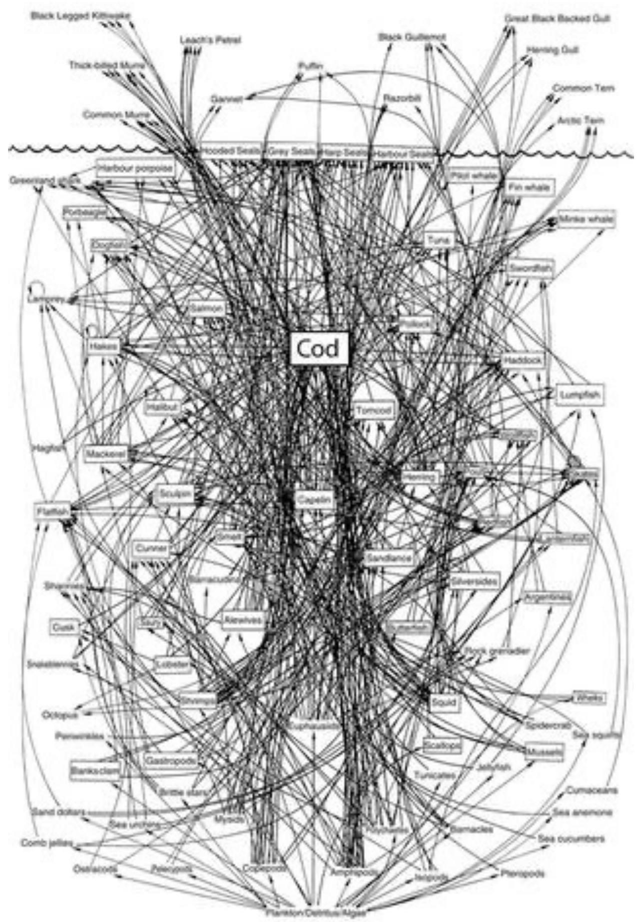
Complexity and stability of empirical food webs

Food webs

Complex systems



A simplified food web for the Northwest Atlantic. © IMMA

Will the ecosystem buffer or amplify a perturbation ?

The complexity stability debate

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

Guyane, tropical forest.

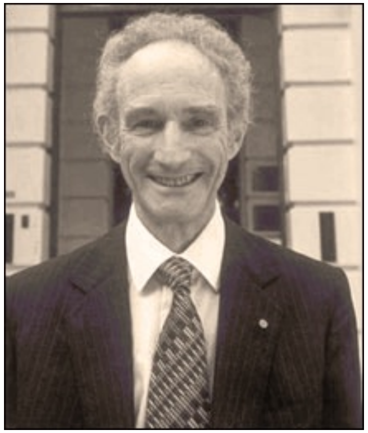
Alaska, boreal forest.

The complexity stability debate

Complexity decreases ecosystem stability (May 1972)

Complexity:

- Species richness S
- Connectance C
- Variance of interaction strengths σ^2



Professor Lord Robert May

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

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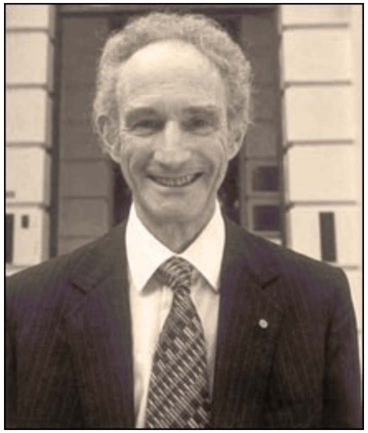

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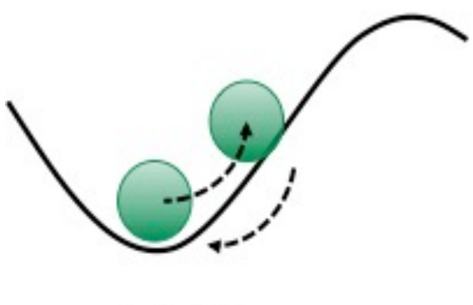
Stability criterion: $\sigma\sqrt{SC} < 1$

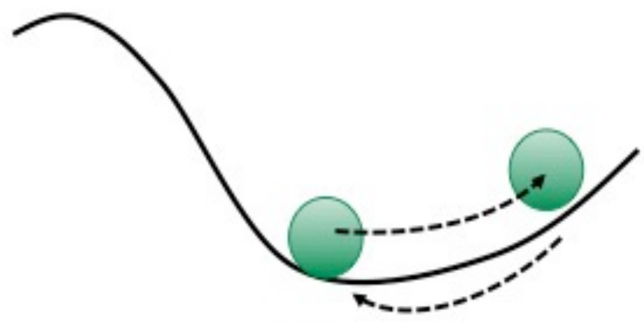
Where does this result come from?

