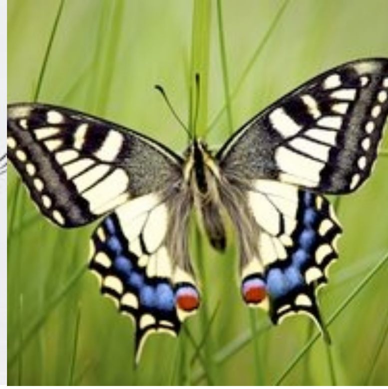

Introduction to species distribution modelling

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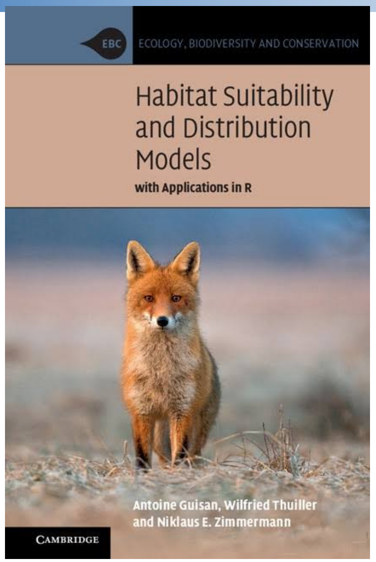
Pictures from www.undekade-biologischevielfalt.de

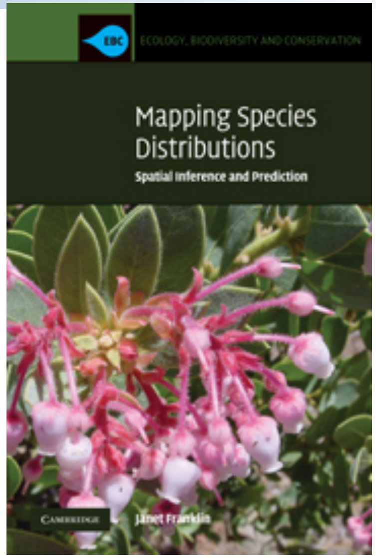
Outline

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

Literature



DOI: 10.1017/9781139028271



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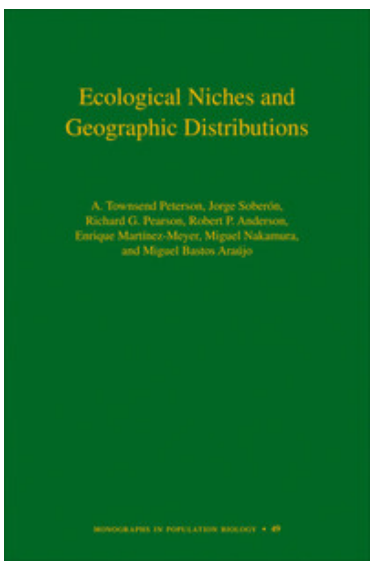

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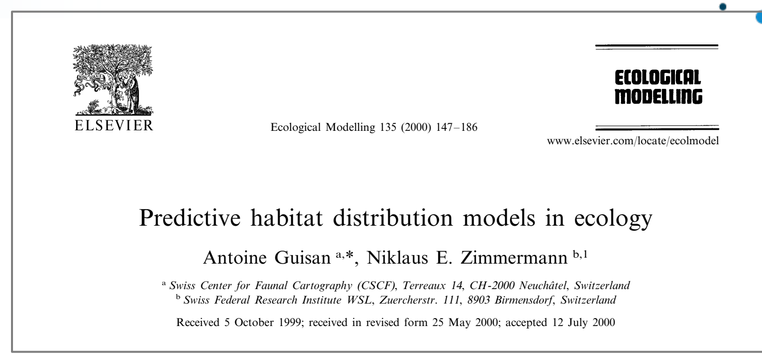

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Ecological Modelling 135 (2000) 147–186

ECOLOGICAL MODELLING

www.elsevier.com/locate/ecolmodel

Predictive habitat distribution models in ecology

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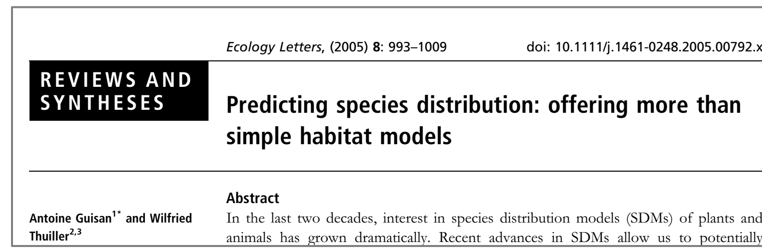


Ecology Letters, (2005) **8**: 993–1009 doi: 10.1111/j.1461-0248.2005.00792.x

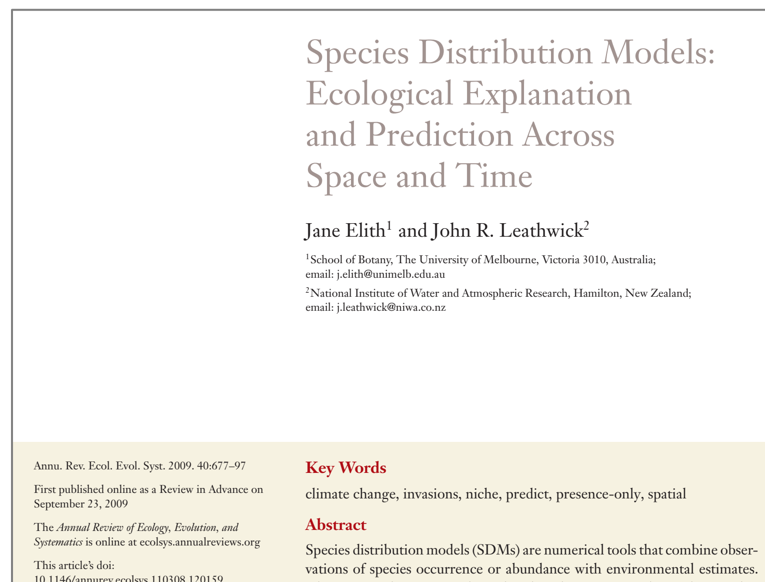
REVIEWS AND SYNTHESES

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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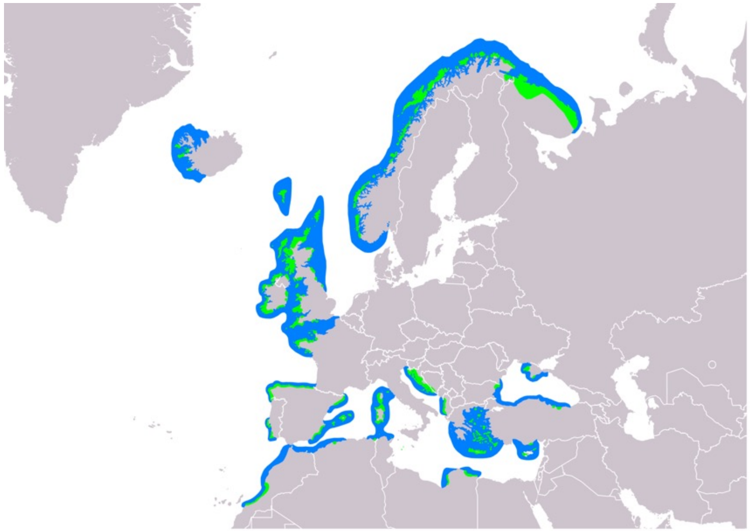
Key Words

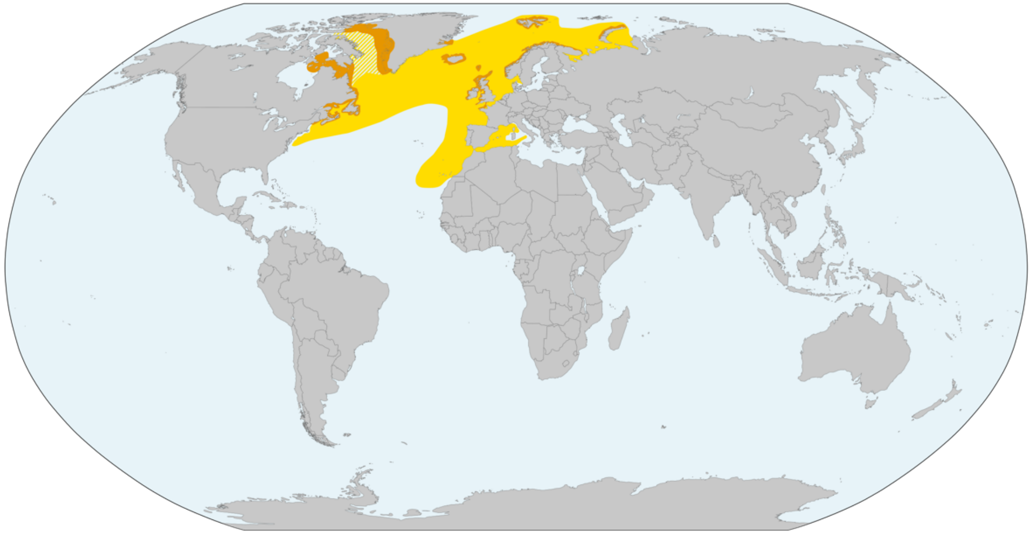
climate change, invasions, niche, predict, presence-only, spatial

