

Ecological networks, indeterminacy and reconstruction

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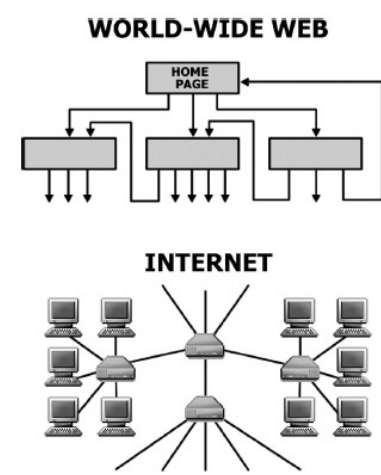
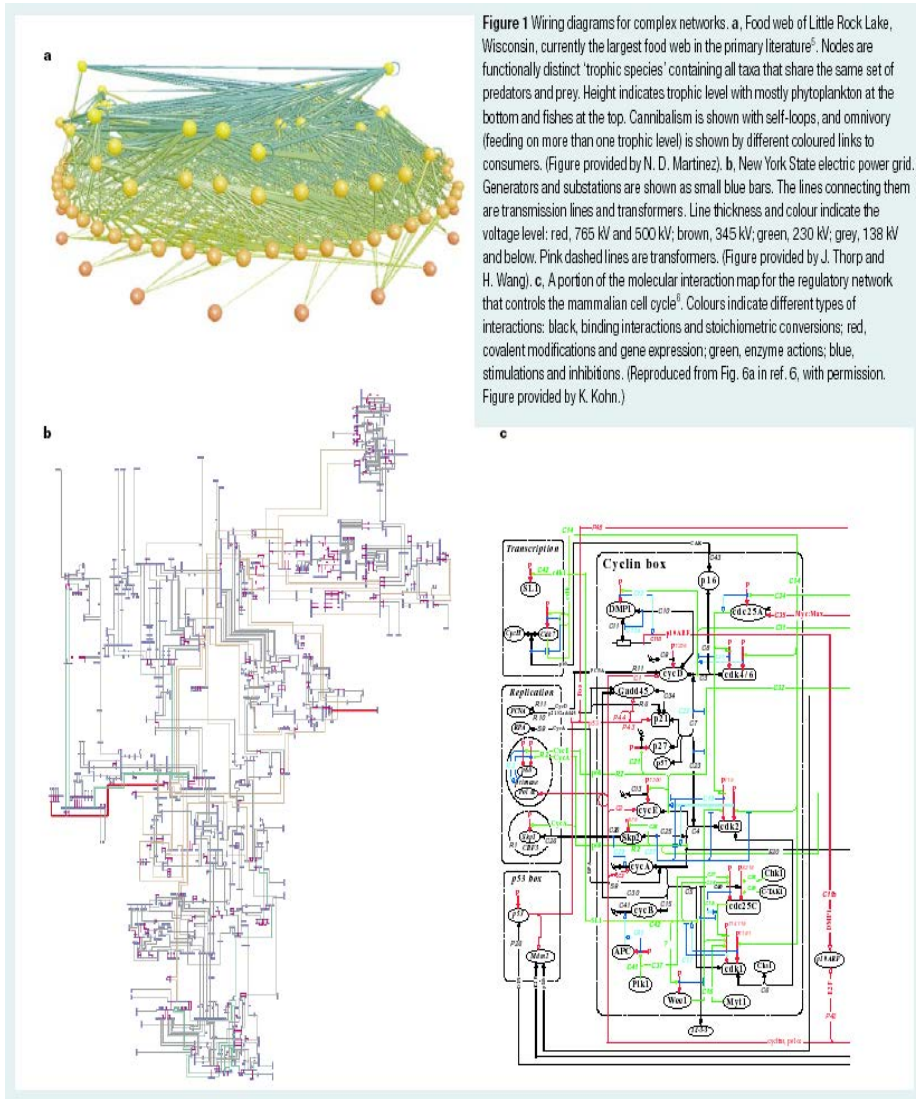


The living at all levels of organization is characterized by being composed of networks that carry out four basic functions.

Acquisition
Transformation
Storage
Transmission

OF

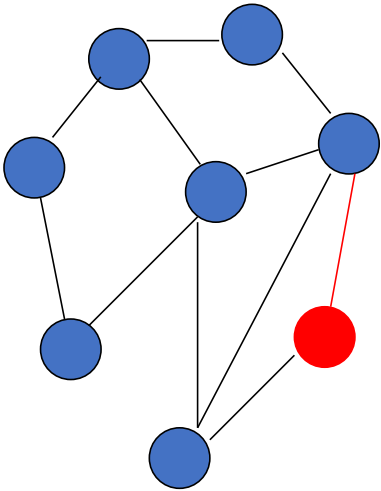
Energy
Matter
Information



Alberts & Barabasi (2002)

Strogatz (2001)

$G=(V,E)$



Diversity begets stability

MacArthur (1955) “a large number of paths through each species is necessary to reduce the effects of overpopulation of one species.”

“stability increases as the number of links increases” and that stability is easier to achieve in more diverse assemblages of species, thus linking community stability with both increased trophic links and increased numbers of species.

Connectance of Large Dynamic (Cybernetic) Systems: Critical Values for Stability

MARK R. GARDNER
W. ROSS ASHBY*

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Urbana, Illinois 61801.

We have attempted to answer: What is the chance that a large system will be stable? If a large system is assembled (connected) at random, or has grown haphazardly, should we expect it to be stable or unstable? And how does the expectation change as n , the number of variables, tends to infinity?

$$\mathbb{X} = \{x_i, \dots, x_n\}$$

Is a vector and each x_i is a time dependent Variable, with dynamics given by

$$\dot{\mathbb{X}} = A\mathbb{X}$$

Where A is a random matrix of interactions, whose values are Taken from a uniform distribution between -1 and 1, and with Connectance (C) or percentage of connection C .

NATURE VOL. 228 NOVEMBER 21 1970

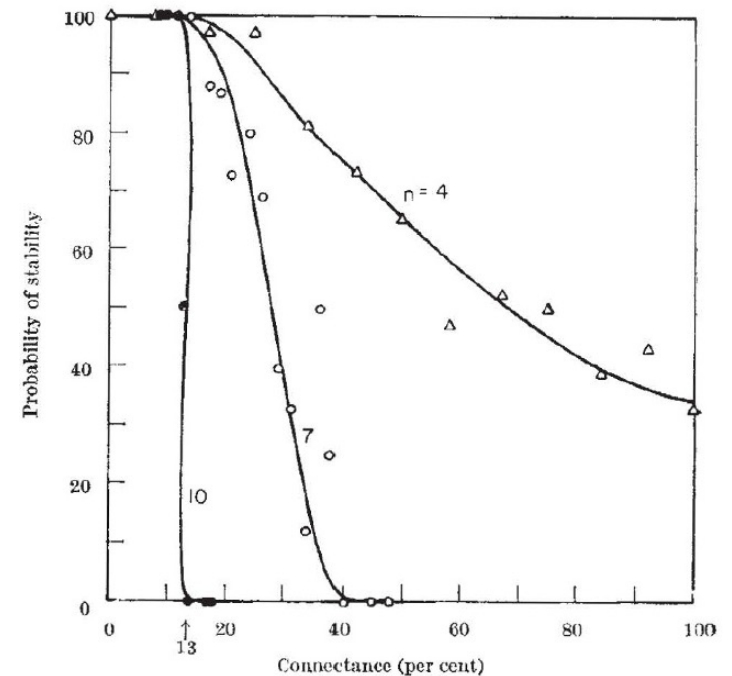


Fig. 1. Variation of stability with connectance.

Will a Large Complex System be Stable?

