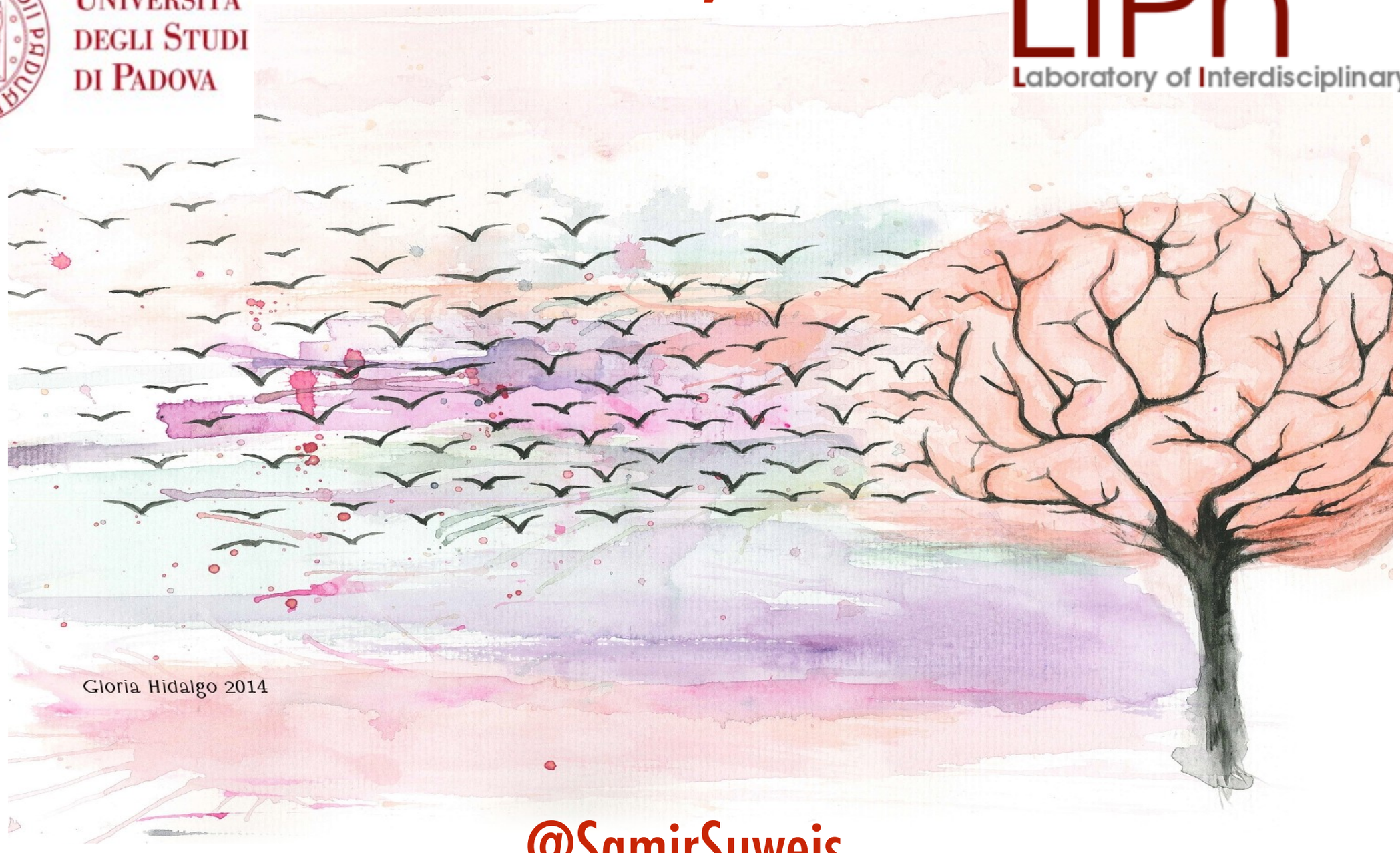
UNIVERSITÀ DEGLI STUDI DI PADOVA

25.10.2018, GSSI

LIPh
Laboratory of Interdisciplinary Physics



@SamirSuweis

Fisica Statistica dei sistemi ecologici e fenomeni di auto-organizzazione

www.liphlab.com

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Teoria della Probabilità

Fisica Statistica

Biologia

Ingegneria Ambientale

Ecologia & Scienze Forestali

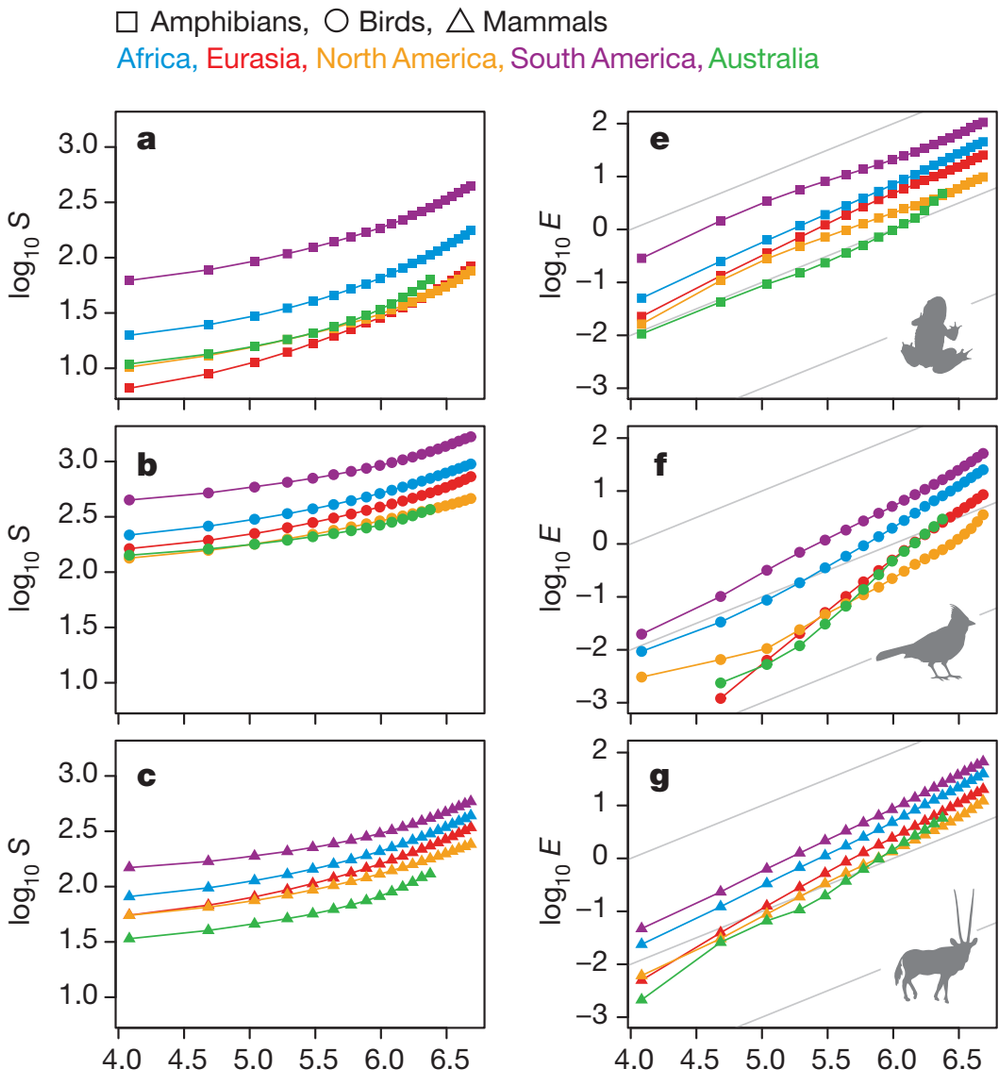
Scienze Sociali/Politiche

NeuroScienze

Thanks to: A. Maritan; J. Grilli; J. Hidalgo; J. Banavar, L. Pacciani, A. Tovo...

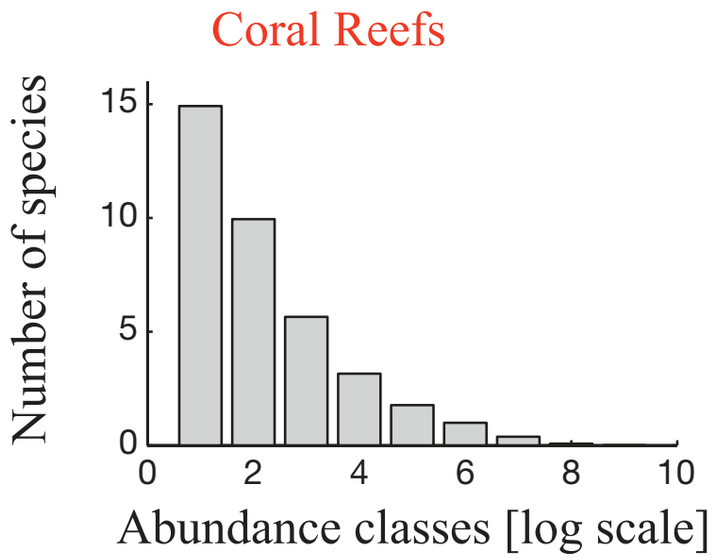
Pattern Emergenti e Auto-organizzazione in Ecologia

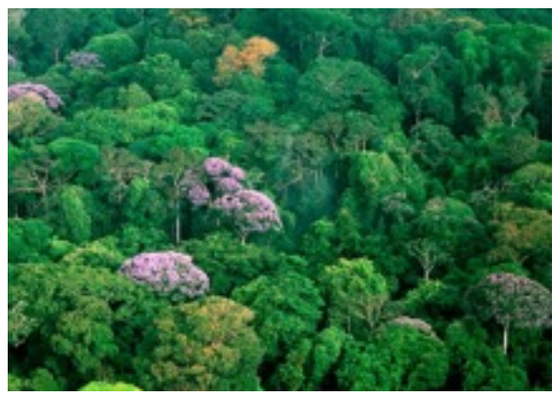
SAR & EAR

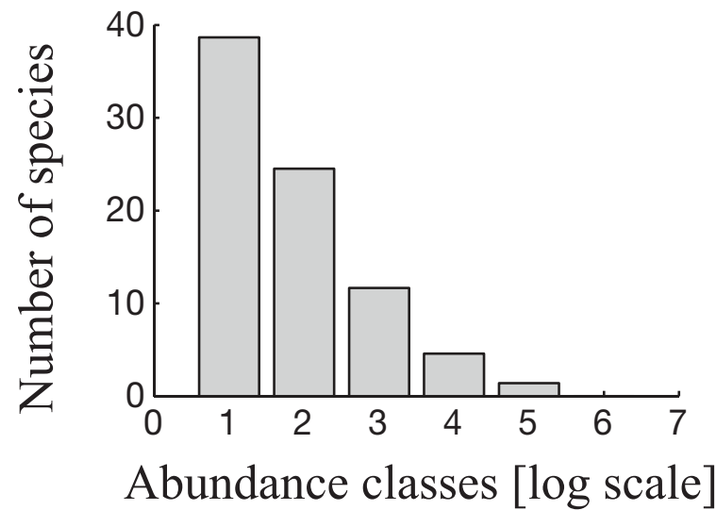


Storch et al. *Nature*, 2012

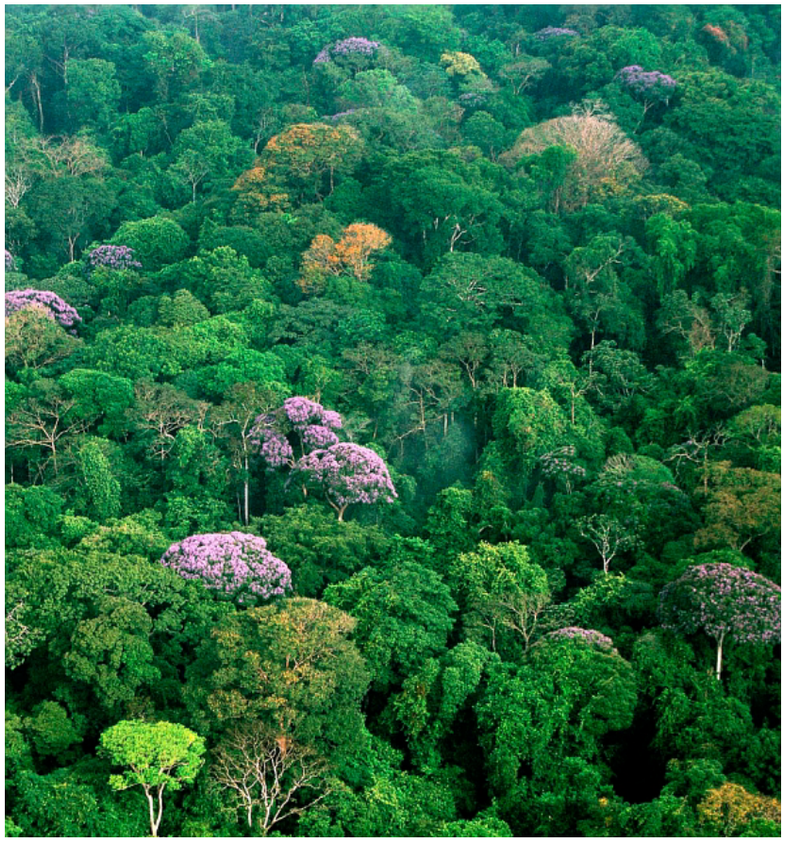
RSA

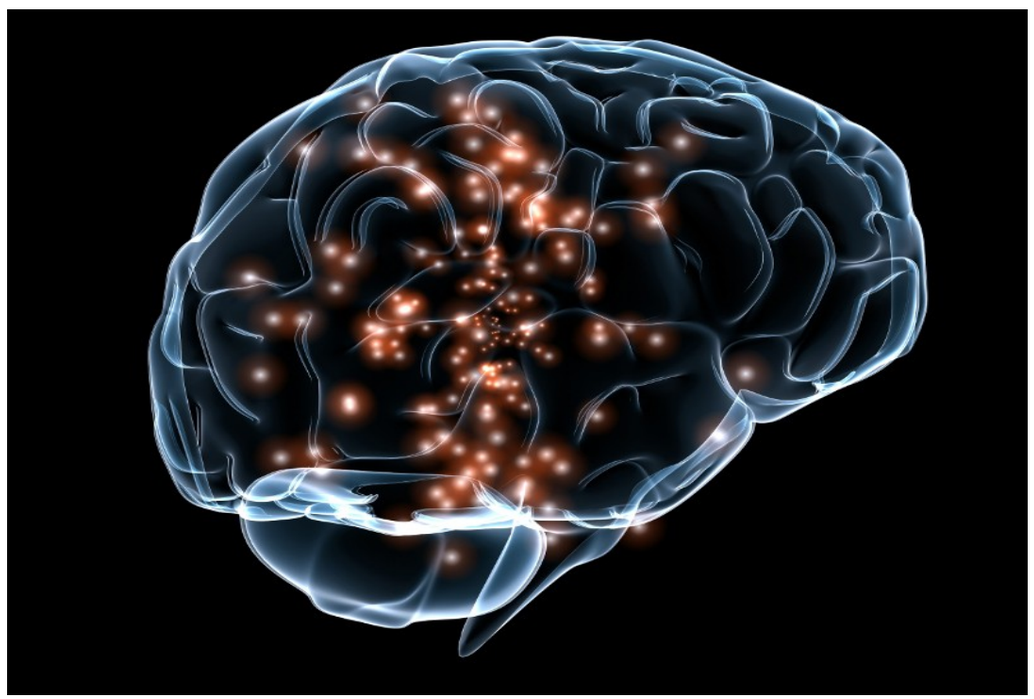




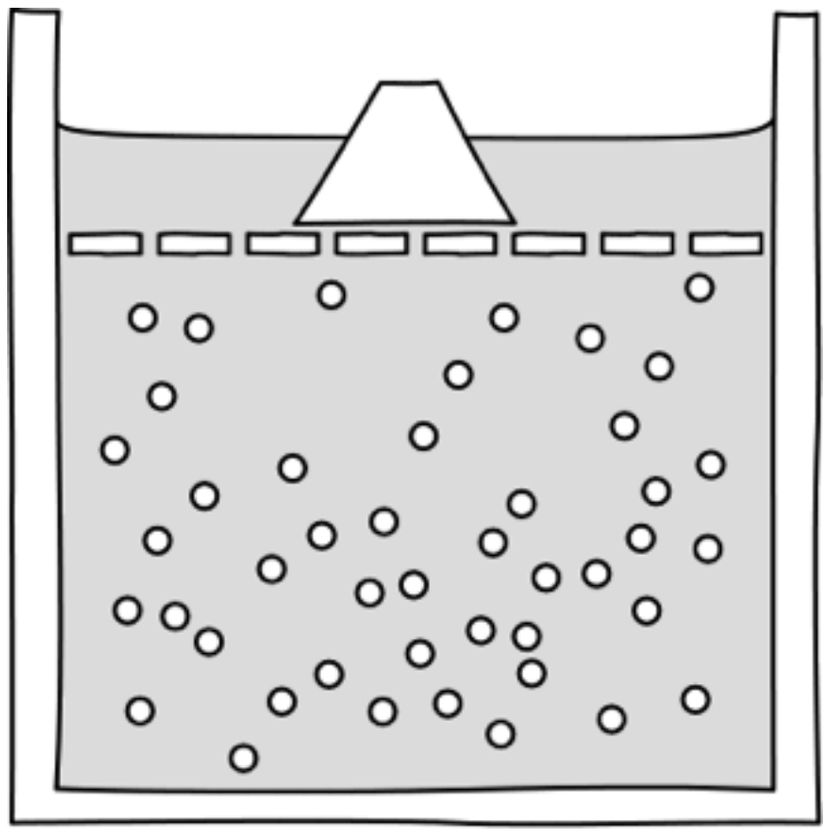


Come studiare "da Fisico" questi sistemi?