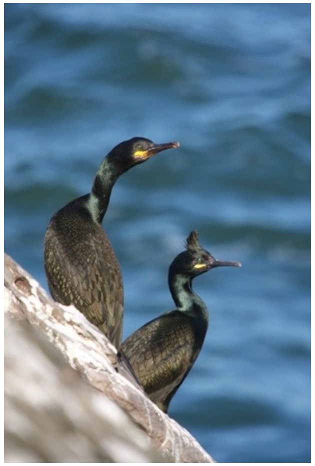
Abstract

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?

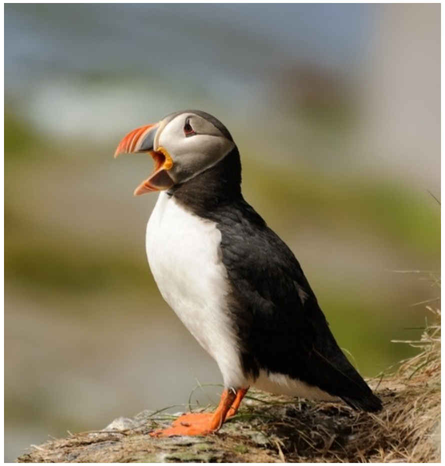






European Shag

Atlantic Puffin



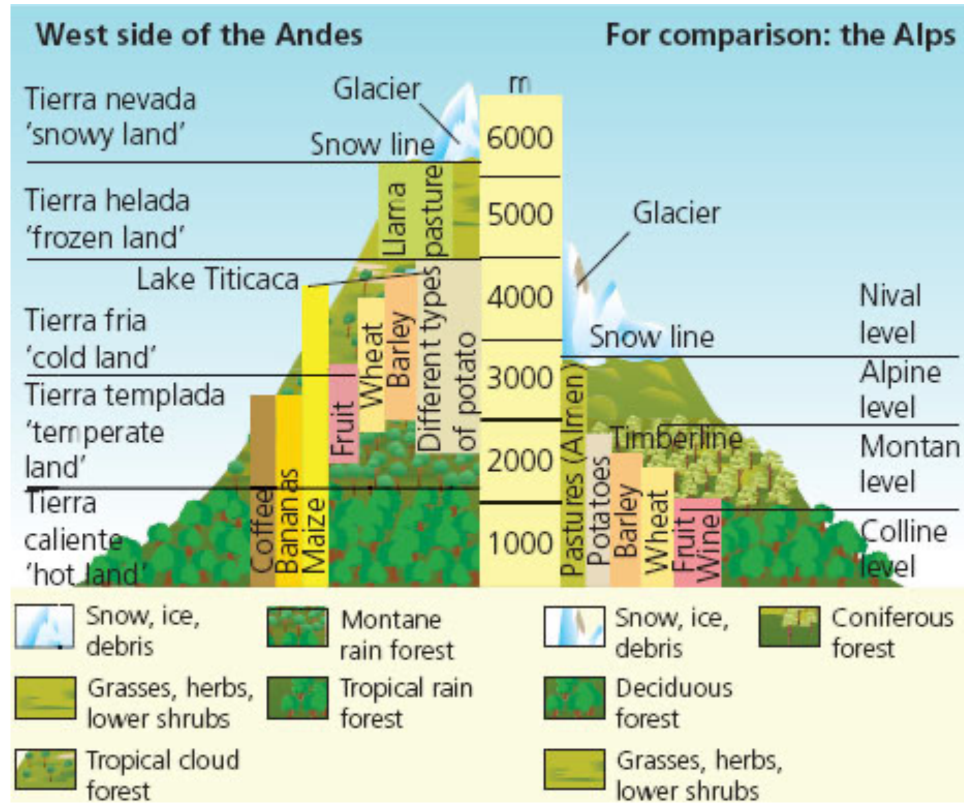
Maps from Wikipedia.org
Pictures from iucnredlist.org

What limits species‘ distributions?

- 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)

Climate

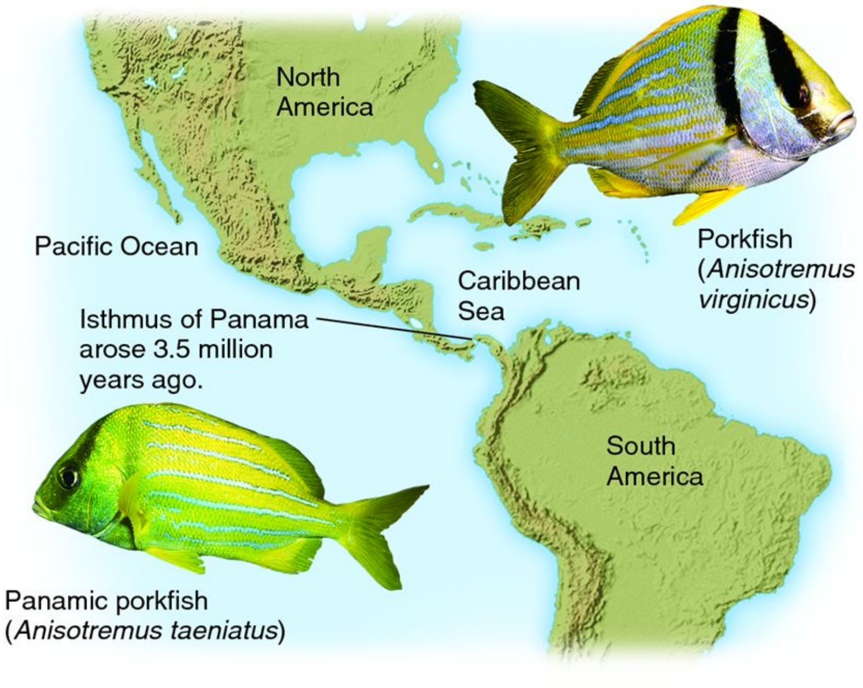


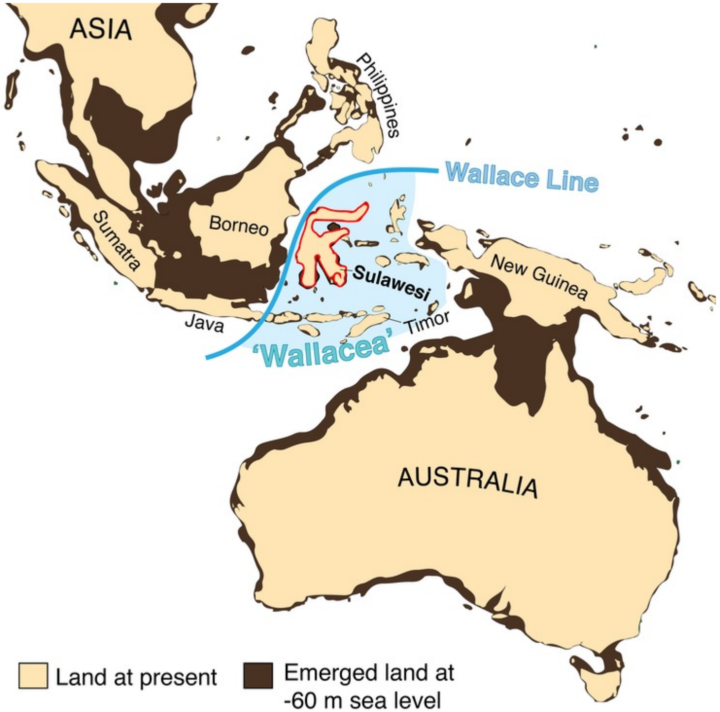
https://www.britannica.com/place/Europe/Plant-life

http://ebooks.dynamic-learning.co.uk

Physical barriers

- Directly limit distribution
- Limit by environmental tolerance or dispersal
- Also driver of allopatric speciation





