
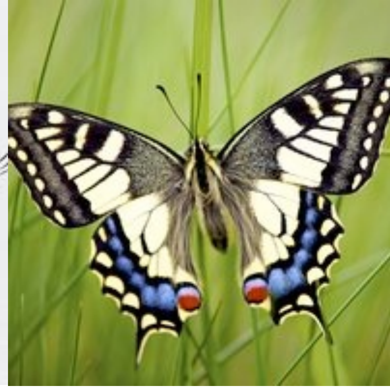


Understanding and predicting regional to global biodiversity dynamics

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Ecology & Macroecology

https://damariszurell.github.io

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Pictures from www.undekade-biologischevielfalt.de

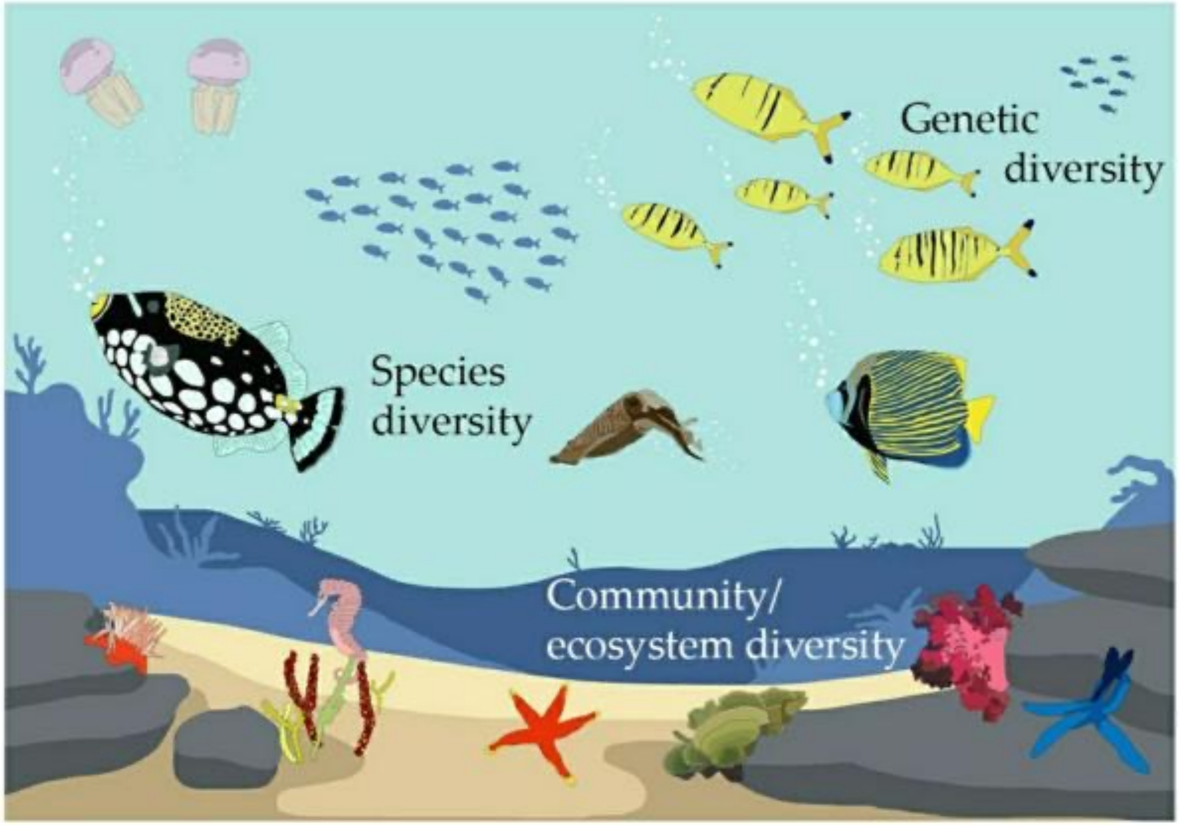
Research questions

How does biodiversity respond to human-driven environmental change ?

- Improve **predictive capacity, data** and **uncertainty** quantification
- Improve understanding of relevant **processes** and **feedbacks**
- Improve scientific basis for environmental **management** and **monitoring**

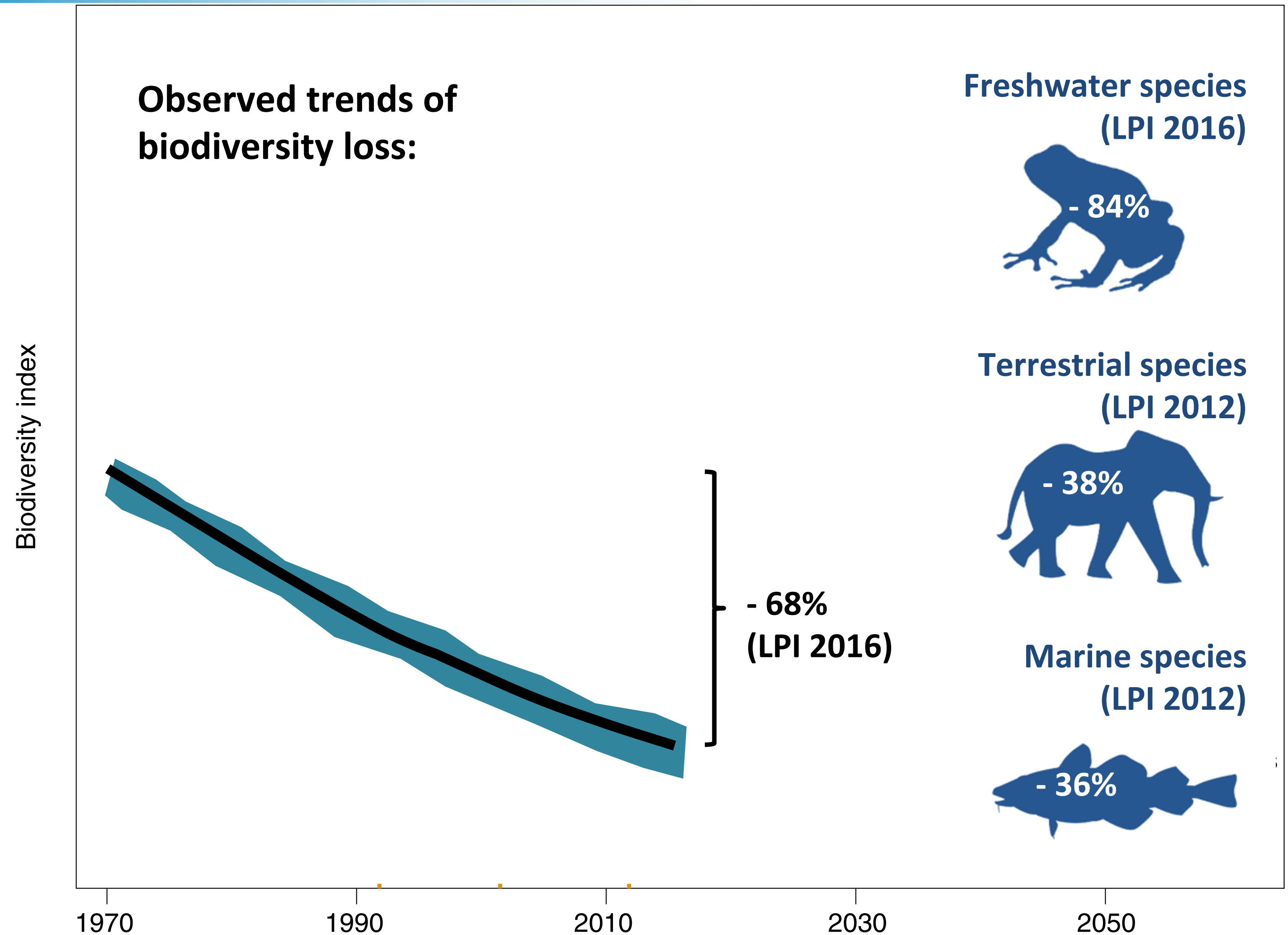
What is biodiversity?

Biological diversity means the variety of life on Earth – within species, between species and of entire ecosystems (*Convention on Biological Diversity, 1992)*



Wilson & Primack (2019) Open Book Publisher.

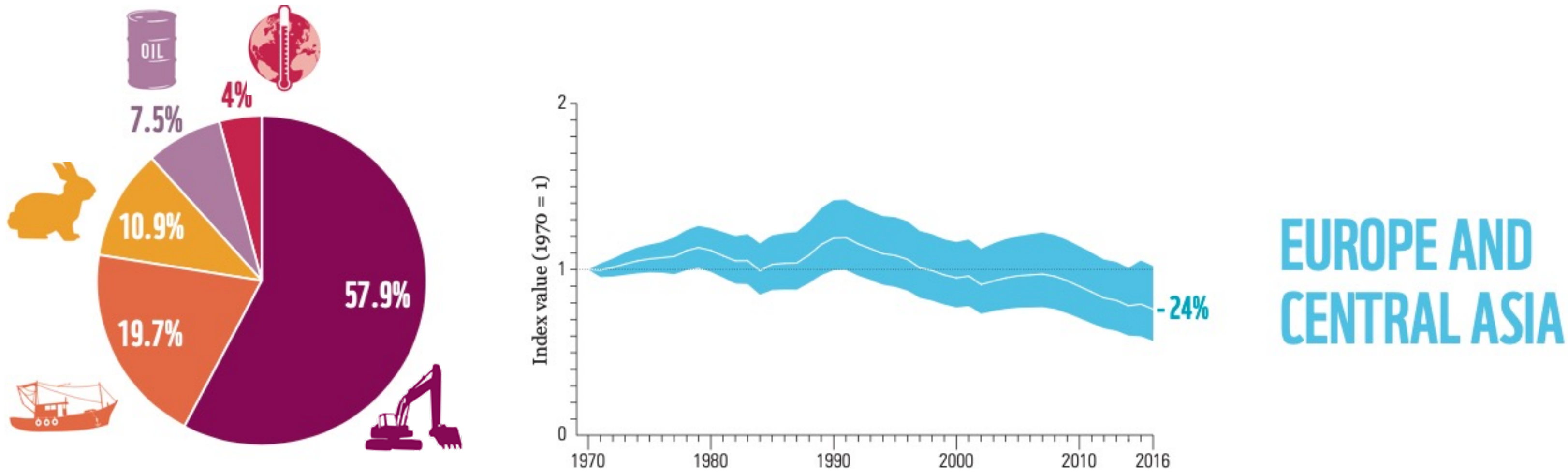
The global biodiversity crisis

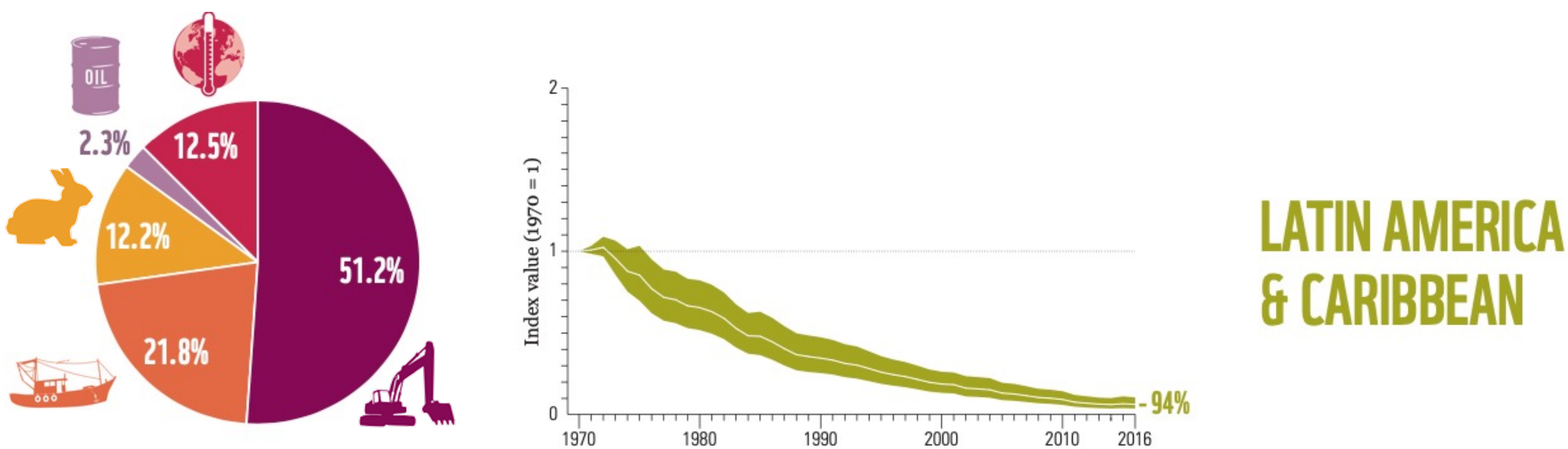


Living Planet Index (2018) WWF.

