Niche ecology and niche modelling

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Content

1) An introduction to the ecological niche

2) Niche modelling

3) Short take-home messages

The Niche

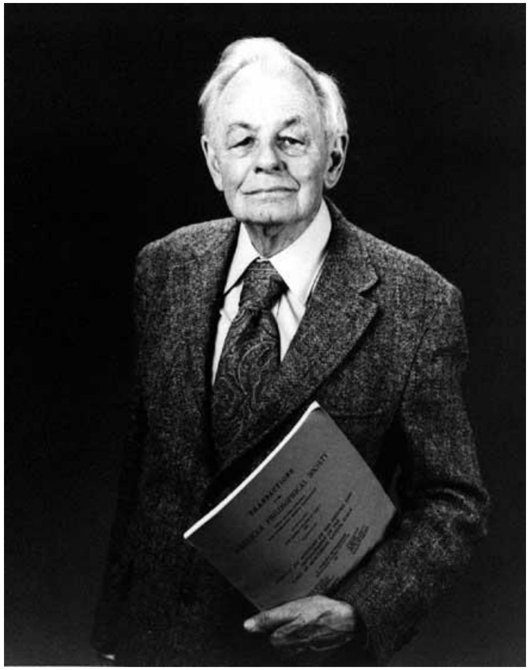
1) The niche is an autoecology concept: a species property

2) But what is the ecological niche?

„The ecological space occupied by a species"
Krebs: Ecology, 2009

„It is an imaginary space, but measurable"
Van Horne & Ford 1982

„n-dimensional hypervolume"
Hutchinson, 1957



Hutchinson

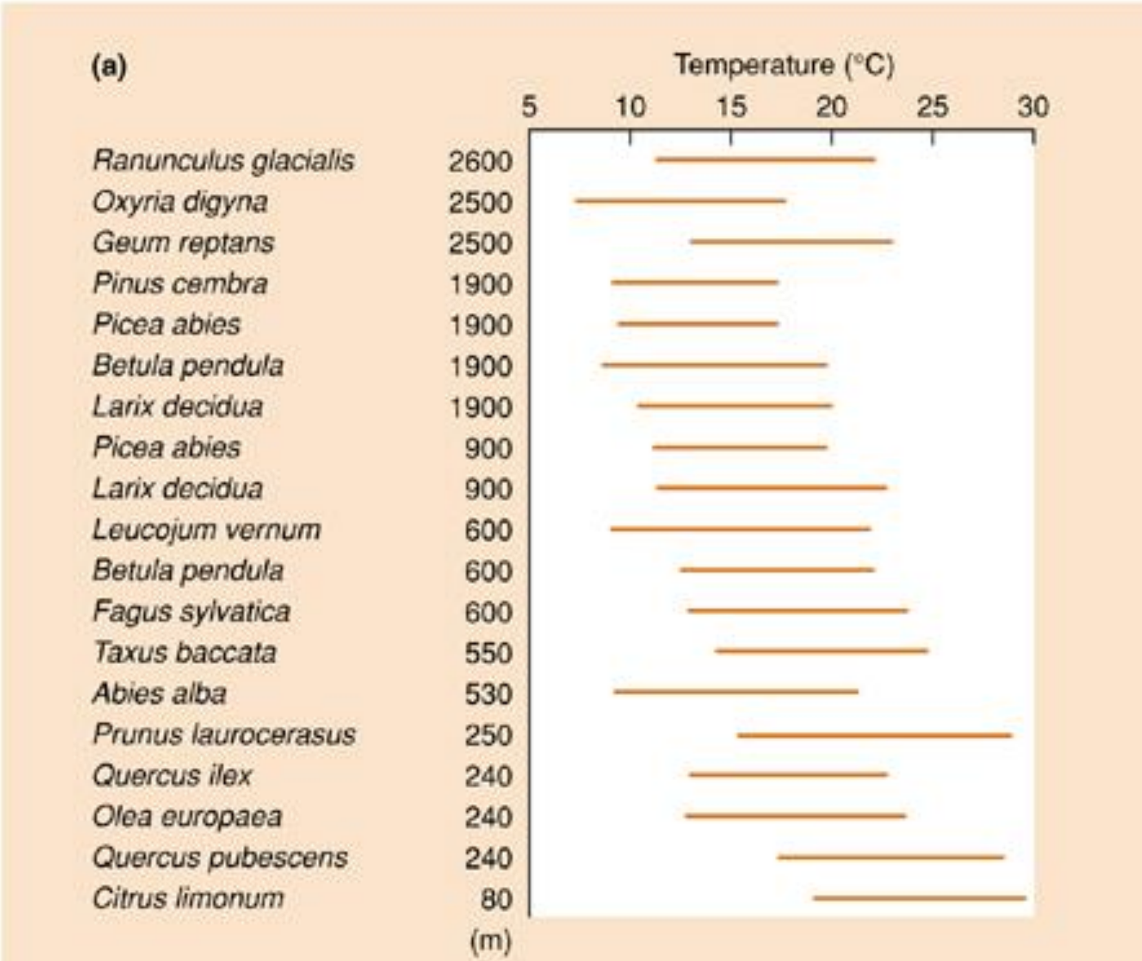
McInerny & Etienne 2012 Journal of Biogeography: the ditch, stitch and pitch the niche trilogy papers

Niche

1) Relevance for communities and ecosystems:
   - Overlapping leads to competition and thus to altered dominance patterns in communities

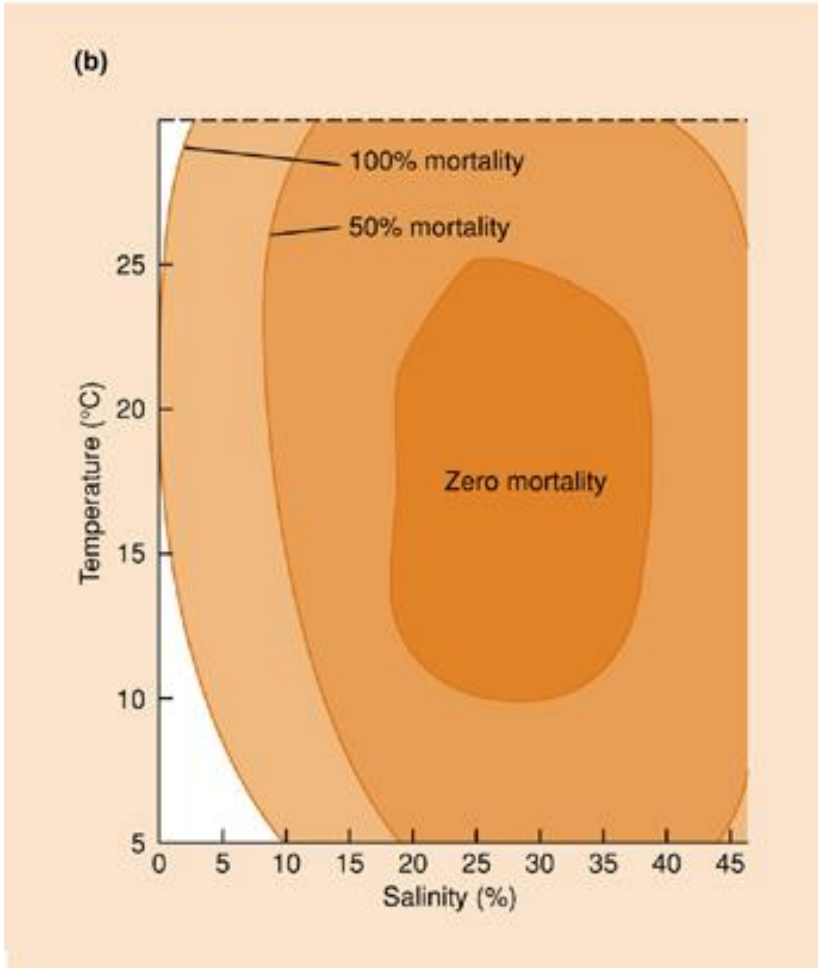
2) How to represent the niche? Dimensions? Display format? Labelling of axes?
   → 1D – 3D

Niche: 1D



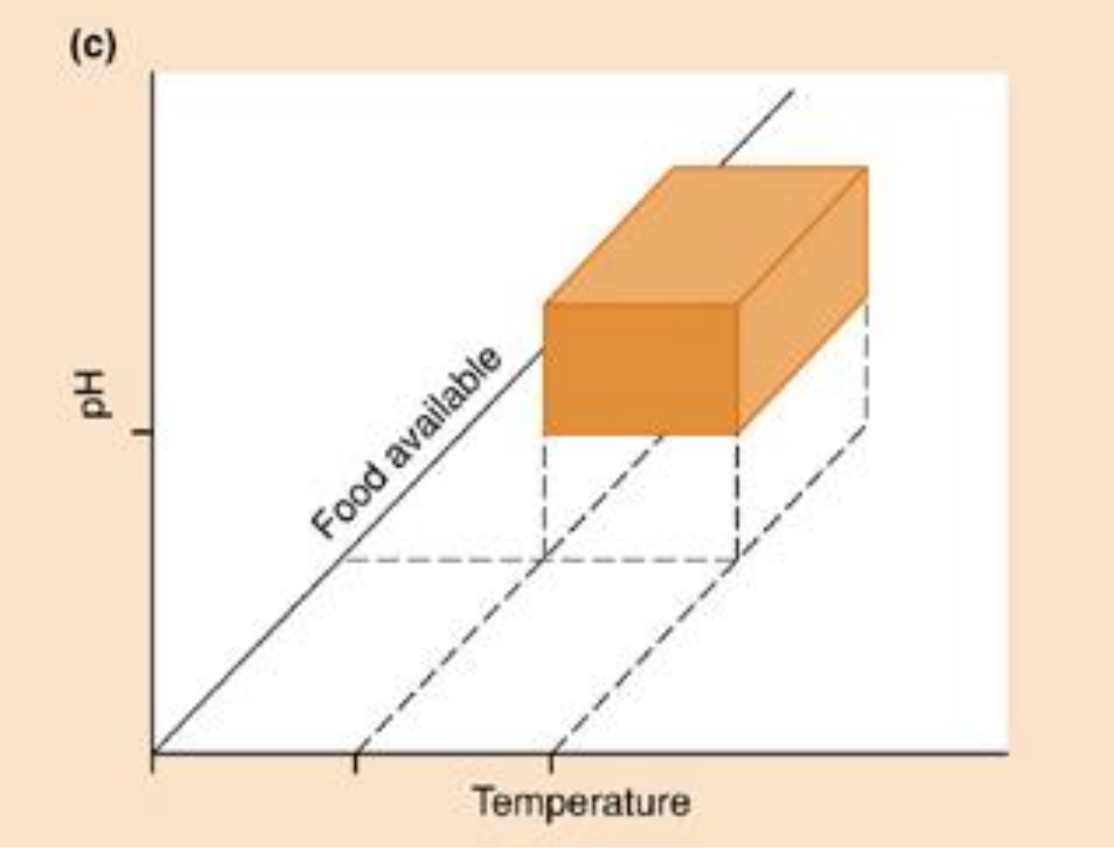
Example:
Plants in the Alps and their temperature ranges at which photosynthesis is still possible at low irradiation (by Piesek et al. 1973; in Begon et al. Ecology, 2006)

Niche: 2D



Example:
Survival of prawns (*Crangon septemspinosa*) depending on temperature and salinity (by Haefner, 1970; in Begon et al. Ecology, 2006)

Niche: 3D



Example:
3D-niche for a hypothetical aquatic organism (Begon et al. Ecology, 2006)

Defining niches: Resources vs. Conditions

„Conditions: Abiotic environmental factors that influence the functioning of living organisms"
Begon et al.: Ecology, 2006

→ Scenopoetic variables (Hutchinson, 1957) or Grinnellian niche (Grinnell, 1917)

„Resources: That which may be consumed by an organism and, as a result, becomes unavailable to another, e.g. food, water, nesting sites, etc … "
Begon et al.: Ecology, 2006

→ Bionomic variables (Hutchinson, 1957) or Eltonian niche (Elton, 1927)

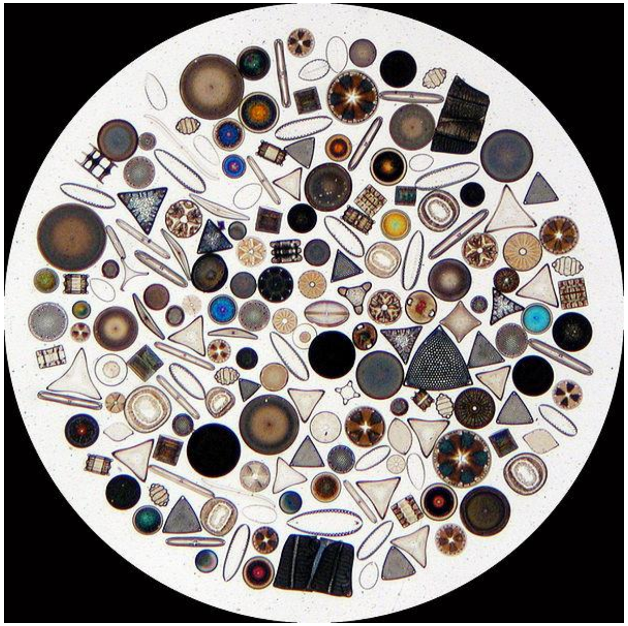
Defining niches: Resources vs. Conditions

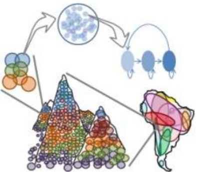
- Which conditions are relevant in an ecosystem?
  → temperature, pH, salinity, wind, waves, currents, fire
- Which abiotic resources are relevant resources?
  → radiation/light, water, CO_2, O_2, N, P, K
- Which of the two can be used to define a niche?
  → Both, but often conditions are more suitable than resources, because continuous variables are needed and resources are not always continuous (e.g. number of mice or other biotic resources)

Begon et al.: Ecology, 2006

Defining niches: The R*-concept

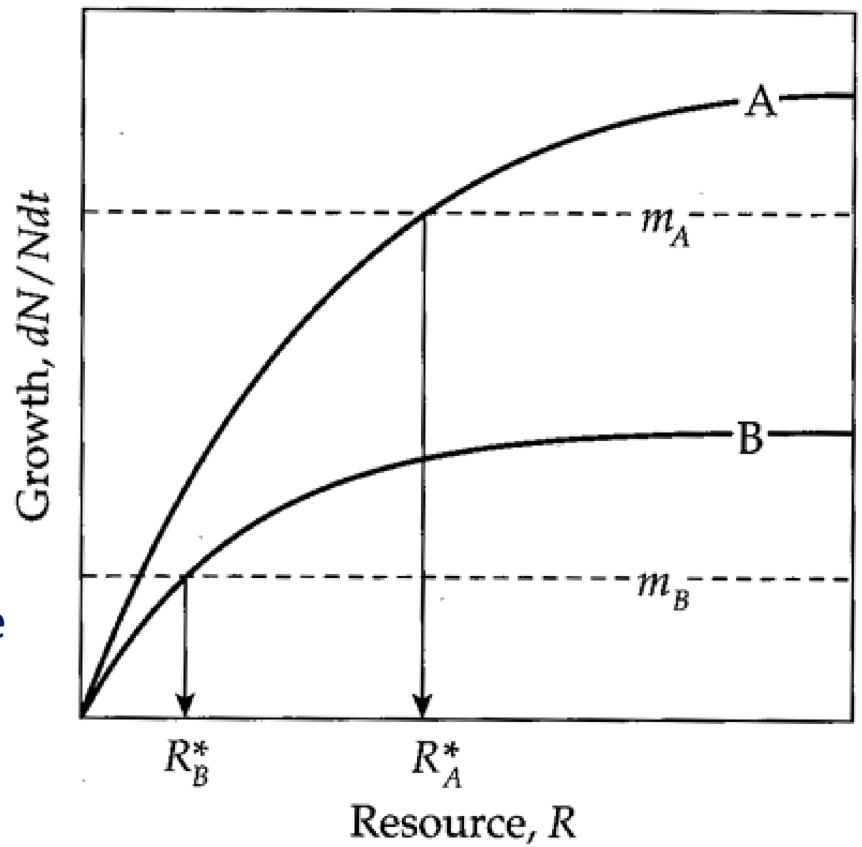
- Experiments on the resource use of diatoms
- David Tilman: Resource competition & community structure, 1982





