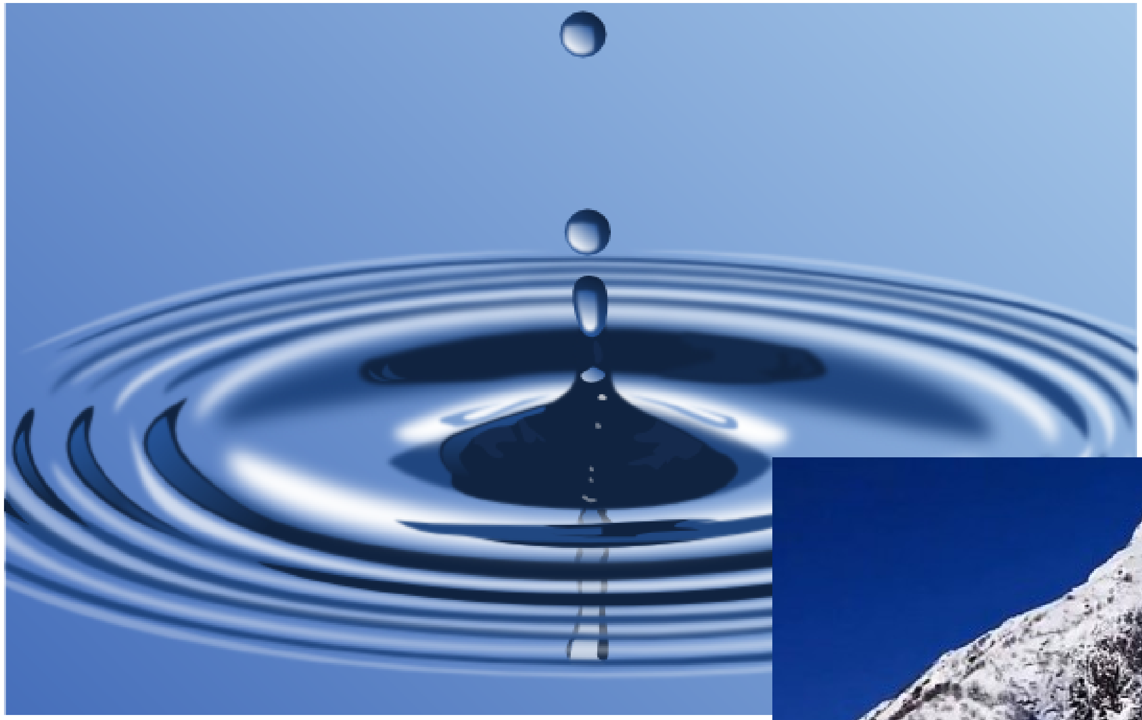
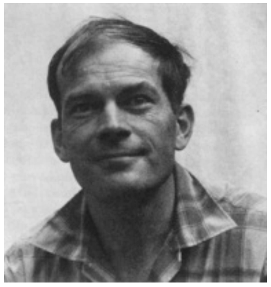
The trophic coherence of food webs and its effects on stability, feedback loops and motifs

Samuel Johnson (Warwick);
Virginia Domínguez-García, Luca Donetti &
Miguel A. Muñoz (Granada);
Nick S. Jones (Imperial College London);
Janis Klaise (Warwick).

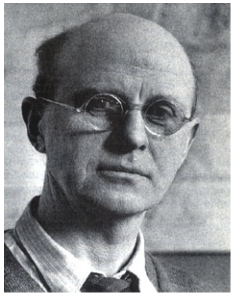
Stability



Diversity vs. Stability



R. H. MacArthur (1955); C. S. Elton (1958)



“simple communities are more easily upset than […] richer ones; that is, more subject to destructive oscillations in populations, and more vulnerable to invasions.”

R. May (1972): Diversity destabilises community dynamics!

“That stability may usually go with complexity in the natural world, but not usually in general mathematical models, is not really paradoxical. In nature we deal not with arbitrary complex systems, but rather with ones selected by a long and intricate process.”

Linear stability

$$\left.\begin{aligned} \mathbf{x}(t) &= \mathbf{x}^* + \zeta(t) \\ \frac{d}{dt}\zeta(t) &= \mathbf{Df}(\mathbf{x}^*)\zeta(t) \end{aligned}\right\} \qquad R = Re(\lambda_{max})$$

R = Degree of self-regulation required for system to be stable.

$$R \sim \sqrt{SC} \qquad\qquad SC = K$$

letters to nature

Nature **238**, 413 - 414 (18 August 1972); doi:10.1038/238413a0

Will a Large Complex System be Stable?

ROBERT M. MAY*

Long debate

Science | AAAS

Stability and Diversity of Ecosystems
Anthony R. Ives, *et al.*
Science **317**, 58 (2007);
DOI: 10.1126/science.1133258

NATURE | VOL 405 | 11 MAY 2000 | www.nature.com

insight review articles

The diversity–stability debate

Kevin Shear McCann

Ecology, 77(2), 1996, pp. 350–363
© 1996 by the Ecological Society of America

BIODIVERSITY: POPULATION VERSUS ECOSYSTEM STABILITY[1]

David Tilman

Vol 449 | 4 October 2007 | doi:10.1038/nature06154 — nature

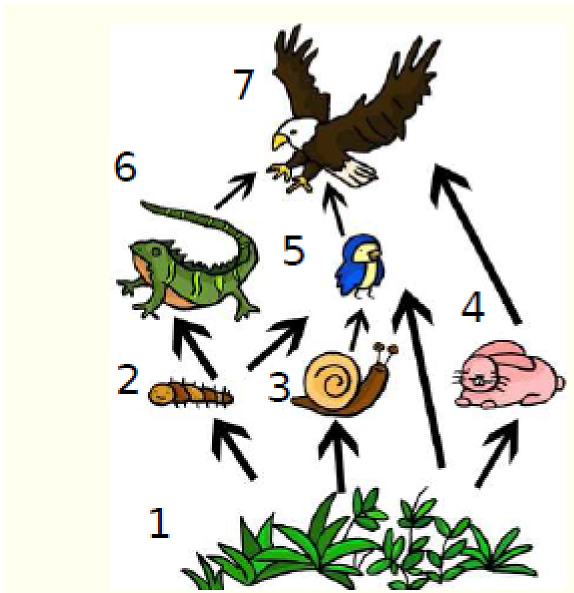
LETTERS

Reconciling complexity with stability in naturally assembling food webs

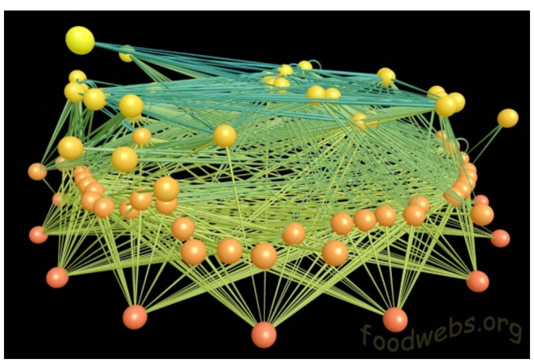
Anje-Margriet Neutel[1]†, Johan A. P. Heesterbeek[2], Johan van de Koppel[3], Guido Hoenderboom[4], An Vos[5], Coen Kaldeway[5], Frank Berendse[6] & Peter C. de Ruiter[5,7]

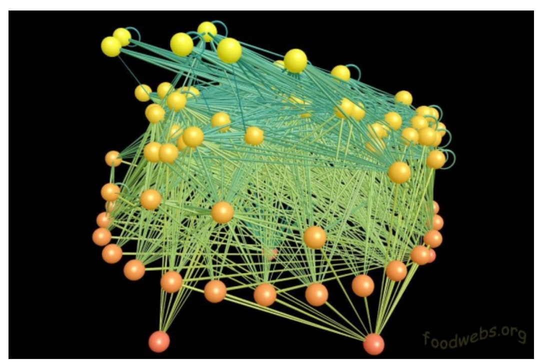


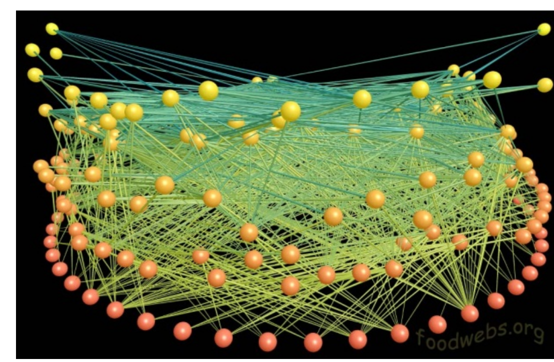

© Alamy

$$
\begin{pmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 1 & 1 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 1 & 1 & 0
\end{pmatrix}
$$







www.foodwebs.org

Dynamics

$$\frac{d}{dt}x_i = \eta \sum_j a_{ij} F(x_i, x_j) - \sum_j a_{ji} F(x_j, x_i) + G(x_i)$$

⬇

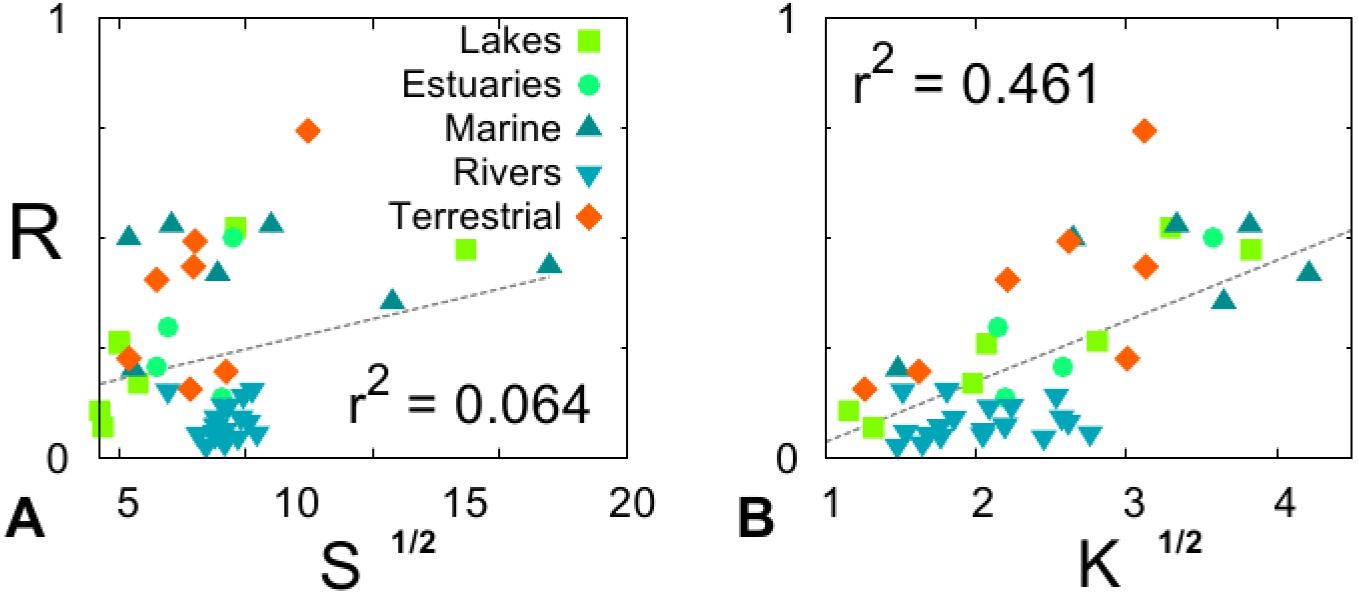
$$W = \eta A - A^T$$

⬇

$$R = Re(\lambda_{max})$$

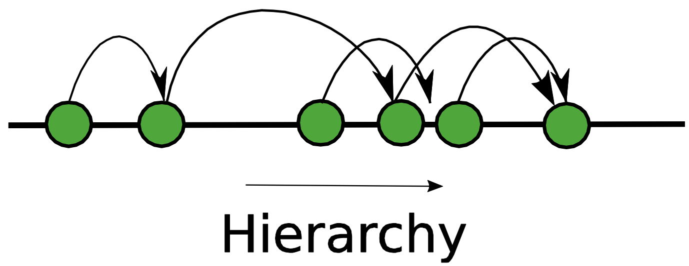
No complexity-stability relationship in natural communities

Claire Jacquet[1], Charlotte Moritz[1,2], Lyne Morissette[2], Pierre Legagneux[1], François Massol[3], Phillippe Archambault[2], and Dominique Gravel[1]

