# Introduction to species distribution modelling

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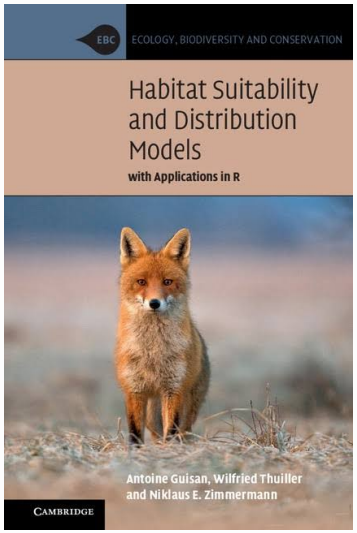
# Outline

- What limits species‘ distributions?
- Formal definitions of ecological niche
- Species distribution models - SDMs
  - Typical applications of SDMs
  - Modelling workflow

# Literature

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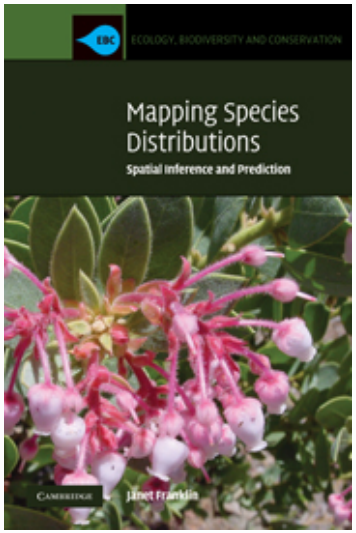


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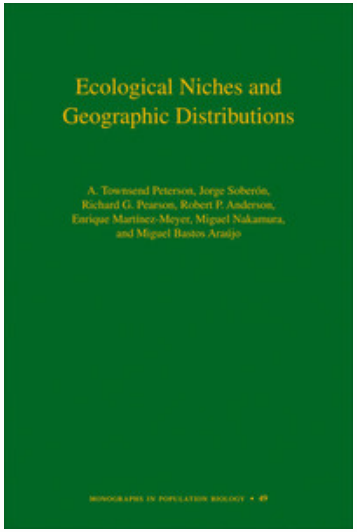


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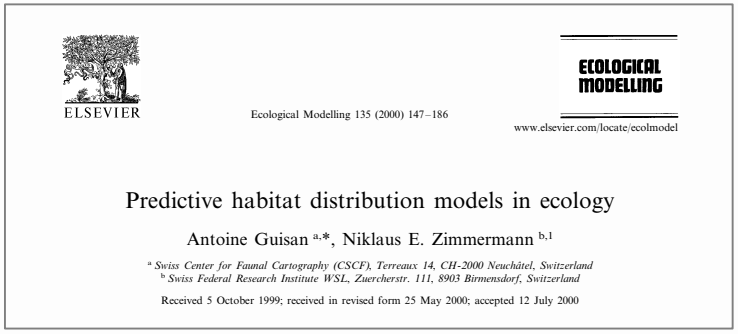
ELSEVIER

Ecological Modelling 135 (2000) 147–186

ECOLOGICAL MODELLING

www.elsevier.com/locate/ecolmodel

Predictive habitat distribution models in ecology

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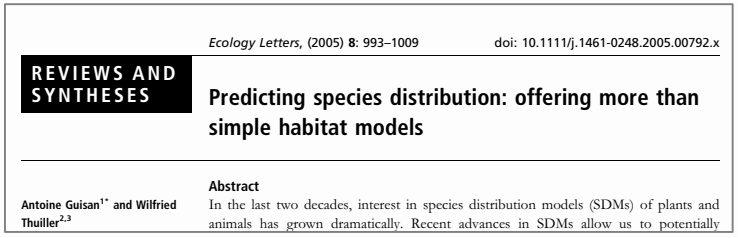

*Ecology Letters*, (2005) **8**: 993–1009 doi: 10.1111/j.1461-0248.2005.00792.x

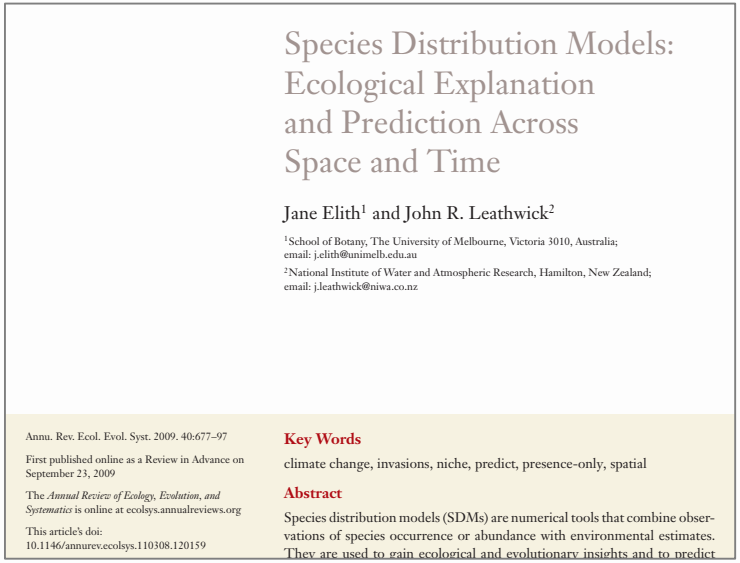
REVIEWS AND SYNTHESES

**Predicting species distribution: offering more than simple habitat models**

Antoine Guisan[1*] and Wilfried Thuiller[2,3]

**Abstract**

In the last two decades, interest in species distribution models (SDMs) of plants and animals has grown dramatically. Recent advances in SDMs allow us to potentially


Species Distribution Models: Ecological Explanation and Prediction Across Space and Time

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**Key Words**

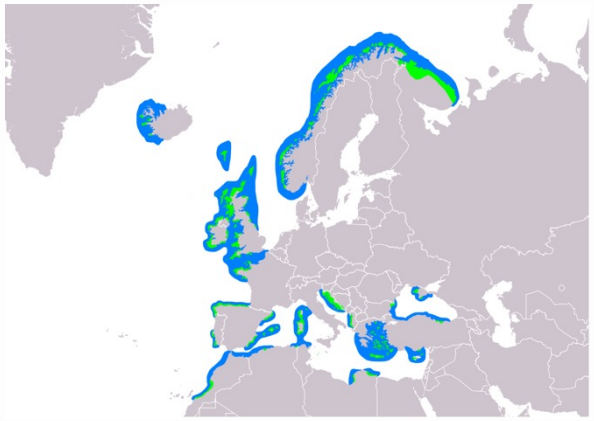
climate change, invasions, niche, predict, presence-only, spatial

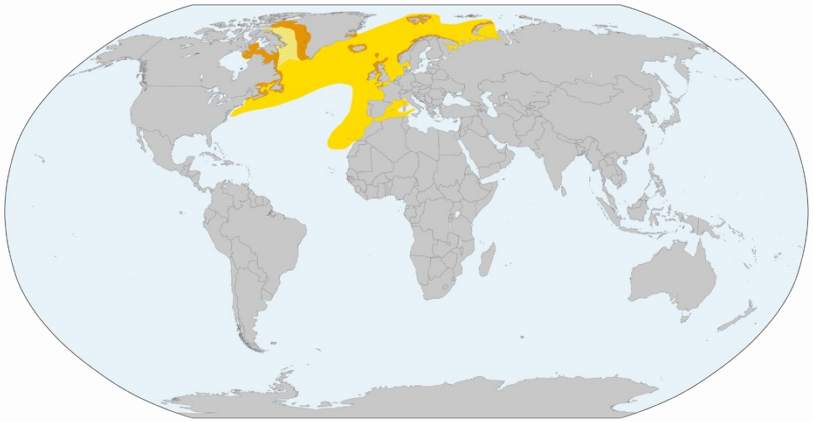
**Abstract**

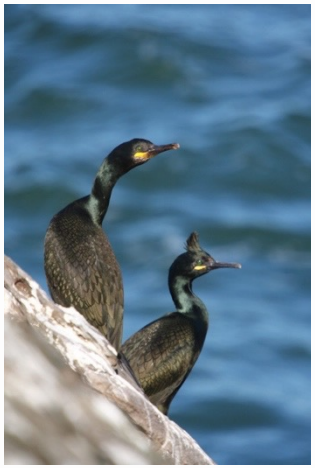
Species distribution models (SDMs) are numerical tools that combine observations of species occurrence or abundance with environmental estimates. They are used to gain ecological and evolutionary insights and to predict

