Niche theory for a complicated world

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ESA Annual Meeting: FROM OCEANS TO MOUNTAINS
Sacramento, 2014

Outline

Is there such thing, as niche theory?

- Once upon a time we have it:
  - Gause's principle & limiting similarity
  - Lotka-Volterra model & resource utilization function
  - Hutchinson's niche space
- Before long, the picture fell apart:
  - Ecology became too complicated for Lotka-Volterra.
  - Mechanistic models did not lead general results.
  - No clear conclusion on Gause and limiting similarity.
- Since, theoretical ecology has grown up:
  - Beyond the specific models (eg. Caswell).
  - Renewed interest in coexistence theory (eg. Chesson).
  - Niche has remained controversial.

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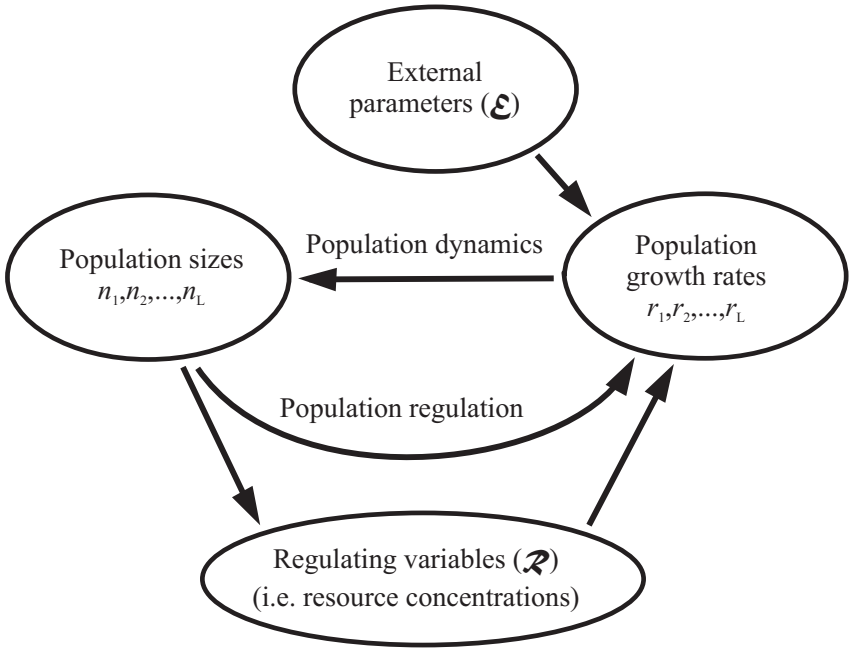
Goal: Clarity to niche theory!

- Needed: a comprehensive mathematical theory of ecological niche.
- It should be applicable to any ecological situation.
- It should provide biological insight.

Steps from LV & classical niche to modern theory

1. Resources ⇒ Regulating variables
2. Lotka Volterra ⇒ linearization of dynamics
3. Resource utilization ⇒ impact & sensitivity
4. Limit of similarity ⇒ Robustness of coexistence



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Any model can be linearized!

Lotka-Volterra competition:

$$r_i = r_{0i} - \sum_j a_{ij} n_j$$

Generalized competition coefficient:

$$a_{ij} = -\frac{\partial r_i}{\partial n_j}$$

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Classical niche theory (*ad hoc*):

$$a_{ij} \sim \sum_k u_{ik} u_{jk}$$

Resource utilization

Proposed theory (derived):

$$-a_{ij} = \frac{\partial r_i}{\partial n_j} = \sum_k \frac{\partial r_i}{\partial \mathcal{R}_k} \frac{\partial \mathcal{R}_k}{\partial n_j} = \boldsymbol{S}_i \cdot \boldsymbol{I}_j$$

Sensitivity of Species i

Impact of Species j

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Equilibrium:

$$\boldsymbol{r}(\boldsymbol{\mathcal{R}}(\boldsymbol{n}), \boldsymbol{\mathcal{E}}) = 0$$

Perturbation:

$$\frac{\partial \boldsymbol{n}}{\partial \boldsymbol{\mathcal{E}}} = \boldsymbol{a}^{-1} \frac{\partial \boldsymbol{r}}{\partial \boldsymbol{\mathcal{E}}}$$

Robustness:

$$\det \boldsymbol{a} = \det(\boldsymbol{S}_i \boldsymbol{I}_j)$$

must be large!