Mace et al. (2018) Nat Sustain 1: 448-451.

The global biodiversity crisis



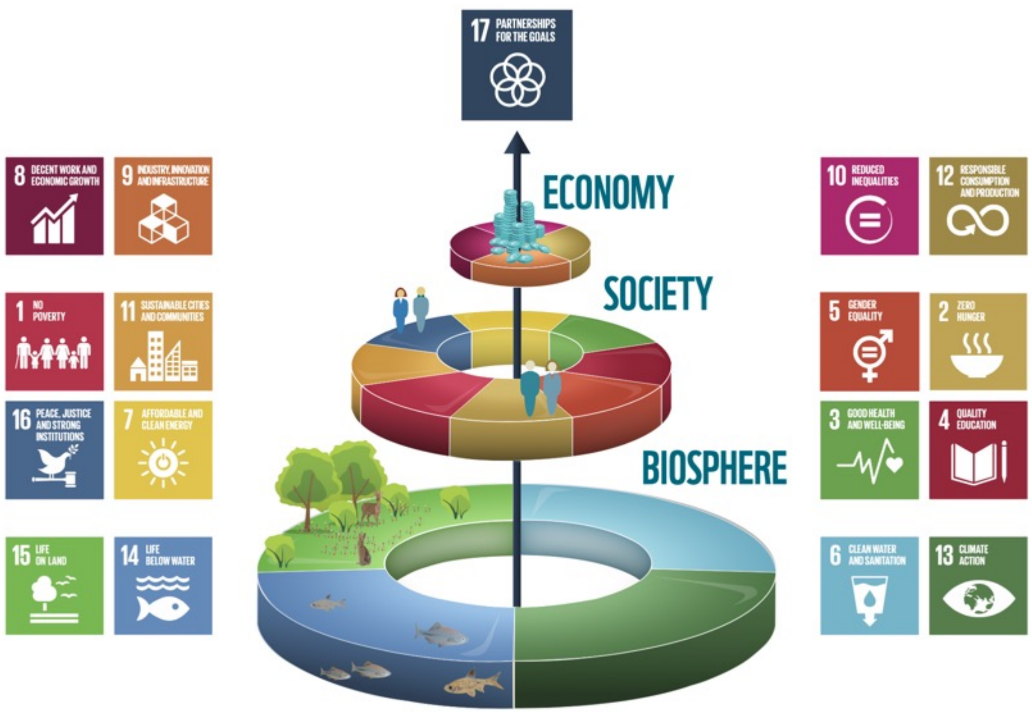


Living Planet Index (2020) WWF.

Biodiversity loss is a self-preservation issue

Alexander von Humboldt: „*all natural forces are linked together, and made mutually dependent upon each other*“

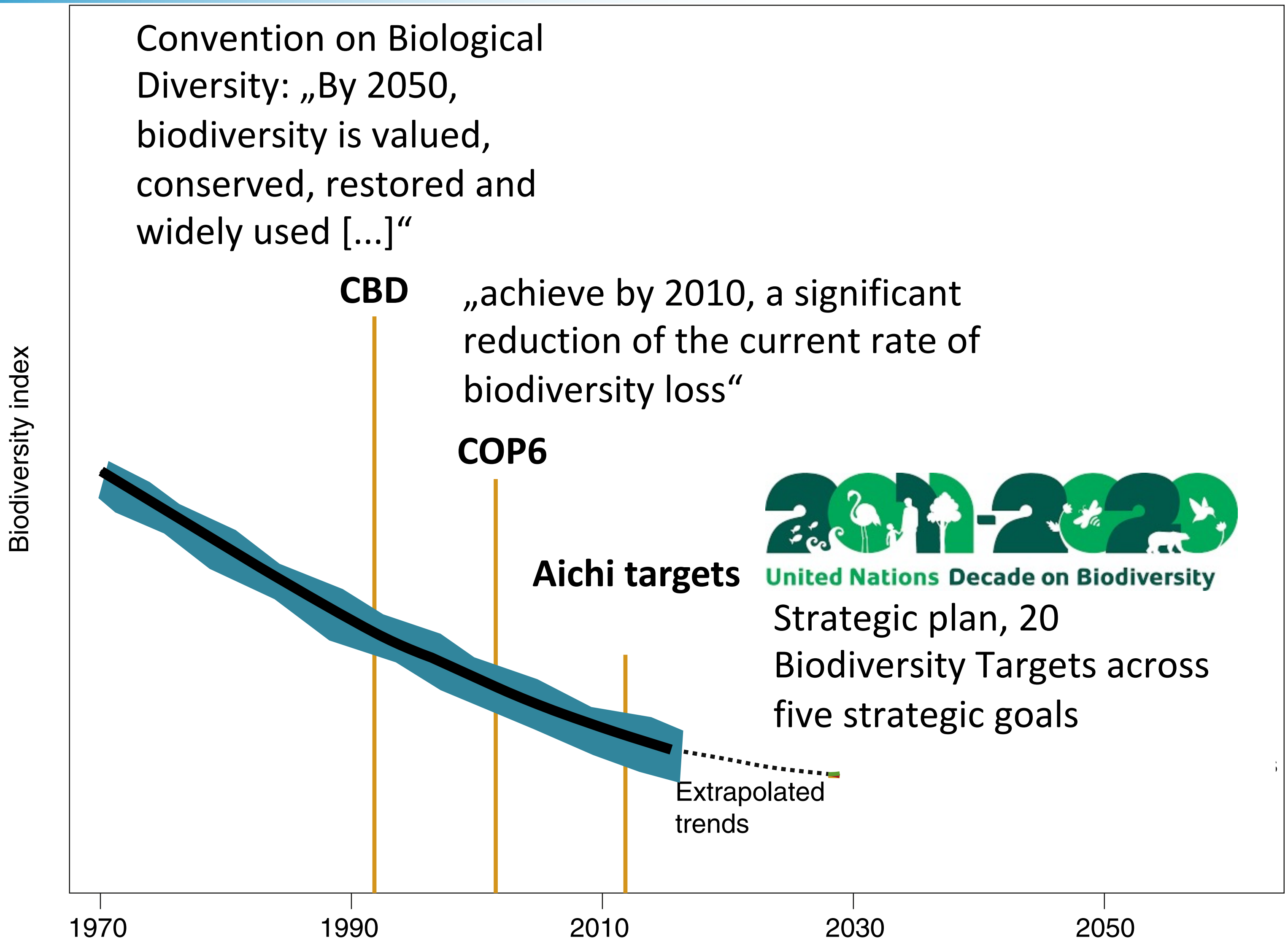
➔ Biodiversity loss will jeopardize the achievement of the sustainable development goals (SDGs)



Humboldt (1845) Cosmos. A Physical description of the Universe.

Living Planet Report (2018) WWF.

