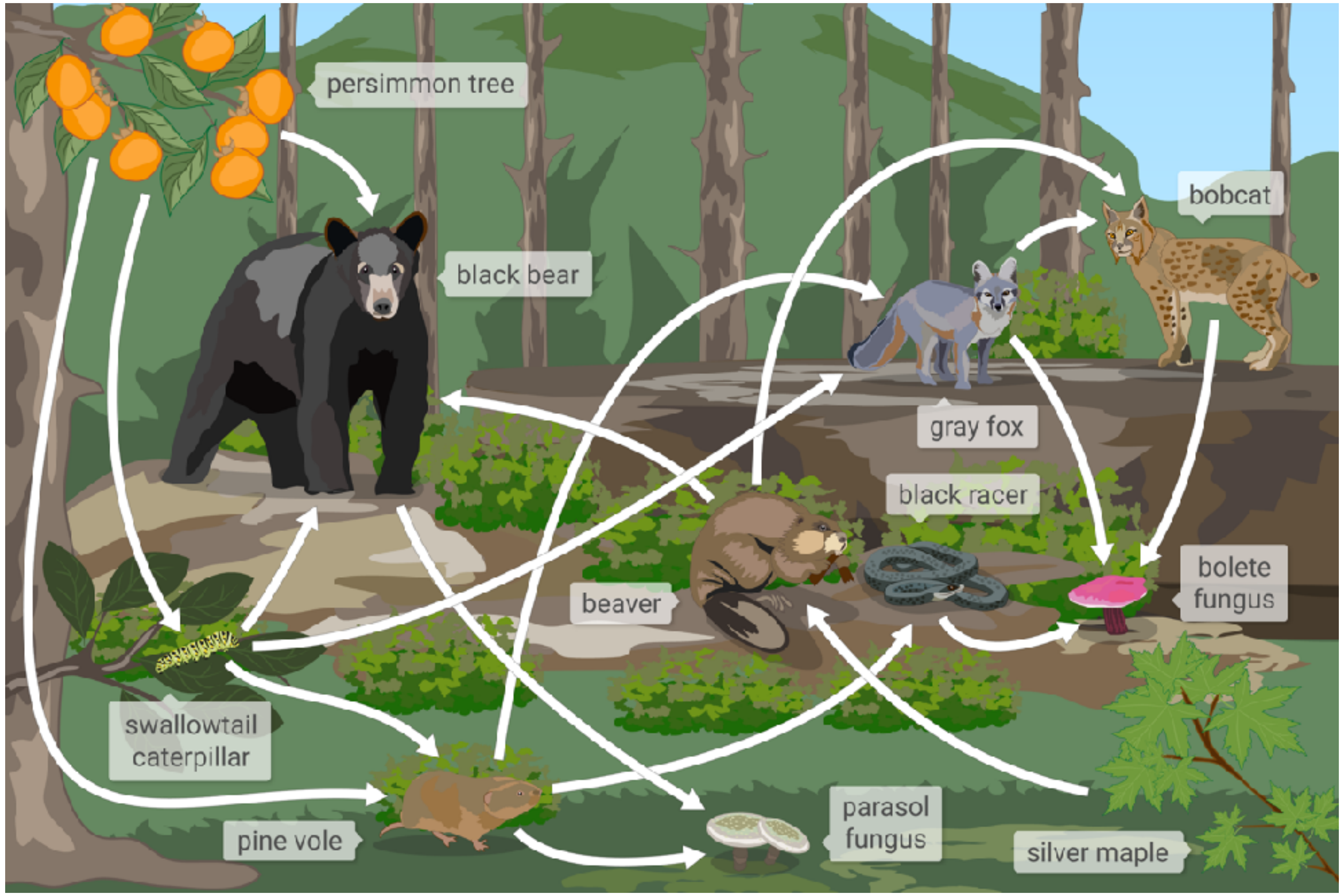
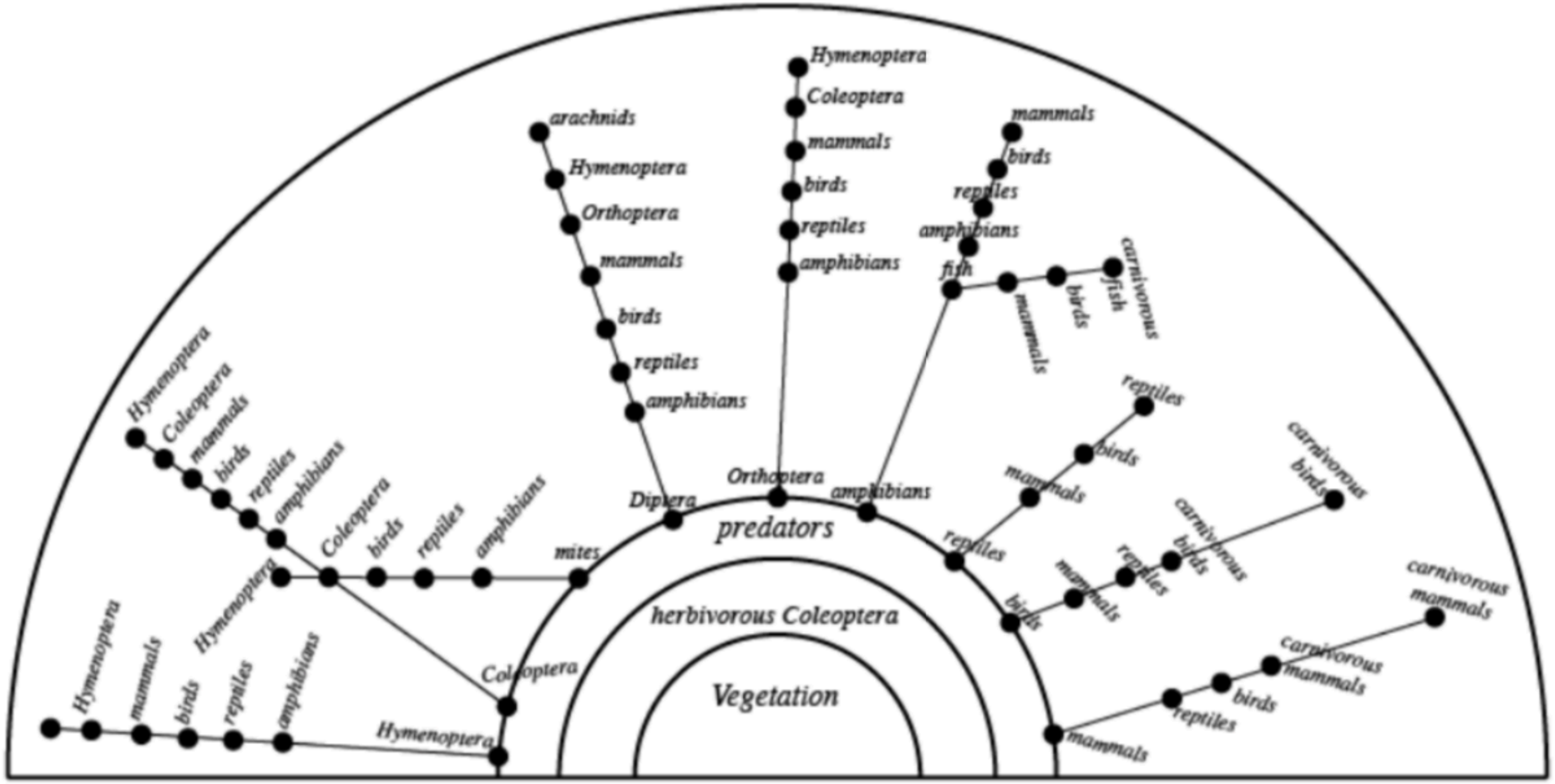
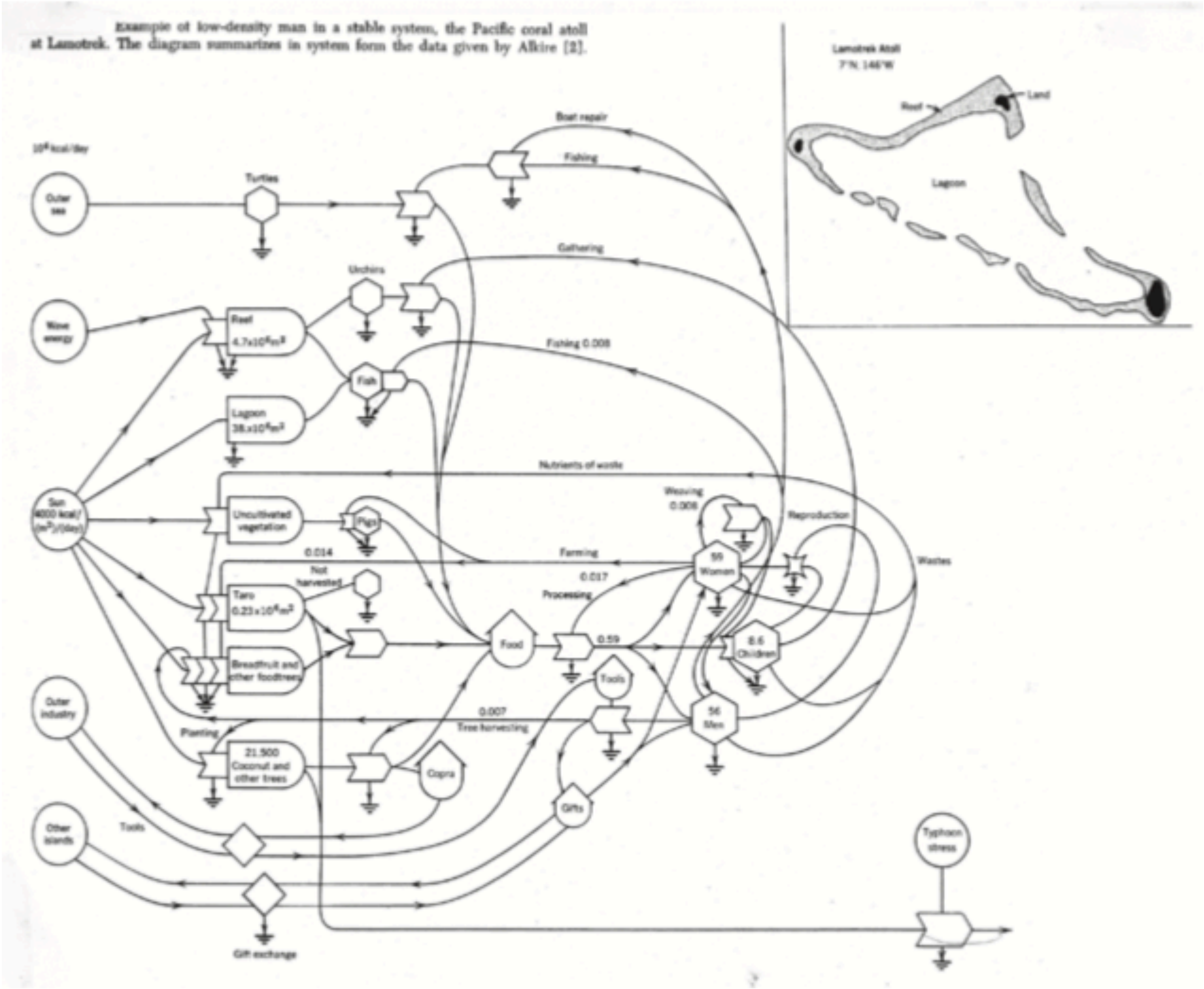
food webs


persimmon tree
black bear
bobcat
gray fox
black racer
bolete fungus
beaver
swallowtail caterpillar
pine vole
parasol fungus
silver maple



