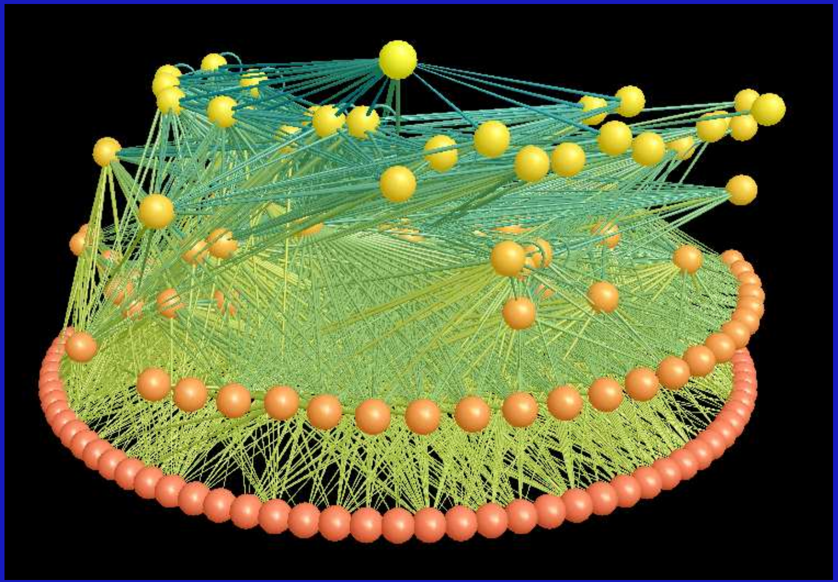
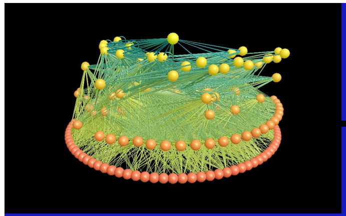
Where does species size matter the most?
Stability and interaction strengths in complex food webs

Ulrich Brose
Complex Ecological Networks Lab
Emmy Noether Group
Darmstadt University of Technology

Lake Tahoe food web



Food web graphics by Web3D © Rich Williams

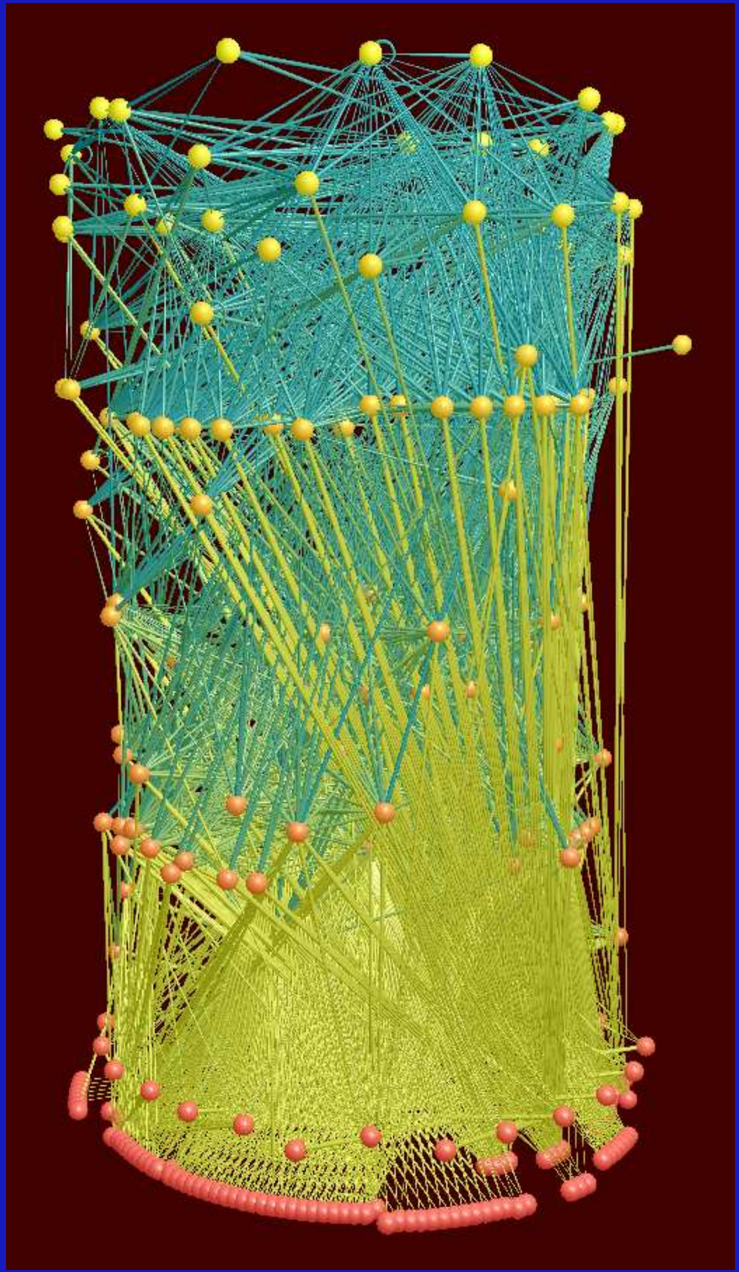


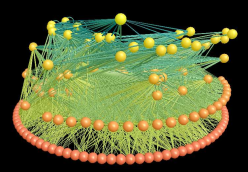
Complex ecological networks

The Weddell Sea food web Antarctica (Jacob et al. unpublished):

492 species, 16137 trophic interactions

Does body size matter?





Complex ecological networks

Body size affects food-web structure

Proc. R. Soc. Lond. B **224**, 421–448 (1985)
Printed in Great Britain

A stochastic theory of community food webs
I. Models and aggregated data

By J. E. Cohen[1] and C. M. Newman[2]

Cohen & Newman 1985 PRSLB

Cascade model

Feeding hierarchy amongst species

Michael G. Neubert · Steven C. Blumenshine
Daniel E. Duplisea · Tomas Jonsson · Brenda Rashleigh

Body size and food web structure:
testing the equiprobability assumption of the cascade model

Neubert et al 2000
Oecologia

Feeding hierarchy and
body size

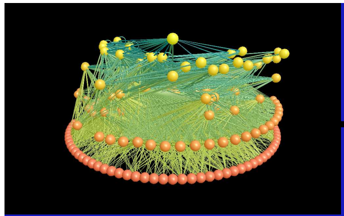
Simple rules yield complex food webs

Richard J. Williams & Neo D. Martinez

Williams & Martinez 2000

Niche model

Interval feeding ranges on niche axis

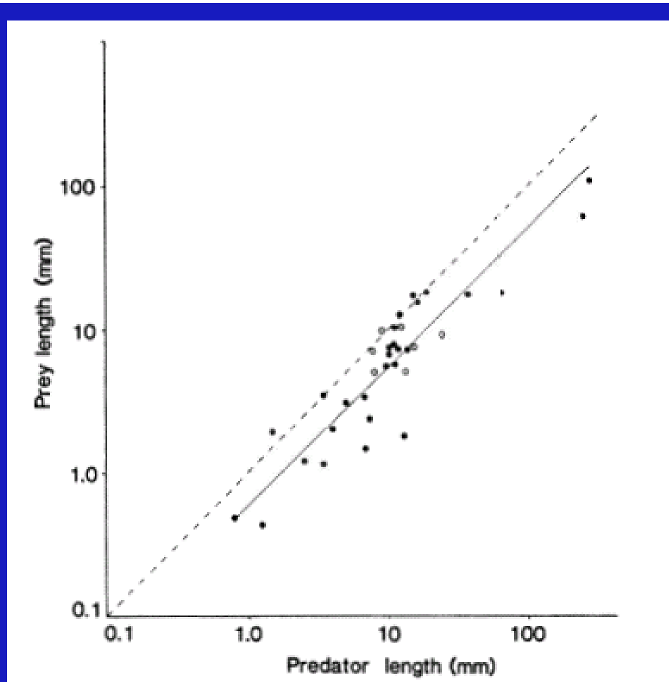


Complex ecological networks

Body size affects food-web structure

Invertebrate predator-prey body size relationships: an explanation for upper triangular food webs and patterns in food web structure?

P.H. Warren and J.H. Lawton
Department of Biology, University of York, Heslington, York YO1 5DD, UK