# What limits species‘ distributions?

- Species do not occur everywhere

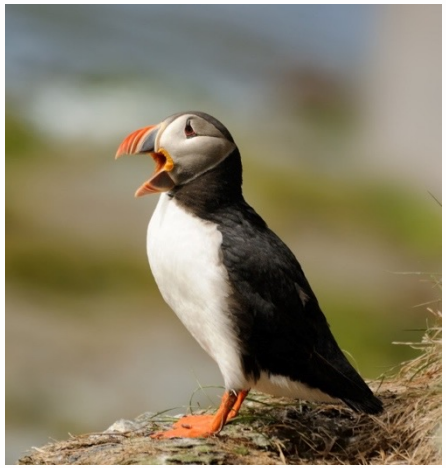






European Shag

Atlantic Puffin



Maps from Wikipedia.org
Pictures from iucnredlist.org

# What limits species‘ distributions?

- Species do not occur everywhere
- Most species have tolerance limits to environmental factors beyond which they cannot survive, grow or reproduce

- Abiotic factors: climate, physical barriers, lack of resources, disturbances
- Biotic factors: Competition, predation, parasites
- (Population dynamics at range margins)

# Range limits and species‘ niches

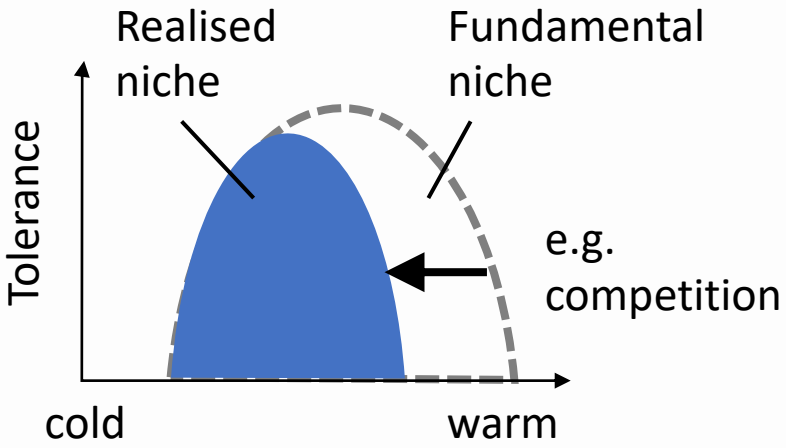
Pole

Realised distribution

Potential distribution

Equator

*Geographic space*




*Environmental space*

# Range limits and species‘ niches

- Hutchinson‘s niche theory: two main factors that limit species’ ranges

1. The **abiotic environment** that determines the **fundamental niche** of a species

2. The **biotic environment** that comprises all **interactions** with other species

Soberon (2007) Ecology Letters 10: 1115-1123.

# Range limits and species‘ niches

- Hutchinson‘s niche theory:

1. The **fundamental niche** is the n-dimensional hyperspace comprising all environmental conditions where a species has a **positive population growth rate** and can **persist** indefinitely

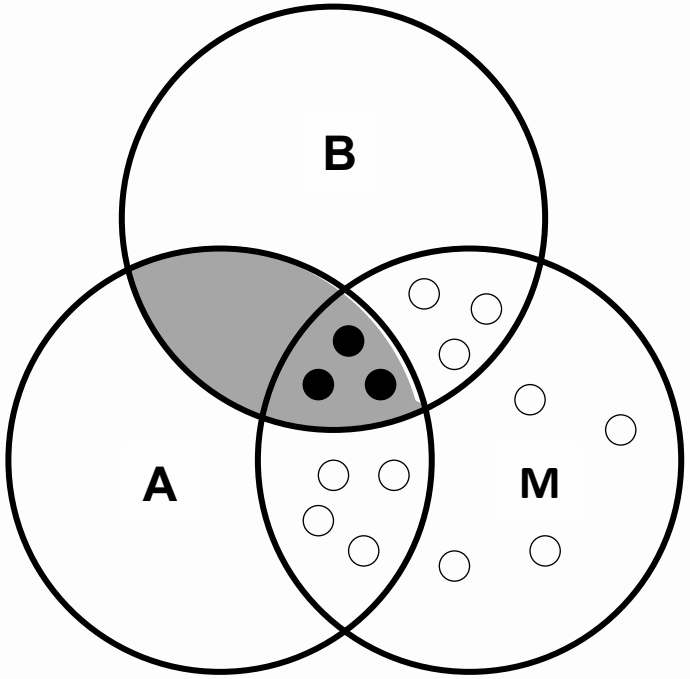
2. The biotic environment determines if a species can prevail in the presence of other species. The intersection between abiotic and biotic environment is usually referred to as the **realised niche**.

Soberon (2007) Ecology Letters 10: 1115-1123.

# Range limits and species‘ niches

- Hutchinson‘s niche theory:
  - A .. Abiotic environment
  - B .. Biotic environment
  - ■ Realised niche

- Source-sink and metapopulation dynamics:
  - M .. Movement
  - ○ Sinks
  - ● Sources



