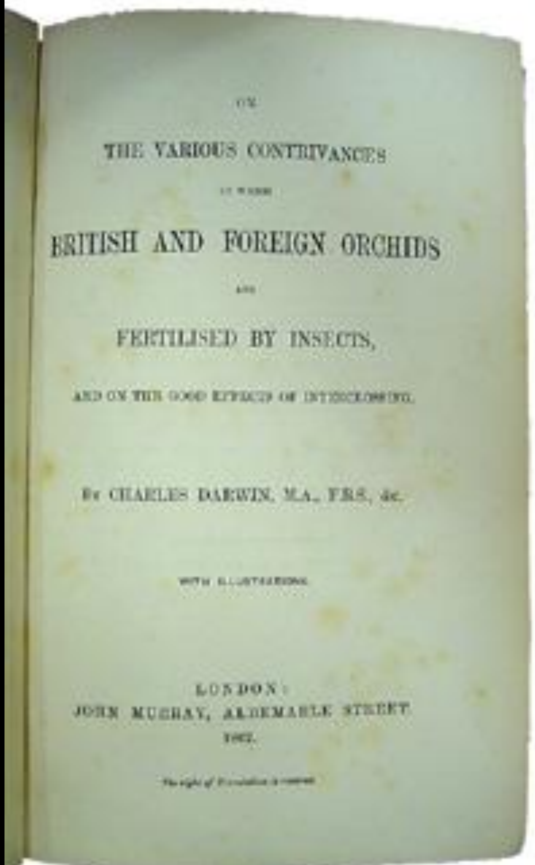
the Architecture of Biodiversity:

A world of cooperation

Biodiversity

Interactions

Mutualistic Interactions


ON

THE VARIOUS CONTRIVANCES

BY WHICH

BRITISH AND FOREIGN ORCHIDS

ARE

FERTILISED BY INSECTS,

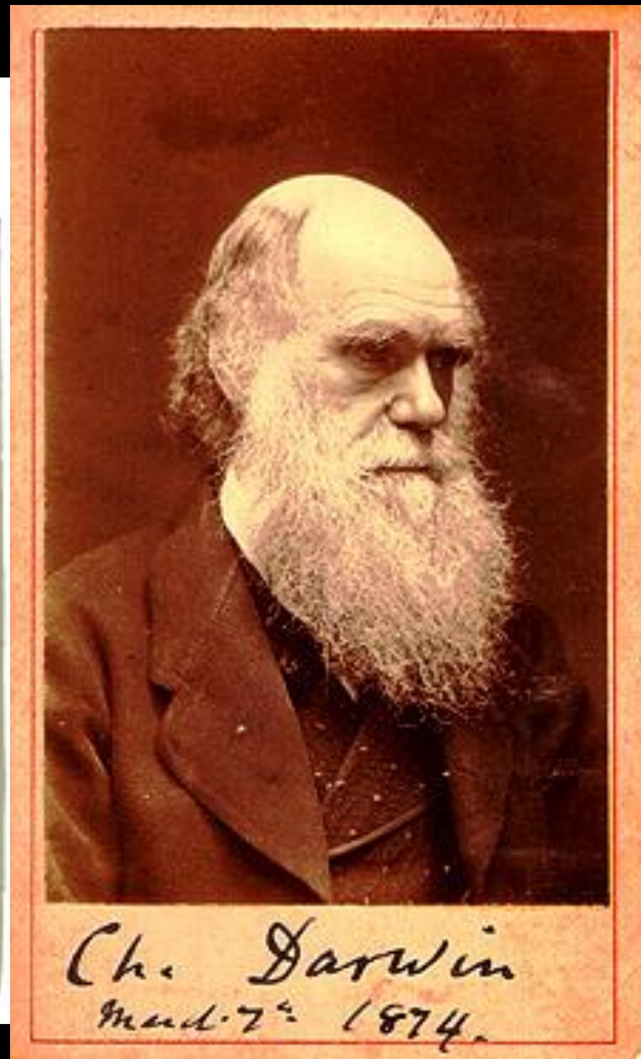
AND ON THE GOOD EFFECTS OF INTERCROSSING.

