Evolutionary Food Web Modelling

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Food Web Modelling Approaches

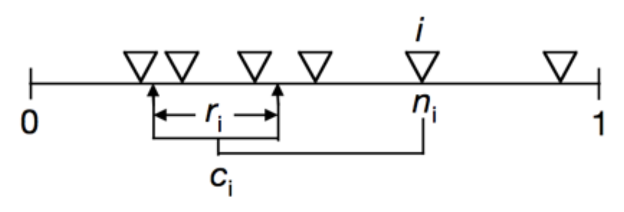


Diagram of the Niche Model
(Williams and Martinez 2000)

- Static, Statistical Models:
  - Cascade (Cohen 1985)
  - Niche (Williams and Martinez 2000)
    - Assigns species a one-dimensional niche (n_i), a feeding midpoint (c_i) beneath its niche value, and a feeding range (r_i).
  - Nested-Hierarchy (Cattin et al 2004)

- Community Assembly
  - Includes population dynamics (typically Lotka-Volterra).
  - Species are added to the model over time from a limited, fixed pool of species, with pre-defined trophic position.
  - E.g. Newman et al 1996, Morton and Law 1997, Drake 1990, Law 1999.

- Eco-Evolutionary Models
  - Evolutionary Niche Model (Guill and Drossel 2007)
  - Matching model (Rossberg 2006, 2008)
  - Yoshida 2003
  - Ito and Ikegami 2006

Eco-evolutionary Models with one continuous species characteristic: Body-Size

- Loeuille-Loreau (Loeuille and Loreau 2005):

$$\frac{\mathrm{d}N_i}{\mathrm{d}t} = N_i\left(- m(x_i) + f(x_i)\sum_{j=0}^{i-1}\gamma(x_i - x_j)N_i - \sum_{k=i+1}^{n}\gamma(x_k - x_i)N_k - \sum_{l=1}^{n}\alpha(|x_i - x_l|)N_l\right)$$

  - A single continuous trait, body mass, characterises a species and imposes a feeding hierarchy.
  - Mass-specific production efficiency *f*, mortality rate *m*, decrease with body size.
  - Linear functional response γ centred on prey a set distance 'below' the predator on the body-mass spectrum.
  - Interference competition α occurs between species of a similar size.
  - Speciation: the child has body size drawn within 20% of that of it's parent.

- Allhoff et al 2015
  - Three separately-evolving traits: body mass, preferred body mass of prey, and feeding range.

Webworld Model
(Drossel et al 2001)

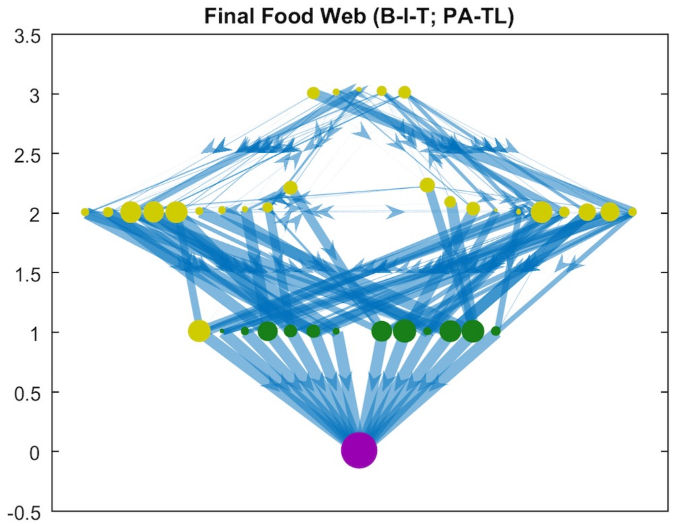
Start with a resource and one phenotype.

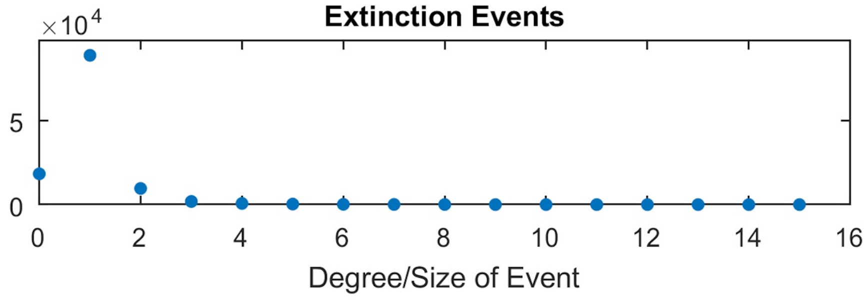
Species reproduce according to the balance equations:

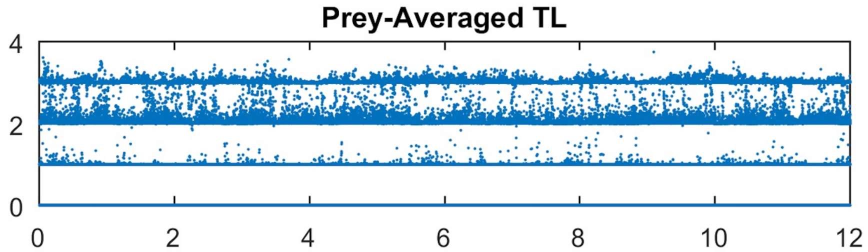
$$\frac{\mathrm{d}N_i}{\mathrm{d}t} = -N_i + \lambda \sum_{j=0}^{n} N_i g_{i,j}(t) - \sum_{k=1}^{n} N_k g_{k,i}(t)$$

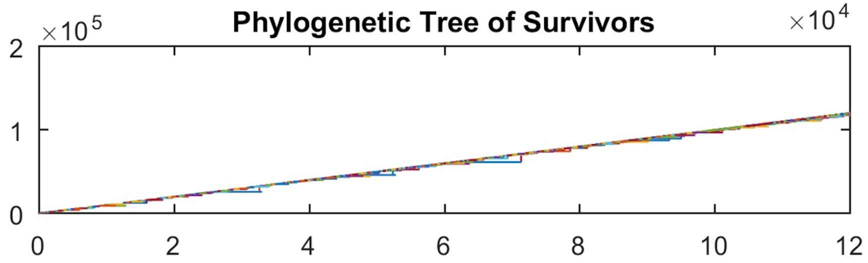
- Features:
  - Each species is defined by the 10 (out of 500 possible) binary traits that it possesses.
  - Uniform mortality and ecological efficiency λ.
  - Their binary trait strings determine the existence and strength of predator-prey interactions between species.
  - Ratio-dependent functional response g and adaptive foraging strategy with which it is consistent.
  - Speciation mechanism: the mutant child retains 9 of its parent's 10 traits, with the other randomly exchanged.

Webworld Model:
Reproduction of original results





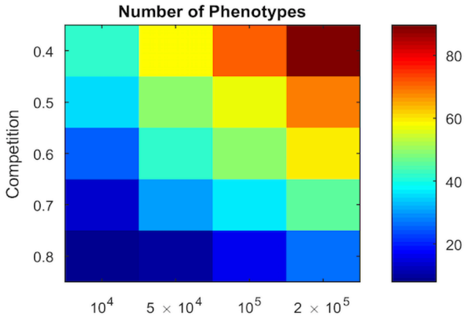


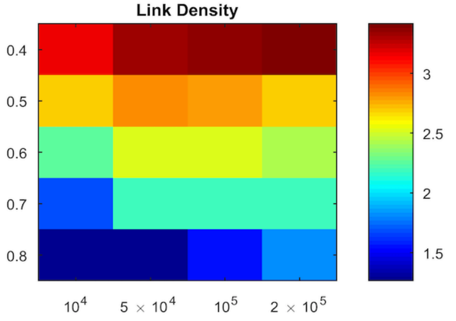


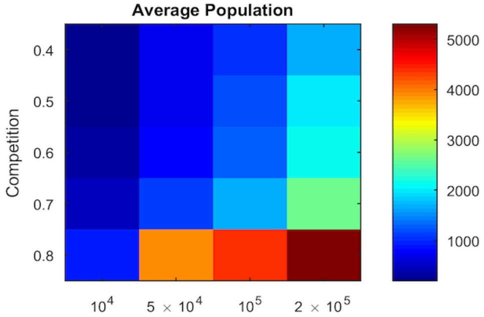
- Per-simulation data:
  - Phylogenetic tree of survivors shows turnover.
  - Frequency of extinction events.
  - Degree distribution.
  - All prey-averaged trophic levels occupied over time.
  - Variation of B-I-T ratios, L/S, C, trophic levels, and omnivory.

