# Ecological Networks

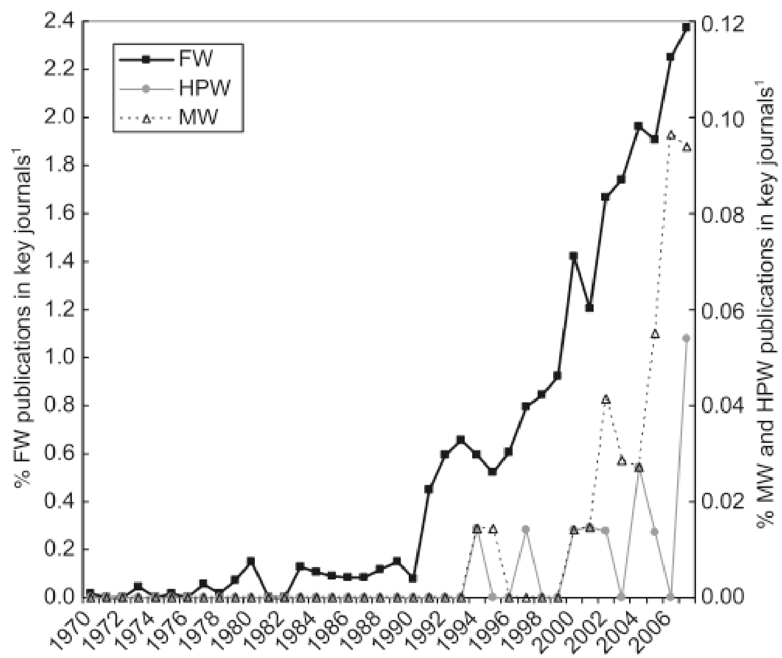
15 September 2009

# Types of ecological networks

- Community
  - nodes: species
  - links: interactions between species
- Population
  - nodes: populations of one species
  - links: dispersal between populations
- Individual
  - nodes: individual organisms
  - links: genetic relatedness (paternity/maternity)

# Community networks

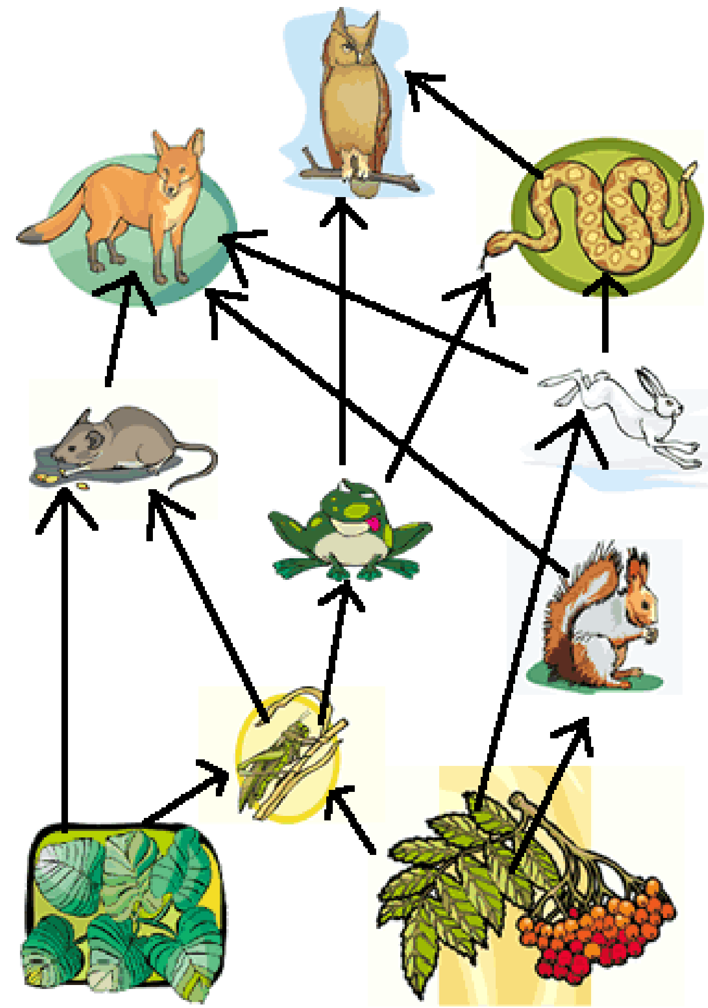
- Antagonistic networks
  - Food webs
  - Host-parasite/parasitoid webs
- Mutualistic networks
  - Plant-seed disperser webs
  - Plant-pollinator webs
  - Plant-ant webs



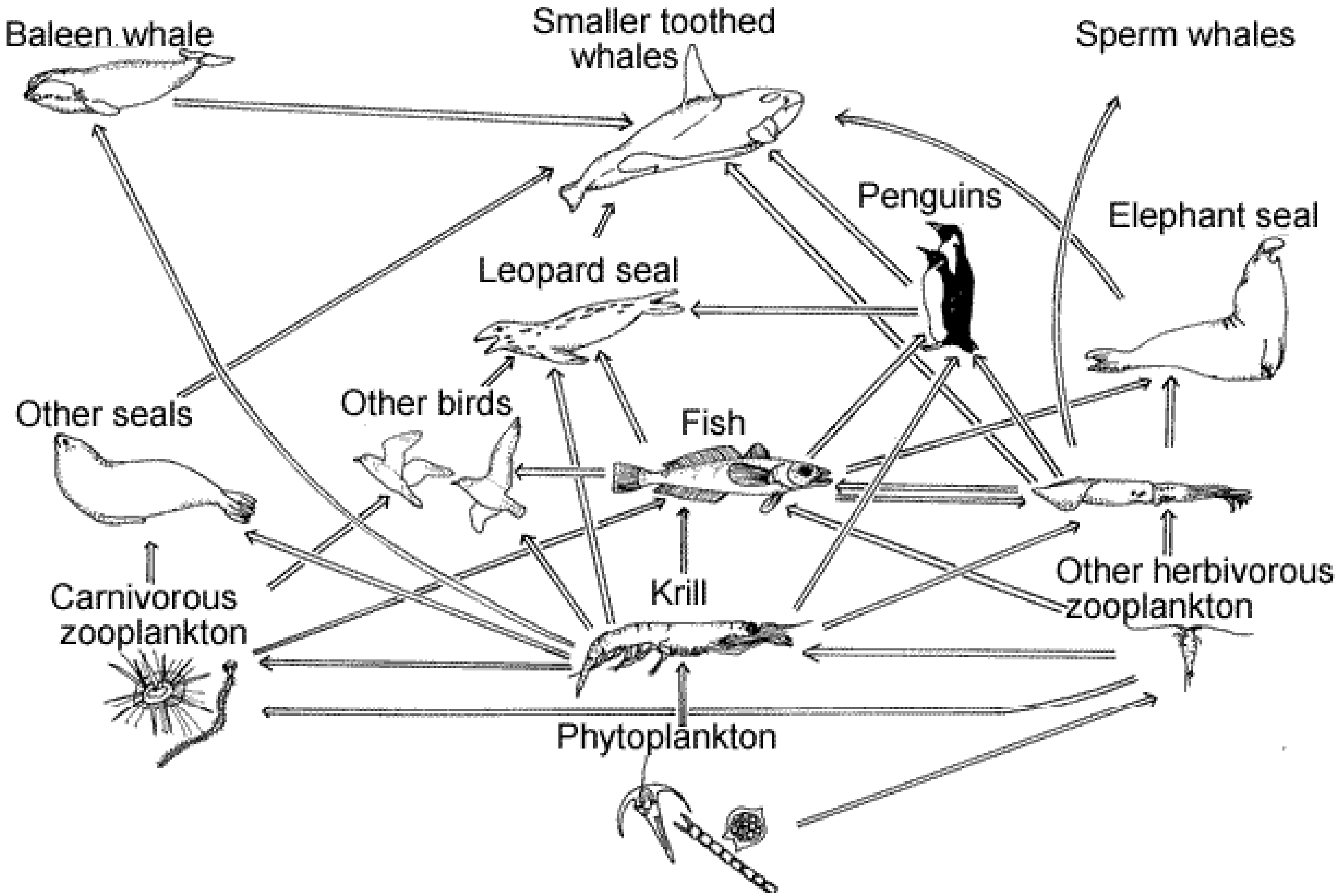

Ings et al 2009 J Animal Ecol

# Food webs

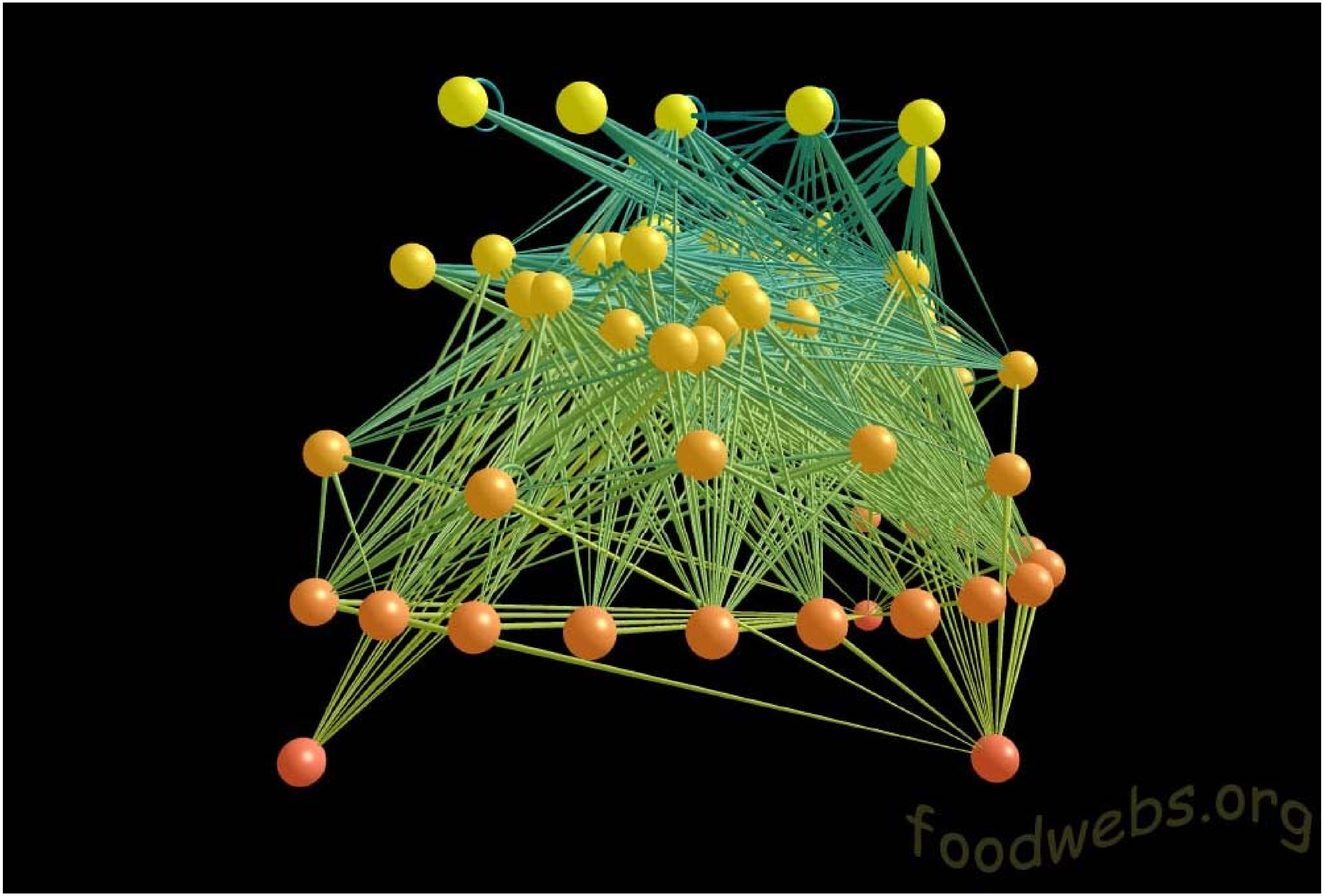
- Directed links denote direction of energy flow