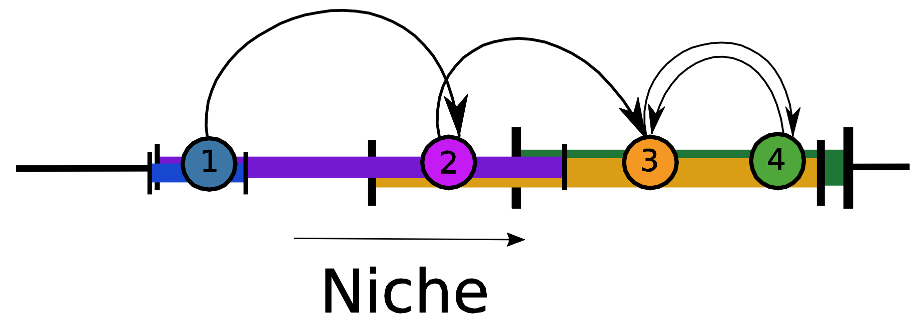


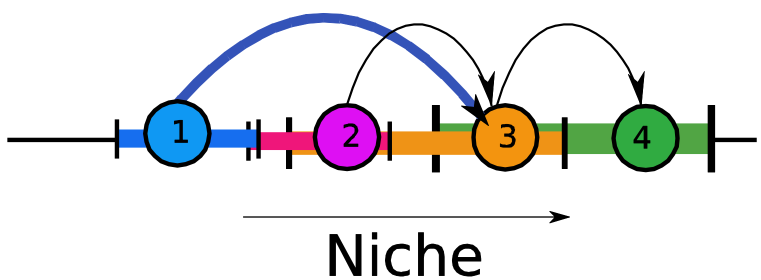
Structural food-web models

Cohen & Newman (1985)
Cascade Model



Williams & Martinez (2000)
Niche Model





Stouffer *et al.* (2005)
Generalised Niche Model

Science AAAS

Generalized Models Reveal Stabilizing Factors in Food Webs
Thilo Gross, *et al.*
Science **325**, 747 (2009);
DOI: 10.1126/science.1173536

The probabilistic niche model reveals substantial variation in the niche structure of empirical food webs

Richard J. Williams[1] and Drew W. Purves
Microsoft Research, 7 J J Thomson Avenue, Cambridge CB3 0FB United Kingdom

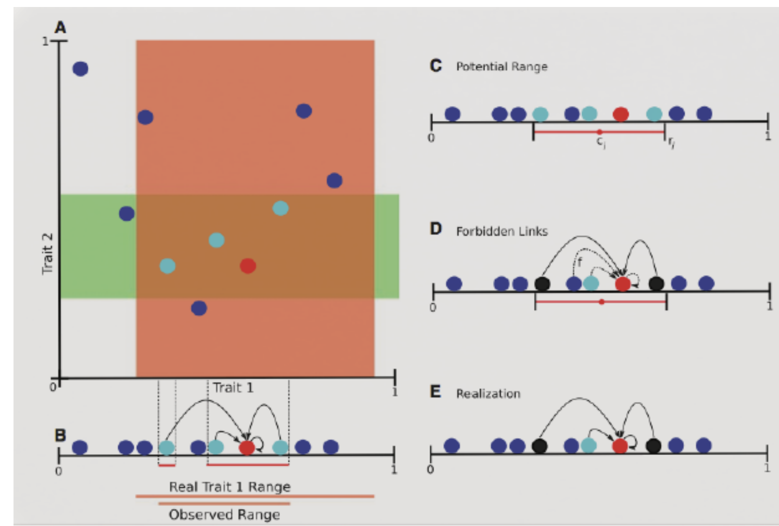
Structural food-web models

More niche-based models...

Minimum Potential Niche Model

Science AAAS

A General Model for Food Web Structure
Stefano Allesina, *et al.*
Science **320**, 658 (2008);
DOI: 10.1126/science.1156269



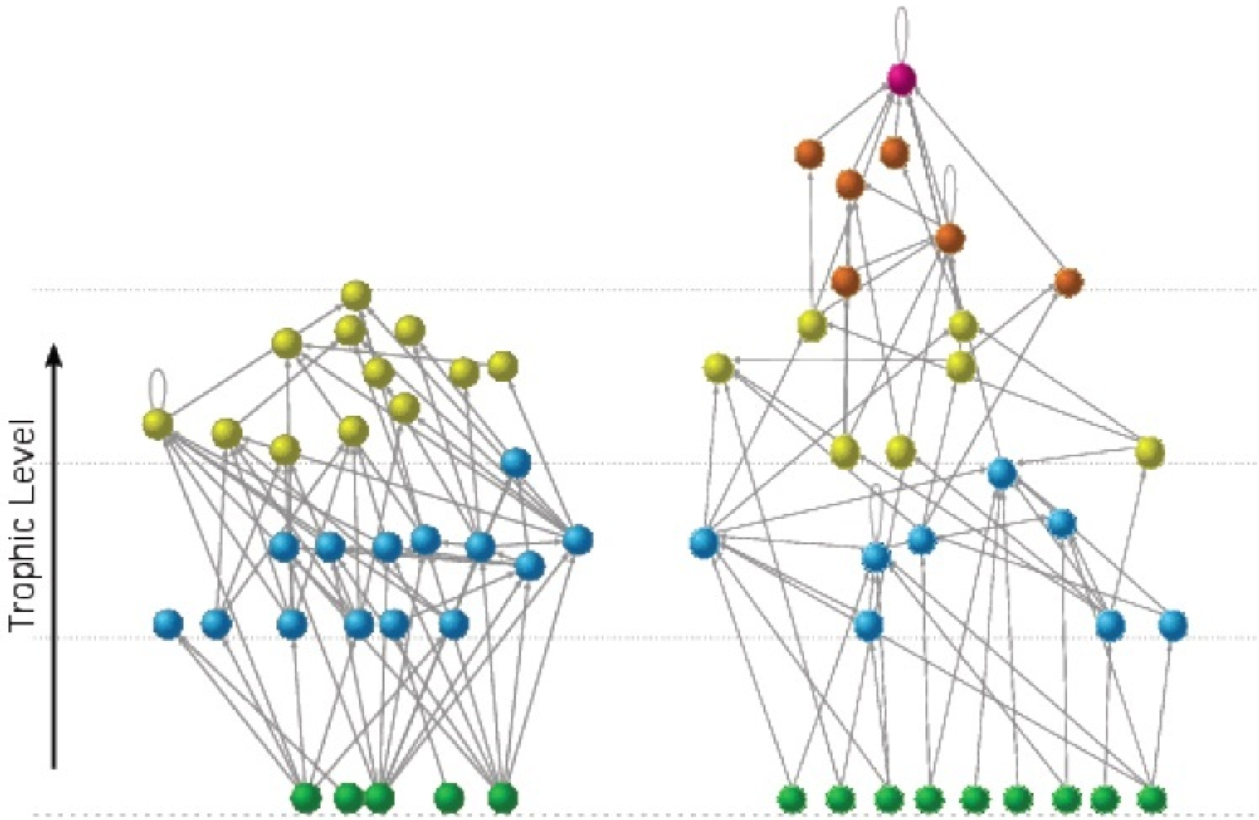
Phylogenetic constraints and adaptation explain food-web structure

Marie-France Cattin[1], Louis-Félix Bersier[1,2], Carolin Banašek-Richter[1], Richard Baltensperger[3] & Jean-Pierre Gabriel[3]