Local stability analysis

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



High stability



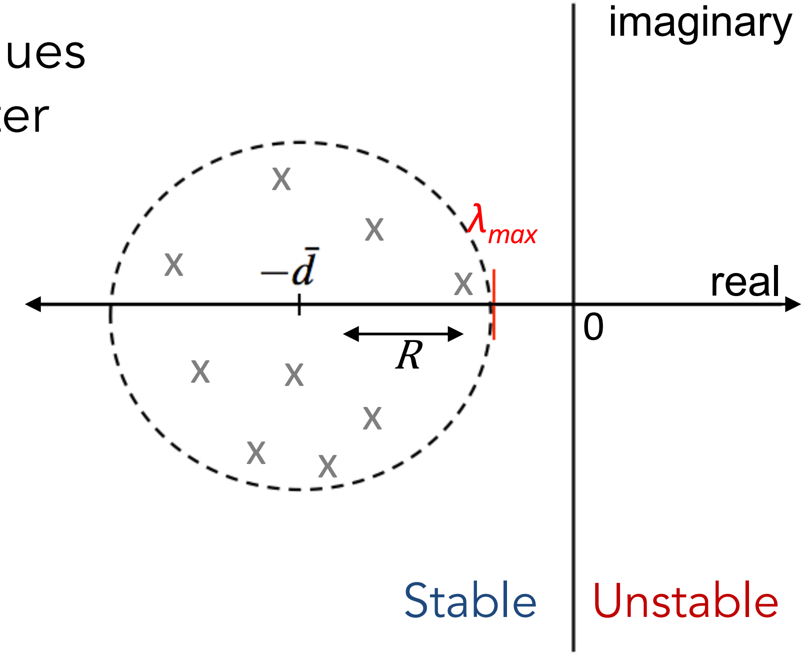
Low stability

Largest eigenvalue of the community matrix (its real part)

The circular law

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

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



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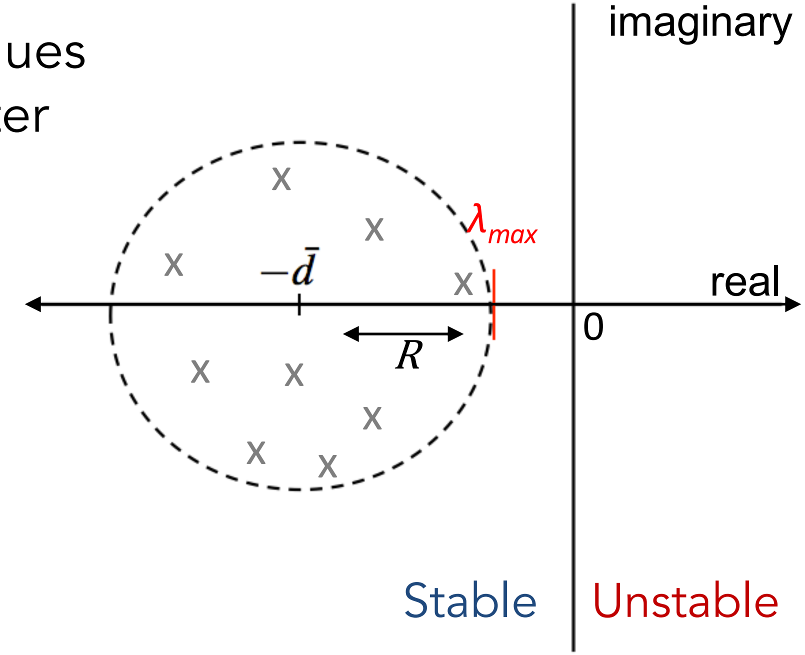

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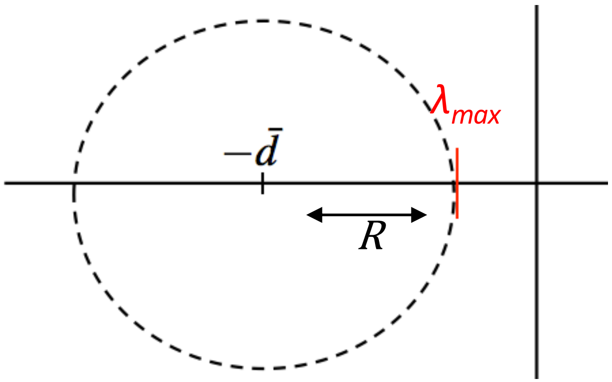
Stability criterion: R < d

