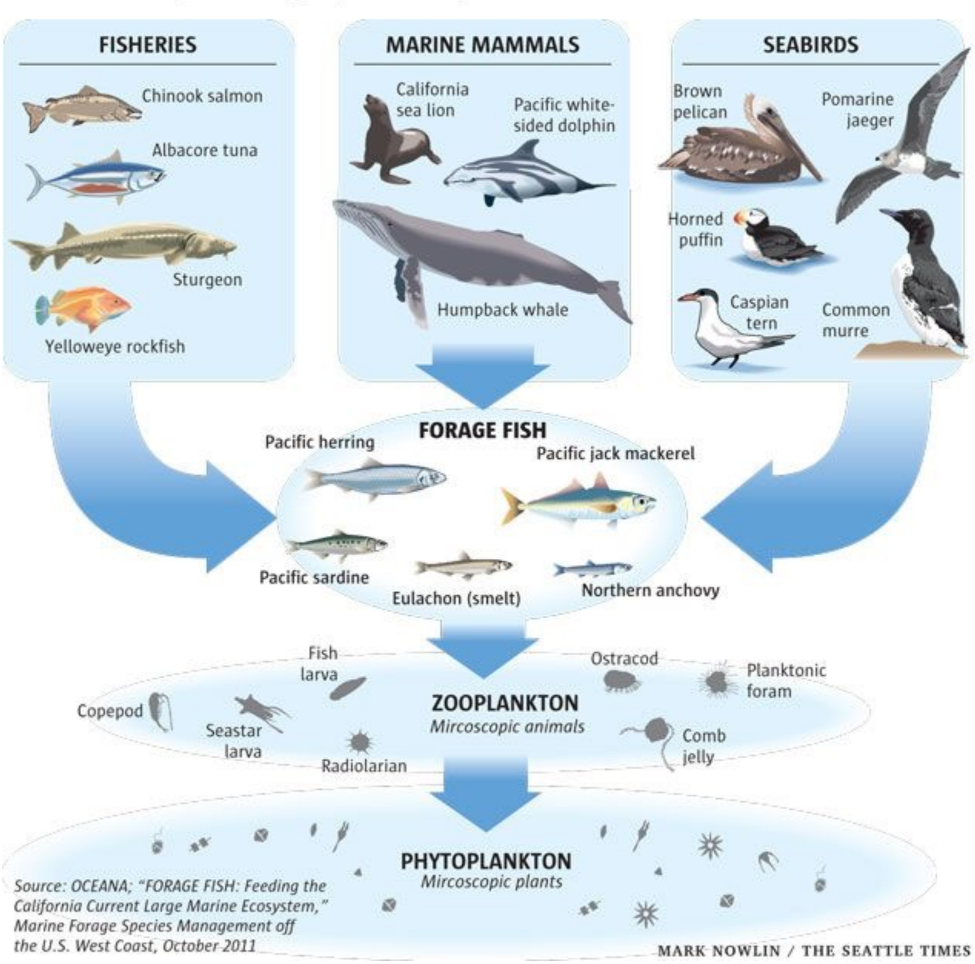
Complexity and stability of empirical food webs