Nested Hierarchy Model

Structural food-web models

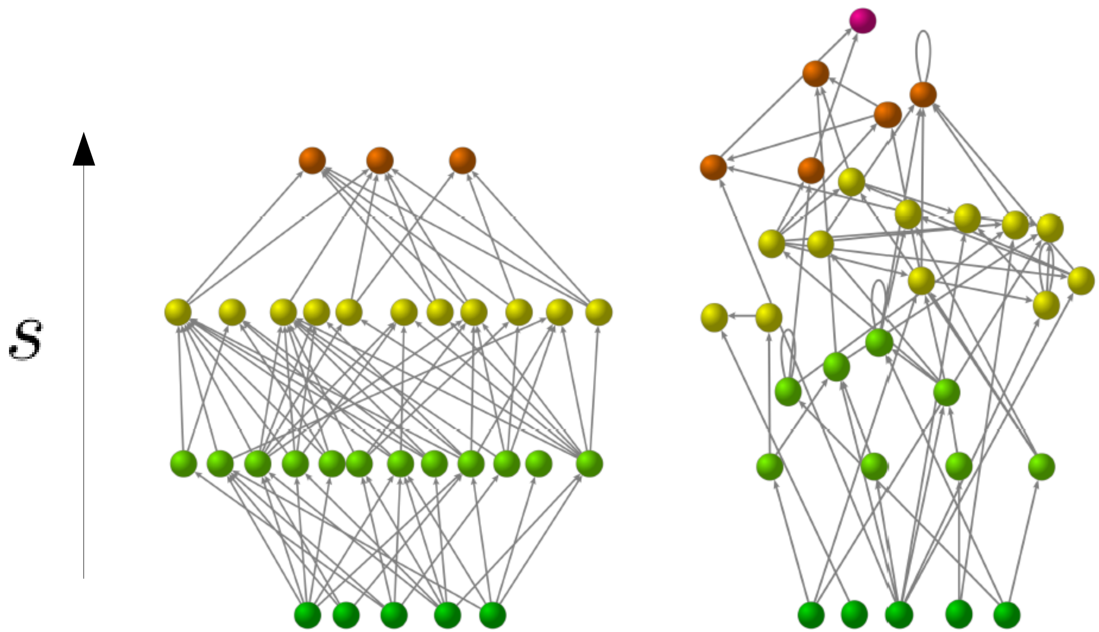
Structural food-web models



Chesapeake Bay

Minimum Potential
Niche Model

Trophic coherence



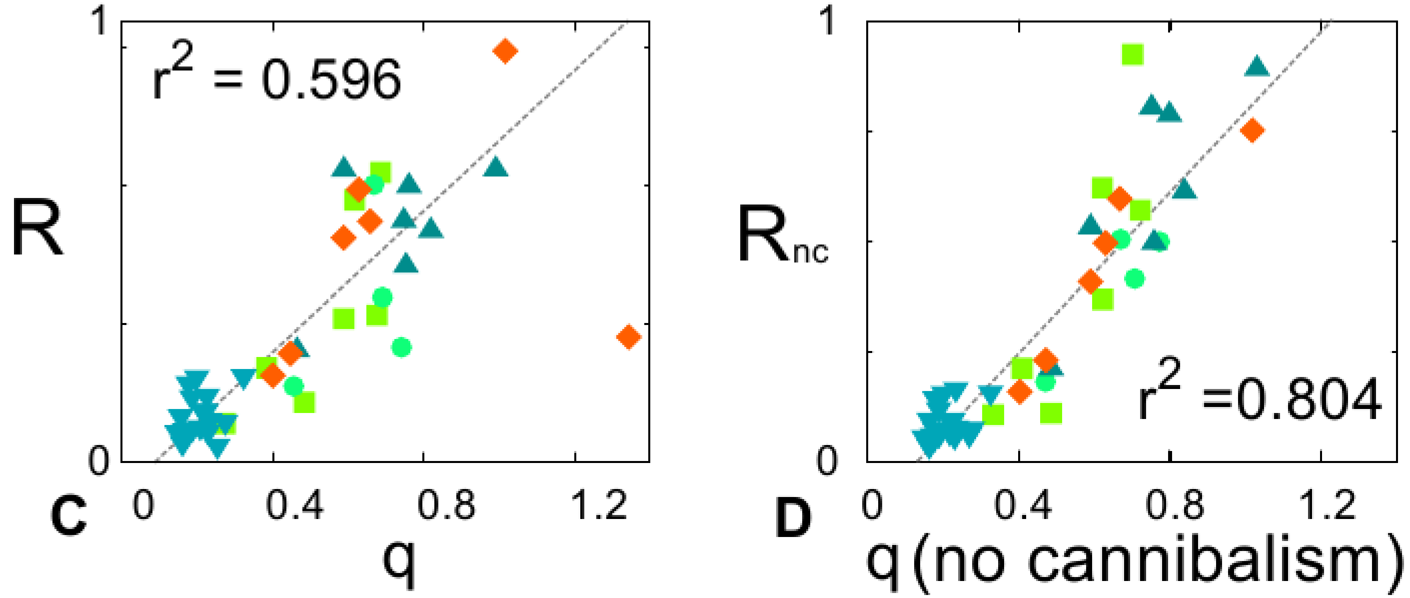
$q = 0$ $\qquad$ $q = 0.7$

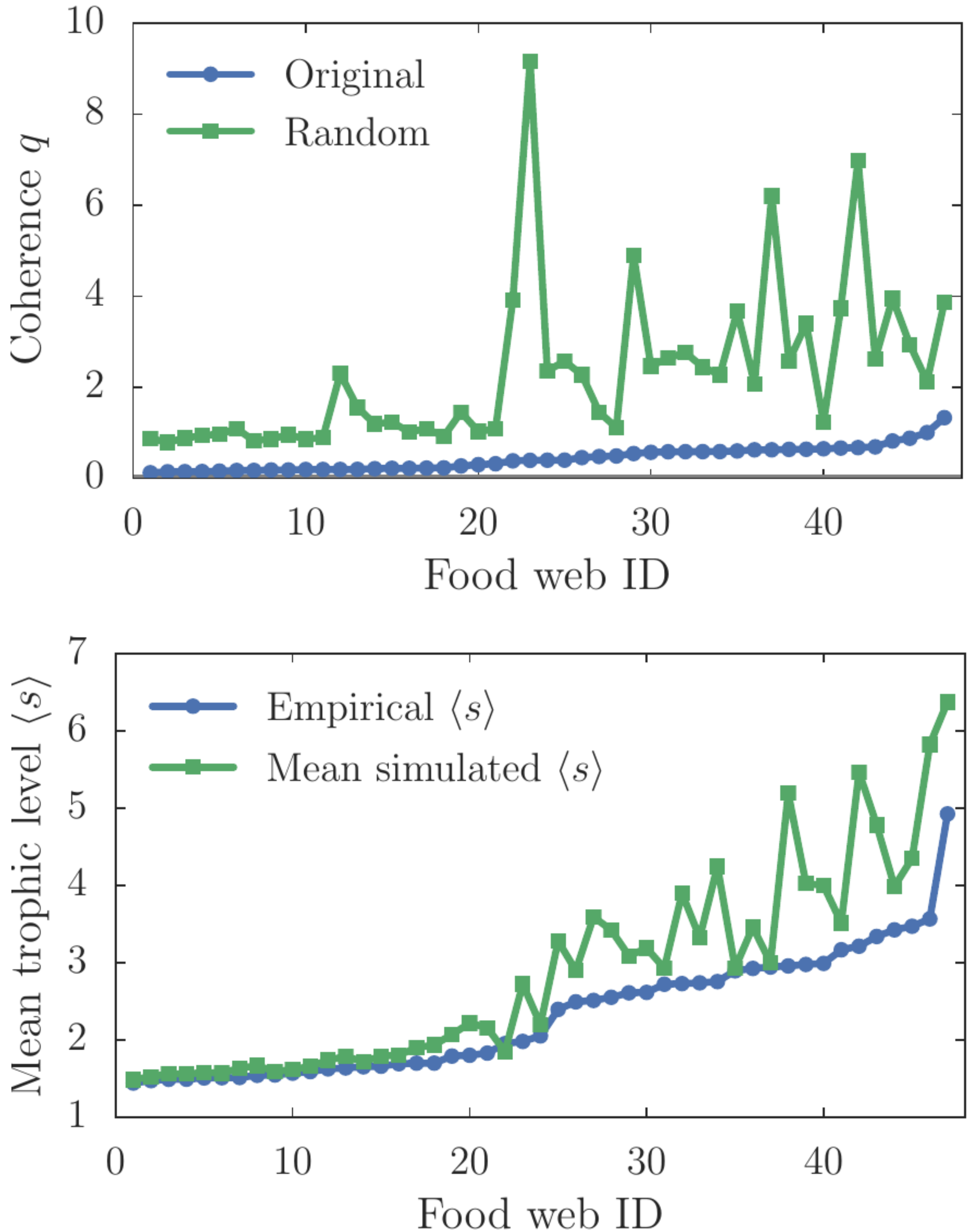
$$s_i = 1 + \frac{1}{k_i^{in}} \sum_j a_{ij} s_j$$

$$x_{ij} = s_i - s_j$$

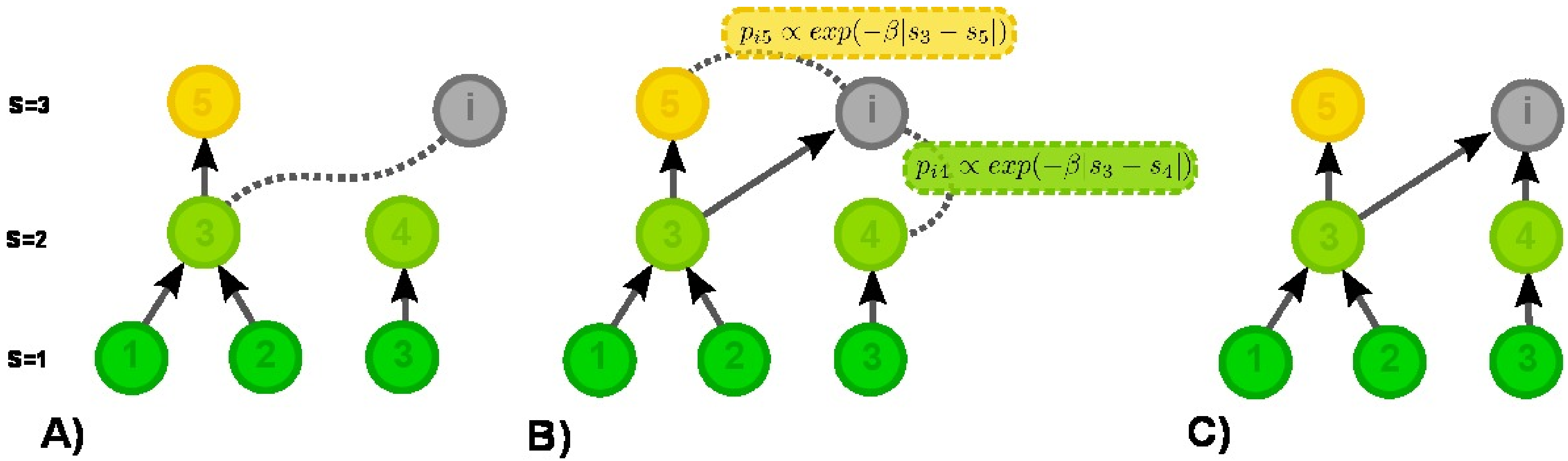
$$p(x) \begin{cases} \langle x \rangle = 1 \\ \sigma = q \end{cases}$$

Trophic coherence



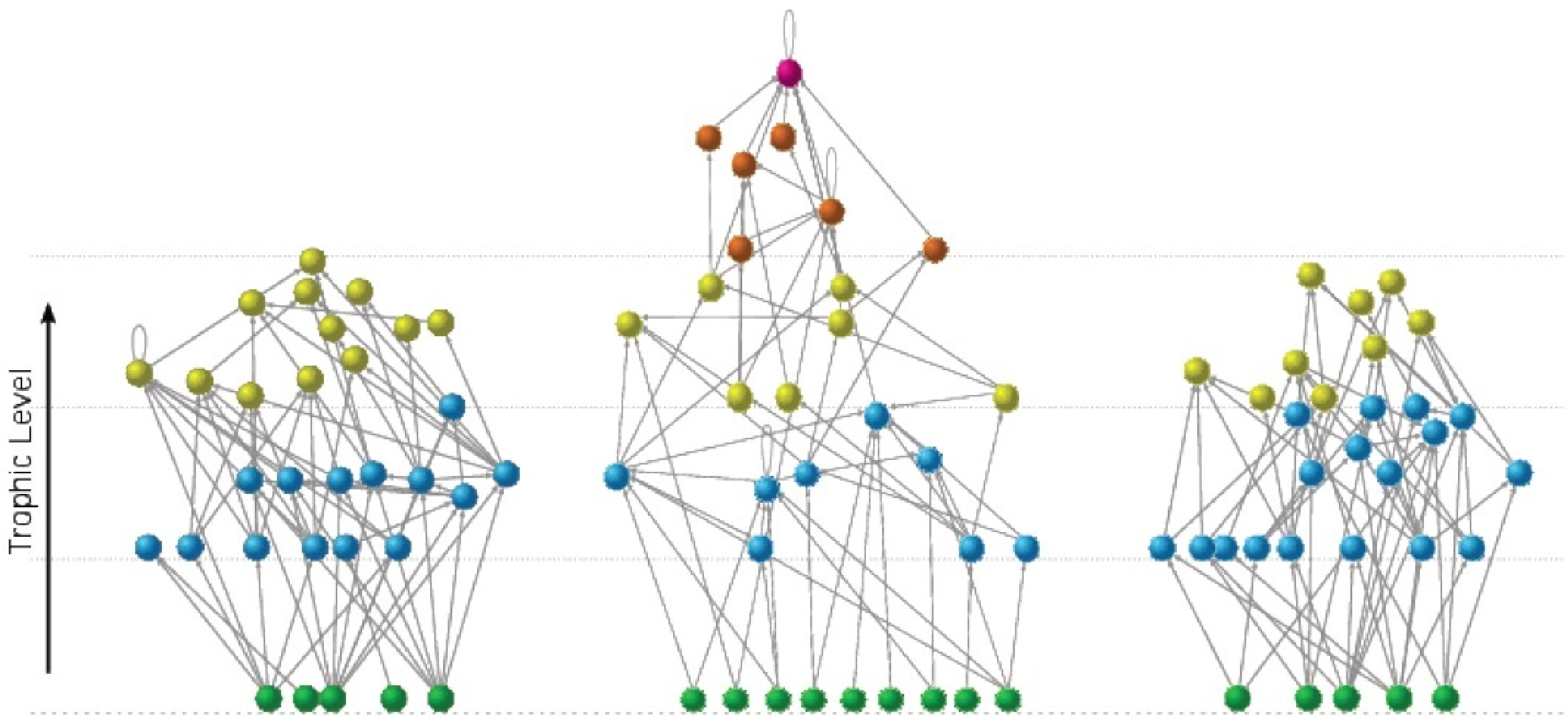

Original
Random
Coherence q
Food web ID
Empirical $\langle s \rangle$
Mean simulated $\langle s \rangle$
Mean trophic level $\langle s \rangle$
Food web ID

