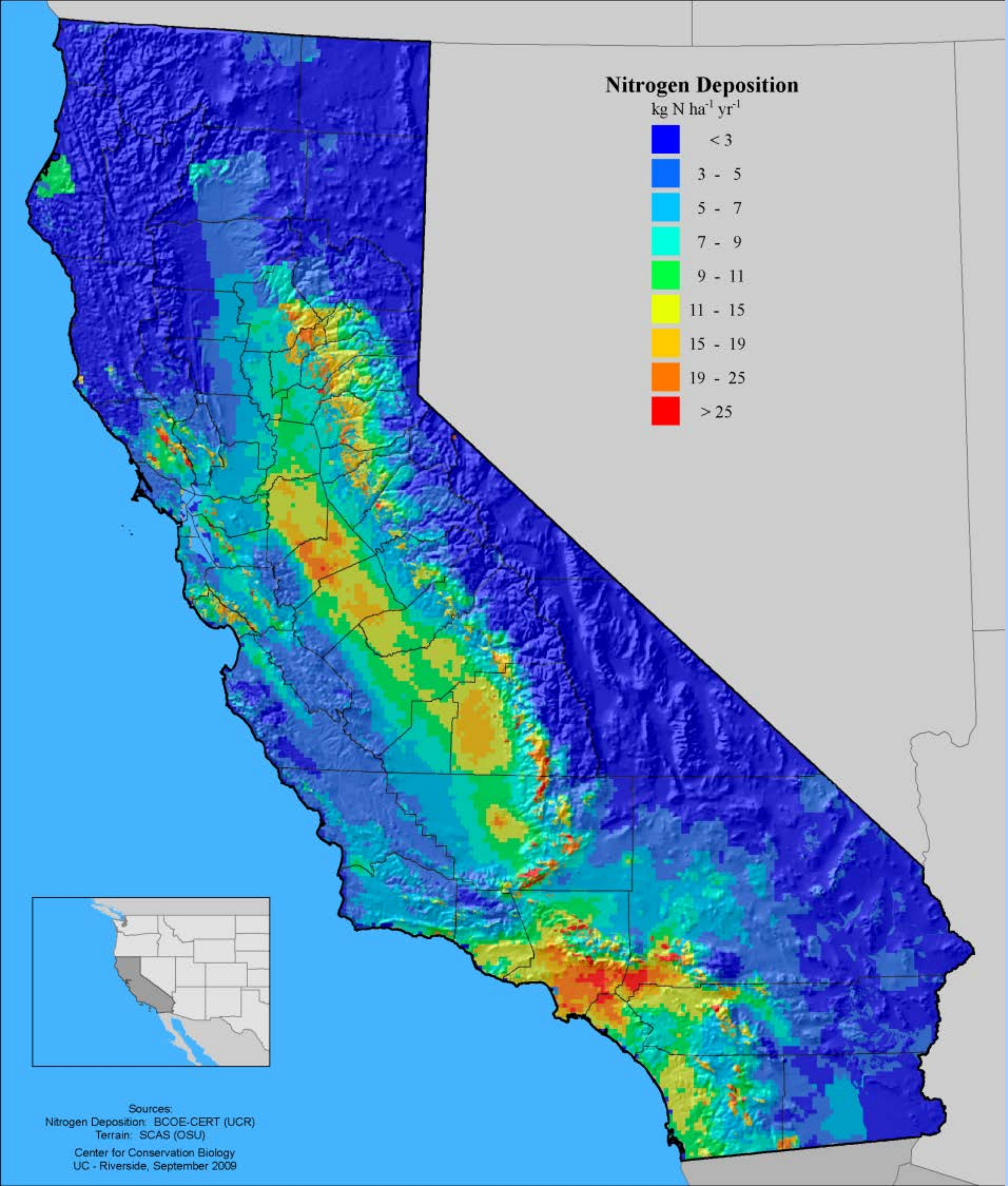
Relationships between annual plant productivity, nitrogen deposition and fire in California desert scrub

E.B. Allen[1], L.E. Rao[1], J.R. Matchett[2],
M.L. Brooks[2], R.F. Johnson[1], R.A. Minnich[1]
[1]Center for Conservation Biology, UCR
[2]USGS, Western Ecological Research Center

UNIVERSITY of CALIFORNIA Riverside

Community Multiscale Air Quality (CMAQ) Model Output (Tonnesen et al. 2007) for California

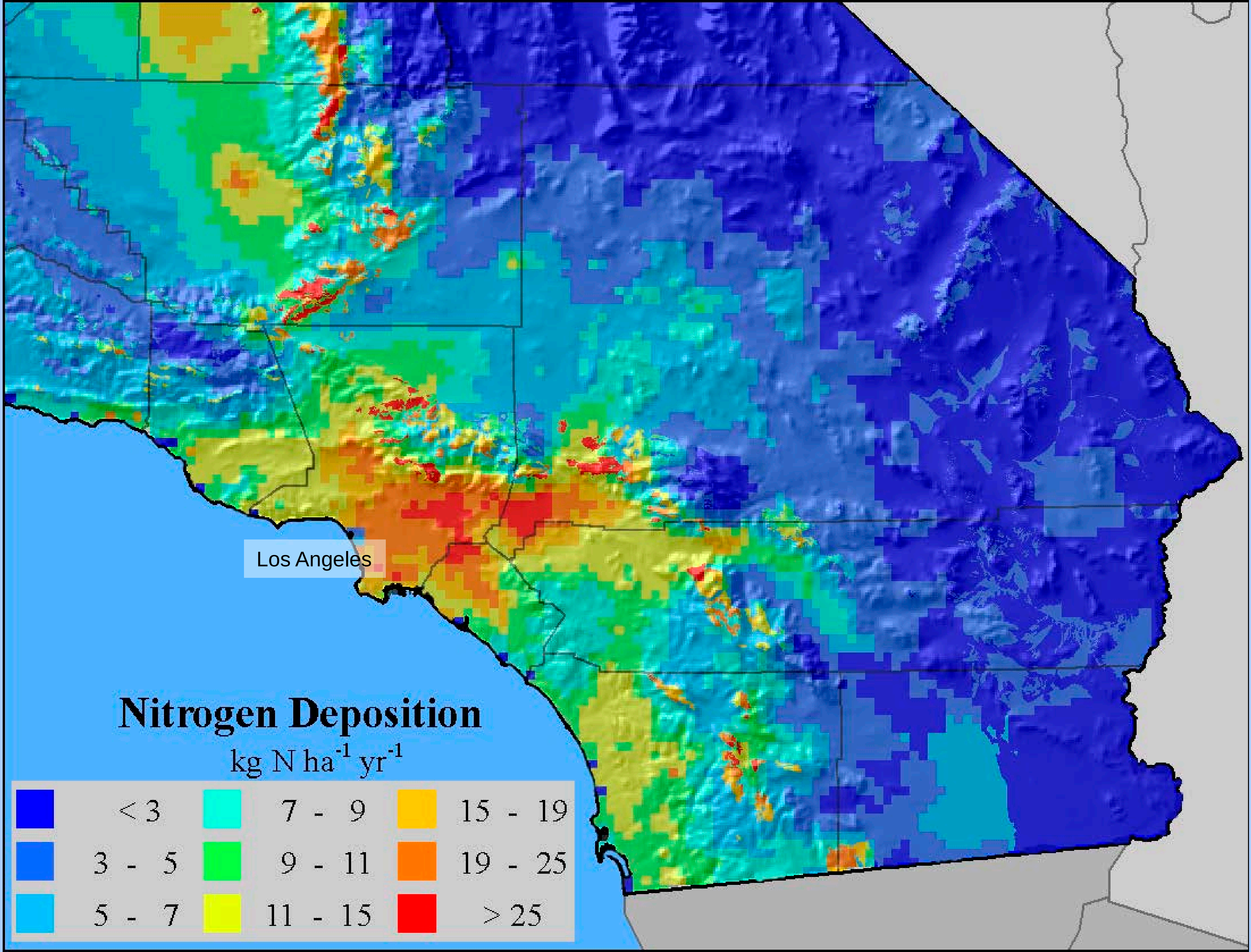


Sources:
Nitrogen Deposition: BCOE-CERT (UCR)
Terrain: SCAS (OSU)

Center for Conservation Biology
UC - Riverside, September 2009

Anthropogenic Nitrogen (N) Deposition

- Caused by emissions from combustion (nitrate, some ammonia) and agriculture (ammonia)
- Ionic (dominant form) and particulate forms of oxidized and reduced N move downwind of emission sources
- Most N deposition occurs as dryfall during the dry season
- N is deposited to leaf and soil surfaces, rainfall moves it to the soil rooting zone for uptake by plants



Nitrogen Deposition

kg N ha^{-1} yr^{-1}

Objectives

1. In an experimental garden and in natural vegetation during years of variable precipitation, test the interaction between N and precipitation to determine whether biomass produced by annual vegetation exceeds the fire threshold more frequently under N deposition.

