Species distribution modelling (SDM)

Franka Gaiser and Manuel Steinbauer

Science School of Quantitative Ecology 2025

bit.ly/SSoQE

Aims

1. **Understand the basic functioning** of SDMs.
2. Get a feeling for the **variability** of SDMs.
3. Learn how to **build a simple correlative SDM** in R.
4. Learn about **resources** for future SDM building.

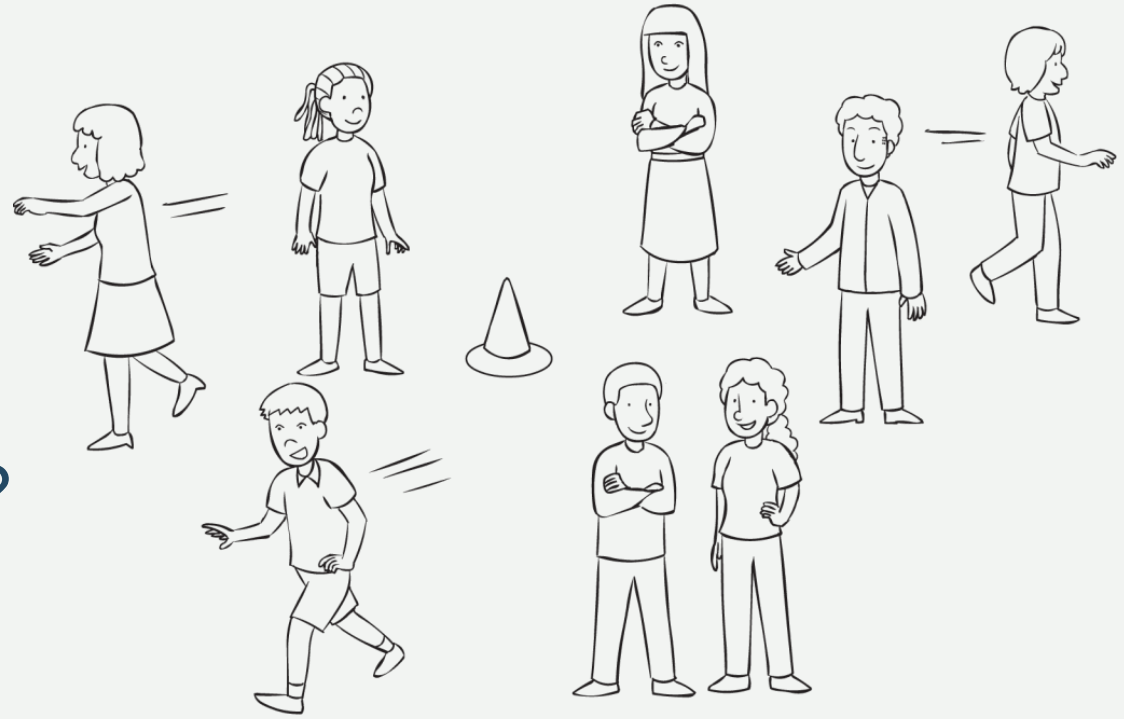
Roadmap

1. Icebreaker
2. Introduction to SDMs
3. Introduction to dynamic documents in R
4. SDMs in R (live coding together)
5. SDMs in R (individual exercise)
6. Pros and cons of correlative SDMs
7. Resources
8. Feedback

Icebreaker – group map

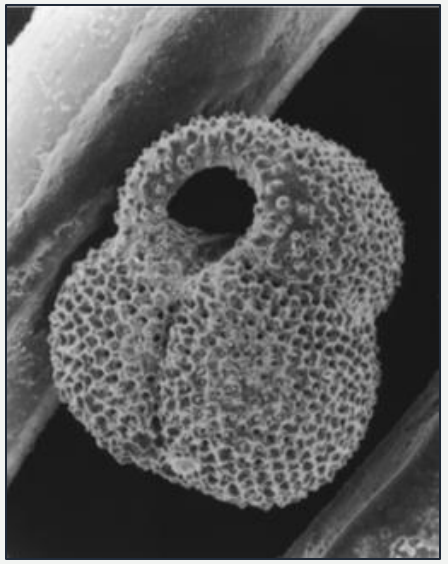
Activity: move in the room

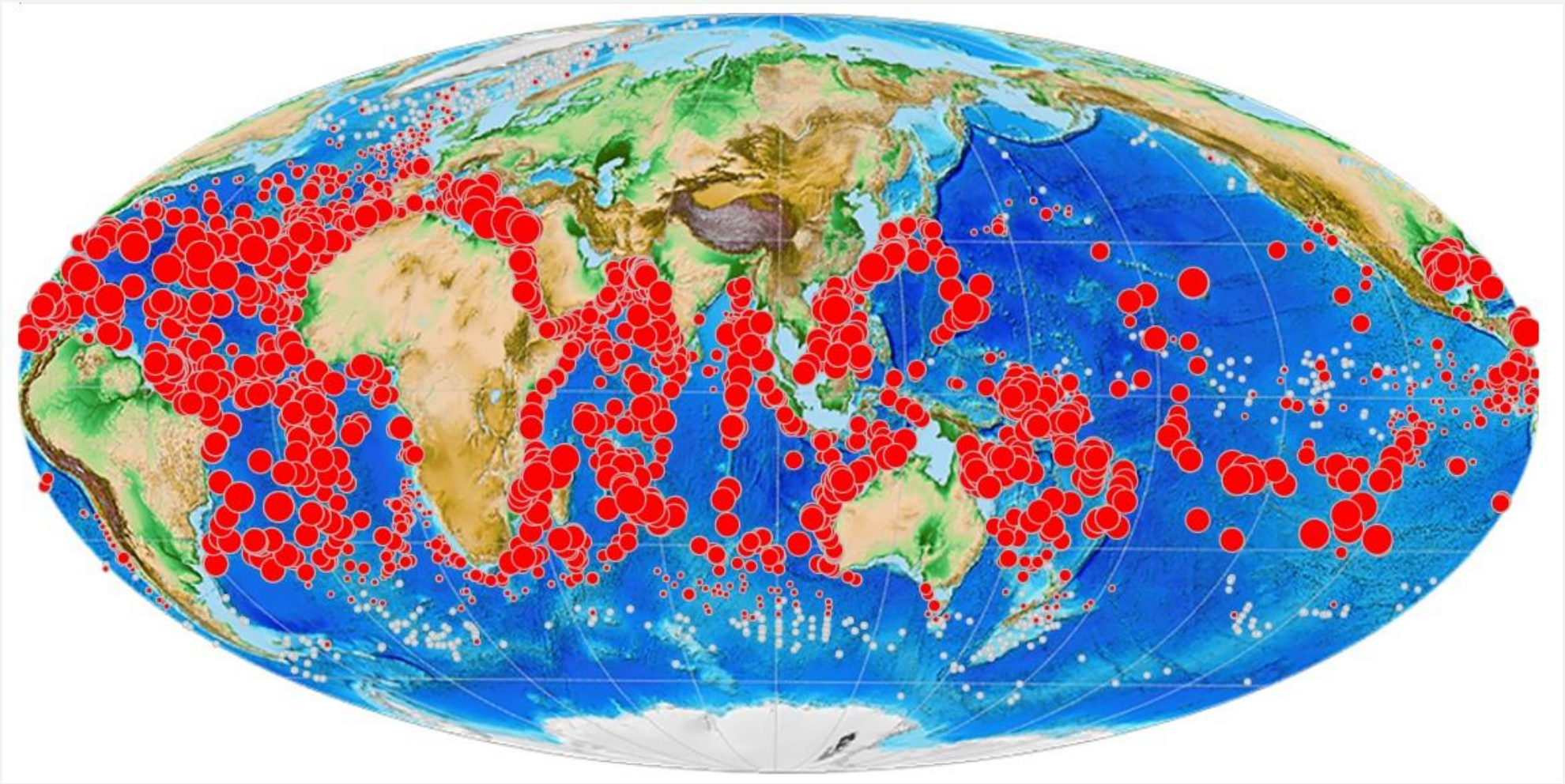
- Where do you come from?
- How much do you know about SDM?
- Species distribution



Distribution of species

Planctonic **foraminifera**
(Globigerinoides ruber)





Abundance indicated by red point size ; white points represent absences

maps from pforams@mikrotax, photos by Dennis Greig (Chevron, USA)

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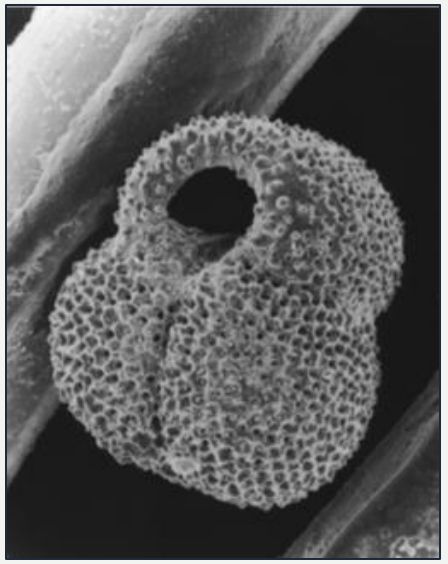
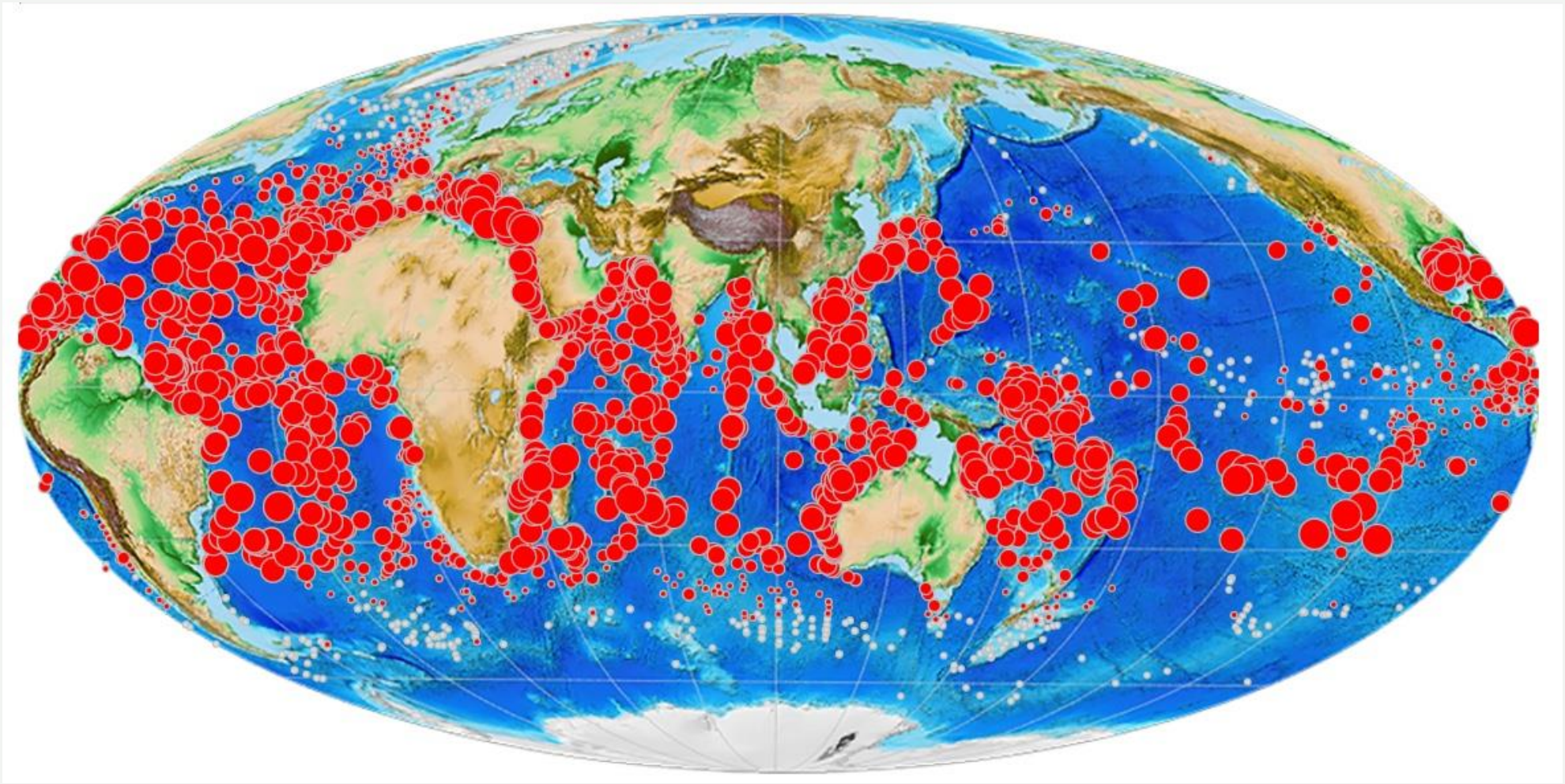


Eye of a needle
X 20



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Species niche

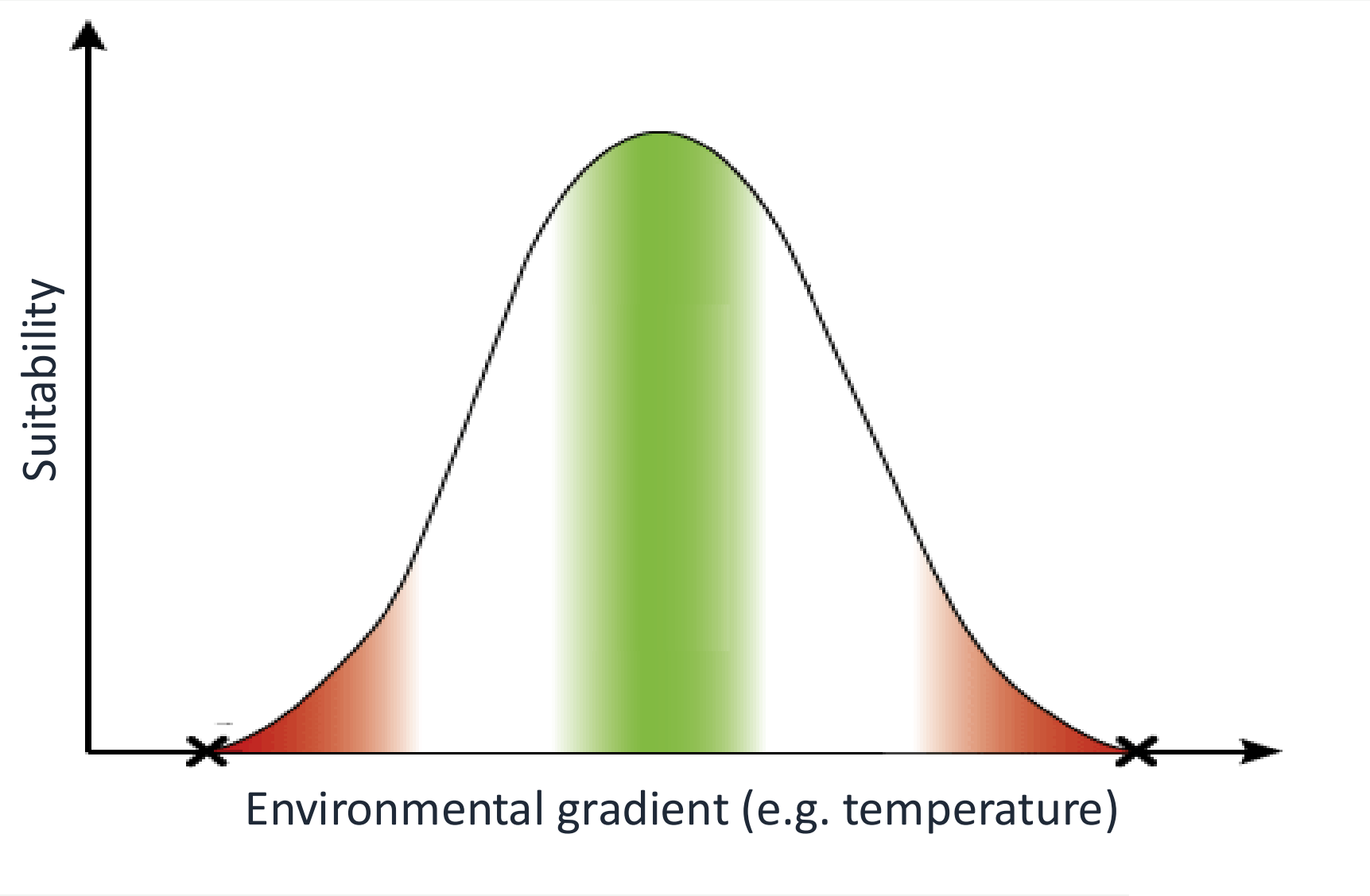
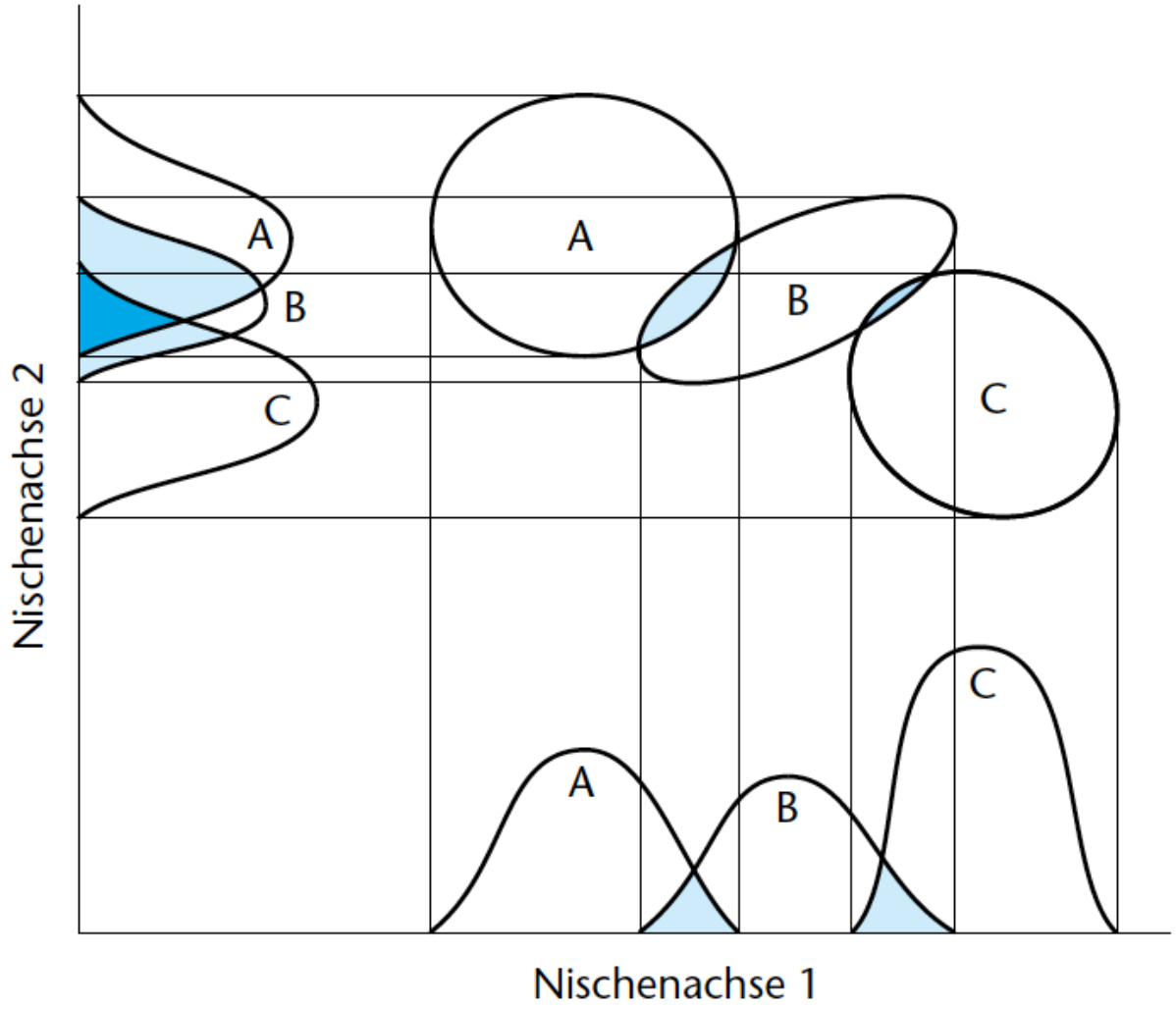