Preferential Preying Model



$$P_{il} \propto \exp\left(-\frac{|s_j - s_l|}{T}\right)$$

Preferential Preying Model

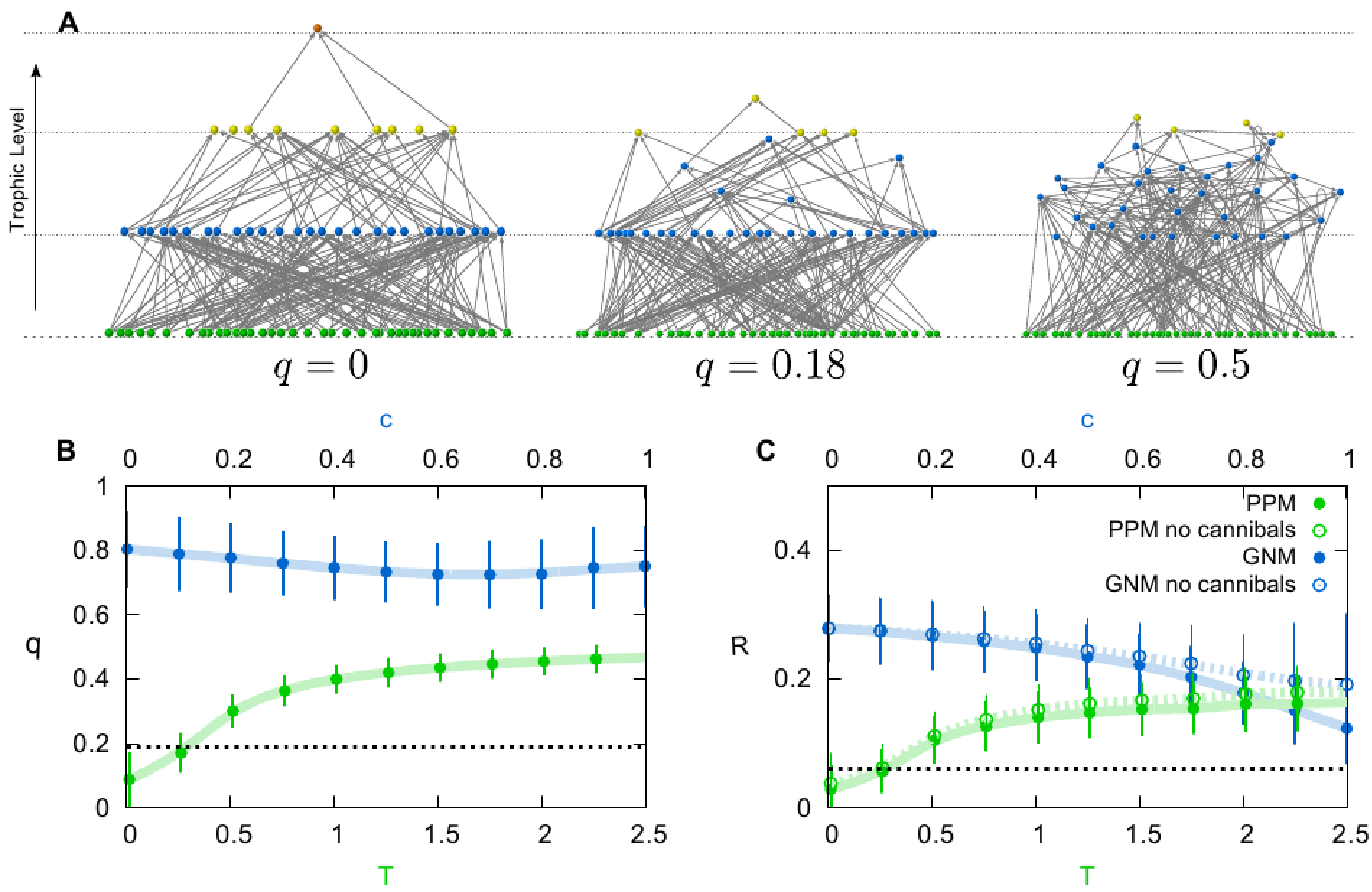


Chesapeake Bay

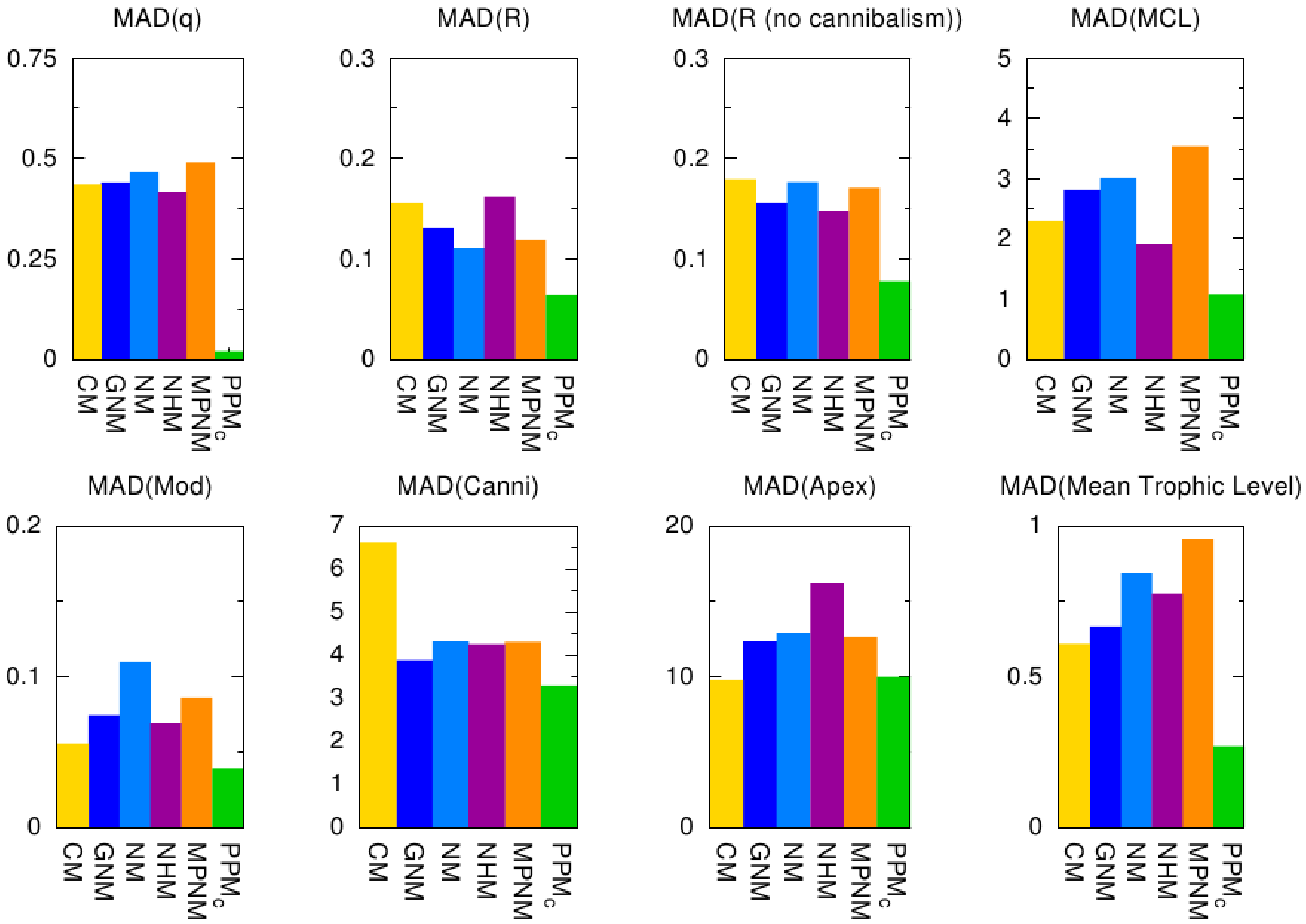
Minimum Potential Niche Model

Preferential Preying Model

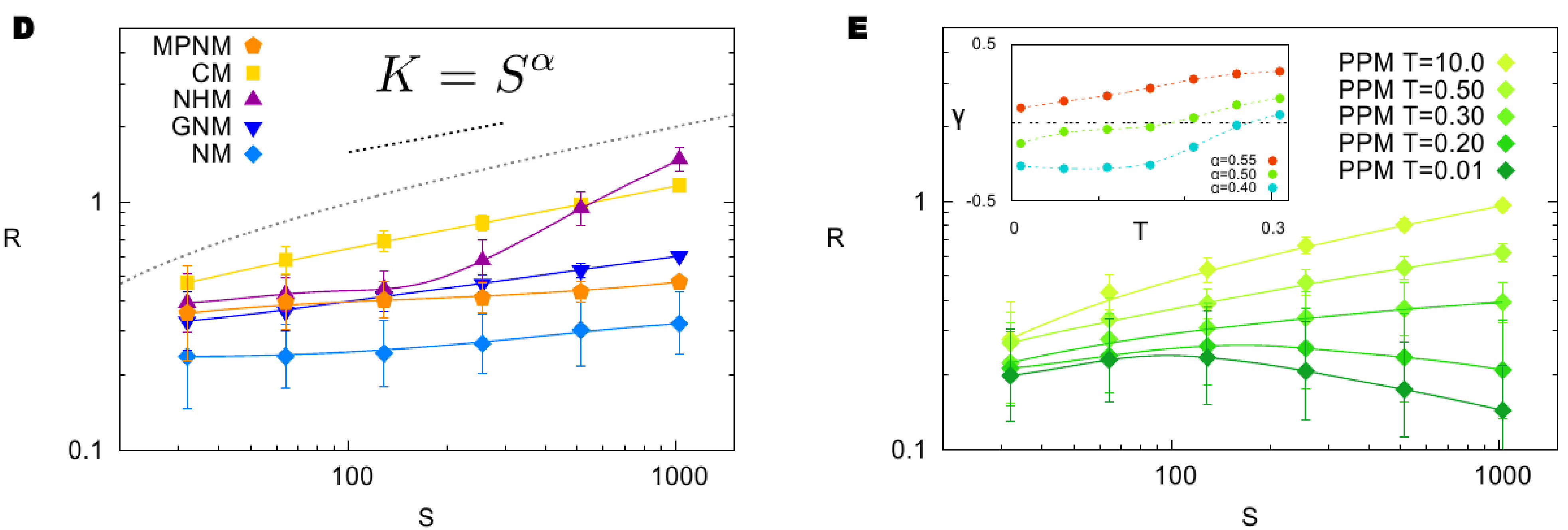
Preferential Preying Model



Preferential Preying Model

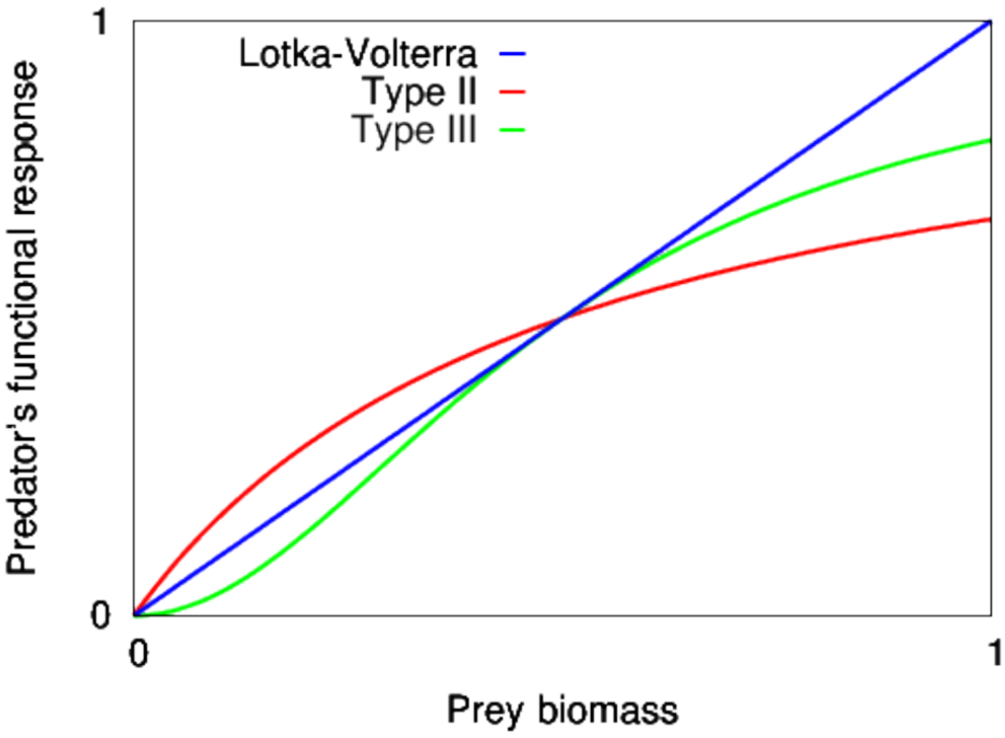


May's Paradox

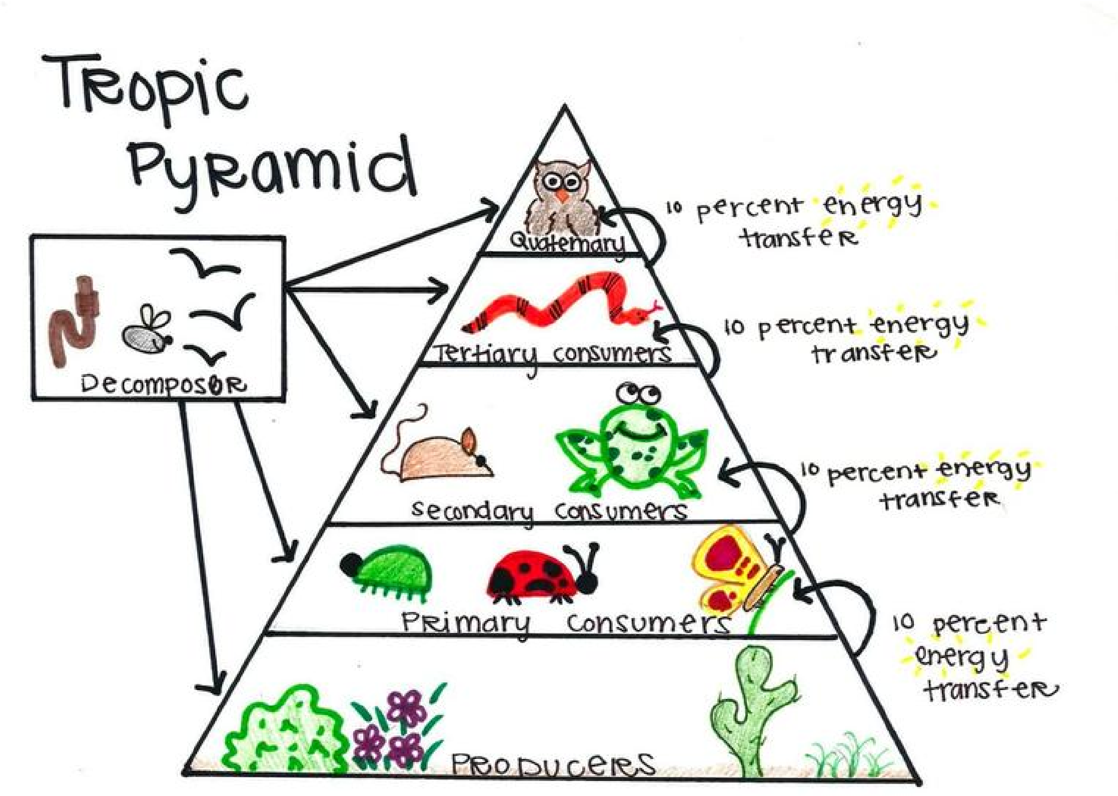


