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

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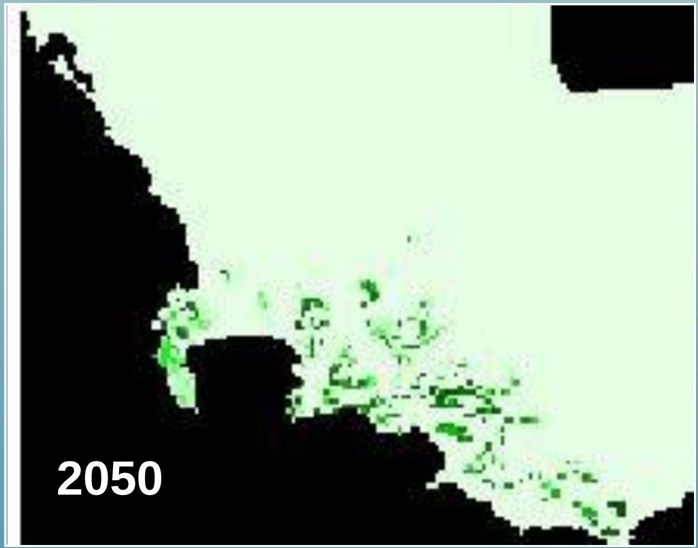
The need for demographic data to assess climate change impacts

Difficulty of inferring extinction risk from range shifts:

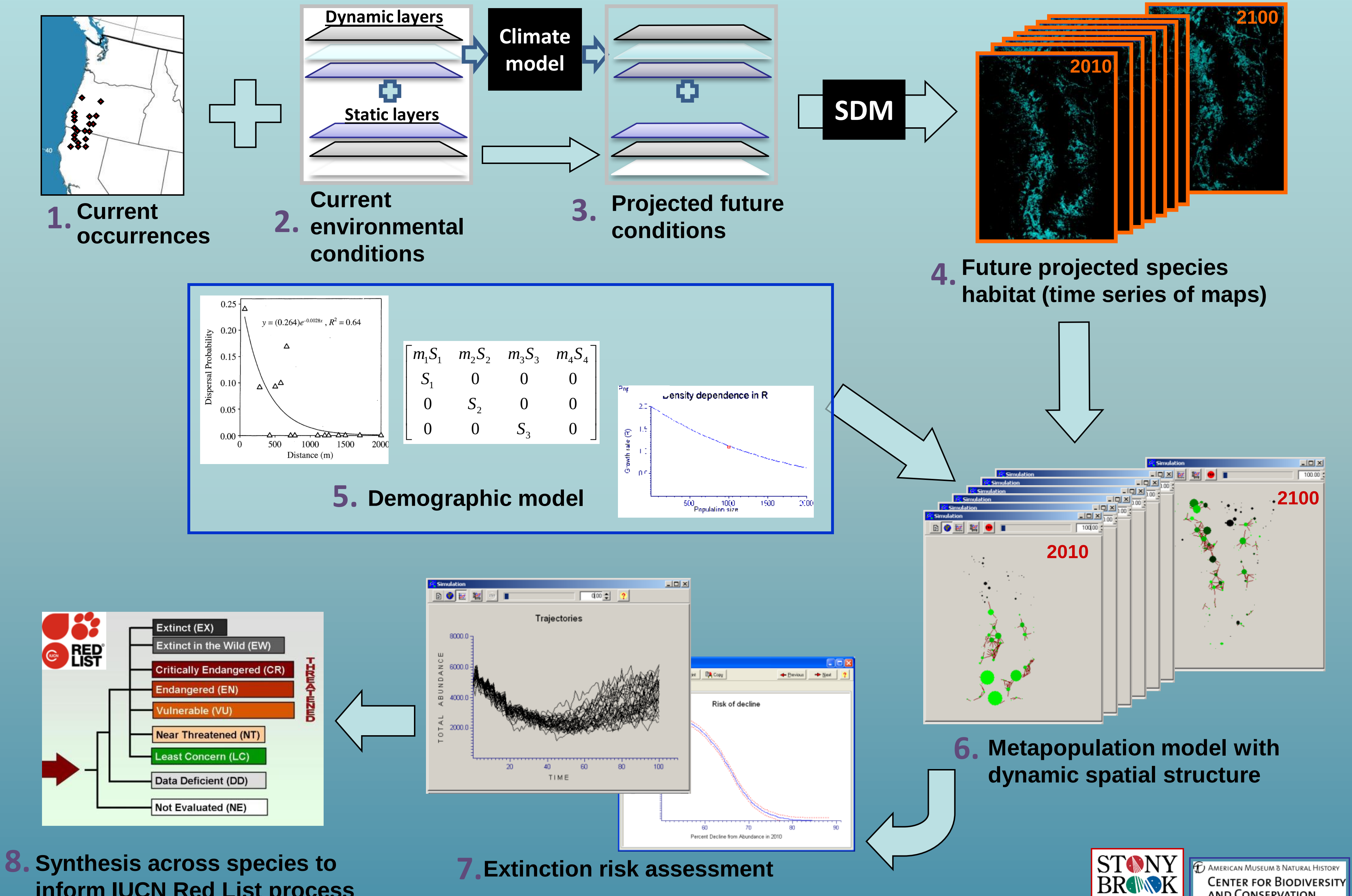
- **Dispersal limitations**
- **Reduced recolonization ability of declining species**
- **Increased fragmentation**
- **Increased fluctuations**
- **Time delays due to population growth**
- **Time delays in habitat suitability**
- **Behavioral characteristics (e.g. site fidelity)**
- **Changes in species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



