

# Ecological networks, indeterminacy and reconstruction

Pablo A. Marquet

Department of Ecology,  
Catholic University of Chile



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

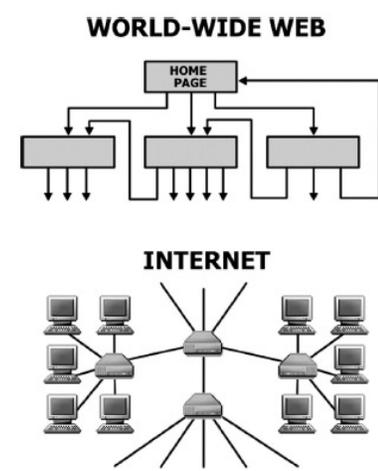
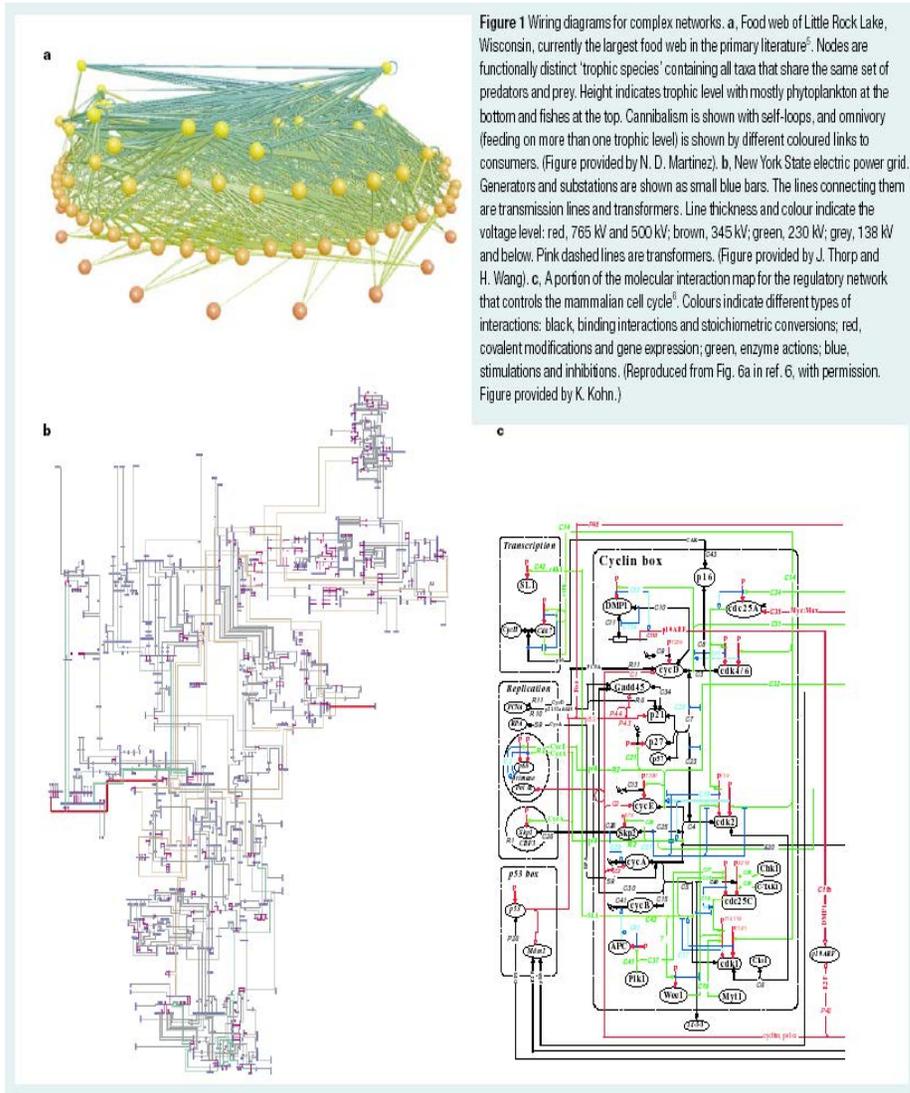
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Acquisition  
Transformation  
Storage  
Transmission

OF

Energy  
Matter  
Information

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Alberts & Barabasi (2002)

Strogatz (2001)



## **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\*

Biological Computer Laboratory,  
University of Illinois,  
Urbana, Illinois 61801.

NATURE VOL. 228 NOVEMBER 21 1970

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?

$$\mathbb{X} = \{x_1, \dots, x_n\}$$

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

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

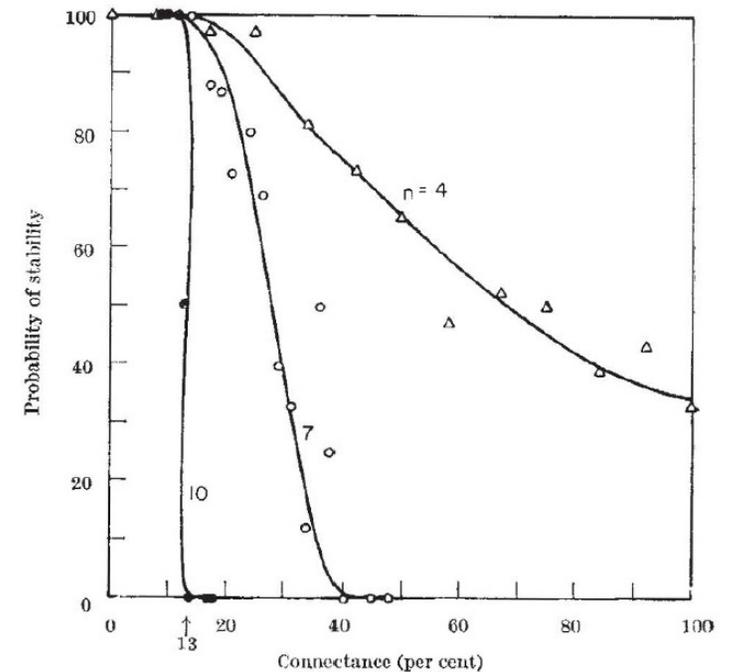


Fig. 1. Variation of stability with connectance.

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  $C$ .

# Will a Large Complex System be Stable?

ROBERT M. MAY\*

*Institute for Advanced Study,  
Princeton, New Jersey 08540*

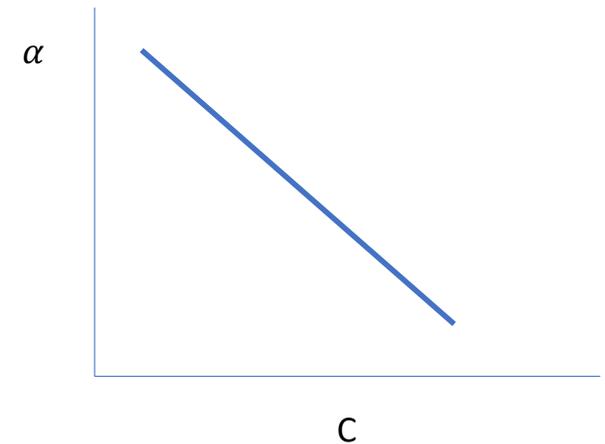
Interacting networks would be stable if

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

$\alpha$  = average magnitude of interaction strength

S = Number of species (nodes)