figure from: Philipp Hauer

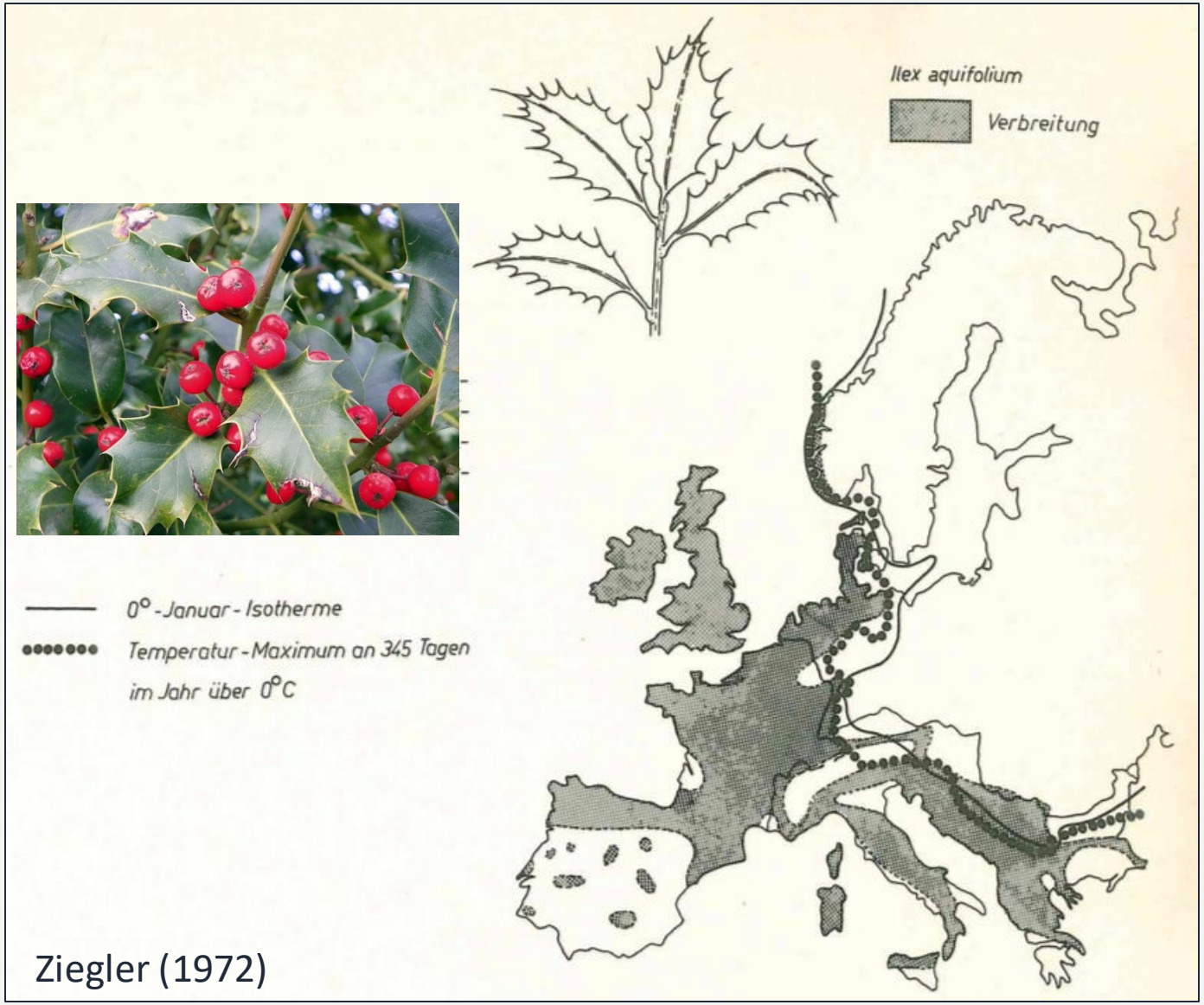
n-dimensional hyperspace



Hutchinson (1957):
n-dimensional hypervolume, axes represent the resources/environment

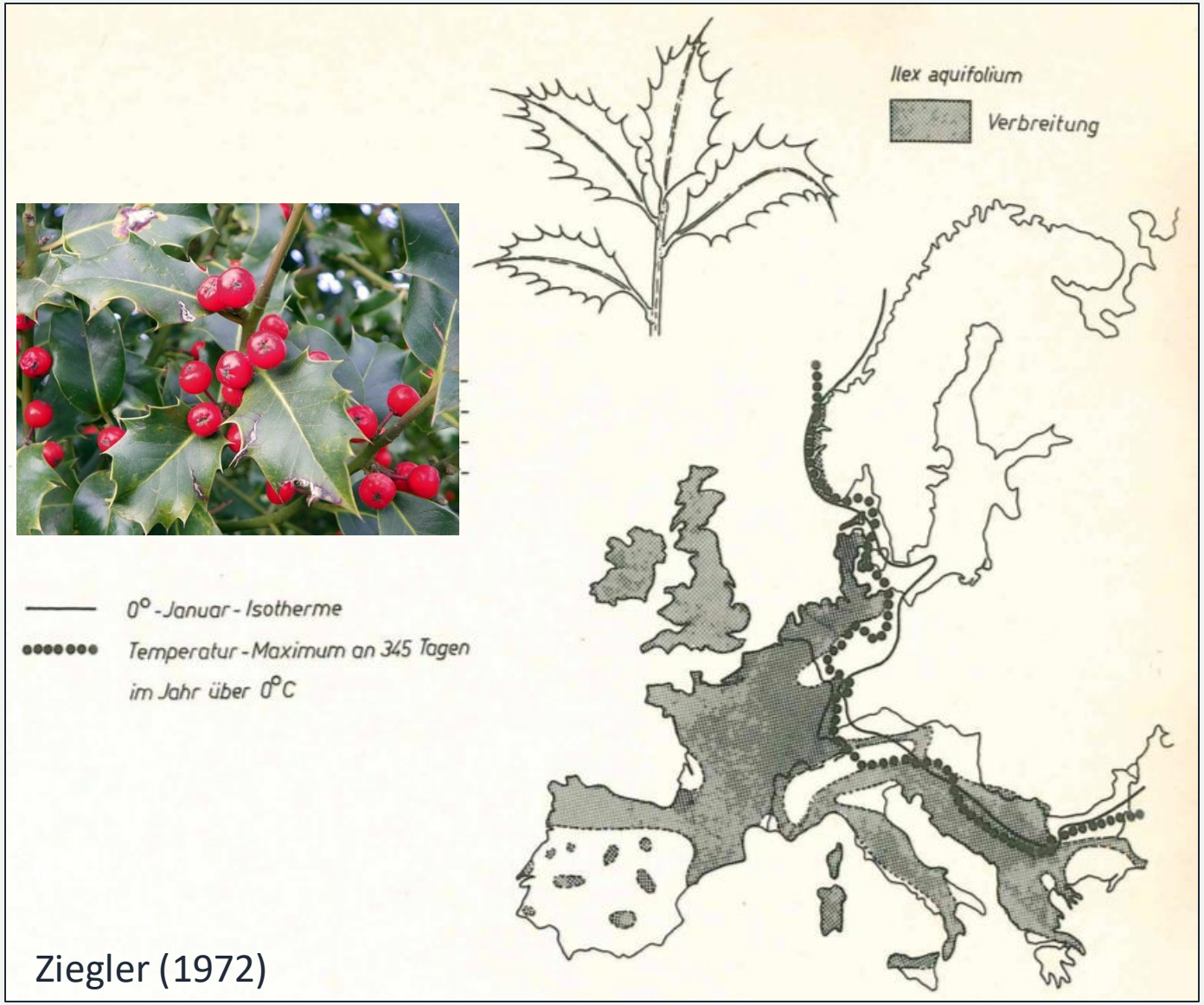
Figure from Begon et al. 2017

Geographic versus environmental space



Ziegler (1972)

Geographic versus environmental space



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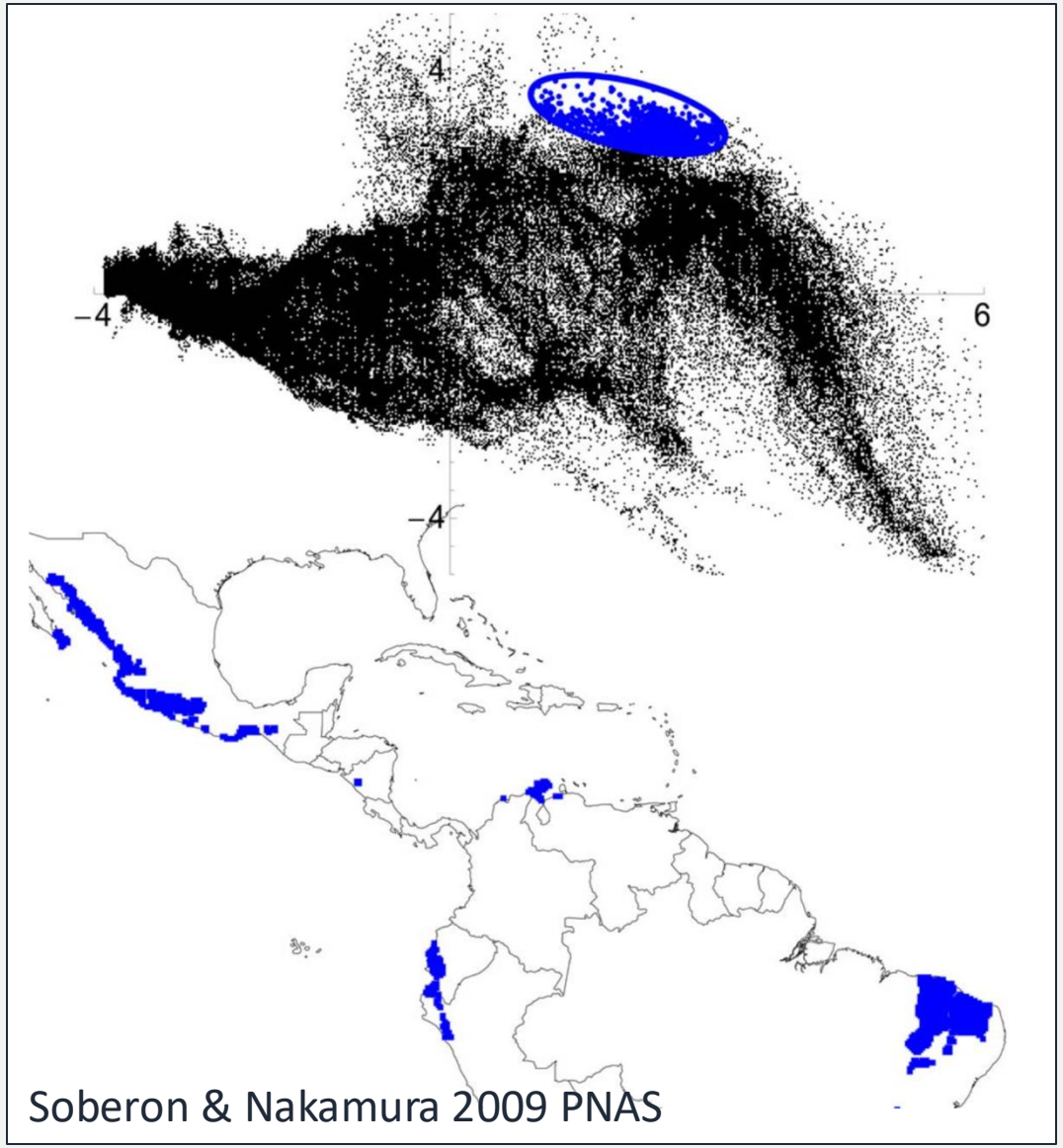
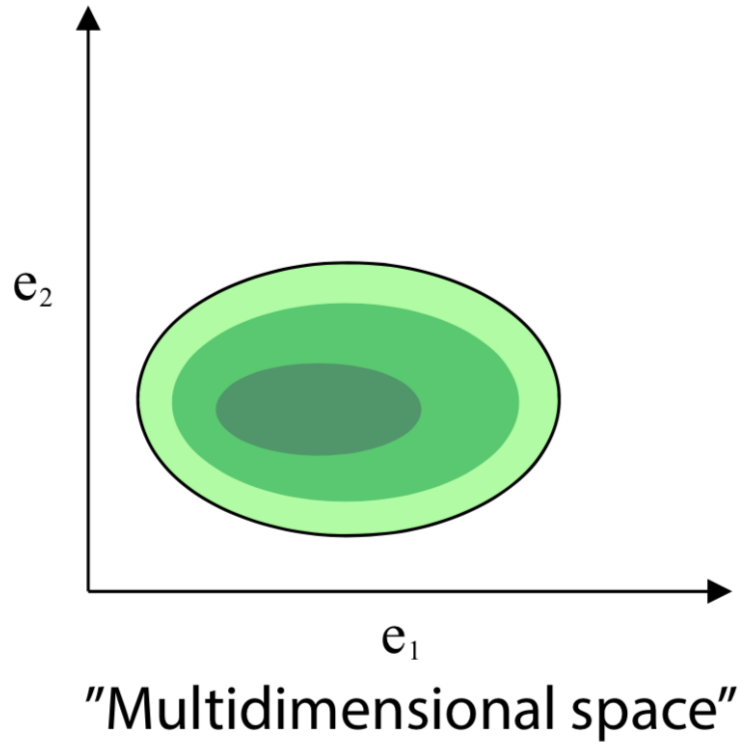
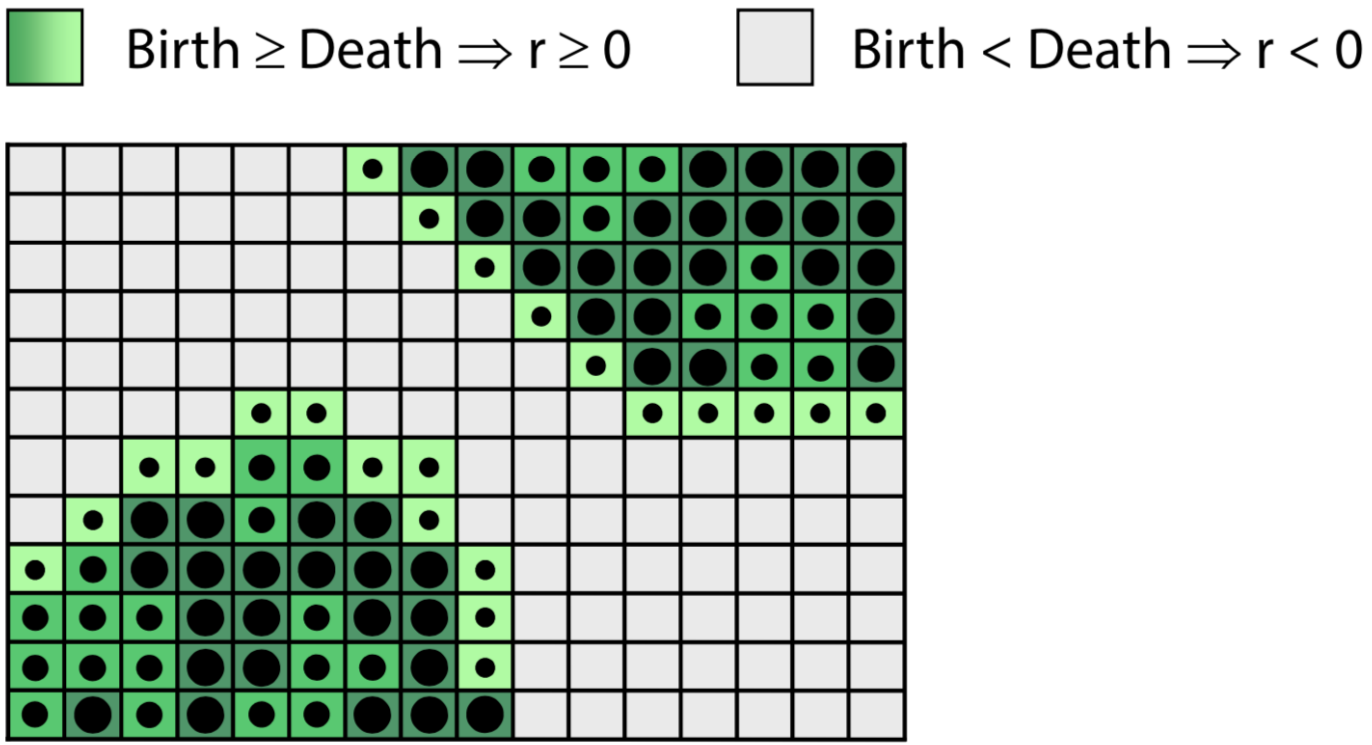