Bending the curve of biodiversity loss



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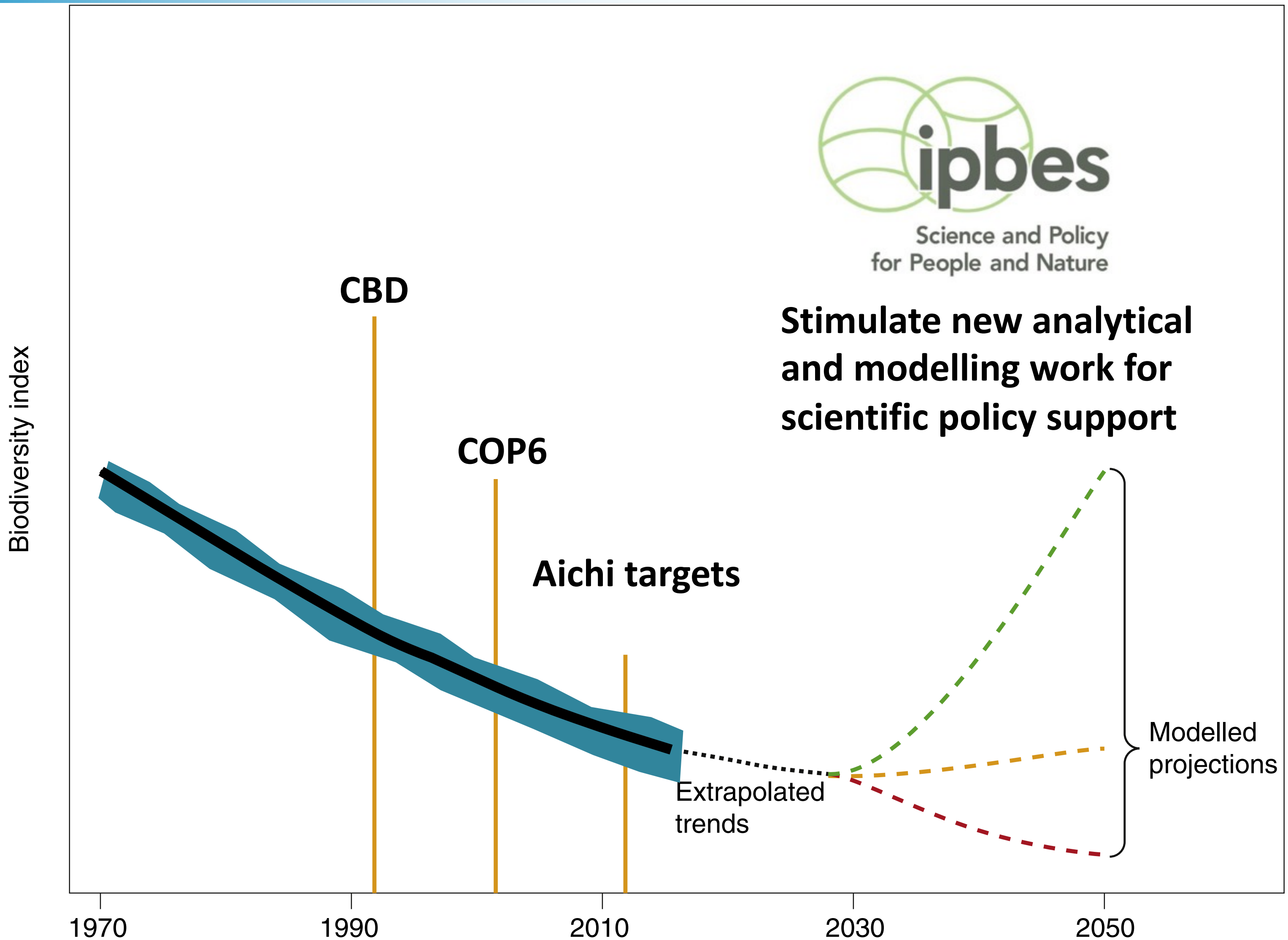
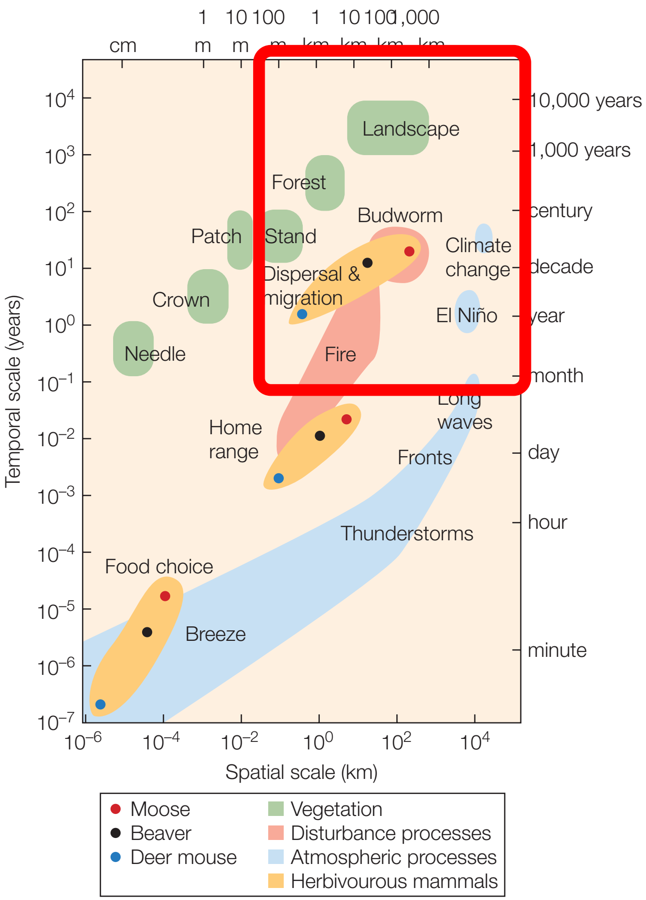
Mace et al. (2018) Nat Sustain 1: 448-451.

Bending the curve of biodiversity loss



Living Planet Index (2018) WWF.
Mace et al. (2018) Nat Sustain 1: 448-451.

Biodiversity scales and processes



Ecosystems

Communities

Populations

Individuals

Dynamic global vegetation models

Correlative models

➔ Models at conservation-relevant scales

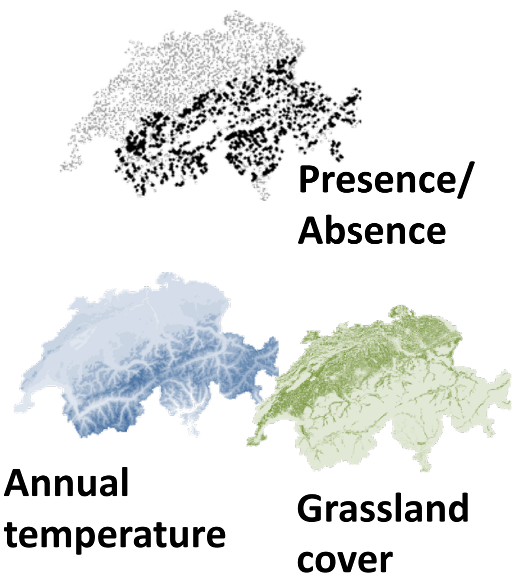
With (2019) Oxford Univ. Press.

IPBES (2016) Methodological assessment report.

Modelling biodiversity response

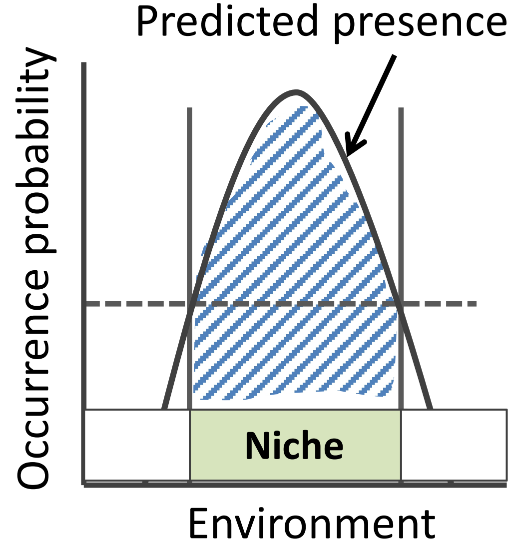
- Correlative species distribution models (SDMs)

Biodiversity & environmental data

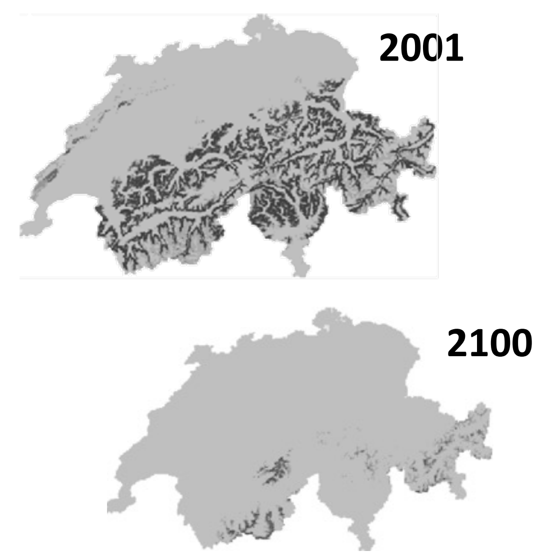


SDMs

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



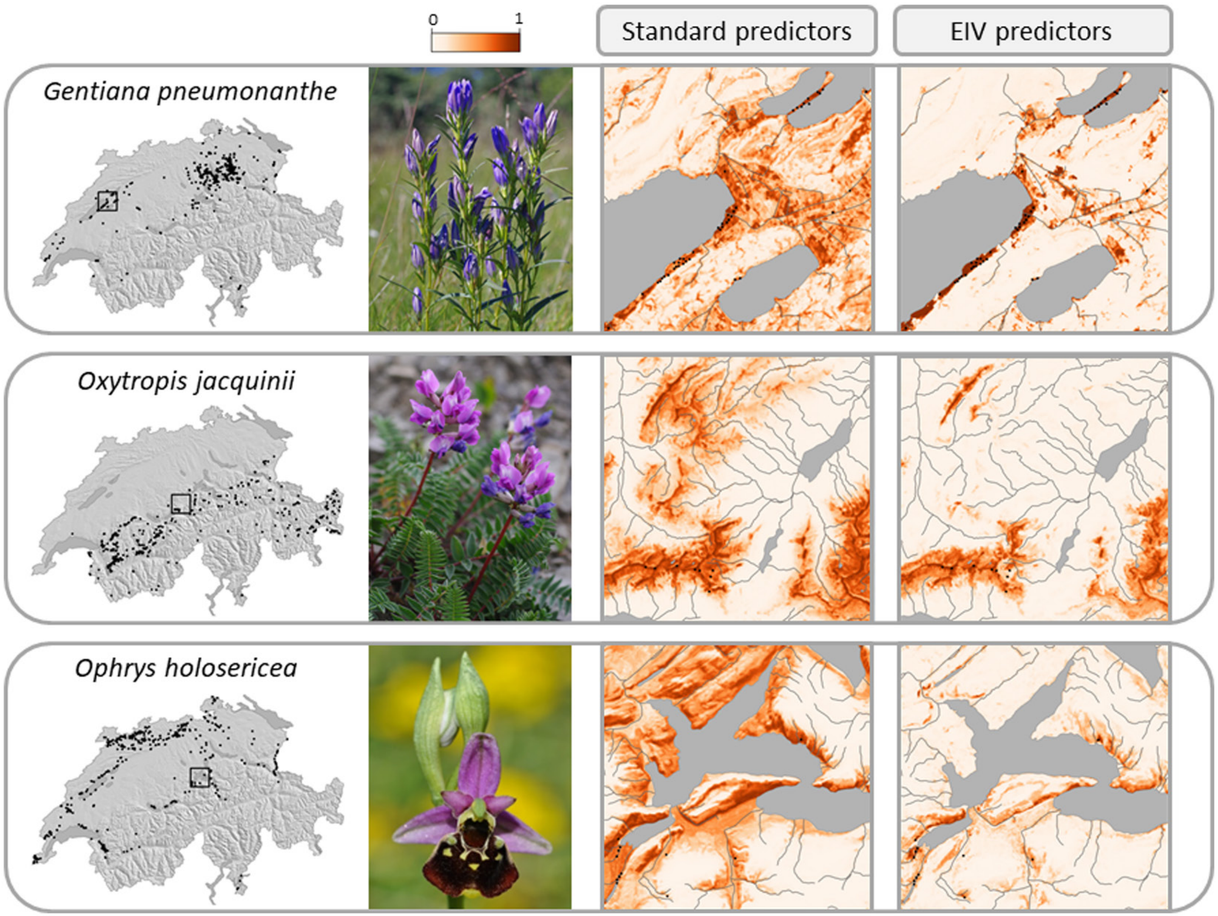
Predicting potential distribution



Examples: Zurell et al. (2012) Ecography 35: 590-603.
Zurell et al. (2016) Diversity and Distributions 22: 905-917.
Zurell et al. (2018) Nature Climate Change 8: 992-996.