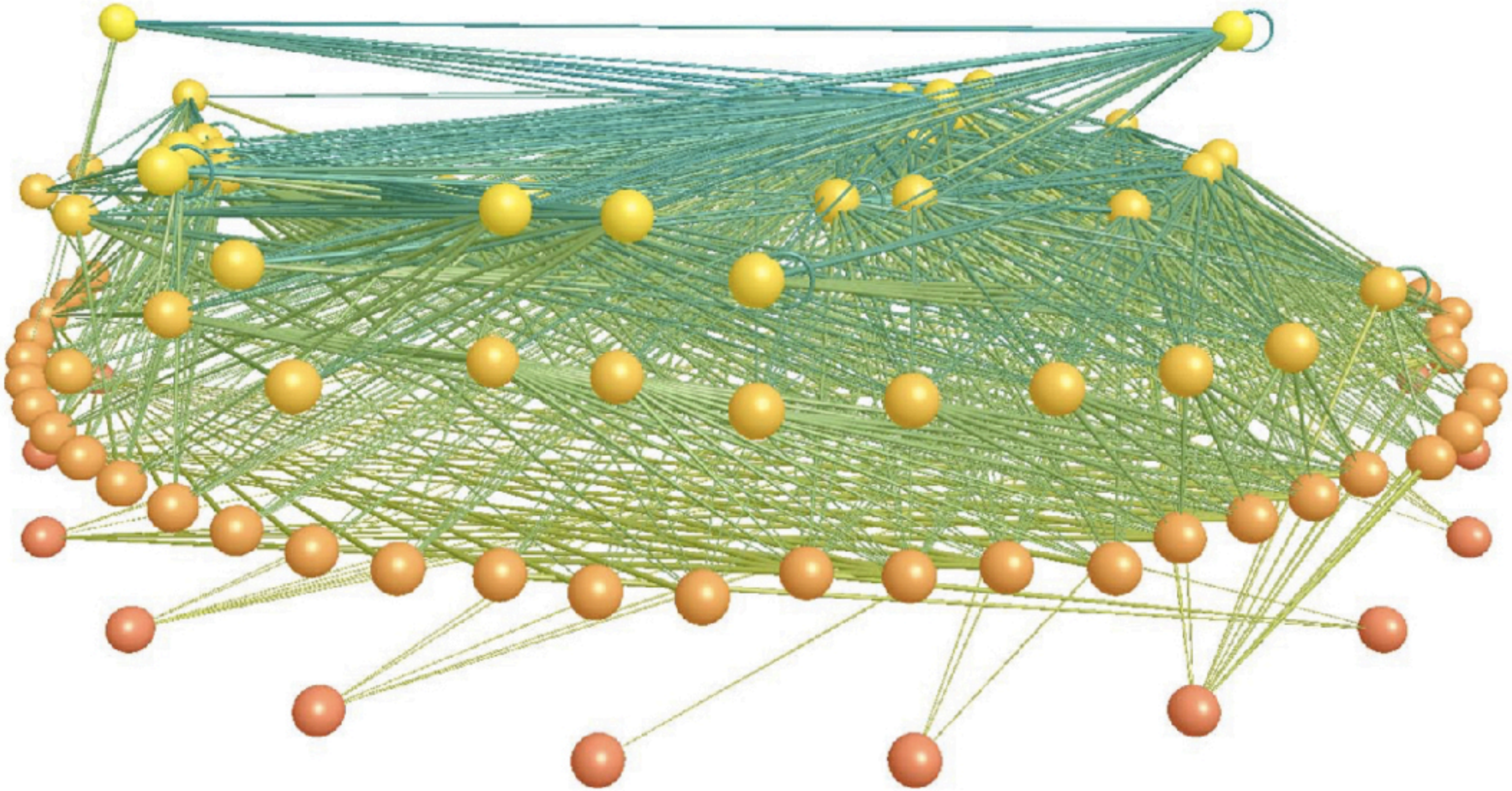
First food web (generalized) reported in the literature by Camerano in1880 (Cohen 1994)

Historical account in the next few slides by Frank Egerton (2007)



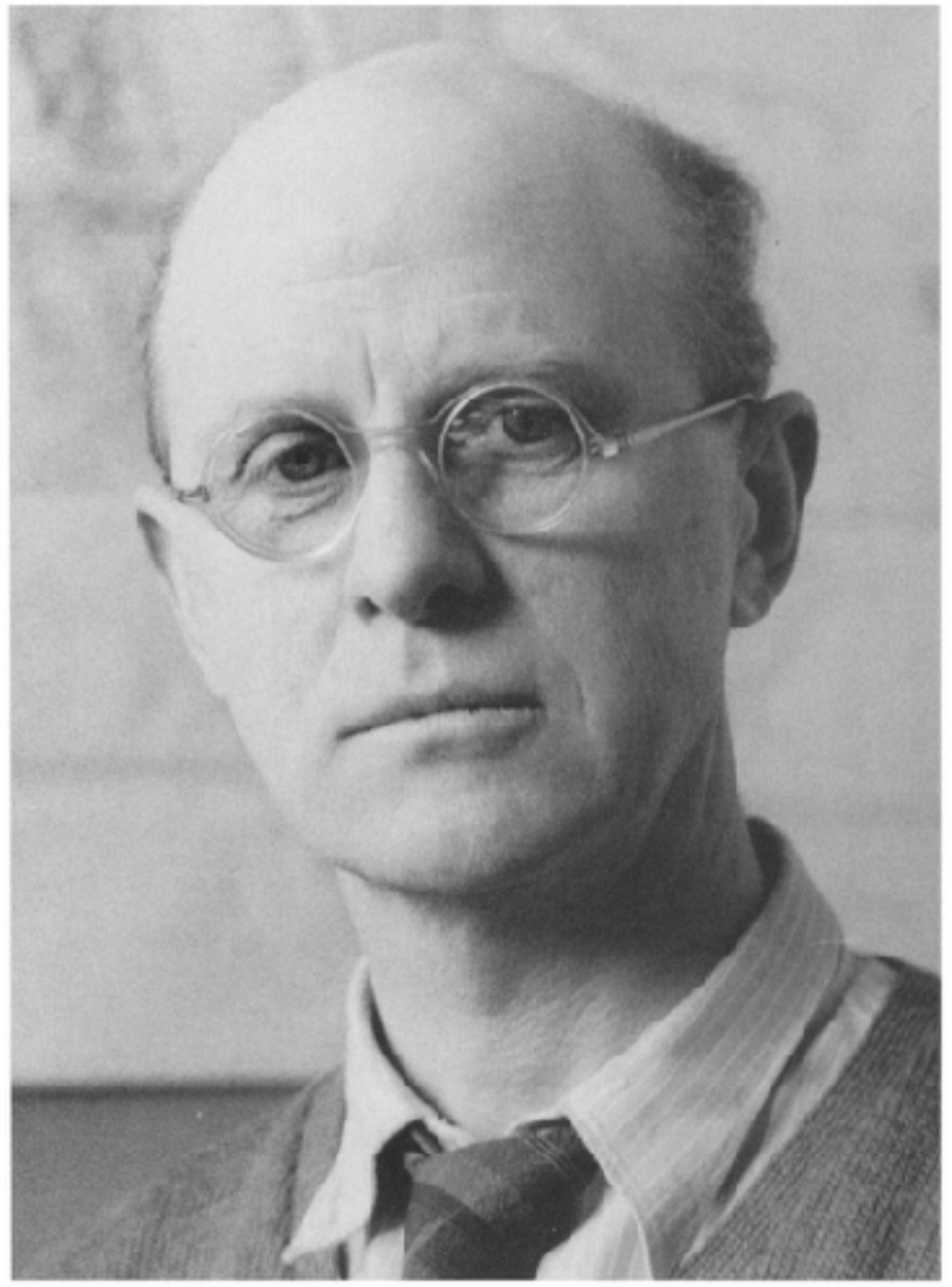
Example of low-density man in a stable system, the Pacific coral atoll at Lamotrek. The diagram summarizes in system form the data given by Alkire [2].

Howard T. Odum1971



Food webs as complex networks (Dunne, Martinez, and Williams)

stability and complexity (I)



Charles Elton

Robert MacArthur

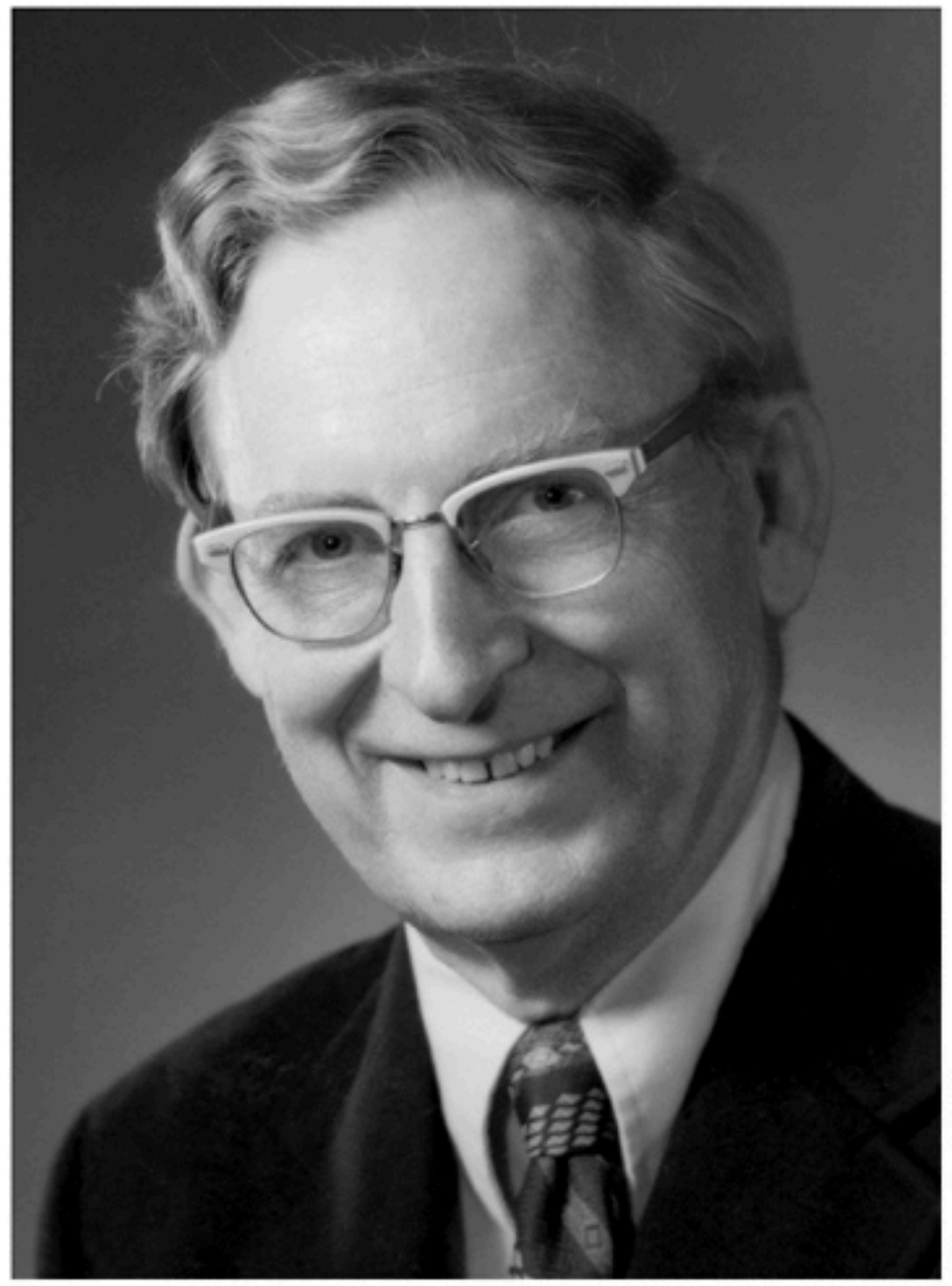
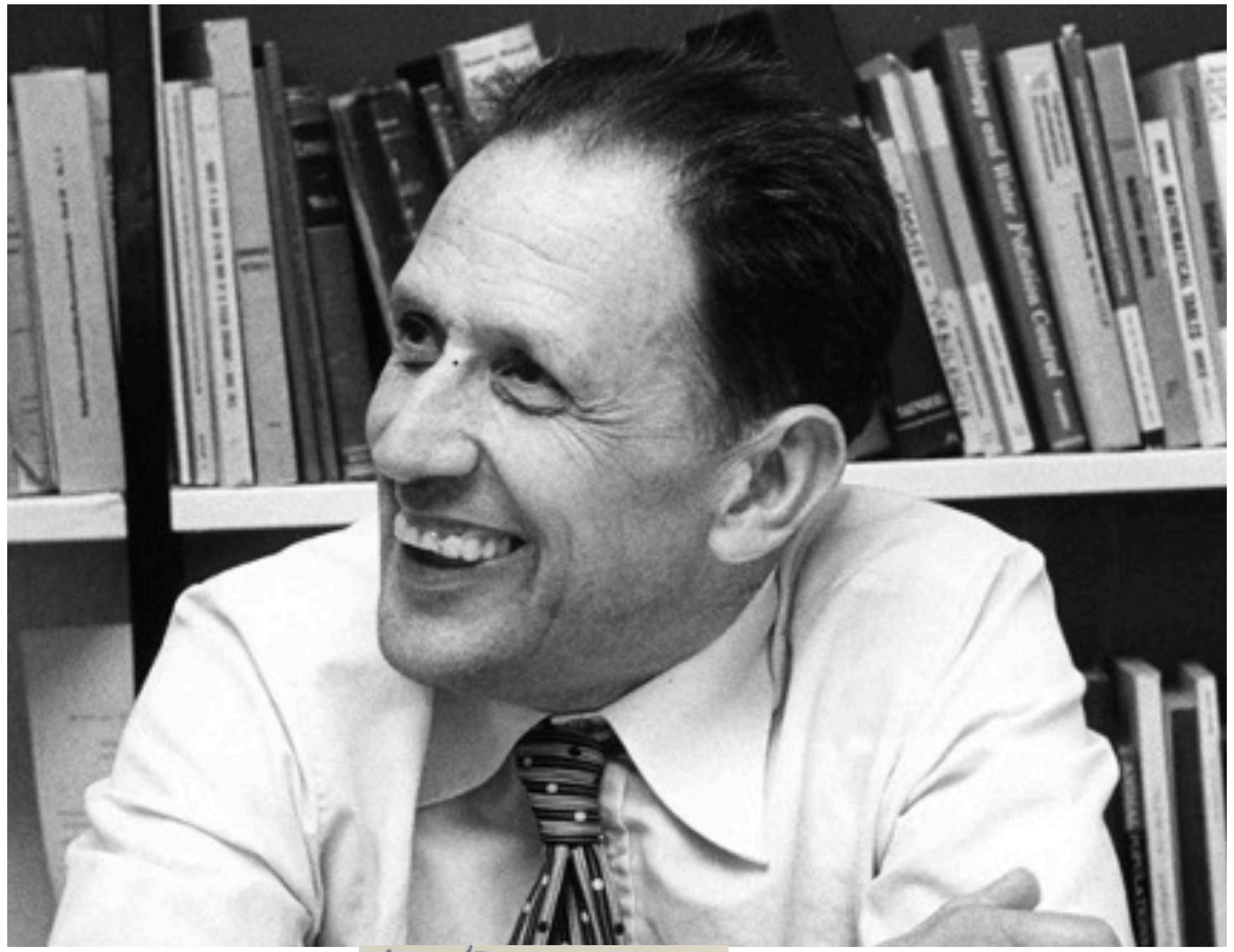