Soberon & Nakamura 2009 PNAS

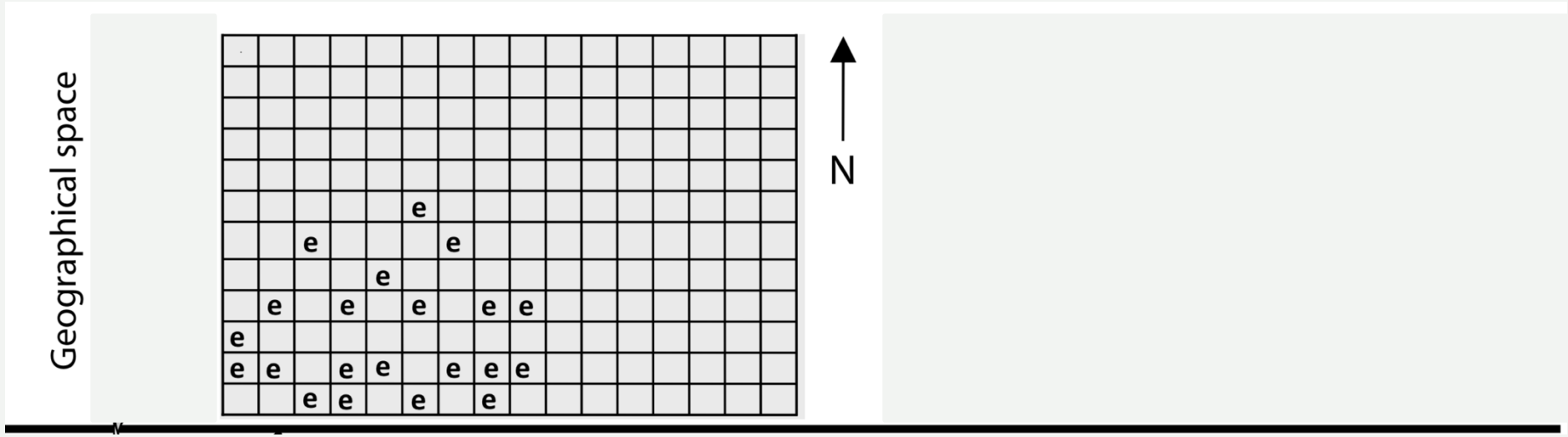
“To a first approximation, a species’ range is a spatial expression of its niche”





Araújo & Guisan (2006) J Biogeo; Holt et al. (2005) Oikos

Projecting areas of suitable climate



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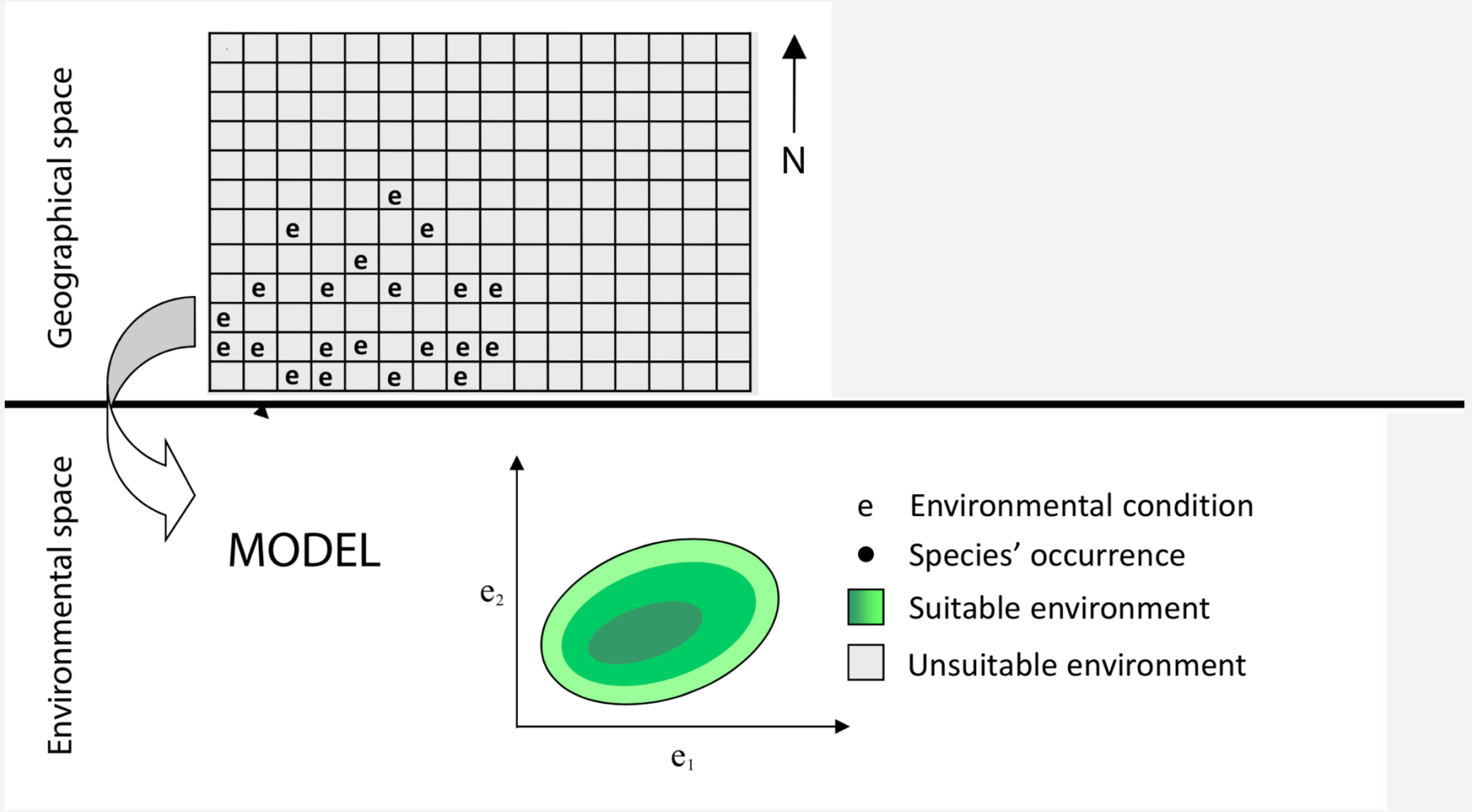

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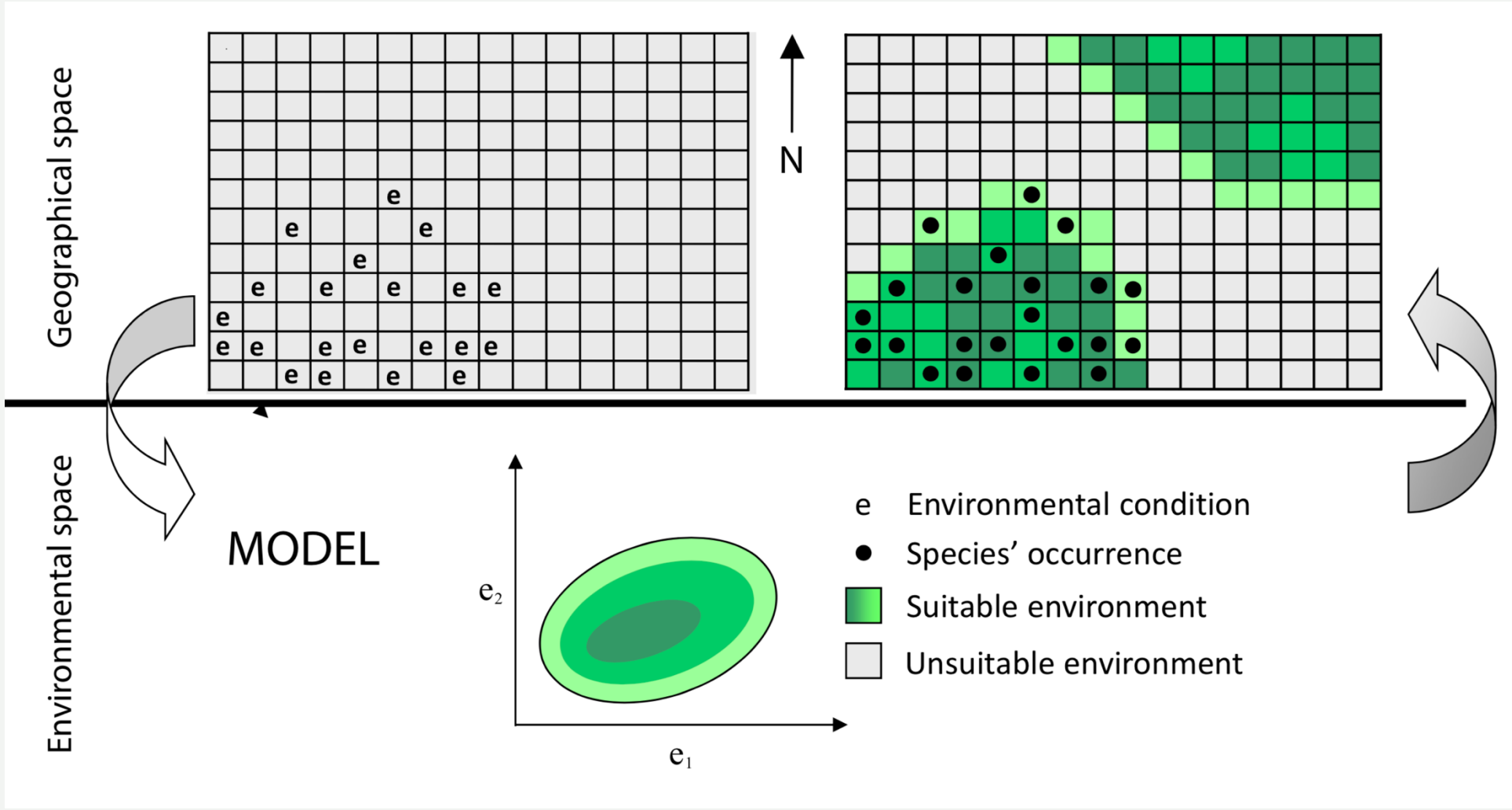

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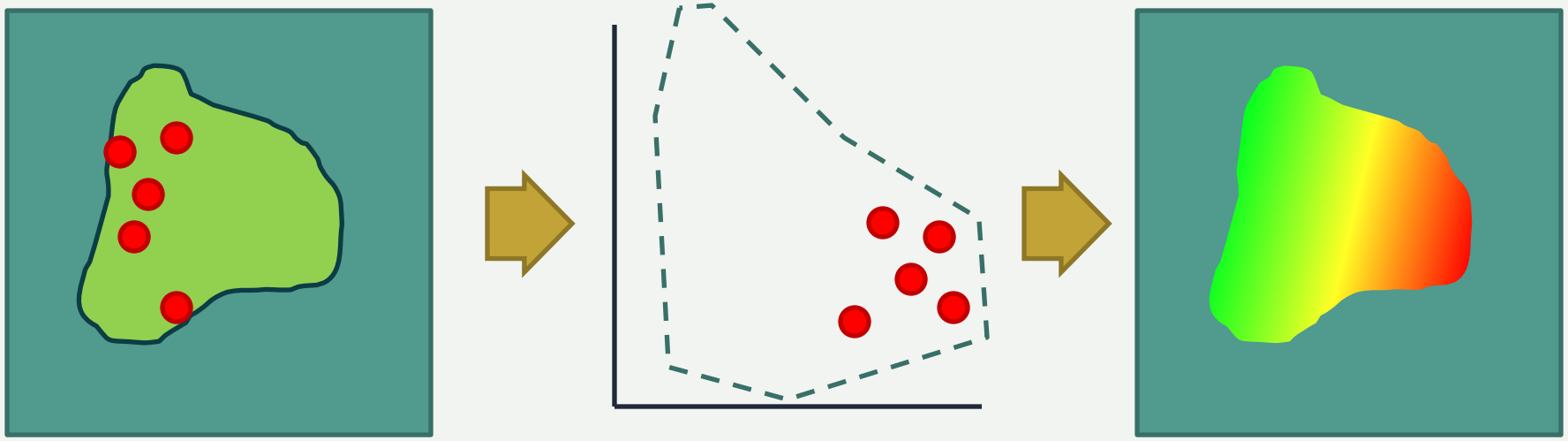
How it works

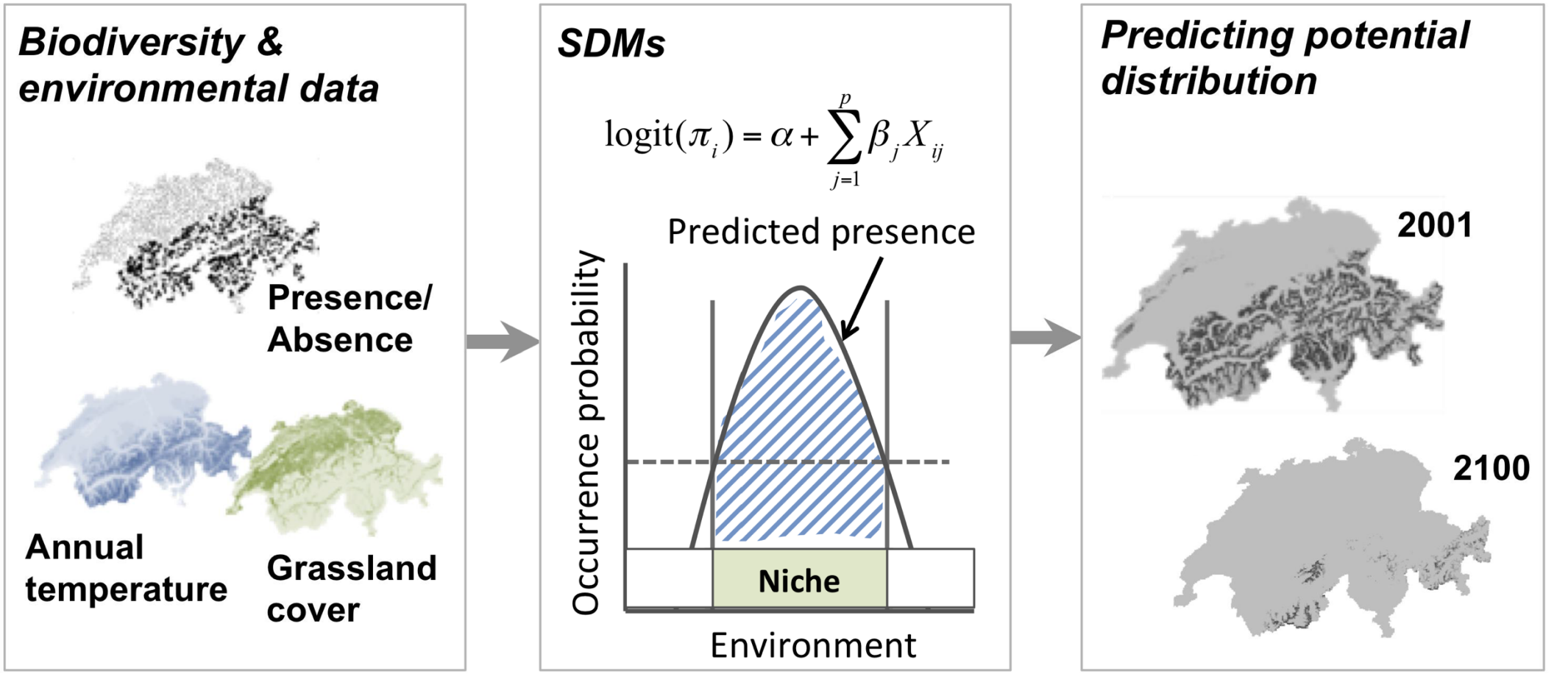


Geographic space

Environmental space

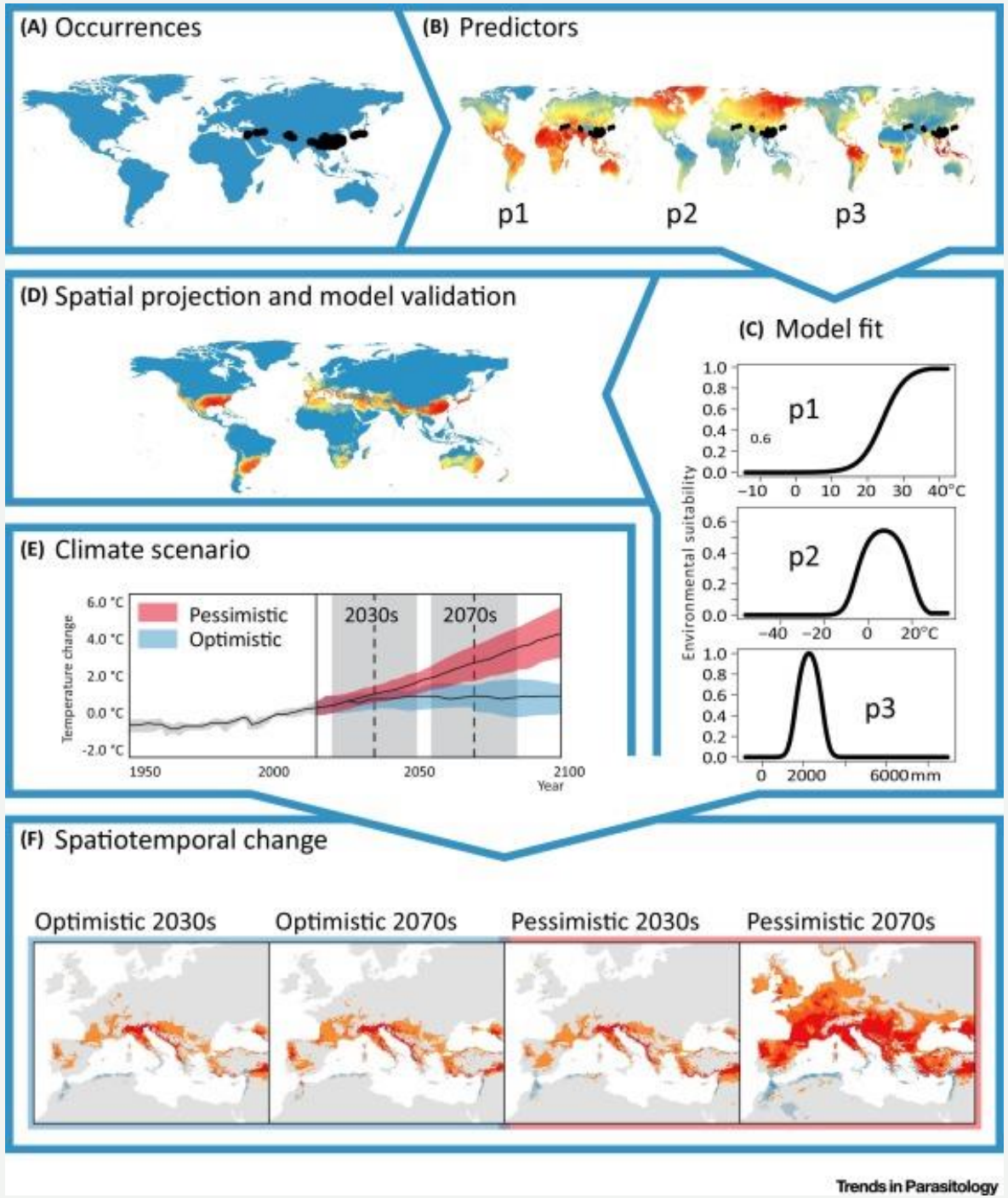
Geographic space

Main components of a SDM (correlative)