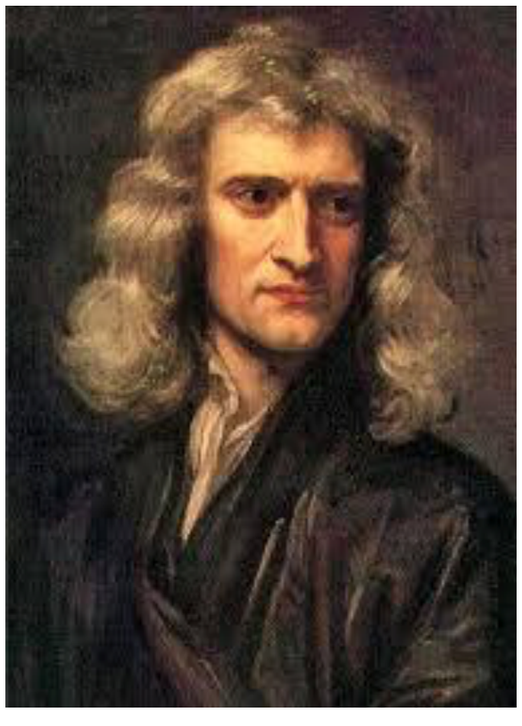




Come studiare sistemi a molti corpi?



10^23 molecole



F=m a

Moto dei corpi:

1- è facile

2 - è (diventato) facile

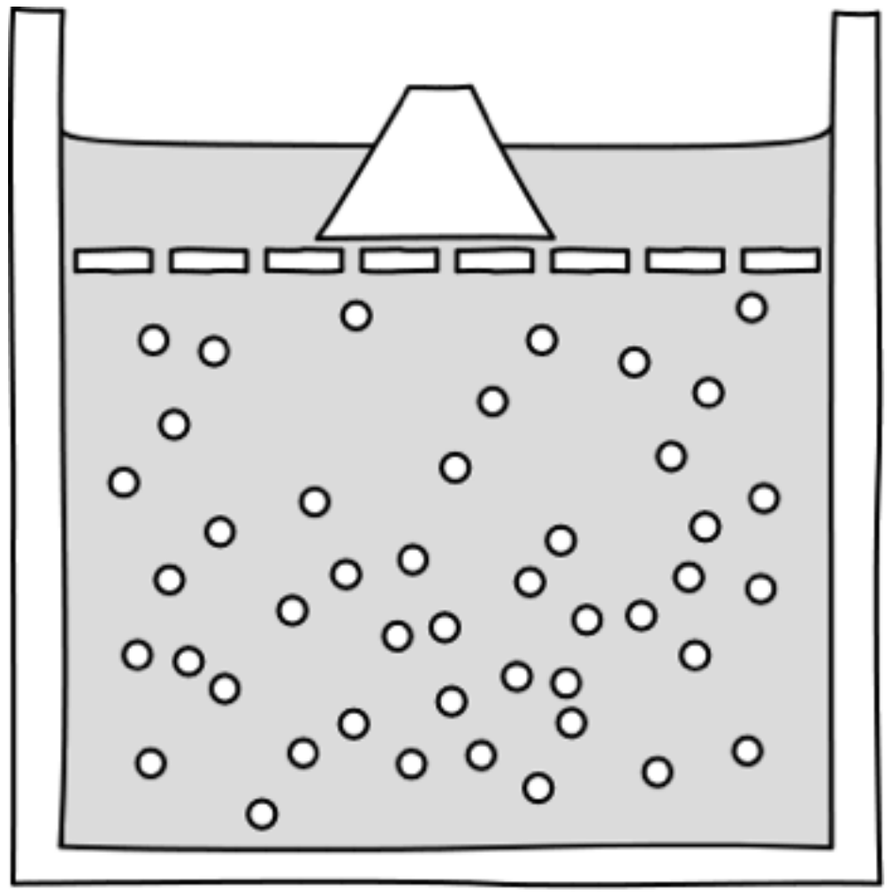
3 - è impossibile

Come studiare sistemi a molti corpi?

N atomi di massa m, moto casuale

Atomi molto lontani tra loro
(no interazione)

Collisioni elastiche (conservazione E)



Specific volume

Absolute temperature

$$P \cdot v = R \cdot T$$

Absolute pressure

Gas constant

Come legare il micro al macro: la fisica statistica

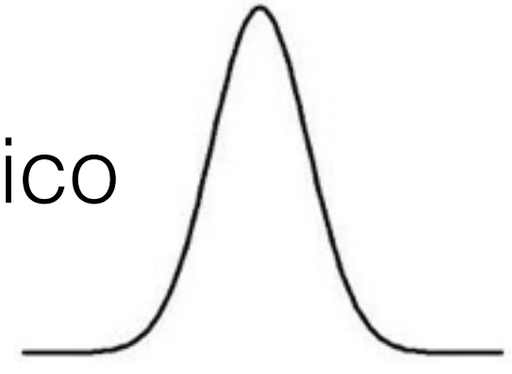
Il legame è probabilistico

Spazio delle configurazioni

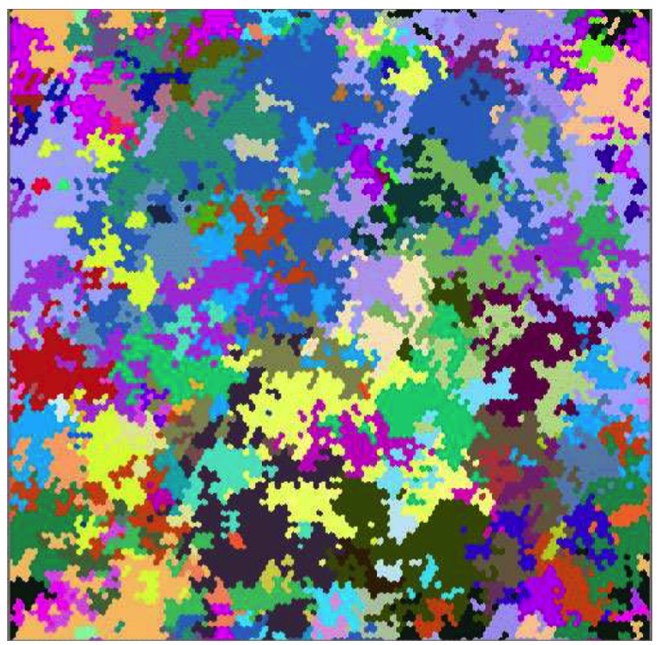
Termodinamica: limite $N = \infty$

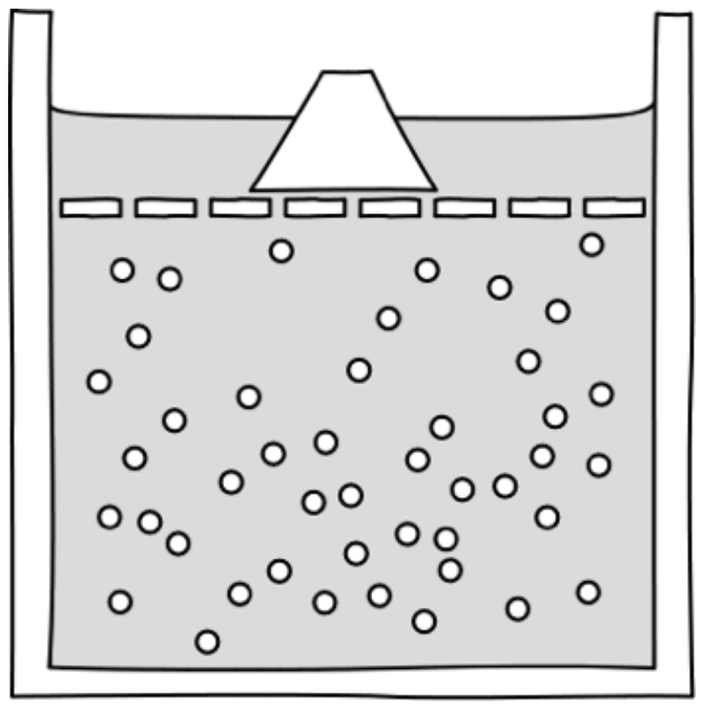
11 12 21 22 13 31 .... 16 61 34 43 25 52

stato
macroscopico



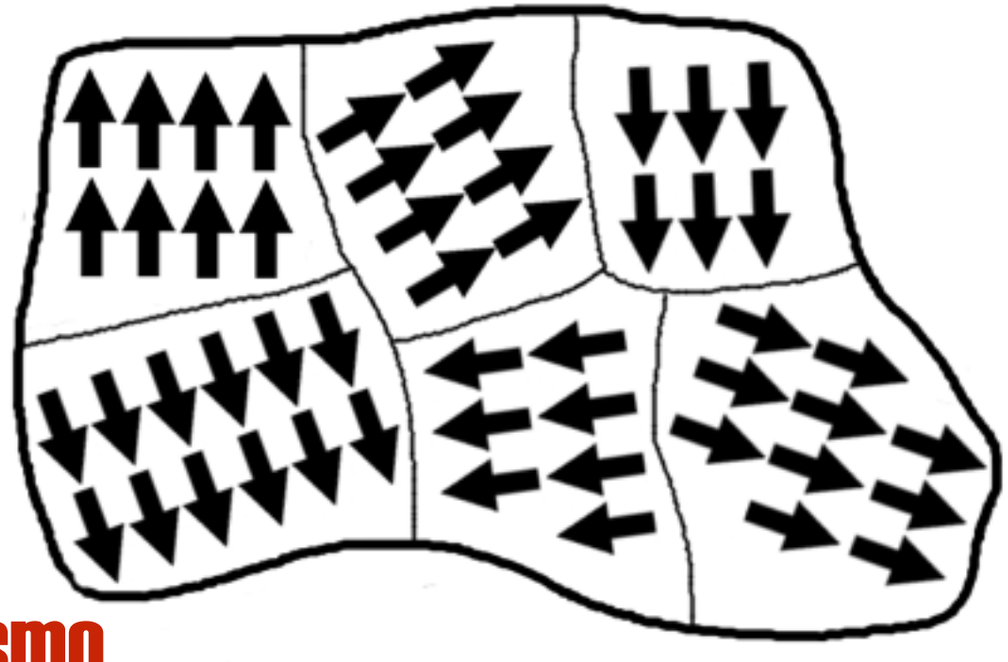
Come studiare sistemi complessi?





Modelli di particelle interagenti

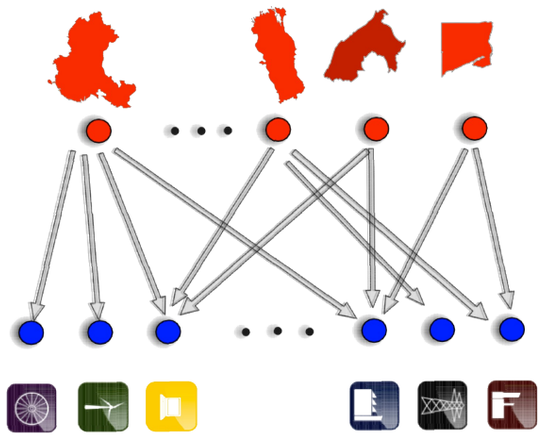
P V = n R T



Proprietà Emergenti

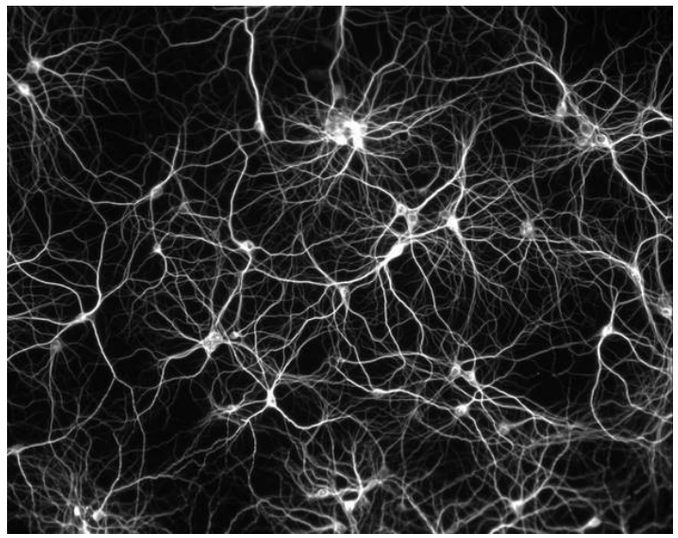
Ferromagnetismo

economia



materiali magnetici

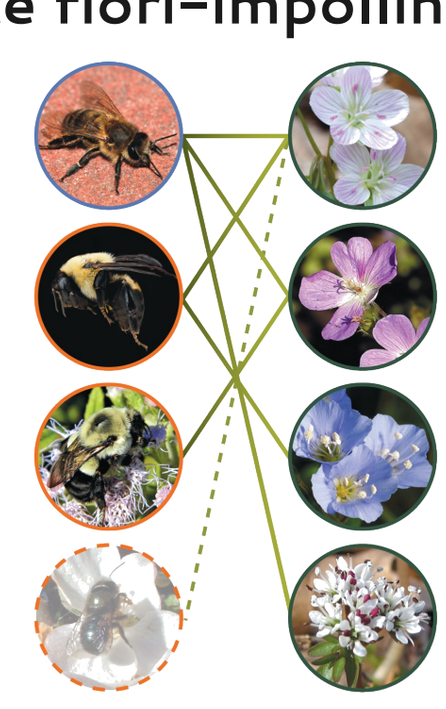
rete neurale



Cosa hanno in comune ?

ecosistemi (foreste)

rete fiori-impollinatori

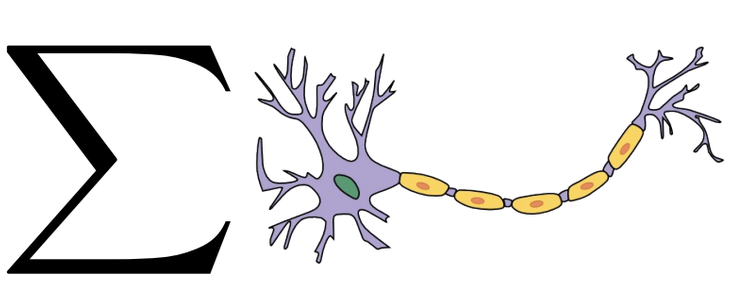


Thanks to Matteo Adorisio

Caratteristica di un **sistema complesso:**

"many entities + interactions"

emergenza di **proprietà macroscopiche** non legate direttamente agli enti "microscopici"



$\neq$

Come investigarle ?

Thanks to Matteo Adorisio

Messaggi semplici dai sistemi complessi

- **"many entities + interactions":** emergenza di fenomeni macroscopici a prescindere dal tipo di "atomi" (insetti,neuroni,elettroni ...)

- **pattern ricorrenti** in sistemi apparentemente diversi

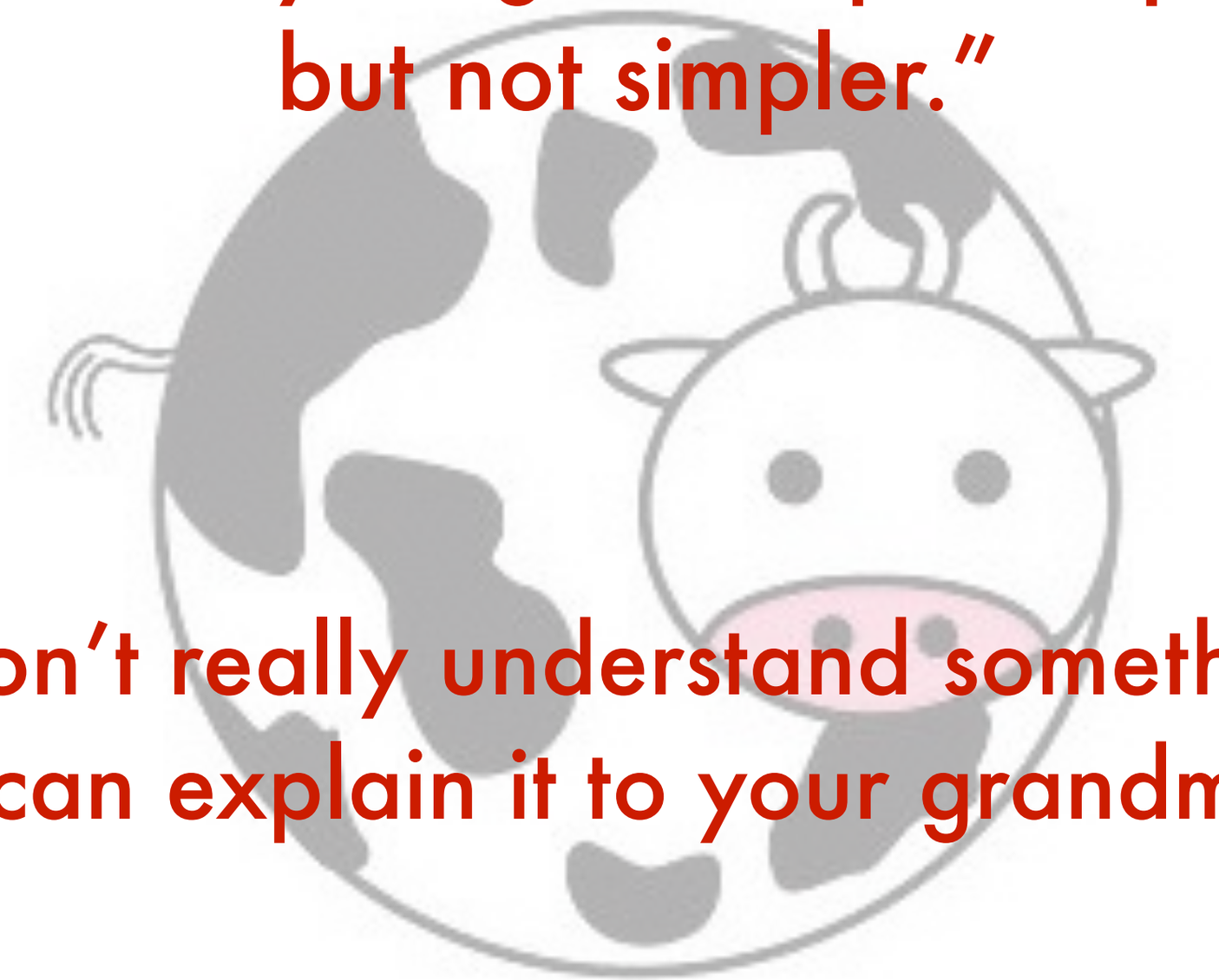
- **"Do not model bulldozers with quarks" ***
  la comprensione dei fenomeni emergenti può essere ottenuta a partire da regole semplici

* Goldenfeld, Kadanoff *Simple lessons from complexity*, Science 1999

Thanks to Matteo Adorisio

The Physicist Style

"Make everything as simple as possible, but not simpler."