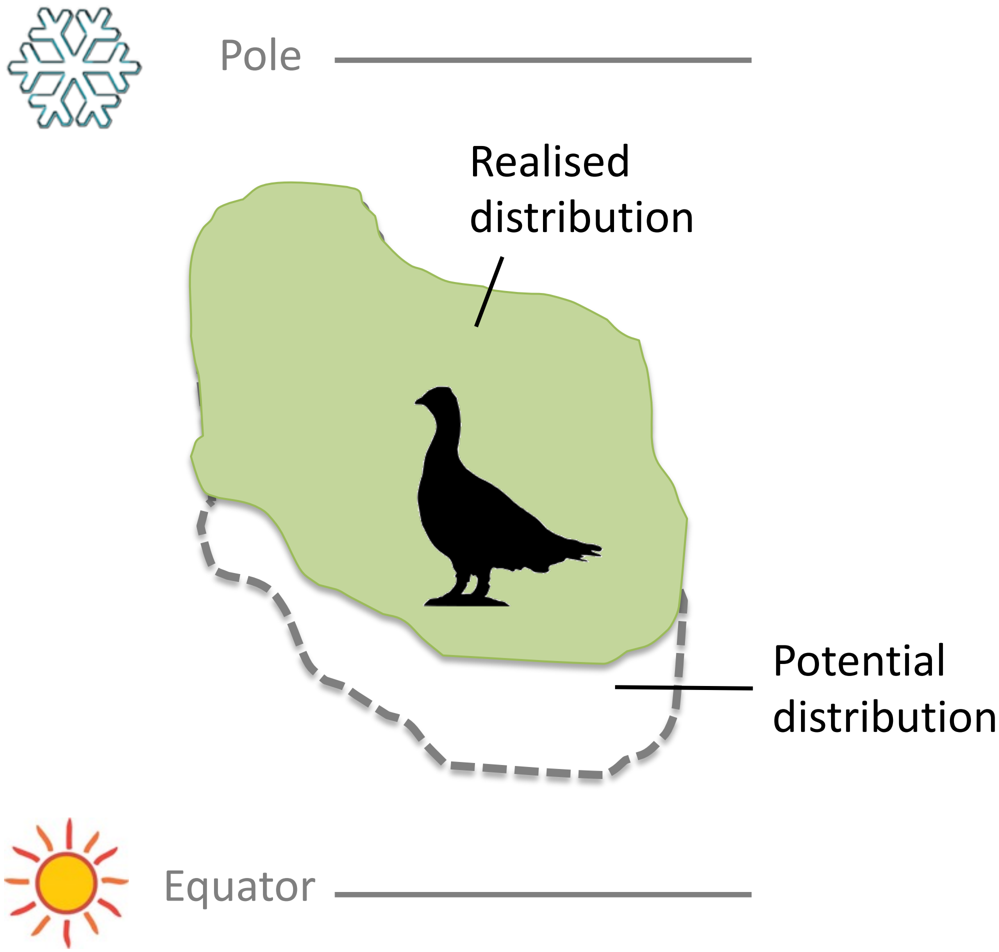
Disturbance

- Abiotic: fire, volcanism, floods, hurricanes, etc.
- Biotic: insect outbreaks, pathogens herbivore grazing, etc.

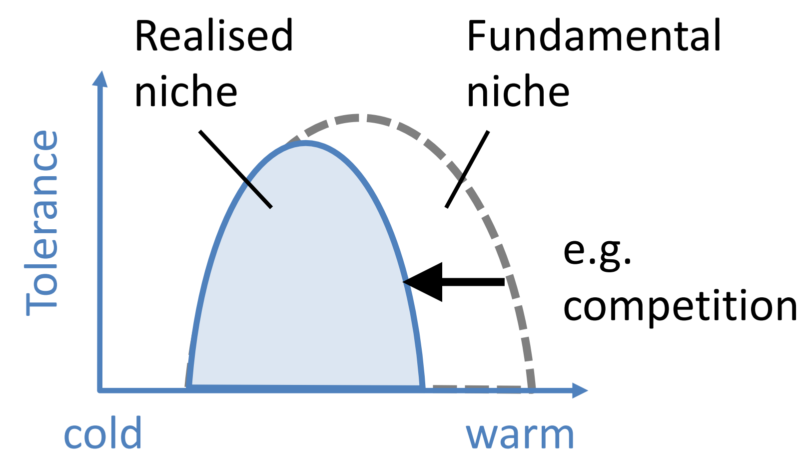
Species interactions

Interaction	Species A	Species B
Mutualism	+	+
Commensalism	+	0
Predation	+	-
Herbivory	+	-
Parasitism	+	-
Amensalism	0	-
Competition	-	-
Neutralism	0	0

Range limits and species‘ niches



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

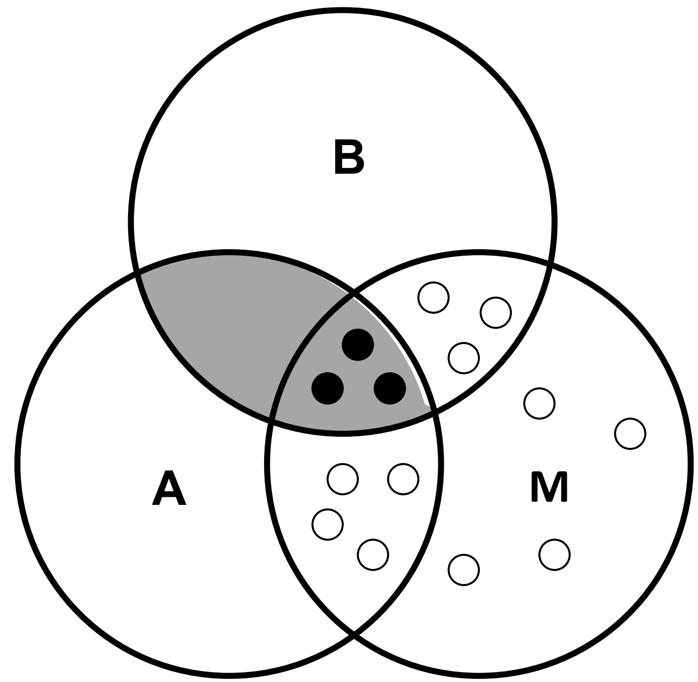
  ■ Realised niche

- Source-sink and metapopulation dynamics:

  M .. Movement

  ○ Sinks

  ● Sources



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

Dichotomy in niche definition

- Grinell, 1917: habitat concept, emphasis on **geographical and structural locations** where a species lives; incl. physiological tolerances, morphological limitations, feeding habitats, interspecific interactions (predation)
  - Focuses on ecological requirements