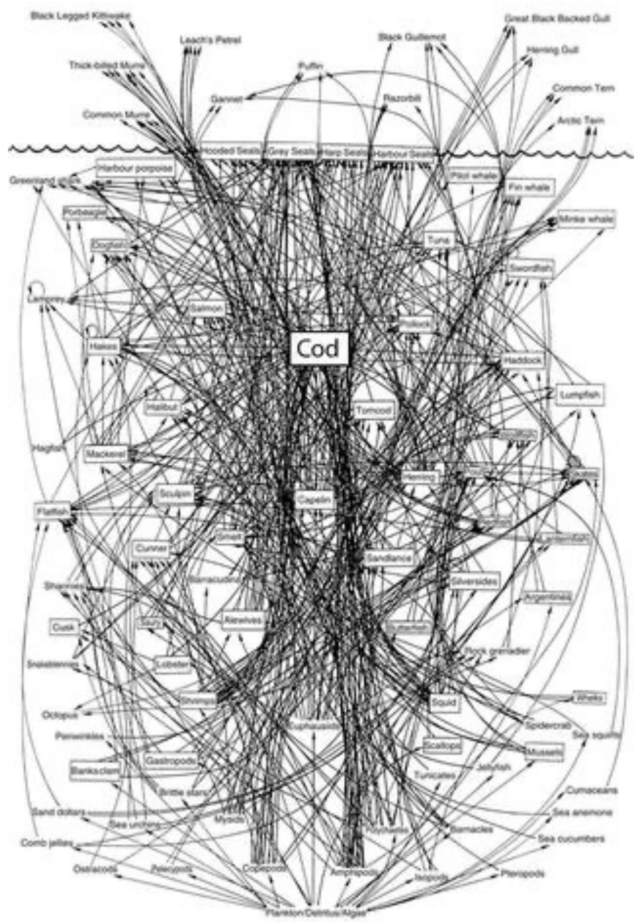
Food webs

Describe energy and material flows among species



Food webs

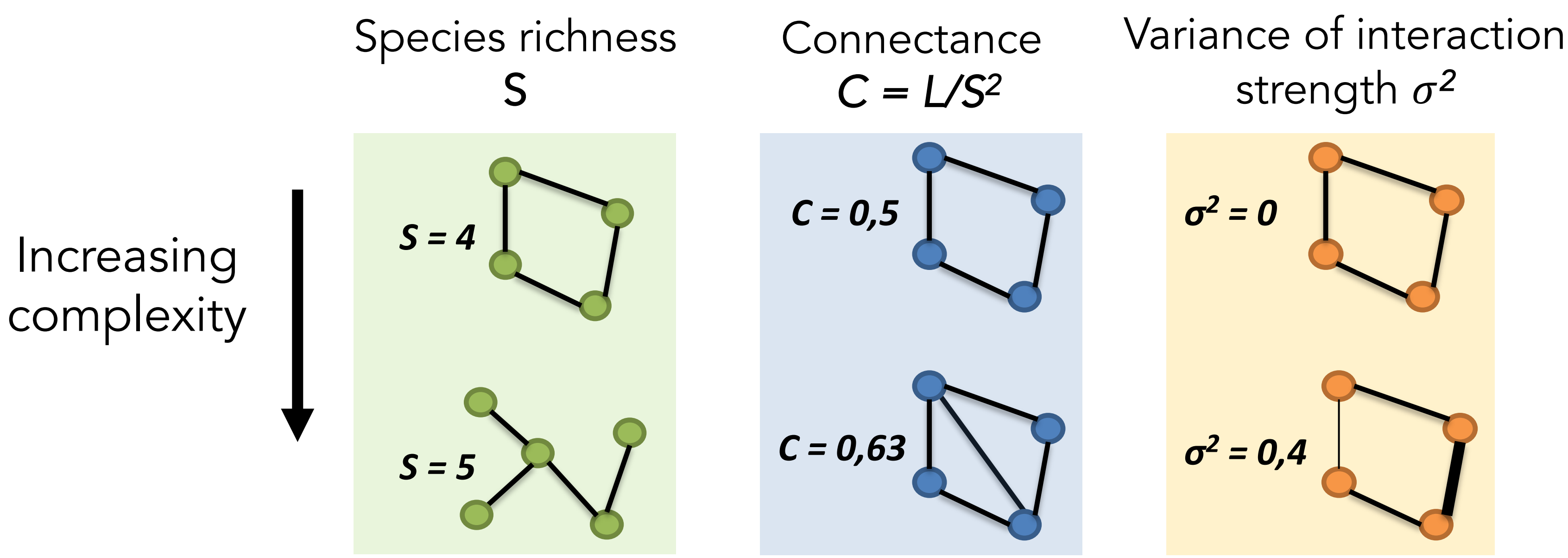
Complex systems



A simplified food web for the Northwest Atlantic. © IMMA

Will the ecosystem buffer or amplify a perturbation ?

Ecosystem complexity



The complexity stability debate

Until the 70's:
Diversity stabilizes ecosystems (Odum 1953, Elton 1958, MacArthur 1955)

Guyane, tropical forest.

Alaska, boreal forest.

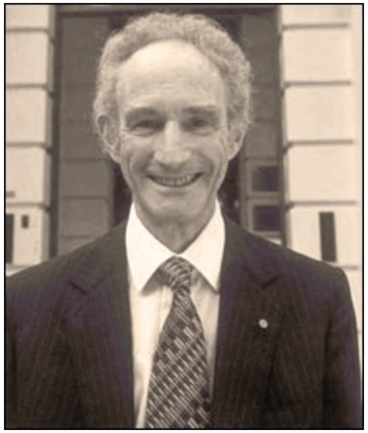
The complexity stability debate

Complexity decreases ecosystem stability (May 1972)

Complexity:

- Species richness S
- Connectance $C = L/S^2$
- Variance of interaction strengths σ^2