Photo by Gittings

Eugene P. Odum



Ramón Margalef

stability and complexity (I)

FLUCTUATIONS OF ANIMAL POPULATIONS, AND A MEASURE OF COMMUNITY STABILITY[1]

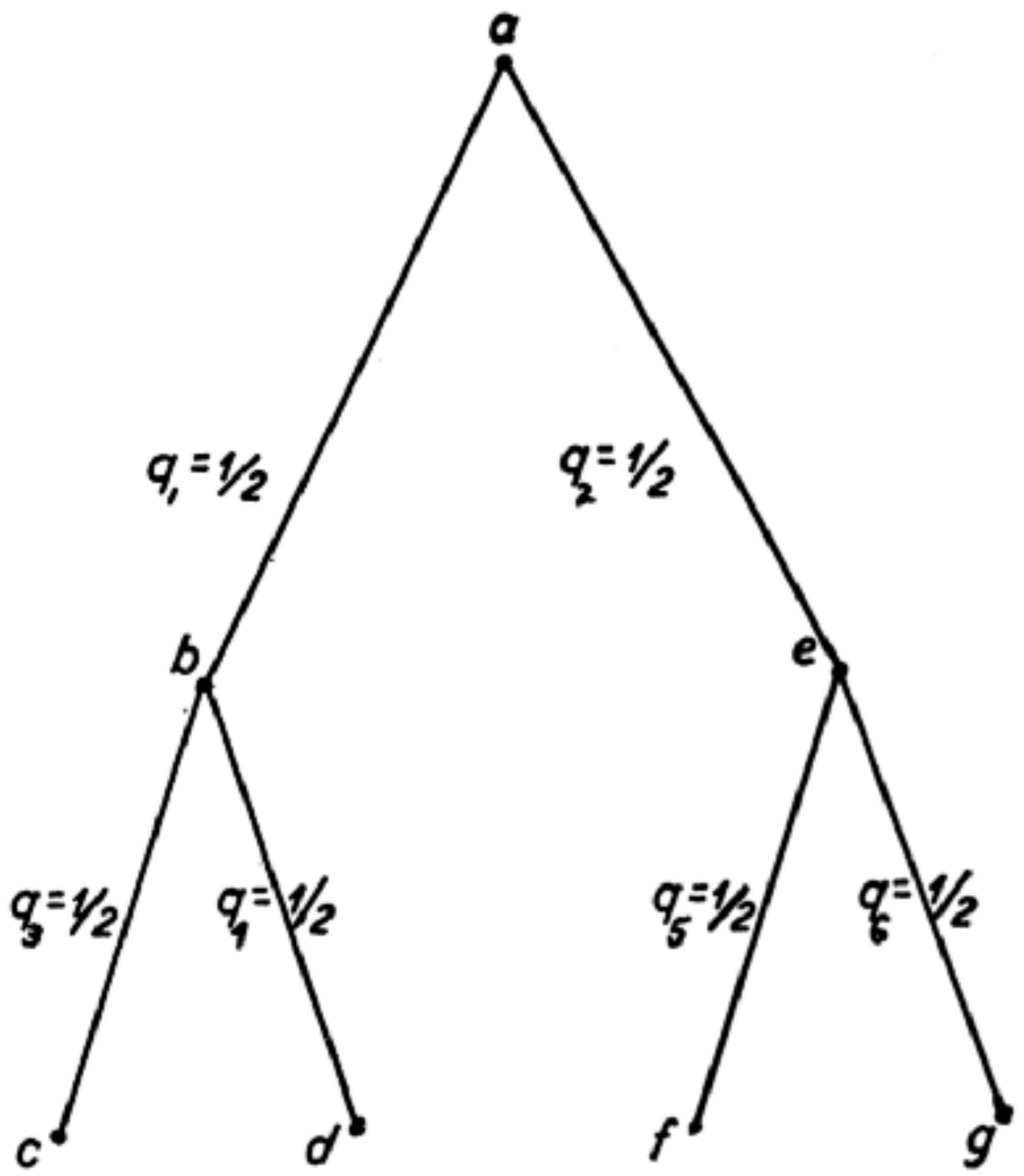


FIG. 3. A food web. *a, b, c, d, e, f* and *g* are species, and *q* on the line joining predator and prey signifies that fraction of the total number of prey species formed by the prey species in consideration.

$$S = -\sum p_i \log p_i = -4\left(\frac{1}{4}\log\frac{1}{4}\right) = \log 4$$

"Suppose, for some reason, that one species has an abnormal abundance… The less effect this abnormal abundance has on the other species, the more stable the community."

"The amount of choice which the energy has in following the paths up through the food web is a measure of the stability of the community."

"If each species has just one predator and one prey the stability should be minimum, … as the number of links in the food web increases the stability should increase."

MacArthur 1955, *Ecology* 36: 533-536

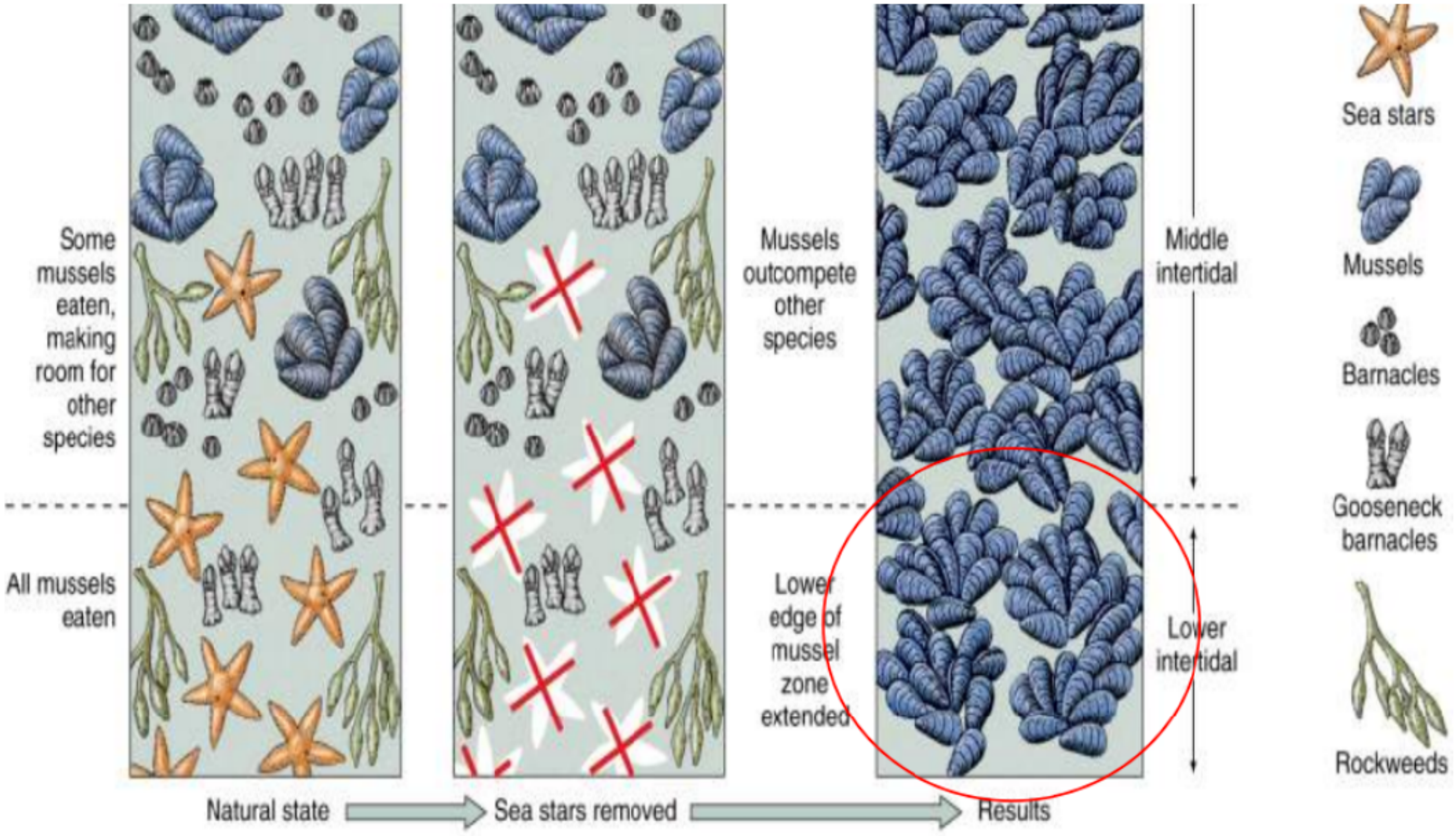
trophic cascades

Vol. 100, No. 910 The American Naturalist January–February, 1966

FOOD WEB COMPLEXITY AND SPECIES DIVERSITY

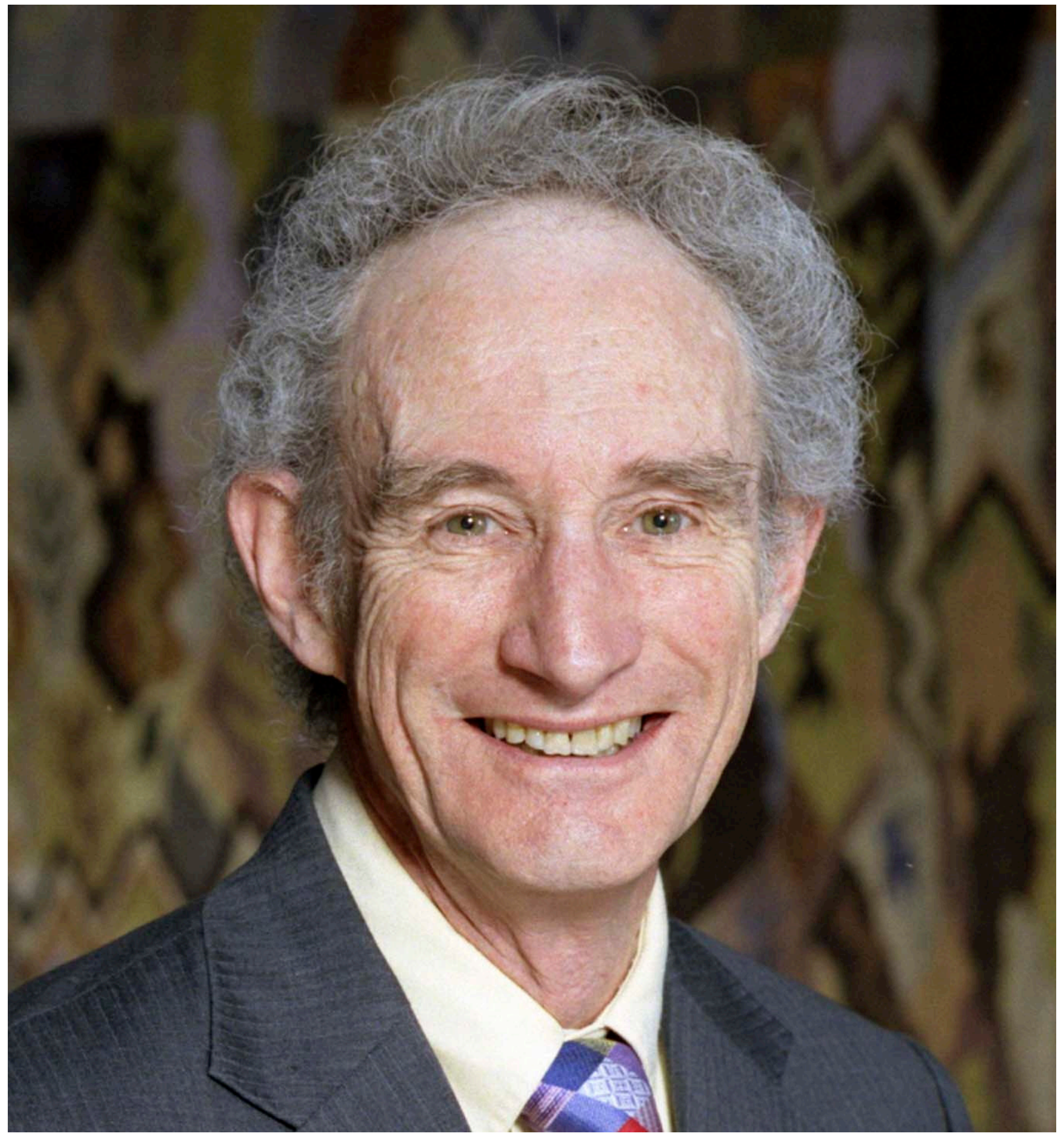
ROBERT T. PAINE

Department of Zoology, University of Washington, Seattle, Washington



keystone species

stability and complexity (II)