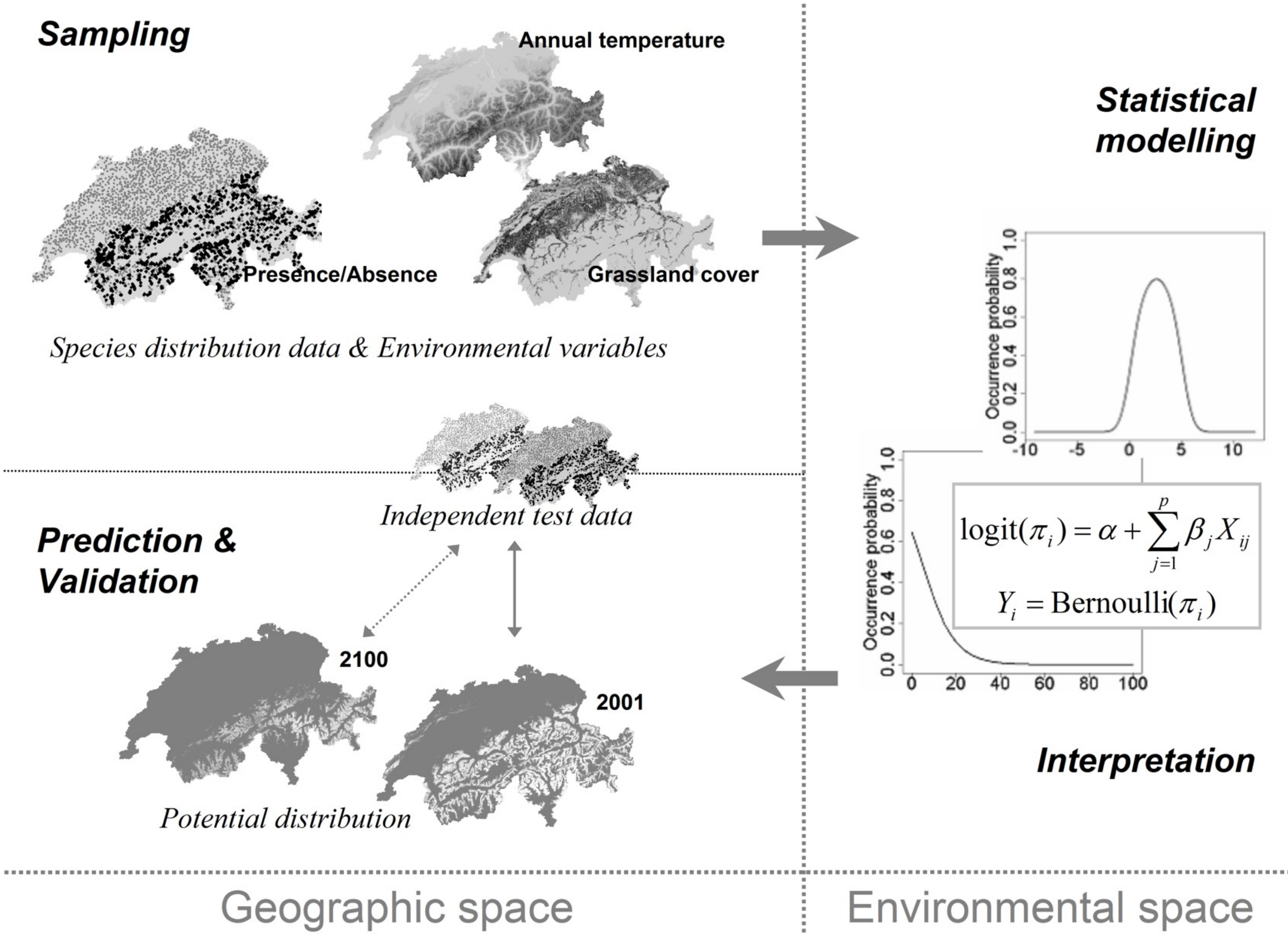
- Elton, 1927: functional concept, emphasis on **functional role** of species in food chain and its **impact** on the environment
  - Focuses on ecological role in community

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)

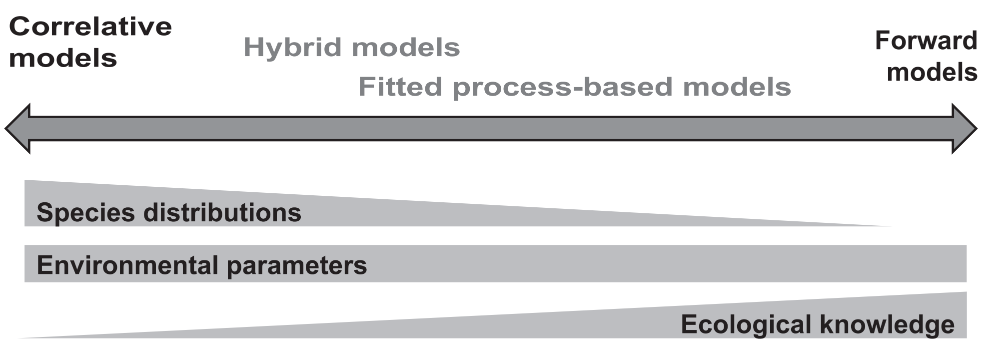
Species = f(Environment)

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

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

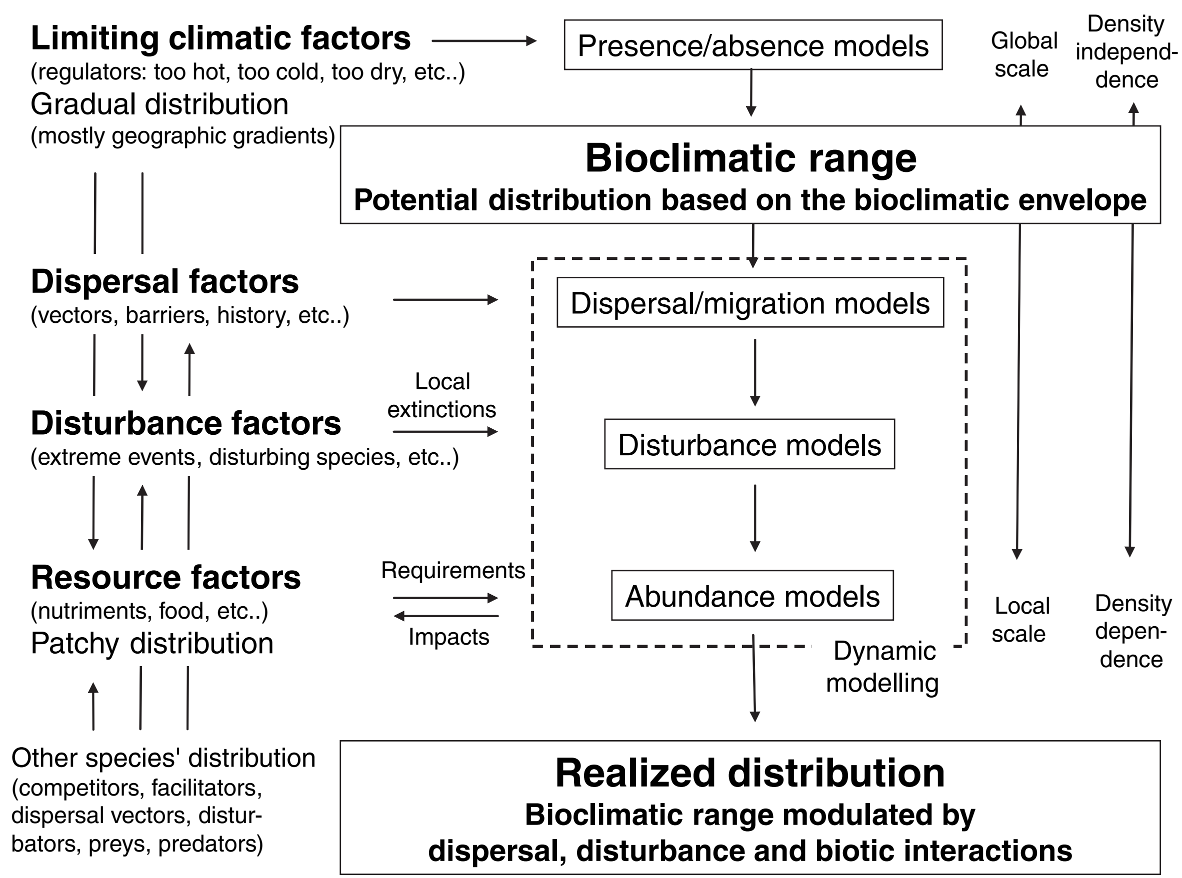
Distal/indirect (proxy)
- No direct effect, but often highly correlated with proximal factors
- Altitude, slope, exposition, latitude

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



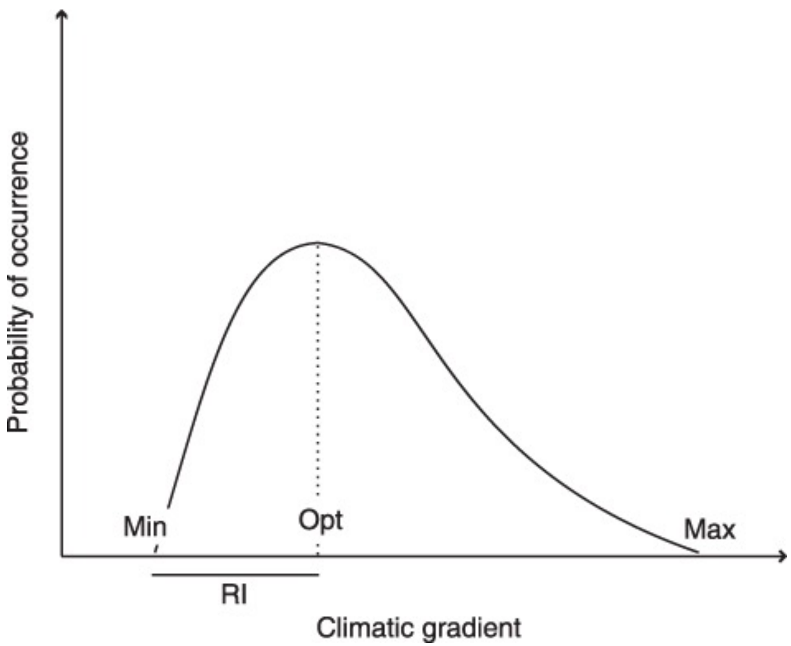
Guisan and Thuiller (2005) Ecology Letters 8: 993-1009.