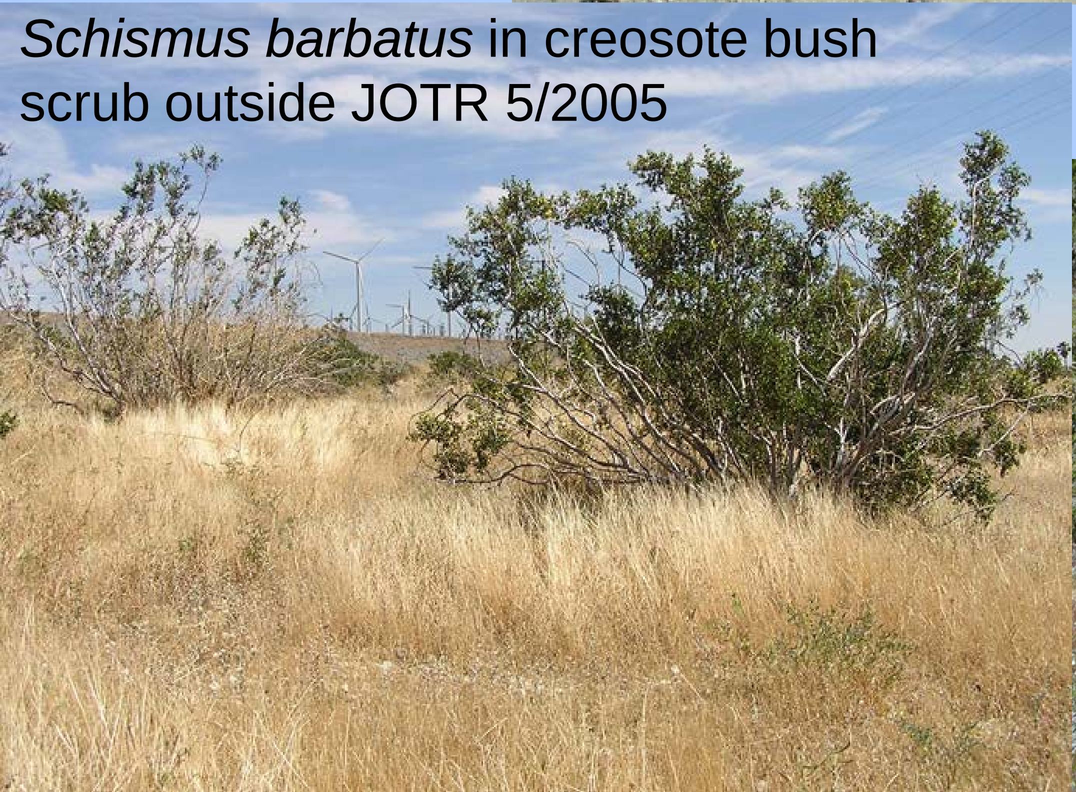
2. Use DayCent to model annual production under elevated N and determine critical load of N for fire risk in the deserts of southern California.

3. Using historic fire data, compare the relationship between nitrogen deposition and precipitation with fire size to that of modeled herbaceous fine fuel biomass and fire size, and identify a biomass threshold.

Nitrogen Critical Load

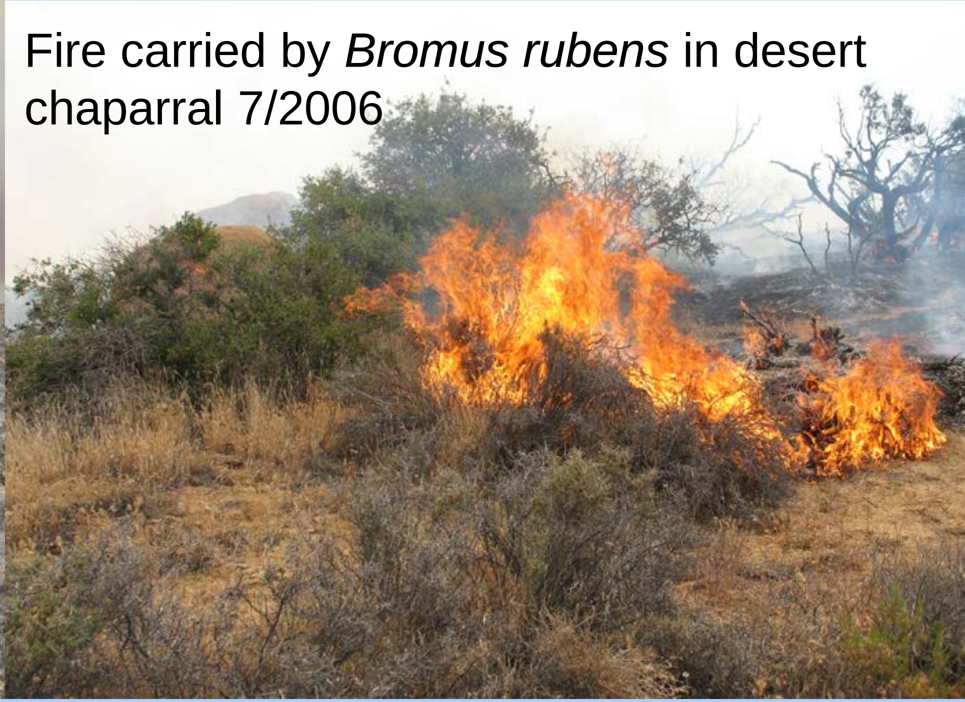
- A critical load for nitrogen is that amount of N deposition above which there are negative impacts on an ecosystem.
- Impacts can be measured as changes in
  - organisms (e.g., loss of native species,
    - increase in invasive species)
  - ecosystem processes (increased productivity, altered nutrient cycling rates, fire risk)

Air pollution outside Joshua Tree National Park (12/2004)
10-12
kg N ha^{-1}yr^{-1}



Schismus barbatus in creosote bush scrub outside JOTR 5/2005

Bromus rubens in pinyon-juniper woodland Covington Flat 4/2008



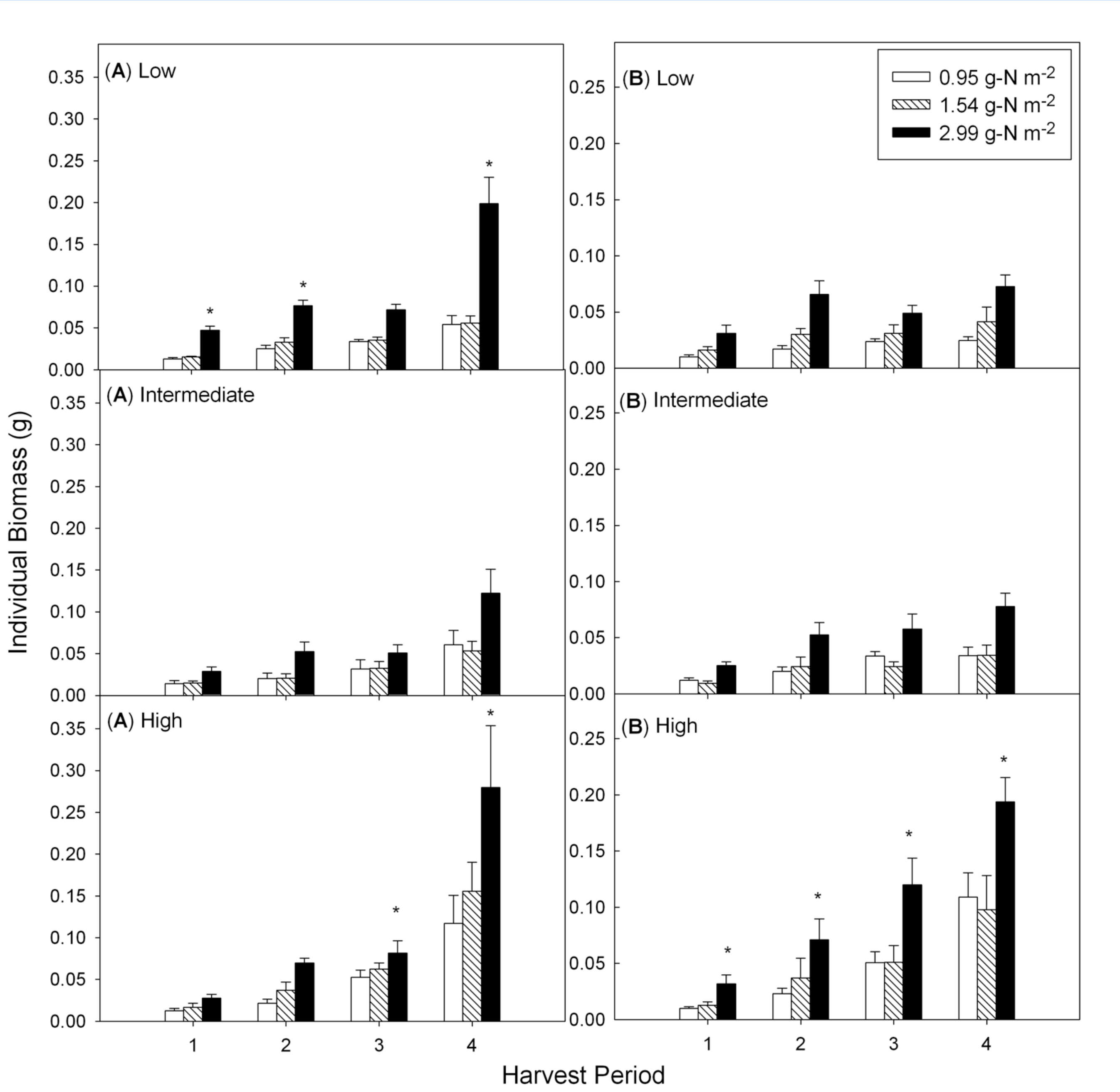
Fire carried by *Bromus rubens* in desert chaparral 7/2006