May's Paradox

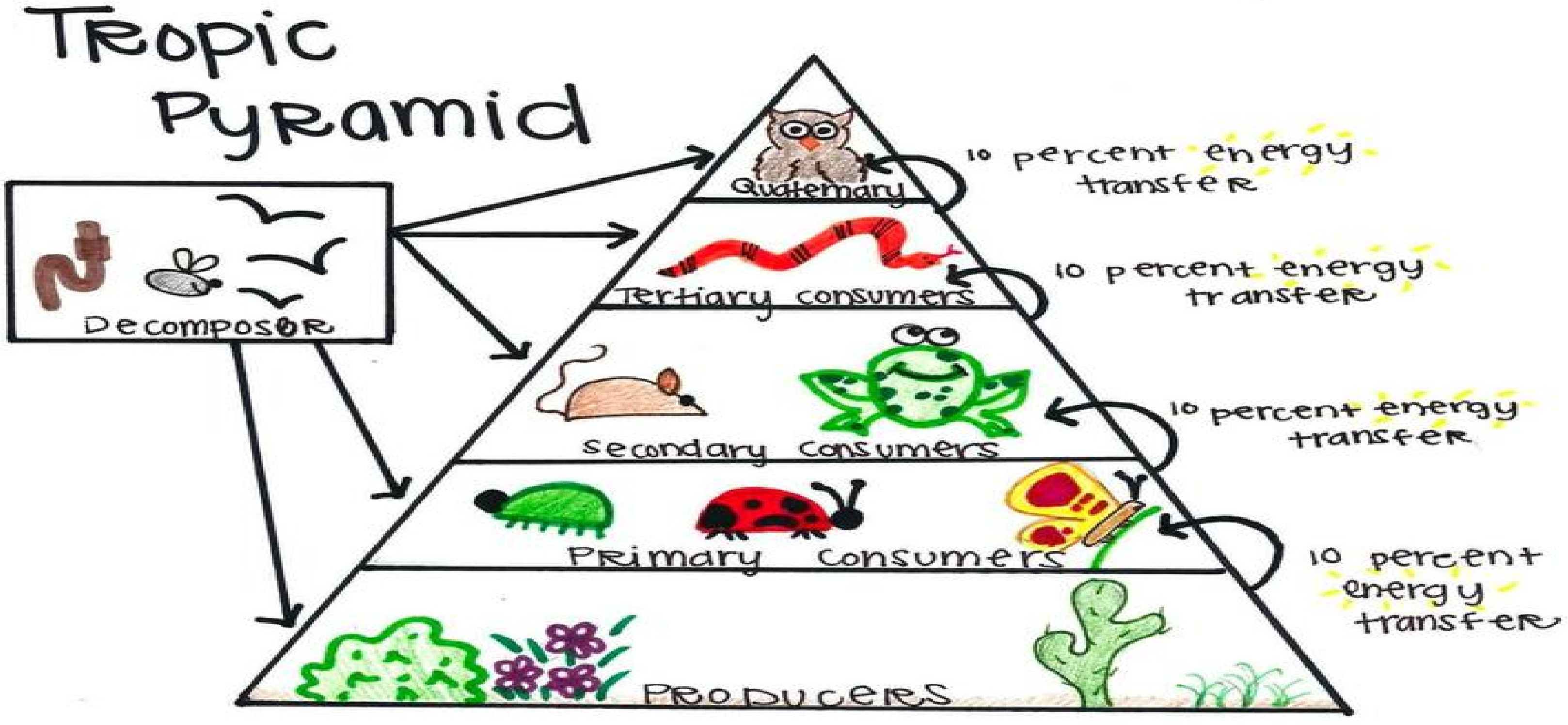
$$W = \eta A - A^T$$



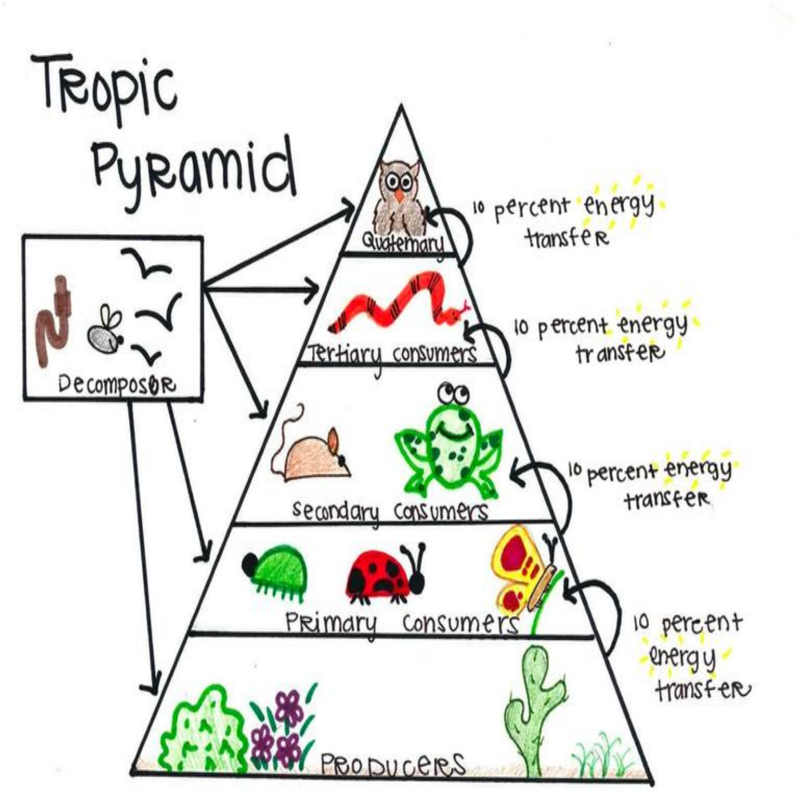
May's Paradox



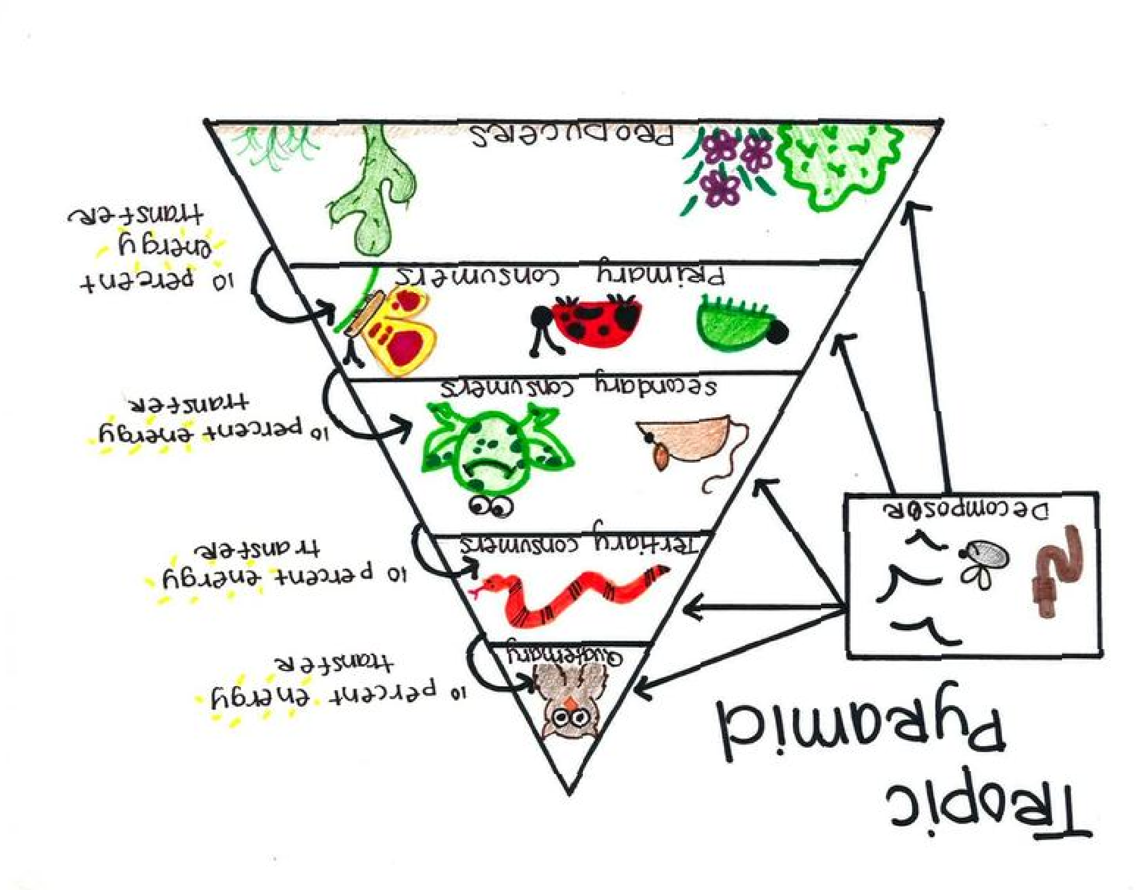
May's Paradox



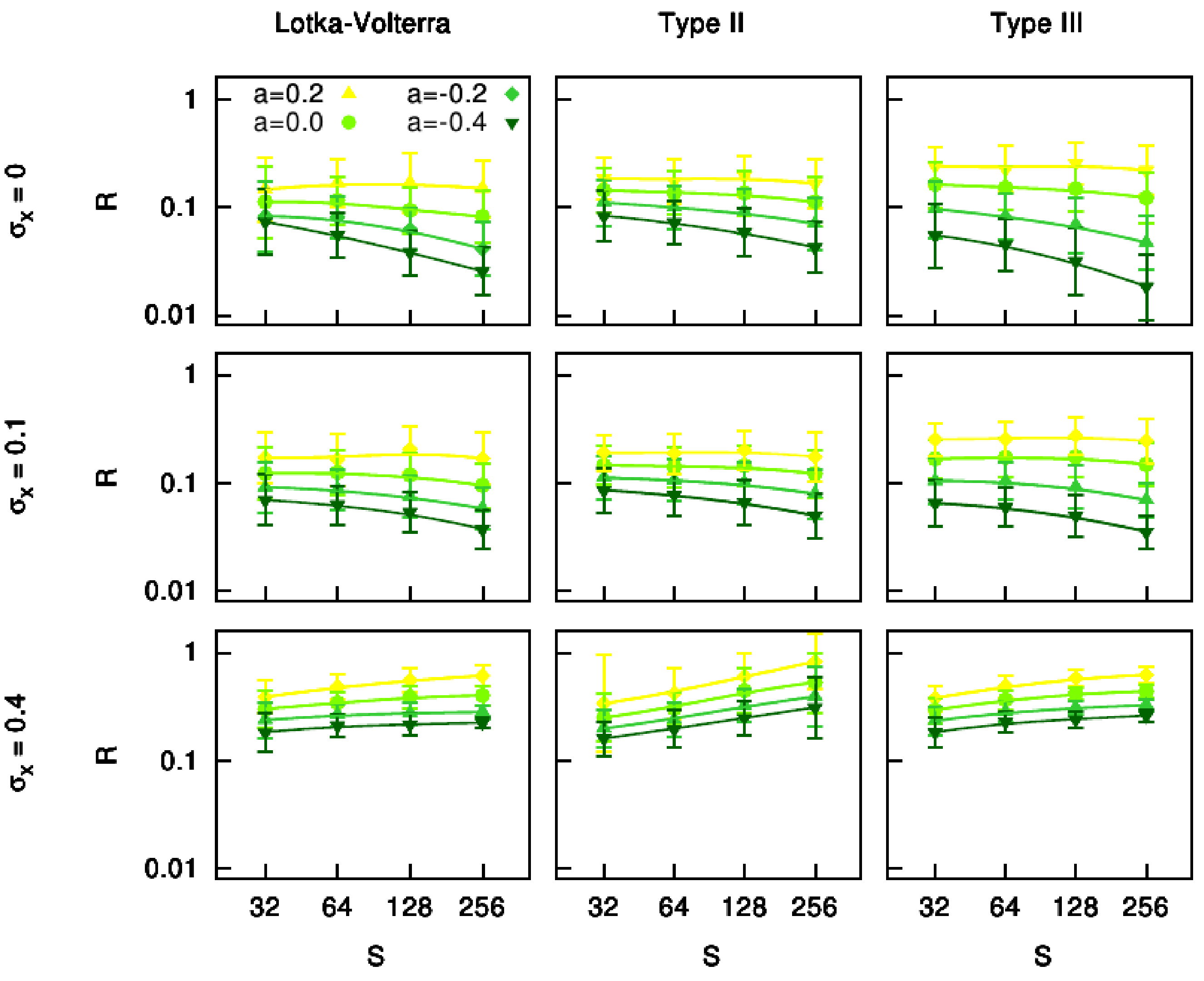
May's Paradox



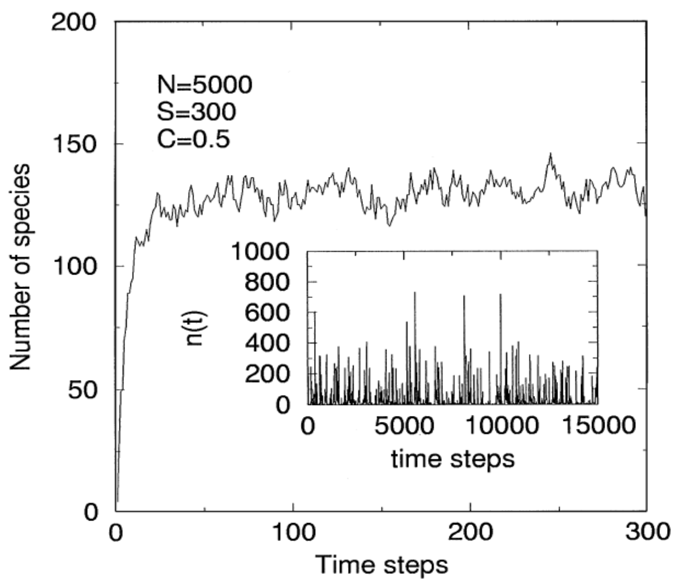
May's Paradox



May's Paradox

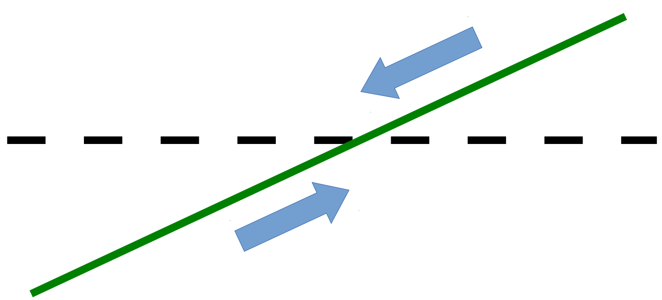


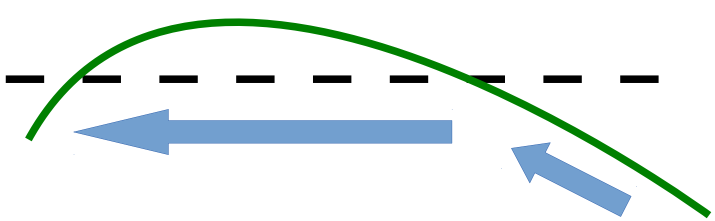
Tipping points



