

A new framework for modeling rangewide threats to MDT populations: preliminary results and next steps

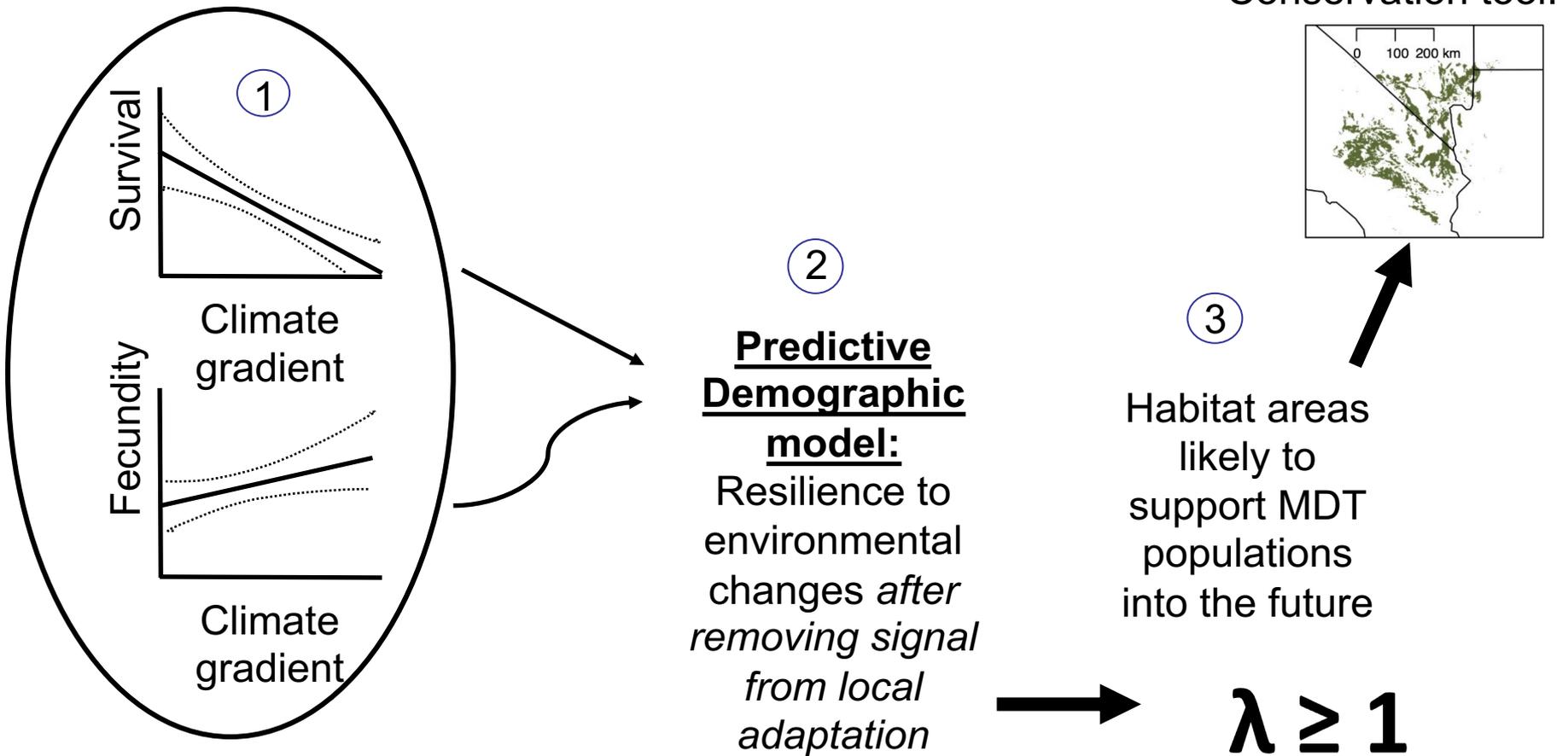
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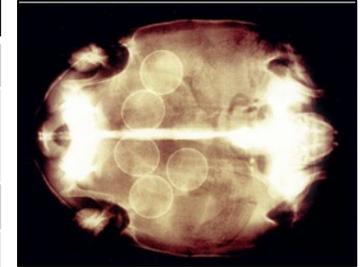
SERDP-funded research project

Objective: define the range of climate change MDT populations are capable of withstanding



Data sources

	Vital rate	Data source
Fecundity	Age & size at maturity	Diagnostic imaging, morphometrics
	Probability of reproduction	Diagnostic imaging, telemetry, published literature
	Egg production	Diagnostic imaging, telemetry
	Nest success	Published literature
	Hatching success	Nest-site monitoring
	Mean hatchling sex ratio	Nest-site monitoring, hormone assays
	Hatchling survival	Published literature
Survival	Juvenile & adult survival	Existing capture-mark-recapture and telemetry data, published literature



Site	Nests found	Nests depredated	Hatchlings processed
Bird Spring, NV (2019)	7	1	24
Boulder City, NV (2021)	2	0	4
Coyote Springs, NV (2017-2018)	23	16	32
Fort Irwin, CA (2021)	0	-	-
Large Scale Trans Site, NV (2019)	11	1	30
Trout Canyon, NV (2018)	12	2	33
TOTAL	55	19	123



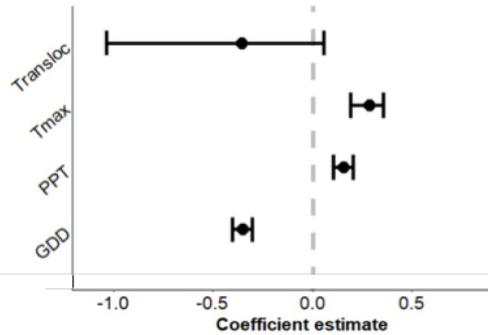
MDT climate sensitivities

	Vital rate	Desert Tortoise
Fecundity	Age, size at maturity	Temperature, precipitation
	Probability of reproduction	Temperature, precipitation
	Egg production (clutch size)	Temperature, precipitation
	Nest success	NA
	Hatching success	Temperature
	Mean hatchling sex ratio (% female)	Temperature
	Hatchling survival	NA
Survival	Juvenile survival	NA
	Adult survival	Precipitation

