

# Species Distribution Models

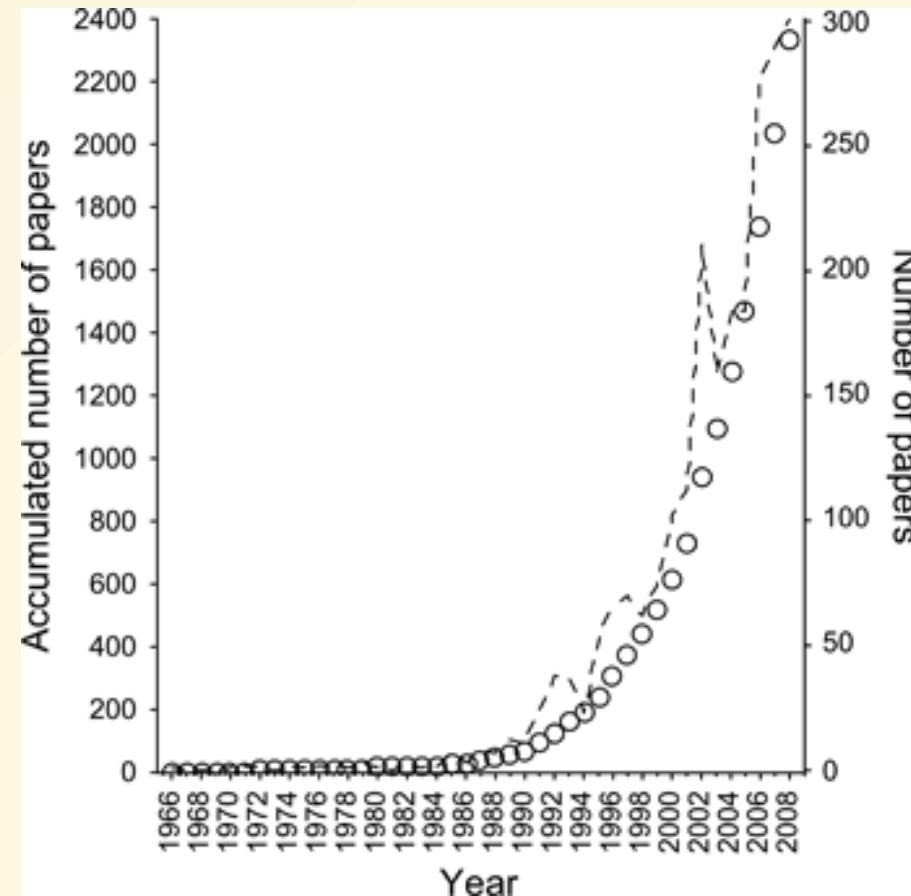
David Orme



# Outline

- Introduction
- Process overview
- Theoretical framework
- Applications
- Assessing predictive performance
- Concerns and future directions

# The unstoppable rise of SDMs



# How do I know a SDM when I see it?



From Elith et al. 2006 Ecography 29: 129-151, Table 4

# How do I know a SDM when I see it?

Many different terms:

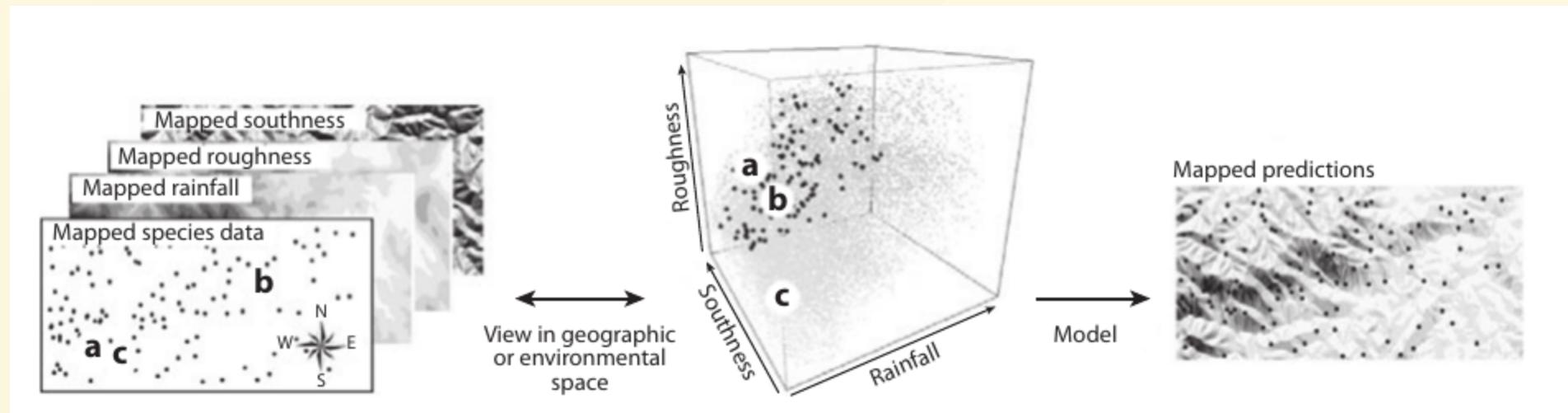
- Species Distribution Modelling
- Climate Envelope Modelling
- Bioclimate Envelope Modelling
- Habitat Distribution Modelling
- Niche Modelling

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# What are species distribution models?

- Interpolating biological survey data in space
- Quantitative predictive models of species / environment relationships



# Overview of SDM process

- **Data** on species occurrence in geographical space
- **Maps** of environmental data
- A **model** to link occurrence data to the environmental variables
- A **GIS** with which to produce a map of predicted species occurrence
- A way to **validate** the predictions

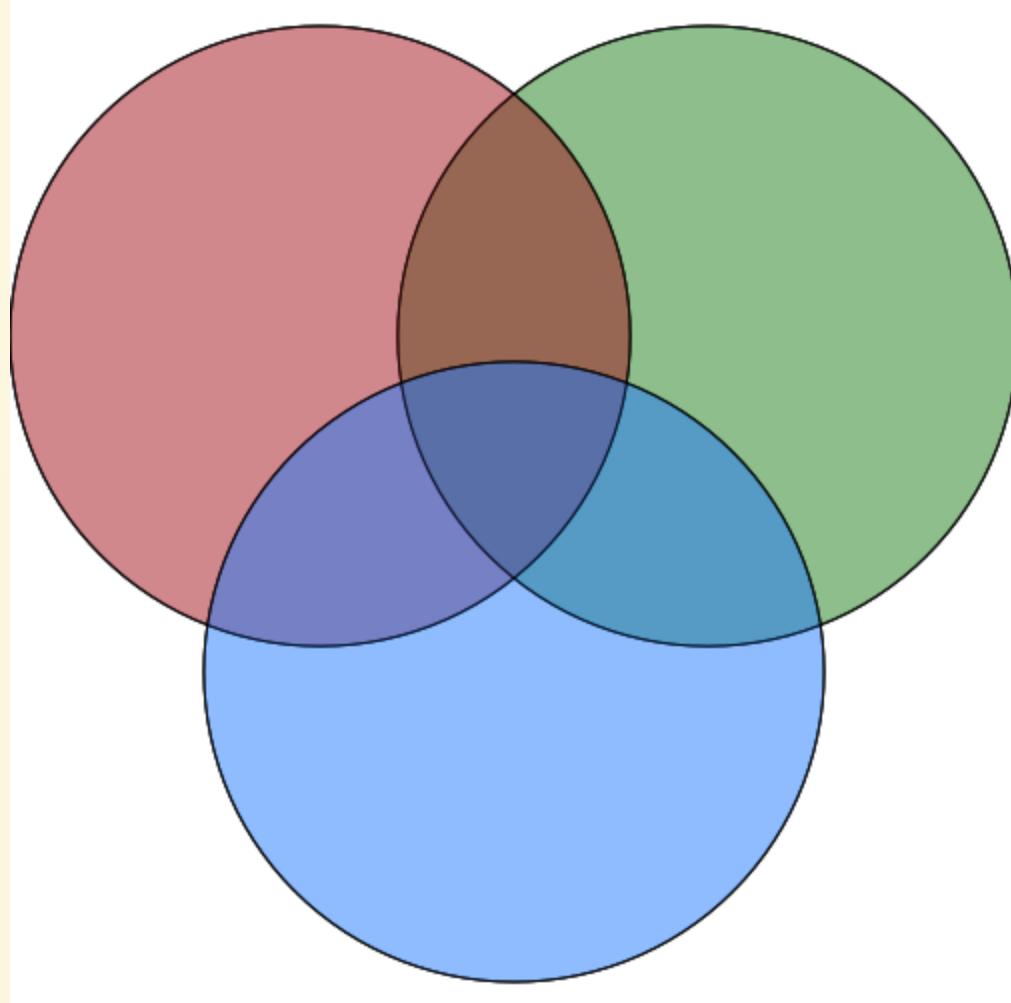
# Why?

- To **understand** species distributions
- To **predict** the occurrence of a species for locations where good survey data are lacking
  - Guide for field surveys
  - Assess climate change impacts
  - Predict invasive species spread
  - Inform reserve selection

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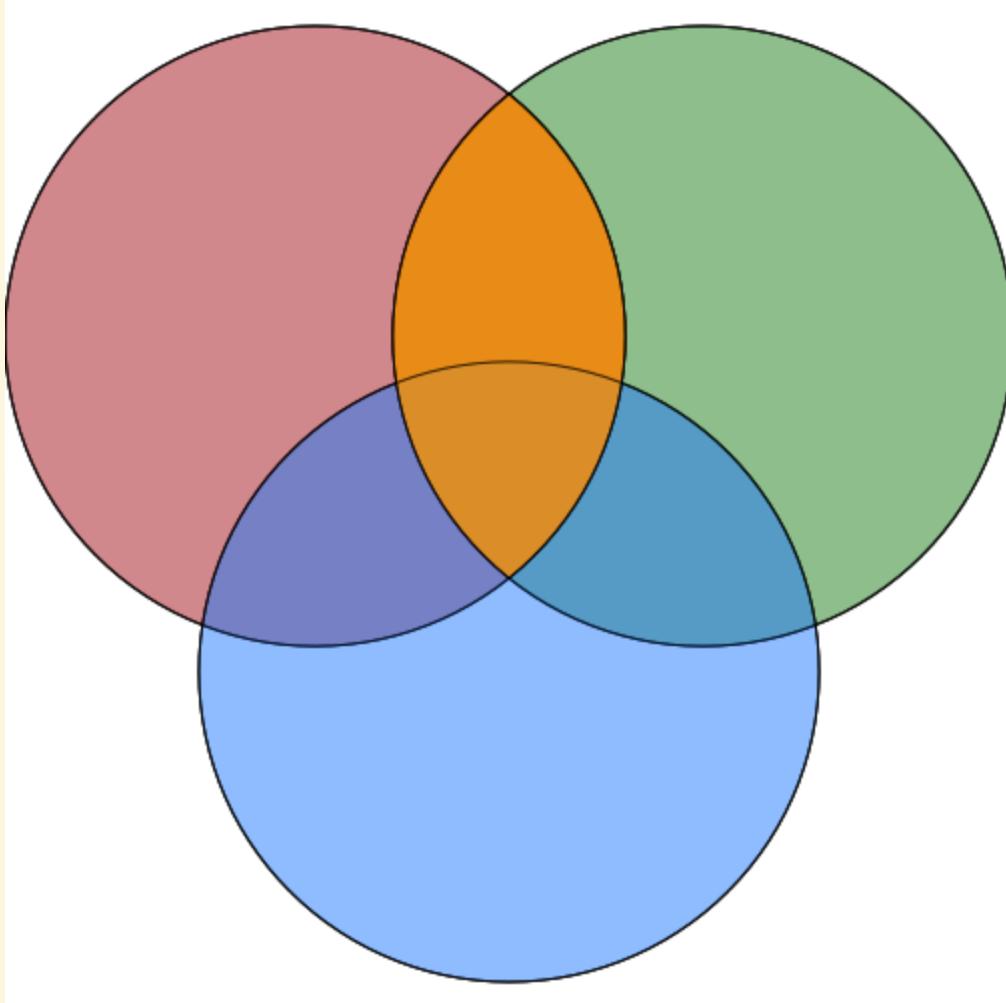
# Niche theory



- Abiotic
- Biotic
- Accessible area

Soberón & Peterson (2005)