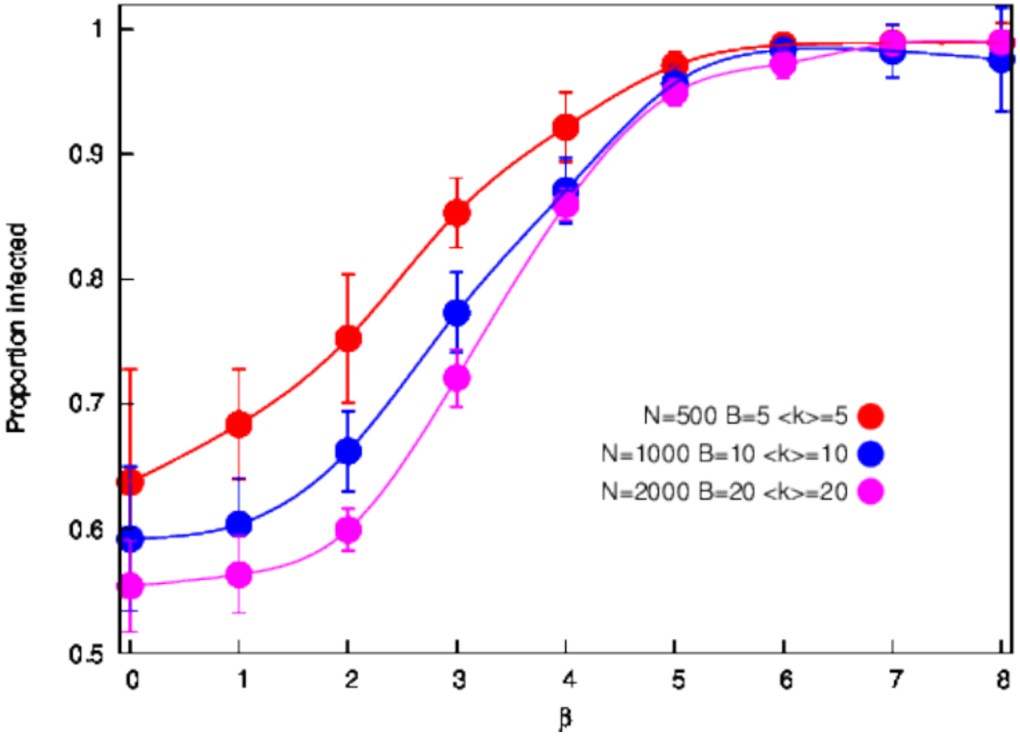
Scaling in a network model of a multispecies ecosystem

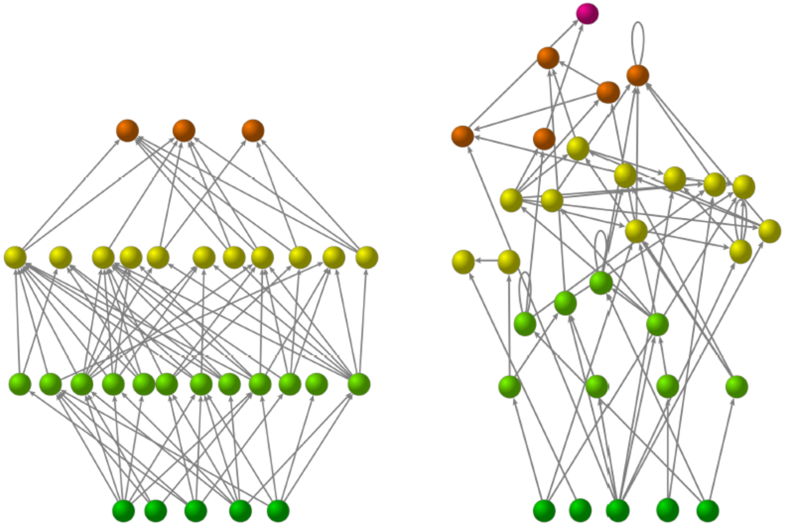
Ricard V. Solé[a,b,*], David Alonso[a,c], Alan McKane[d]

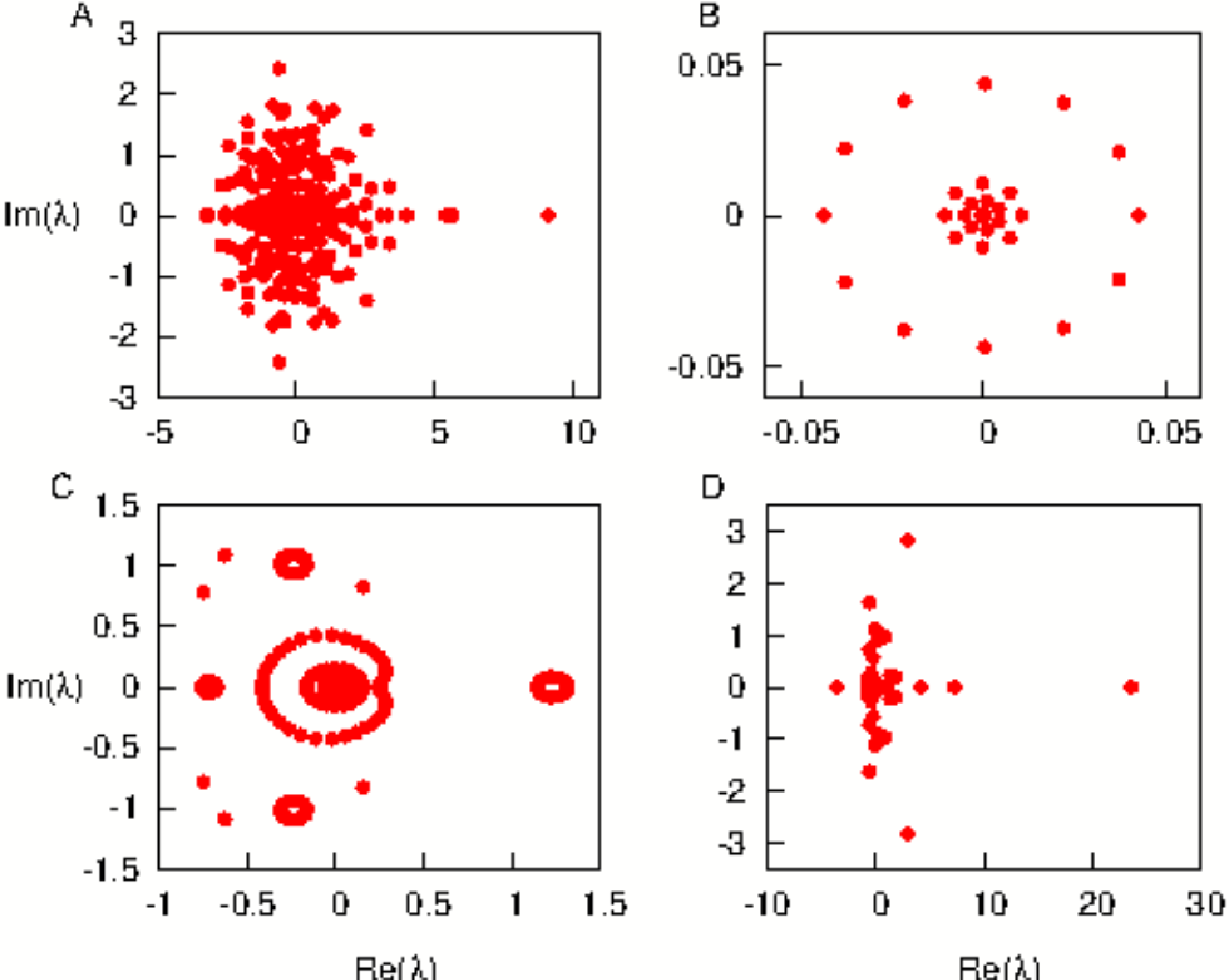




Spreading


Proportion infected
β
N=500 B=5 <k>=5
N=1000 B=10 <k>=10
N=2000 B=20 <k>=20
0.5
0.6
0.7
0.8
0.9
1
0
1
2
3
4
5
6
7
8




A
B
C
D
Im(λ)
Re(λ)
3
2
1
0
-1
-2
-3
-5
0
5
10
0.05
0
-0.05
1.5
1
0.5
-0.5
-1
-1.5
-10
20
30