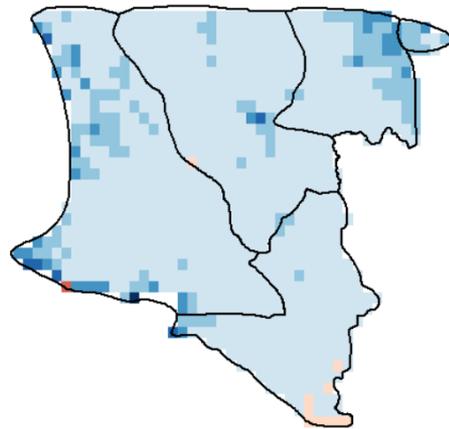
Positive, Negative

Growth, age/size at maturity

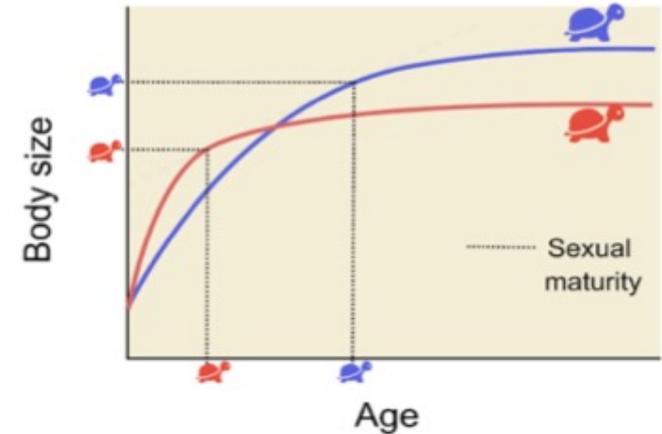
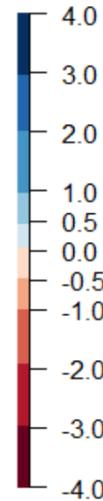
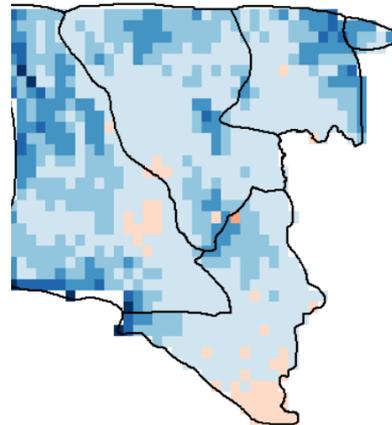
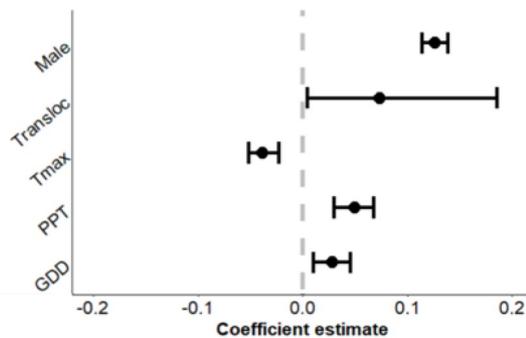
A. Growth rate k



High-risk Scenario



B. Asymptotic size a

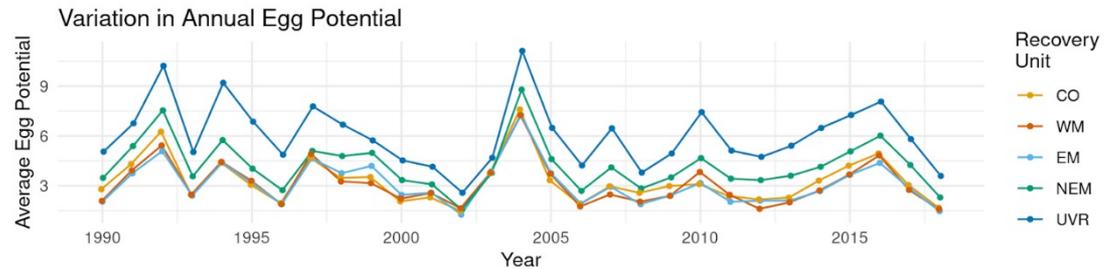
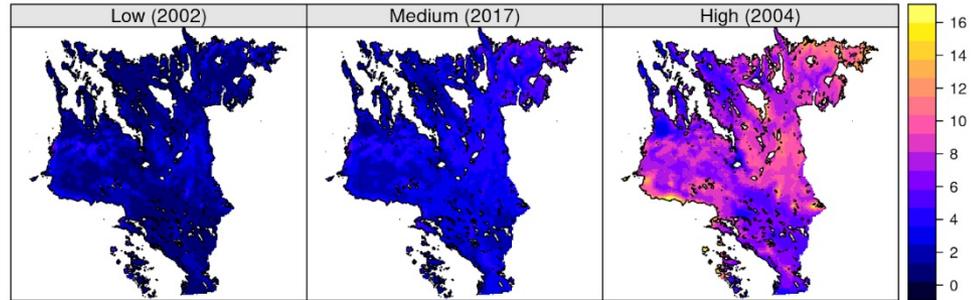
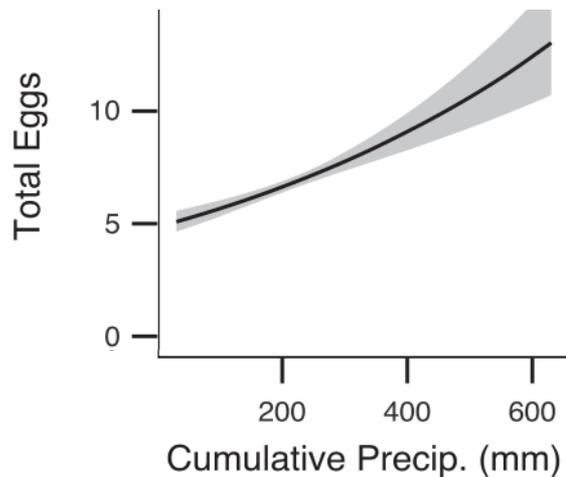
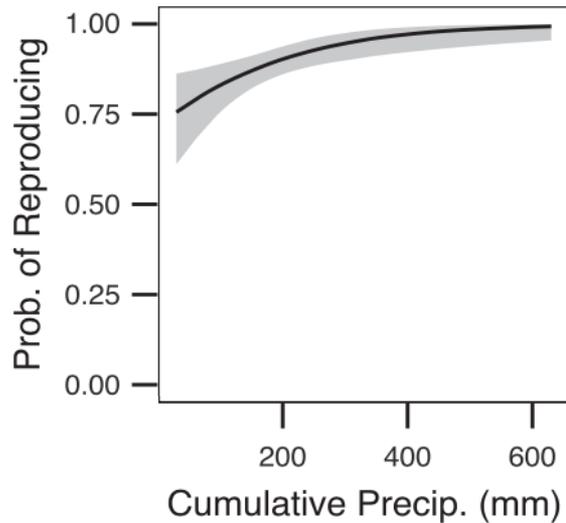


Growth influenced by temperature and precipitation

- Warmer climate could increase asymptotic size and decrease age at maturity

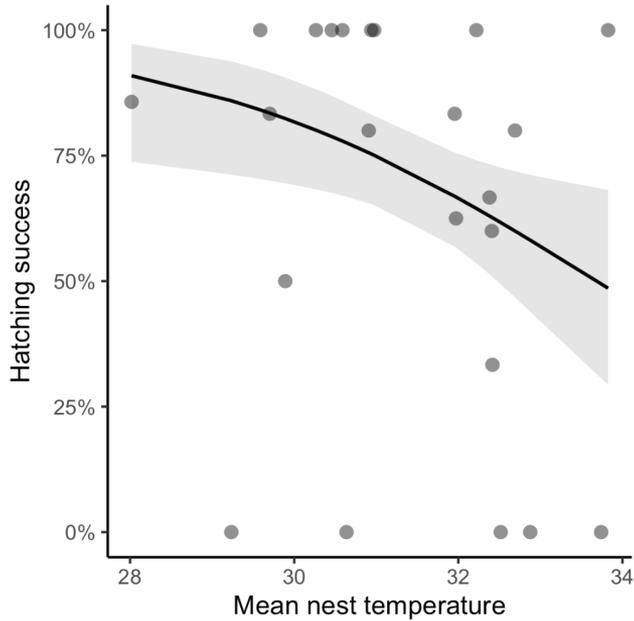
Egg production

Positive effect of prior-year precipitation -> drier futures may reduce egg production