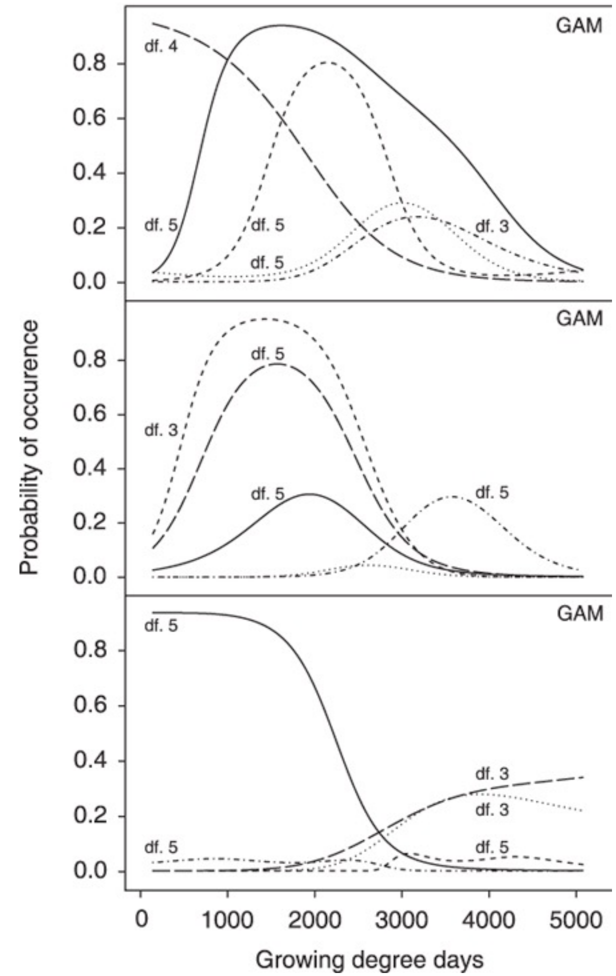
SDM applications

- What are typical applications of SDMs?

SDM applications

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

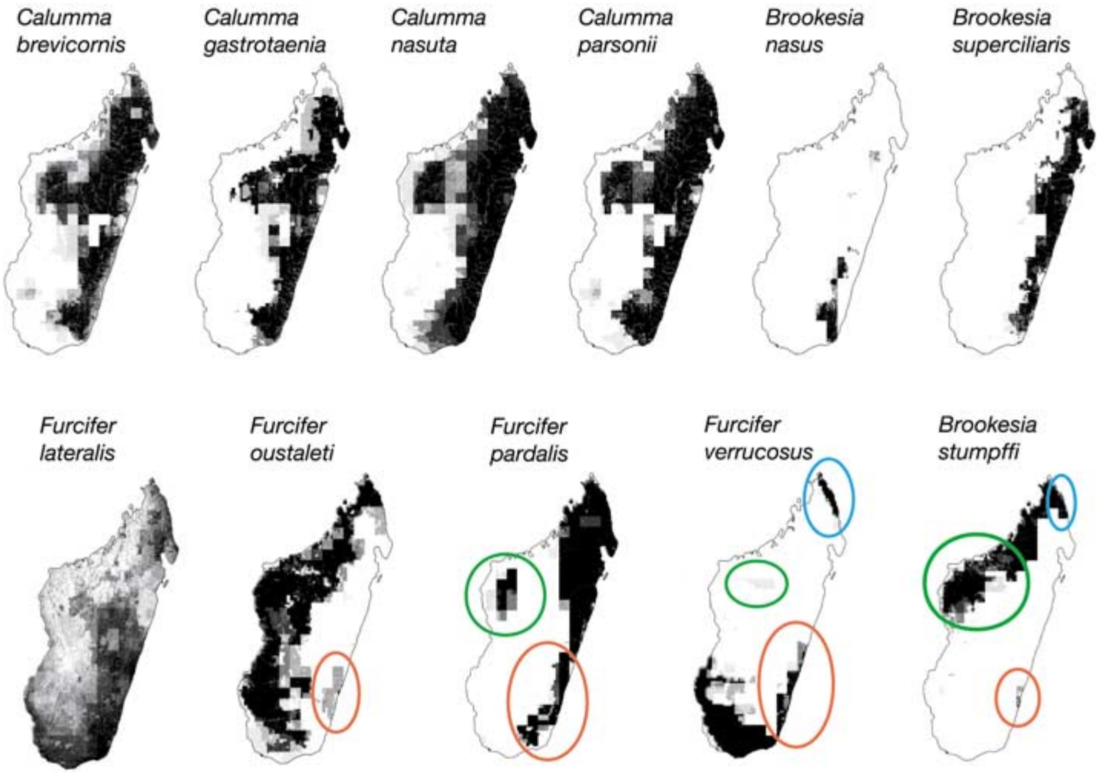




Normand et al. (2009) Glob Ecol Biogeogr 18: 437-449.

SDM applications

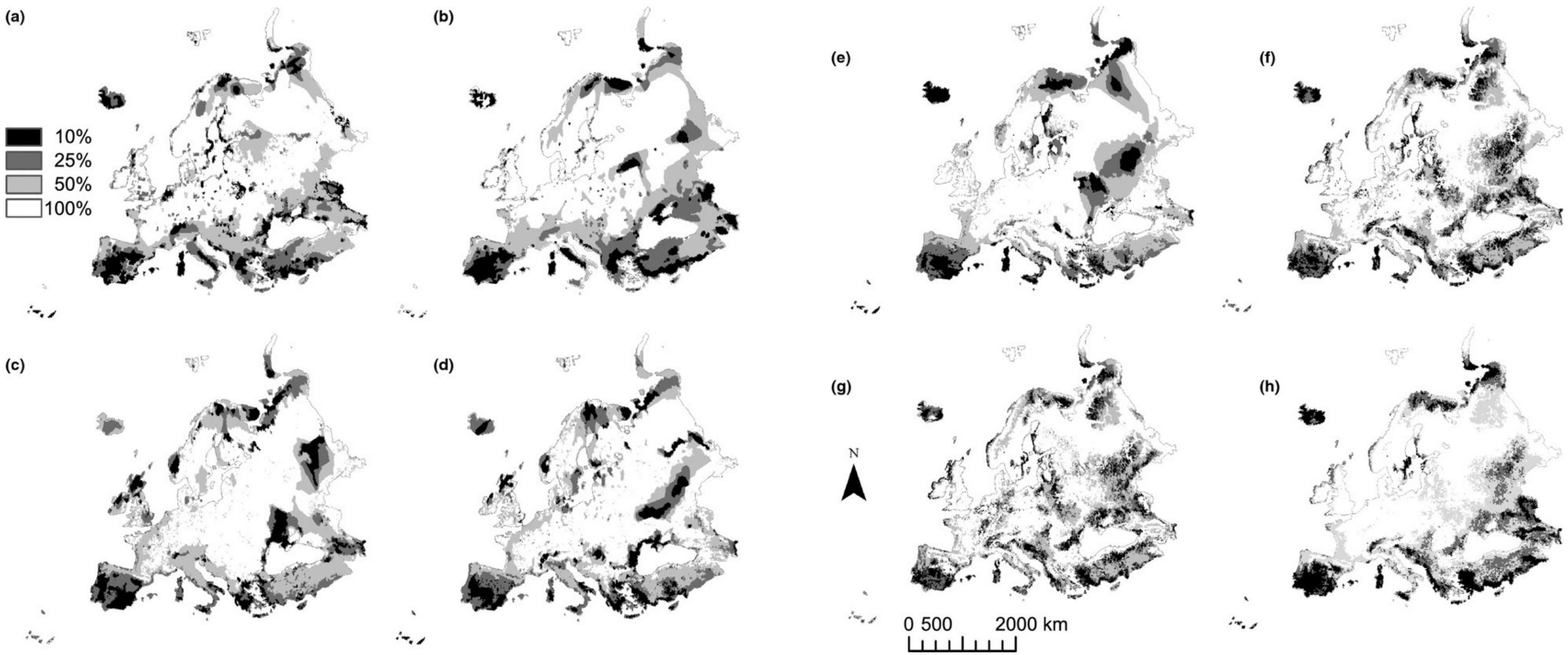
- Discovering biodiversity
  - Discovering populations, species limits, rare and unknown species
  - Guide survey design