The circular law

Link the stability of a matrix to its properties



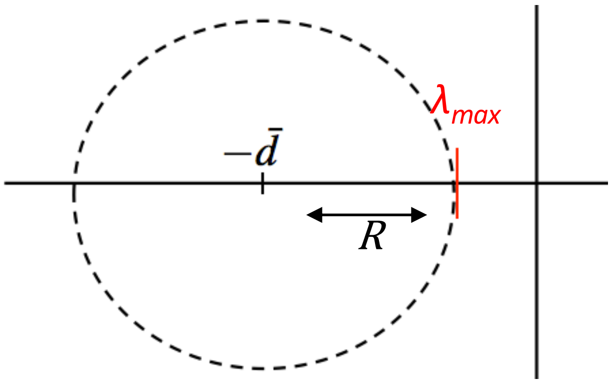
$$C = \begin{pmatrix} -d_1 & +c_{2,1} & +c_{3,1} & 0 \\ -c_{1,2} & -d_2 & 0 & +c_{4,2} \\ -c_{1,3} & 0 & -d_3 & +c_{4,3} \\ 0 & -c_{2,4} & -c_{3,4} & -d_4 \end{pmatrix}$$

$\bar{\boldsymbol{d}}$ **:** mean of diagonal terms of C

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

The circular law

Link the stability of a matrix to its properties



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$\bar{d}$: mean of diagonal terms of C (magnitude of density dependence)

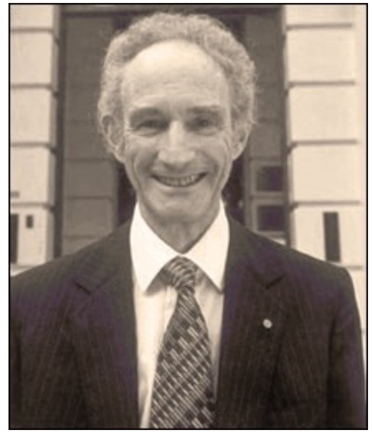
In ecological communities : $R = \sigma\sqrt{SC}$

σ^2: *variance of* interaction strengths

S: species richness

C: connectance

Let’s check this result in R



« 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?

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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}

Assumption: food webs are at equilibrium

Derivation of interaction strengths from data

What we want:

α_{rc} : negative effect of consumer *c* on resource *r*

α_{cr}: positive effect of resource *r* on consumer *c*

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What is measured:

- biomass B_i (tons/km^2)
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- diet composition DC_{ji}

From De Ruiter *et al.* (1995):

$$\alpha_{rc} = -\left(DC_{cr} \times (Q/B)_c\right) / \mathrm{B}_r$$

$$\alpha_{cr} = \left(DC_{cr} \times (P/B)_c\right) / \mathrm{B}_r$$

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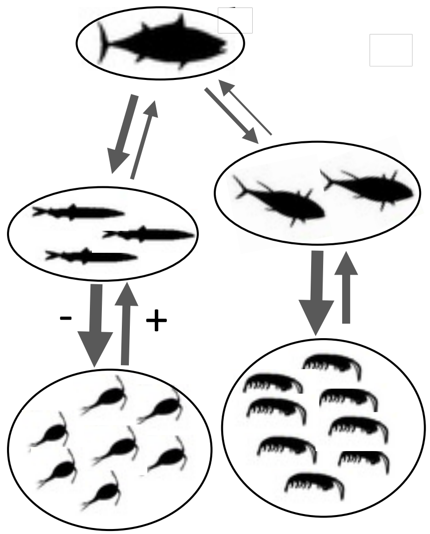
$$\alpha_{cr} = \alpha_{rc} \times e_{rc}, \text{ with } e_{rc} = (P/B)_c / (Q/B)_c$$

$$\rightarrow \alpha_{cr} \leq \alpha_{rc}$$

Practice in R

1. computing food-web complexity and stability
2. analysing the relationship between complexity and stability in empirical food webs
3. comparing the complexity-stability relationship of empirical and « randomized » food webs

What are the non-random properties of food webs?



$$M = \begin{pmatrix} -d_1 & +\mathbf{c}_{2,1} & +\mathbf{c}_{3,1} & 0 \\ -\mathbf{c}_{1,2} & -d_2 & 0 & +\mathbf{c}_{4,2} \\ -\mathbf{c}_{1,3} & 0 & -d_3 & +\mathbf{c}_{4,3} \\ 0 & -\mathbf{c}_{2,4} & -\mathbf{c}_{3,4} & -d_4 \end{pmatrix}$$

- H_1: food web topology (who eat whom)
- H_2: correlation between $+c_{ji}$ and $-c_{ij}$
- $H_{3:}$ interaction strength distribution