C = Connectance



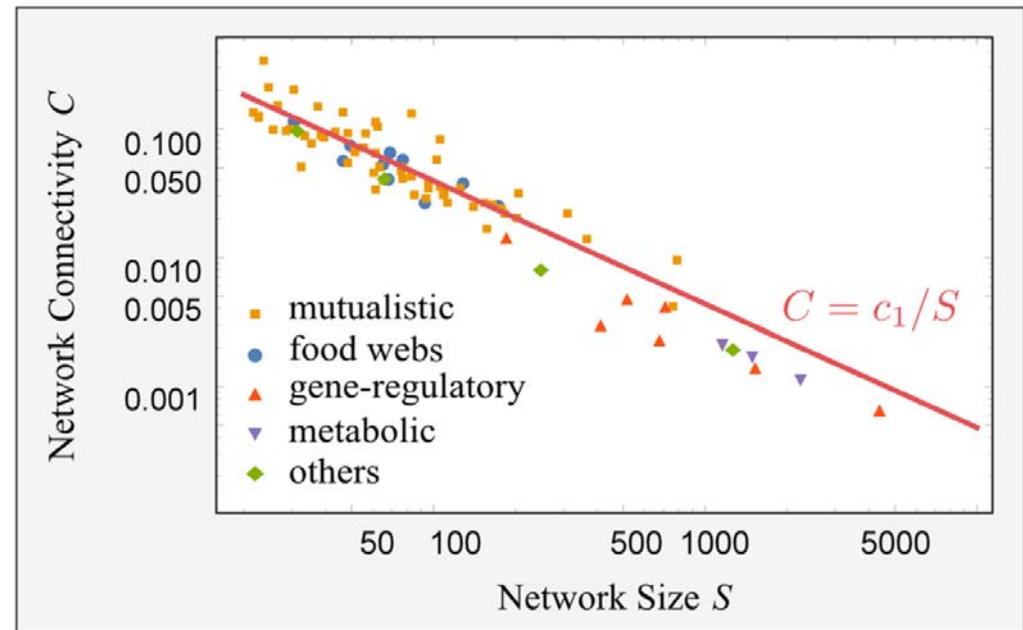
Such examples suggest that our model multi-species communities, for given average interaction strength and web connectance, will do better if the interactions tend to be arranged in “blocks”—again a feature observed in many natural ecosystems.

Interacting networks would be stable if

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

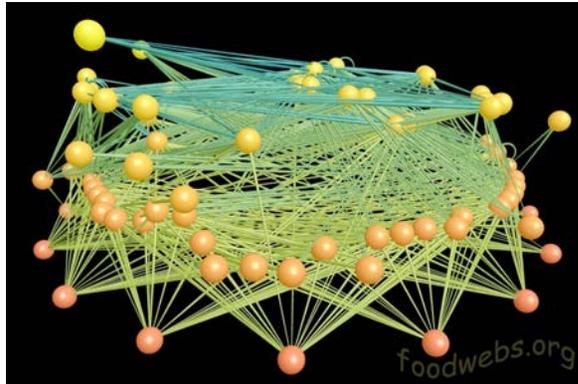
Or they are sparse such that:

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



Busiello et al. (2017)

East River Valley Foodweb



Caribbean Reef Foodweb

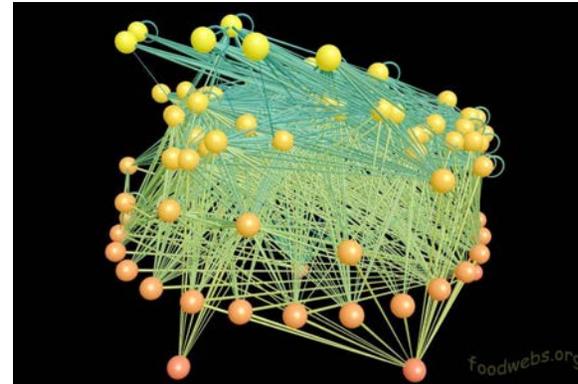
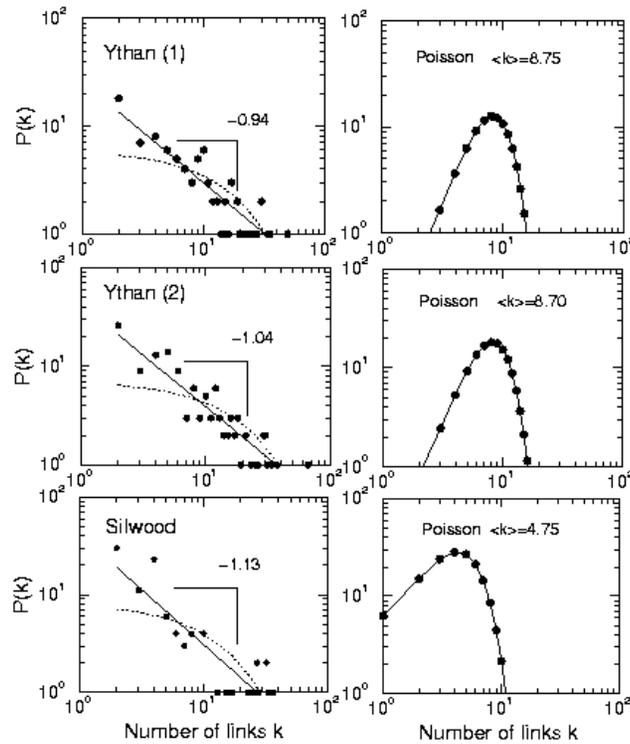


Image produced with FoodWeb3D, written by R.J. Williams and provided by the Pacific Ecoinformatics and Computational Ecology Lab ([www.foodwebs.org](http://www.foodwebs.org), Yoon et al. 2004)