ROBERT M. MAY*

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Princeton, New Jersey 08540*

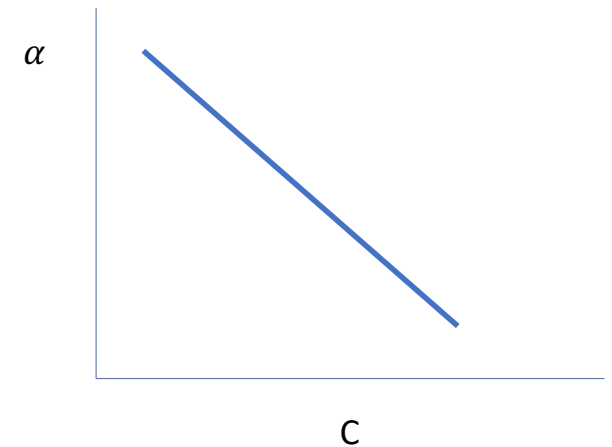
Interacting networks would be stable if

$$\alpha\sqrt{SC} < 1$$

α = average magnitude of interaction strength

S = Number of species (nodes)

C = Connectance



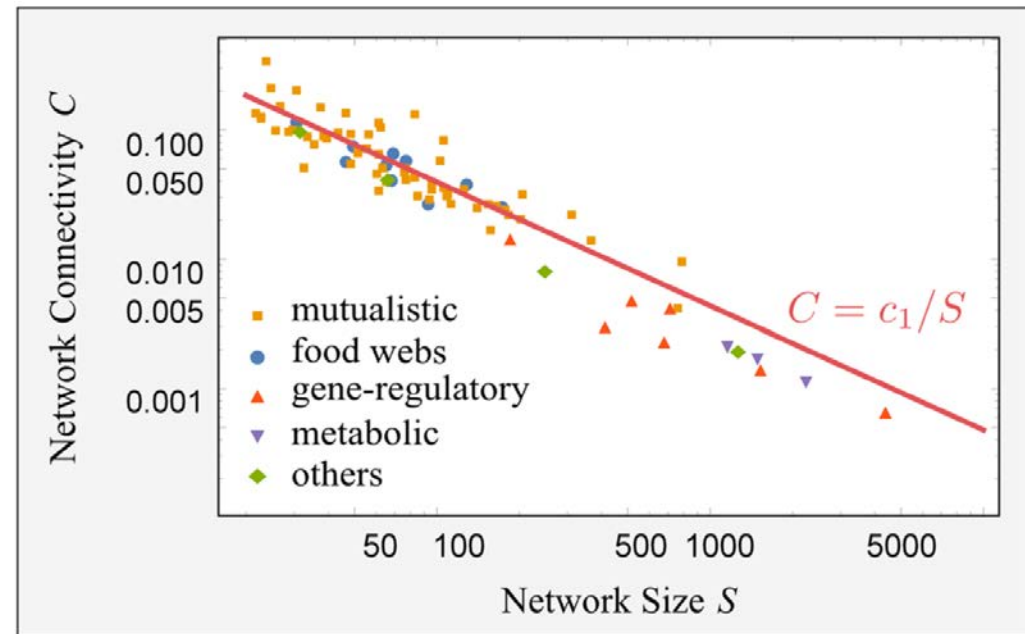
Such examples suggest that our model multi-species communities, for given average interaction strength and web connectance, will do better if the interactions tend to be arranged in “blocks”—again a feature observed in many natural ecosystems.

Interacting networks would be stable if

$$\alpha\sqrt{SC} < 1$$

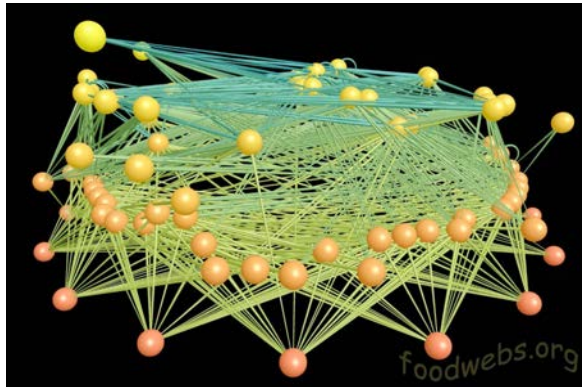
Or they are sparse such that:

$$S \propto C^{-1}$$



Busiello et al. (2017)

East River Valley Foodweb



Caribbean Reef Foodweb

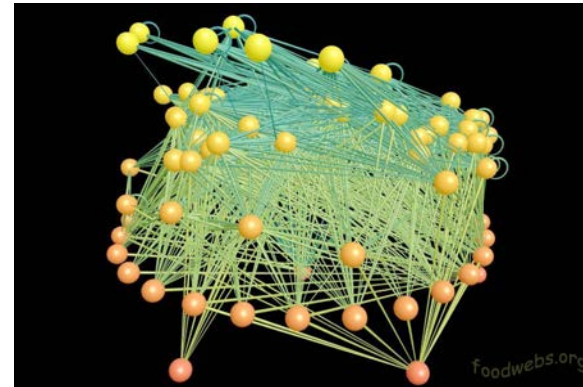
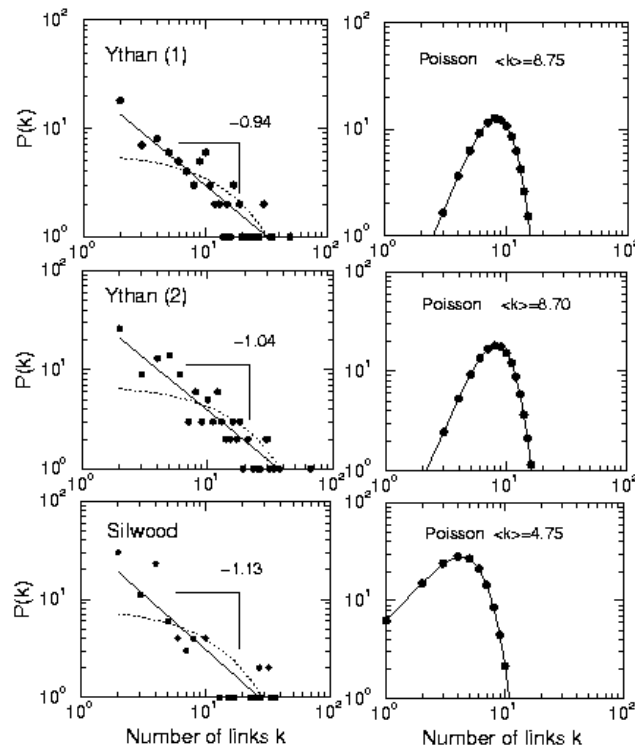


Image produced with FoodWeb3D, written by R.J. Williams and provided by the Pacific Ecoinformatics and Computational Ecology Lab (www.foodwebs.org, Yoon et al. 2004)