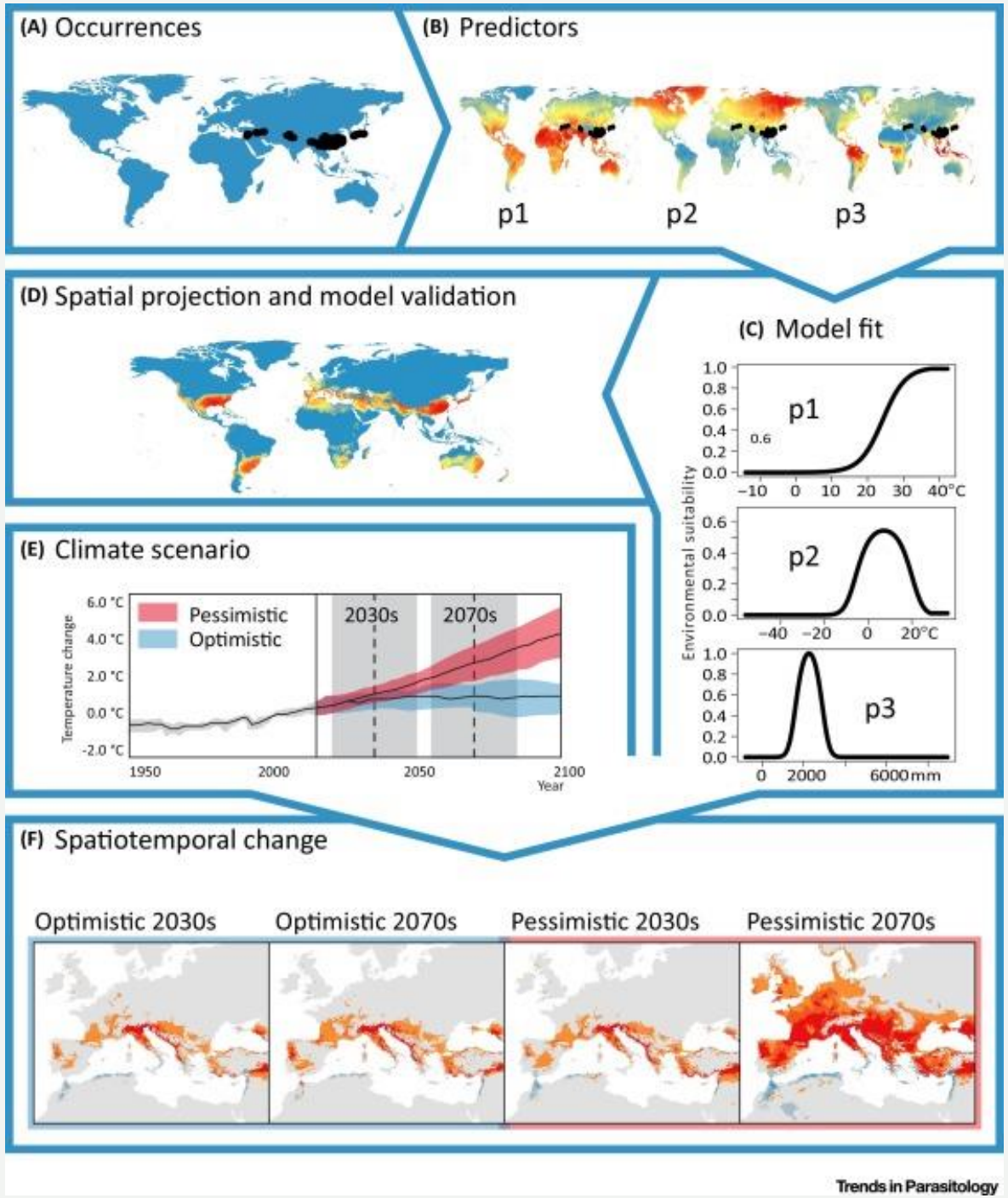


Zurell, 2022

Climate change

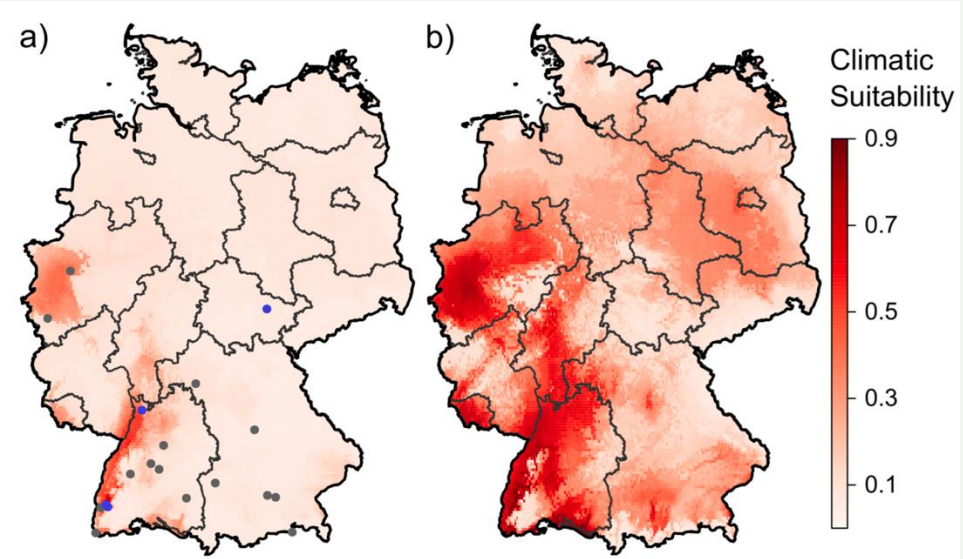


Tjaden et al. (Tre. Parasit., 2018), Thomas et al. (2018, Public Health)



Asian tiger mosquito
(*Aedes albopictus*)

Transfers:
Dengue fever
Zikavirus
Chikungunya Fever

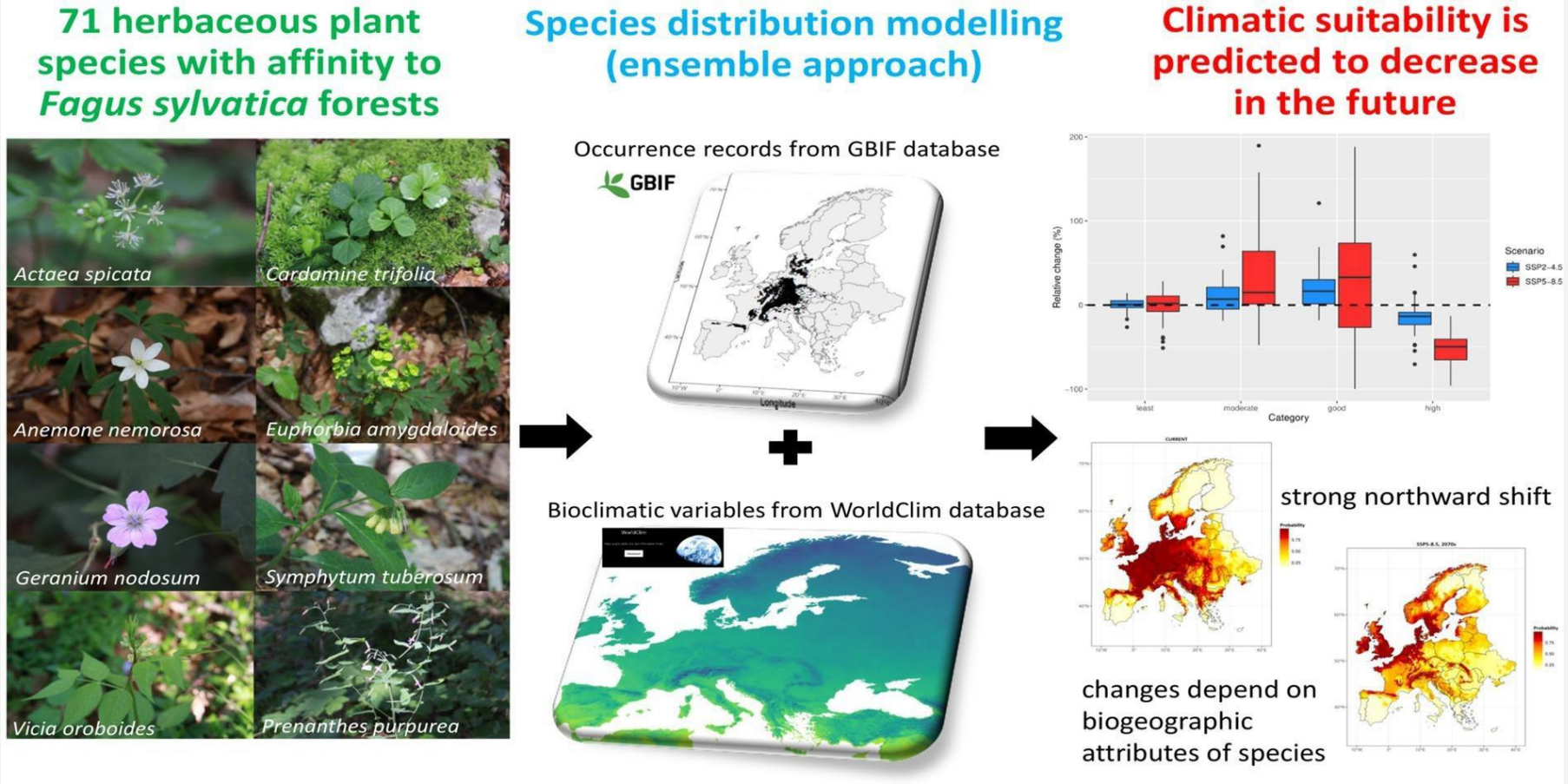


Today

Prediction 2020-40 (RCP 8.5)

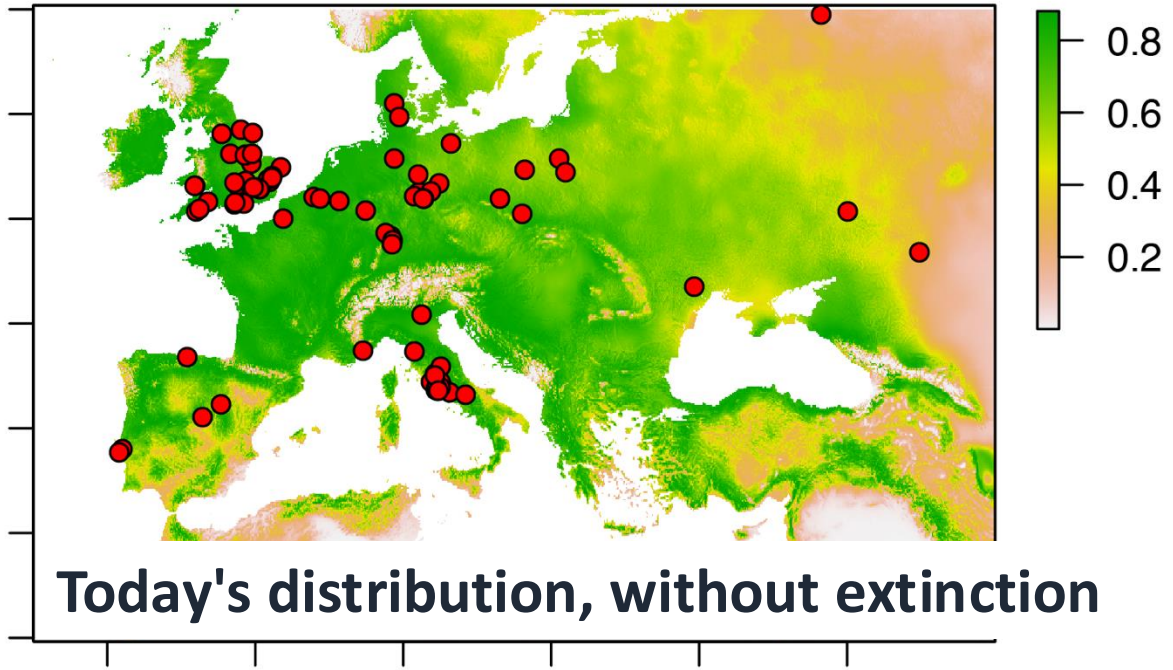
Tjaden et al. (Tre. Parasit., 2018), Thomas et al. (2018, Public Health)

Predicting into the future

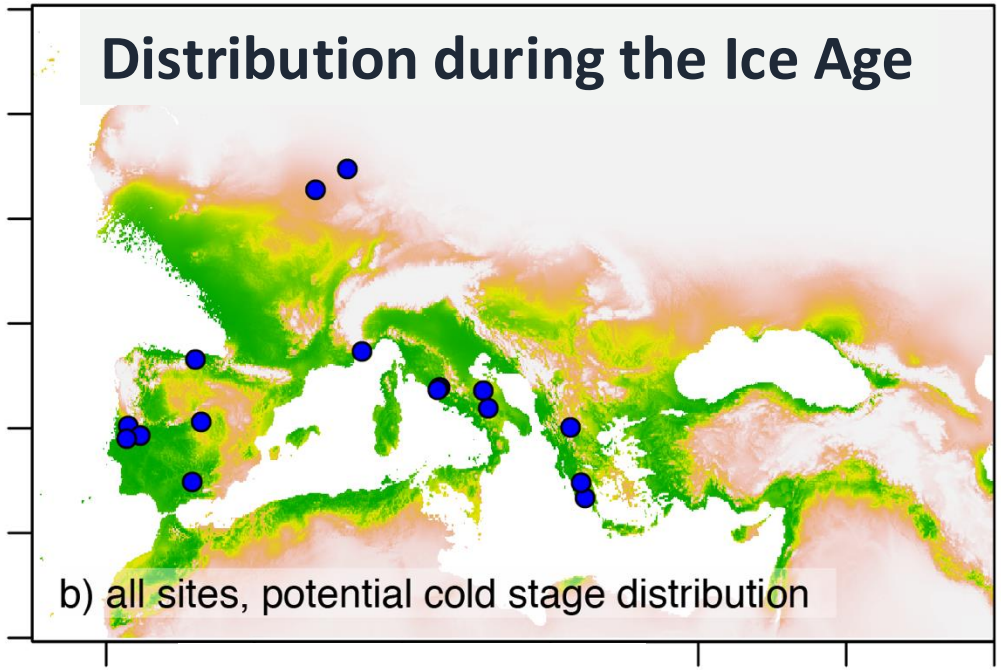


Climatic suitability for European beech forest herbs under climate change

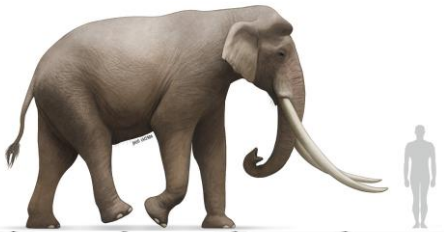
Kermavnar et al., 2023



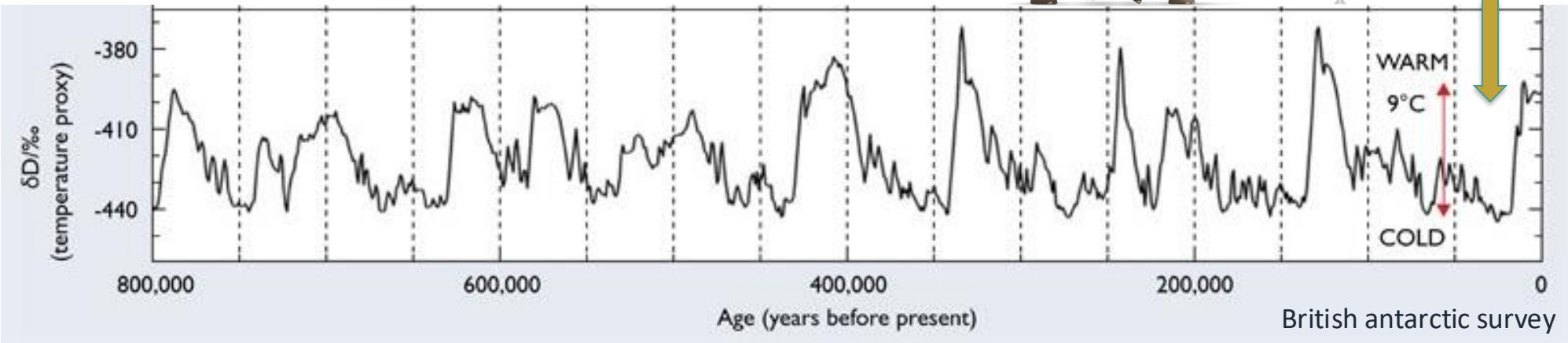
Today's distribution, without extinction



European Elephant (*Palaeoloxodon antiquus*)



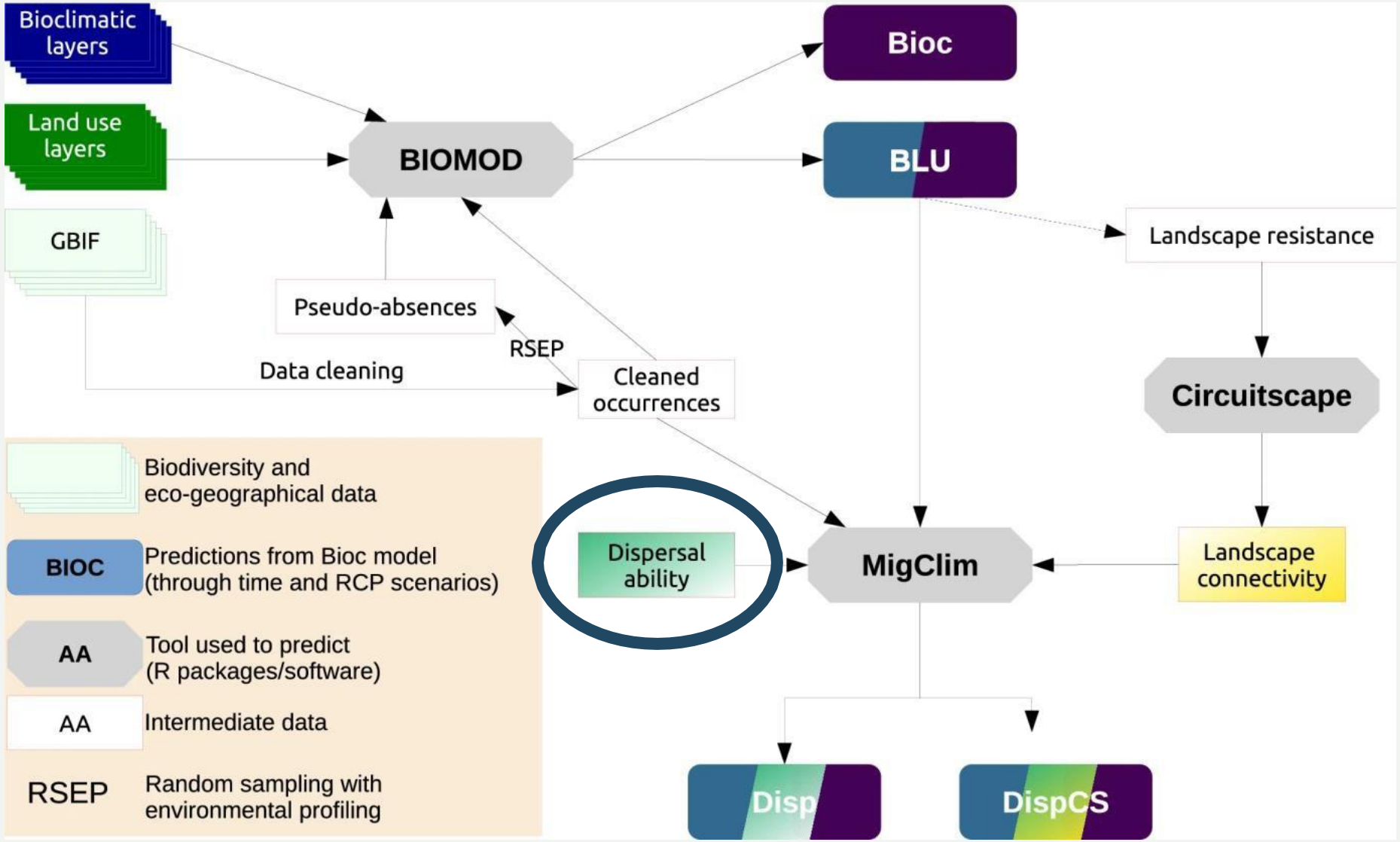
Extinction



Temperature of the last 800.000 years

Gaiser et al. (Front.BioGeo., 2025)

