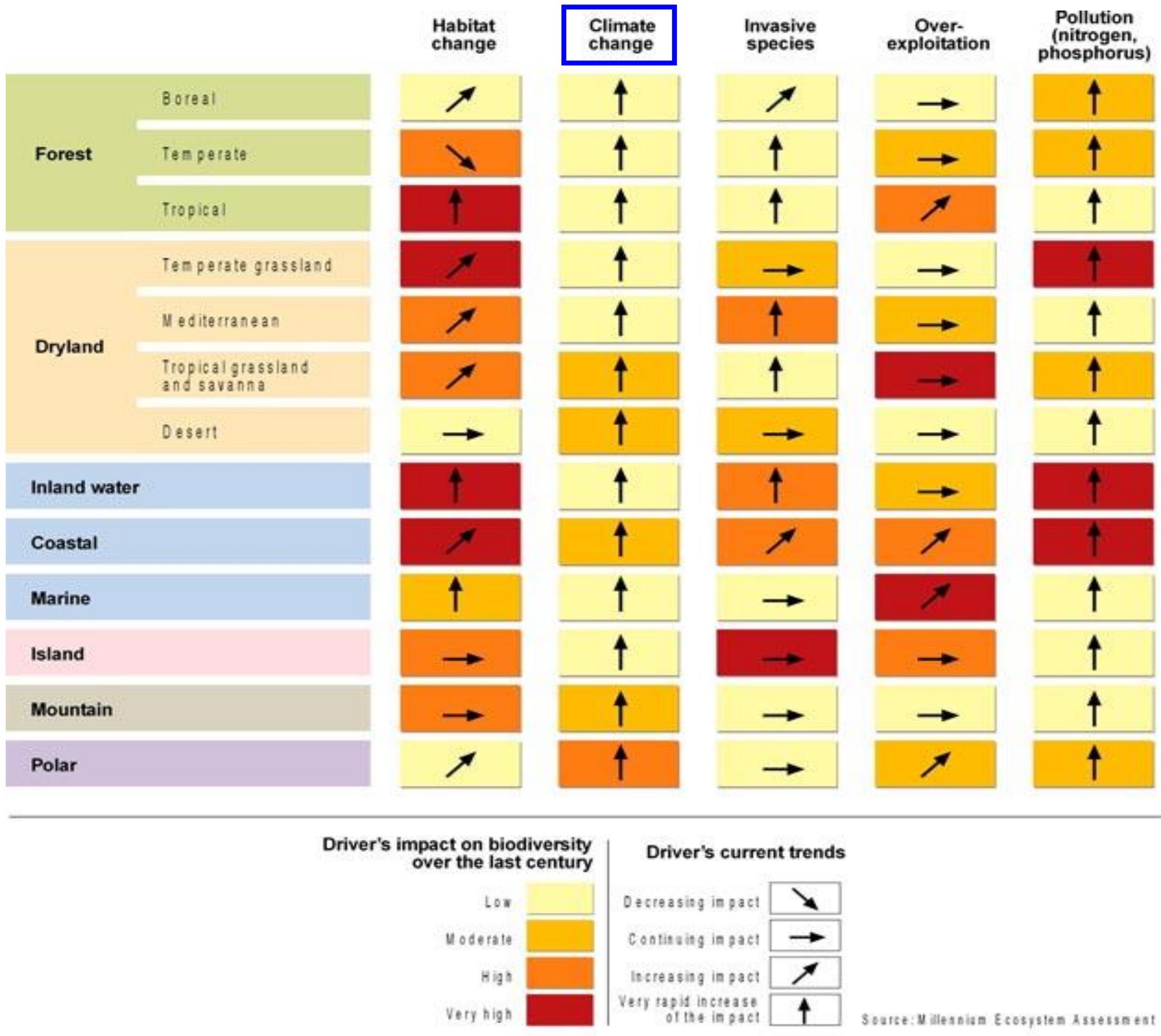


Why Study Deserts?

- Arid and semi-arid regions constitute 32% of the earth's surface and are increasing in area on a global basis through desertification (Miegs, 1953 and Dregne, 2002)
- 13% of the world's population lives in deserts (Allan and Warren, 1993) and 37% near deserts
- Deserts are extreme environments and are predicted to be highly responsive to global change

USGS Map of Arid Land

Driver impacts on biodiversity

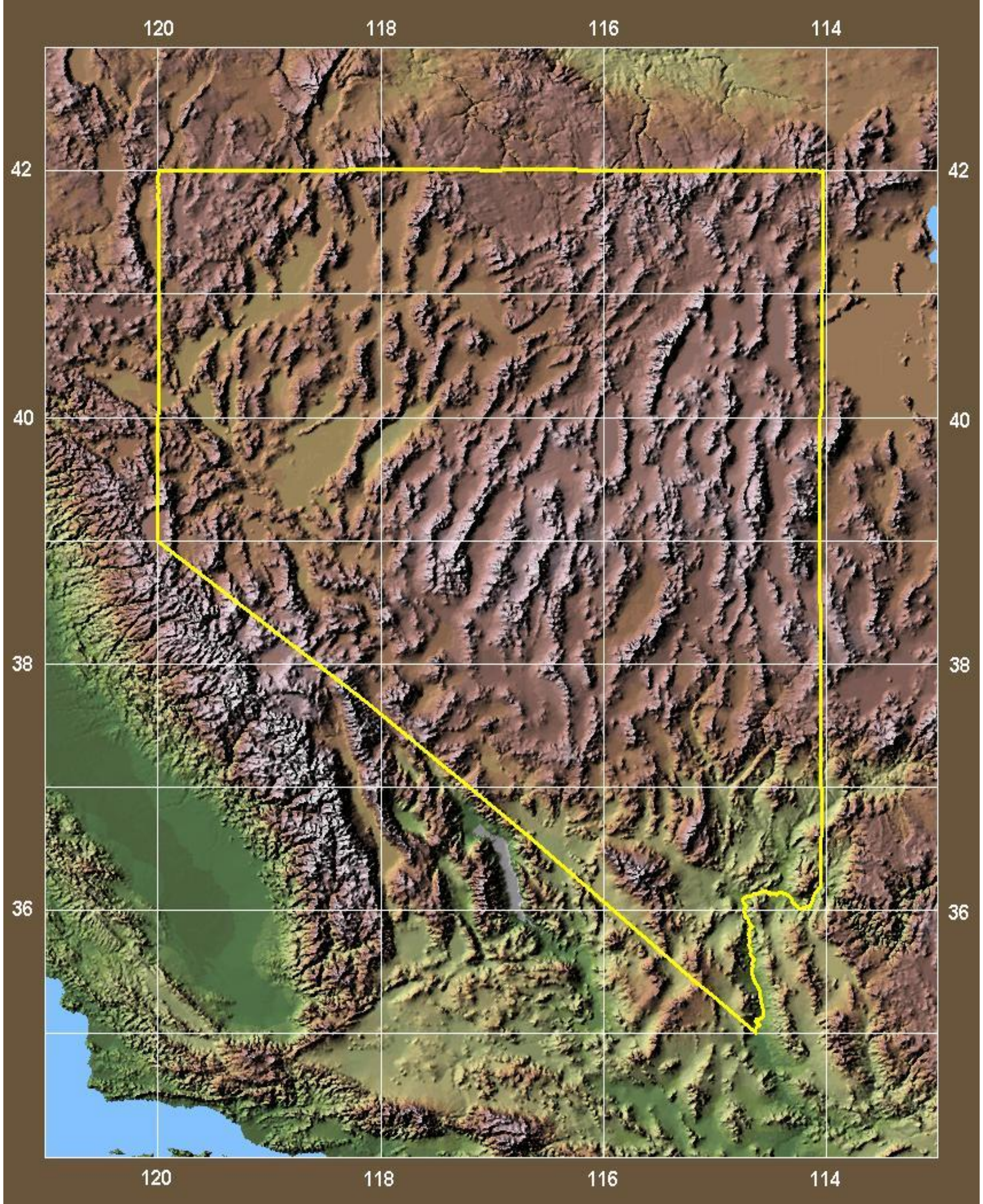


Millennium Ecosystem Assessment

Nevada's

Montane

"Sky Islands"



Death Valley

Pupfish

S. Lema (2008)

Amer. Sci.

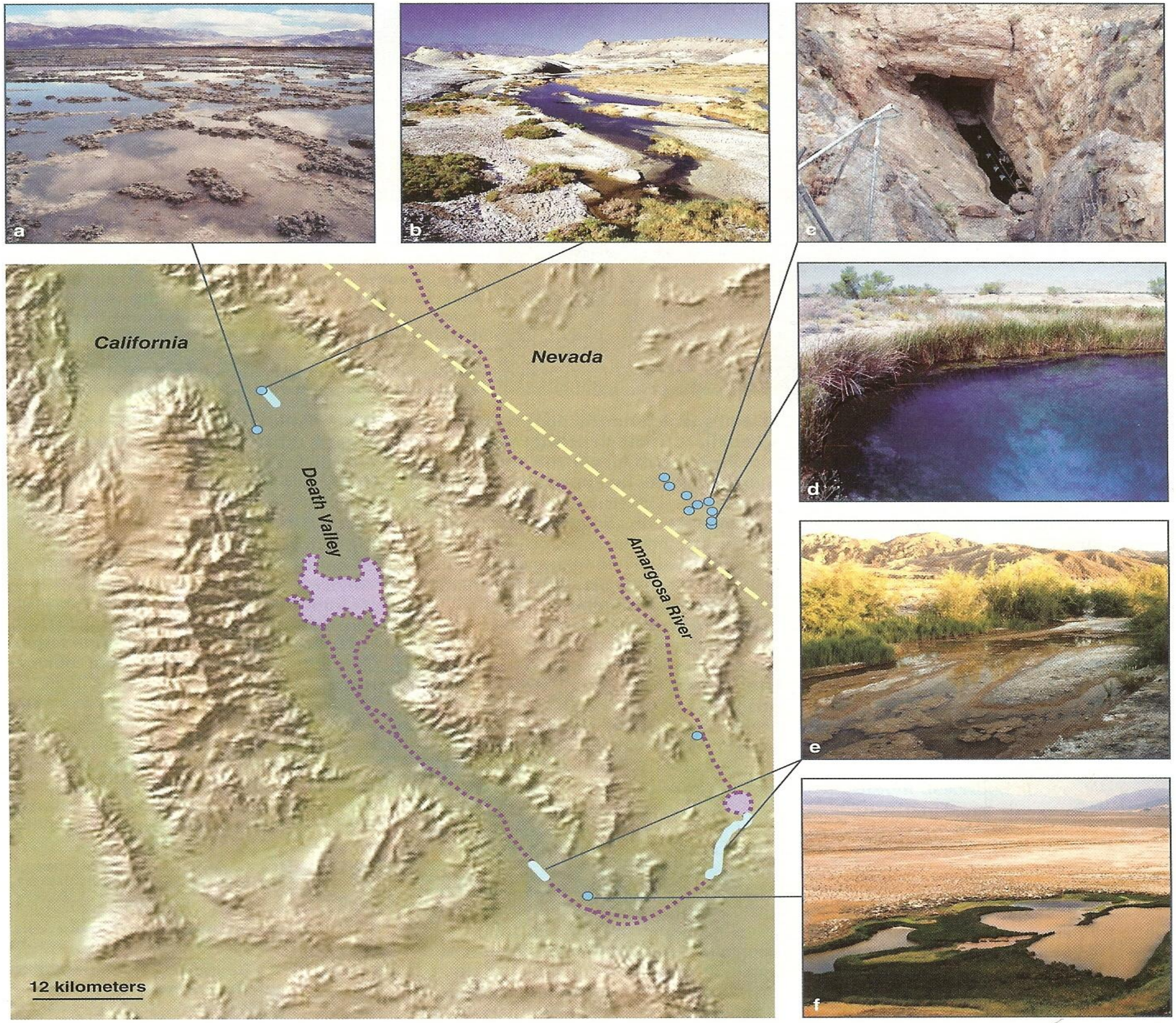


Figure 3. Permanent bodies of water are few and far between in Death Valley, and the pupfish that live here are scattered in these remote springs, marshes and streams. Two salt-tolerant species, the Cottonball Marsh pupfish (*Cyprinodon salinus milleri*) and the Salt Creek pupfish (*Cyprinodon salinus salinus*) make their homes in Cottonball Marsh and Salt Creek in the northern reaches of Death Valley (*a* and *b*). Devils Hole pupfish (*Cyprinodon diabolis*) are among the rarest of the remaining seven species, with fewer than a hundred individuals remaining (*c*). Big Spring (*d*) hosts the Ash Meadow pupfish (*Cyprinodon nevadensis mionectes*). The Amargosa River pupfish (*Cyprinodon nevadensis amargosae*) lives at two locations along the Amargosa River (*e*), whereas Saratoga Springs and Marsh provide habitat for the Saratoga pupfish (*Cyprinodon nevadensis nevadensis*) (*f*). The Warm Spring pupfish (*Cyprinodon nevadensis pectoralis*) is found near Devil's Hole. Two other species, *Cyprinodon nevadensis calidae* and *Cyprinodon nevadensis shoshone*, are extinct.

