Sustaining Ecological Networks and their Services: Network theory of biodiversity and ecosystem function

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Towards a theory of diversity and system function.

Knowledge:
- informs operator
- role of parts
- consequence of loss
- implications of change

Modules/communities

Components
Food-web theory of Biodiversity and Ecosystem function

“Dominant Processes governing biodiversity”
Consumer-resource interactions
Network Structure and Function


Food-web Structure Theory

Inputs are Species Diversity and Network Complexity

Species Diversity ($S$) = 92, Connectance ($C=L/S^2$) = 0.12
Apparent Complexity

Marine

Estuary

Lake

Rain-forest

Desert
Paleofoodwebs

Compilation and Network Analyses of Cambrian Food Webs
Dunne, Williams, Martinez, Wood & Erwin et al. 2008
PLoS Biology
Bioenergetic model for complex food webs

Extending Yodzis & Innes 1992

\[
B_i'(t) = G_i(B) - x_i B_i(t) + \sum_{j=1}^{n} \left( x_i y_{ij} \alpha_{ij} F_{ij}(B) B_i(t) - x_j y_{ji} \alpha_{ji} F_{ji}(B) B_j(t)/e_{ij} \right)
\]

Rate of change in biomass = \text{Production rate of basal spp.} - \text{Loss of biomass to metabolism} + \text{Gain of biomass from resource spp.} - \text{Loss of biomass to consumer spp.}

Time evolution of species' biomasses in a food web result from:

- Basal species grow via a carrying capacity, resource competition, or Tilman/Huisman models
- Other species grow according to feeding rates and assimilation efficiencies (\(e_{ij}\))
- All species lose energy due to metabolism (\(x_i\)) and consumption
- Functional responses determine how consumption rates vary
- Rates of production and metabolism (\(x_i\)) scale with body size
- Metabolism specific maximum consumption rate (\(y_{ij}\)) scales with body type

Theory predicts Population Dynamics and Evolution: 2 species in the lab

Crossing the Hopf Bifurcation in a Live Predator-Prey System
Gregor F. Fussmann,1* Stephen P. Ellner,1,2 Kyle W. Shertzer,2 Nelson G. Hairston Jr.1

17 NOVEMBER 2000 VOL 290 SCIENCE

Rapid evolution drives ecological dynamics in a predator–prey system
Takehito Yoshida*, Laura E. Jones*, Stephen P. Ellner*, Gregor F. Fussmann† & Nelson G. Hairston Jr*

* Department of Ecology and Evolutionary Biology, Cornell University, Ithaca, NY 14853, USA

Nature | Vol 424 | 17 July 2003

Predator–prey cycles in an aquatic microcosm: testing hypotheses of mechanism
Kyle W. Shertzer*, Stephen P. Ellner†, Gregor F. Fussmann‡, and Nelson G. Hairston Jr†

Journal of Animal Ecology 2002
71, 802–815

Cryptic Population Dynamics:
Rapid Evolution Masks Trophic Interactions
Takehito Yoshida1*, Stephen P. Ellner1, Laura E. Jones1, Brendan J. M. Bohannan2, Richard E. Lenski3, Nelson G. Hairston Jr.1*

September 2007 | Volume 5 | Issue 9 | e235
Simple prediction of interaction strengths in complex food webs

Eric L. Berlow, Jennifer A. Dunne, Neo D. Martinez, Philip B. Stark, Richard J. Williams, and Ulrich Brose

Allometric Trophic Network (ATN) Model

Food Web Structure: Niche Model
→ Williams & Martinez 2000

Predator-Prey Interactions: Bioenergetic Model
→ Yodzis & Innes 1992
→ Williams & Martinez 2004
→ Brose et al. 2006

Plant Population Dynamics: Plant-Nutrient Model
→ Tilman 1982
→ Huisman & Weissing 1999
Simulation Methods

- **STEP ONE:**
Create 150 Niche model webs \((t=0)\)
  - 30 species, initial \(C=0.05, 0.15, 0.30\)

- **STEP TWO:**
Create 100 niche invaders \((t=0)\)
  - 30 species, initial \(C=0.15\)

- **STEP THREE:**
Generating persistent webs \((t=0 \text{ to } t=2000)\)
  - S and C range

- **STEP FOUR:**
  - Introducing invaders in the webs \((t=2000 \text{ to } t=4000)\)
  - Running the simulations without invasions \((t=2000 \text{ to } t=4000)\)
Economic Effects of Humans on Ecosystems

Effects of Body Size on Fish Biomass

- Increasing Carnivore Size
- Increasing Herbivore Size

Effects of Body Size on Fishing Profit

- Increasing Fishing Profit
- Increasing Carnivore Size
- Increasing Herbivore Size

Add economic nodes to ecological networks

\[ E_k' = n(pqB_i - c)E_k \]  

(Conrad 1999)

- \( E \) = exploitation effort
- \( p \) = price per unit biomass
- \( q \) = catchability
- \( c \) = cost per unit effort
- \( n \) = economic "openness"

Body size of consumers strongly affect the function of trophic networks

- Fishing reduces body size which can reduce profits
- Management can alter body sizes of consumer in exploited ecosystems

with Barbara Bauer, Potsdam University
Visualization

Dynamic Simulation

Biomass

Time

- Plant5
- Bird2
- Insect6
- Plant4
- Insect3
- Parasite1
- Frog1
- Plant1
- Bird3
- Bird1
- Lizard
- Frog2
- Insect4
- Plant2
- Insect5
- Insect1
- Plant6
- Insect2
- Parasite2
- Plant3