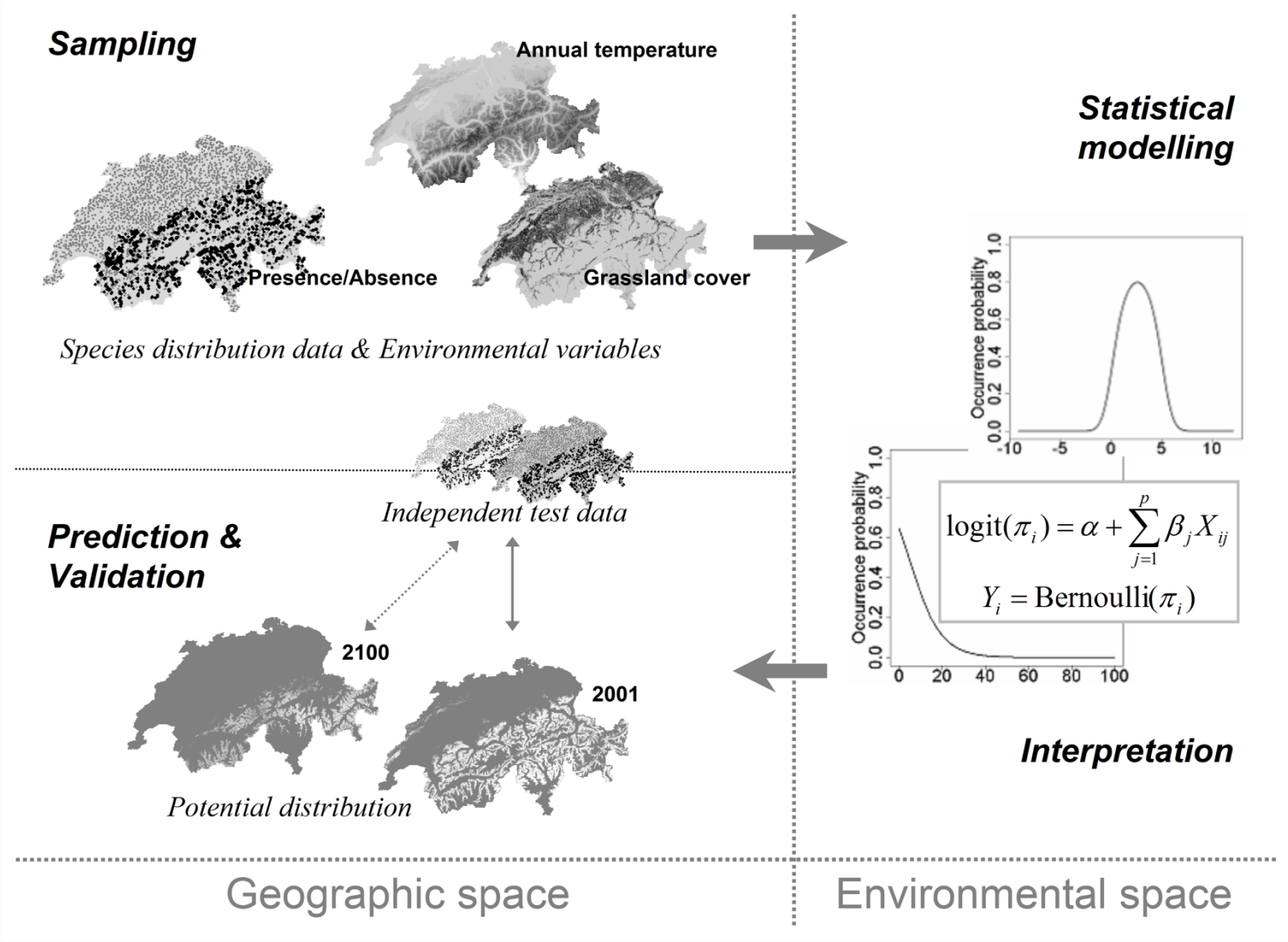

Soberon (2007) Ecology Letters 10: 1115-1123.

# From niche concept to species distribution models

- **Species distribution models (SDMs)** – many names:
  - Ecological niche model, species niche model, environmental niche model
  - Environmental (or climate) envelope model
  - Habitat model, Habitat suitability model
  - …

➔ These different names emphasise the debate of what is captured by SDMs: fundamental vs. realised vs. occupied niche

# Species distribution models (SDM)



# Species distribution models (SDM)

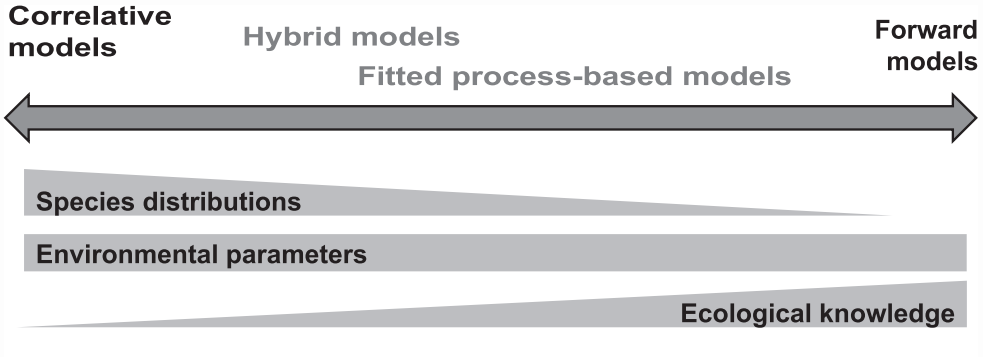
*Species = f(Environment)*

| | **Response** | **Predictor** | |
|---|---|---|---|
| **biotic** | *Response variable* | *Explanatory variable* | **abiotic, biotic** |
| | *Dependent variable* | *Independent variable* | |

# Species distribution models (SDM)

- **Correlation vs. causality**
  - Relate observed distribution of a species to prevailing environmental conditions to describe environmental requirements of that species
  - Top-down, often regarded as ‚black box‘

- As opposed to mechanistic models based on first principles, which incorporate physiological (and behavioural) constraints




Dormann et al. (2012) J Biogeogr 39: 2119-2131.

# SDM predictors

- We should prefer functionally relevant predictors!

## Proximal (causal)

### Resource

- Directly needed for metabolism
- Light, water, nutrients

### Direct

- Affect demography, but are not resource
- temperature, moisture, pH

## Distal/indirect (proxy)

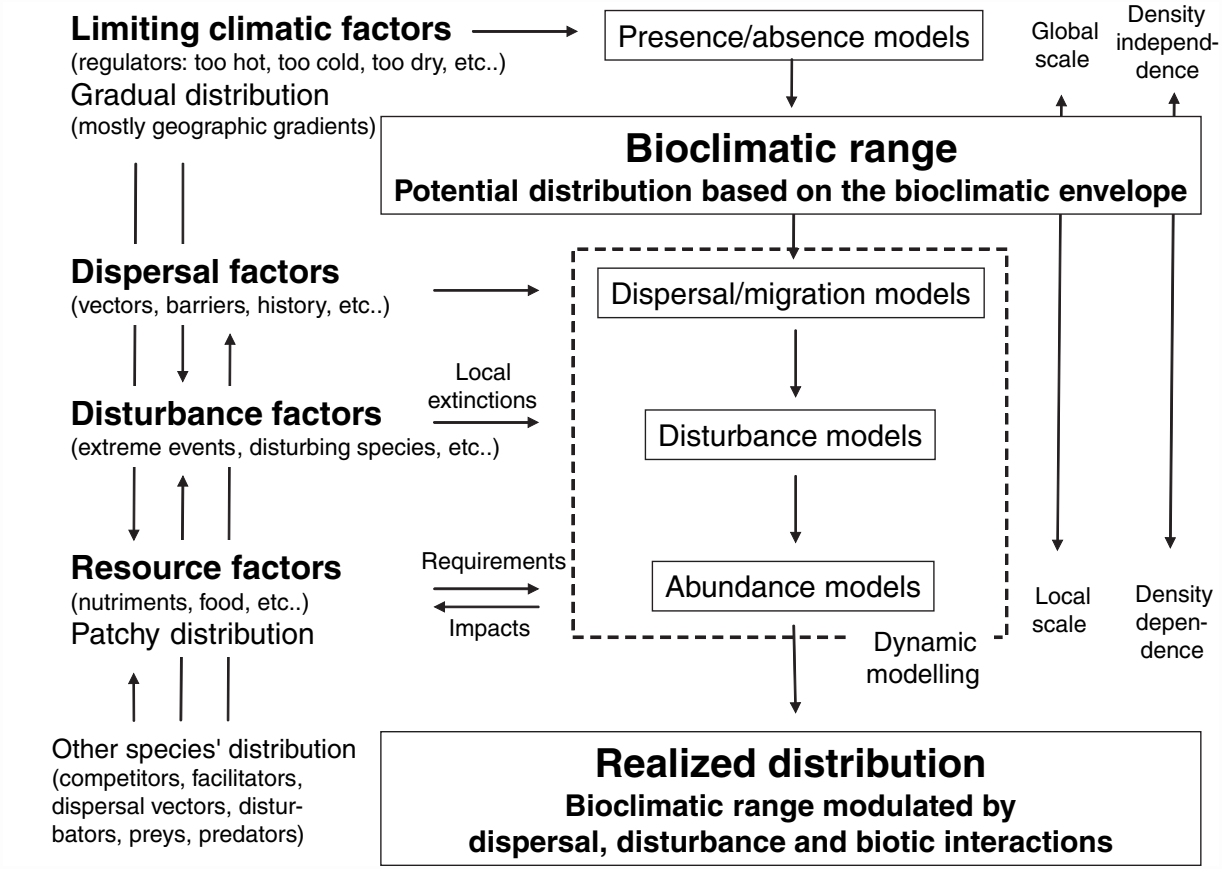
- No direct effect, but often highly correlated with proximal factors
- Altitude, slope, exposition, latitude

Use of ecologically relevant predictors greatly aided by GIS and remote sensing!