The Nevada Desert Research Center

Elevated [CO_2]

Added summer rain
N deposition
Crust removal

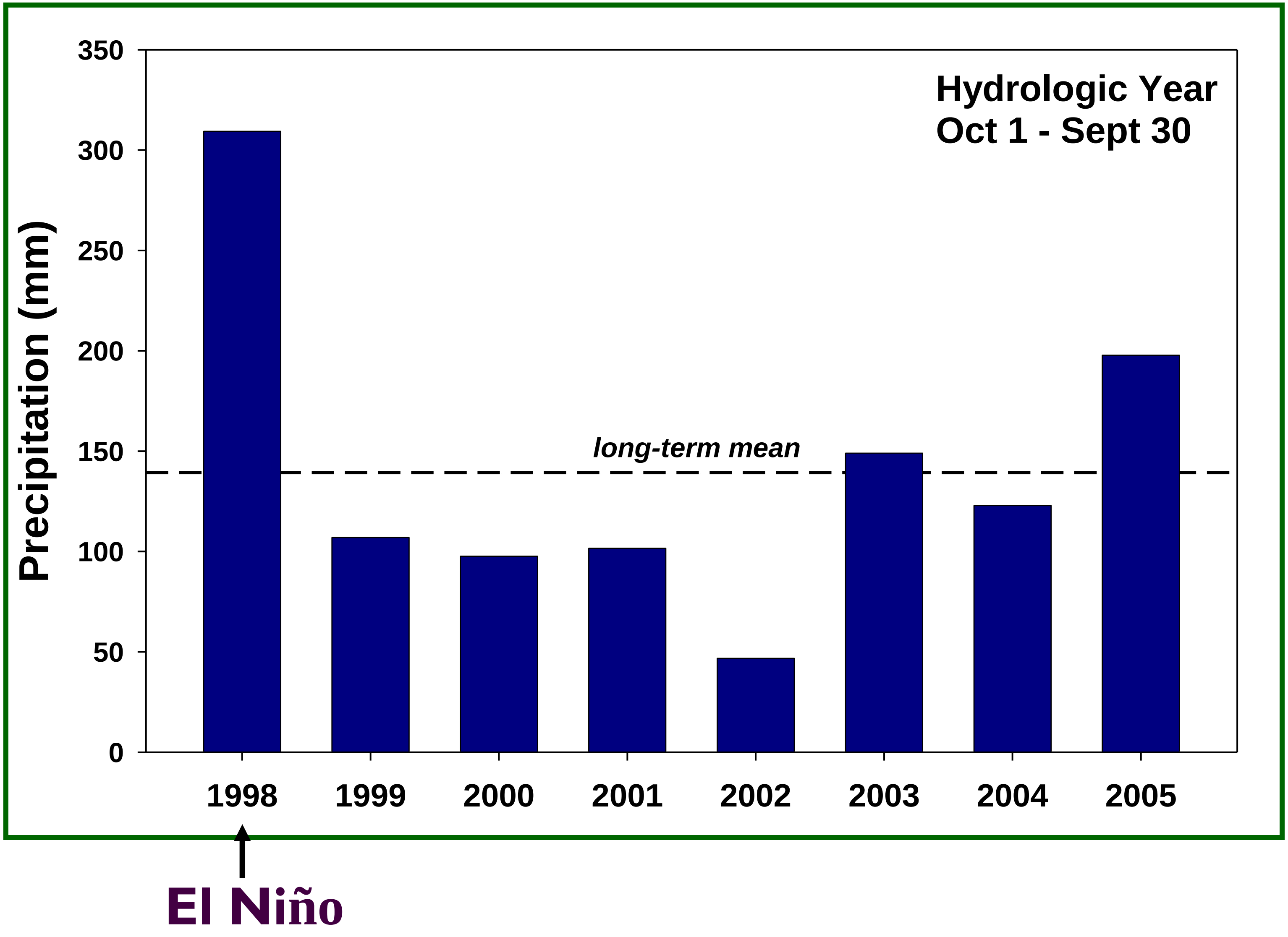
Nevada Desert FACE Facility

- Free-Air Carbon Dioxide Enrichment, operational since 1997
- Located 90 km north of Las Vegas on the Nevada Test Site
- Elevated [CO_2] rings maintained at 550 ppm (n = 3)
- Operates 365 days per year, 24 hours each day

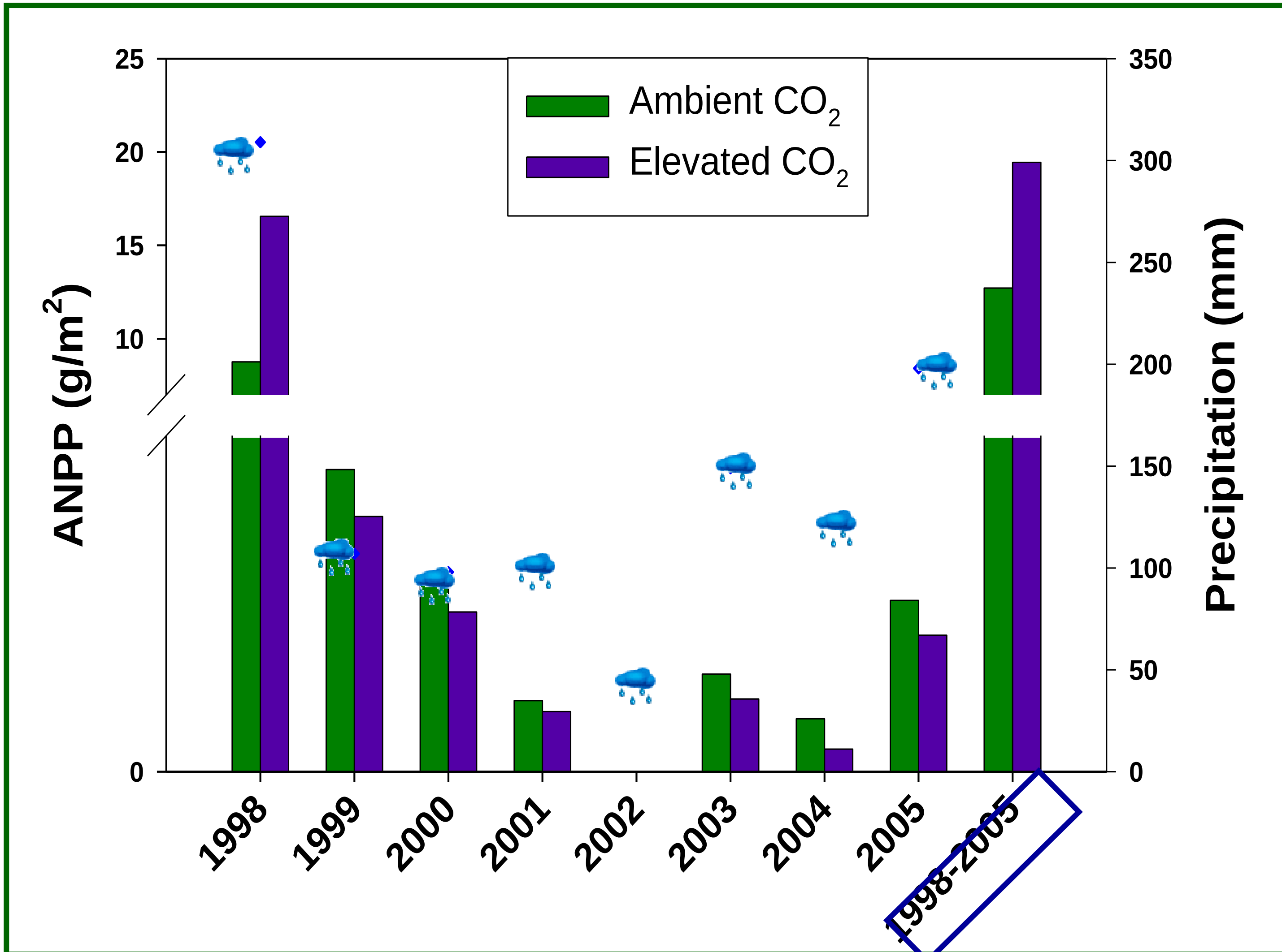
Oblique aerial view of Ring 3; an elevated CO_2 treatment plot