Including dispersal

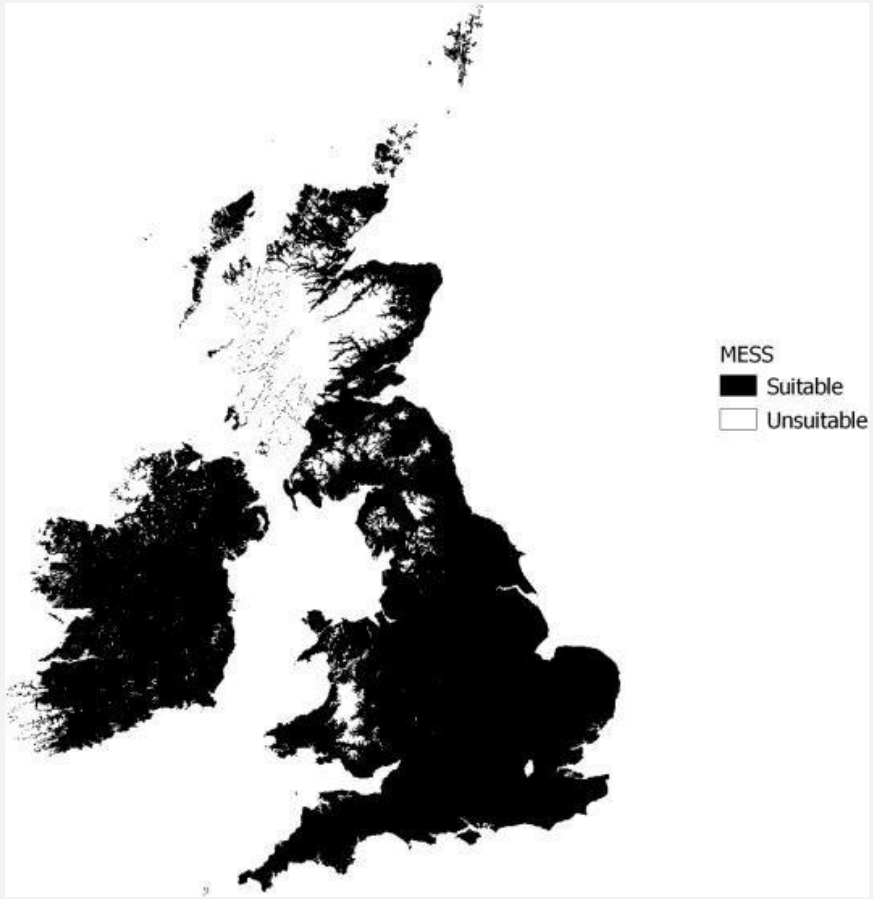


Predictions of SDM in predatory arthropods in Europe

Monsimet et al., 2020

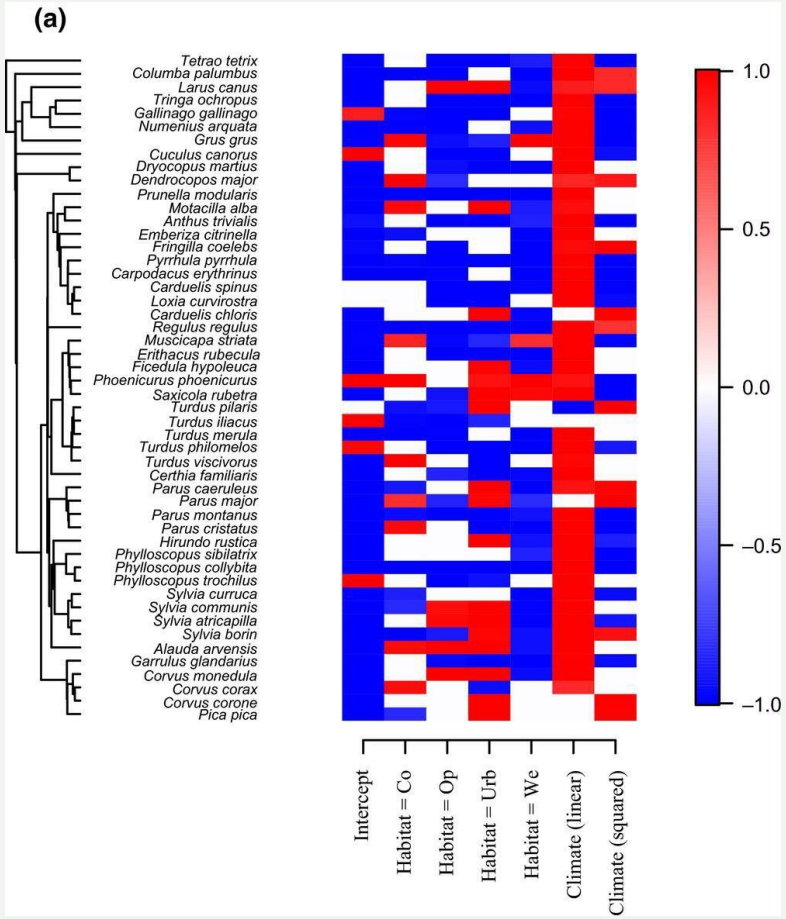
The variability of SDMs - exampels

invasive species distribution model (iSDM)



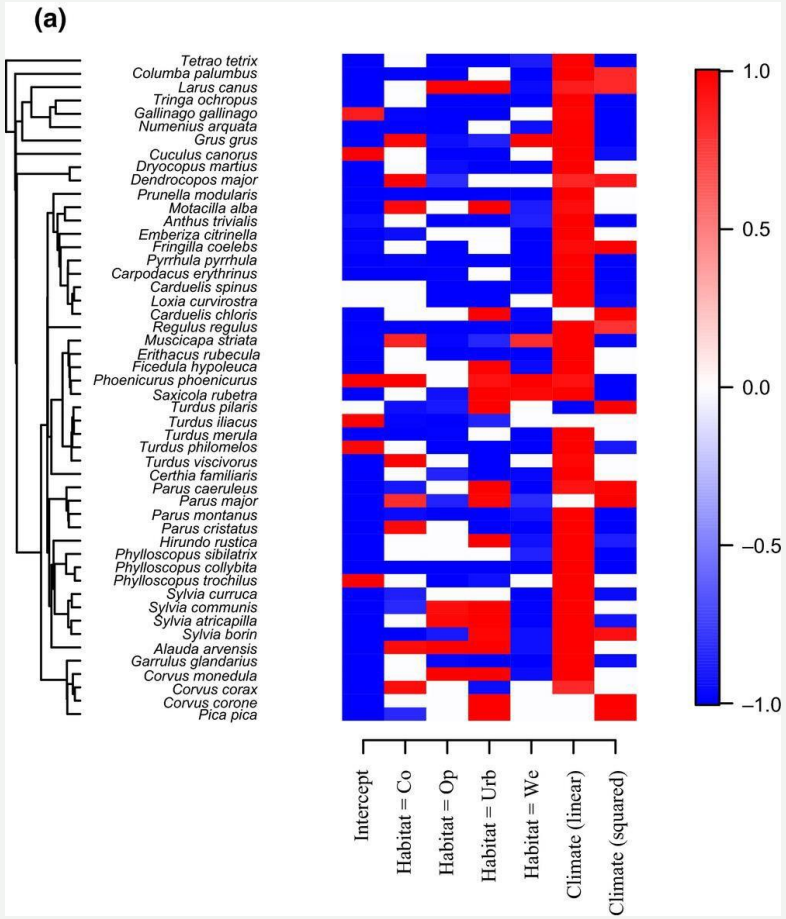
- Predicting the range of muntjac deer in Britain and Ireland
- Incorporation of non-equilibrium bias and survey effort in presence-only iSDM

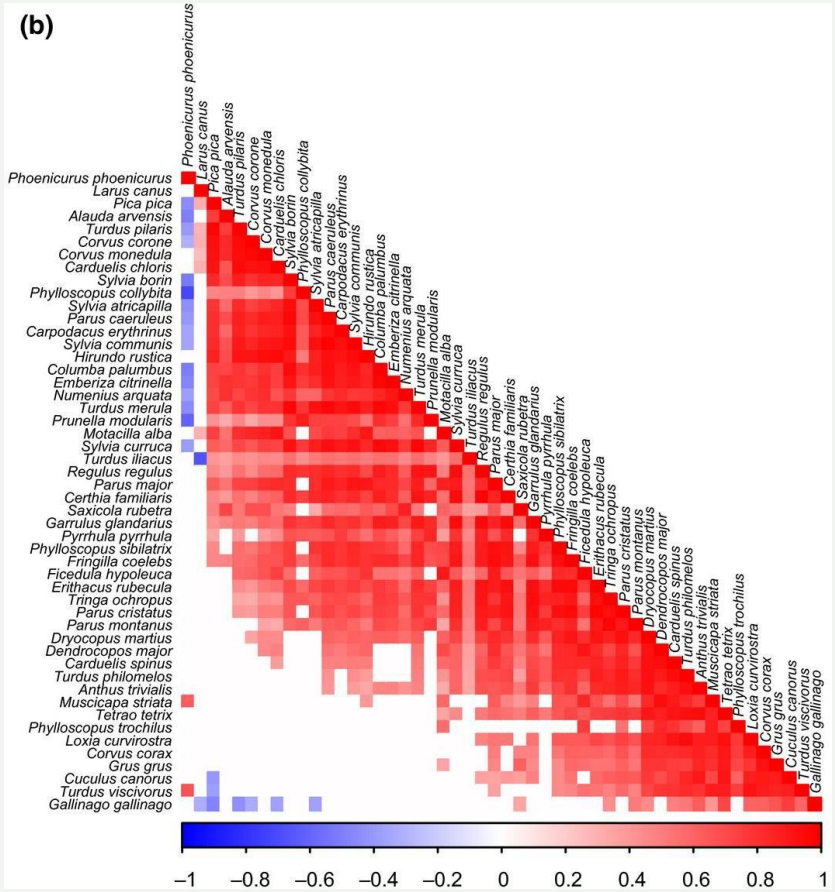
Joint species distribution model (jSDM)



Include species responses to environmental covariates...

Joint species distribution model (jSDM)

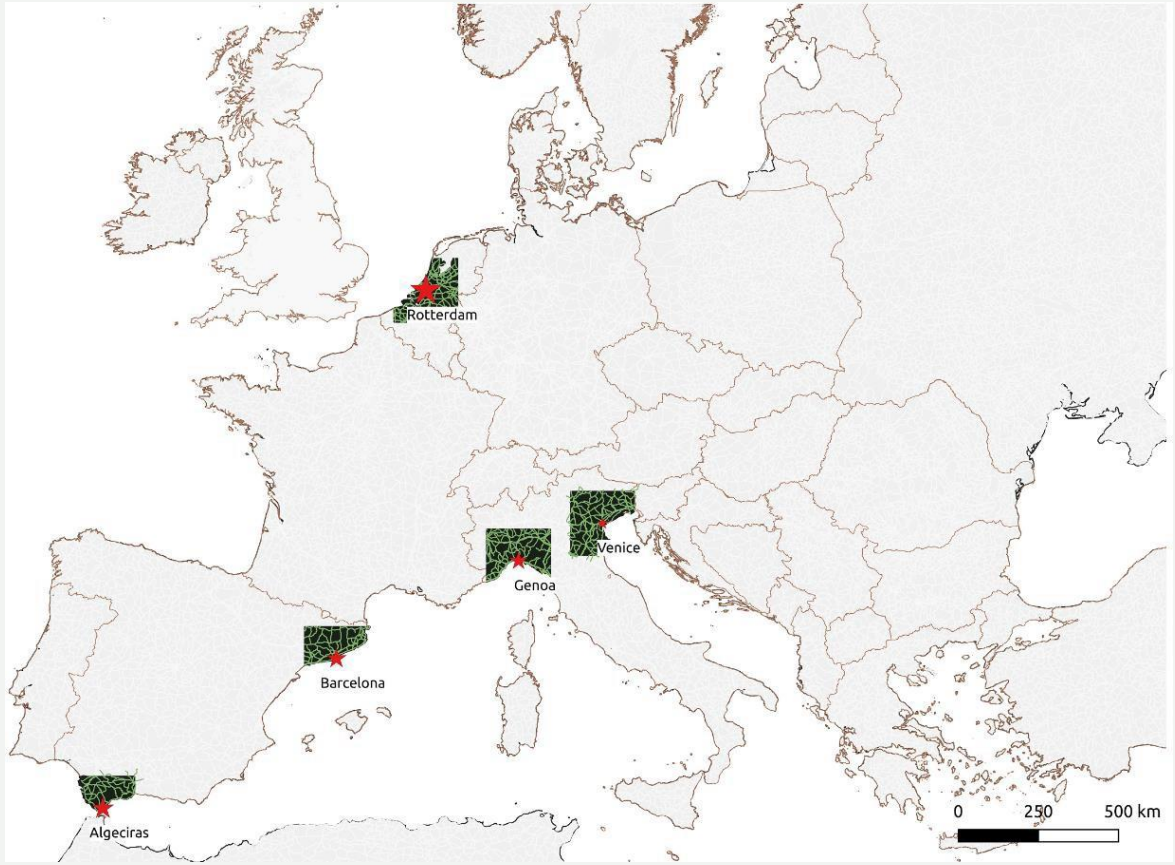




Include species responses to environmental covariates...

…and species‘ associations based on residuals.

Process-based model



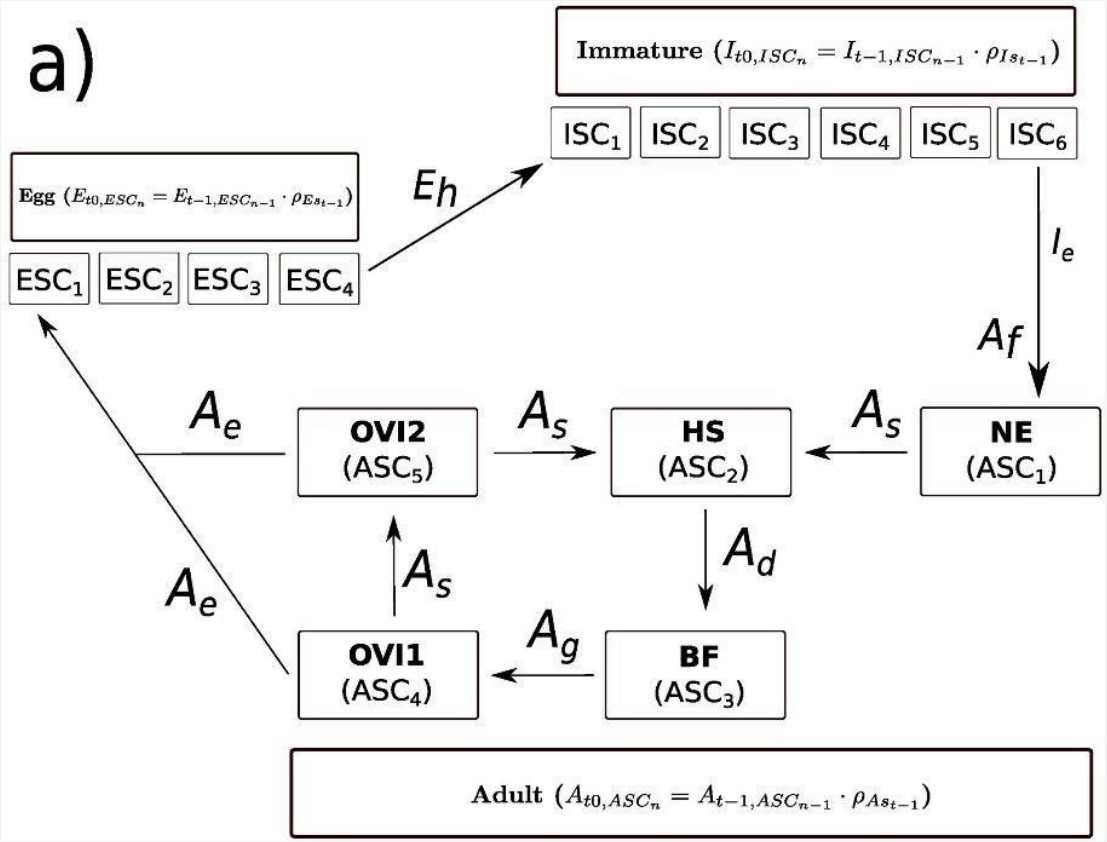
Aedes aegypti

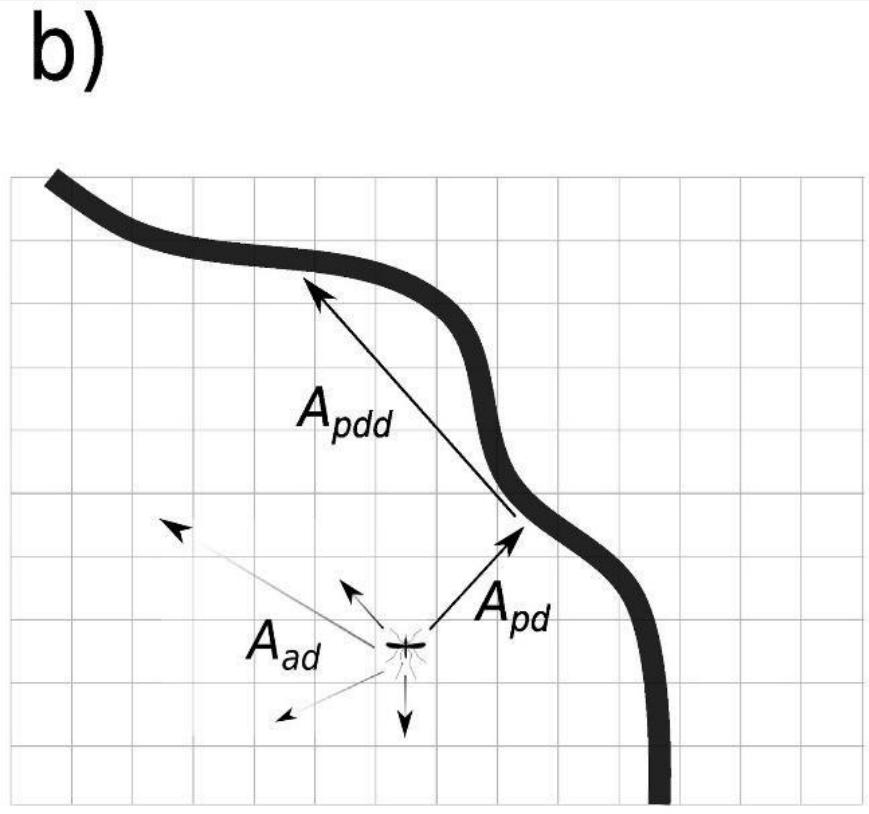
Modeling of *Ae. aegypti* population dynamics in European ports.