Foodwebs

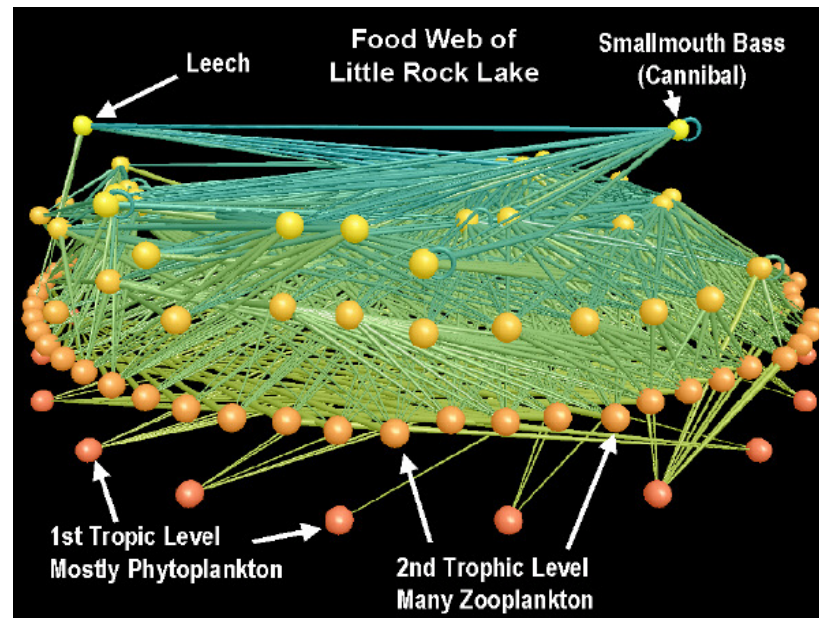
Nodes: Species

Links: Who eats whom



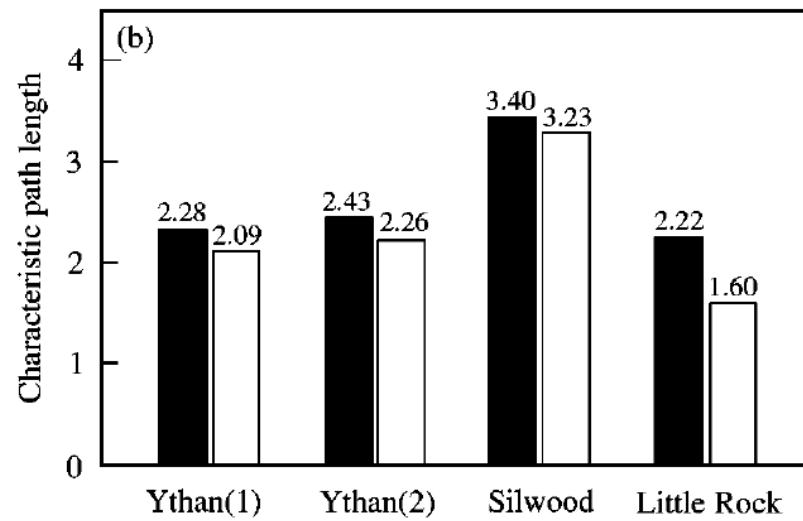
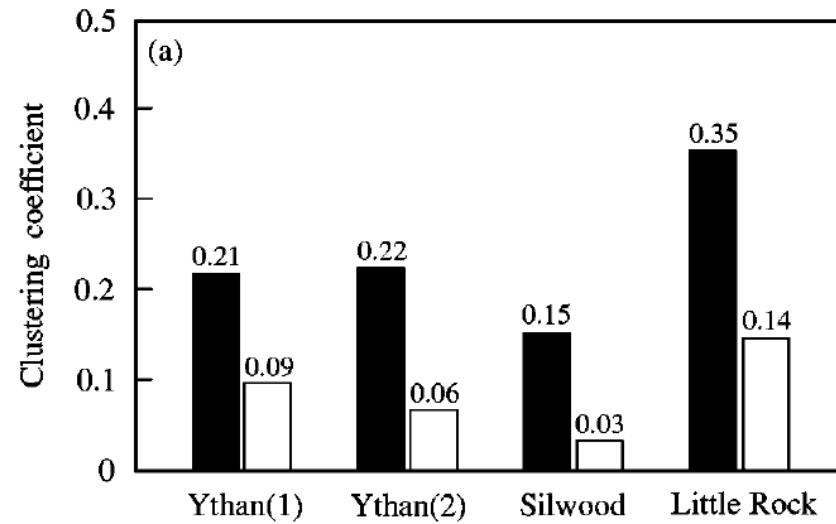
Montoya and Sole (2002)

J. Theor. Biol. (2002) 214, 405-412



R.J. Williams, N.D. Martinez *Nature* (2000)

Ecological networks are more clustered than expected by chance.

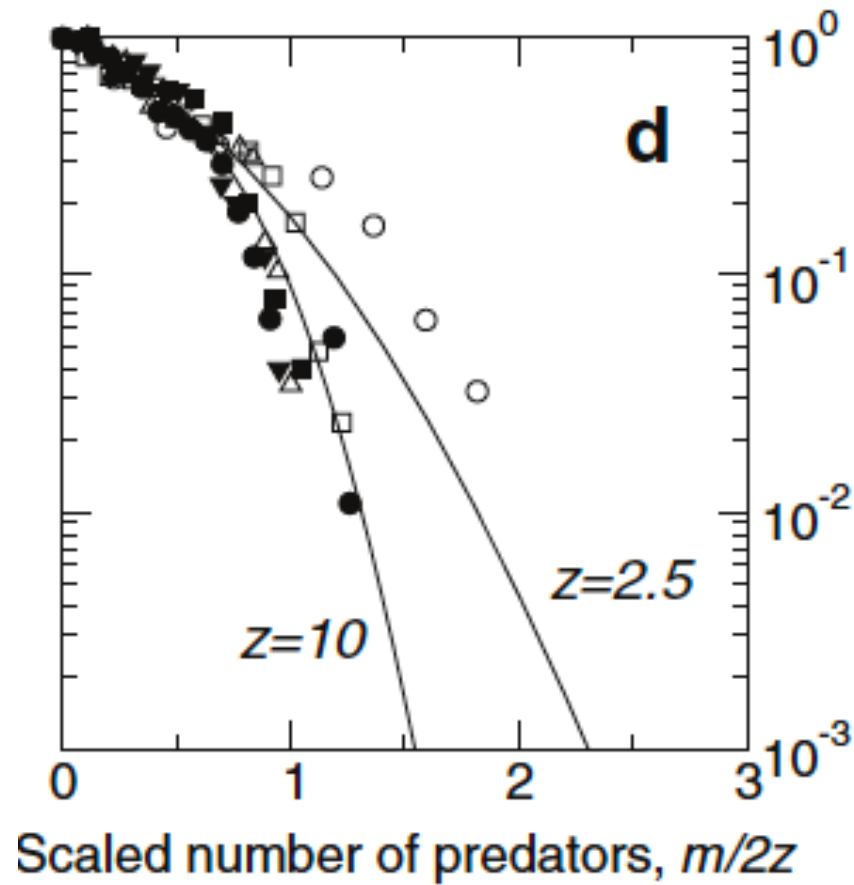


Montoya and Sole (2002)

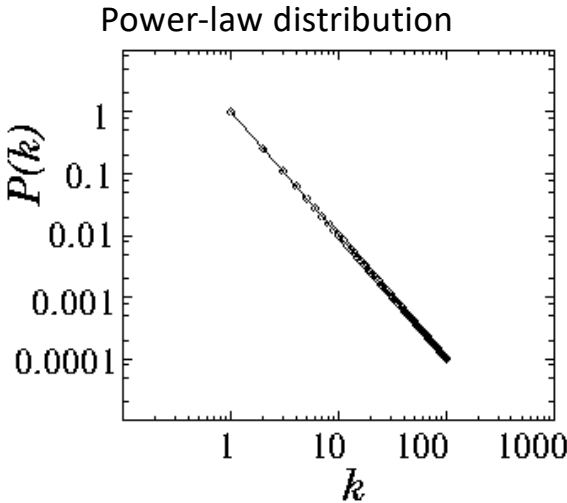
But Camacho et al. (2002) arrive to a different conclusion.

Degree distributions decrease exponentially

This lack of robustness soon made Apparent that is was composed by uncertainty in linkages.



Aerial traffic

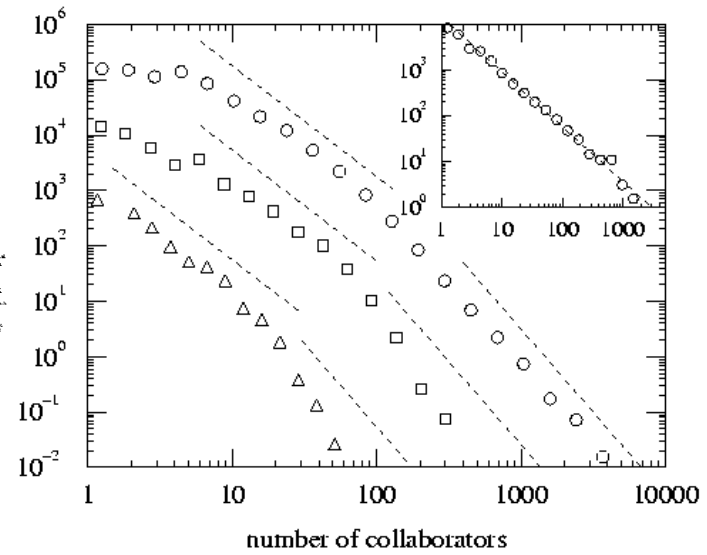
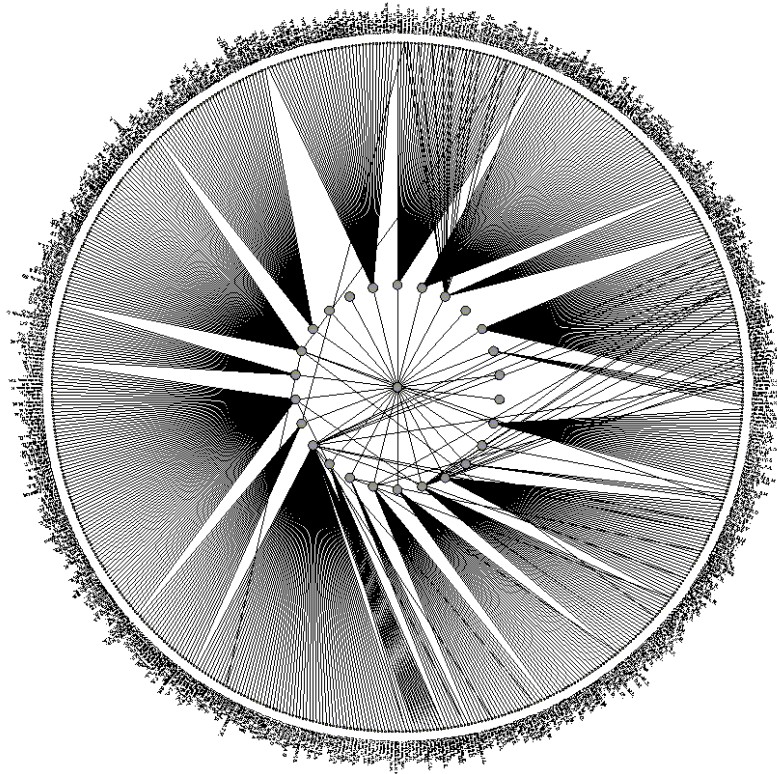