Grass fuel load of 100 g/m2 (= 1 T/ha) will carry fire between shrubs

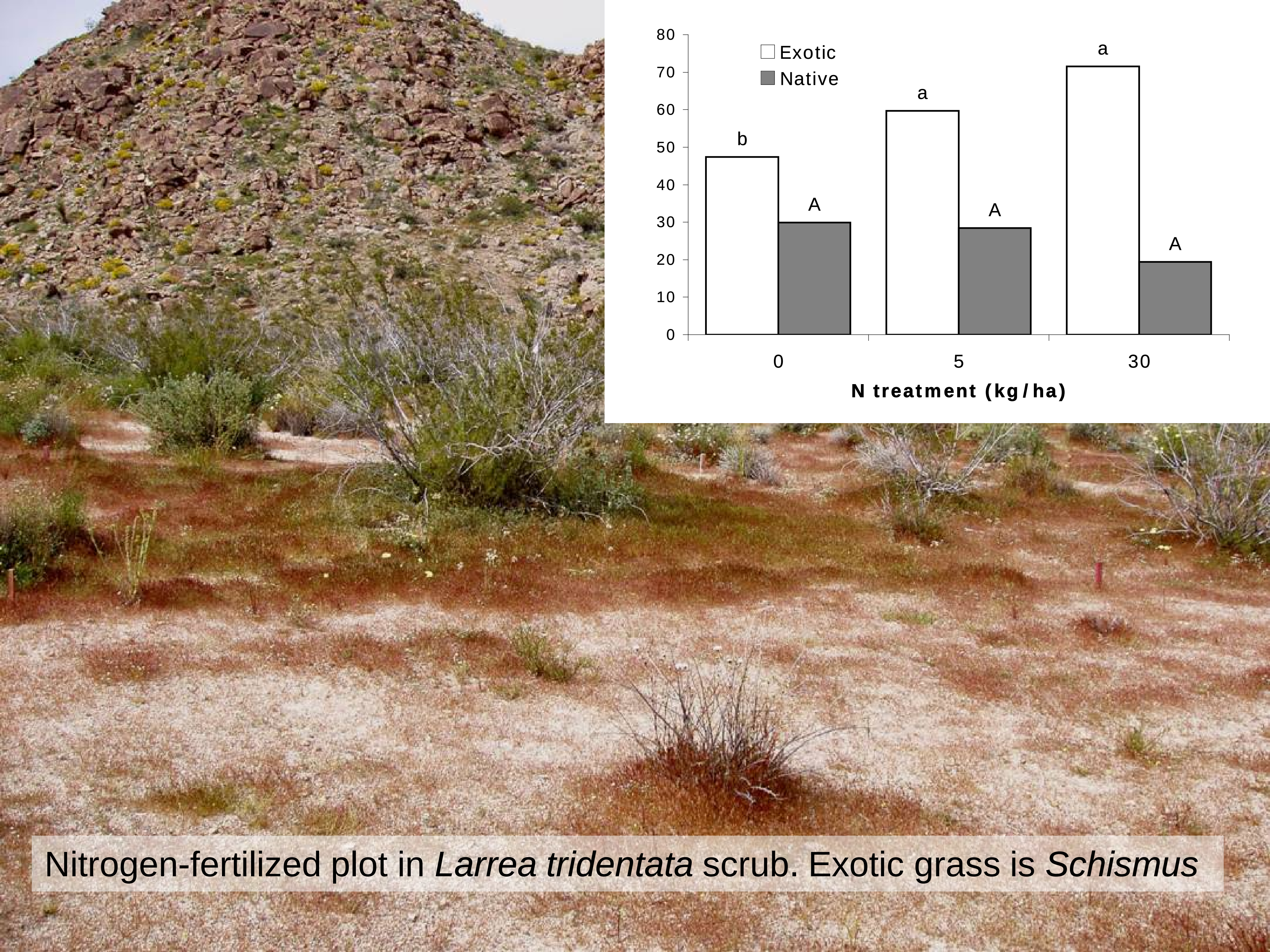
Joshua tree woodland burned in 1999
(2004 photo)

unburned

Amsinckia *Bromus*

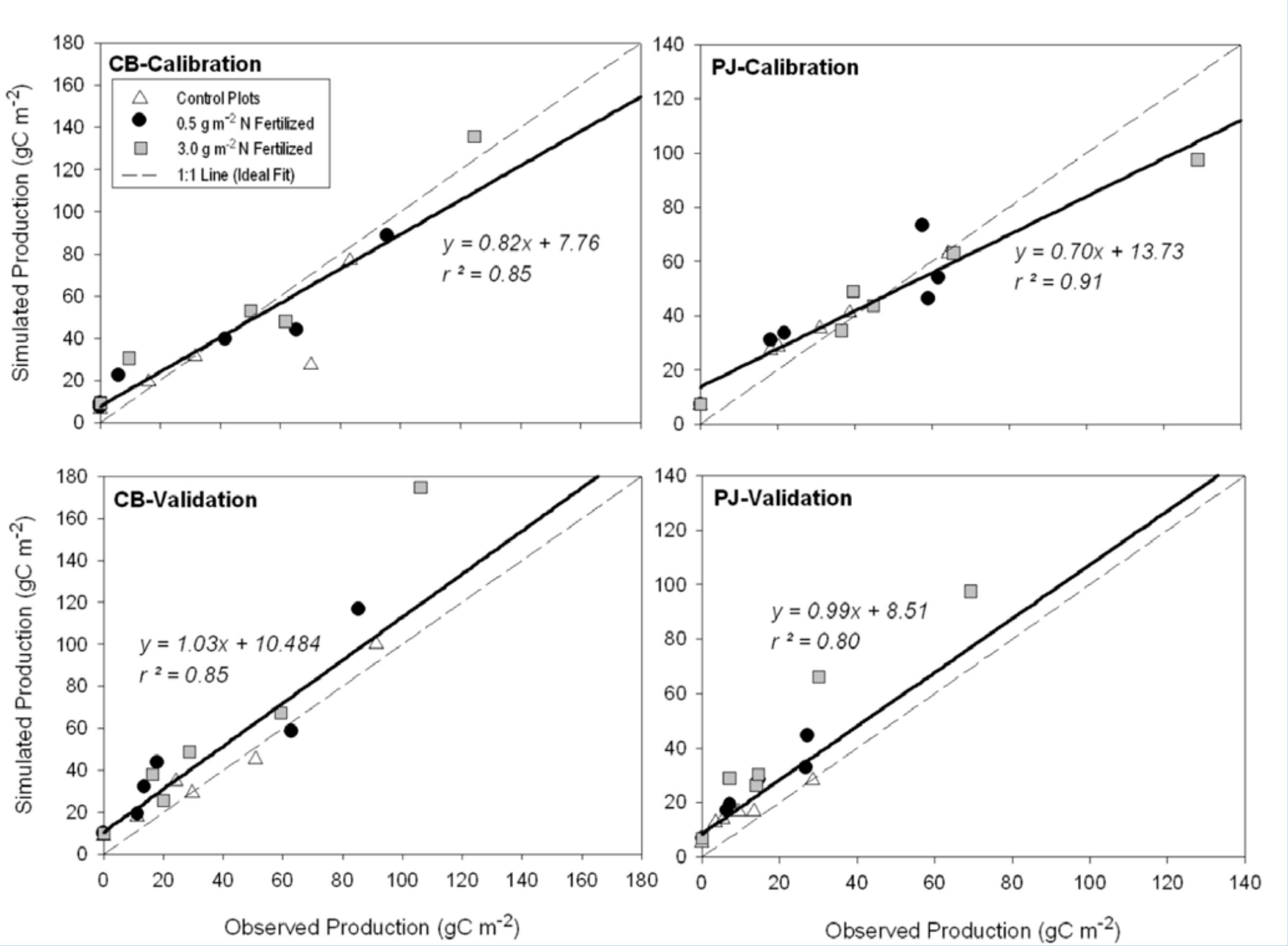


Garden plot study: Effects of N fertilization (0, 5, and 30 kg N/ha) and three water levels (9, 11, 16 cm) on biomass of *Amsinckia tessellata* and *Bromus rubens* (Rao & Allen 2010)