After: Austin 1980, 1985; Austin et al. 1984; Austin & Smith 1989

# SDM predictors and scale

- Hierarchical modelling framework



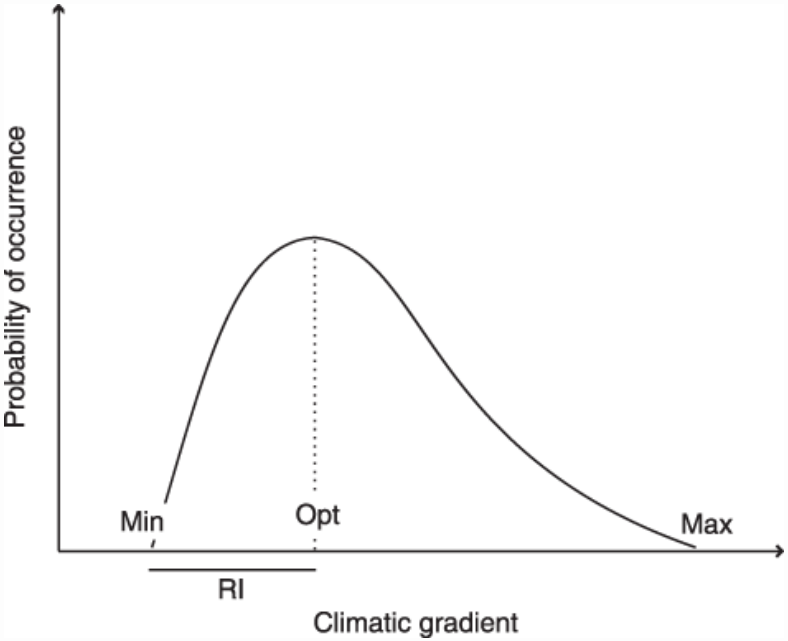

Guisan and Thuiller (2005) Ecology Letters 8: 993-1009.

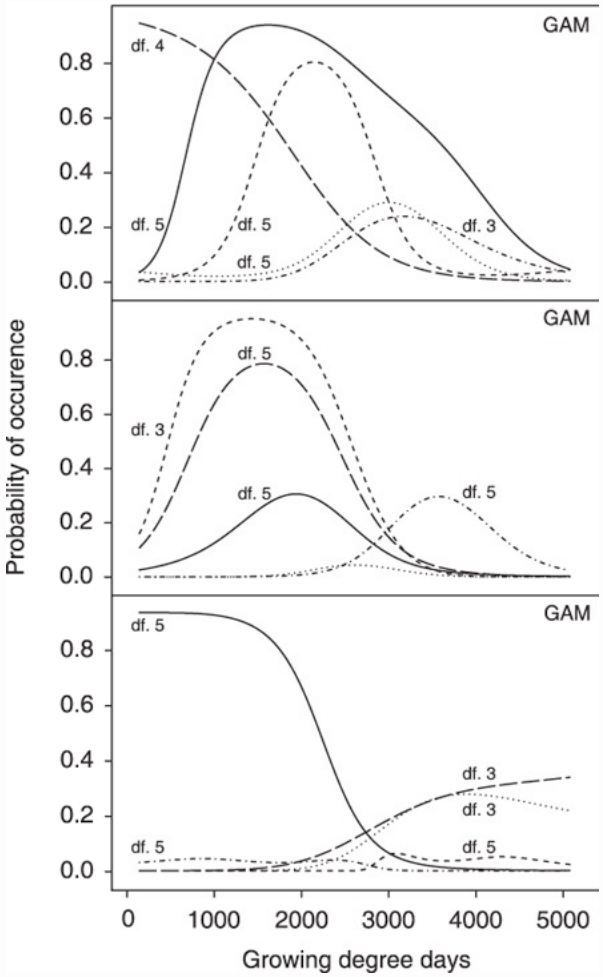
# SDM applications

- What are typical applications of SDMs?

# SDM applications

- Understanding species‘ biology
  - Quantifying abiotic and biotic constraints on species‘ niches
  - Testing hypotheses

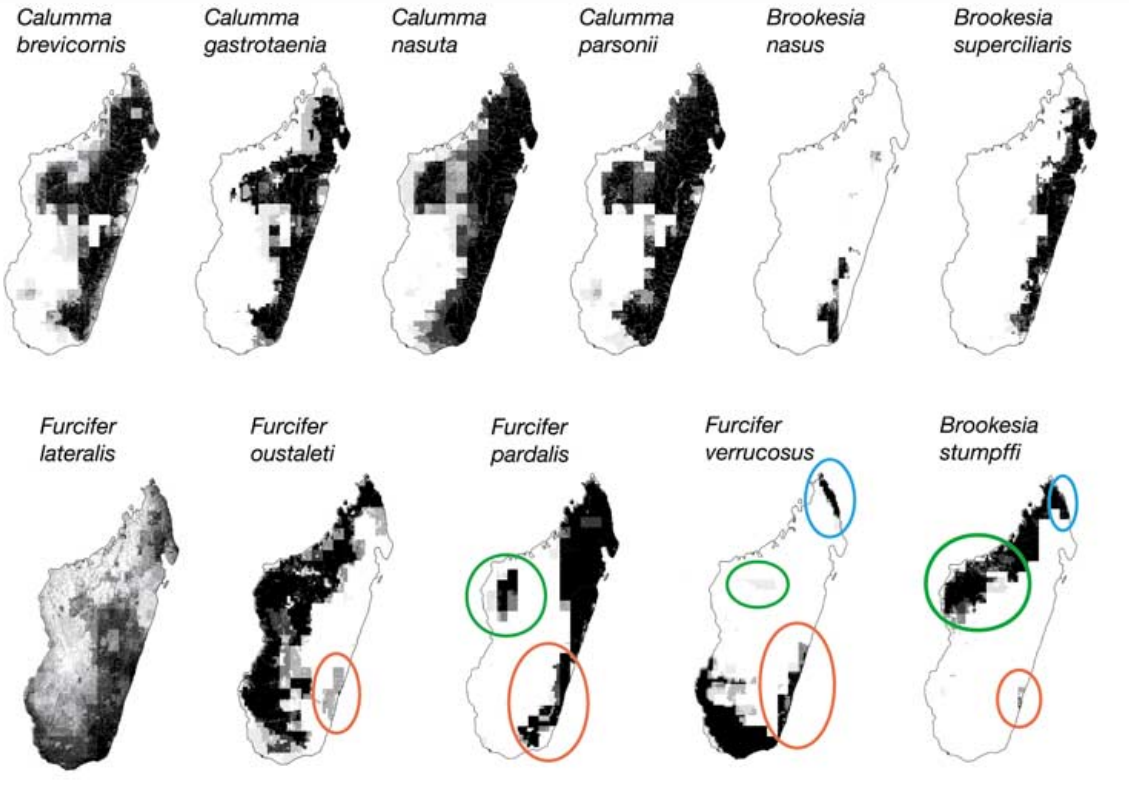



Normand et al. (2009) Glob Ecol Biogeogr 18: 437-449.