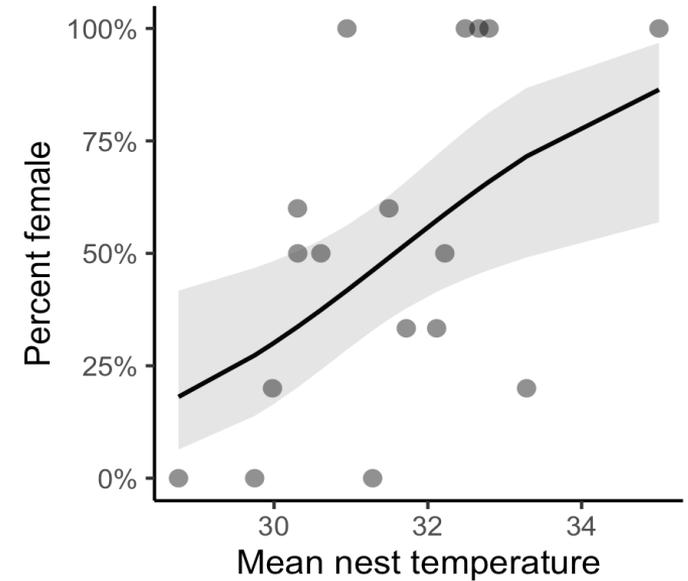


Hatching success and sex ratio

A

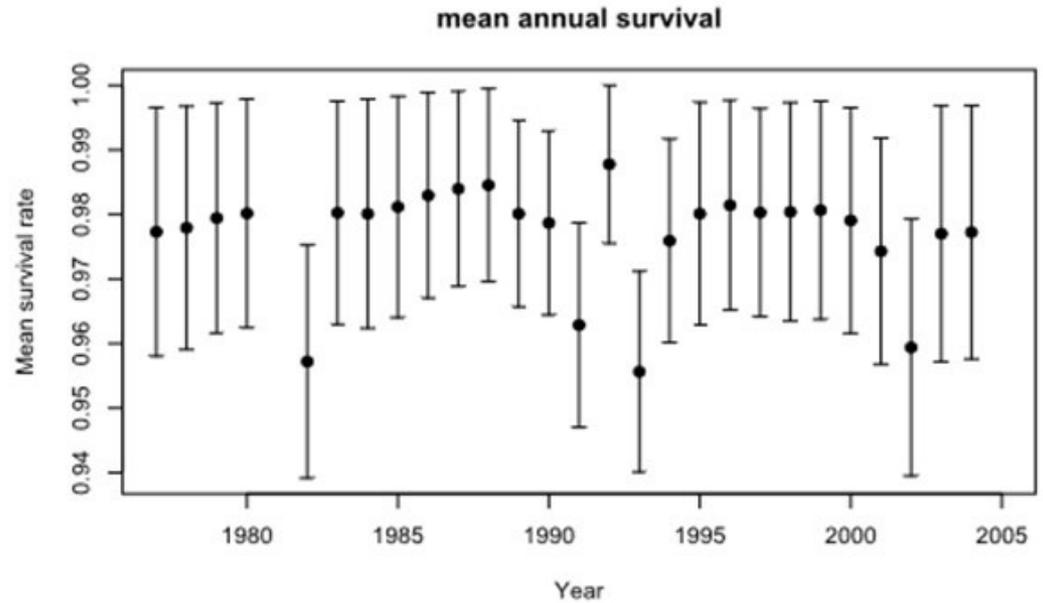
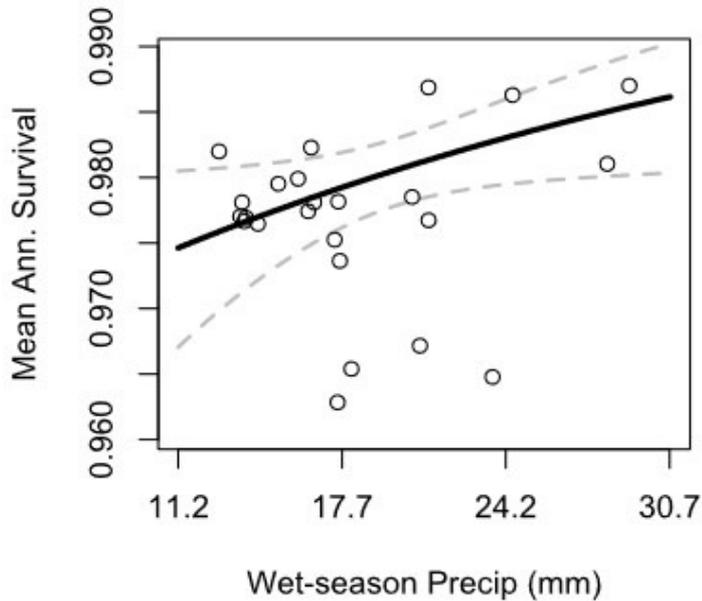


warmer nest temps. reduced hatching success



Warmer nest temps. result in female biased ratios (as expected)

Annual survival



Higher survival in wetter years/sites

Substantial among-year variation

Still refining survival models based on additional data sources (with CSP)



Population model

- With several complex and opposing effects of climate on DT vital rates, the population-level effects of climate change are not immediately clear
- Put it all together in a population model!

	Vital rate	Desert Tortoise
Fecundity	Age, size at maturity	Temperature, precipitation
	Probability of reproduction	Temperature, precipitation
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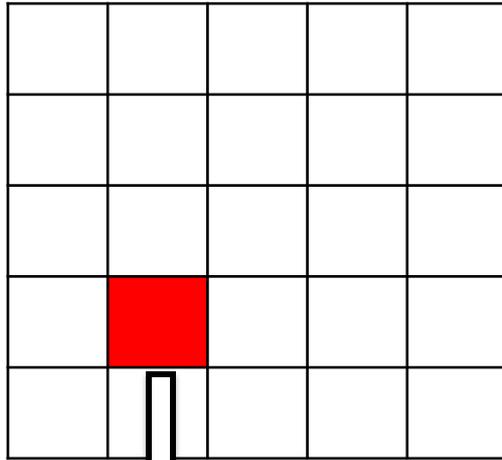
Population model