# Foodwebs

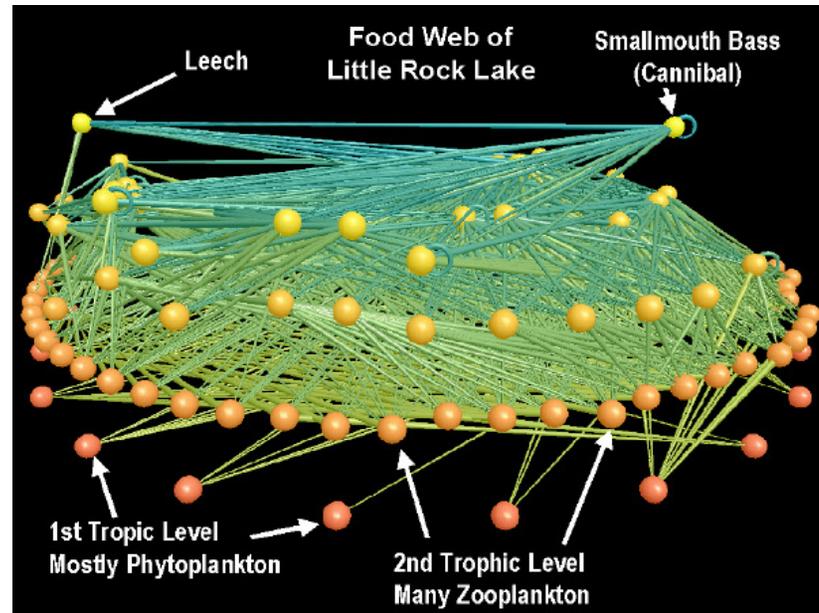
Nodes: Species

Links: Who eats whom



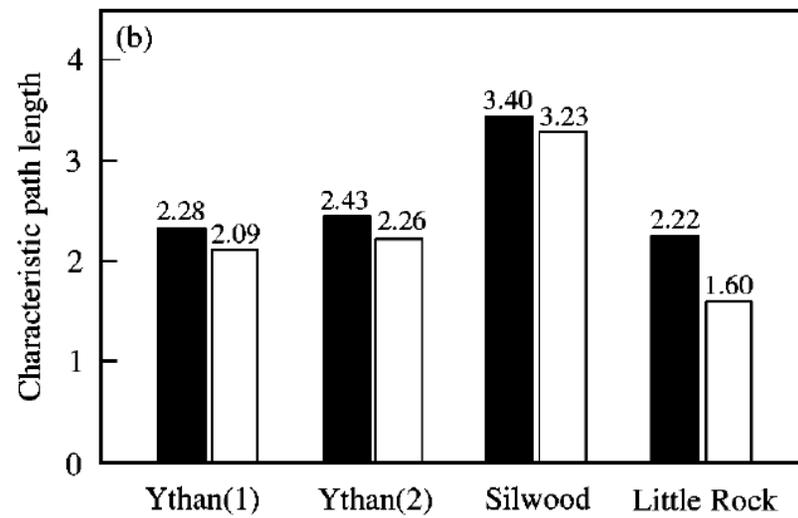
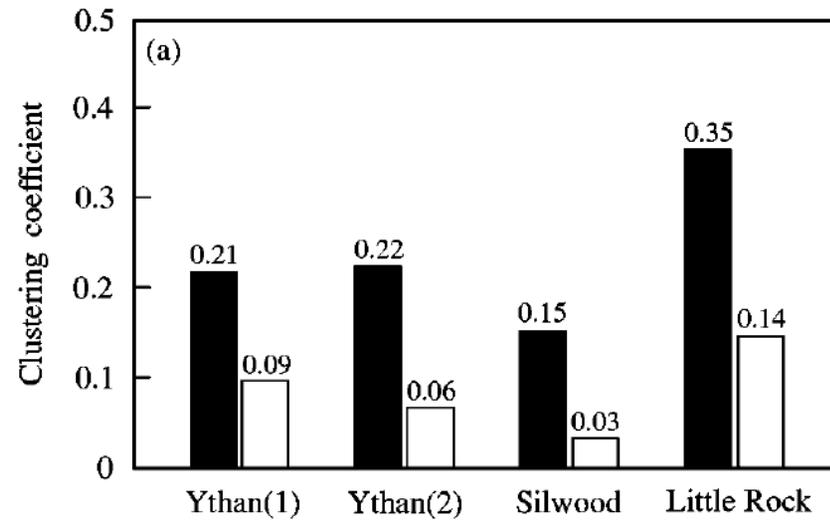
Montoya and Sole (2002)

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



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

Ecological networks are more clustered than expected by chance.

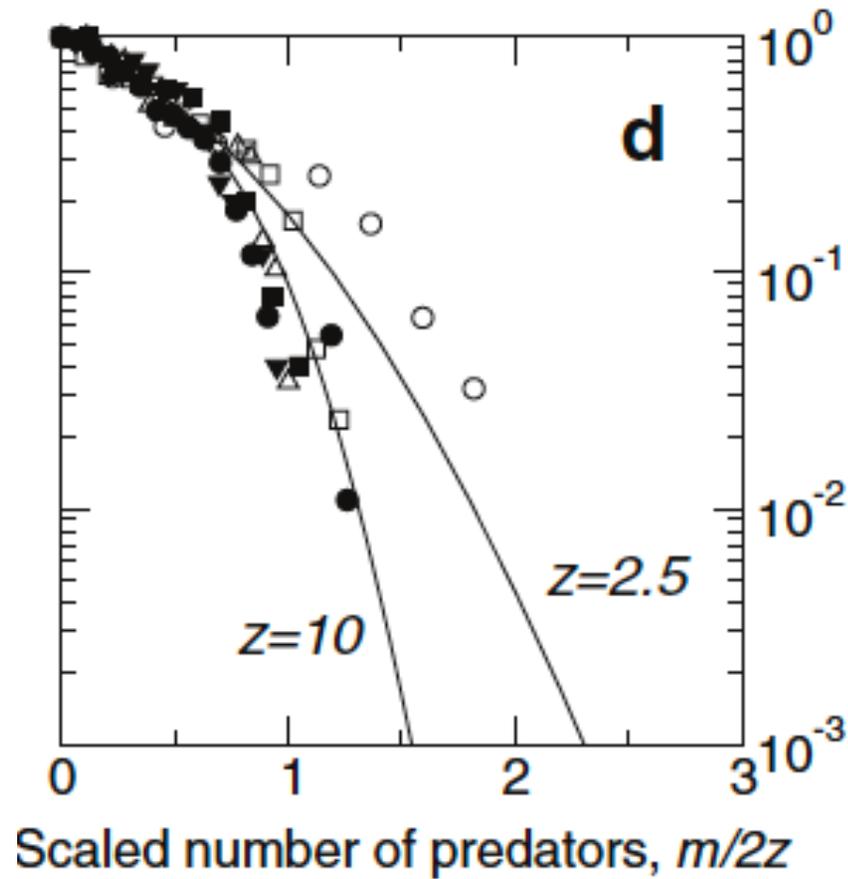


Montoya and Sole (2002)

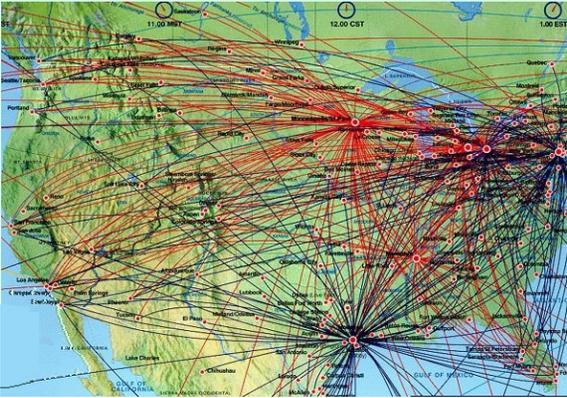
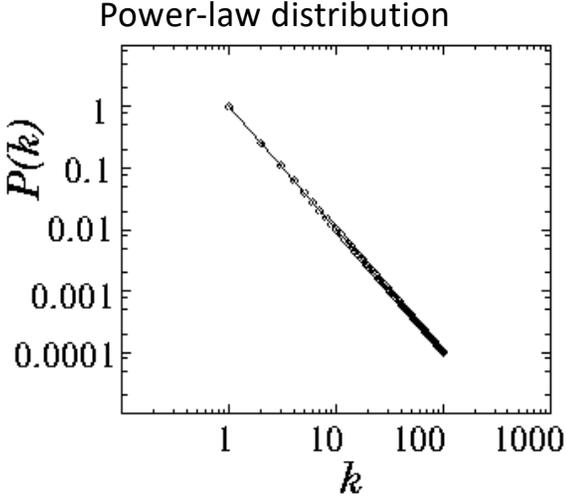
But Camacho et al. (2002) arrive to a different conclusion.

Degree distributions decrease exponentially

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



Aerial traffic

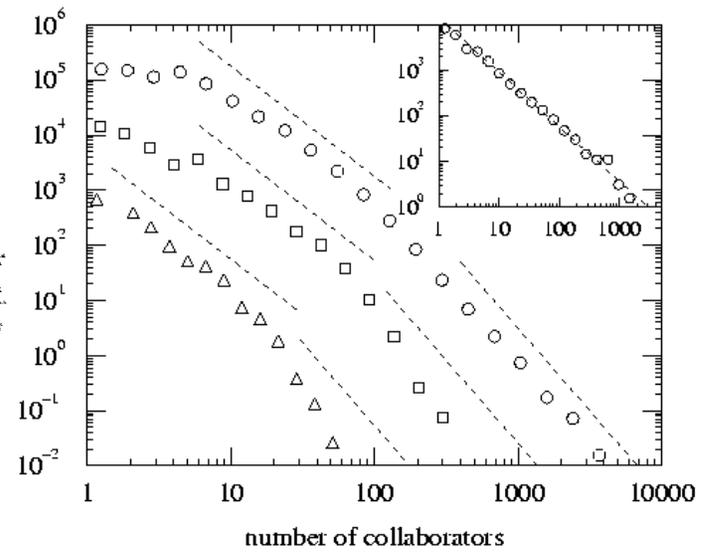
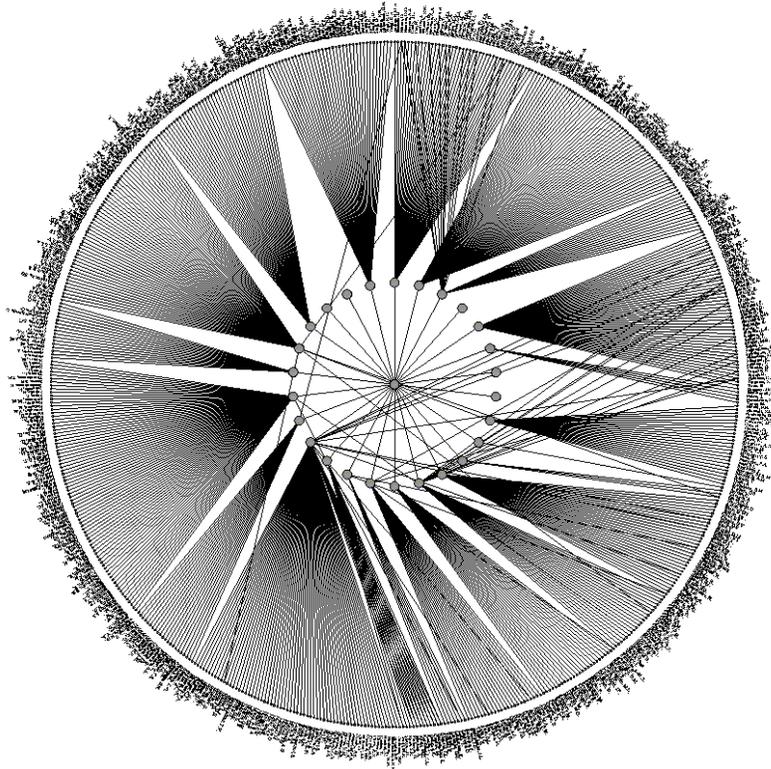