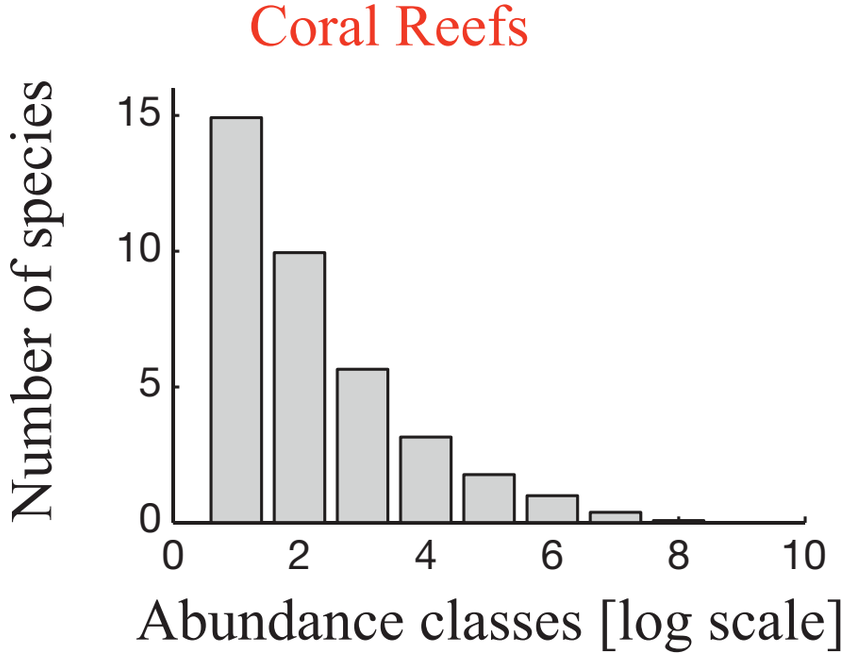


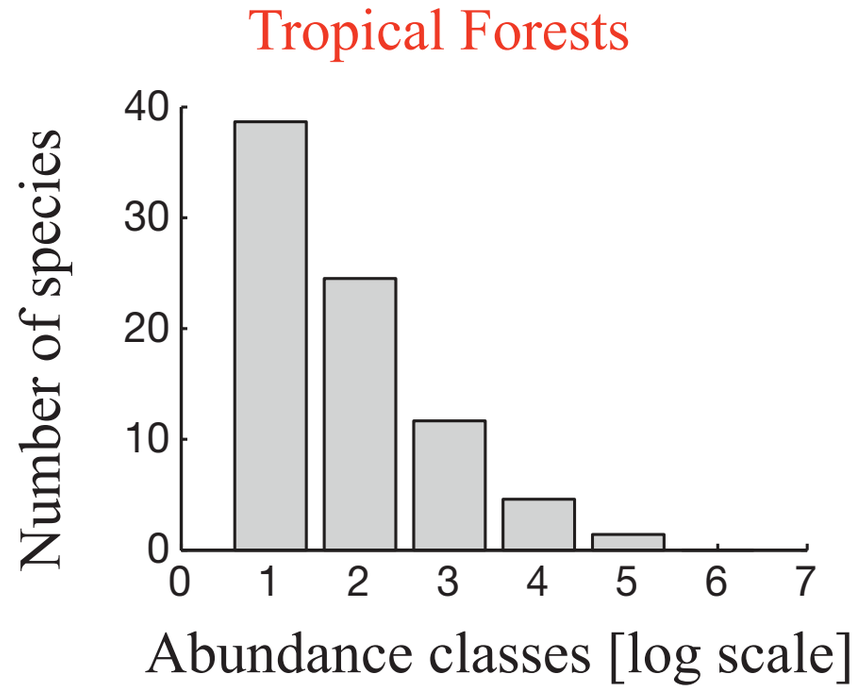
"You don't really understand something unless you can explain it to your grandmother."

A. Einstein

Patterns Emergenti in Ecologia

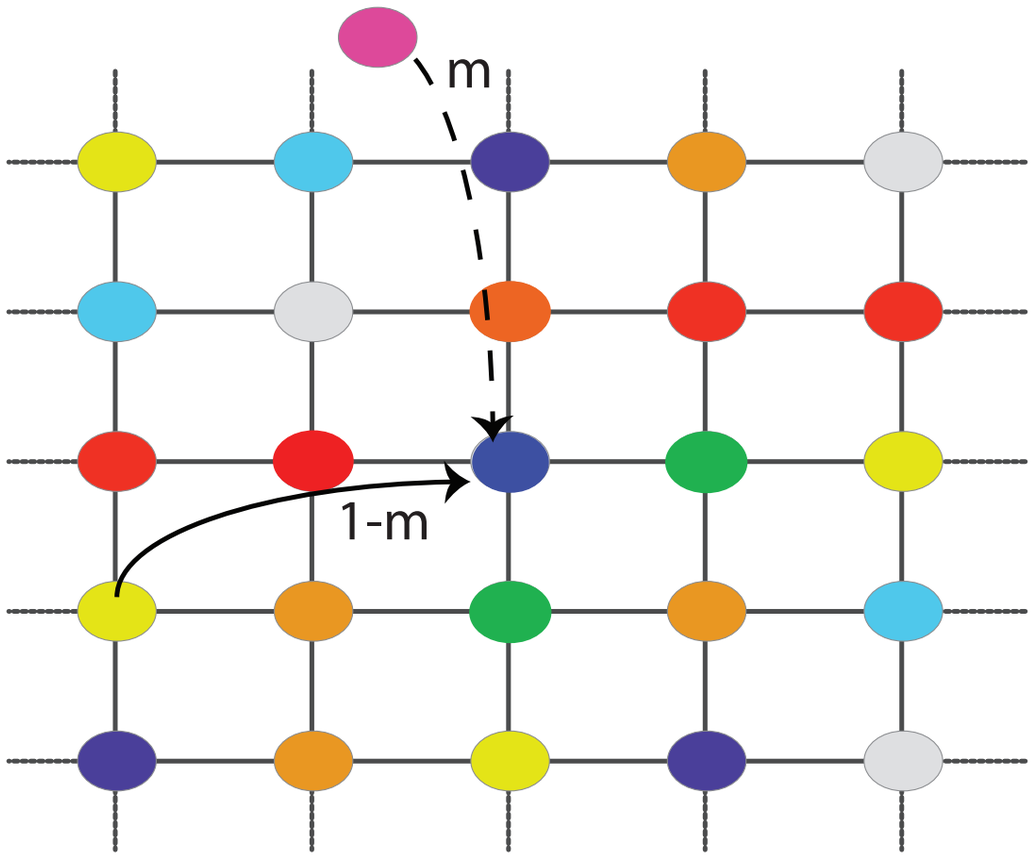
Abbondanza Relativa delle Species (RSA)





Il voter Model in Ecologia

- **Community of N individuals and S species (colours)**
- **Pick at random an individual. It dies.**
- **1-m: replaced it by another random individual in the system**
- **m: it is replaced by an individual of a new species (migration)**



$$\frac{dP_n(t)}{dt} = b_{n-1}P_{n-1}(t) + d_{n+1}P_{n+1}(t) - (b_n + d_n)P_n(t)$$