Correlative species distribution models (SDMs)

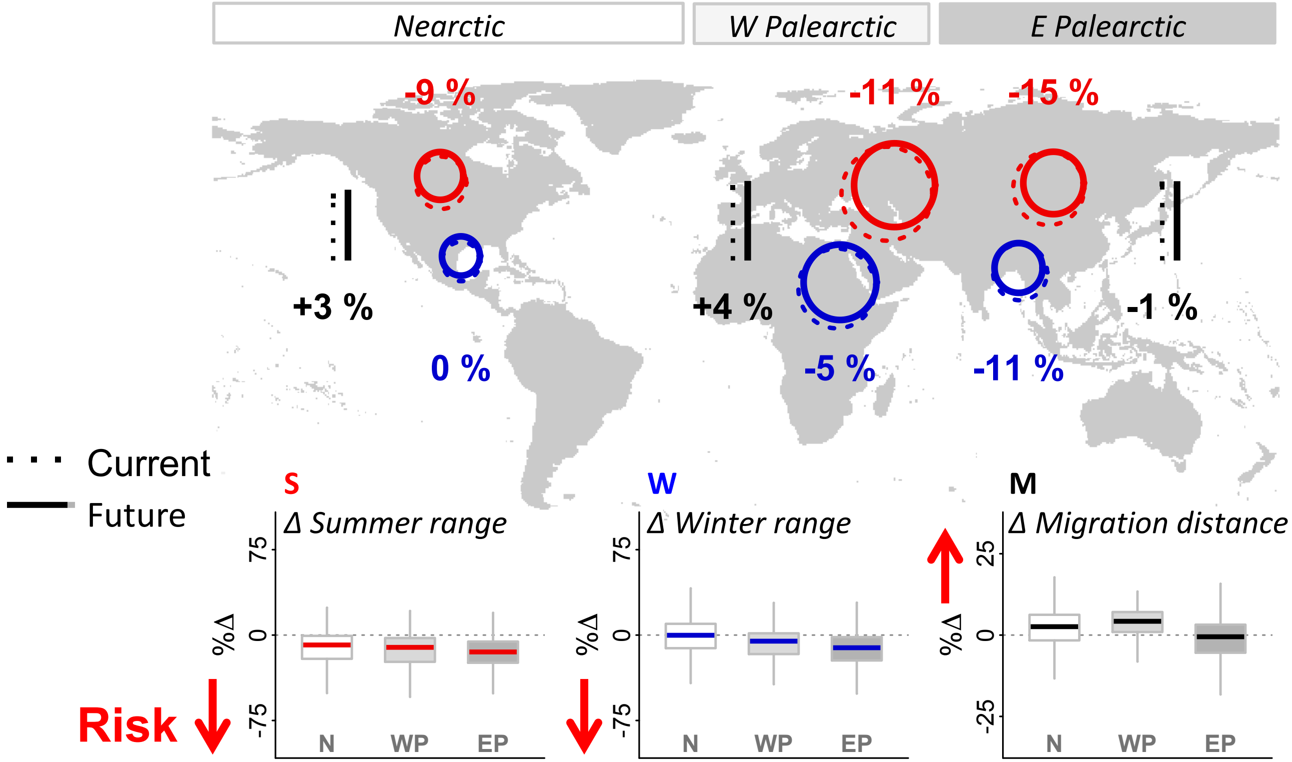
- Example: plant species distribution in Switzerland at 93 m spatial resolution to guide monitoring and citizen scientists



Descombes et al. (2020) Ecography 43: 1448-1463.

Correlative species distribution models (SDMs)

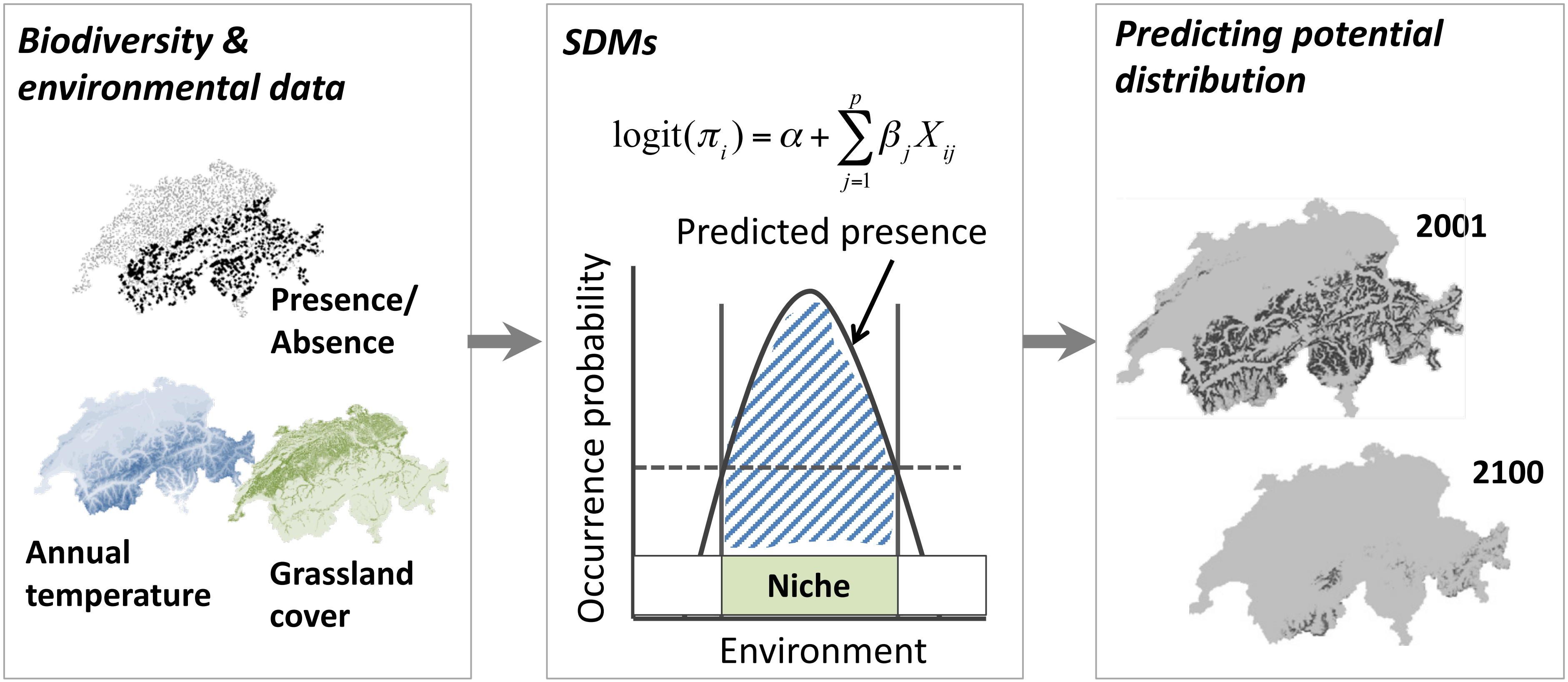
- Example: breeding and wintering ranges of Holarctic long-distance migratory birds at 0.5° spatial resolution



Zurell et al. (2018) Nature Climate Change 8: 992-996.

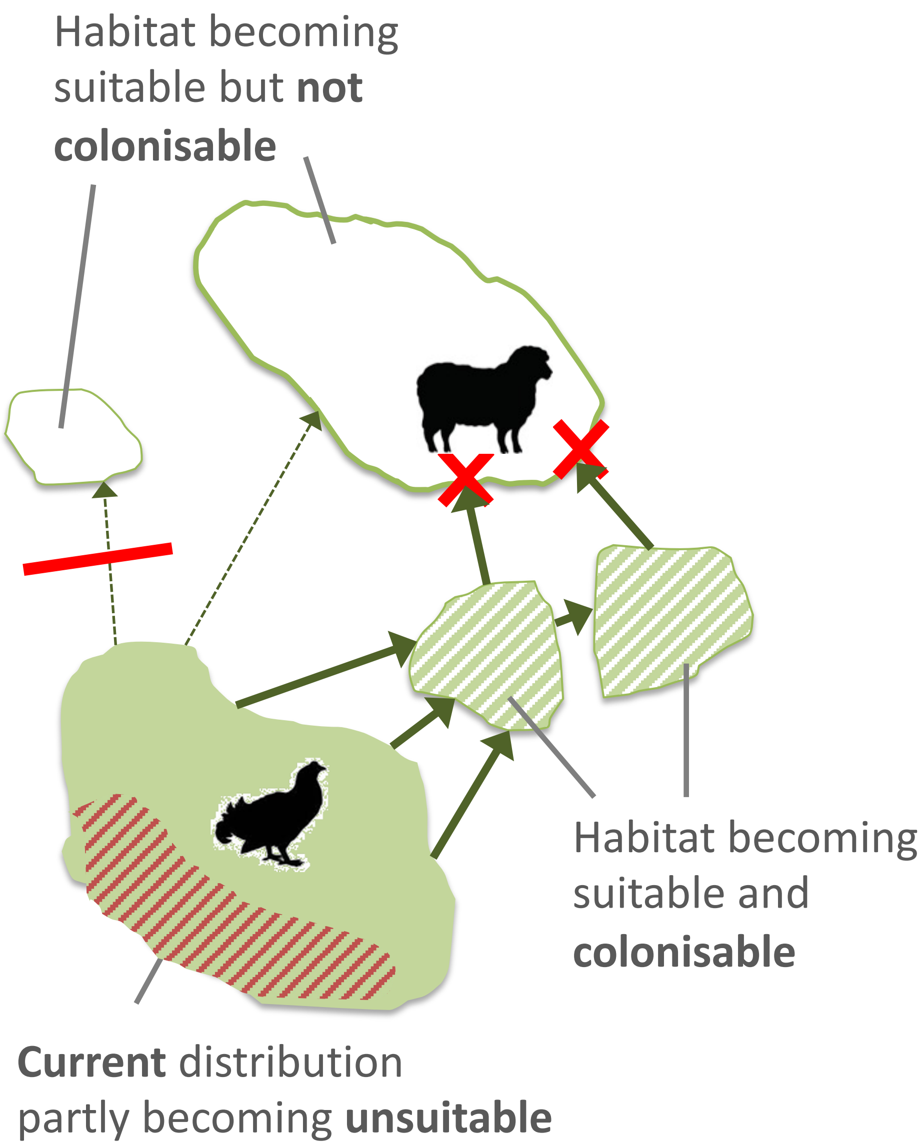
Modelling biodiversity response

- Correlative species distribution models (SDMs)

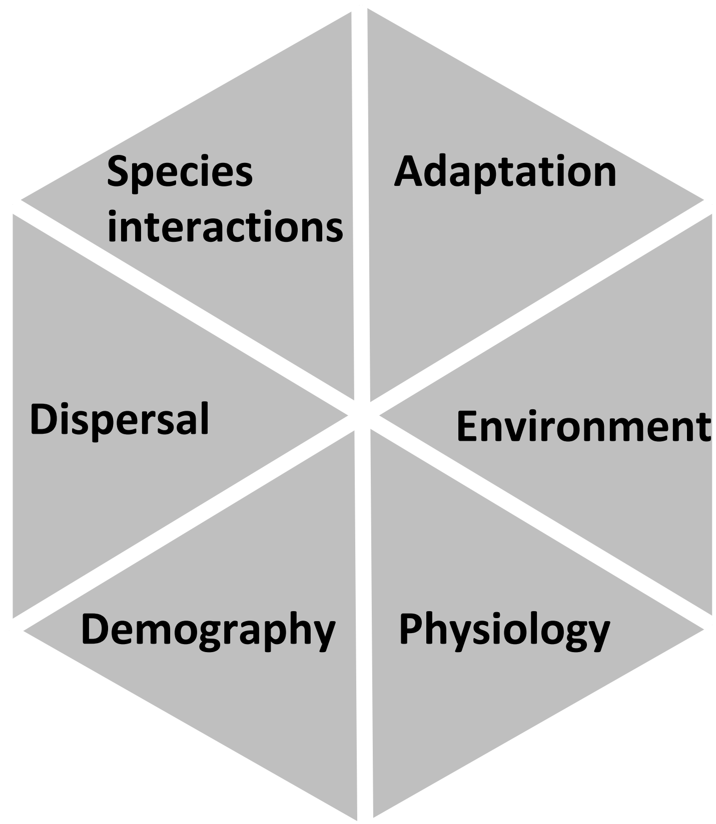


Examples: Zurell et al. (2012) Ecography 35: 590-603.
Zurell et al. (2016) Diversity and Distributions 22: 905-917.
Zurell et al. (2018) Nature Climate Change 8: 992-996.