**Scale-free Network**

# Co-authorships

Nodes: authors

Links: co-authorships



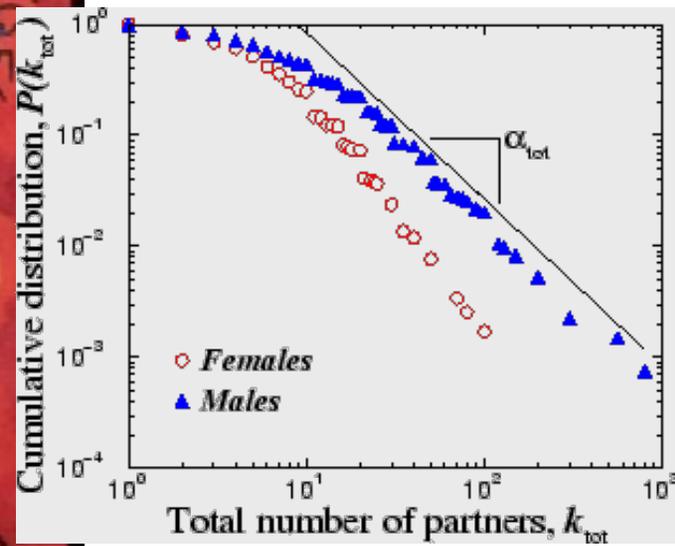
(Newman, 2000, H. Jeong et al 2001)



## Sex-web

Nodes: people

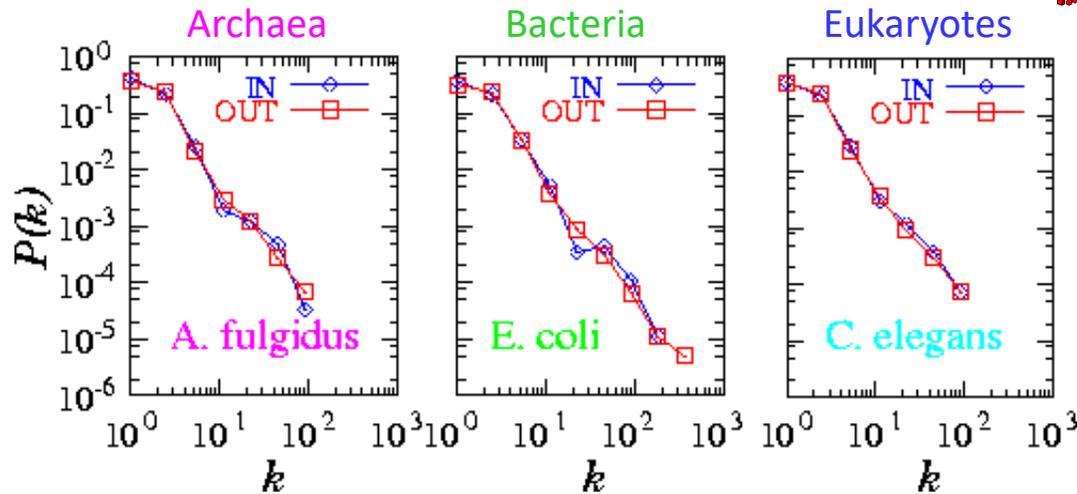
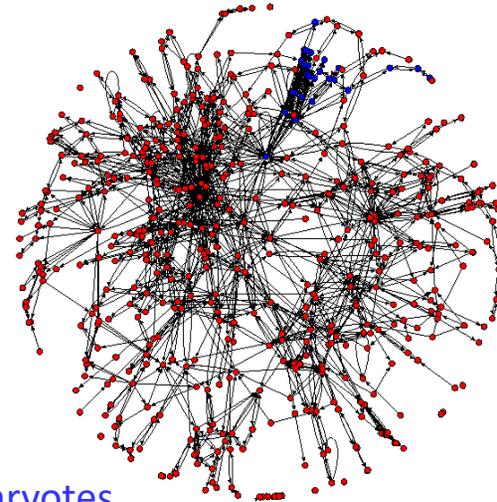
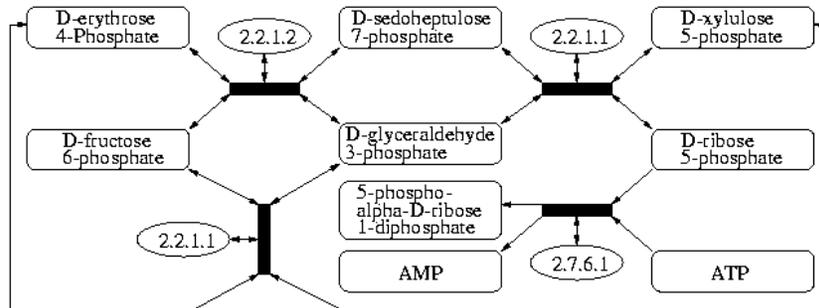
Links: Sexual interaction



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

Liljeros et al. Nature 2001

# Metabolic Networks

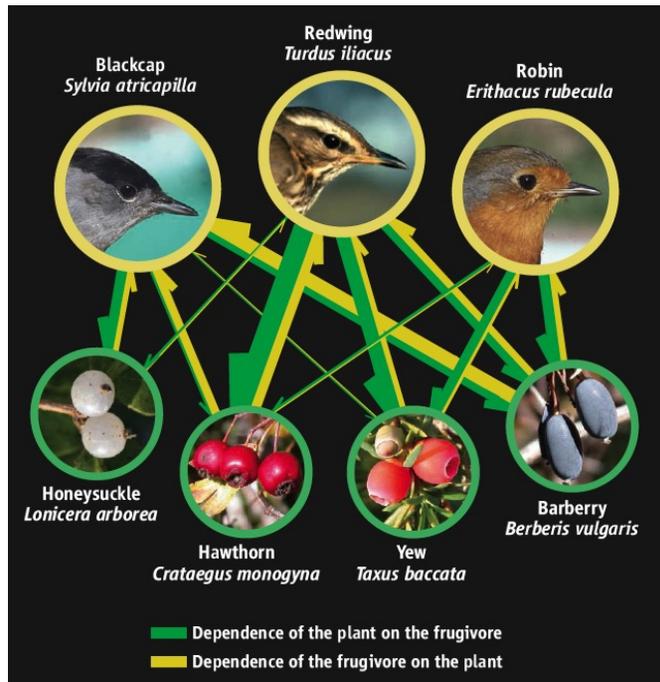


Metabolic networks in three domains of life are scale-free!