http://www.biologycorner.com/resources/foodweb1.gif

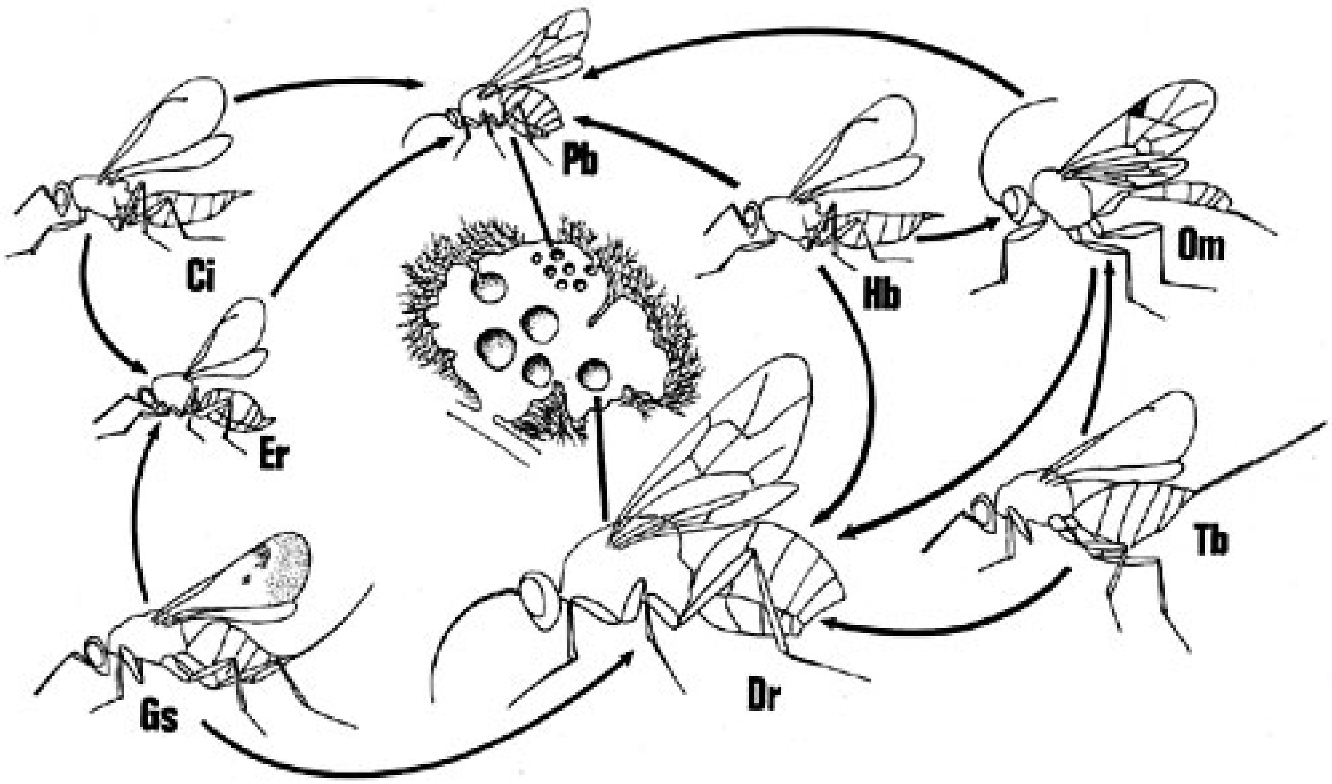



http://www.coolantarctica.com/Antarctica%20fact%20file/wildlife/whales/foodweb.gif


foodwebs.org

# Host-parasitoid

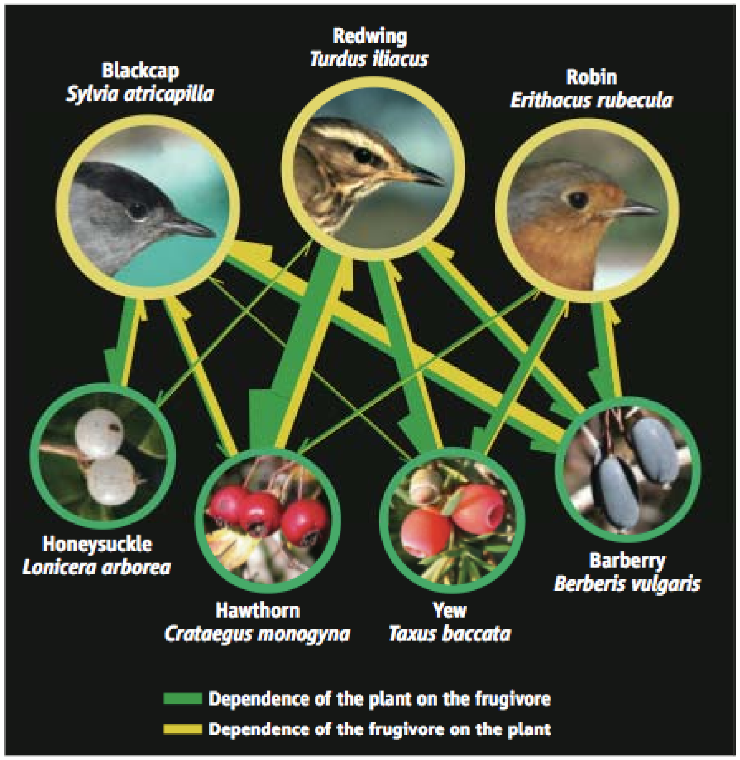
arrows point from parasitoid to host



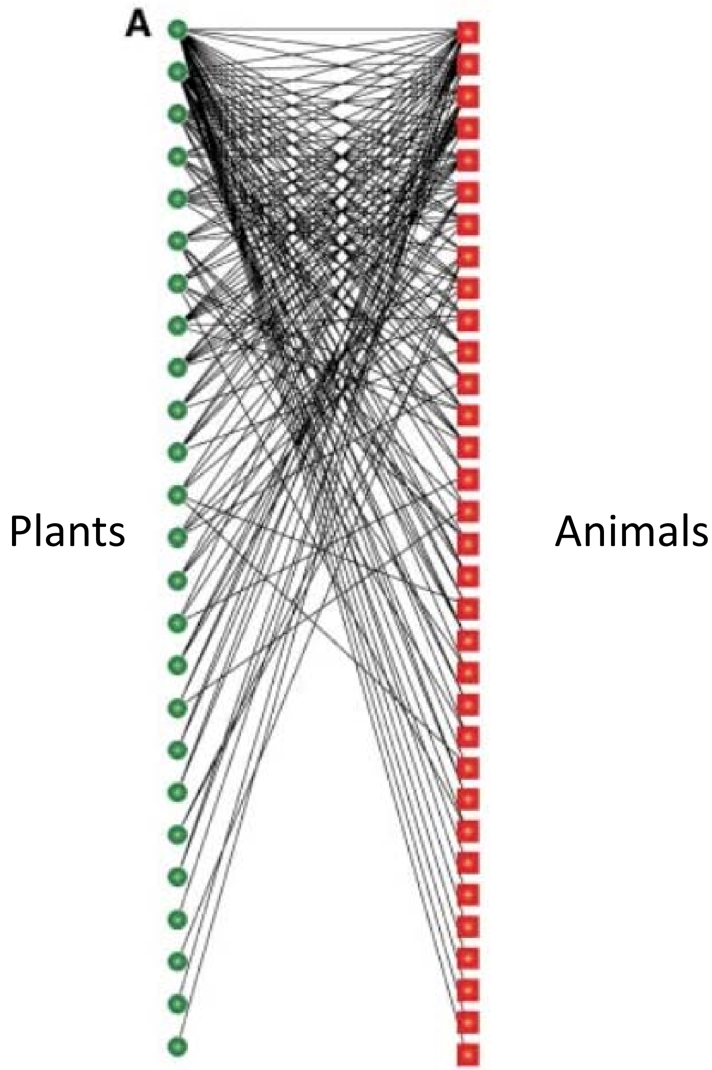


Schilthuizen & Stouthamer 1998 Heredity

# Plant-seed disperser



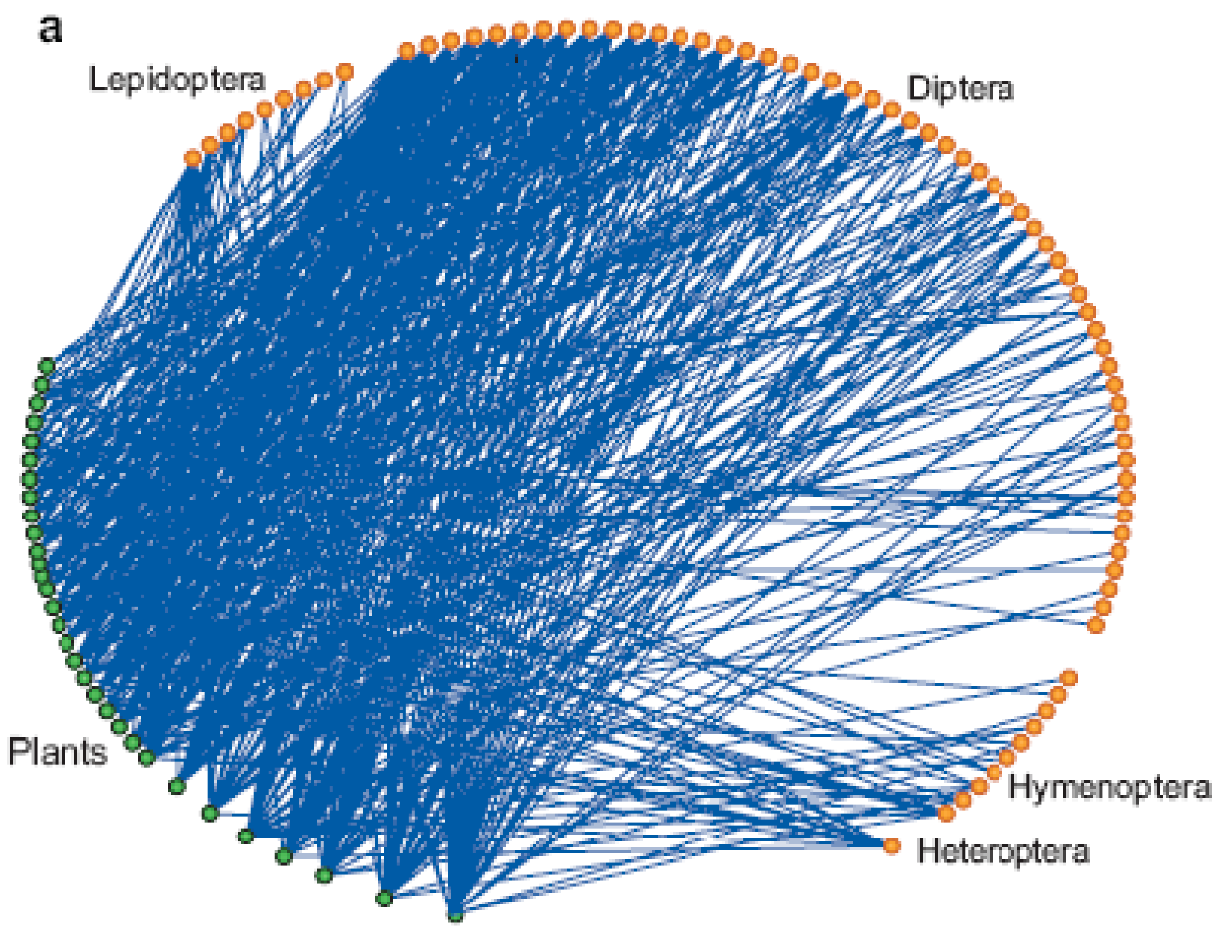

**Asymmetric relationships.** Part of an interaction web from a montane forest in southeast Spain (*1*). Each interaction between frugivore and fruit illustrates two dependence values (green and yellow arrows). The relative frequency of the interaction is shown by the thickness of the arrows.