- **'Matrix generator' function**

- ◆ Generate matrix-based population model 'on the fly' in response to changing environmental conditions (using results from **Task 1**)
- ◆ Broad flexibility to accommodate different ages-at-maturity, survival rates, and reproductive output
- ◆ Parameters sampled from uncertainty distributions (e.g., Bayesian joint posterior distributions)
- ◆ Enables efficient computation of lambda for any environment

$$\begin{pmatrix} a_{11} & a_{12} & a_{13} & \cdots & a_{1n-1} & a_{1n} \\ a_{21} & a_{22} & a_{23} & \cdots & a_{2n-1} & a_{2n} \\ a_{31} & a_{32} & a_{33} & \cdots & a_{3n-1} & a_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ a_{n-1,1} & a_{n-1,2} & a_{n-1,3} & \cdots & a_{n-1,n-1} & a_{n-1,n} \\ a_{n1} & a_{n2} & a_{n3} & \cdots & a_{n,n-1} & a_{nn} \end{pmatrix}$$

Critical Habitat Breadth

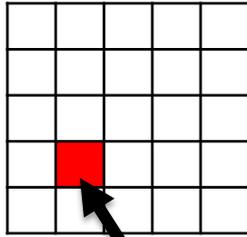


- Lattice (grid-based) population model
 - ◆ Each cell can potentially host a tortoise population
 - ◆ ‘Matrix generator’ function called for each occupied cell each year
 - ◆ Efficient computation of abundance across space and time

$$\begin{pmatrix} N_1^{(t+1)} \\ N_2^{(t+1)} \\ N_3^{(t+1)} \\ \vdots \\ N_{19}^{(t+1)} \\ N_{20}^{(t+1)} \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & a_{13} & \cdots & a_{1n-1} & a_{1n} \\ a_{21} & a_{22} & a_{23} & \cdots & a_{2n-1} & a_{2n} \\ a_{31} & a_{32} & a_{33} & \cdots & a_{3n-1} & a_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ a_{n-1,1} & a_{n-1,2} & a_{n-1,3} & \cdots & a_{n-1,n-1} & a_{n-1,n} \\ a_{n1} & a_{n2} & a_{n3} & \cdots & a_{n,n-1} & a_{nn} \end{pmatrix} \begin{pmatrix} N_1^{(t)} \\ N_2^{(t)} \\ N_3^{(t)} \\ \vdots \\ N_{19}^{(t)} \\ N_{20}^{(t)} \end{pmatrix}$$

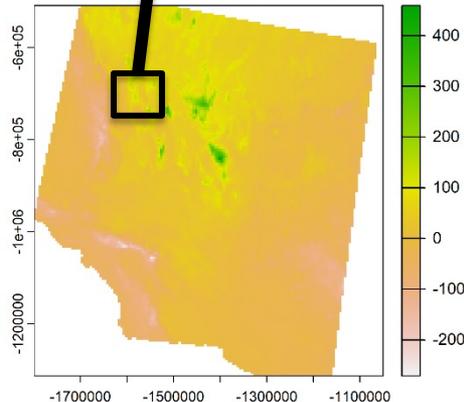
Critical Habitat Breadth

- Lattice (grid-based) model
 - ◆ Facilitate integration with geographic raster data
 - Climate data
 - Habitat suitability data
 - R package 'terra' enables efficient grid based computations

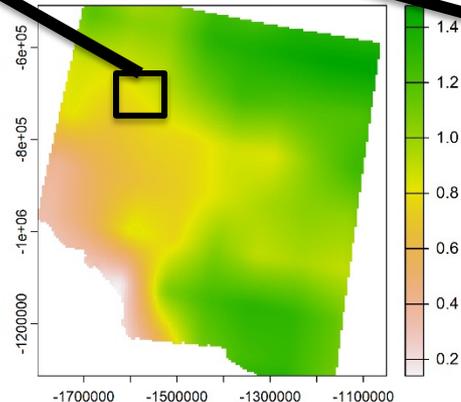


$$\begin{pmatrix} N_1^{(t+1)} \\ N_2^{(t+1)} \\ N_3^{(t+1)} \\ \vdots \\ N_{19}^{(t+1)} \\ N_{20}^{(t+1)} \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & a_{13} & \cdots & a_{1n-1} & a_{1n} \\ a_{21} & a_{22} & a_{23} & \cdots & a_{2n-1} & a_{2n} \\ a_{31} & a_{32} & a_{33} & \cdots & a_{3n-1} & a_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ a_{n-1,1} & a_{n-1,2} & a_{n-1,3} & \cdots & a_{n-1,n-1} & a_{n-1,n} \\ a_{n1} & a_{n2} & a_{n3} & \cdots & a_{n,n-1} & a_{nn} \end{pmatrix} \begin{pmatrix} N_1^{(t)} \\ N_2^{(t)} \\ N_3^{(t)} \\ \vdots \\ N_{19}^{(t)} \\ N_{20}^{(t)} \end{pmatrix}$$

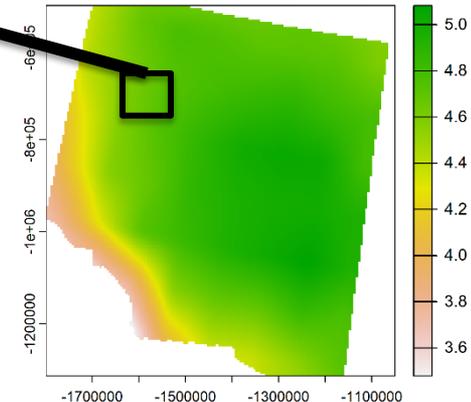
Annual precipitation dif. (mm)



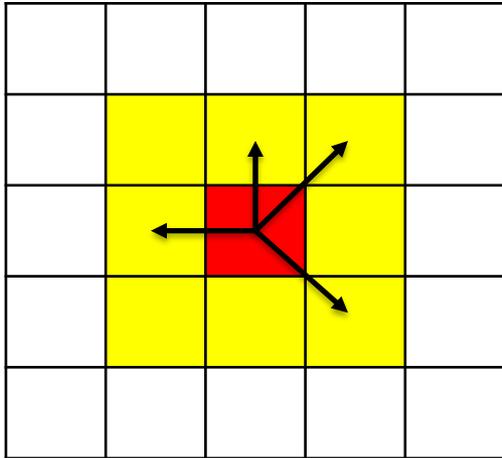
Monthly temperature anomaly (log.)



Spring mean temp range dif. (deg.)