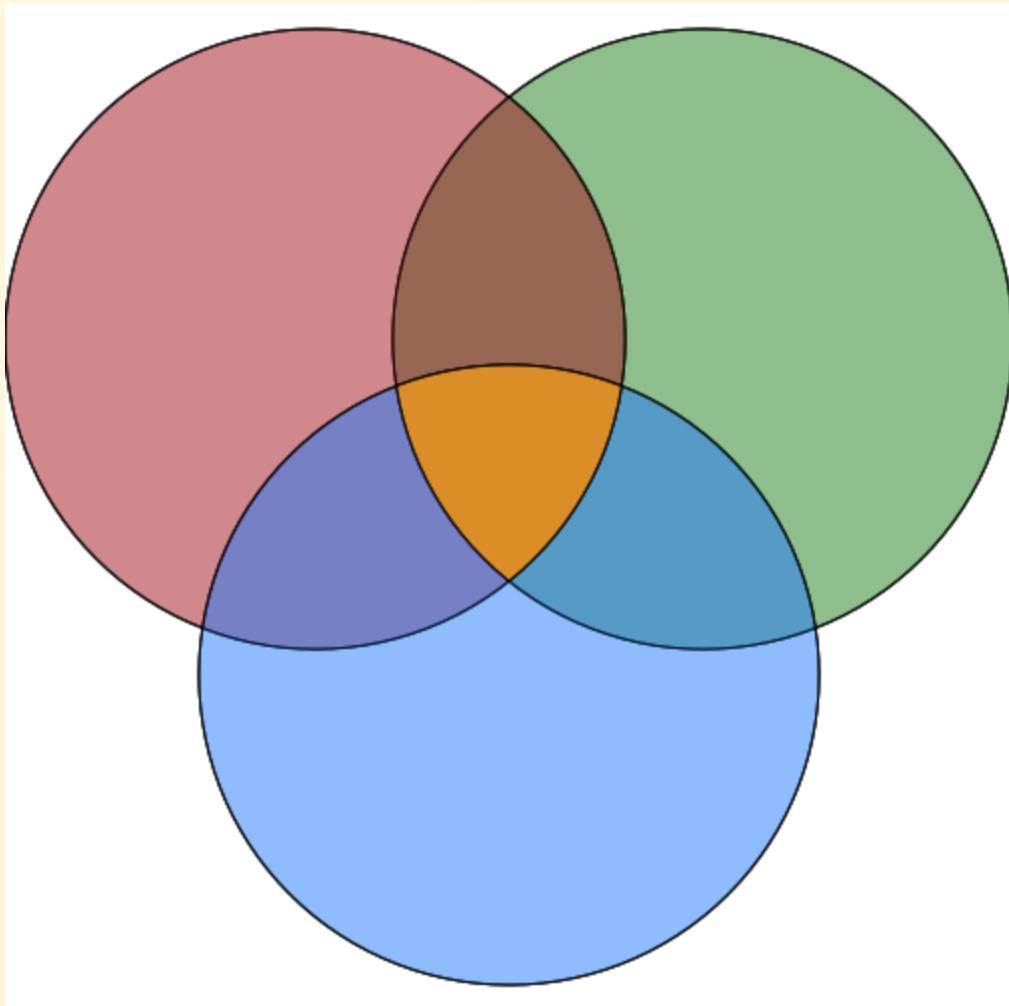
# Niche theory



- Abiotic
- Biotic
- Accessible area
- **Potential niche:** both biotic and abiotic suitability

Soberón & Peterson (2005)

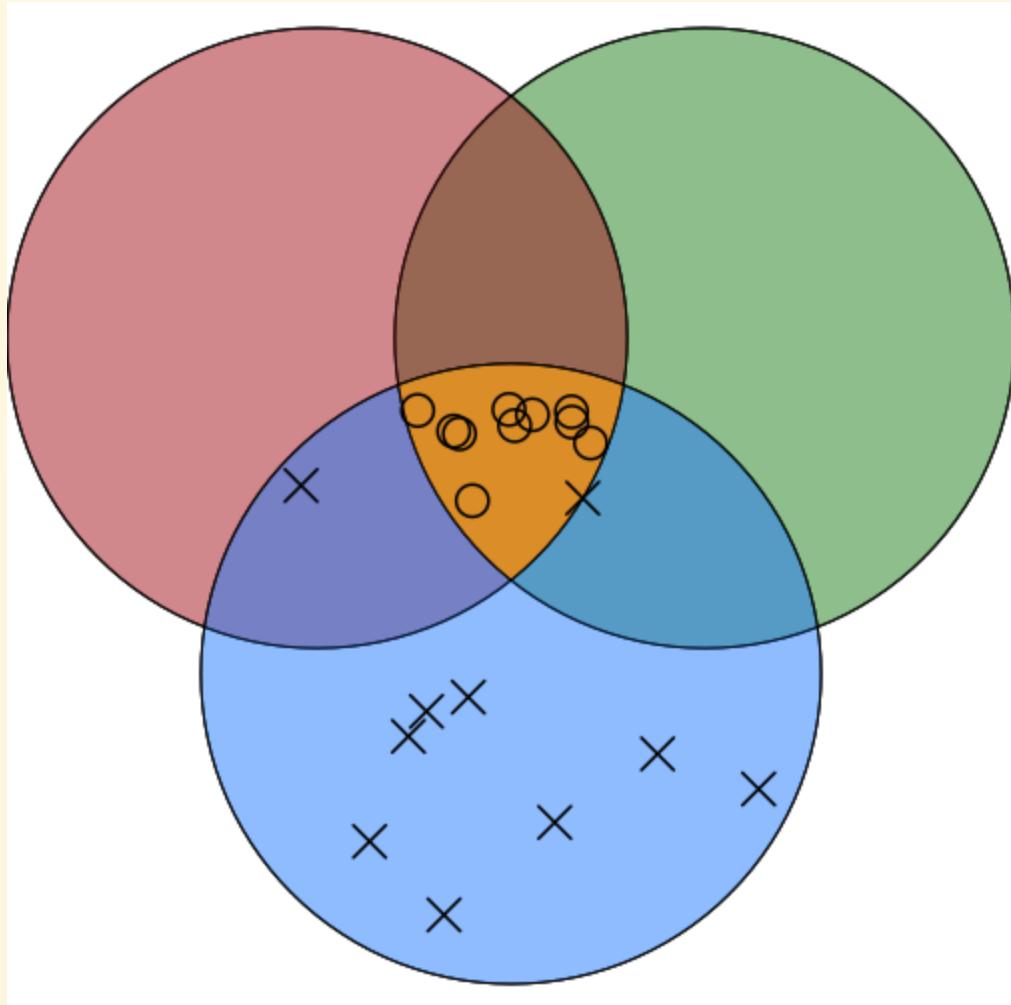
# Niche theory



- Abiotic
- Biotic
- Accessible area
- **Realised niche:** accessible and in potential niche

Soberón & Peterson (2005)

# Niche theory



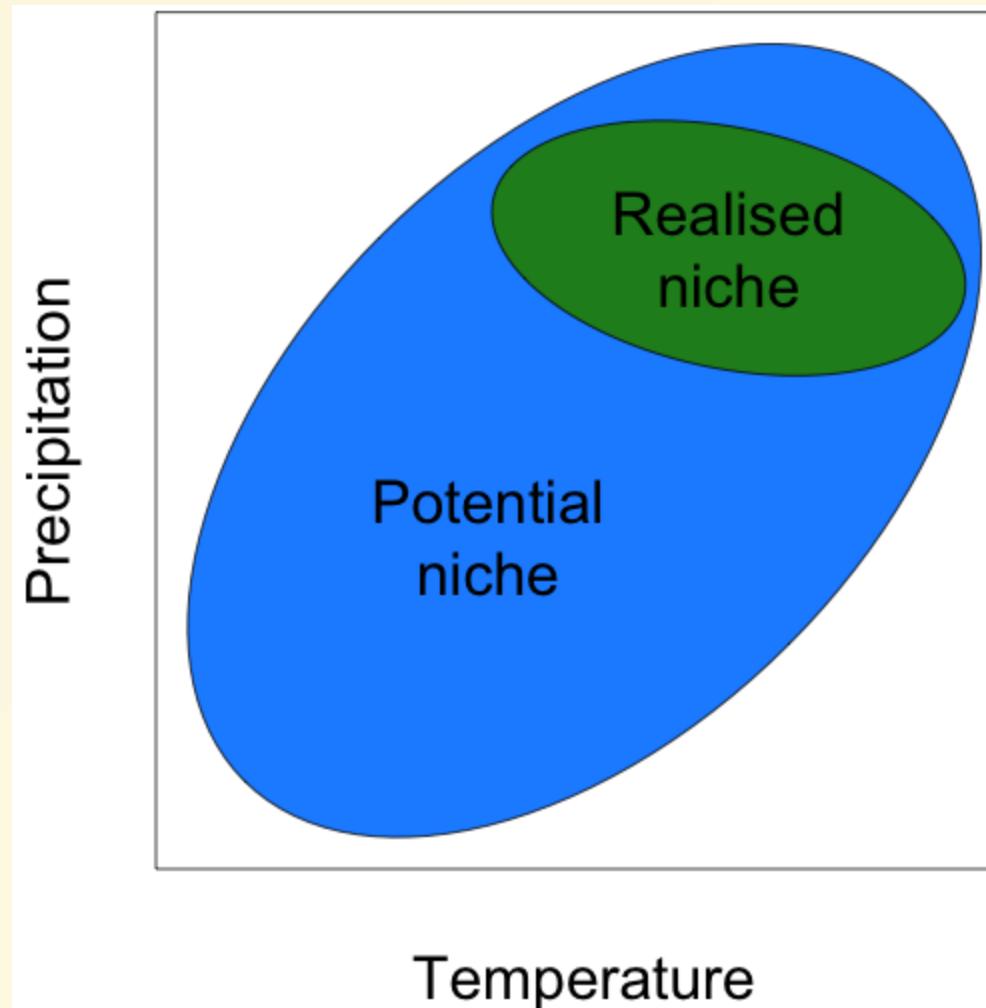
- Abiotic
- Biotic
- Accessible area
- **Populations:** can be both source (o) and sink (x)

Soberón & Peterson (2005)

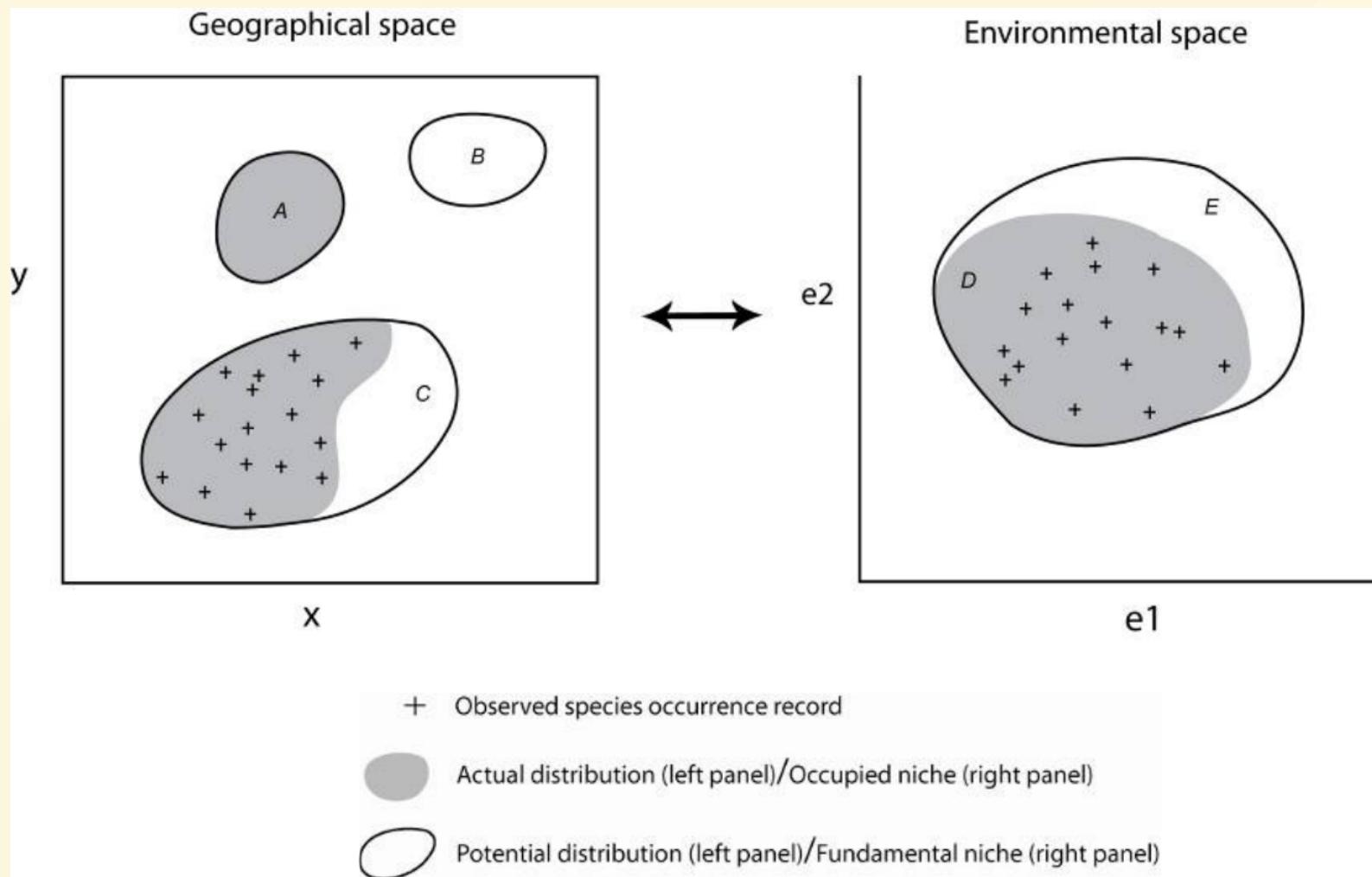
# Niche theory

“ The n-dimensional hypervolume within which that species can survive and reproduce ”

Hutchinson (1957)