Scale-free Network

Co-authorships

Nodes: authors

Links: co-authorships



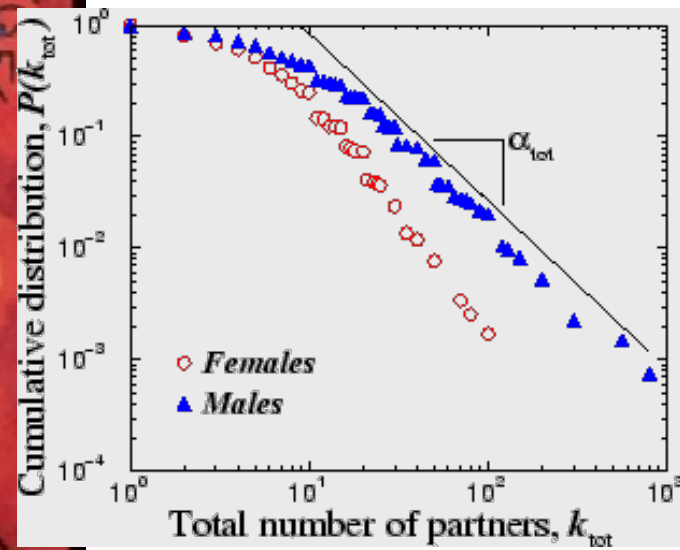
(Newman, 2000, H. Jeong et al 2001)



Sex-web

Nodes: people

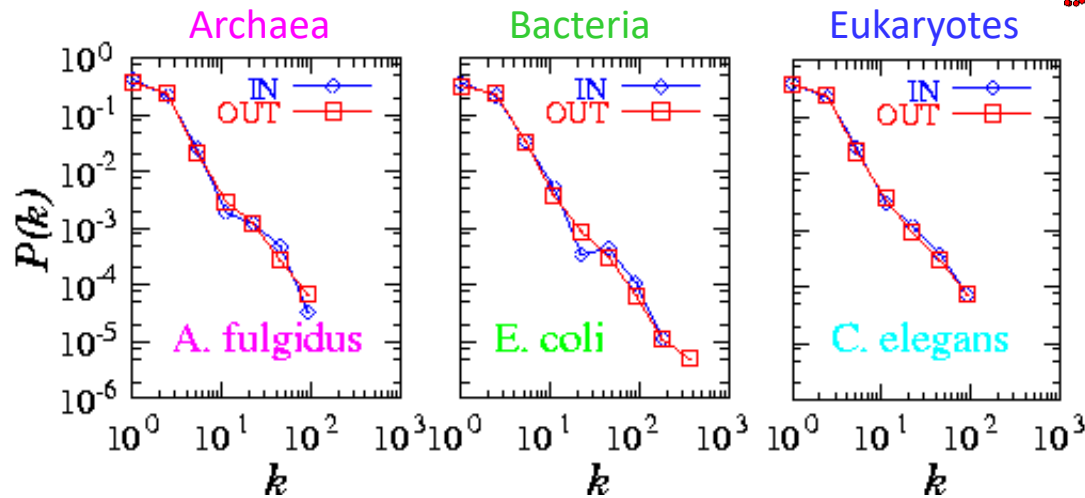
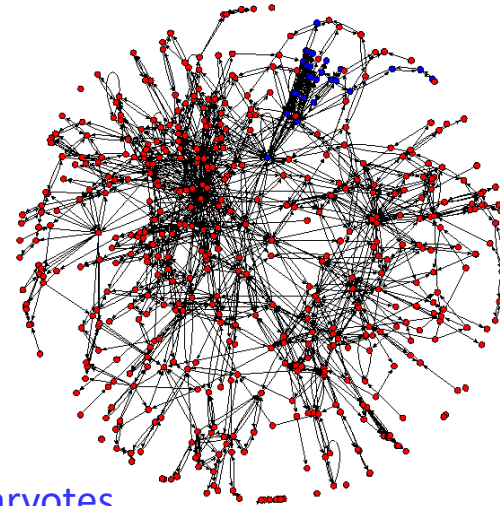
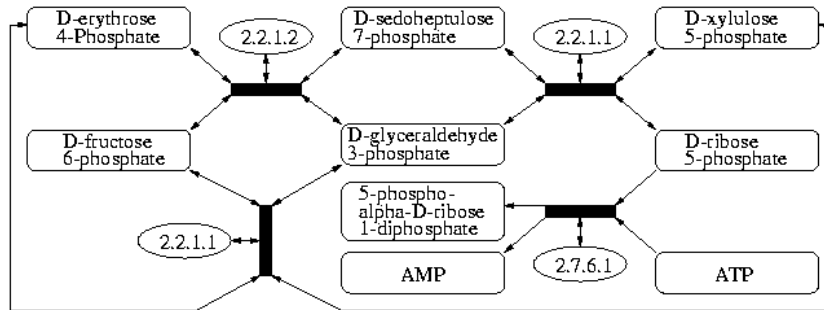
Links: Sexual interaction



4781 Swedes; 18-74;
59% response rate.

Liljeros et al. Nature 2001

Metabolic Networks

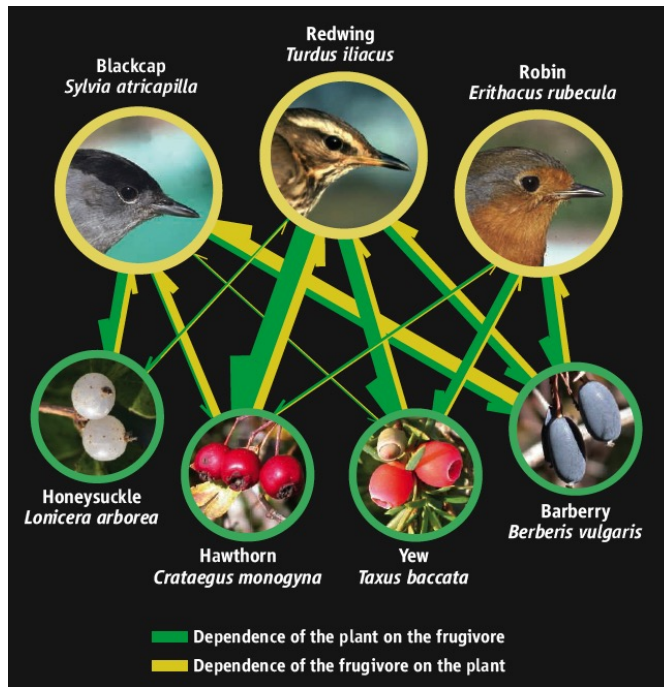


Metabolic networks in three domains of life are scale-free!