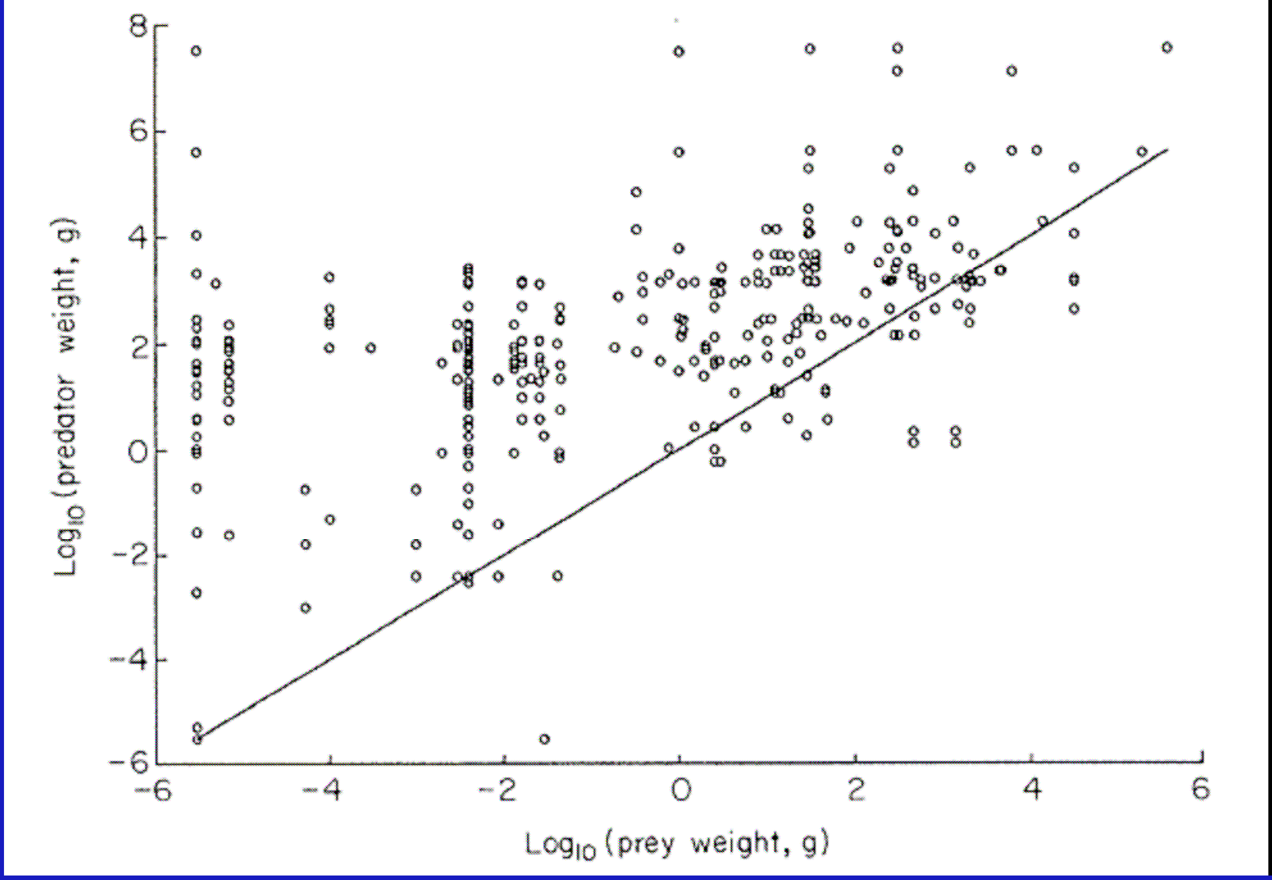
Warren & Lawton 1987 Oecologia

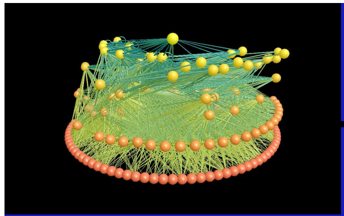
Body size affects food-web structure

Journal of Animal Ecology 1993,
62, 67–78

Body sizes of animal predators and animal prey in food webs

JOEL E. COHEN*, STUART L. PIMM†, PETER YODZIS‡ and JOAN SALDAÑA§





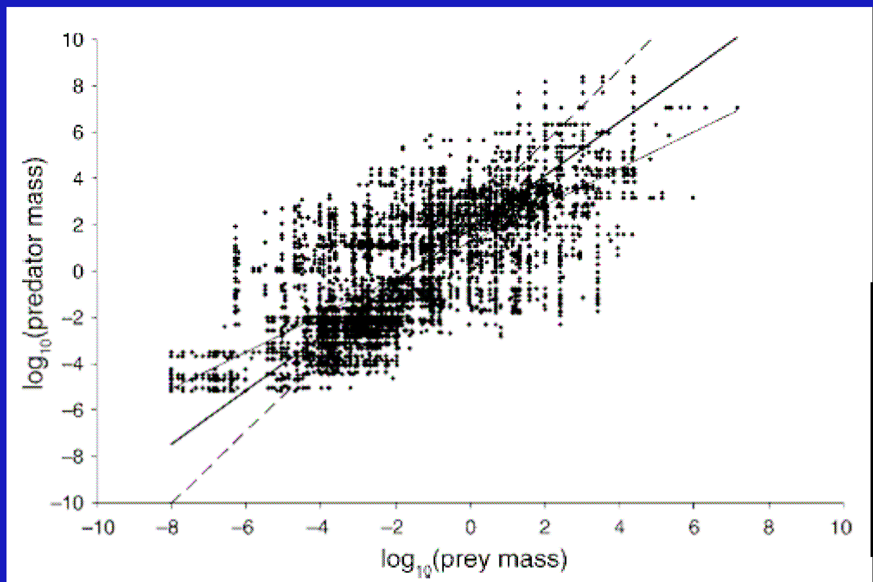
Complex ecological networks

Body size affects food-web structure

Ecology, 87(10), 2006, pp. 2411–2417

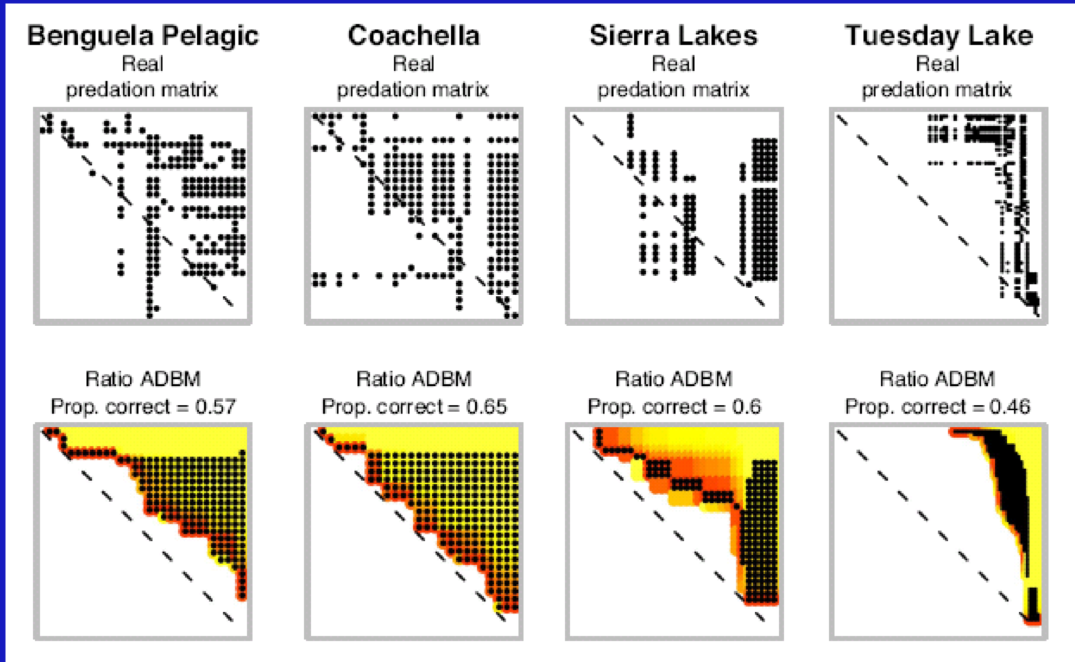
CONSUMER–RESOURCE BODY-SIZE RELATIONSHIPS IN NATURAL FOOD WEBS

Ulrich Brose,[1,2,20] Tomas Jonsson,[3] Eric L. Berlow,[1,2,4] Philip Warren,[5] Carolin Banasek-Richter,[1] Louis-Félix Bersier,[6] Julia L. Blanchard,[7] Thomas Brey,[8] Stephen R. Carpenter,[9] Marie-France Cattin Blandenier,[10] Lara Cushing,[2] Hassan Ali Dawah,[11] Tony Dell,[12] Francois Edwards,[13] Sarah Harper-Smith,[14] Ute Jacob,[8] Mark E. Ledger,[13] Neo D. Martinez,[2] Jane Memmott,[15] Katja Mintenbeck,[8] John K. Pinnegar,[7] Björn C. Rall,[1] Thomas S. Rayner,[12] Daniel C. Reuman,[16] Liliane Ruess,[17] Werner Ulrich,[18] Richard J. Williams,[2,21] Guy Woodward,[19] and Joel E. Cohen[16]

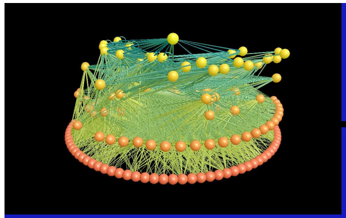


Complex ecological networks

Body size affects food-web structure



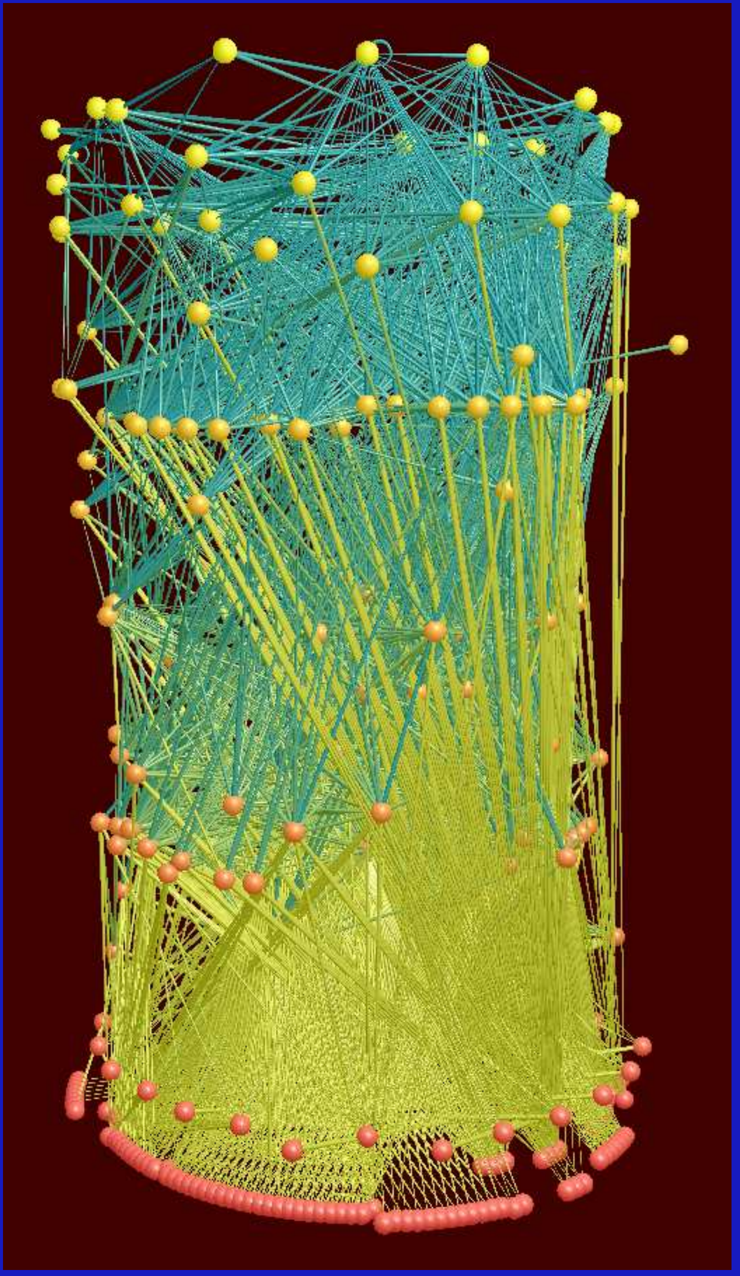
Petchey et al. 2008 PNAS



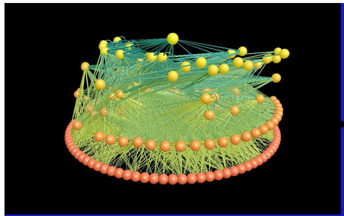
Dynamic food webs:

Where does body size matter?

Methodology:
Dynamic allometric network model



Questions:
→ How do all these species coexist (food-web stability)?
→ What are the consequences of species extinctions (interaction strengths)?



Dynamic network model

Biomass change ~ growth – metabolism + consumption – being consumed

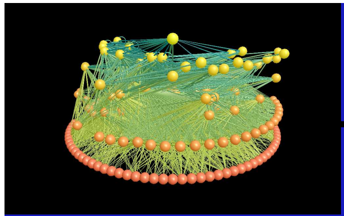
$$B_i'(t) = r_i G_i(\vec{B}) - x_i B_i(t) + \sum_{j=1}^{n} \left(x_i y_{ij} F_{ij}(\vec{B}) B_i(t) - x_j y_{ji} F_{ji}(\vec{B}) B_j(t) / e_{ji} \right)$$

