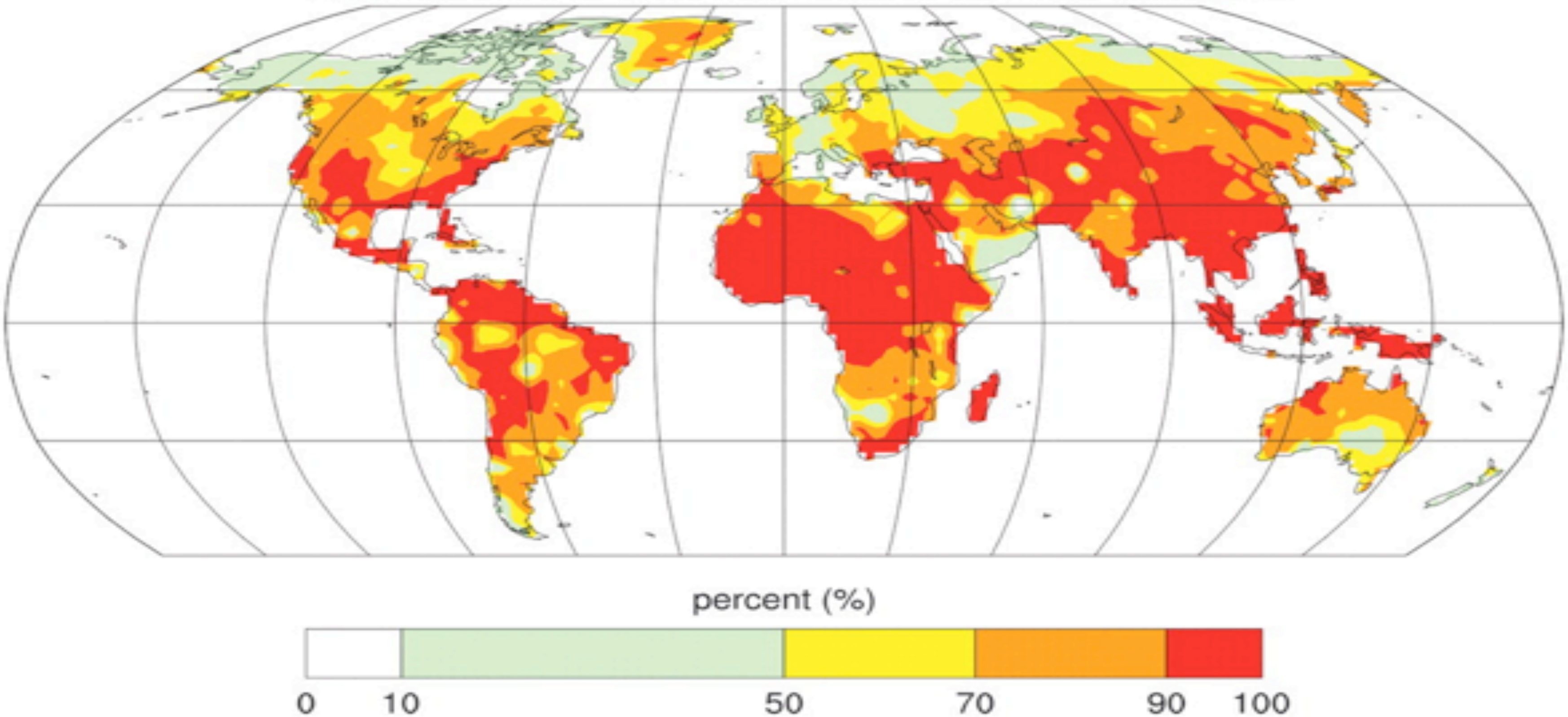
Extinction of *Gopherus agassizii* by 2080 and rewilding potential across the US

Barry Sinervo
And Joseph Stewart
UC Santa Cruz

Part I. Reptile extinctions

Across the world

Probability that the AVERAGE summer temperature at century's end will be WARMER than the highest temperature ever recorded to date



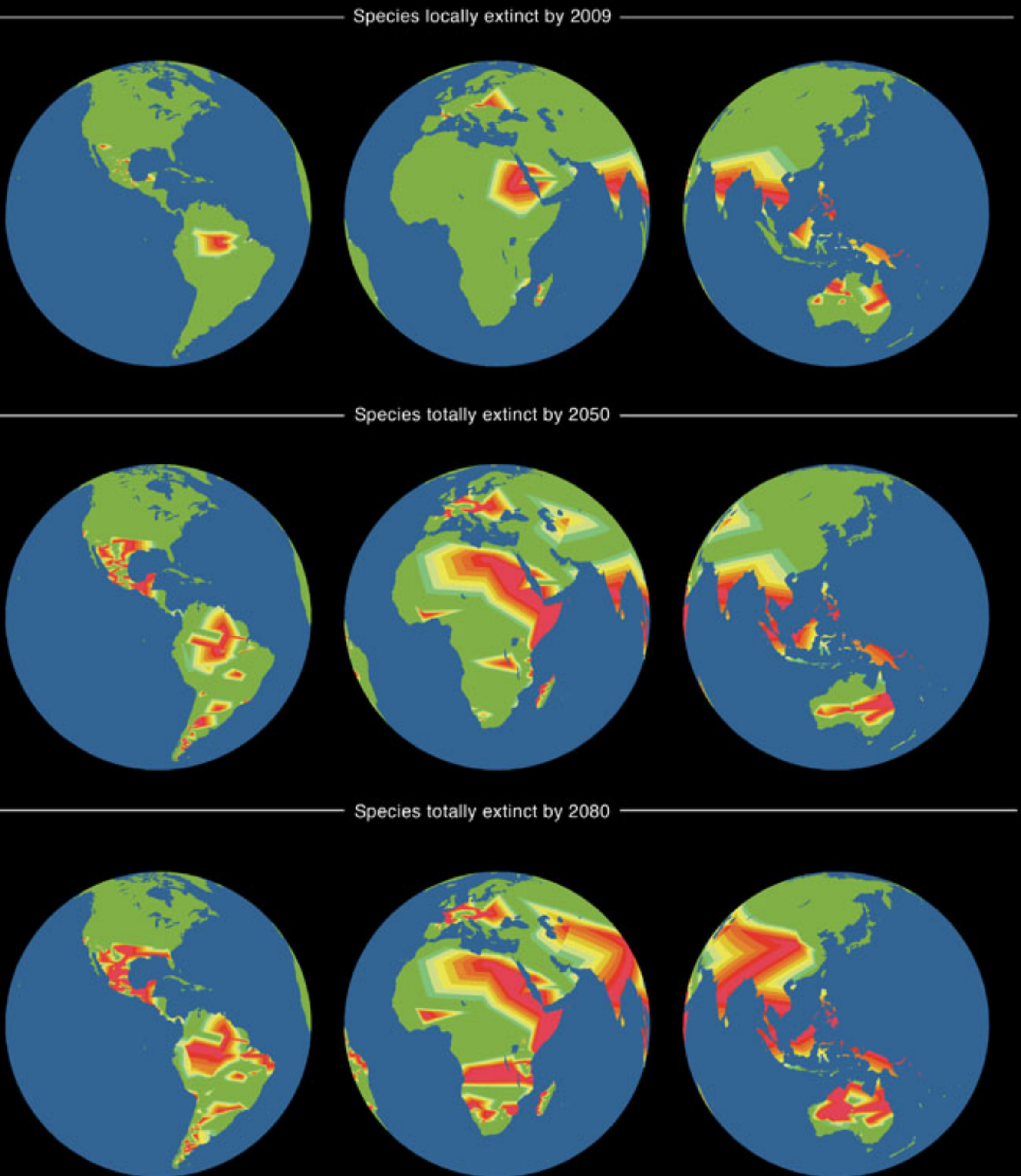
Battisti & Naylor, Science 2009

Erosion of Lizard Diversity by Climate Change and Altered Thermal Niches

Barry Sinervo,[1,15]* Fausto Méndez-de-la-Cruz,[2] Donald B. Miles,[3,15] Benoit Heulin,[4] Elizabeth Bastiaans,[1] Maricela Villagrán-Santa Cruz,[5] Rafael Lara-Resendiz,[2] Norberto Martínez-Méndez,[2] Martha Lucía Calderón-Espinosa,[6] Rubi Nelsi Meza-Lázaro,[2] Héctor Gadsden,[7] Luciano Javier Avila,[8] Mariana Morando,[8] Ignacio J. De la Riva,[9] Pedro Victoriano Sepulveda,[10] Carlos Frederico Duarte Rocha,[11] Nora Ibargüengoytía,[12] César Aguilar Puntriano,[13] Manuel Massot,[14] Virginie Lepetz,[15]† Tuula A. Oksanen,[16] David G. Chapple,[17] Aaron M. Bauer,[18] William R. Branch,[19] Jean Clobert,[15] Jack W. Sites Jr.[20]

It is predicted that climate change will cause species extinctions and distributional shifts in coming decades, but data to validate these predictions are relatively scarce. Here, we compare recent and historical surveys for 48 Mexican lizard species at 200 sites. Since 1975, 12% of local populations have gone extinct. We verified physiological models of extinction risk with observed local extinctions and extended projections worldwide. Since 1975, we estimate that 4% of local populations have gone extinct worldwide, but by 2080 local extinctions are projected to reach 39% worldwide, and species extinctions may reach 20%. Global extinction projections were validated with local extinctions observed from 1975 to 2009 for regional biotas on four other continents, suggesting that lizards have already crossed a threshold for extinctions caused by climate change.

14 MAY 2010 VOL 328 SCIENCE www.sciencemag.org



By the numbers:

2009
- 4% local extinction
- R^2 = 0.72 in a global validation with 8 other lizard families

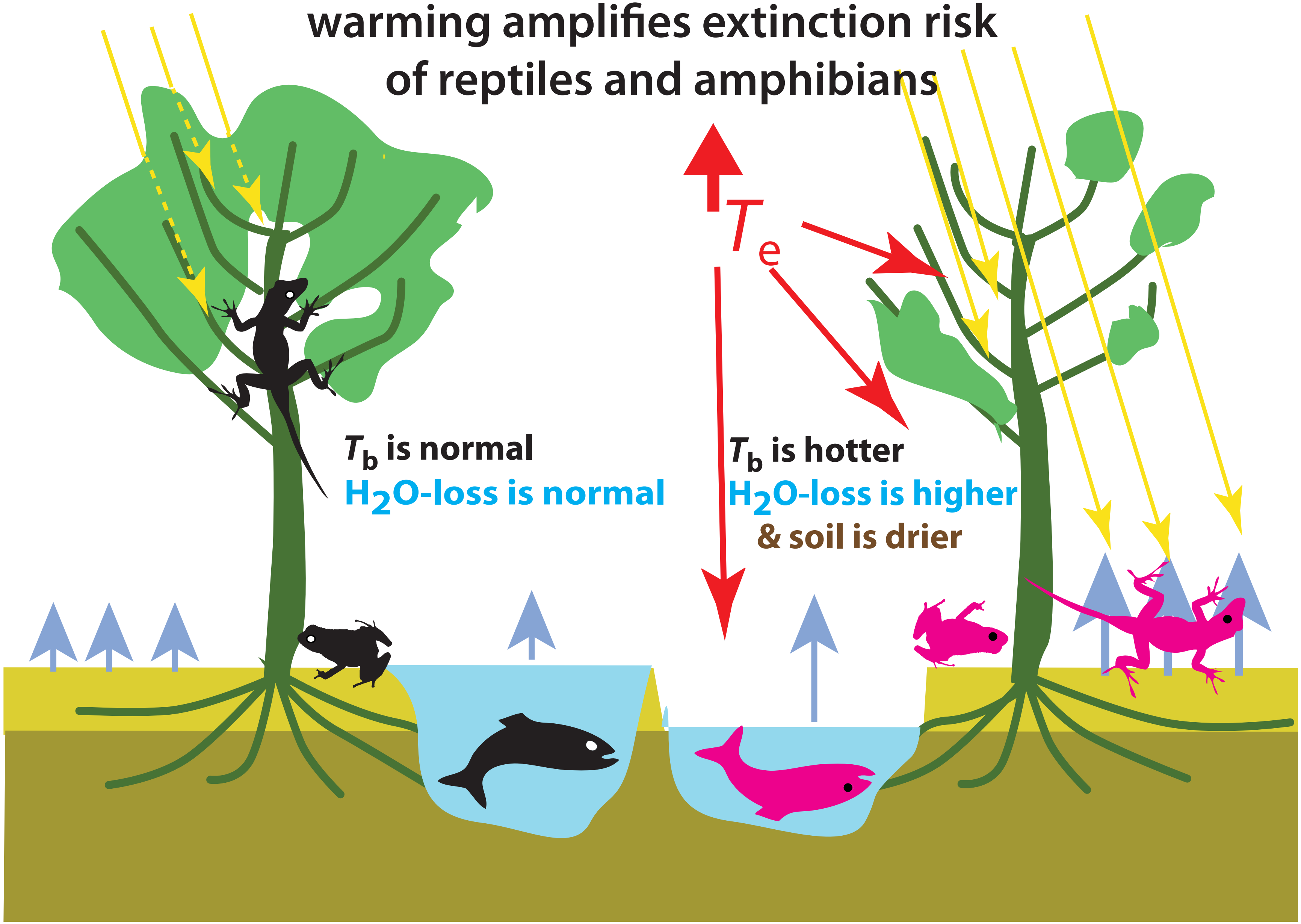
2050
- 6% species extinction
- 100% in some areas

2080
- 20% species extinction
- 100% in many areas

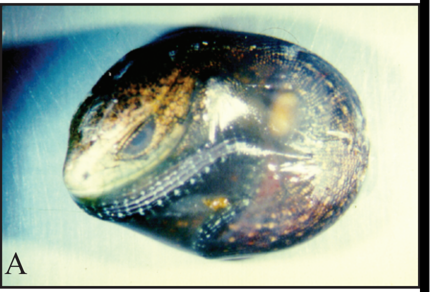
Part II. Plant die-backs and vertebrate extinctions

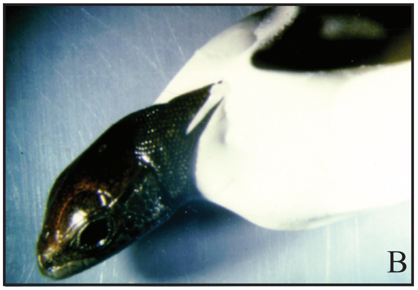
Across the world

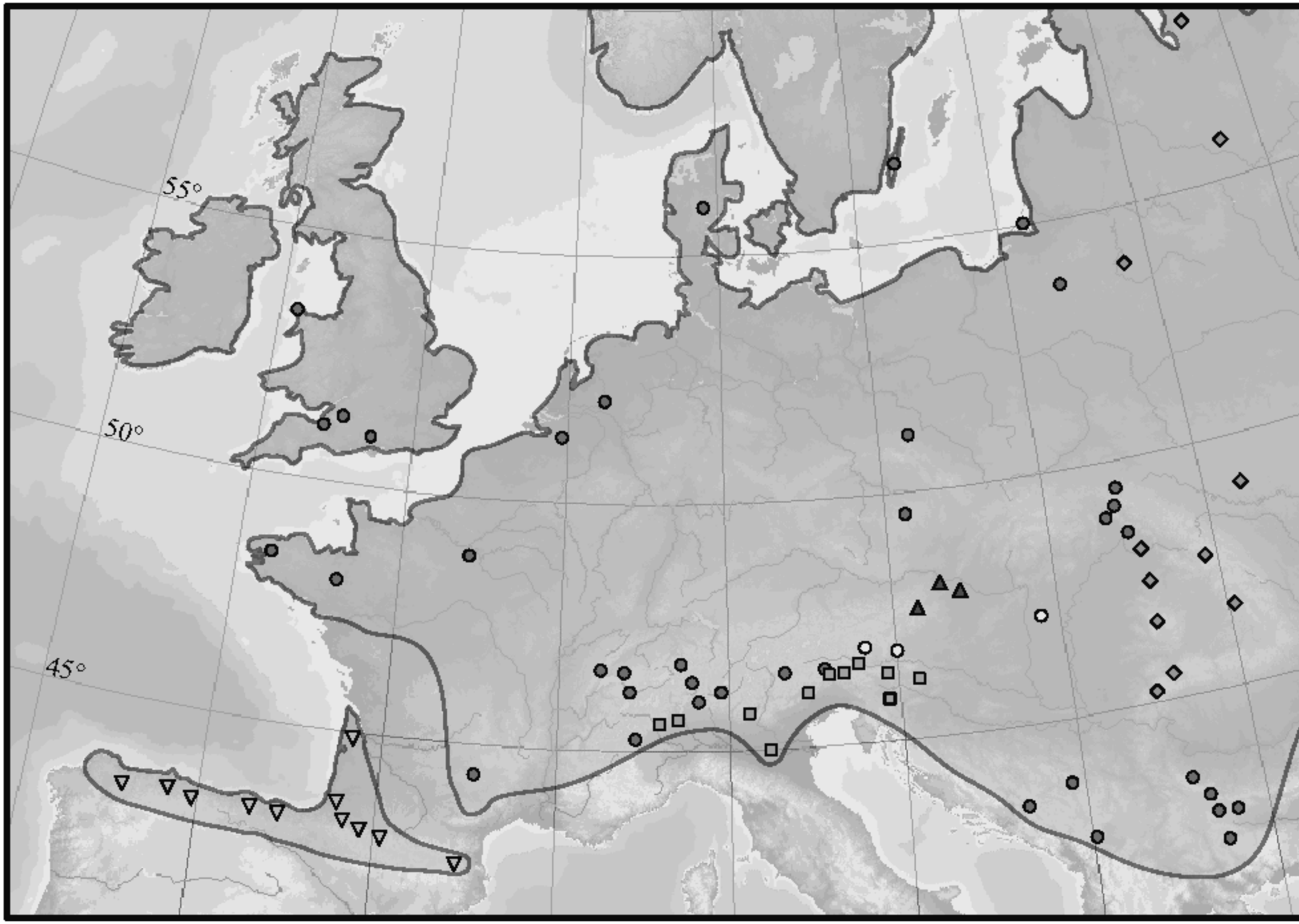
By causing plant die-back, warming amplifies extinction risk of reptiles and amphibians