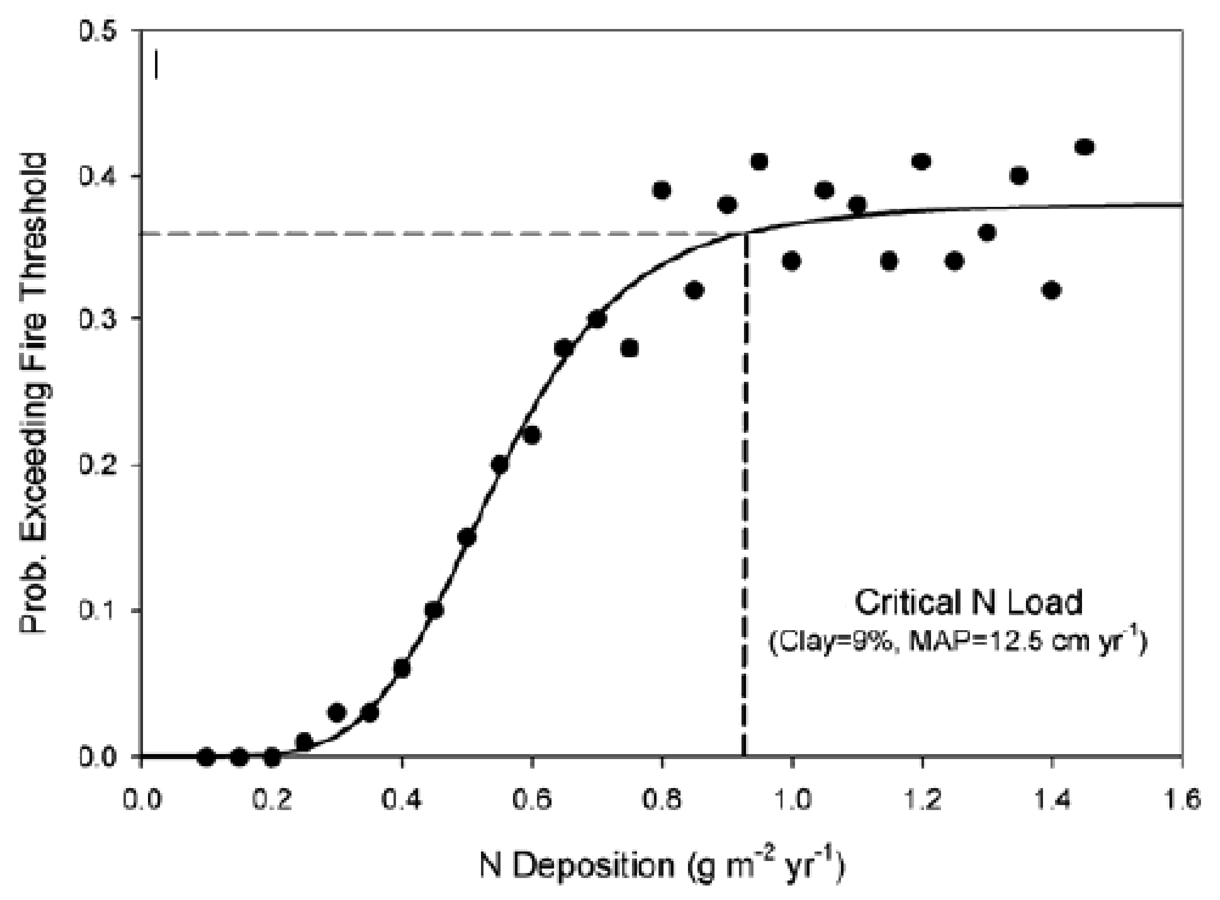


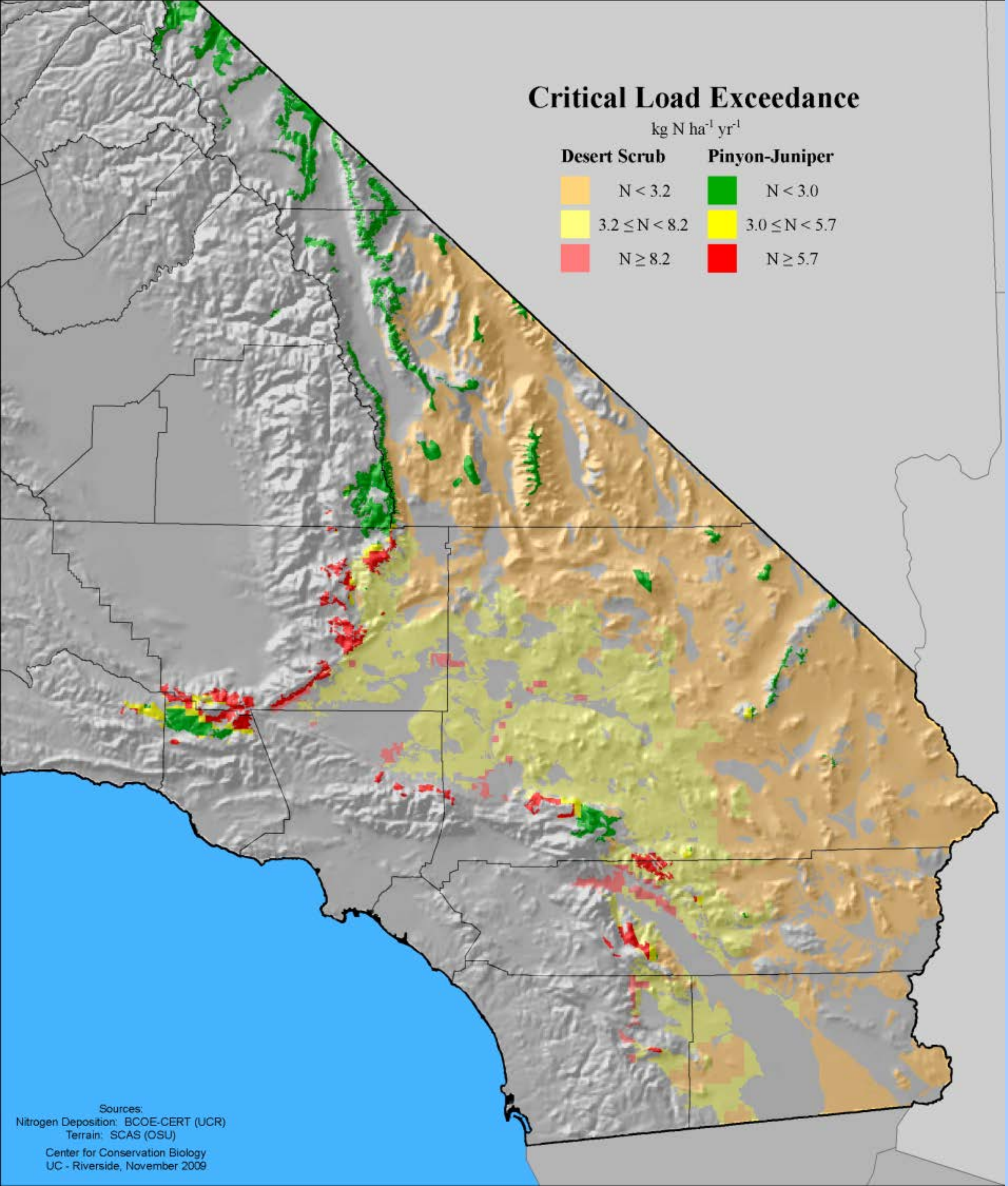
Nitrogen-fertilized plot in *Larrea tridentata* scrub. Exotic grass is *Schismus*

Regressions of observed versus DayCent-simulated production for the calibration and validation sites in creosote bush (CB) and piñon-juniper (PJ). Plots were fertilized each winter and production measured the following spring from December 2002-April 2008. Statistical tests indicate that only the slopes for CB-V and PJ-V are not different from one ($p > 0.9$ for validation sites and $p < 0.002$ for calibration sites); all intercepts are statistically different from zero ($p < 0.015$ in all cases) (Rao et al. 2010).



Probability of Exceeding Fire Threshold (1 T/ha of fine fuel) is 3-9 kg N ha^{-1}yr^{-1} for average precipitation in creosote bush scrub using DayCent simulations (Rao et al. 2010)