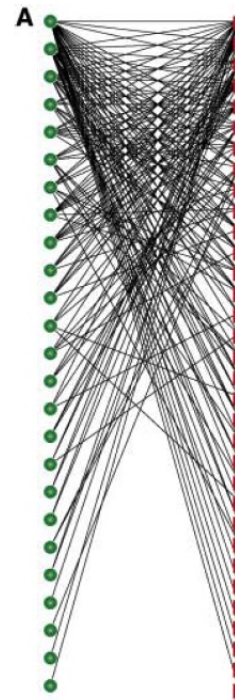
H. Jeong, B. Tombor, R. Albert, Z.N. Oltvai, and A.L. Barabasi, Nature, 407 651 (2000)

Mutualistic networks

Fruit dispersal

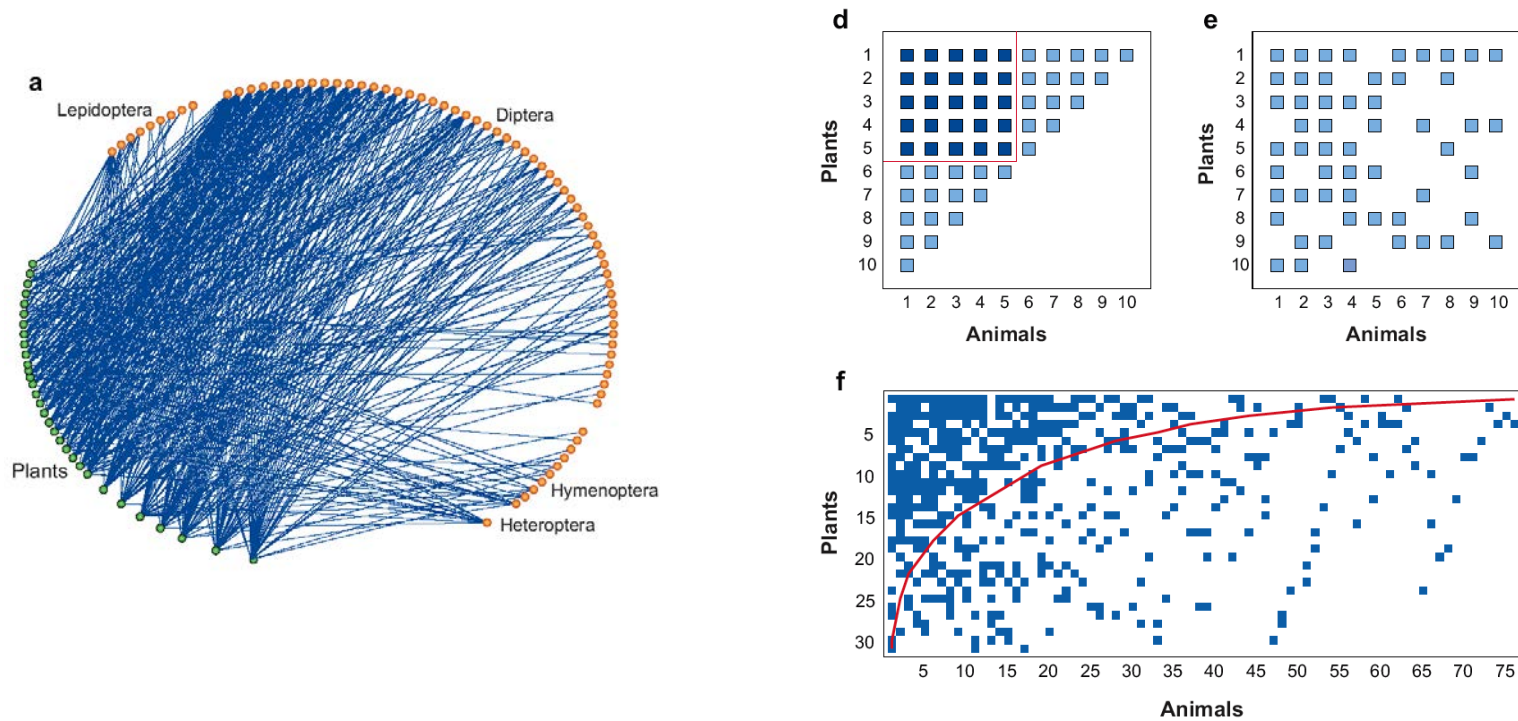


Thompson (2006)



Bascompte et al (2006)

Pollination networks



Asimetría: Generalistas interactúan con especialistas. Esto se asocia a robustez o capacidad para resistir cambios (adiciones o extinciones) sin mayores consecuencias dinámicas (extinciones secundarias).

THE INDETERMINACY OF ECOLOGICAL INTERACTIONS AS PERCEIVED THROUGH PERTURBATION EXPERIMENTS¹

PETER YODZIS

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$$\frac{dN_i}{dt} = f_i(N) \quad i = 1, 2, \dots, s$$

The stability of the equilibrium is determined by the eigenvalues of the "community matrix"

$$A_{ij} = \left(\frac{\partial f_i}{\partial N_j} \right) \Bigg|_{N_e}$$

PRESS PERTURBATION EXPERIMENTS

Suppose we continually add members of species j to the community, at a rate I_j , members per unit area per unit time. How will this affect the equilibrium densities N_e ? Equation (1) is now

$$\frac{dN_j}{dt} = f_j(N) + I_j$$

$$\frac{dN_i}{dt} = f_i(N), \dots i \neq j$$

$$\frac{dN_{ei}}{dI_j} = - (A^{-1})_{ij}$$

Two source of uncertainty

1. Uncertainty due to variation in interaction strengths and signs of the interaction
2. Uncertainties in network topology (who affects whom)

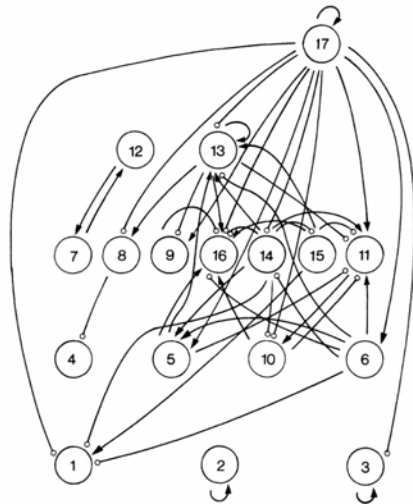


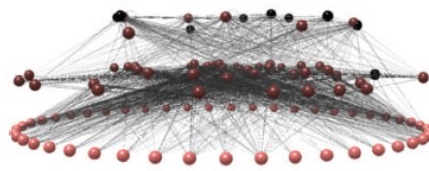
FIG. 3. Major effects on each species of the Narragansett Bay food web, obtained from a randomly generated plausible community matrix. Symbols here have the same meaning as in Fig. 2, except that here they are based on the inverse matrix A^{-1} rather than on the community matrix itself.



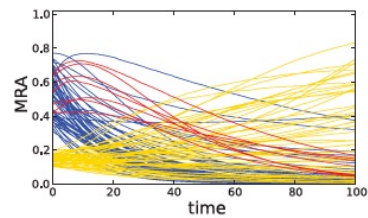
FIG. 4. Major effects on each species of the Narragansett Bay food web, obtained from another randomly generated plausible community matrix. Symbols here have the same meaning as in Fig. 2, except that here they are based on the inverse matrix A^{-1} rather than on the community matrix itself.

Stochastic Approaches

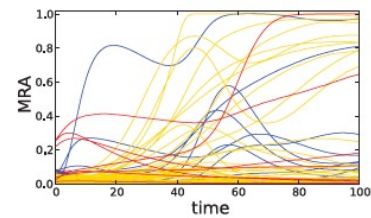
$$\left\{ \begin{array}{l} dX_i(t) = \left(\sum_{j=1, j \neq i}^d \alpha_{j,i}(X(t))X_i(t) - \sum_{j=1}^d \alpha_{i,j}(X(t))X_j(t) \right) dt \\ \quad + \sigma_i(X(t))dW(t) + \eta_i(X(t-))dZ_i(t), \quad (i = 1, \dots, d), \\ X_i(0) = x_i, \end{array} \right.$$



(a) Intertidal food web.