Leucadendron levisanus

Keith et al. 2008, *Biology Letters*

How: An Outline of the Approach



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

STONY BROOK UNIVERSITY

American Museum of Natural History Center for Biodiversity and Conservation Biodiversity Informatics Facility

Application to North American Reptiles and Amphibians

1. How much will climate change increase the probability of extinction?
2. Is it possible to predict extinction due to climate change using present-day information?
3. How long a warning would we have if we continue using current assessment methods?

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

https://cds.nccs.nasa.gov/bioclim/

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BioClim – Fine-Scale Climate Scenarios with Annual Time Steps, 2010-2100, for the Contiguous United States

This dataset comprises two climate scenarios for the contiguous United States at a resolution of ~800m x 800m, with annual time slices from 2010 to 2100. Data include nineteen bioclimatic variables that are commonly used in ecological analyses. The data were first used in the following manuscript, where they are described in full:

- Pearson, R.G., Stanton. J.C., Shoemaker, K.T., Aiello-Lammens, M.E., Ersts, P.J., Horning, N., Fordham, D.A., Raxworthy, C.J., Ryu, H.Y., McNees, J., & Akçakaya, H.R. Life history and spatial traits predict extinction risk due to climate change.

As described in Supplementary Material to the above paper: The procedure for generating an annual time series of climate variables comprised three steps: First, (MAGICC/SCENGEN 5.3), a coupled gas cycle/aerosol/climate model used in the IPCC Fourth Assessment Report[1], was used to generate an annual time series of future climate anomalies (2010 – 2100) using an ensemble of five atmosphere-ocean general circulation models (GCMs). Fordham et al.[2] have highlighted the advantages of working within the MAGICC/SCENGEN framework, rather than using GCM data from the Coupled Model Intercomparison Project 3 (CMIP3) archive. We used two strongly contrasting greenhouse gas emission scenarios: a Reference scenario that assumes high CO_2 concentration (WRE750;[3]) and a Policy scenario that assumes CO_2 stabilization at about 450 ppm (MiniCAM LEV1;[4]). GCMs were chosen according to their superior skill in reproducing seasonal precipitation and temperature across North America. Model performance was assessed following already

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

Jessica C. Stanton[1], Richard G. Pearson[2,3], Ned Horning[2], Peter Ersts[2] and H. Reşit Akçakaya[1]*

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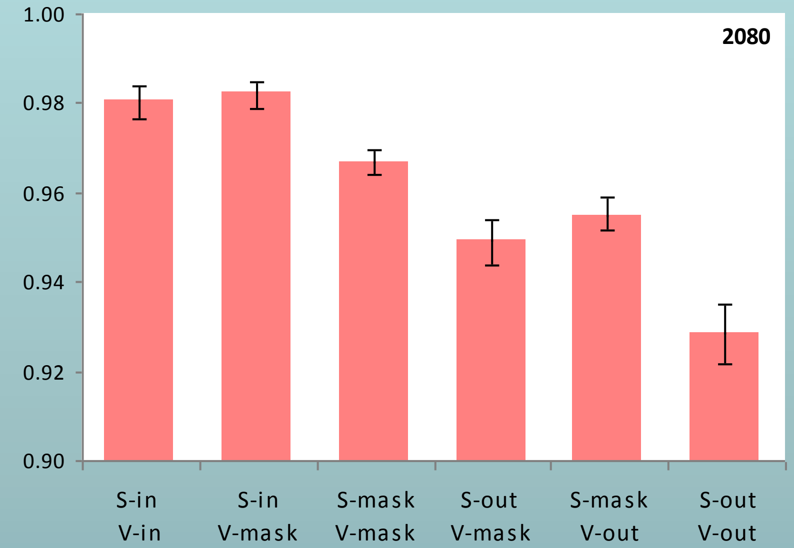
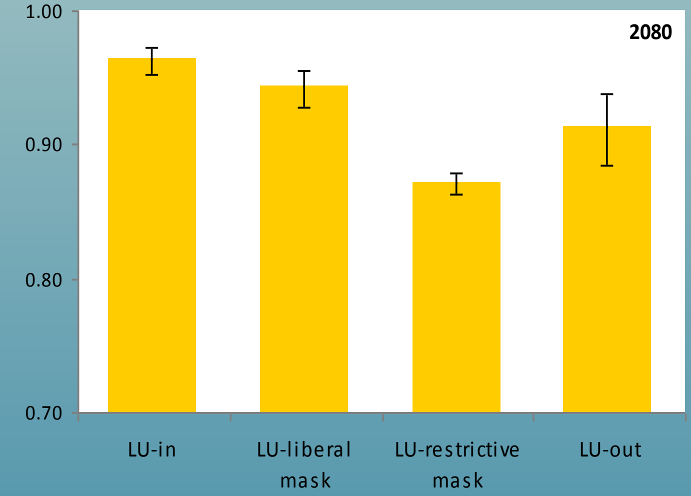
Recommendations:

- 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.

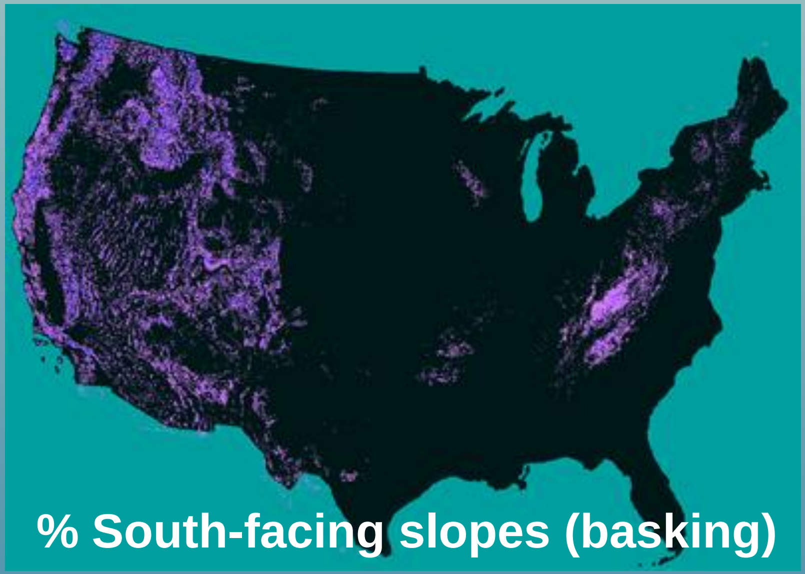


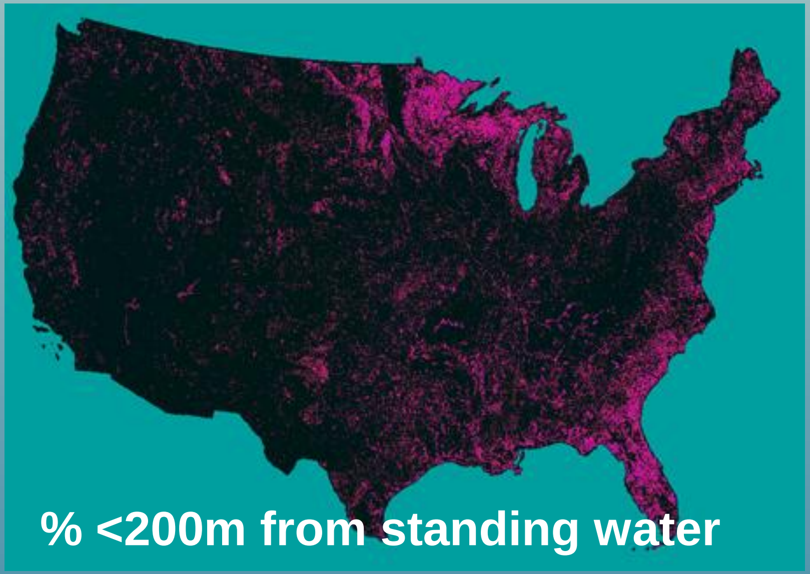


Link to paper: http://onlinelibrary.wiley.com/doi/10.1111/j.2041-210X.2011.00157.x/abstract