Stability criterion: $\sigma\sqrt{SC} < 1$



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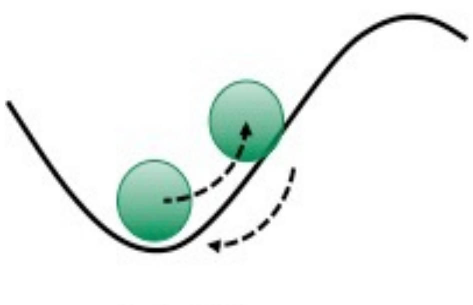
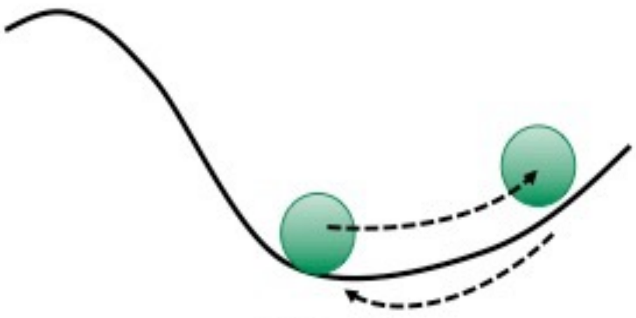
Local stability analysis

Asymptotic stability: rate to which species populations go back to their initial densities after a pulse disturbance



High stability



Low stability

Local stability analysis

Population dynamic: $$\frac{dX_i(t)}{dt} = f_i(\mathbf{X}(t)) \qquad (i = 1, \ldots, S)$$

Equilibrium point X*: $$\left.\frac{dX_i(t)}{dt}\right|_{\mathbf{X}^*} = f_i(\mathbf{X}^*) = 0$$

Coefficients of the community matrix $$M_{ij} = J_{ij}|_{\mathbf{X}^*} = \left.\frac{\partial f_i(\mathbf{X}(t))}{\partial X_j}\right|_{\mathbf{X}^*}$$

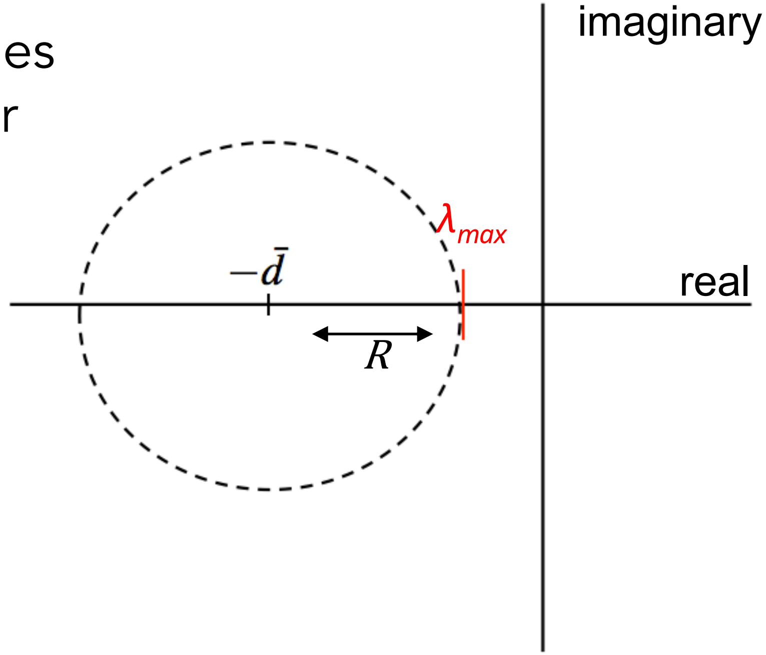
Eigenvalues of **M**: real ($\lambda = a$) or complex ($\lambda = a \pm ib$)

The circular law *(Girko 1985, Tao 2010)*

On a complex plan: all the eigenvalues are contained in a circle of center *(-d, 0)* and radius *R.*

The system is stable if $\mathrm{Re}(\boldsymbol{\lambda}_{max}) < 0$.

Stability criterion?