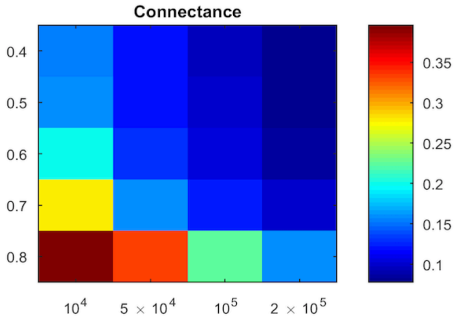
Webworld Model:
Reproduction of original results

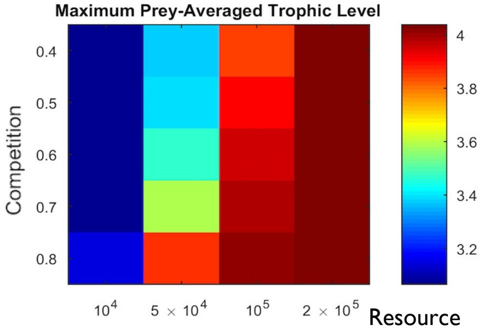
- We collect data averaged over the last 10,000 evolutionary iterations of 30 simulations for:
  - 4 values of resource input size.
  - 5 values of competition strength.
  - Both Taxonomic and Trophic webs.
- 42 properties in total, with standard deviations.

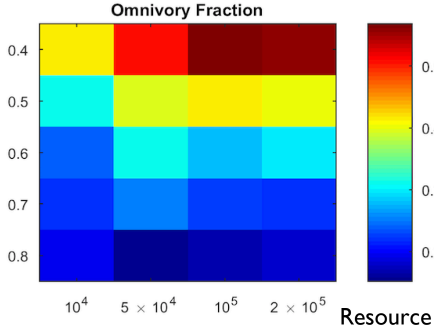

Number of Phenotypes

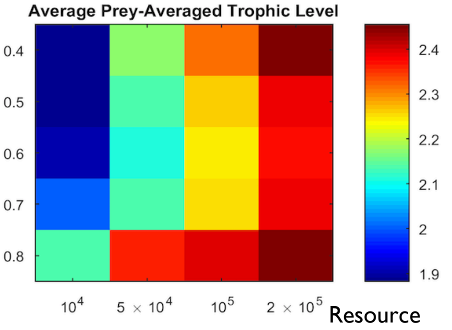

Link Density


Average Population


Connectance


Maximum Prey-Averaged Trophic Level


Omnivory Fraction

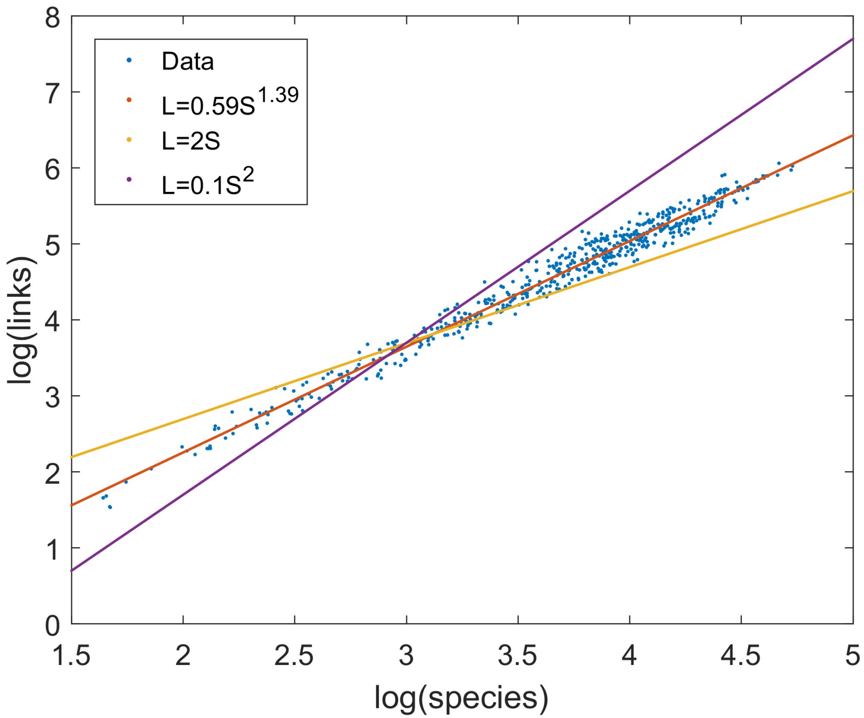

Average Prey-Averaged Trophic Level

Webworld Model:
The Link-Species Relationship

- Consider the link-species relationship $L \sim S^m$
- Data over all 600 simulations supports neither the constant connectance hypothesis, nor the link-species scaling law. Excluding small networks ($S < 20$) does *not* improve the fit, supporting exponent $m = 1.37$.
- Matlab's linear fit functions return a best fit of the form:

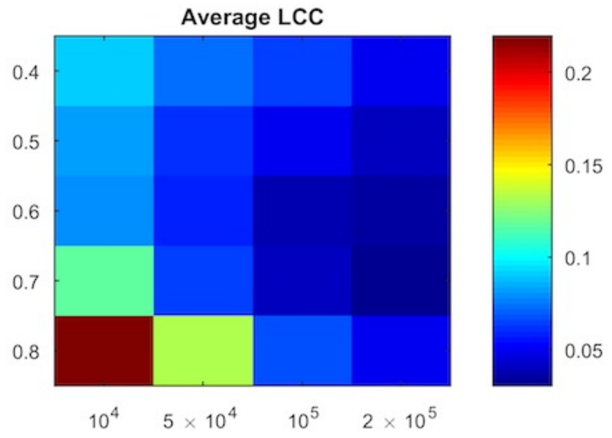
$$L = 0.59S^{1.39}$$

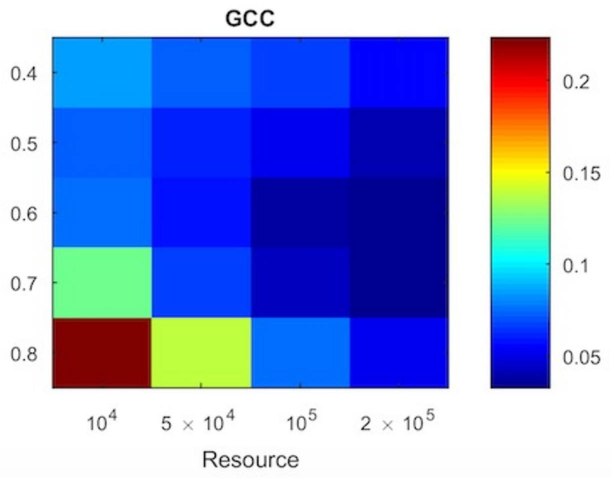
- Exponent $m = 1.39$ with $R^2 = 0.978$.
- Coherent with empirical data exponent $\mathrm{m} = 1.5$ (Dunne 2006).

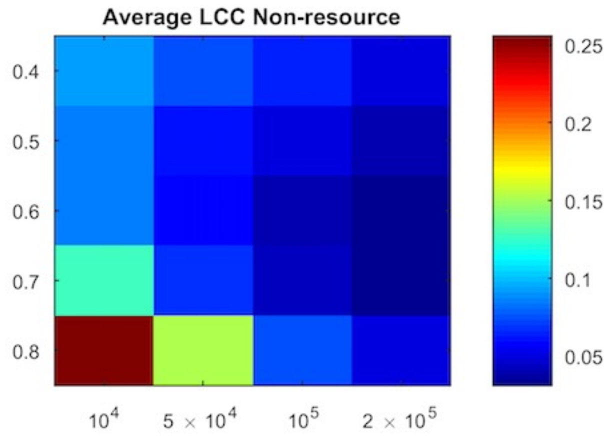


Webworld Model – New Results: Clustering Coefficients

- Local Clustering Coefficient: average (per node) probability that two neighbours of the node are also connected directly.
- Global Clustering Coefficient: probability that paths of length 2 are closed.
- For both, we find an average ~0.07 for large webs.