Picture: Wipeter on wikimedia commons

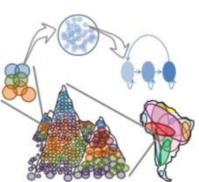
Defining niches: The R*-concept



m: mortality
N: population size
A,B: species

→ Basis for competition theory & stochastic niche concept

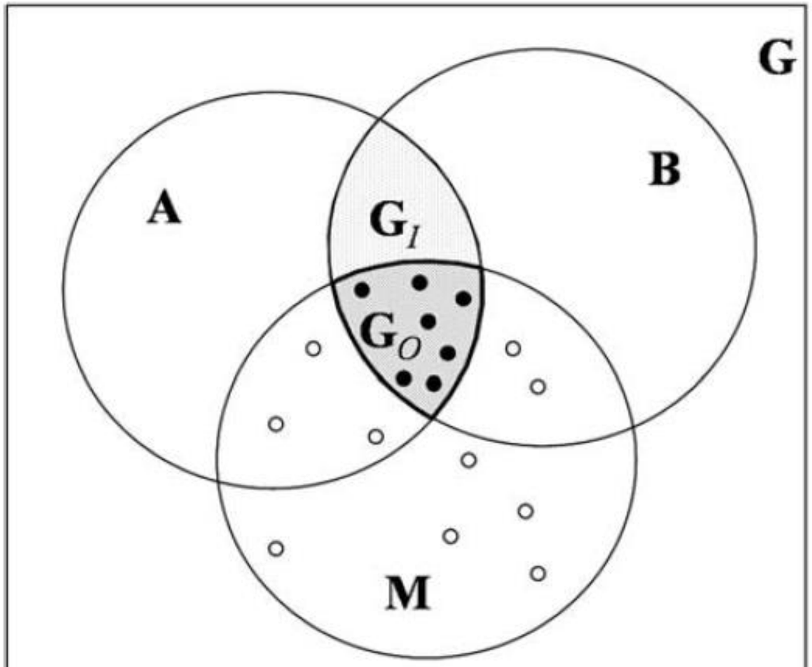
→ Low resource requirements at equilibrium (=R*) lead to competitive superiority (here of species B)



David Tilman: Resource competition & community structure, 1982

Defining niches: beyond conditions and resources

A: Scenopoetic variables/conditions
B: Bionomic variables/resources
M: Dispersal (and demographic) constraints



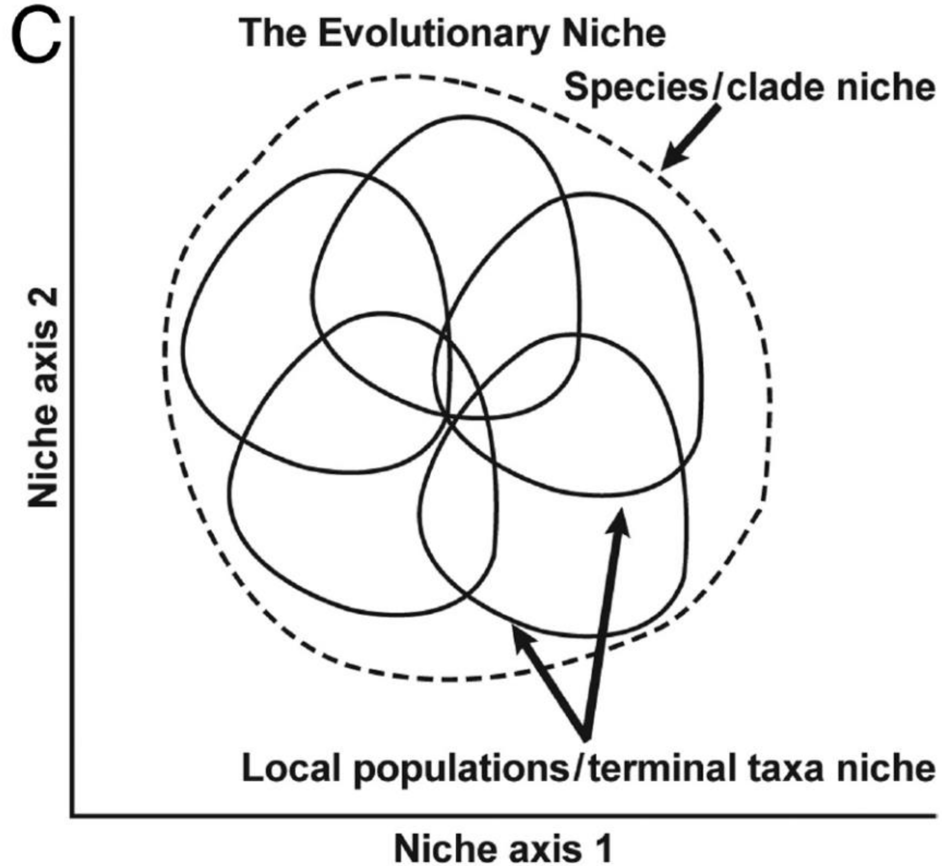
Soberón 2010 Ecography

Fundamental vs. Realized niches (Hutchinson 1957)

Establishment vs. Persistence niches (Holt 2009)

Defining niches: beyond conditions and resources

Niche evolution



Holt 2009 PNAS

Modelling niches

Species distribution models (SDMs):

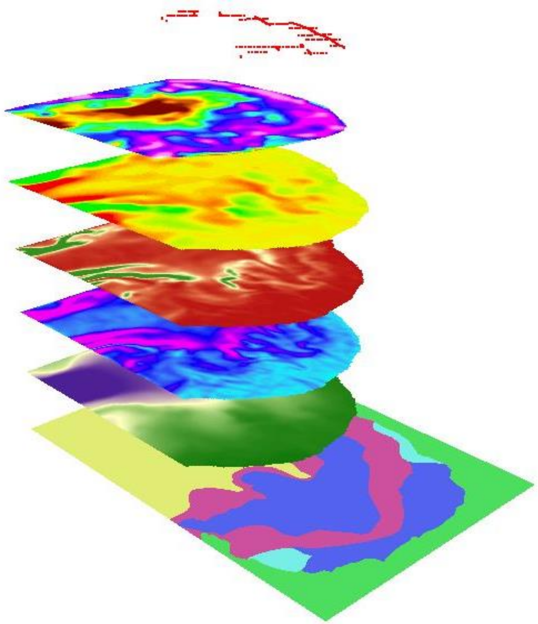
- Phenomenological: also called correlative niche models, climate envelopes or habitat models

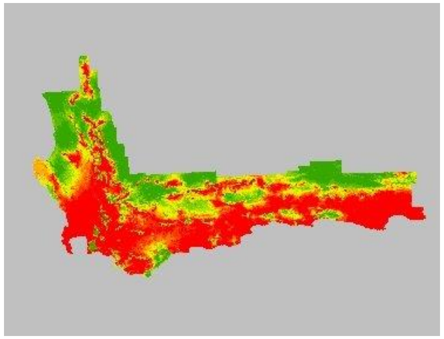
Modelling niches

Species distribution models (SDMs):

- Phenomenological: also called correlative niche models, climate envelopes or habitat models

- Overlaying environmental layers and correlating presence/absence data with local environments

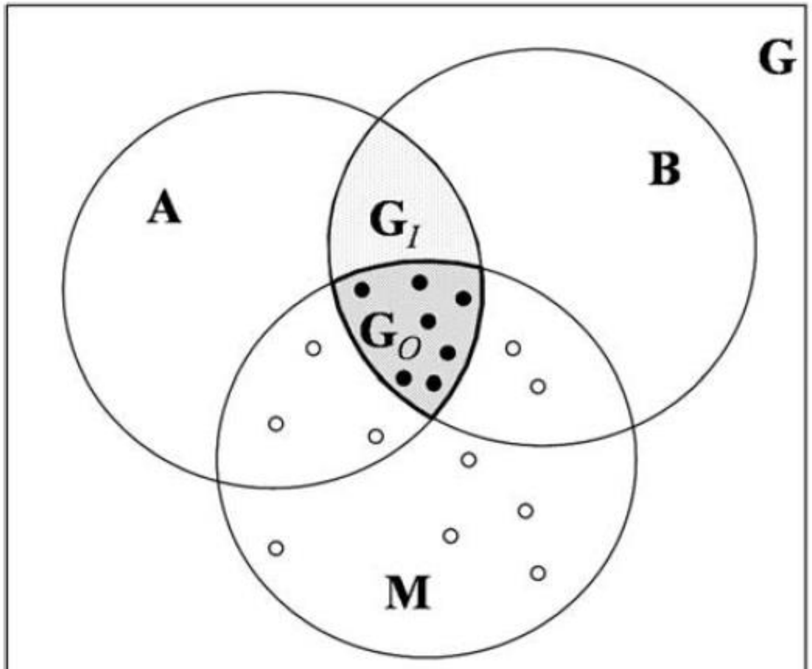




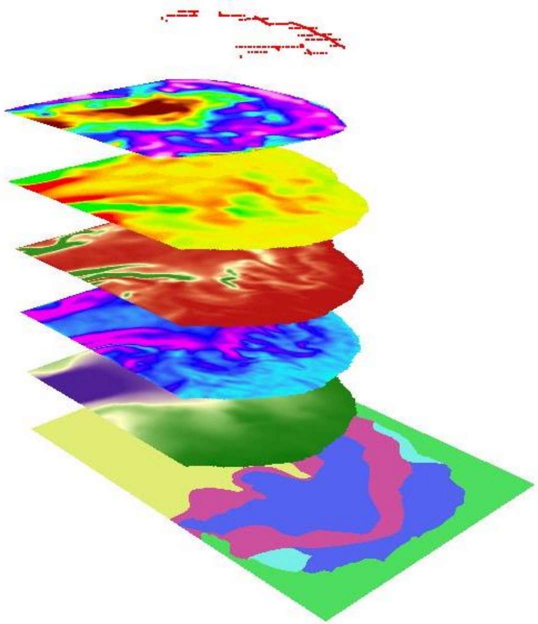
Modelling niches

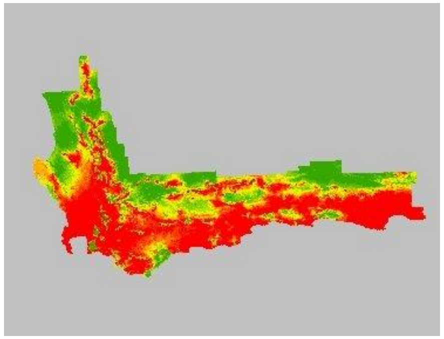
Species distribution models (SDMs):

- But what do they model?



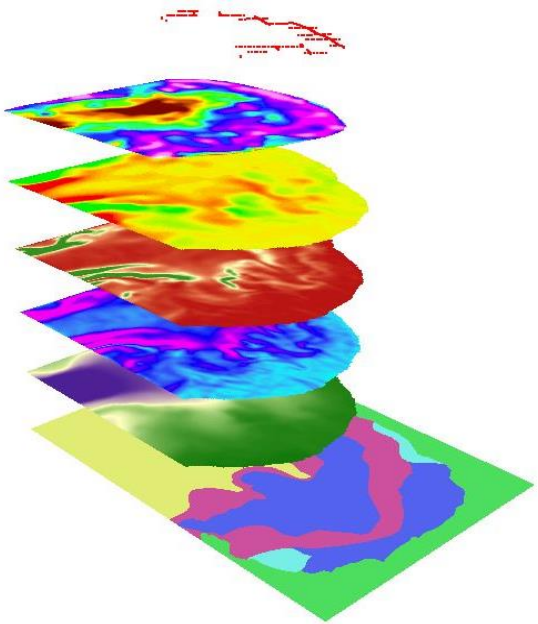
Soberón 2010 Ecography





Modelling niches

Species distribution models (SDMs):



- Pros:

  Simple data required

  Many methods available, ensemble modelling

  Applicable for a large amount of species

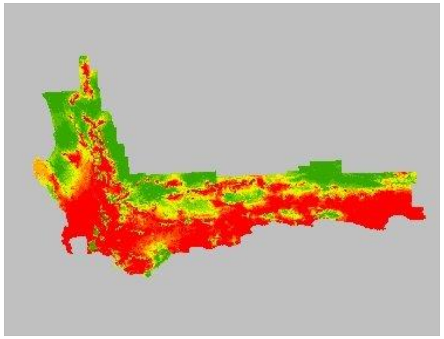
- Cons:

  Sampled from realized niche, often biased data

  Species-environment equilibrium assumption

  Static in time

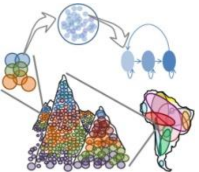
  Rarely validated

    Low spatiotemporal transferability

    Non-suitable for forecasts

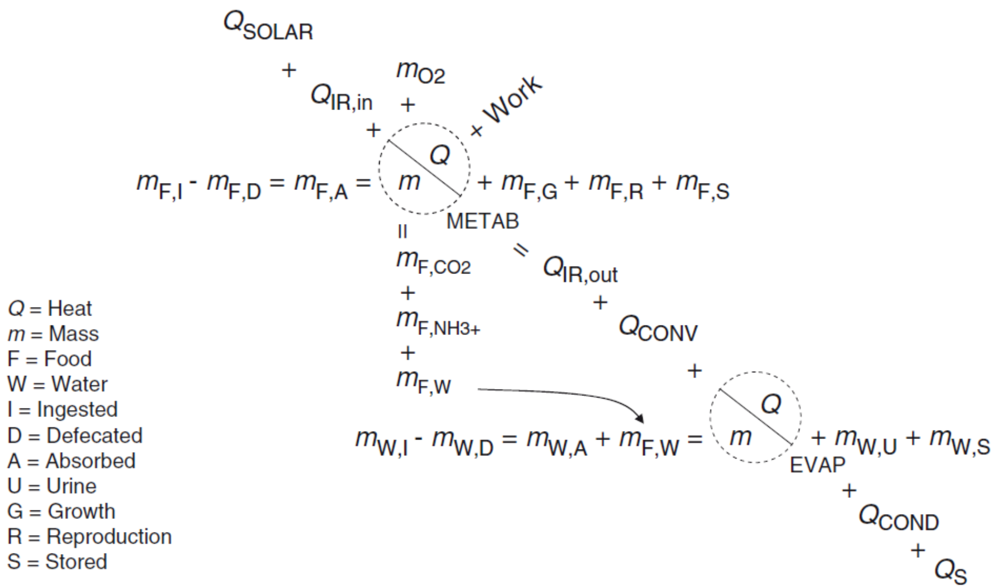
    No causal relationship



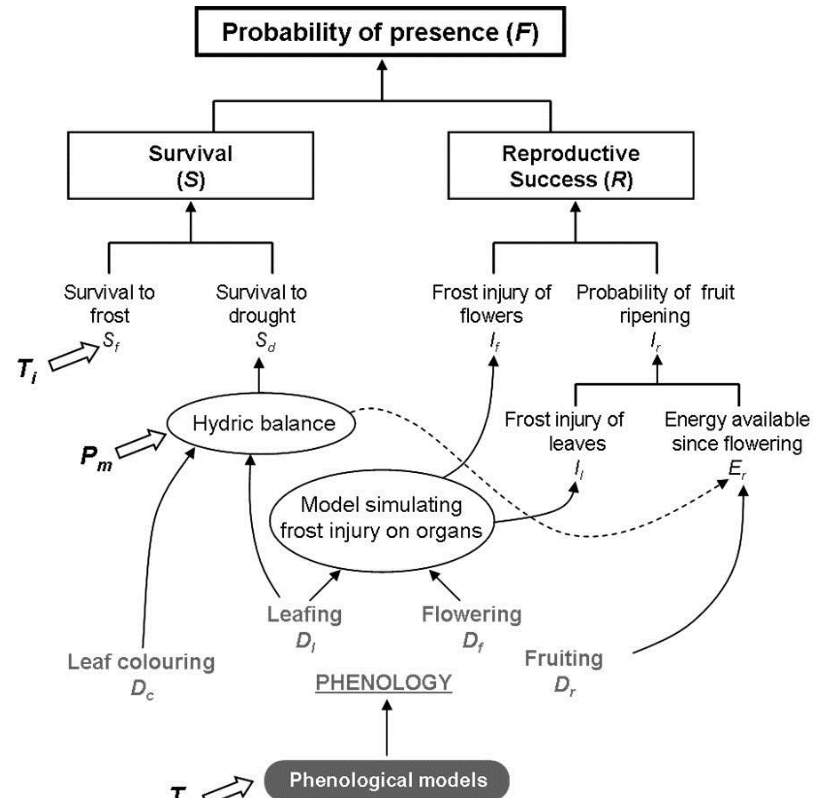
Modelling niches

Species distribution models (SDMs):