View of a NDFF Ring & Sampling Platform

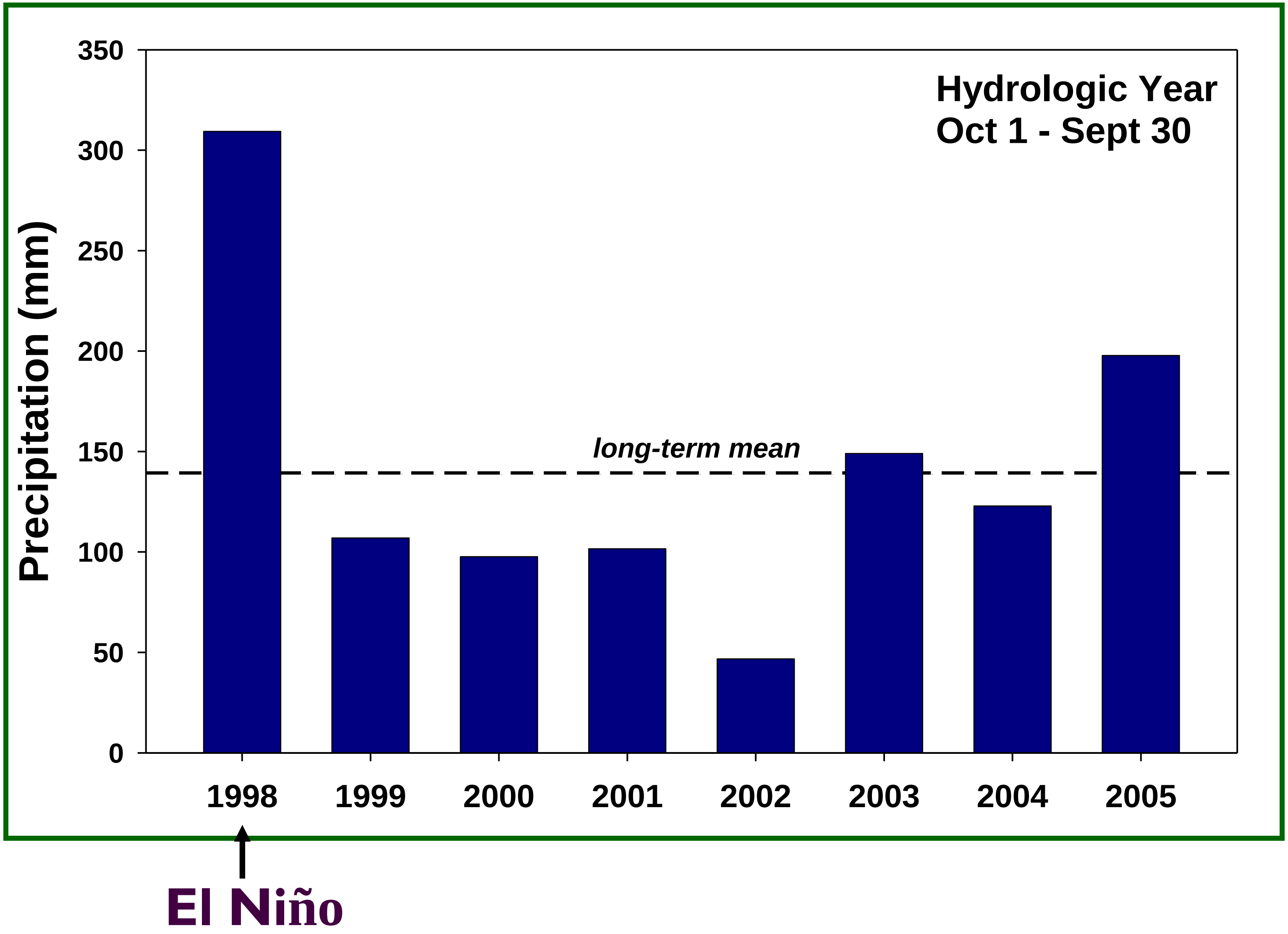
Precipitation at NDFF



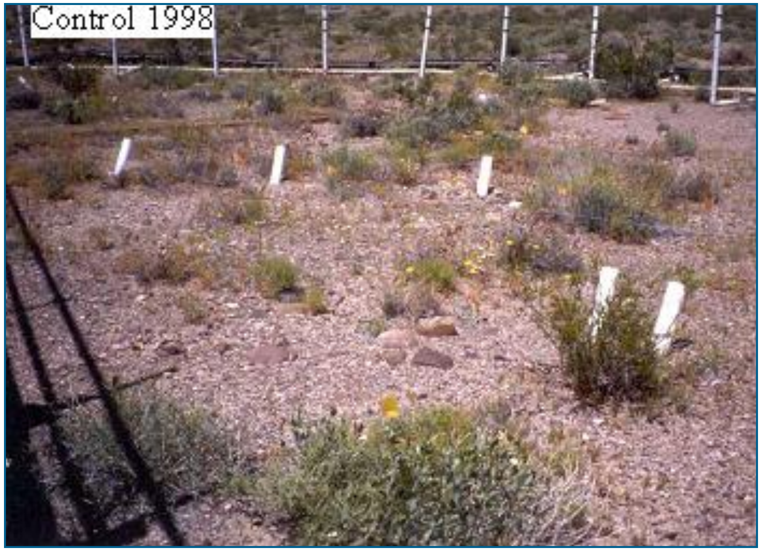
Estimated Aboveground ANPP

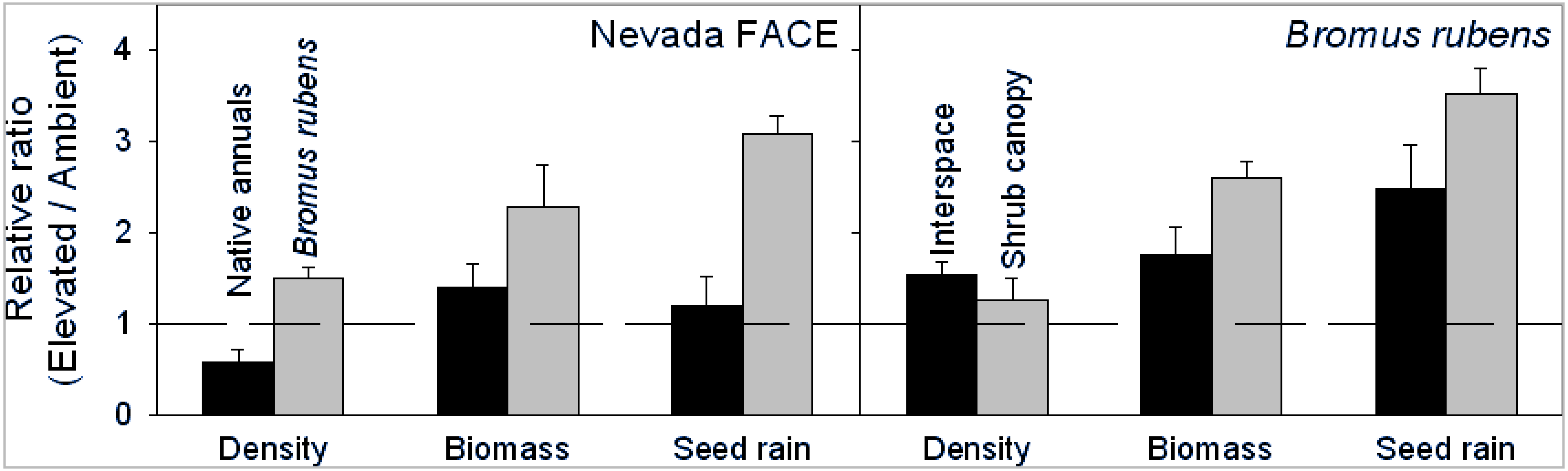


Precipitation at NDFF



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?

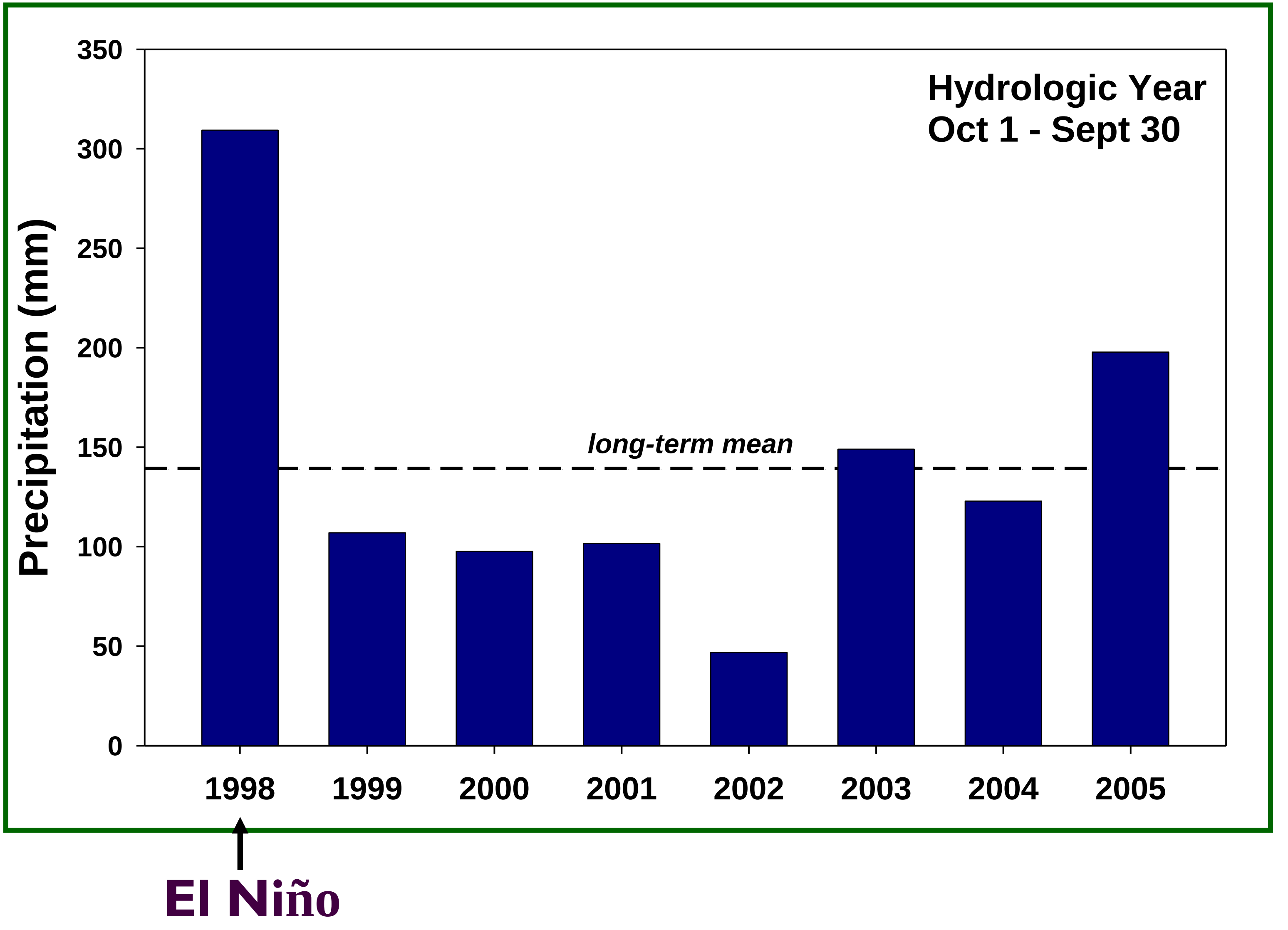
1. Accelerated phenology

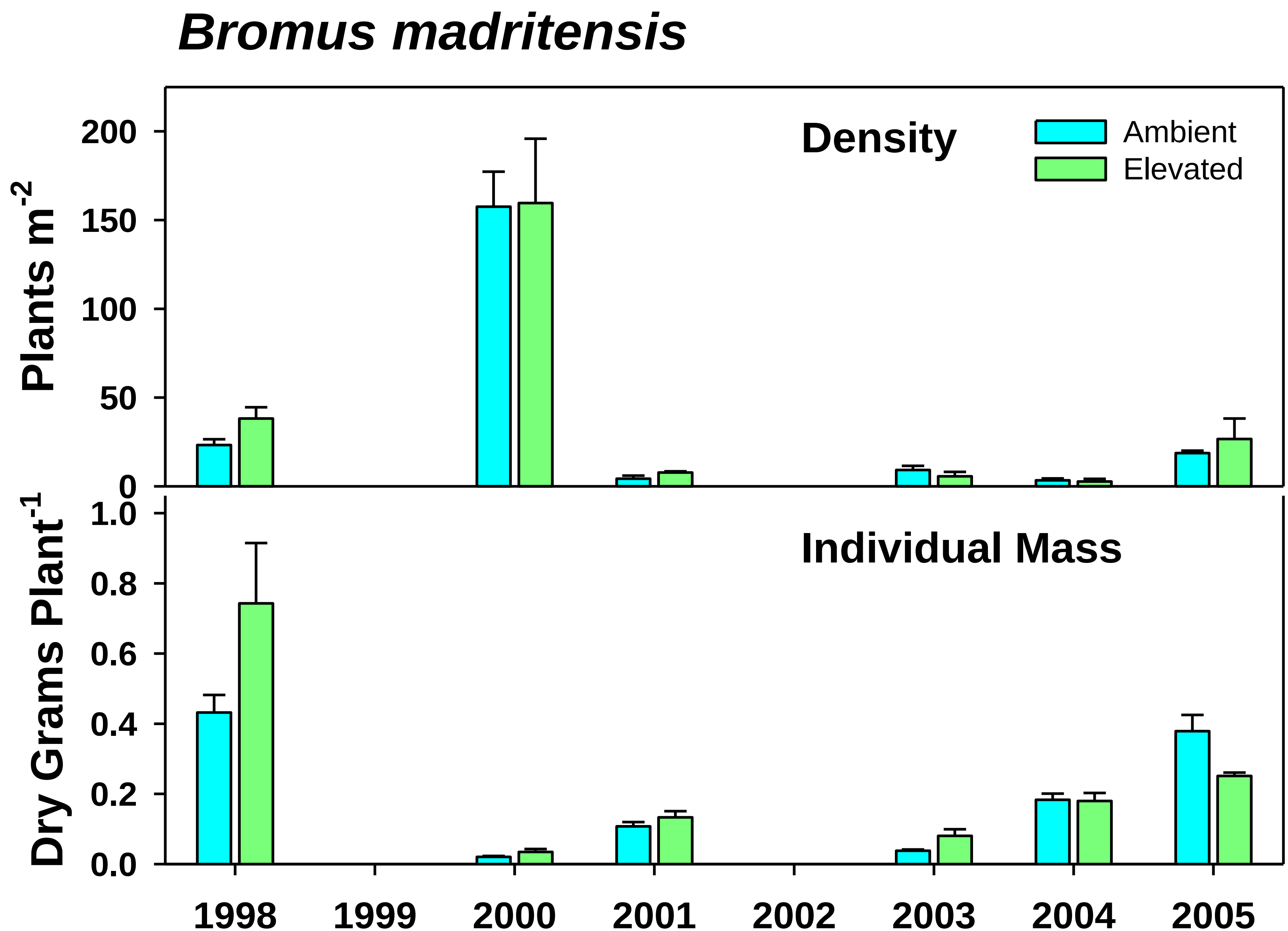
2. Produces smaller, more numerous seeds