Ae. aegypti is a potential vector of yellow fever.

Da Re et al., 2021

Process-based model



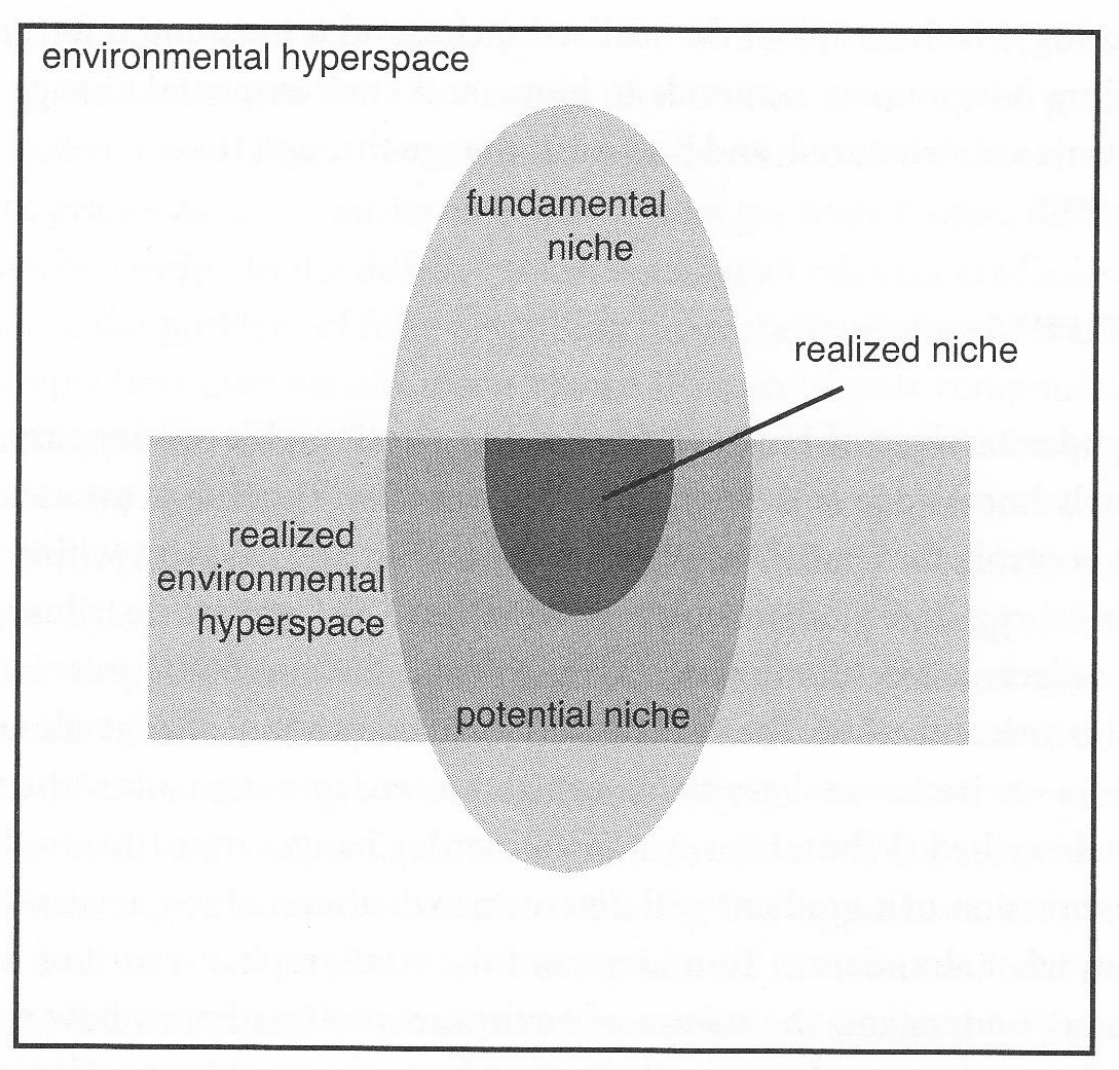


Modeling the life cycle…

…and disperal.

Da Re et al., 2021

Underlying niche theory



Fundamental niche: The part of the niche space that a species could occupy due to its ecological potential.

Potential niche: Part of the fundamental niche that exists.

Realized niche: The part of the fundamental niche that is actually occupied. The realized niche is almost always smaller than the fundamental niche due to e.g. competition.

Holland & Patzkowsky 2012

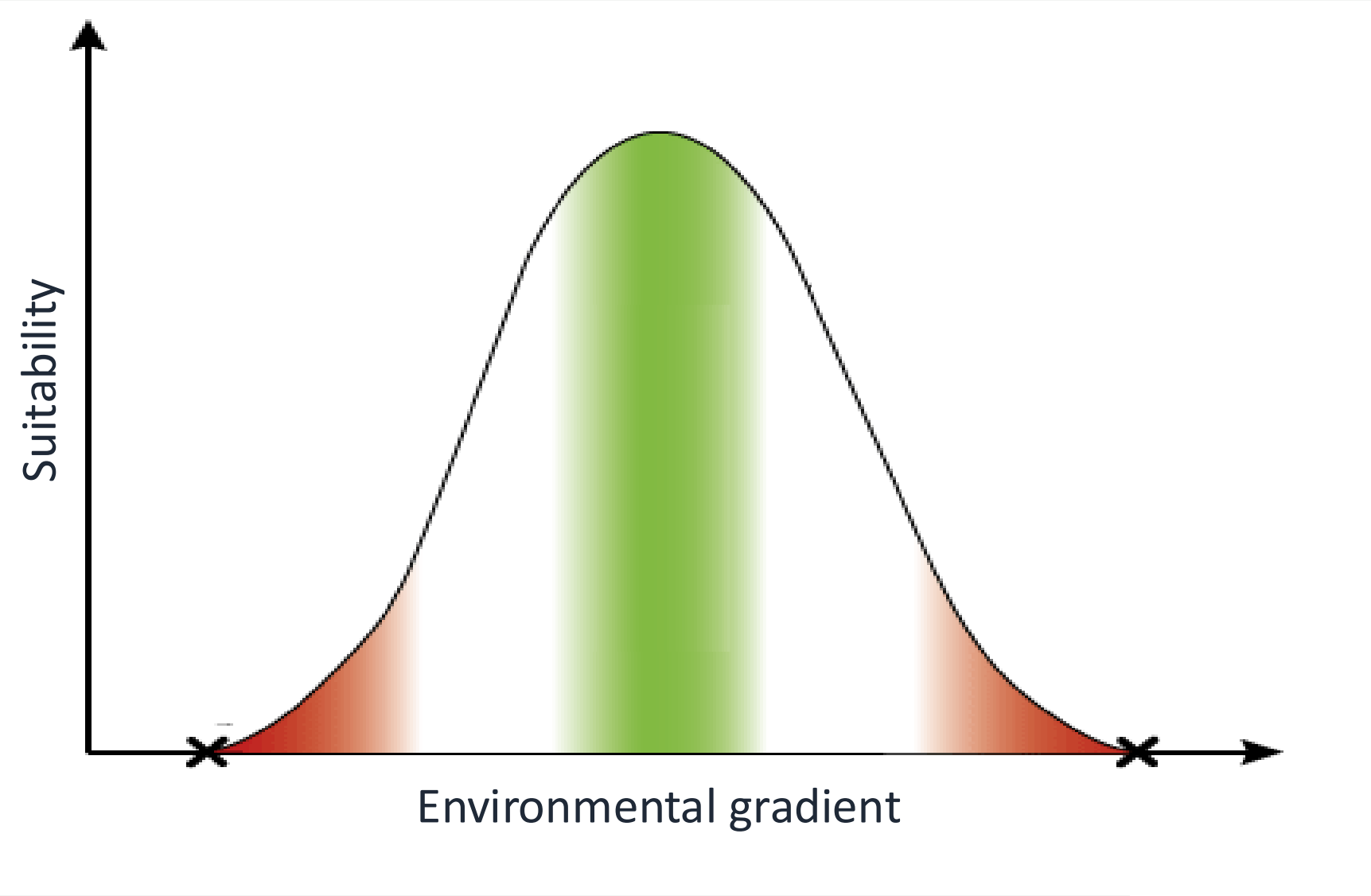
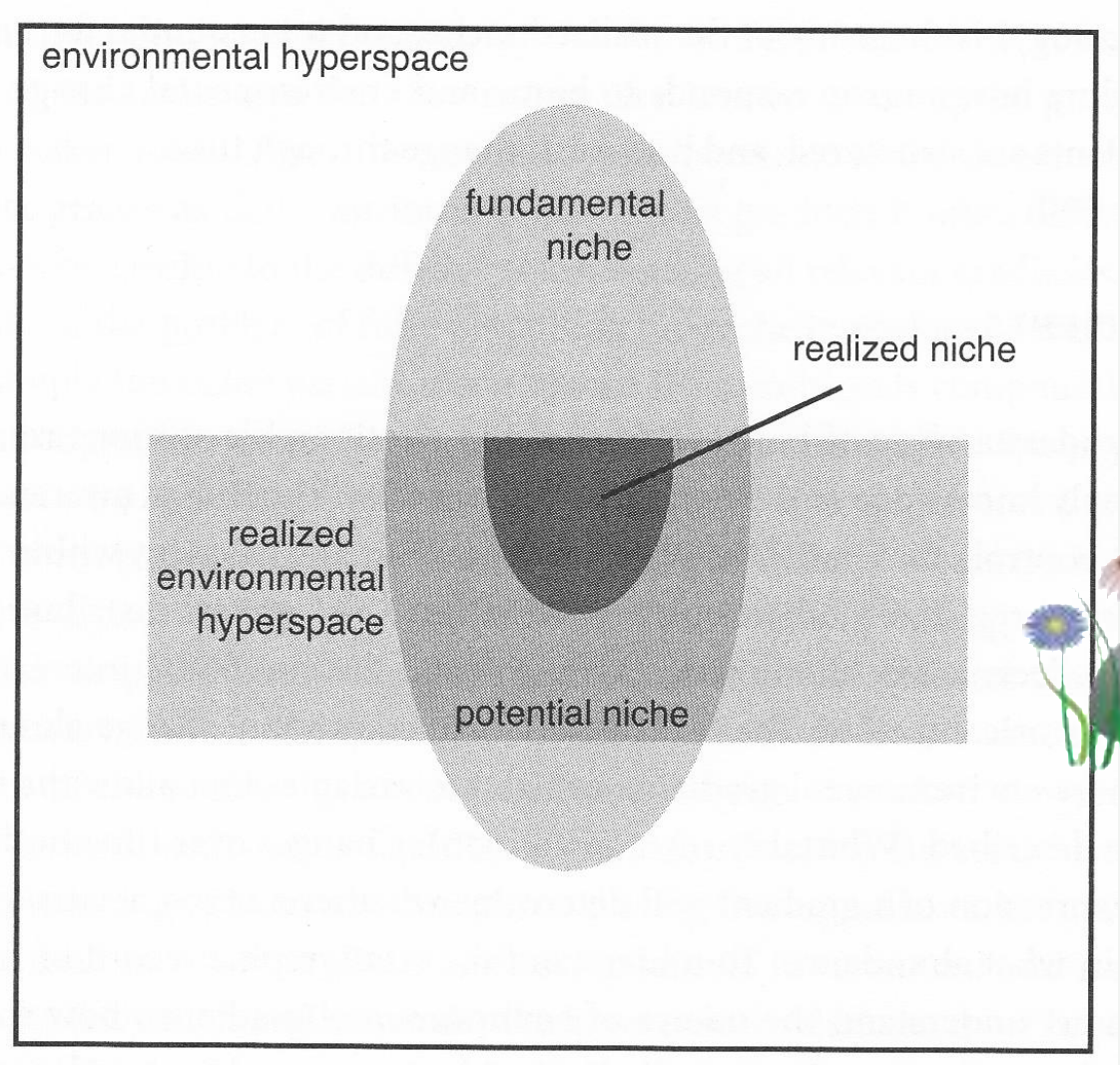


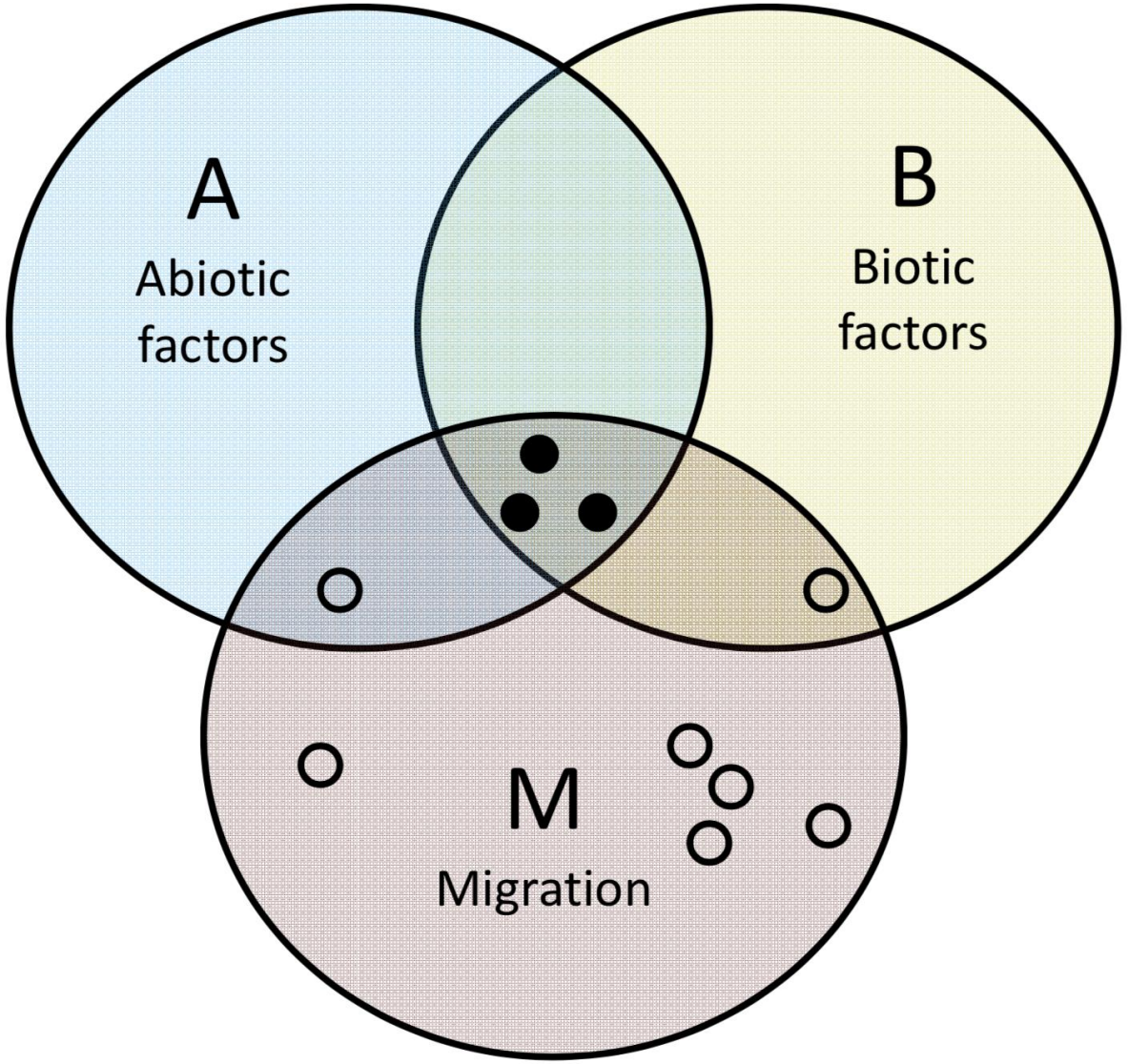
figure from: Philipp Hauer

Underlying niche theory



Holland & Patzkowsky 2012

Steinbauer et al. (J.Veg.Sci., 2016)



- A –area with suitable climatic conditions
  Assuring positive populations growth
- B – area where biotic interactions allow the species to persist, e.g. it is not competitively excluded or are missing mutualistic interactions
- M – area to which the speices can migrate
- Population with positive population growth rate
  $r = b - d \geq 0$
- Population with negative population growth rate

Soberon & Nakamura (2009, PNAS)