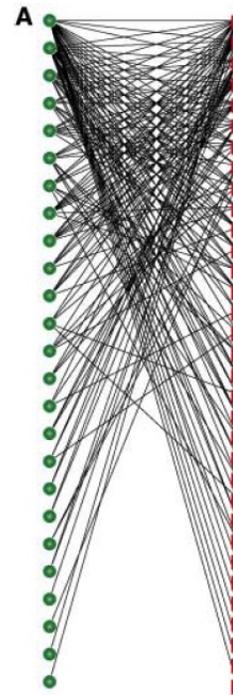
H. Jeong, B. Tombor, R. Albert, Z.N. Oltvai, and A.L. Barabasi, Nature, 407 651 (2000)

# Mutualistic networks

## Fruit dispersal

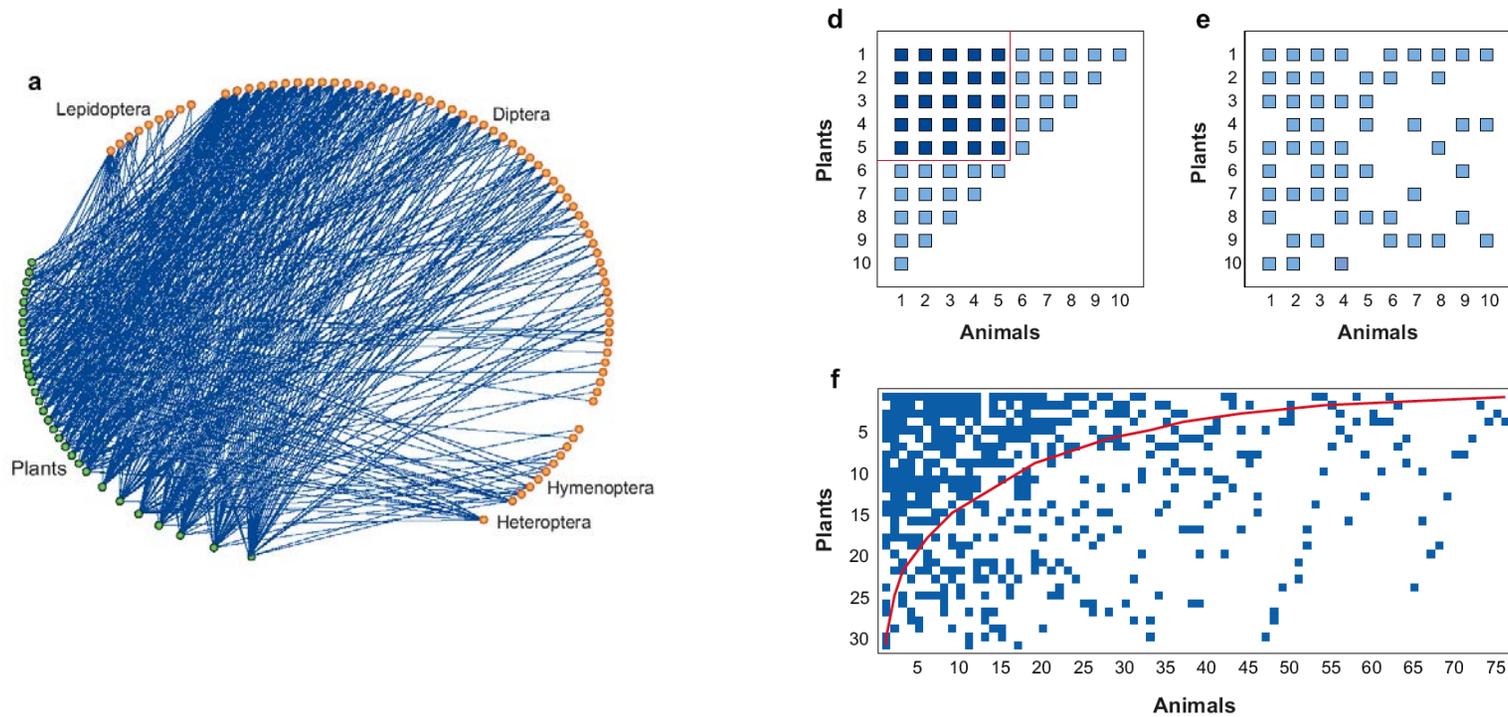


Thompson (2006)



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 EXPERIMENTS<sup>1</sup>

PETER YODZIS

*Department of Zoology, University of Guelph, Guelph, Ontario N1G 2W1 Canada*

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

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)

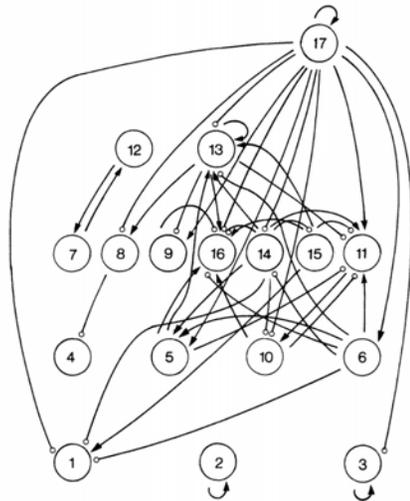


FIG. 3. Major effects on each species of the Narragansett Bay food web, obtained from a randomly generated plausible community matrix. Symbols here have the same meaning as in Fig. 2, except that here they are based on the inverse matrix  $A^{-1}$  rather than on the community matrix itself.

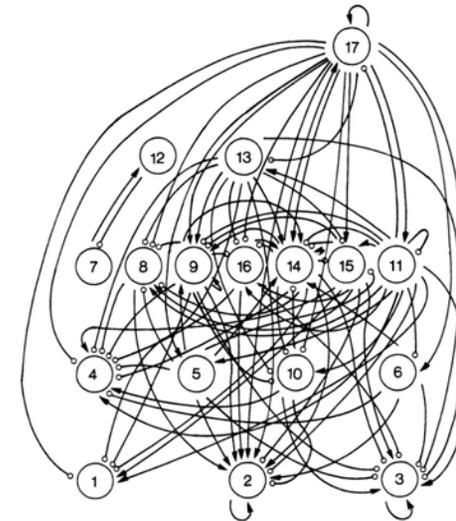
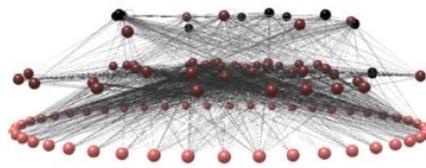


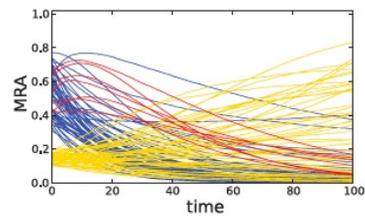
FIG. 4. Major effects on each species of the Narragansett Bay food web, obtained from another randomly generated plausible community matrix. Symbols here have the same meaning as in Fig. 2, except that here they are based on the inverse matrix  $A^{-1}$  rather than on the community matrix itself.

# Stochastic Approaches

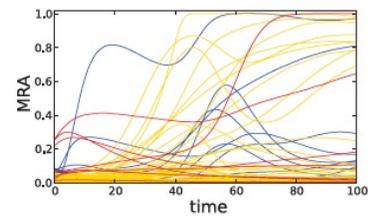
$$\left\{ \begin{array}{l} dX_i(t) = \left( \sum_{j=1, j \neq i}^d \alpha_{j,i}(X(t))X_i(t) - \sum_{j=1}^d \alpha_{i,j}(X(t))X_j(t) \right) dt \\ \quad + \sigma_i(X(t))dW(t) + \eta_i(X(t-))dZ_i(t), \quad (i = 1, \dots, d), \\ X_i(0) = x_i, \end{array} \right.$$



(a) Intertidal food web.