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

SDM applications

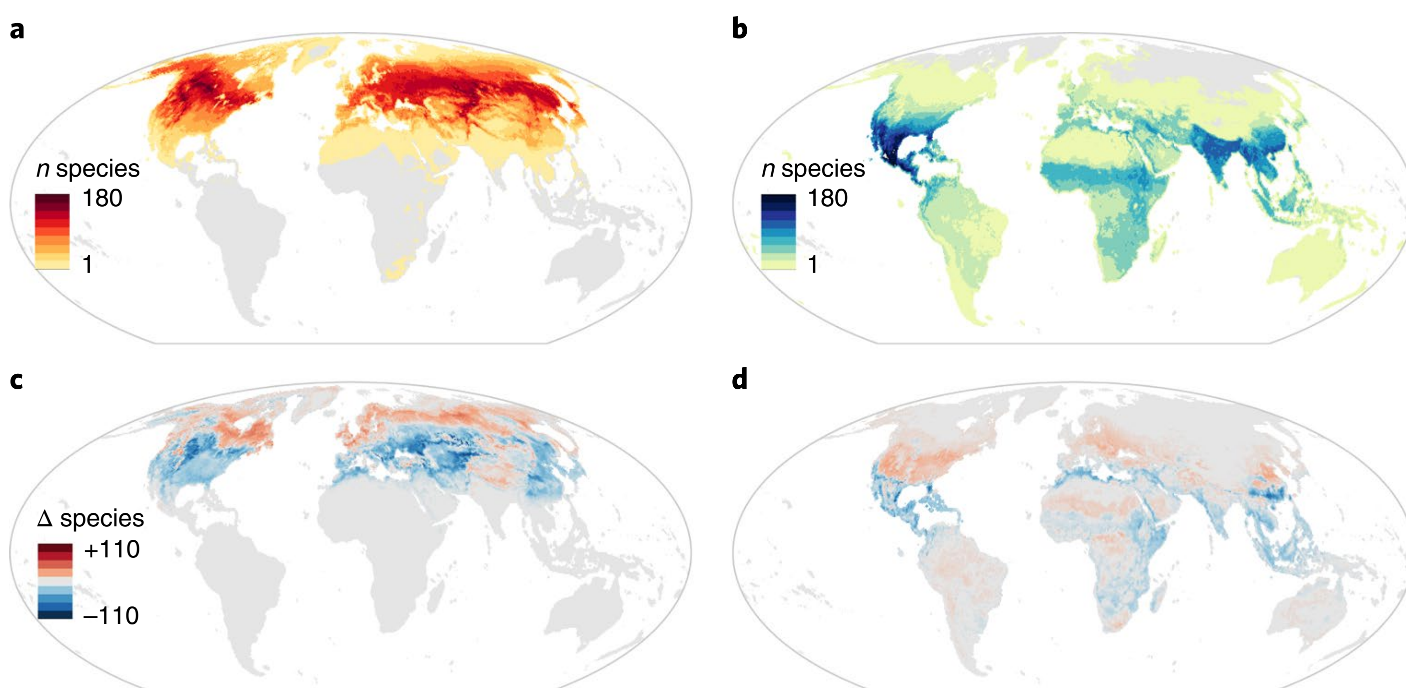
- Conservation planning & reserve selection



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

SDM applications

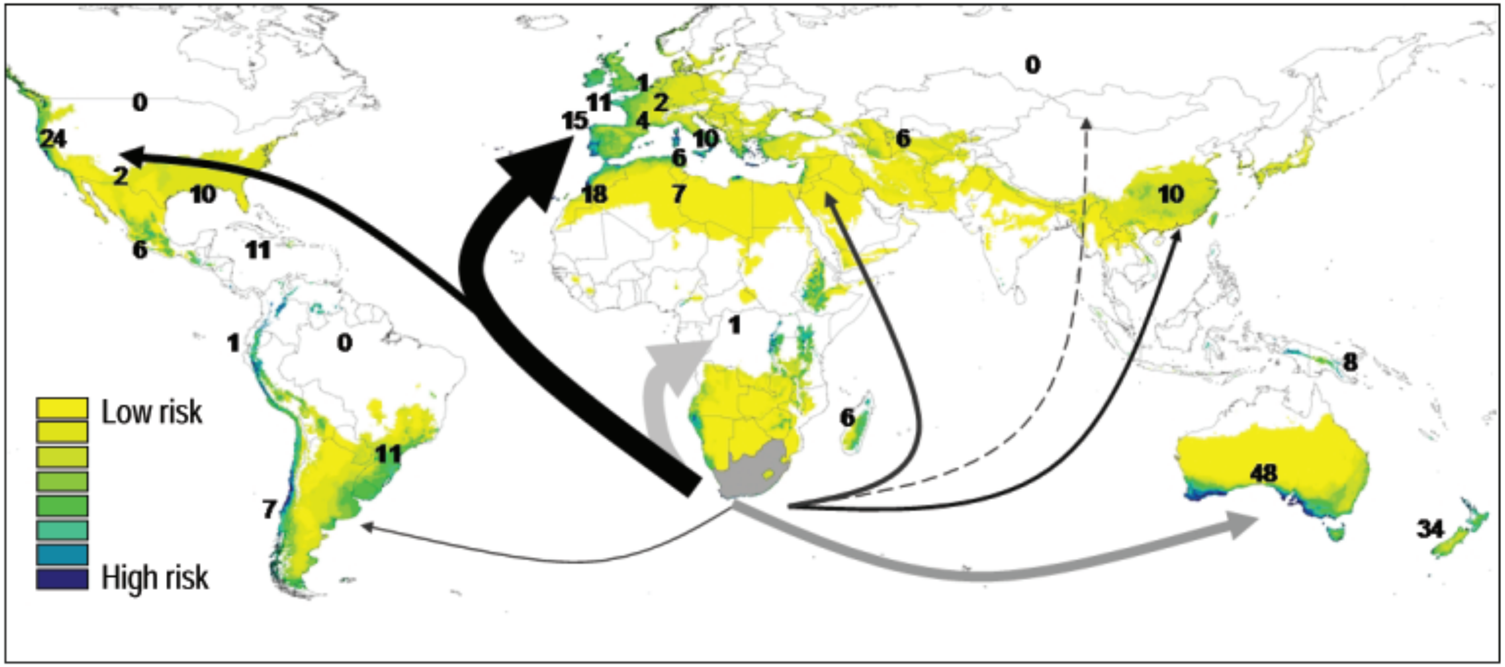
- Global change
  - Assessing impact of climate, land use and other environmental change drivers on species diversity