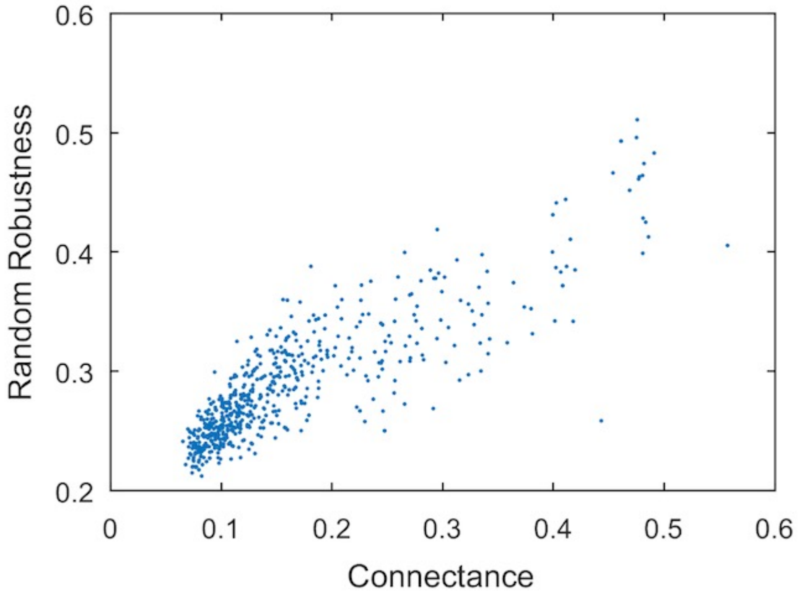

Average LCC

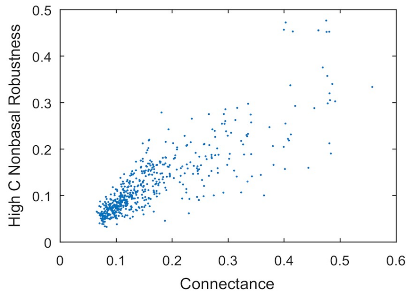

GCC

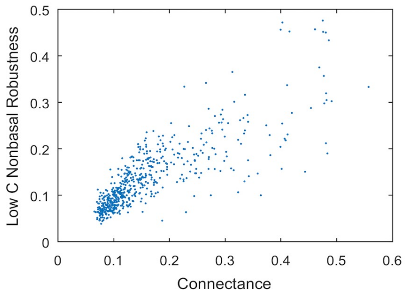

Average LCC Non-resource

Webworld Model – New Results:
Correlation of Connectance and Robustness

- Robustness to species deletion in random, most-, least-connected order.
- Robustness of taxonomic web to random species deletions positively correlated with *connectance*.
  - Coefficient 0.855.
- Coherent with findings from empirical data (Dunne et al 2002, Dunne et al 2004), and the Cascade, Generalised Cascade, Niche and Nested-Hierarchy Models (Dunne and Williams, 2009).
- Robustness to deletions in order of most- or least-connected do not have a strong correlation. However, the correlation becomes strong (0.799 and 0.819 res.) if basal species excluded.