Growth rate

Metabolic rate

Maximum consumption rate

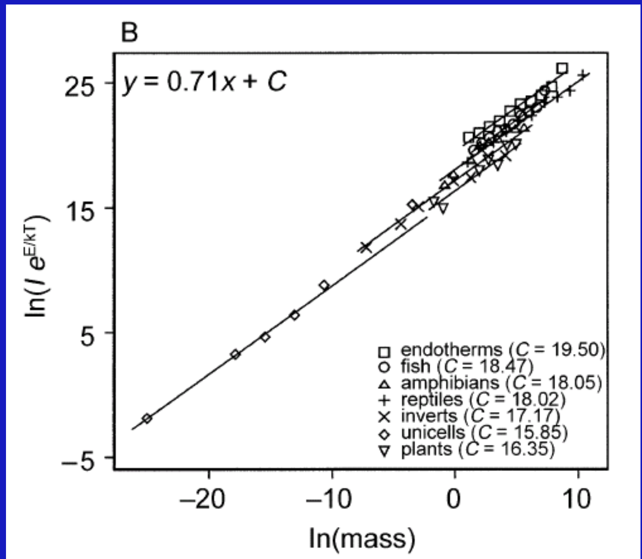
Yodzis & Innes 1992 Am Nat



Complex ecological networks

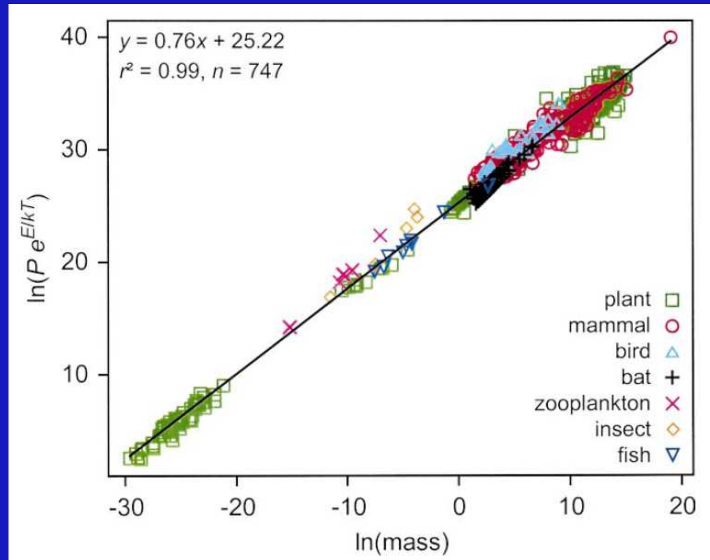
Allometric scaling of biological rates

ln metabolic rate



ln body mass

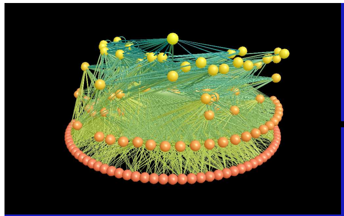
ln production rate



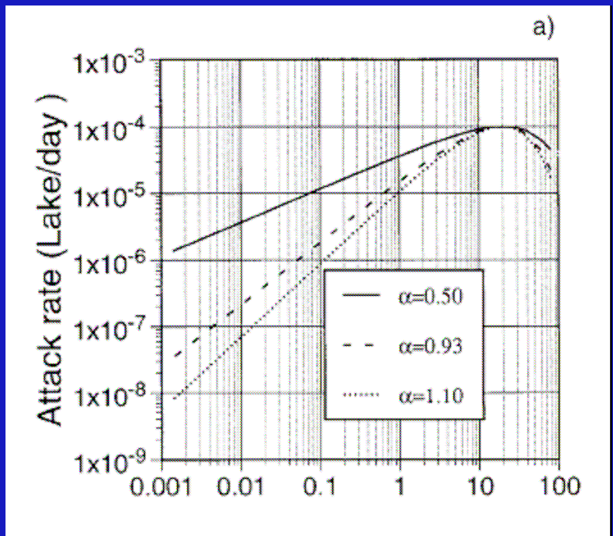
ln body mass

¾ power-law scaling of metabolism, and production

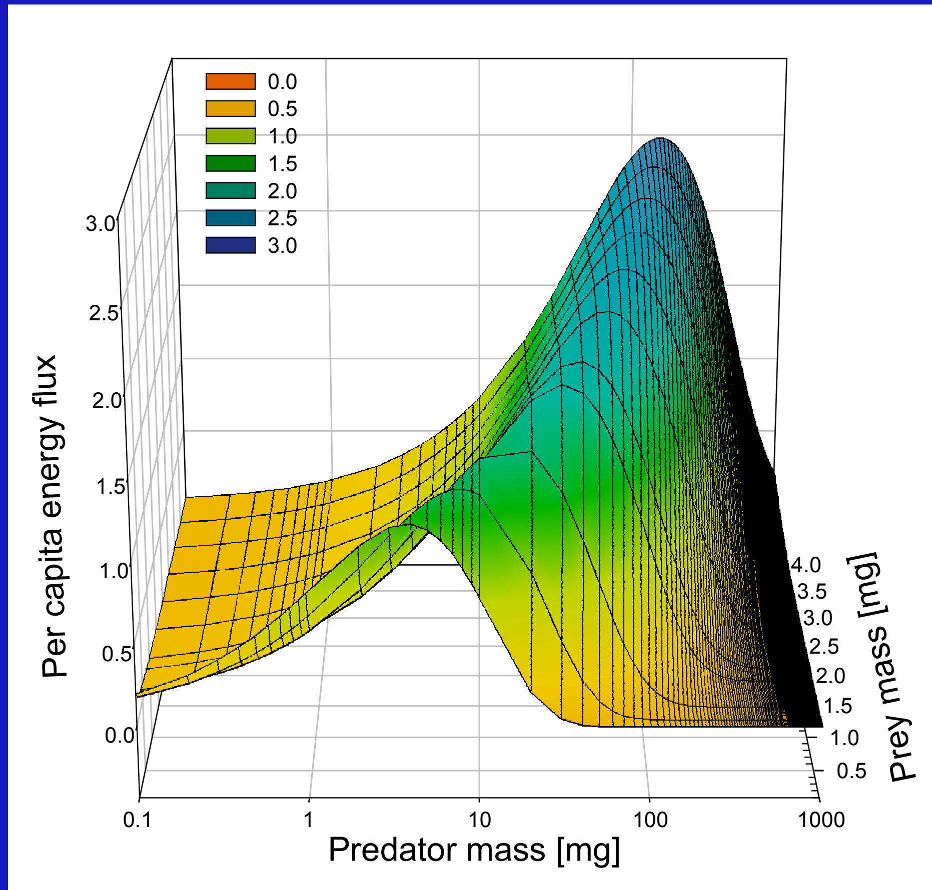
Brown et al 2004 Ecology



Allometric scaling of consumption rates



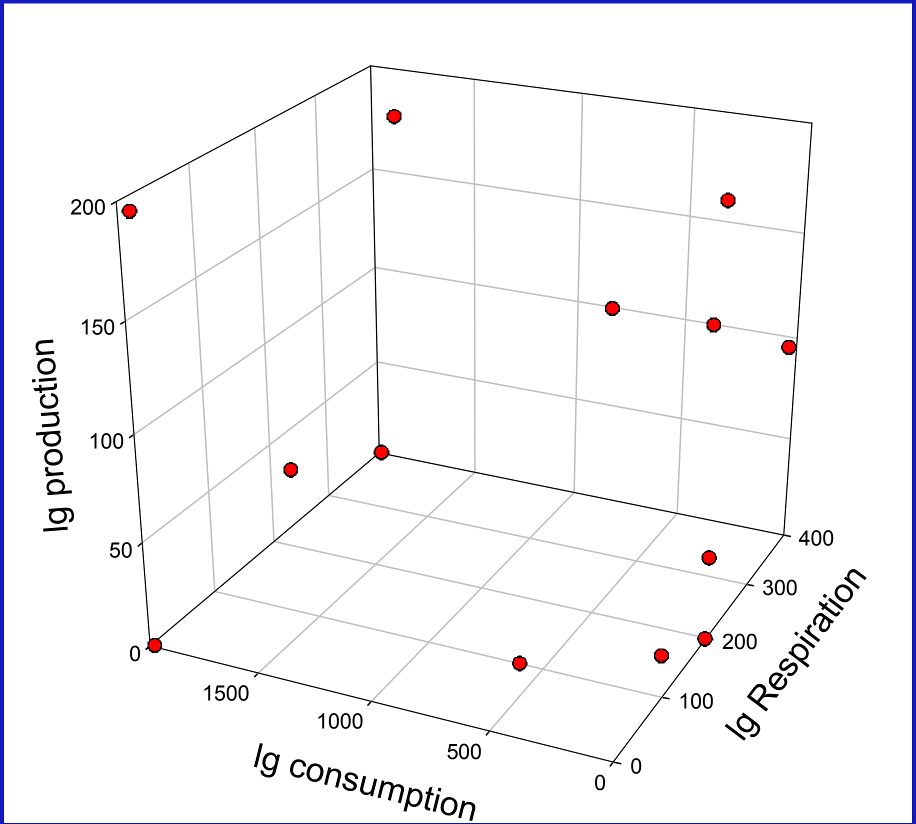
body mass



Persson & Leonardsson 1998 TPB

Brose et al. 2008 Journal of Animal Ecology

Random parameters

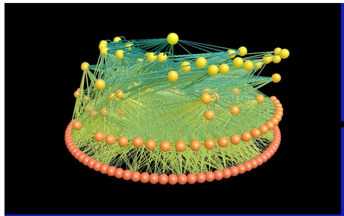


In many population dynamic models:

Parameters of respiration, production and consumption are sampled randomly and independently

→ huge parameter space to be explored;

→ theoretically possible dynamics



Complex ecological networks

Allometric scaling

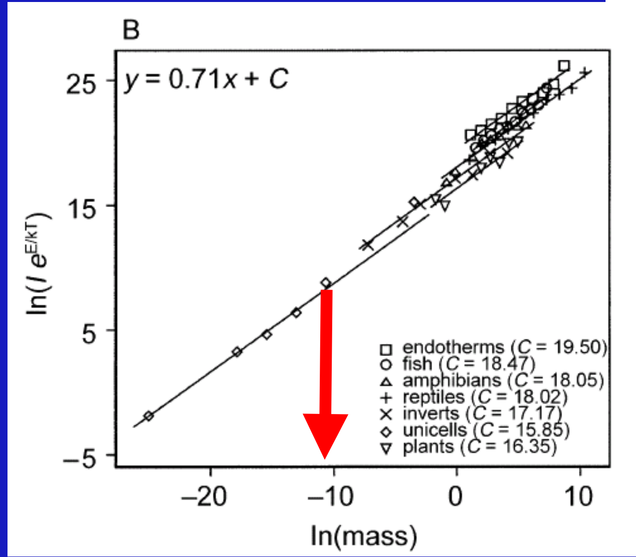
Randomly sampling a respiration rate implies a first body mass

Randomly sampling a production rates implies a second body mass

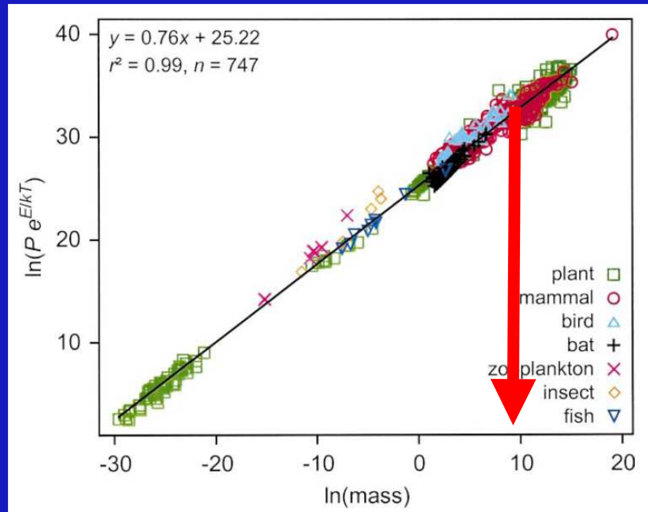
A population cannot have several body masses!

→ Independent random samples are nonsense

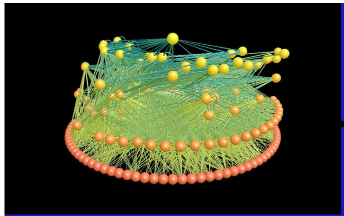
ln respiration rate



ln production rate



ln body mass



Complex ecological networks

Allometric scaling

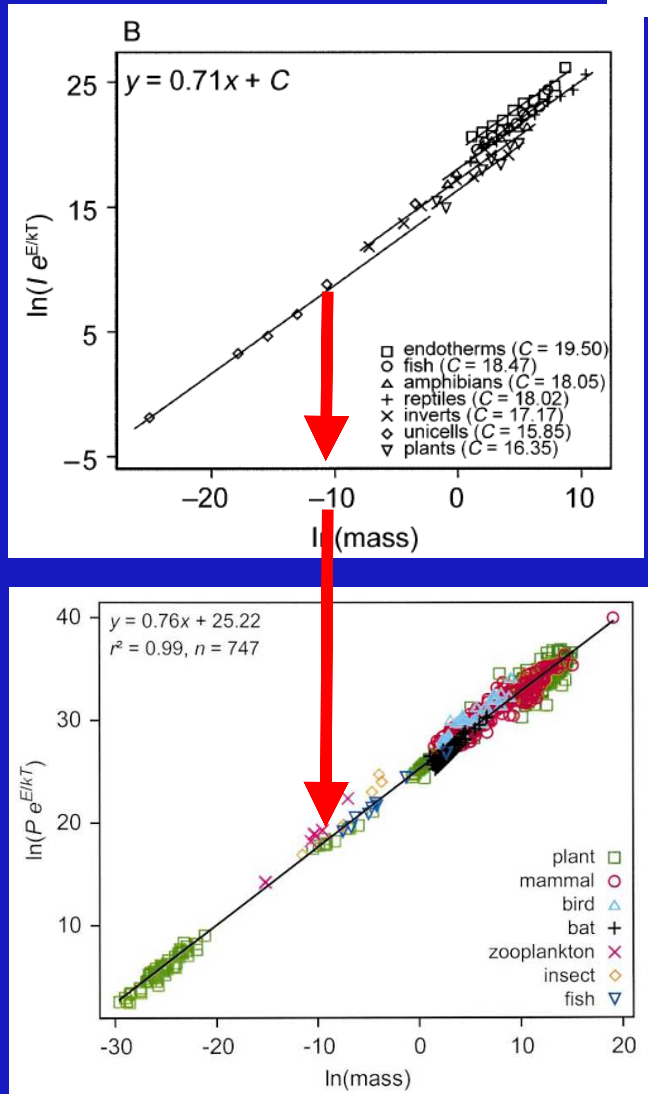
Assigning a respiration rate implies

1) a body mass

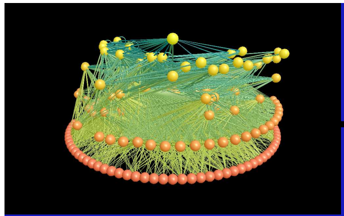
2) a production rate

3) a consumption rate

→ parameters are not independent

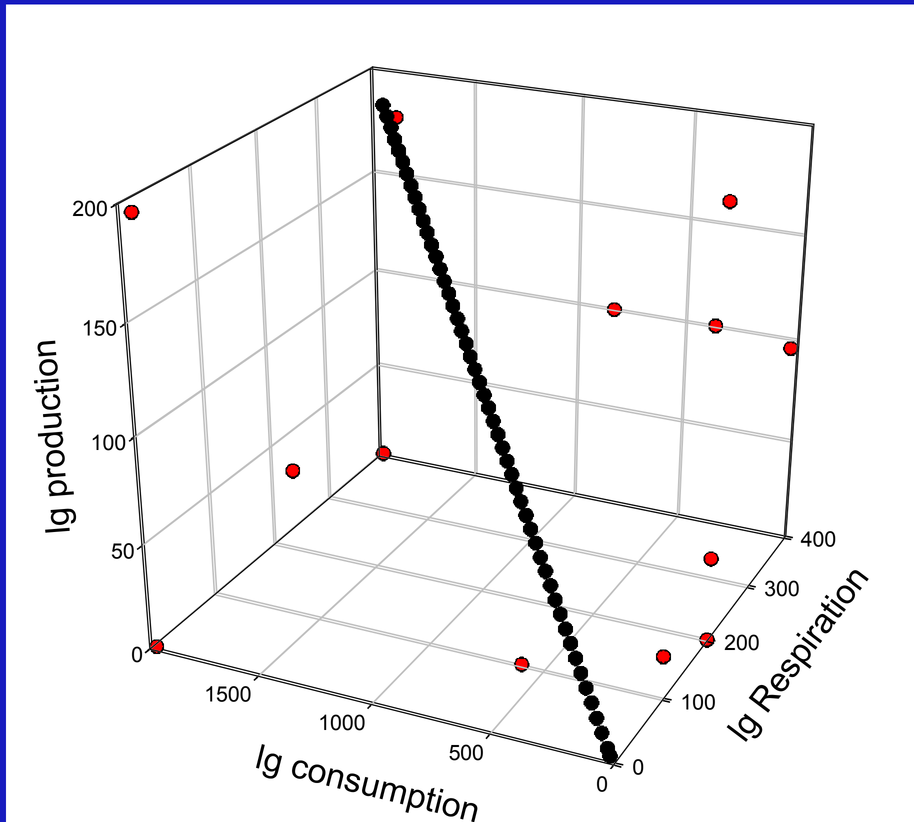


ln body mass

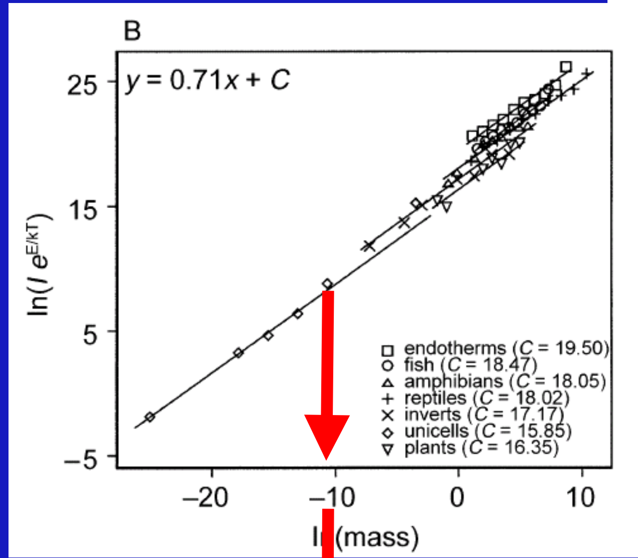


Complex ecological networks

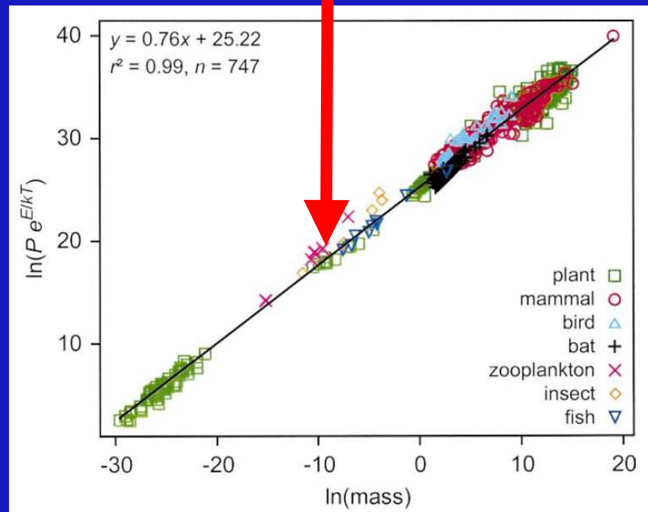
Allometric scaling constraints parameters to restricted space