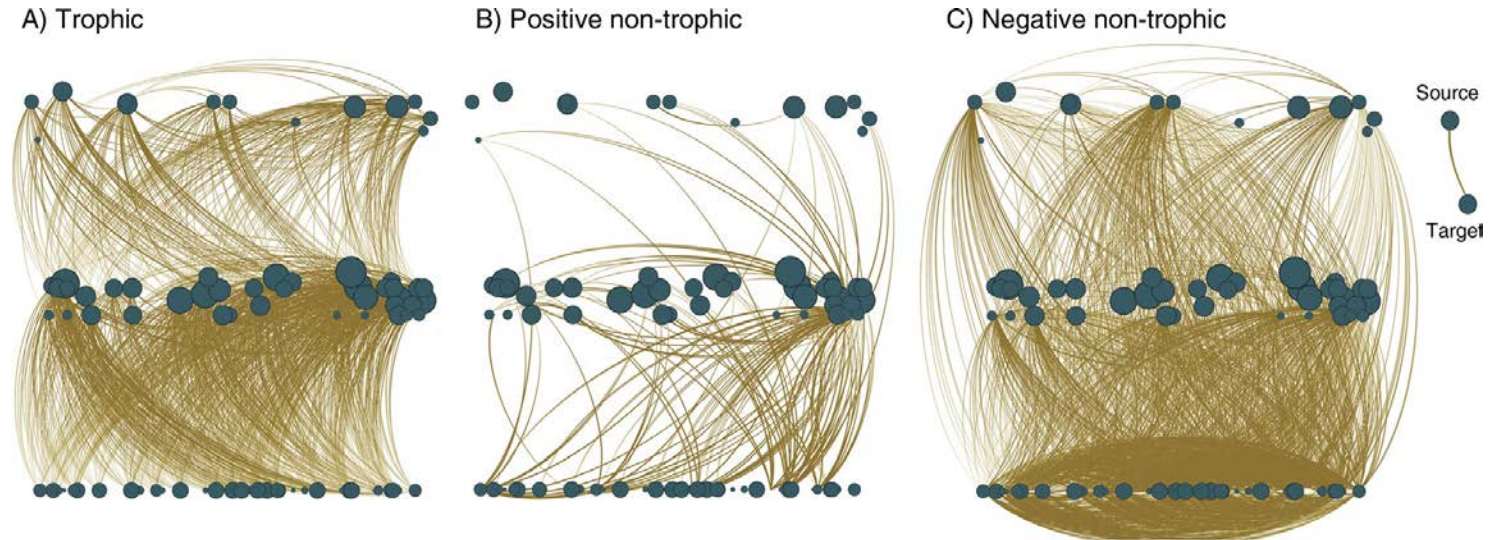
(b) Simulation A.



(c) Simulation B.

Rebolledo et al. (2019) SIAM

TROPHIC and non-trophic interactions in the intertidal of central Chile.



ARTICLE

<https://doi.org/10.1038/s41467-021-24149-x>

OPEN

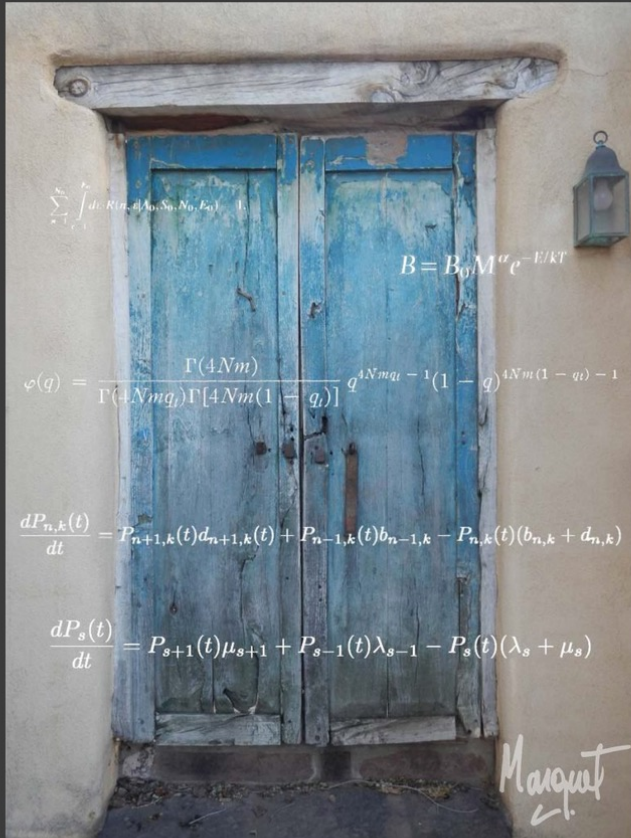
Reconstruction of plant–pollinator networks from observational data

Jean-Gabriel Young^{1,2,3✉}, Fernanda S. Valdovinos^{3,4,5}  & M. E. J. Newman^{3,6} 

Welcome to Neti



Second NETI meeting this coming September at the Santa Fe Institute in Santa Fe New Mexico



On Theory in Ecology

PABLO A. MARQUET, ANDREW P. ALLEN, JAMES H. BROWN, JENNIFER A. DUNNE, BRIAN J. ENQUIST, JAMES F. GILLOOLY, PATRICIA A. GOWATY, JESSICA L. GREEN, JOHN HARTE, STEVE P. HUBBELL, JAMES O'DWYER, JORDAN G. OKIE, ANNETTE OSTLING, MARK RITCHIE, DAVID STORCH, AND GEOFFREY B. WEST

We argue for expanding the role of theory in ecology to accelerate scientific progress, enhance the ability to address environmental challenges, foster the development of synthesis and unification, and improve the design of experiments and large-scale environmental-monitoring programs. To achieve these goals, it is essential to foster the development of what we call efficient theories, which have several key attributes. Efficient theories are grounded in first principles, are usually expressed in the language of mathematics, make few assumptions and generate a large number of predictions per free parameter, are approximate, and entail predictions that provide well-understood standards for comparison with empirical data. We contend that the development and successive refinement of efficient theories provide a solid foundation for advancing environmental science in the era of big data.

Keywords: theory unification, metabolic theory, neutral theory of biodiversity, maximum entropy theory of ecology, big data

BioScience 64: 701–710. (2014)

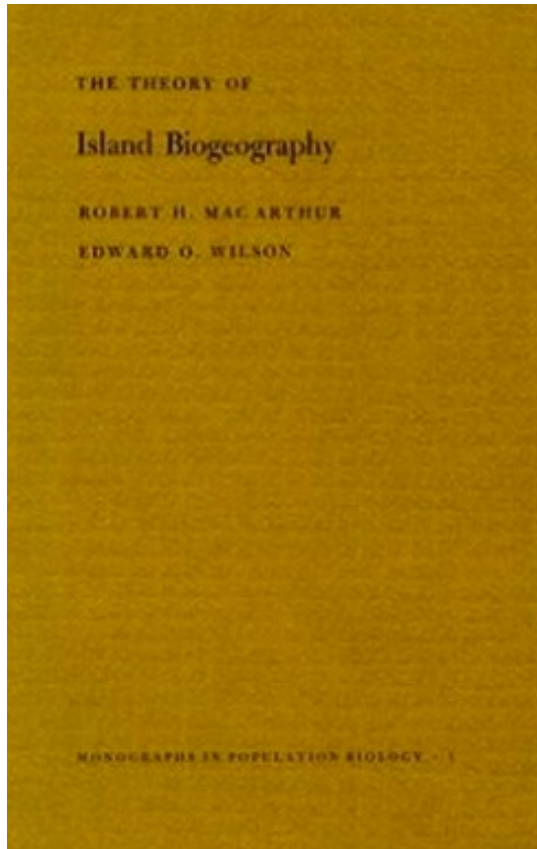


MacArthur & Wilson (1963)

$$S = bA^k$$

AN EQUILIBRIUM THEORY OF INSULAR ZOOGEOGRAPHY

ROBERT H. MACARTHUR¹ AND EDWARD O. WILSON²



$$(3-4) \quad \frac{dP_s(t)}{dt} = -(\lambda_s + \mu_s)P_s(t) + \lambda_{s-1}P_{s-1}(t) + \mu_{s+1}P_{s+1}(t).$$

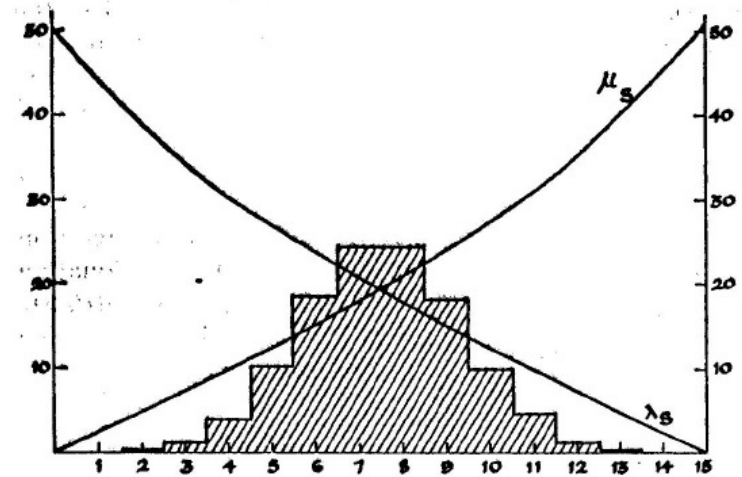
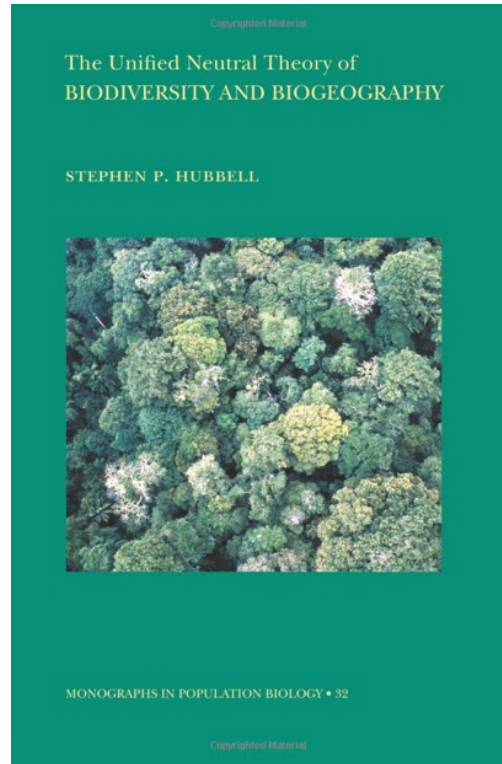