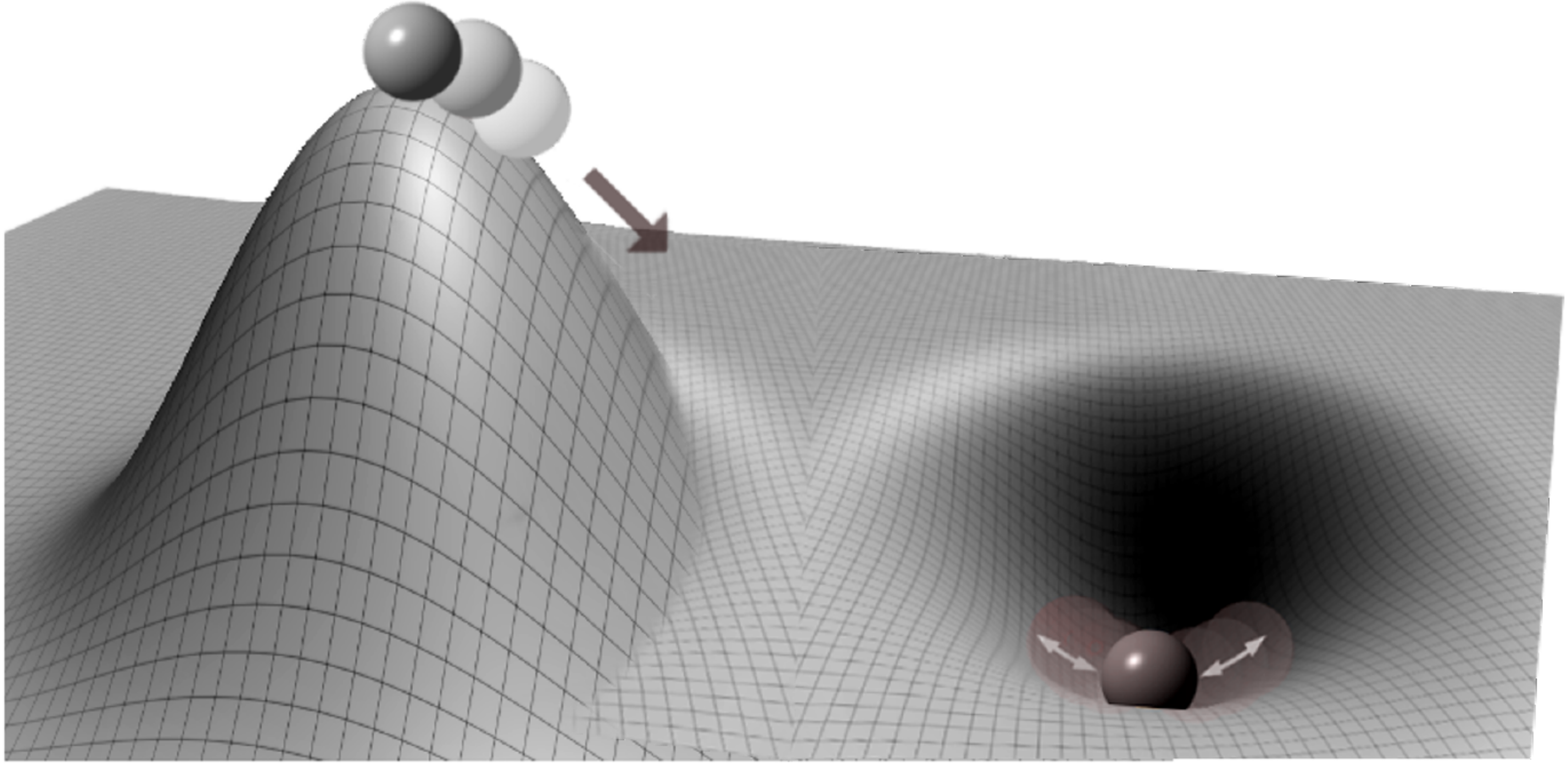
Will a Large Complex System be Stable?

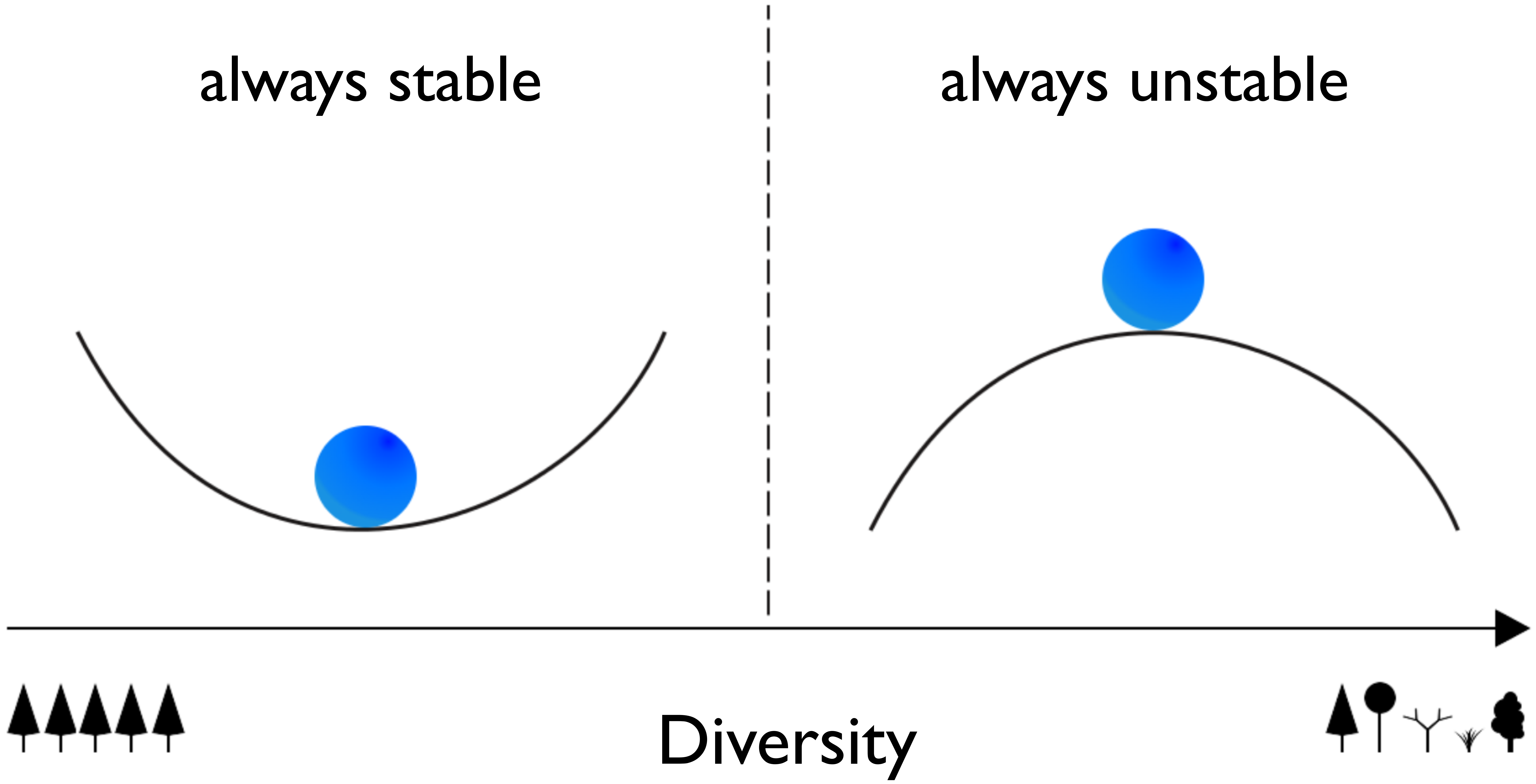
Gardner and Ashby[1] have suggested that large complex systems which are assembled (connected) at random may be expected to be stable up to a certain critical level of connectance, and then, as this increases, to suddenly become unstable. Their conclusions were based on the trend of computer studies of systems with 4, 7 and 10 variables.

Here I complement Gardner and Ashby's work with an analytical investigation of such systems in the limit when the number of variables is large. The sharp transition from stability to instability which was the essential feature of their paper is confirmed, and I go further to see how this critical transition point scales with the number of variables n in the system, and with the average connectance C and interaction magnitude α between the various variables. The object is to clarify the relation between stability and complexity in ecological systems with many interacting species, and some conclusions bearing on this question are drawn from the model.

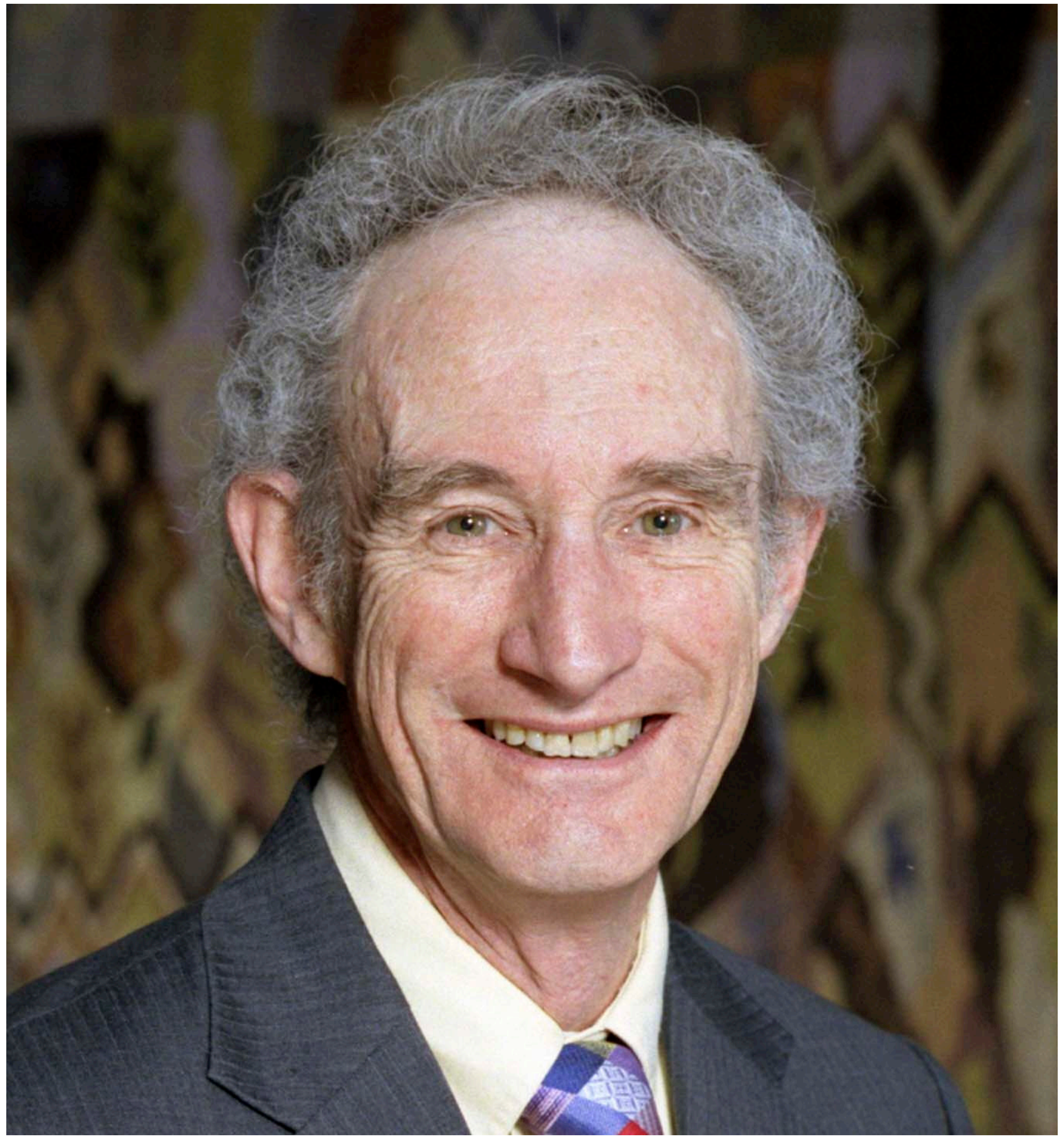
May 1972, *Nature* 238: 413-414

stability and complexity (II)




always stable
always unstable
Diversity

stability and complexity (II)



a food web is stable if (May 1972):