- Mechanistic or process-based:



Kearney & Porter 2009 Ecology Letters

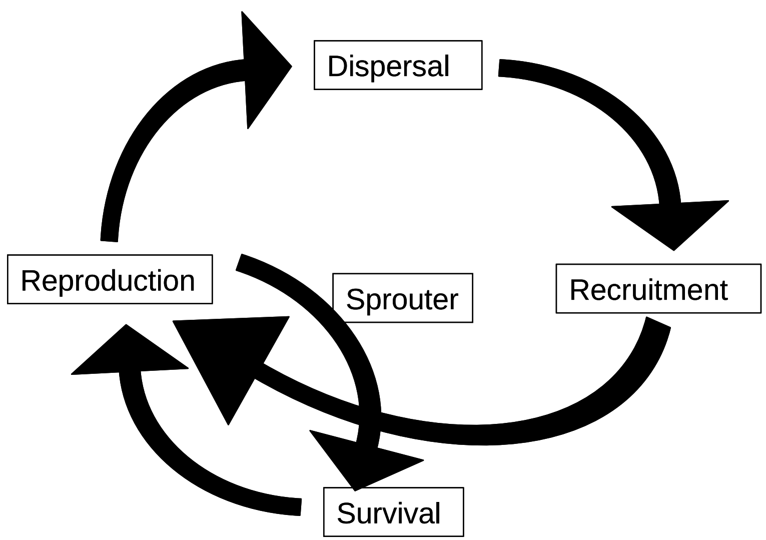


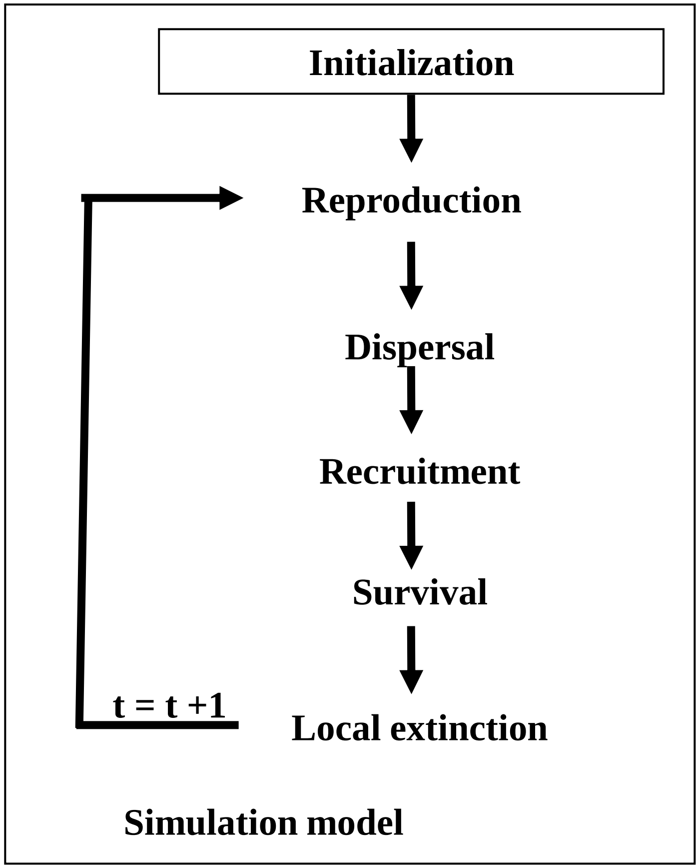
Morin et al. 2008 Journal of Ecology

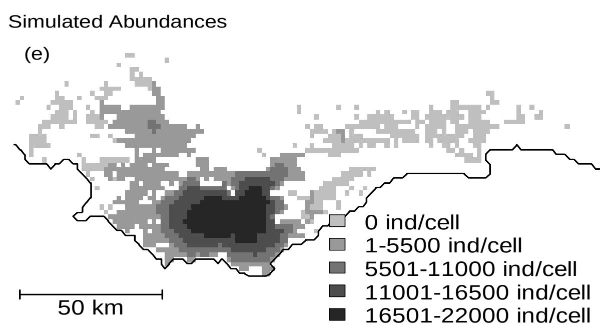
Modelling niches

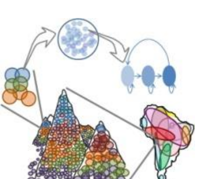
Species distribution models (SDMs):

- Mechanistic or process-based:







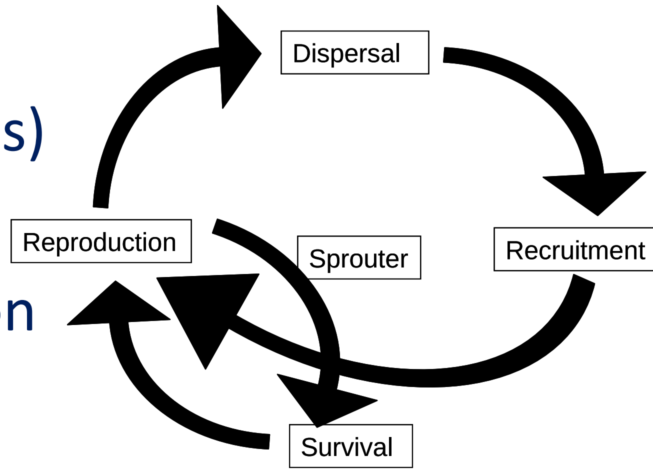


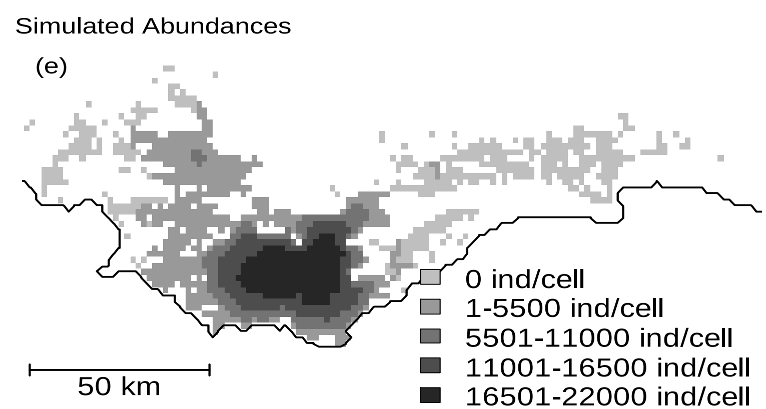
Cabral & Schurr 2010 Global Ecology and Biogeography

Modelling niches

Species distribution models (SDMs):

- Pros:
  - Direct appraisal of processes (causal effects)
  - Interpretable parameters
  - Relaxation from the equilibrium assumption
  - More realistic and useful forecasts
- Cons:
  - Data and computation demanding
  - Species-specific
  - Equifinality





Cabral & Schurr 2010 Global Ecology and Biogeography

Modelling niches

Species distribution models (SDMs):

- Pros:

  Direct appraisal of processes (causal effects)

  Interpretable parameters

  Relaxation from the equilibirum assumption

  More realistic forecasts

- Cons:

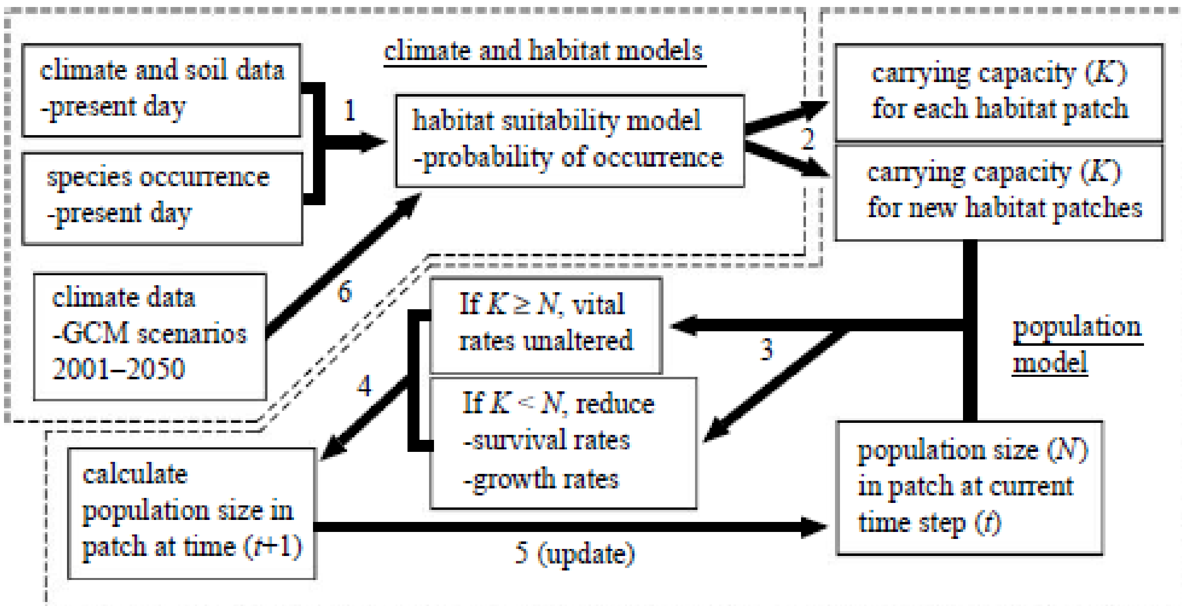
  Data and computation demanding → Fitted vs. Forward models

  Species-specific → Sensitivity analysis

  Equifinality → Data quality and multiple patterns

Modelling niches

Forward models:



biology letters

Biol. Lett. (2008) **4**, 560–563
doi:10.1098/rsbl.2008.0049
Published online 29 July 2008

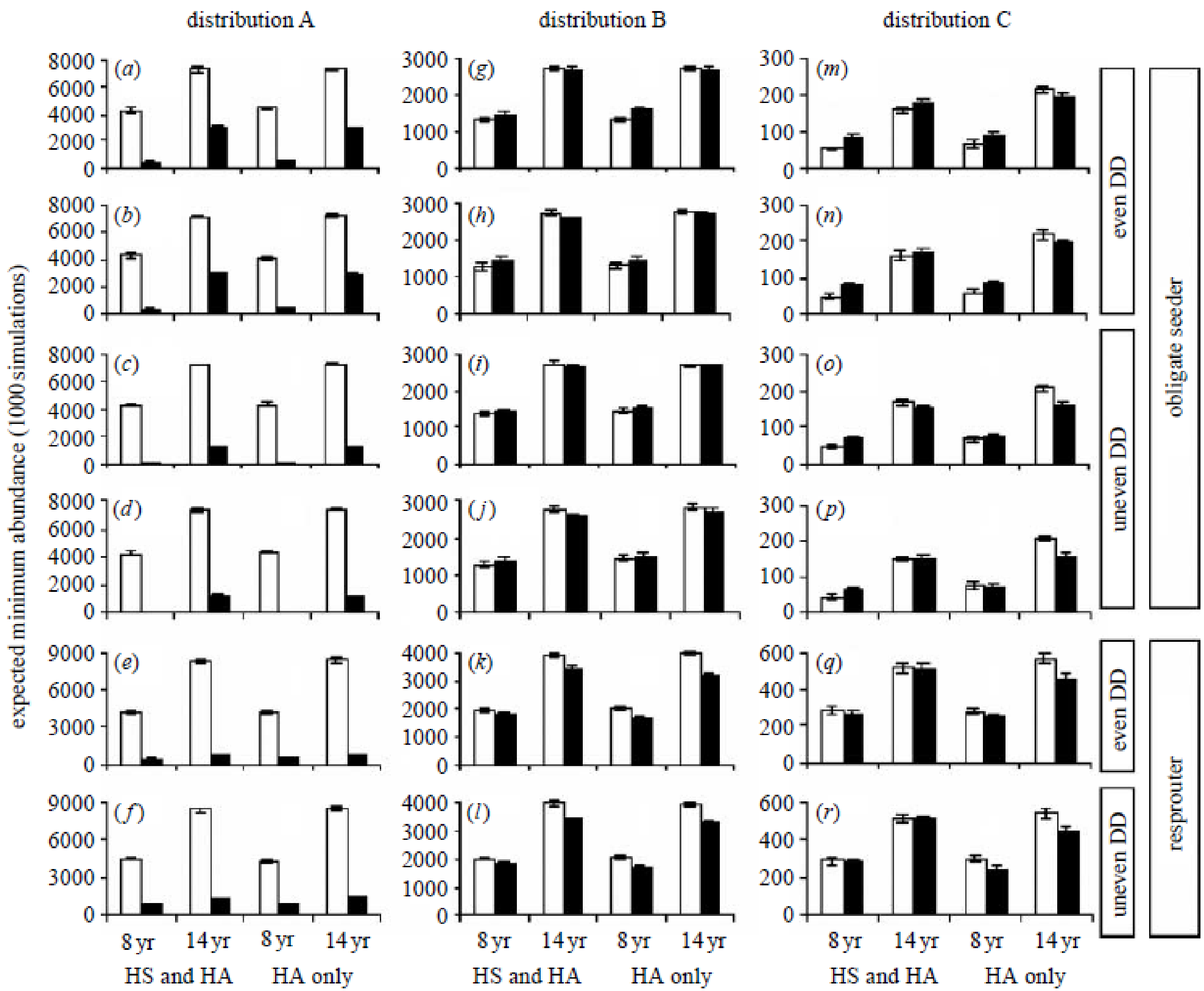
Global change biology

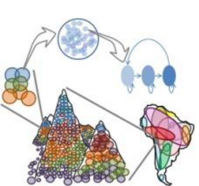
Predicting extinction risks under climate change: coupling stochastic population models with dynamic bioclimatic habitat models

David A. Keith[1,*], H. Resit Akçakaya[2], Wilfried Thuiller[3], Guy F. Midgley[4], Richard G. Pearson[5], Steven J. Phillips[6], Helen M. Regan[7], Miguel B. Araújo[8] and Tony G. Rebelo[4]

Modelling niches

Forward models:

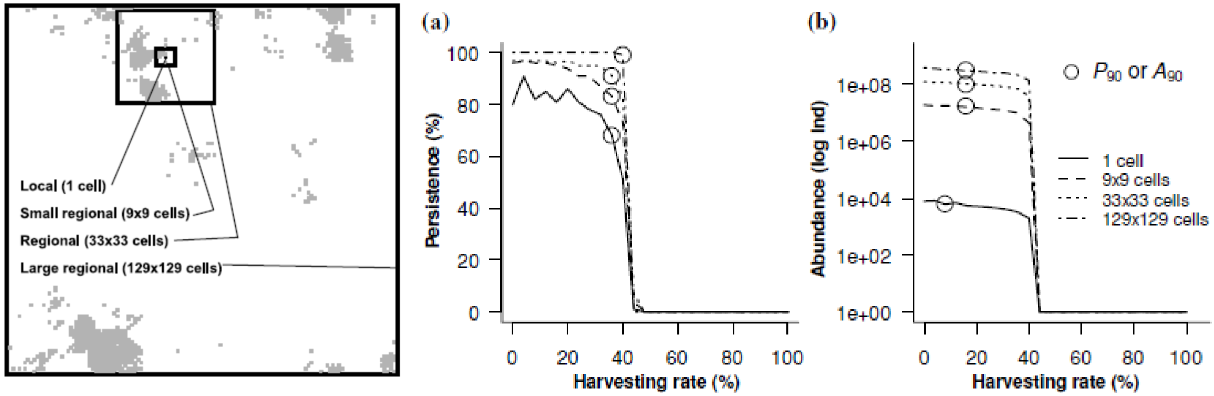


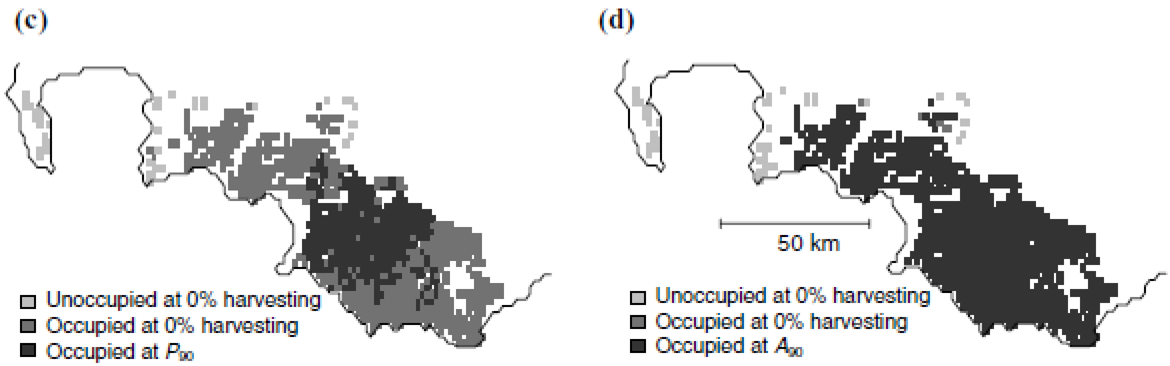


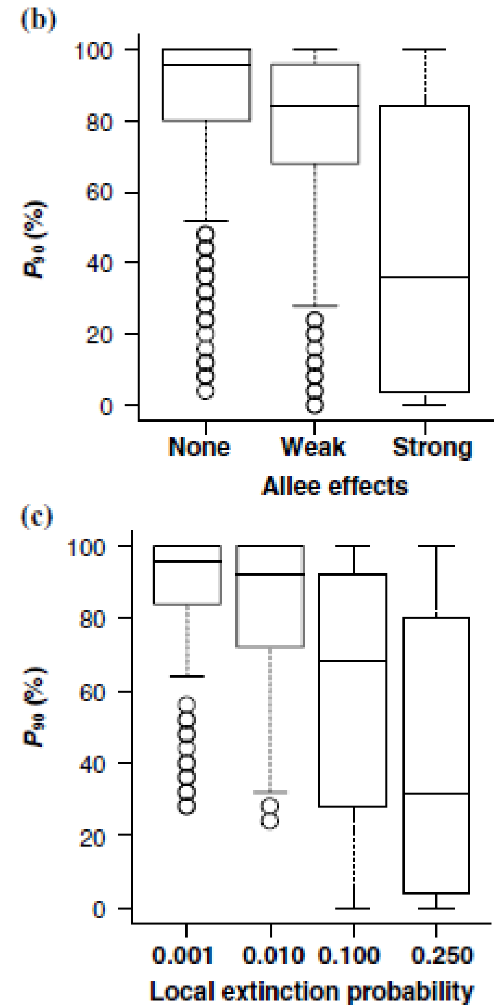
Keith et al. 2008 Biology Letters

Modelling niches

Forward models:







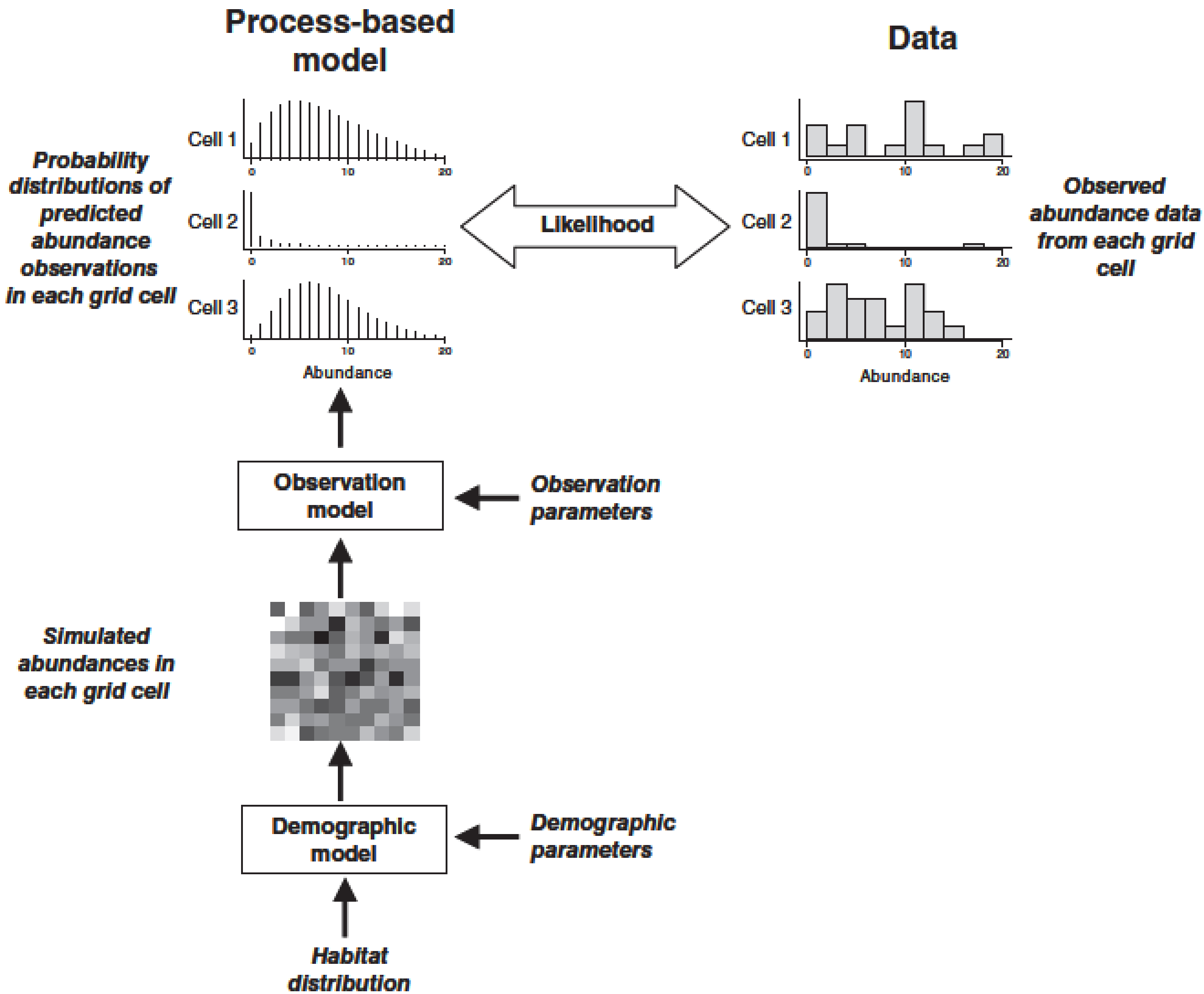
Effects of Harvesting Flowers from Shrubs on the Persistence and Abundance of Wild Shrub Populations at Multiple Spatial Extents

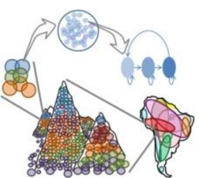
JULIANO SARMENTO CABRAL,*¶ WILLIAM J. BOND,† GUY F. MIDGLEY,‡
ANTHONY G. REBELO,‡ WILFRIED THUILLER,§ AND FRANK M. SCHURR*

Conservation Biology, Volume 25, No. 1, 73–84

Modelling niches

Fitted models:

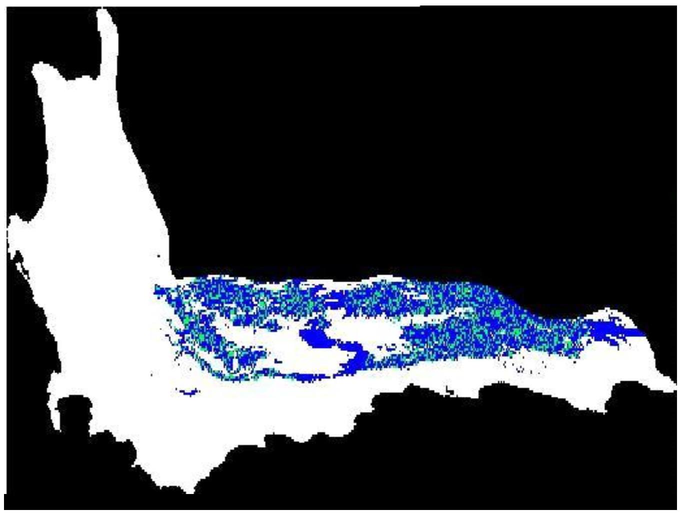


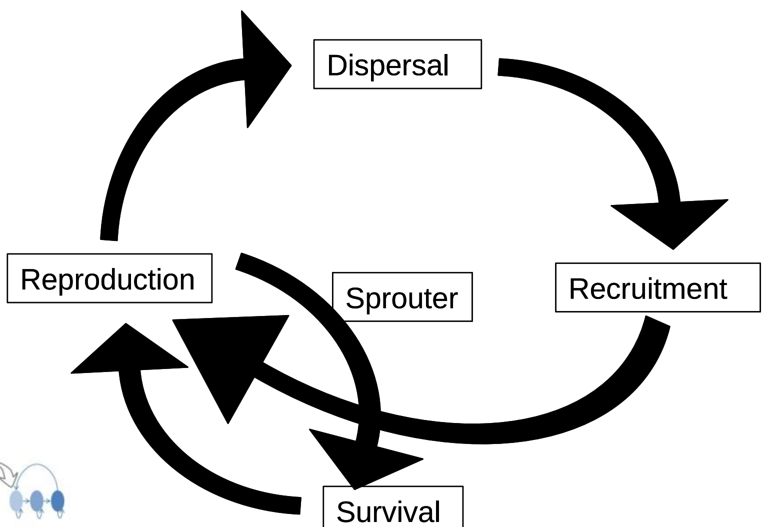


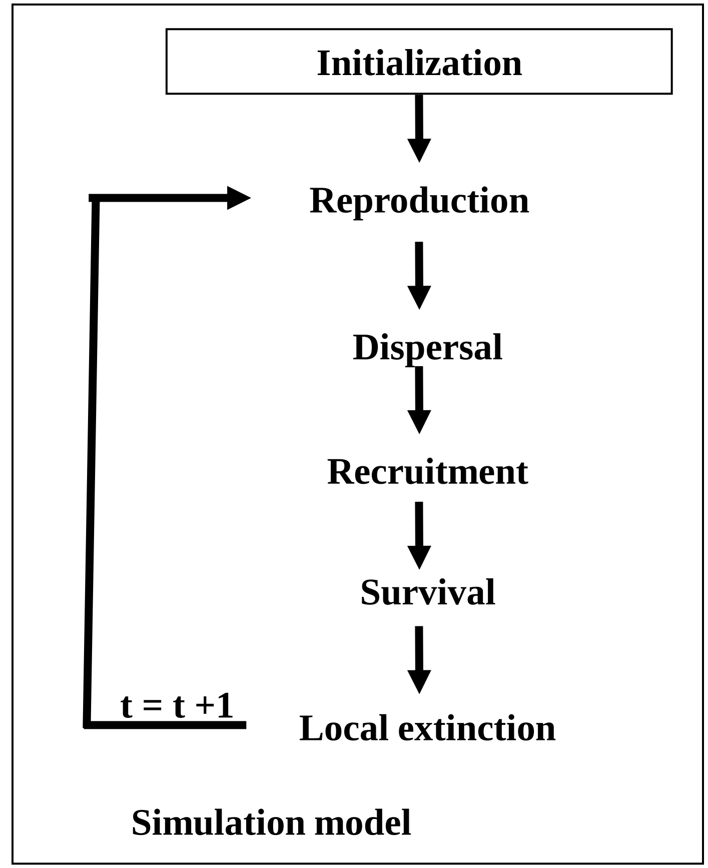
Cabral & Schurr 2010 Global Ecology and Biogeography

Modelling niches

Demographic models: processes







Cabral & Schurr 2010 Global Ecology and Biogeography

Modelling niches

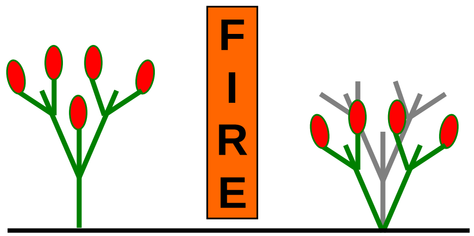
Demographic models: study system

Persistence ability:

Reproductive system:

Population dynamics:

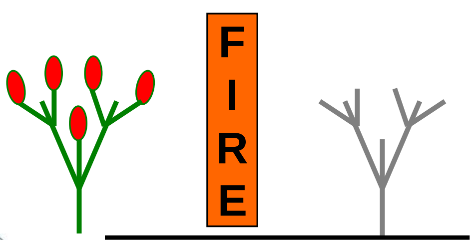
Sprouter
(high persistence ability)



-Monoecious: *Protea*

-Diecious: *Leucadendron*

Nonsprouter
(low persistence ability)