Metapopulation model



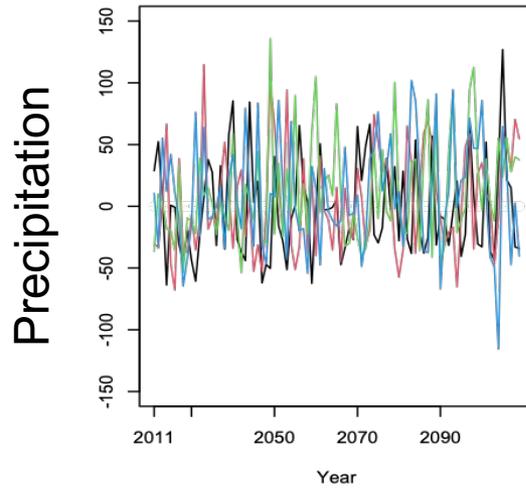
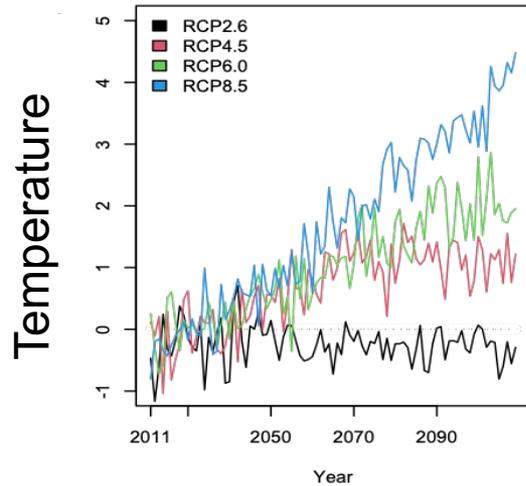
- Metapopulation dynamics
 - ◆ Negative exponential dispersal kernel
 - Currently movement is only allowed between adjacent grid cells, but movement across multiple smaller grid cells is possible
 - ◆ Greater movement rates to cells with higher suitability
 - ◆ No dispersal related mortality (but trivial to implement)
 - ◆ Stochasticity enabled (multinomial distribution)

$$w(d) = \begin{cases} \gamma \cdot \exp\left(-\frac{d}{\sigma}\right) & \text{if } d \leq d_{max} \\ 0 & \text{if } d > d_{max} \end{cases}$$

Metapopulation model

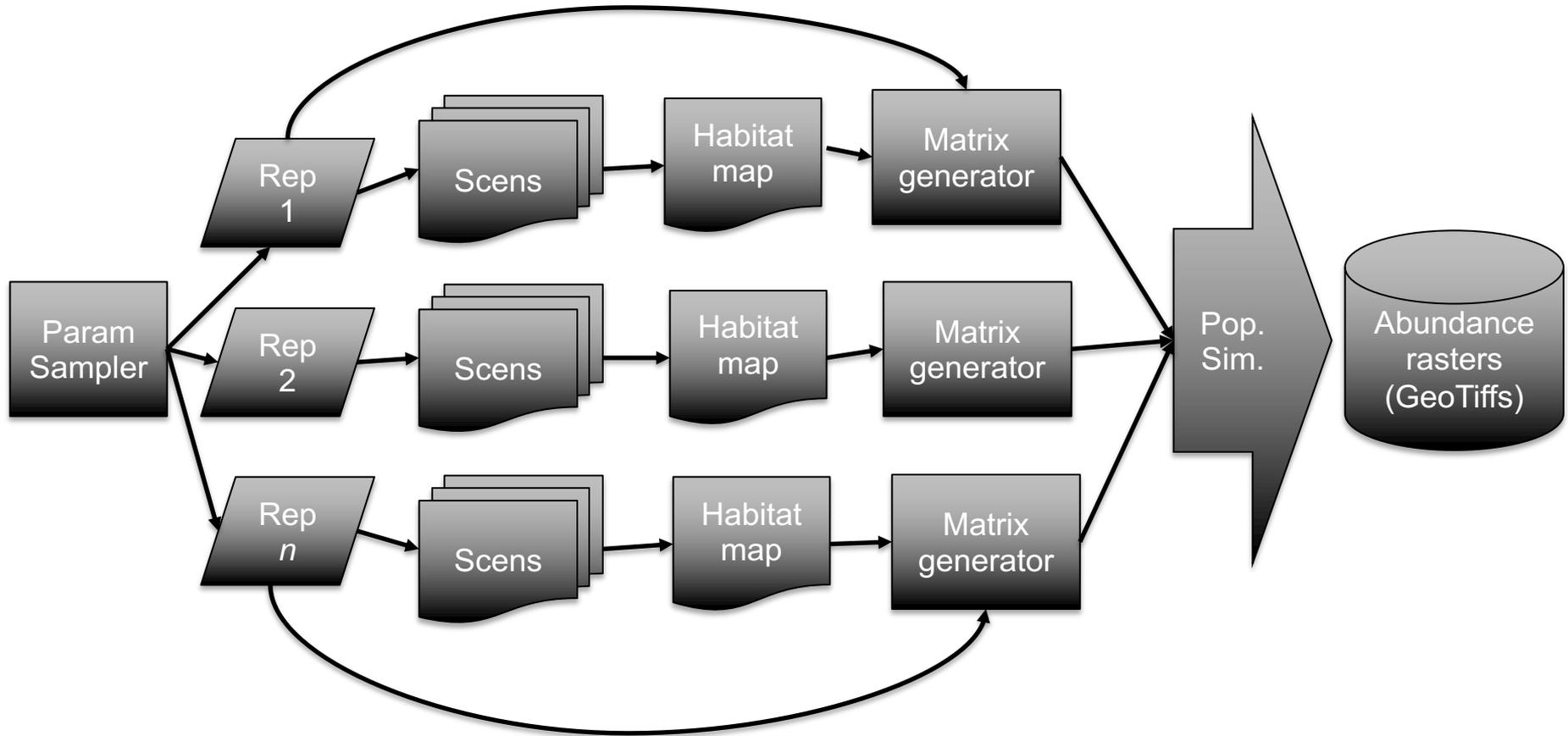
- Lattice (grid-based) model: additional features
 - ◆ Ceiling density-dependence
 - Maximum density based on habitat suitability
 - Prevents unrealistic exponential growth
 - ◆ Spatial and temporal stochastic environmental variance
 - Accommodate unexplained variance in vital rates
 - ◆ Demographic stochasticity
 - Realistic variance in births, deaths, dispersal in each grid cell
 - ◆ Coded in R
 - Code available via GitHub:
<https://github.com/kevintshoemaker/GopherusPVA>