FIGURE 19. A particular case of a predicted distribution of numbers of species on a family of island biotas all with identical extinction and immigration curves and all having had time to reach equilibrium. The histogram represents the number of islands with each number of resident species in an equilibrium situation. The species pool from which the biotas were assembled contained 15 species. If the immigration and extinction curves were straighter, the variance of equilibrium species numbers would be even greater; yet this large variance is still consistent with the equilibrium condition.

"In principle one could solve eq. 3-4....for our purpose is more useful to find the mean $M(t)$ and the variance, $var(t)$, of the number of species at time t . These can be estimated in nature by measuring the mean and variance in number of species of a series of islands of about the same distance and are and hence of the same λ and μ ." pp.33-34



Master equation for the probability of observing k species with n individuals

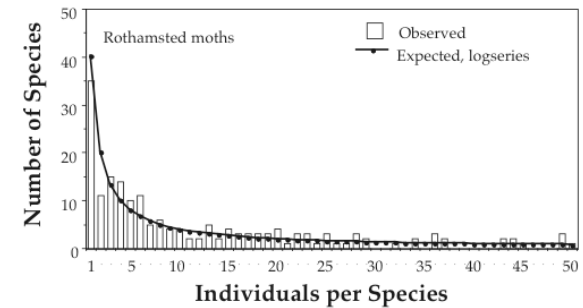
$$\frac{dP_{n,k}(t)}{dt} = P_{n+1,k}(t)d_{n+1,k}(t) + P_{n-1,k}(t)b_{n-1,k} - P_{n,k}(t)(b_{n,k} + d_{n,k})$$

Assumptions:

- i) The species are assumed to be demographically identical, i.e. $b_{n,k} = b_n$ and $d_{n,k} = d_n$.
- ii) Density independent case, i.e. $b_n = b * n$ and $d_n = d * n$ ($n > 0$)

Fisher's Log-series distribution

$$\langle \Phi_n \rangle = \theta \frac{x^n}{n}$$



where $x = b/d$ and $\theta = SP_{0\nu}/d$ biodiversity parameter.

Neutral theory and relative species abundance in ecology

Igor Volkov¹, Jayanth R. Banavar¹, Stephen P. Hubbell^{2,3}
& Amos Maritan^{4,5}

ME for the number of species within communities (islands)

$$\frac{dP_s(t)}{dt} = P_{s+1}(t)\mu_{s+1} + P_{s-1}(t)\lambda_{s-1} - P_s(t)(\lambda_s + \mu_s),$$

ME for the number of individuals within species

$$\frac{dP_{n,k}(t)}{dt} = P_{n+1,k}(t)d_{n+1,k}(t) + P_{n-1,k}(t)b_{n-1,k} - P_{n,k}(t)(b_{n,k} + d_{n,k})$$

They cannot be true at the same time!

Diffusion processes



Sewall Wright



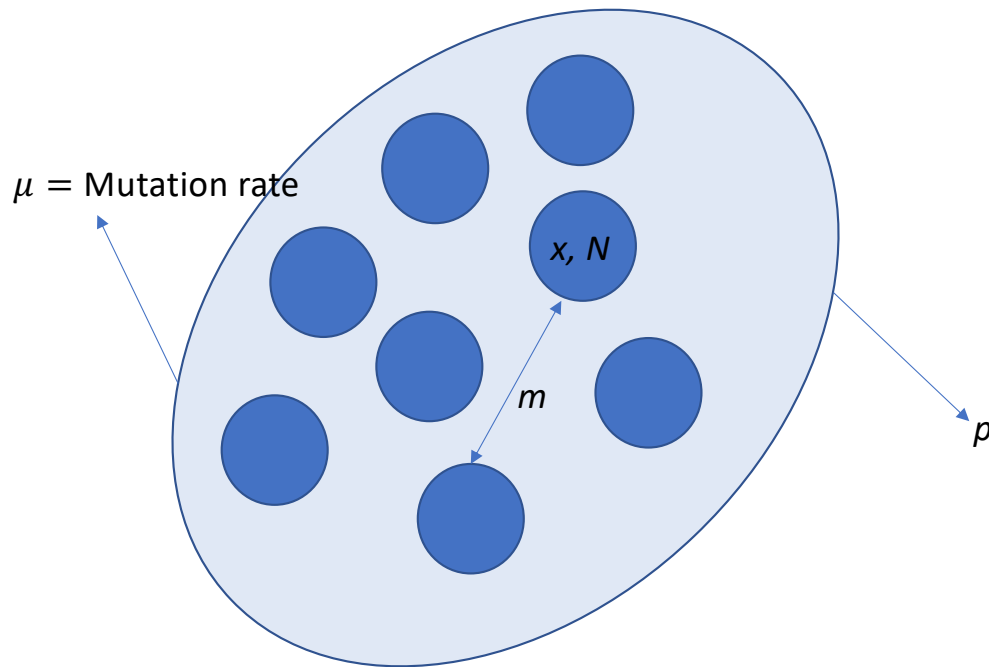
Andrey Kolmogorov



Ronald Fisher

- The frequency of genes in a structured population

$$\rho_{\infty}(x) = \frac{\Gamma(4Nm)}{\Gamma(4Nmp)\Gamma(4Nmq)} x^{4Nmq-1} (1-x)^{4Nmp-1}.$$

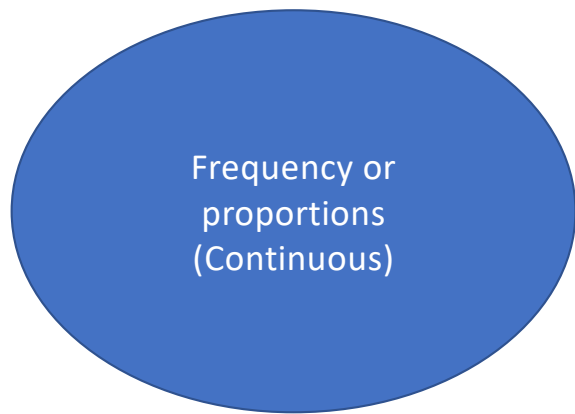


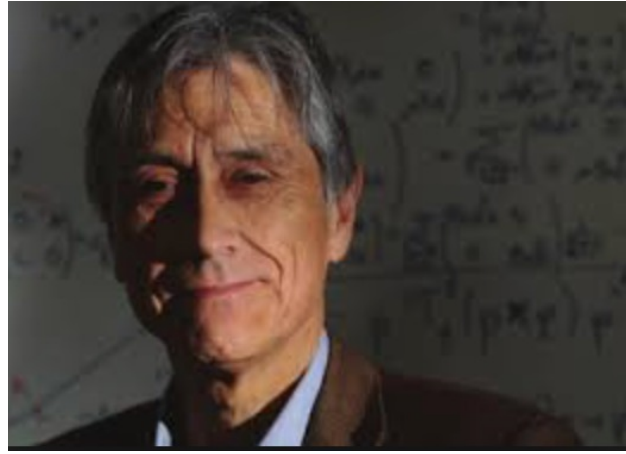
x = Frequency of a given allele in a local population

N = Effective population size

m = Proportion of migrating individuals among population each generation.