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

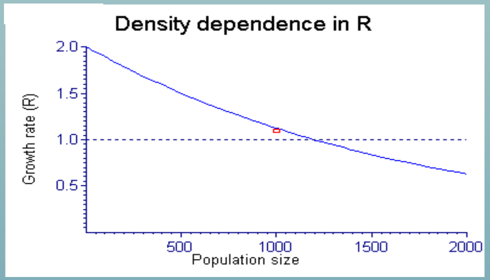


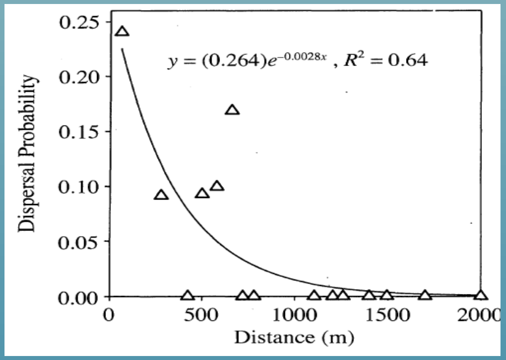


Data & Methods: Life history and population demography

- 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

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

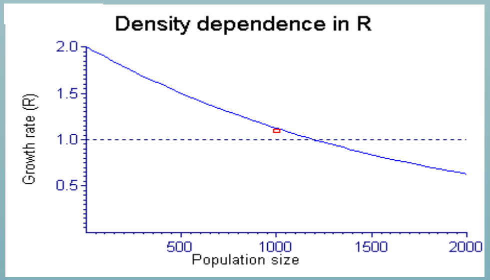


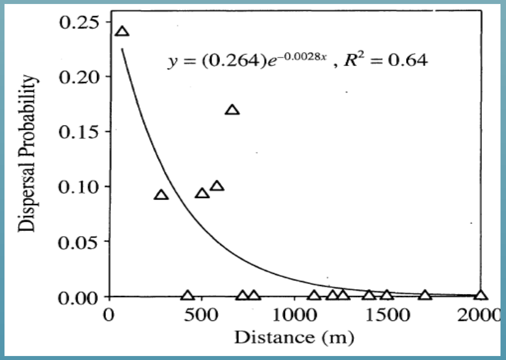


Data & Methods: Life history and population demography

- "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:

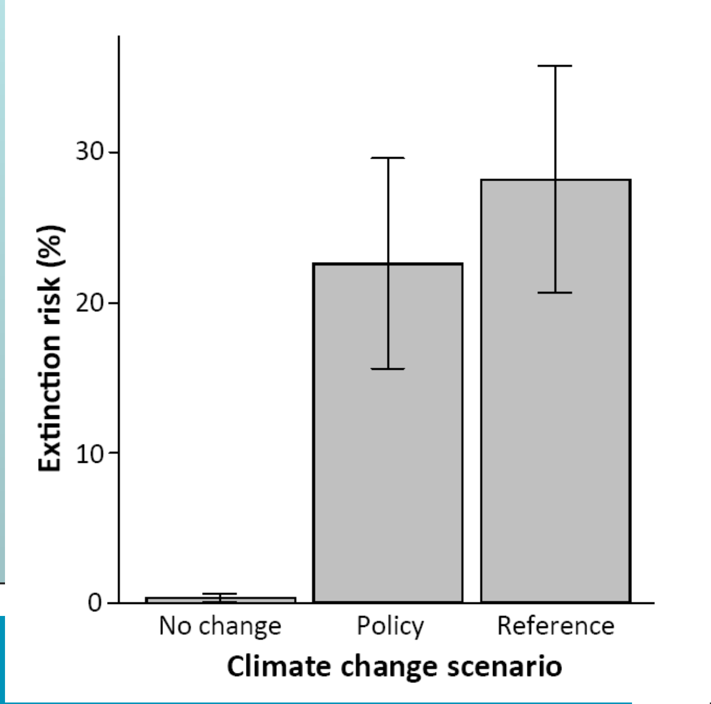
Species (36 species, with species-specific spatial structures)
    Life history types (6 types; 2 used for each species)
        Scenarios (3 scenarios: No climate change; Reference; Policy)
            Demographic Models (40-50 selected from the parameter space)

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!