European common lizards

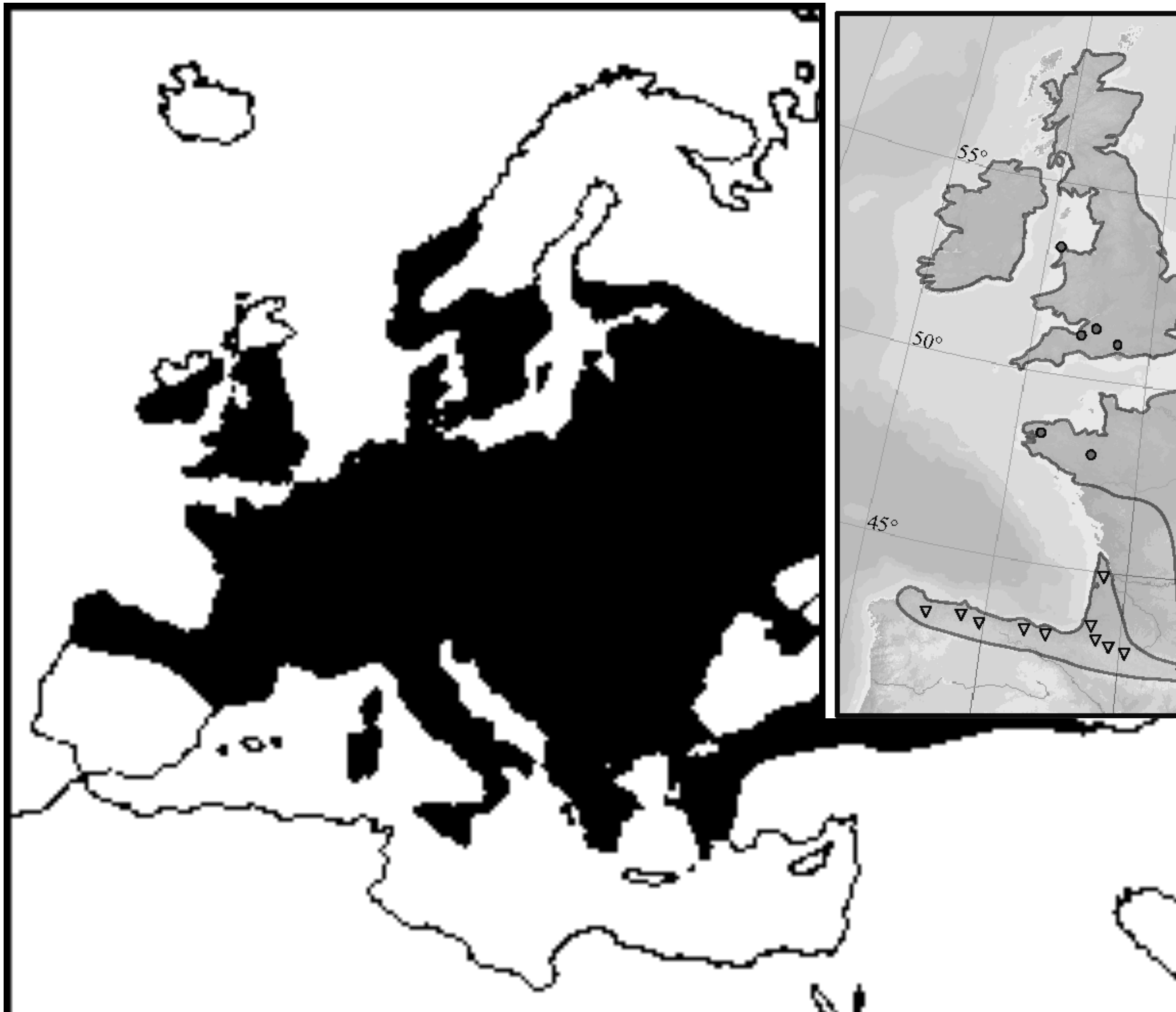




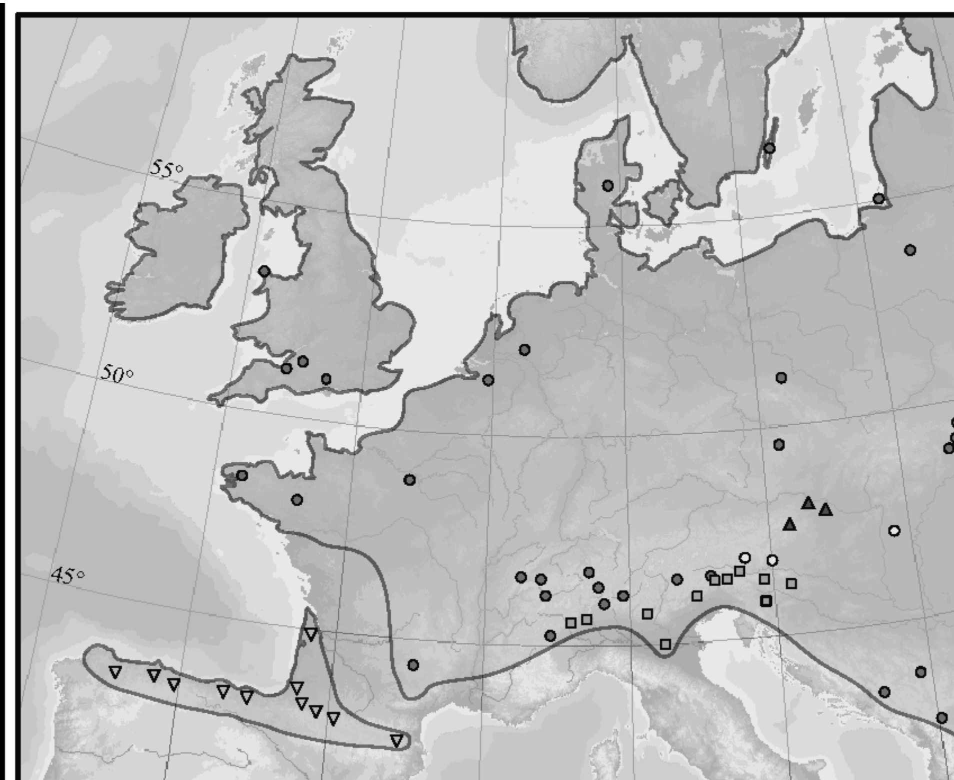


Ranges are coincident

Fraxinus excelsior – Ash



Common lizards



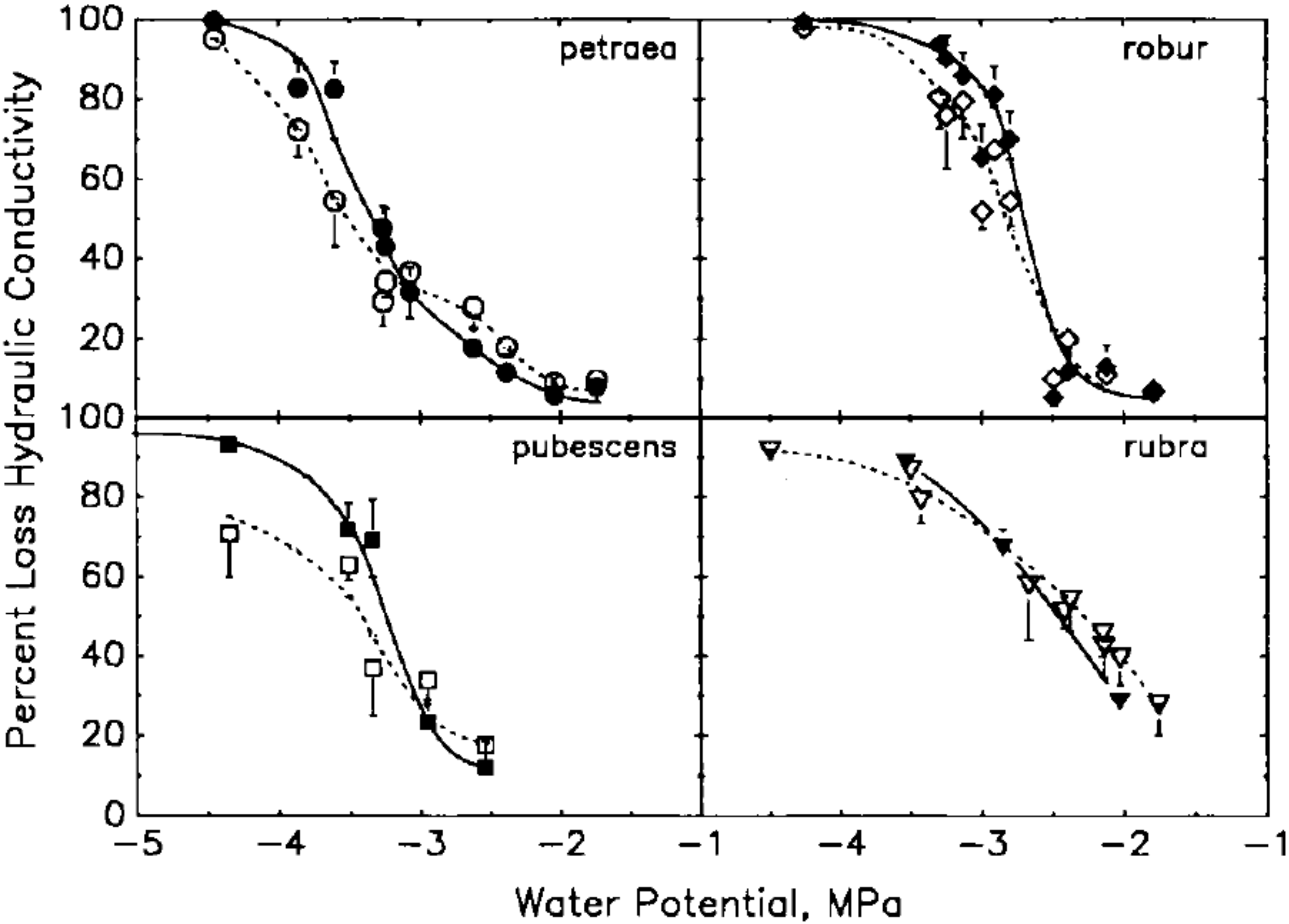
Reason for the linkage

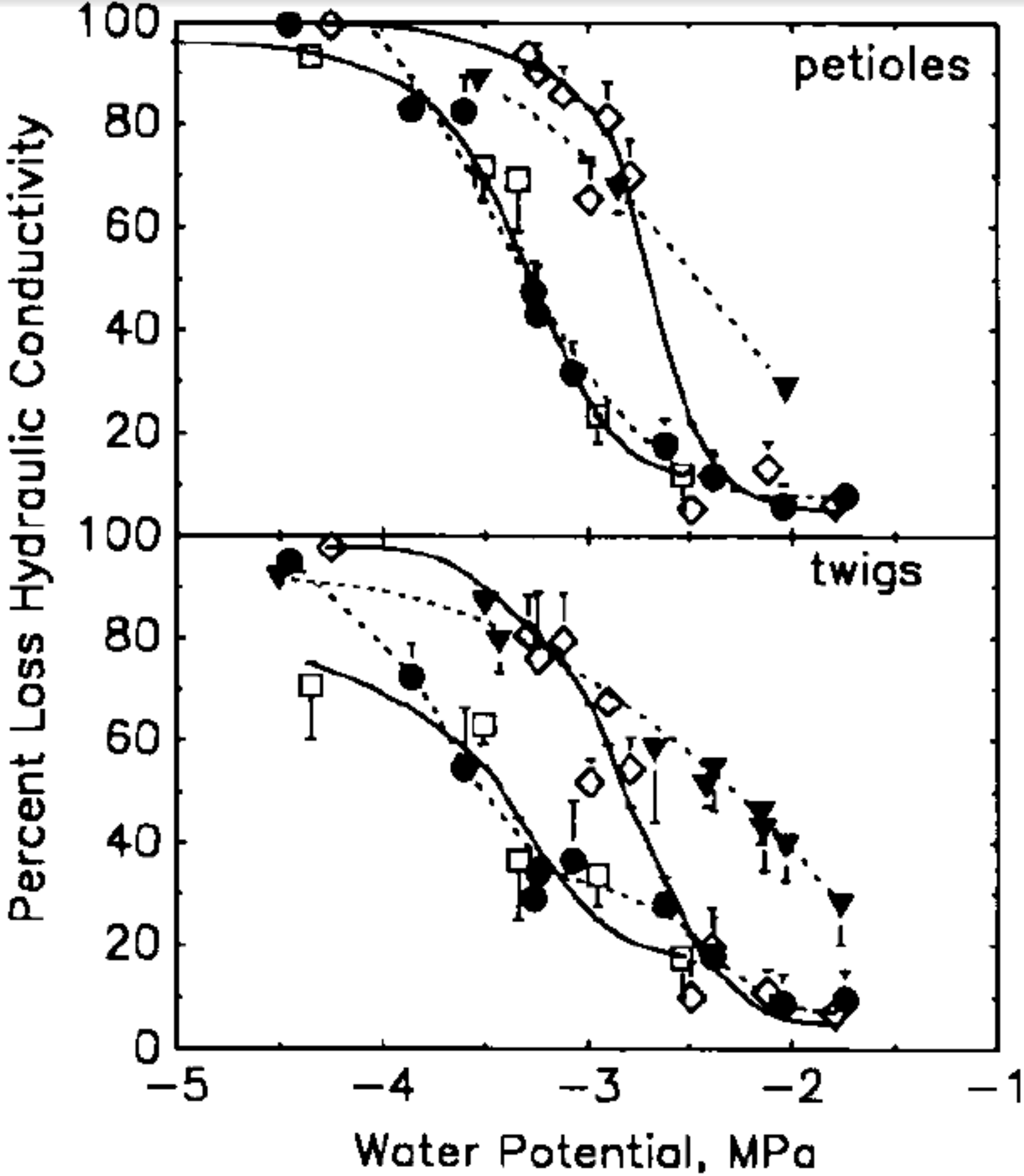
- The warm spells and droughts have similar physiological effects
- In plants droughts generate cavitation in the conducting xylem decreasing hydraulic efficiency, lowering evapotranspiration, and thus the leaves warm and die (evapotranspiration lowers leaf surface temperatures by the latent heat of evaporation).

A physiological model

- Rather than use temperature tolerances (as in lizards), in plants go directly to hydraulic performance under varying water potentials
- This hydraulic performance curve can be linked to the tandem effects of extreme climate on temperature and droughts
- Parameterize these models with the data set Pittermann manages (N=1200) for hydraulic performance of plants around the world.