Thompson 2006 Science

Bascompte et al. 2006 Science

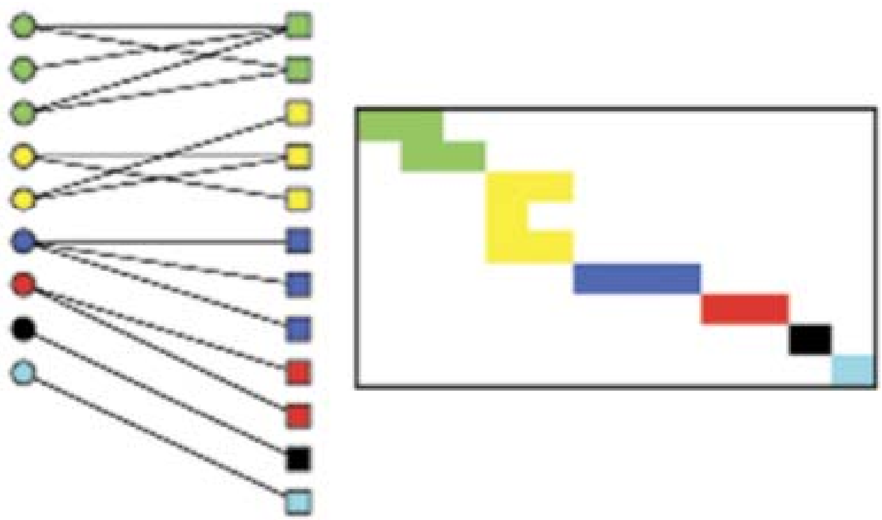
# Plant-pollinator




Greenland plant-pollinator network

Bascompte & Jordano 2007 Ann Rev Ecol Evo Syst

# Plant-ant

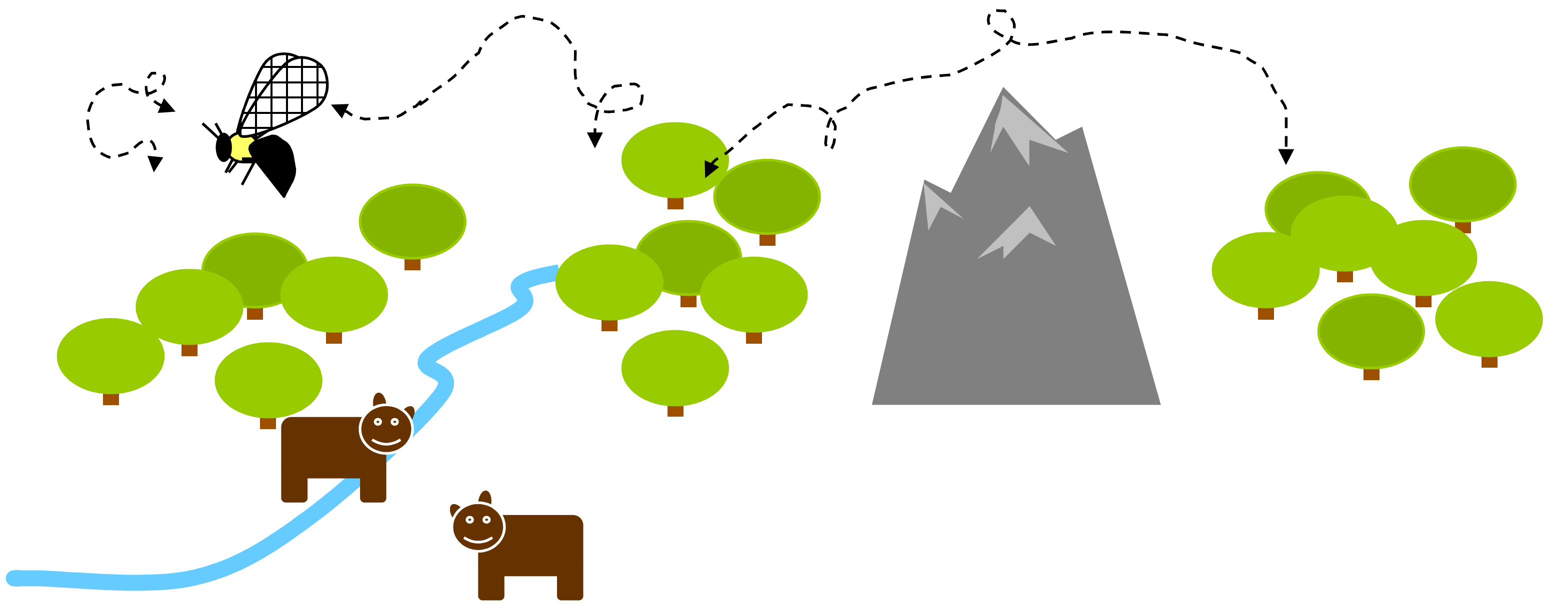
Guimarães et al. 2007 Curr Biol

# Antagonistic vs. Mutualistic Webs

- How are these two types of community webs similar?
- Different?

# Population

- Used to describe patterns of movement
  - dispersal
  - migration
  - genetic relatedness (e.g., through parentage)



# Habitat connectivity paths

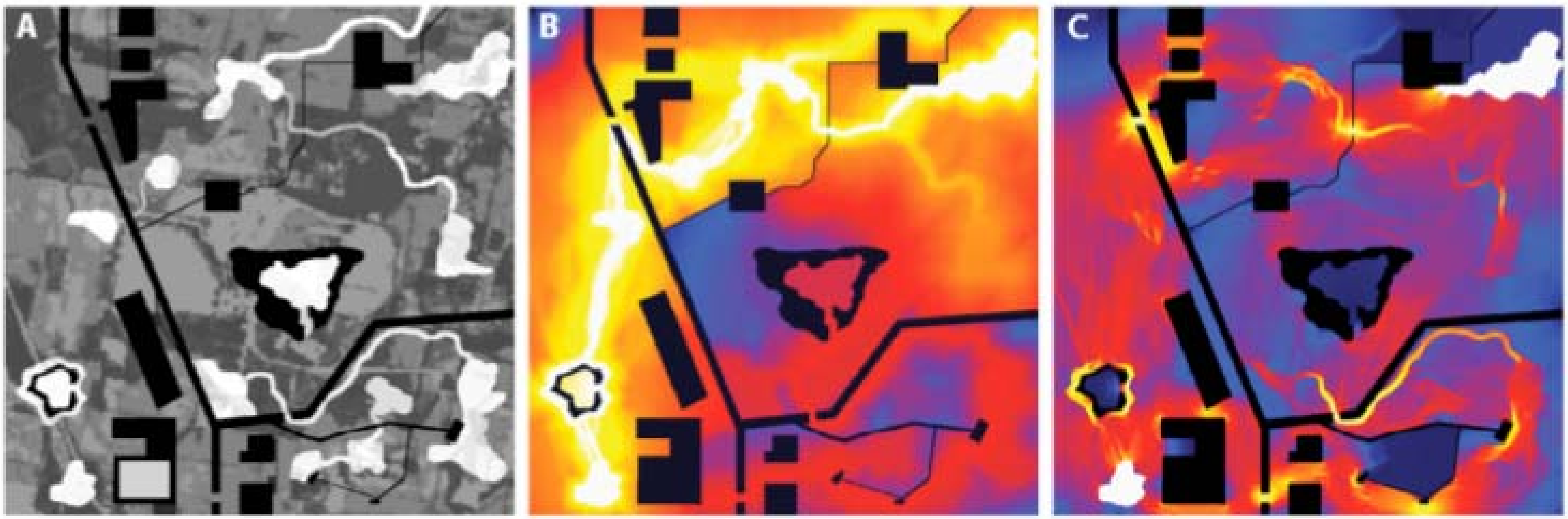



FIG. 8. Connective elements identified using least-cost path and circuit models in a complex landscape. (A) Map of the landscape, with resistances and costs for circuit and least-cost path analyses ranging from 1 (light gray) to 100 (dark gray) to infinite (black). (B) Results from least-cost modeling between habitat patches in lower left and upper right corners of the map. The value assigned to each cell indicates the cost accumulated moving along the most efficient possible route that passes through the cell from one habitat patch to the other; brighter areas indicate cells along the route of lowest cumulative cost. Some habitat cul-de-sacs are highlighted because the most efficient path connecting one patch to the other via the cul-de-sac has a low cost relative to most other features in the landscape. For the same reason, some "corridors to nowhere" are highlighted, such as the one leading off of the top of the map. (C) Current map between the same two habitat patches. Higher current densities indicate cells with higher net passage probabilities for random walkers moving from one patch to the other. The map highlights "pinch points," or critical habitat connections, between the two patches. Habitat cul-de-sacs have minimal current flow because they do not contribute new, independent pathways between habitat patches.