Climate projections



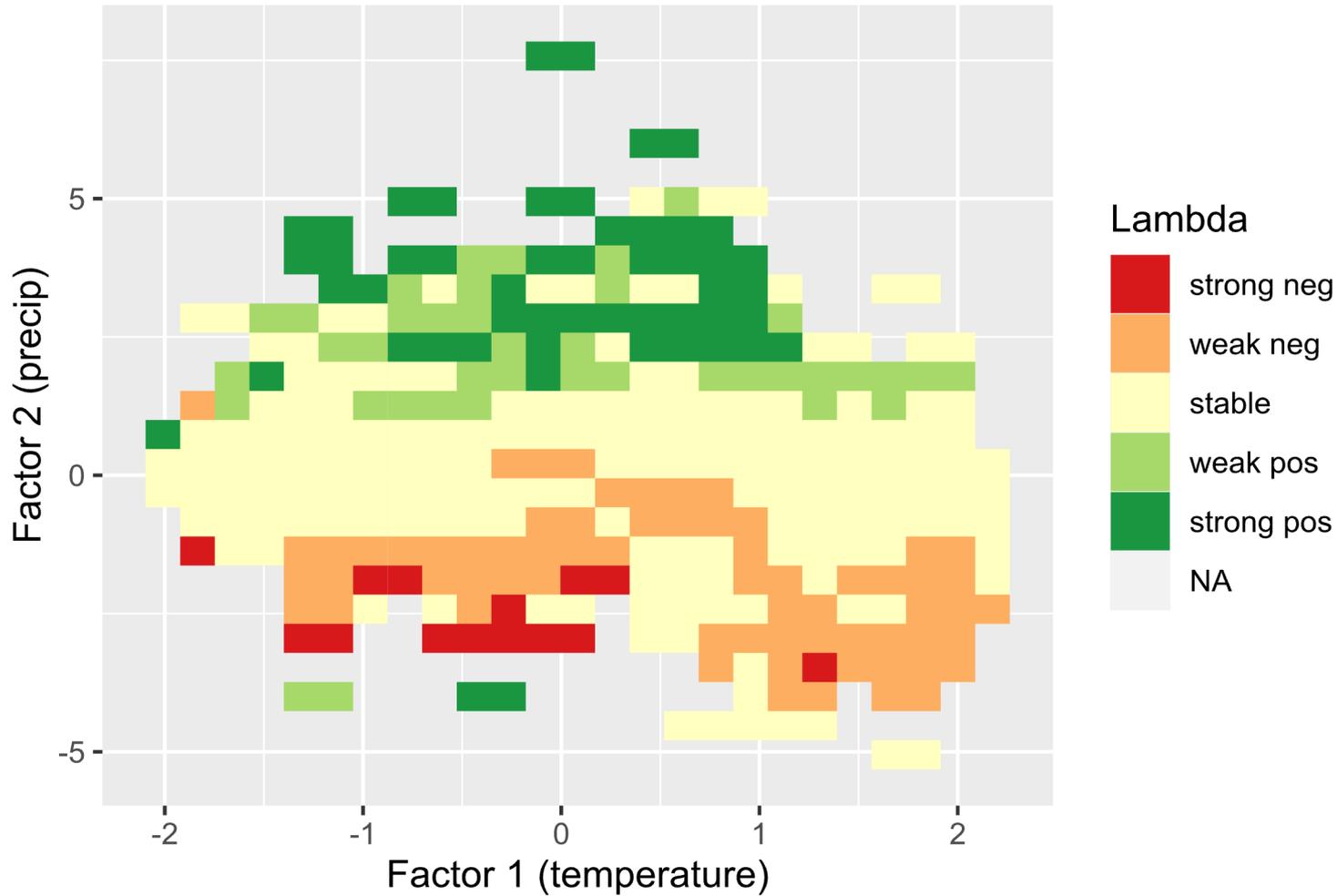
- Models varied in amount of temperature increase
- Precipitation predictions highly variable (but little trend)

Modeling workflow

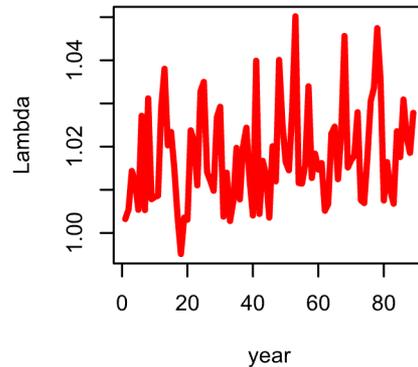
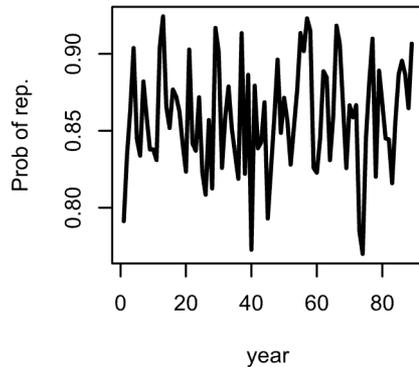
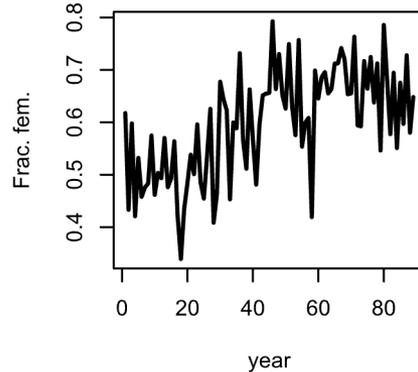
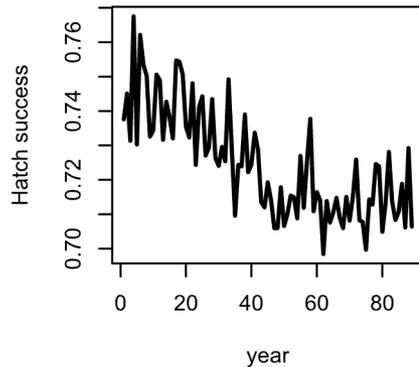
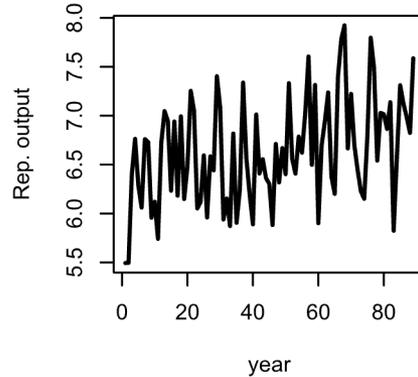
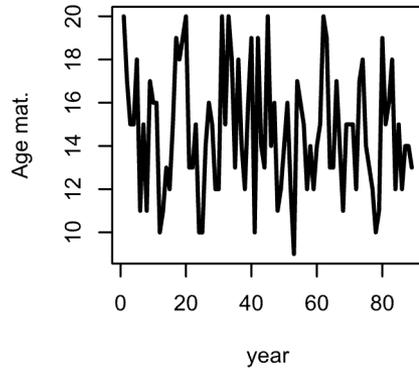