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

SDM applications

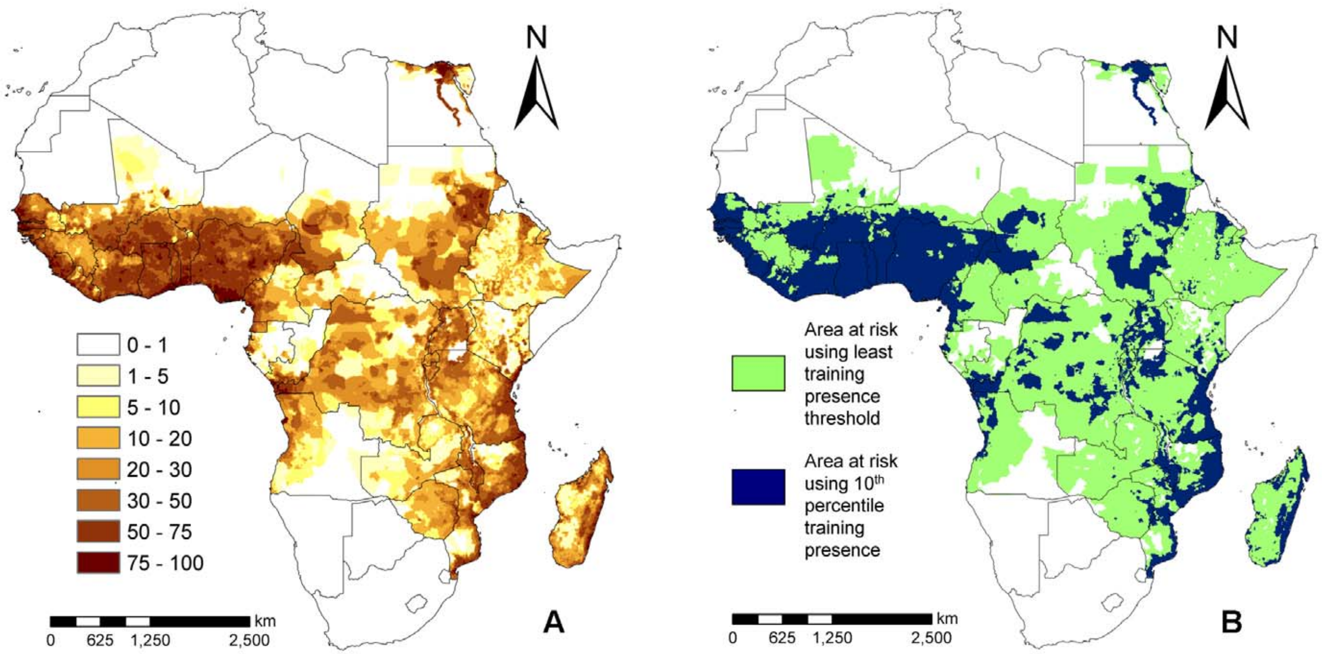
- Invasive species
  - Assessing species invasion risk



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

SDM applications

- Epidemiology
  - Parasite ENMs for informing infection control

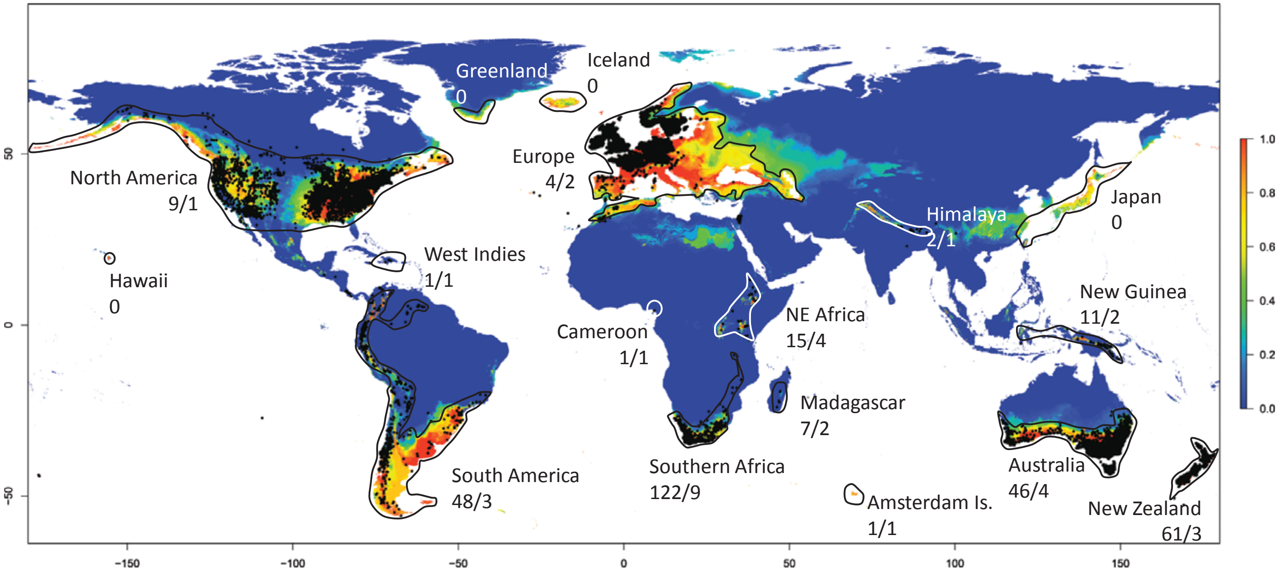


e.g. elephantiasis

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

SDM applications

- Niche evolution
  - Better understand niche diversification, speciation modes, range (in)filling ...



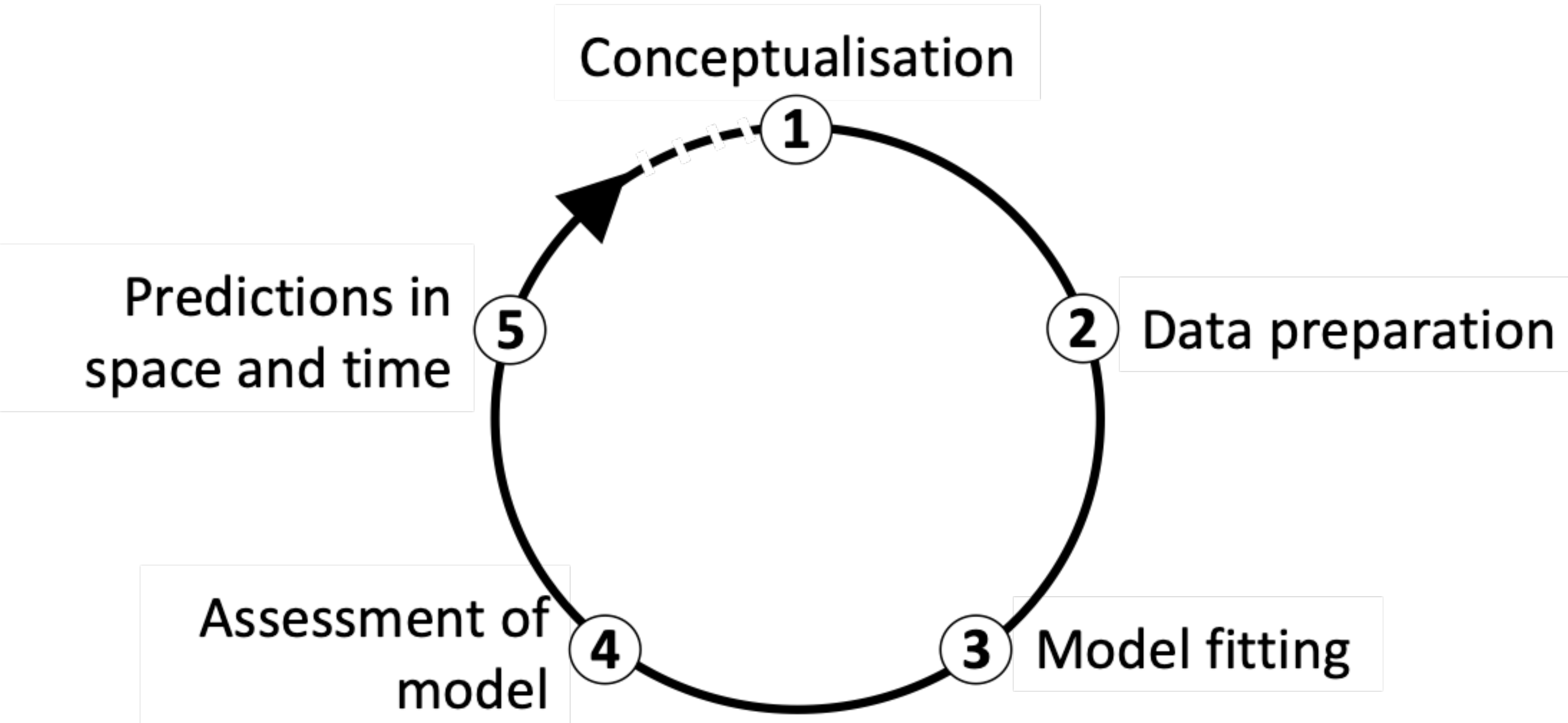
e.g. danthonioid grasses, c. 250 spp

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

SDMs – model building steps

- What are the main modelling steps in SDMs?

