Integrating Remotely Sensed Data and Ecological Models to Assess Species Extinction Risks under Climate Change

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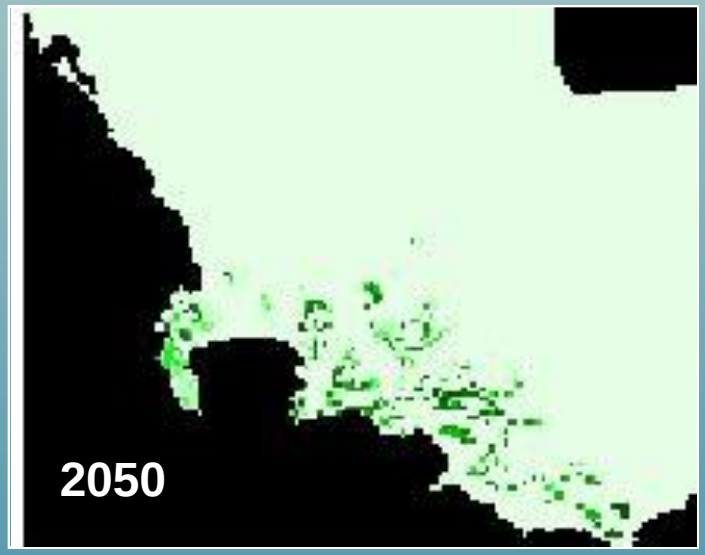
NASA

The need for demographic data to assess climate change impacts

Difficulty of inferring extinction risk from range shifts:

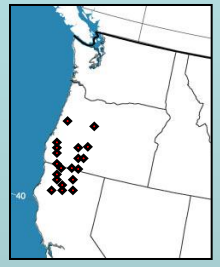
- **Dispersal limitations**
- **Reduced recolonization ability of declining species**
- **Increased fragmentation**
- **Increased fluctuations**
- **Time delays due to population growth**
- **Time delays in habitat suitability**
- **Behavioral characteristics (e.g. site fidelity)**
- **Changes in species interactions**



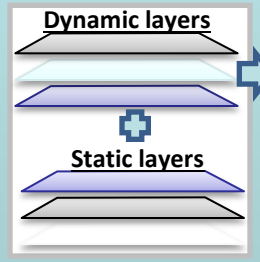
Leucadendron levisanus

Keith et al. 2008, *Biology Letters*

How: An Outline of the Approach

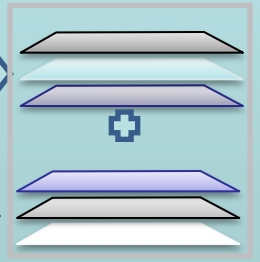


1. Current occurrences



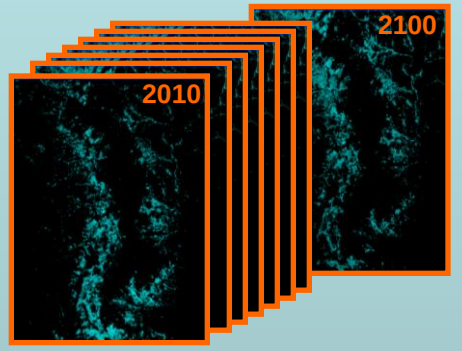
Climate model

2. Current environmental conditions

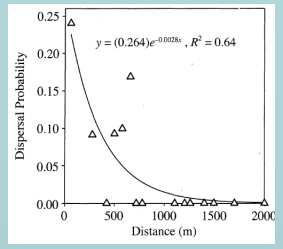


3. Projected future conditions

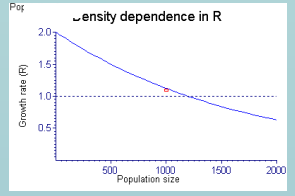
SDM



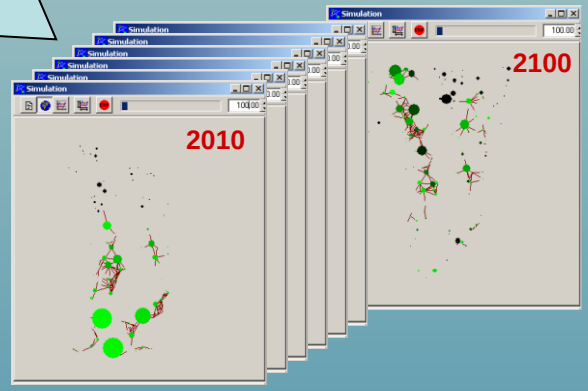
4. Future projected species habitat (time series of maps)