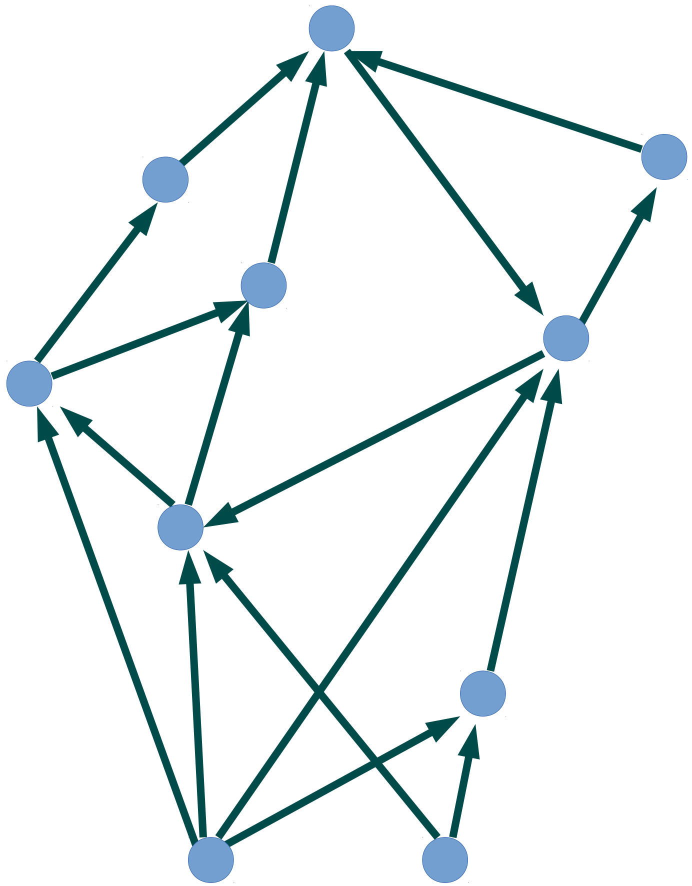
Cycles and spectra

$$\langle \lambda^\nu \rangle = \frac{1}{N} \mathrm{Tr}(A^\nu)$$

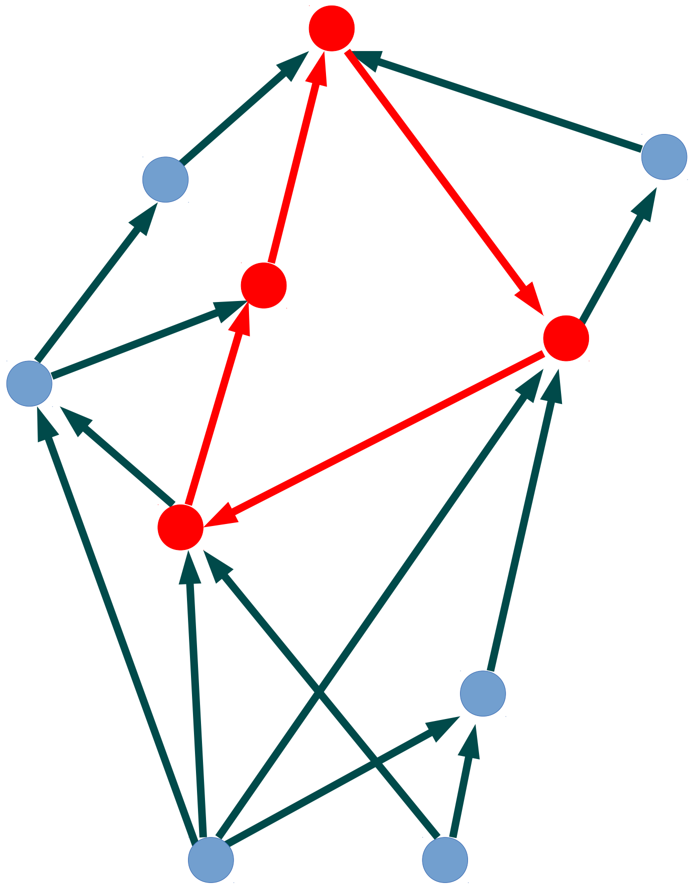
$$\tilde{q} = \sqrt{\frac{N}{B} - 1}$$

Coherence ensemble: $\{\boldsymbol{k}^{in}, \boldsymbol{k}^{out}, q\}$

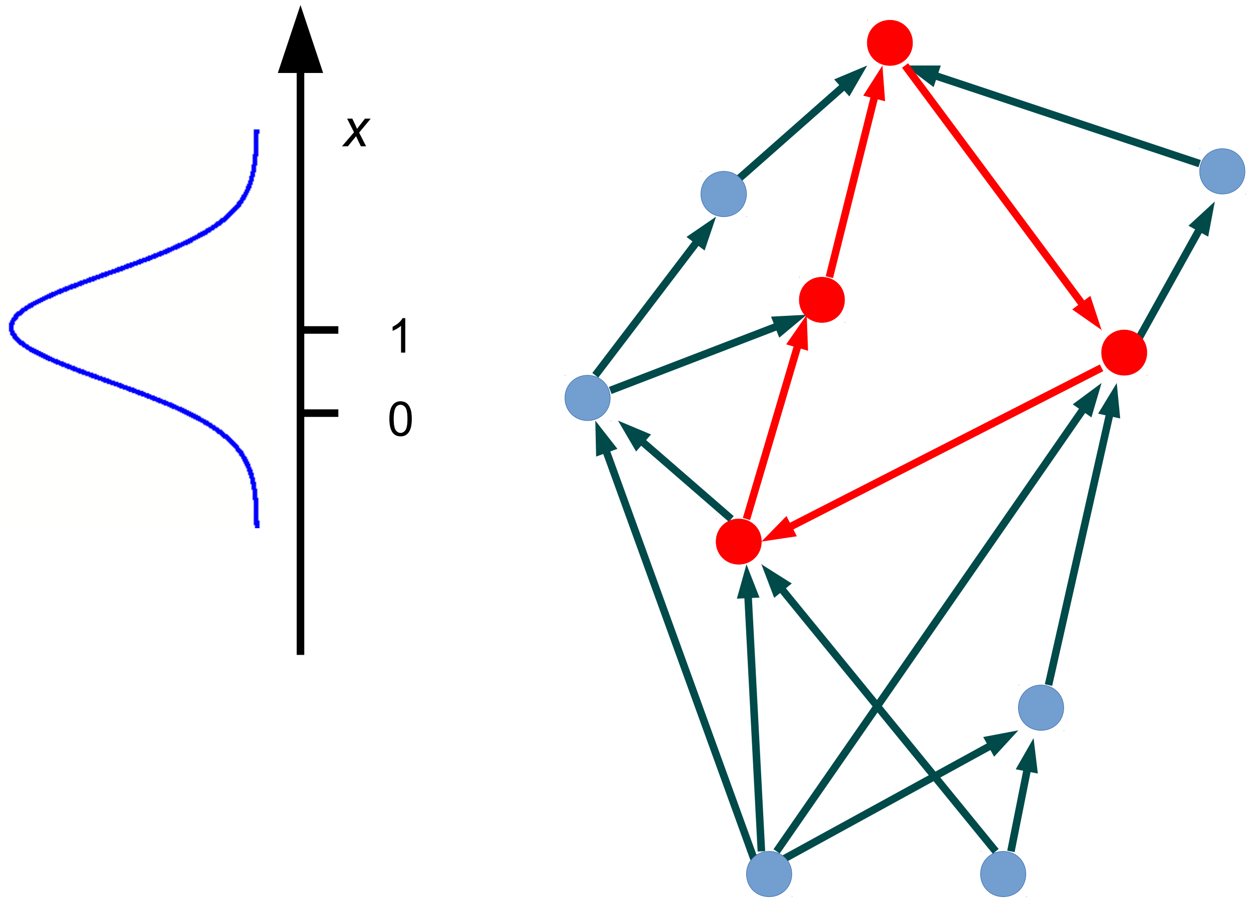
Cycles and spectra



Cycles and spectra



Cycles and spectra



Cycles and spectra

$$\overline{m}_{\nu} = \frac{\tilde{q}}{q} e^{\tau \nu}$$

$$\tau = \ln \alpha + \frac{1}{2\tilde{q}^2} - \frac{1}{2q^2}$$

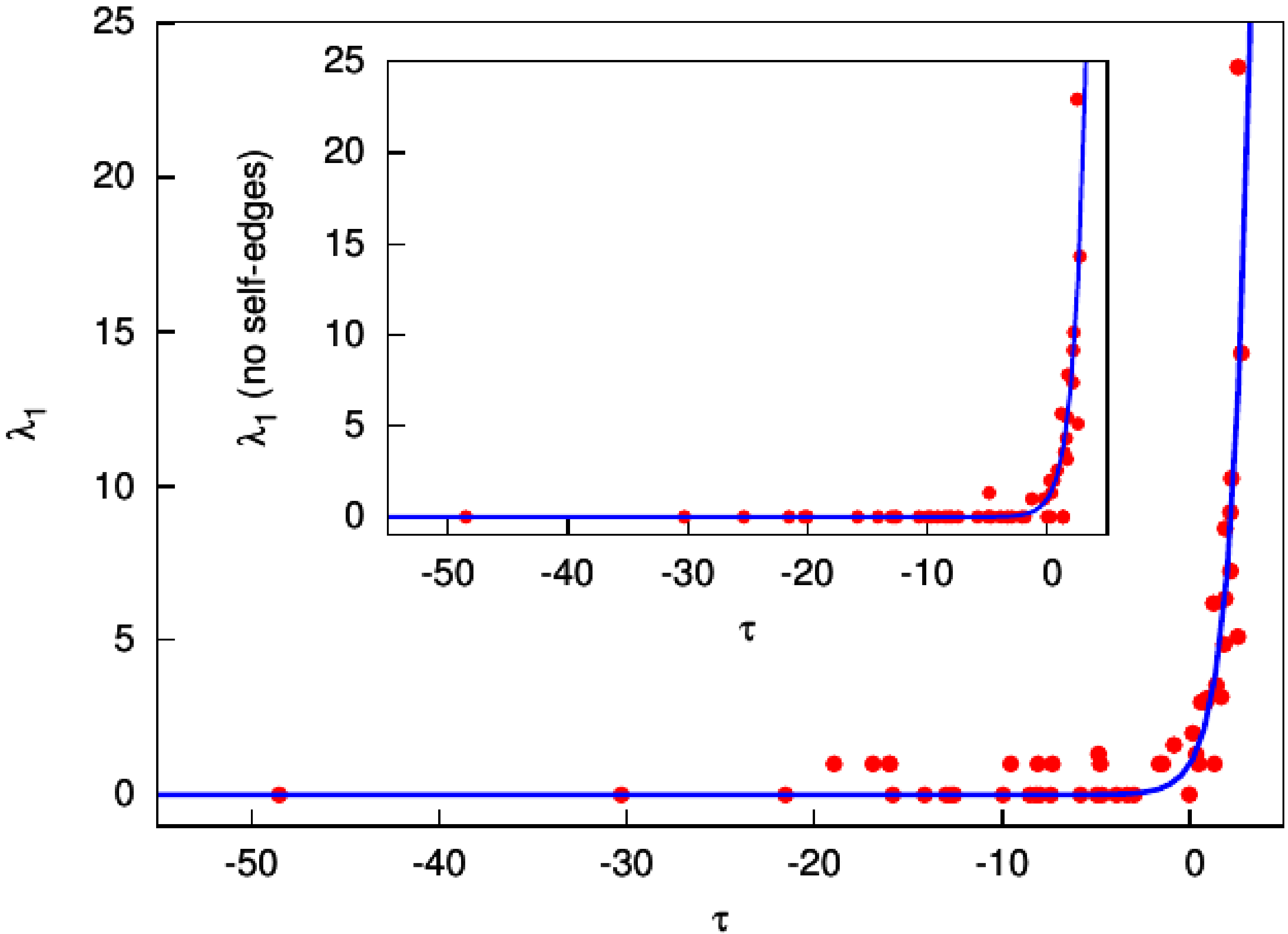
$$\alpha \equiv \frac{\langle k^{in} k^{out} \rangle}{\langle k \rangle}$$

Cycles and spectra

$$\overline{\langle \lambda^{\nu} \rangle} = \frac{1}{N} \frac{\tilde{q}}{q} e^{\tau \nu}$$

$$\overline{\lambda_1} = e^{\tau}$$

Cycles and spectra

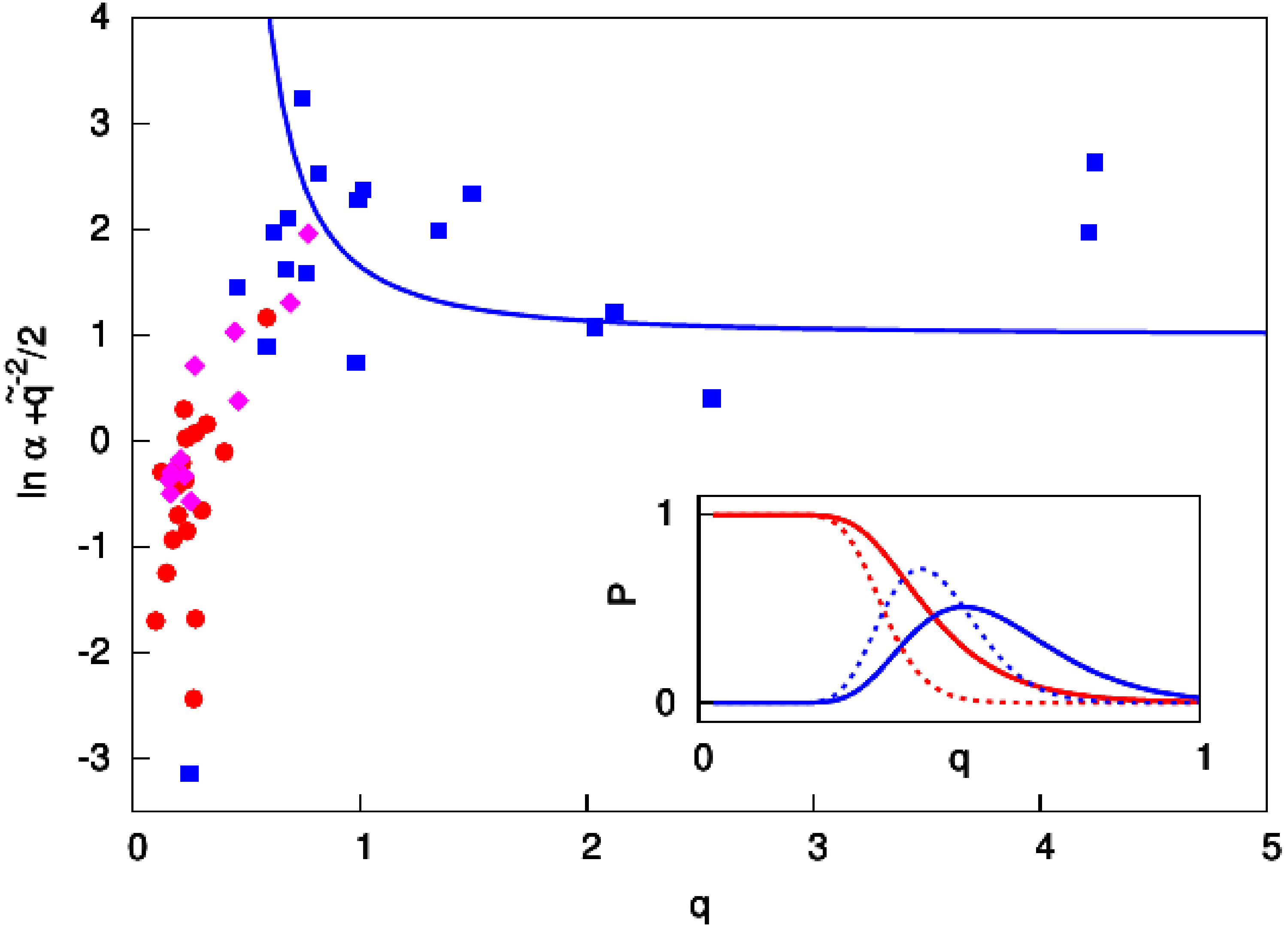


Cycles and spectra

$$P_{DAG} \simeq \exp\left[-\frac{\tilde{q}}{q}\frac{1}{(e^{-\tau}-1)}\right]$$

$$P_{OSC} \simeq \exp\left[-\frac{\tilde{q}}{q}\frac{e^{\tau}}{(e^{-\tau}-1)}\right] - P_{DAG}$$

Cycles and spectra



eLIFE
elifesciences.org

RESEARCH ARTICLE

Buffered Qualitative Stability explains the robustness and evolvability of transcriptional networks

Luca Albergante[1]*, J Julian Blow[1*†], Timothy J Newman[1,2*†]

[1]College of Life Sciences, University of Dundee, Dundee, United Kingdom; [2]School of Engineering, Physics and Mathematics, University of Dundee, Dundee, United Kingdom

Oikos 000: 001–006, 2015
doi: 10.1111/oik.02176

Subject Editor: Stefano Allesina. Editor-in-Chief: Dries Bonte. Accepted 20 January 2015