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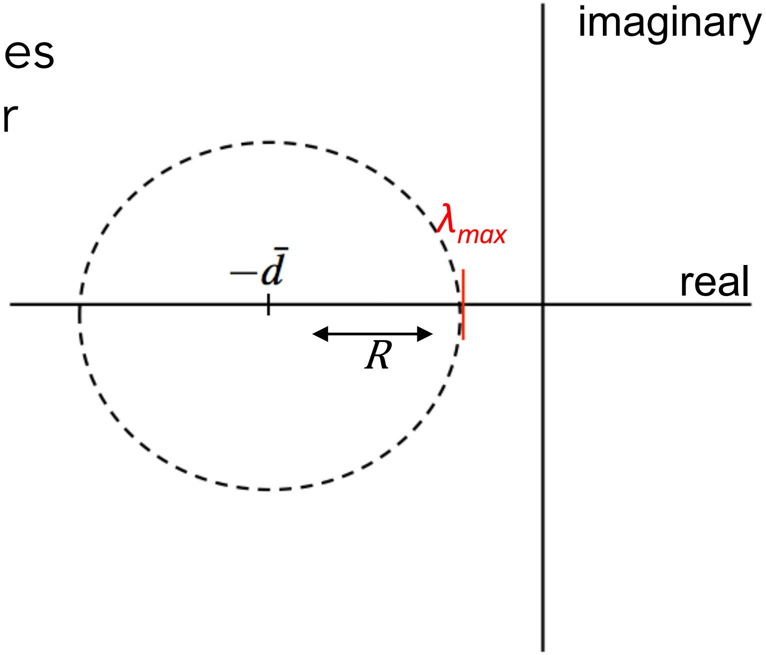

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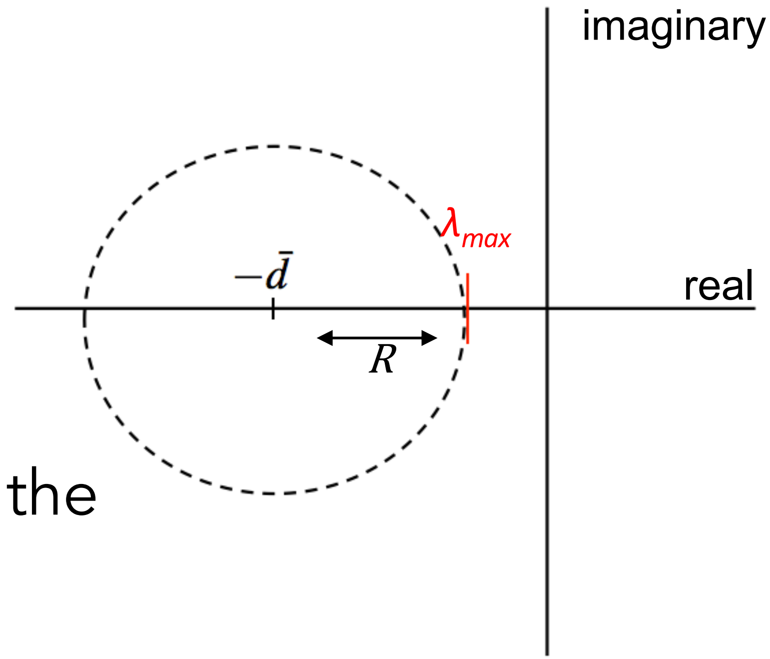
Stability criterion: R < d

The circular law *(Girko 1985, Tao 2010)*

$$C = \begin{pmatrix} -d_1 & +c_{2,1} & +c_{3,1} & 0 \\ -c_{1,2} & -d_2 & 0 & +c_{4,2} \\ -c_{1,3} & 0 & -d_3 & +c_{4,3} \\ 0 & -c_{2,4} & -c_{3,4} & -d_4 \end{pmatrix}$$



$\bar{\boldsymbol{d}}$ corresponds to the mean of the diagonal terms of C

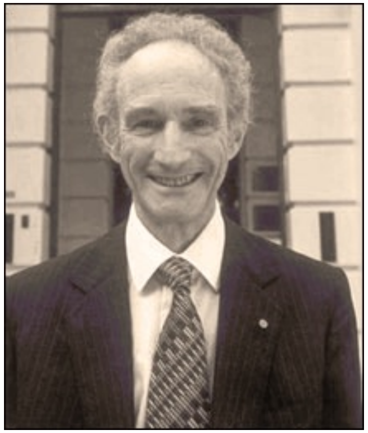
In random communities: $\boldsymbol{R = \sigma\sqrt{SC}}$
$\boldsymbol{\sigma^2}$: variance of c_{ij}
S: size of the matrix
C: proportion of non-zero terms

Application to ecological networks

May's stability criterion: $\sigma\sqrt{SC} < 1$

- Species richness S
- Connectance $C = L/S^2$
- Variance of interaction strengths σ^2

- $\bar{d}$: Magnitude of intraspecific competition
(diagonal terms of the matrix) → set to 1



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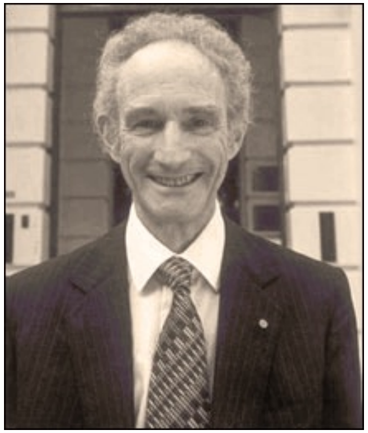

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Theoretical communities:

- species interact at random
- interaction strengths are picked from a normal distribution

« In short, there is no confortable theorem assuring that increasing diversity and complexity beget community stability; rather, as a mathematical generality the opposite is true.