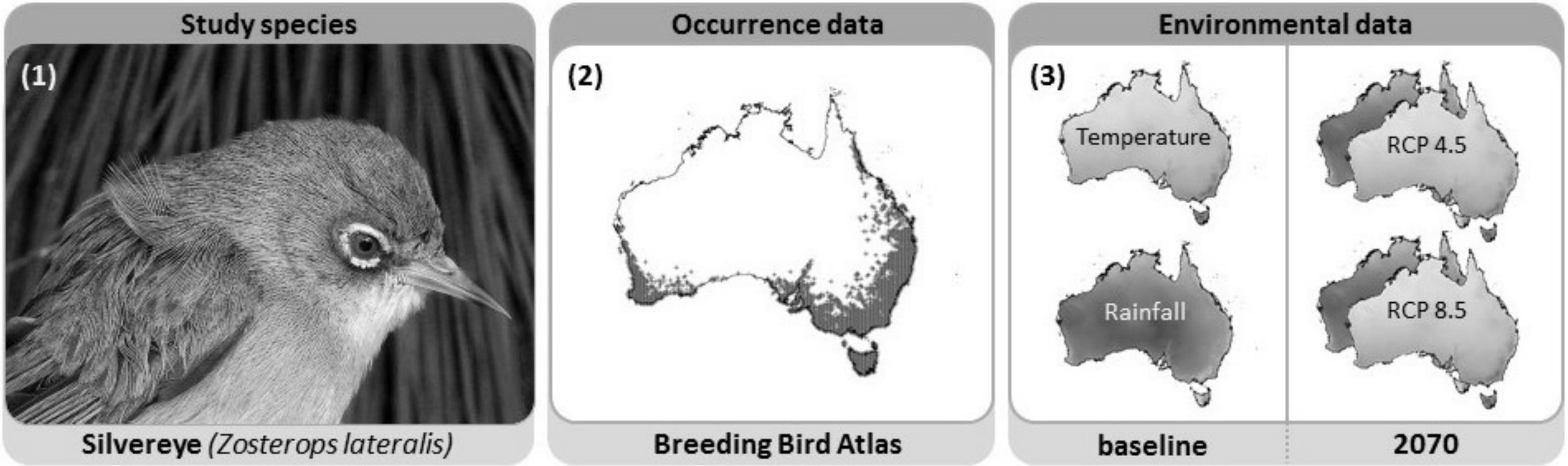
SDMs – model building steps



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

SDMs – model building steps

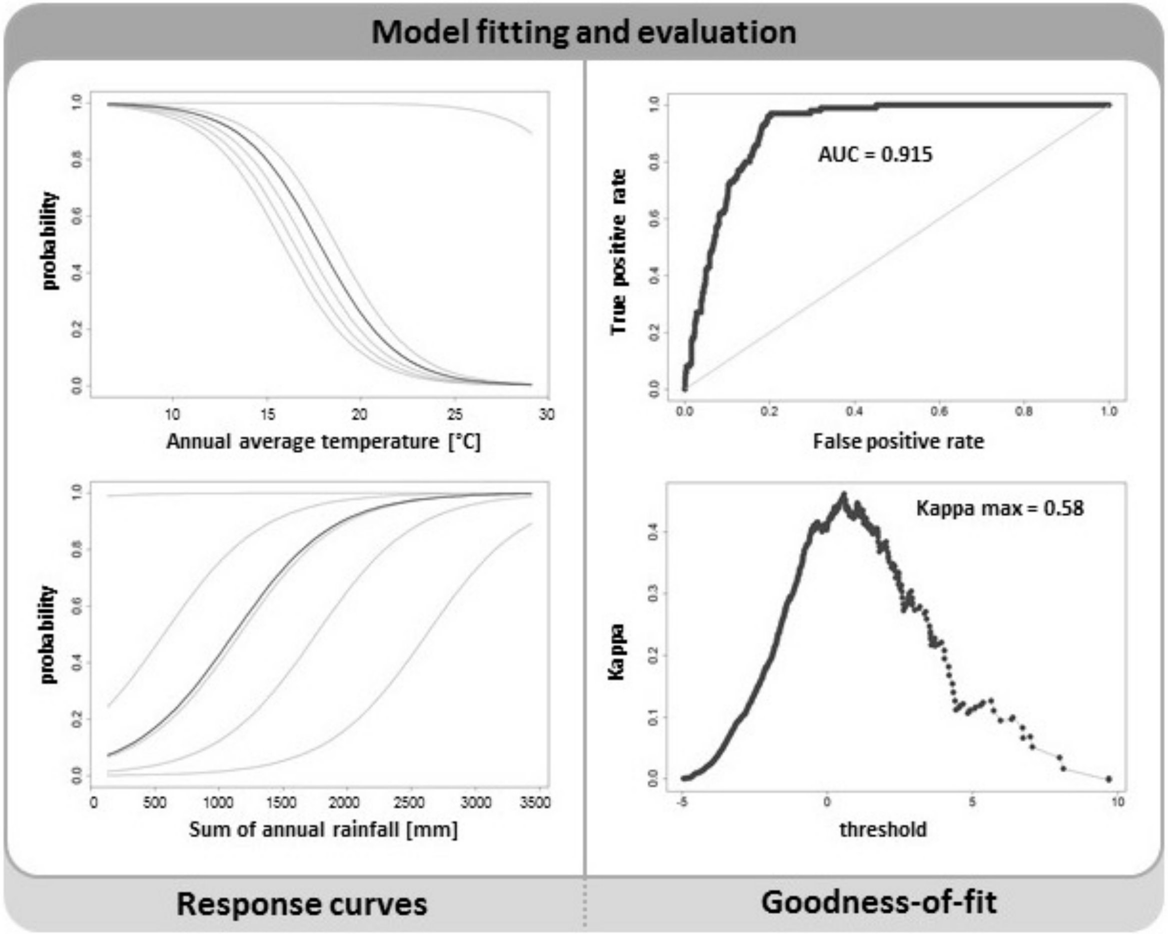
- Conceptualisation and data preparation



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

SDMs – model building steps

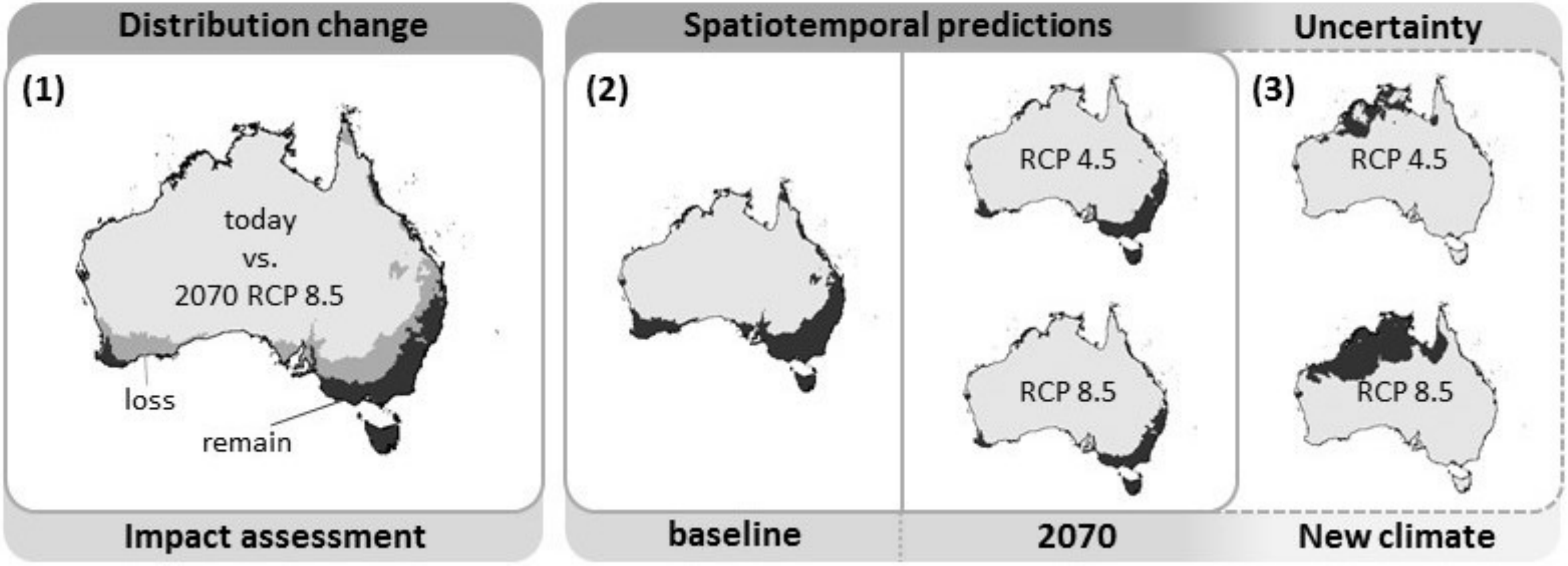
- Model fitting and model assessment (evaluation)



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.

Thank you for your interest

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