3. Lower construction cost

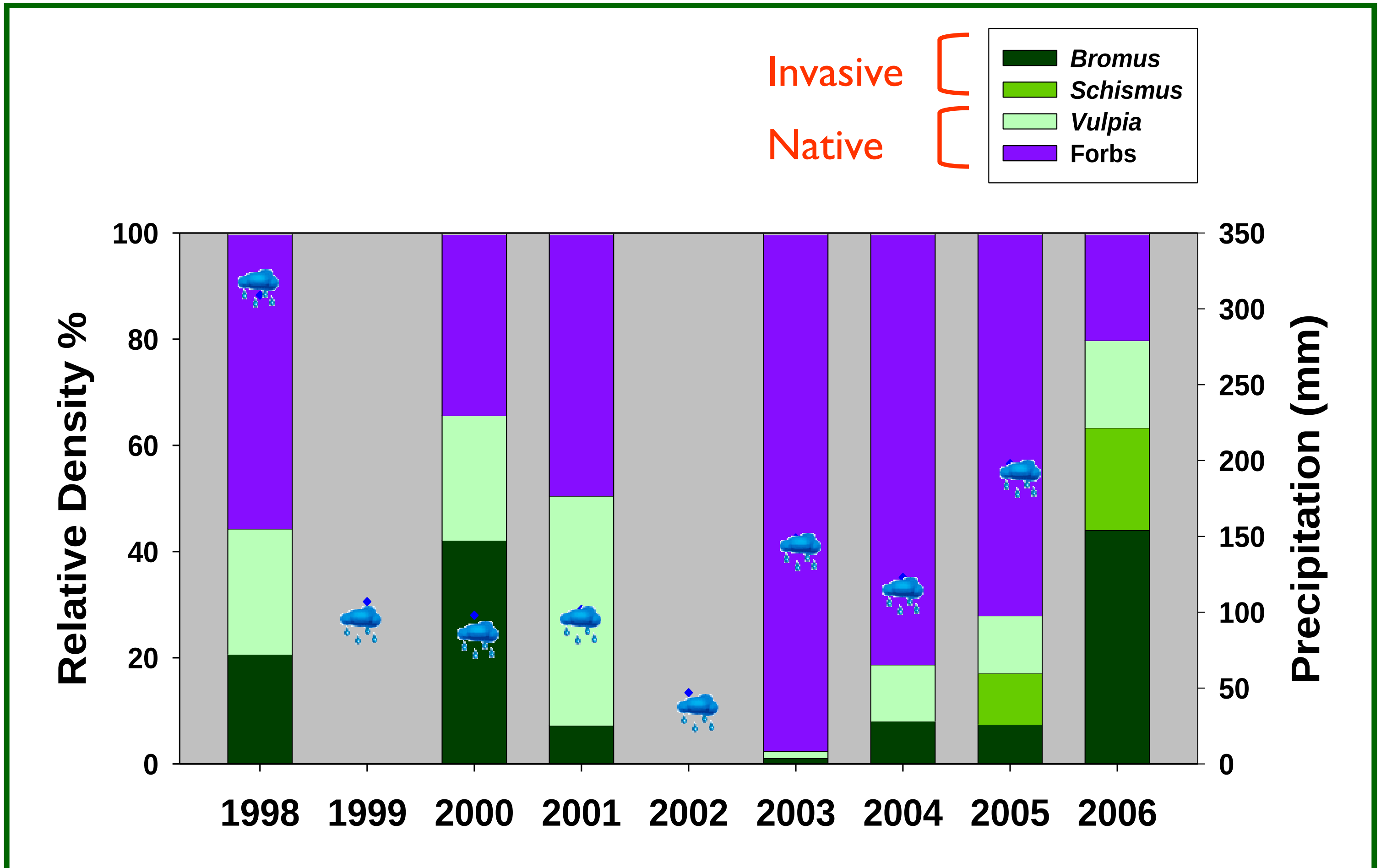
1,2: Huxman *et al.* (1999, 2000, 2001)
3: Nagle *et al.* (*Ecology*, 2004)

Precipitation at NDFF




Bromus madritensis
Density
Ambient
Elevated
Plants m-2
Individual Mass
Dry Grams Plant-1
200
150
100
50
0
1.0
0.8
0.6
0.4
0.2
0.0
1998
1999
2000
2001
2002
2003
2004
2005

Native v. Invasive Annuals



FACE Conclusions

- **Primary production is stimulated by elevated CO_2 primarily in wet years**
- **Elevated CO_2 thus results in more variable inter-annual production cycles**
- **Intensified drought should reduce the stimulatory effects of CO_2 and may negate invasive success**
- **However, if precipitation significantly increases in this region, ANPP should dramatically increase at elevated CO_2, as will exotic species and fire frequency and severity**

Nevada climate change

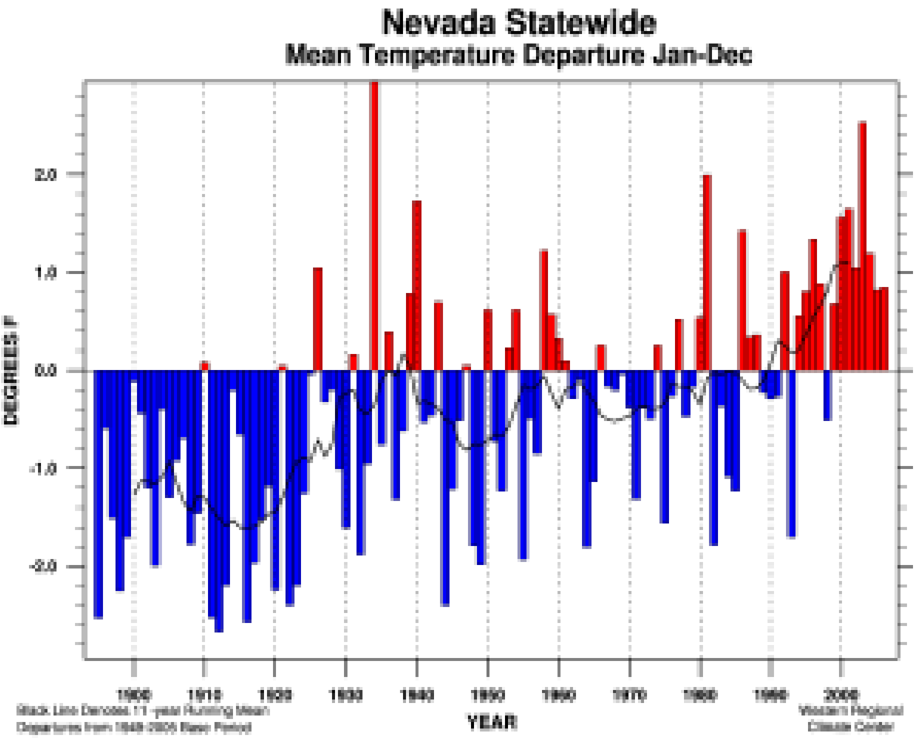


Figure 1: Nevada Statewide average temperature from 1896 to 2006. (source: Western Regional Climate Center).

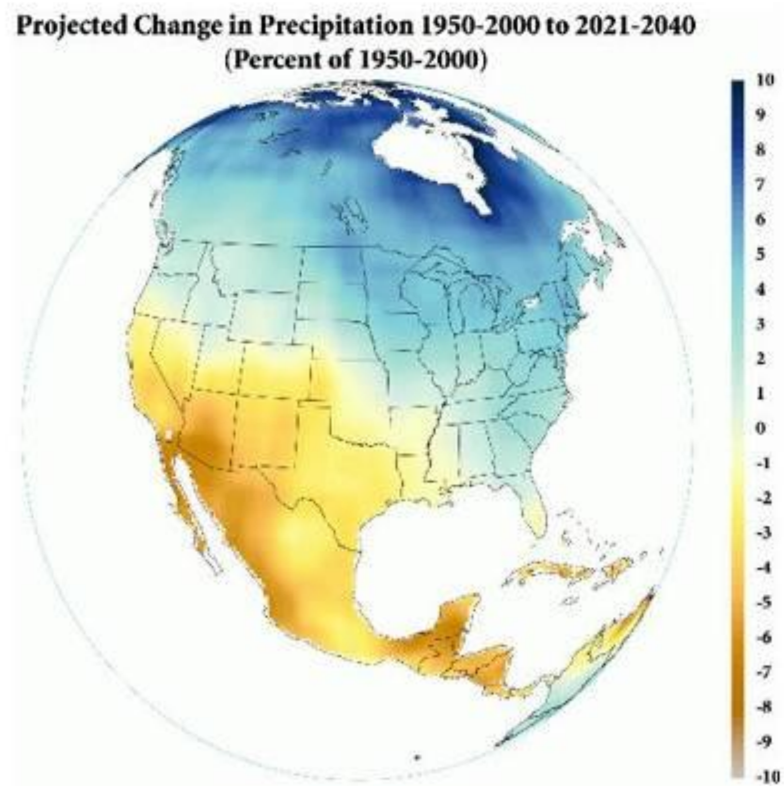
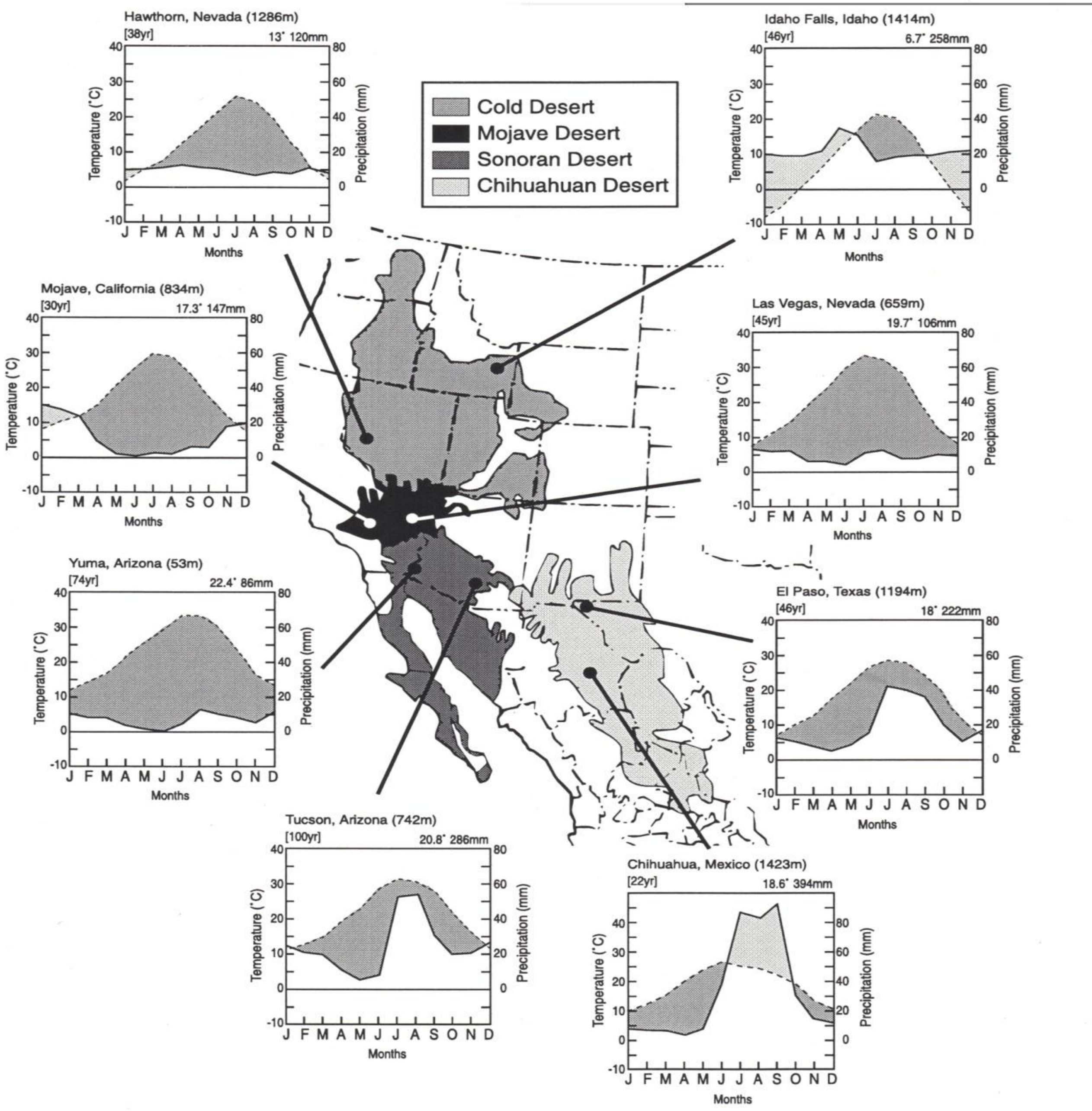


Figure 2: North American projected changes in precipitation for the period 2021 - 2040. (source: Seager et al., 2007).