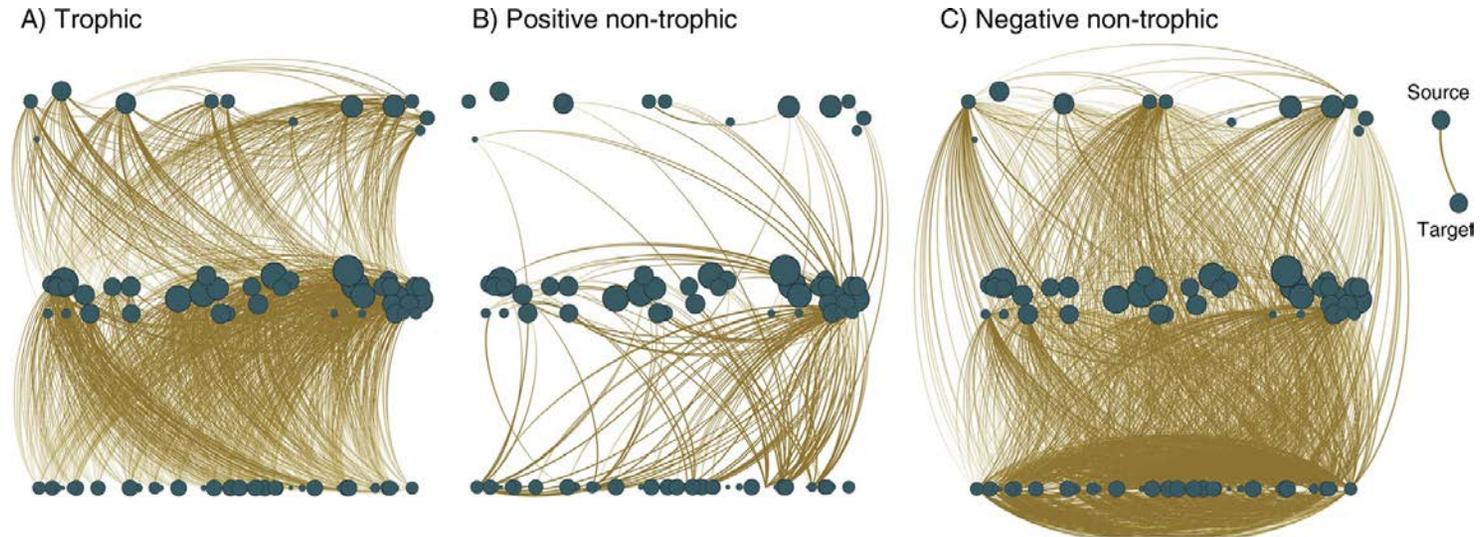
(b) Simulation A.



(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

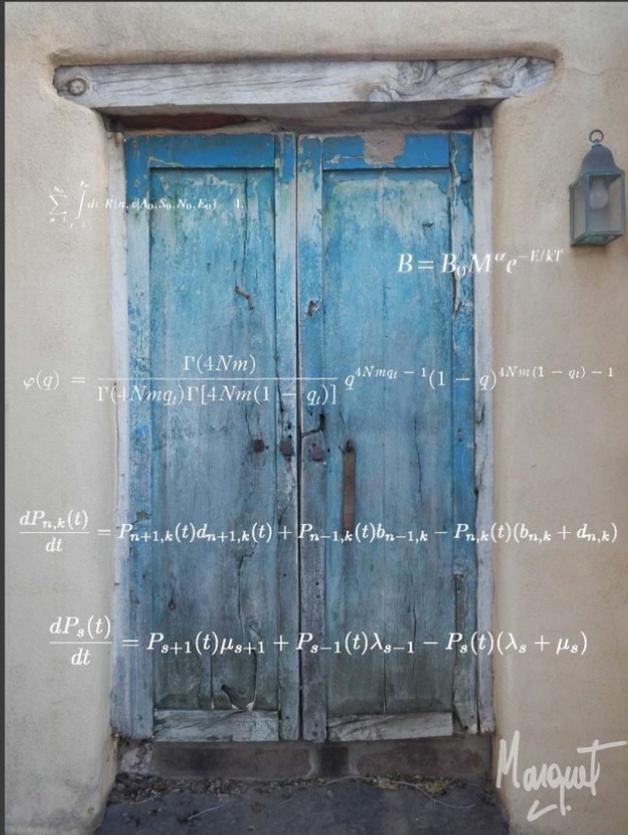
# Reconstruction of plant–pollinator networks from observational data

Jean-Gabriel Young<sup>1,2,3</sup>✉, Fernanda S. Valdovinos<sup>3,4,5</sup>  & M. E. J. Newman<sup>3,6</sup> 

**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)

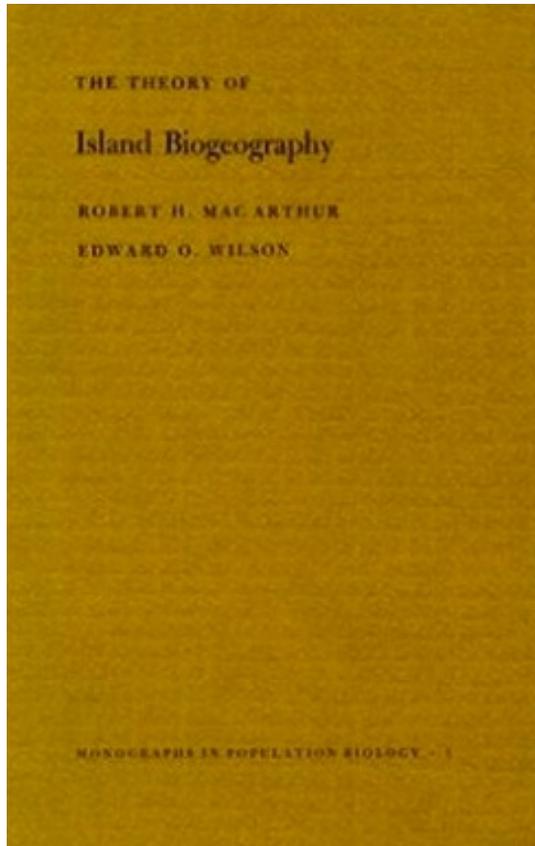


MacArthur & Wilson (1963)

$$S = bA^k$$

AN EQUILIBRIUM THEORY OF INSULAR ZOOGEOGRAPHY

ROBERT H. MACARTHUR<sup>1</sup> AND EDWARD O. WILSON<sup>2</sup>



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

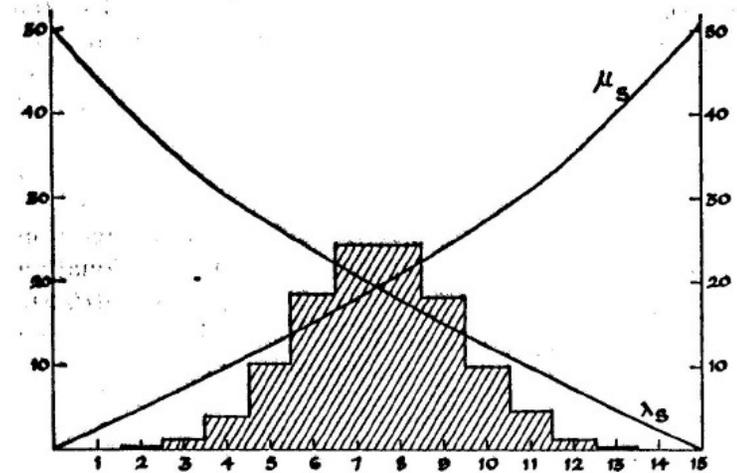
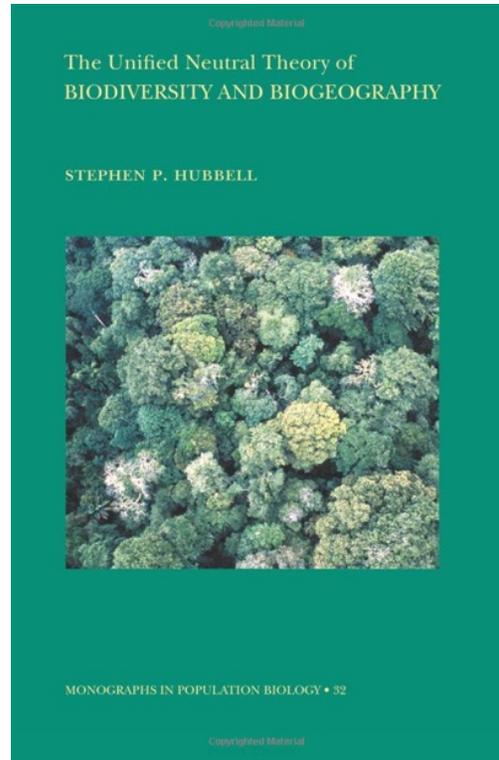