McRae et al. 2008 Ecology

# Population graphs

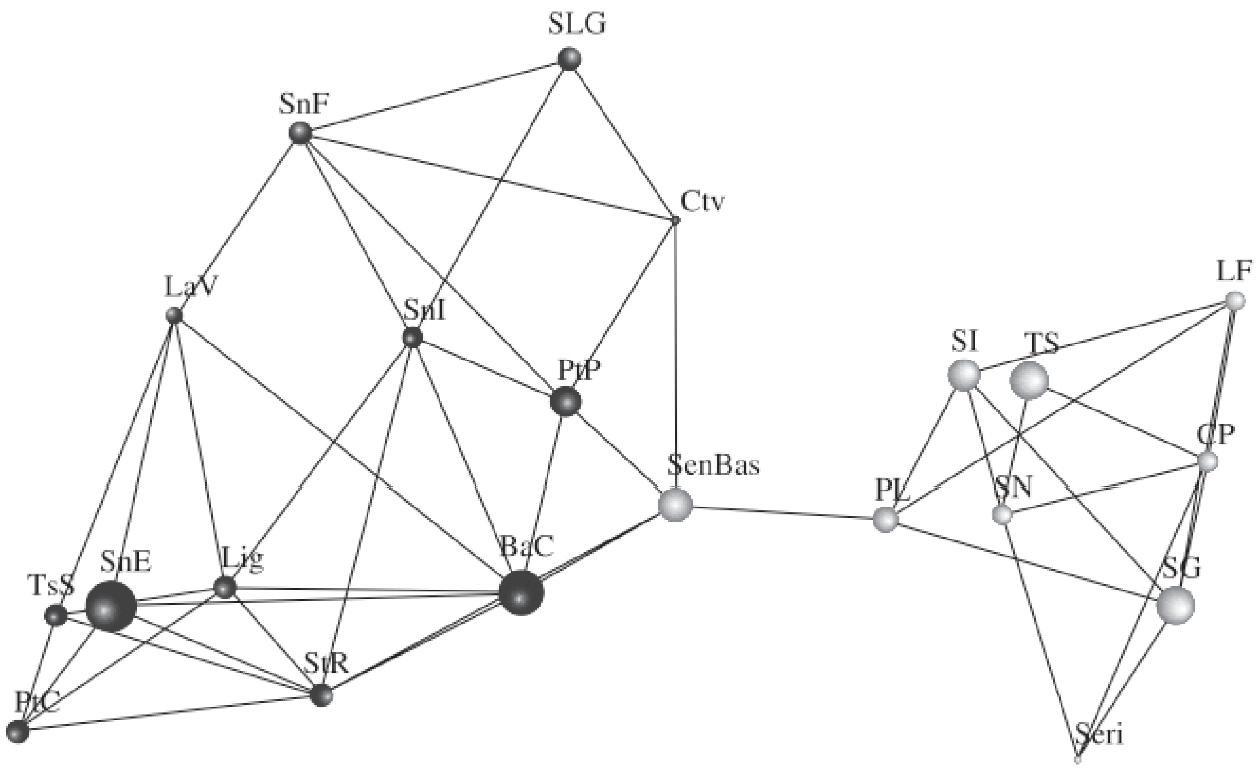



**Fig. 2** Population Graph representing the genetic relationships among Peninsular (dark nodes) and Continental (light nodes) populations of *Lophocereus schottii*. The differences in node size reflect differences in within population genetic variability, whereas the edge lengths represent the among population component of genetic variation due to the connecting nodes. Both node sizes and edge lengths are projected within a three-dimensional drawing space.

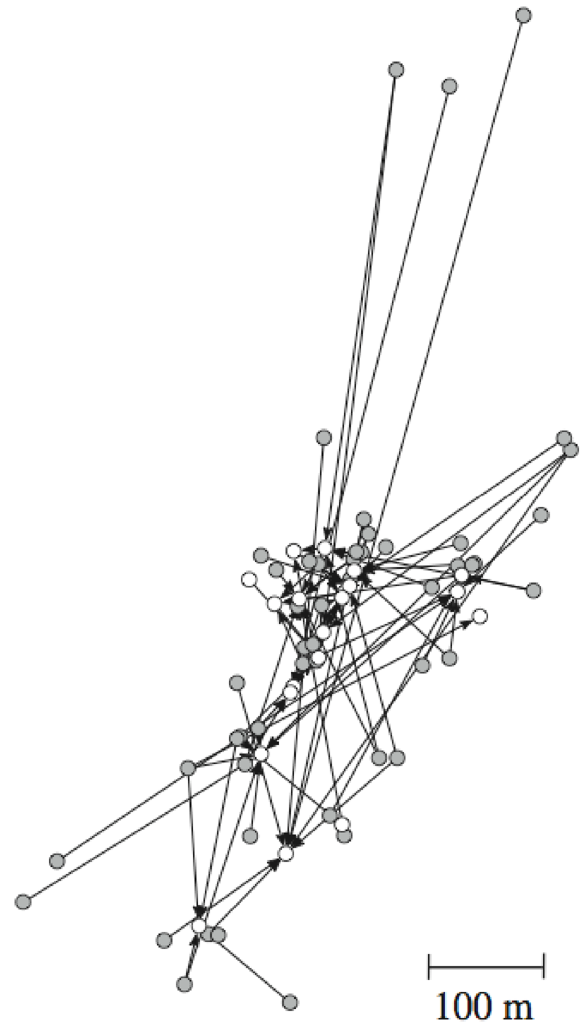
Dyer & Nason 2004

http://www.tnstate.edu/ganter/John%27s%20Senita.JPG

# Individual

Mahaleb cherry paternity study

(a)

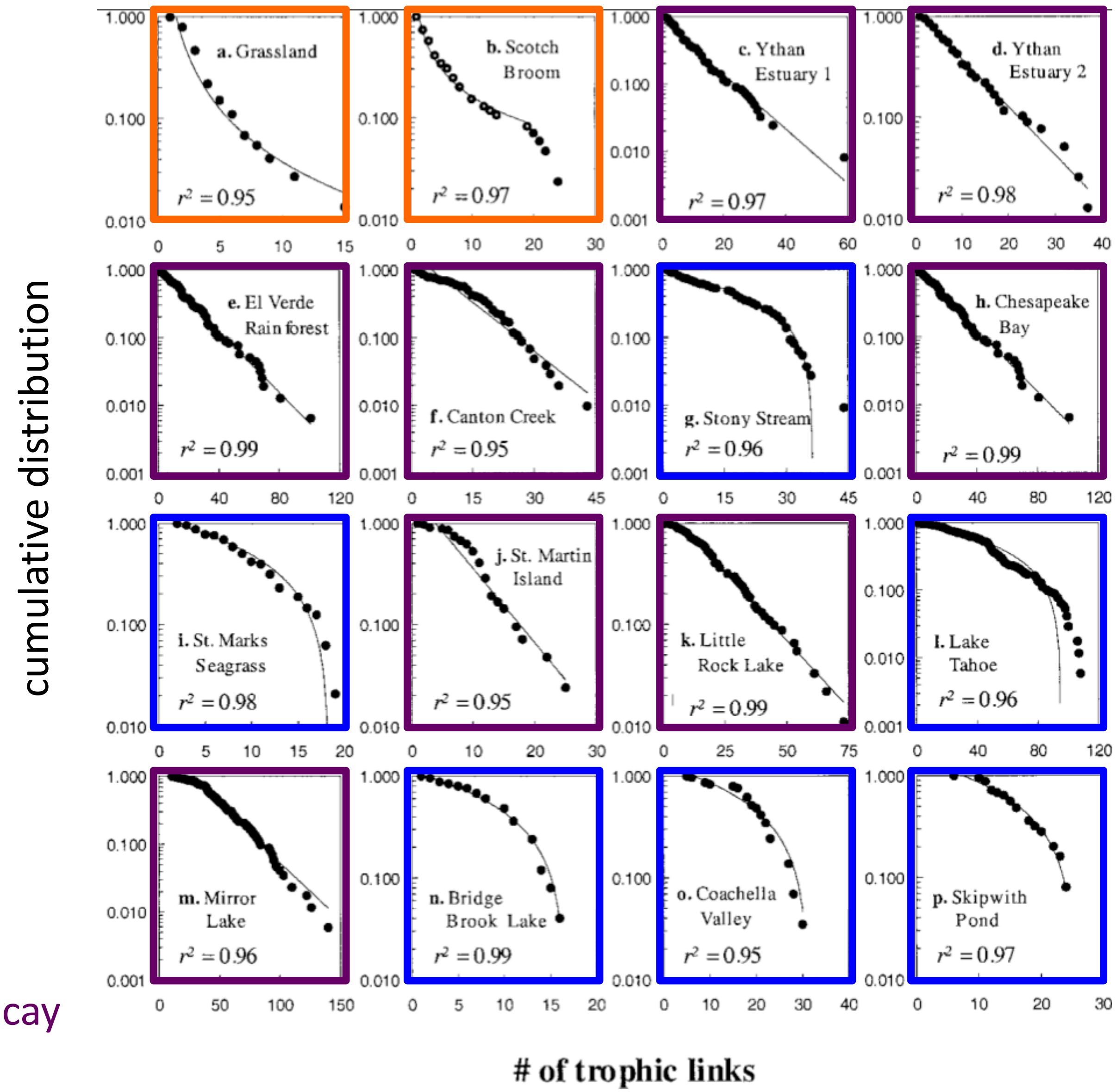



Fortuna et al. 2008 Ecol Lett

# Structural properties

- Degree distribution
- Hierarchy
- Path lengths
- Modularity

# Food webs: Degree distribution




power law

exponential decay

uniform

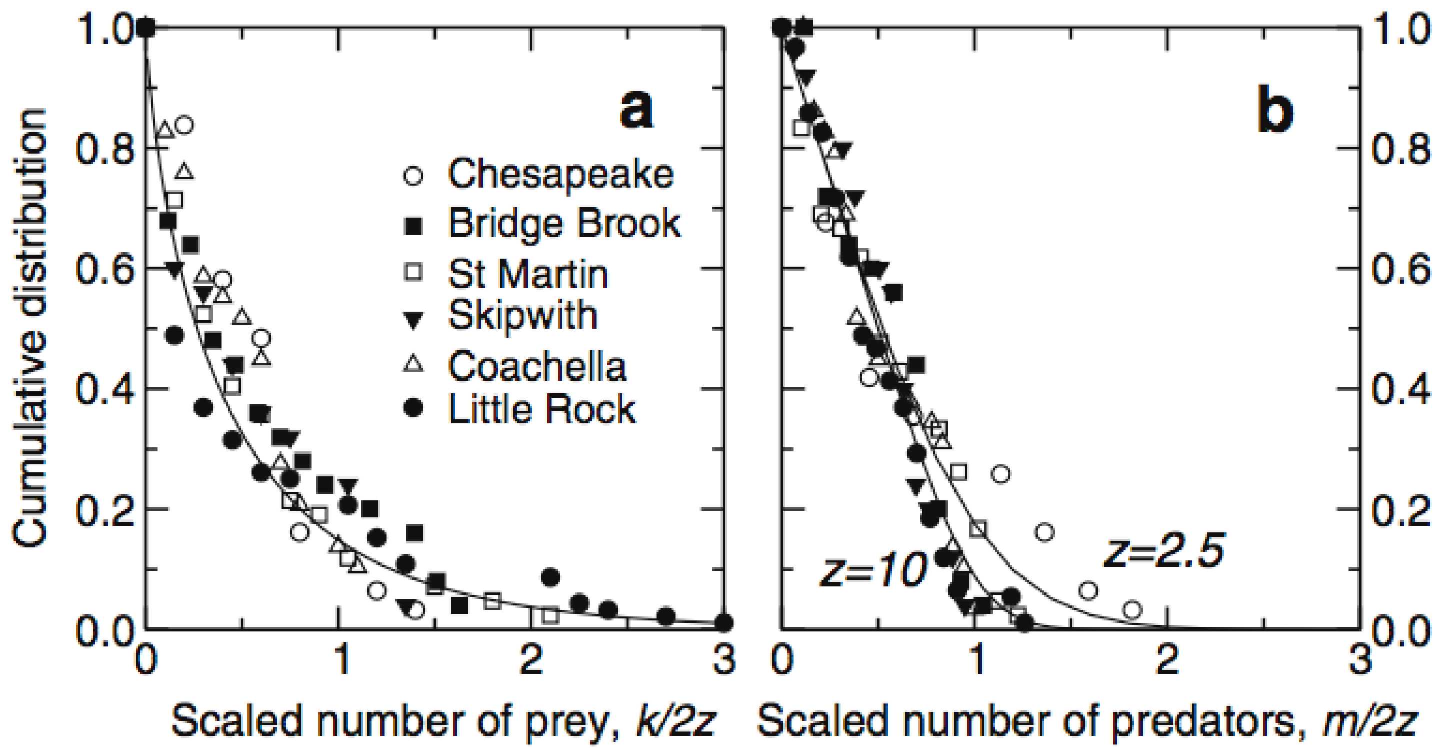
Dunne et al 2002 PNAS

# Food webs: Degree distribution

- Distribution is correlated with connectance ($C=E/N^2$)
  - uniform distribution & high connectance
  - exponential distribution & intermediate connectance
  - power-law & low connectance
- Networks may be built according to available niches