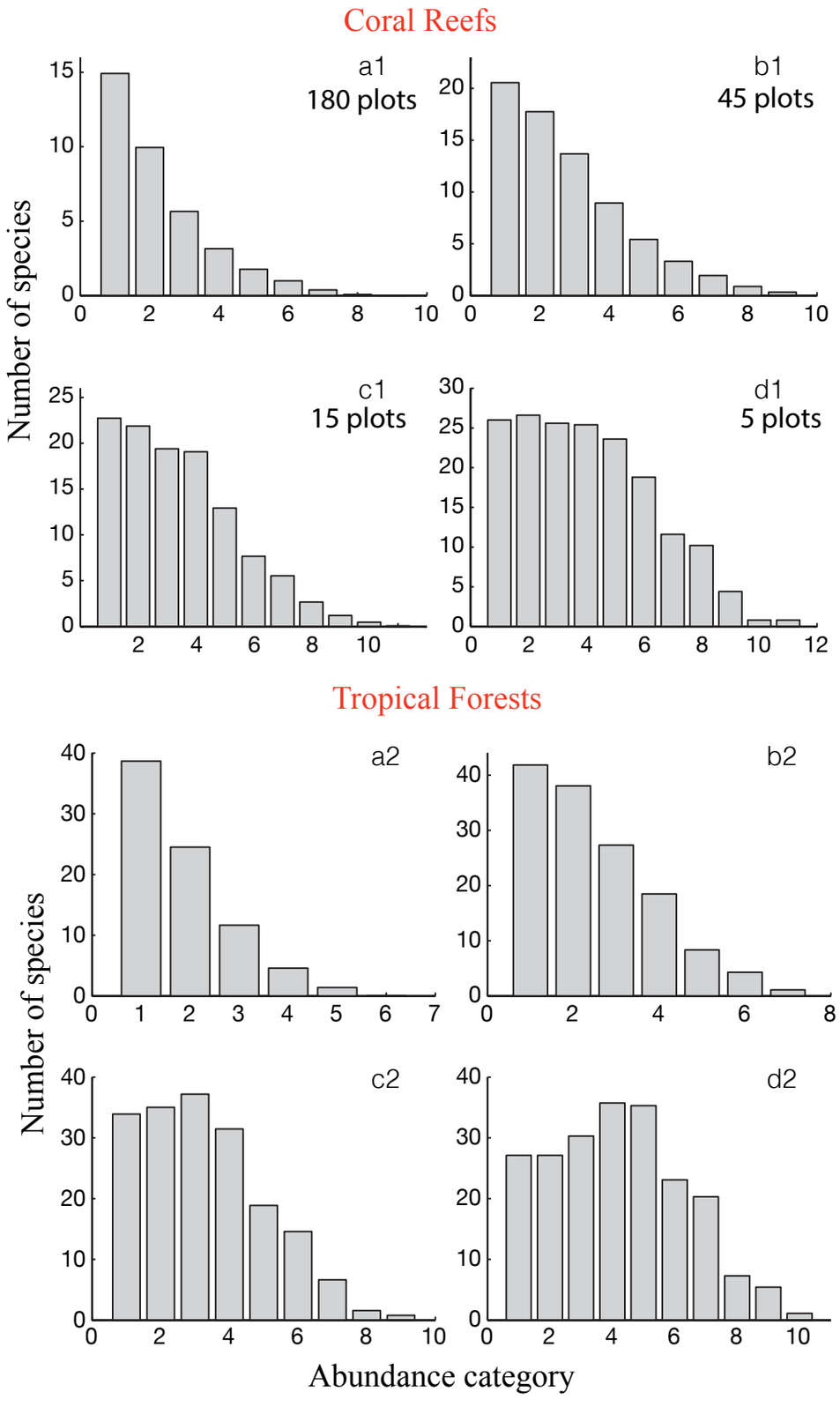
Parameters: b_n/d_n and $m = b_0$

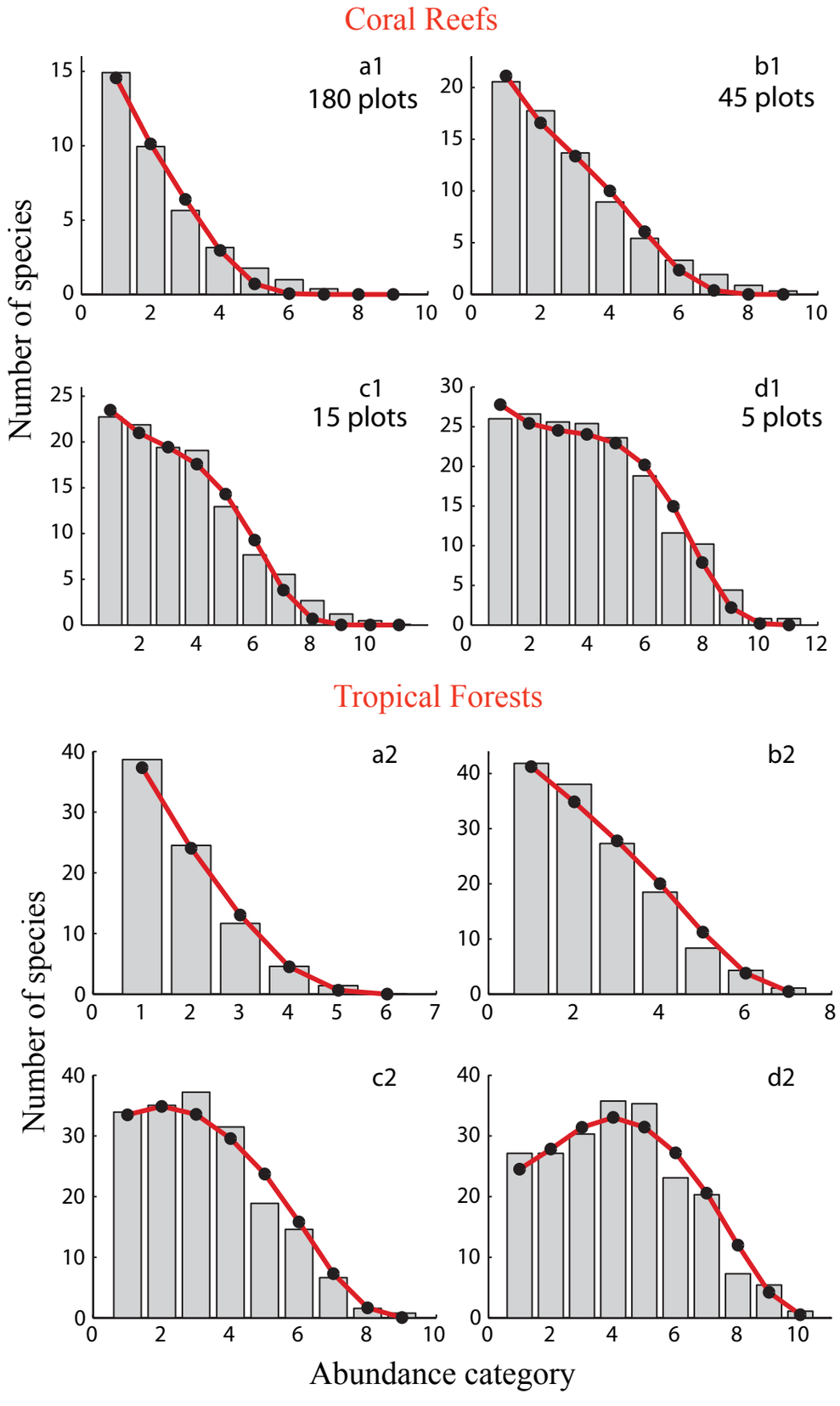
If m=0 -> absorbing state

Functional form of b_n

Density dependent effects

Risultati

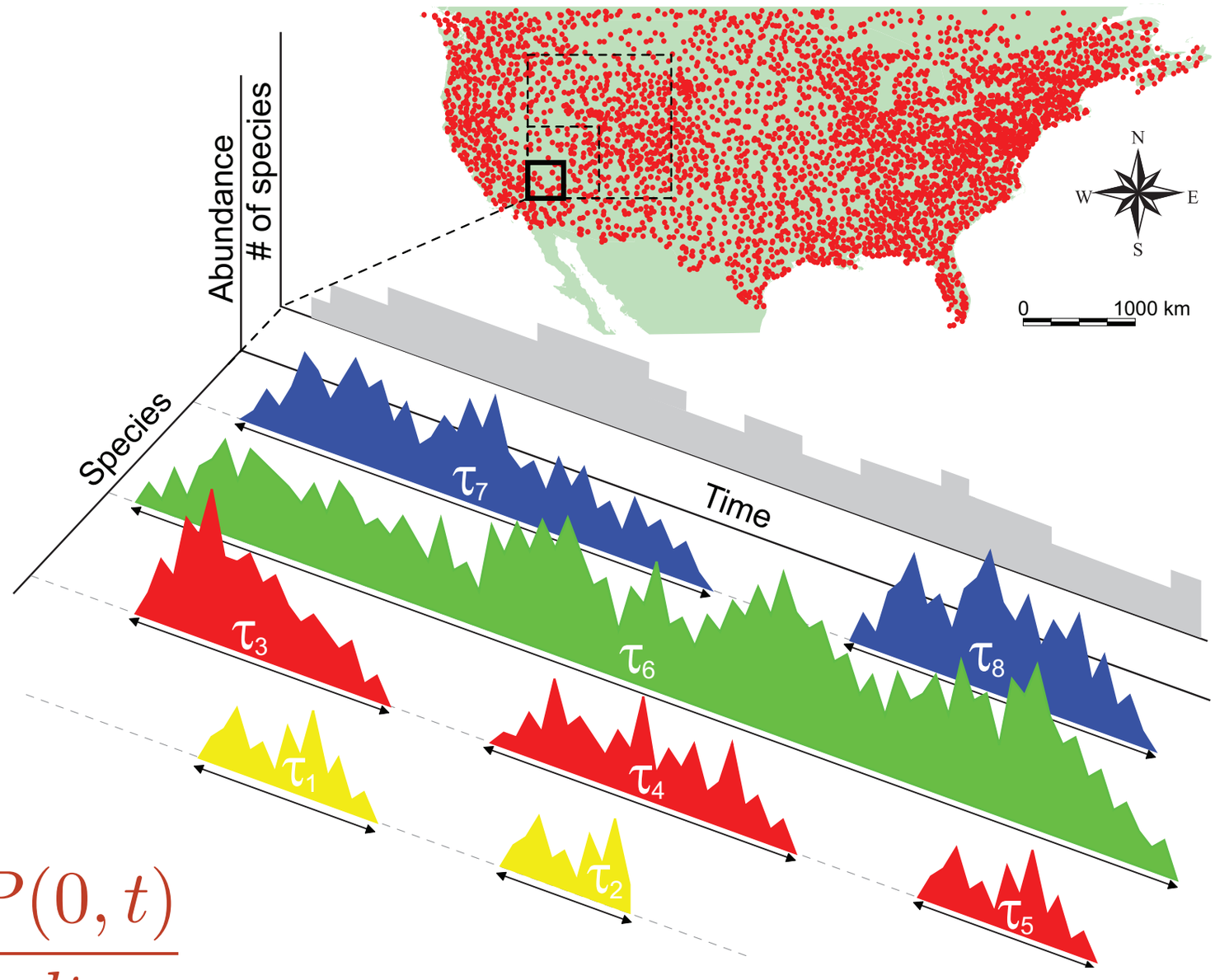




Azaele et al., Review of Modern Physics 2016

Volkov et al., Nature 2007

Tempi di persistenza delle specie



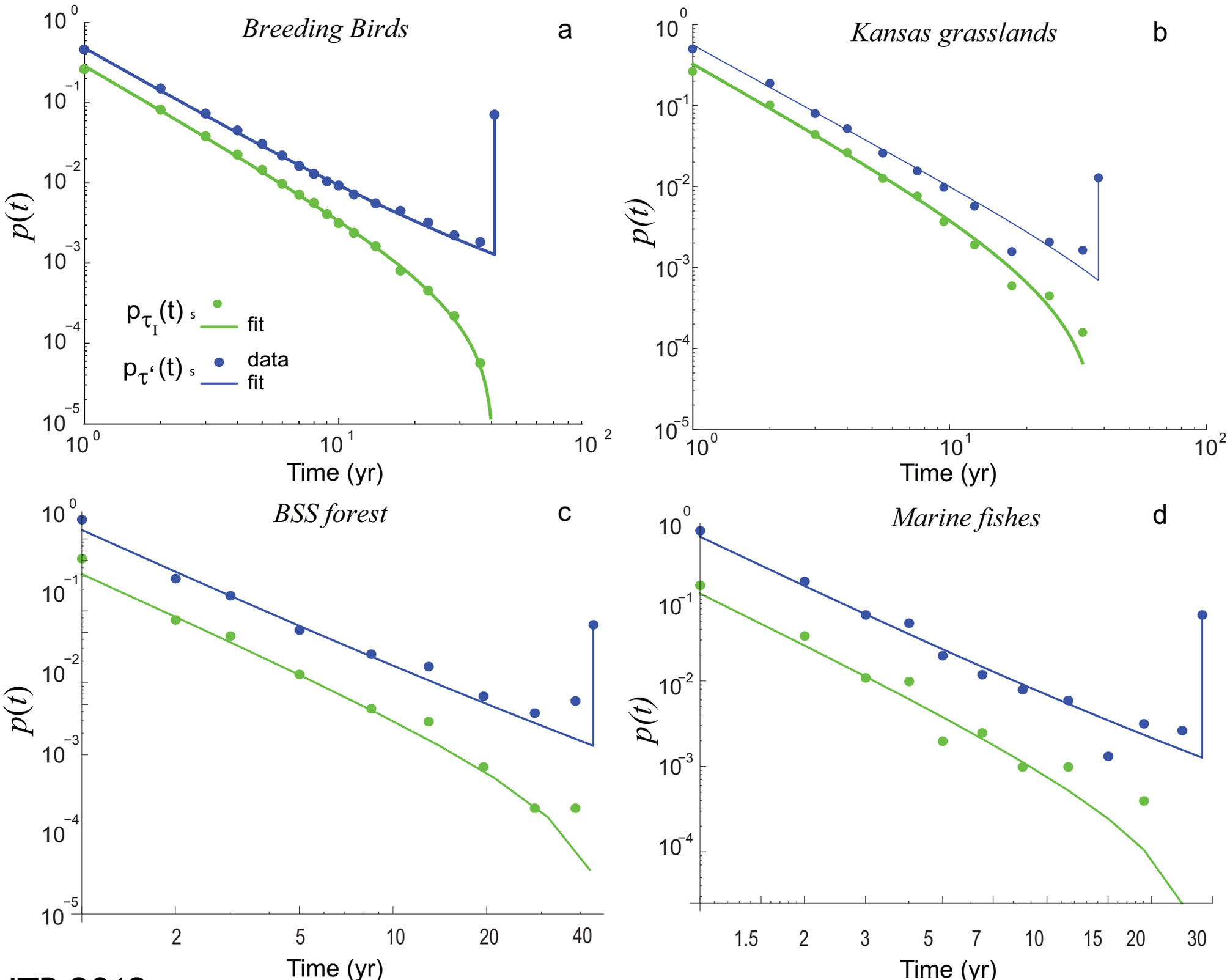
$$p_\tau(t) = \frac{dP(0,t)}{dt}$$

$$p_\tau(t) = Ct^{-\alpha}e^{-\nu t}$$

Bertuzzo et al., PNAS 2011
Suweis et al.,JTB 2012

Can simple models help to discover new patterns?

Un nuovo pattern emergente!

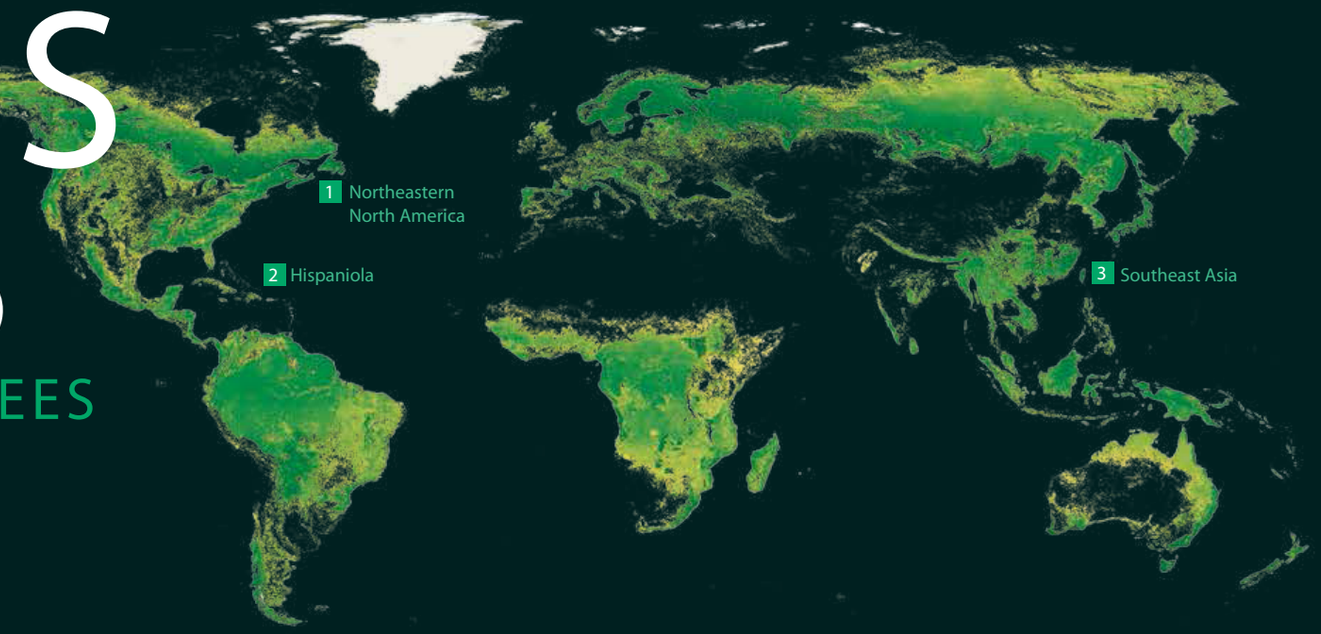


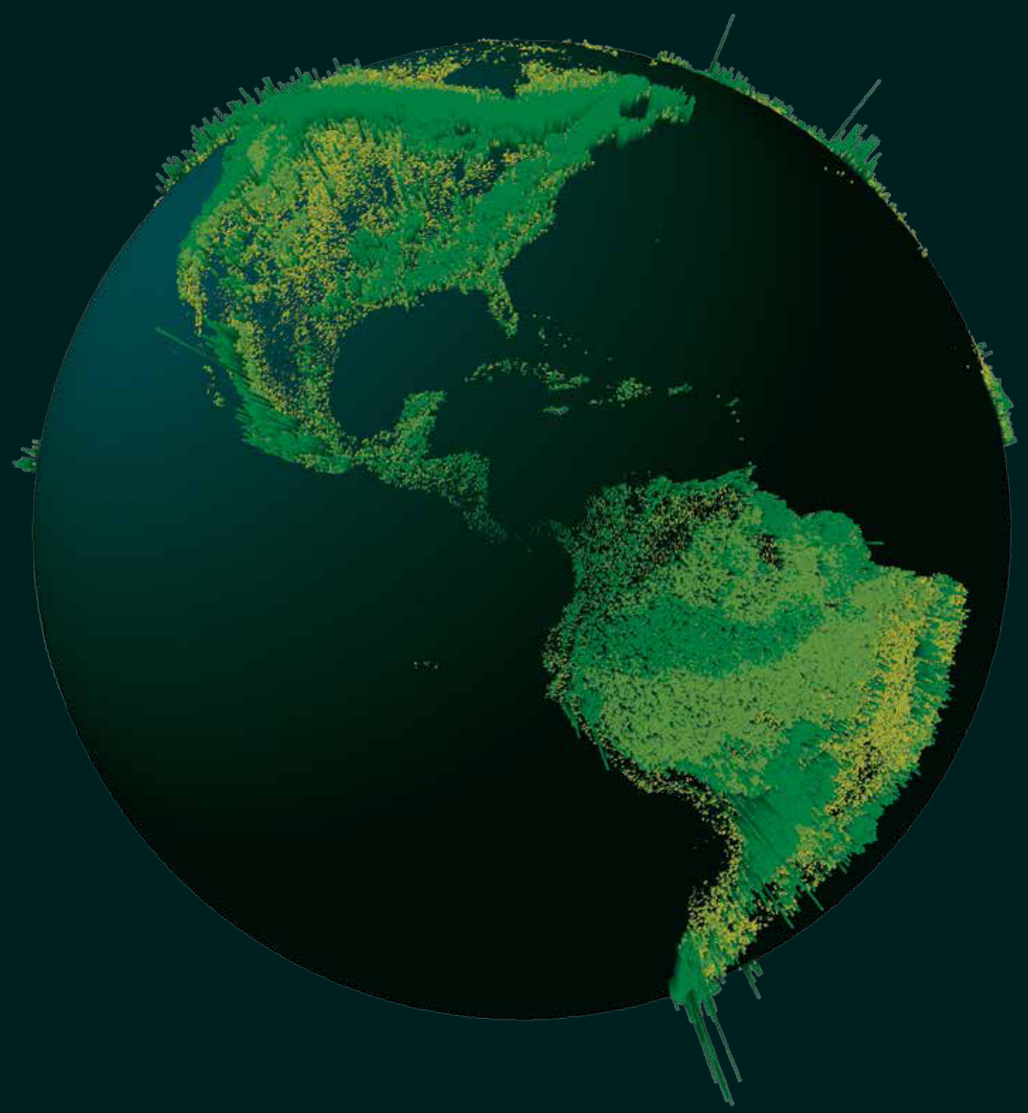
Suweis et al.,JTB 2012

TRILLIONS OF TREES

SURVEY OF SURVEYS FINDS 422 TREES FOR EVERY PERSON ON EARTH

BY RACHEL EHRENBERG
DATA VISUALIZATION BY JAN WILLEM TULP





BUT HOW MANY SPECIES?

A method to upscale biodiversity from ecological samples

A.Tovo, S. Suweis, A. Maritan

M. Formentin, M. Favretti, I. Volkov, Jayanth R. Banavar, S. Azaele

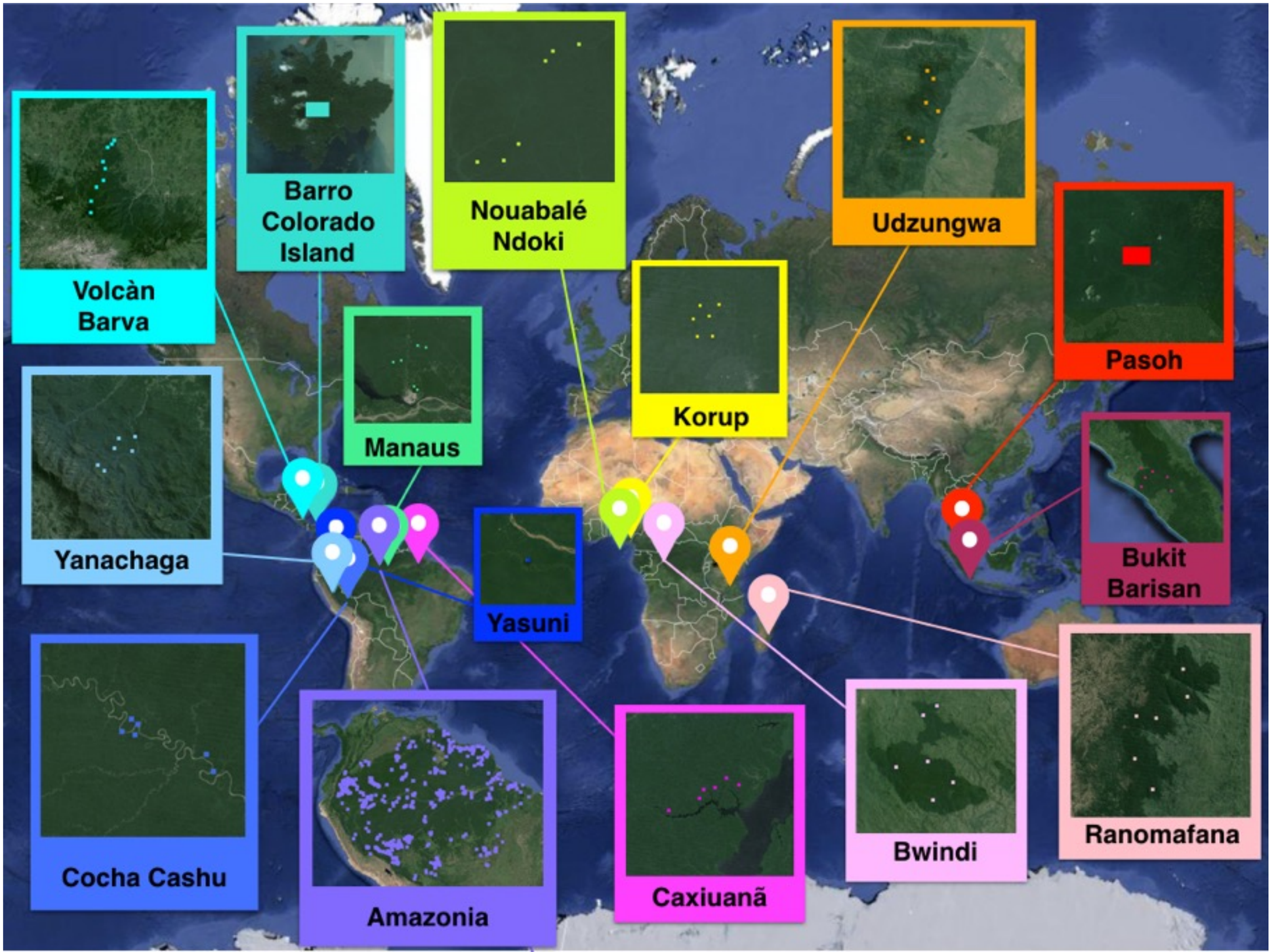
SCIENCE ADVANCES | RESEARCH ARTICLE

TROPICAL ECOSYSTEMS

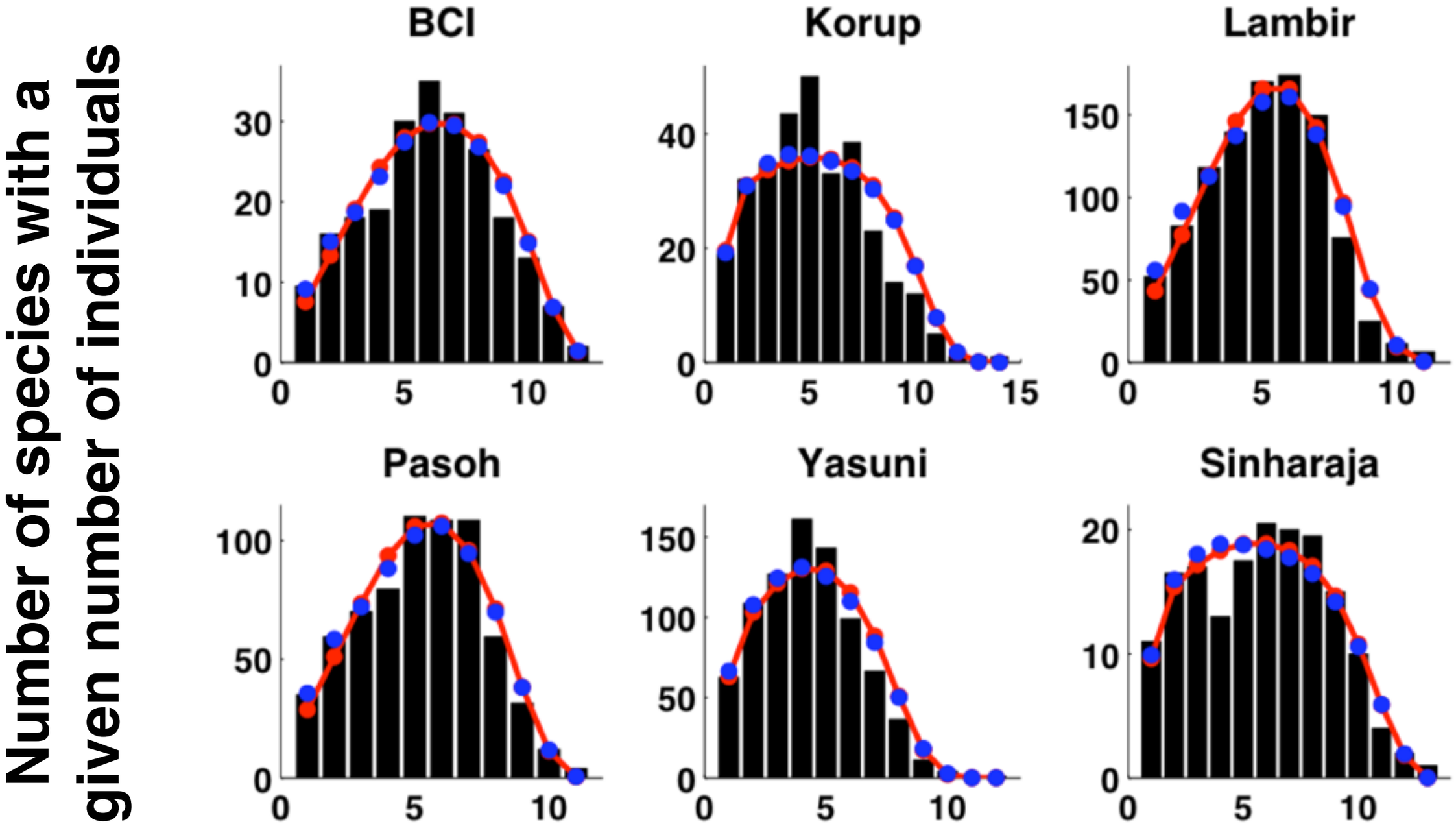
Upscaling species richness and abundances in tropical forests

Anna Tovo,[1]* Samir Suweis,[2]* Marco Formentin,[1†] Marco Favretti,[1] Igor Volkov,[3] Jayanth R. Banavar,[3,4†] Sandro Azaele,[5] Amos Maritan[2]

Can we go from local census, to forest scale biodiversity?