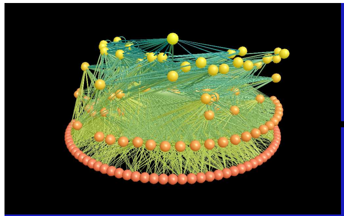
ln respiration rate



ln production rate

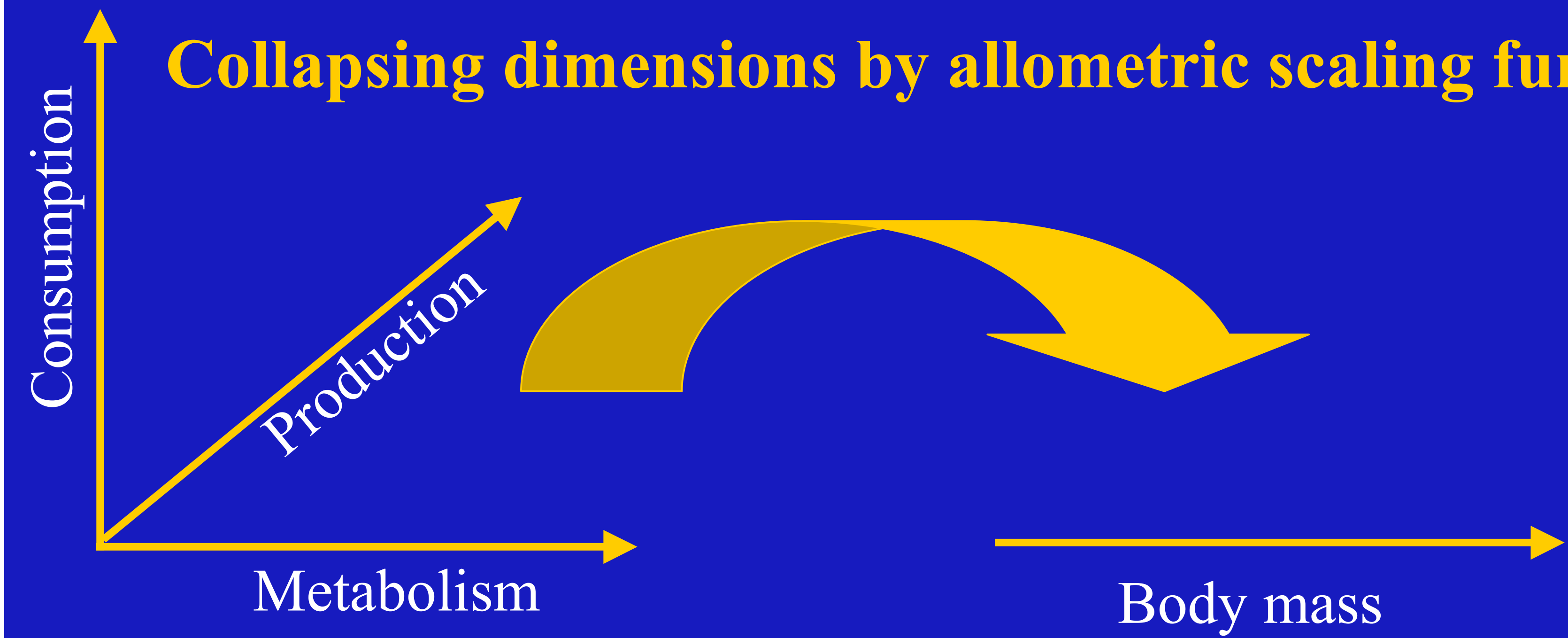


ln body mass



Complex ecological networks

Collapsing dimensions by allometric scaling functions



Random parameters:

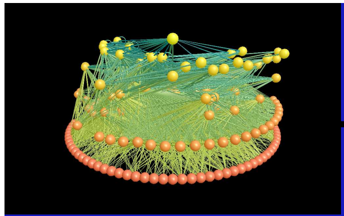
→ huge parameter space to be explored;

→ theoretically possible dynamics

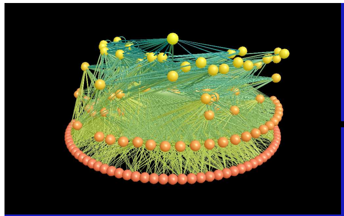
Allometric parameters:

→ body masses constrain parameter space;

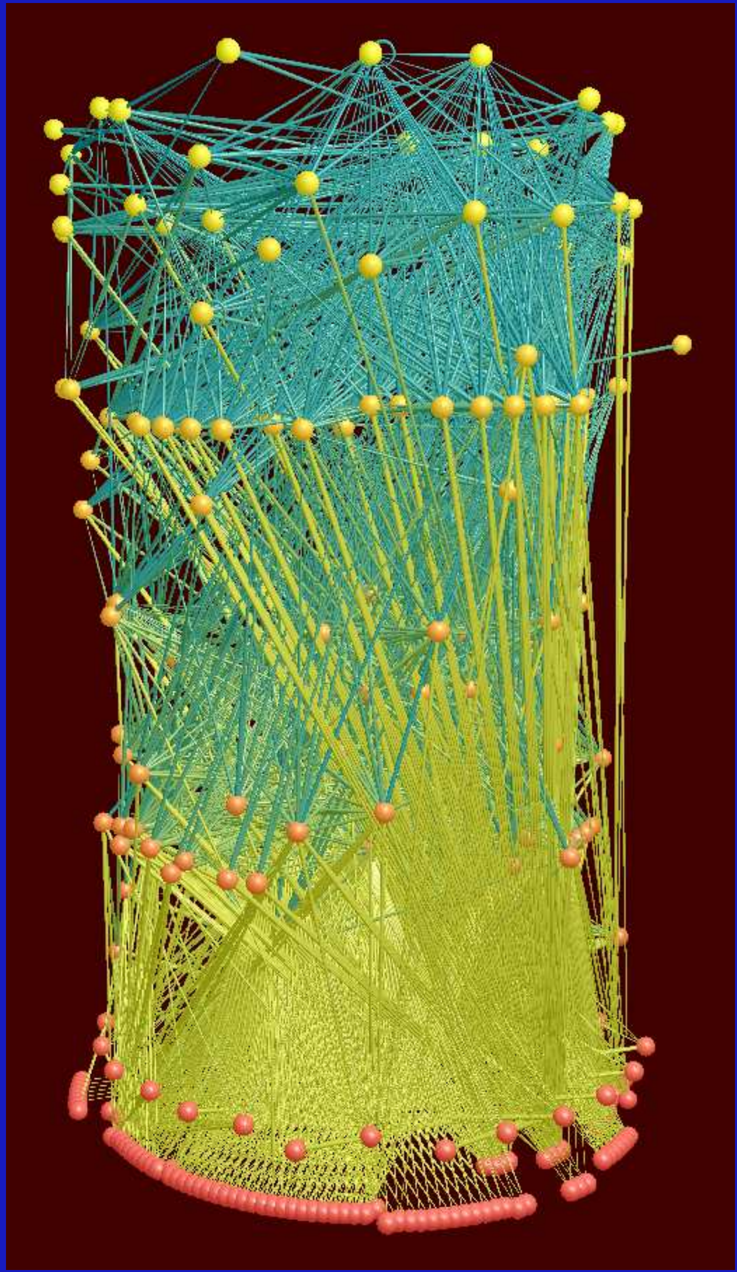
→ empirically possible dynamics



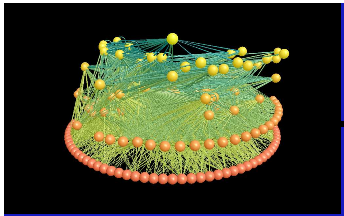
Allometric scaling: is it important for complex food webs?



Complex ecological networks

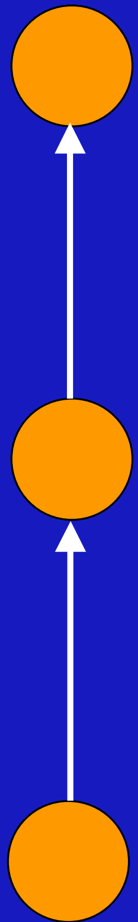


- → Dynamic allometric network model
- →How do all these species coexist (food-web stability)?
- → What are the consequences of species extinctions (interaction strengths)?

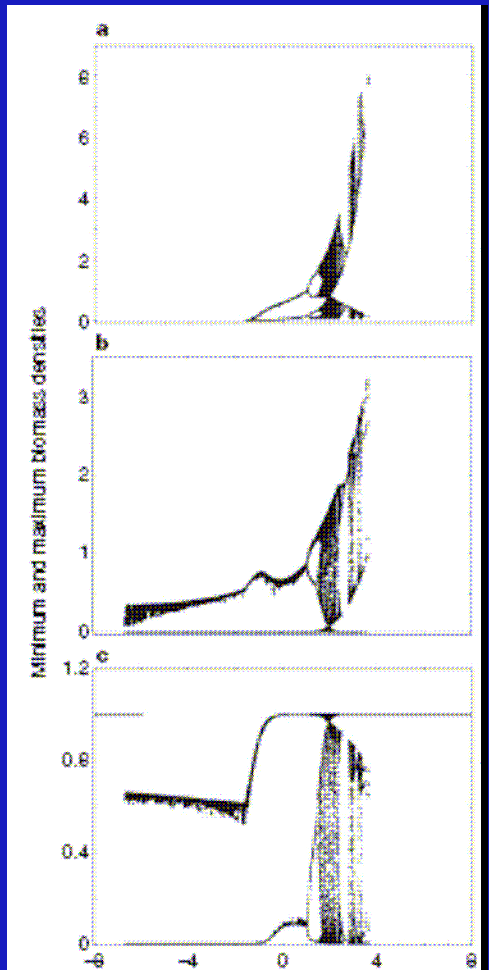


Complex ecological networks

Food-chain simulations



Population minima and maxima

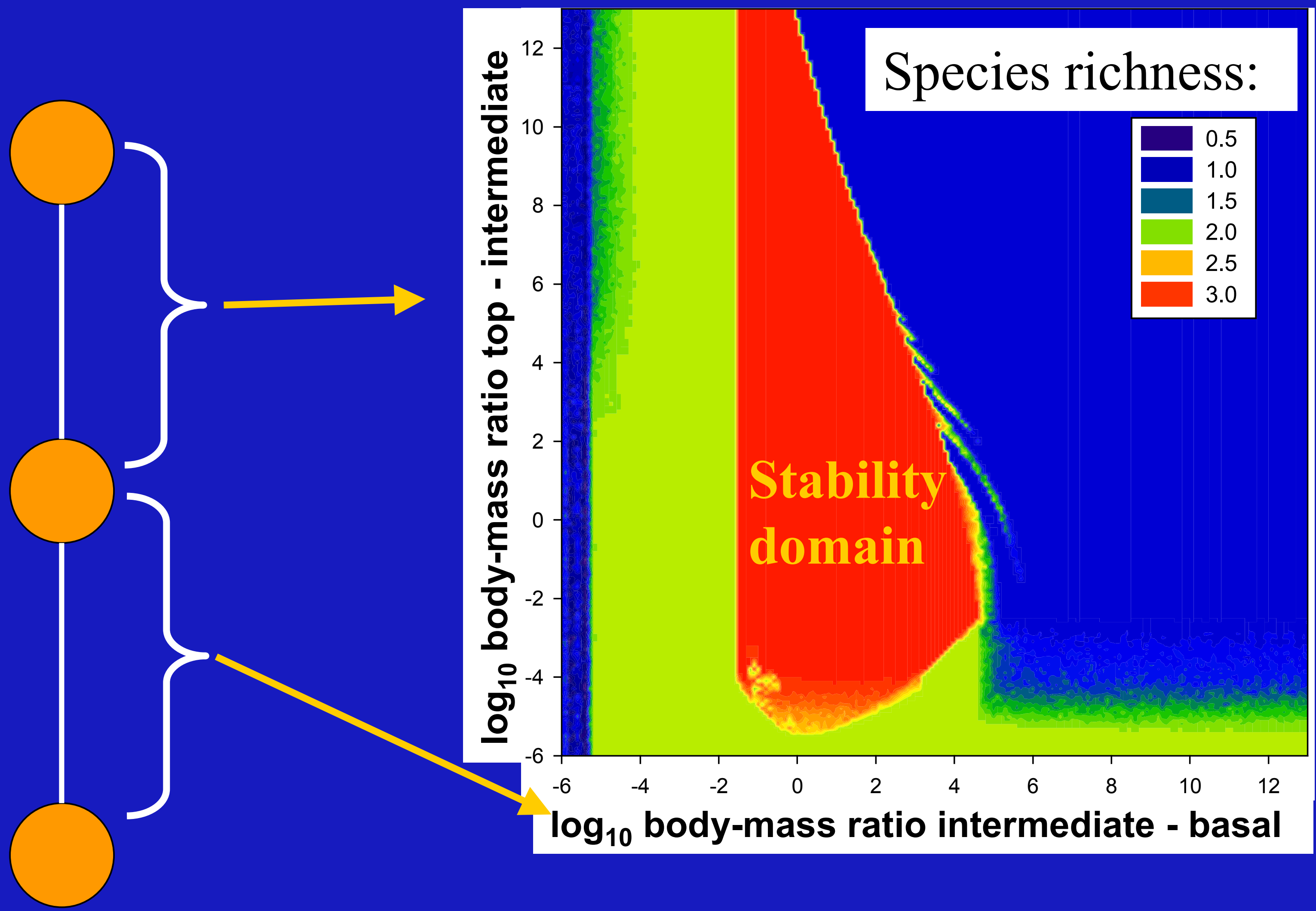


1) Body masses affect population dynamics;
2) Coexistence only in a limited domain of body masses.