BY CHARLES DARWIN, M.A., F.R.S., &c.

WITH ILLUSTRATIONS.

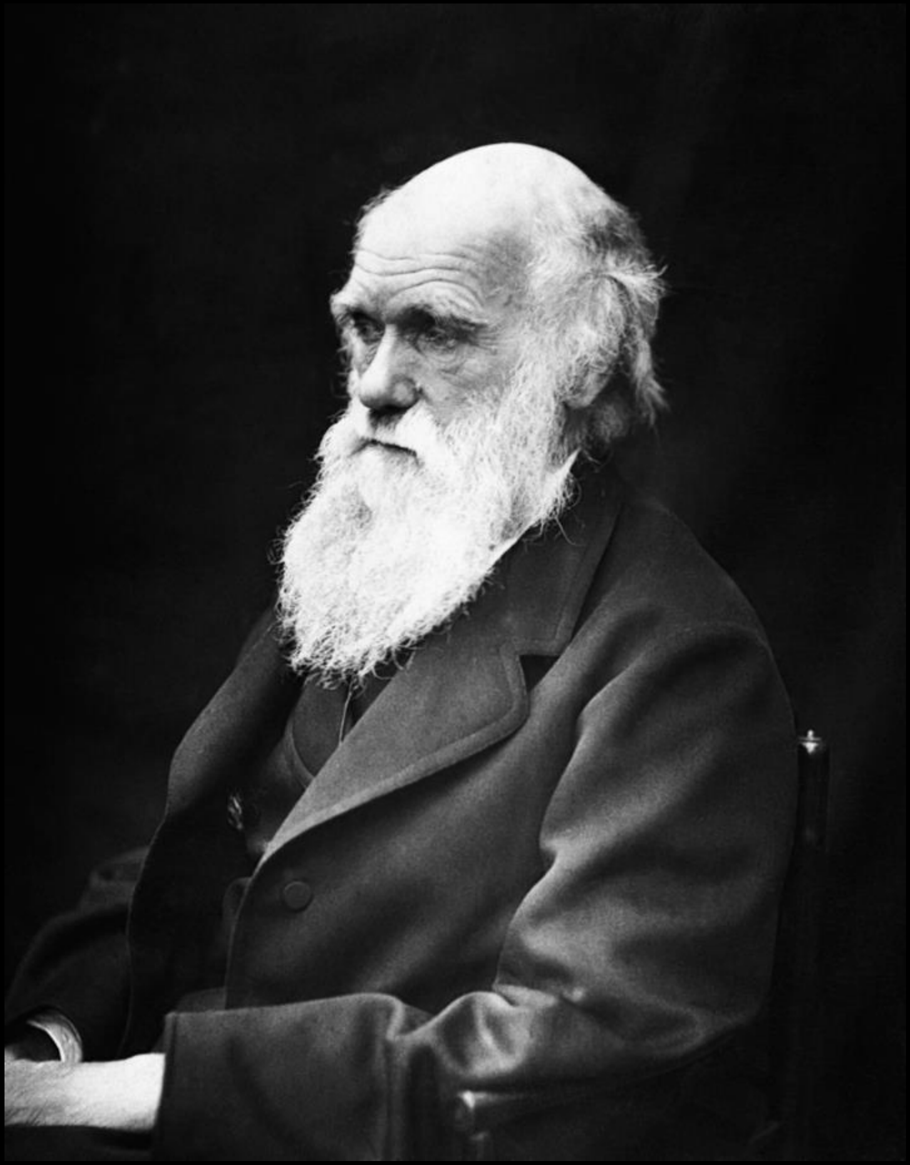
LONDON:
JOHN MURRAY, ALBEMARLE STREET.
1862.

The right of Translation is reserved.