⇒ Species should be different!

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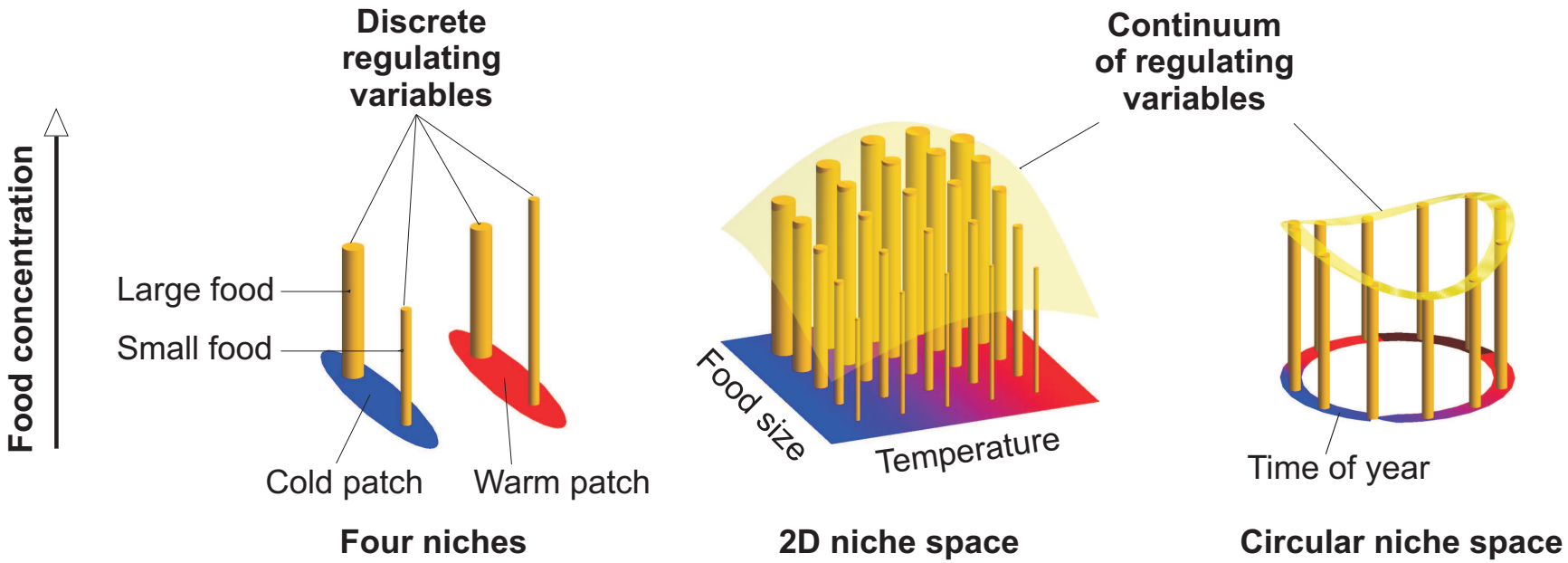
Larger similarity in
*I*mpact or *S*ensitivity
⇓
Weaker robustness
of coexistence

[No absolute limit of similarity!]

Niche space: Ways of niche segregation

Varieties for niche space:



Niche space: set of regulating variables.
Not necessarily an Euclidean space of a few dimension!