The Mojave: Climate Transition Between the Cold and Hot Deserts



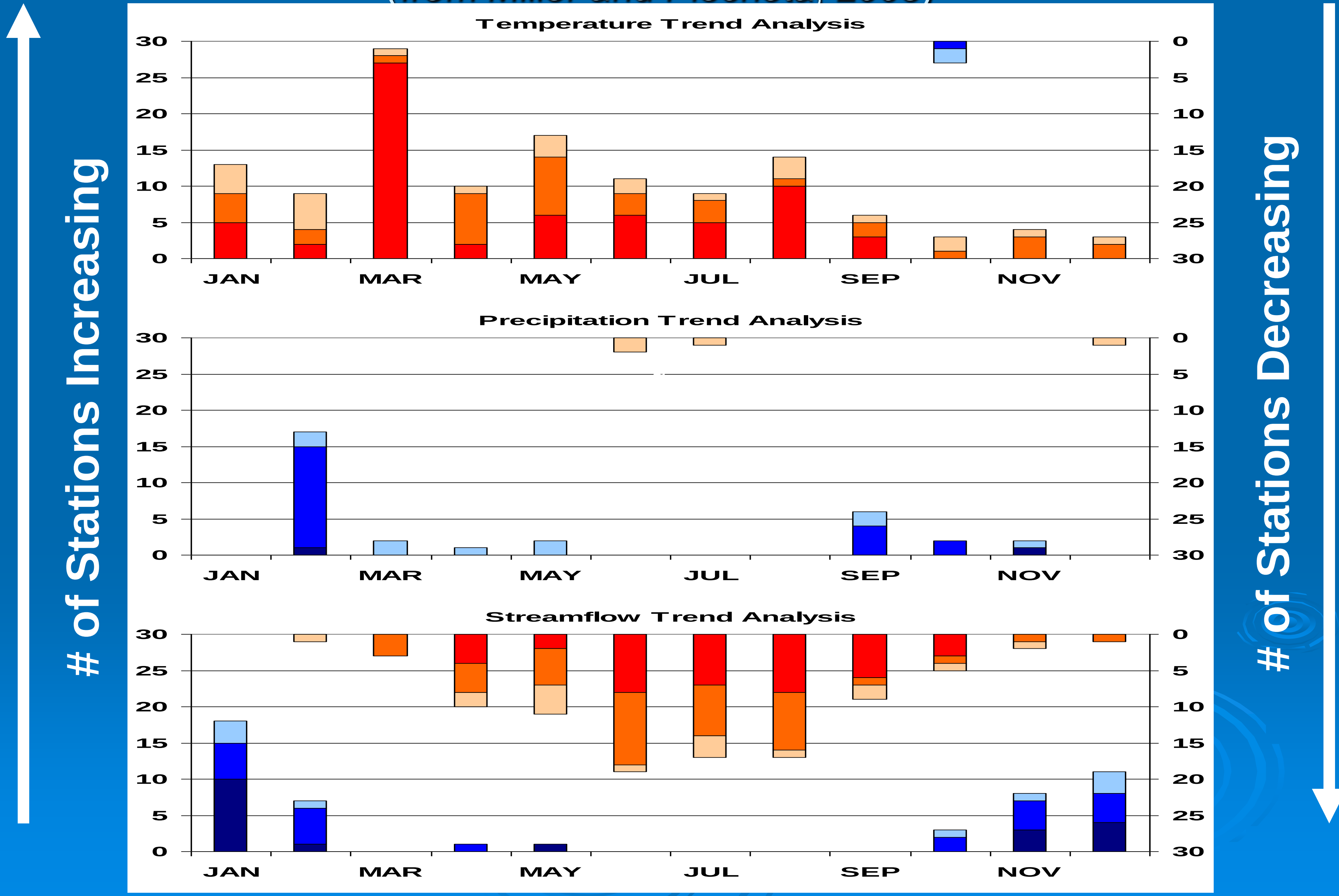
Photographs taken during a severe heat wave in western Australia in January 2009 (supplied by Northern /guardian Newspaper)

Figure 1. Dead Budgerigars (*Melopsittacus undulatus*) during a severe heat wav western Australia during January 2009. The birds appear to have been seeking sl when they perished from dehydration and/or hyperthermia.

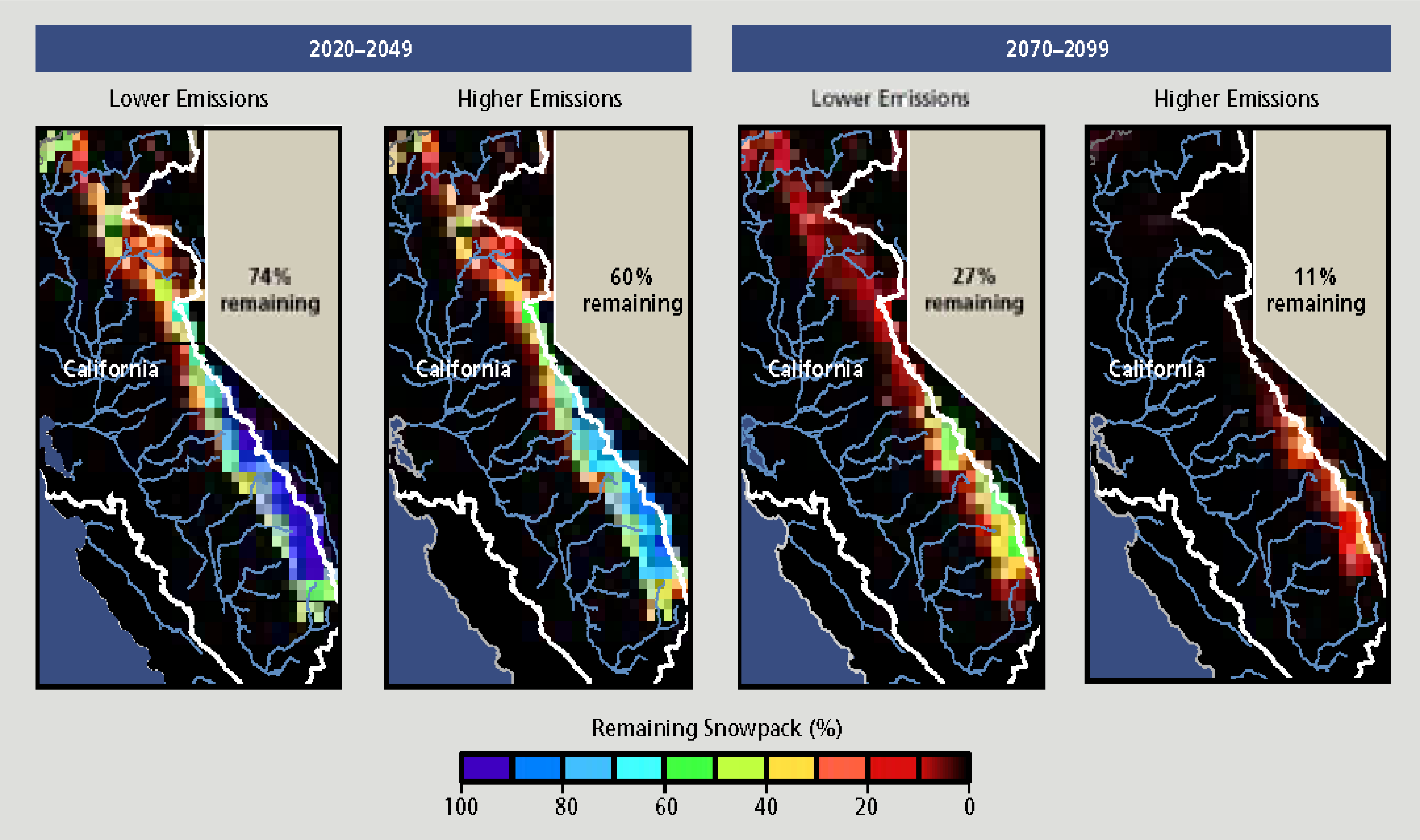
Figure 5. Large numbers of dead Budgerigars near Carnarvon, western Australia, during a severe heat wave during January 2009. This image reiterates the potential of extreme heat waves to result in the deaths of many thousands, or potentially even millions, of birds.

Summary of Trends

(from Miller and Piechota, 2008)



Sierra Nevada Snowpack Projections Based on Different Emissions/Warming Scenarios



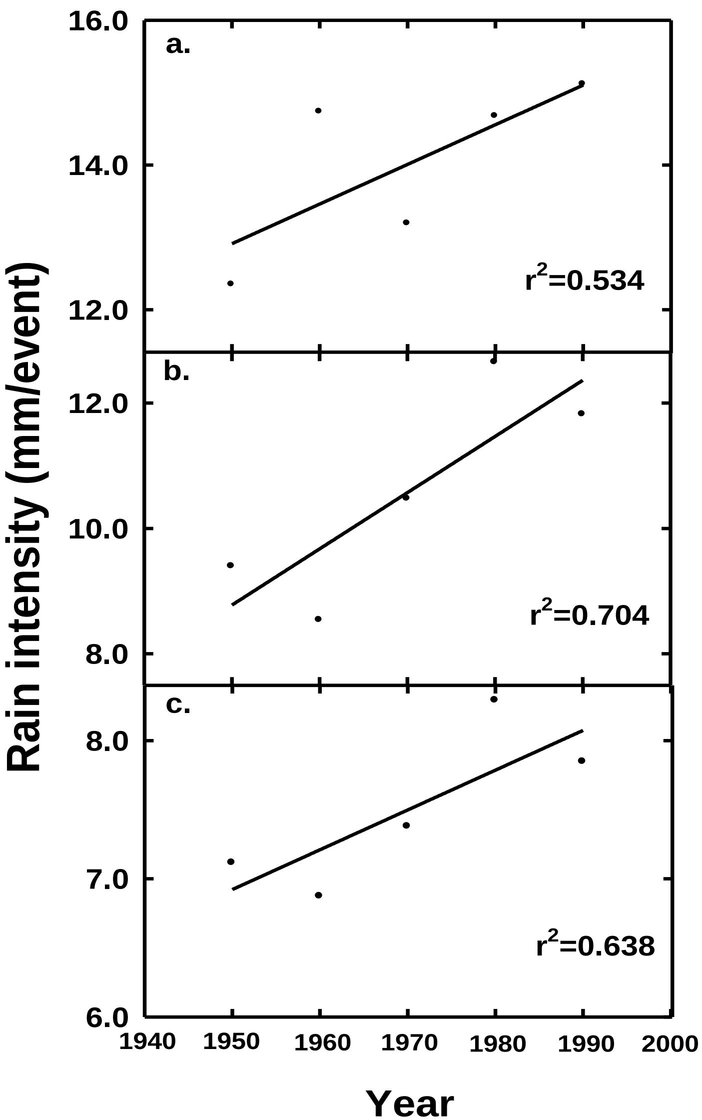
Hayhoe, Cayan, Field et al. (2004) PNAS 101:12422-12427