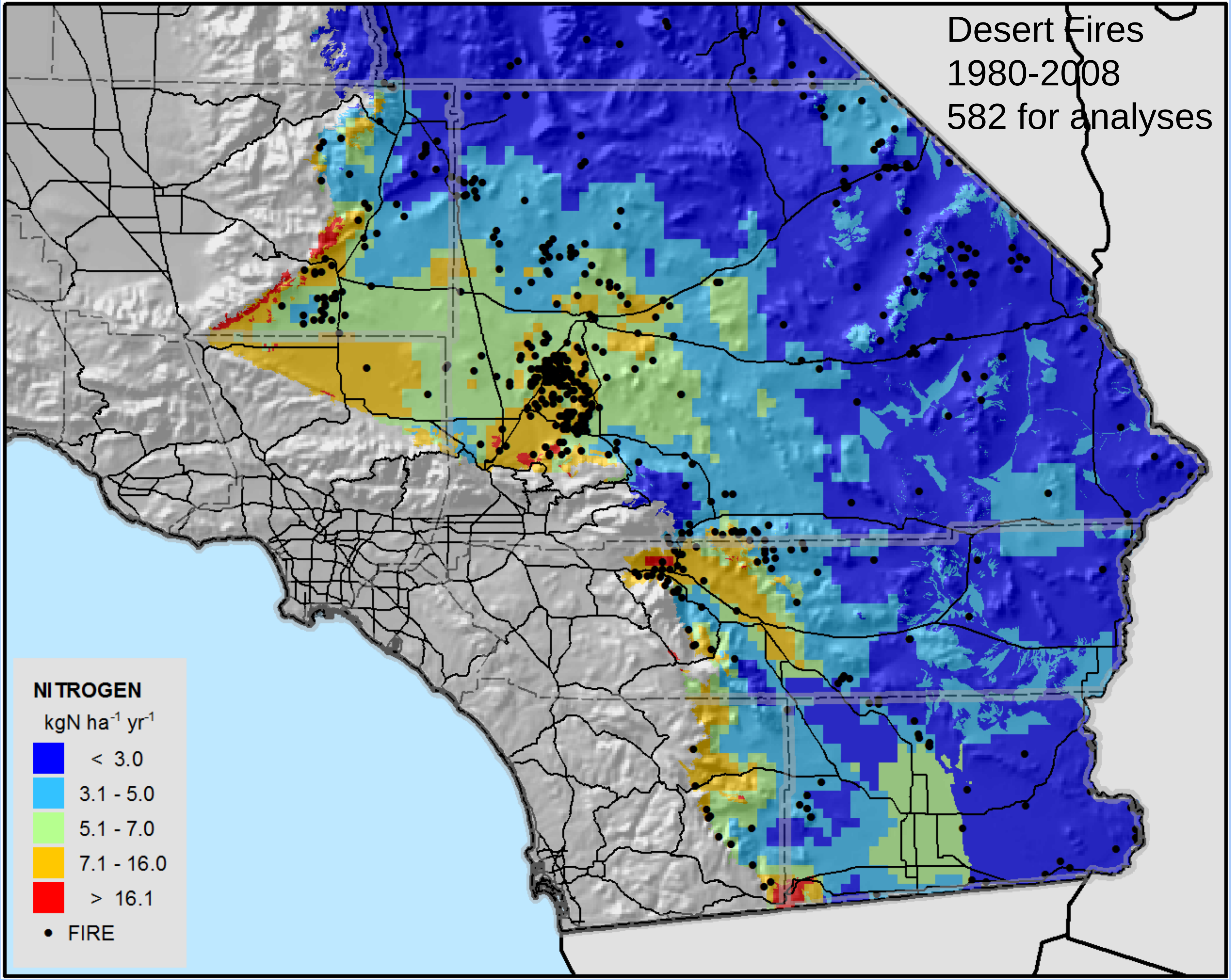


Critical N load for desert scrub:

3.2 to 9.2 $\text{kg N ha}^{-1}\text{ yr}^{-1}$ for increased fire risk
(fine fuel = 1 T/ha).

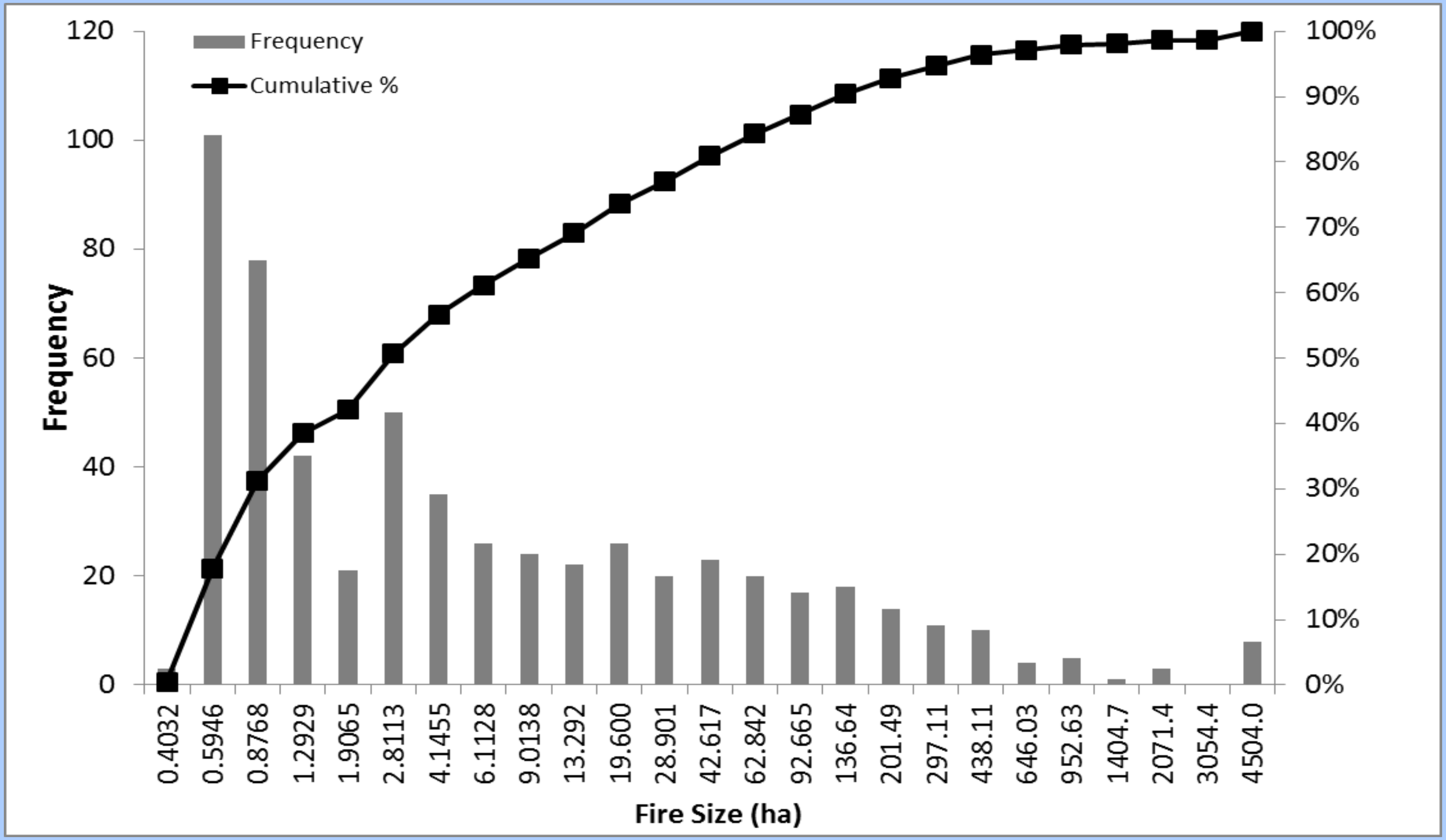
35% of desert land area exceeds CL of 3.2 (yellow)

1.5% exceeds CL of 9.2 (red), at high risk of fire

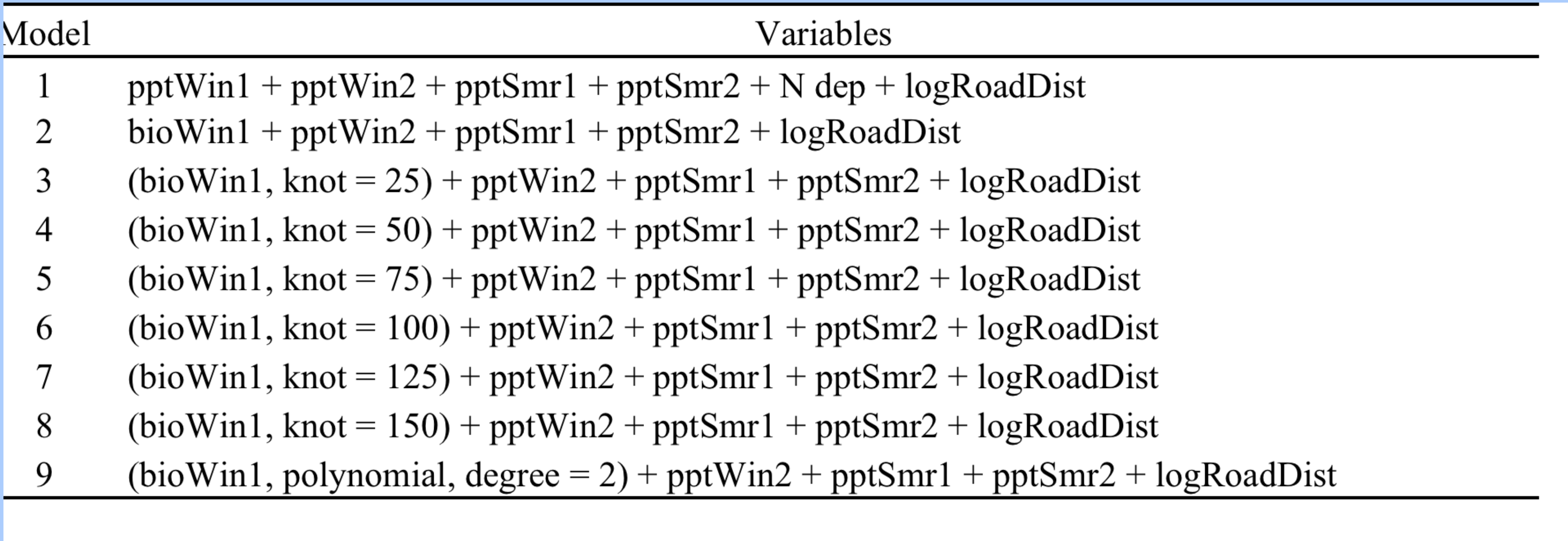


Desert Fires
1980-2008
582 for analyses

Cumulative and frequency distributions of fire size ($\log_{10}$(hectares)). Axes are presented with untransformed fire size values. Percent values (right axis) were used to estimate tau (τ) modeling functions resulting in multiple changes of slopes for different categories of fire sizes.