Critical Habitat Breadth

DT, rep 2, rcp85

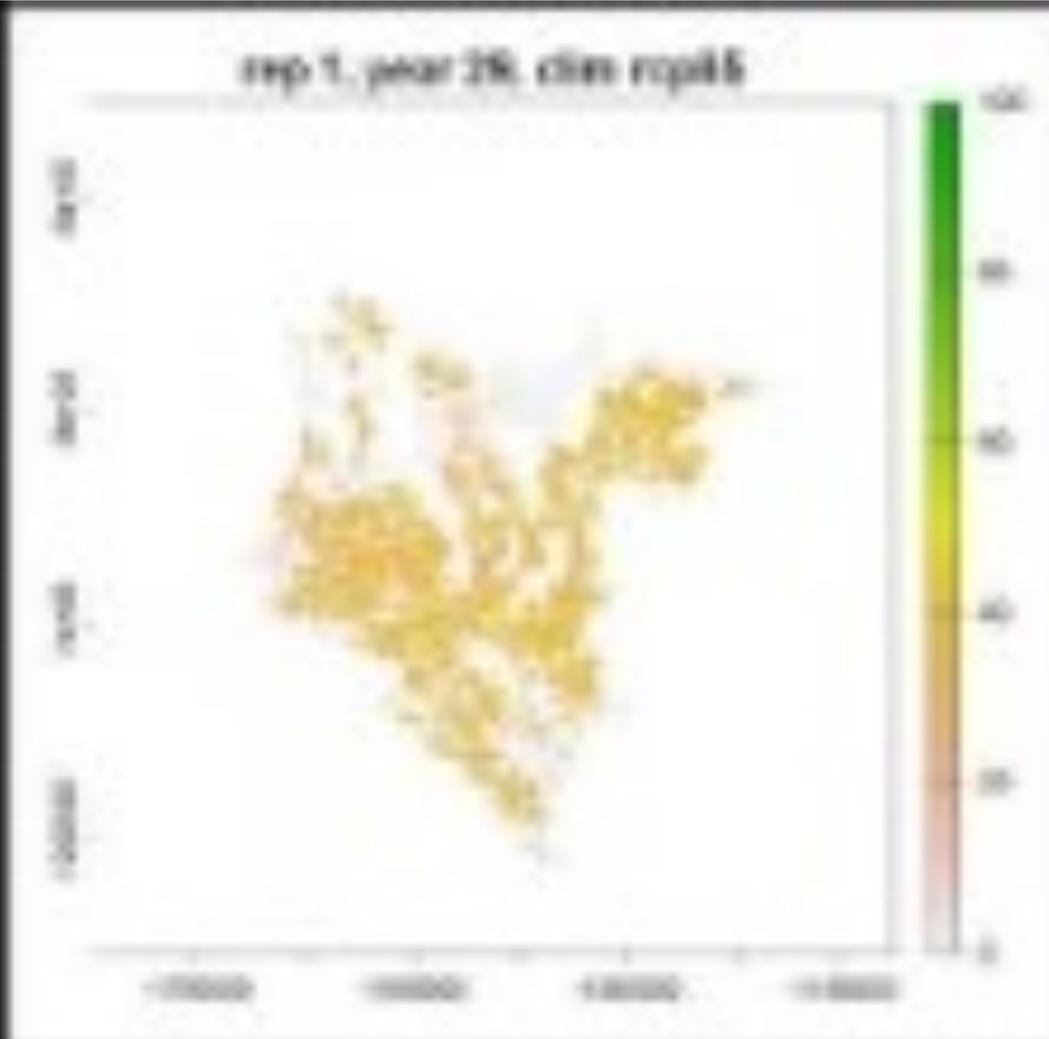


Desert Tortoise

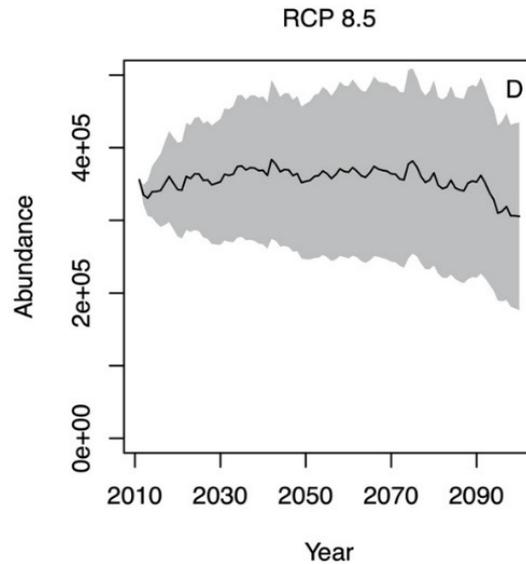
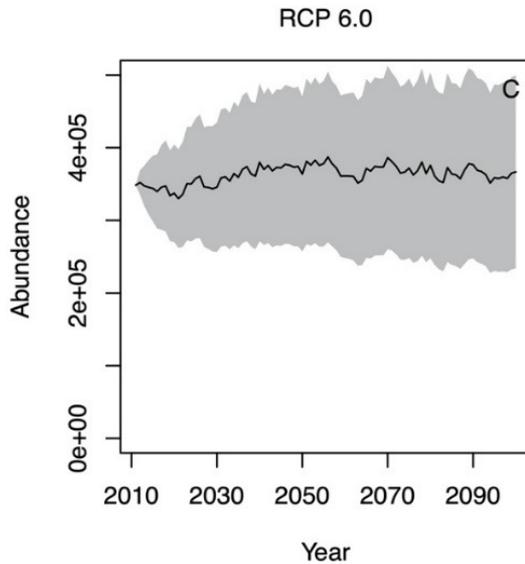
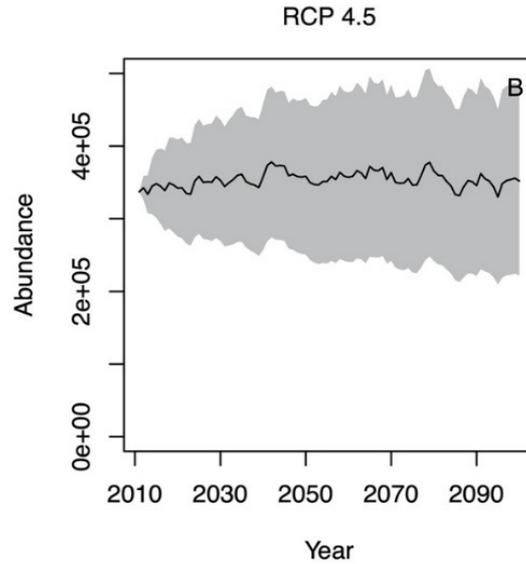
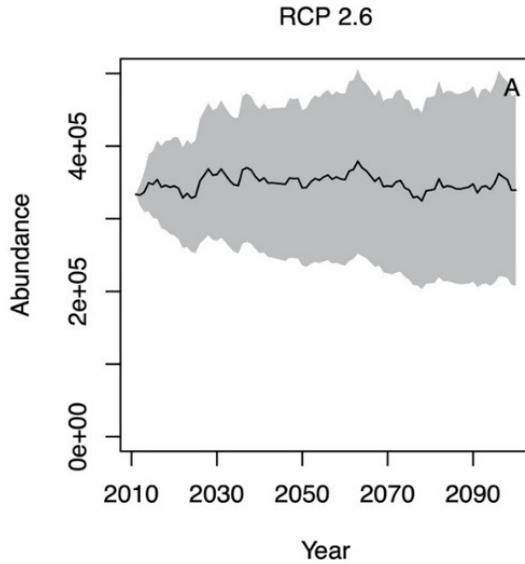


- For DT, negative effects of climate change (e.g., **reduced hatching success**) are often offset by positive effects (e.g., increased reproductive output).
- Lambda (in red) remains relatively stable across much of the range.