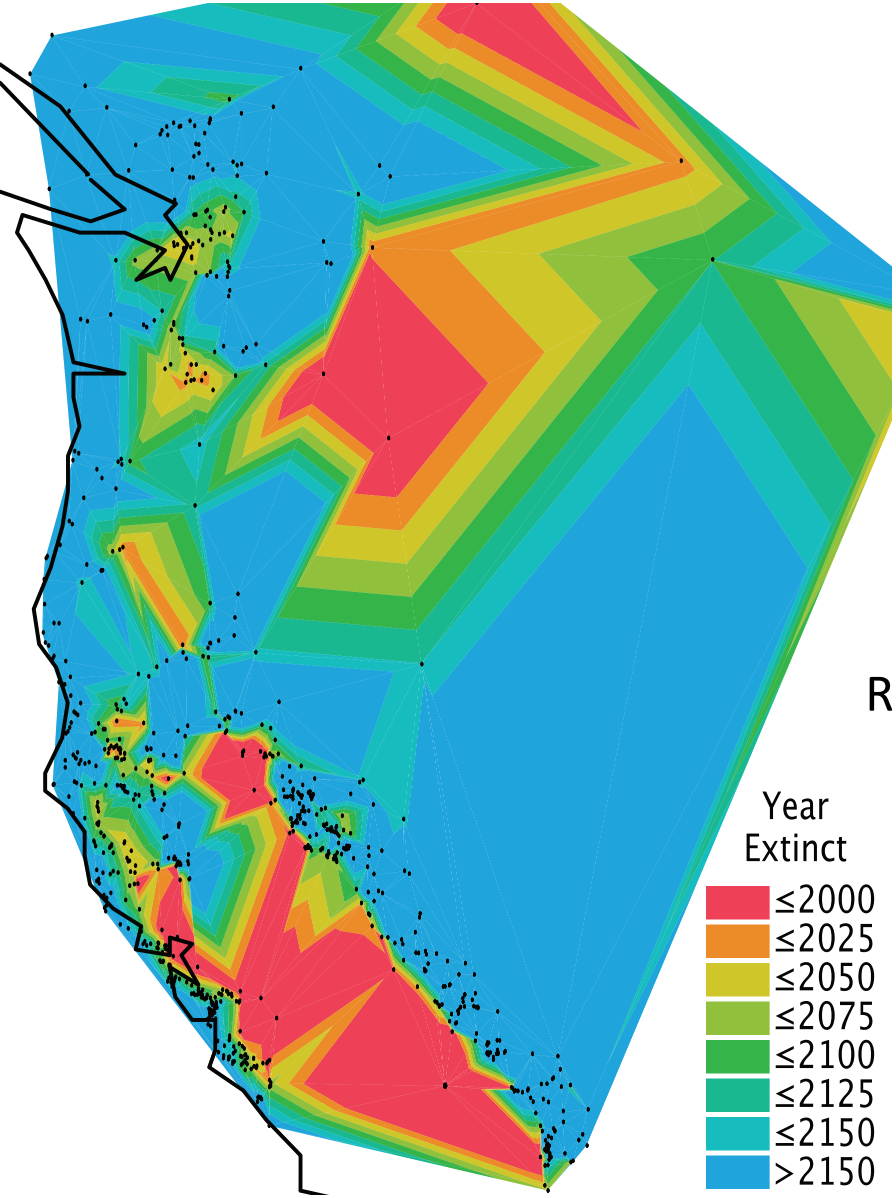
Hydraulic performance in 4 Oak (*Quercus*) species (Cochard 1992)





petioles
twigs
100
80
60
40
20
100
80
60
40
20
0
−5
−4
−3
−2
−1
Percent Loss Hydraulic Conductivity
Water Potential, MPa

Extinctions of Northern Alligator Lizards (viviparous)



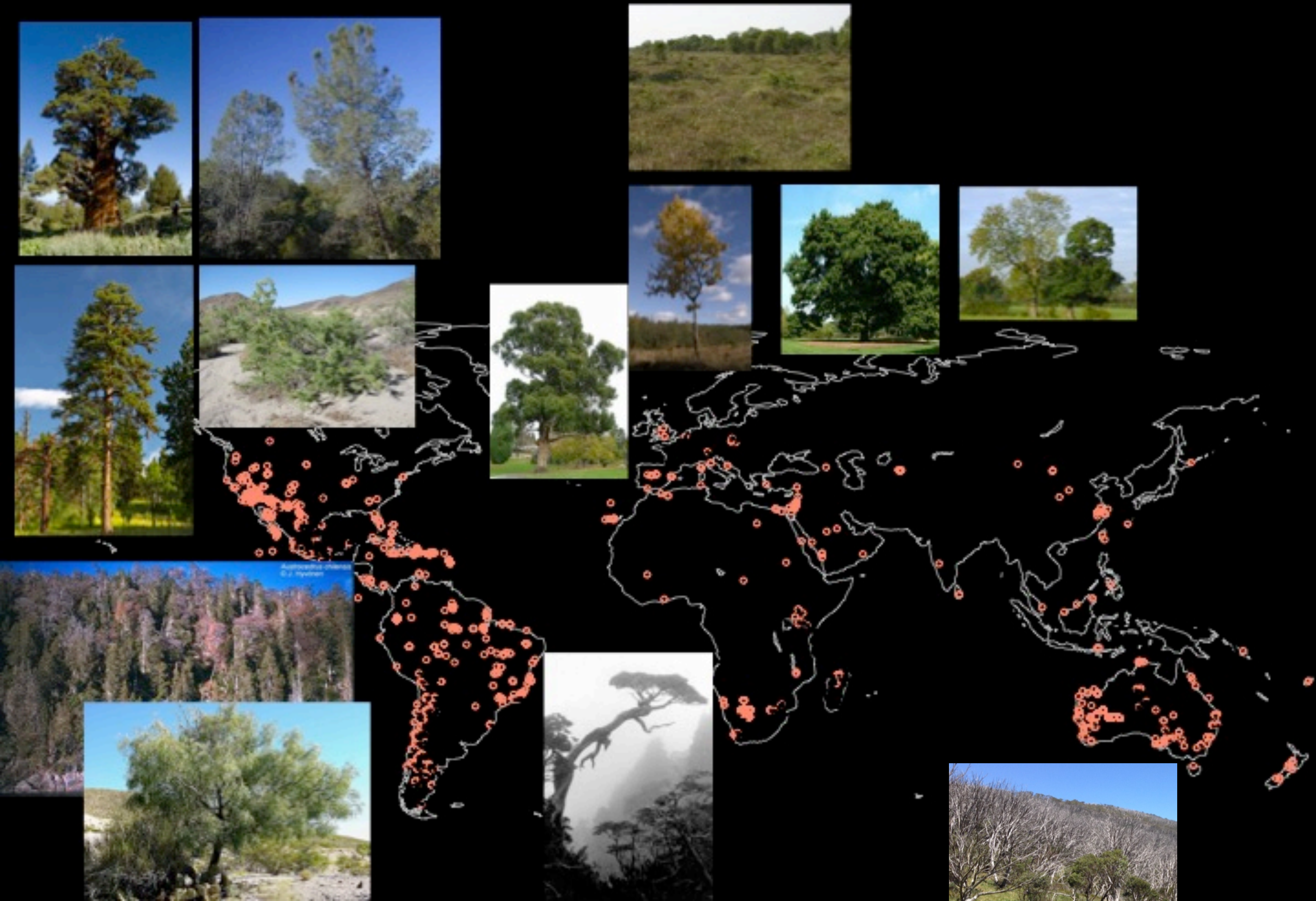
DYING PINES

INTACT PINES

Ho

Rest

Plants are dying off at all the lizard extinction sites.