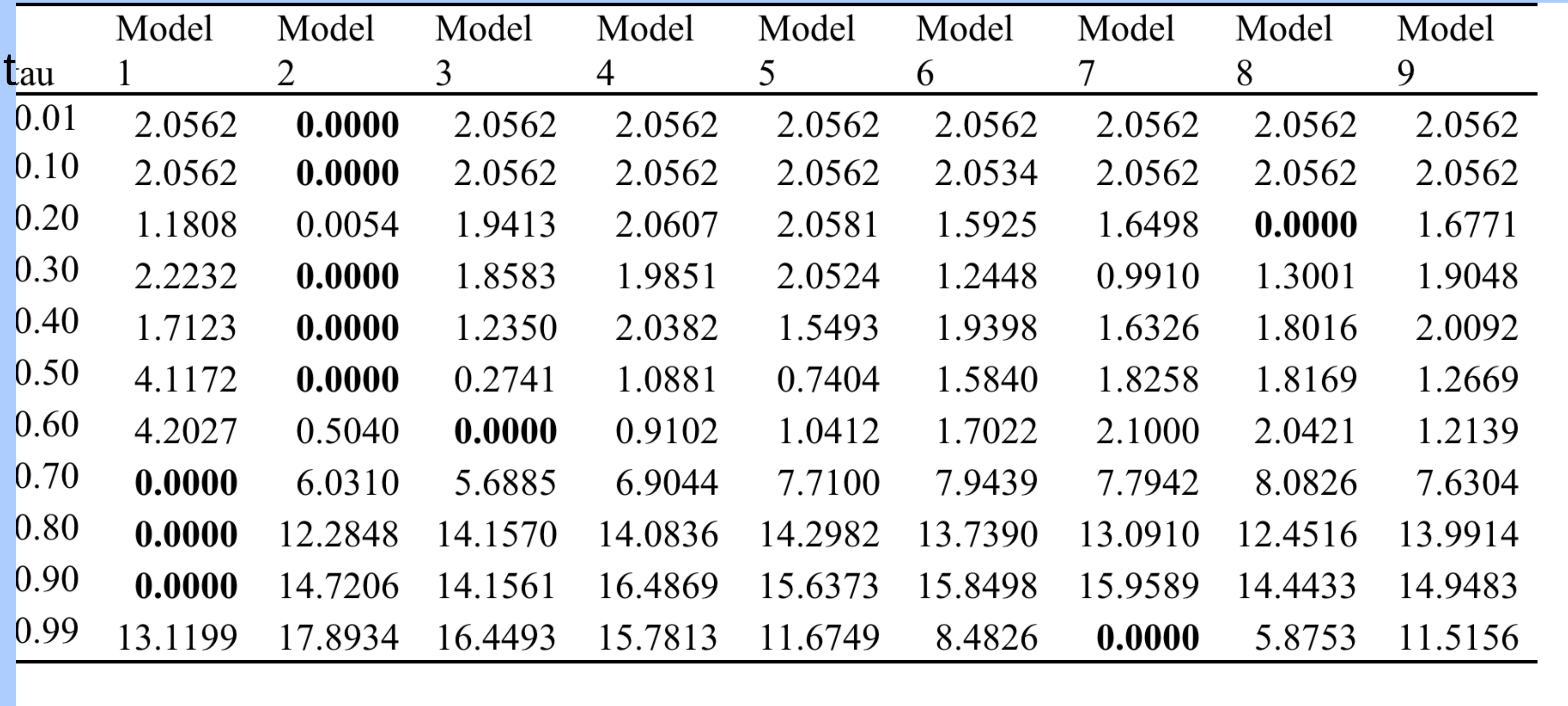


List of models used in the quantile regressions. Model 1 uses precipitation and N deposition as the primary variables; model 2 uses biomass and prior precipitation as the primary variables; models 3-8 evaluate biomass thresholds at 6 different levels; model 9 evaluates a second degree polynomial on winter biomass. Knot analyses are based on annual herb biomass to detect a threshold of fuel to carry a fire (25 to 150 g/m^2). Ppt Win1, Win2, Smr1, Smr2 = winter and summer precip 1 and 2 years prior to fire.



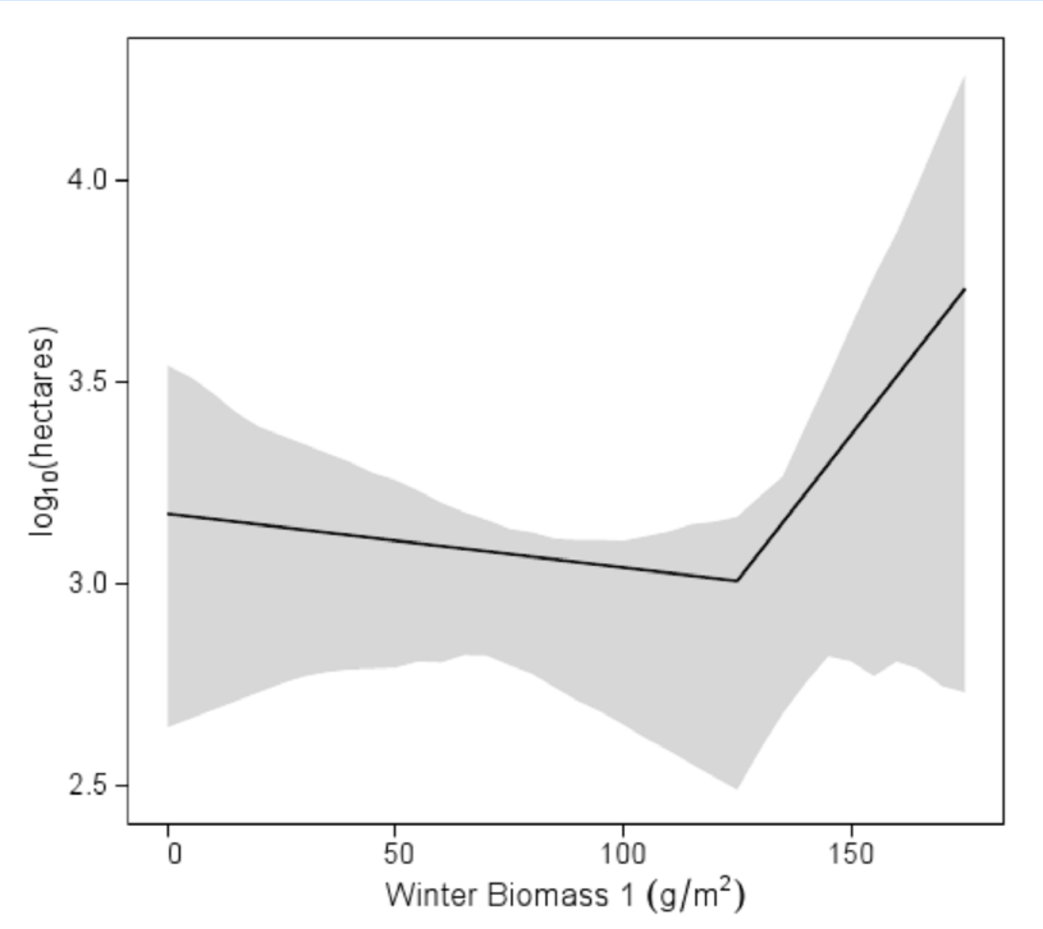
Model	Variables
1	pptWin1 + pptWin2 + pptSmr1 + pptSmr2 + N dep + logRoadDist
2	bioWin1 + pptWin2 + pptSmr1 + pptSmr2 + logRoadDist
3	(bioWin1, knot = 25) + pptWin2 + pptSmr1 + pptSmr2 + logRoadDist
4	(bioWin1, knot = 50) + pptWin2 + pptSmr1 + pptSmr2 + logRoadDist
5	(bioWin1, knot = 75) + pptWin2 + pptSmr1 + pptSmr2 + logRoadDist
6	(bioWin1, knot = 100) + pptWin2 + pptSmr1 + pptSmr2 + logRoadDist
7	(bioWin1, knot = 125) + pptWin2 + pptSmr1 + pptSmr2 + logRoadDist
8	(bioWin1, knot = 150) + pptWin2 + pptSmr1 + pptSmr2 + logRoadDist
9	(bioWin1, polynomial, degree = 2) + pptWin2 + pptSmr1 + pptSmr2 + logRoadDist

AIC minus minimum AIC values for each model evaluated using quantile regression. A zero indicates that the given model performed best at that level of tau. Tau refers to the percentile of fires in different size classes (small to large fires)