Results: Extinction Risk Under Climate Change



nature climate change

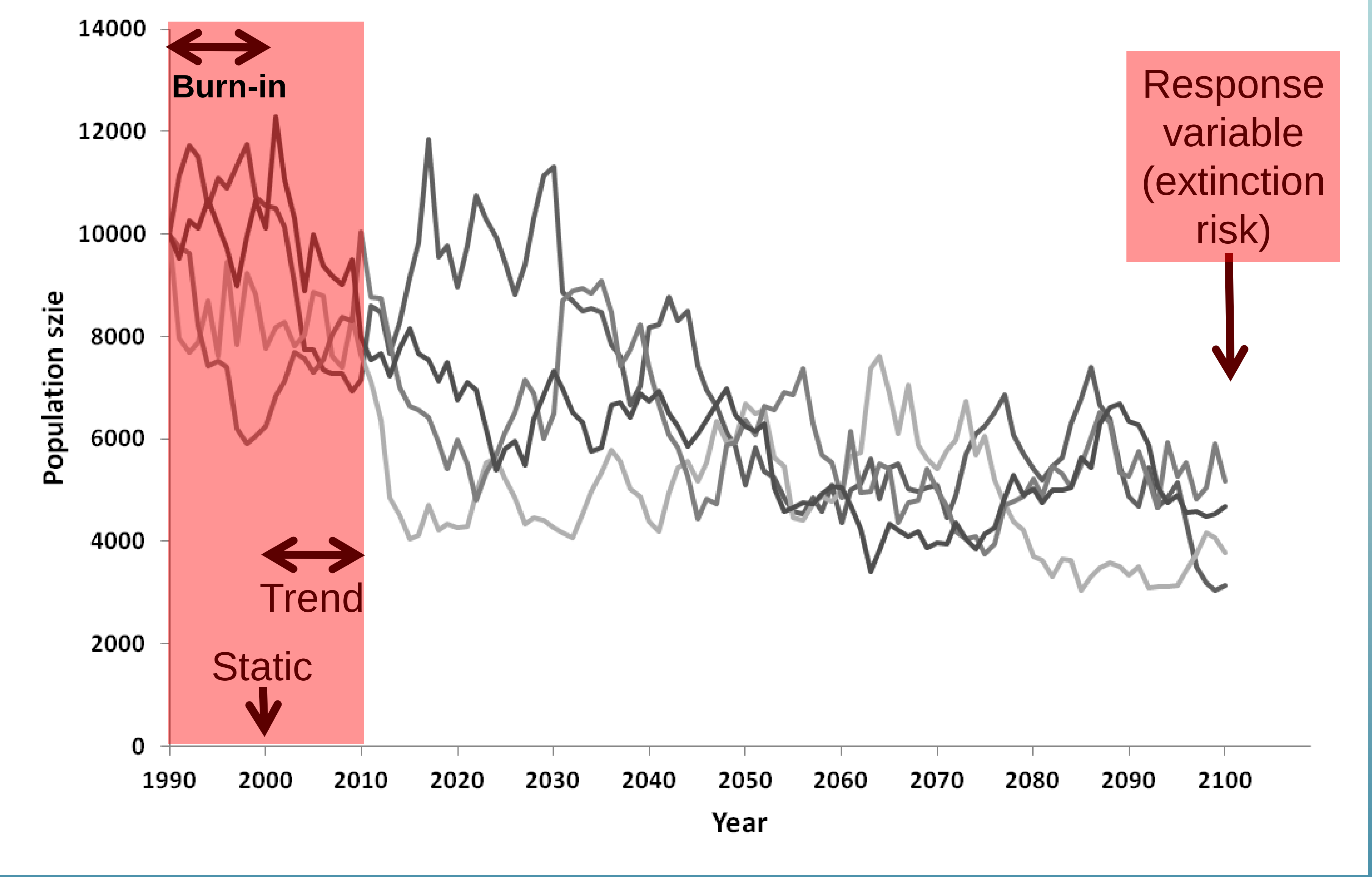
PUBLISHED ONLINE: 26 FEBRUARY 2014 | DOI: 10.1038/NCLIMATE2113

Life history and spatial traits predict extinction risk due to climate change

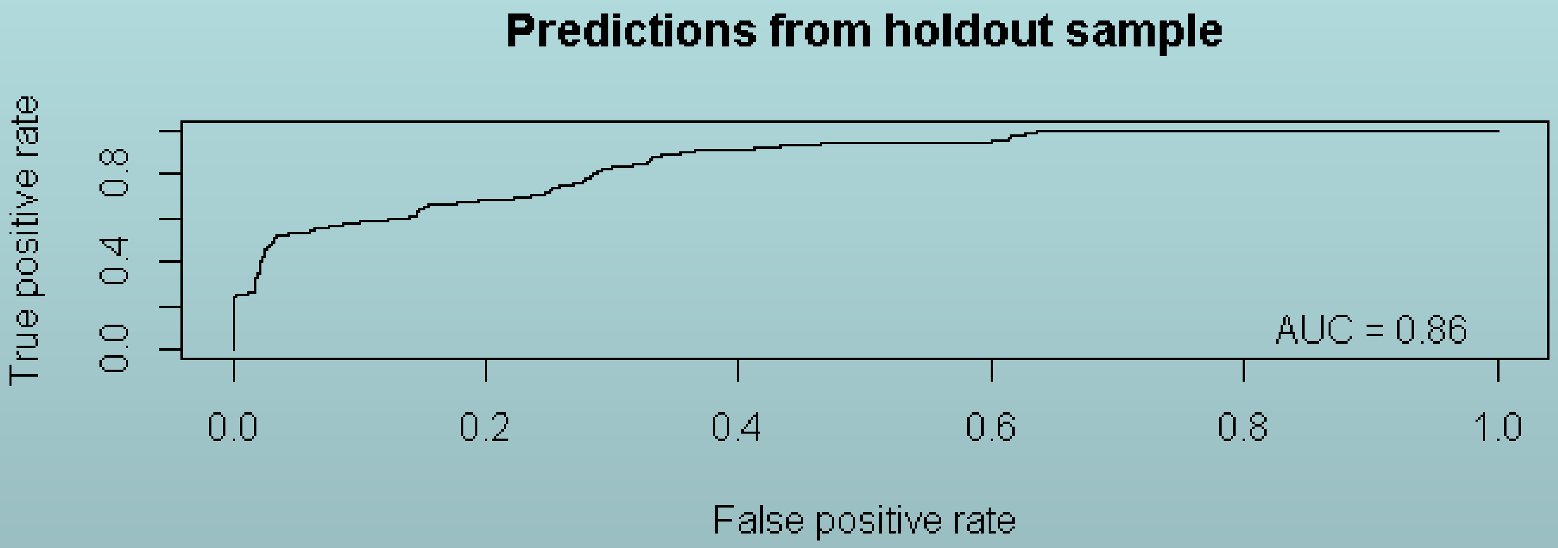
Richard G. Pearson[1,2], Jessica C. Stanton[3], Kevin T. Shoemaker[3], Matthew E. Aiello-Lammens[3], Peter J. Ersts[2], Ned Horning[2], Damien A. Fordham[4], Christopher J. Raxworthy[2], Hae Yeong Ryu[3], Jason McNees[5] and H. Reşit Akçakaya[3]*