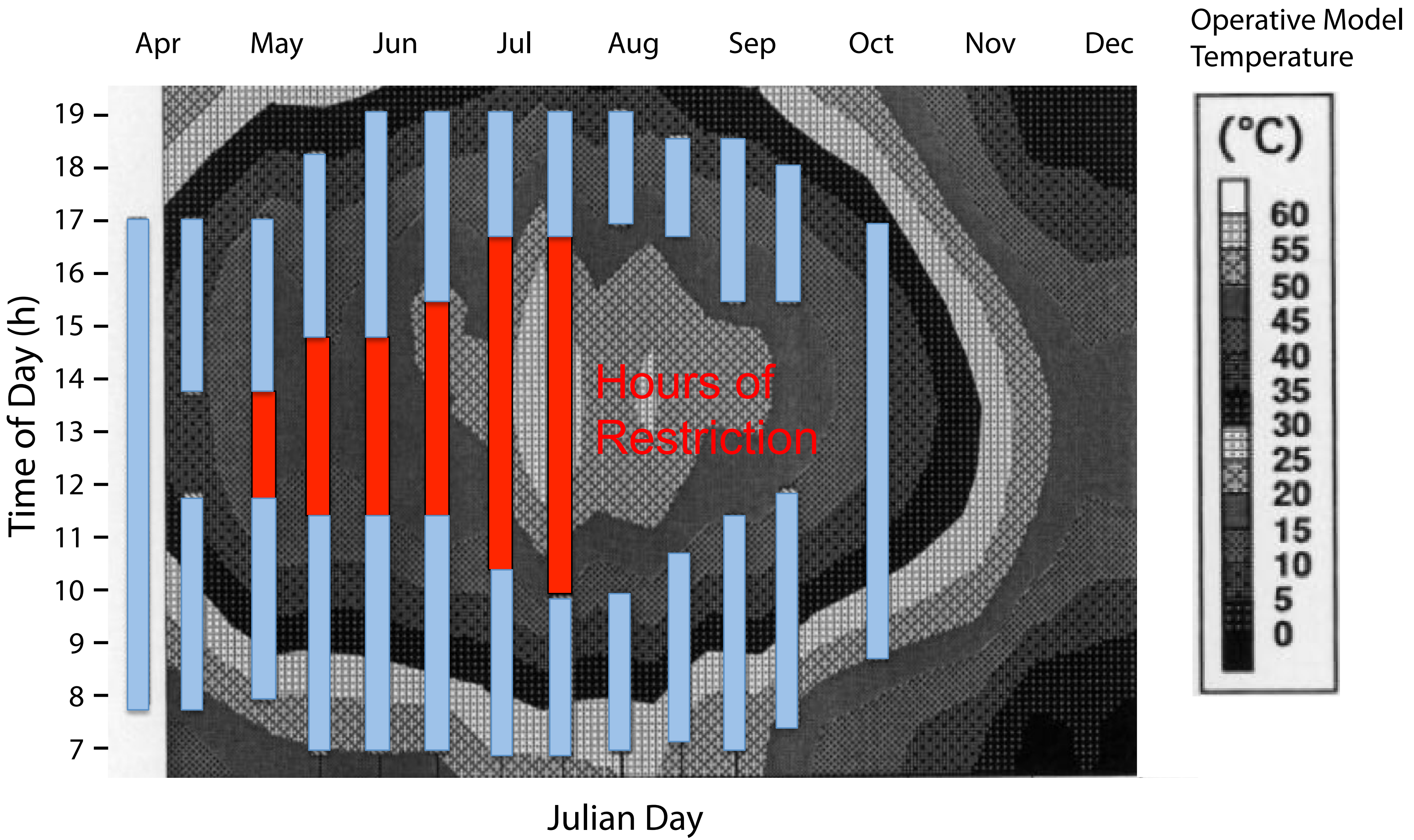


Part III. Going paleo – Extinctions of tortoises across the ages

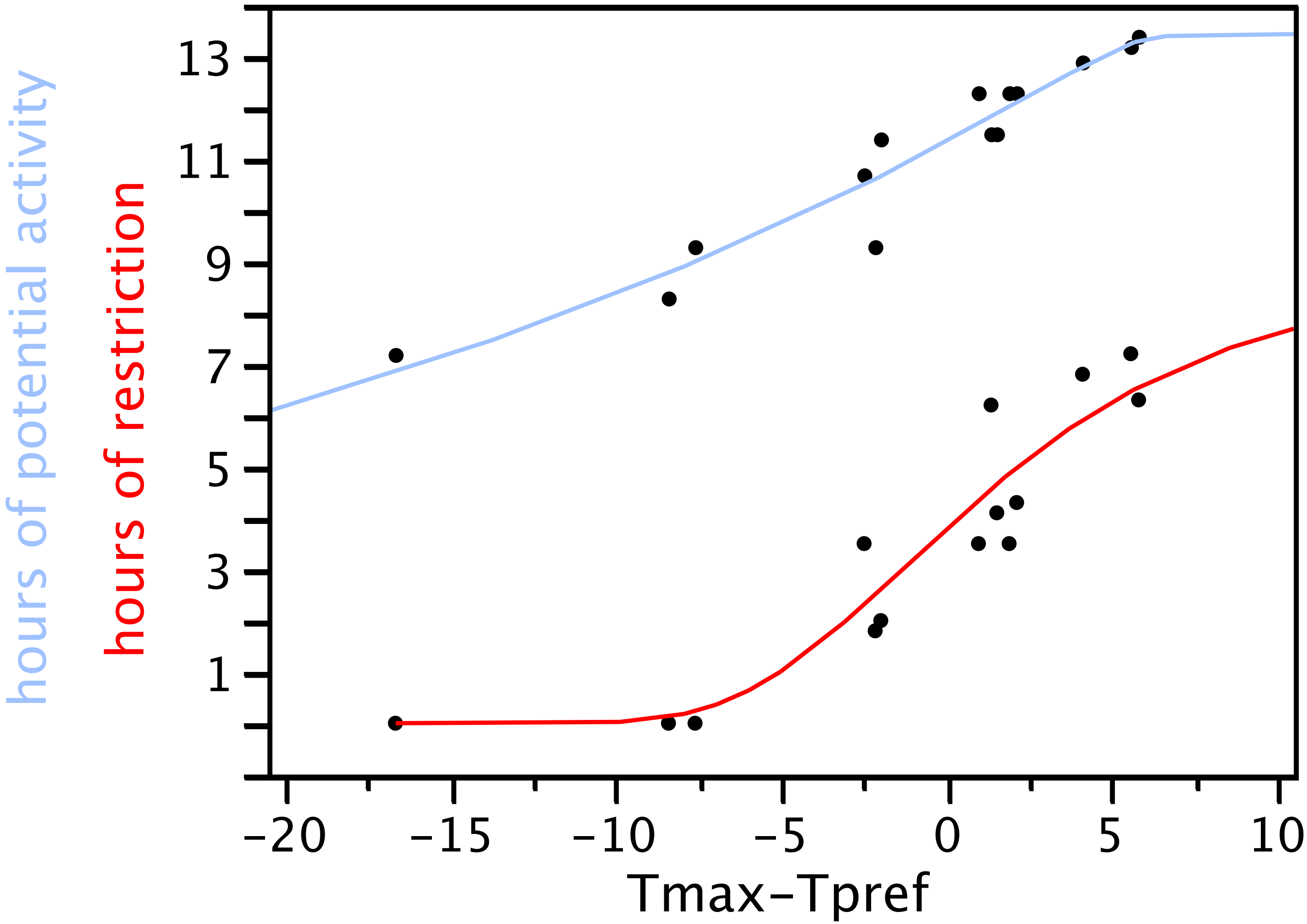
The full Population Viability Model

Reconstructing Species Distributions from first principles of Demography

Hours of restriction during the breeding season



Sigmoidal relationships for hours of restriction and activity



Gopherus Life Table

Age at maturity

All zero

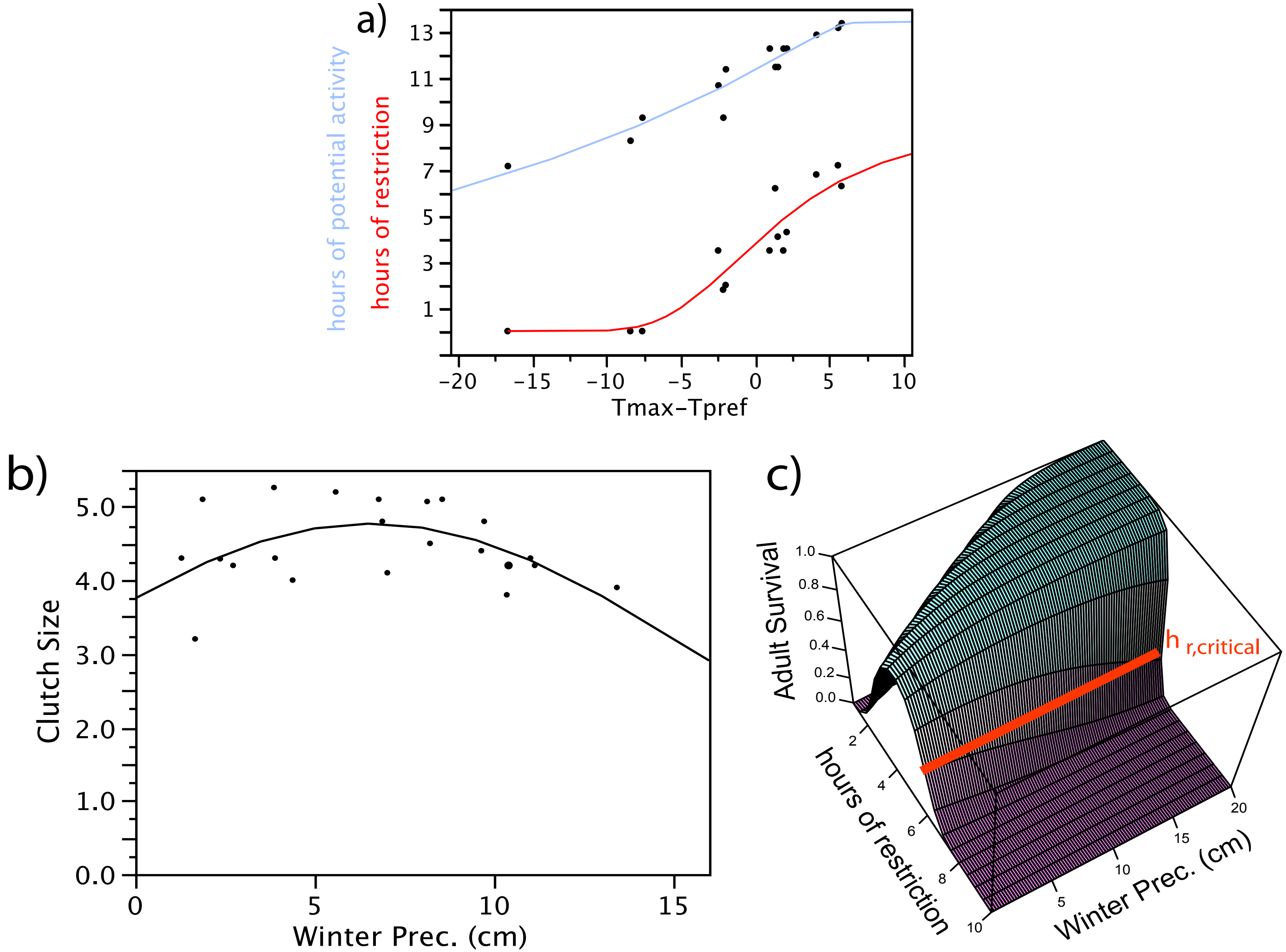
m_x = function(size, climate)

f_0	f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8	f_9	f_{10}	f_{11}	f_{12}	f_{13}	f_{14}	f_{15}	f_{16}	f_{17}	f_{18}	f_{19}	f_{20}	f_{21}	f_{22}	f_{23}	f_{24}
l_0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	l_1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	l_2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	l_3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	l_4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	l_5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	l_6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	l_7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	l_8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	l_9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	l_{10}	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	l_{11}	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	l_{12}	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	l_{13}	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	l_{14}	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	l_{15}	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	l_{16}	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	l_{17}	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	l_{18}	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	l_{19}	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	l_{20}	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	l_{21}	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	l_{22}	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	l_{23}	0

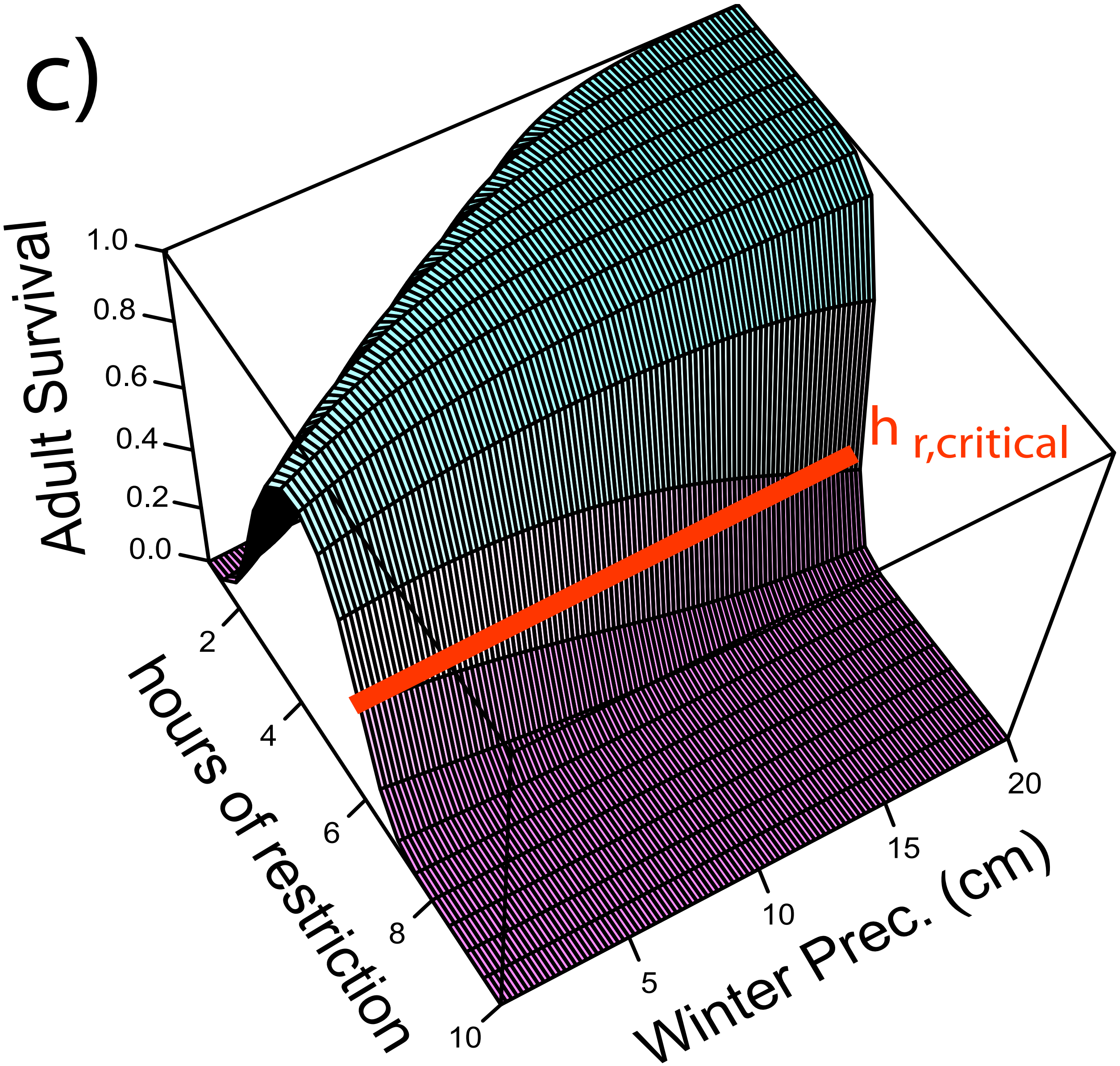
JUVENILE l_x = function(climate?)

ADULT l_x = function(climate)

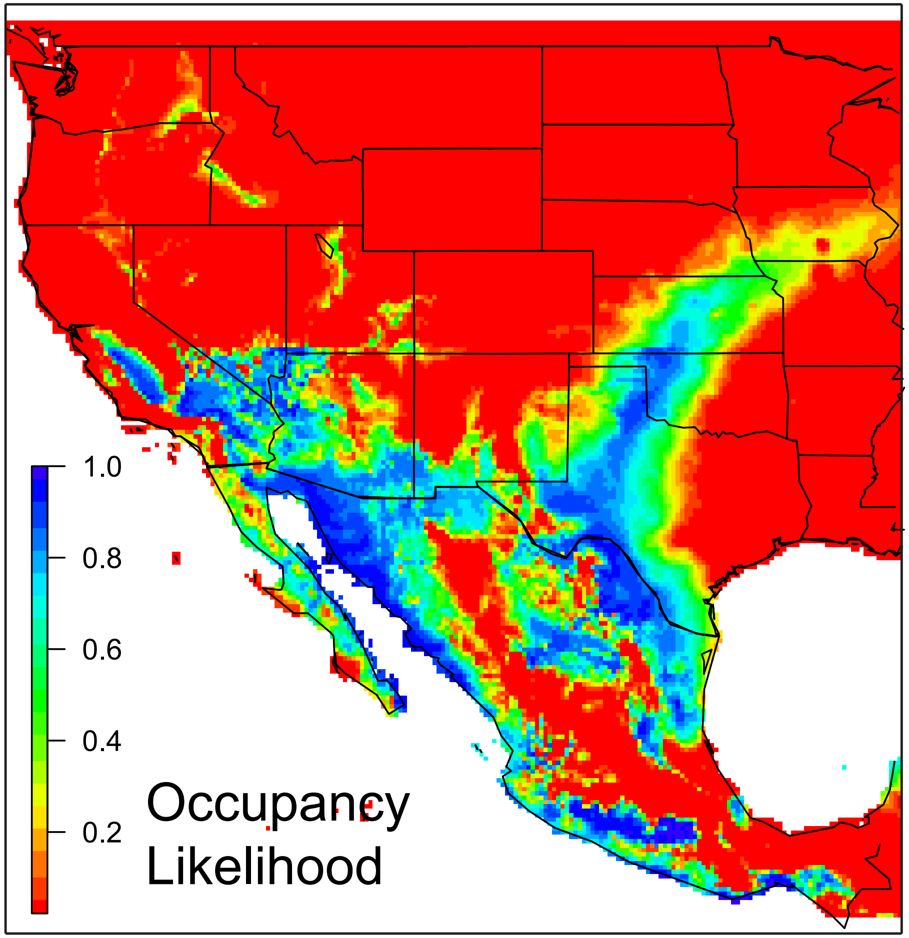
Ecophysiological envelop

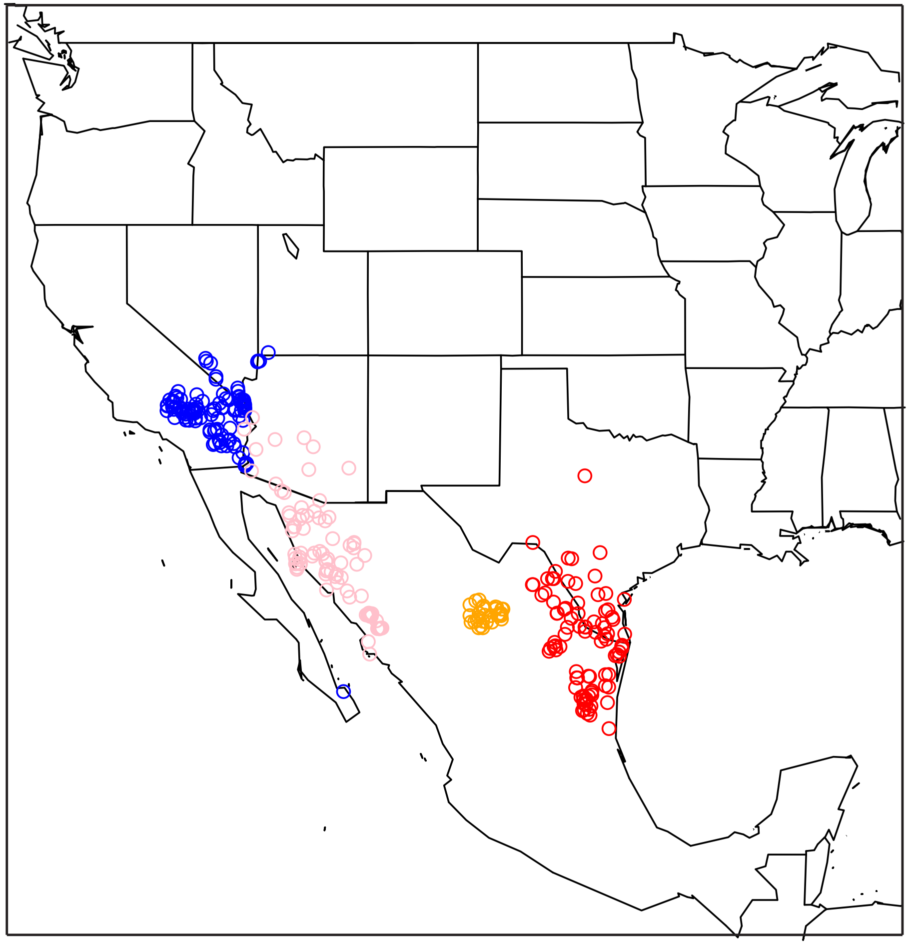


Eco-physiological envelop

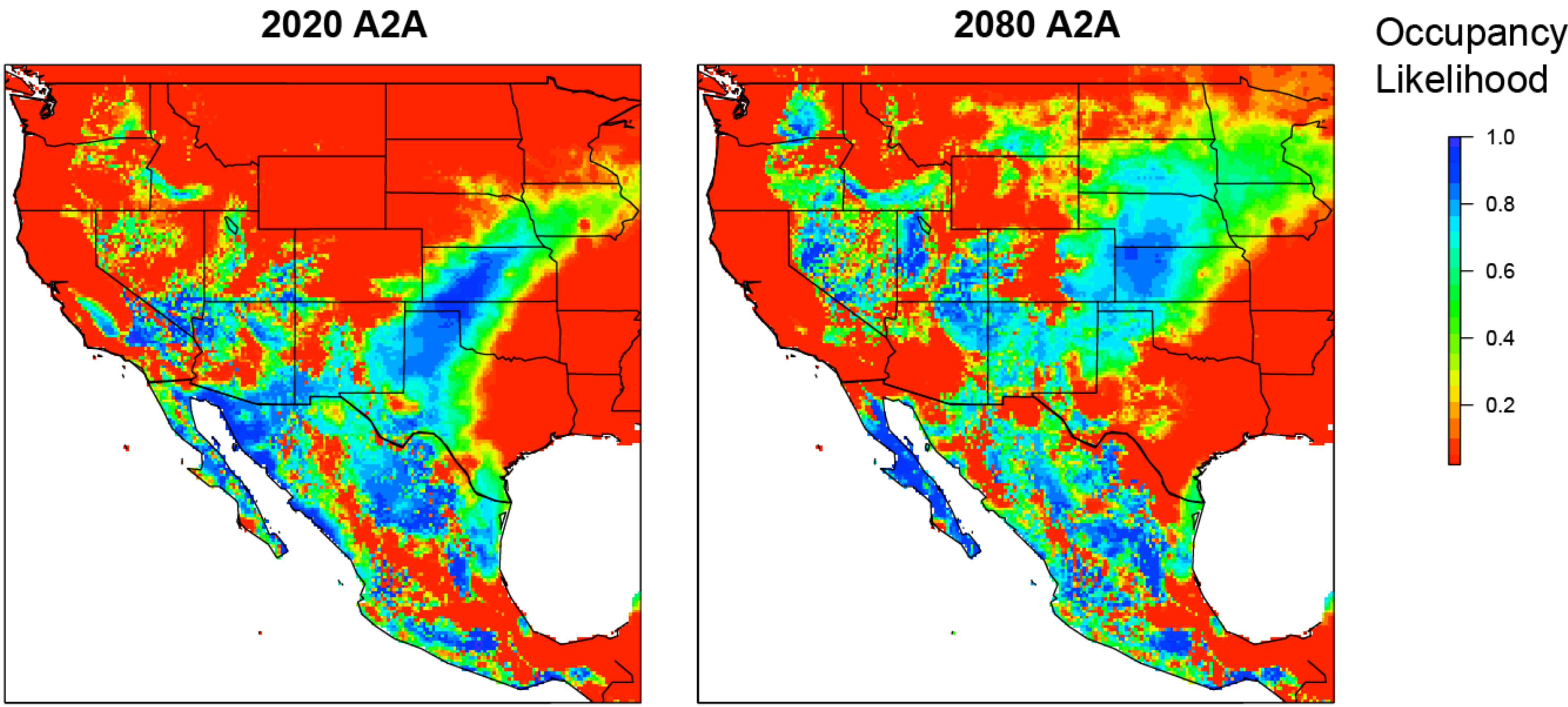


SDM with Physiology (AUC = 0.92) vs SDM with Maxent (AUC = 0.62)





Species Distribution Models of the Desert Tortoise under future climate (2020, 2080)