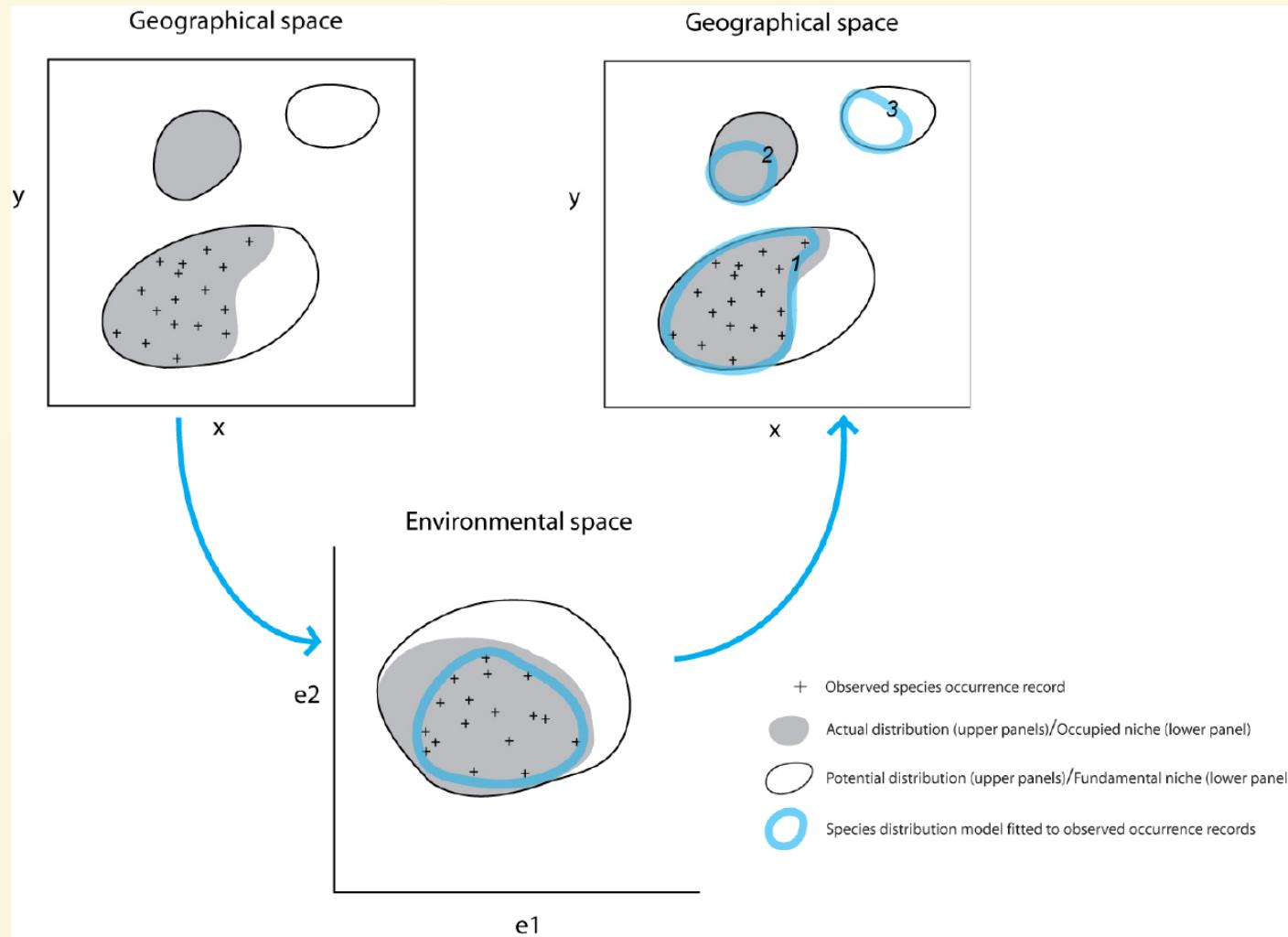


# Environmental & geographical space



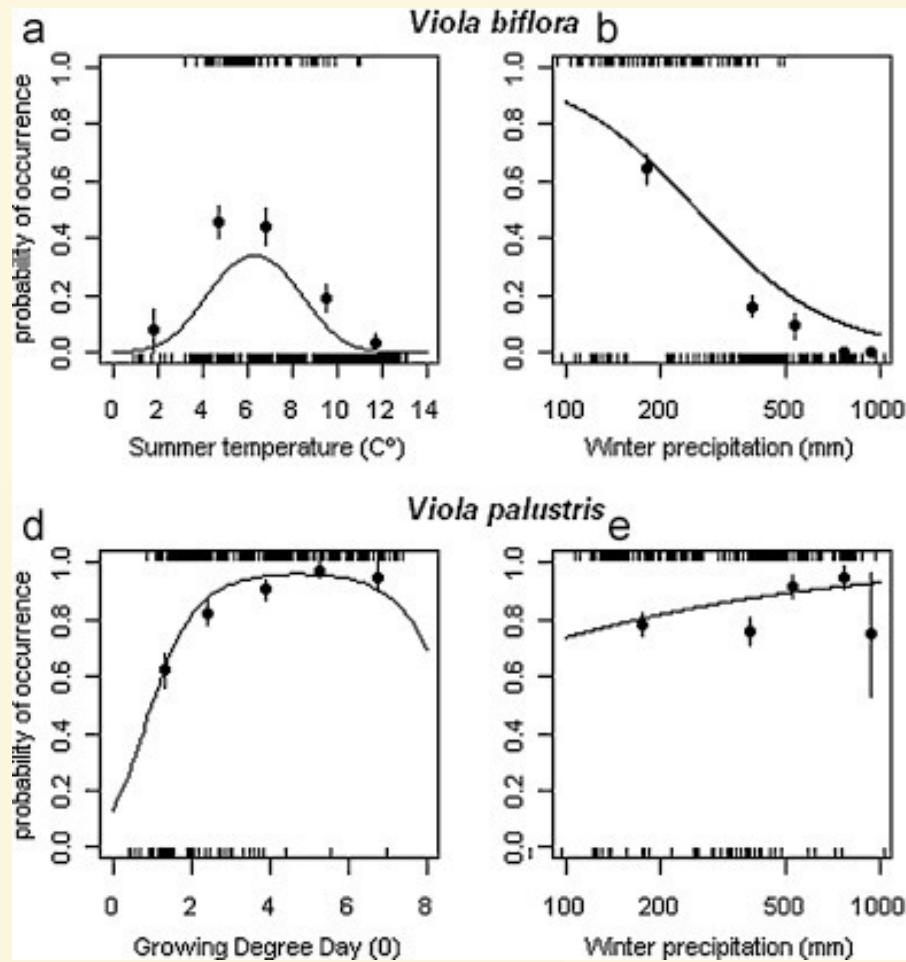
Pearson 2007., see  
also Peterson et al.  
2011

# Environmental & geographical space



Pearson 2007., see also  
Peterson et al. 2011

# Modelled relationship



Meineri et al (2012) Ecol Modelling  
231: 1-10

# Model algorithms

Approach	Software
Rectilinear envelope	BIOCLIM
ENFA	BIOMAPPER
Maximum Entropy	MAXENT
Genetic algorithm	GARP
Regression	e.g. R
Machine-learning	e.g. R
Classification methods	Classification Tree Analysis

# Summary

Species Distribution Models:

- identify areas in a landscape,
- that have similar environments to localities,
- where the species has been observed.

**That's it!**

However, this information can be extremely useful in a wide range of applications.

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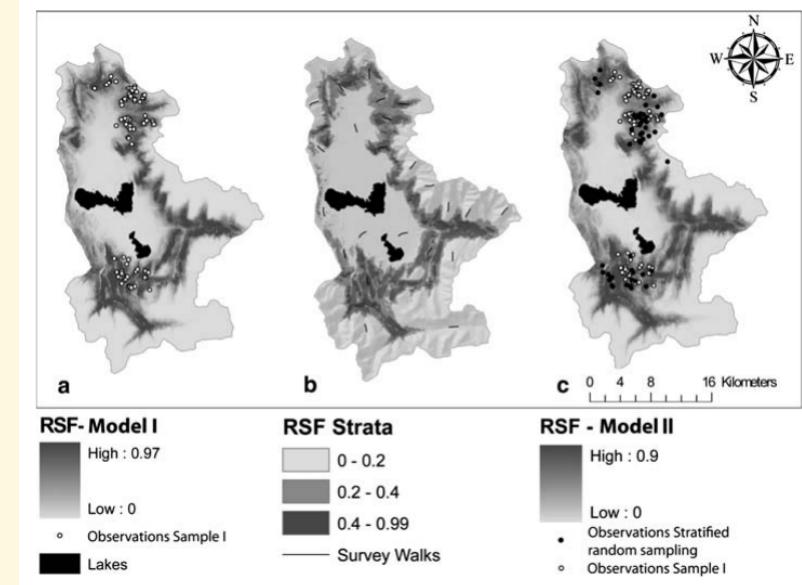
# Guiding field studies

Biodivers Conserv (2009) 18:2893–2908  
DOI 10.1007/s10531-009-9615-5

ORIGINAL PAPER

## Using habitat suitability models to sample rare species in high-altitude ecosystems: a case study with Tibetan argali

Navinder J. Singh · Nigel G. Yoccoz · Yash Veer Bhatnagar ·  
Joseph L. Fox



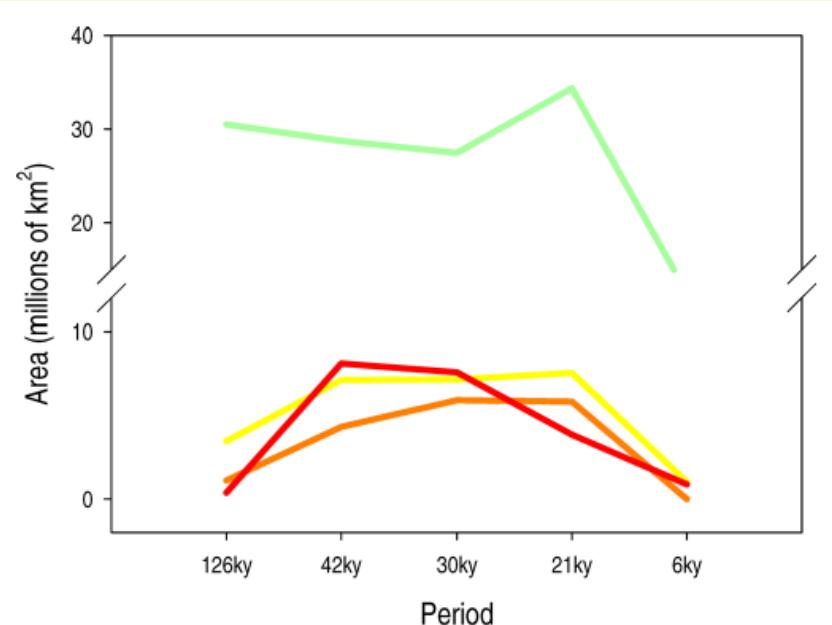
# Informing our view of the past

OPEN  ACCESS Freely available online

PLOS BIOLOGY

## Climate Change, Humans, and the Extinction of the Woolly Mammoth

David Nogués-Bravo<sup>1\*</sup>, Jesús Rodríguez<sup>2</sup>, Joaquín Hortal<sup>3</sup>, Persaram Batra<sup>4</sup>, Miguel B. Araújo<sup>1</sup>



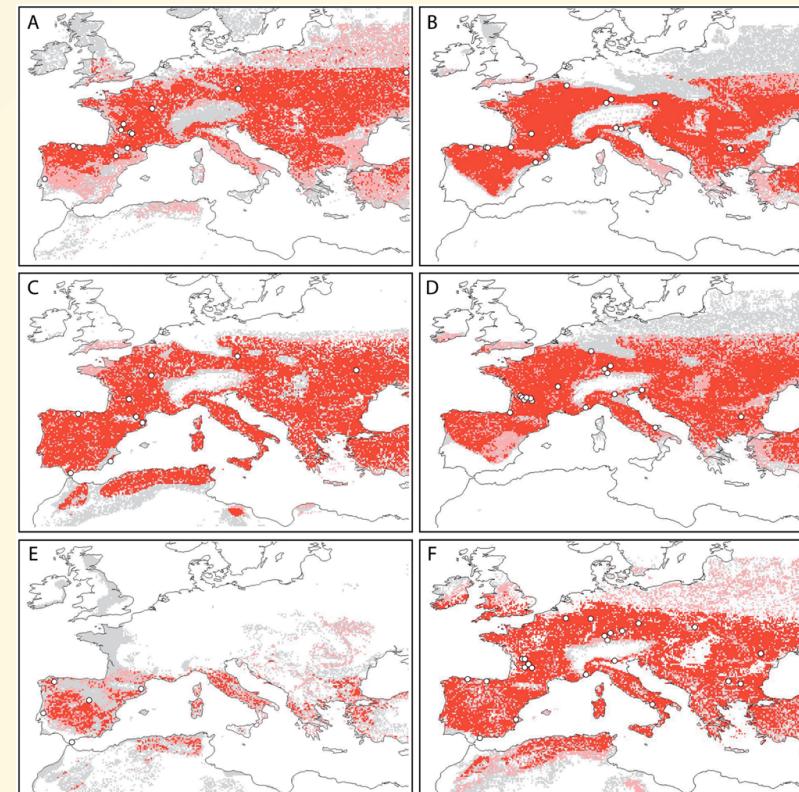
**Figure 2.** Change in the Area (%) of the Different Suitable Climatic Conditions for Woolly Mammoths