-Monoecious : *Protea*

-Diecious : *Leucadendron*

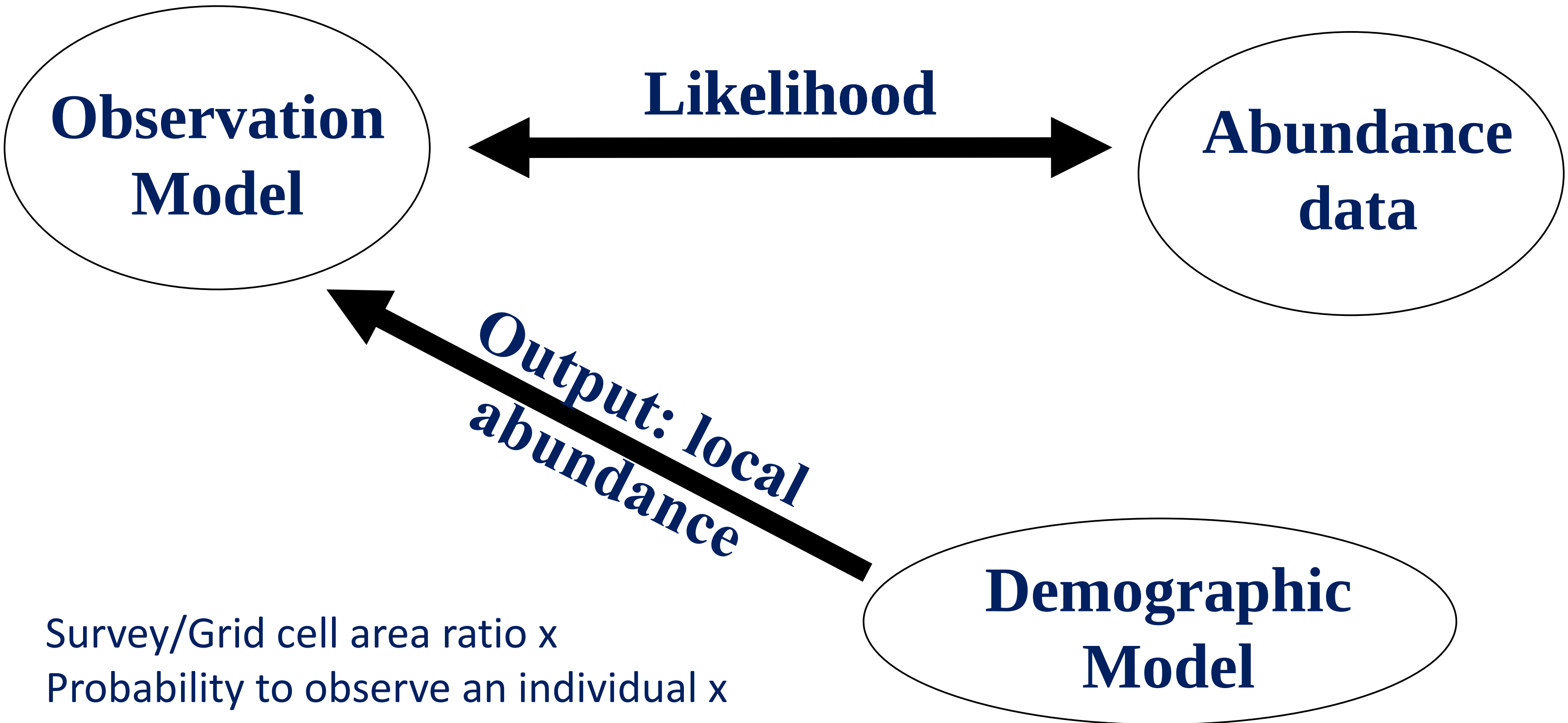
Ricker Model

Beverton-Holt Model

Cabral & Schurr 2010 Global Ecology and Biogeography

Modelling niches

Observation models: Accounting for imperfect detection

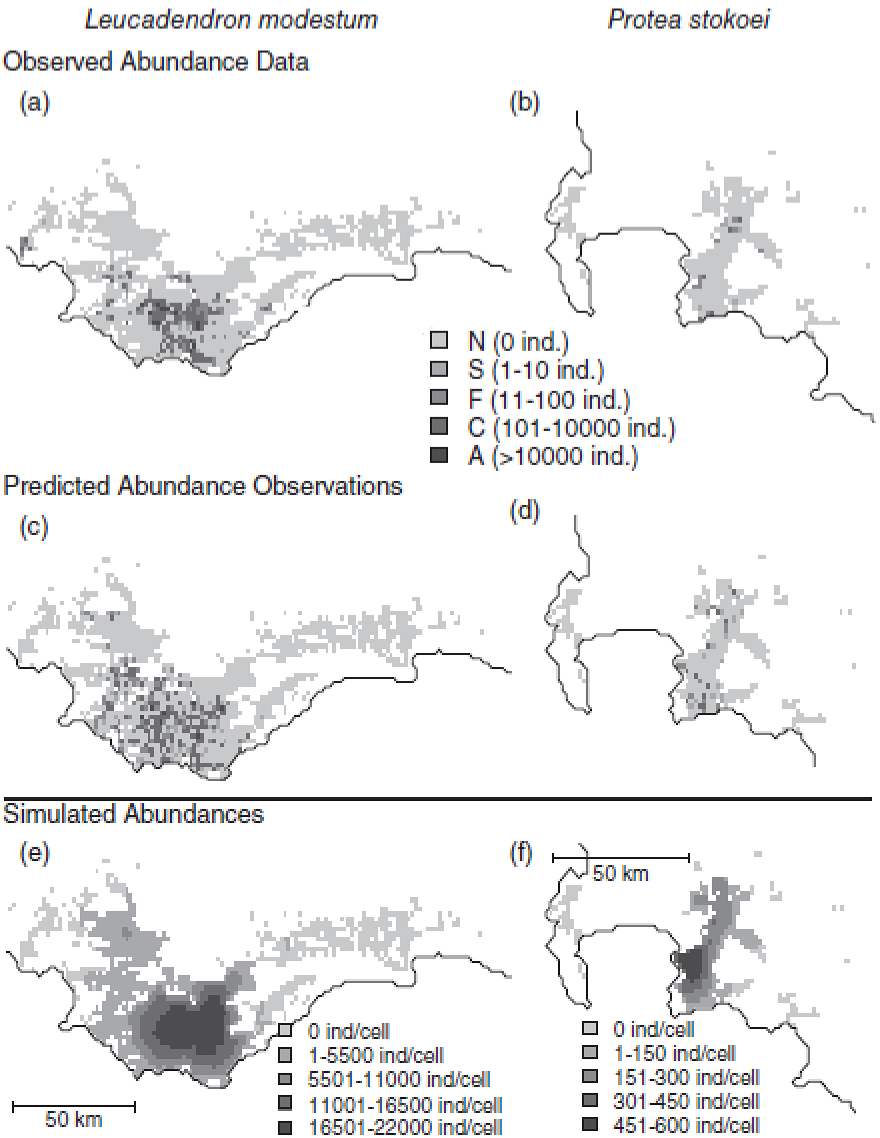


Survey/Grid cell area ratio x
Probability to observe an individual x
Long-term mean Abundance (ecological output)

Cabral & Schurr 2010 Global Ecology and Biogeography

Modelling niches

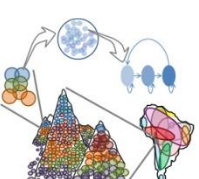
Range dynamics: spatial predictions



Observed Abundances – Protea Atlas

Predicted observations

Simulated abundances



Cabral & Schurr 2010 Global Ecology and Biogeography

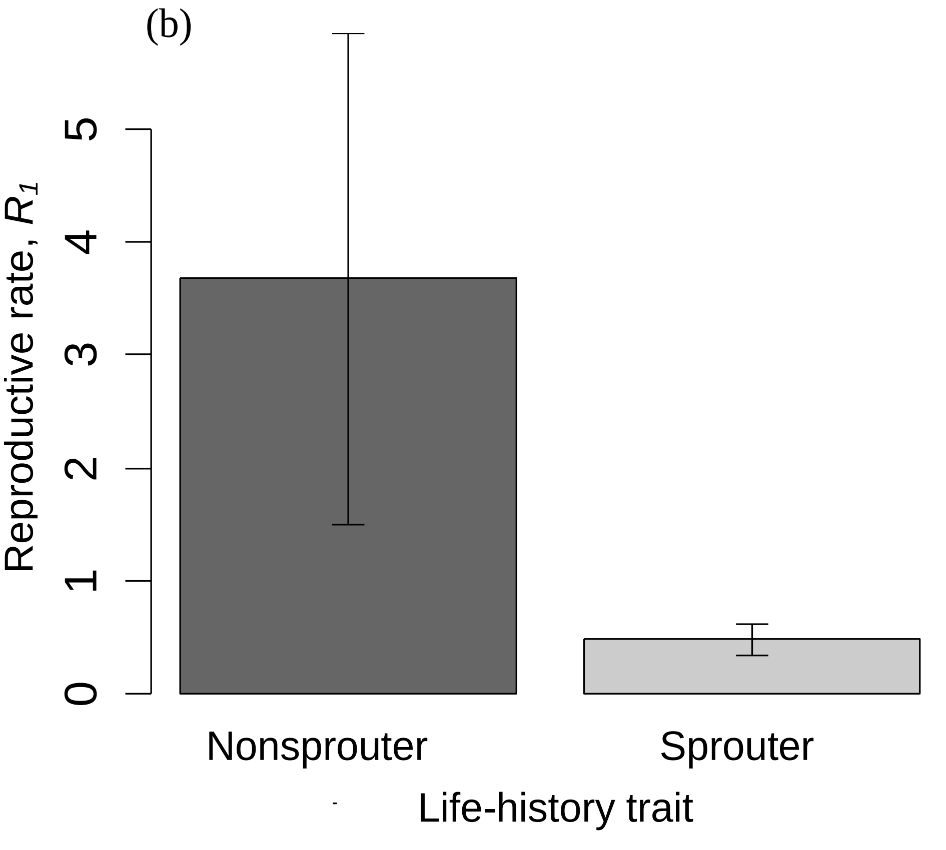
Modelling niches

Range dynamics: parameter values

=> Realistic parameter values;

=> Parameter values can be compared to independent estimates;

=> Values obtained generally agree with species traits.



Cabral & Schurr 2010 Global Ecology and Biogeography

Modelling niches

Range dynamics under non-equilibrium:

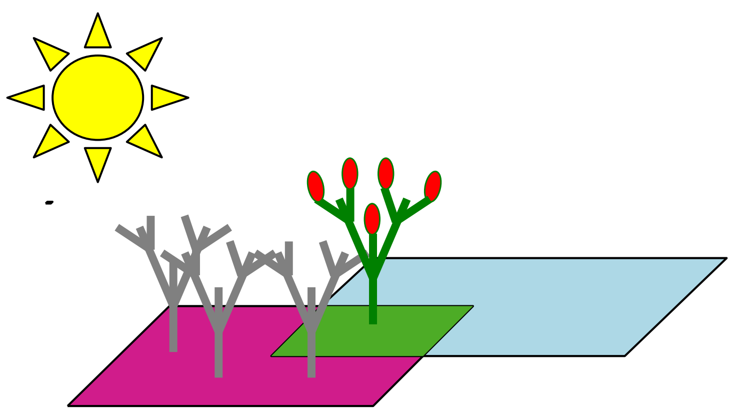
Diversity and Distributions, (Diversity Distrib.) (2013) **19**, 363–376

BIODIVERSITY RESEARCH

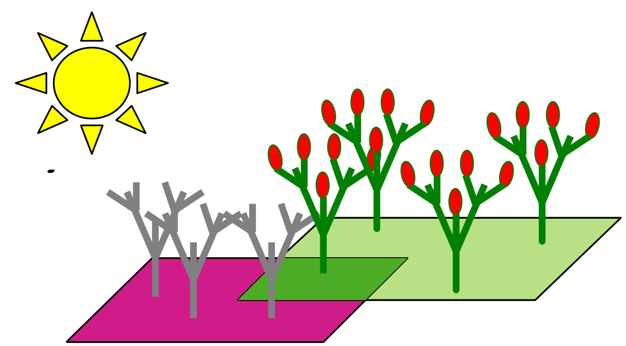
Impacts of past habitat loss and future climate change on the range dynamics of South African Proteaceae

Juliano Sarmento Cabral[1,2*], Florian Jeltsch[1], Wilfried Thuiller[3], Steven Higgins[4], Guy F. Midgley[5,6], Anthony G. Rebelo[5], Mathieu Rouget[7] and Frank M. Schurr[1,8]

no migration



perfect migration



Modelling niches

Range dynamics under non-equilibrium: design

Scenarios:

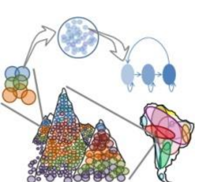
Simulation until quasi-stationary state

No habitat loss
- **No climate change** — Control
- **With climate change** — CC

With habitat loss
- **No climate change** — HL
- **With climate change** — HL/CC

300 Generations (~ 3000 yr) | **5 Generations (~ 50 yr)** | **5 Generations (~ 50 yr)** → **Time step or generation**

Present



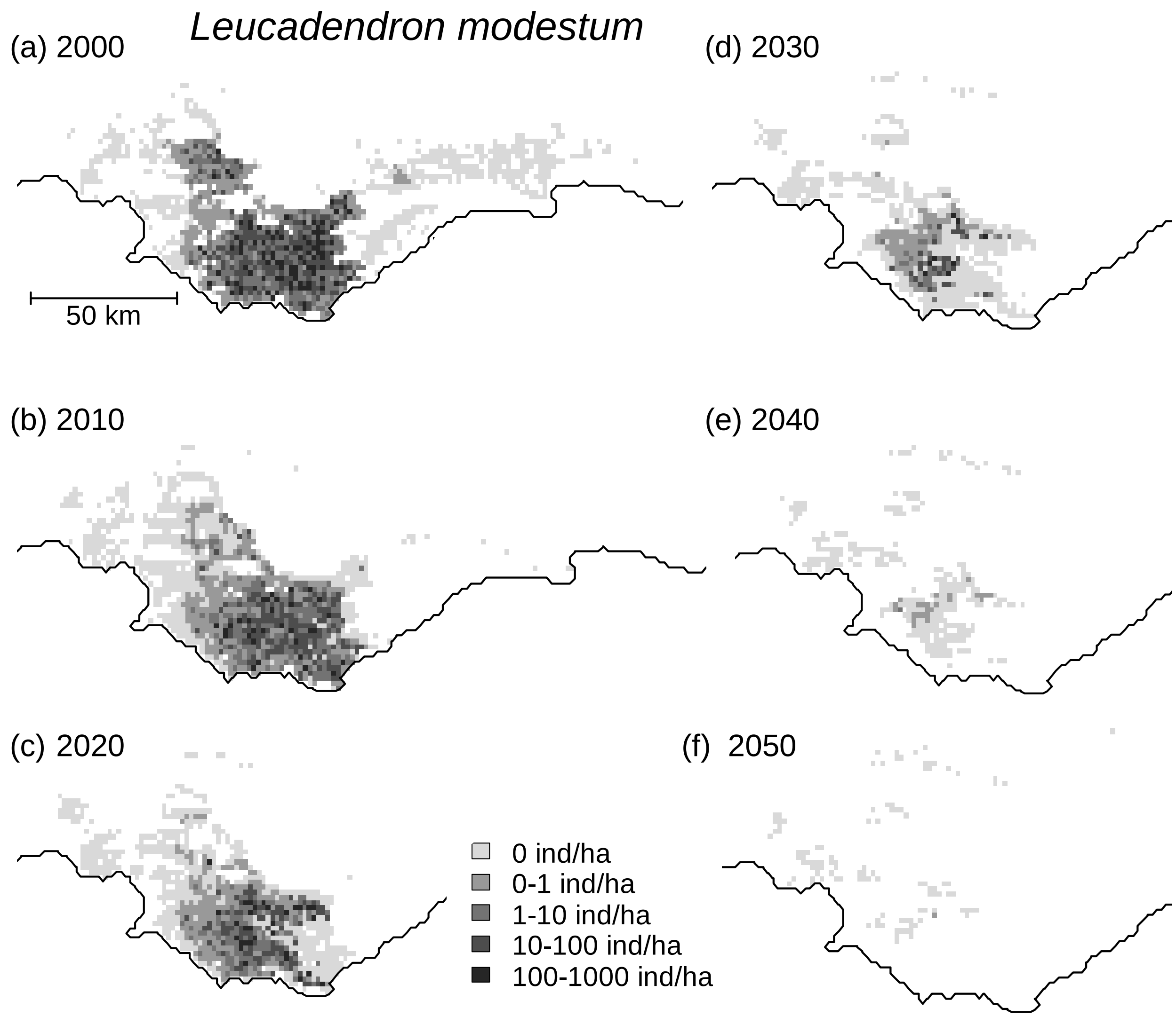
Each cell looses a percentage in area (lower carrying capacity)

Time-series of habitat models

Cabral et al. 2013 Diversity and Distributions

Modelling niches

Range dynamics under non-equilibrium: time-series

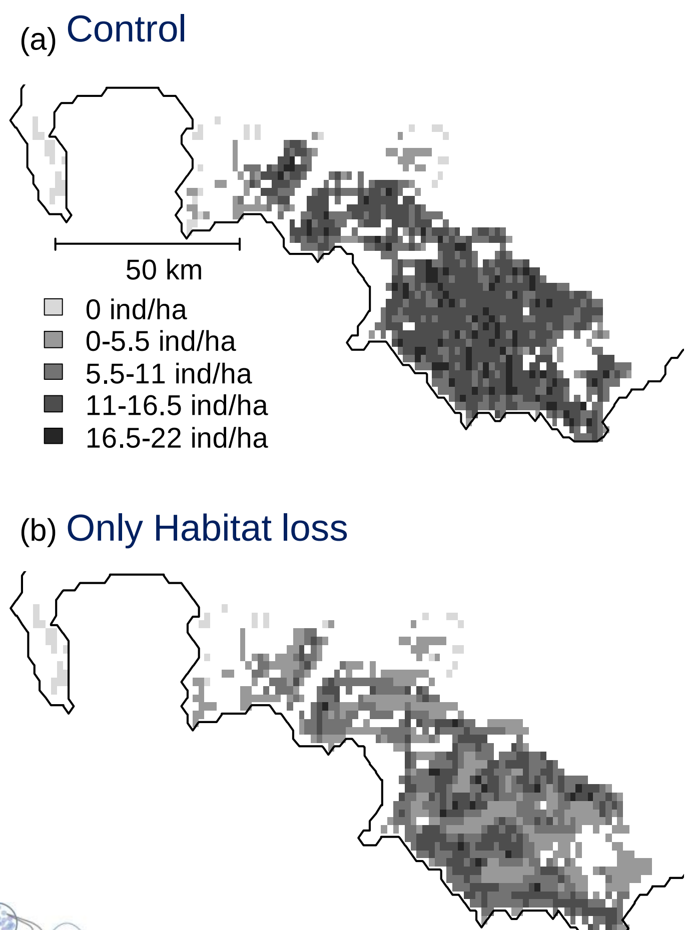


Cabral et al. 2013 Diversity and Distributions

Modelling niches

Range dynamics under non-equilibrium: scenarios

Protea compacta



Occupied range affected:

- Little colonization;

- Importance of range remaining suitable

Vorst scenario, but etter than the sum f separate effects:

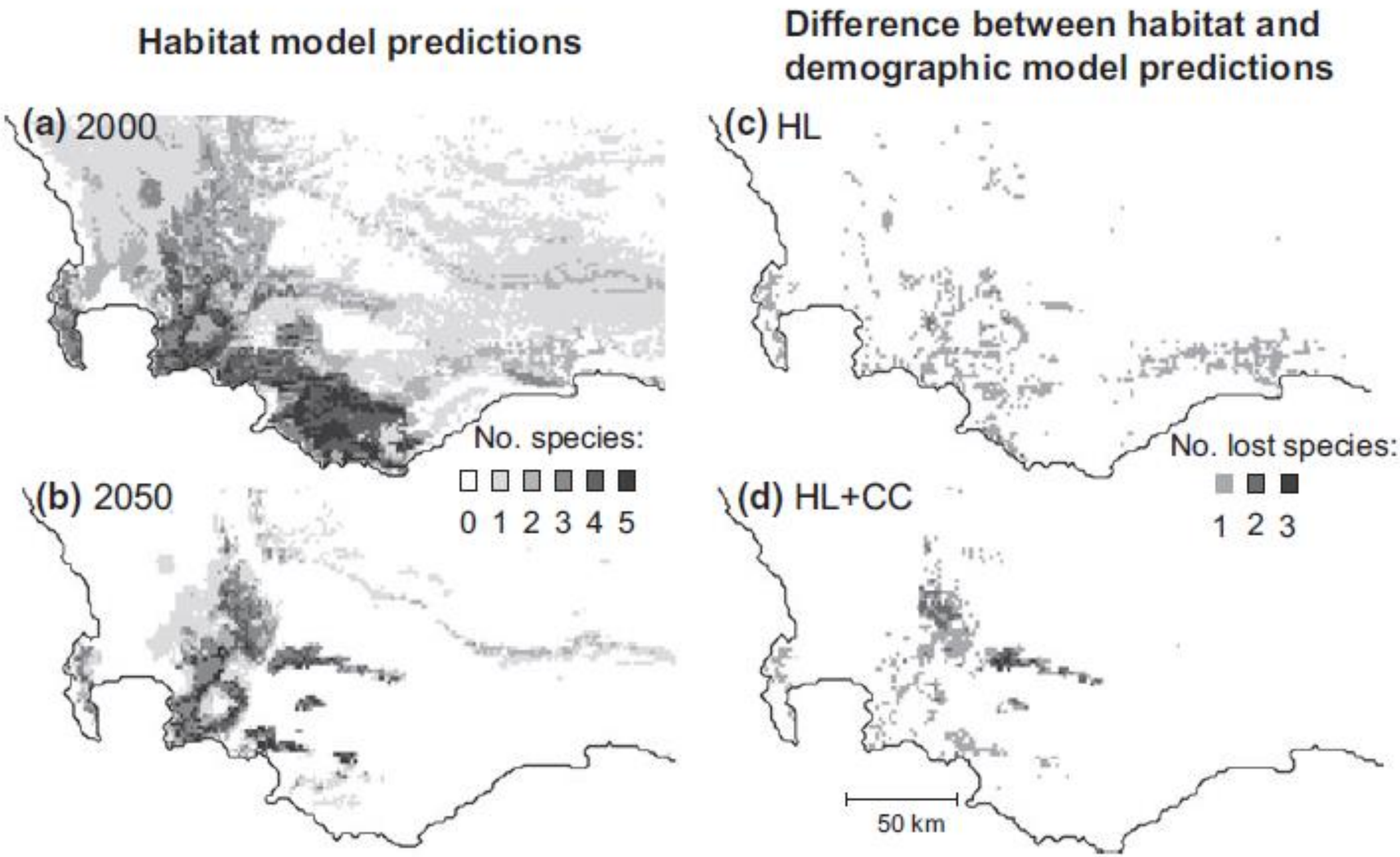
he role of pristine efugia in range emaining suitable

Local abundances affected

Cabral et al. 2013 Diversity and Distributions

Modelling niches

Range dynamics under non-equilibrium: viable refugia



Cabral et al. 2013 Diversity and Distributions

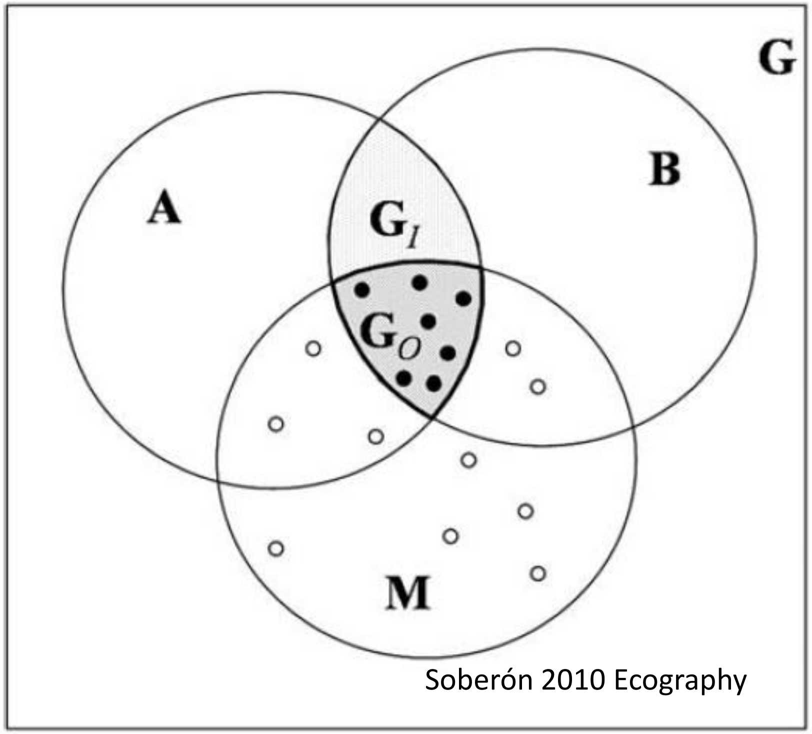
Modelling niches

Species distribution models (SDMs):

- Mechanistic or process-based:

  What is missing?

  - Physiological constraints
  - Biotic interactions
  - Evolutionary processes
  - Integrate all processes



Soberón 2010 Ecography

Modelling niches

Including interactions (multi-species models):

Journal of Biogeography (*J. Biogeogr.*) (2012) **39**, 2212–2224

SPECIAL ISSUE

Linking ecological niche, community ecology and biogeography: insights from a mechanistic niche model

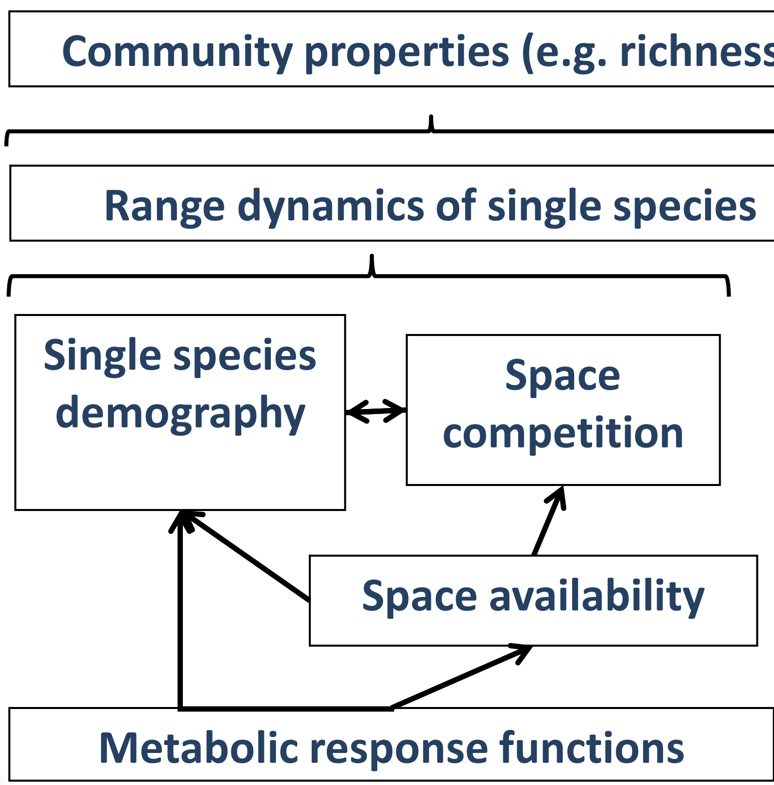
Juliano Sarmento Cabral* and Holger Kreft

Modelling niches

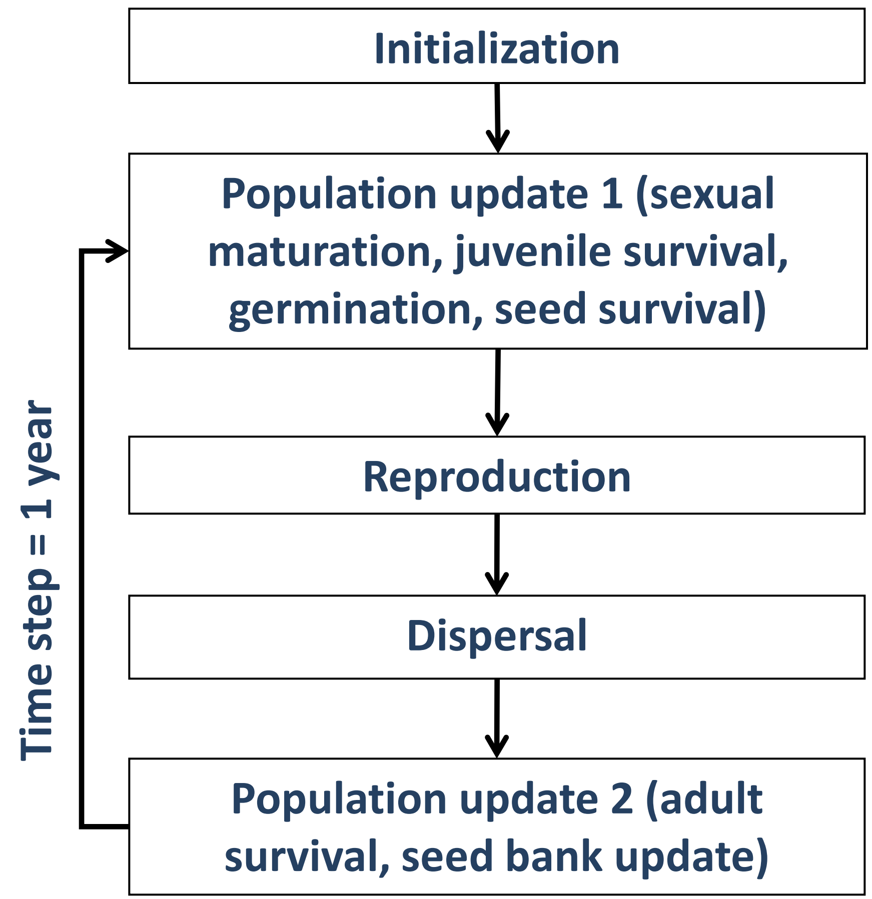
Including interactions (multi-species models):

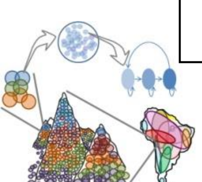
Species vary in traits and habitat requirements

Hierarchical structure:



Flow chart:





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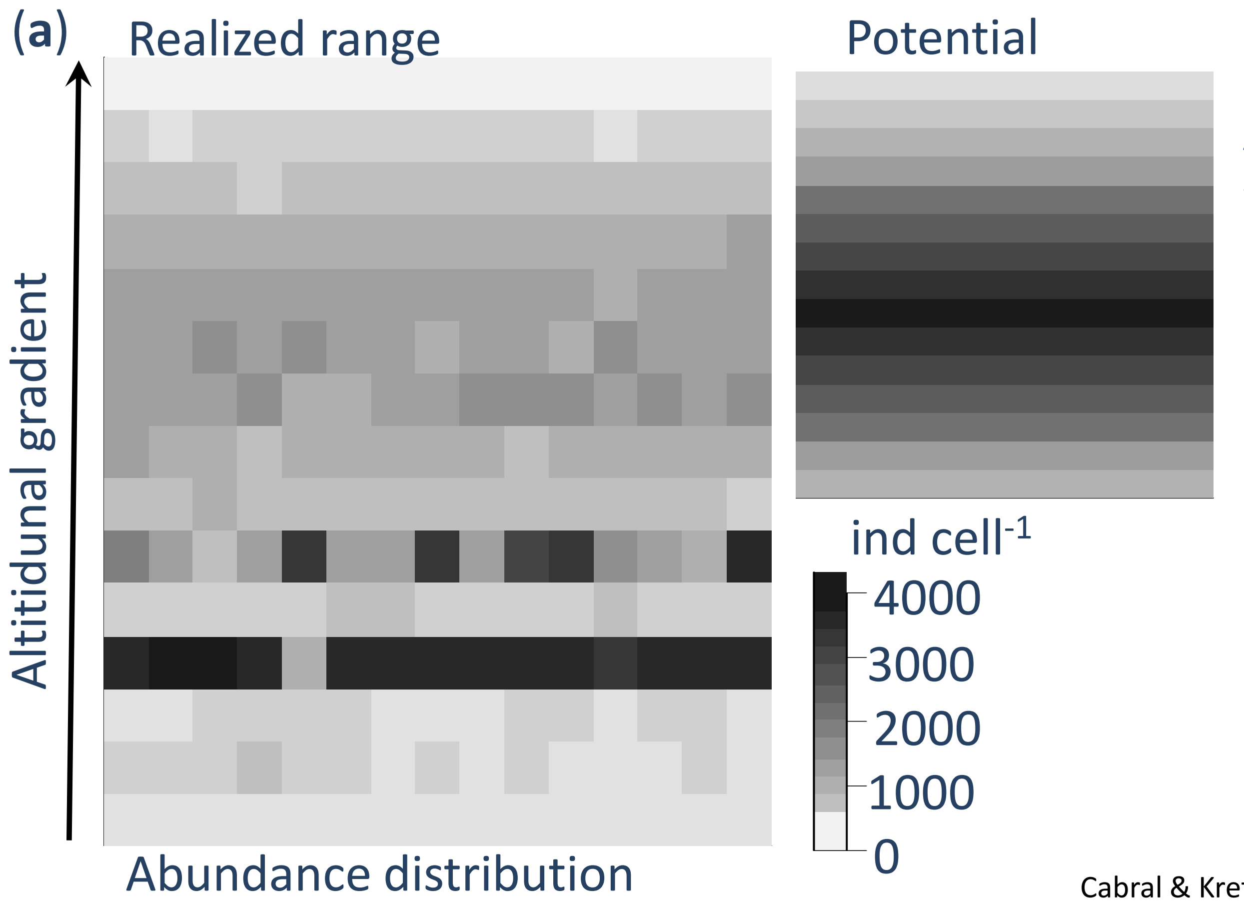
Modelling niches

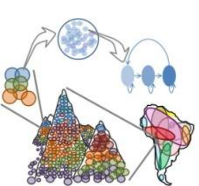
Including interactions (multi-species models):