Complications abound

What about

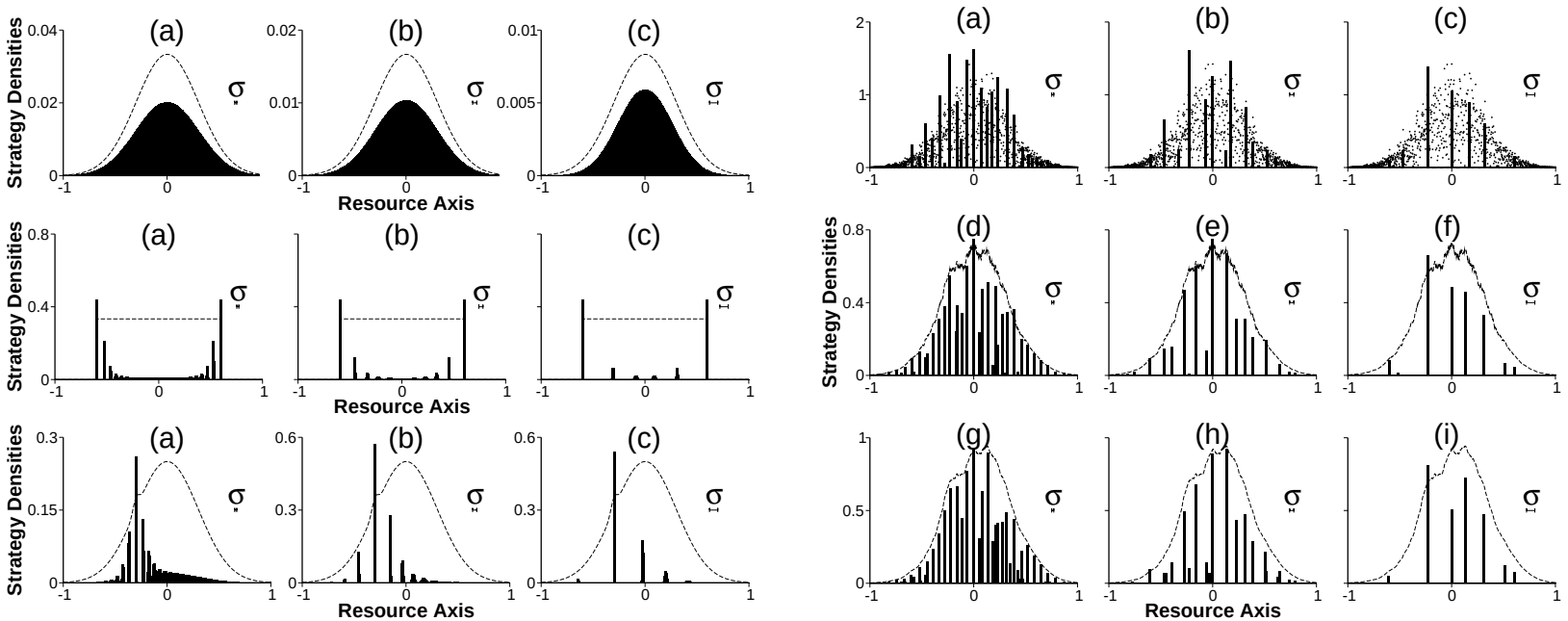
- population structure?
- spatial structure?
- temporal structure?
- facilitation?
- etc.

We have papers about them...

Structural instability of continuous coexistence

(Szabó & Meszéna, Oikos, 2006)

Lotka-Volterra competition for a resource continuum;
Gaussian competition kernel.



Except the immediate vicinity of continuous coexistence:
Segregation by niche width!

Self-organised similarity?

Scheffer & Nes, PNAS, 2006

Claim: coexistence of similars!!!!!

(Scheffer & Nes: Self-organized similarity, PNAS, 2006)

Model:

$$r(y) = r_0 \left(1 - \frac{\int \alpha(y,x) n(x) dx}{K(y)}\right) - g \frac{n(y)}{[n(y)]^2 + H^2} \quad (1)$$

apparent competition

Generalized competition:

$$\frac{\delta r(y)}{\delta n(x)} = -\frac{r_0}{K(y)} \alpha(y,x) - g\delta(y-x)... \quad (2)$$