Link to paper: http://www.nature.com/nclimate/journal/v4/n3/full/nclimate2113.html

Is it possible to predict extinction, based only on current information?



Predictive power

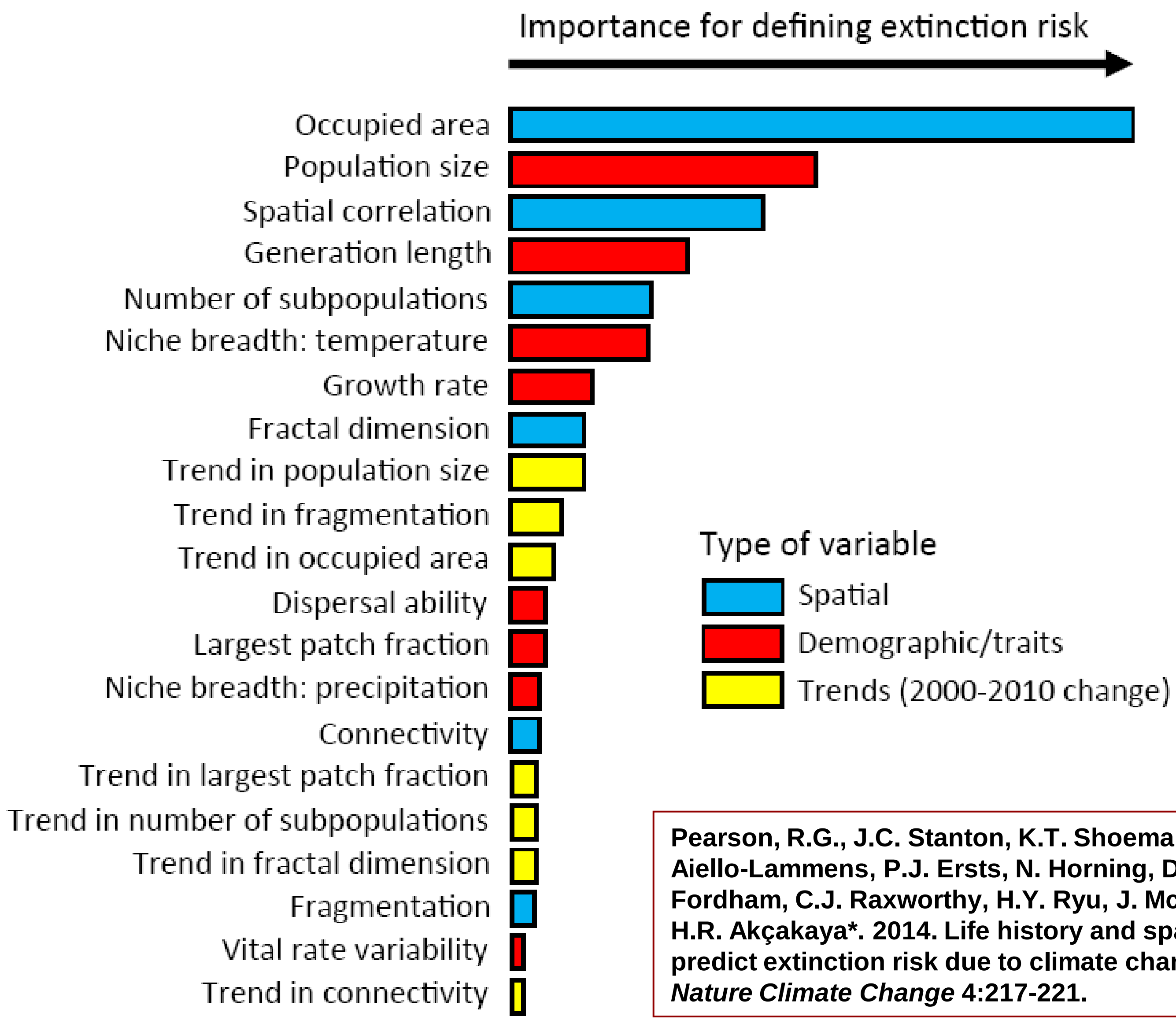