p = Frequency of a given allele in the total population



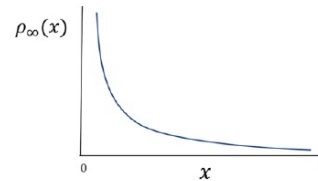
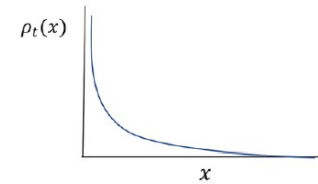
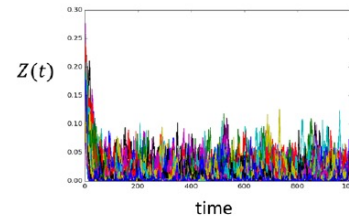
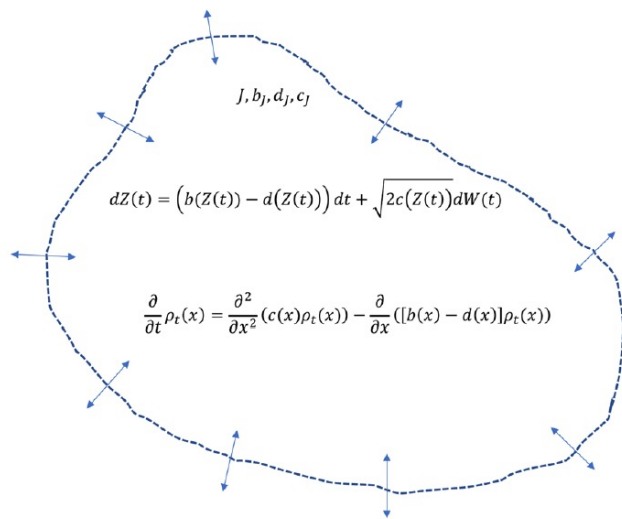


Prof. Rolando Rebolledo

**La méthode des martingales appliquée à l'étude de
la convergence en loi de processus**

Mémoires de la S. M. F., tome 62 (1979), p. I-V+1-125.

http://www.numdam.org/item?id=MSMF_1979__62__R1_0



$$\rho_\infty(x) = \frac{\Gamma(\alpha + \beta)}{\Gamma(\alpha) + \Gamma(\beta)} x^{\alpha-1} (1-x)^{\beta-1}$$

$$B_J(n) = b_J(n) + c_J(n)$$

$$D_J(n) = d_J(n) + c_J(n).$$

$$b(x) = b_0 + b_1x$$

$$d(x) = d_0 + d_1x$$

$$c(x) = \gamma x(1-x),$$

SCIENTIFIC REPORTS

OPEN On the proportional abundance of species: Integrating population genetics and community ecology

16: 24 March 2017
16: 21 November 2017

Pablo A. Marquet^{1,2,3,4,5}, Guillermo Espinoza¹, Sebastian R. Abades⁴, Angela Ganz⁶ & Rolando Rebolledo^{2,8}

$$\rho_{\infty}(x) = \frac{\Gamma(\alpha + \beta)}{\Gamma(\alpha) + \Gamma(\beta)} x^{\alpha-1} (1 - x)^{\beta-1}$$

The Proportional Species Abundance Distribution (PSAD)

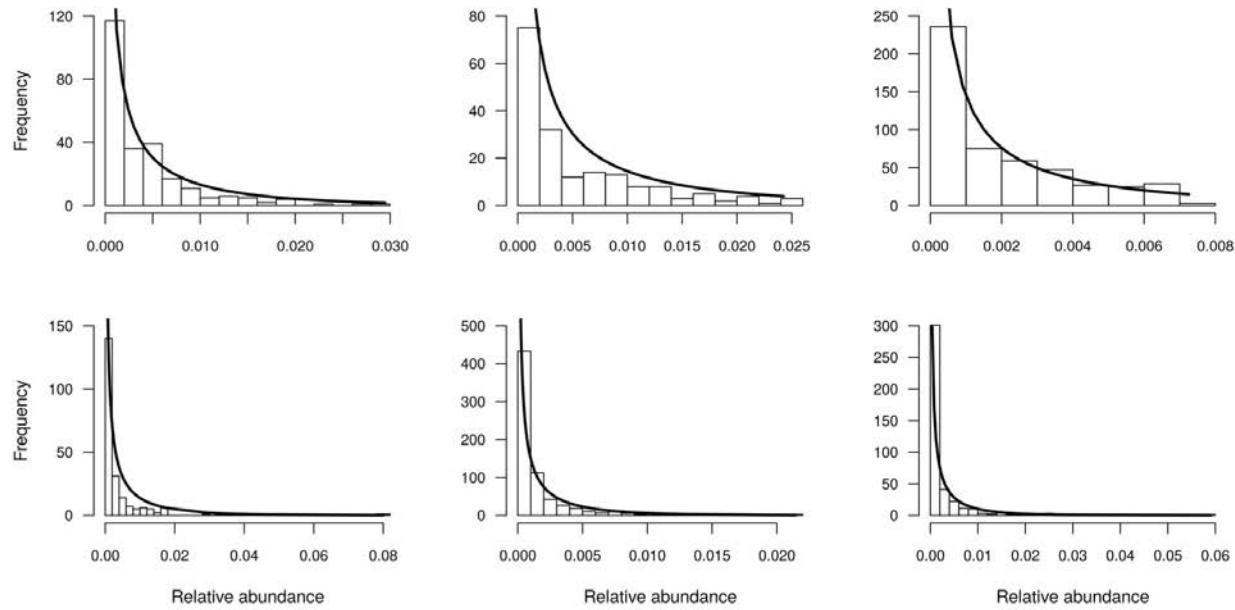
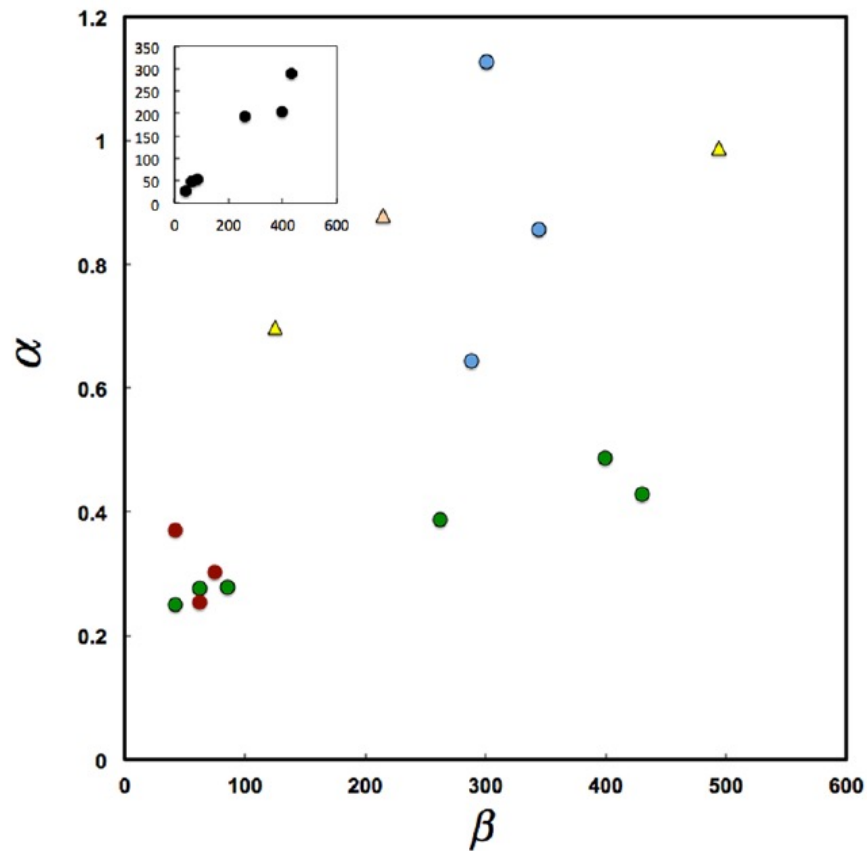


Figure 1. Fit of the Beta distribution to different animal and plant communities. First row, from left to right Amazon birds (community 10 in Table 1), Lepidoptera (12 in Table 1), butterflies (11 in Table 1), second row from left to right Tropical trees (6 in Table 1), Tropical trees (2 in Table 1) and Coral reefs (14 in Table 1)

$$\rho_{\infty}(x) = \frac{\Gamma(\alpha + \beta)}{\Gamma(\alpha) + \Gamma(\beta)} x^{\alpha-1} (1-x)^{\beta-1}$$



- Marine communities
- Shrublands
- Tropical Forest
- ▲ Bird communities

$\alpha \sim$ Dispersal

$\beta \sim$ Speciation