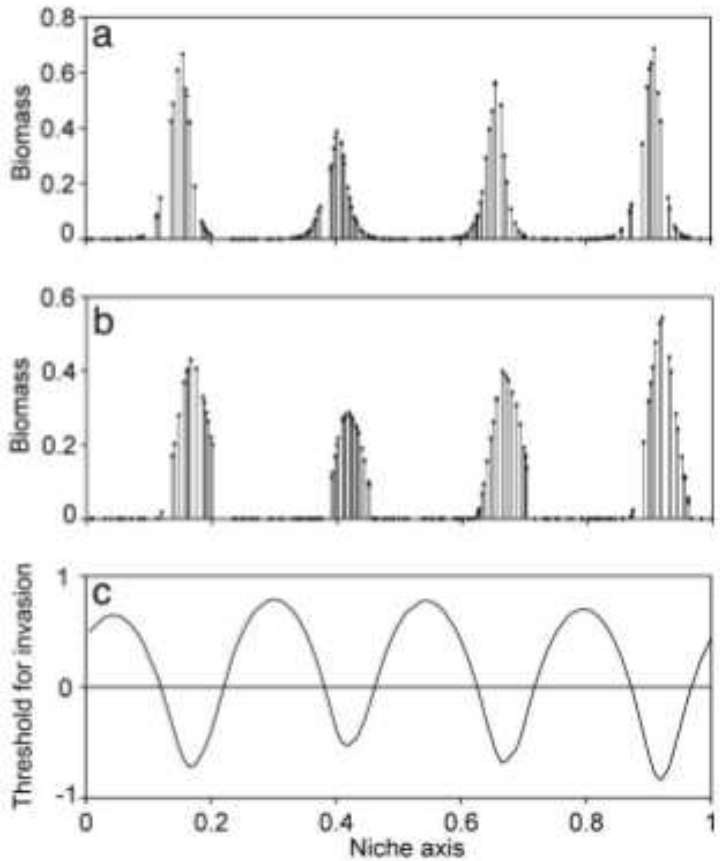
Degeneracies:

- They choose $K(y)$ =const.
- Delta function for apparent competition!

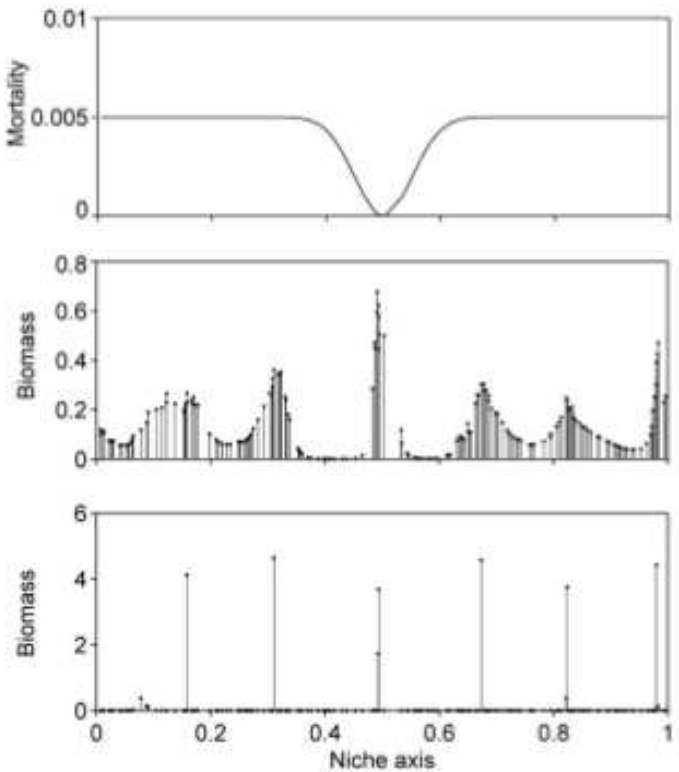
Self-organised similarity?