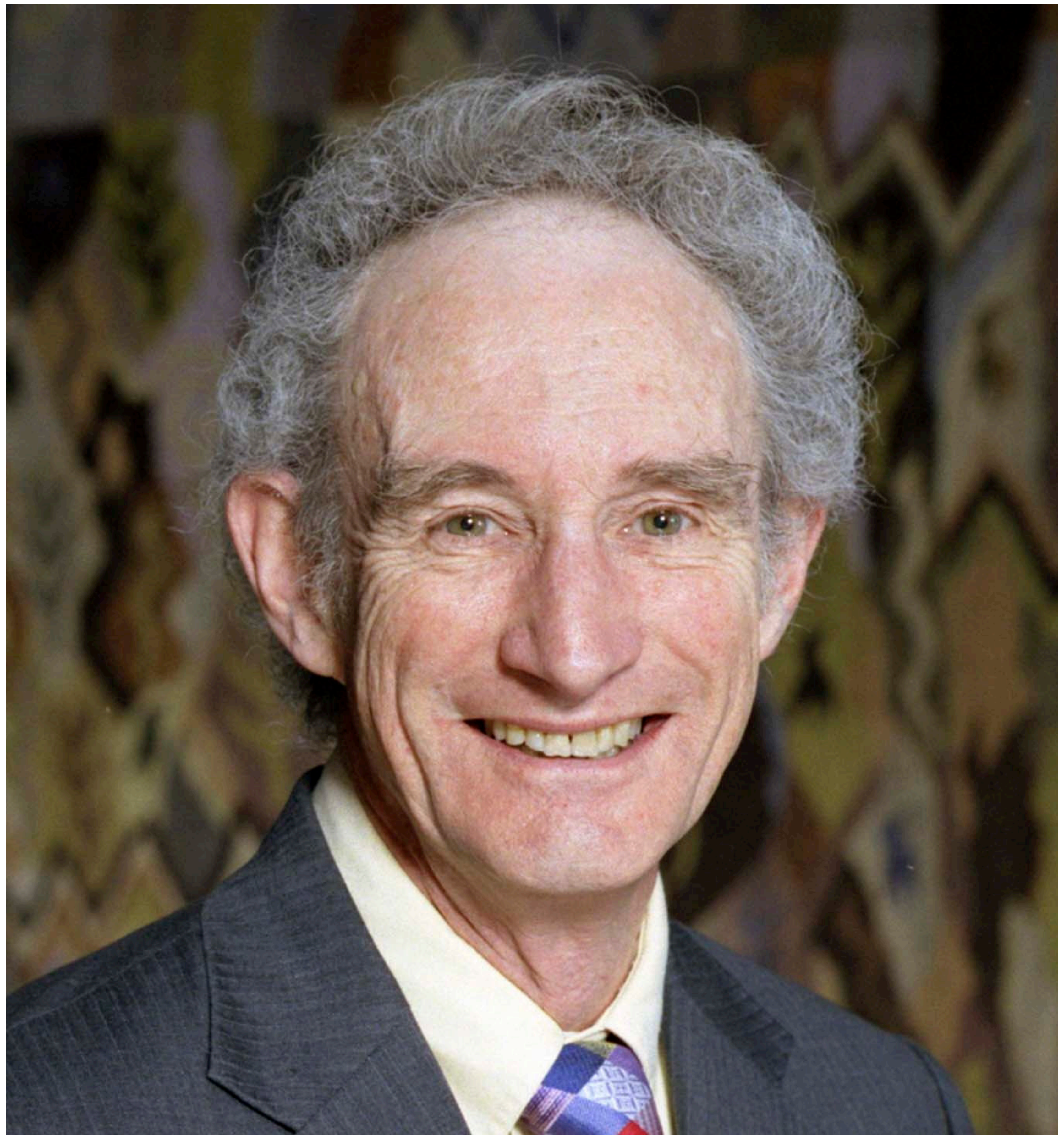
interaction strength

number of species

$$\alpha < (n\,C)^{-\frac{1}{2}}$$

connectivity

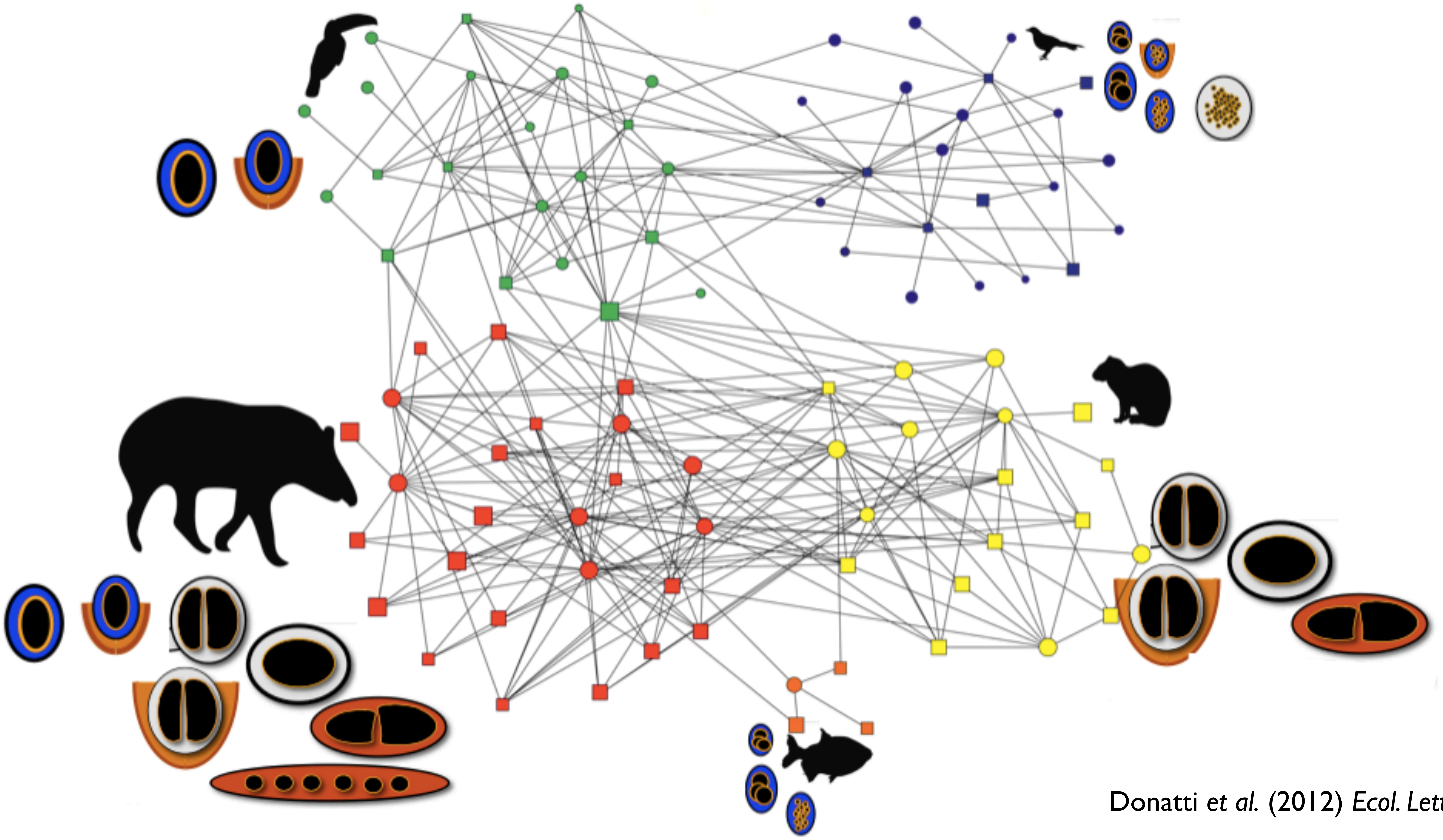
stability and complexity (II)



Will a Large Complex System be Stable?

Such examples suggest that our model multi-species communities, for given average interaction strength and web connectance, will do better if the interactions tend to be arranged in "blocks"—again a feature observed in many natural ecosystems.

May 1972, *Nature* 238: 413-414



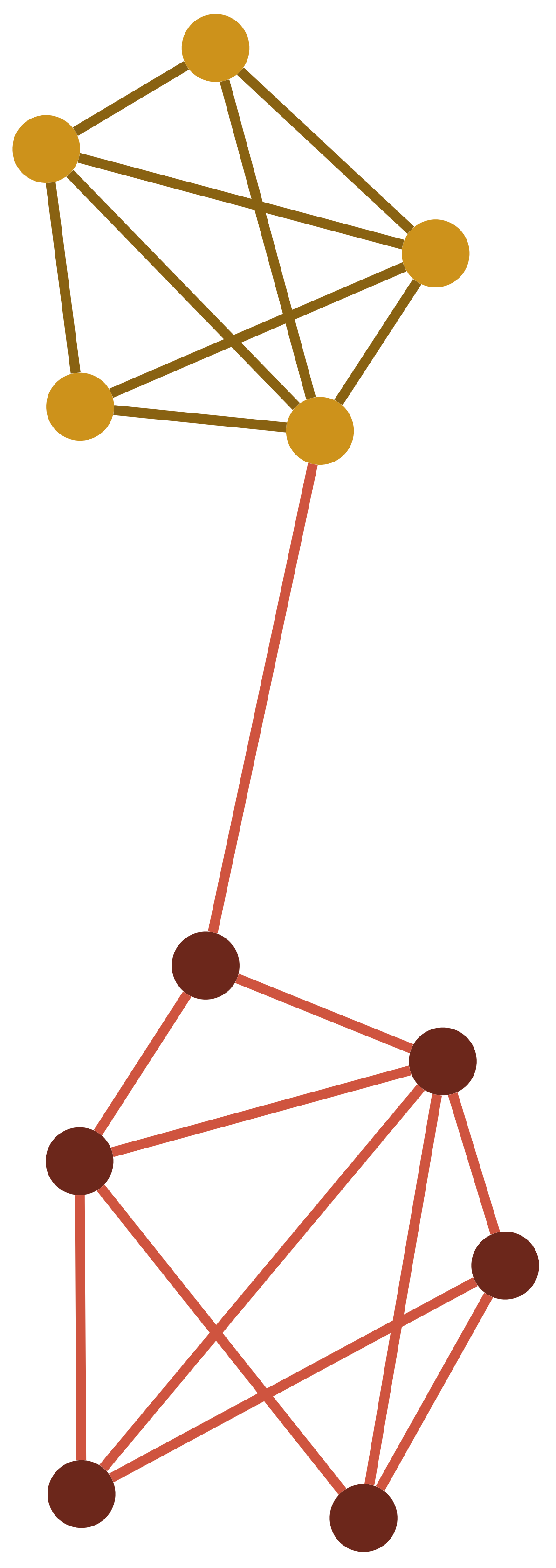
Donatti *et al.* (2012) *Ecol. Lett.*

modularity

$$M = \sum_{\text{all modules s}} \left[\frac{l_s}{L} - \left(\frac{d_s}{2L} \right)^2 \right]$$