Dunne et al 2002 PNAS

# Food webs: Degree distribution

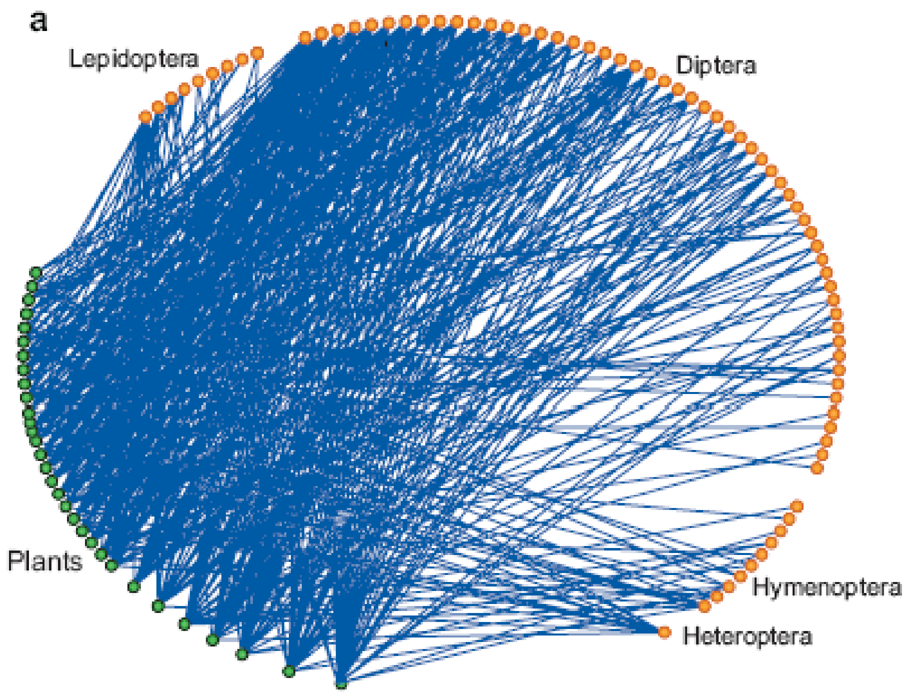



Food web degree distribution is also explained by linkage density (*z*)

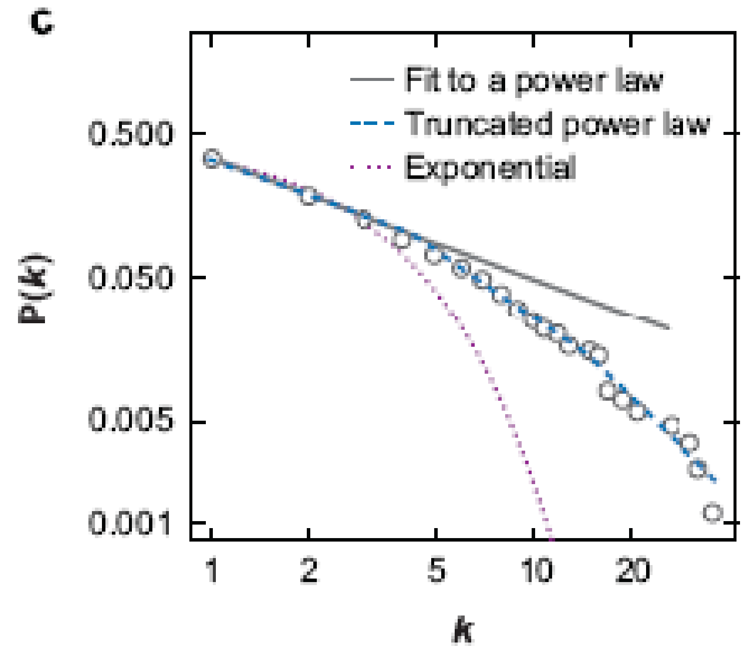
$$z \equiv L / S$$

Camacho et al. 2002 Phys Rev Lett

# Mutualistic webs: Degree distribution




Greenland plant-pollinator network




A truncated power law fits most mutualistic networks

$$p(k) \propto k^{-\gamma} e^{-\frac{k}{k_c}}$$

Bascompte & Jordano 2007 Ann Rev Ecol Evo Syst

# Mutualistic webs: Degree distribution

- Constraints restrict edges that can be established
  - Morphological mismatch
  - Phenological mismatch

Jordano et al. 2003 Ecol Lett

# Hierarchy

- Highly nested

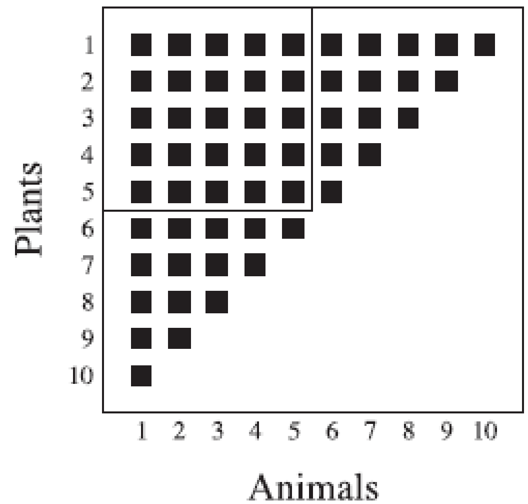
<u>Nestedness</u>

Perfect 1

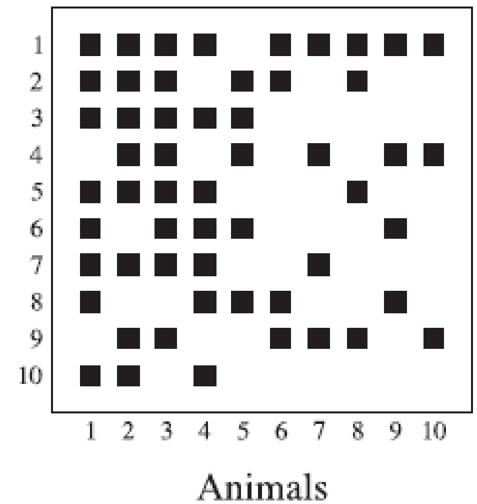
Random 0.55

Real 0.74

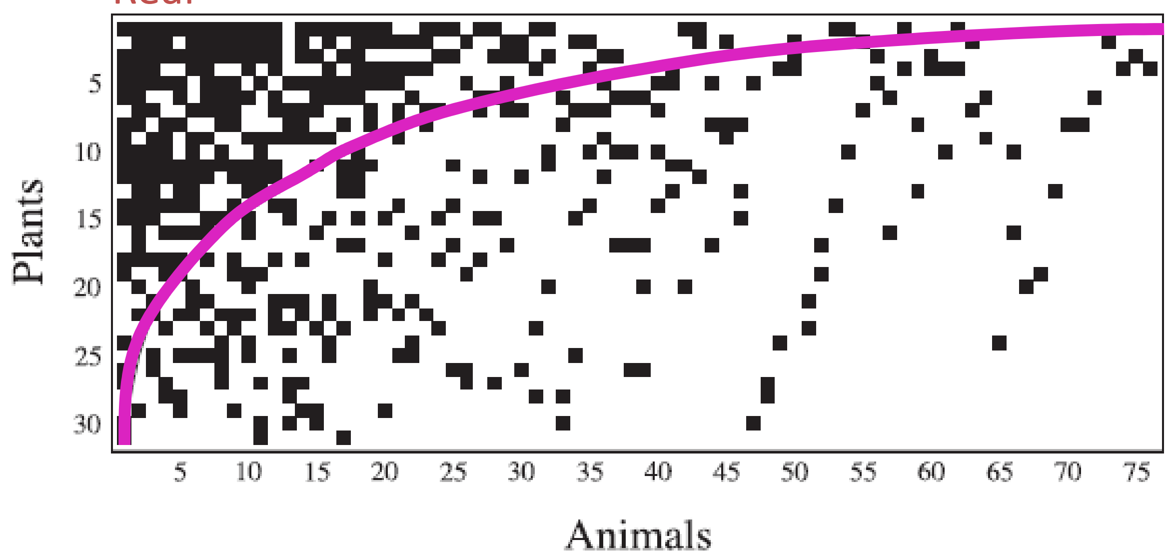
Perfectly nested




Randomly nested




Real




Bascompte et al. 2003 PNAS

# Mutualistic networks: Small-world

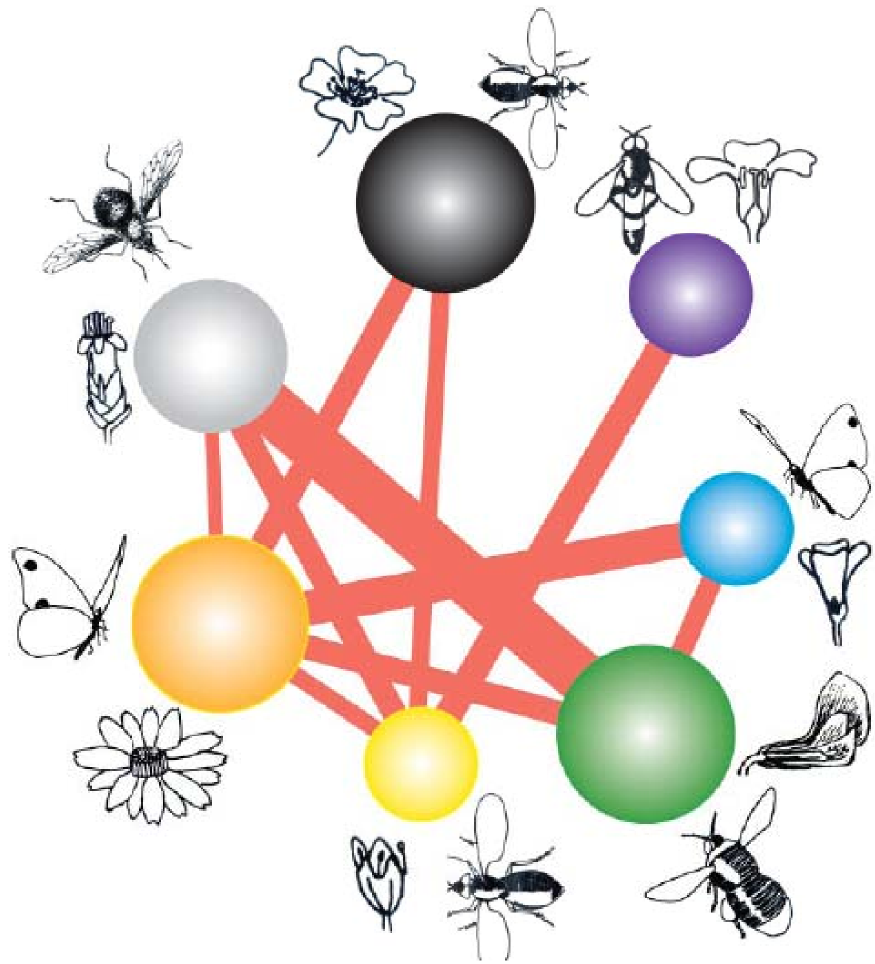
- Converted 2-mode to 1-mode networks
- 2-mode & 1-mode properties correlated
- Path length increased with network size
  - <l>=0.82+0.46logN
  - (WWW, <l>=0.35+2.06logN)
- For ecological webs, “everything is connected to everything” Williams et al. 2002

| | Pollinator | Plant |
|---|---|---|
| <<l>> | 1.7 | 1.5 |
| <<c>> | 0.85 | 0.84 |