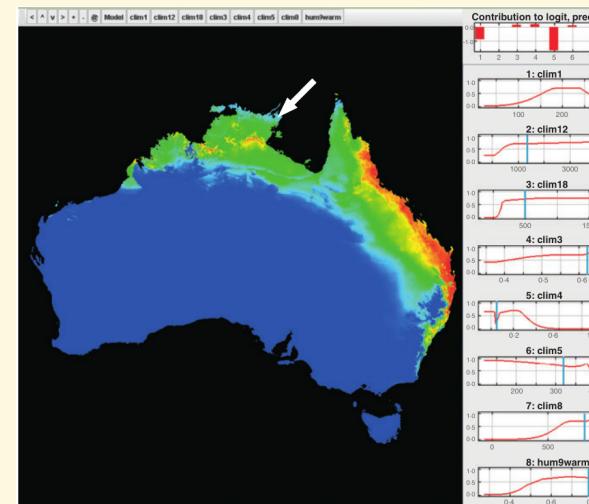
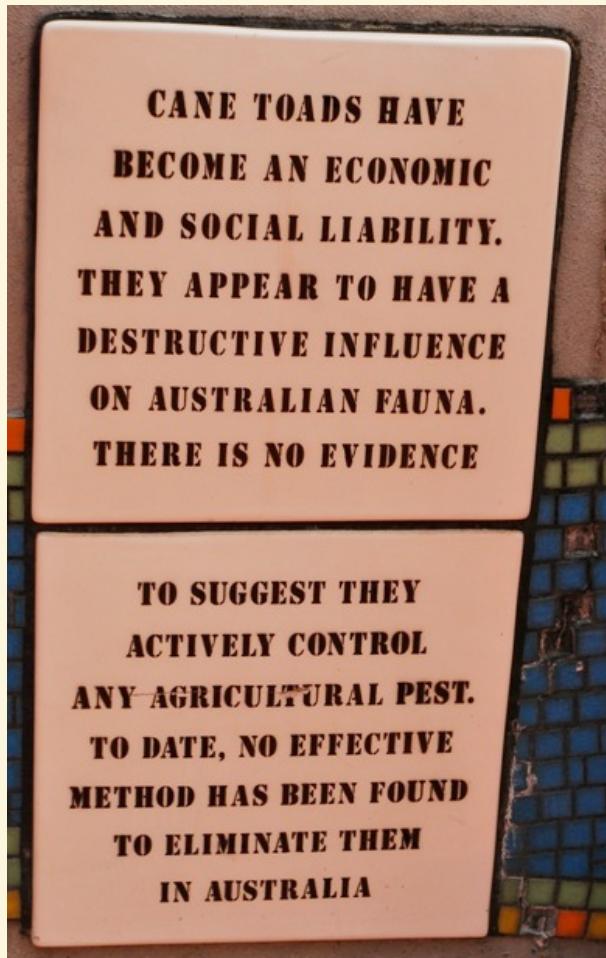
# Informing our view of the past

## Neanderthal Extinction by Competitive Exclusion

William E. Banks<sup>1\*</sup>, Francesco d'Errico<sup>1,2</sup>, A. Townsend Peterson<sup>3</sup>, Masa Kageyama<sup>4</sup>, Adriana Sima<sup>4</sup>,  
Maria-Fernanda Sánchez-Goñi<sup>5</sup>



# Spread of invasive species



# Impacts of climate change

the guardian

News | Sport | Comment | Culture | Business | Money | Life & style

Environment > Wildlife

## Climate change driving species out of habitats much faster than expected

Animals and plants have adapted to warming by moving regions up to three times faster than previously thought, report shows

Fiona Harvey, environment correspondent  
The Guardian, Thursday 18 August 2011 19.00 BST



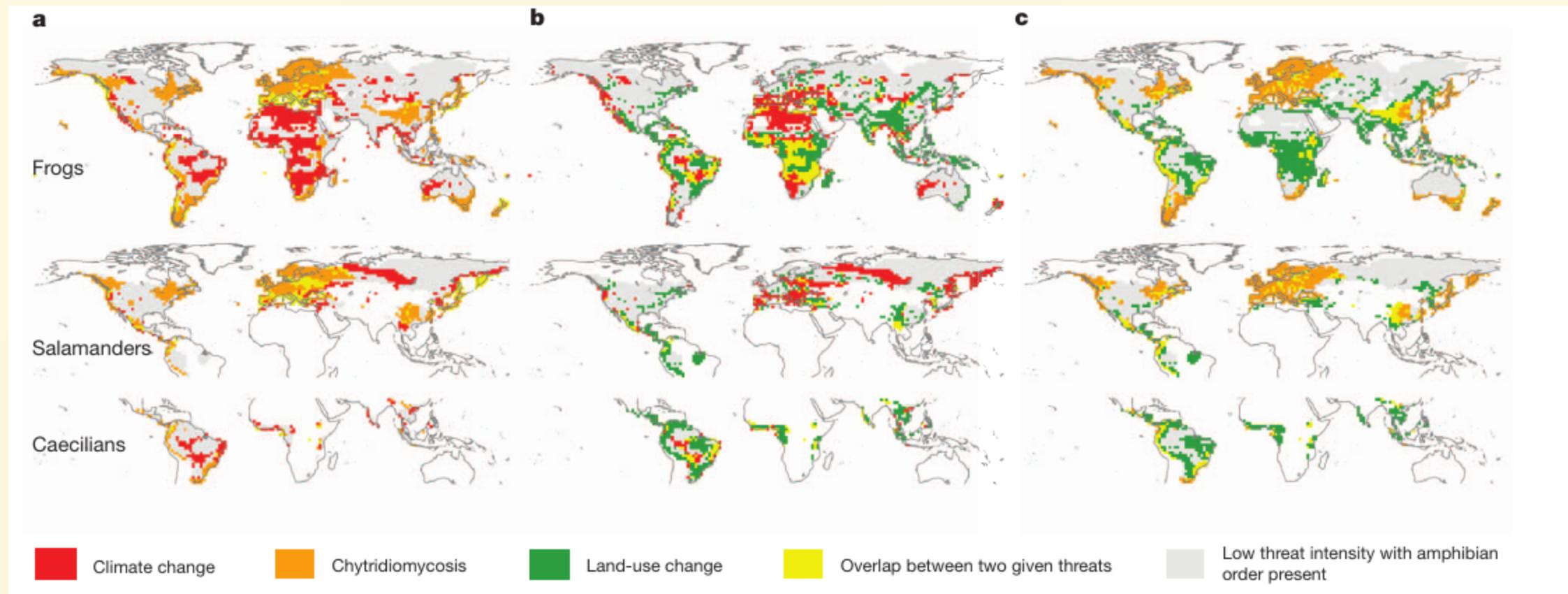
The Cetti's warbler has moved 150 km further north within the UK in the past 40 years, in response to the changing climate. Photograph: George Reszeter/Alamy

## Extinction risk from climate change

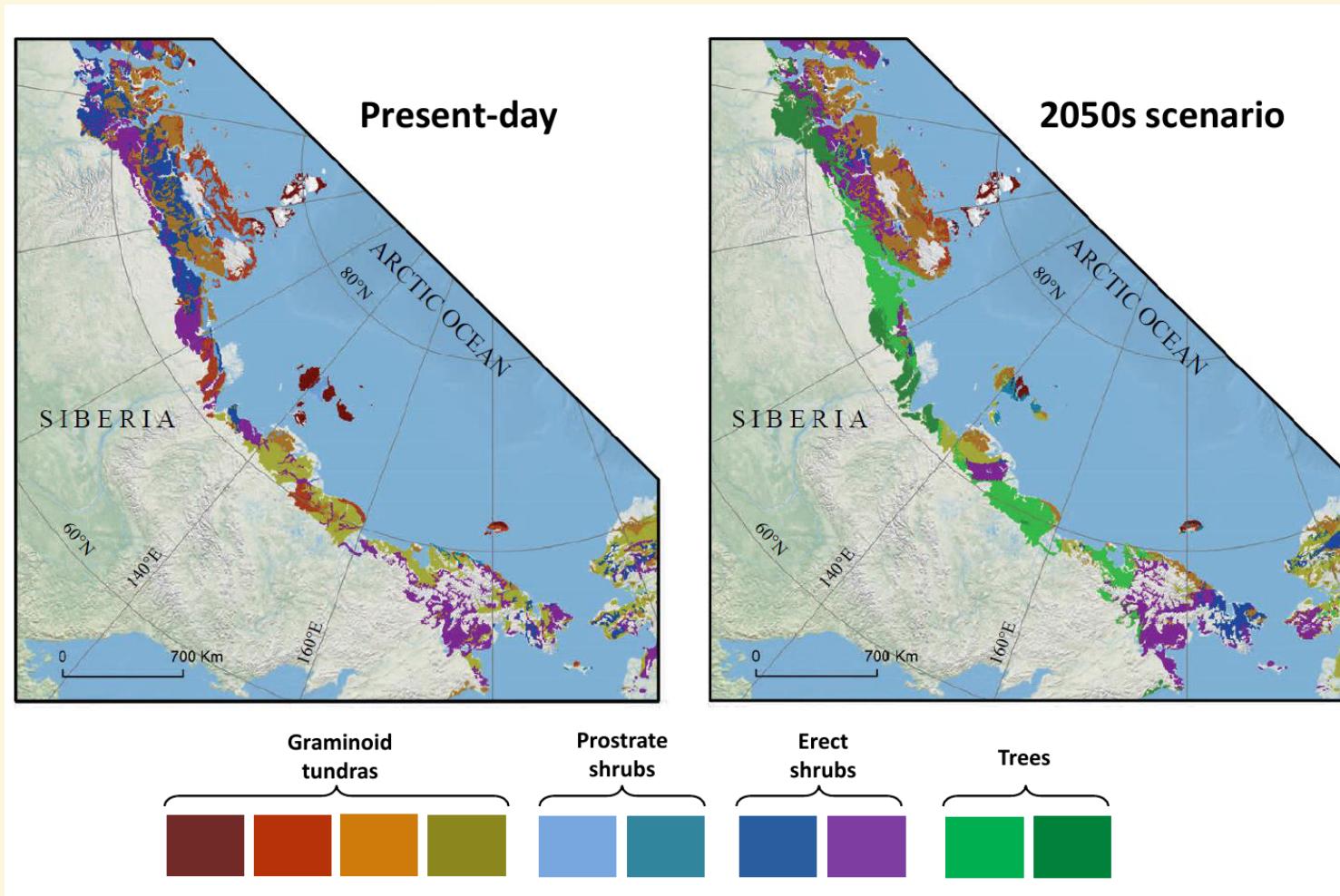
Chris D. Thomas<sup>1</sup>, Alison Cameron<sup>1</sup>, Rhys E. Green<sup>2</sup>, Michel Bakkenes<sup>3</sup>, Linda J. Beaumont<sup>4</sup>, Yvonne C. Collingham<sup>5</sup>, Barend F. N. Erasmus<sup>6</sup>, Martinez Ferreira de Siqueira<sup>7</sup>, Alan Grainger<sup>8</sup>, Lee Hannah<sup>9</sup>, Lesley Hughes<sup>4</sup>, Brian Huntley<sup>5</sup>, Albert S. van Jaarsveld<sup>10</sup>, Guy F. Midgley<sup>11</sup>, Lera Miles<sup>8\*</sup>, Miguel A. Ortega-Huerta<sup>12</sup>, A. Townsend Peterson<sup>13</sup>, Oliver L. Phillips<sup>8</sup> & Stephen E. Williams<sup>14</sup>



# Comparing drivers



# Future predictions

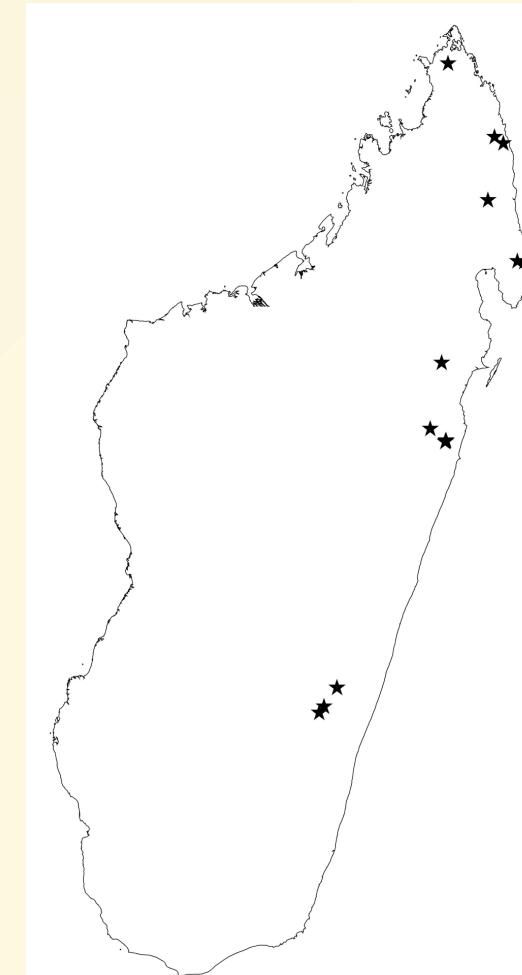
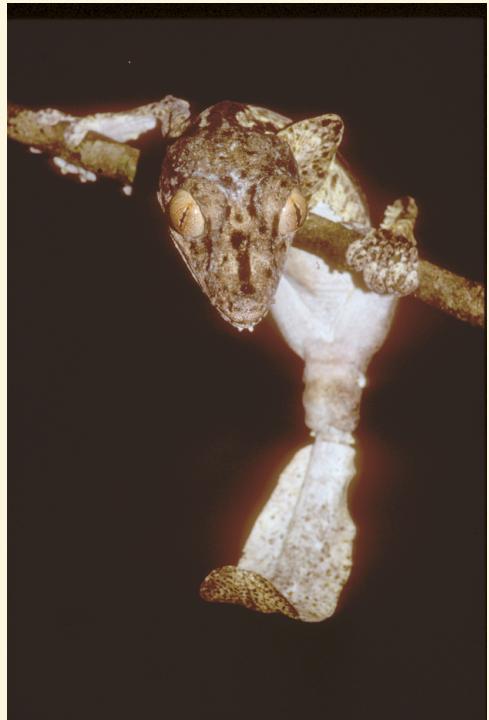