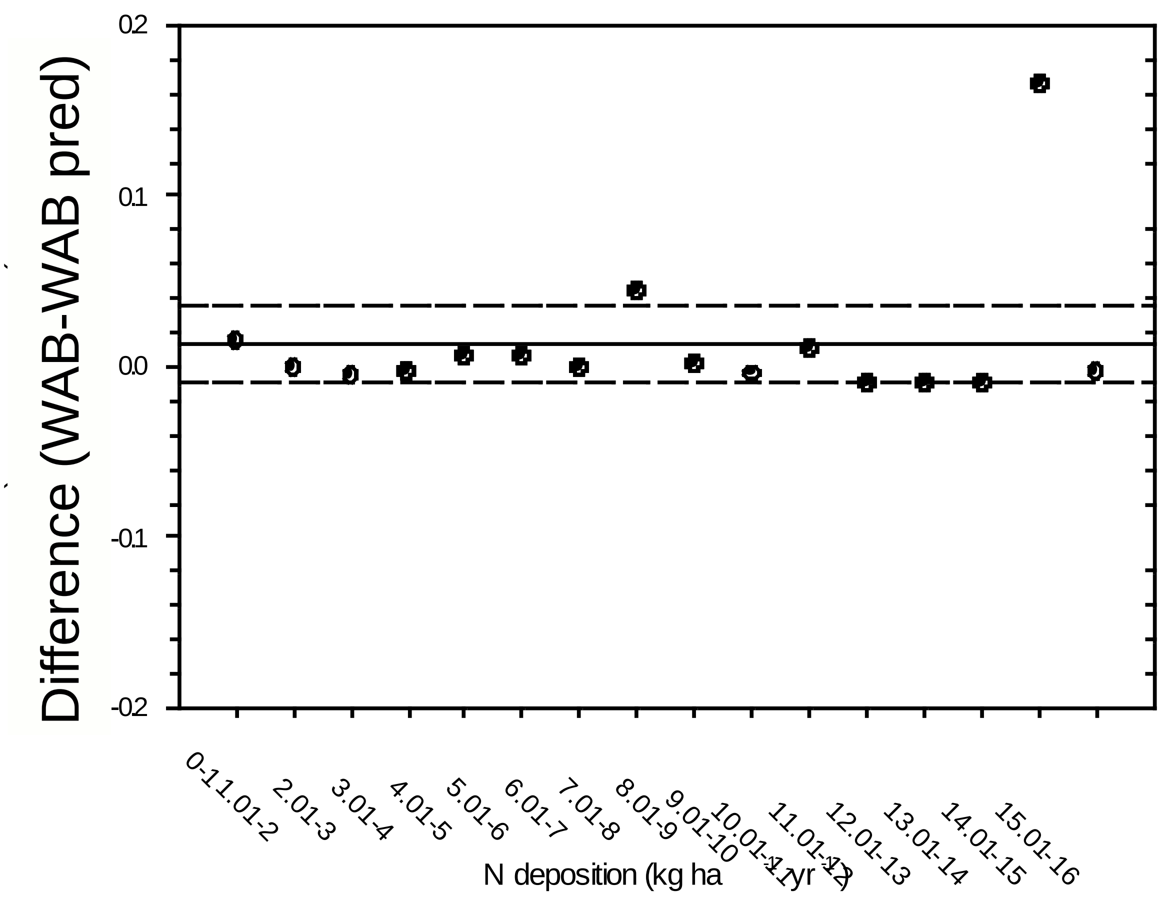


tau	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
0.01	2.0562	**0.0000**	2.0562	2.0562	2.0562	2.0562	2.0562	2.0562	2.0562
0.10	2.0562	**0.0000**	2.0562	2.0562	2.0562	2.0534	2.0562	2.0562	2.0562
0.20	1.1808	0.0054	1.9413	2.0607	2.0581	1.5925	1.6498	**0.0000**	1.6771
0.30	2.2232	**0.0000**	1.8583	1.9851	2.0524	1.2448	0.9910	1.3001	1.9048
0.40	1.7123	**0.0000**	1.2350	2.0382	1.5493	1.9398	1.6326	1.8016	2.0092
0.50	4.1172	**0.0000**	0.2741	1.0881	0.7404	1.5840	1.8258	1.8169	1.2669
0.60	4.2027	0.5040	**0.0000**	0.9102	1.0412	1.7022	2.1000	2.0421	1.2139
0.70	**0.0000**	6.0310	5.6885	6.9044	7.7100	7.9439	7.7942	8.0826	7.6304
0.80	**0.0000**	12.2848	14.1570	14.0836	14.2982	13.7390	13.0910	12.4516	13.9914
0.90	**0.0000**	14.7206	14.1561	16.4869	15.6373	15.8498	15.9589	14.4433	14.9483
0.99	13.1199	17.8934	16.4493	15.7813	11.6749	8.4826	**0.0000**	5.8753	11.5156

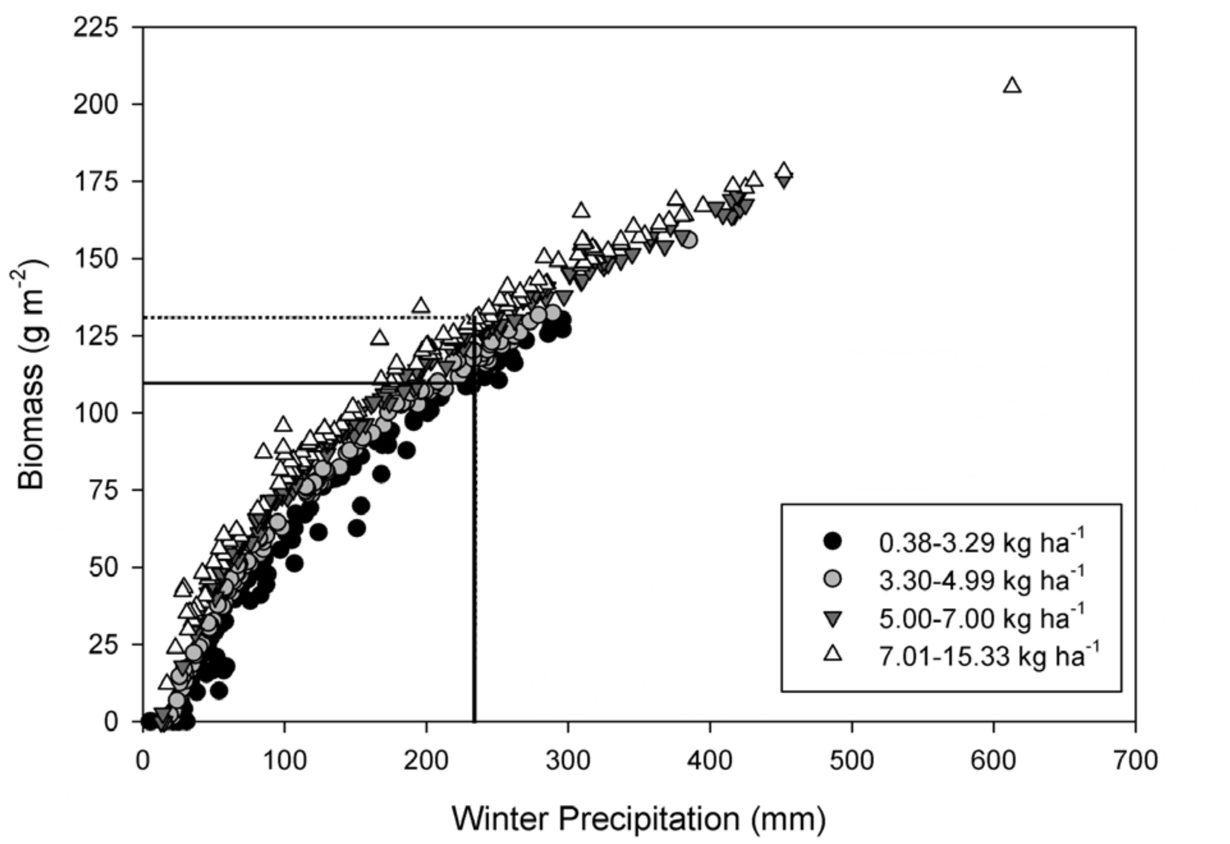
Relationship between winter biomass produced one year prior to the fire and fire size for model 7 and τ = 0.99. The model indicates the presence of a biomass threshold at 125 g m^{-2}, above which fire size increases with increasing winter biomass produced. Grey shaded area represents bootstrapped uncertainty limits at 95%. (Rao et al. in review)



Difference between the weighted area burned (WAB) and predicted weighted area burned (WAB_{pred}) with increasing N deposition. The solid line is the mean difference, and the dotted lines are the 95% confidence intervals. More area burned than expected at both 7 kg N ha^{-1} and 14 kg N ha^{-1}



Annual plant biomass, winter precipitation, and N deposition for fires. Winter precipitation is the primary driver of annual biomass production. However, in areas of high N deposition biomass may be increased sufficiently such that it is greater than the fire-carrying threshold (125 g m^{-2} from this study) for a given amount of winter precipitation. (Rao et al. in review)