fraction of interactions within module *i*

expected fraction of interactions within module *i*



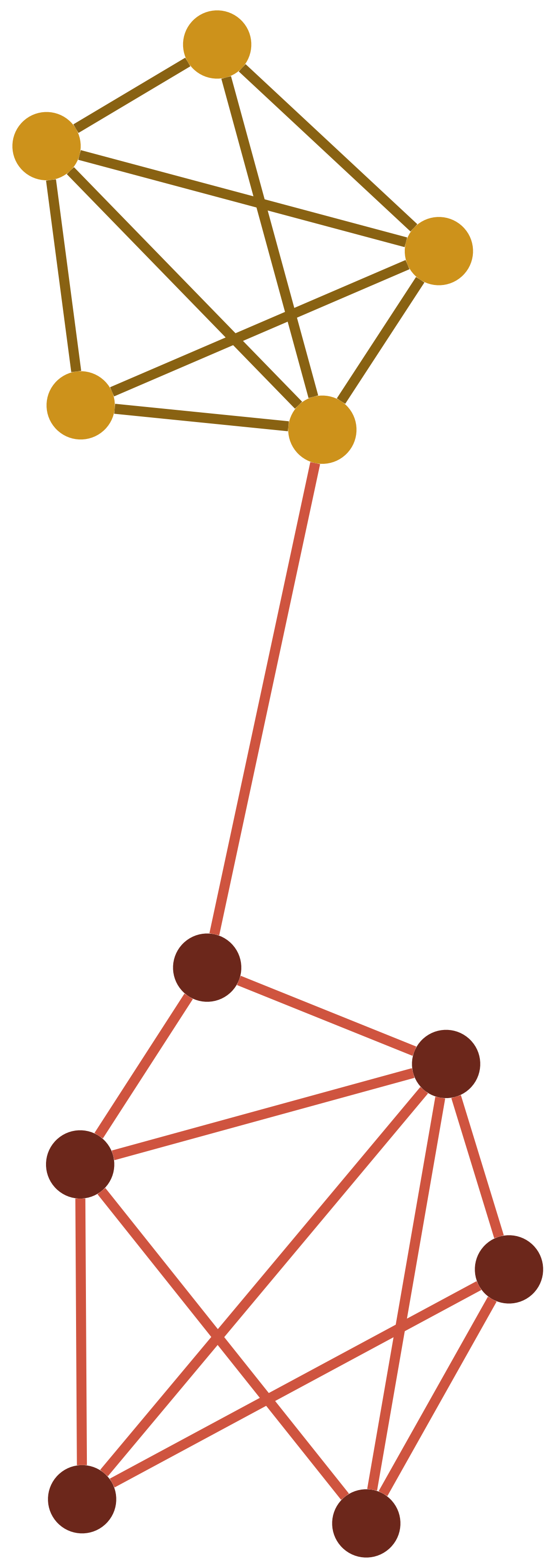
(Newman & Girvan 2004, Guimerà & Amaral, 2005)

# of interactions inside module s

sum of the species' degree inside module s

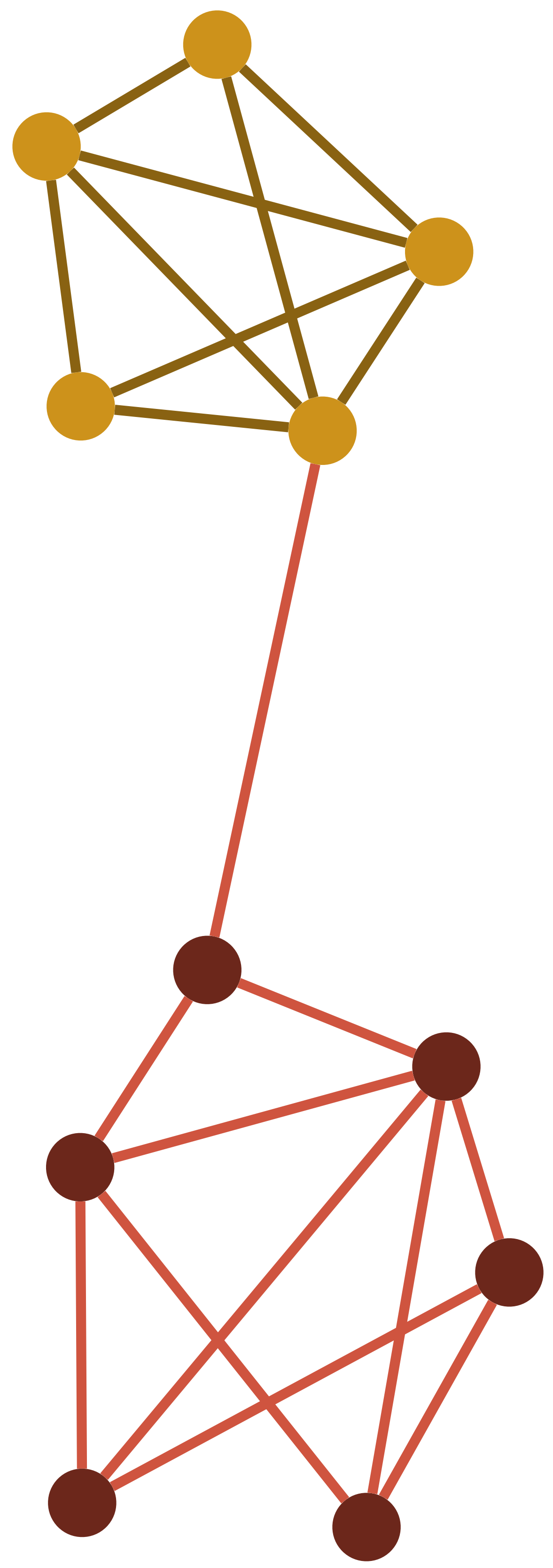
$$M = \sum_{\text{all modules s}} \left[\frac{l_s}{L} - \left(\frac{d_s}{2L}\right)^2\right]$$

# of interactions in the whole network



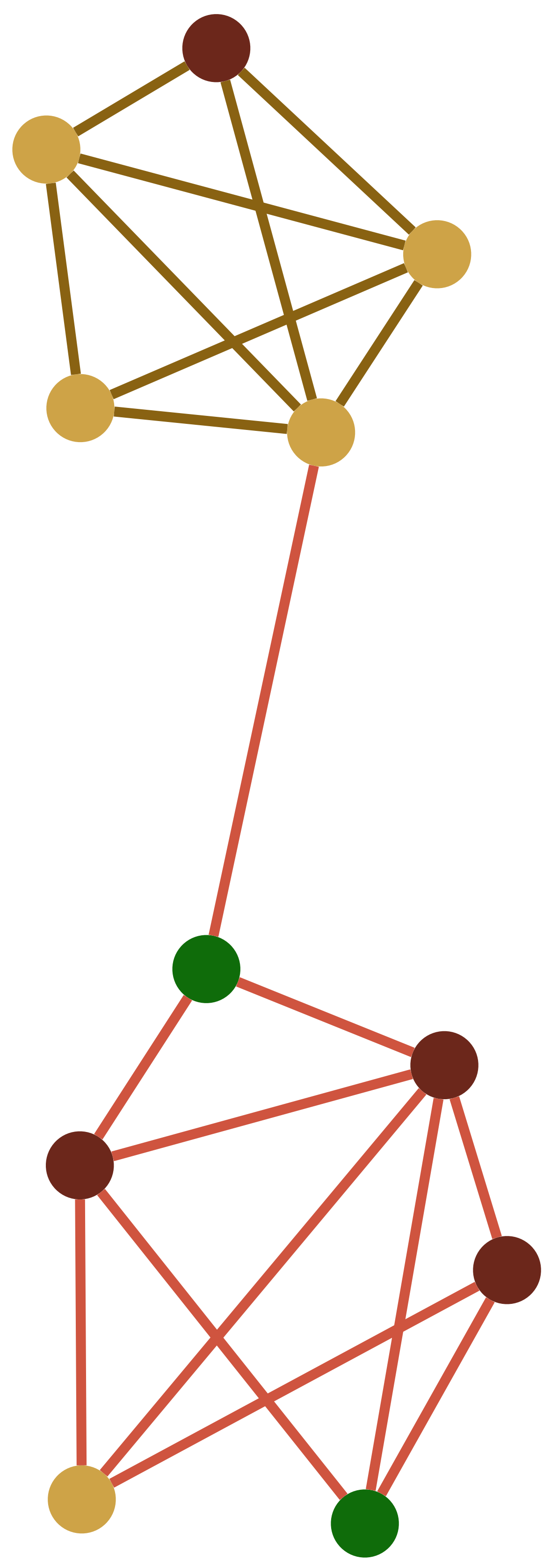
how to find the modules?

$$M = \sum_{\text{all modules s}} \left[\frac{l_s}{L} - \left(\frac{d_s}{2L} \right)^2 \right]$$



how to find the modules?

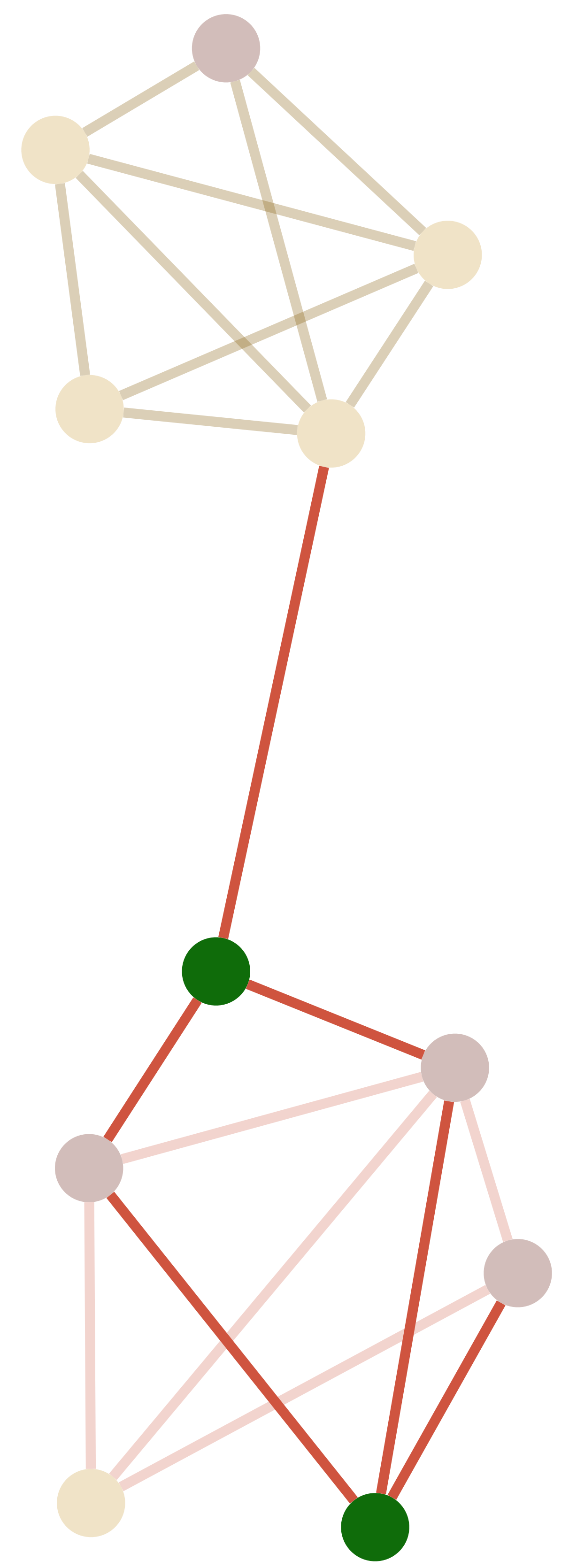
$$M = \sum_{\text{all modules s}} \left[\frac{l_s}{L} - \left(\frac{d_s}{2L} \right)^2 \right]$$



how to find the modules?

$$M = \sum_{\text{all modules s}} \left[\frac{l_s}{L} - \left(\frac{d_s}{2L} \right)^2 \right]$$