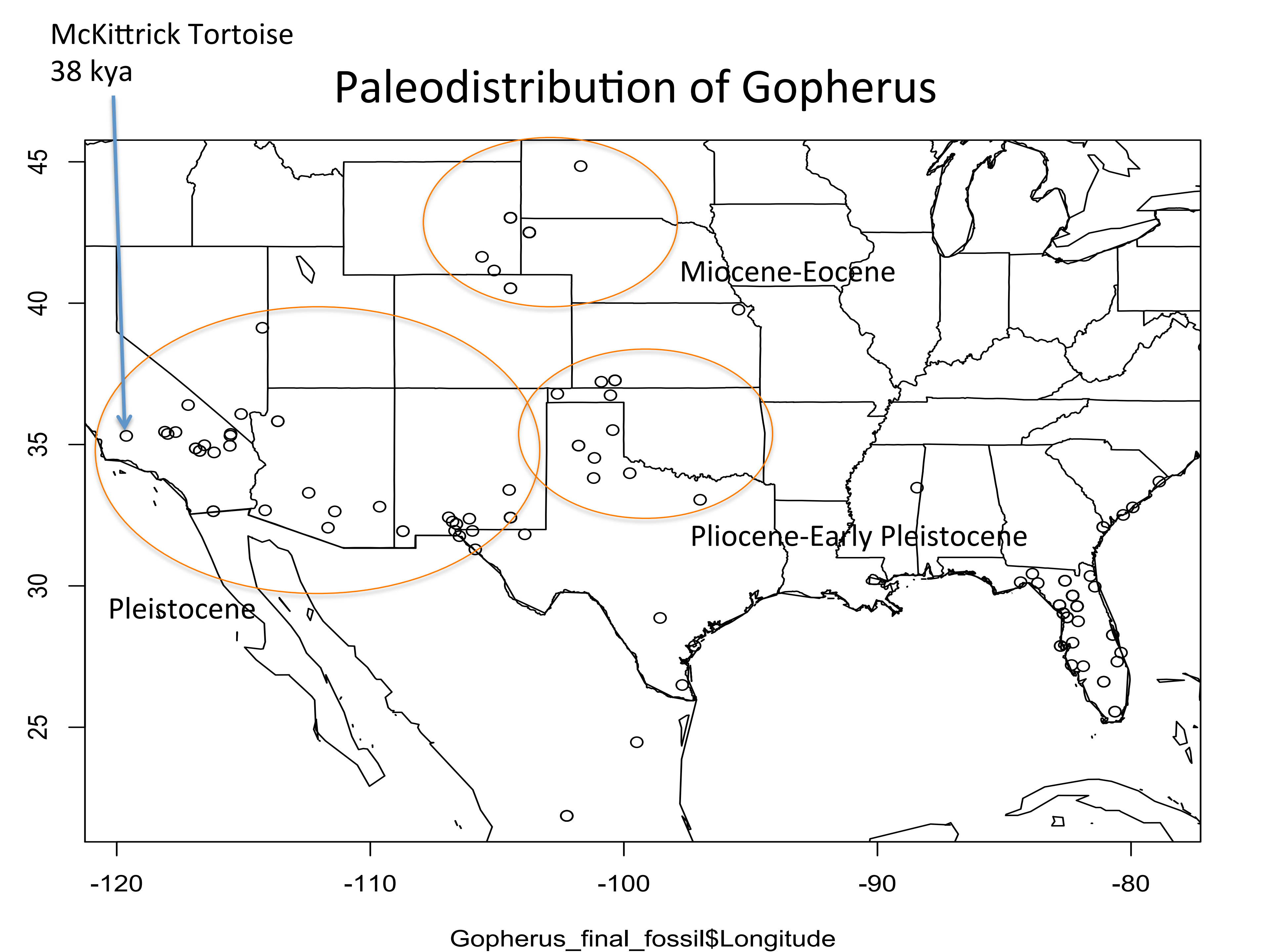


Part IV. Rewilding Eocene and Miocene Tortoises

Where can we site G. agassizii populations if they go extinct throughout their current range?

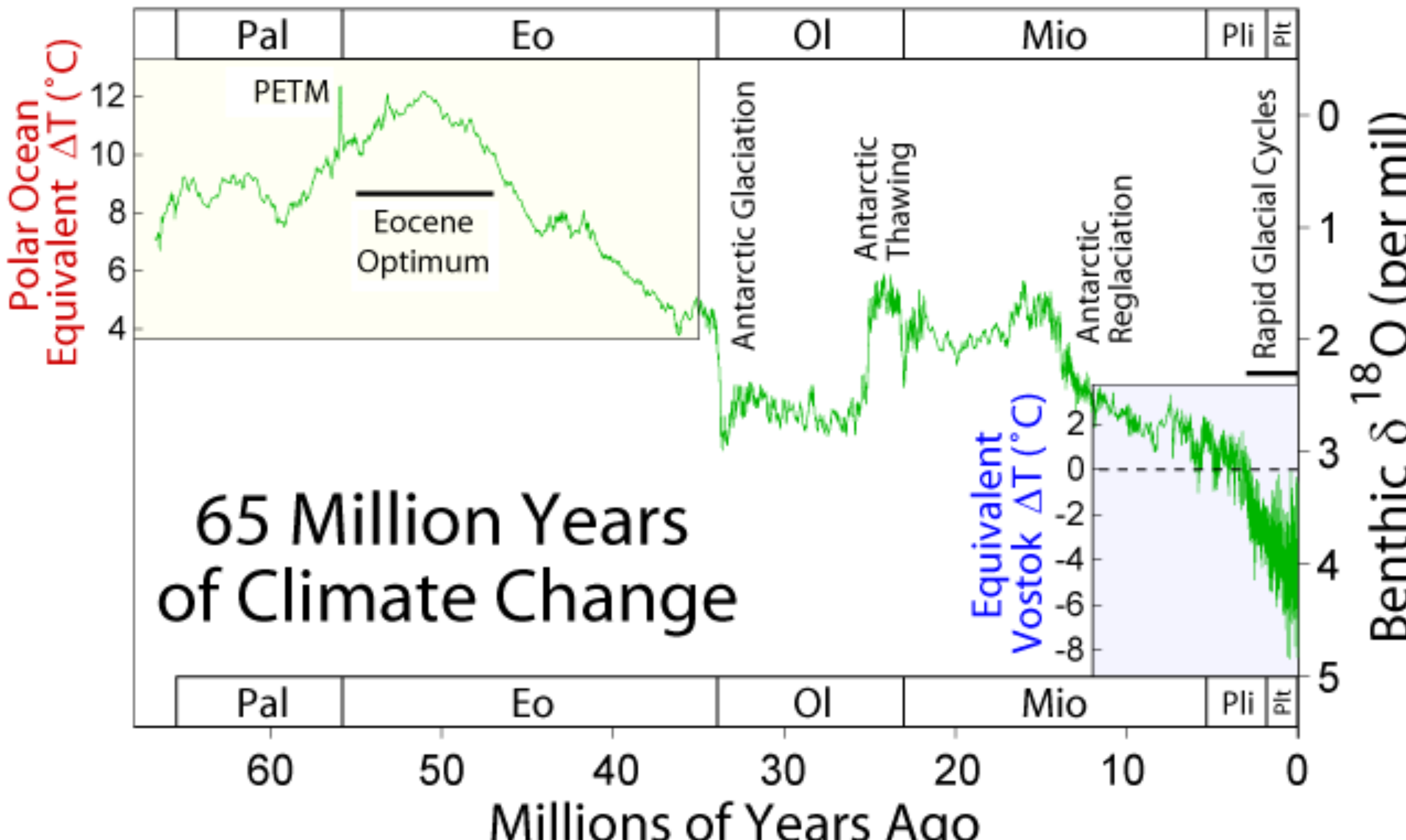

Rewilding Eocene Tortoises to the Great plains?
How about a little closer to home?
Rewilding tortoises to the Central Valley of CA
adidas

Paleodistribution of Gopherus

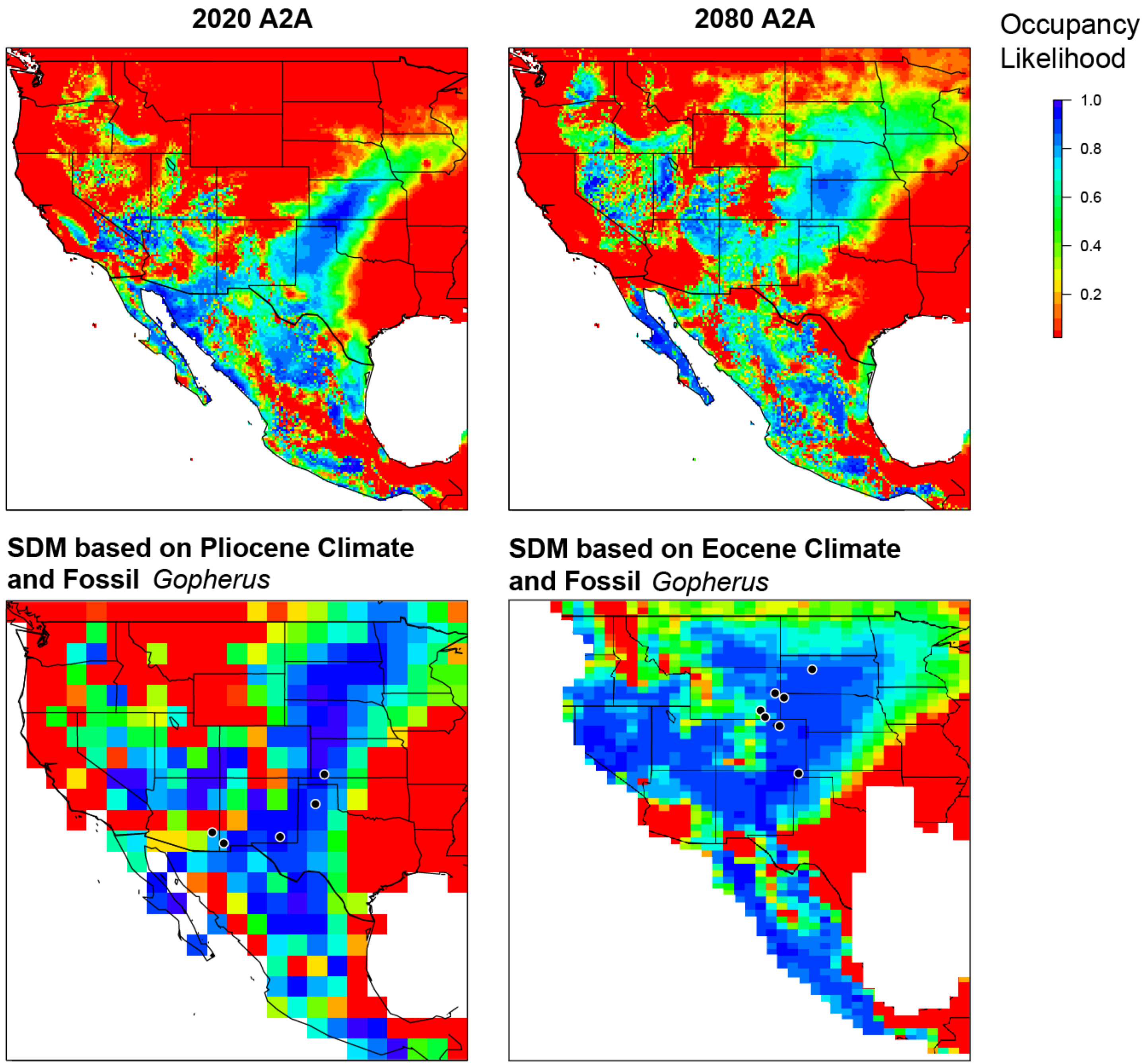


65 million years

Paleocene–Eocene Thermal Maximum (PETM) ΔT=6°C in 20,000: and the warmest temperatures occur at the Eocene Optimum



Species Distribution Models of the Desert Tortoise under future climate (2020, 2080)