Sfruttiamo il fatto che conosciamo la RSA

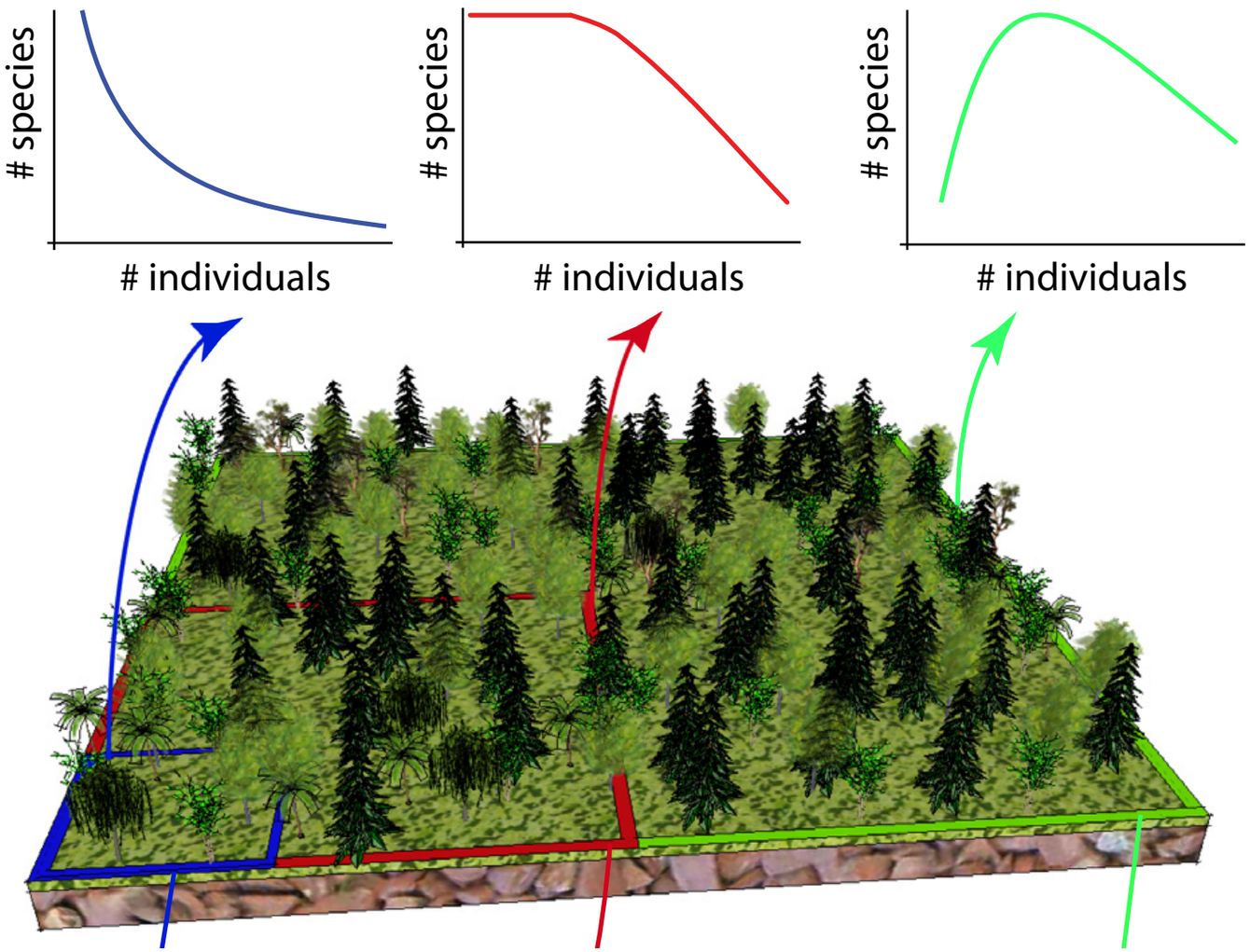


Scaling e proprietà di Self-similarità

$$\mathcal{P}(k|\hat{r}_p,\hat{\xi}_p)=\sum_{n=1}^{\infty}\mathcal{P}(k,n|\hat{r}_p,\hat{\xi}_p)=\sum_{n=1}^{\infty}\mathcal{P}(k|n,\hat{r}_p,\hat{\xi}_p)\mathcal{P}(n|r,\xi).$$

$$\mathcal{P}(k|n,\hat{r}_p,\hat{\xi}_p)=\binom{n}{k}p^k(1-p)^{n-k}.$$

NB also at different scales!

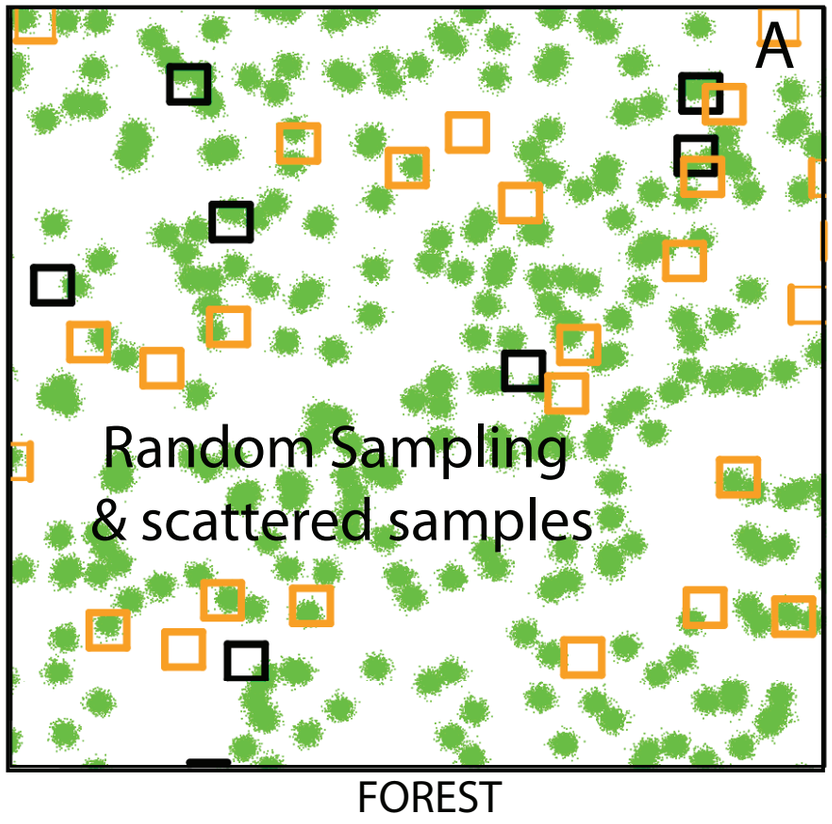


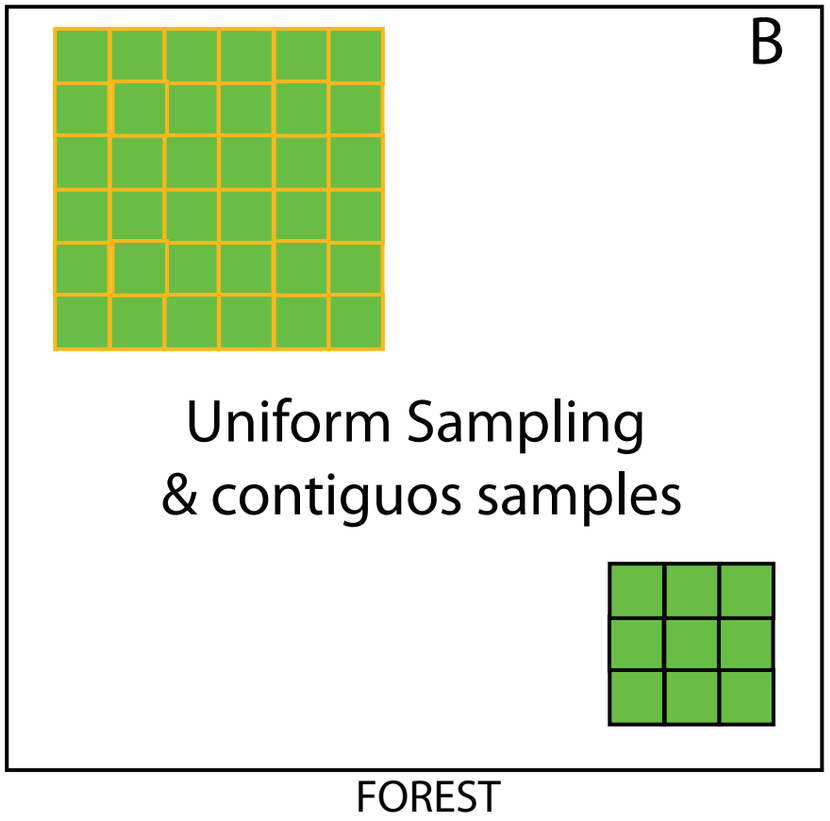
$$\hat{\xi}_p=\frac{p\xi}{1-\xi(1-p)}.$$

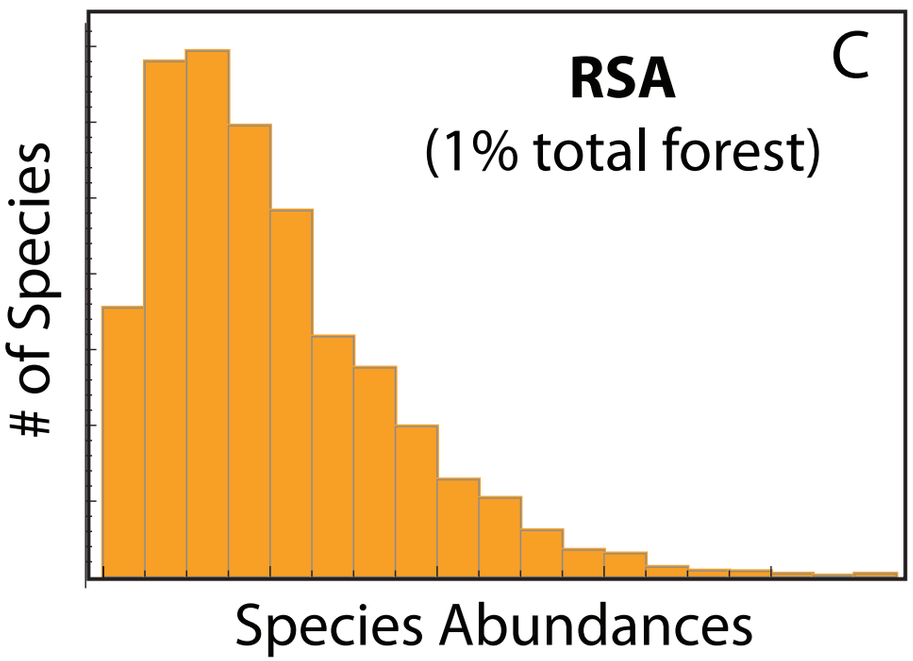
$$\hat{r}_p=r$$

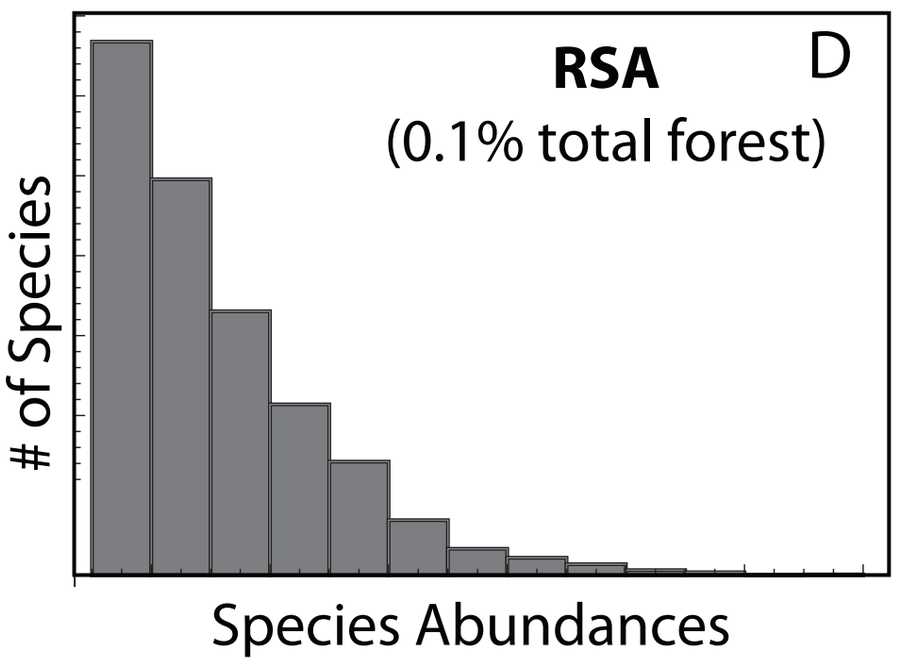
$$S=S_p\frac{1-(1-\xi)^r}{1-(1-\xi_p)^r},$$

Tests on computer-generated forests.