The task, therefore, is to elucidate the devious strategies which make for stability in enduring natural systems. » (May 2001).

1. What is the actual complexity-stability relationship in empirical communities?

1. What is the actual complexity-stability relationship in empirical communities?

2. What are the « *devious strategies* » of real communities that allow them to persist despite their complexity?

Food-web dataset

116 quantitative food webs from Ecopath models (Christensen 1992)

For each species *i*:

- biomass B_i (tons/km^2)
- *production* $(P/B)_i$ (year^{-1})
- consumption $(Q/B)_i$ (year^{-1})
- diet composition DC_{ji}

Derivation of interaction strengths from data

α_{ij} : per capita effect of species *j* on species *i* (mass^{-1}year^{-1})

e_{ij} : efficicency *of j* to convert *i* into its own biomass

$\alpha_{ji} = e_{ij} \times \alpha_{ij}$

Data for each species:

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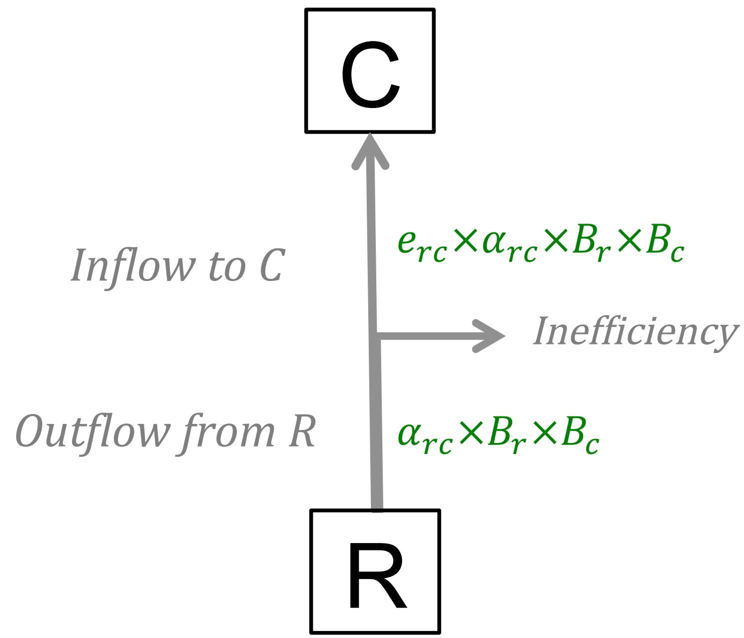

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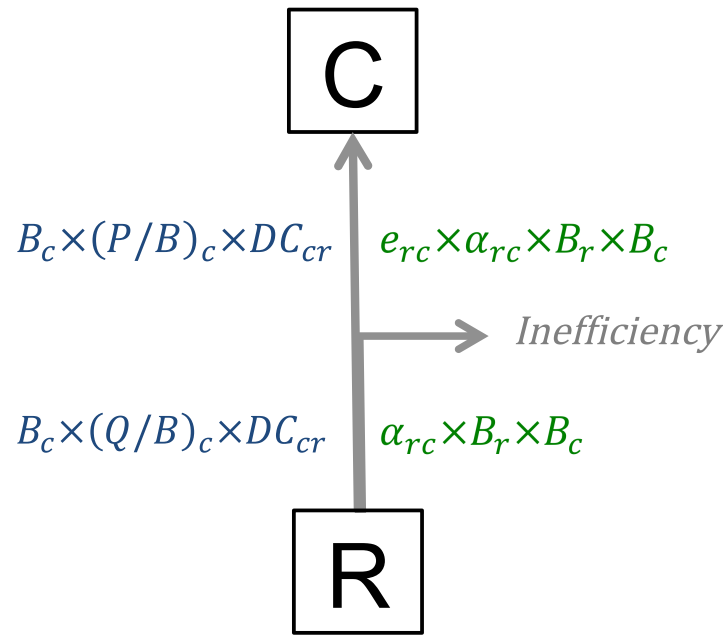

Practice

1. computing food-web complexity and stability in R

2. analysing the relationship between complexity and stability in empirical food webs

3. comparing the complexity-stability relationship of empirical and « randomized » food webs