# SDM applications

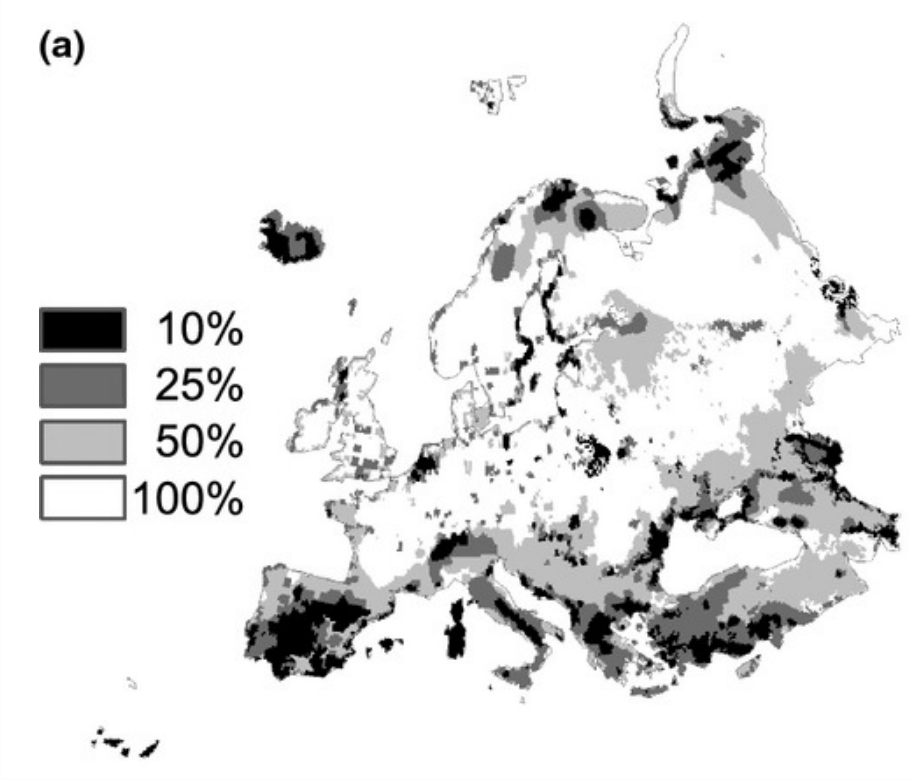
- Discovering biodiversity
  - Discovering populations, species limits, rare and unknown species
  - Guide survey design

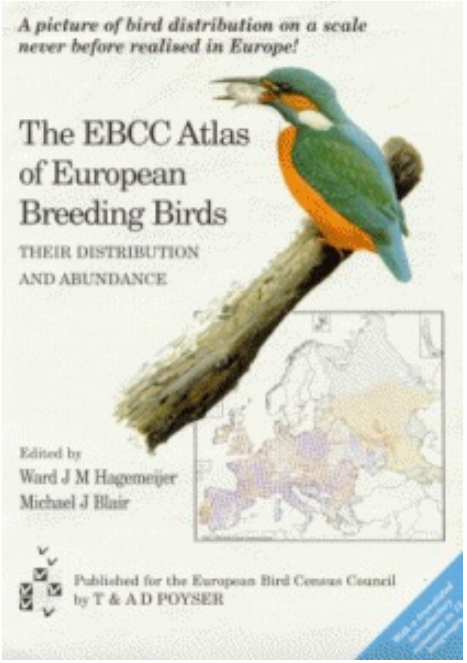



Raxworthy et al. (2003) Nature 426: 837-841.

# SDM applications

- Conservation planning & reserve selection

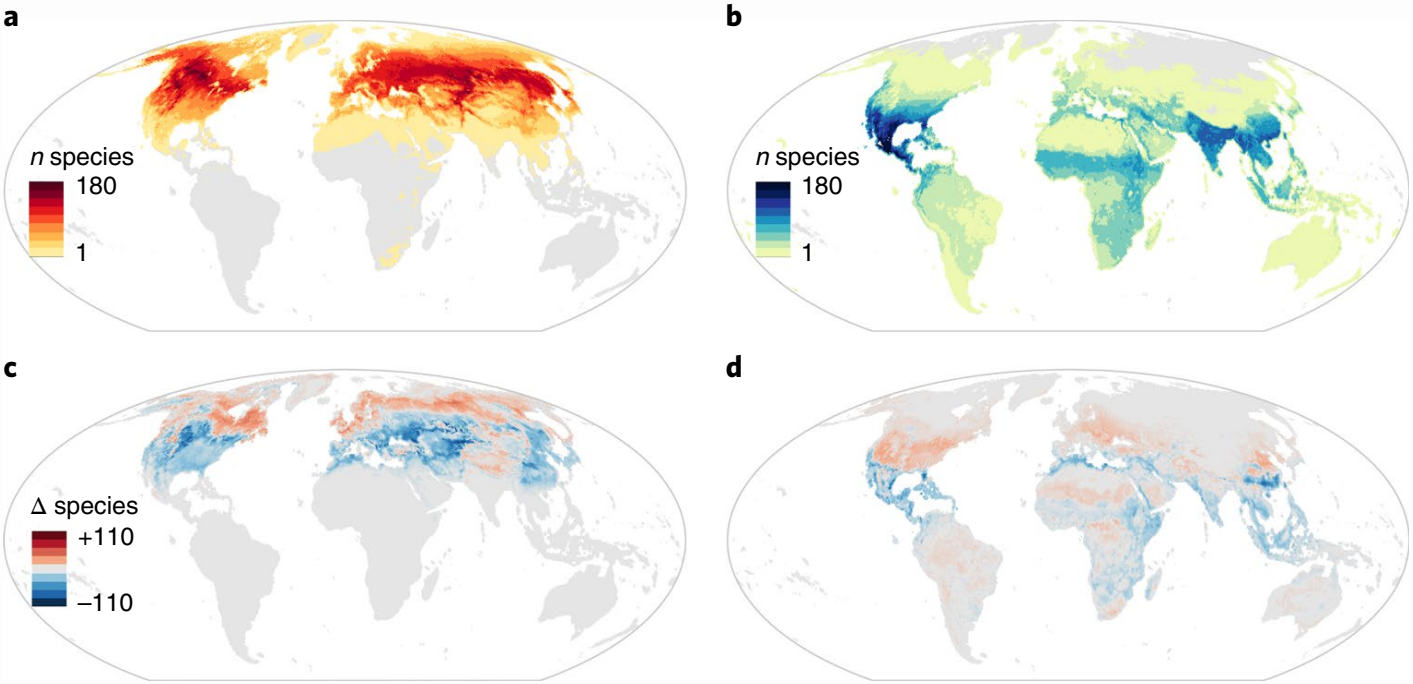



Meller et al. (2014) Div Distrib 20: 309-321.