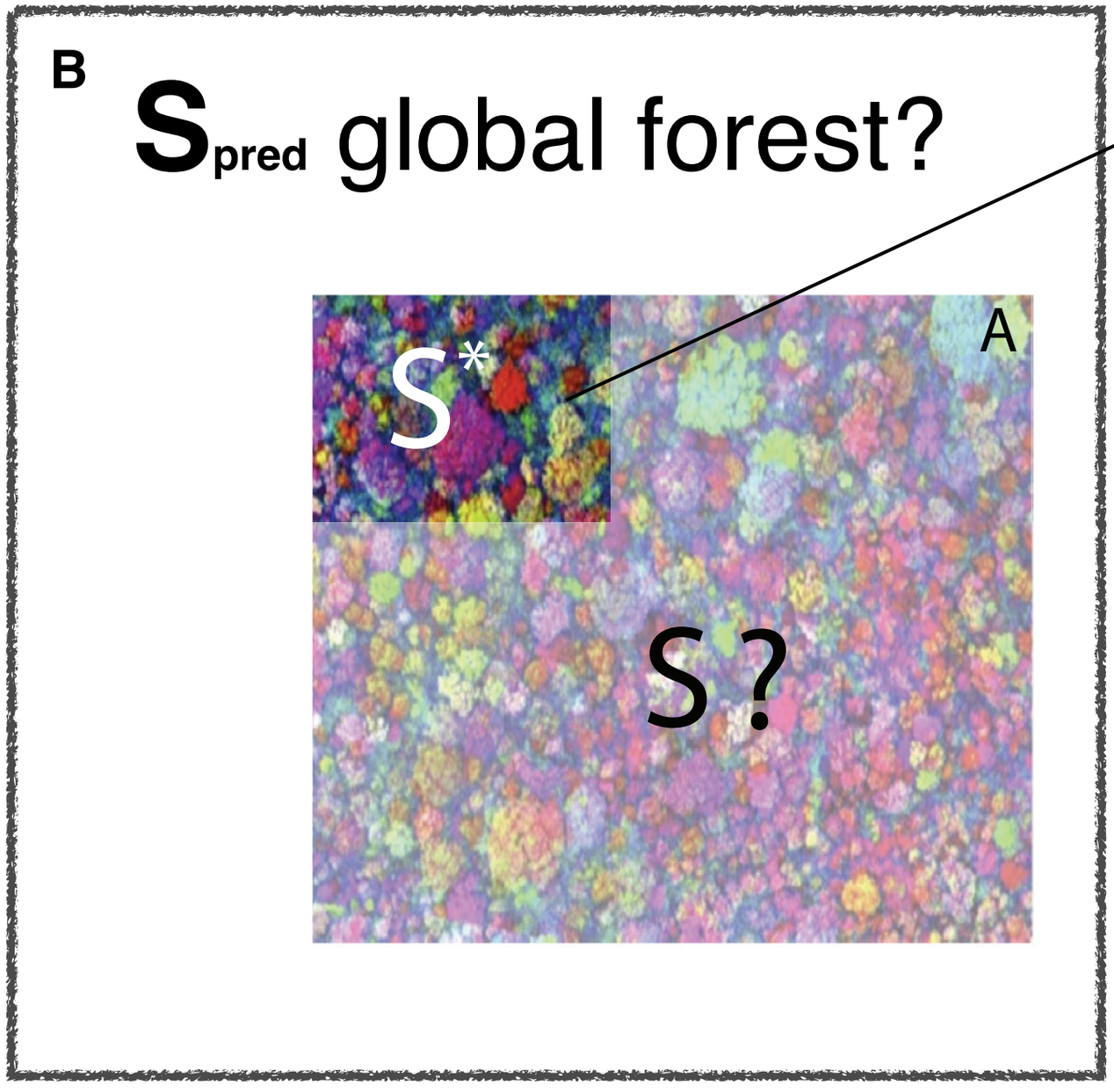


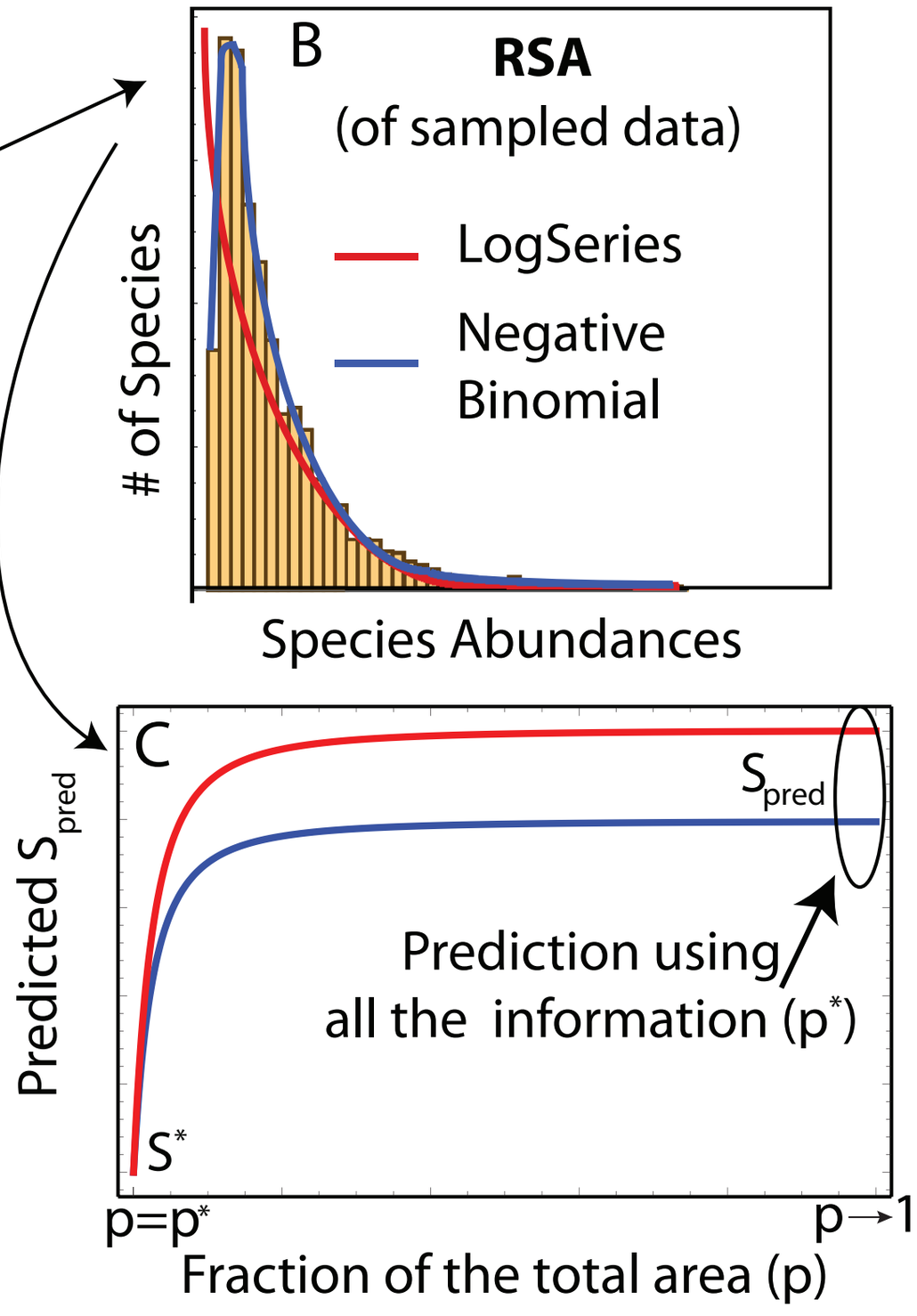






Test su dati empirici





Amazonia

A

S_{pred}

5000
4800
4600
4400
4200
4000

Slik
NB Method
$Chao_{wor}$
S^*

0.0 0.2 0.4 0.6 0.8 1.0

p

BCI

B

S_{pred}

340
330
320
310
300
290
280
270

0.0 0.2 0.4 0.6 0.8 1.0

p

SAR Amazonia

C

SAR(a)

14 000
12 000
10 000
8000
6000

0.0 0.2 0.4 0.6 0.8 1.0

a

SAR BCI

B

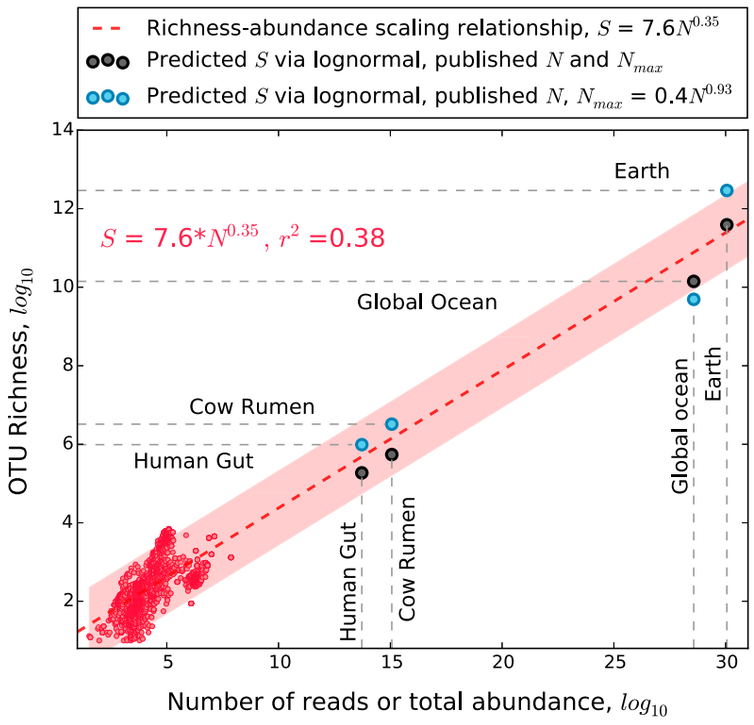
SAR(a)

500
450
400
350
300
250

0.0 0.2 0.4 0.6 0.8 1.0

a

Applicazione ad altri campi

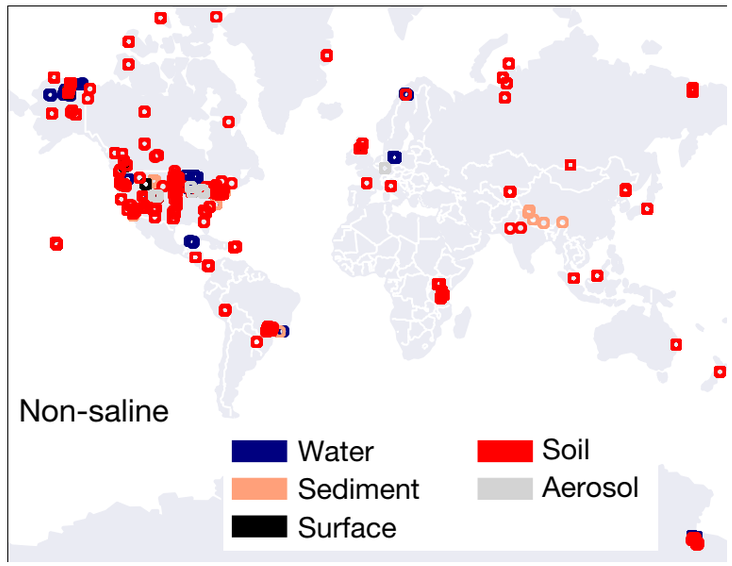


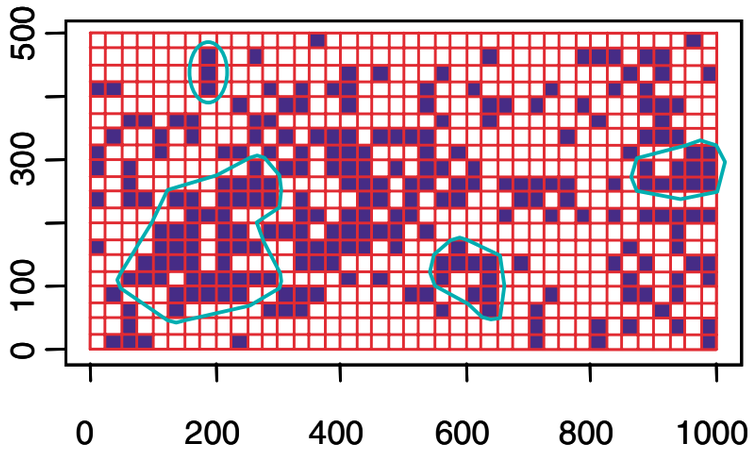
ARTICLE

OPEN

doi:10.1038/nature24621

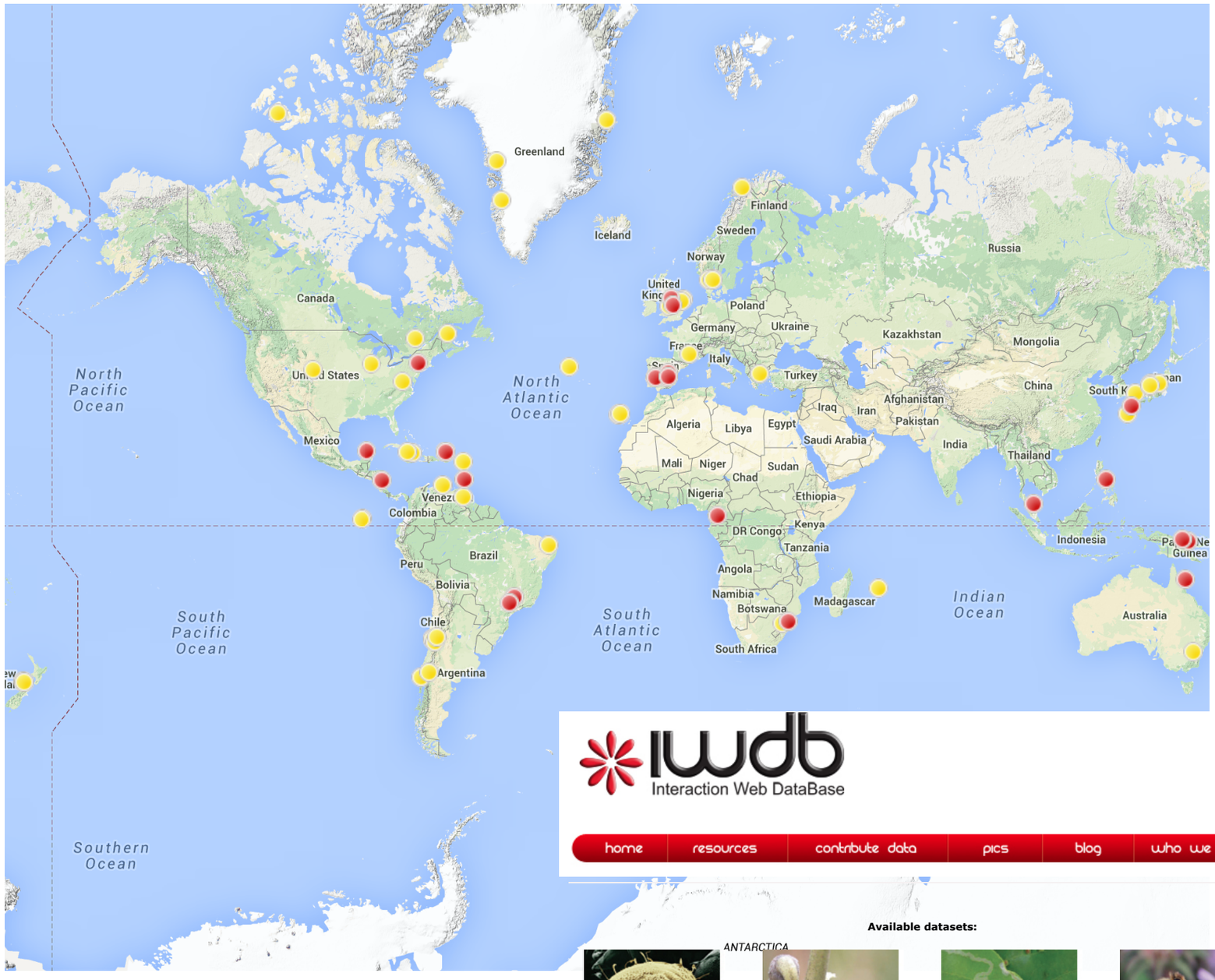
A communal catalogue reveals Earth's multiscale microbial diversity

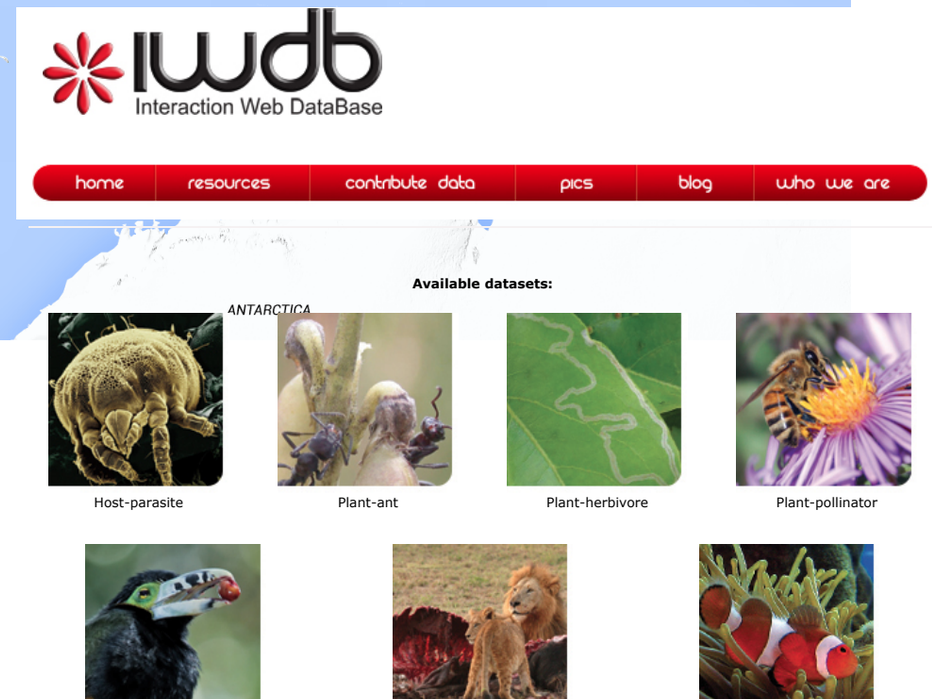




Using only presence/absence data?

Ecological Networks





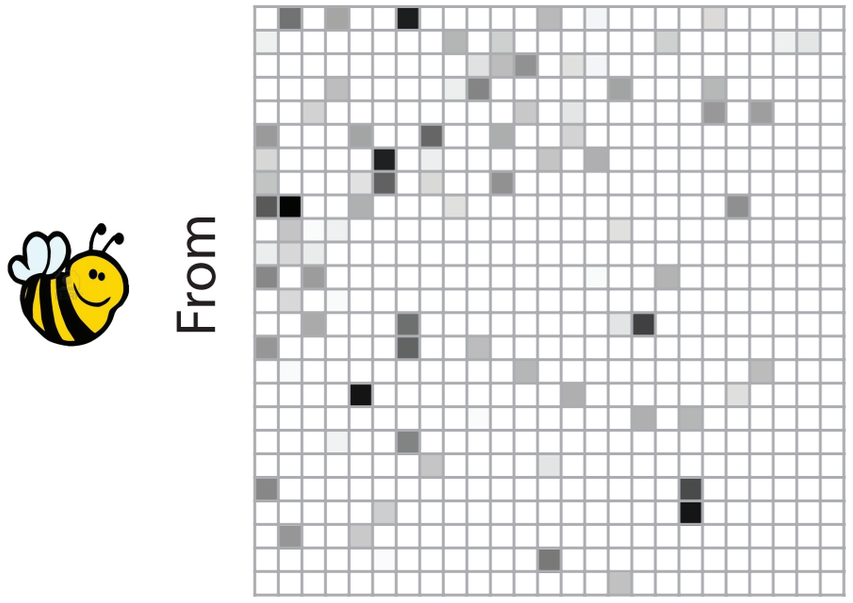
S=A+P species

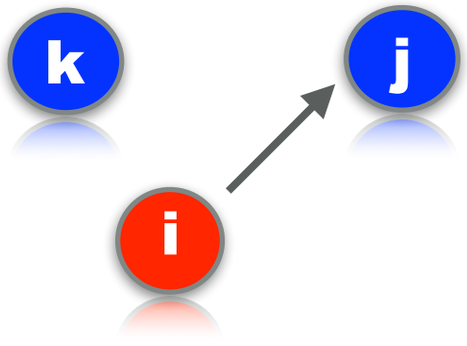
C=L/(A*P)

Cosa è una rete (network)?