Olesen et al. 2006 J Theor Bio

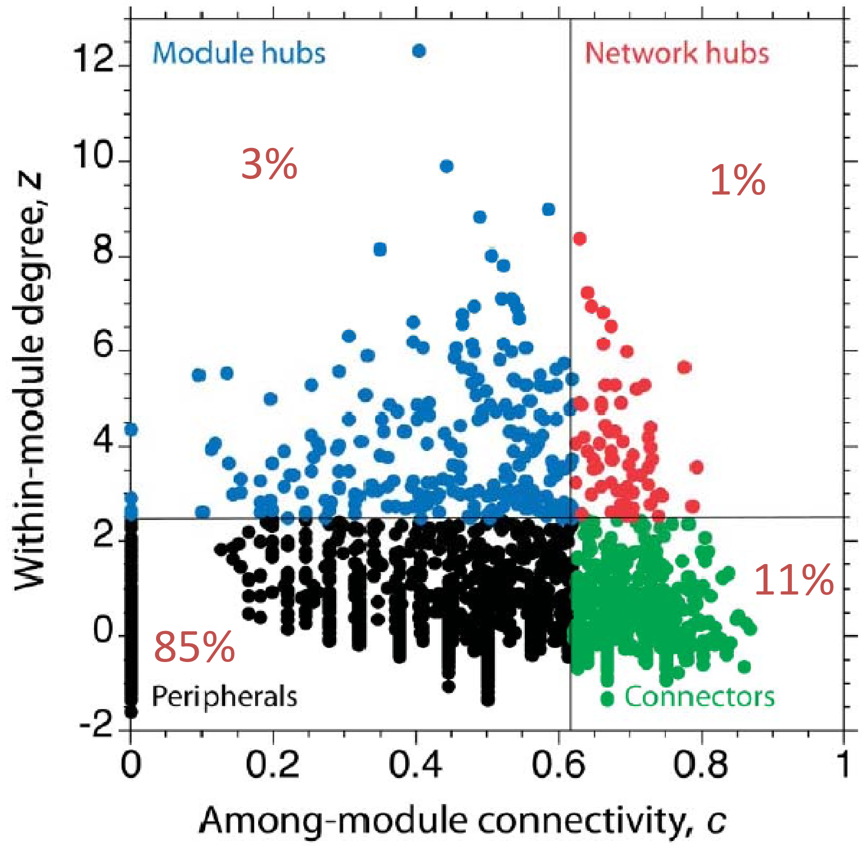
# Modularity

- Module: (aka compartment, community) areas within a network that are densely linked, separated by areas that are sparsely linked
- Syndrome: correlated traits shaped by similar interaction
- Are modules related to syndromes?



Olesen et al. 2007 PNAS

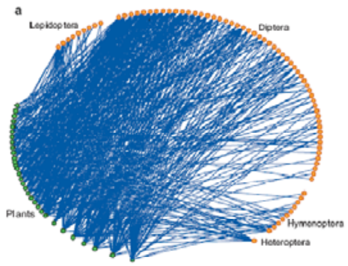
# Modularity




Olesen et al. 2007 PNAS

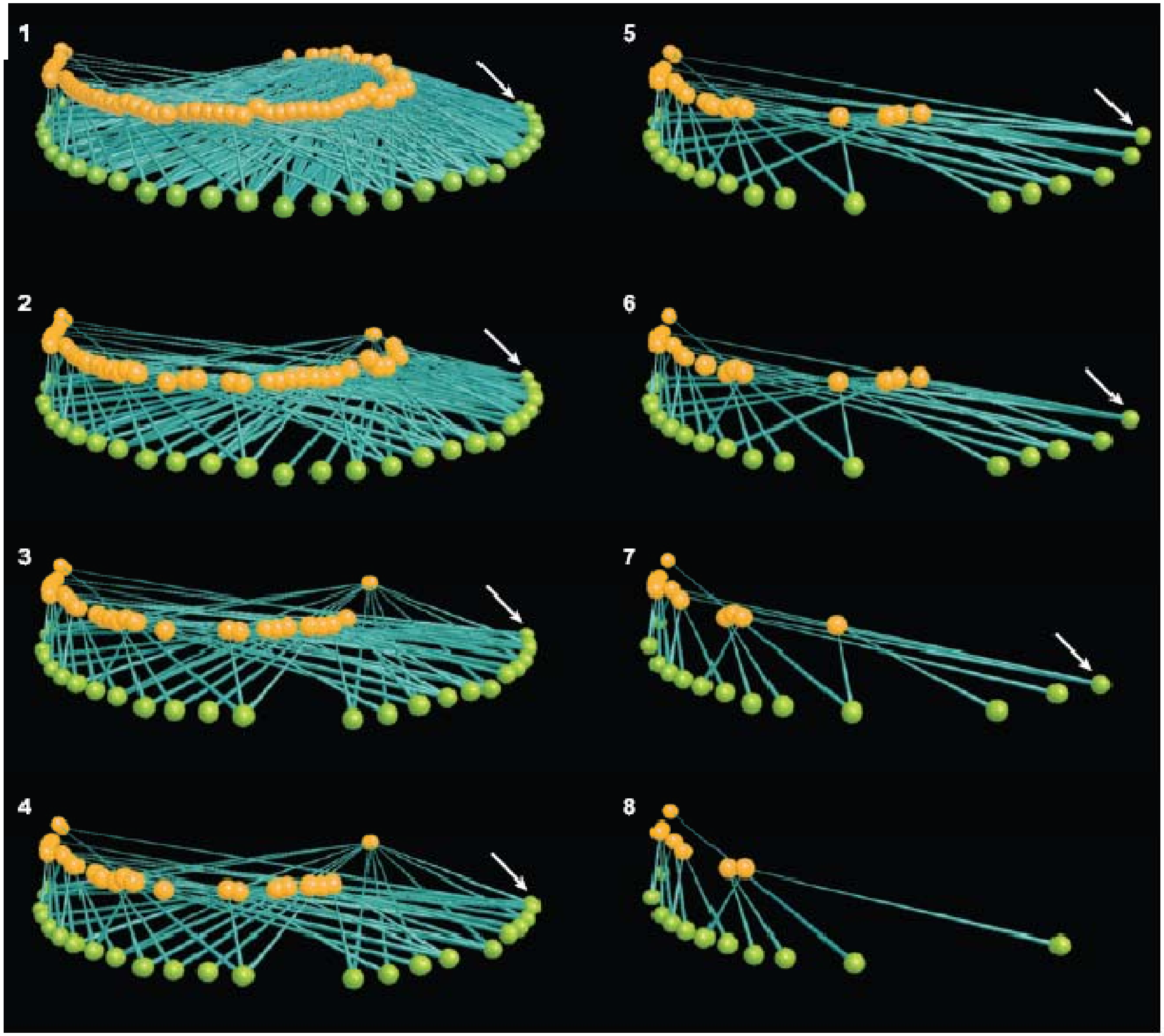
# Stability of ecological networks

- The presence of a species (node) or an interaction (link) is not necessarily constant
  - species may go extinct
  - new species may colonize
  - phenology (timing)
  - …
- How might the network change as a result?




# Robustness

Greenland plant-pollinator network




Bascompte & Jordano 2007 Ann Rev Ecol Evo Syst

# Robustness

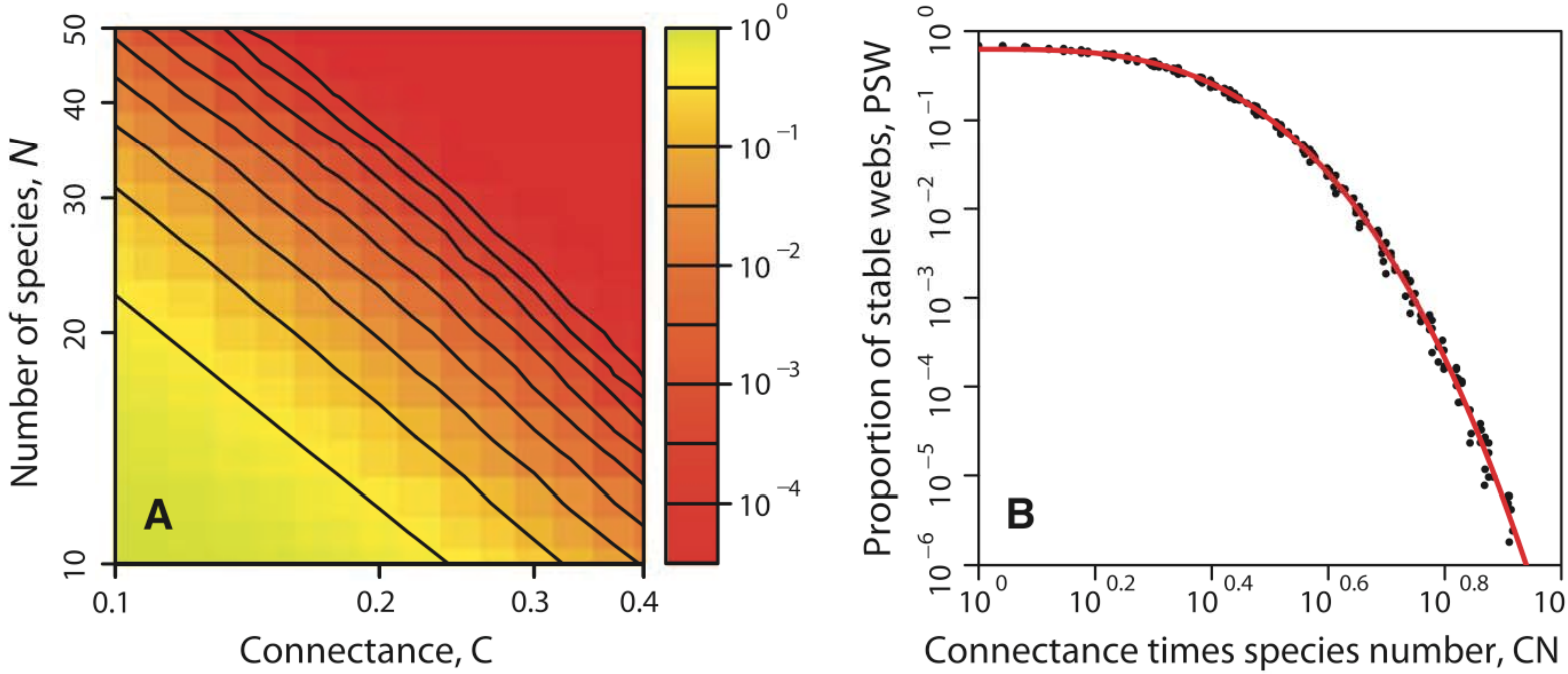



**Fig. 2.** Dependence of food-web stability on $N$ and $C$. (**A**) The PSW decreases with increasing $N$ and $C$, as shown by the color coding and the logarithmically spaced level lines. (**B**) The power law $\log_{10}(\mathrm{PSW}) + a = bx^c$ (red curve) with $x = \log_{10}(CN)$, $a = 0.2090$, $b = -7.025$, and $c = 3.138$ explains 99.64% of the shown variation.