# SDM applications

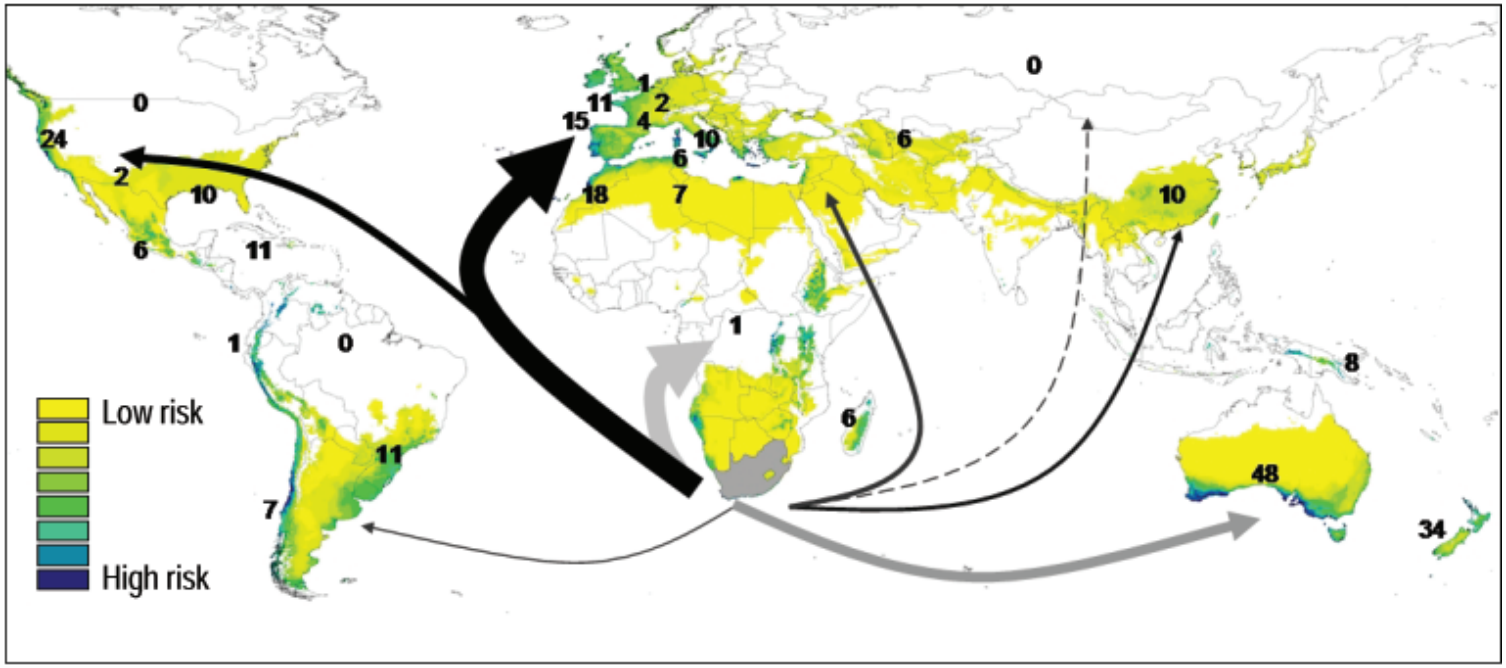
- Global change
  - Assessing impact of climate, land use and other environmental change drivers on species diversity




Zurell et al. (2018) Nature Clim Ch 8: 992-996.

# SDM applications

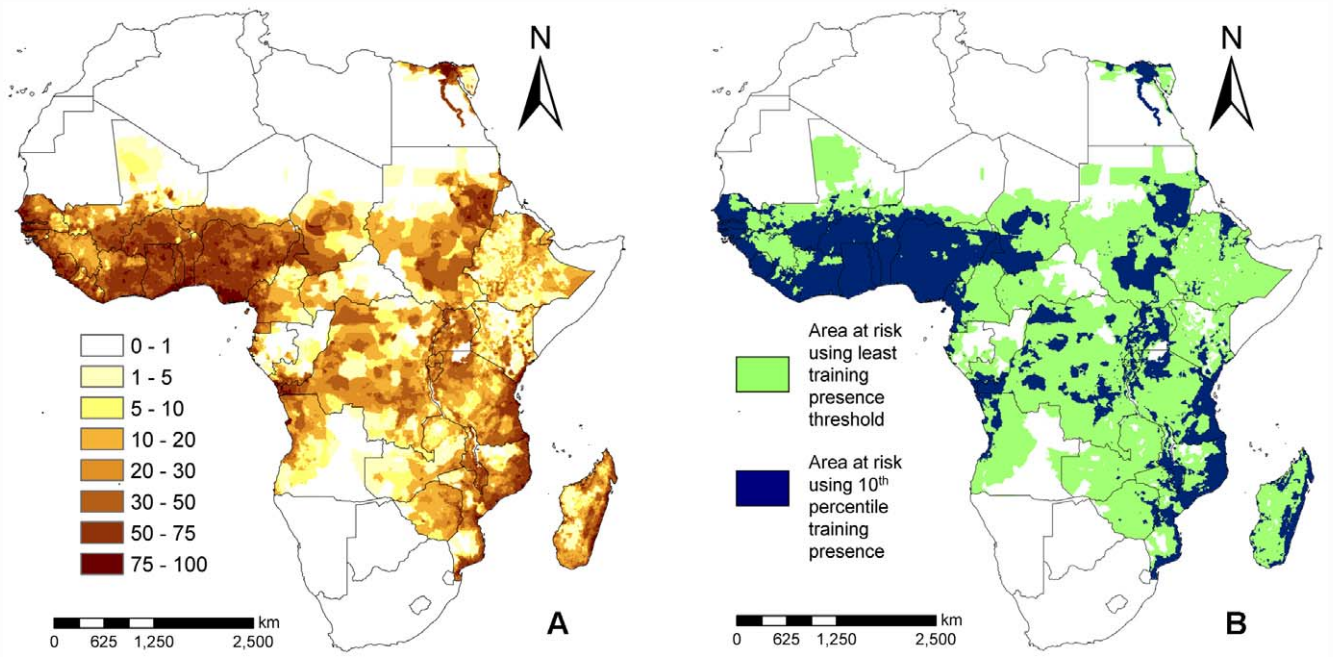
- Invasive species
  - Assessing species invasion risk




Thuiller et al. (2005) Global Change Biology 11: 2234-2250.

# SDM applications

- Epidemiology
  - Parasite ENMs for informing infection control

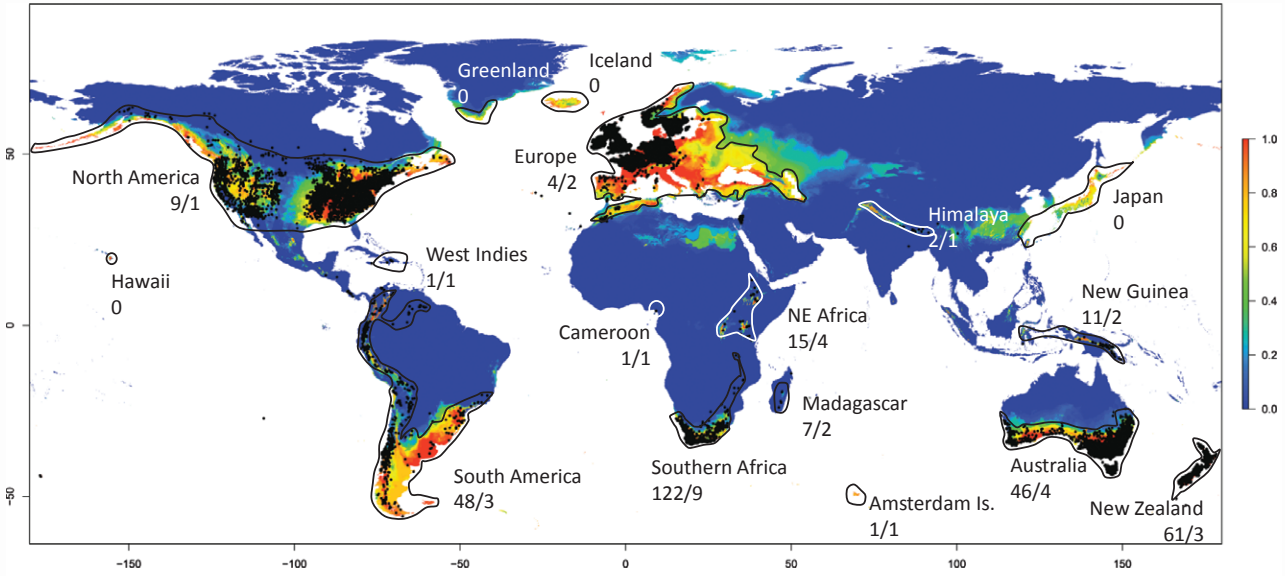



e.g. elephantiasis

Slater and Michael (2012) Plos ONE 7: e32202.