=> Sloped plane: decreasing temperature

=> Single species in a pool of 400 competing species



Also obtained when simulated alone



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Modelling niches

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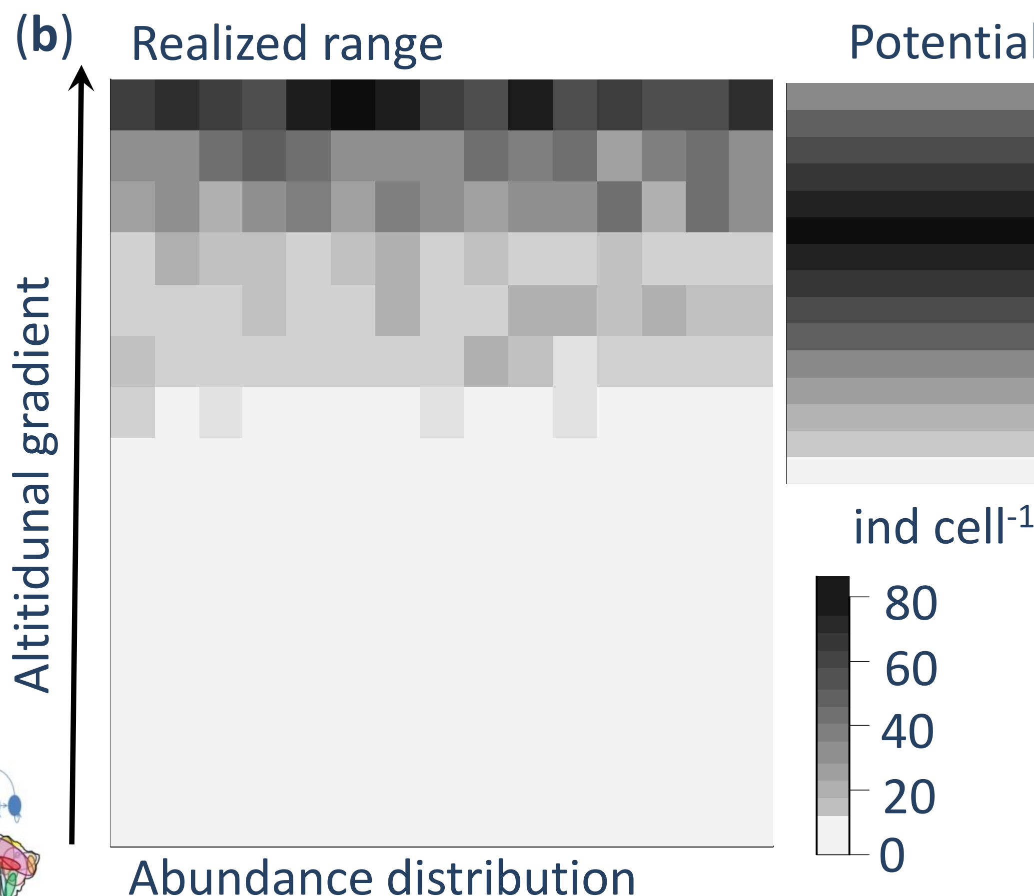

Also obtained when simulated alone

Species may be more abundant under suboptimal conditions if competition is considered.

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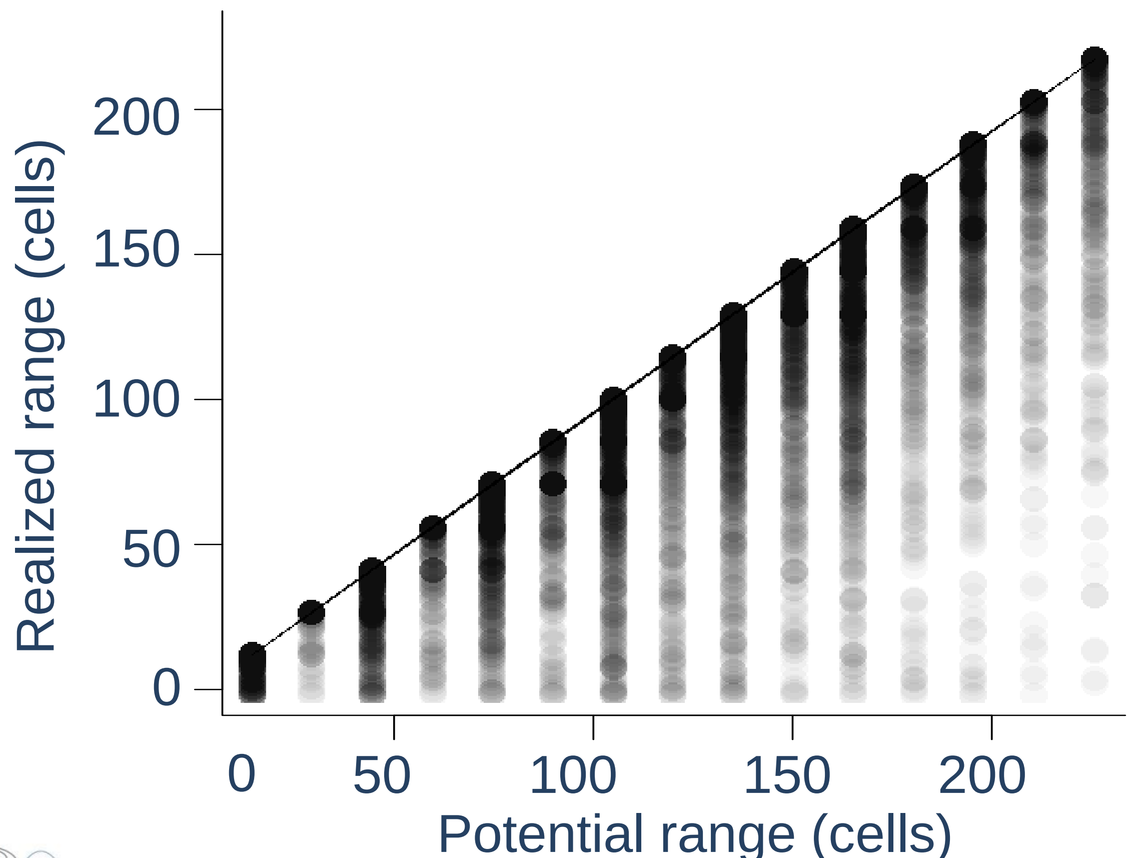
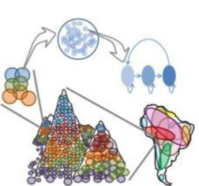
Modelling niches

Including interactions (multi-species models):



34% of all species could not fill their potential range when simulated alone; 49% under competition.



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Modelling niches

Including interactions (multi-species models):

=> GLM: RF ~ Traits + habitat requirements + species richness

Significant variables:

Body mass (+);

LDD (+, mostly for herbs);

Mean dispersal distance (+, mostly for trees);

Allee effect (-, mostly for herbs);

Being annual (-);

Optimal temperature (- for trees);

Species richness (+ for herbs, - for trees).

Importance of species traits as well as competition pressure (i.e. Species richness)

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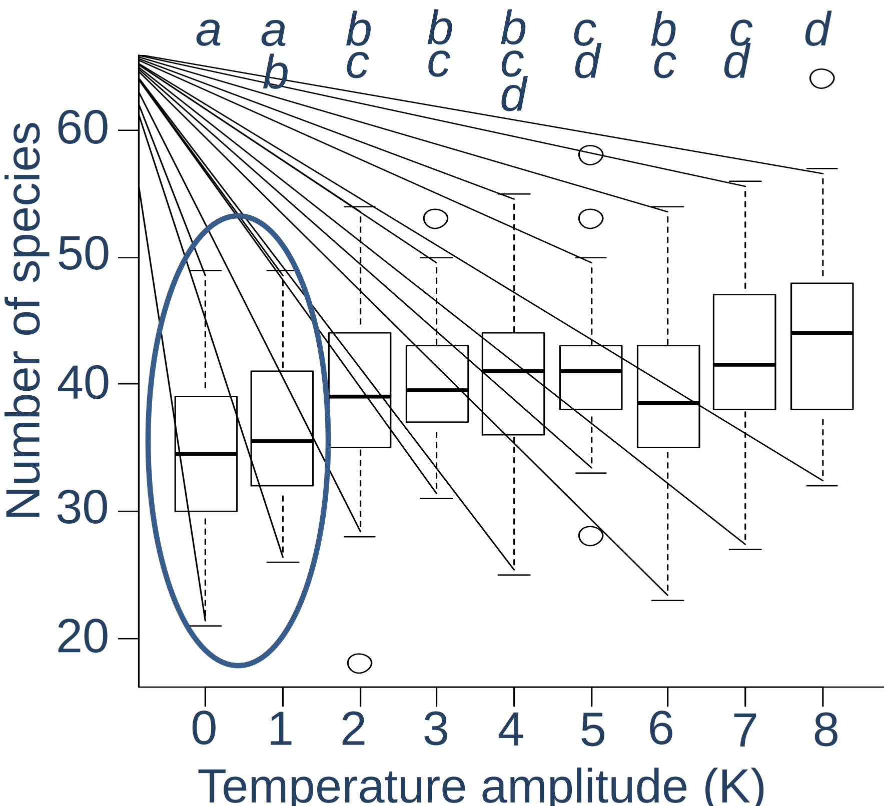
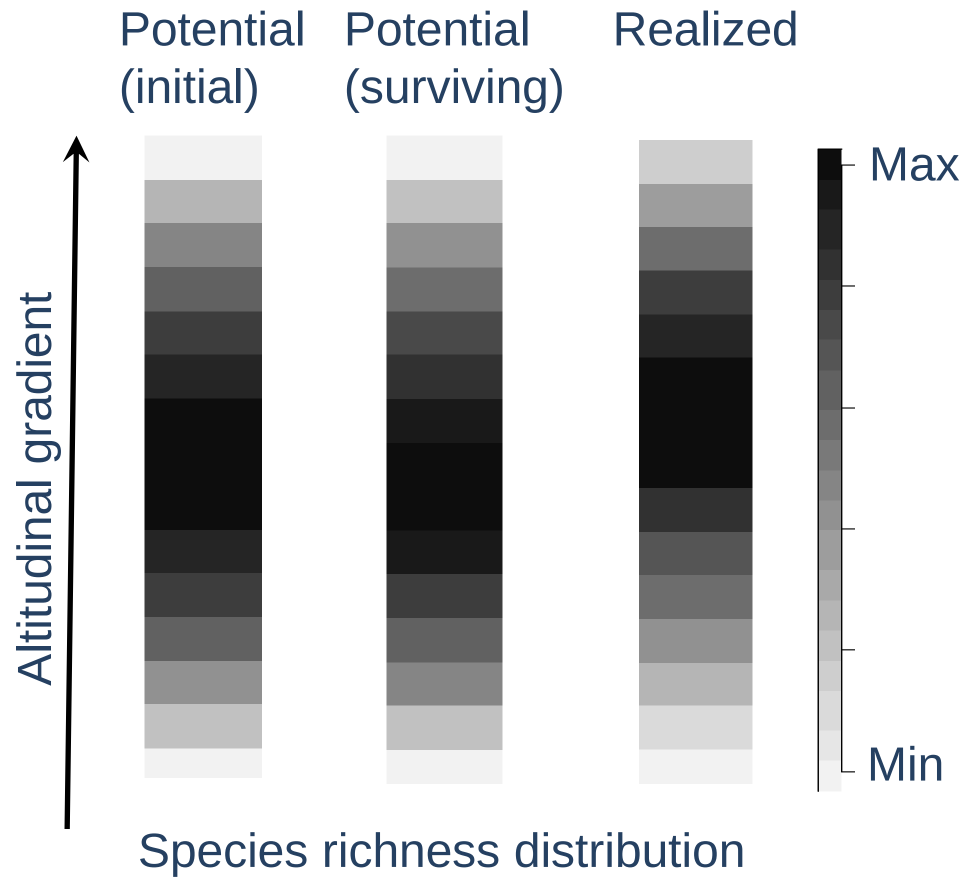
Modelling niches

Including interactions (multi-species models):

=> Surviving community:





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Modelling niches

Next steps:

=> Understanding niche evolution and ecological factors influencing speciation

=> Range dynamics of competing species under environmental change

=> Long spatiotemporal scales: emergent biogeographical patterns by simulating range dynamics

=> Richness patterns across environmental gradients emerging from range dynamics

Take-home Messages

Species niches can be quantified, modelled and predicted

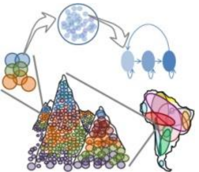
Abiotic, biotic and auto-ecological factors shape the niche

Observed species occurrences is product of an array of processes

Correlative niche models can be used to pinpoint important factors shaping occurrences

Process-based niche models can be used to assess important processes shaping occurrences

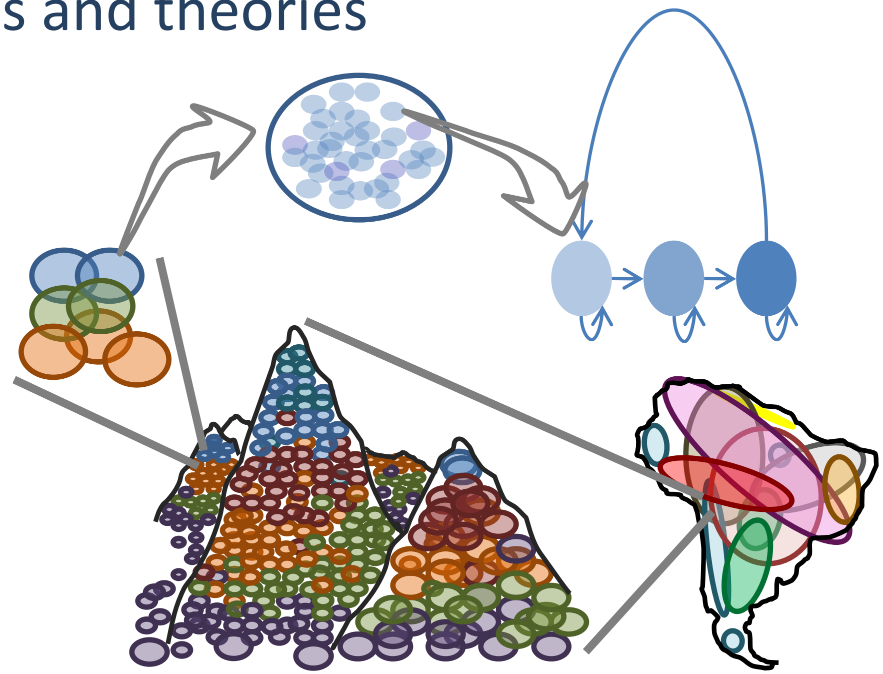
Once relevant processes are modelled, it is easy to apply the model to non-equilibrium and hypothetical conditions



Take-home Messages

Increasing model complexity must be coupled with increasing emergent patterns to avoid equifinality and to enable multiple validations

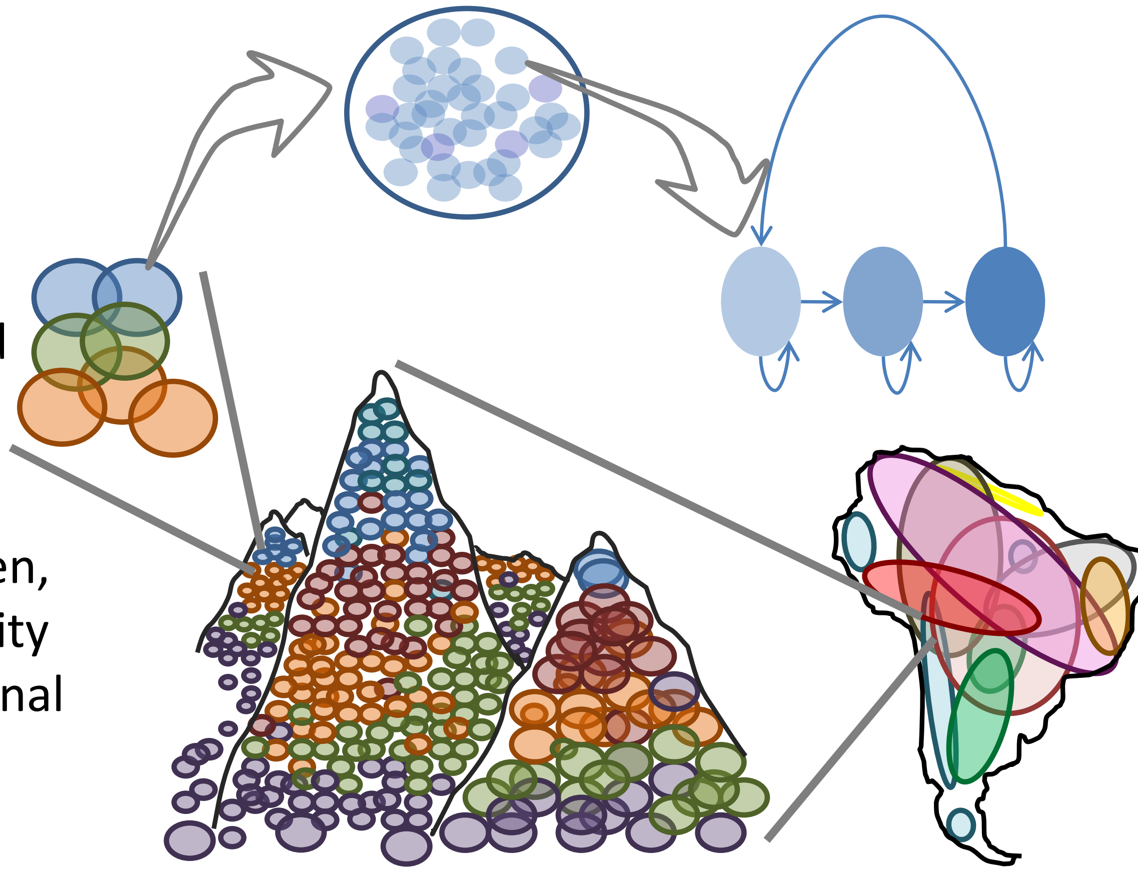
Investigating niche dynamics opens a new window to investigate biodiversity and macroecological patterns, unifying different ecological fields and theories



Thank you for your attention! Obrigado!