Scheffer & Nes, PNAS, 2006

Original model



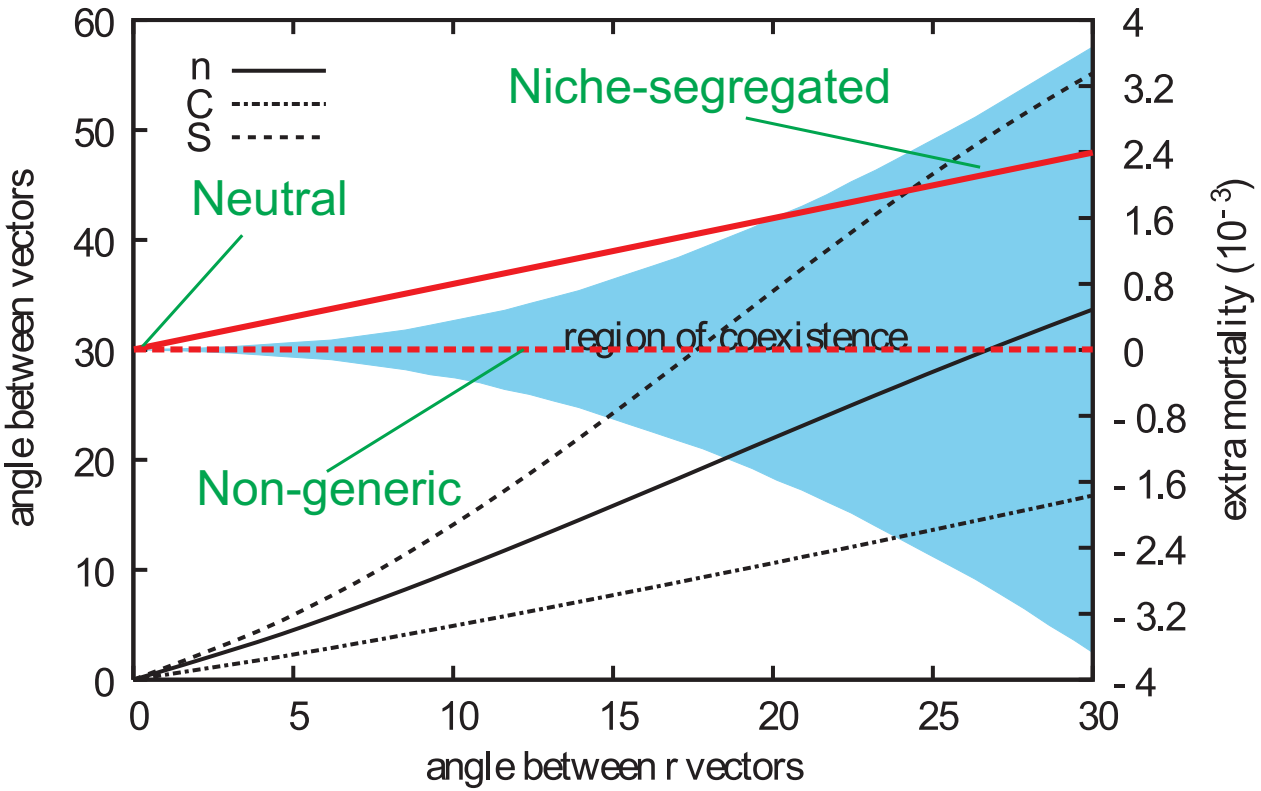
Degeneracies removed



No degeneracies $\Rightarrow$ No coexistence of similars at $t = \infty$!

Niche-neutrality continuum?

No!



EITHER strictly neutral OR sufficiently niche-segregated!

Conclusion: We have the theory

Coexisting species must differ
in their way of regulation!

- Niche space: set/list of regulating variables.
- Niche of a species: impact and sensitivity.
- Robustness of coexistence is lost when either the impact, or the sensitivity niches are too similar.
- Intuitive requirement for niche segregation by niche width prevails as a rule of thumb.
- Self-organized similarity and niche-neutrality are wrong concepts.

Thanks for the coworkers!

- István Czibula
- Mats Gyllenberg (University of Helsinki)
- Éva Kisdi (University of Helsinki)
- Hans Metz (University of Leiden)
- Kalle Parvinen (University of Turku)
- Péter Szabó (Szent István University)
- András Szilágyi (Eötvös University)

Thanks for your attention!