Pearson et al. 2013  
Nature Climate Change  
3:673–677

# Outline

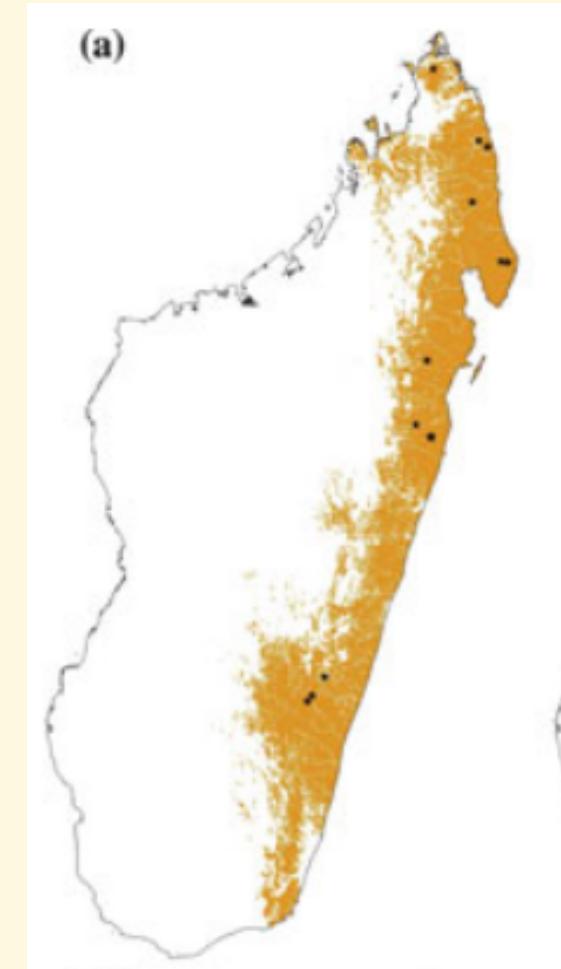
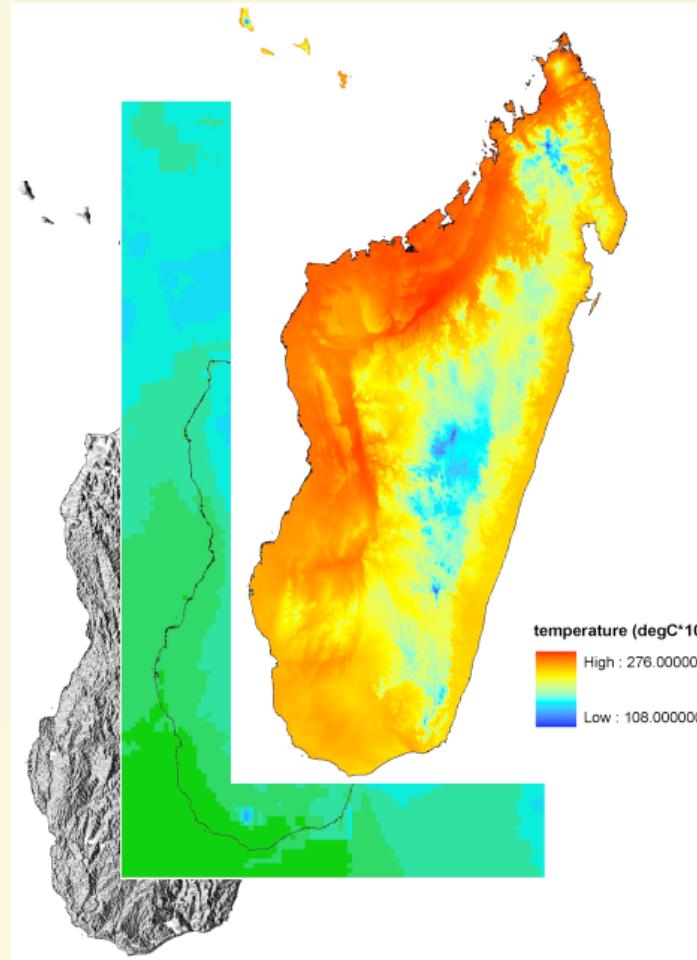
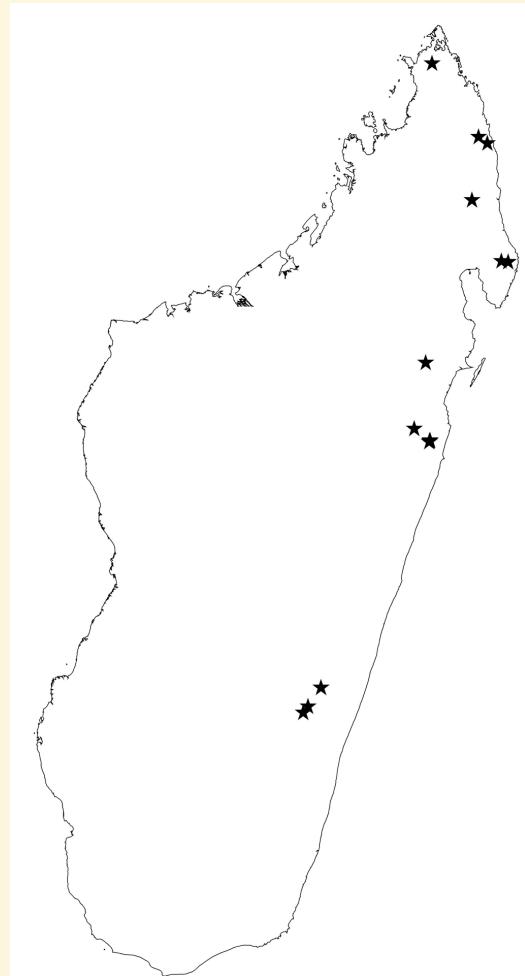
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# Madagascan geckos



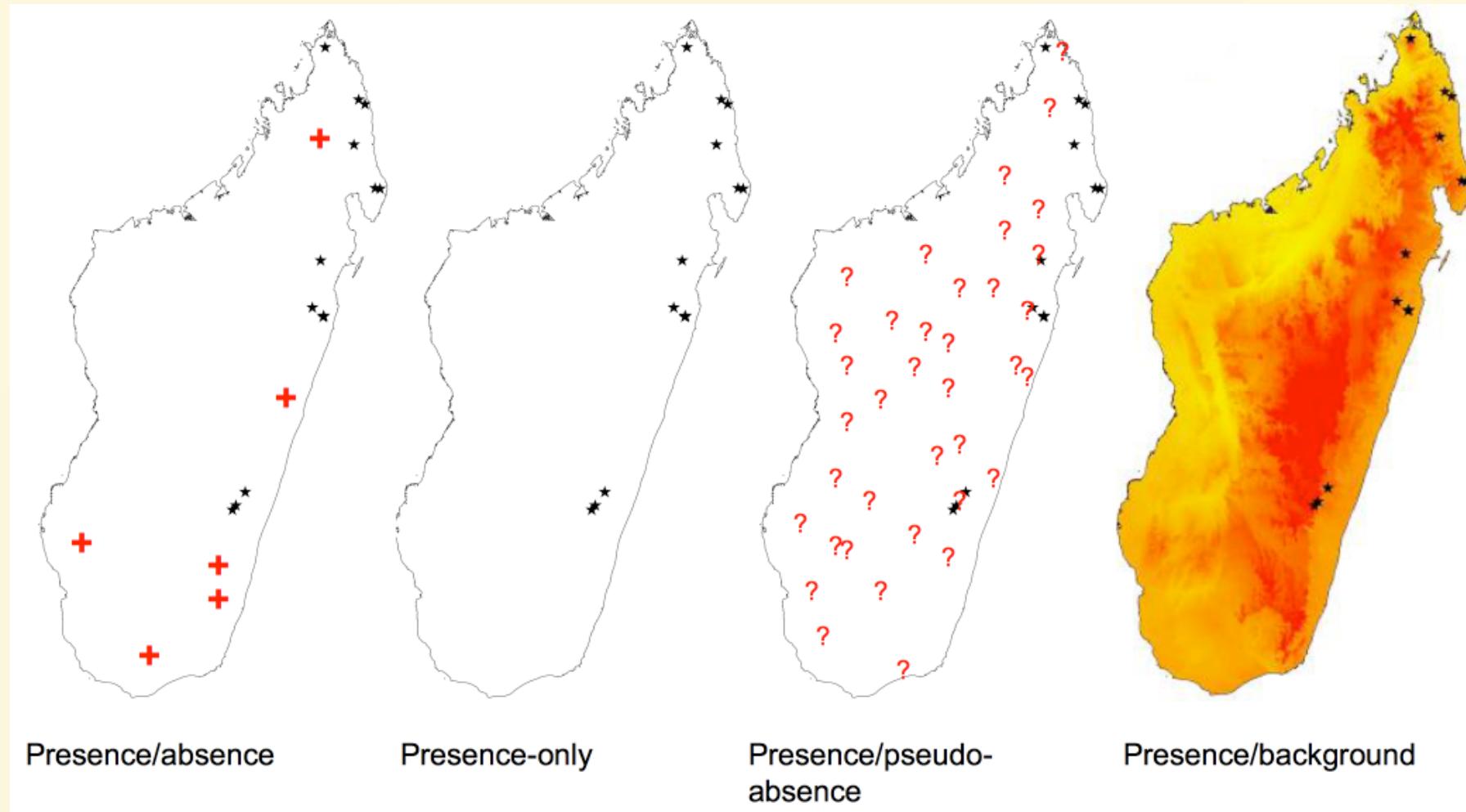
*Uroplatus* sp. Pearson et al. (2007) J.  
Biogeog 34: 102-117

# Madagascan geckos

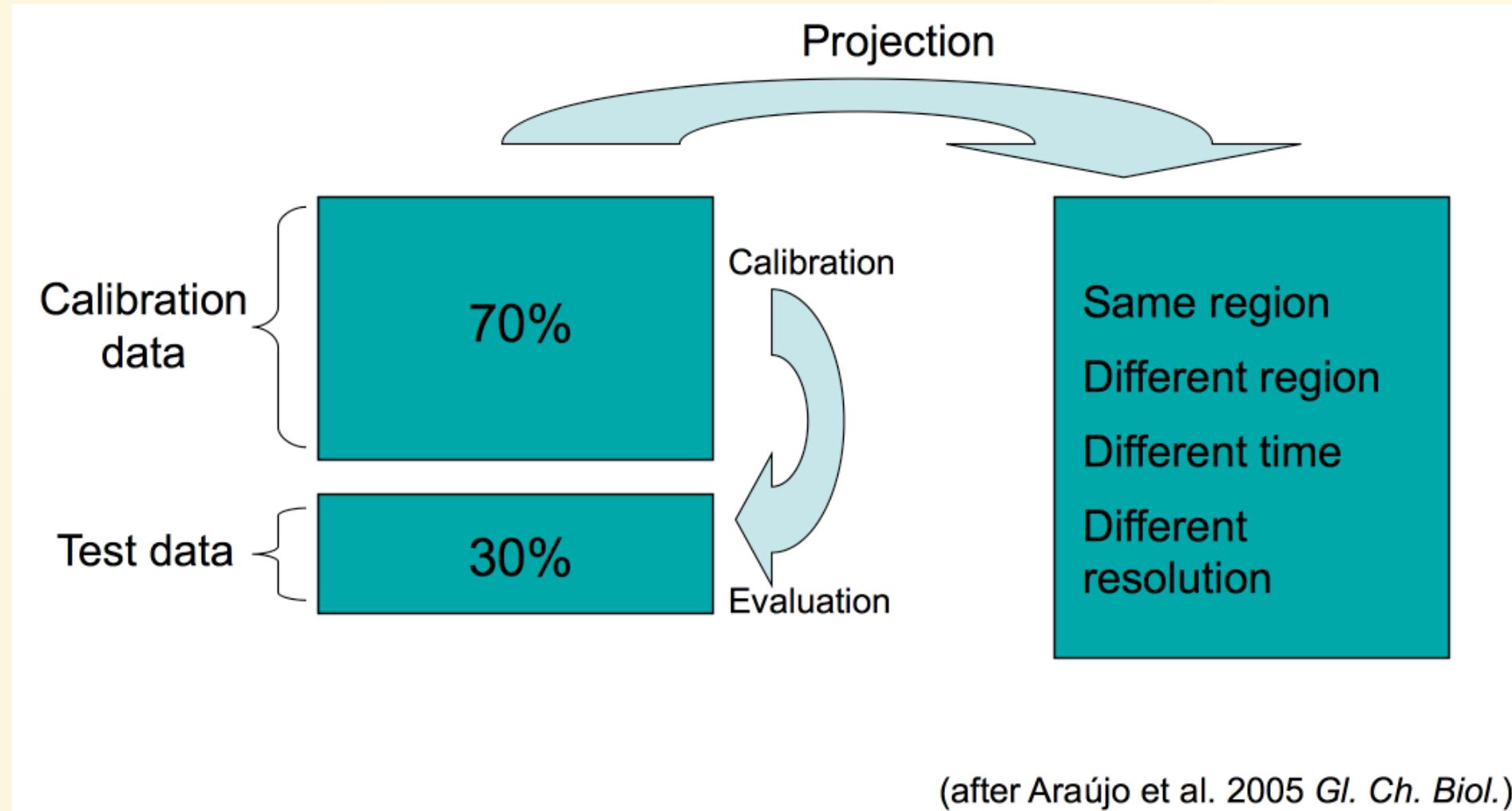


(a)