# SDM applications

- Historic biogeography
  - Better understand niche diversification, range (in)filling, disjunction ...



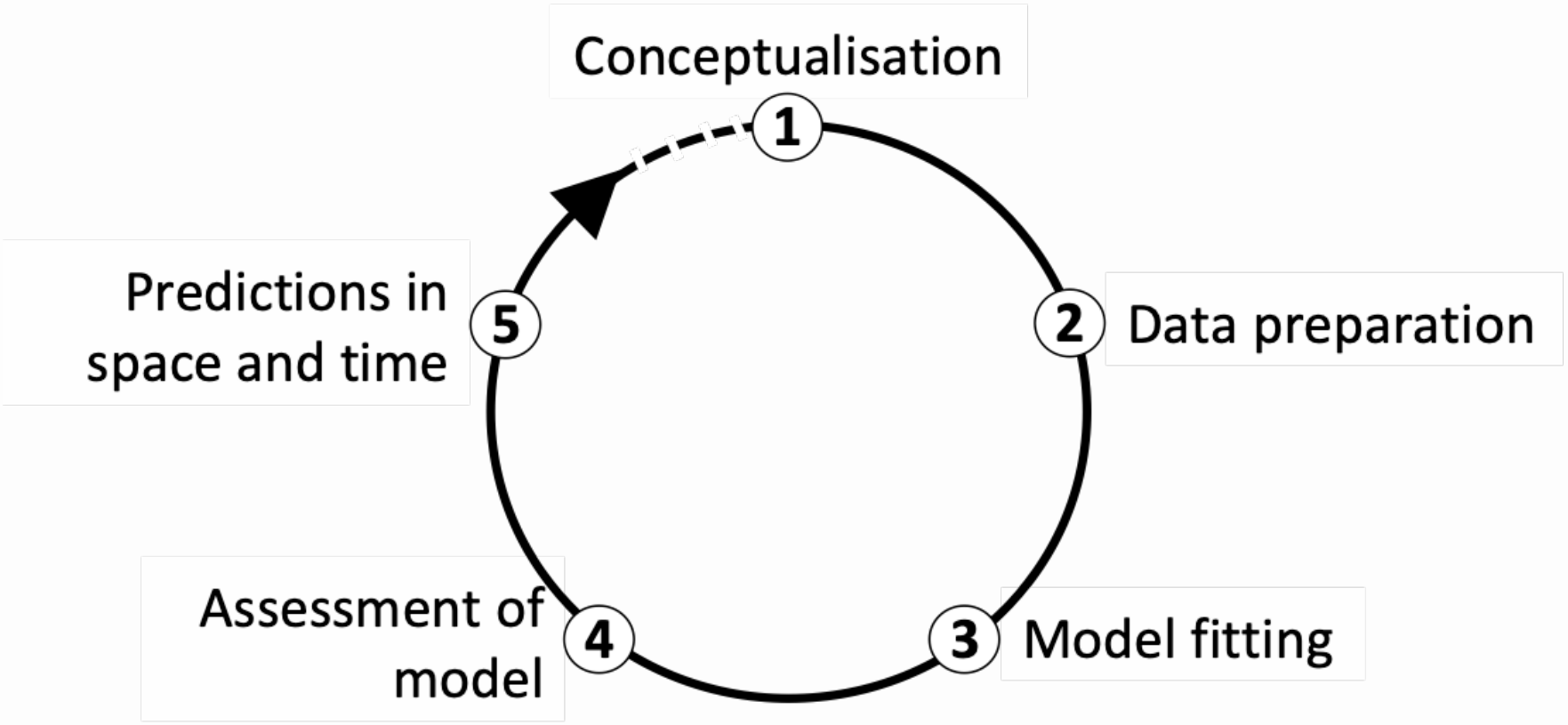

e.g. danthonioid grasses, c. 250 spp

Linder et al. (2013) Journal of Biogeography 40: 821-834.

# SDMs – model building steps

- What are the main modelling steps in SDMs?

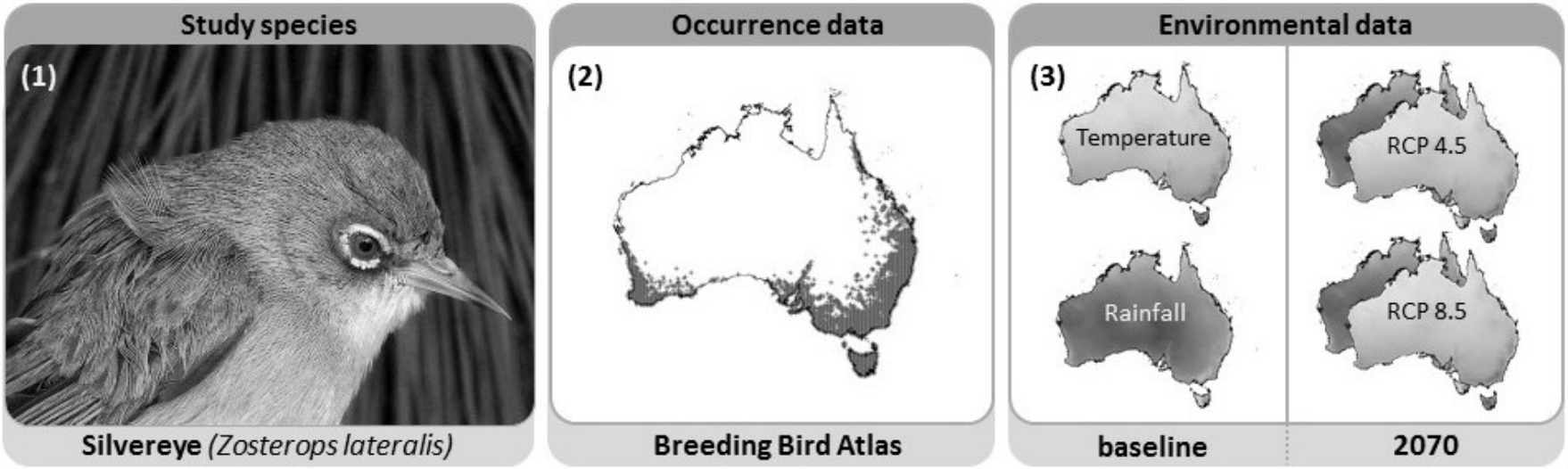
# SDMs – model building steps




Zurell et al. (2020) Ecography 43: 1261-1277.