Criticism I: Dymamic response to global change

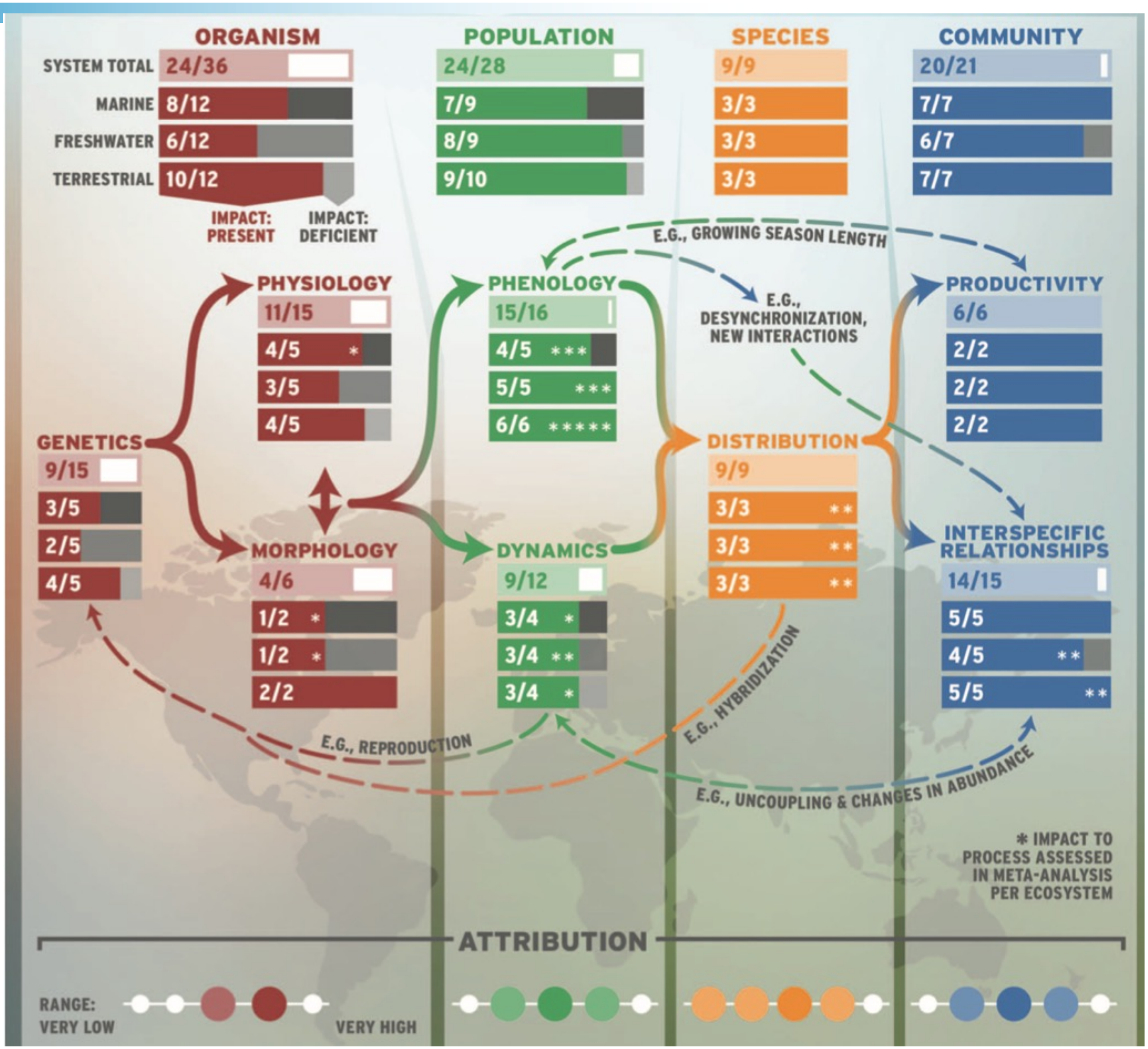


Six key mechanisms for predicting biodiversity response:



Ferrier et al. Eds (2016) IPBES.
Urban et al. (2016) Science 353: aad8466.

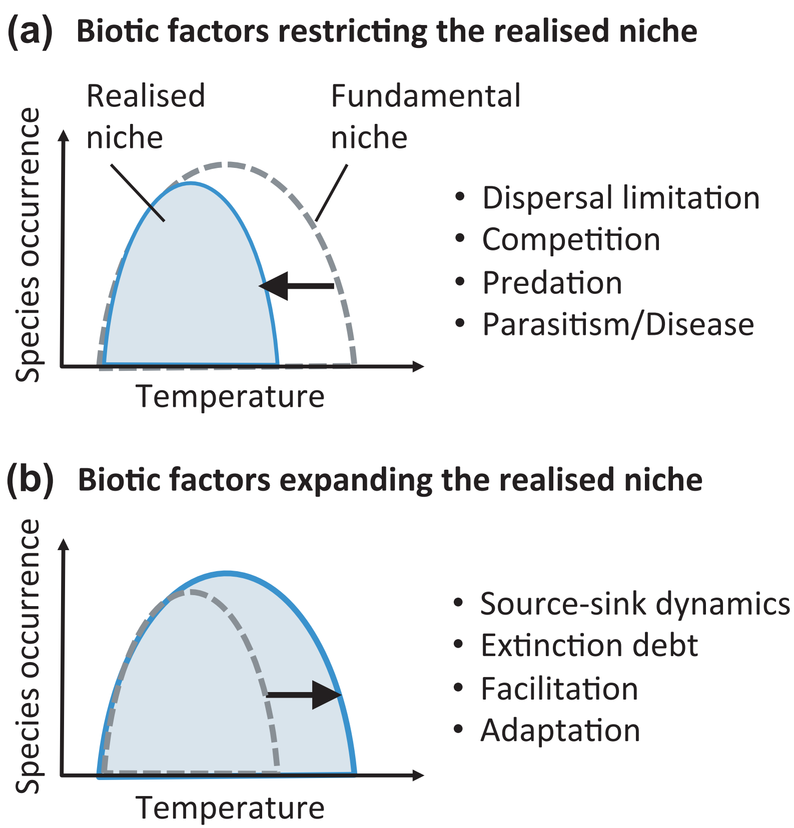
Dymamic response to global change



Scheffers et al. (2016) Science 354: aaf7671.

Criticism II: Biotic constraints on the niche

- Different biological processes might constrain current patterns
- Realised and observed niche are affected by demographic and community processes



Zurell (2017) J Avian Biol 48: 1505-1516.

Dynamic distribution models

- Understanding structure and dynamics of populations
- Explicitly model population growth and dispersal:

$$N_{t+1} = N_t + B_t + I_t - D_t - E_t$$

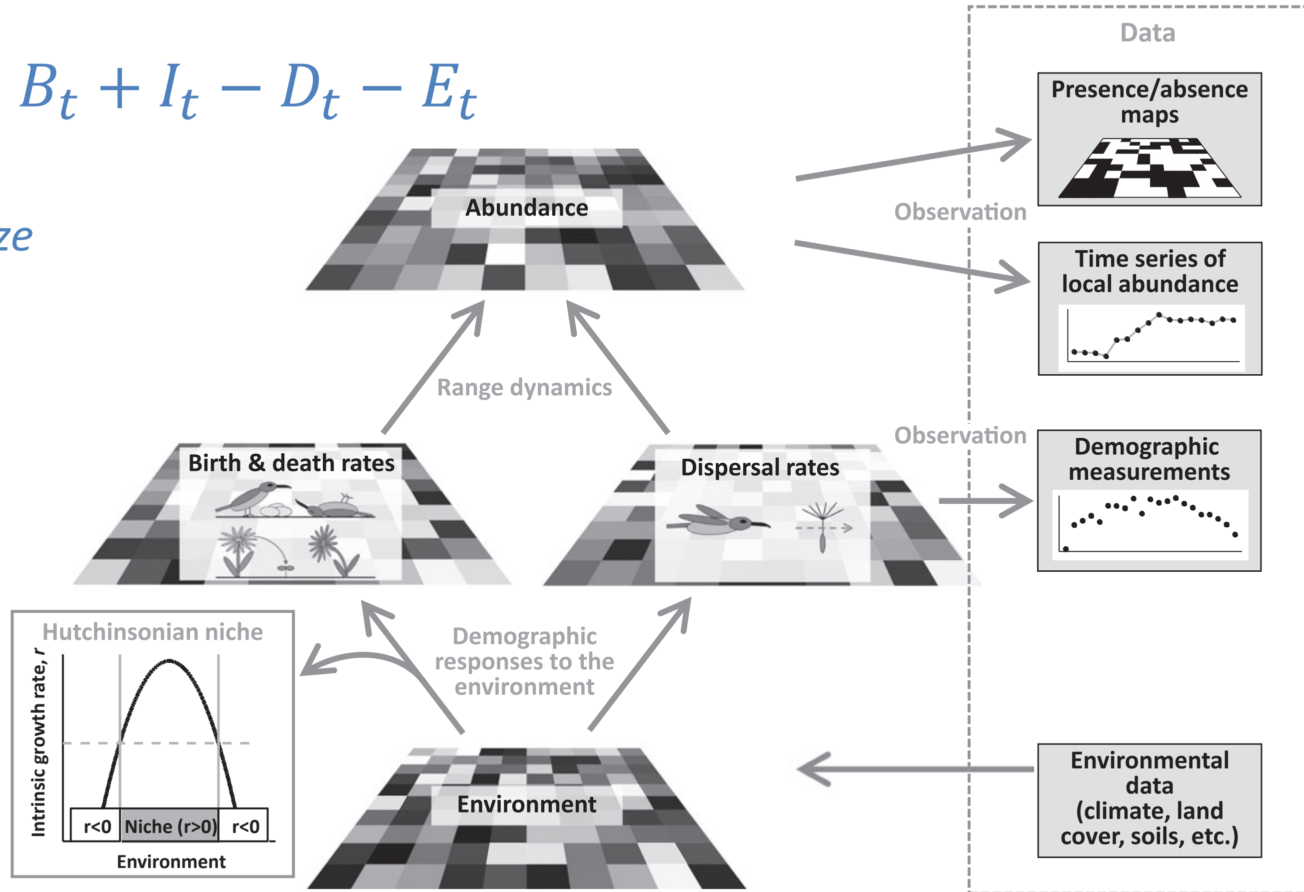
N .. Population size

B .. Birth rate

D .. Death rate

I .. Immigration

E .. Emigration

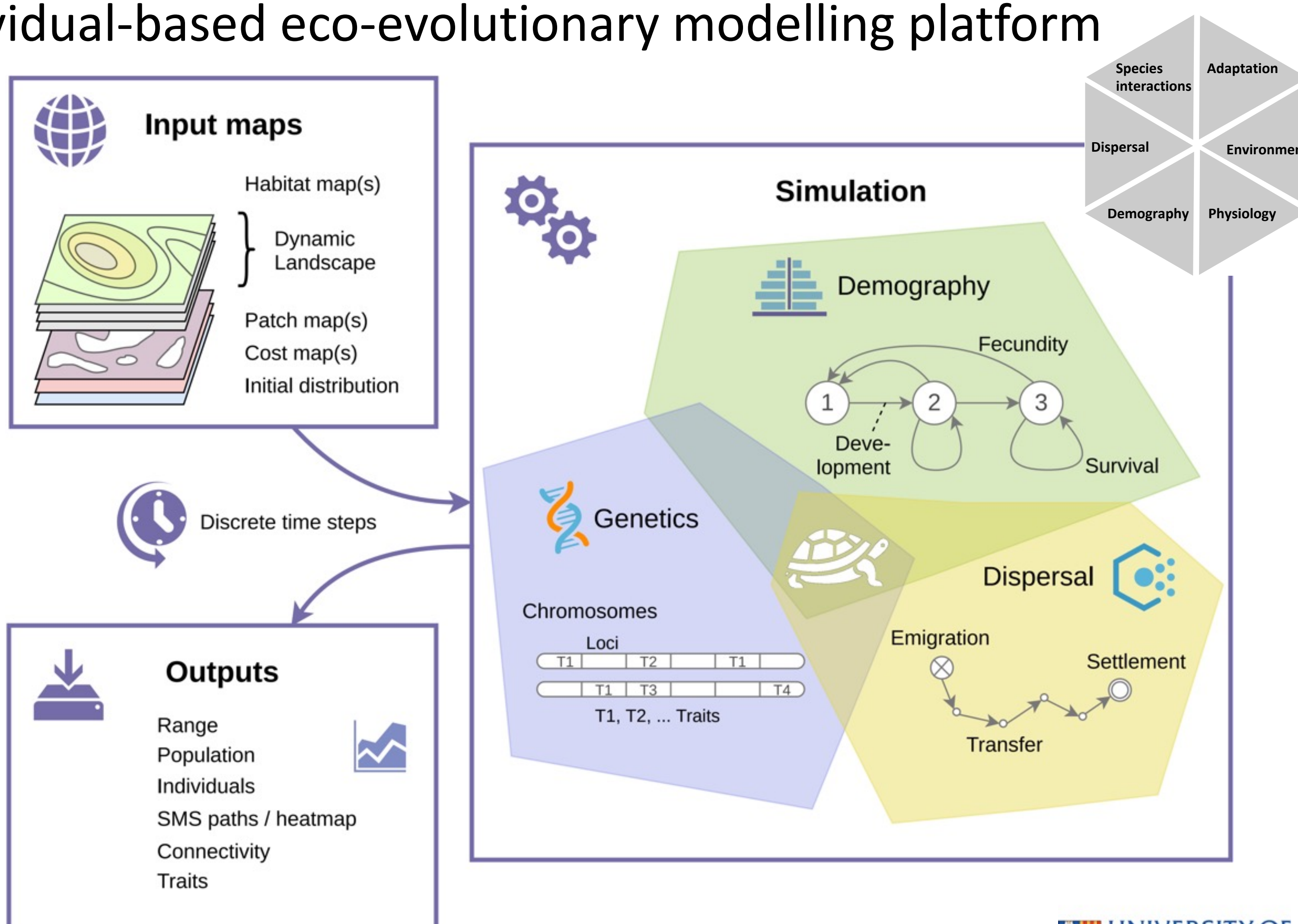


Schurr et al. (2012) J Biogeogr 39: 2146-2162.

RangeShifter modelling platform

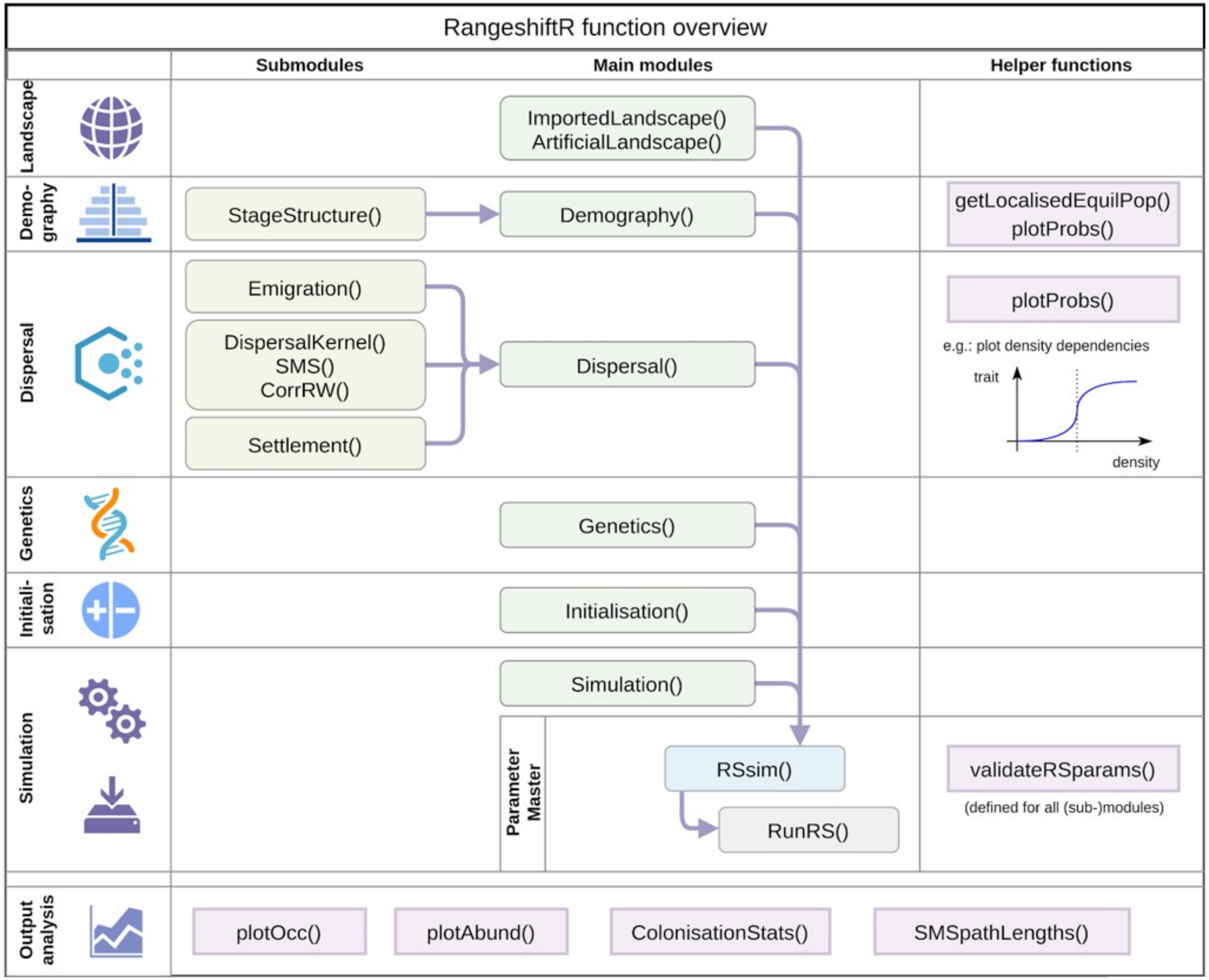
➢ An individual-based eco-evolutionary modelling platform

Anne Malchow



Malchow et al. (2020) bioRxiv 2020.11.17.384545
Building on Bocedi et al. (2012) Methods Ecol Evol 5: 388-396.

RangeShifter modelling platform



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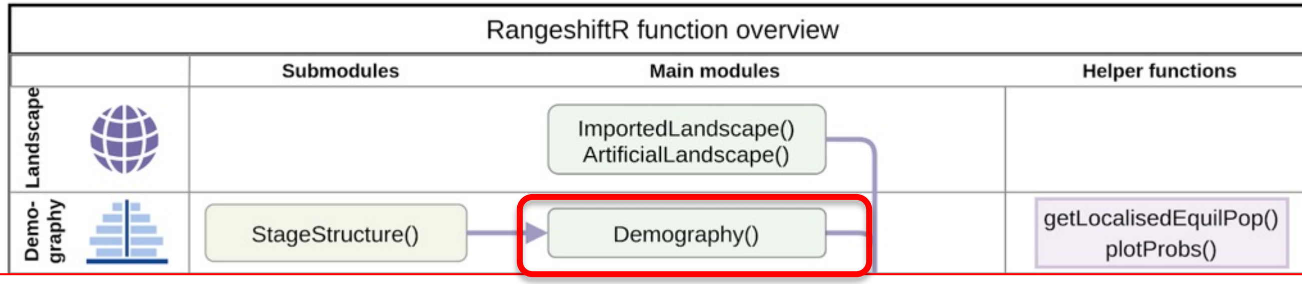
RangeShifter modelling platform



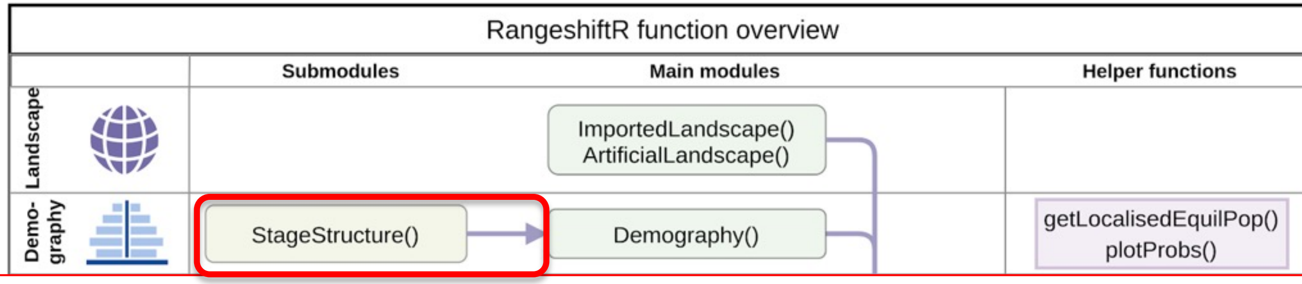
RangeShiftR

Maynard-Smith & Slatkin (1973):

$$Poisson\left(\frac{R_{i,t}}{1+\left|R_{i,t}-1\right| * \left(\frac{N_{i,t}}{K_{i,t}}\right)^{b_c}}\right)$$

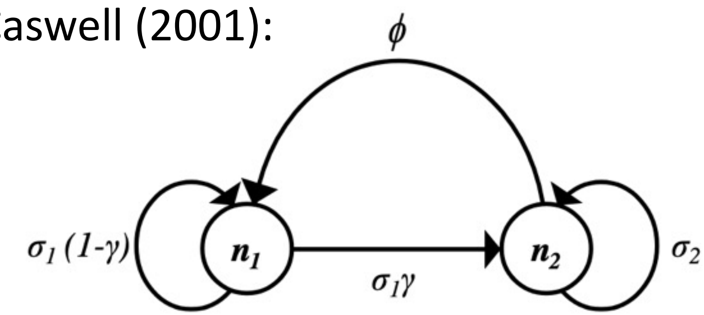
Malchow et al. (2020) bioRxiv 2020.11.17.384545
Building on Bocedi et al. (2012) Methods Ecol Evol 5: 388-396.