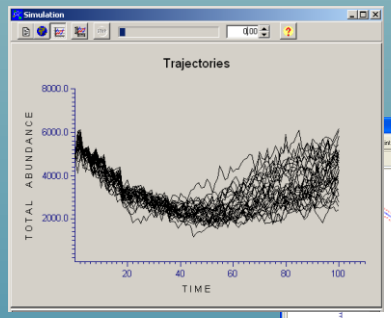
$$\begin{bmatrix} m_1S_1 & m_2S_2 & m_3S_3 & m_4S_4 \\ S_1 & 0 & 0 & 0 \\ 0 & S_2 & 0 & 0 \\ 0 & 0 & S_3 & 0 \end{bmatrix}$$

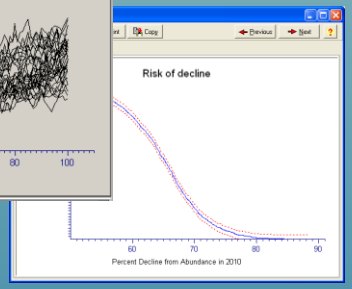


5. Demographic model

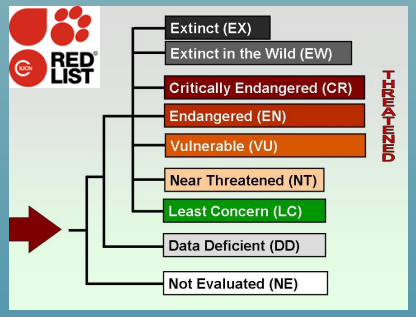


6. Metapopulation model with dynamic spatial structure





7. Extinction risk assessment



8. Synthesis across species to inform IUCN Red List process

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Application to North American Reptiles and Amphibians

1. **Increase in probability of extinction due to climate change**
2. **Factors causing increased extinction risk under climate change**

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Data & Methods: Ecological Niche Models

Species occurrence data

- 36 amphibian and reptile species, endemic to U.S.
- Variety of life histories
- Data from NatureServe

Oregon Slender Salamander

Climate data and future scenarios

- Baseline: monthly; 1971-2000 normals; 800 m, PRISM
- MAGICC/SCENGEN to emulate multiple GCMs for two emissions scenarios (IPCC 5th AR); annual maps to 2100 (see Fordham et al. 2012 *Ecography* 35:4-8)
- Generated 7 bioclimate variables relevant to physiology and life history of the species

Combining static and dynamic variables in species distribution models under climate change

Methods in Ecology and Evolution

Methods in Ecology and Evolution doi: 10.1111/j.2041-210X.2011.00157.x

Combining static and dynamic variables in species distribution models under climate change

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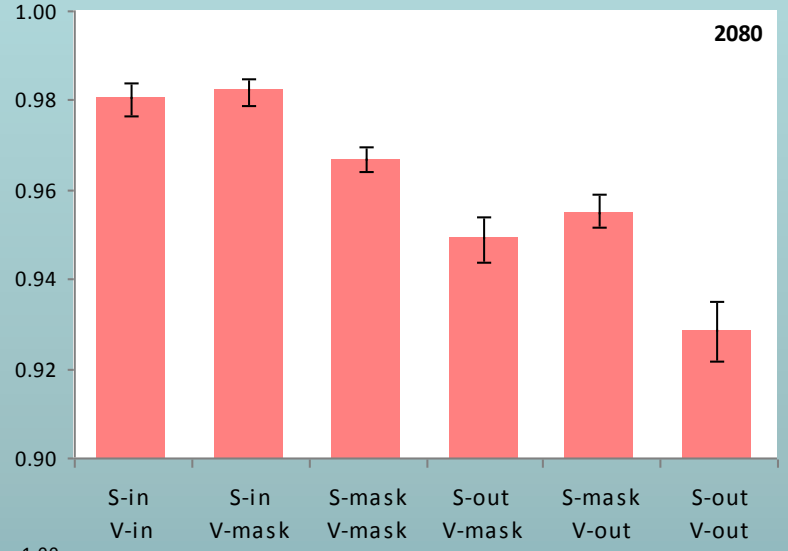
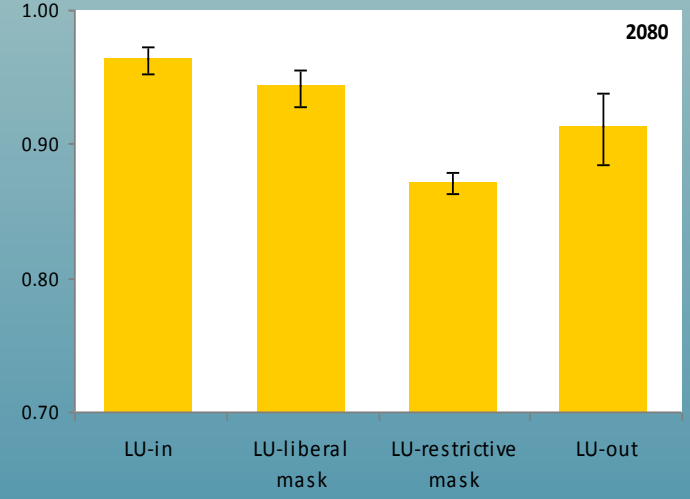
Recommendations:

- static variables highly correlated with climate variables should be **excluded,**
- static variables that interact with climate variables (e.g., soil), should be **included in the model,**
- static variables that do not interact with climate variables can be either **included in the model**, or **used as a mask,**
- dynamic non-climate variables (e.g., land use) can be either **included in the model**, or **used as a mask**, *even if future change in these variables cannot be predicted*, and thus only the current maps can be used.