Distribution of species

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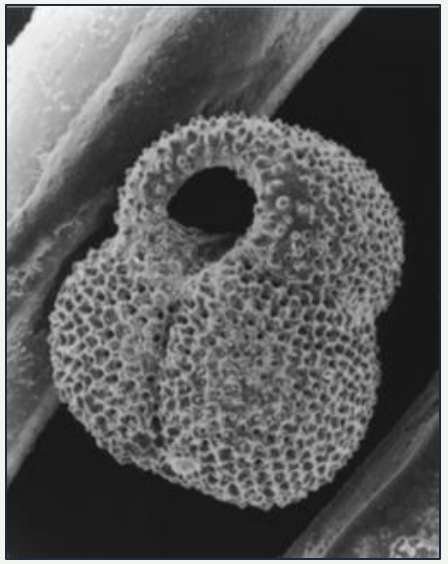
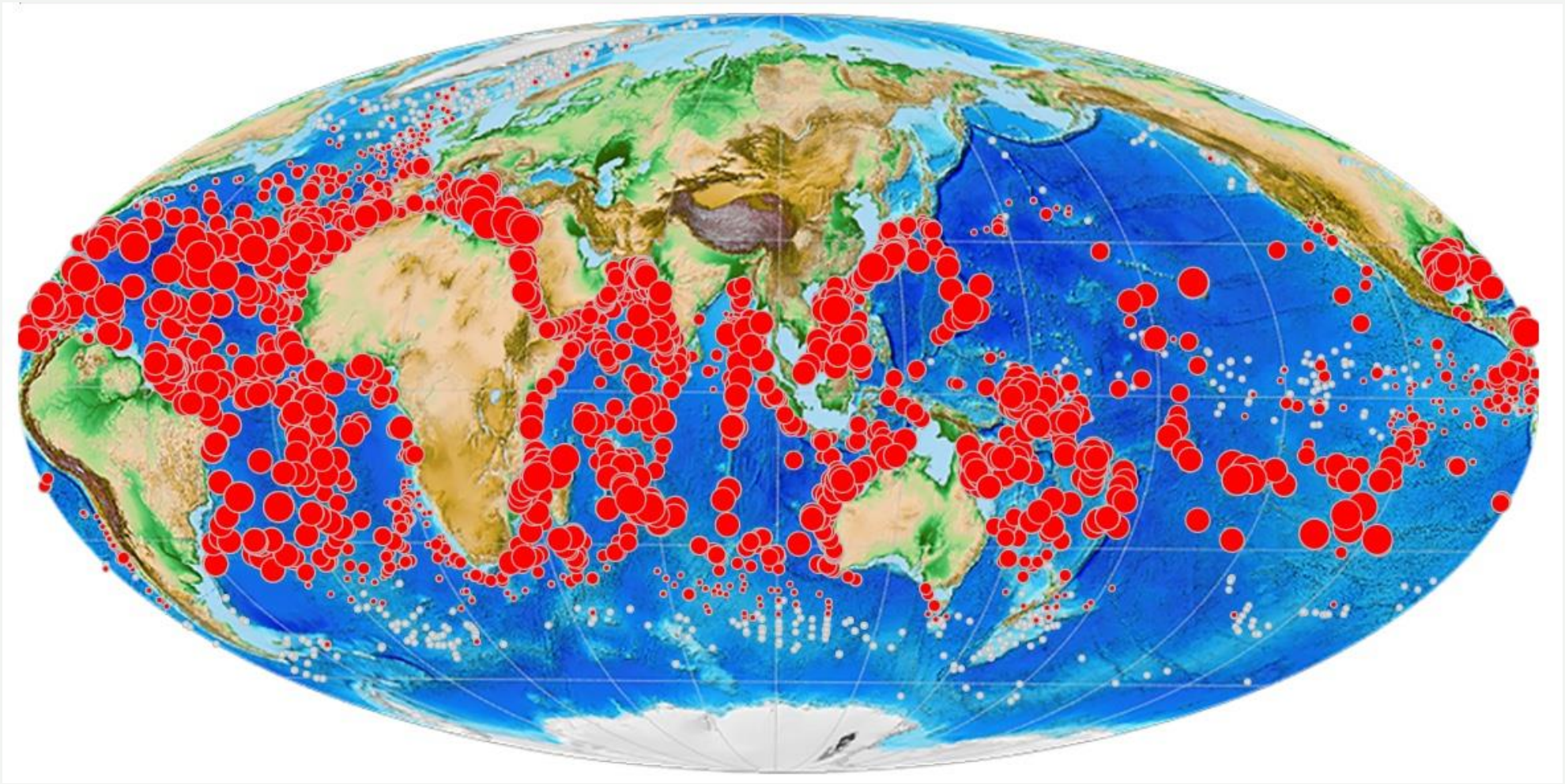


Eye of a needle
X 20



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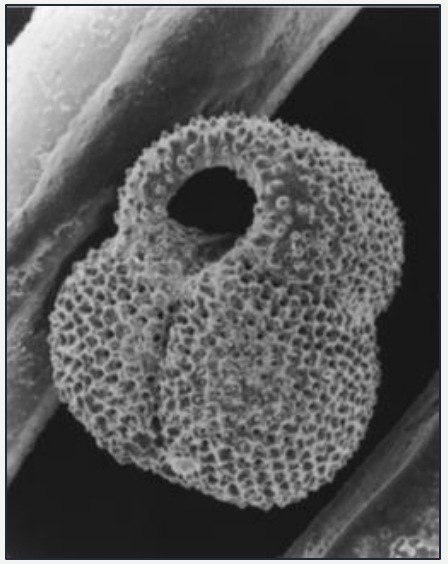

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X 20

Abundance indicated by red point size ; white points represent absences

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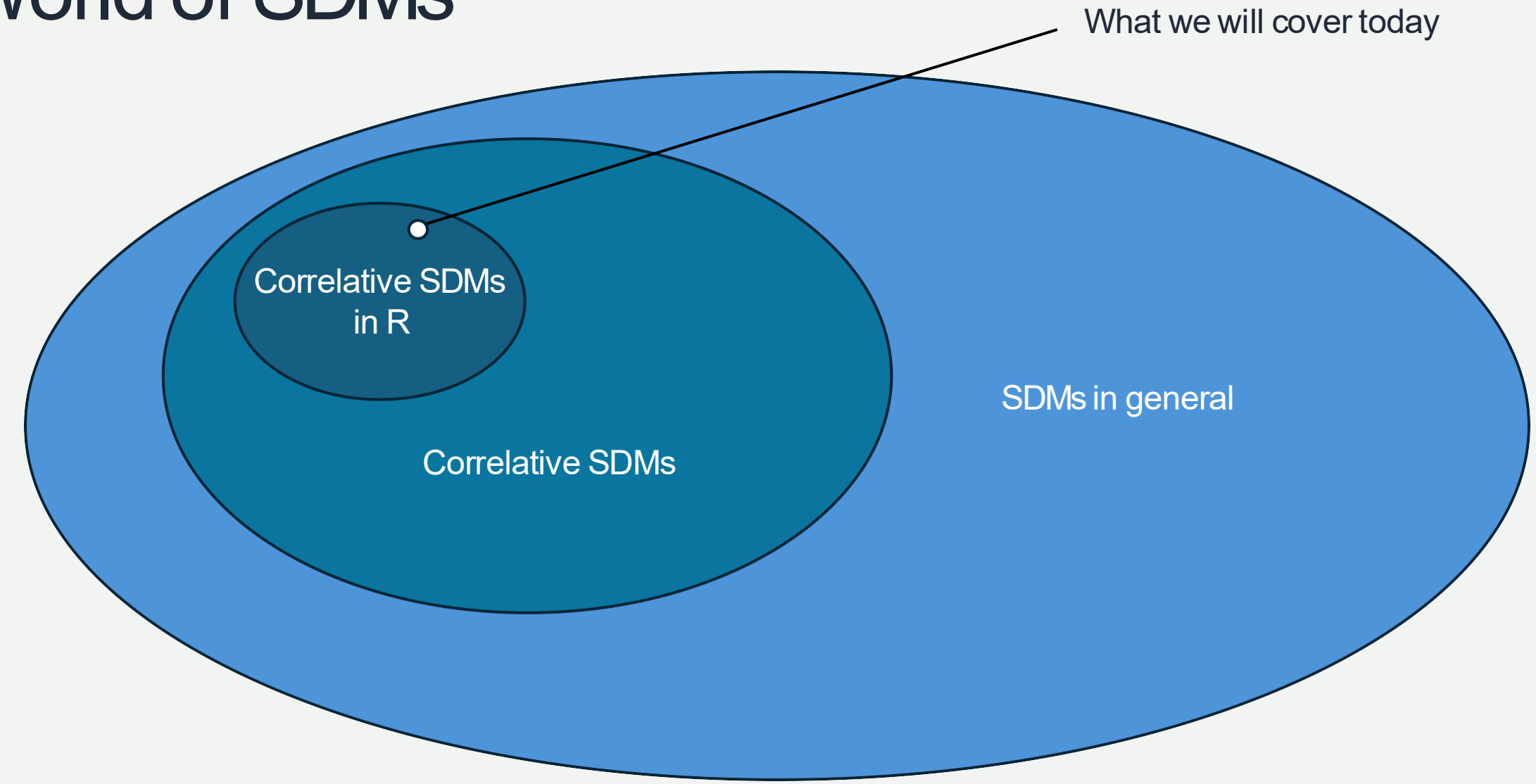
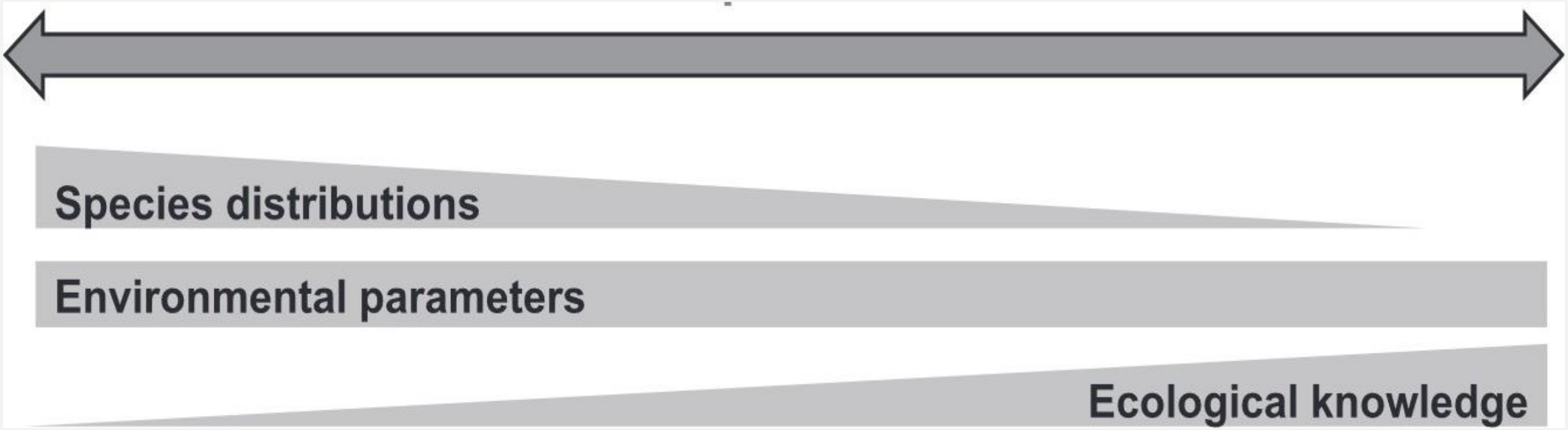
World of SDMs

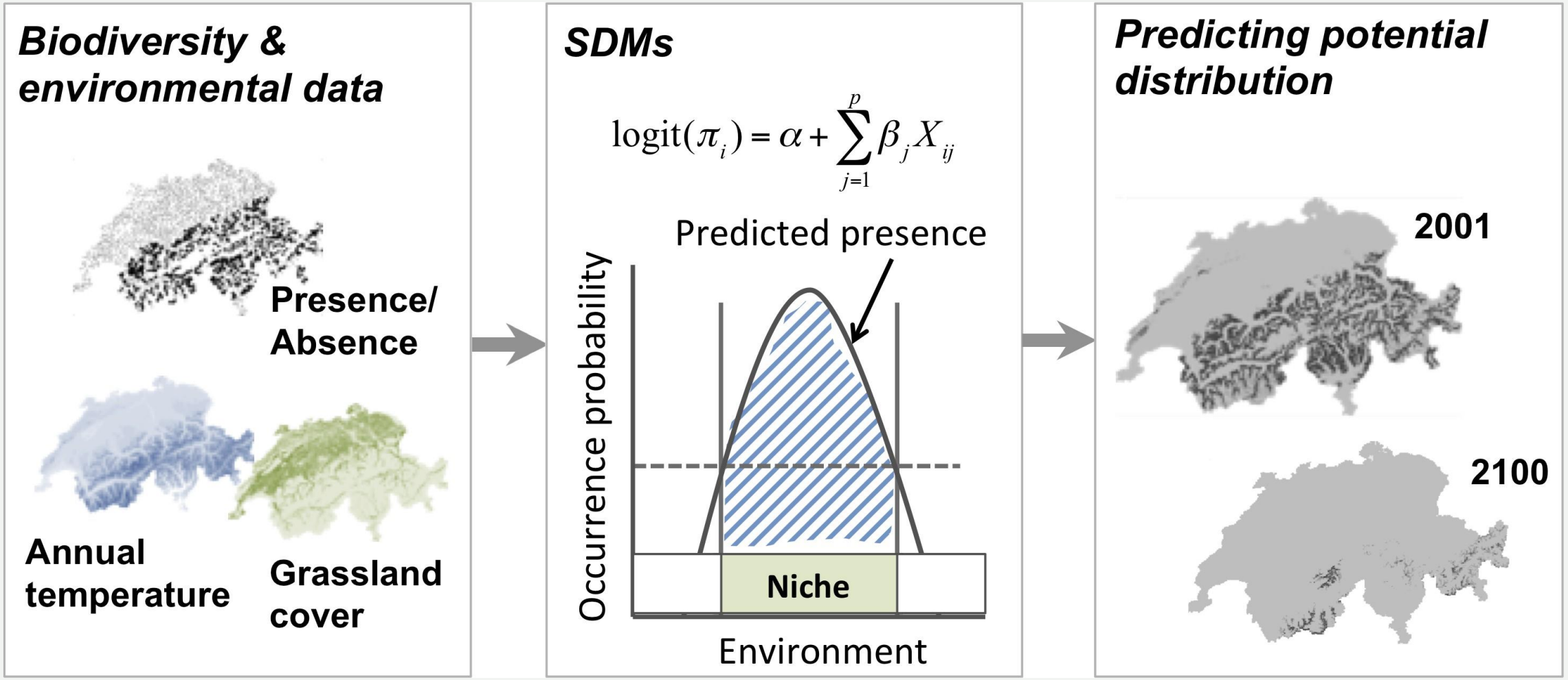


Correlative vs. process-based models



Dormann et al., 2011

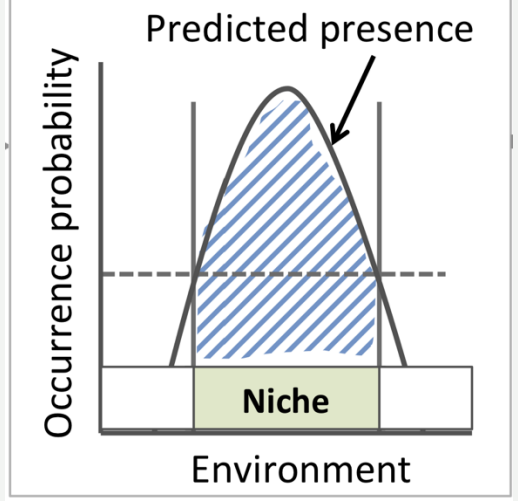
Our goal: build simple correlative SDM

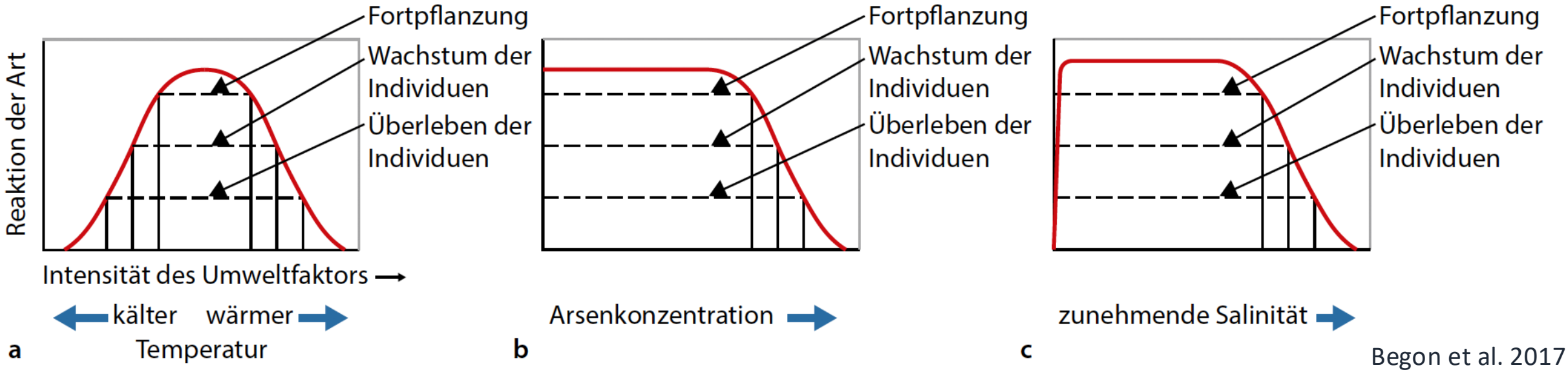


Zurell, 2022

SDMs

$$\text{logit}(\pi_i) = \alpha + \sum_{j=1}^{p} \beta_j X_{ij}$$





Begon et al. 2017

Questions?

5 minutes activity break?

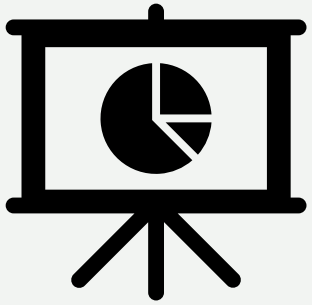
Introduction to quarto

Create **dynamic documents** …

… that combine **code and text**

… in various formats (html, pdf, ms word)

… for various purposes (articles, presentations, dashboards)



Quarto Guide: https://quarto.org/docs/guide/

TUTORIAL: HELLO, QUARTO

HTTPS://QUARTO.ORG/DOCS/GET-STARTED/HELLO/RSTUDIO.HTML

4. SDMs in R (live coding together)

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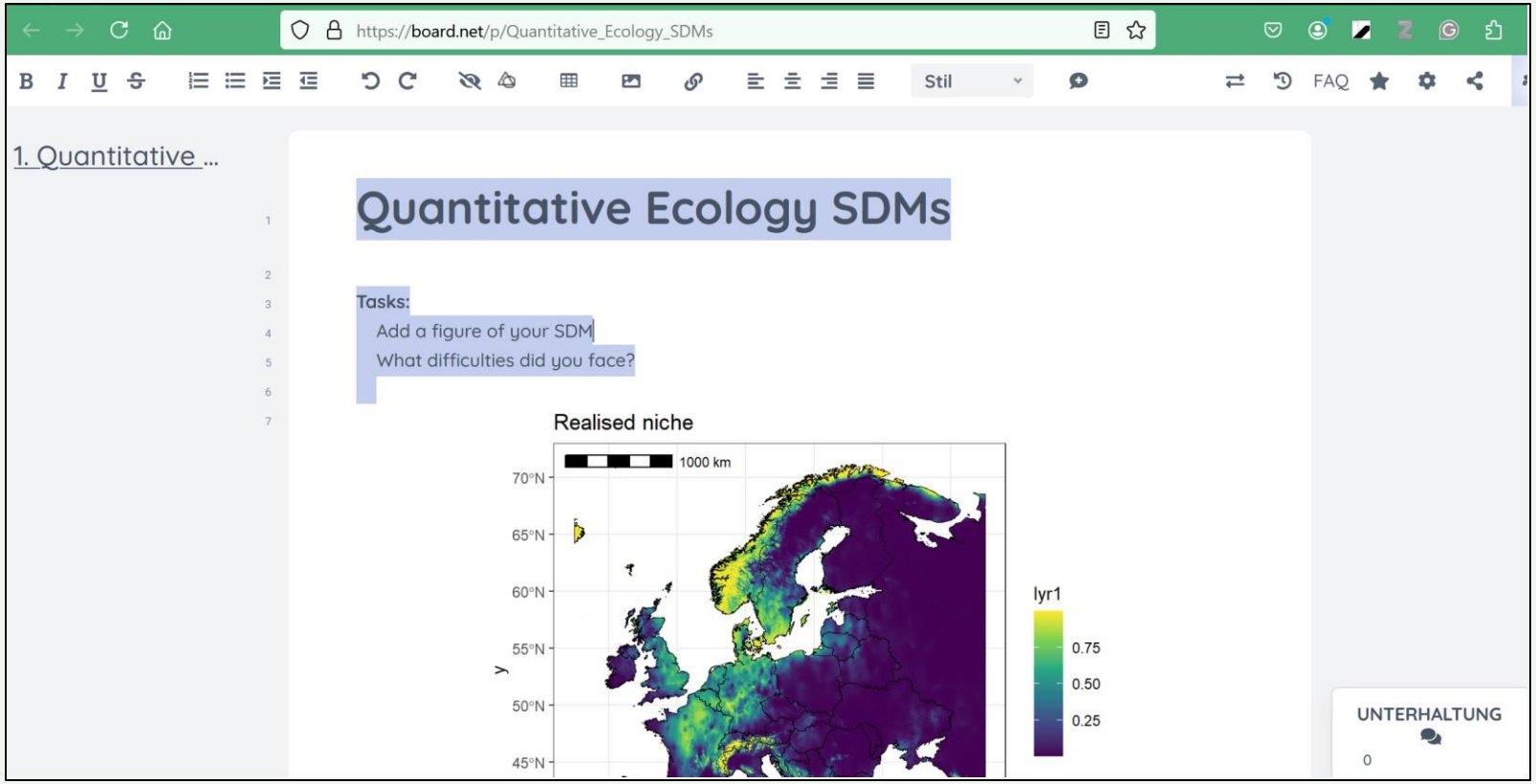
Your SDMs



https://board.net/p/Quantitative_Ecology_SDMs

Pros & cons correlative SDMs

Think per share

1. Take **5 minutes** to think about the pros and cons of correlative SDMs **individually**.
2. Take **10 minutes** to discuss the topic in **groups of 2-3 people**.
3. Share your results in the **plenary.**