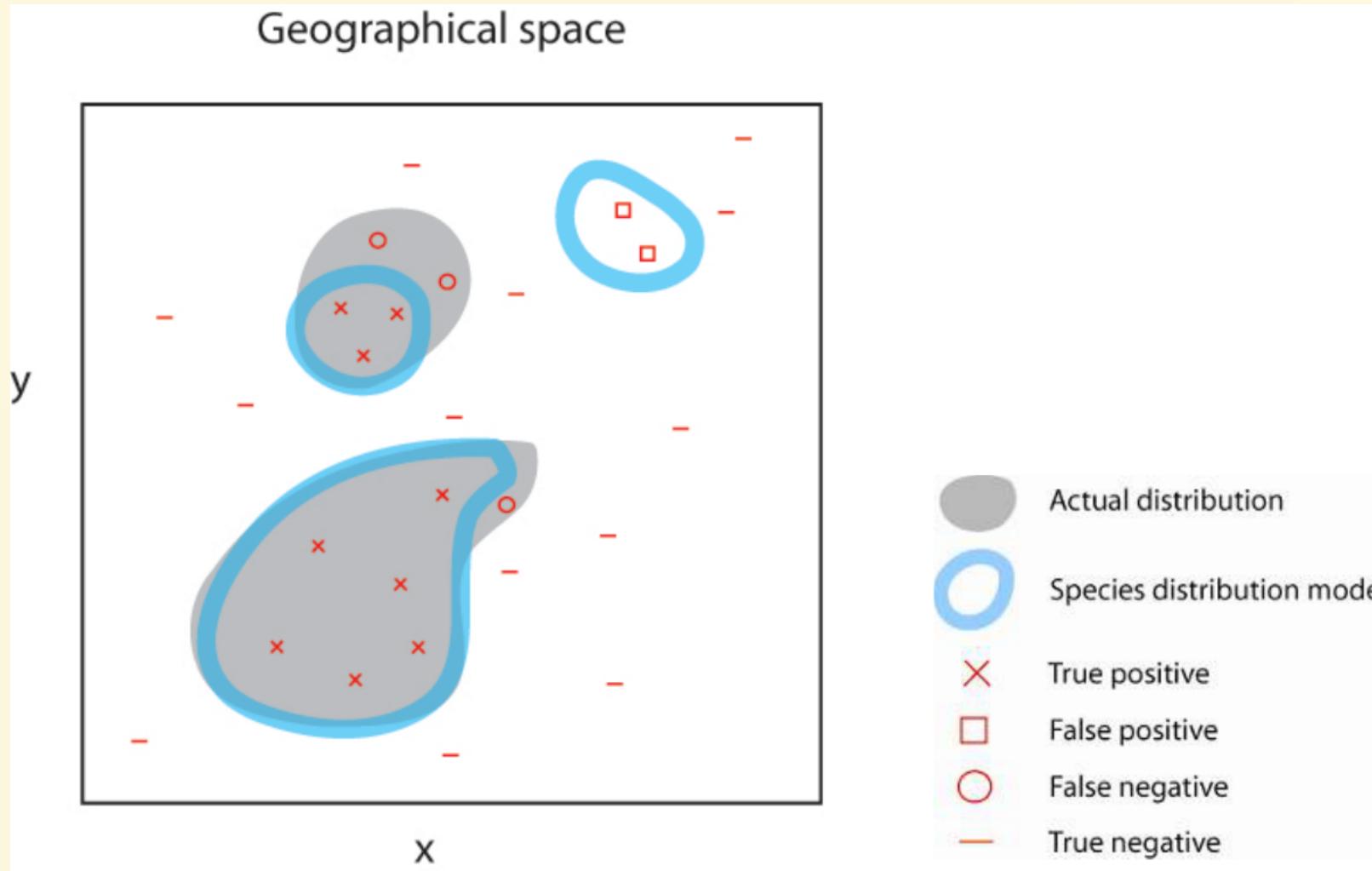
# Madagascan geckos



# Model evaluation



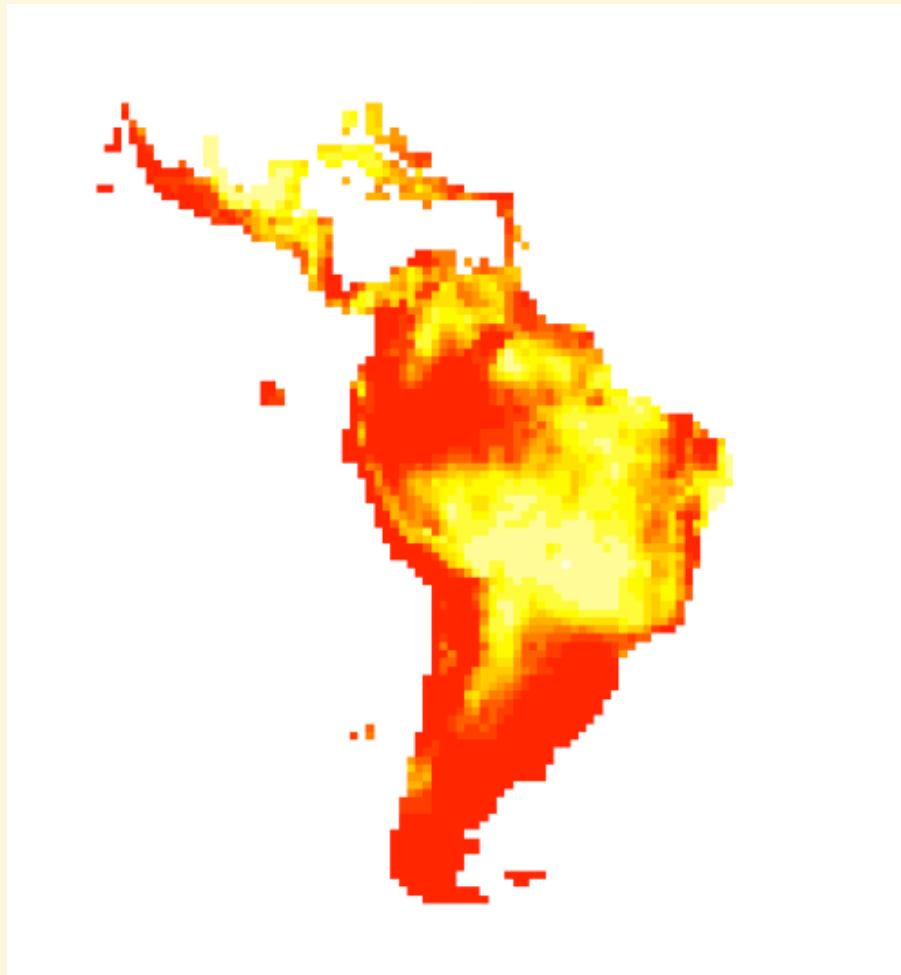
# Model errors



# Confusion matrix

	Pred. Present	Pred. Absent	Sum
Obs. Present	9	3	12
Obs. Absent	2	13	15
Sum	11	16	27

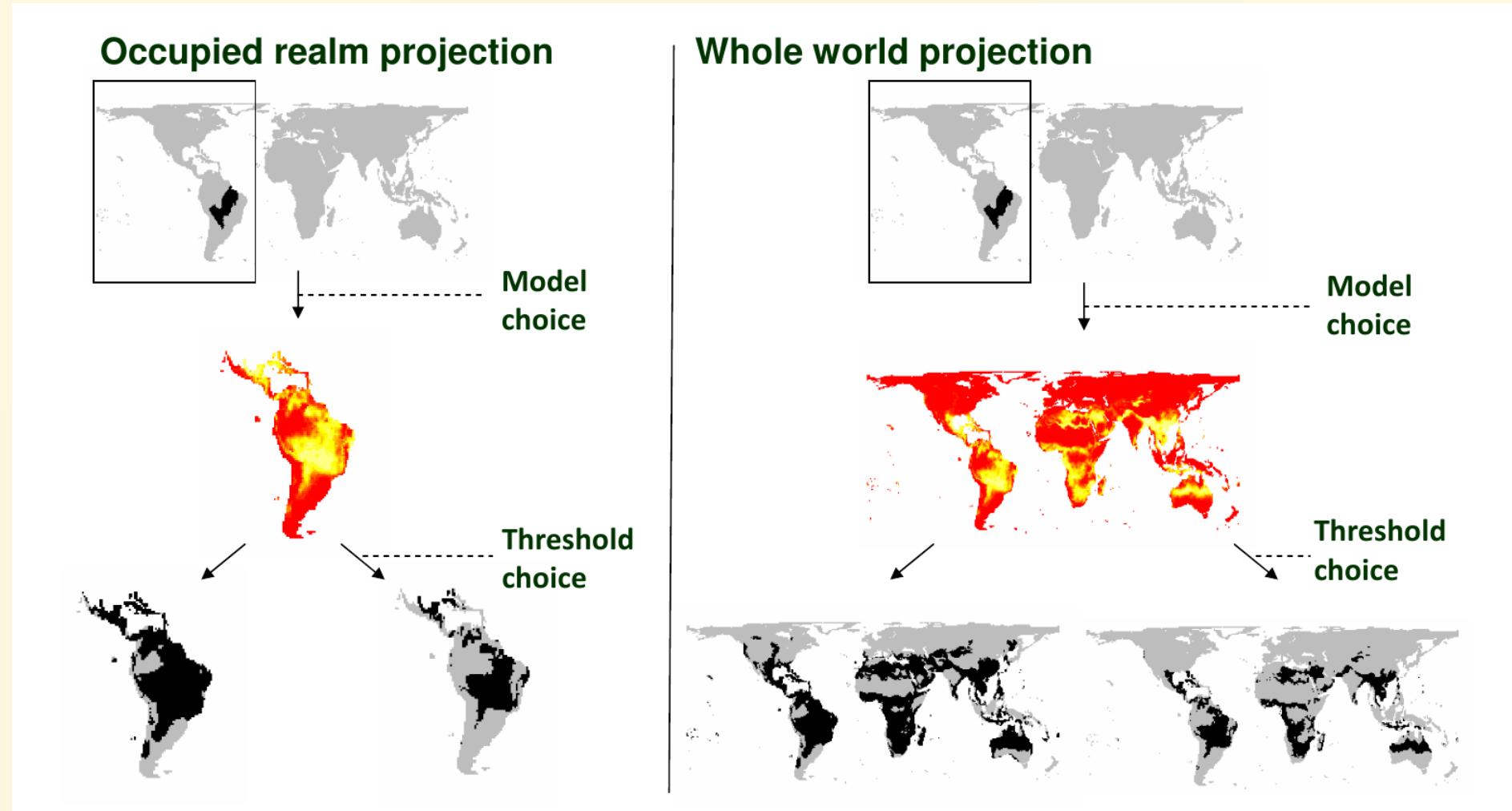
# Probability to presence



# Outline

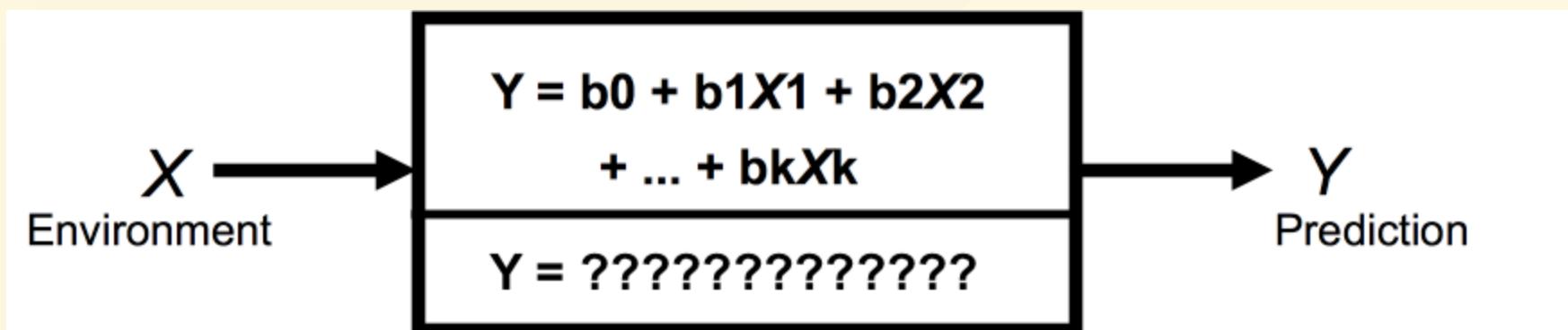
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# Model choices matter