(0/20) – (6/40)²



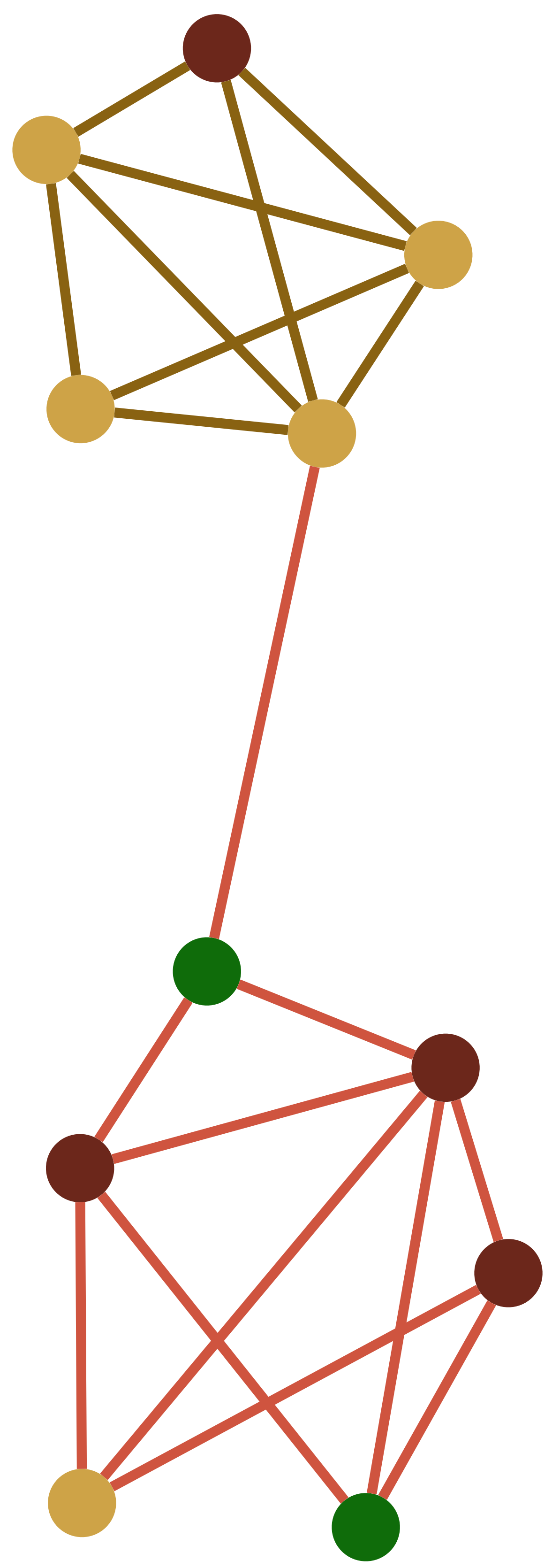
how to find the modules?

$$M = \sum_{\text{all modules s}} \left[\frac{l_s}{L} - \left(\frac{d_s}{2L} \right)^2 \right]$$

● $(2/20) - (15/40)^2$

● $(6/20) - (18/40)^2$

● $(0/20) - (6/40)^2$



how to find the modules?

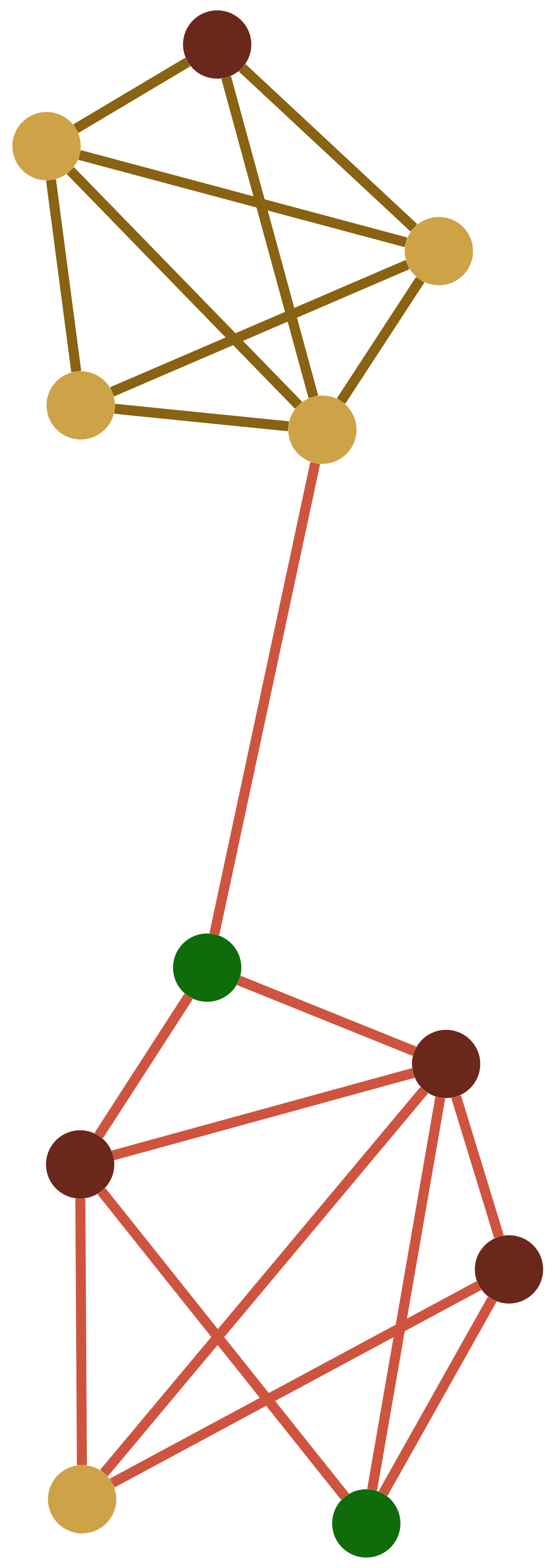
$$M = \sum_{\text{all modules s}} \left[\frac{l_s}{L} - \left(\frac{d_s}{2L} \right)^2 \right]$$

- 0.04

0.10

- 0.02

M = 0.04



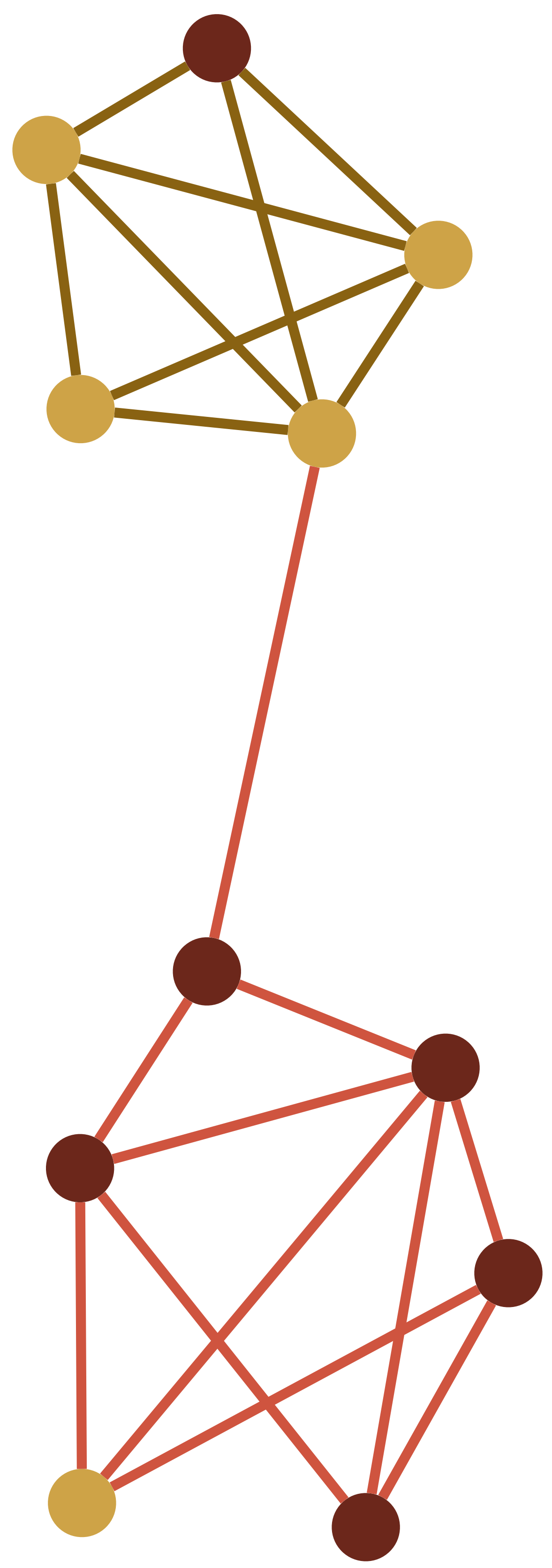
how to find the modules?

$$M = \sum_{\text{all modules s}} \left[\frac{l_s}{L} - \left(\frac{d_s}{2L} \right)^2 \right]$$

0.01

0.15

M = 0.16



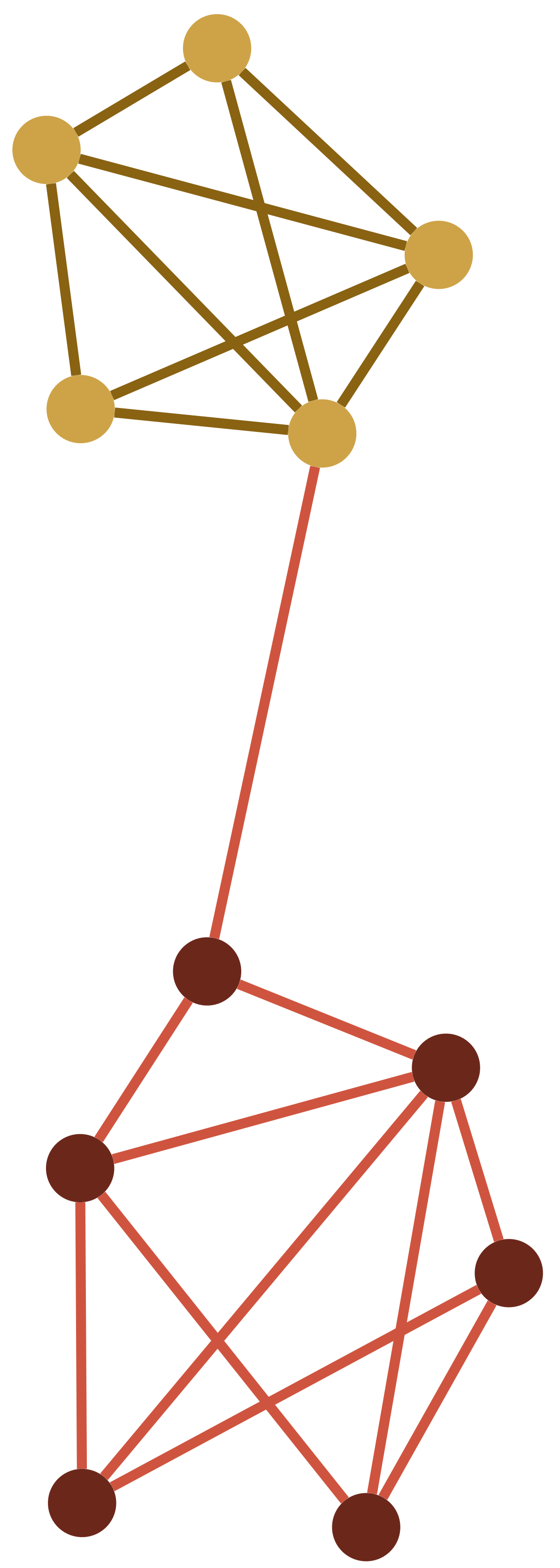
how to find the modules?

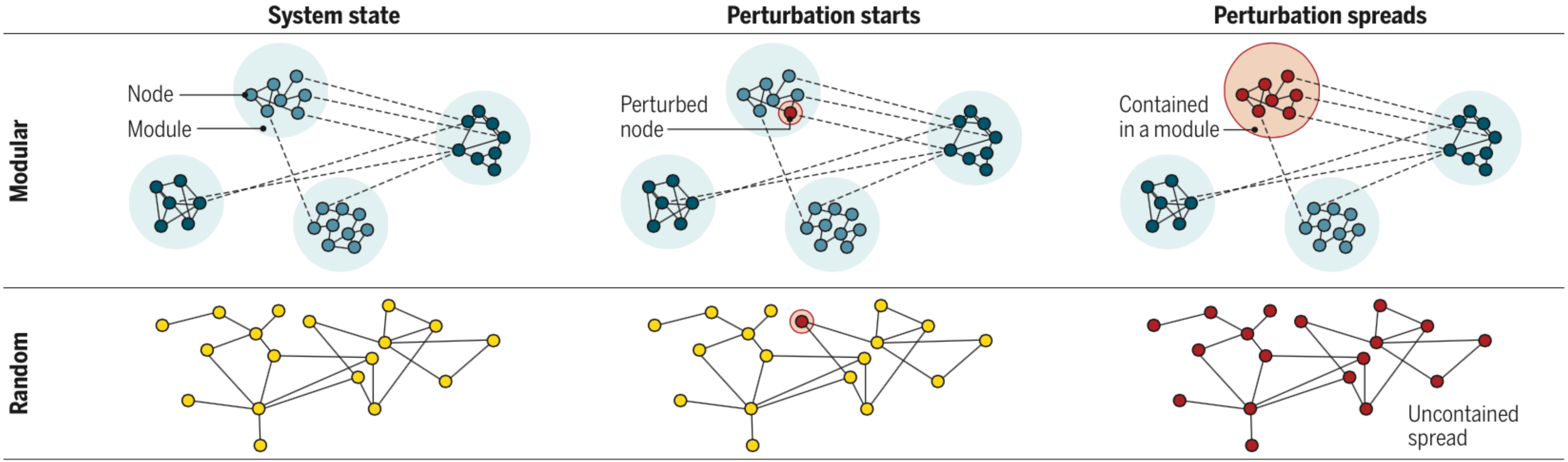
$$M = \sum_{\text{all modules s}} \left[\frac{l_s}{L} - \left(\frac{d_s}{2L} \right)^2 \right]$$