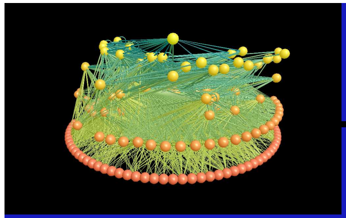
Predator-prey body-mass ratio

Complex ecological networks

Food-web stability



Otto et al. 2007 Nature



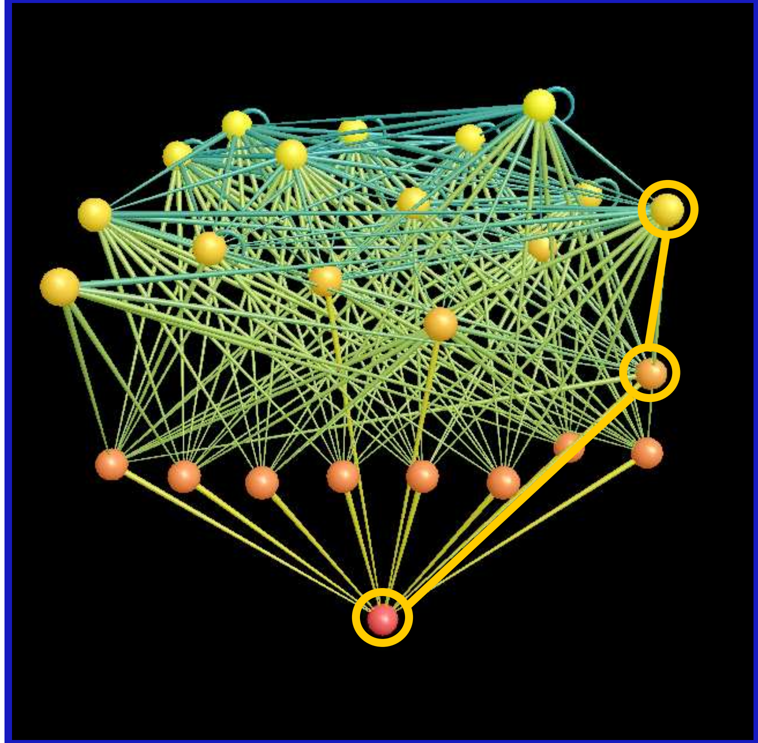
Complex ecological networks

Food-web stability

Empirical food web

isolate food chains

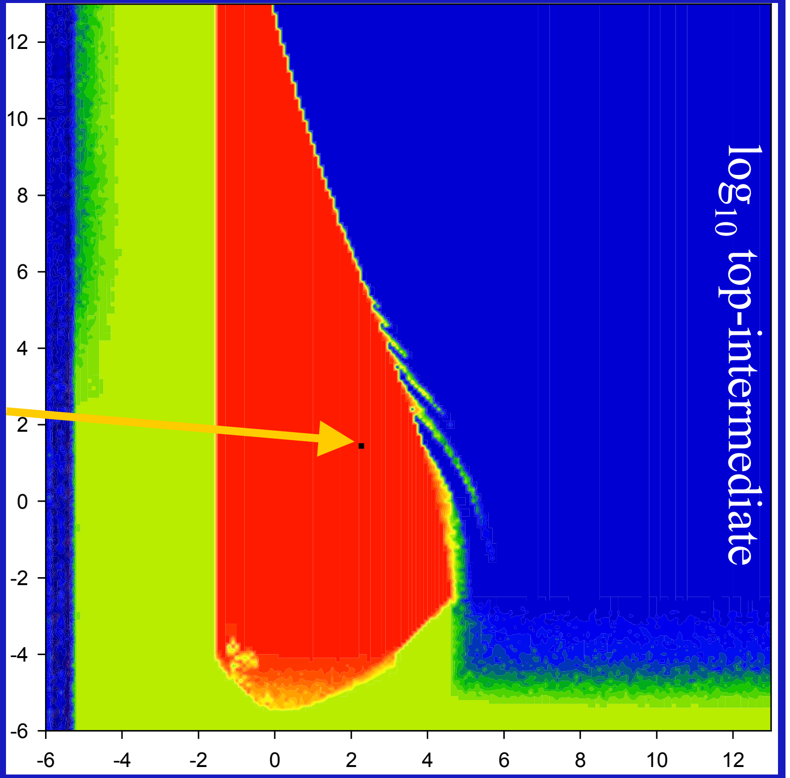
Compare to model predictions



Calculate body-mass ratios

top-inter

inter-basal



$\log_{10}$ intermediate-basal

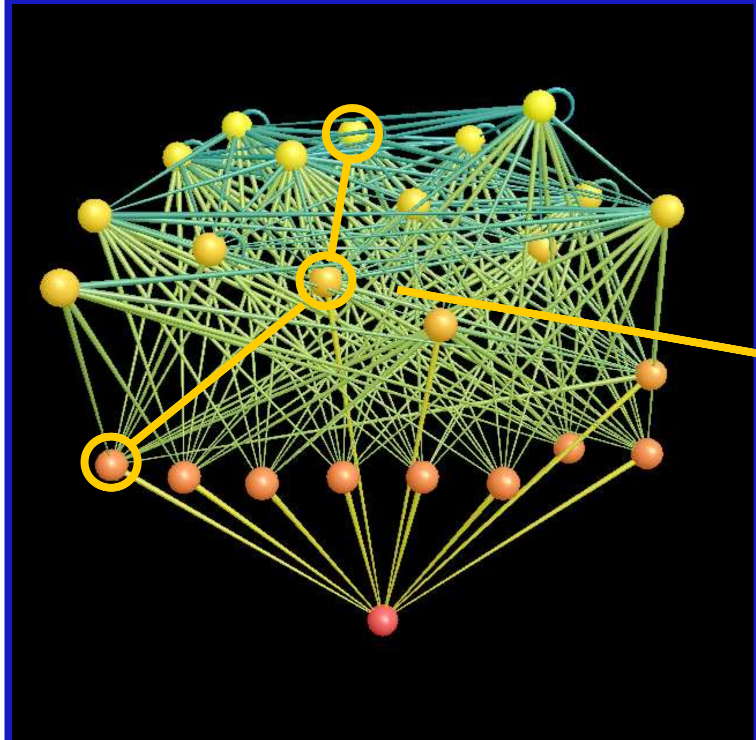
e.g. Skipwith Pond
Warren 1989, Oikos

Otto et al. 2007 Nature

Complex ecological networks

Food-web stability

Empirical food web



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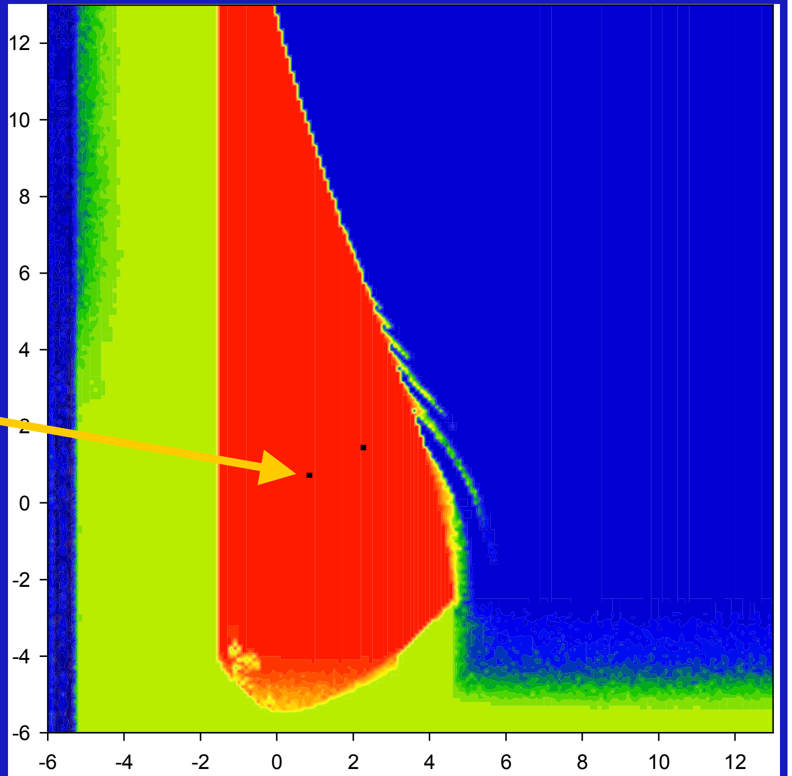
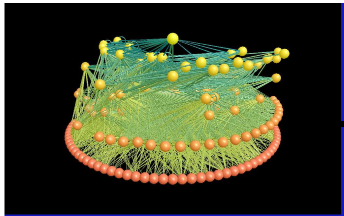
Compare to model predictions



Otto et al. 2007 Nature



Complex ecological networks

Food-web stability

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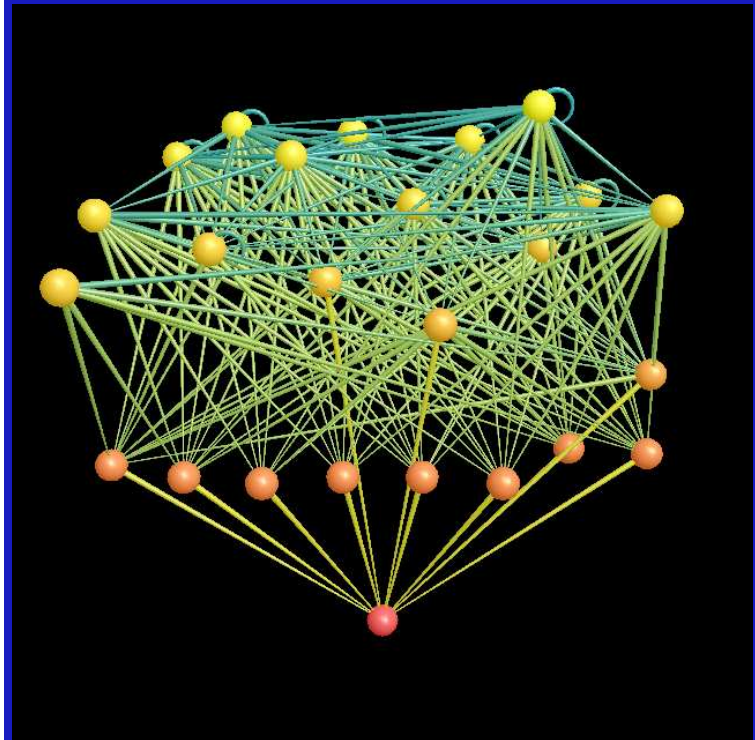