Cross validation:

AUC = 0.86

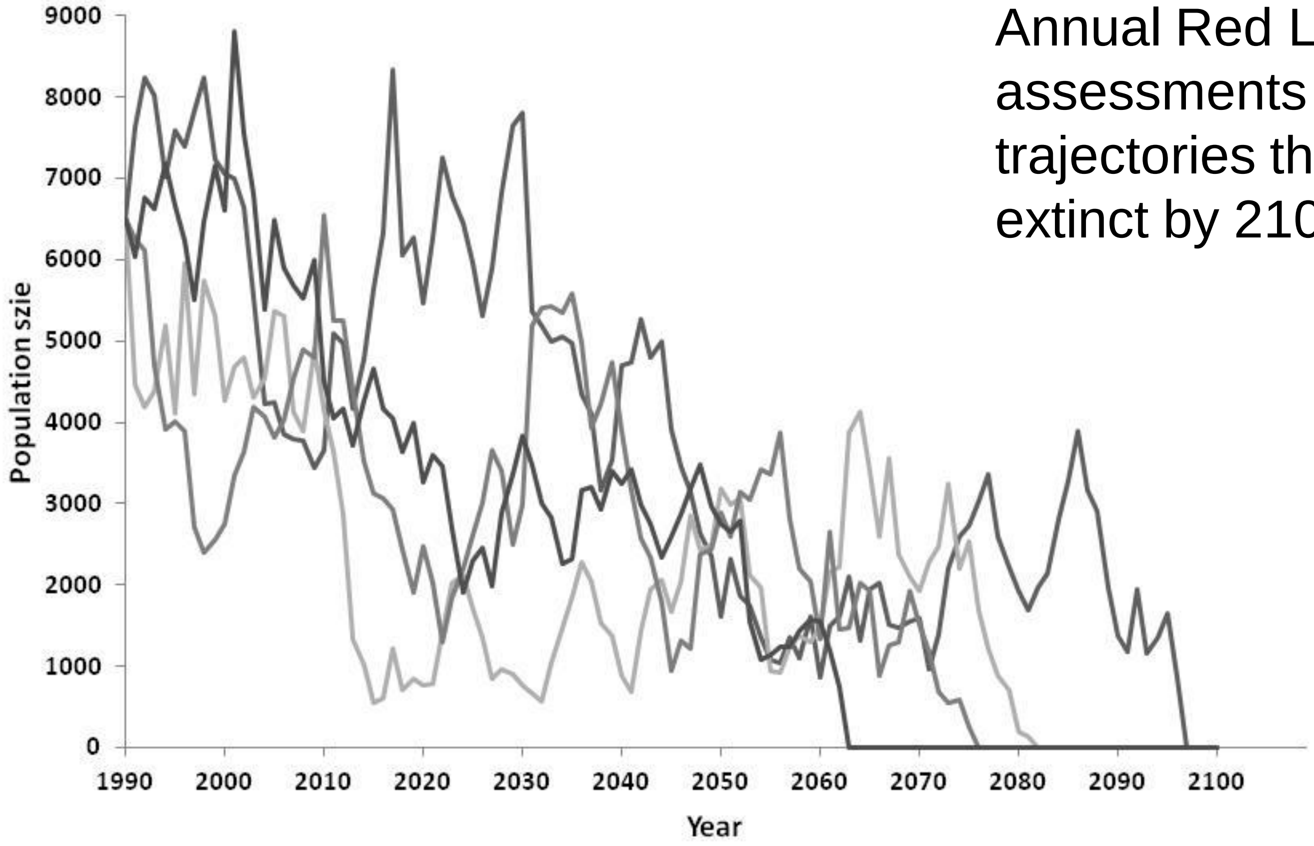
Leave one species out at a time (not standard 10-fold)

Influential Variables (result of Random Forest analysis)