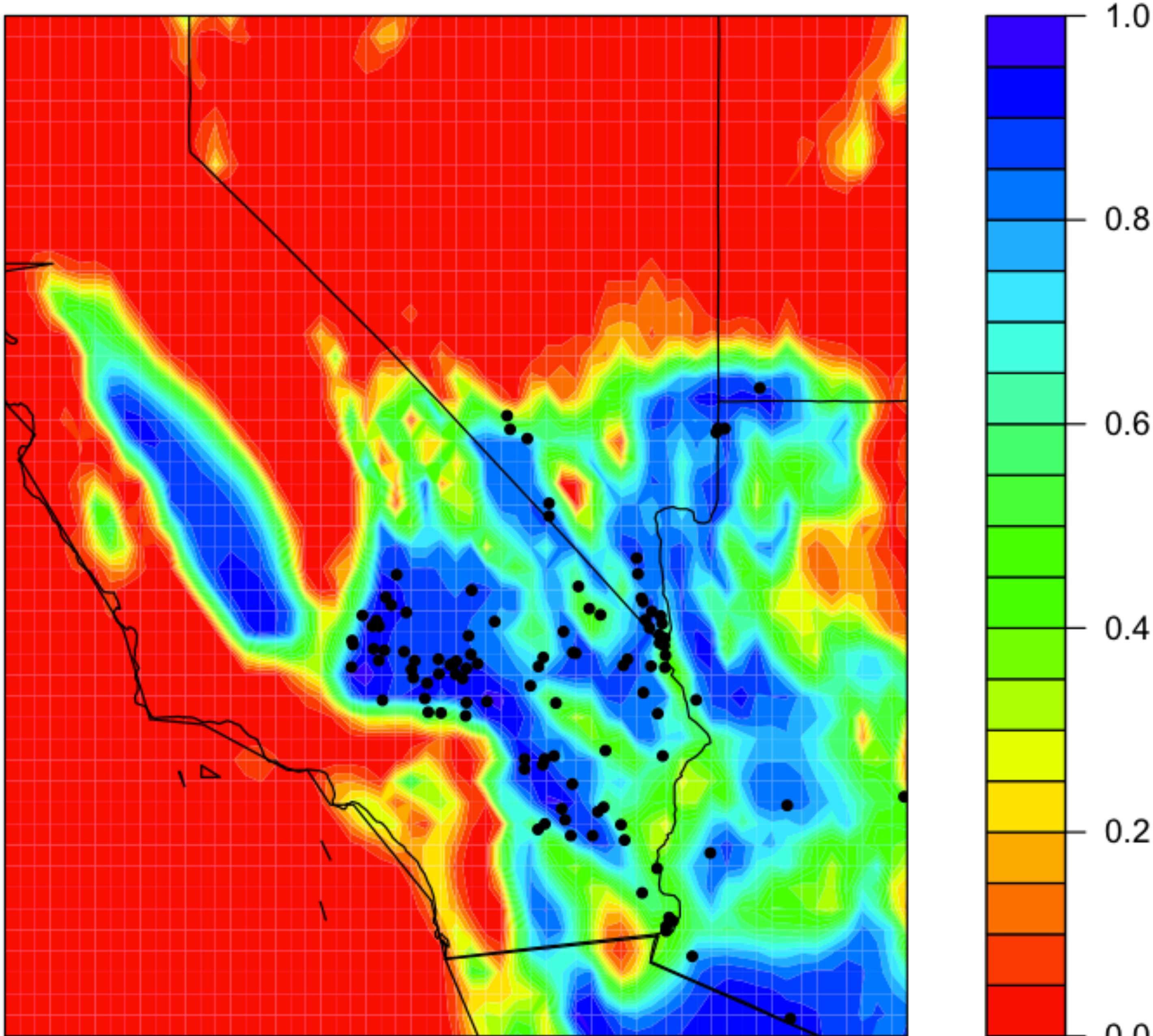


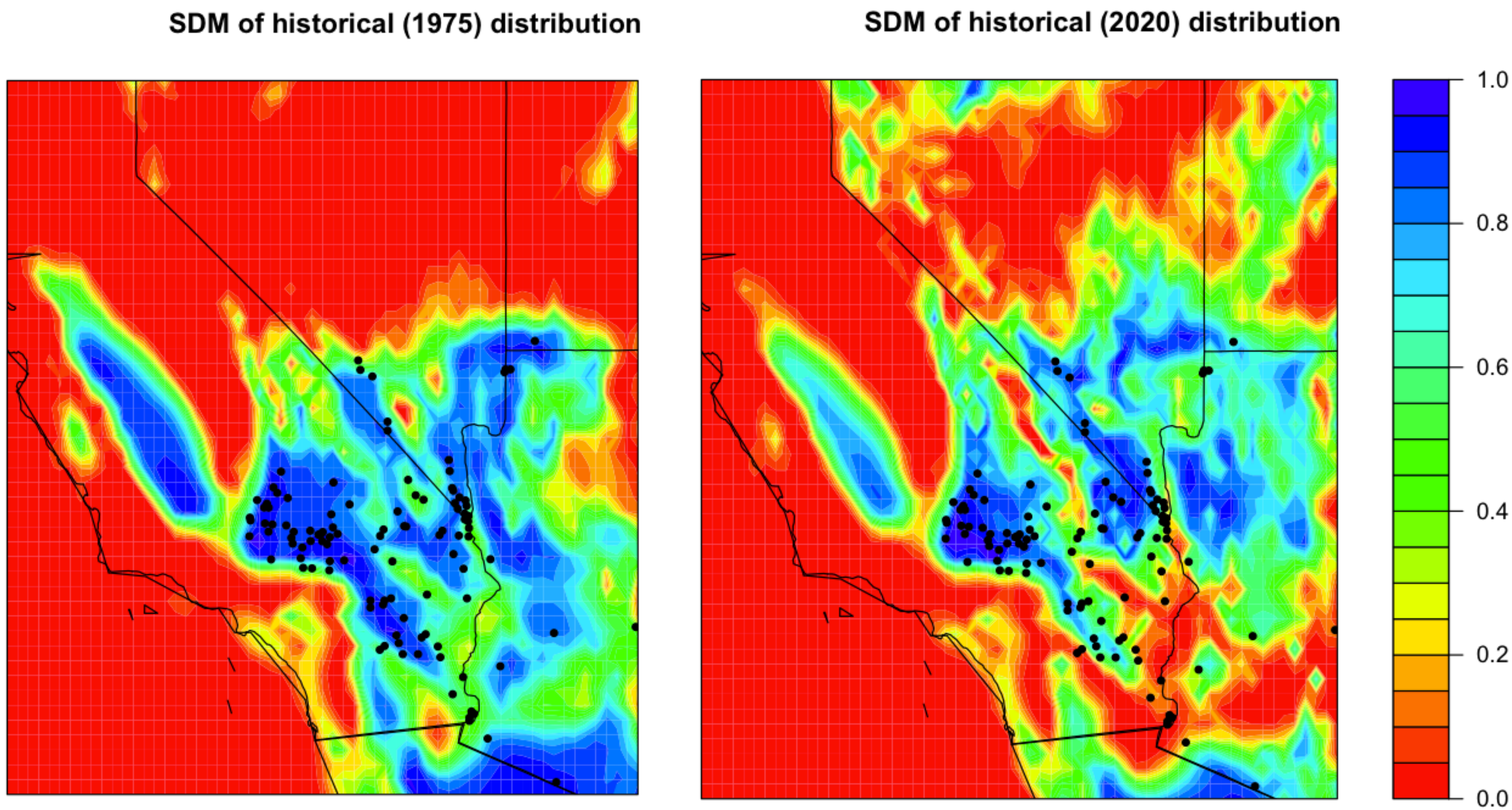
SDM under Paleoclimate scenarios during the Pliocene (Sloan et al. 1995) and Eocene (Sewall & Sloan 2004, 2006).

How about rewilding Central Valley?

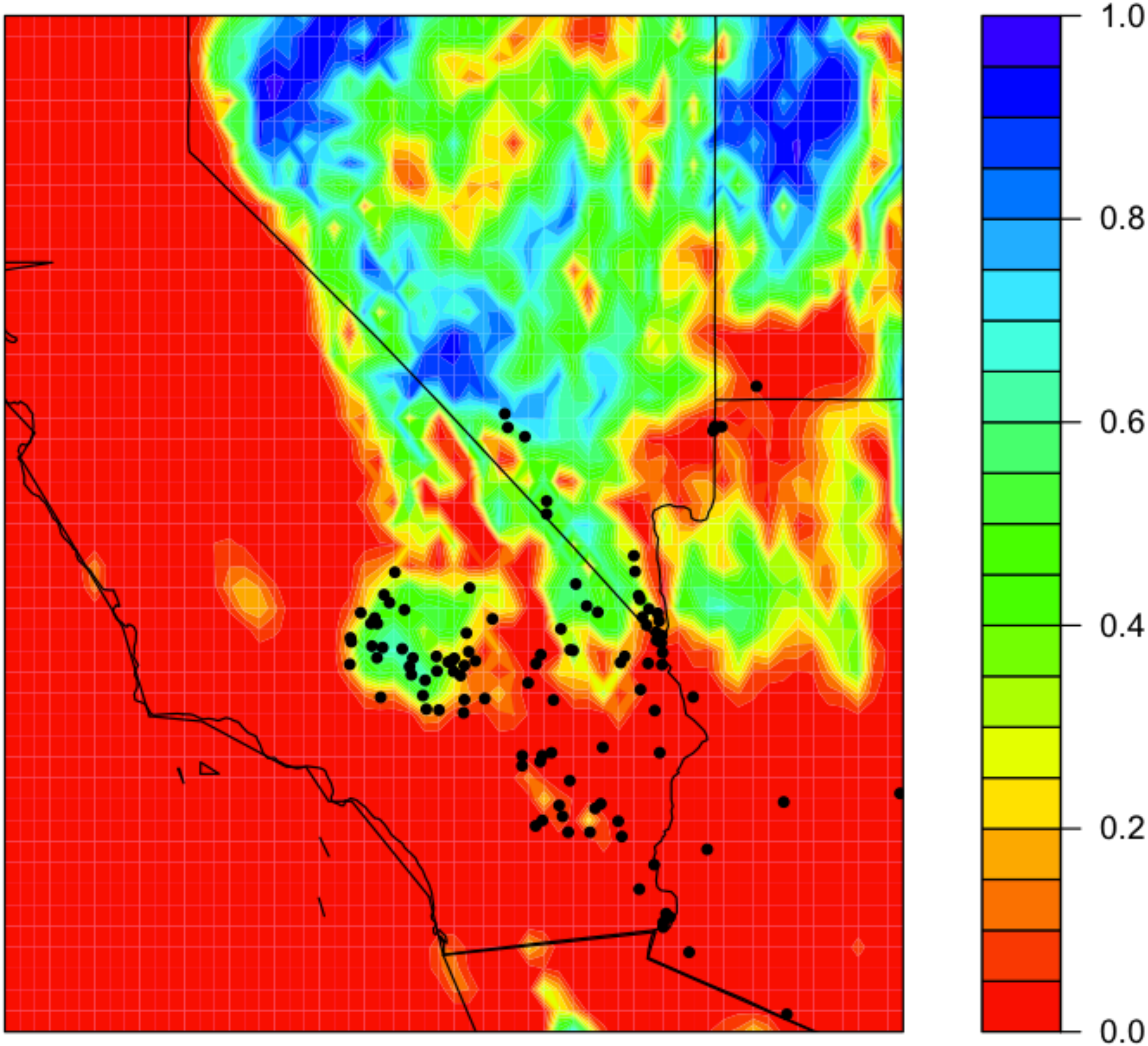
- Look at likelihood of population viability under IPCC Ivth climate assessment for *Gopherus agassizii*

SDM of historical (1975) distribution




SDM of historical (1975) distribution
SDM of historical (2020) distribution
1.0
0.8
0.6
0.4
0.2
0.0

SDM of historical (2080) distribution



Modeling refinements

- Use Bayesian methods to correct for biases in climate forecasting (collaboration with Bruno Sanso and Esther Salazar).
- This is required because the IPCC assessments do a very poor job of predicting future climate in a region dominated by monsoonal precipitation.

De-biasing surfaces (Sanso & Salazar)

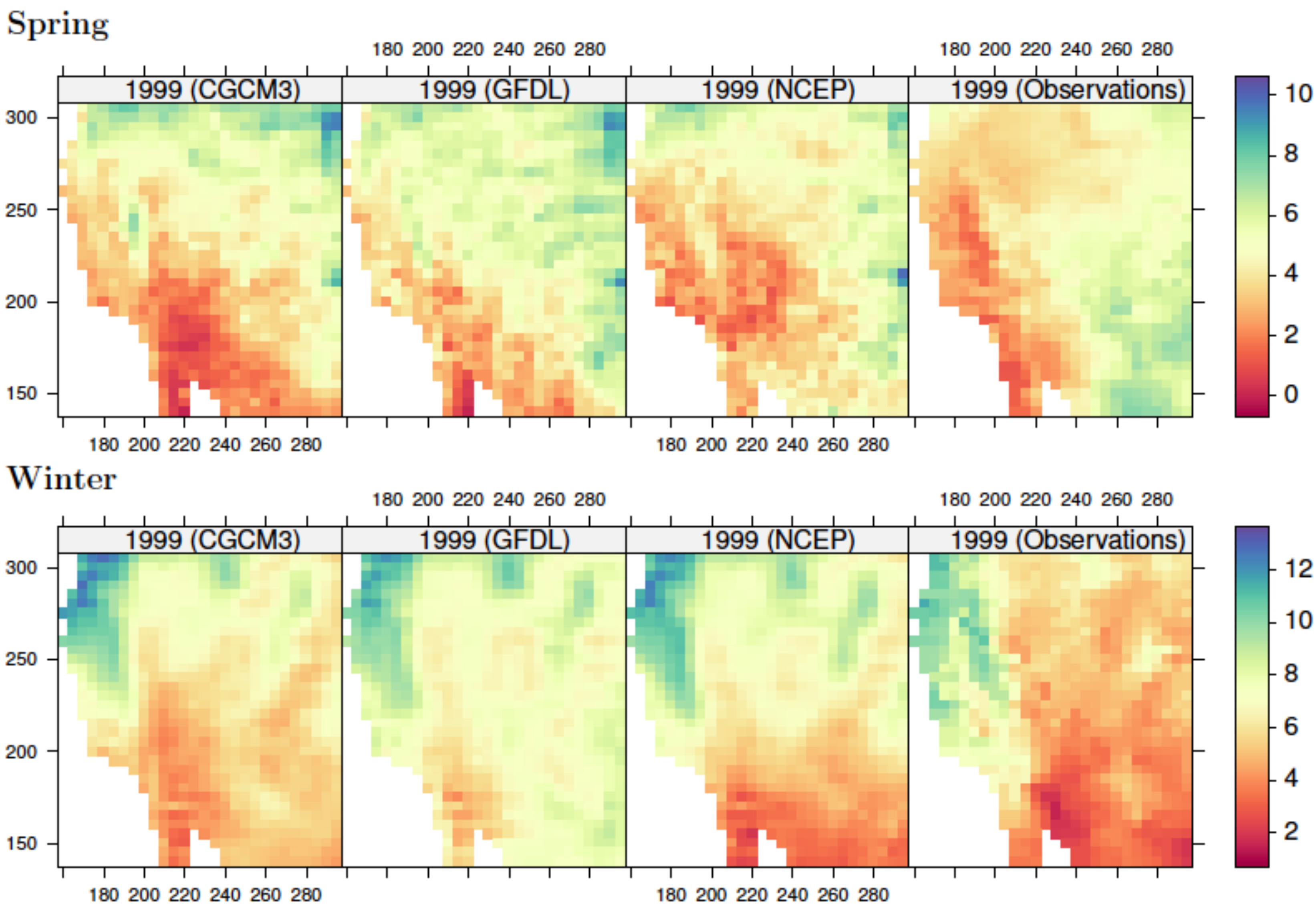


Figure 1: Data: cube root of the precipitation volume for spring and winter for the year 1999.