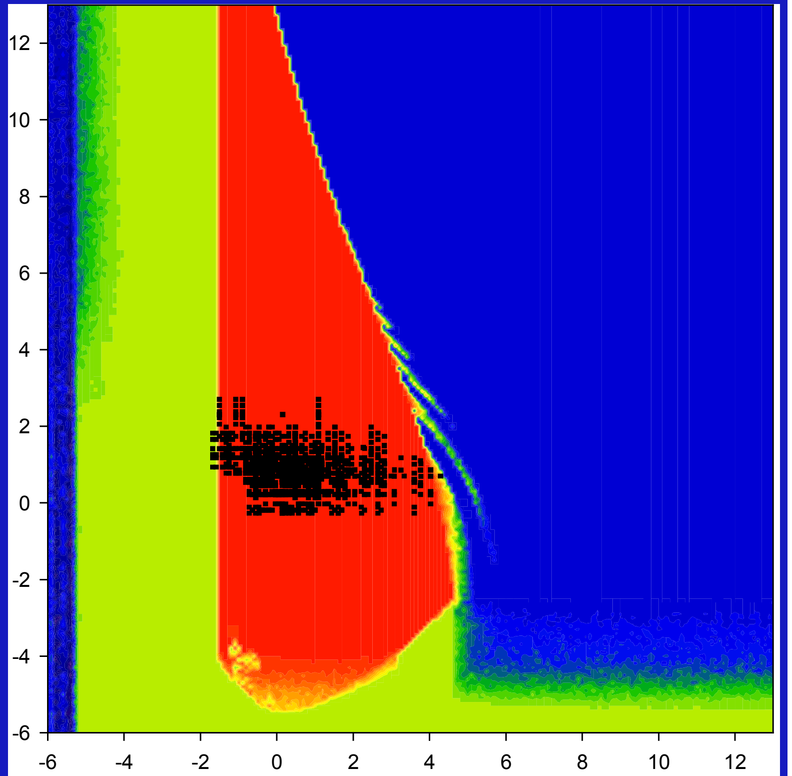

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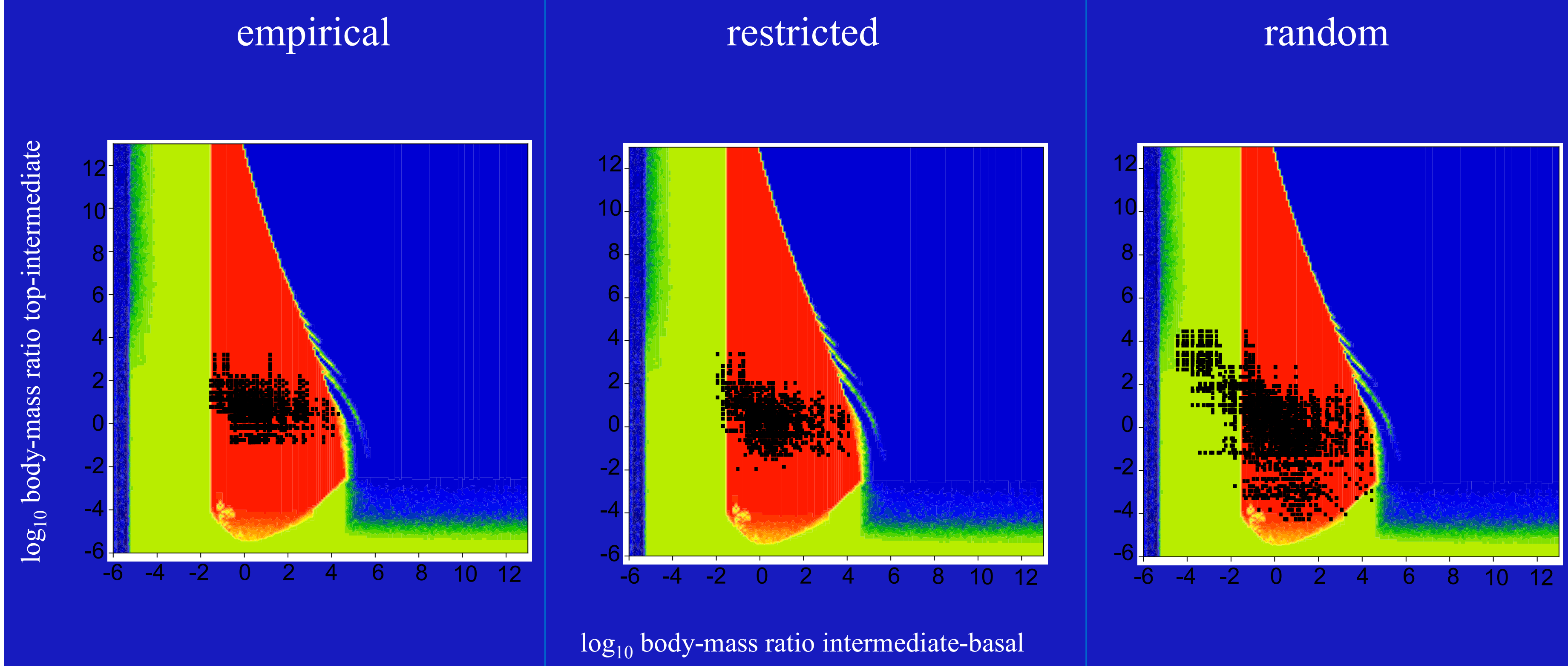
Otto et al. 2007 Nature

Complex ecological networks

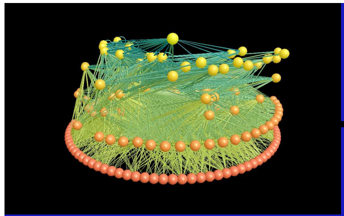
Food-web stability



97.5% 94.7% 81%

$p = 0.17$ $p = 0.05$

Otto et al. 2007 Nature



Complex ecological networks

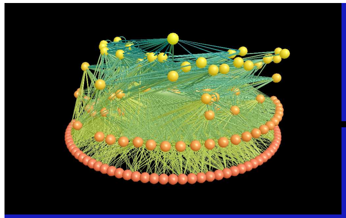
Energetics, Patterns of Interaction Strengths, and Stability in Real Ecosystems

Peter C. de Ruiter,* Anje-Margriet Neutel, John C. Moore

Ecologists have long been studying stability in ecosystems by looking at the structuring and the strengths of trophic interactions in community food webs. In a series of real food webs from native and agricultural soils, the strengths of the interactions were found to be patterned in a way that is important to ecosystem stability. The patterning consisted of the simultaneous occurrence of strong "top down" effects at lower trophic levels and strong "bottom up" effects at higher trophic levels. As the patterning resulted directly from the energetic organization of the food webs, the results show that energetics and community structure govern ecosystem stability by imposing stabilizing patterns of interaction strengths.

Body-mass structures of food webs might drive interaction strength patterns

De Ruiter et al. 1995, Science



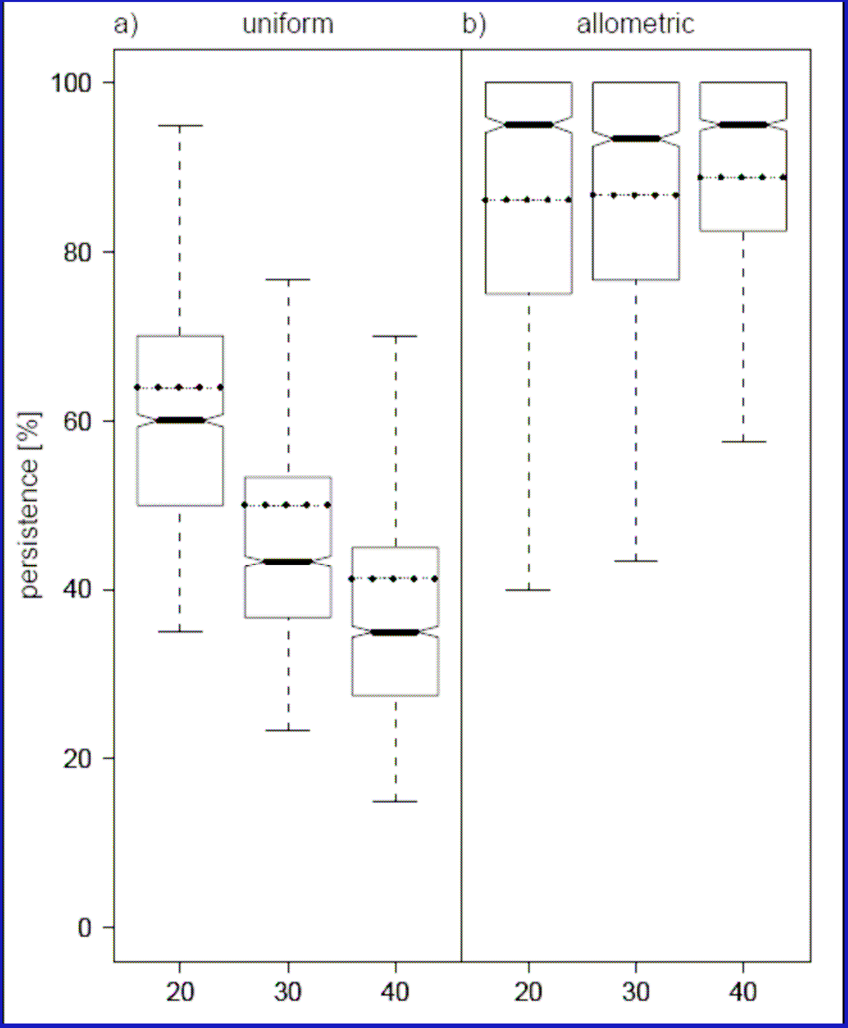
Complex ecological networks

Simulations of complex food webs

Body-mass structure:

Without With

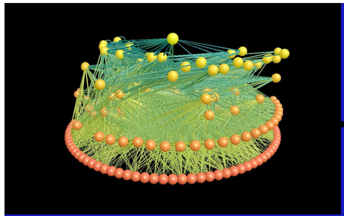
% persistent populations



Body-mass structure

- stabilizes food webs;
- converts negative into neutral diversity-stability relationships.

Brose et al. 2006, Ecology Letters

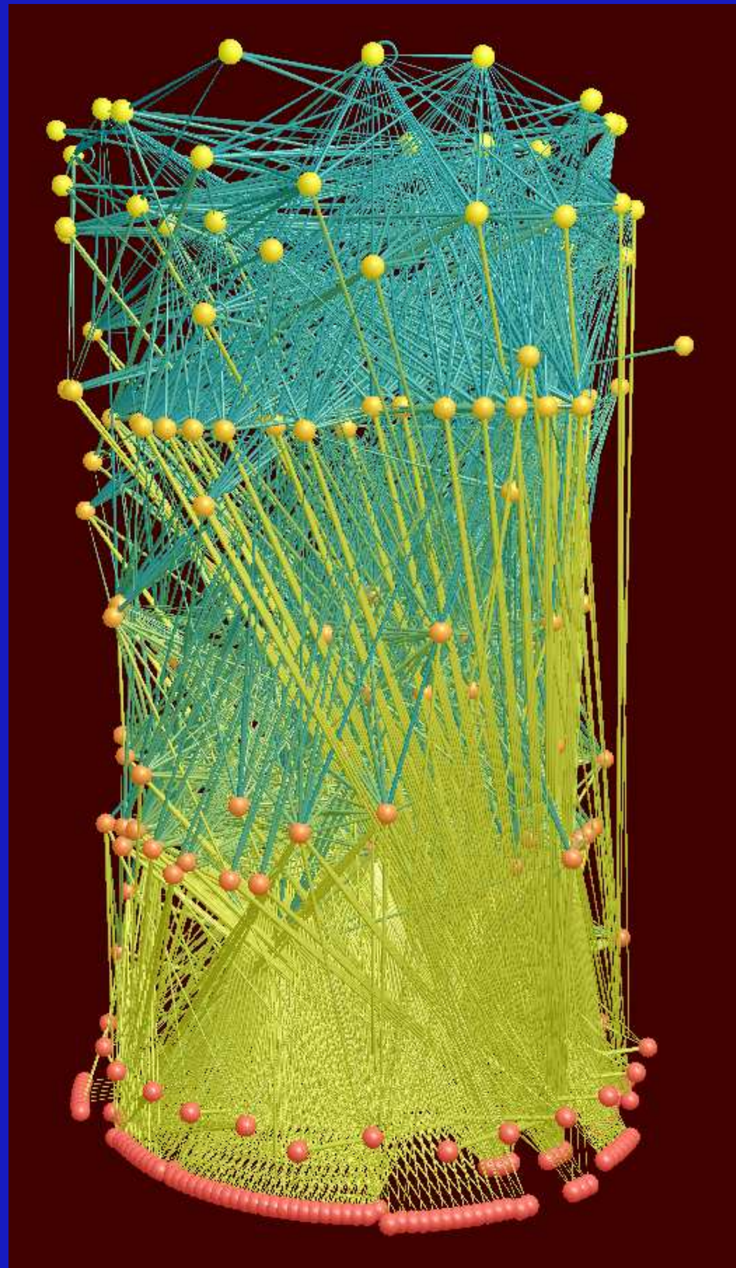


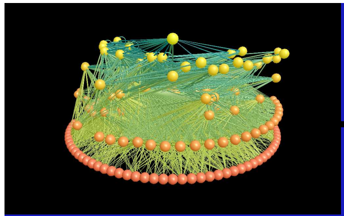
Complex ecological networks

→ Dynamic allometric network model

→How do all these species coexist?

→ What are the consequences of species extinctions?





Complex ecological networks

Intact community

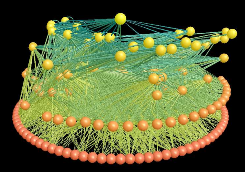
Manipulated community

T biomass increases after removal of R

→ negative effect of R on T (in intact community)

per capita $I = (B_{T+} - B_{T-})/N_R$

Berlow et al. submitted



Complex ecological networks

Intact community

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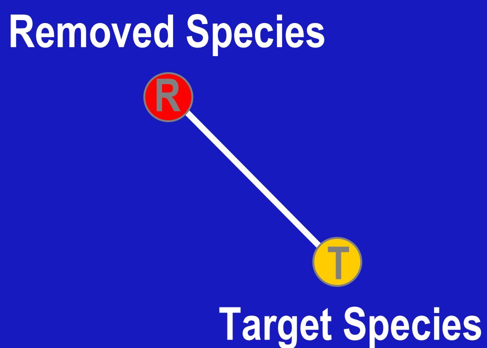
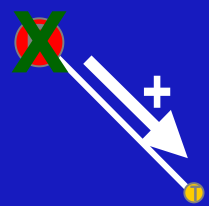


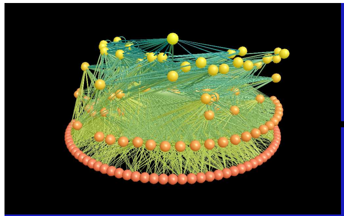


T biomass decreases after removal of R

→ positive effect of R on T (in intact community)