GRAFO BIPARTITO

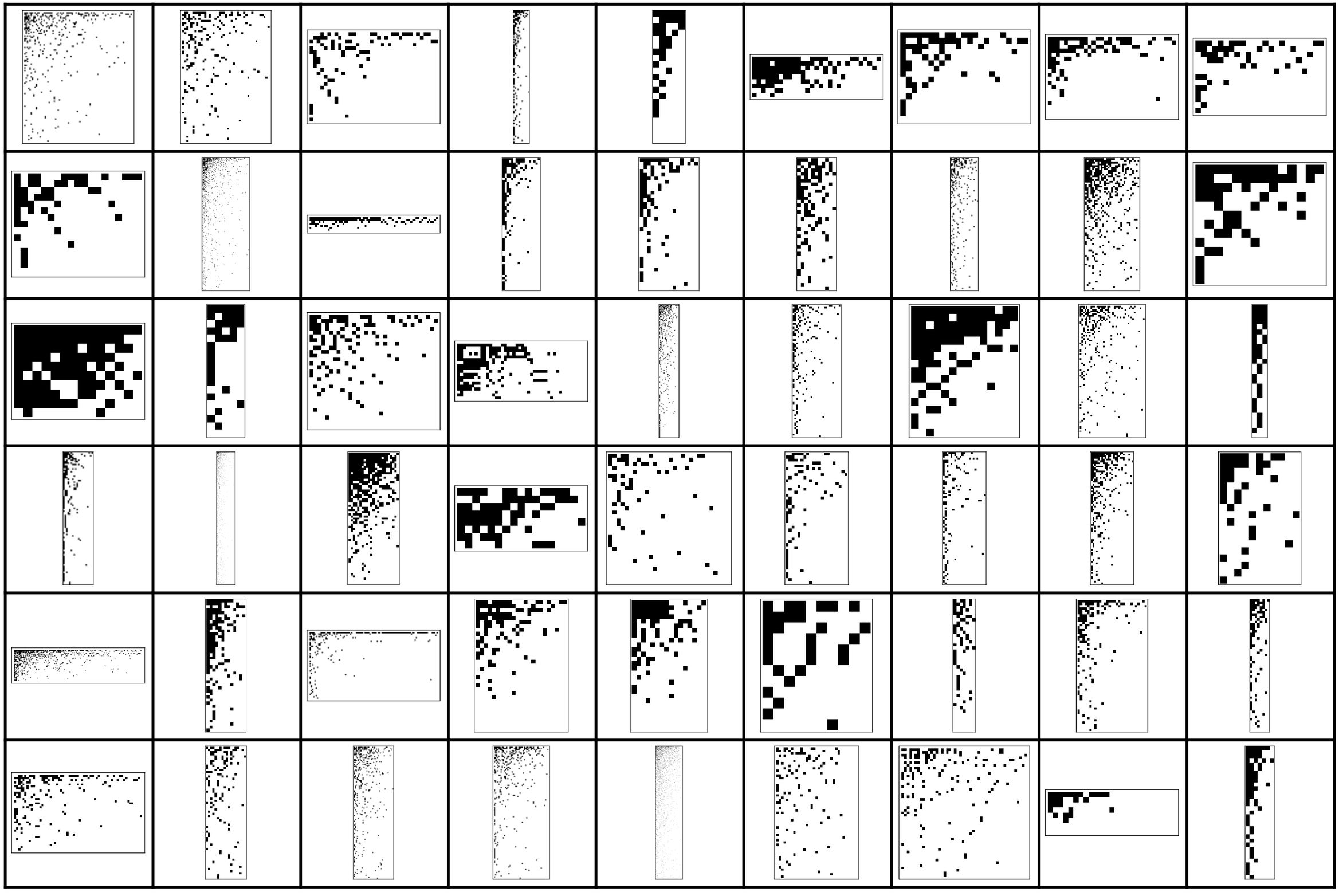
Matrice (tabella) di adiacenza: A
Se “pesata” M matrice di interazione





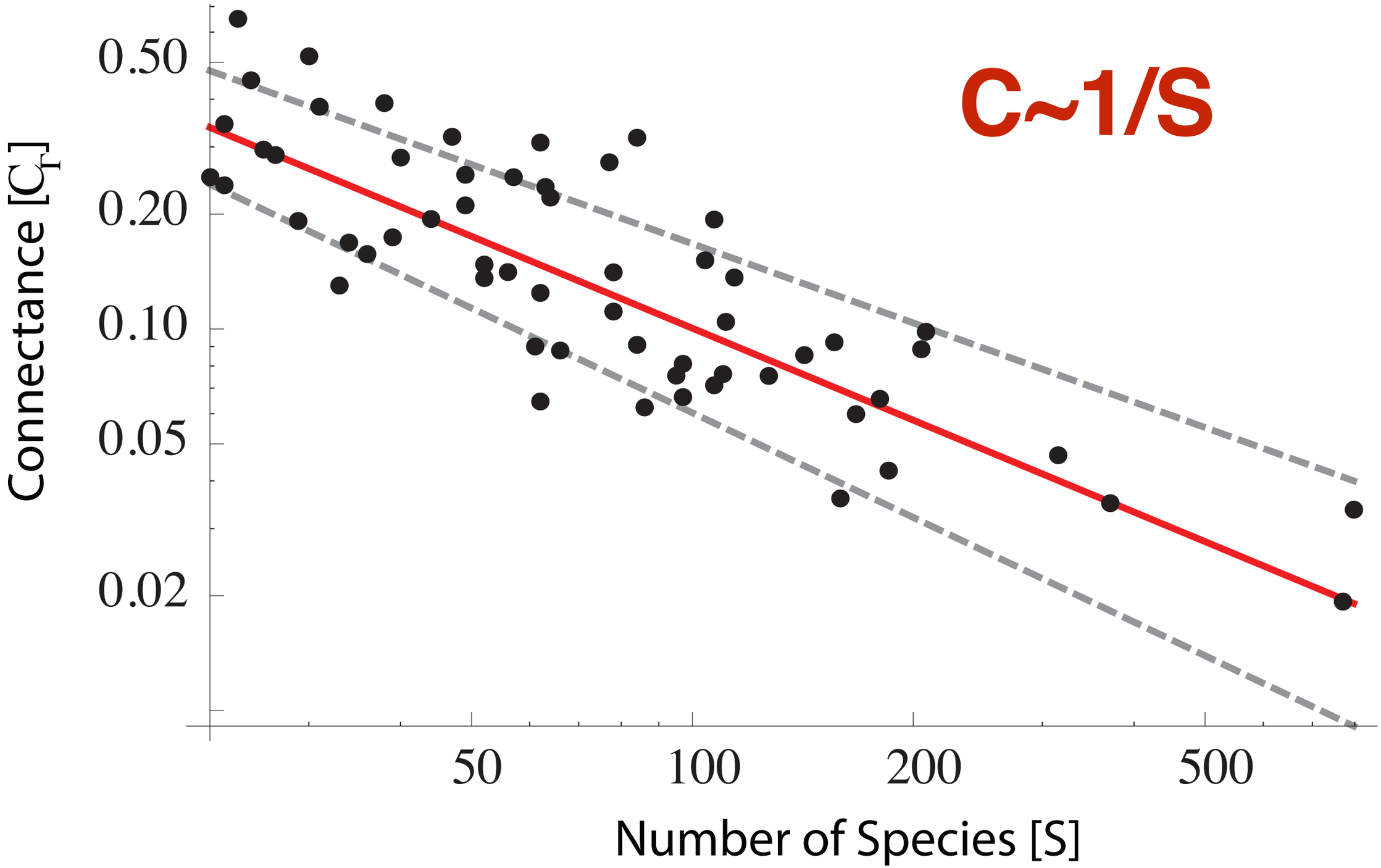
$a_{ij}=1$ $a_{ik}=0$
$a_{ji}=1$ $a_{ki}=0$

Ancora patterns emergenti!



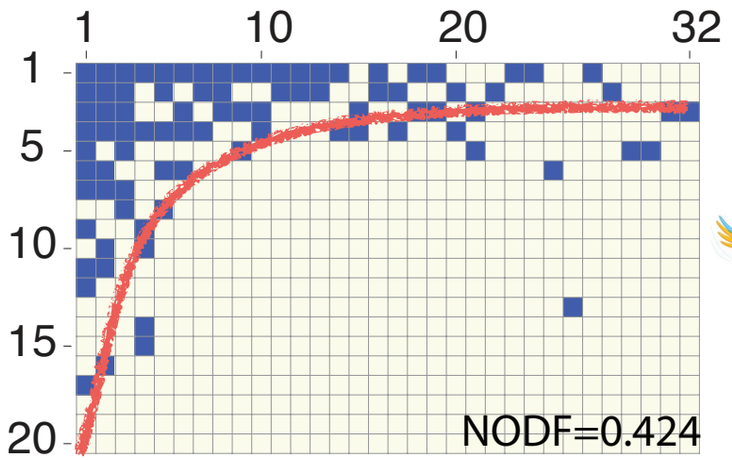
a_{ij}^{PA}

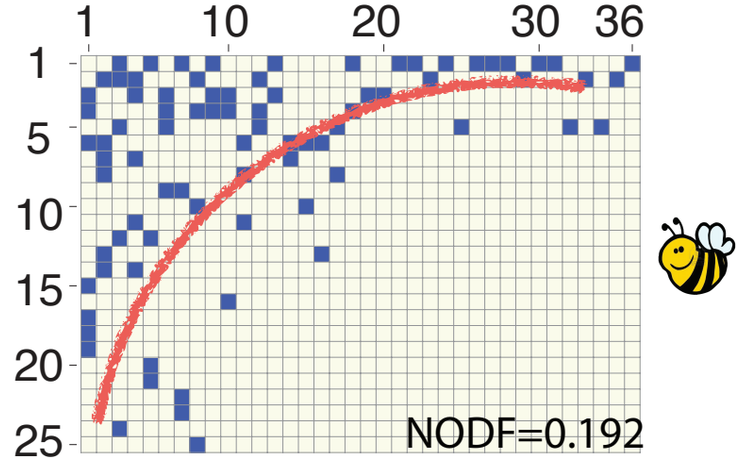
Ancora patterns emergenti!



Un' occhiata da più vicino

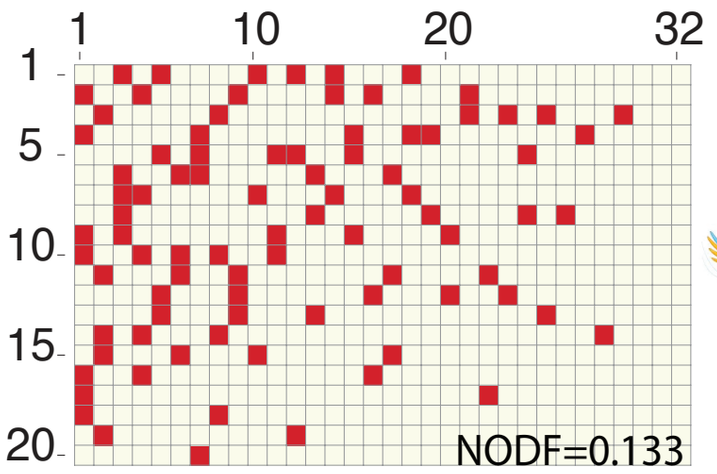
Avian fruit web in Puerto Rico Carlo, et al.

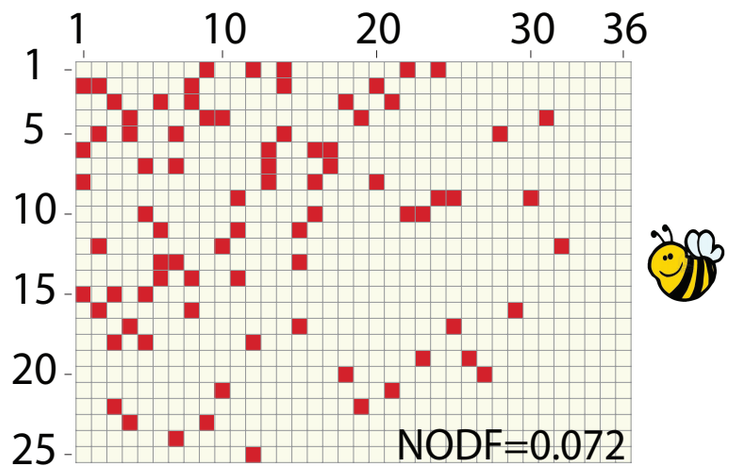




Plant Pollinator web in Chile Arroyo, et al.

Random same S,C





Random same S,C

Annidamento —> NODF

Perchè queste proprietà emergente?

Che vantaggio hanno le specie ad auto-organizzarsi in quel modo?

LETTER

doi:10.1038/nature12438

Emergence of structural and dynamical properties of ecological mutualistic networks

Samir Suweis[1], Filippo Simini[2,3], Jayanth R. Banavar[4] & Amos Maritan[1]

A. Maritan, J. Grilli, J.R. Banavar, F. Simini,
B. S. Allesina, J. Hidalgo, D. Busiello

SCIENTIFIC REPORTS

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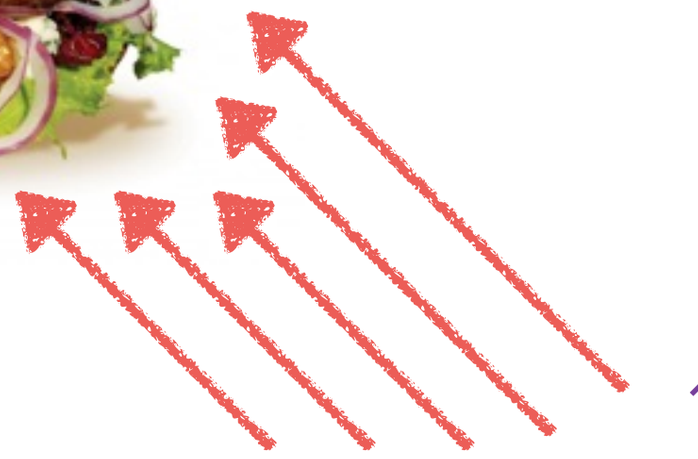
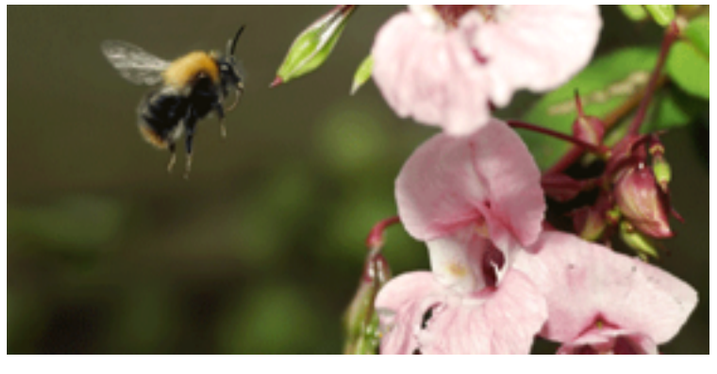
Explorability and the origin of network sparsity in living systems

La mia strategia

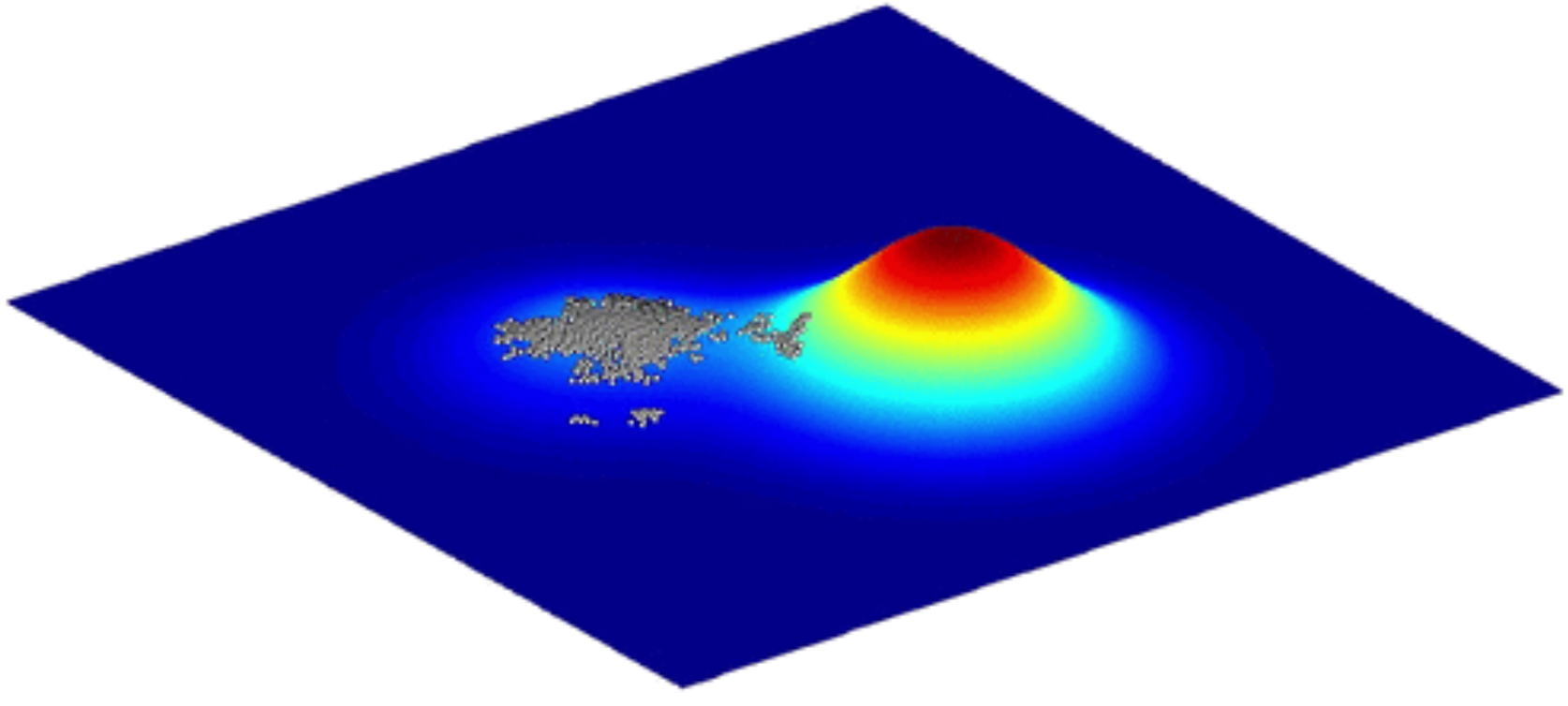


Stessa idea!