Gross et al. 2009 Science

# Robustness

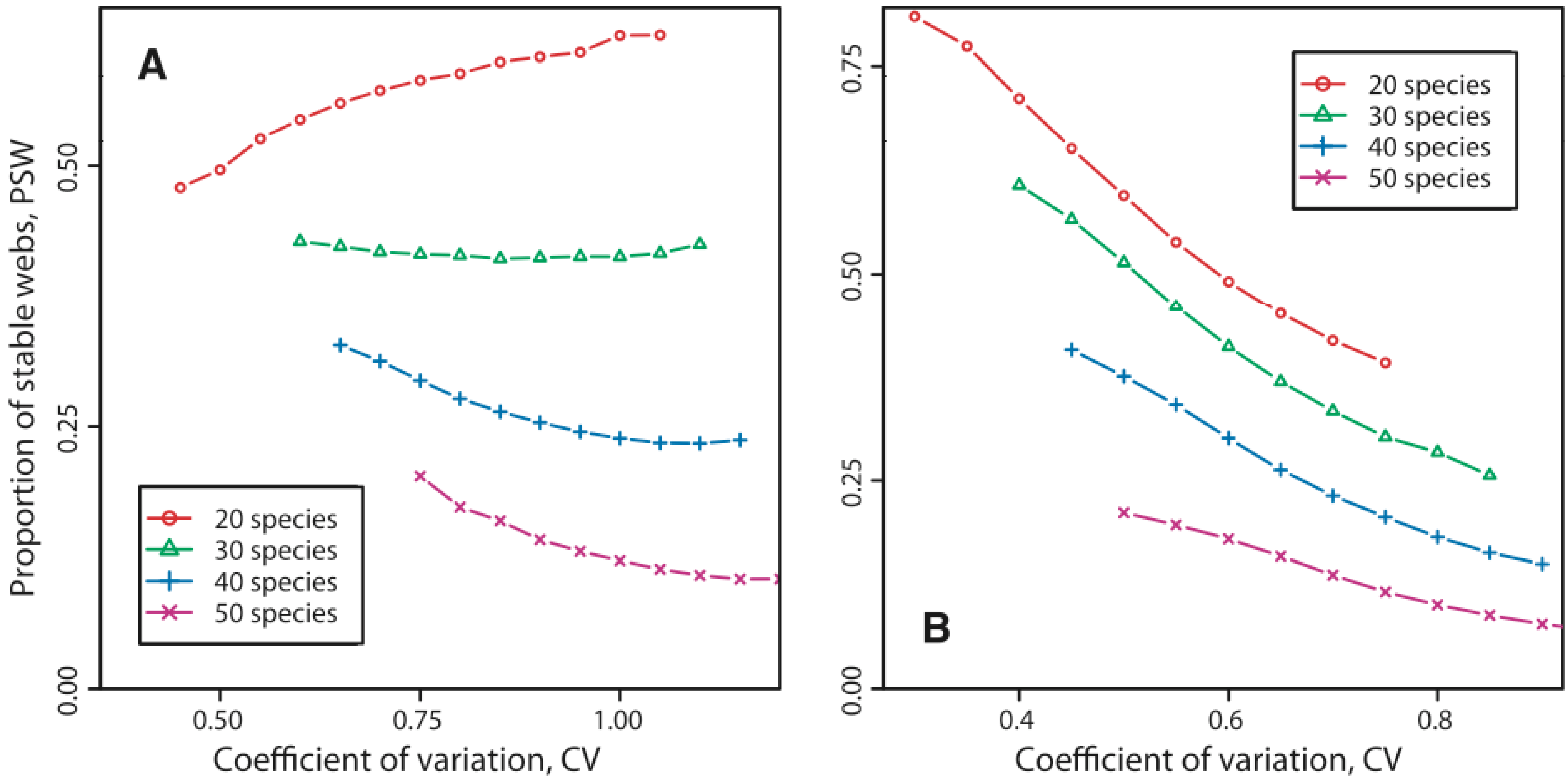



**Fig. 3.** Dependence of food-web stability on link-strength variability. The former is characterized by PSW and the latter by CV. Link strength is normalized by (**A**) the predator's total influx or (**B**) the prey's total outflux. Link-strength variability enhances stability in small food webs but has a destabilizing effect in larger webs.

Gross et al. 2009 Science

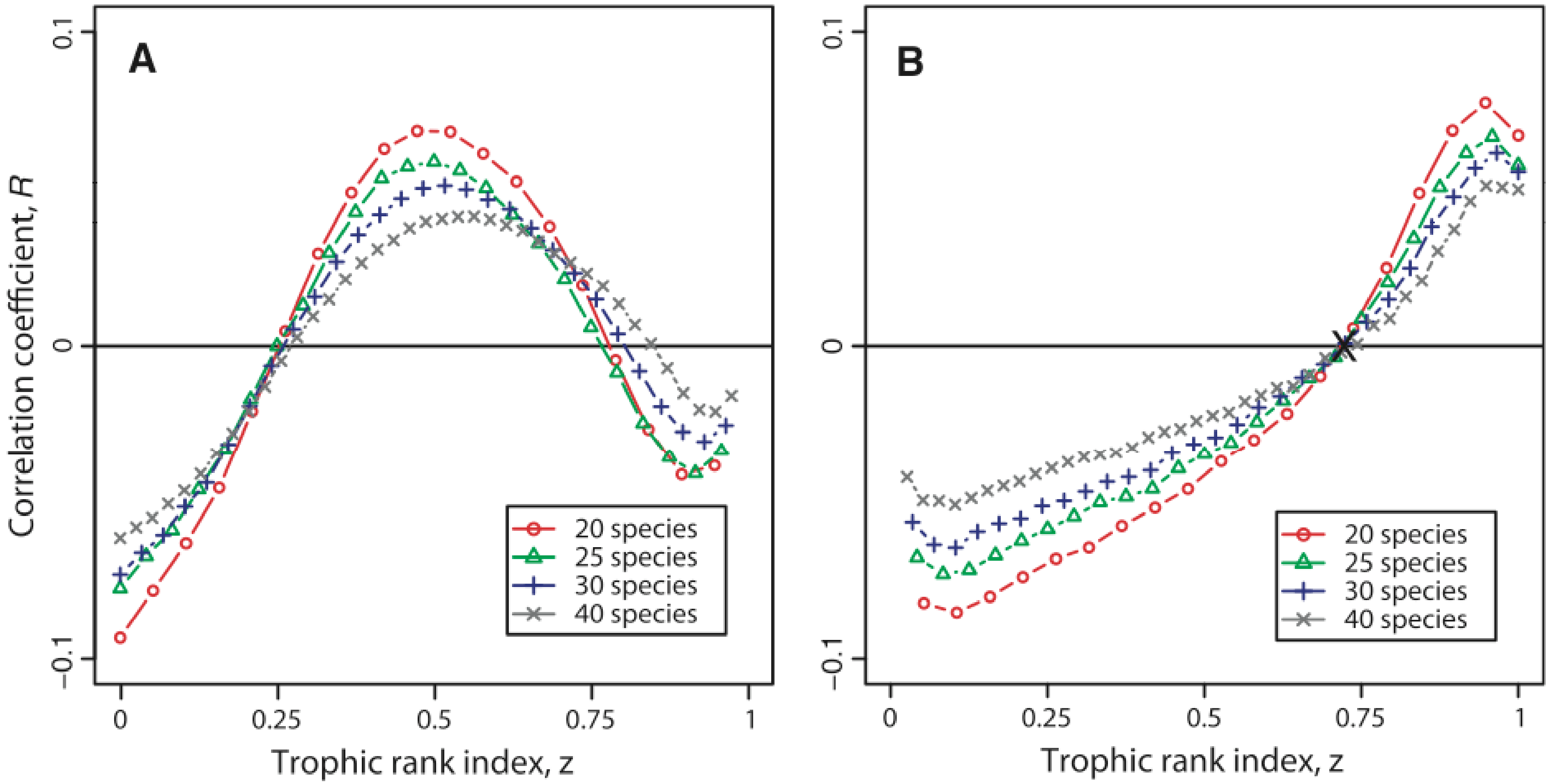
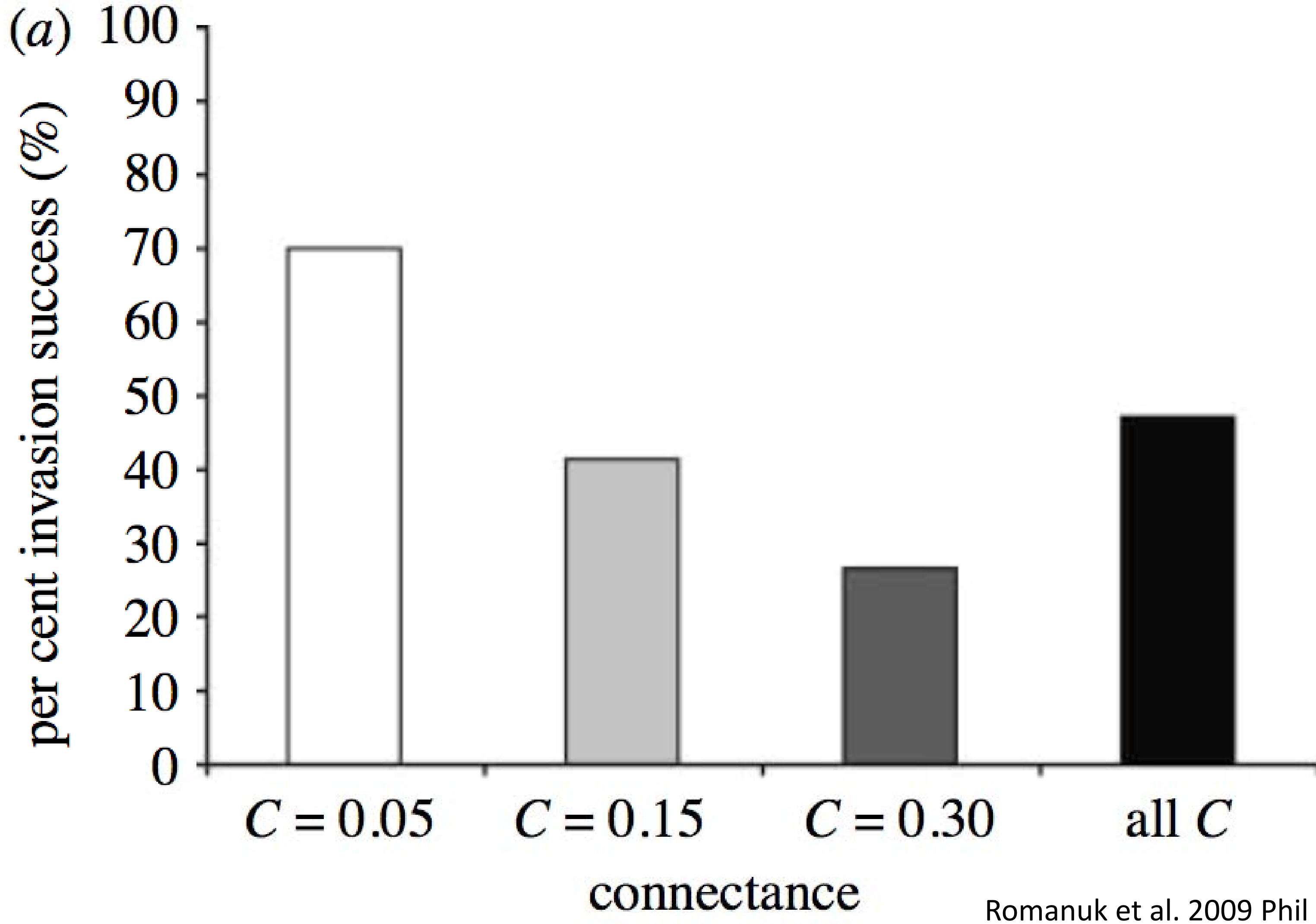



**Fig. 4.** Dependence of food-web stability on the distribution of links. (**A**) Correlation of stability with the number of predator species preying on a focal species, in dependence on the trophic position of the focal species as measured by its trophic-rank index *z*. Stability is enhanced if most species prey upon intermediate species, which are characterized by indices around $z = 0.5$. (**B**) Correlation of stability with the number of prey species predated upon by a focal species, in dependence on the trophic position of the focal species. Stability is enhanced if apical predators are generalists, whereas intermediate predators are specialists.