De-biased

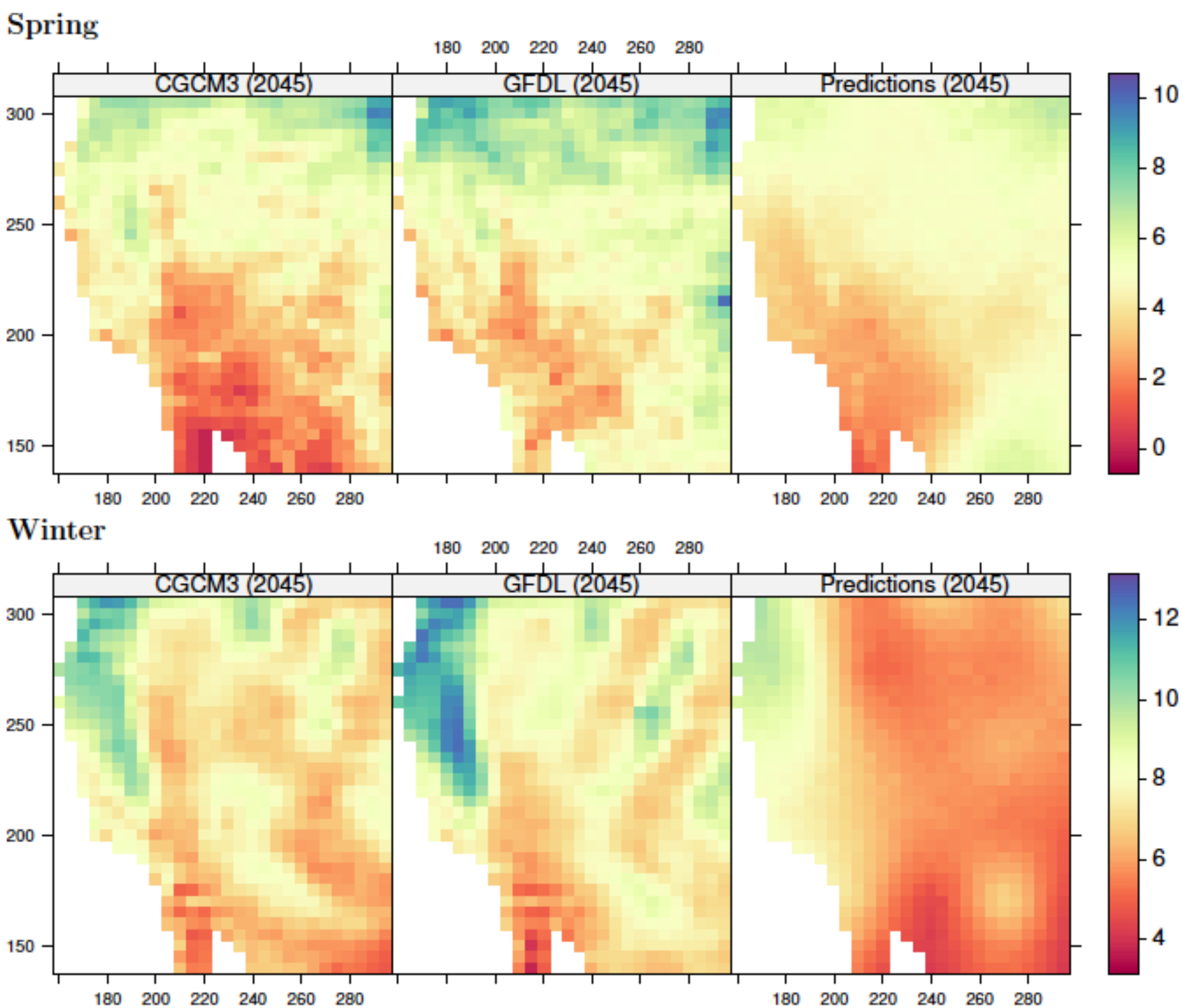
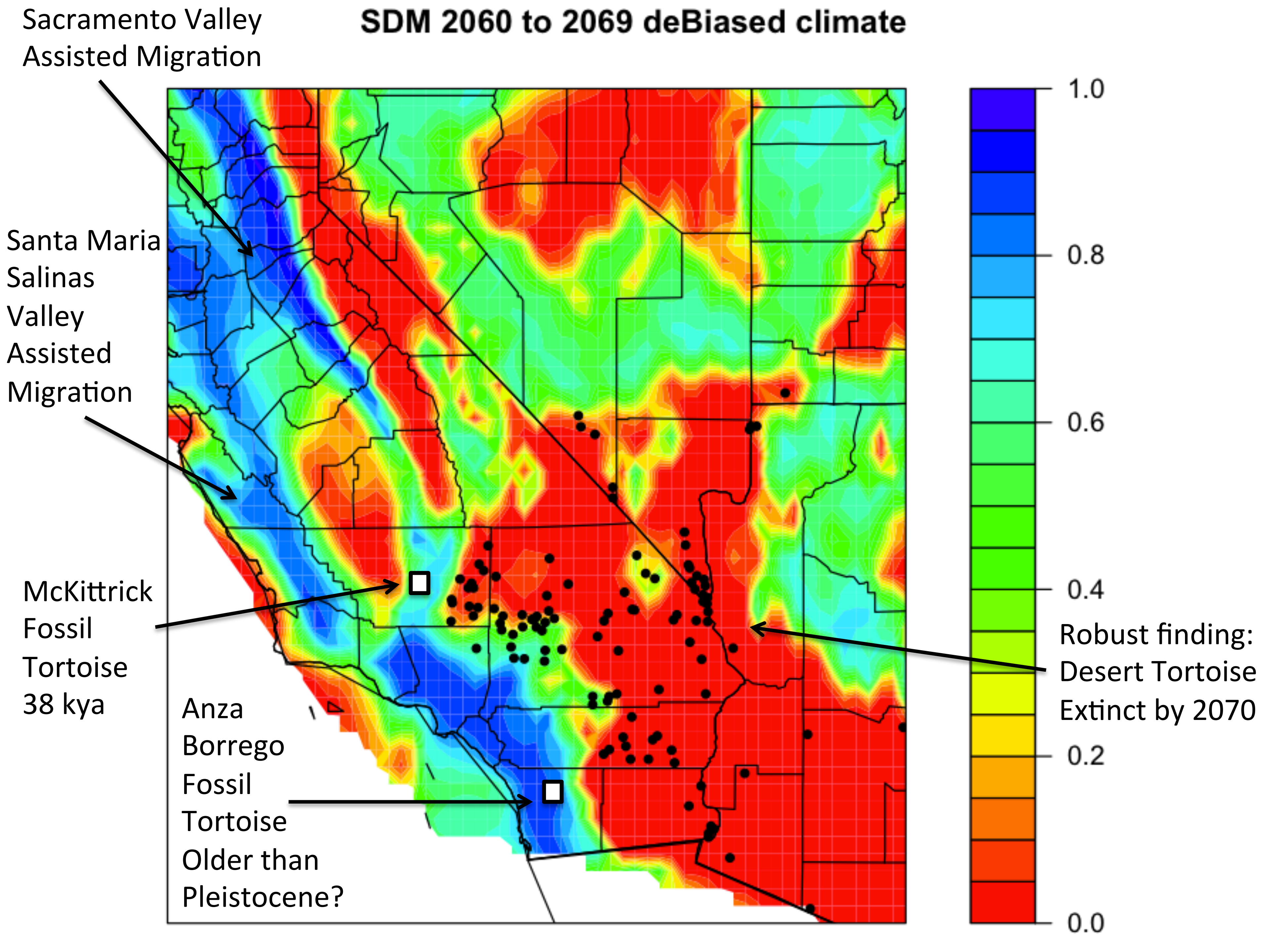
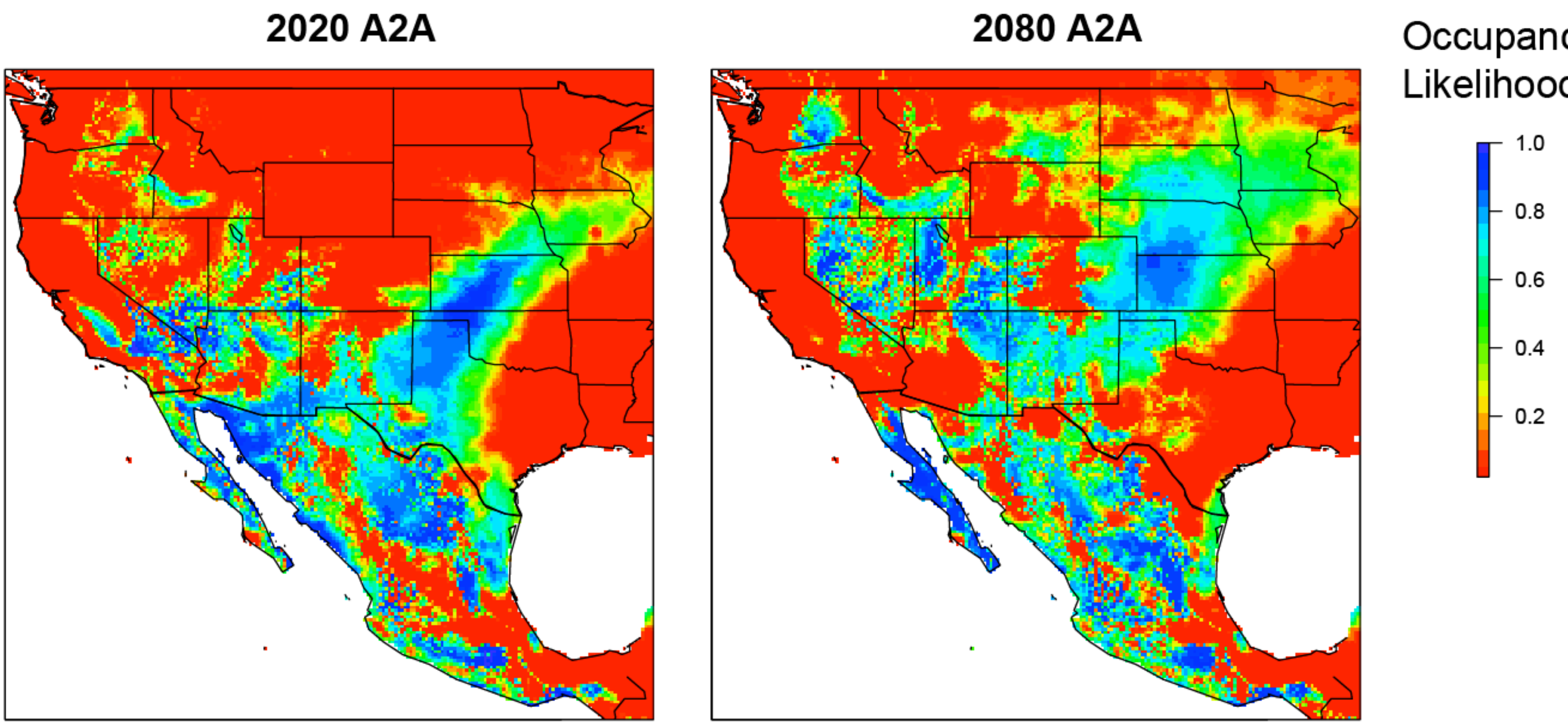


Figure 4: Predicted transformed precipitation for the year 2045.


SDM 2060 to 2069 deBiased climate
Sacramento Valley Assisted Migration
Santa Maria Salinas Valley Assisted Migration
McKittrick Fossil Tortoise 38 kya
Anza Borrego Fossil Tortoise Older than Pleistocene?
Robust finding: Desert Tortoise Extinct by 2070
1.0
0.8
0.6
0.4
0.2
0.0

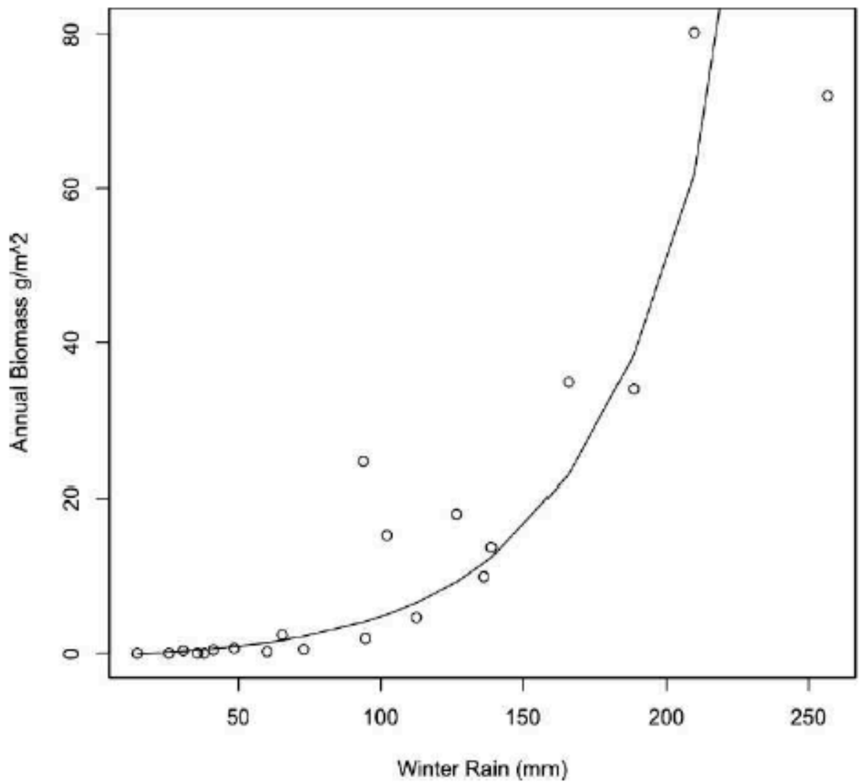
Species Distribution Models of the Desert Tortoise under future climate (2020, 2080) also predict other refuges in Kansa (this region does not suffer as seriously from the biases in the IPCC predictions, which are present in the desert futurecasts where there are strong Mosoonal impacts).



Other modeling refinements (in the works)

- Instead of using precipitation as a proxy for food, use NDVI to reconstruct plant habitat
- And then tie in NDVI to an Equilibrium Vegetation Ecology Model to predict plant ecosystems changes (collaboration with Jon Bergengren)

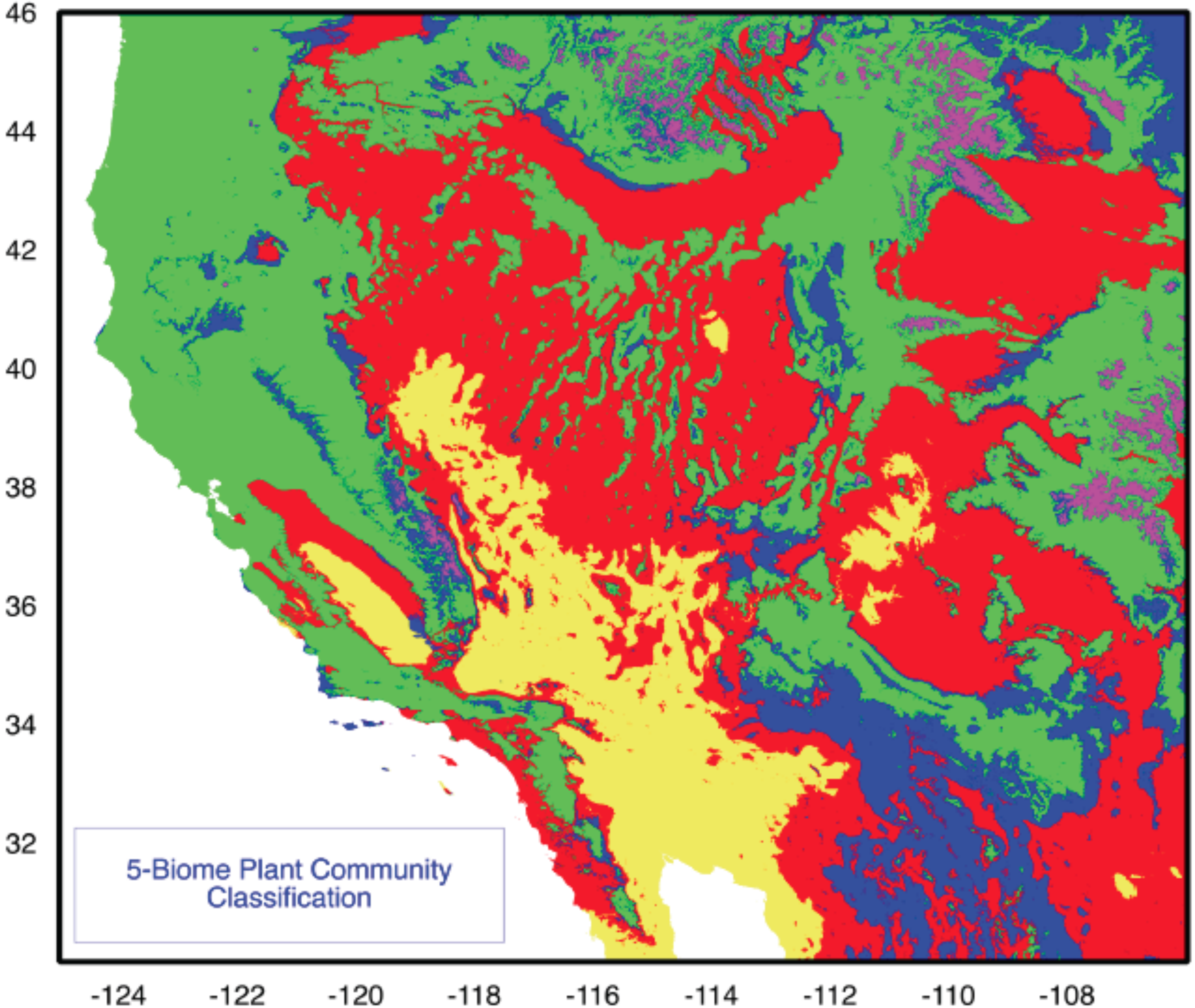
- Plant Biomass and winter precipitation

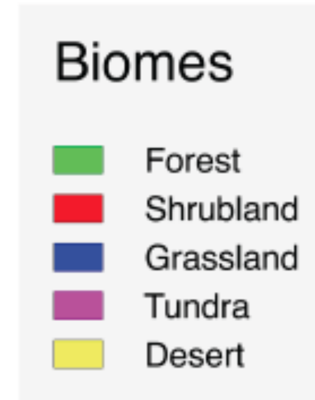


Medica et al. 2012

- Increased winter precipitation → vegetation growth for *Gopherus agassizii* (Warrick et al. 1998; Medica et al. 2012)

SW USA Study Area





Jon Bergengren

EVE: Equilibrium Vegetation Model


Bones can you save it? Let me measure its temperature with my probe.
He's dead. Dammit Jim!! I'm a Doctor, not a Miracle Worker
Quite Logical. What do you expect for a tropical forest conformer?

But at least we can study why:

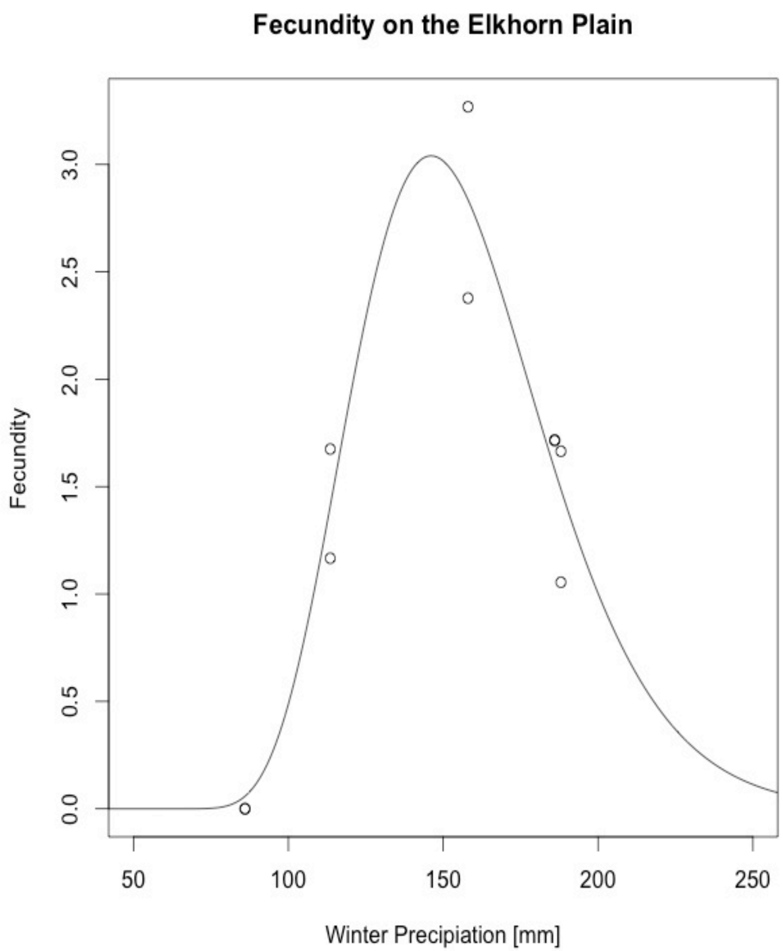
Warming is directly impacting thermal environments of reptiles