Consequences of More Extreme Precipitation Regimes for Terrestrial Ecosystems

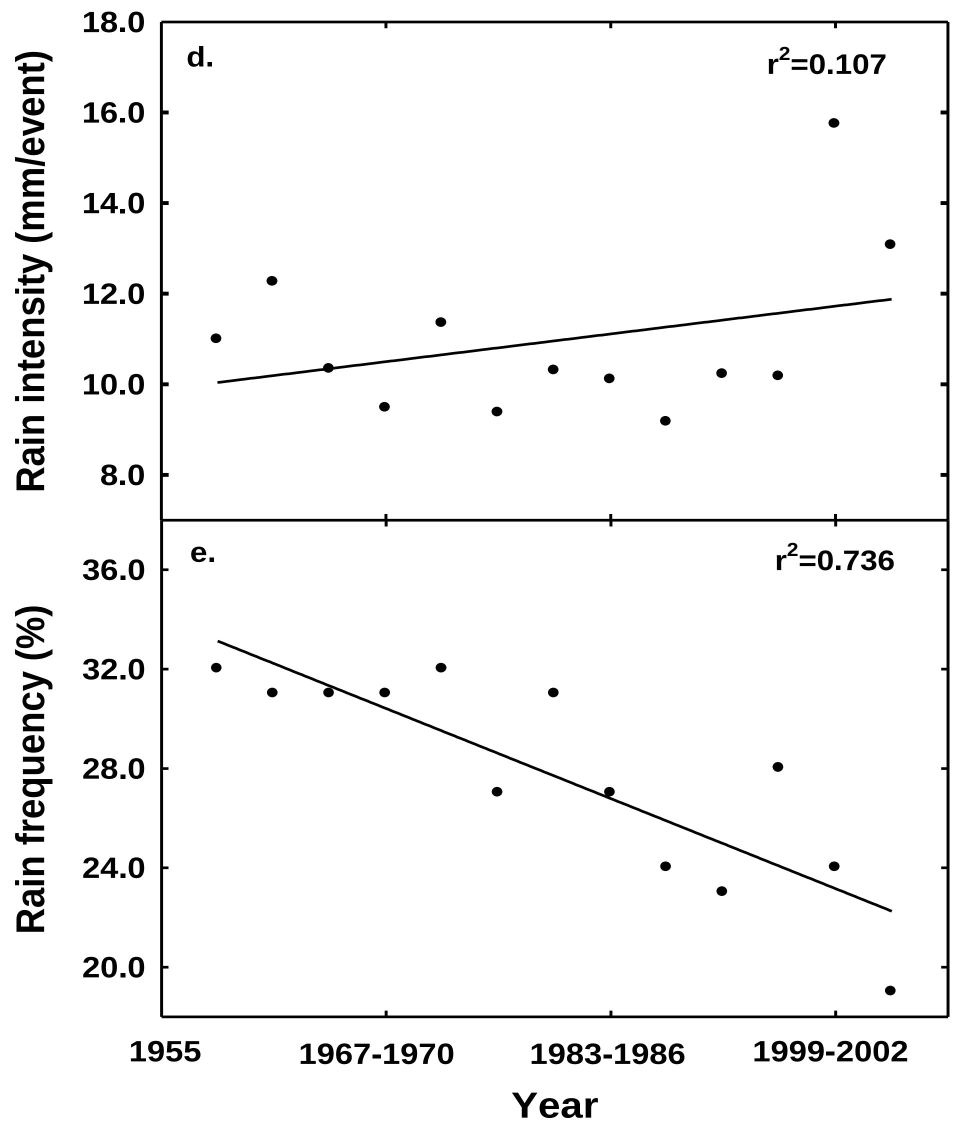
ALAN K. KNAPP, CLAUS BEIER, DAVID D. BRISKE, AIMÉE T. CLASSEN, YIQI LUO, MARKUS REICHSTEIN, MELINDA D. SMITH, STANLEY D. SMITH, JESSE E. BELL, PHILIP A. FAY, JANA L. HEISLER, STEVEN W. LEAVITT, REBECCA SHERRY, BENJAMIN SMITH, AND ENSHENG WENG