Metapopulation model



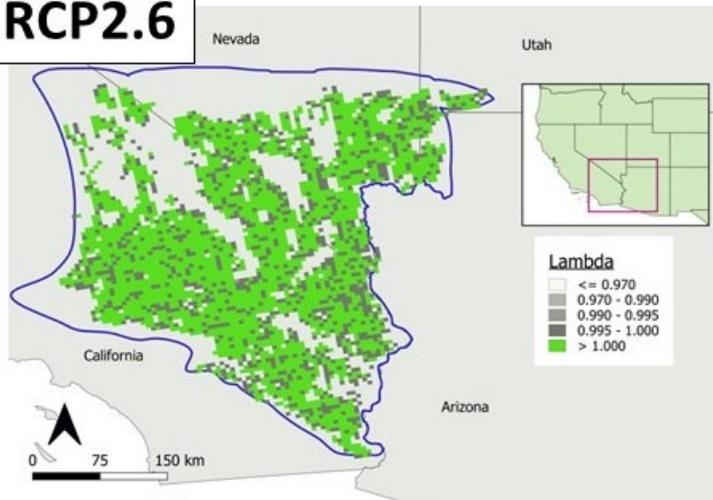
Population forecasts



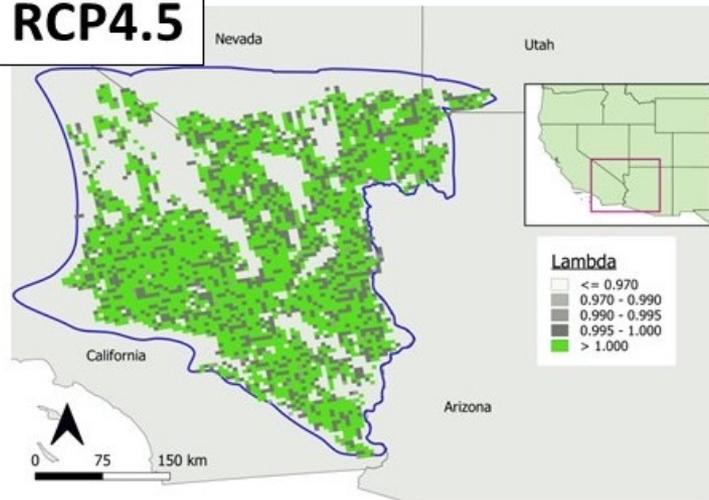
- Abundance summed across the range was relatively stable
- Emissions scenarios had little influence on final outcome

Population forecasts

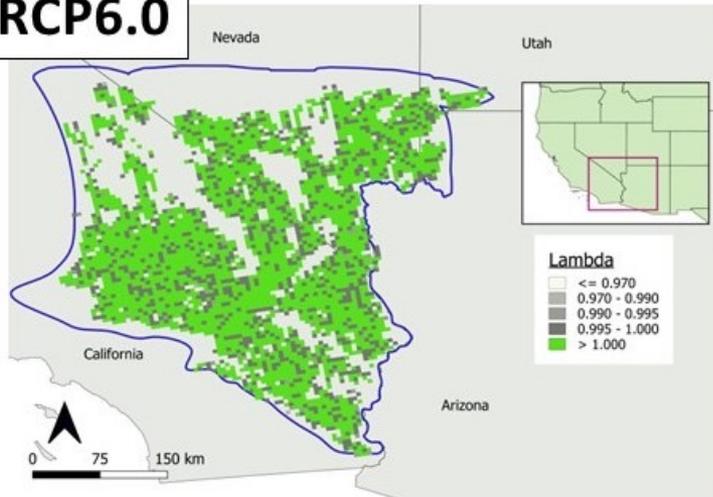
RCP2.6



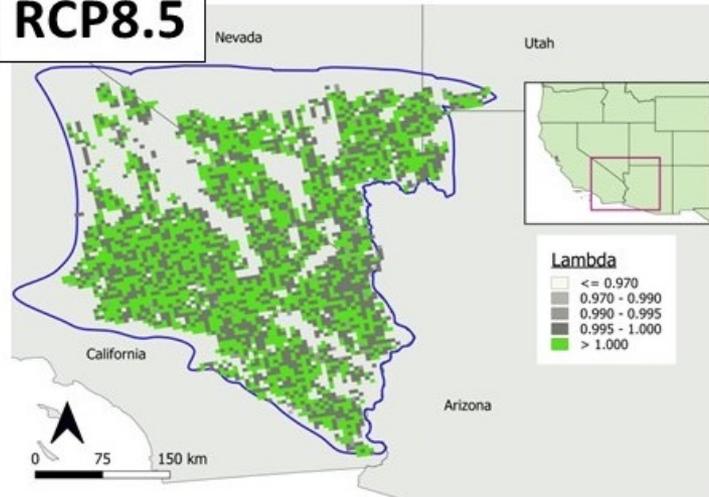
RCP4.5



RCP6.0



RCP8.5



Conservation Planning Tool

https://kevintshoemaker.shinyapps.io/Mitch-clim_v01/

MITCH-CLIM v0.1

Model-based Insights into Tortoise Critical Habitat under CLIMate change

Overview Application Figures About More Info

STEP 1: Select Scenario

Select climate effects to be activated:

- Adult survival
- Egg production
- Probability of reproduction
- Hatching success
- Sex ratio
- Somatic growth

Climate scenario

rcp2.6

Load Scenario

typical download time: 90 seconds



X Clear ROI Download Polygon

R-shiny tool:

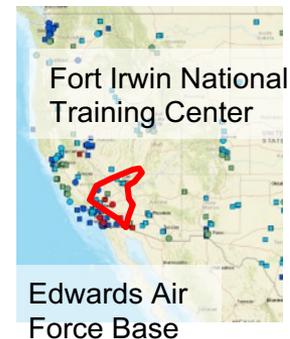
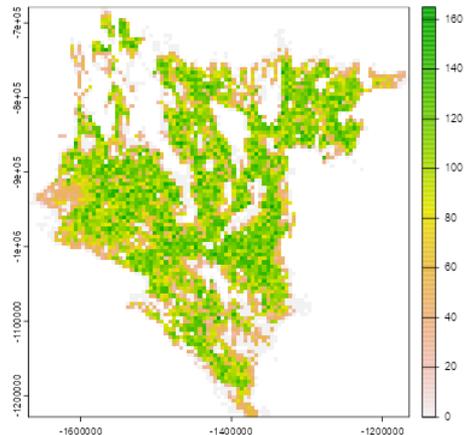
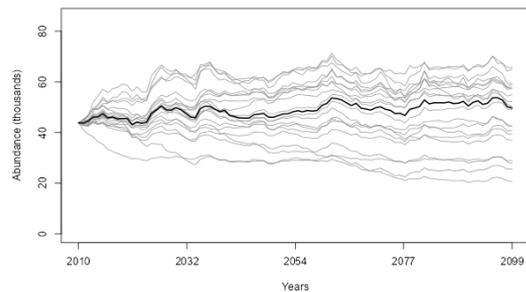
- Users can identify areas of interest (drawn or uploaded)
- Users can turn climate effects on and off.
- Visualization of climate change impacts to population viability on maps and in graphs

Outputs: ↓

Main Results:

Current Run Age Structure Comparisons Maps

Region of Interest



Next steps?

- Incorporate improved model of annual survival
- More detailed movement model (parameterized using Nussear individual-based model?)
- Incorporate additional threats?
 - ◆ Energy development, raven densities, OHV etc.
 - ◆ Straightforward to incorporate additional raster layers as covariates (fitting the models may take more time/thought!)

Questions?

SERDP-funded research project

Objective: define the range of climate change MDT populations are capable of withstanding

Focal species: Desert Tortoise, Gopher Tortoise