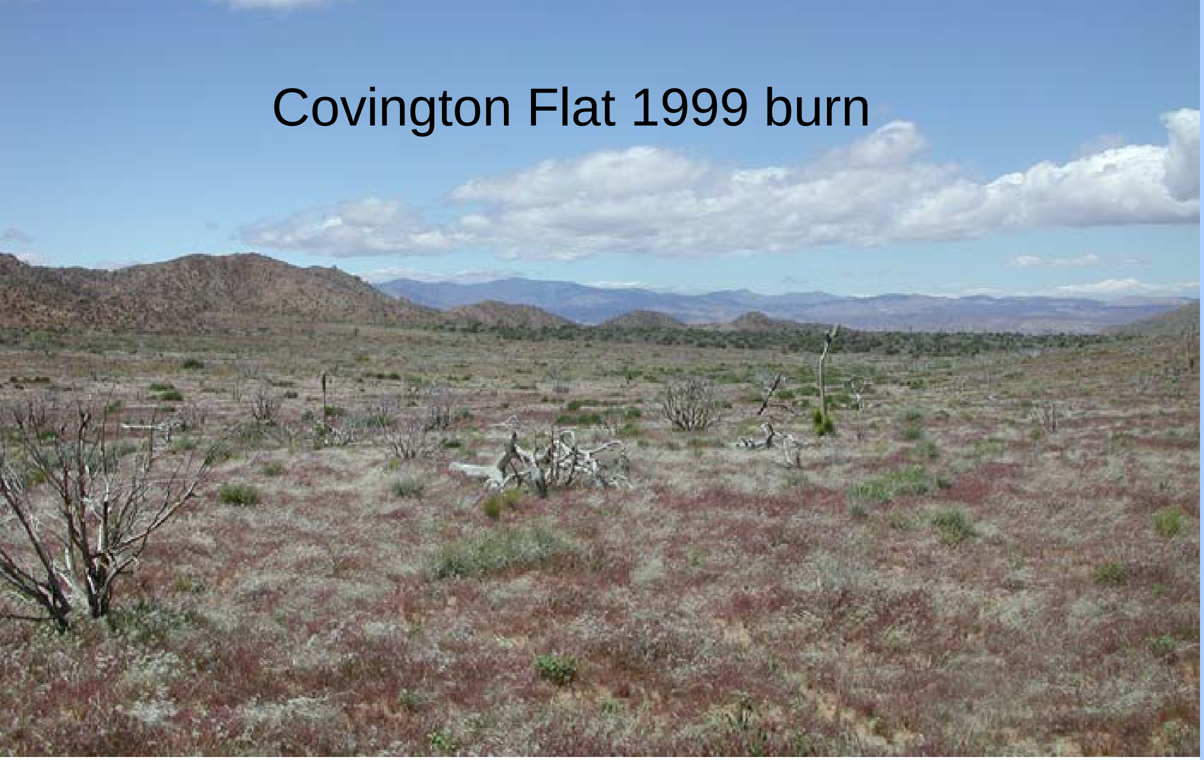


Conclusions

1. Experimental N fertilization increased exotic and native annual biomass at higher levels of watering and during years of higher precipitation.
2. DayCent modeling using 100 g m^{-2} as a threshold for fine fuel productivity showed increased fire risk at 3-9 kg N $ha^{-1}yr^{-1}$.
3. Using quantile regression, models of annual biomass have similar predictive ability as models using precipitation and N deposition for small fires. For intermediate-to-large fires, two years of winter precipitation were significantly correlated with fire size. No biomass threshold was found except for the 99th percentile of fires, in which fire size increased with greater than 125 g m^{-2} of winter fine fuel production. While no single N deposition threshold was found, overall more area burned than expected at both 7 and 14 kg-N $ha^{-1}yr^{-1}$.
4. Legislative controls on N deposition would reduce exotic grass productivity, but modeling the exact critical load of N for increased fire size is still elusive.

Ustilago bullata (head smut) and invasive brome grasses: a new biocontrol?

Covington Flat 1999 burn



2005
dominated by
Bromus rubens

2014
Bromus << 1%
cover, native
shrubs and
grasses
recovering

What happened to *Bromus*? Drought (Salo 2004) and smut fungus

May 2013
90% of *B. rubens* and *B. tectorum*
Infected with *Ustilago bullata*

April 2014
Bromus << 1% cover at previously
burned sites on Covington Flat

Ustilago bullata
observed on
Bromus rubens,
B. tectorum,
and
B. diandrus
(sect. Genea)

Future directions for research on *Ustilago-Bromus* interaction

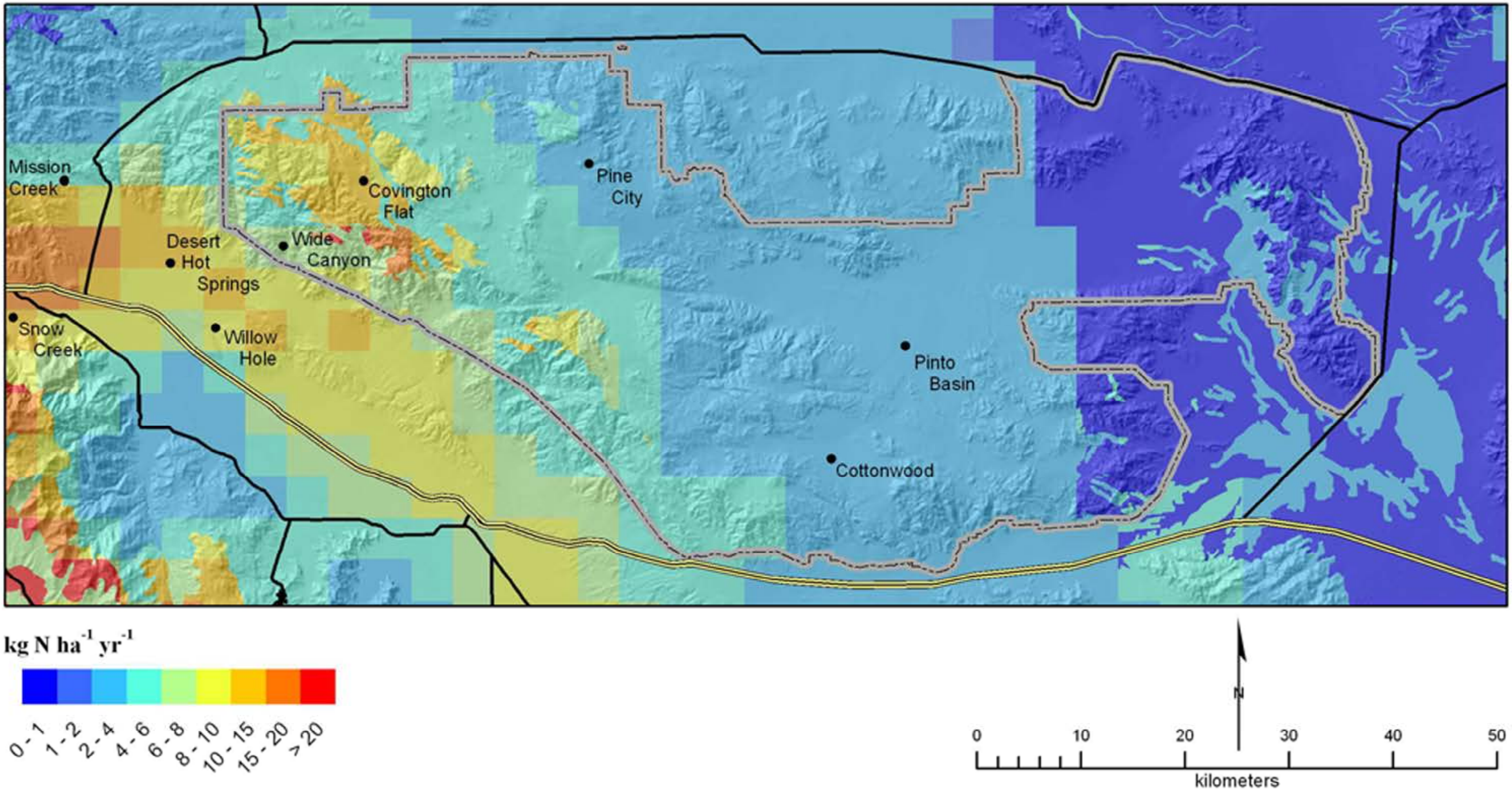
- Nearly identical strain has been found in Spain on *B. rubens* based on DNA analysis
- Grow smut in culture (not as easy as it sounds)
- Test for host specificity (found in sect. Genea, test native brome species and closely related grasses, esp. cereal crops)
- Inoculate in field trials
- Find funding for this research!

Acknowledgements

Leela Rao, Robert Steers, Christopher True, Mike Bell, Heather Schneider, Sara Jo Dickens, Robert Johnson, Tracy Tennant, Sheila Kee, Mike Allen, Richard Minnich (UCR), Mark Fenn, Andrzej Bytnerowicz (USFS), Tom Meixner (U AZ), Jane Rodgers, Josh Hoines (NPS) and many others.

Research funded by National Park Service, National Science Foundation, UC-Agriculture and Natural Resources

CMAQ modeled N deposition at JOTR (Tonnesen et al. 2007) with corrections for high elevation (Fenn et al. 2010)



Desert fires

1980-2008