# SDMs – model building steps

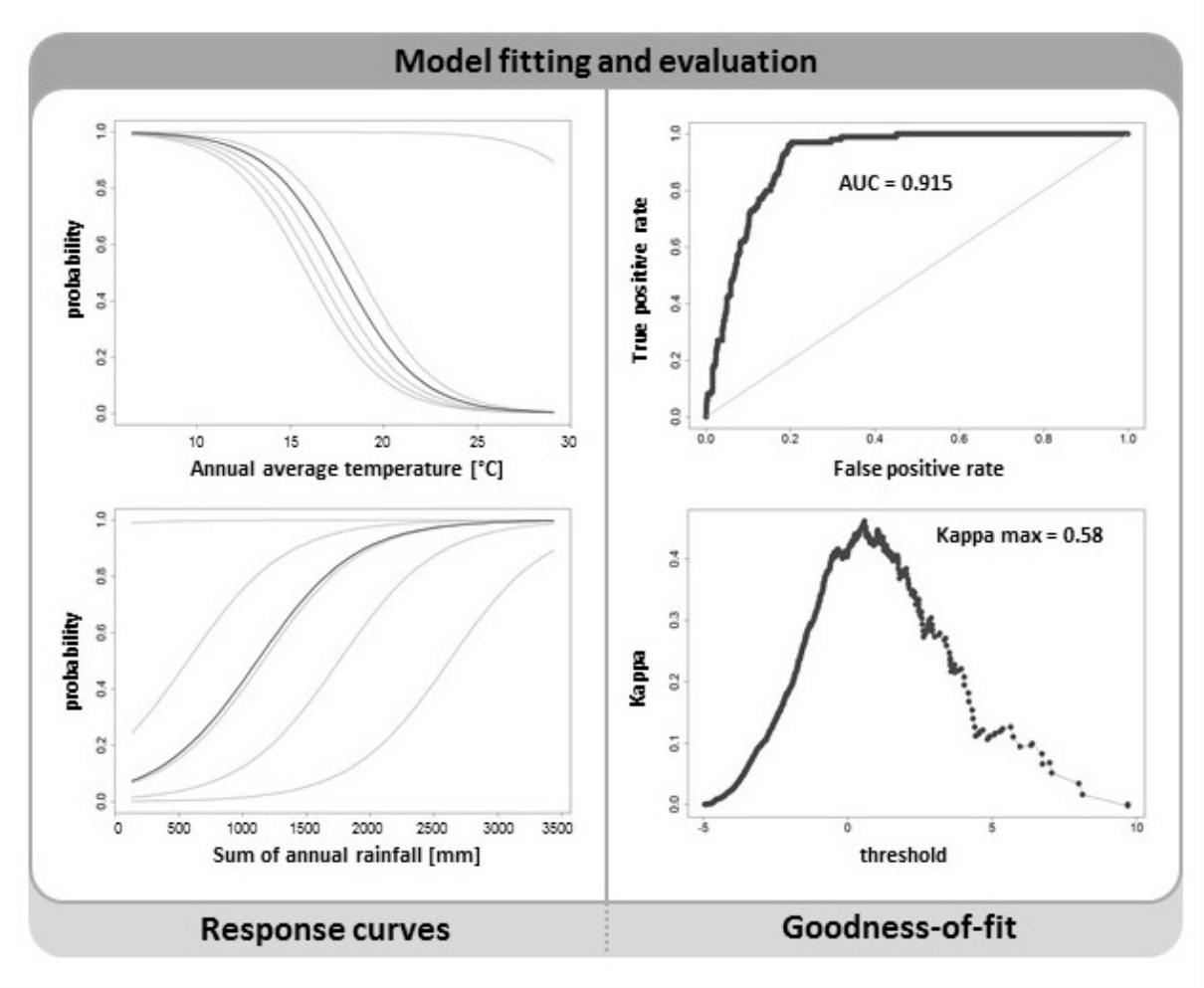
- Conceptualisation and data preparation




Zurell & Engler (2019) in Dunn & Møller (eds) Oxford Univ. Press.

# SDMs – model building steps

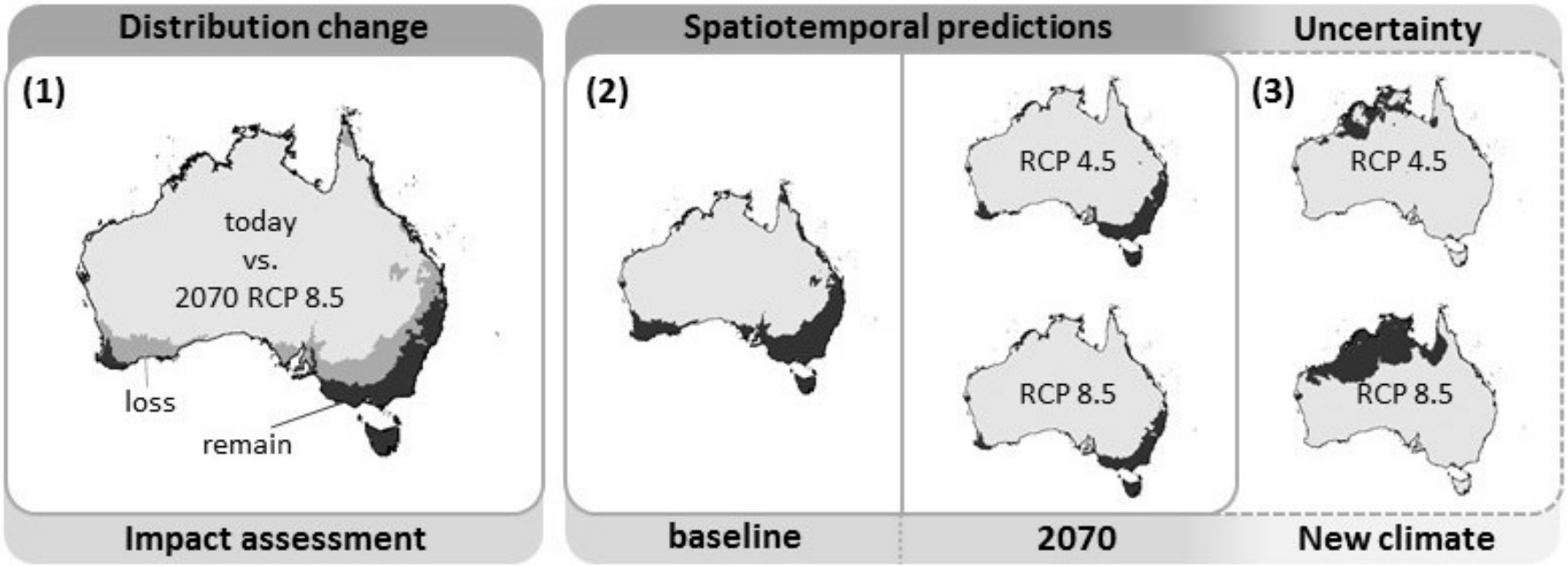
- Model fitting and model assessment (evaluation)




Zurell & Engler (2019) in Dunn & Møller (eds) Oxford Univ. Press.

# SDMs – model building steps

- Predictions in space and time




Zurell & Engler (2019) in Dunn & Møller (eds) Oxford Univ. Press.

# SDM assumptions

- Species niche is stable = in equilibrium  with environment
- Distribution primarily determined by (abiotic) environment
- As a result, a species can be found +/- wherever the environment is suitable
- Conceptual considerations tell us that this is not always true
  ➔ some species will be modelled more easily than others

# SDM assumptions

| Assumption | Description |
|---|---|
| Species–environment equilibrium | Species fill their niche and do not occur elsewhere |
| No observation bias issues | Species data are free from observational bias (sampling bias, imperfect detection), or it is accounted for in the model |
| Independence of species observations | Each species record represents new information (e.g. not the same individual reported twice) |
| Availability of all important predictors | Key explanatory variables are available and incorporated in the model; ideally these should be *proximal* predictors, particularly when the objective is model transfer |
| Predictors are free of error | Predictors are measured (or estimated) without error |
| Niche stability/constancy, Niche conservatism | Species retain their niches across space and time; particularly relevant when transferring predictions |
| No other extrapolation issues | Relationship fitted under current conditions apply when transferring predictions, even when projected beyond the range of the training data; No change in correlation structure of environmental variables; No change in key limiting processes (e.g. biotic interactions) |

Zurell et al. (2020) Ecography 43: 1261-1277.

# Pitch your project

What is your research about?

Could SDMs be useful in your research project?