Please note down your group results in the following etherpad:

https://board.net/p/Quantitative_Ecology_SDMs_pros_cons

Tutorials

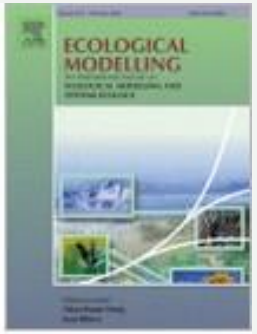
- A very brief introduction to species distribution models in R by Jeff Oliver: jcoliver.github.io/learn-r/011-species-distribution-models.html
- Introduction to species distribution modelling (SDM) in R by Damaris Zurell: damariszurell.github.io/SDM-Intro
- Downloading and cleaning GBIF data with R by A.M. Barbosa: www.r-bloggers.com/2021/03/downloading-and-cleaning-gbif-data-with-r
- Accessing, handling, and referencing open biodiversity data using the Global Biodiversity Information Facility (GBIF) by Eric Kusch: www.erikkusch.com/courses/gbif
- Joint Species Distribution Modeling in R with Hmsc: earthlab.colorado.edu/blog/joint-species-distribution-modeling-r-hmsc

R packages

ELSEVIER

Ecological Modelling

Volume 476, February 2023, 110242



A curated list of R packages for ecological niche modelling

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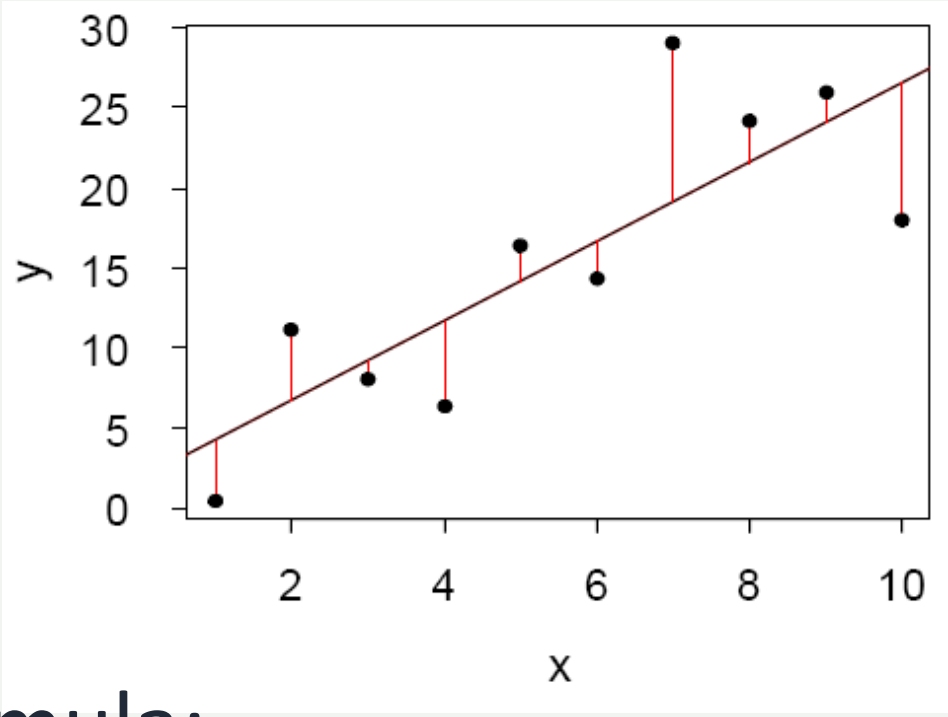
Sillero, 2023

Questions?

Thank you!

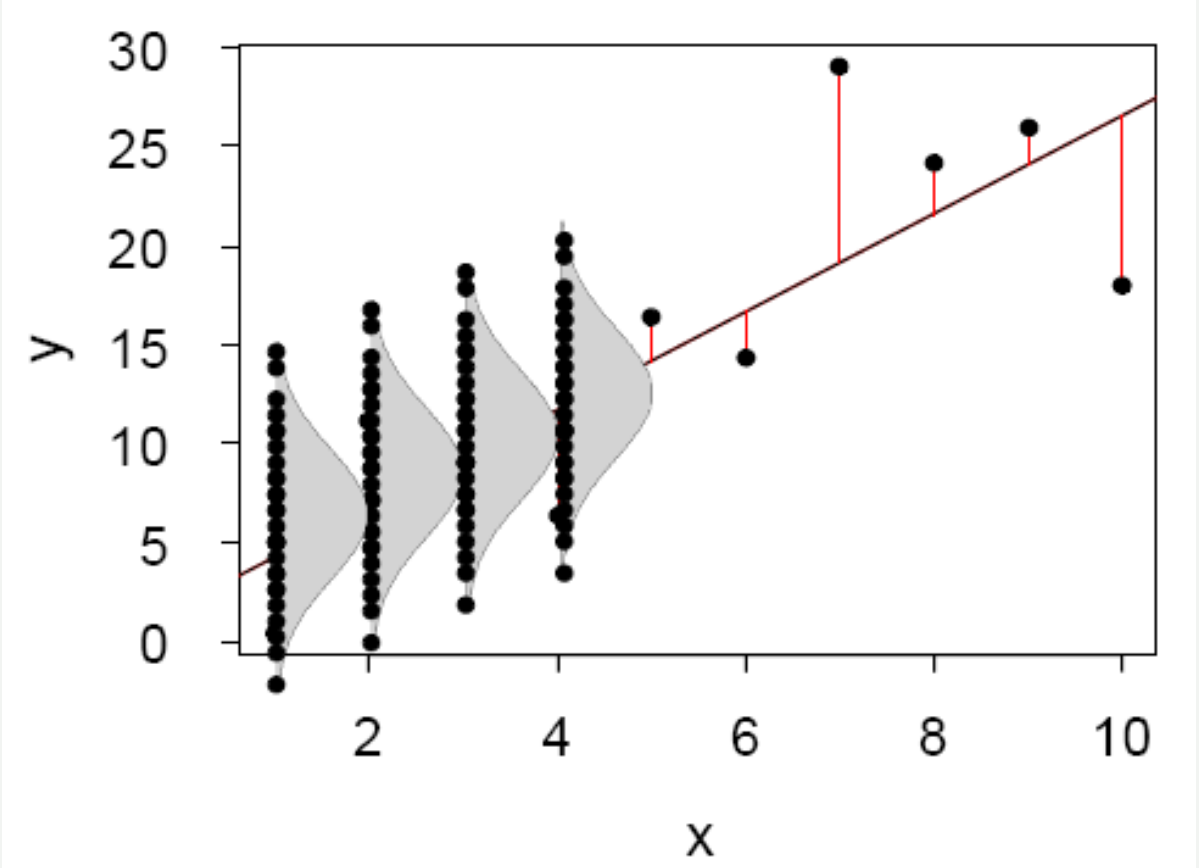
Linear regression



Model formula:

$y = \beta_0 + \beta_1 x + \boldsymbol{\varepsilon}$ $\qquad$ $\boldsymbol{\varepsilon}_{i's} \sim N(0,\sigma^2)$

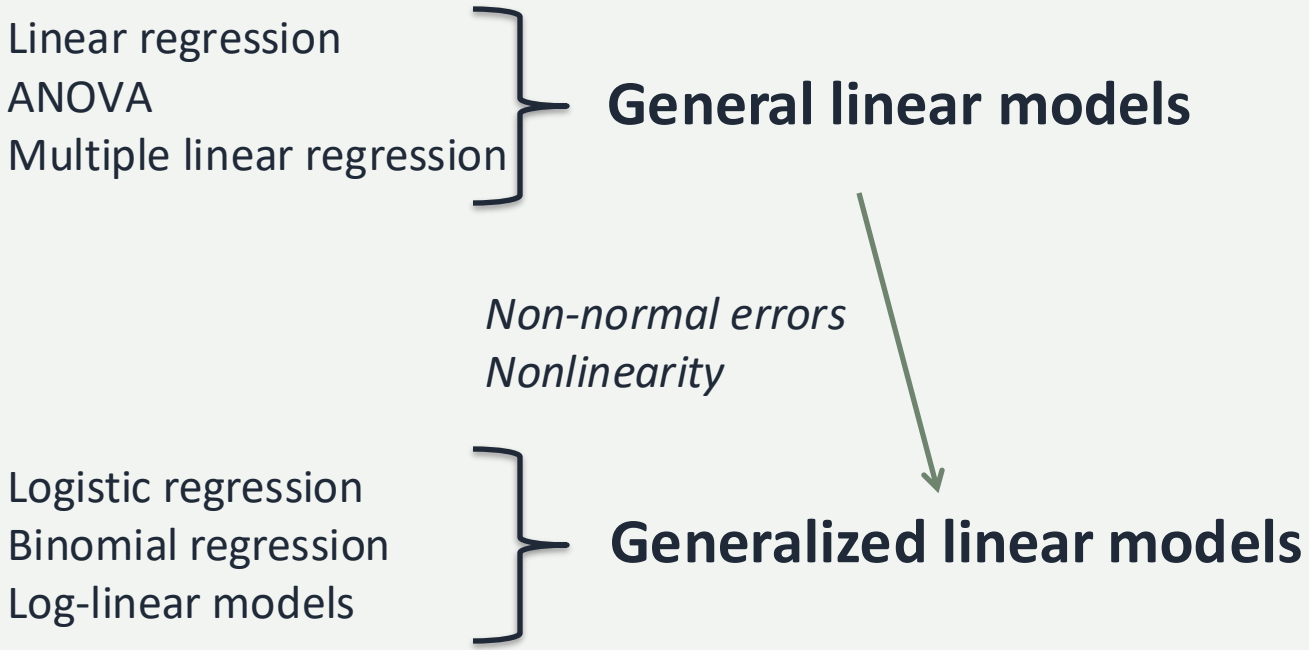
Linear regression



$\in$ is normally distributed with the same variance for each x value

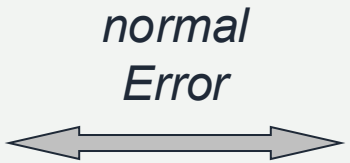
Linear regression
ANOVA
Multiple linear regression

General linear models


Linear regression
ANOVA
Multiple linear regression
General linear models
Non-normal errors
Nonlinearity
Logistic regression
Binomial regression
Log-linear models
Generalized linear models

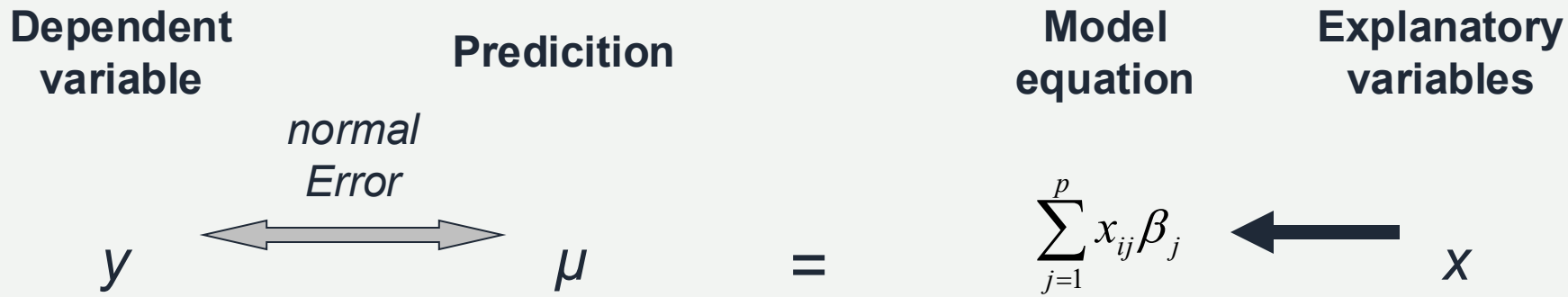
Lineares Modell:

Dependent variable | **Predicition** | **Model equation** | **Explanatory variables**

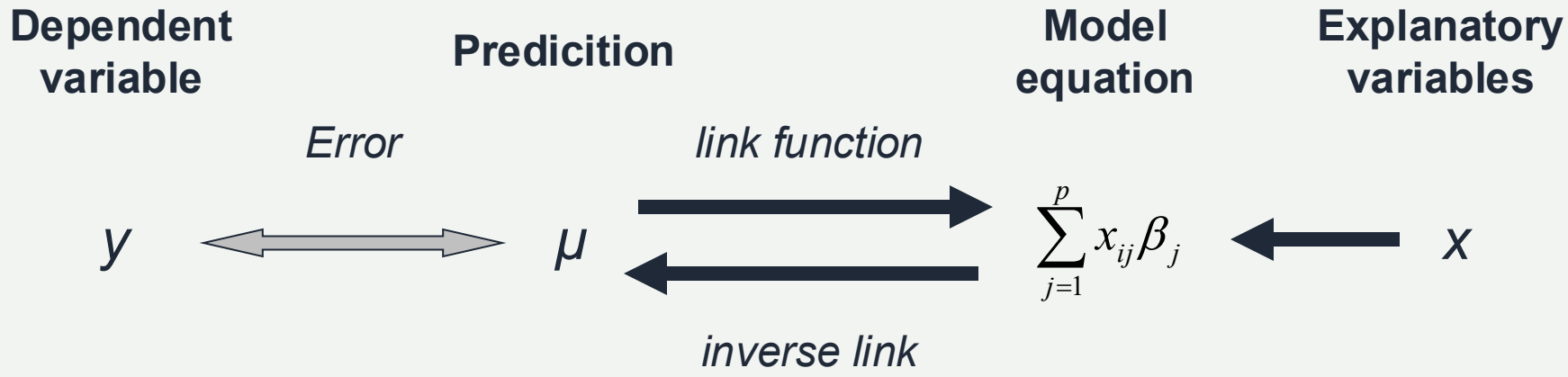


$y \quad \mu \quad = \quad \sum_{j=1}^{p} x_{ij}\beta_j \quad x$

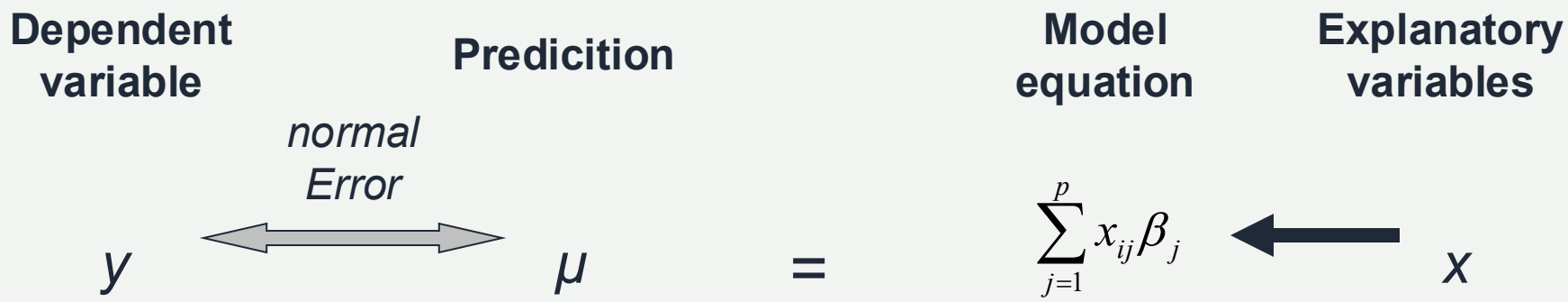
Lineares Modell:



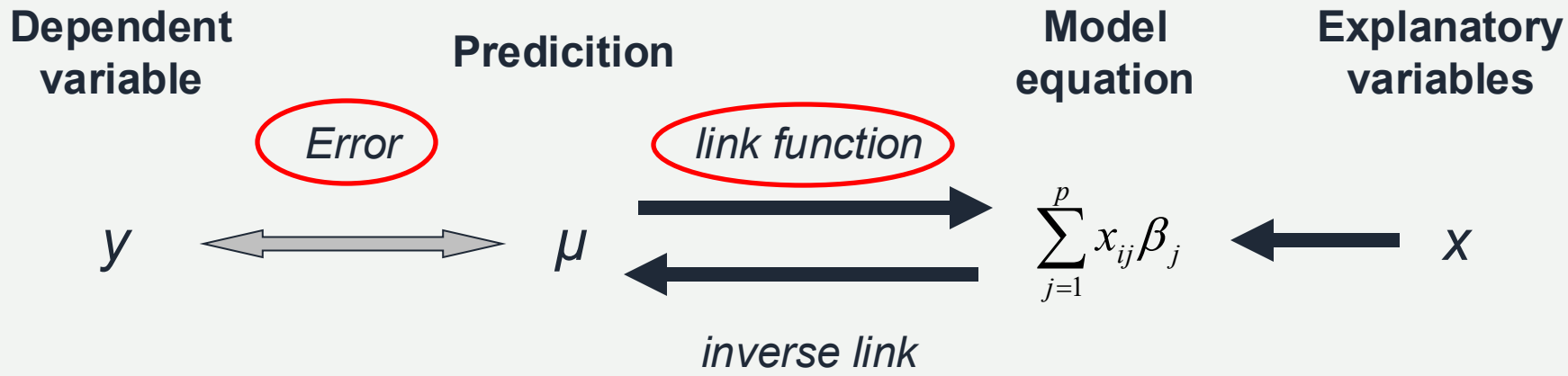
GLM:



Lineares Modell:



GLM:



Important distributions

Data	Example	Distribution
Measures	Changes in weight for mice with new food	Normal distribution
Count data	# of species at certain locations	Poisson distribution
Binary data	How many of 100 seeds germinate?	Binomial distribution

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glm(y~x)