Further thanks to:

Working groups Biodiversity, Macroecology and Conservation Biogeography; Plant Ecology and Nature Conservation.



Financial support from the **DFG**, **DAAD**, **BMBF**, **Unibund** Göttingen, University of Göttingen, University of Potsdam, South African National Biodiversity Institute and GEOINOVACE Project.

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http://www.uni-goettingen.de/en/128741.html

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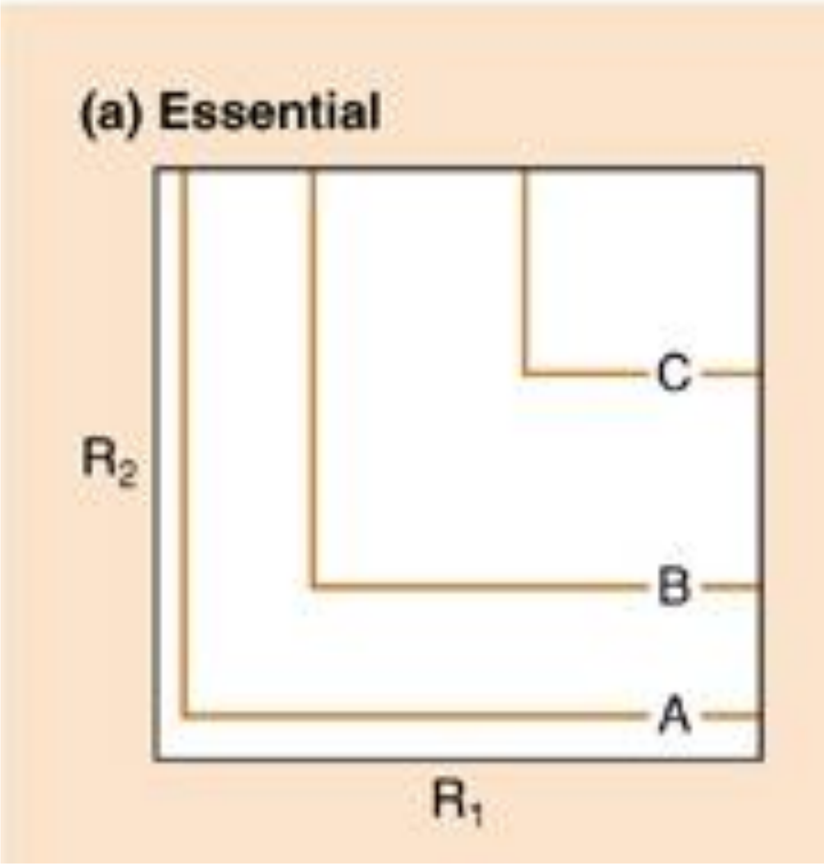
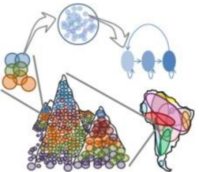
UNIVERSITAS MASARYKIANA BRUNENSIS

Defining niches: Resources

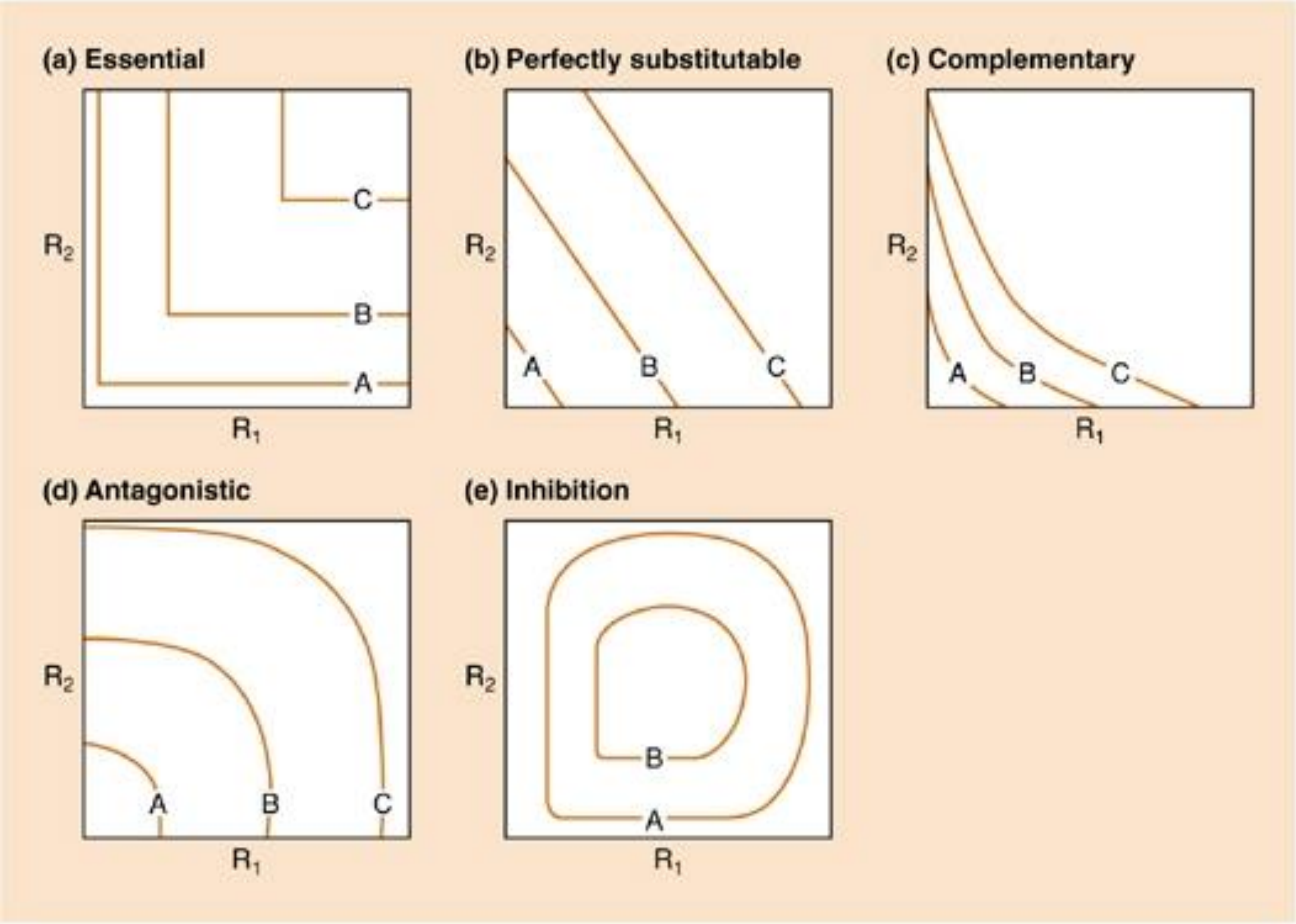


Isoclines of population growth depending on two **essential** resources R_1 and R_2.
A: negative growth
B: zero growth
C: positive growth
(After Tilman, 1982)



Begon et al.: Ecology, 2006

Defining niches: Resources



Begon et al.: Ecology, 2006

Method

$$f(N_{t,i}) = N_{t,i} \frac{R_{\max}}{1 + \frac{R_{\max} N_{t,i}}{K_p}}$$

$$f(N_{t,i}) = N_{t,i} \frac{R_{\max}}{1 + k\left(N_{t,i} - c\right)^2}$$

$$K = c + \sqrt{\frac{\left(R_{\max} - M\right)}{Mk}}$$

$$C = c - \sqrt{\frac{\left(R_{\max} - M\right)}{Mk}}$$

$$f(N_{t,i}) = N_{t,i} R_{\max}{}^{1 - \frac{N_{t,i}}{K}}$$

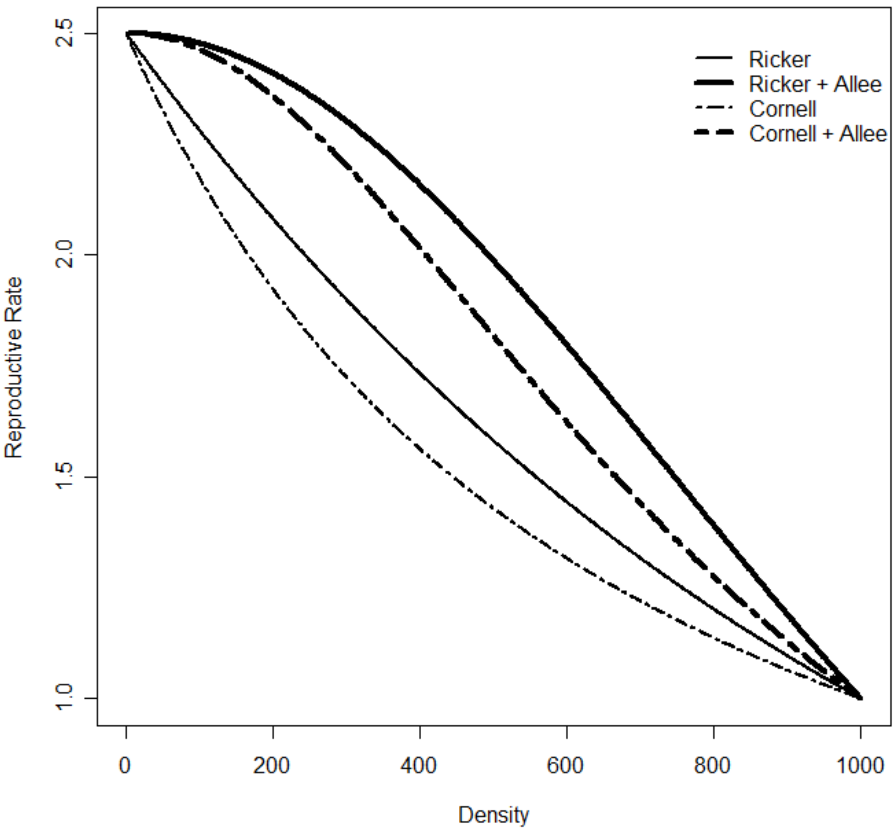
$$f(N_{t,i}) = N_{t,i} R_{\max}{}^{\frac{4\left(K - N_{t,i}\right)\left(N_{t,i} - C\right)}{(K - C)^2}}$$

Method

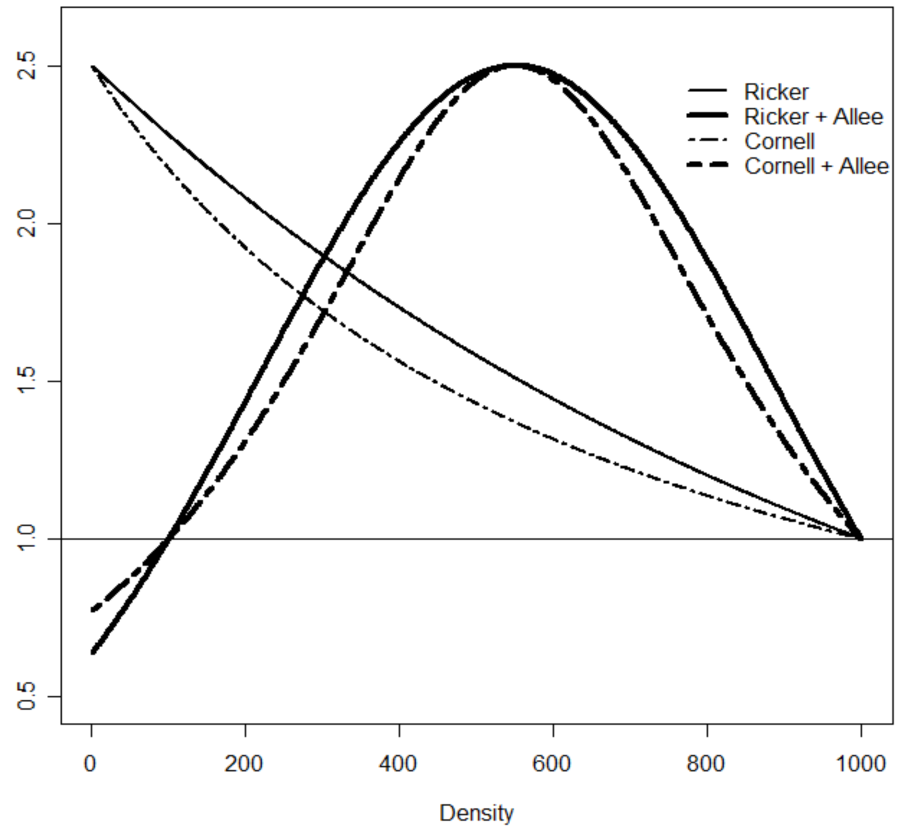
$$\ln L(\mathrm{A}|\beta) = \sum_{i=1}^{Ncells} \sum_{o=1}^{Nobs(i)} \ln P(A_{i,o}|\beta)$$

$$P(A_{i,o}|\beta) = PDF(A_{i,o}, \mu = f\rho\overline{N}_i, s = s)$$

Method



Reproductive Rate
2.5
2.0
1.5
1.0
0
200
400
600
800
1000
Density
Ricker
Ricker + Allee
Cornell
Cornell + Allee



2.5
2.0
1.5
1.0
0.5
0
200
400
600
800
1000
Density
Ricker
Ricker + Allee
Cornell
Cornell + Allee

Methods

Effects of wild flower harvesting:

Harvest levels: 0-100% in steps of 4%

- under climate change;

Habitat displacement per timestep

- different scales;

Local => Spatial-implicit;

Regional or intermediate;

Global or large;

} **Spatial-explicit**

- different species traits.

Fat-Tailed x Thin-Tailed dispersed;

No x Weak x Strong Allee effects;

Different Rmax, E, M and K values.

2. The model

Formulas

Area occupied by an individual: $b_0 B_a^{-3/4} e^{E/kBT}$

Biological rates: $b_0 B_s^{-1/4} e^{-E/kBT}$

Local reproduction (Beverton-Holt extended with Allee effects):

$S_{(i,j)} = (N_{(i,j)} R_{max})/(1+k(N_{(i,j)} - c)^2)$, where

$k=4(R_{max} - m_a)/(m_a(K_{(i,j)} - C)^2)$,

$c=C + \sqrt{((R_{max} - m_a)/(m_a k))}$,

$K_{(i,j)} =((A_c - A_{t(i)})/A_{a(j)}) H_{(i,j)}$, where *A* represents areas and *H* habitat suitability

Seeds coming in a cell: $S_{(z,j)} = D_{(z,i)} S_{(i,j)}$