0.22

0.25

M = 0.47



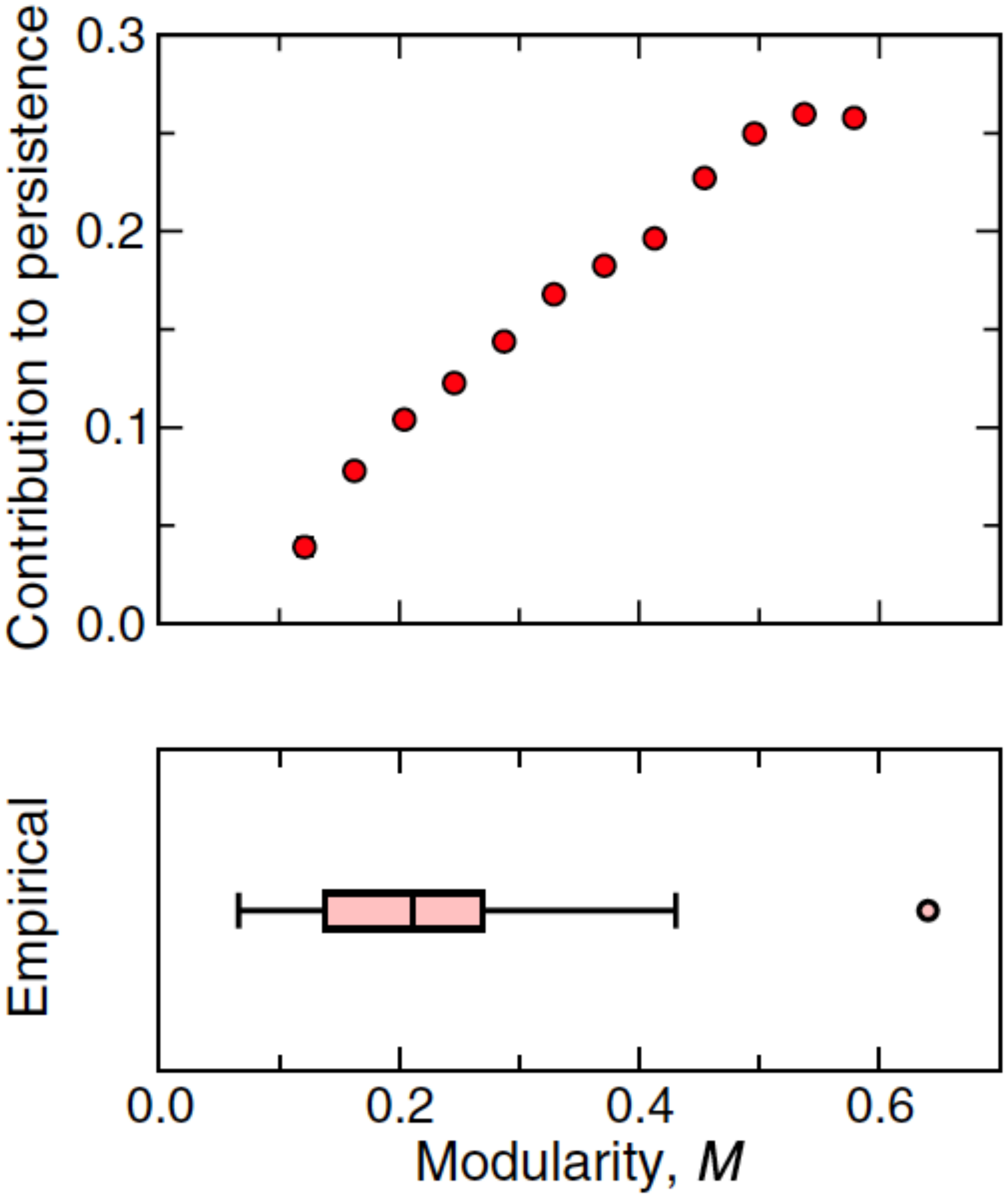


System state
Perturbation starts
Perturbation spreads
Modular
Random
Node
Module
Perturbed node
Contained in a module
Uncontained spread

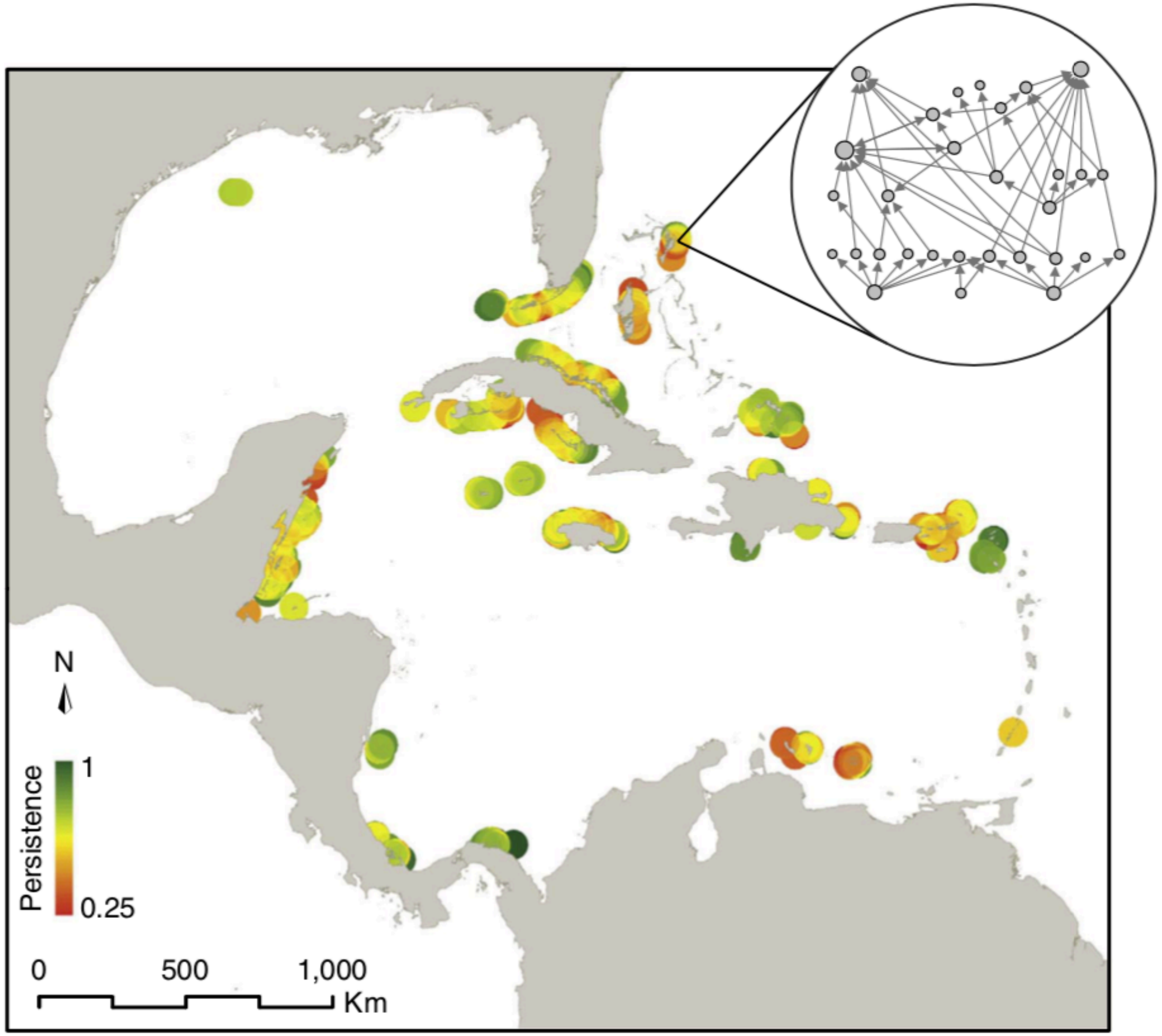
a metabolic model of a food web

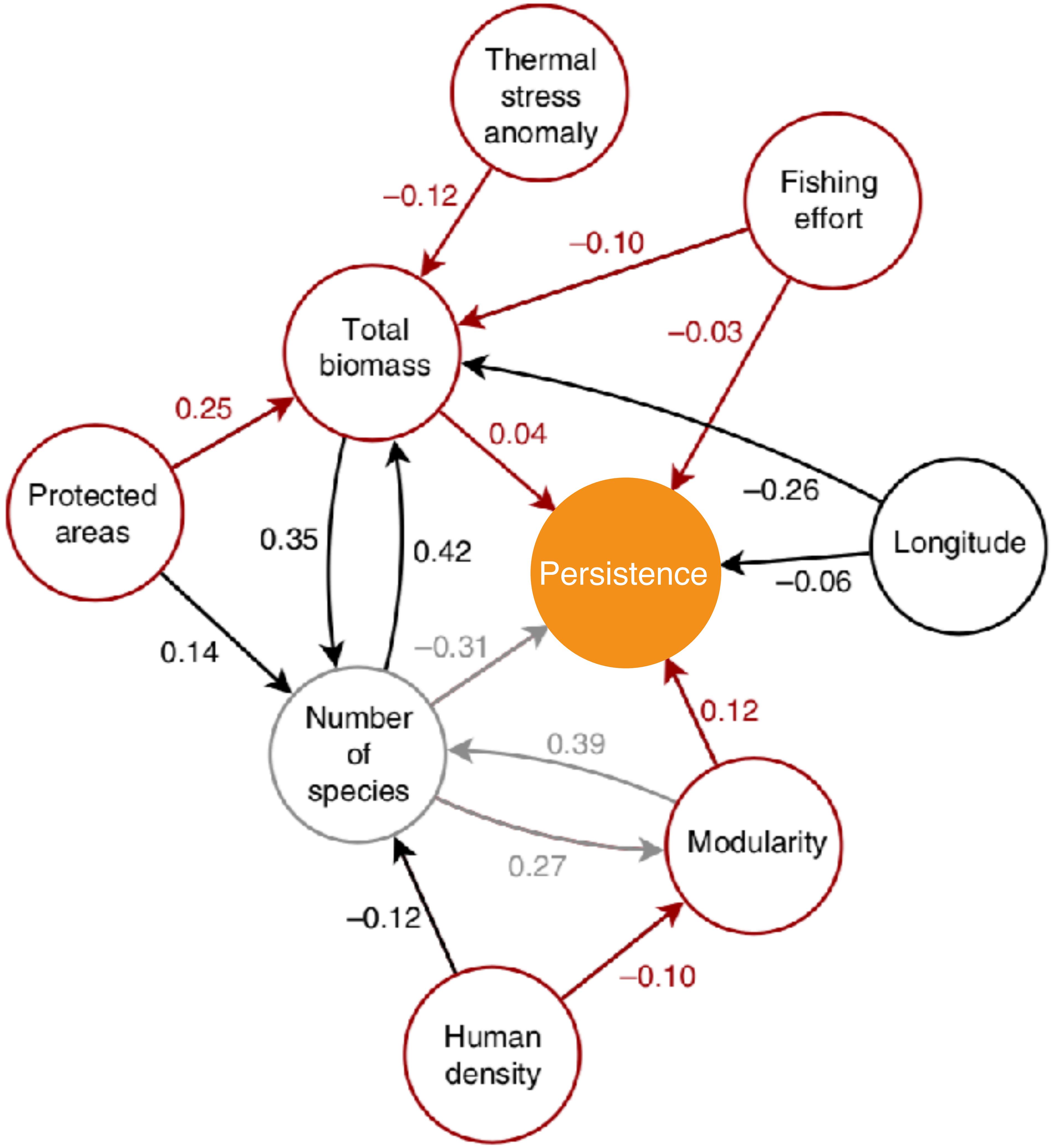
$$\frac{dB_i}{dt} = r_i G_i B_i - B_i x_i + B_i x_i \sum_{j=prey}^{n} y_i F_{ij} - \sum_{k=pred}^{n} \frac{x_k y_k B_k F_{ki}}{e_{ki}}$$

(The change in biomass is a function of growth, respiration, and biomass gain and loss trough predation)



Stouffer and Bascompte (2011) *PNAS*





[Gilarranz, Mora, and Bascompte (2016) *Nat. Commun.* 7: 10737]