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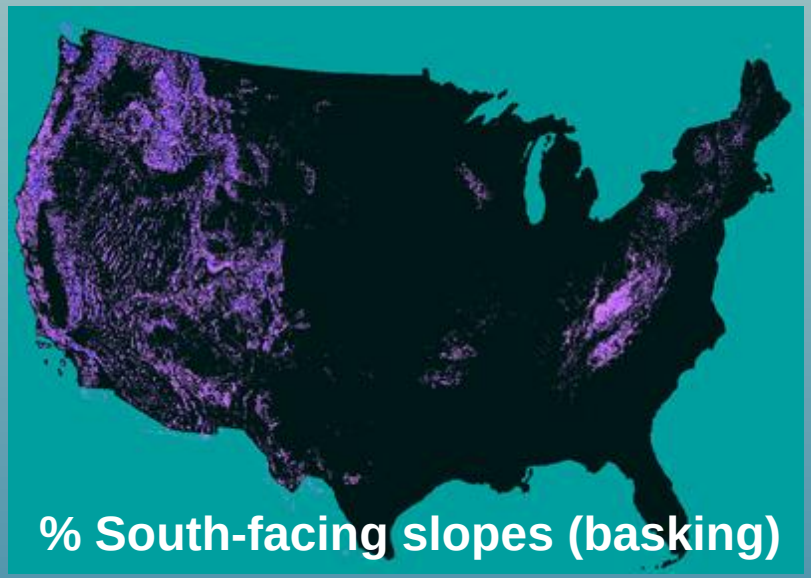
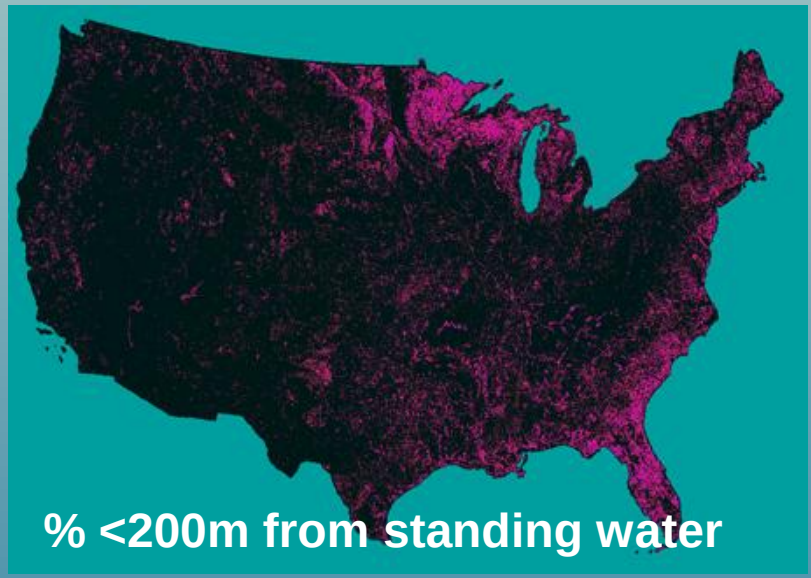
Data & Methods: Remote sensing products and other static variables

- **Land cover: National Land Cover Database.**
- **Land surface form: National Elevation Dataset**
- **Proximity to water: National Hydrography Dataset**

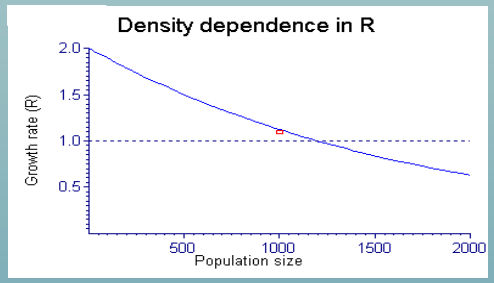


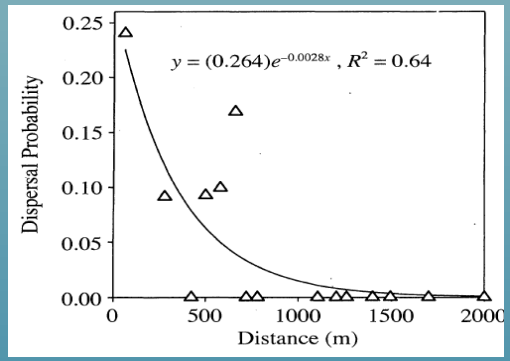


Data & Methods: Life history and population demography

- Generic models for species groups:
  - Small Salamander
  - Large Salamander
  - Tortoise
  - Turtle
  - Snake
  - Lizard
- Basic life history information:
  - Age/stage/sex structure; survival rates
  - Reproduction (age of 1st breeding; fecundity)
  - Density dependence
  - Dispersal