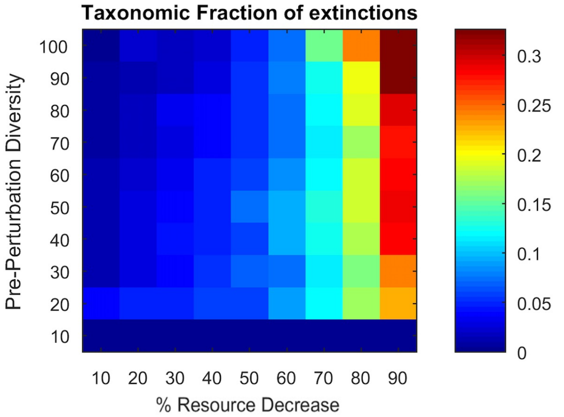


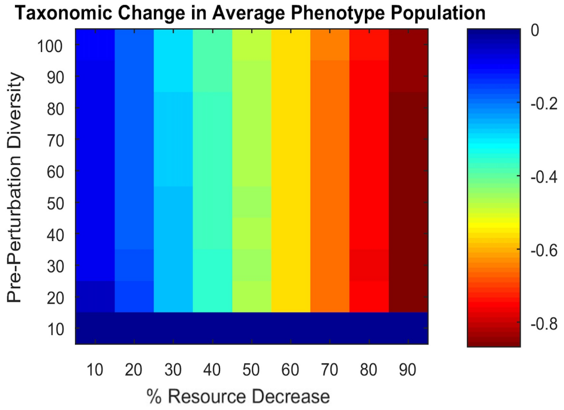


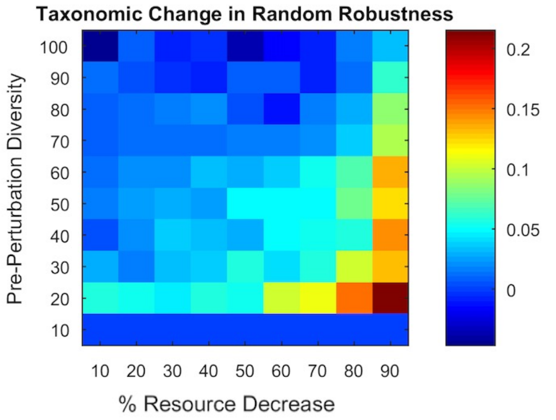


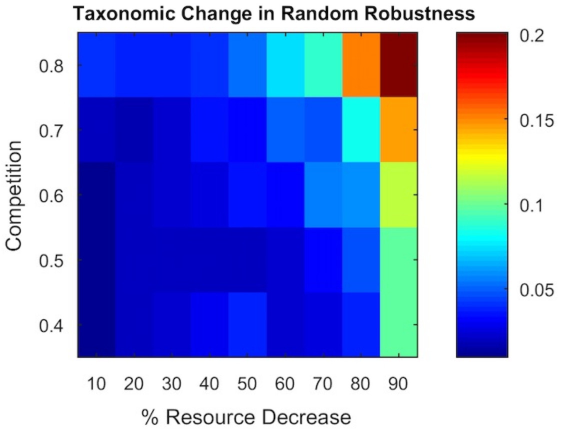
Webworld Model – New Results:
Response to Perturbation of the Resource

- We allow the web to develop for 100,000 time steps, before dropping the amount/biomass of the resource.
  - Average populations decrease with the resource.
  - The number of species extinctions is correlated with high species numbers and low competition (low *c* networks had higher species counts prior to permutation).
  - Robustness increases – perhaps as ‘loose’ species are dislodged.
  - The fewer species (higher *c*) and greater the perturbation, the larger the robustness increase.


Taxonomic Fraction of extinctions


Taxonomic Change in Average Phenotype Population

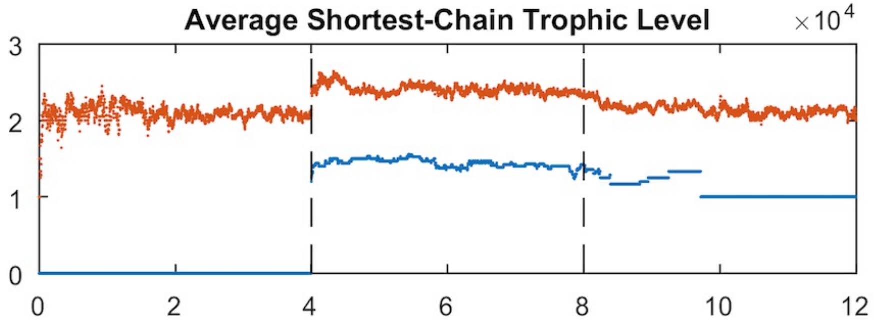

Taxonomic Change in Random Robustness


Taxonomic Change in Random Robustness

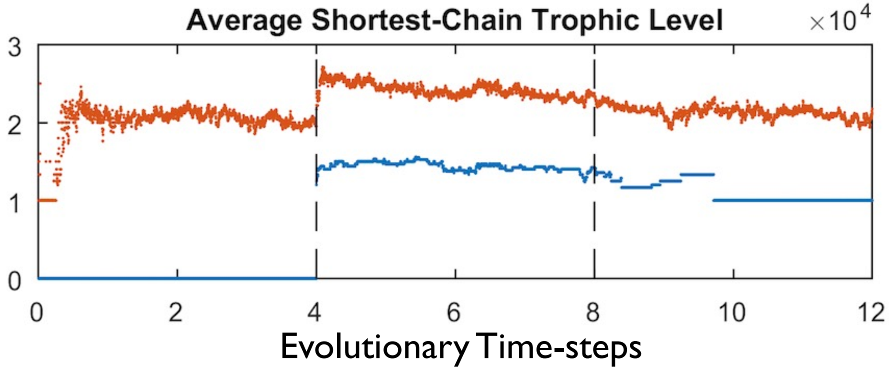
Webworld Model – New Results: Metacommunity Variant

- Consider a spatial variant with two cells and diffusion migration following feeding between evolutionary timesteps 40,000 and 80,000:
  - No obvious effect on *S*, *L*/*S*, *C*, Robustness, or trophic levels averaged over all species in each cell.
- Then average properties separately over *shared* and *unique* (to that cell) species:
  - Shared species occupy lower trophic levels than unique species, due to larger populations facilitating diffusion migration.

Cell 1



Cell 2



Red = Unique, Blue = Shared.

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  - Ulster University
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Future work

- Spatial version of the Webworld model
  - 3x1 with spatial and temporal resource variation.
  - 2x1 with a different *resource* and initial species in each cell.
  - Create a hybrid model by adding a loose feeding hierarchy, variable mortality and feeding efficiency determined by a body-size trait as in Loeuille-Loreau.
  - Migration rate determined by body size.

References

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