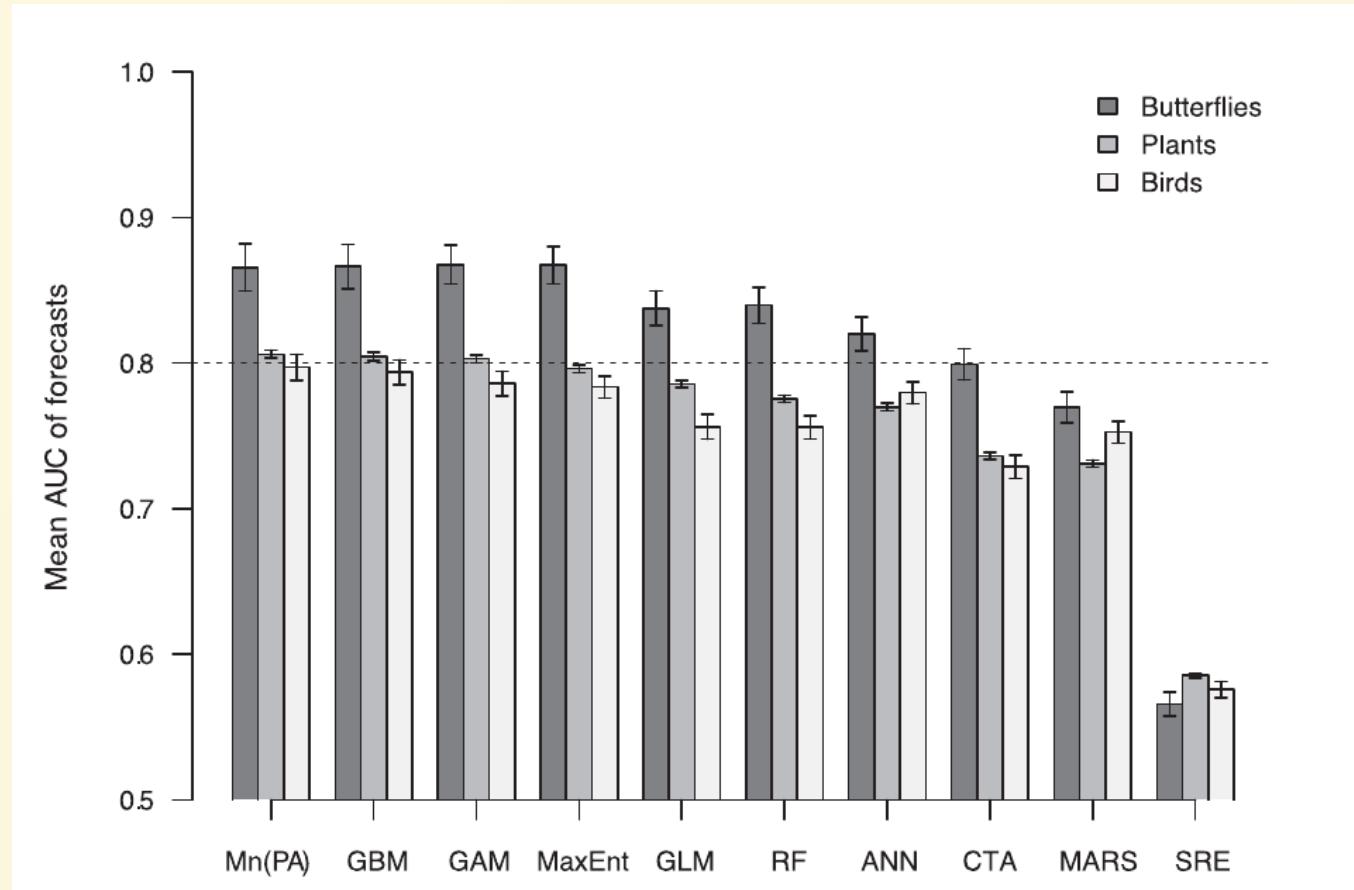


# Explain vs. Predict

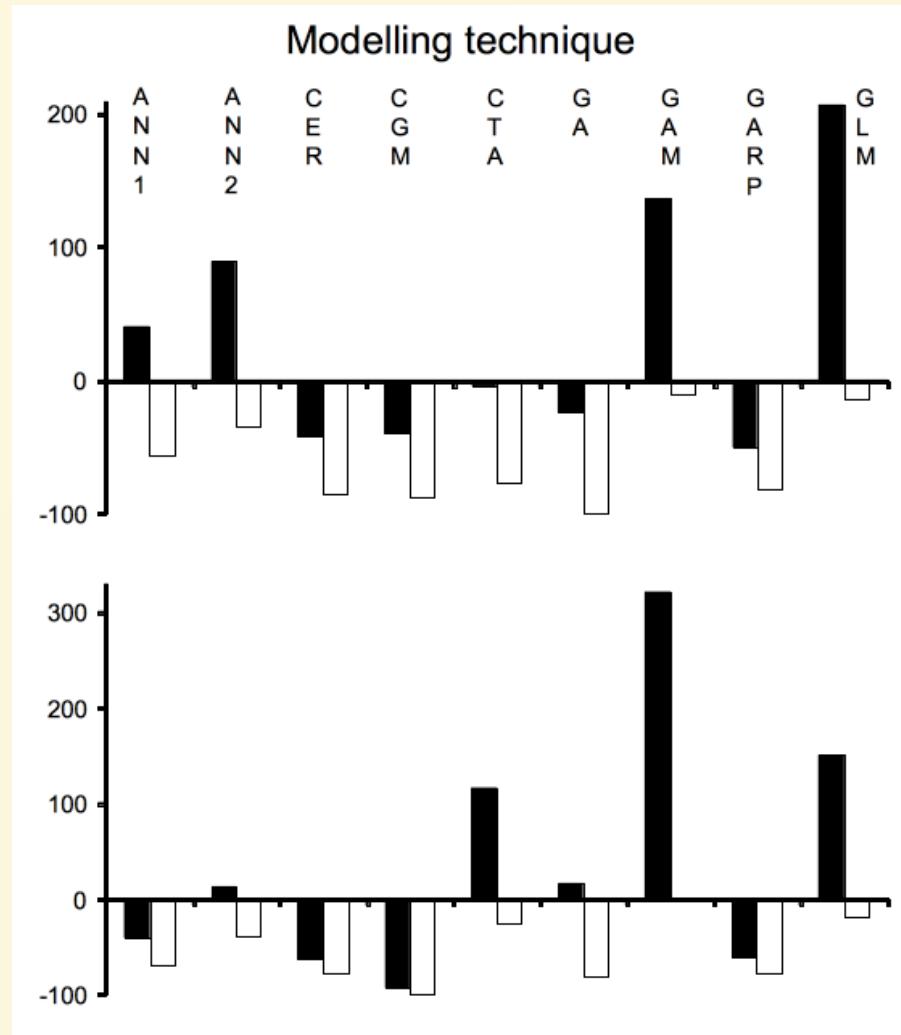
- Occam's razor: prefer a simple good explanation (model simplification)
- Prediction: prefer the best explanation even if elements are minor or unclear. Unavoidable with some methods.



# Model performance



# Model uncertainty



*D. divaricata*

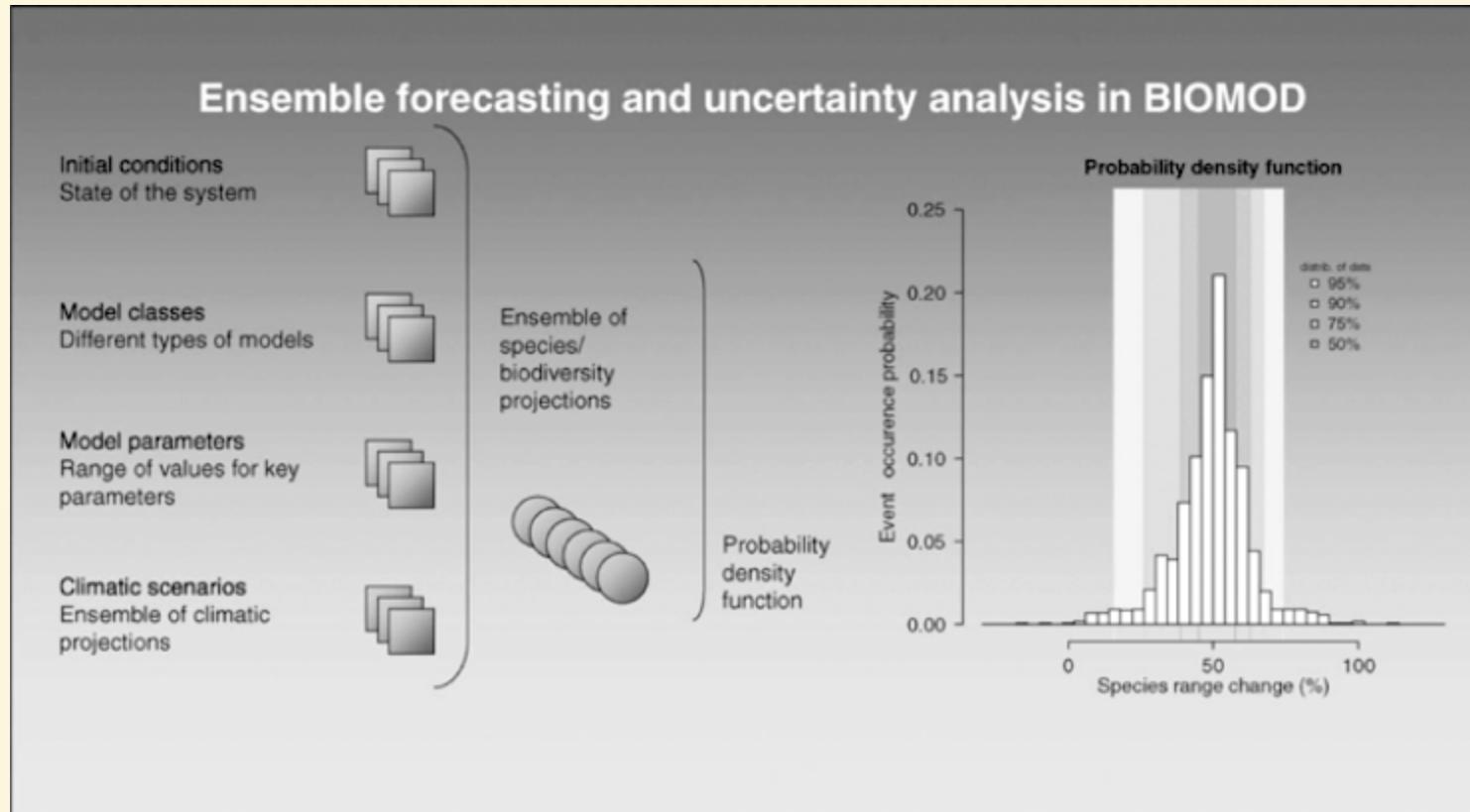


*L. hypophyllocarpodendrum*



Pearson et al., 2006 "Biogeography"

# Ensemble forecasting



Thuiller et al (2009) Ecography 32: 369 - 373

# Danger, Will Robinson

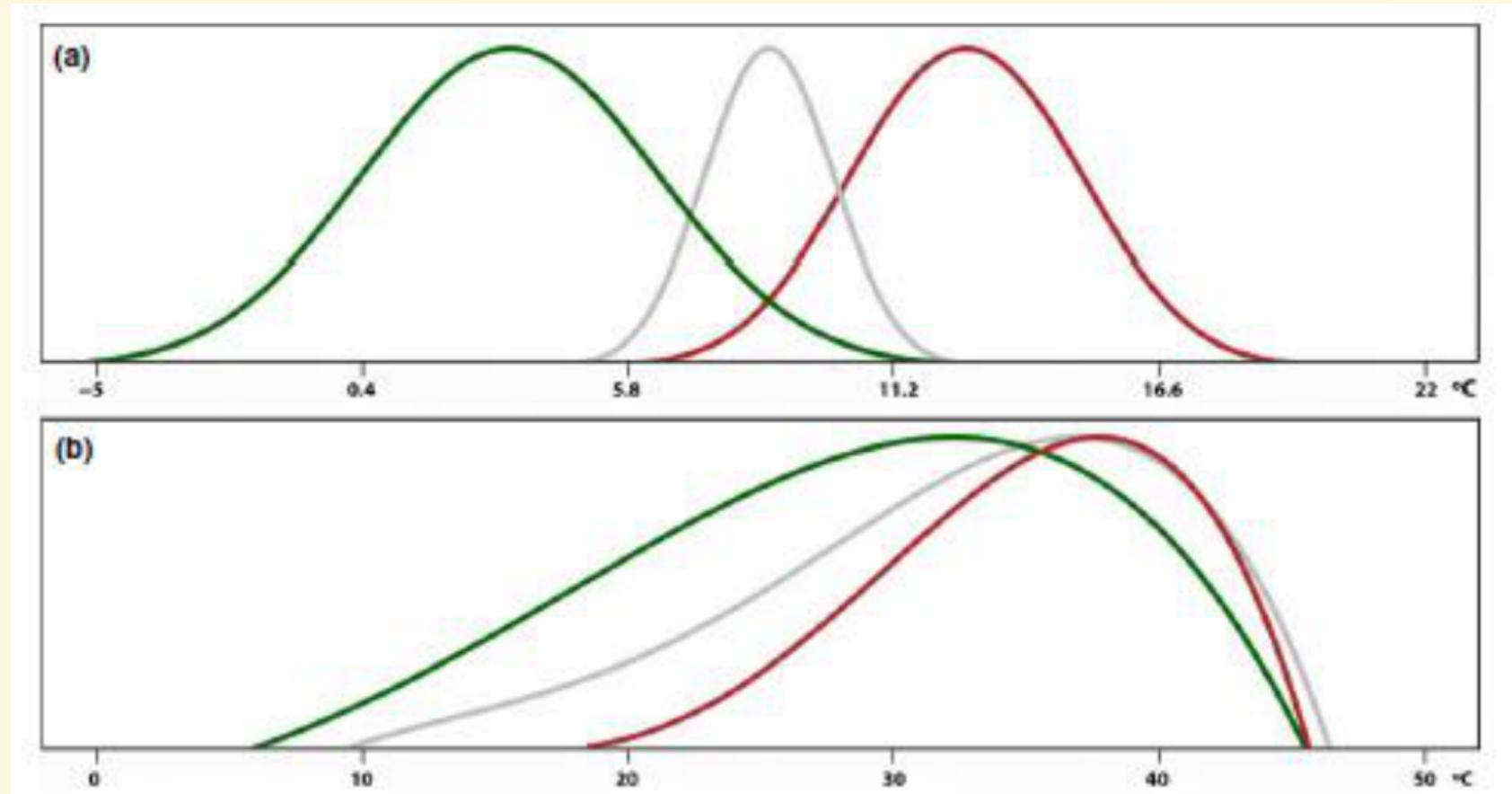
## Assumptions

- Appropriate data exist at a relevant scale
- Species are at equilibrium with their environment...