$$\begin{bmatrix} m_1S_1 & m_2S_2 & m_3S_3 & m_4S_4 \\ S_1 & 0 & 0 & 0 \\ 0 & S_2 & 0 & 0 \\ 0 & 0 & S_3 & 0 \end{bmatrix}$$

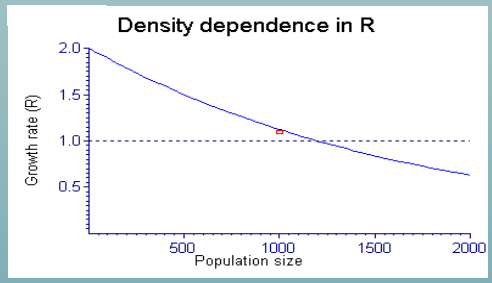


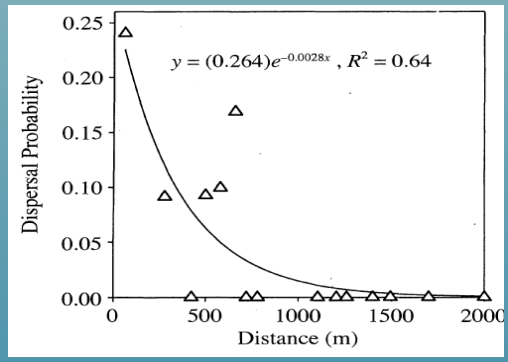


Data & Methods: Life history and population demography

- "Generic model" with a standard set of 4 to 5 parameters:
  - Growth rate (R_{max} or λ)
  - Survival rates & Fecundities
  - Temporal variability in survival & fecundity
  - Dispersal
  - Spatial correlation
- Range (min & max) for each parameter
- Sampled random models with Latin hypercube (10 per dimension)
- Combine with habitat maps; run simulations; estimate viability

$$\begin{bmatrix} m_1S_1 & m_2S_2 & m_3S_3 & m_4S_4 \\ S_1 & 0 & 0 & 0 \\ 0 & S_2 & 0 & 0 \\ 0 & 0 & S_3 & 0 \end{bmatrix}$$





Simulations

Nested computations:

Species (36 species, with species-specific spatial structures)
- Life history types (6 types; 2 used for each species)
  - Scenarios (3 scenarios: No climate change; Reference; Policy)
    - Demographic Models (40-50 selected from the parameter space)

Summary for ~10,000 models

- Replications (1,000 iterations to model stochasticity and estimate risks)
  - Time steps (110 time steps from 1990 to 2100)

Total of ~1.1 Billion time steps simulated!

Preliminary Results:
Extinction Risk Under Climate Change

- **23-28% risk of extinction in 100 years under climate change**
- **Actual extinction risk (not "committed to extinction")**
- **Not an overestimate: <1 % with no CC**

Caveats

- **Species not randomly selected** (restricted range species)
- **Generic population models** (specific ENM)

Application to North American Reptiles and Amphibians

1. Increase in probability of extinction due to climate change

2. **Factors causing increased extinction risk under climate change**

Is it possible to predict which species will be at increased risk of extinction, **based only on current information?**

Response variable: Extinction Risk by 2100

Predictor variables: (76 total; 21 used)

Demographic/Life History

- Population size
- Growth rate
- Vital rate variability
- Generation length
- Dispersal ability
- Niche breadth: temperature
- Niche breadth: precipitation

Spatial

- Occupied area (AOO)
- Spatial correlation
- Number of subpopulations
- Connectivity
- Fragmentation
- Fractal dimension*
- Largest patch fraction*

Trends

- Trend in AOO
- Trend in population size
- Trend in number of subpopulations
- Trend in fractal dimension
- Trend in connectivity
- Trend in fragmentation
- Trend in largest patch fraction

Highlights

The first study to…

- show high extinction risk due to climate change (based on actual extinction risk)
- demonstrate that extinction risk due to climate change can be predicted with present-day data
- identify demographic and spatial variables that determine extinction risk due to climate change

Also…

- novel new approach (GLH modeling)
- results that are relevant to conservation

Next Steps

- Develop a prediction tool
- Contribute to IUCN red-listing guidelines
- Incorporate species interactions
- Explore assisted migration strategies