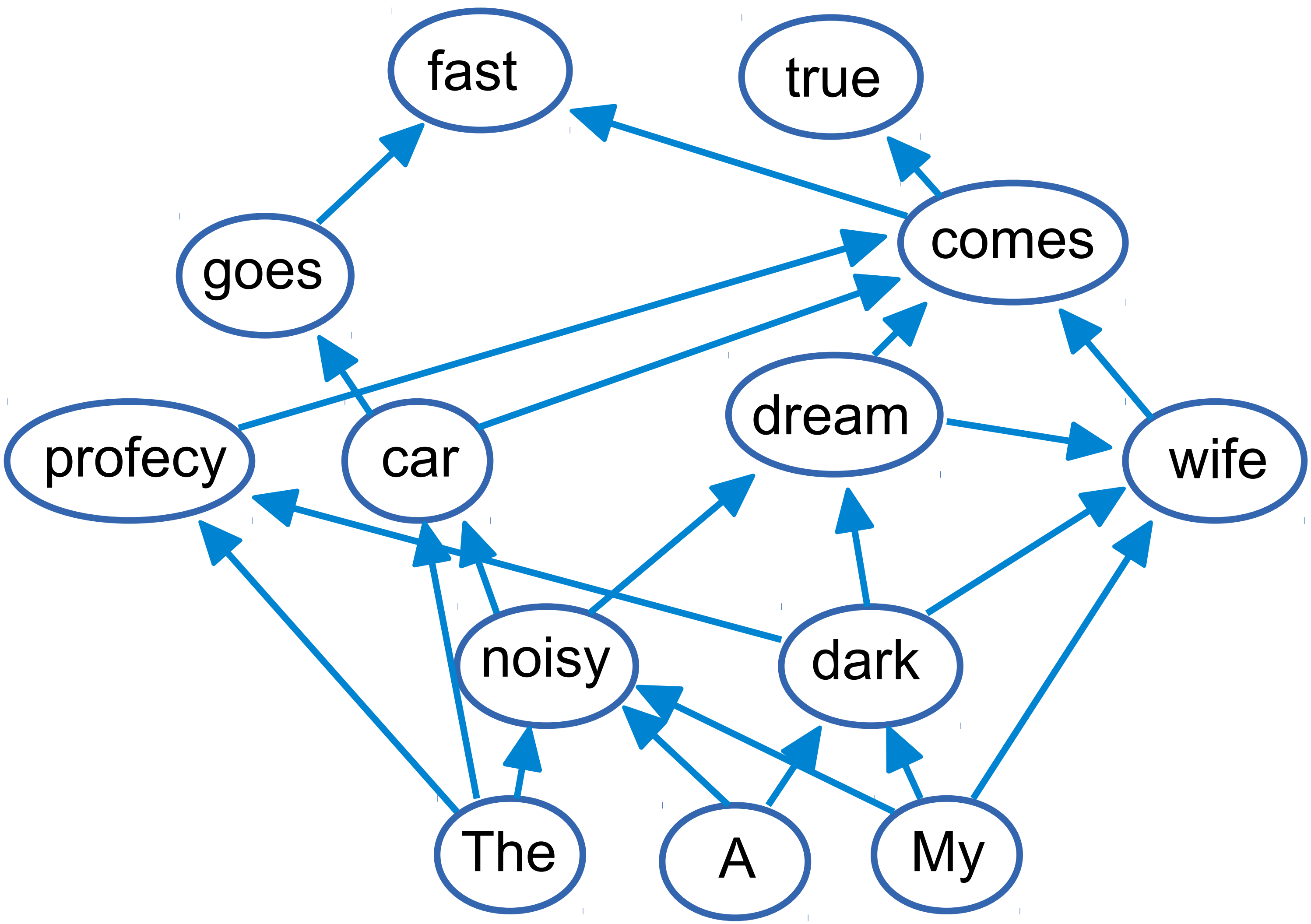
Selection against instability: stable subgraphs are most frequent in empirical food webs

Jonathan J. Borrelli

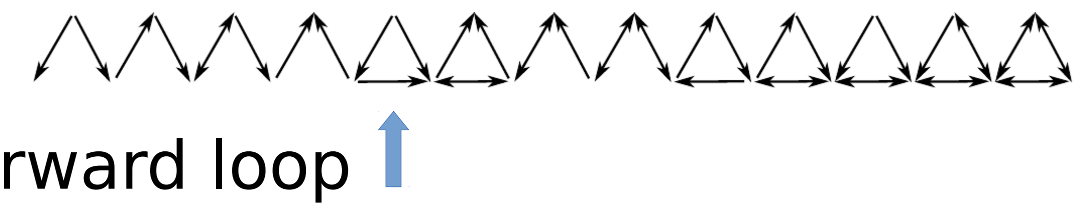
J. J. Borrelli (orcid.org/0000-0003-1700-8116)(jonathan.borrelli@stonybrook.edu), Dept of Ecology and Evolution, Stony Brook Univ., Stony Brook, NY 11794, USA.

No natural selection

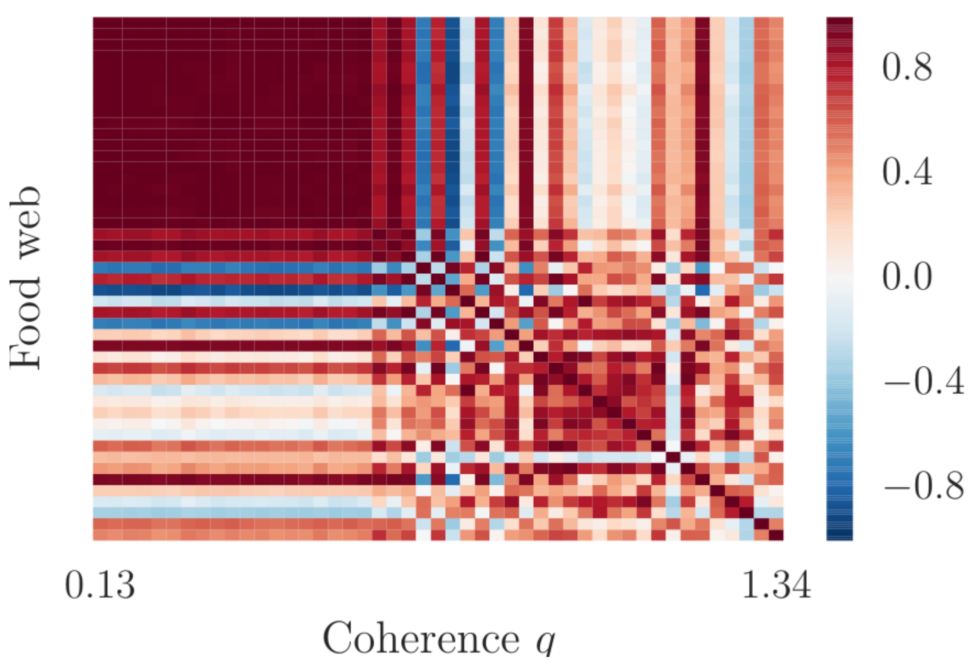
Why are networks coherent?

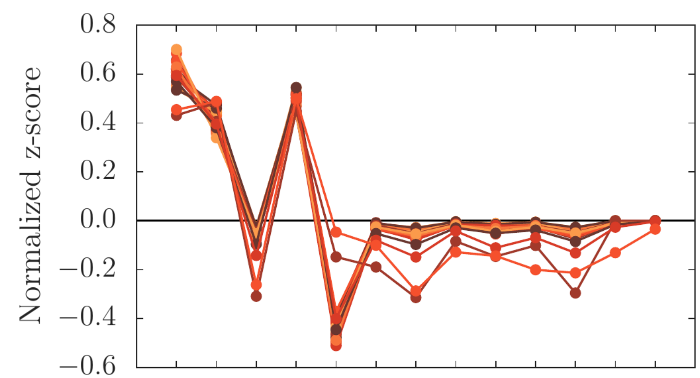


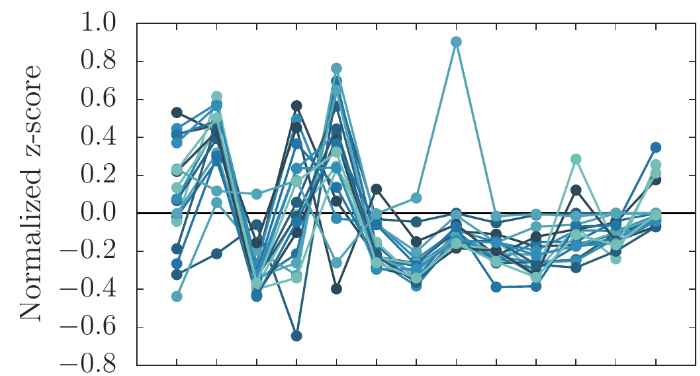
Motifs



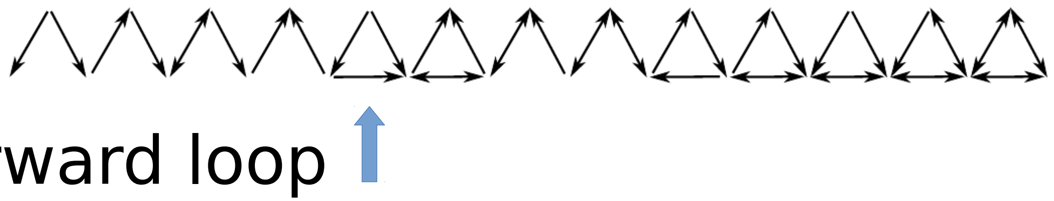
Feed-forward loop



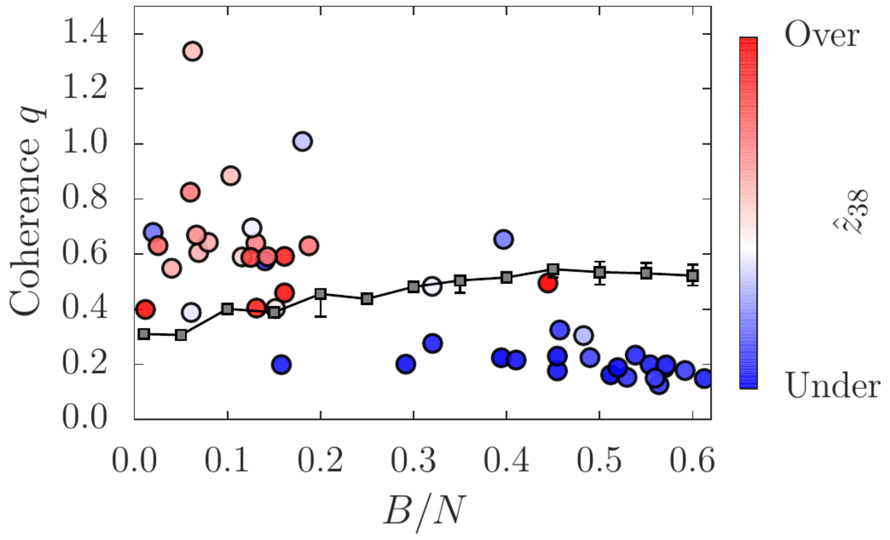


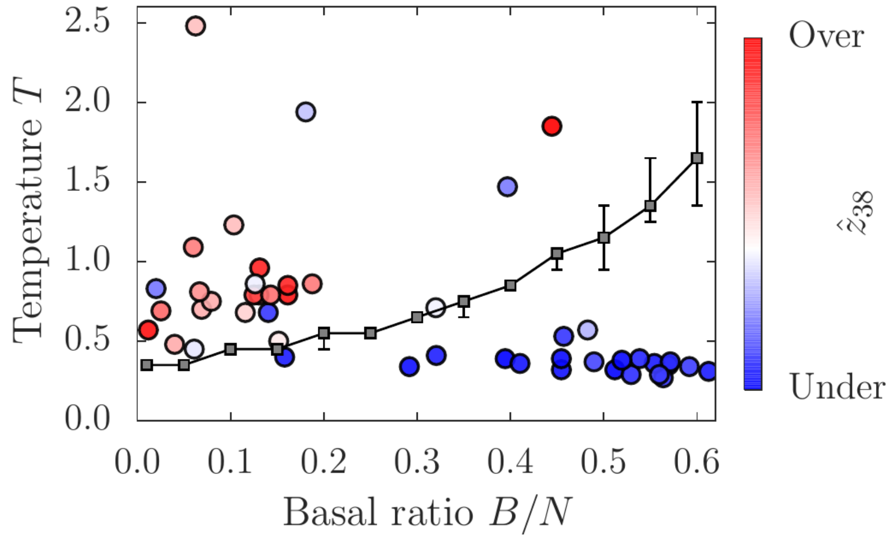


Motifs



Feed-forward loop





Conclusions

Preferential Preying Model better than niche-based models.

Trophic coherence key to:

- May's paradox, tipping points?, spreading phenomena?
- Cycle structure, eigenspectra, and motif signature of directed networks. Loopless and loopful regimes.
- Ubiquity of “qualitatively stable” systems

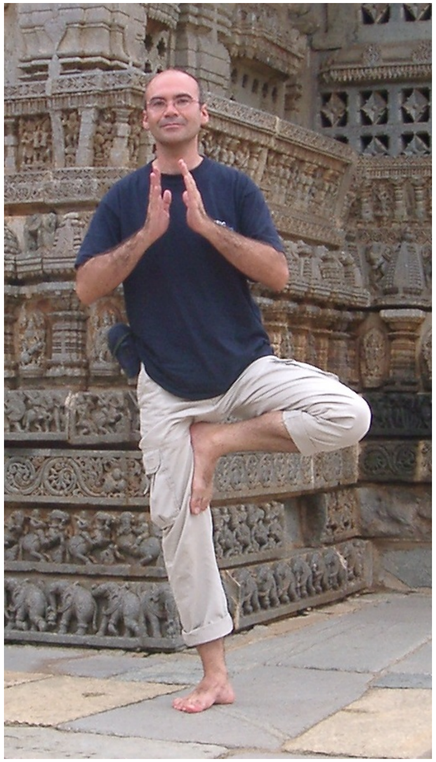
What mechanisms lead to trophic coherence?

More refined food-web model?

SJ, V Domínguez-García, L Donetti, MA Muñoz (2014) PNAS.

SJ & NS Jones (2015) arXiv:1505.07332

SJ & J Klaise, in preparation.



Miguel Ángel
Muñoz

Luca Donetti

Virginia Domínguez-García

Nick S. Jones

Janis Klaise

Thank you for your attention!!