FIGURE 19. A particular case of a predicted distribution of numbers of species on a family of island biotas all with identical extinction and immigration curves and all having had time to reach equilibrium. The histogram represents the number of islands with each number of resident species in an equilibrium 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  $\lambda$  and  $\mu$ ." pp.33-34*



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

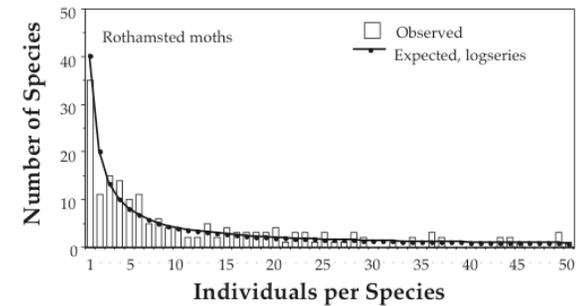
$$\frac{dP_{n,k}(t)}{dt} = P_{n+1,k}(t)d_{n+1,k}(t) + P_{n-1,k}(t)b_{n-1,k} - P_{n,k}(t)(b_{n,k} + d_{n,k})$$

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 Volkov<sup>1</sup>, Jayanth R. Banavar<sup>1</sup>, Stephen P. Hubbell<sup>2,3</sup>  
& Amos Maritan<sup>4,5</sup>

ME for the number of species within communities (islands)

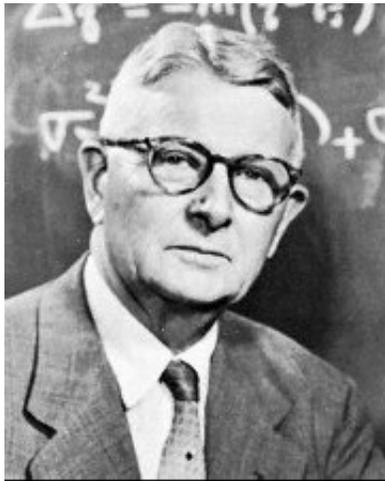
$$\frac{dP_s(t)}{dt} = P_{s+1}(t)\mu_{s+1} + P_{s-1}(t)\lambda_{s-1} - P_s(t)(\lambda_s + \mu_s),$$

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



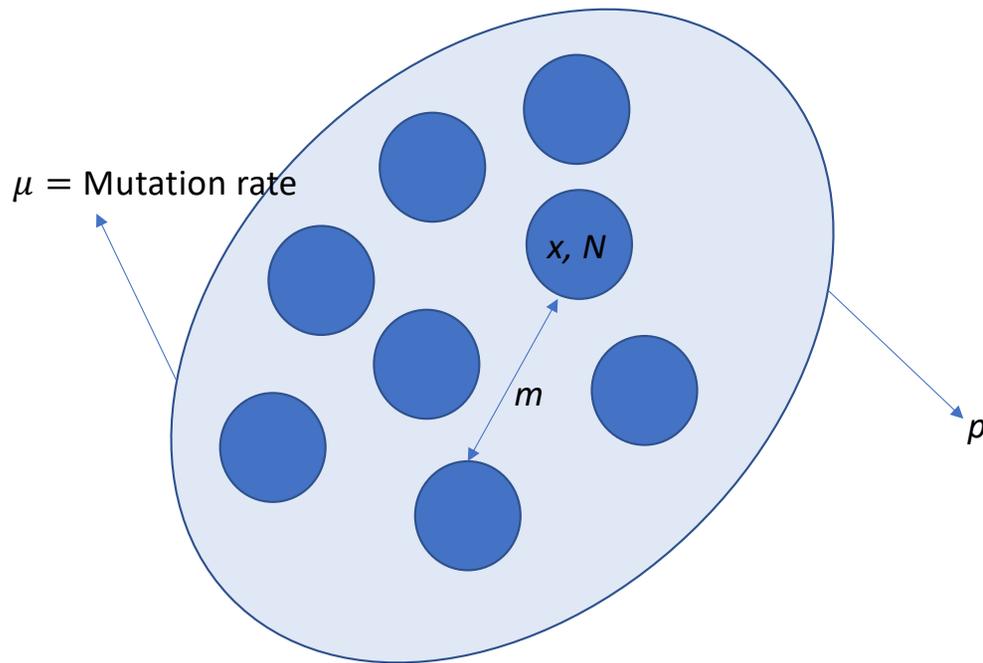
Andrey Kolmogorov



Ronald Fisher

- The frequency of genes in a structured population

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

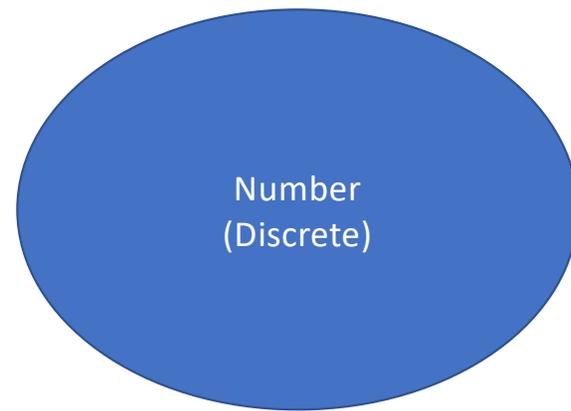
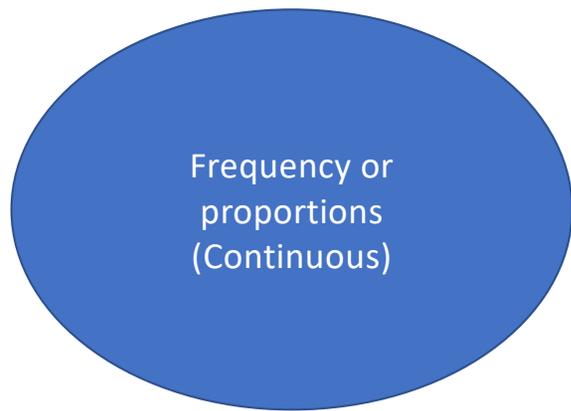


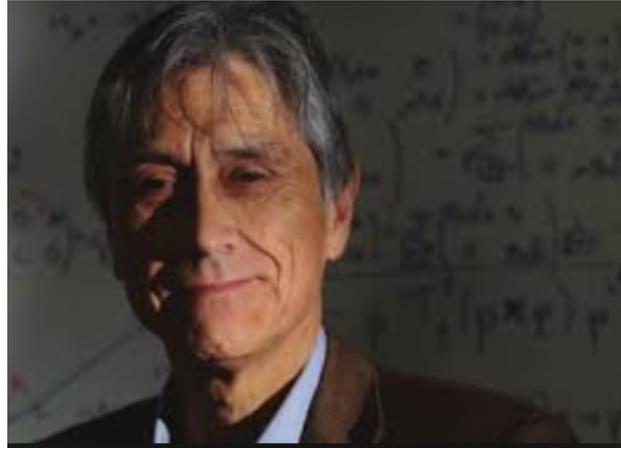
$x$  = Frequency of a given allele in a local population

$N$  = Effective population size

$m$  = Proportion of migrating individuals among population each generation.