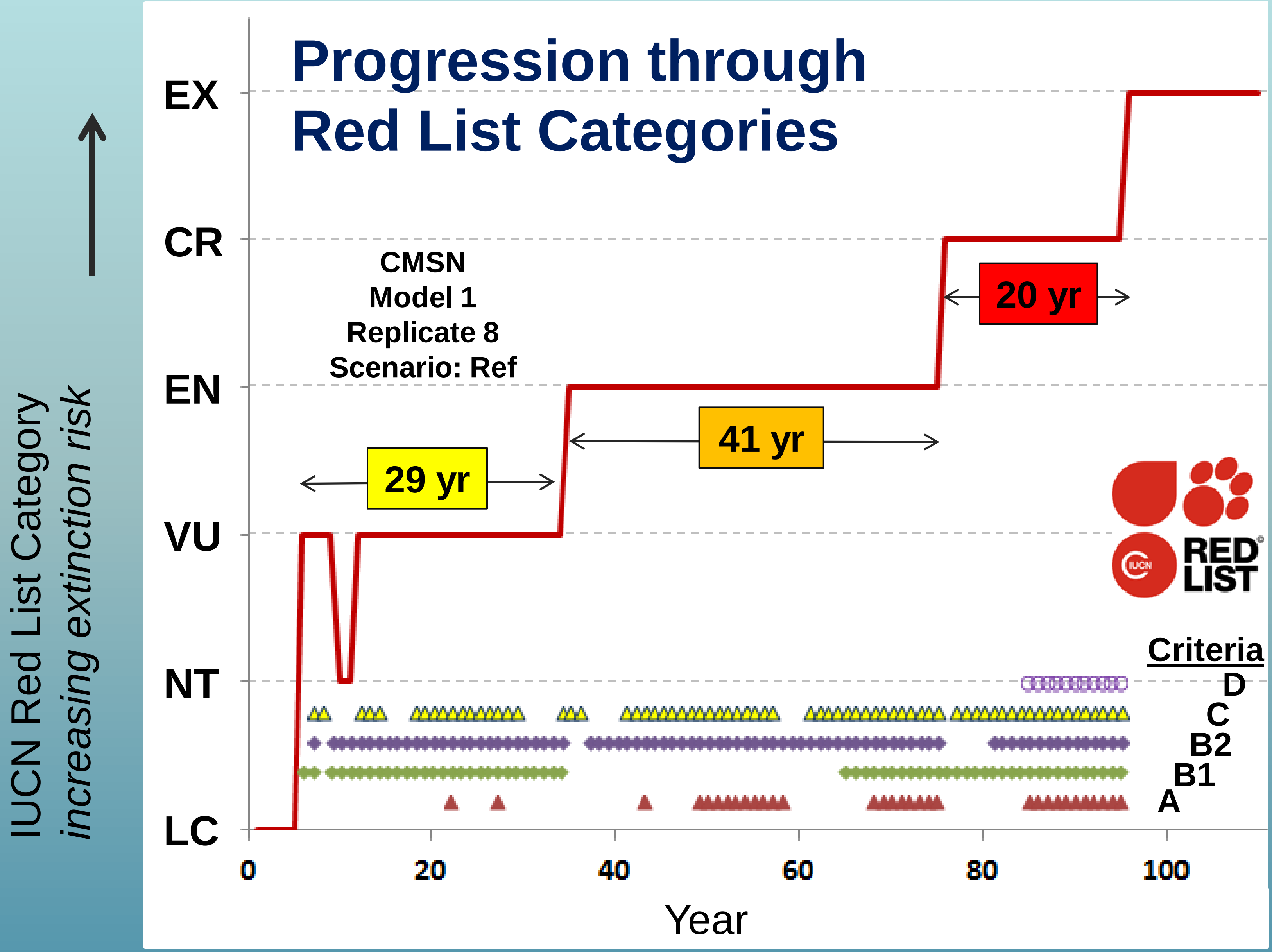


Pearson, R.G., J.C. Stanton, K.T. Shoemaker, M.E. Aiello-Lammens, P.J. Ersts, N. Horning, D.A. Fordham, C.J. Raxworthy, H.Y. Ryu, J. McNees, and H.R. Akçakaya*. 2014. Life history and spatial traits predict extinction risk due to climate change. *Nature Climate Change* 4:217-221.

Warning time for species going extinct due to climate change



Annual Red List assessments of all trajectories that went extinct by 2100


Progression through
Red List Categories
IUCN Red List Category
increasing extinction risk
EX
CR
EN
VU
NT
LC
CMSN
Model 1
Replicate 8
Scenario: Ref
29 yr
41 yr
20 yr
RED LIST
IUCN
Criteria
D
C
B2
B1
A
0
20
40
60
80
100
Year

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

- Apply to a whole class of organisms
- Develop a prediction tool
- Contribute to IUCN red-listing guidelines
- Incorporate species interactions
- Evaluate conservation strategies (e.g. assisted migration)