RangeShifter modelling platform



RangeShiftR

Caswell (2001):



$$A = \begin{pmatrix} \sigma_1(1-\gamma) & \phi \\ \sigma_1\gamma & \sigma_2 \end{pmatrix}$$

Neubert & Caswell (2000):

$$\phi_i = \phi_{0,i} * e^{-bN_t}$$

Malchow et al. (2020) bioRxiv 2020.11.17.384545
Building on Bocedi et al. (2012) Methods Ecol Evol 5: 388-396.

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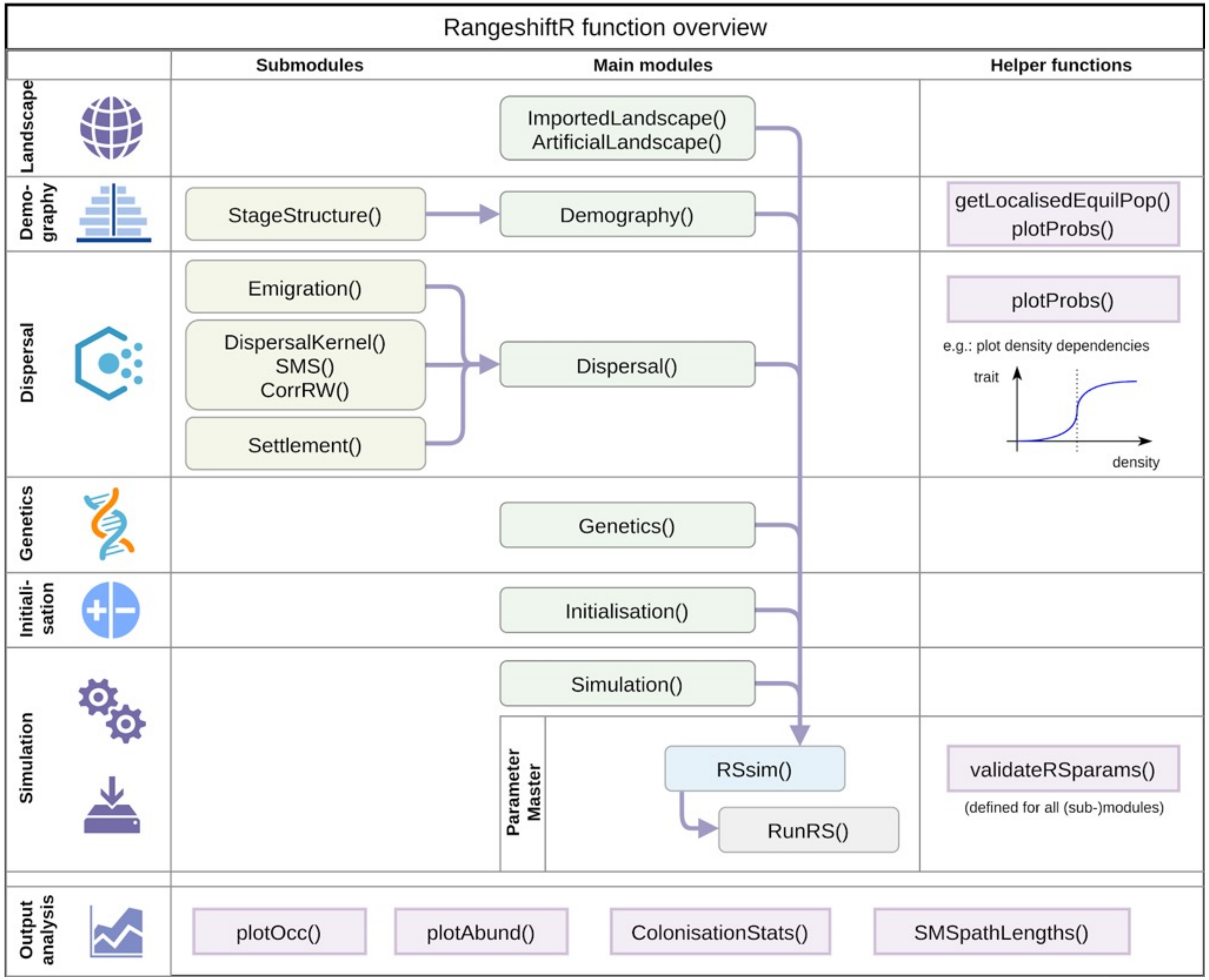
RangeShifter modelling platform

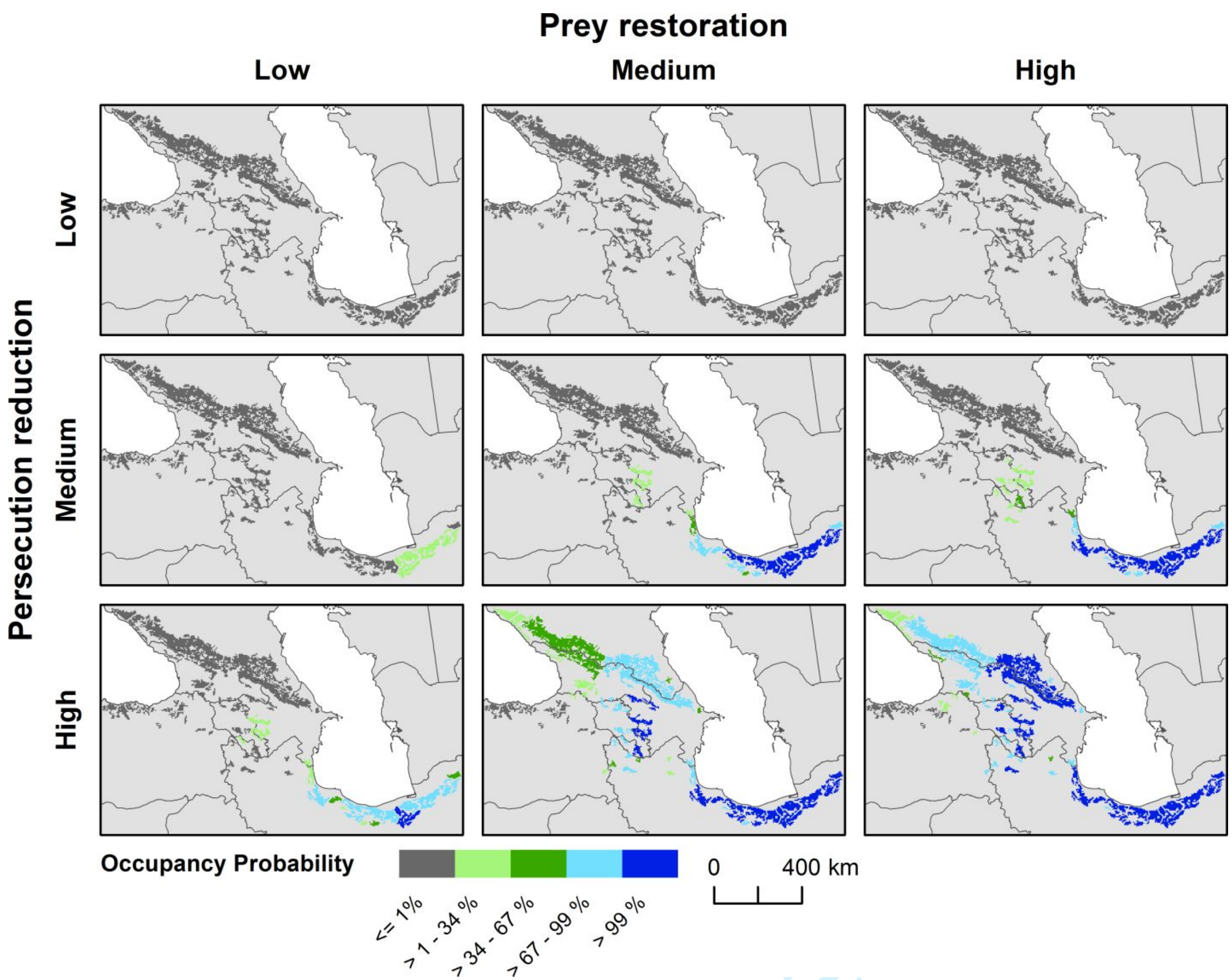


Malchow et al. (2020) bioRxiv 2020.11.17.384545
Building on Bocedi et al. (2012) Methods Ecol Evol 5: 388-396.

Applying dynamic distribution models

Example: Caucasian leopard

- Stage-structured model, individual-based movement decisions

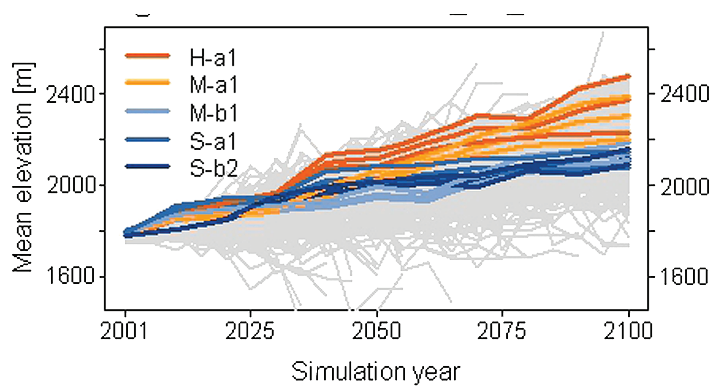


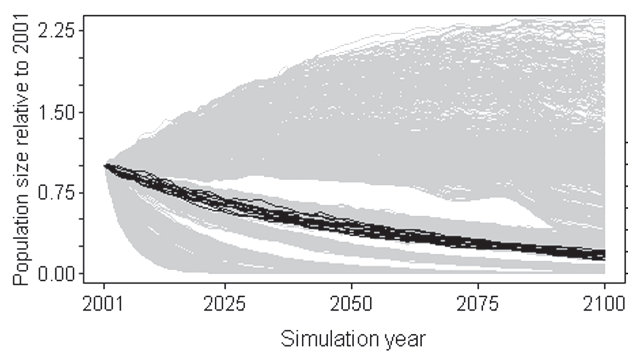
Bleyhl et al. (2021) Ecol Appl. DOI: 10.1002/eap.2338