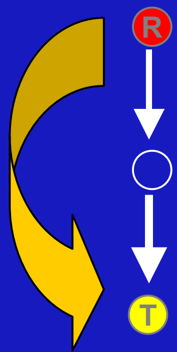
per capita $I = (B_{T+} - B_{T-})/N_R$

Berlow et al. submitted



Complex ecological networks

Positive effect

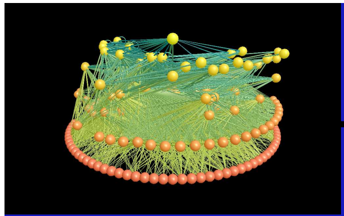


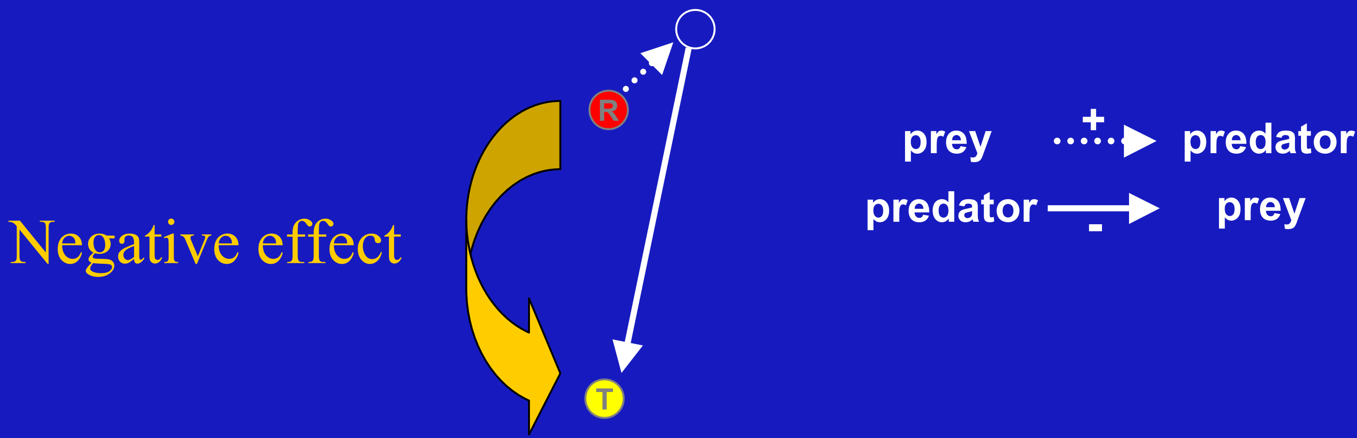
prey ·····+····▶ predator

predator ——–——▶ prey

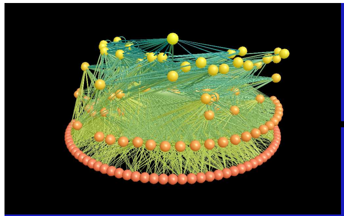
Berlow et al. submitted

Complex ecological networks



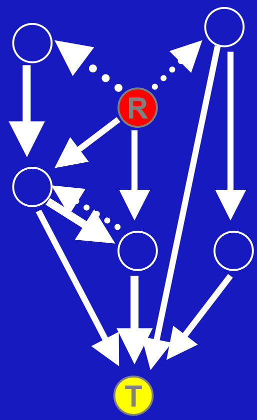


Berlow et al. submitted



Complex ecological networks

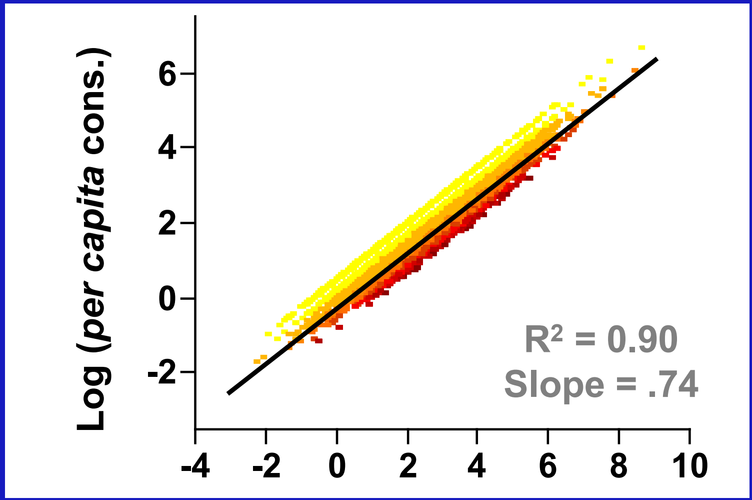
Negative or
positive effect?



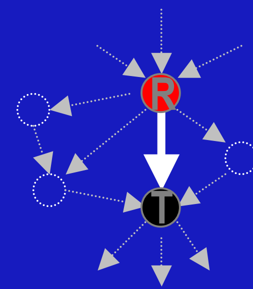
prey ··+··▶ predator
predator ——▶ prey -

Predicting the consequences of species loss in complex networks is intractable (Yodzis 1988, Ecology)

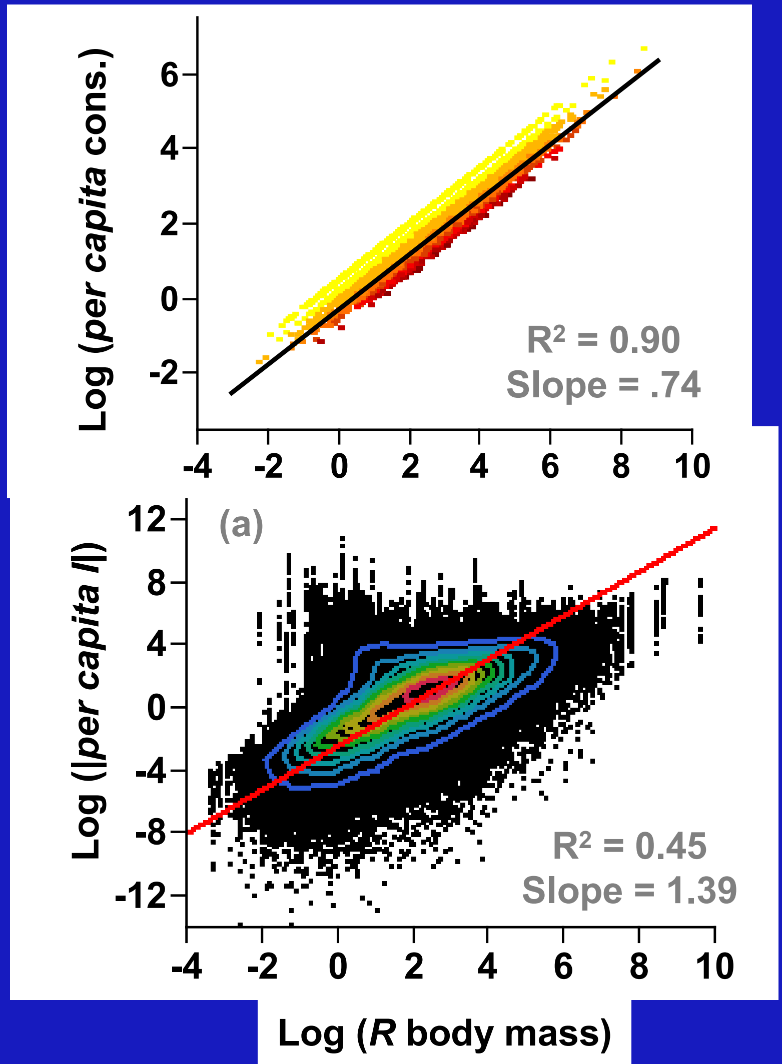
Berlow et al. submitted



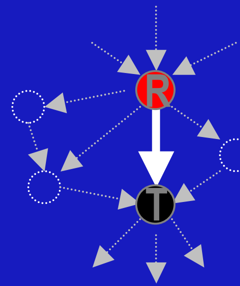
<u>Input parameter:</u> each feeding interaction scales with (body size)$^{0.75}$



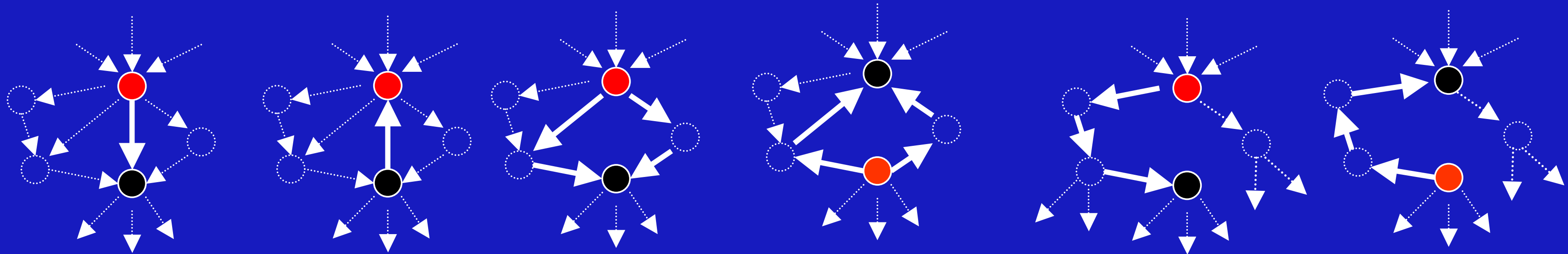
Berlow et al. submitted

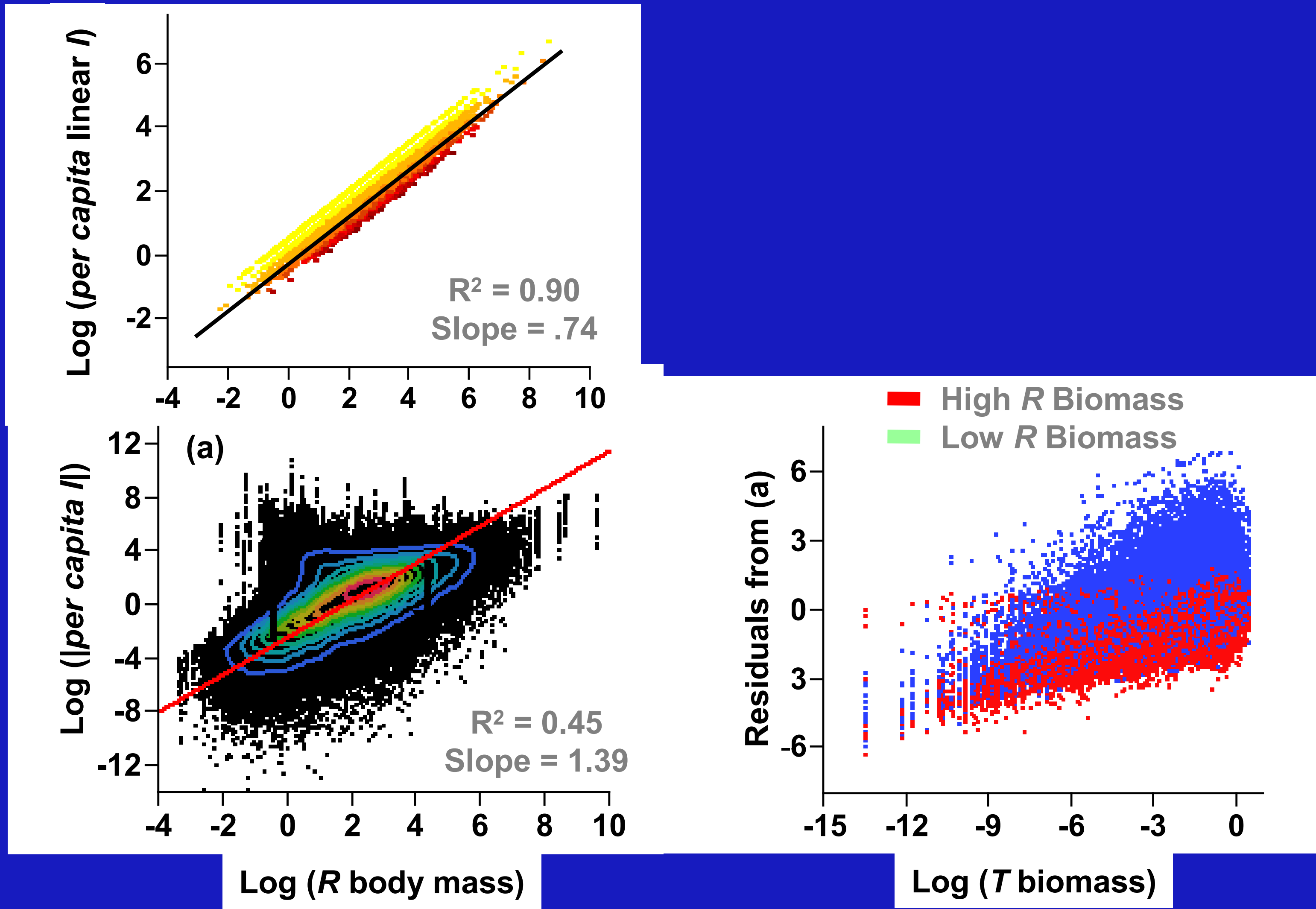


Input parameter: each feeding interaction scales with (body size)$^{0.75}$



Result: interaction strength scale with (body size)$^{1.39}$



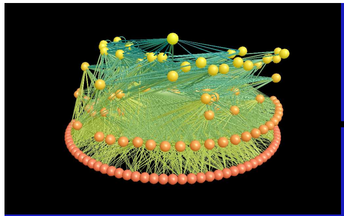


Summary:

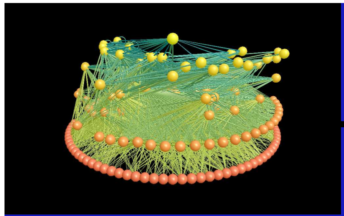
(1) 3/4 scaling disappears in complex networks,

(2) strongest per capita I: large bodied, low biomass R effects on high biomass T, $R^2 = 0.88$

Berlow et al. submitted

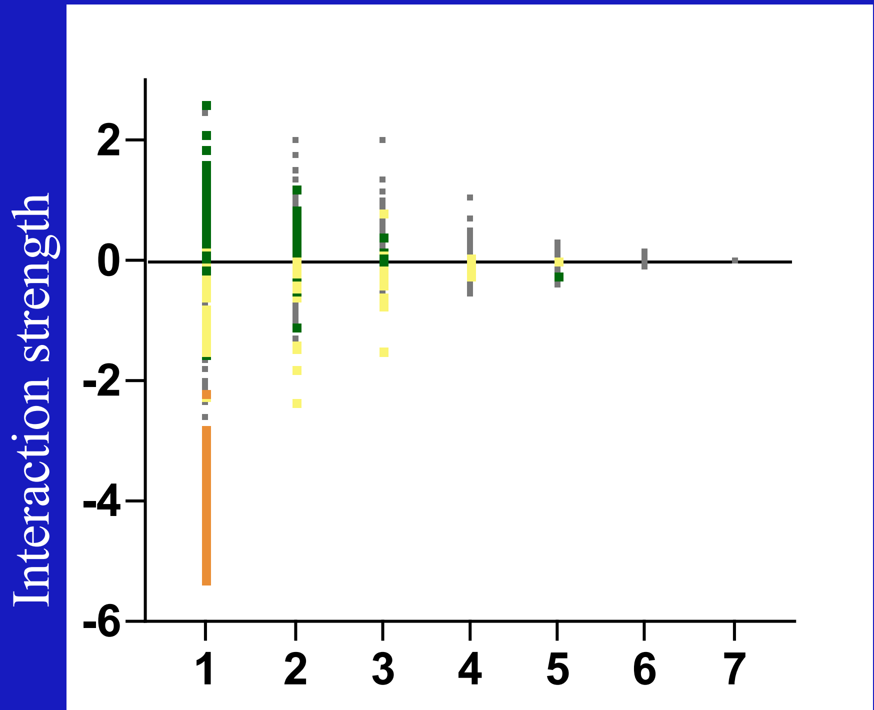


How can it be so simple?