## Warnings

- Garbage in, garbage out
- Model extrapolation in time or space (transferability)
- The lure of complicated technology

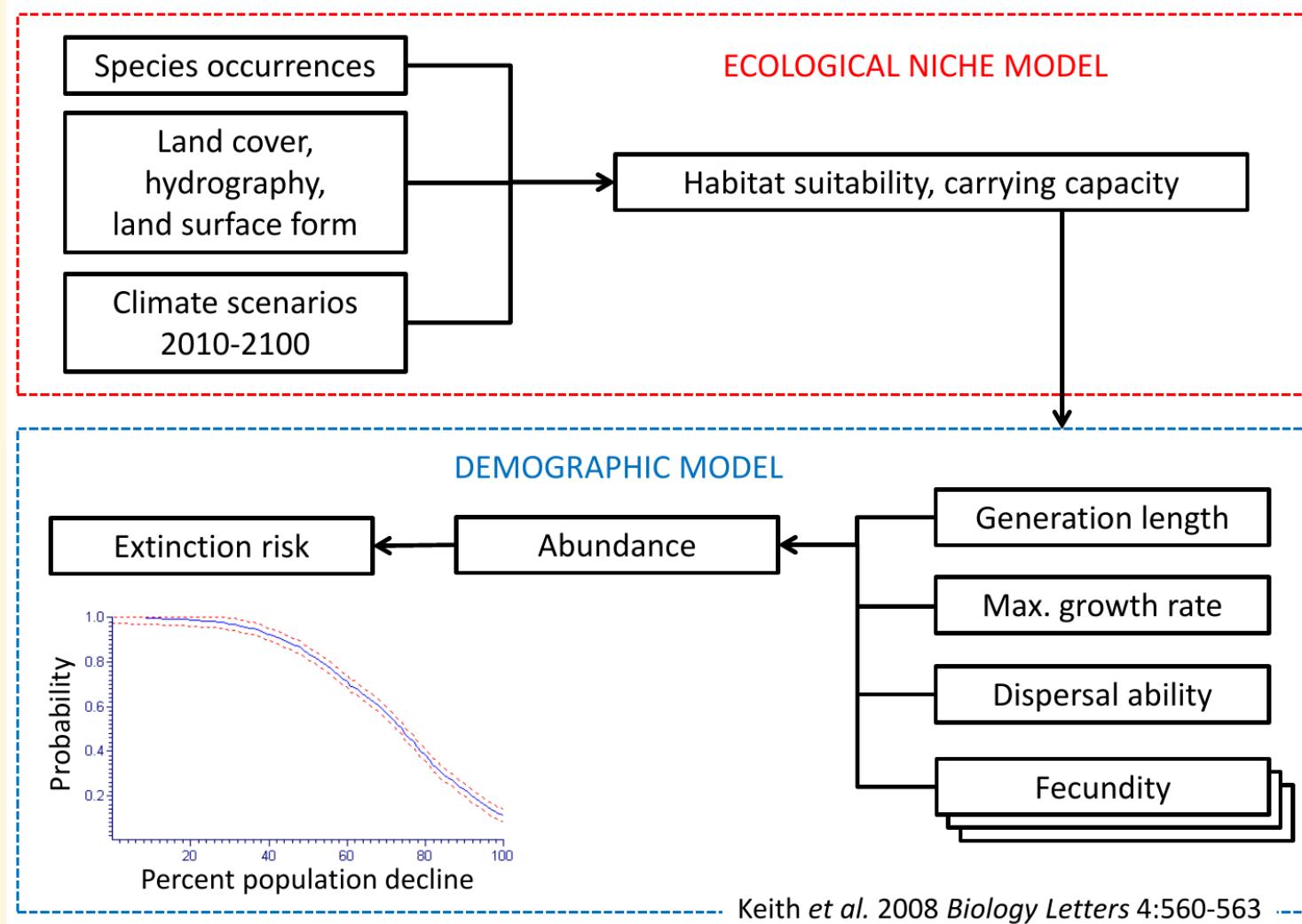
# Lab data



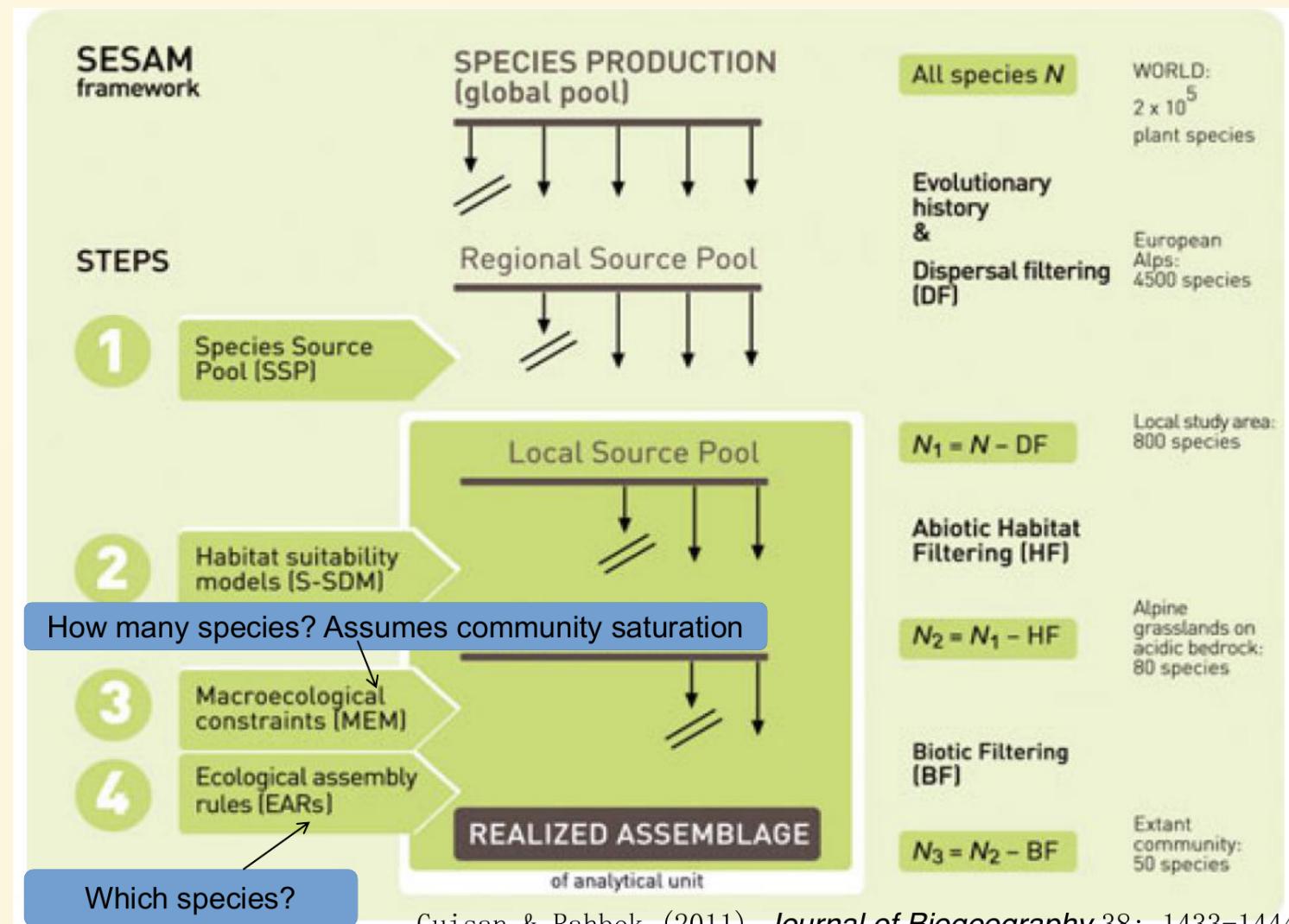
# Future directions

- Incorporating **dispersal**
- Incorporating **biotic** interactions
- More **mechanistic** models

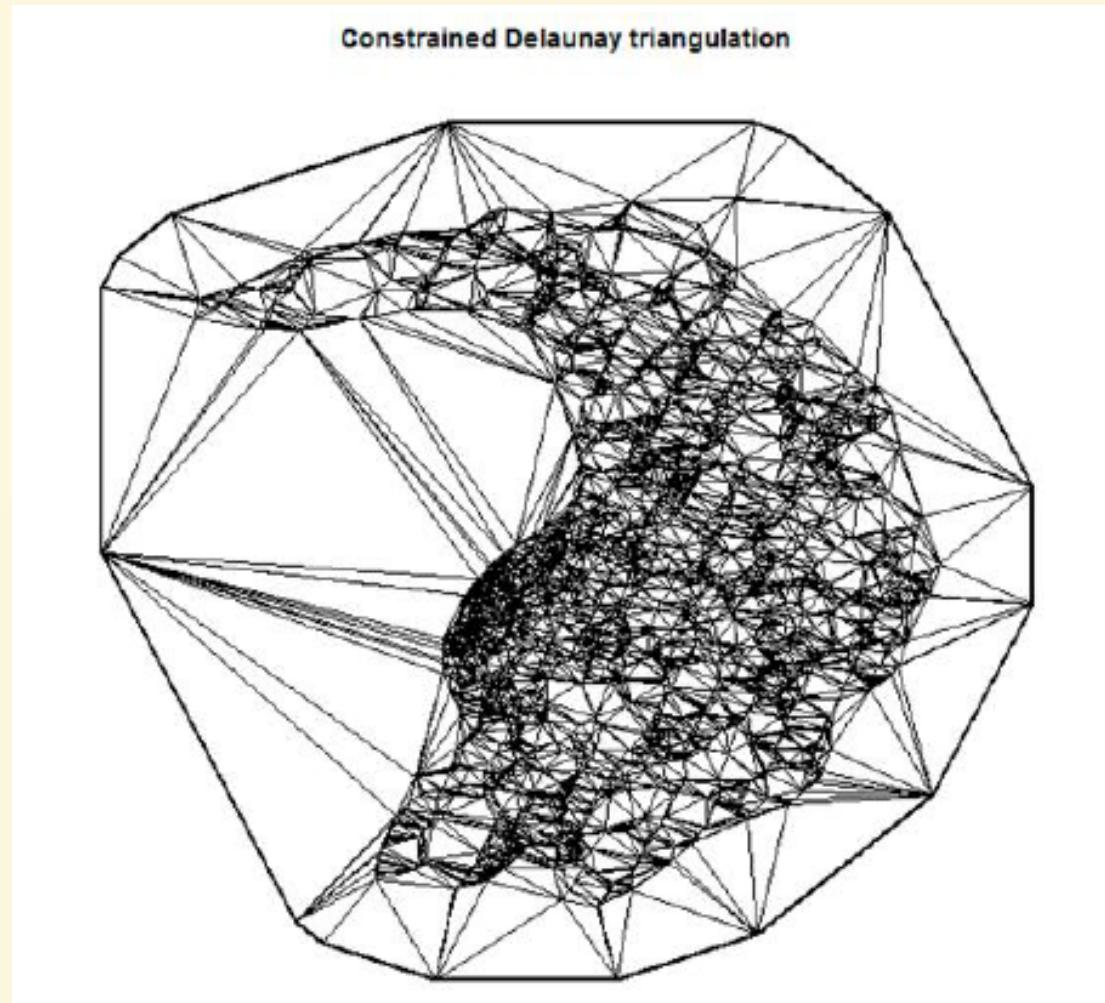
# Connect to demography



# Community assembly



# Bayes and spatial autocorrelation



Blangiardo et al 2013  
Spatial and spatio-temporal models with R-INLA. *Spatial and Spatio-temporal Epidemiology* 4:33-49

# General reading

- Franklin, J. (2009) Mapping species distributions: spatial inference and prediction Cambridge, Cambridge University Press.
- Guisan, A., and N. E. Zimmermann. (2000) Predictive habitat distribution models in ecology. Ecological Modelling, 135:147-186.
- Elith J, Graham CH: (2009) Do they? How do they? WHY do they differ? On finding reasons for differing performances of species distribution models. Ecography, 32:66–77.
- Beale, C.M. and Lennon, J.K. (2012) Incorporating uncertainty in predictive distribution modelling. Phil Trans R. Soc. B 367:247-258

# Applied examples

- Singh, N.J., Yoccoz, N.G., Bhatnagar, Y.V., Fox, J.L. (2009) Using habitat suitability models to sample rare species in high-altitude ecosystems: A case study with Tibetan argali. *Biodiversity and Conservation*, 18: 2893-2908.
- Nogués-Bravo D., Rodríguez J., Hortal J., Batra P., Araújo M. B. (2008) Climate change, humans, and the extinction of the woolly mammoth. *PLoS Biol*, 6, e79.
- Thomas, C. D., A. Cameron, R. E. Green, M. Bakkenes, L. J. Beaumont, Y. C. Collingham, B. F. N. Erasmus et al. (2004.) Extinction risk from climate change. *Nature* 427:145-148.
- Smolik, M. G., S. Dullinger, F. Essl, I. Kleinbauer, M. Leitner, J. Peterseil, L.-M. Stadler et al. (2009). Integrating species distribution models and interacting particle systems to predict the spread of an invasive alien plant. *Journal of Biogeography* 37:411-422.

# Methods background

- Guisan, A., T. C. Edwards, and T. Hastie. 2002. Generalized linear and generalized additive models in studies of species distributions: setting the scene. *Ecological Modelling* 157:89-100
- Thuiller, W., B. Lafaucade, R. Engler, and M. B. Araújo. 2009. BIOMOD - a platform for ensemble forecasting of species distributions. *Ecography* 32:369 - 373.
- Elith, J., J. R. Leathwick, and T. Hastie. 2008. A working guide to boosted regression trees. *Journal of Animal Ecology* 77:802-813.
- Phillips, S. J., R. P. Anderson, and R. E. Schapire. 2006. Maximum entropy modeling of species geographic distributions. *Ecological Modelling* 190:231-259.