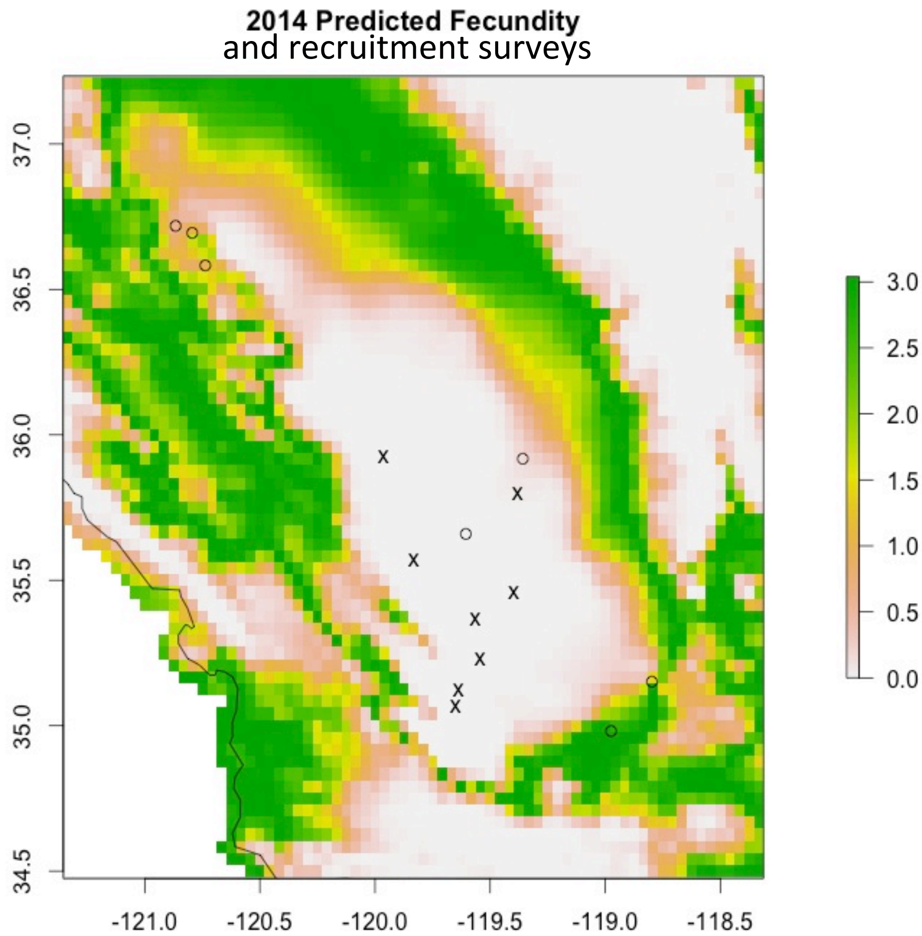
and indirectly accelerating plant diebacks, thereby accelerating reptile extinctions

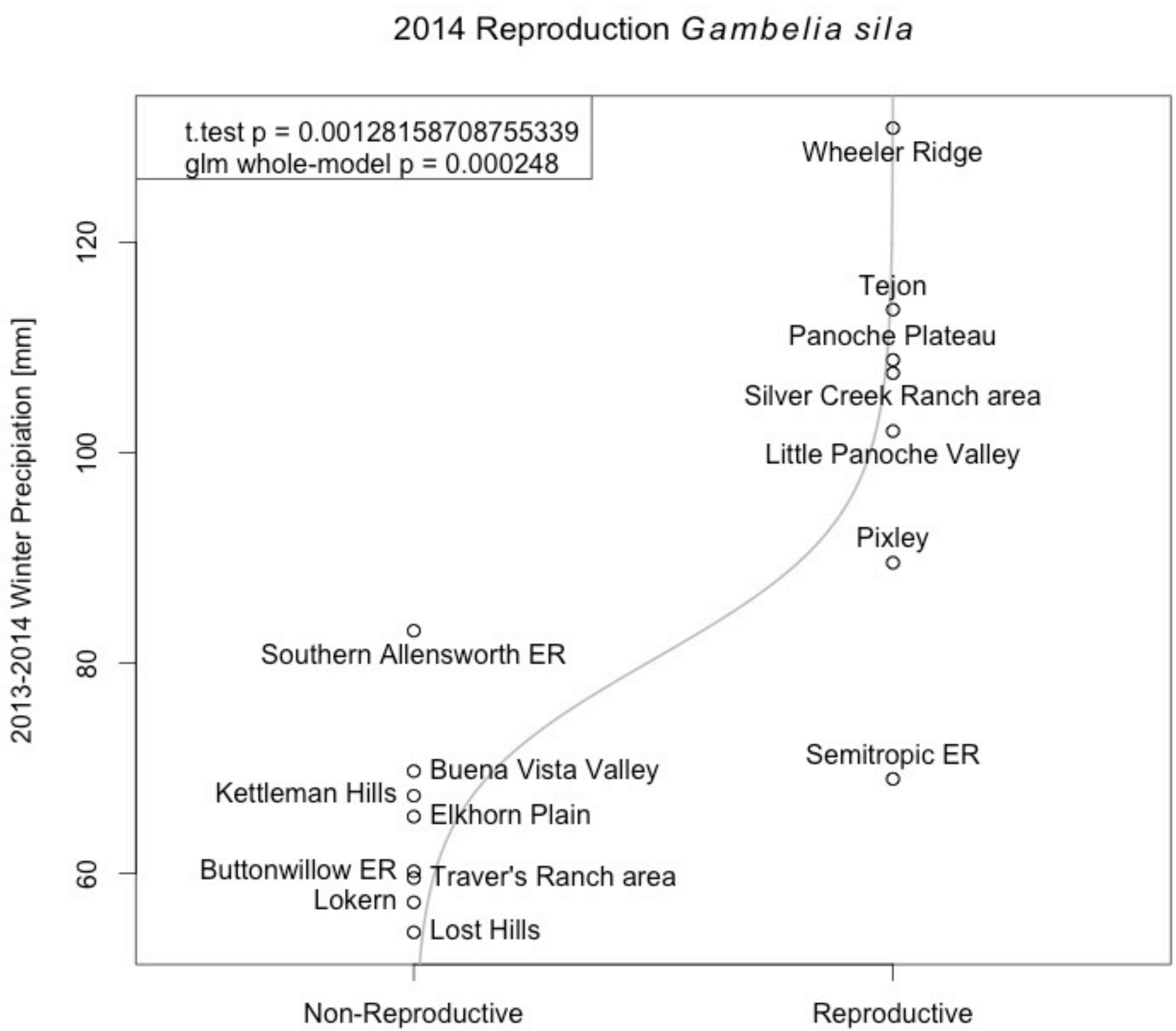
Hell Hole

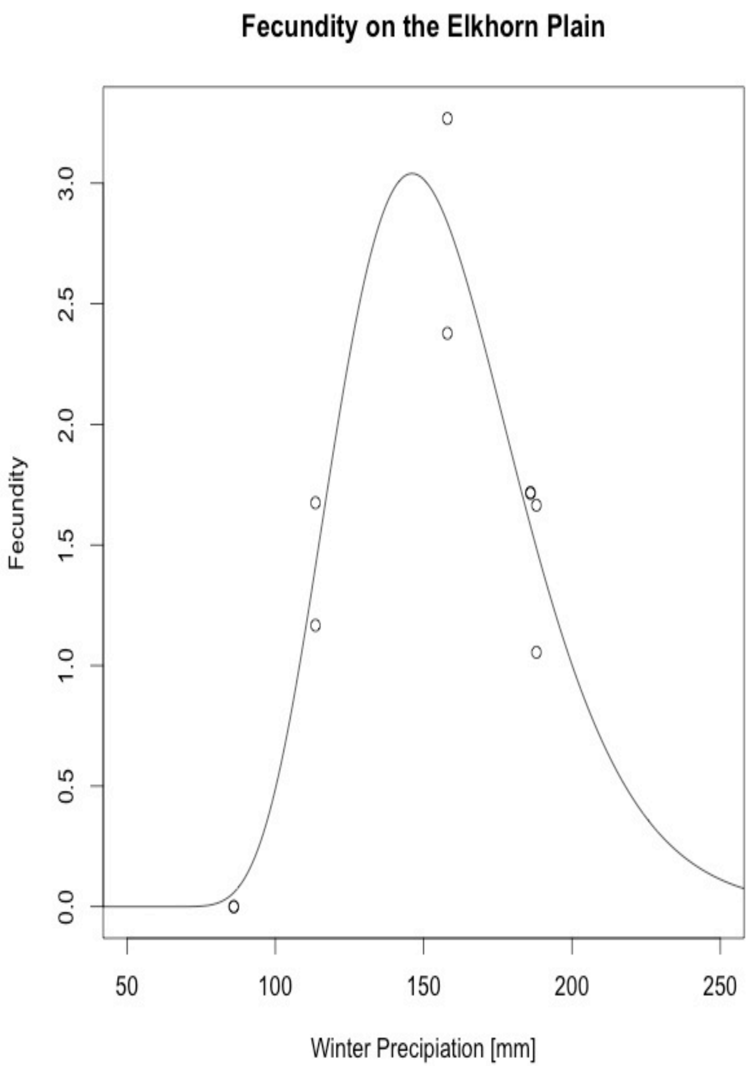
Part V. Blunt-Nosed Leopard Lizards

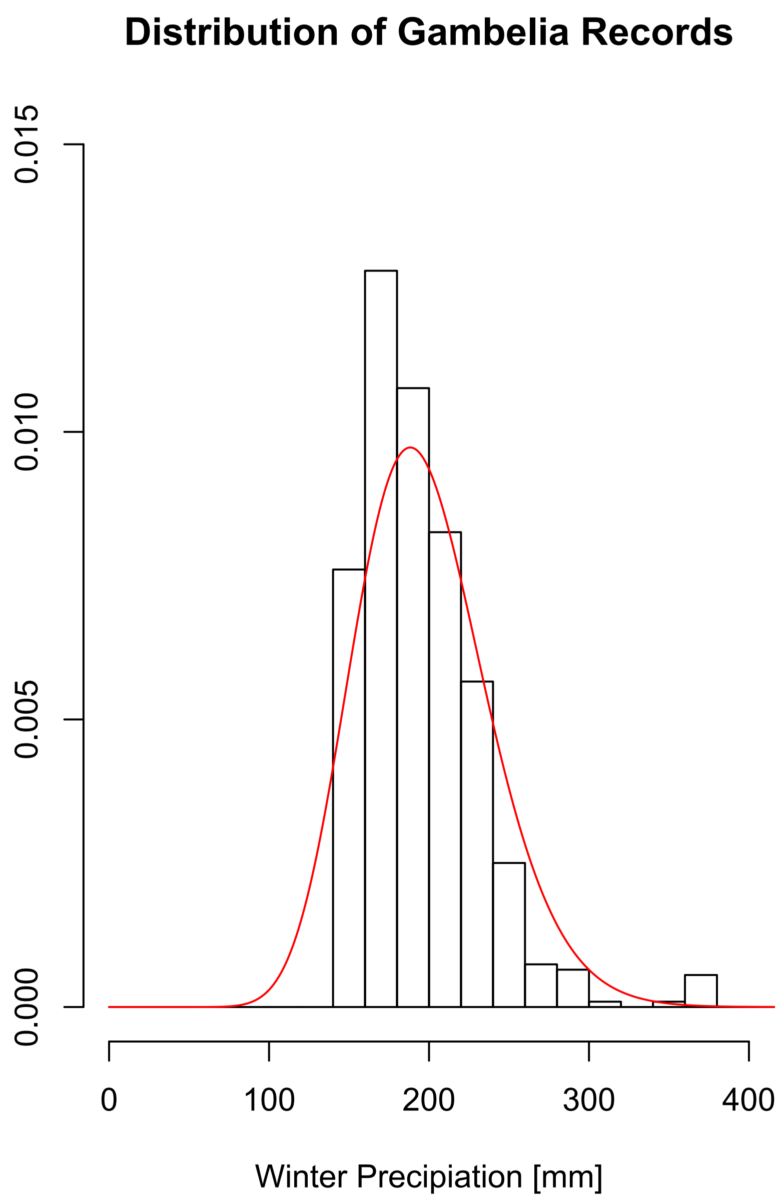
In which we use leopard lizard demography, ecology, and physiology to predict climate-mediated extinctions.


Fecundity on the Elkhorn Plain
Fecundity
0.0
0.5
1.0
1.5
2.0
2.5
3.0
50
100
150
200
250
Winter Precipiation [mm]

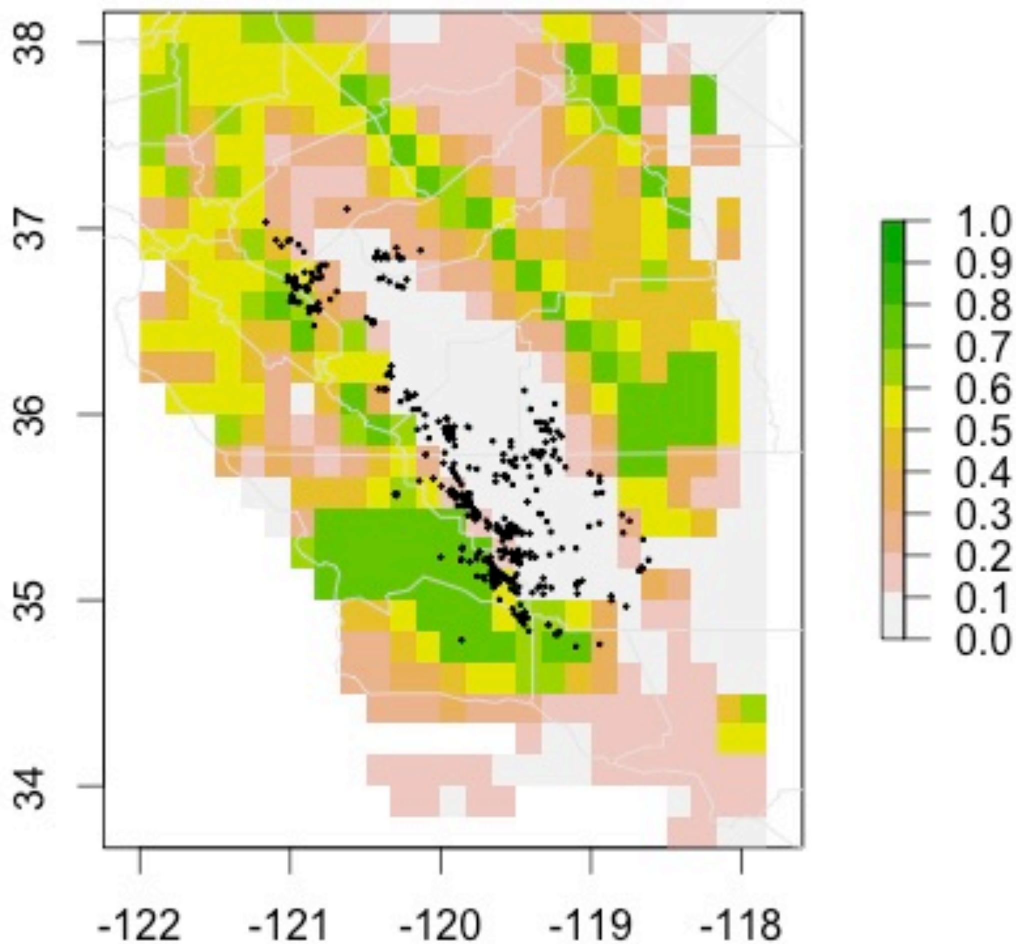

2014 Predicted Fecundity
and recruitment surveys
34.5
35.0
35.5
36.0
36.5
37.0
-121.0
-120.5
-120.0
-119.5
-119.0
-118.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0


2014 Reproduction *Gambelia sila*
t.test p = 0.00128158708755339
glm whole-model p = 0.000248
2013-2014 Winter Precipiation [mm]
120
100
80
60
Wheeler Ridge
Tejon
Panoche Plateau
Silver Creek Ranch area
Little Panoche Valley
Pixley
Southern Allensworth ER
Semitropic ER
Buena Vista Valley
Kettleman Hills
Elkhorn Plain
Buttonwillow ER
Traver's Ranch area
Lokern
Lost Hills
Non-Reproductive
Reproductive


Fecundity on the Elkhorn Plain
Fecundity
0.0
0.5
1.0
1.5
2.0
2.5
3.0
50
100
150
200
250
Winter Precipiation [mm]


Distribution of Gambelia Records
0.000
0.005
0.010
0.015
0
100
200
300
400
Winter Precipiation [mm]

Proportion of CMIP5 future climate scenarios with average BNLL fecundity > 1



Mean = 74% site loss