***BioScience* 58:811-822 (2008)**

Oklahoma Precip. Gradient

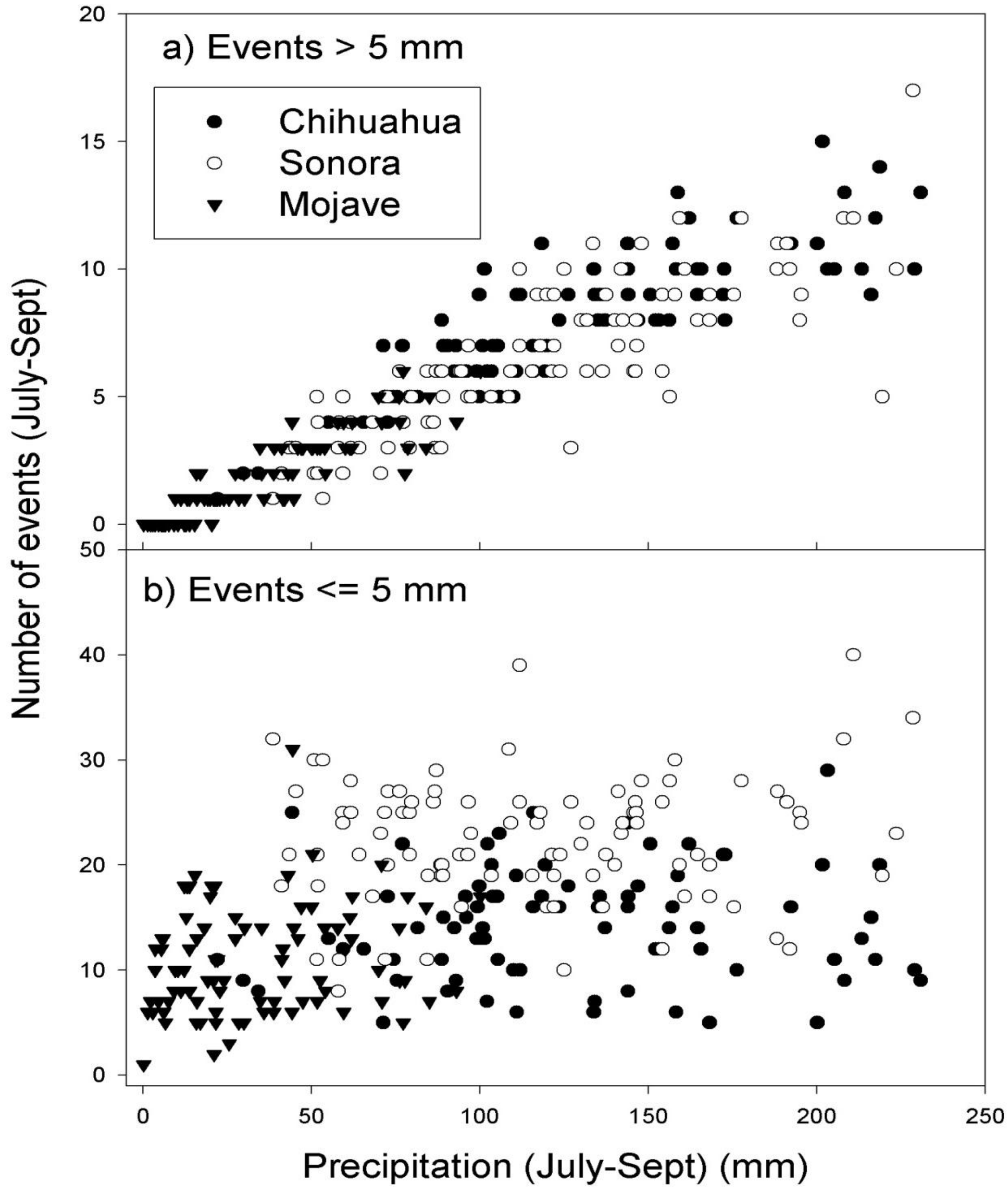


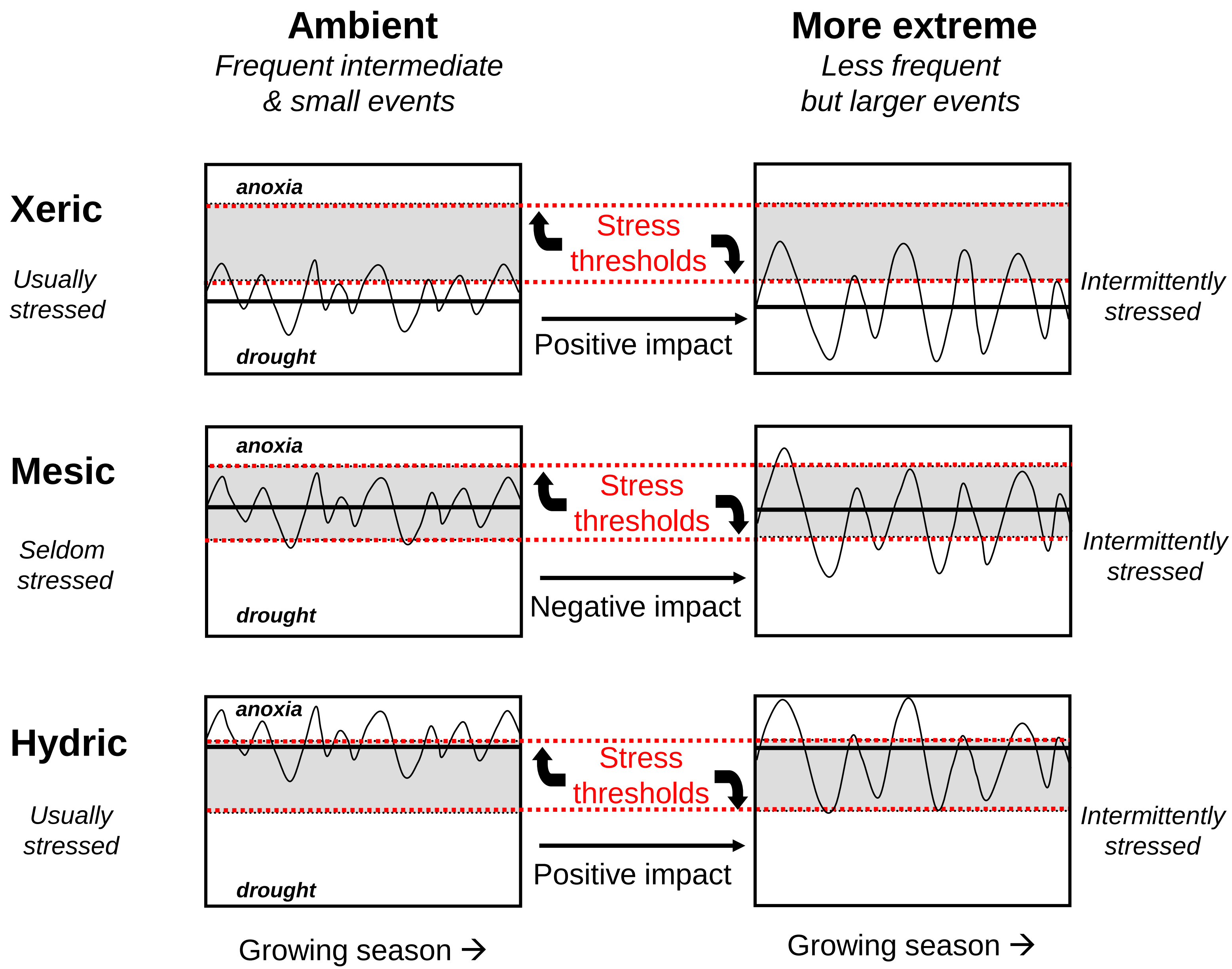
Greece



Precipitation in the Southwest Deserts

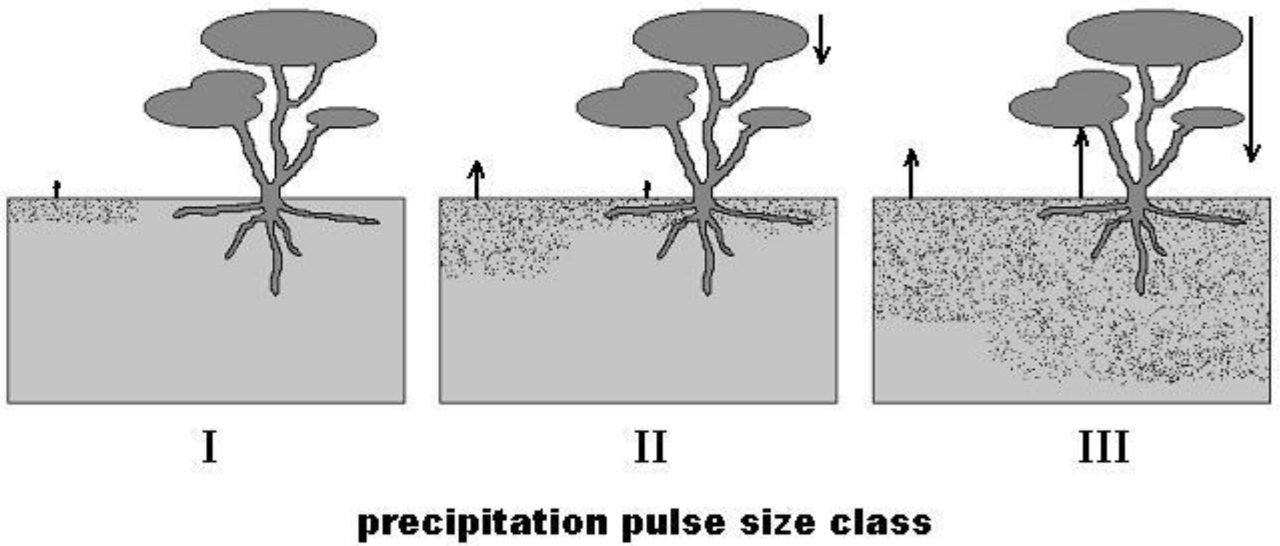
Huxman et al. (2004)



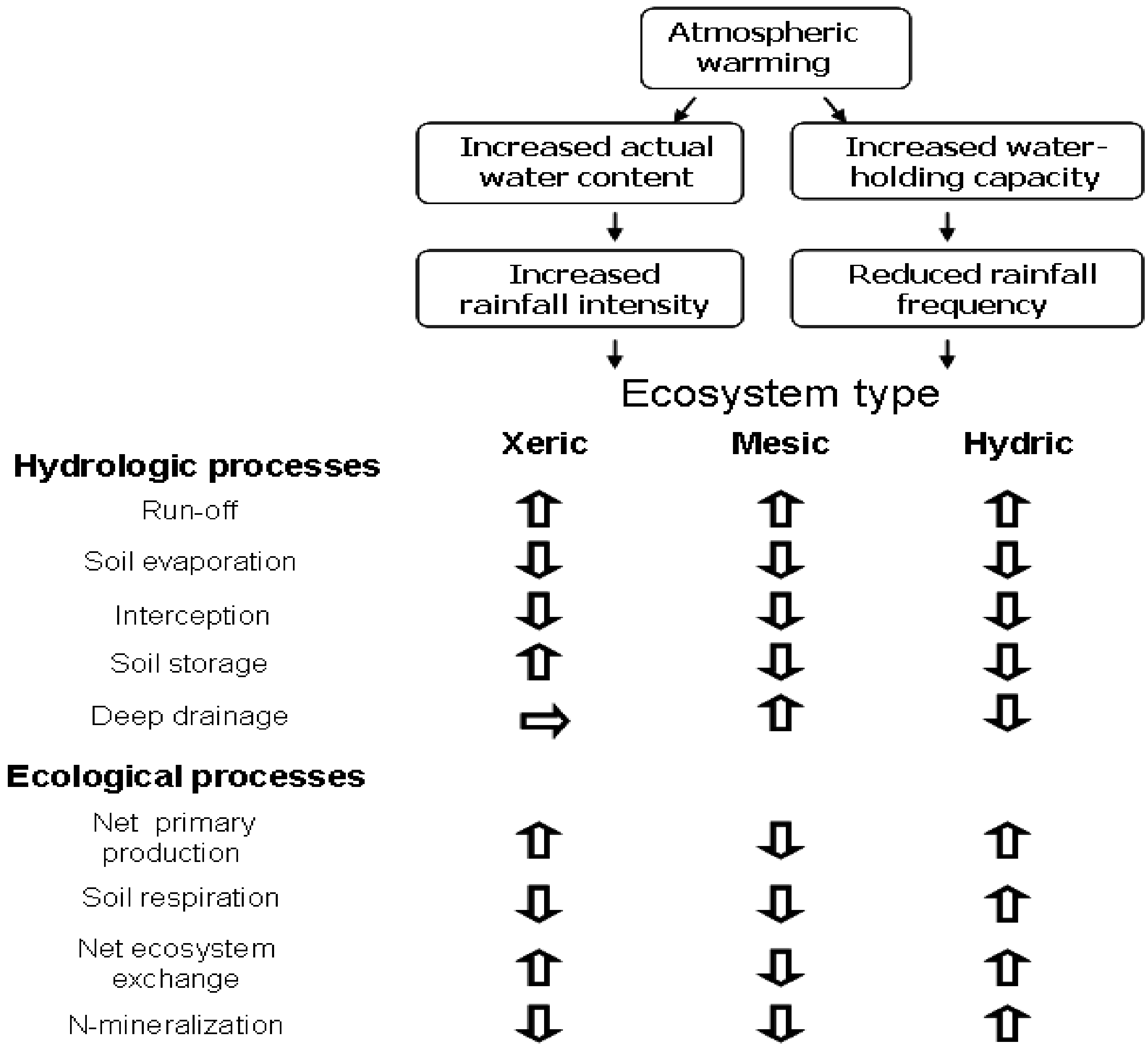

Ambient
Frequent intermediate & small events
More extreme
Less frequent but larger events
Xeric
Usually stressed
anoxia
drought
Stress thresholds
Positive impact
Intermittently stressed
Mesic
Seldom stressed
anoxia
drought
Stress thresholds
Negative impact
Intermittently stressed
Hydric
Usually stressed
anoxia
drought
Stress thresholds
Positive impact
Intermittently stressed
Growing season →
Growing season →

Net Ecosystem Exchange of CO_2 (NEE) as a Function of Pulse Size

(Huxman et al. 2004)

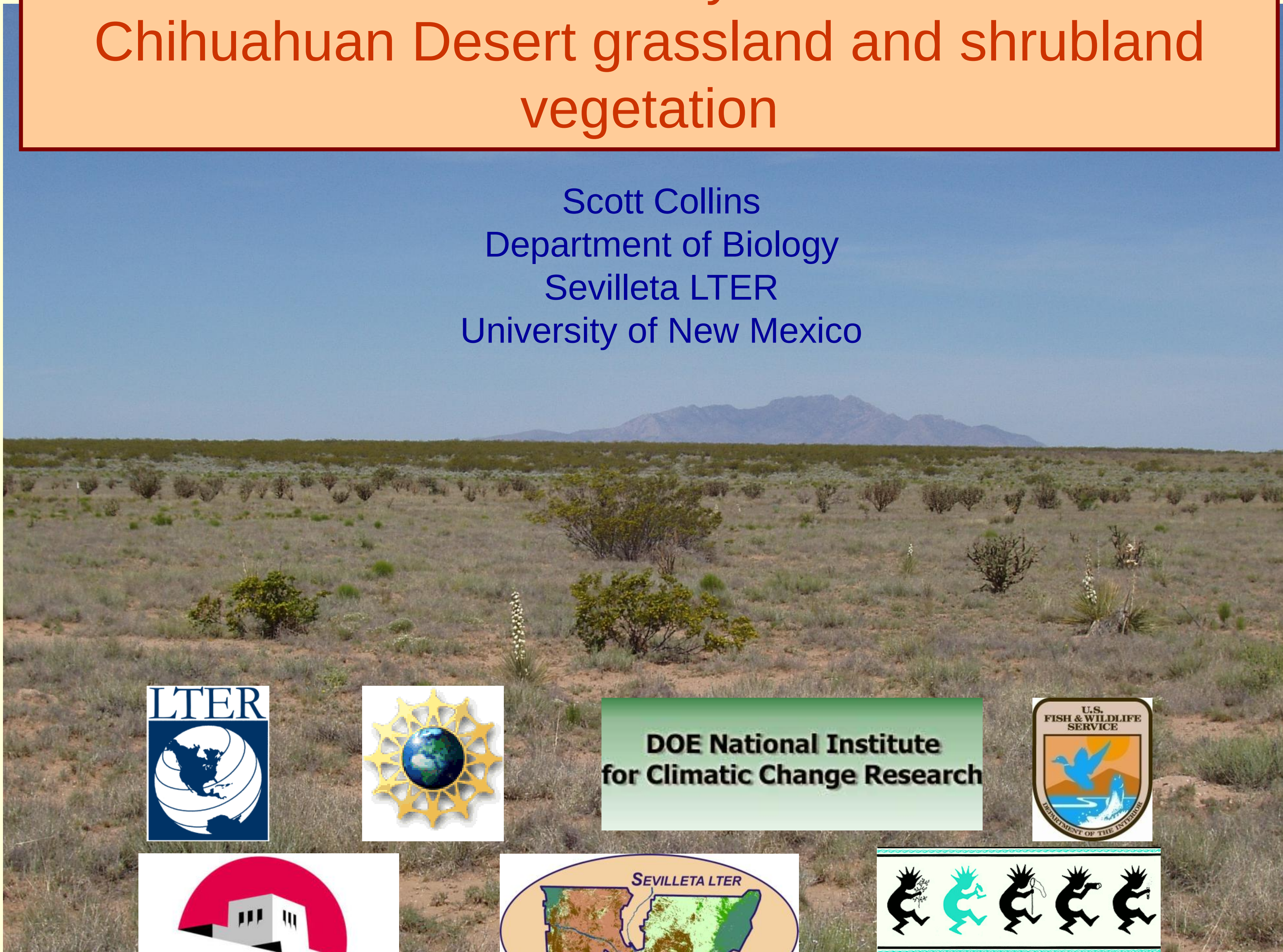


NEE (–) NEE (0) NEE (+)


Atmospheric warming
Increased actual water content
Increased water-holding capacity
Increased rainfall intensity
Reduced rainfall frequency
Ecosystem type
Xeric
Mesic
Hydric
Hydrologic processes
Run-off
Soil evaporation
Interception
Soil storage
Deep drainage
Ecological processes
Net primary production
Soil respiration
Net ecosystem exchange
N-mineralization

Effect of climate variability and consumers on Chihuahuan Desert grassland and shrubland vegetation