$p$  = Frequency of a given allele in the total population



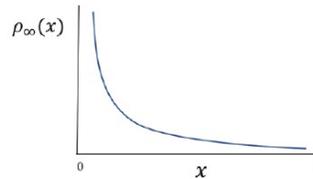
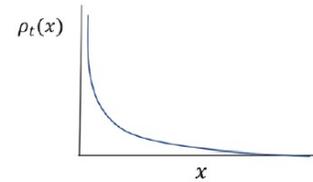
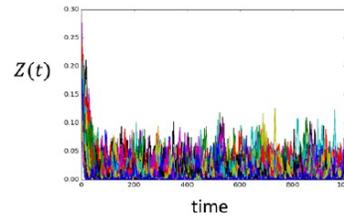
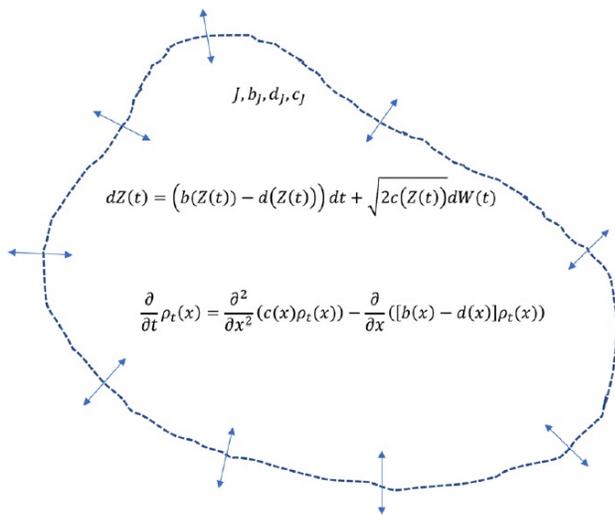


**Prof. Rolando Rebolledo**

**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](http://www.numdam.org/item?id=MSMF_1979__62__R1_0)



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

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

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

$$b(x) = b_0 + b_1 x$$

$$d(x) = d_0 + d_1 x$$

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

SCIENTIFIC REPORTS

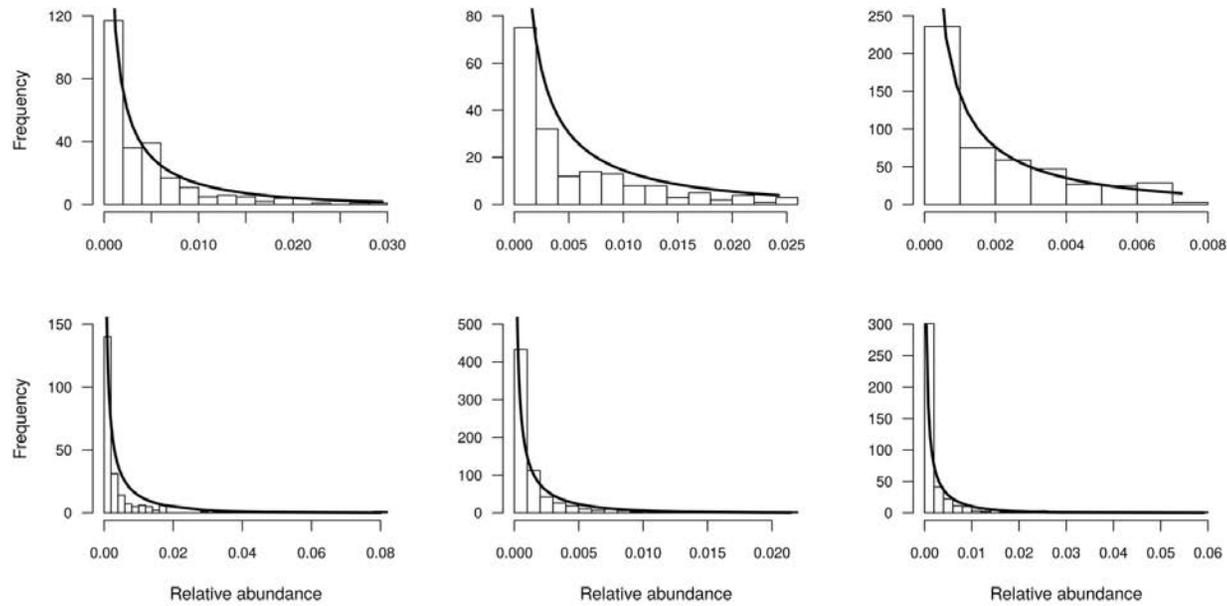
**OPEN** On the proportional abundance of species: Integrating population genetics and community ecology

16: 24 March 2017  
16: 21 November 2017

Pablo A. Marquet<sup>1,2,3,4,5</sup>, Guillermo Espinoza<sup>1</sup>, Sebastian R. Abades<sup>5</sup>, Angela Ganz<sup>6</sup> & Rolando Rebolledo<sup>7,8</sup>

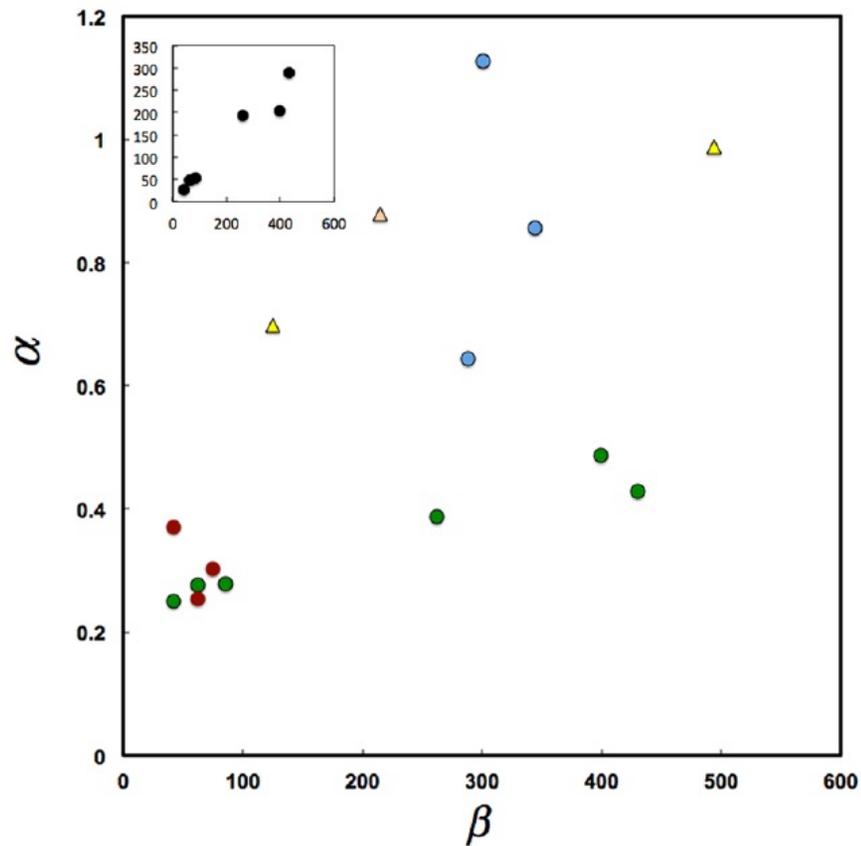
$$\rho_{\infty}(x) = \frac{\Gamma(\alpha + \beta)}{\Gamma(\alpha) + \Gamma(\beta)} x^{\alpha-1} (1 - x)^{\beta-1}$$

### 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