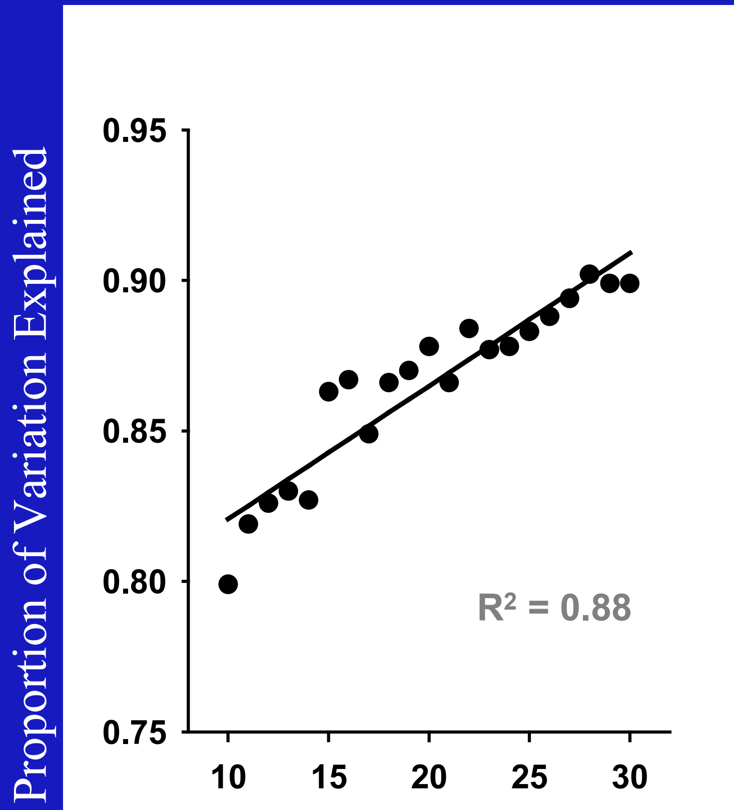
Complex ecological networks

Multiple pathways cancel out



degrees separated

More Complex is More Simple



Number of Species

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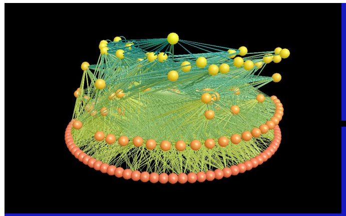
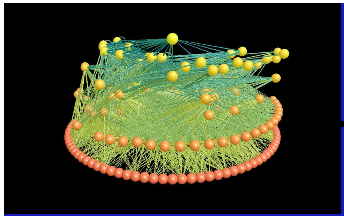


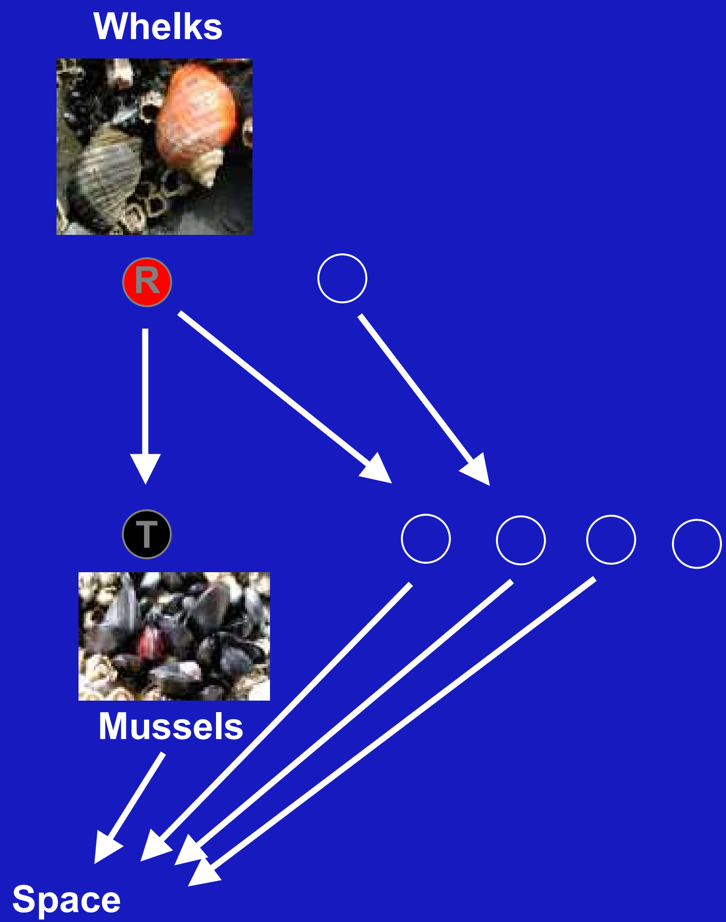
Does it apply to natural ecosystems?

Complex ecological networks

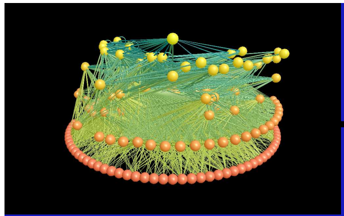
Berlow 1999 *Nature* 398:330

Complex ecological networks

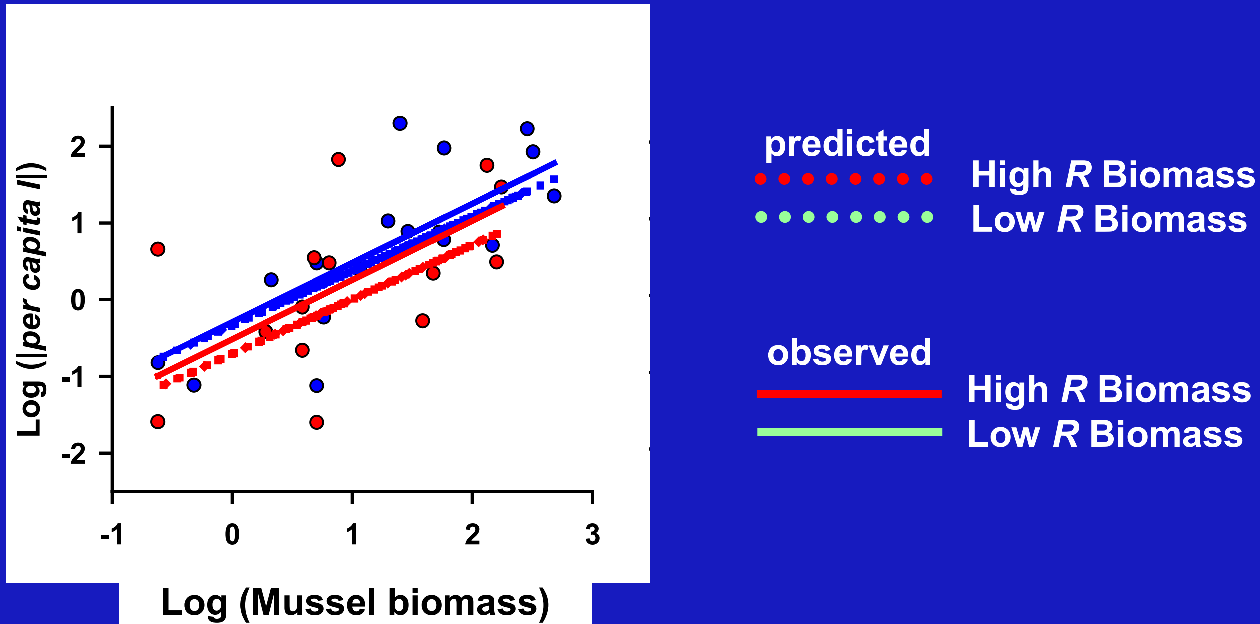




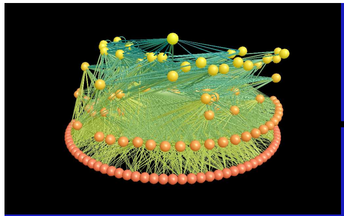
Berlow et al. submitted



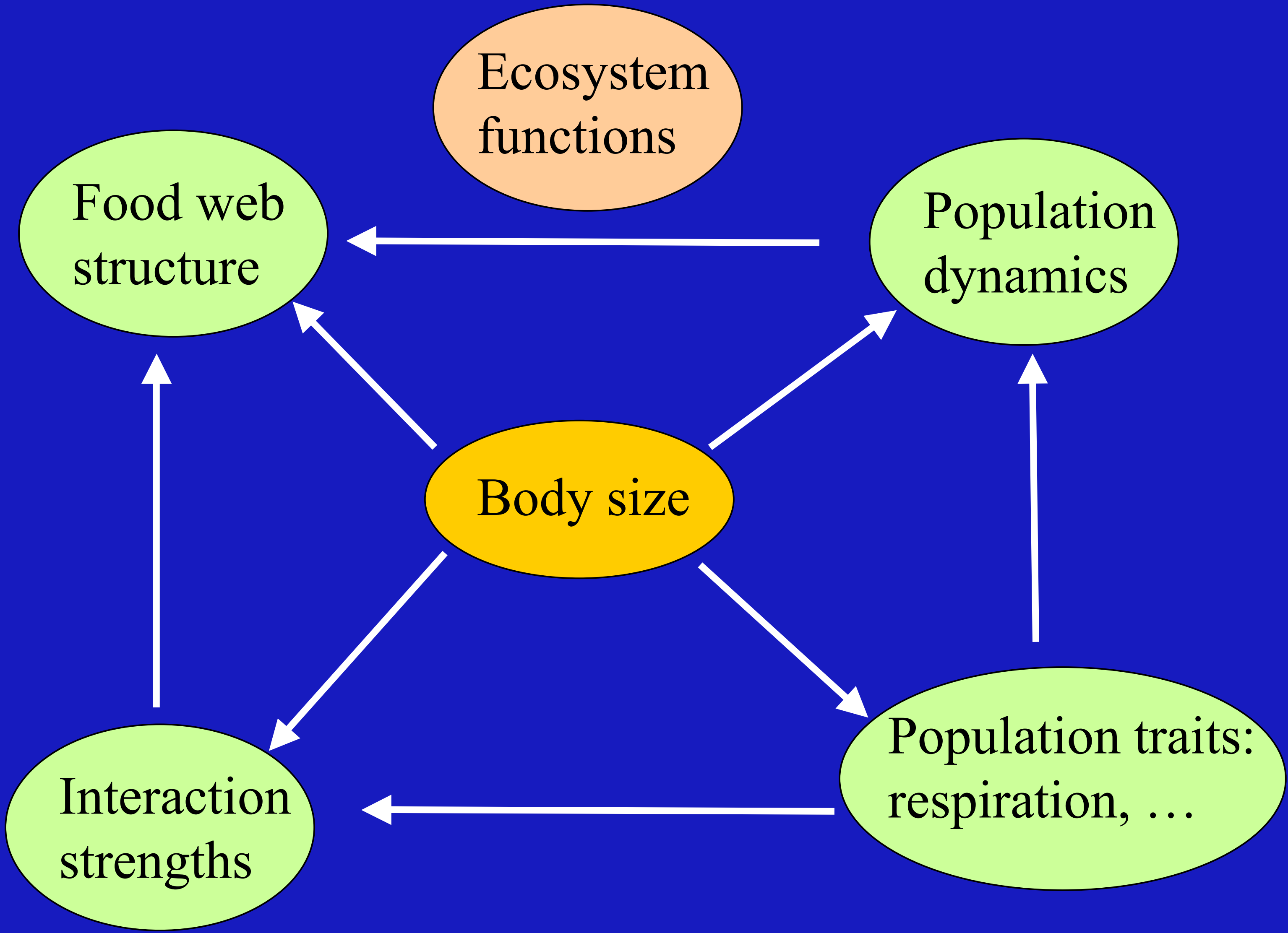
Complex ecological networks

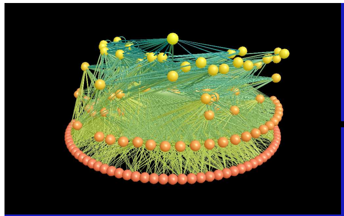


Berlow et al. submitted



Where does species identity (size) matter the most?





Complex ecological networks

AG Brose EcoNetLab

Eric Berlow
(Interaction strengths)

Björn Rall
(Temperature scaling in food webs)

Jens Riede
(Body-size structure of food webs)

Gregor Kalinkat
(multi-species functional responses)

Roswitha Ehnes
(Metabolism / Macroecology)

Olivera Vucic-Pestic
(Functional responses)

Carolin Banasek-Richter
(Spatial food webs)

Sonja Otto
(Species' extinction / food-web stability)

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DFG