Principio di ottimizzazione

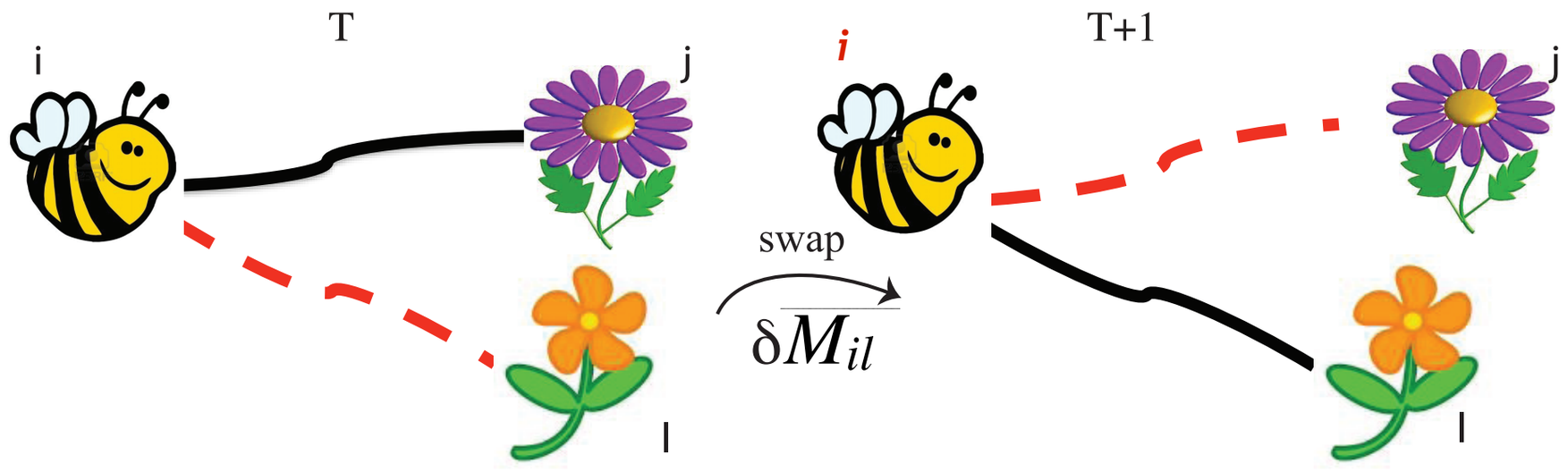
- Variabile che indica le popolazioni delle specie $X = \{X_1, X_2, \ldots, X_S\}$
- Matrice di interazione M scelta a caso
- Modello dinamico per l'evoluzione della popolazione data M



Population size, N = 2,304
Mutation rate, μ = 0.5 per trait

Implementazione del principio di Ottimizzazione

Iniziamo con popolazioni a caso e M a caso

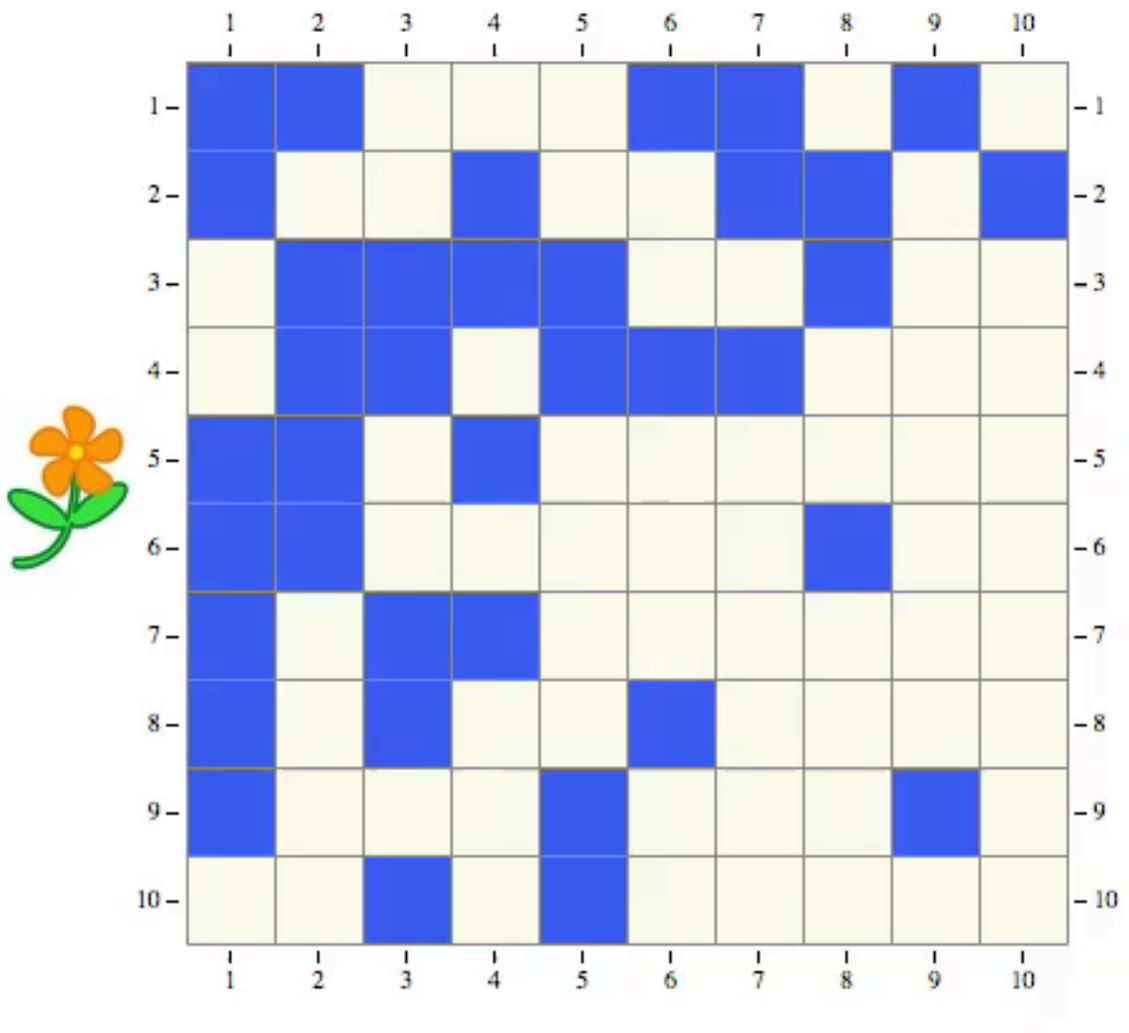


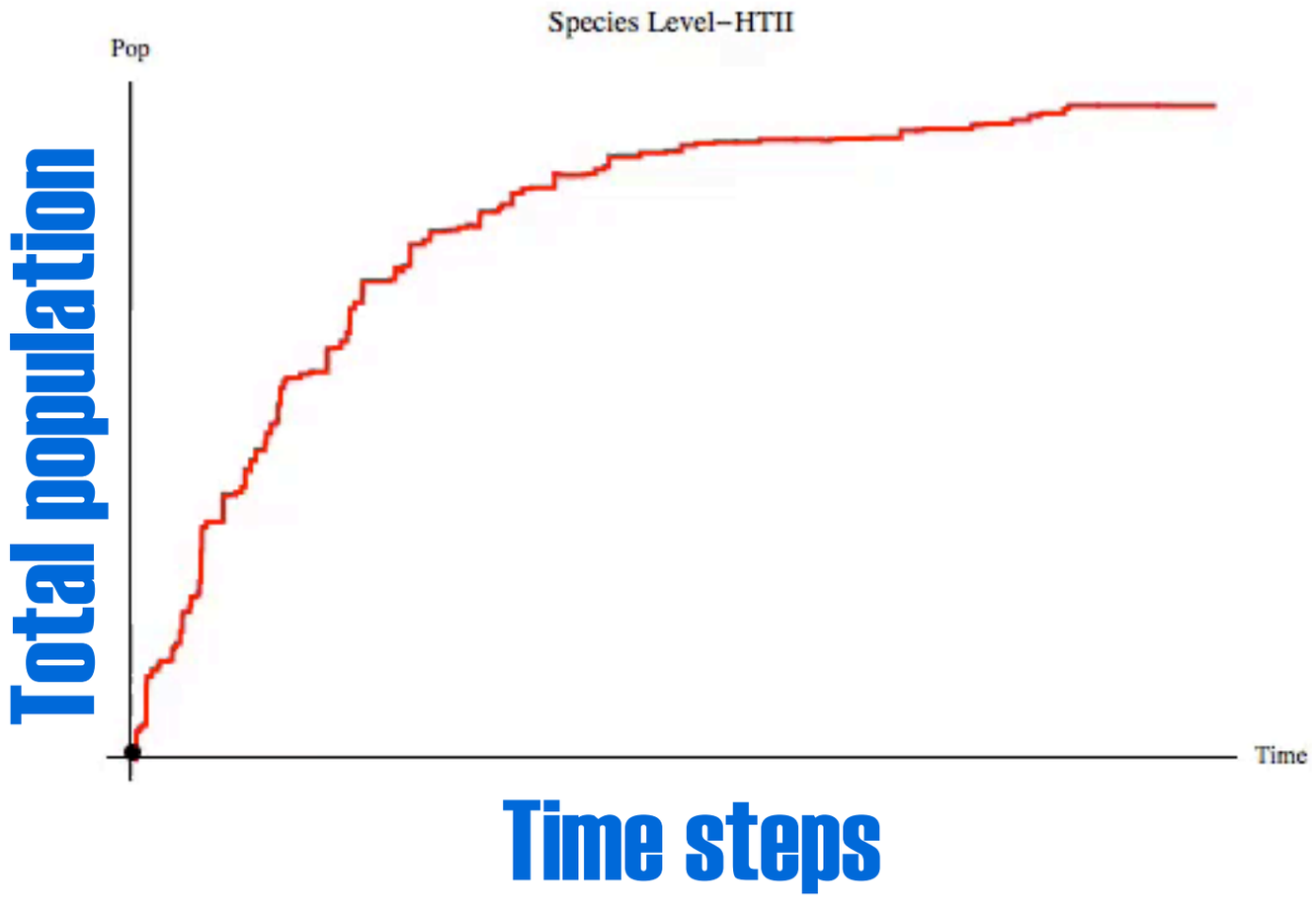
Strategia: se mangio meglio cambio fiore!

$$M \Rightarrow M'$$

$$\text{if } x_i^{',*} > x_i^*$$

Simulazione del modello: Emergenza di annidamento





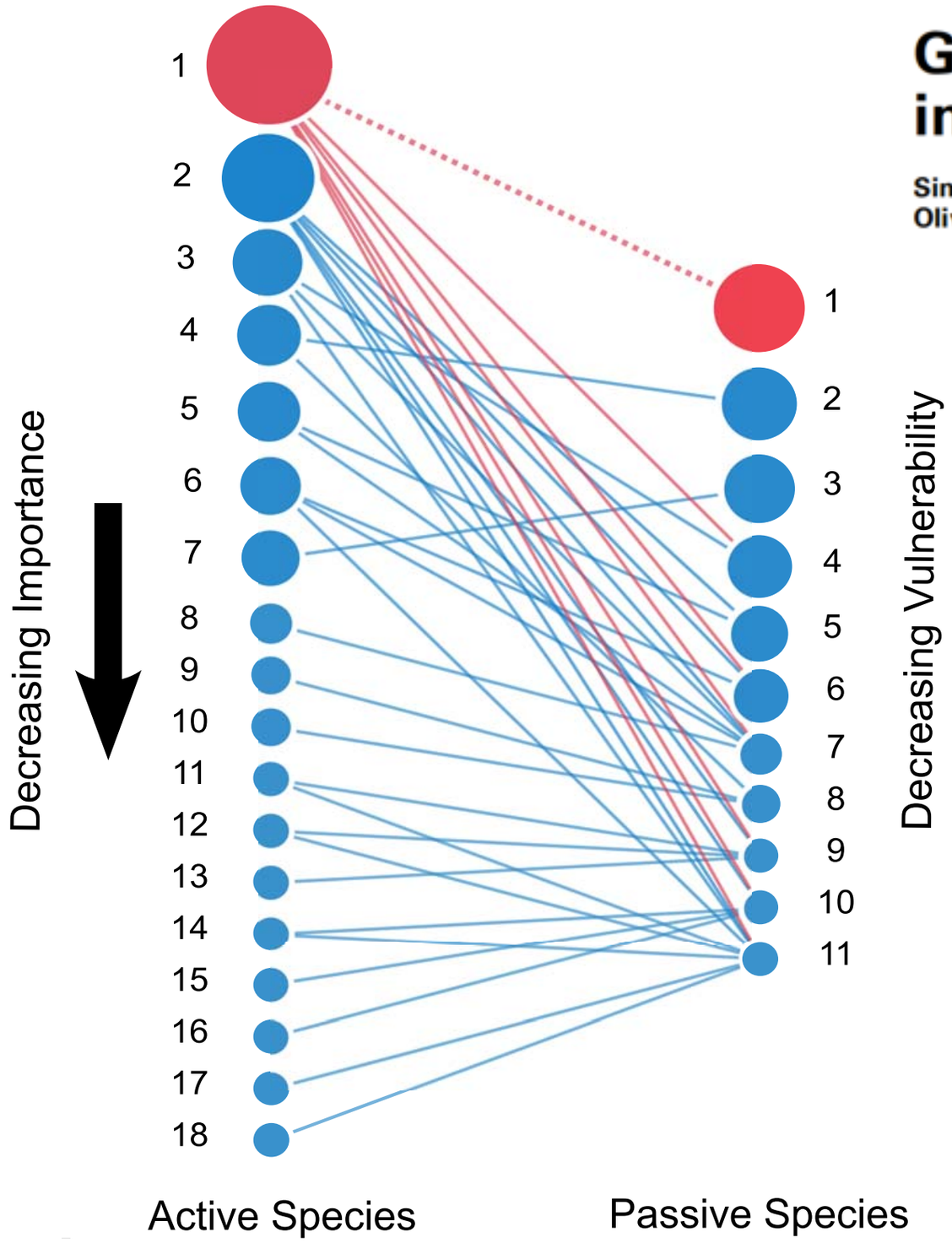
Suweis et al., Nature 2013

Perchè studiare questi sistemi?

Servizi ecosistemici

- Circa 1/3 of del cibo è prodotto grazie all'azione degli impollinatori.
- Ci sono più di 20,000 differenti specie di api
- Circa il 75% dei campi coltivati (tra cui caffè, molti frutti, mandorle e cioccolato) dipende dall'impollinazione
- I servizi annui prodotti dall'impollinazione sono valutati 10 miliardi$

Declino di biodiversità e cascata di estinzioni

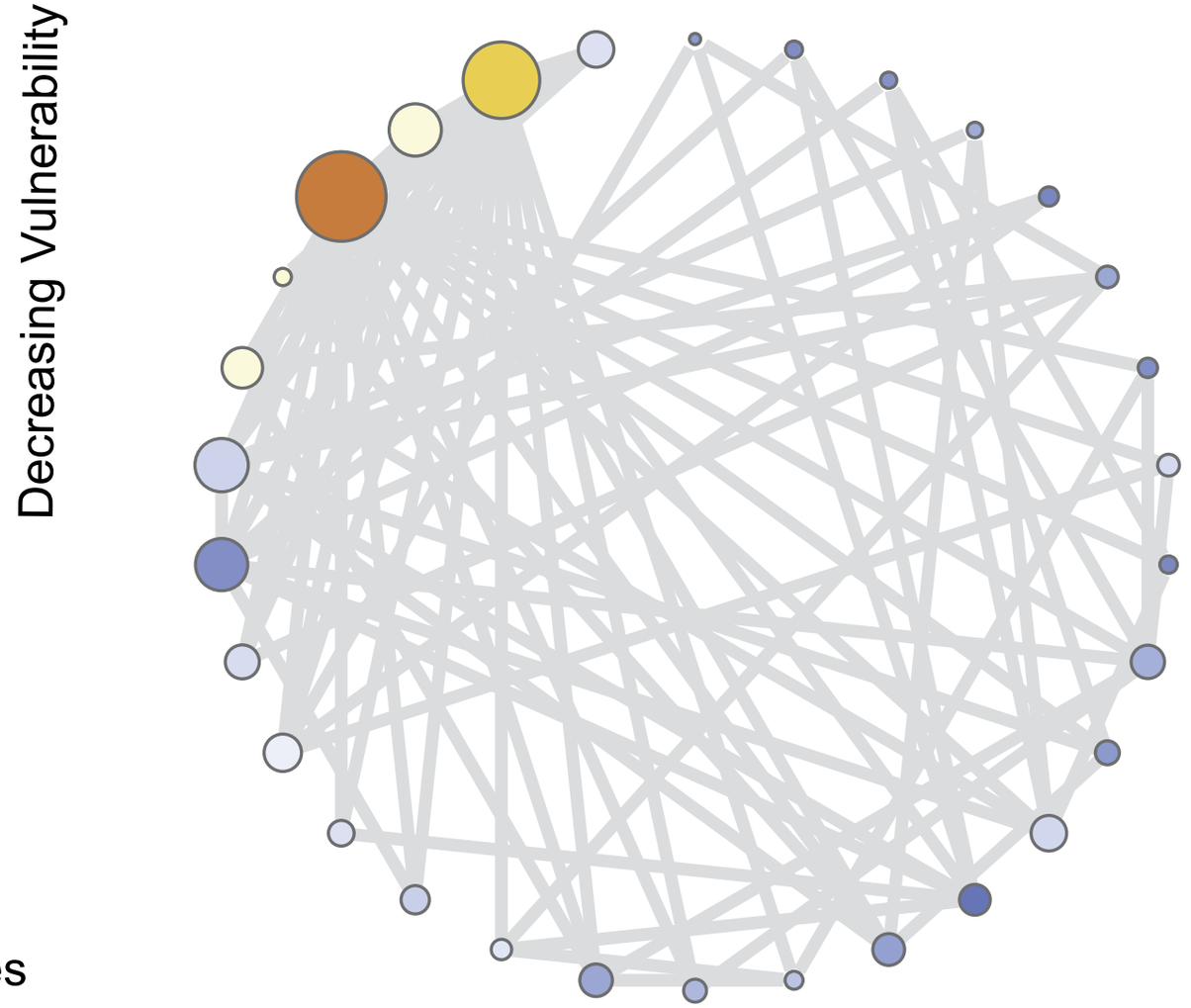


Review

Cell

Global pollinator declines: trends, impacts and drivers

Simon G. Potts[1], Jacobus C. Biesmeijer[2], Claire Kremen[3], Peter Neumann[4], Oliver Schweiger[5] and William E. Kunin[2]



Domínguez-García, V., & Munoz, M. A. (2015). Scientific reports, 5, 8182.

GRAZIE A VOI PER L'ATTENZIONE E A TUTTI I MIEI COLLABORATORI!

References:

Azaele et al, Review of Modern Physics, 2016
Suweis et al., *Nature* 2013;
Suweis et al, Oikos 2014
Suweis et al. *Nature Communications* 2015
Grilli et al. 2015, Arxiv
Busiello et al., 2017, Scientific Report