Scott Collins
Department of Biology
Sevilleta LTER
University of New Mexico



LTER

DOE National Institute
for Climatic Change Research

U.S. FISH & WILDLIFE SERVICE
DEPARTMENT OF THE INTERIOR

The University of New Mexico

SEVILLETA LTER

UNM BIOLOGY

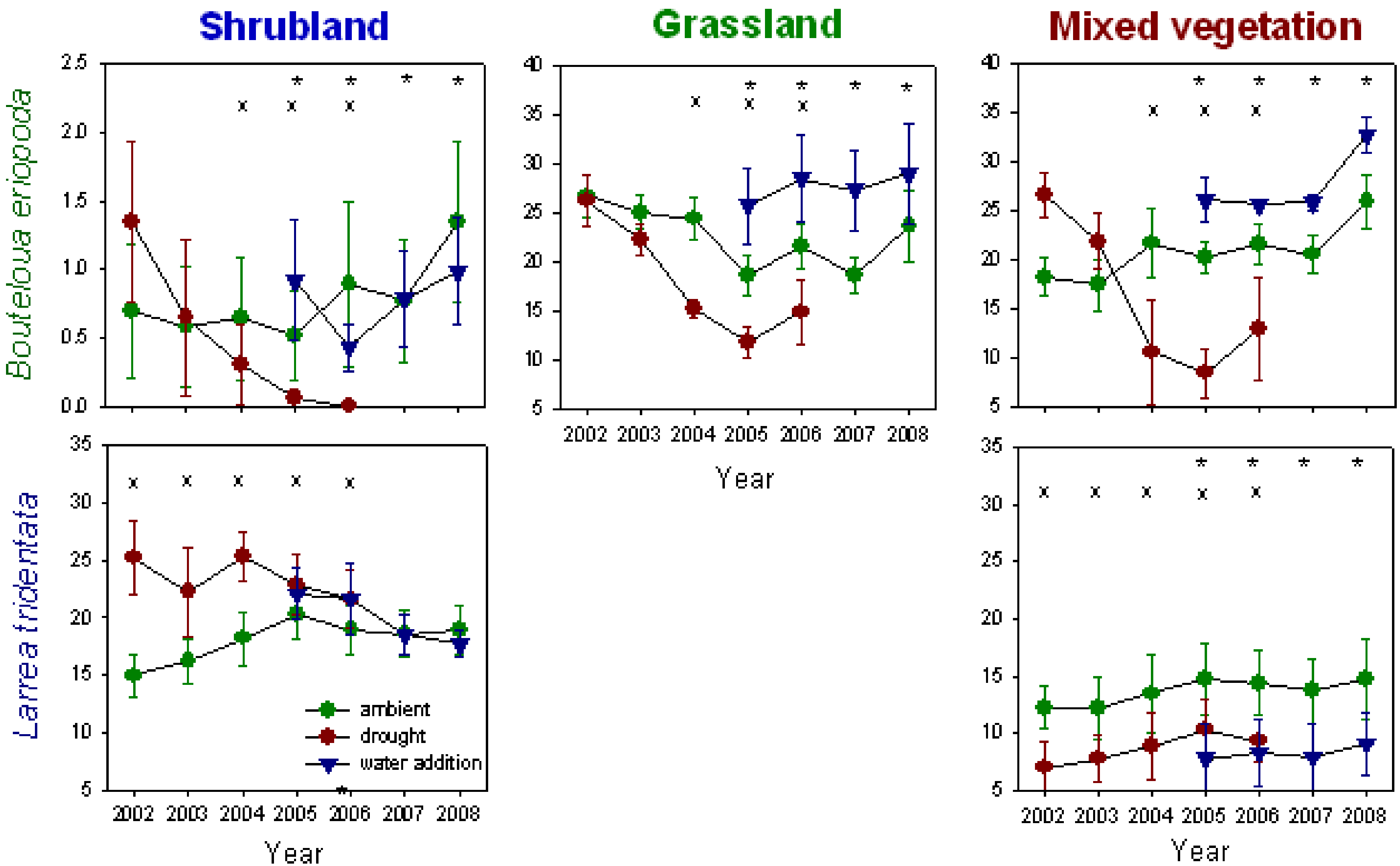
Annual rainfall manipulation experiment

Will Pockman
Eric Small
Selene Báez
Scott Collins
Jennifer Johnson
JimBob Elliott

Reduce annual rainfall by 50%

Increase annual rainfall by 50%

Chronic drought reduced cover of *Bouteloua* by +50%, whereas *Larrea* cover was unaffected by drought



Báez et al., in review

Across the grassland to shrubland transition zone:

- Chronic drought reduced cover of the grass *Bouteloua eriopoda* by 30-50%
- Chronic drought reduced plant species diversity
- Chronic drought had little impact on the cover of the shrub *Larrea tridentata*
- Therefore, periodic severe drought cycles are like decadal pulses that lead to increased dominance by woody vegetation and a loss of herbaceous plant diversity

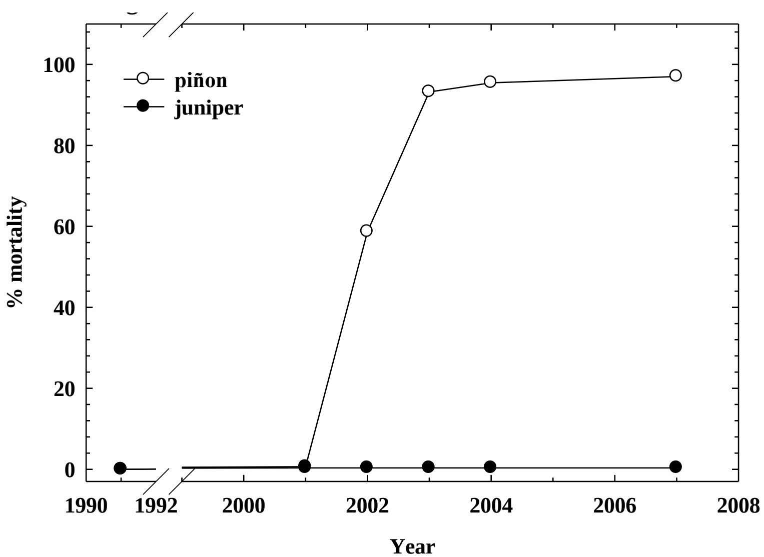
Piñon-juniper rainfall manipulation experiment,
Sevilleta LTER, NM

W.T. Pockman (UNM) and N.G. McDowell (LANL), PIs

Funding from DOE – Program for Ecosystem Research

Differential mortality in piñon-juniper woodland during severe drought

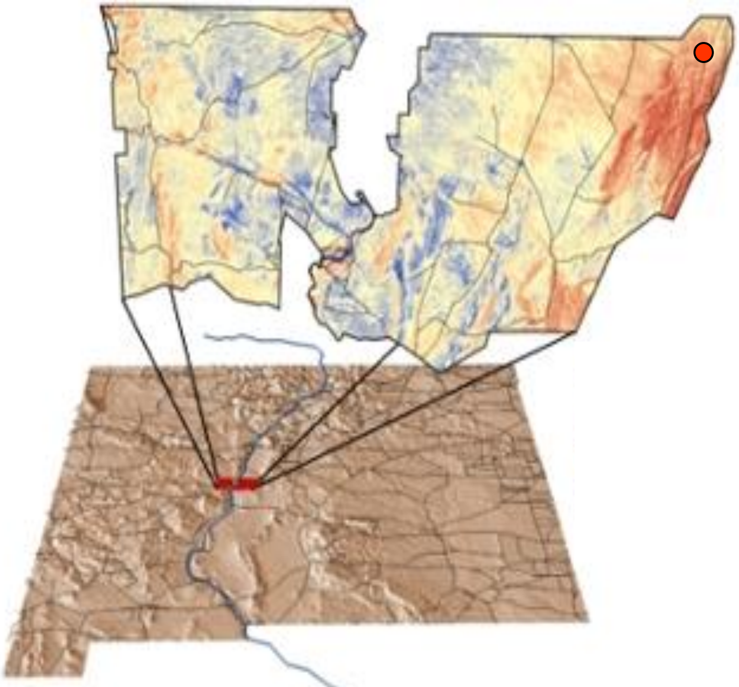
Photo's: Los Alamos, Craig Allen, USGS



- 2001 – 03: Severe drought led to widespread piñon mortality in the Southwest
- Possible mechanisms
  - Hydraulic failure
  - Carbon starvation
  - Pathogen attack

piñon-juniper rainfall manipulation

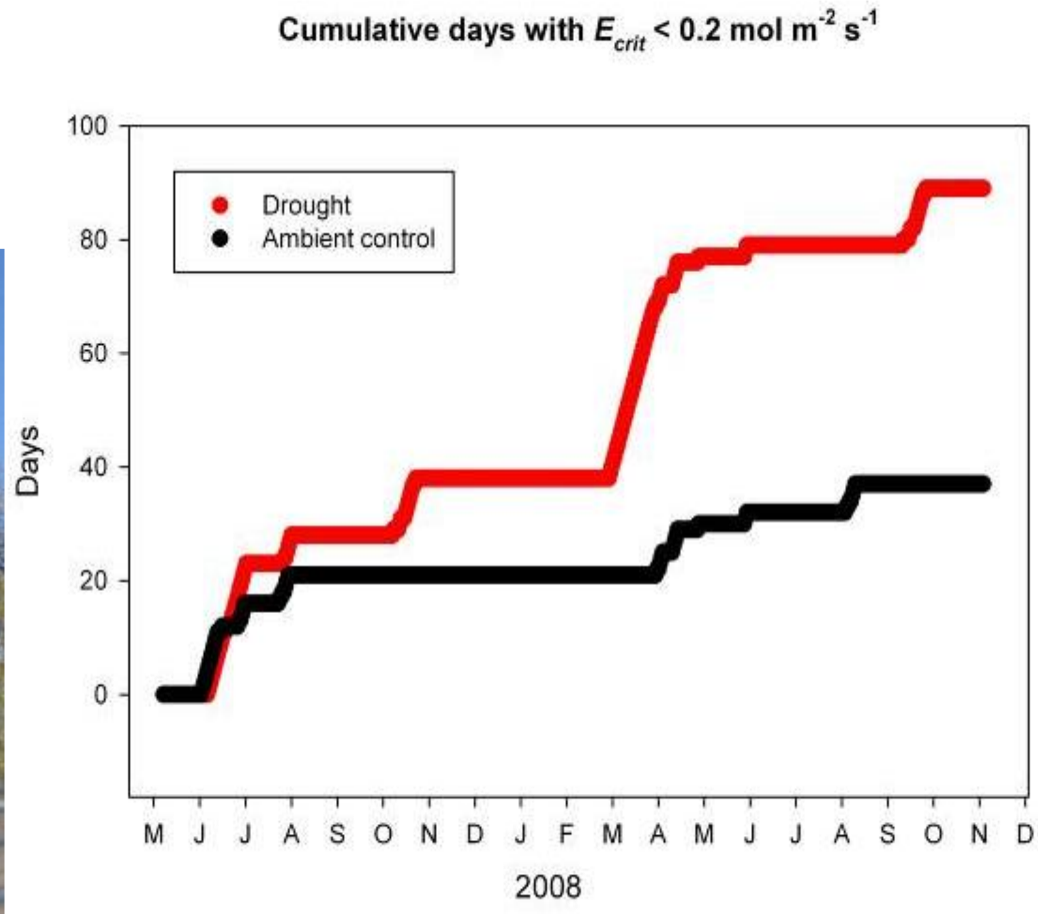
Sevilleta NWR-LTER (NM)



2008 drought plot piñon mortality

- 20% vs 8% of days at extremely low E_{crit}
- No mortality on control plot

Cumulative days with *Ecrit* < 0.2 mol m^{-2} s^{-1}



Plaut et al. in review

Fungal mechanisms

- All dead pinons infected with *Ophiostoma*
- vector: bark/twig beetles
- occludes xylem & alters hydraulic characteristics
- compounds stomatal limitations during drought

Ecological Effects of Global Change

External Variable	Internal Variables	New Regime
Elevated CO_2	Greater plant production Increased invasion	More productive ecosystem Fire-controlled grassland
Higher Temperature		
More heat waves Relaxed freezing	Greater mortality Species range expansions Increased pathogen attack	Loss of biodiversity Community disequilibrium Mortality in woodlands
Altered Precipitation		
Wetter Drier	Greater plant production Increased mortality	Semiarid ecosystem-type Species-poor system

Global Change: How May it Affect Ecosystem Management?

- Increased climatic variability
- Increased/decreased environmental stress
- Shifting boundaries of reserves/corridors
- Potential decoupling of mutualisms
- Stimulation of invasive species
- Challenges for references, implementation

Adaptation: Managing Ecosystems to Withstand Climate Change Impacts (ESA 2010)

- Because freshwater resources are of particular risk, take additional steps to protect water quality and quantity
- Enable natural species migrations across human dominated landscapes (corridors)
- Improve capacity to predict extreme events and their ecosystem impacts
- Manage collaboratively at the ecosystem level

Nevada Infrastructure for Climate Change Science, Education, and Outreach

<u>Project Director</u>
Gayle Dana (DRI)

<u>Principal Investigators</u>
Nick Lancaster (DRI)
Mike Collopy (UNR)
Tom Piechota (UNLV)

Legacies (Infrastructure Building)

- Regional Climate Modeling
- Observational Network
  - Central and Southern Nevada
  - Water resources and ecology
- Climate Change Data Portal
- Enhanced Computational Abilities (e.g., clusters, visualization)
- Climate change education (NSHE and K-12)
- Seven (7) new faculty in NSHE