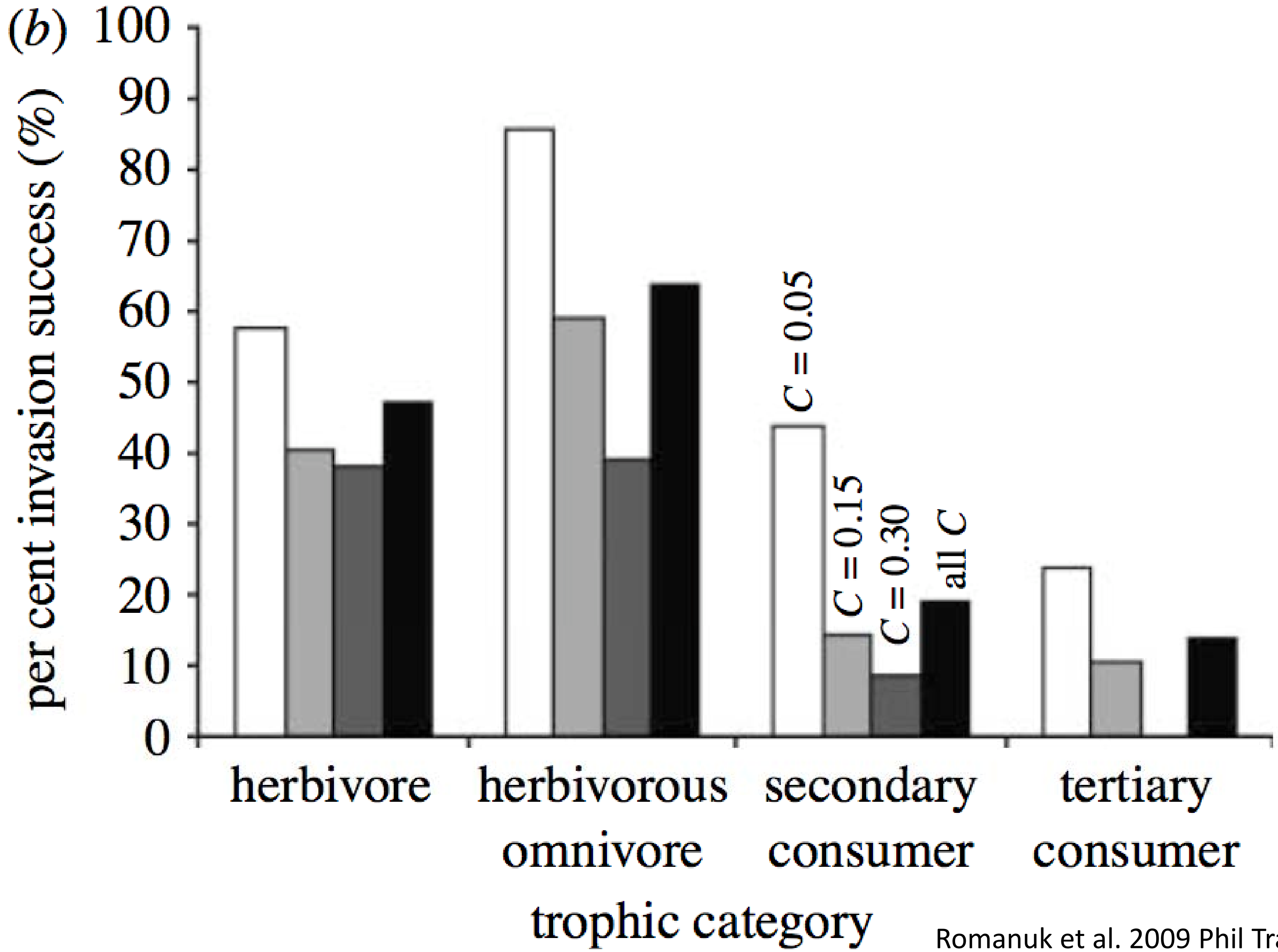
Gross et al. 2009 Science

# Resistance to invasion




Romanuk et al. 2009 Phil Trans R Soc B

# Resistance to invasion




Romanuk et al. 2009 Phil Trans R Soc B

# Stability of ecological network

- Mutualistic networks are vulnerable to extinction of high-degree nodes (generalists)
- Food web stability decreases with increasing network size and connectance
- Food web stability is greatest when predators are neither specialists nor generalists (intermediate degree)
- Invasion success decreases with increasing connectance
- Invasion success higher for generalist invaders

# Assembly

- Large disturbances can cause whole communities to go extinct
- Eventually, species will accumulate to create another community
- How are communities formed over time?


Before

Mount St. Helens erupted in 1980


After

# Assembly models

- Species originate from a ‘regional species pool’
- Each species is introduced in sequence
  - random
  - optimized
- Colonization is successful or not
  - Secondary extinctions occur or do not occur

# Assembly models

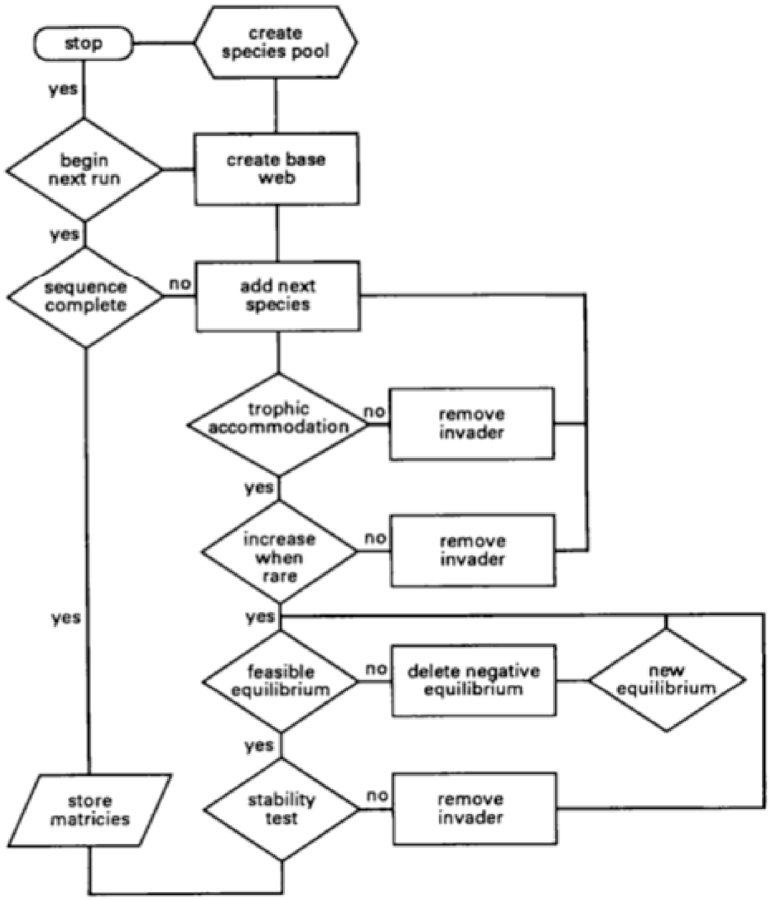
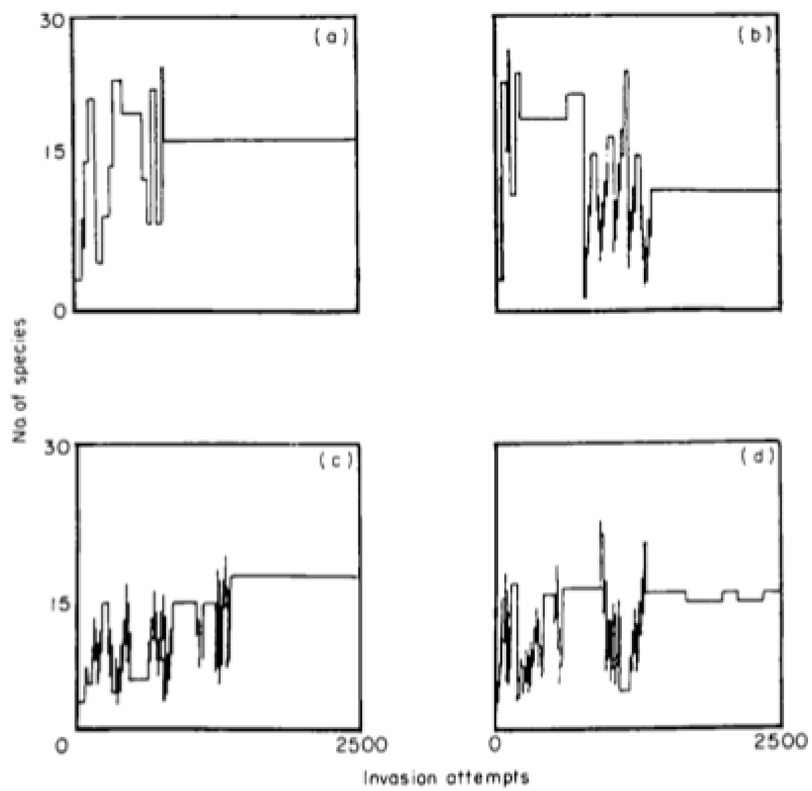



FIG. 1. General structure of the community assembly algorithm.

Outcomes differ according to sequence

- same regional species pool, but different order of introduction yields different network sizes




Drake 1990 J Theor Biol

# Network inference

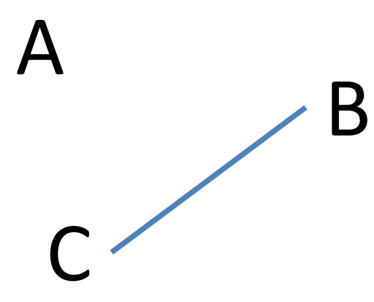
- As for other complex systems, data for ecological networks are hard to obtain directly
- Passive sampling can produce copious data, for relatively little effort
  - insect traps, video surveillance, etc.


http://www.omafra.gov.on.ca/english/crops/hort/news/hortmatt/2005/06hrt05a9f5.jpg

# Network inference

- Passive sampling produces copious presence/absence or frequency animal data, over time but NO plant data
- Goal of network inference is to use this animal data to construct the relationships in the network

| | A | B | C |
|---|---|---|---|
| $t_0$ | 0 | 1 | 1 |
| $t_1$ | 0 | 1 | 1 |
| $t_2$ | 0 | 1 | 1 |



# Inference methods

- Developed for biochemical networks
- No rigorous test of accuracy exists yet
- Assumptions of inference method are important!

- **Boolean:** REVEAL (Reverse engineering algorithm)
- **Polynomial:** Jarrah et al. 2007 Adv in Appl Math; Vera-Licona & Laubenbacher 2008 Ann Zool Fennici
- **Bayesian:** Yu et al. 2004 Bioinformatics