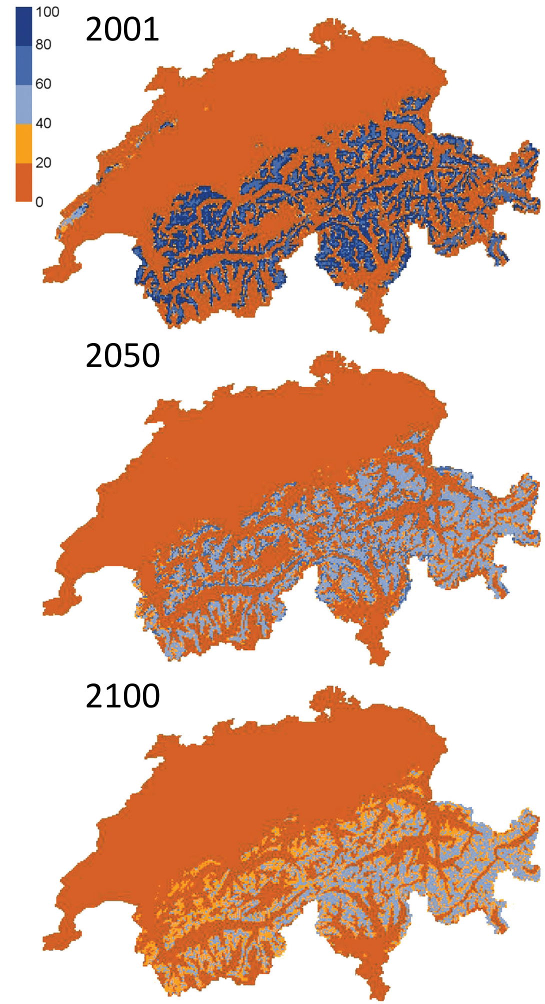
Applying dynamic distribution models

Example: black grouse in Switzerland

- Stage-structured model, individual-based movement decisions



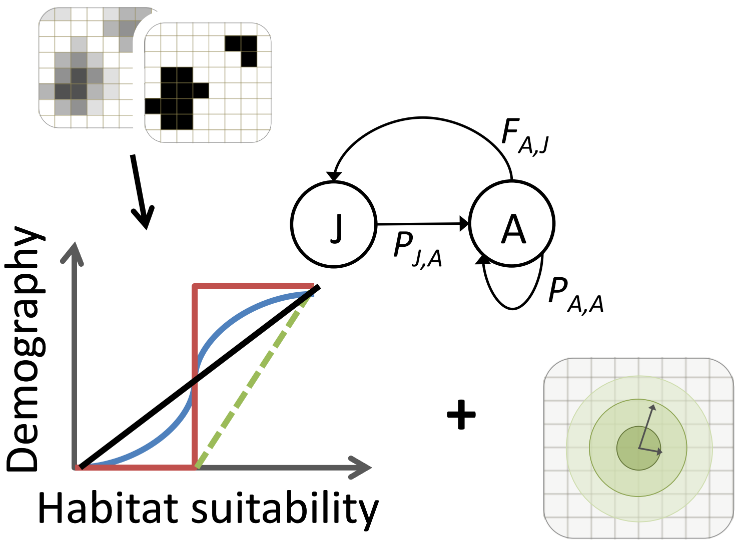




Zurell et al. (2012) Ecography 35: 590-603.

State-of-the-art dynamic distribution models

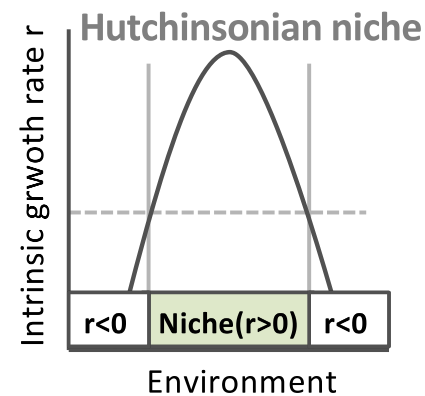
Coupled SDM-demography models



Example: Zurell et al. (2012) Ecography 35: 590-603.

Hierarchical models simultaneously infer process rates and demography-environment relationship

$$N_{t+1} = N_t e^{r\left(1-\frac{N_t}{k}\right)}$$



Example: Pagel & Schurr (2012) Glob Ecol Biogeogr 21: 293-304.

Theoretical underpinning

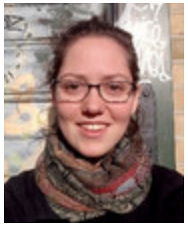
Flexibility

Next steps: calibration workflows

Fitting single-species simulation models to data

➔ Model selection & process attribution

➔ Validation of predictive accuracy, cross-validation

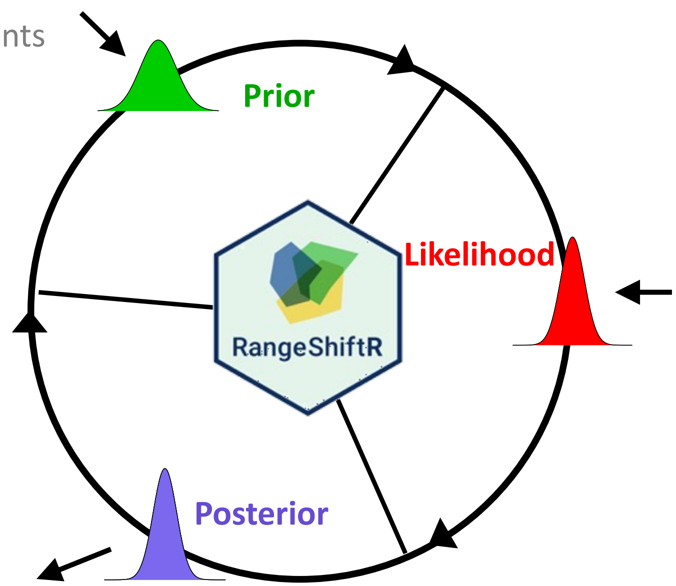


Direct calibration

Integration of existing information

- Demographic rates
- Meta-analyses/experiments
- Dispersal submodels

Repeat and add new information



Inverse calibration

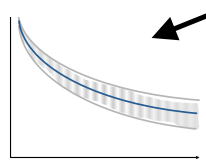
Comparison of model and data

Model selection

	Occupancy	Pop Dyn
A	✓	✗
B	✗	✓
C	✓	✓

Forecasting

Quantification of uncertainty



Modified from Hartig et al. (2012) J Biogeogr 39: 2240-2252.

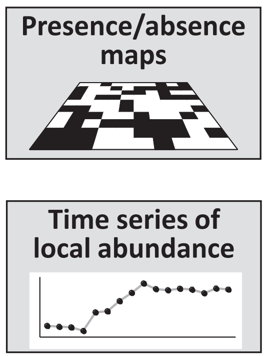
Next steps: calibration workflows

Fitting single-species simulation models to data

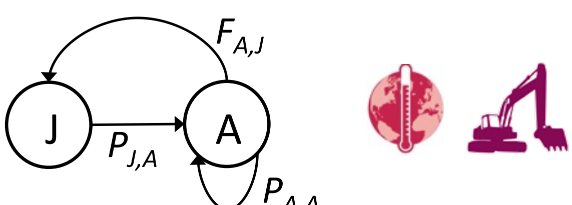
➔ Model selection & process attribution

➔ Validation of predictive accuracy, cross-validation


Sampling grid + data



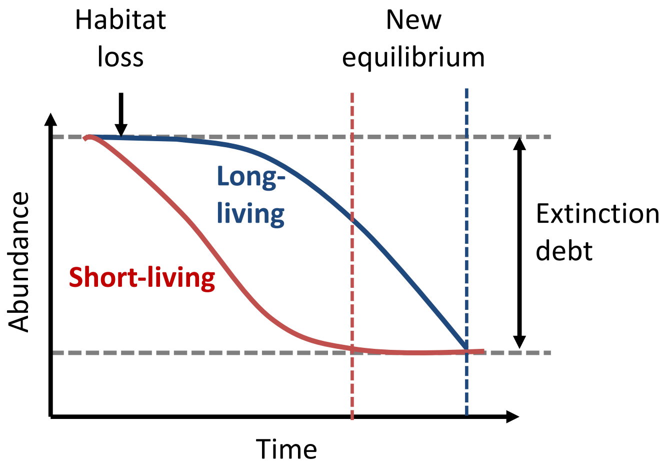
Model complexity & statistical support?



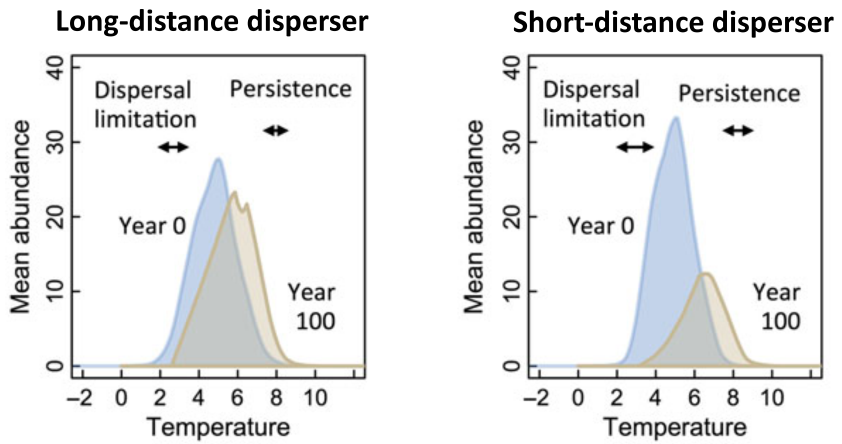
Spatial block-cross validation

Next steps: process attribution

- Capturing disequilibrial dynamics and legacies: extinctions debts and colonisation credits

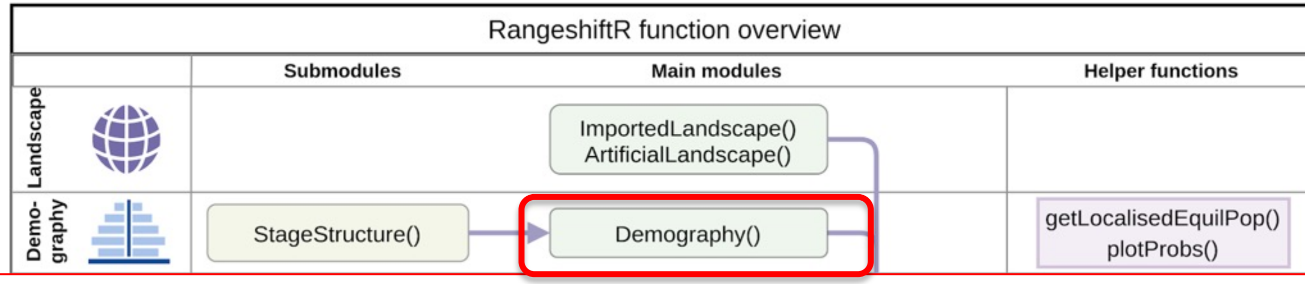


Modified from Kuussari et al. (2009) Trends Ecol Evol 24: 564-571.



Zurell et al. (2016) Glob Ch Biol 22: 2651-2664.

Next steps: model extension



Maynard-Smith & Slatkin (1973)

$$Poisson\left(\frac{R_{i,t}}{1+|R_{i,t}-1|*\left(\frac{N_{i,t}}{K_{i,t}}\right)^{b_c}}\right)$$

=> extend to multi-species model

$$Poisson\left(\frac{R_{i,t}}{1+|R_{i,t}-1|*\left(\frac{N_{i,t}+\beta_i}{K_{i,t}}\right)^{b_i}}\right)$$

Malchow et al. (2020) bioRxiv 2020.11.17.384545
Building on Bocedi et al. (2012) Methods Ecol Evol 5: 388-396.

Next steps: integrated modelling platform

- Feedbacks between biodiversity dynamics and drivers
  - E.g. feedback between climate change-induced pollinator population decrease & demand for agricultural land

Sorry, work in progress, and thus not open …

Next steps: integrated modelling platform

- Feedbacks between trophic levels
  - E.g. feedback between vegetation and herbivores, options for wildlife management and restoration

Sorry, work in progress, and thus not open …

Next steps: integrated modelling platform

- Computer-aided adaptive management

Sorry, work in progress, and thus not open …

Wanted

The Swiss army knife of biodiversity modelling

Sorry, work in progress, and thus not open …

Thank you for listening!

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Emmy Noether-Programm

DFG Deutsche Forschungsgemeinschaft