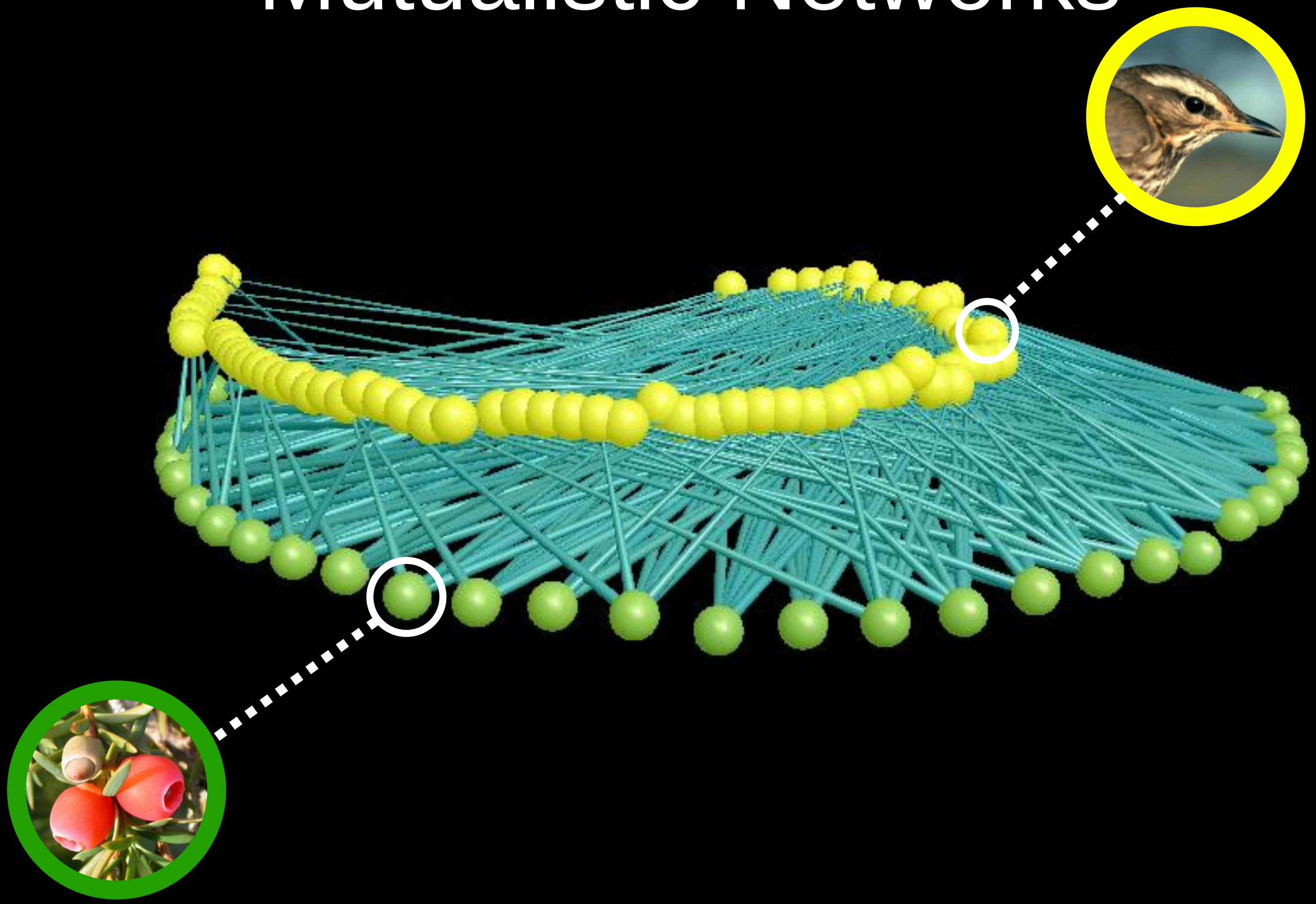


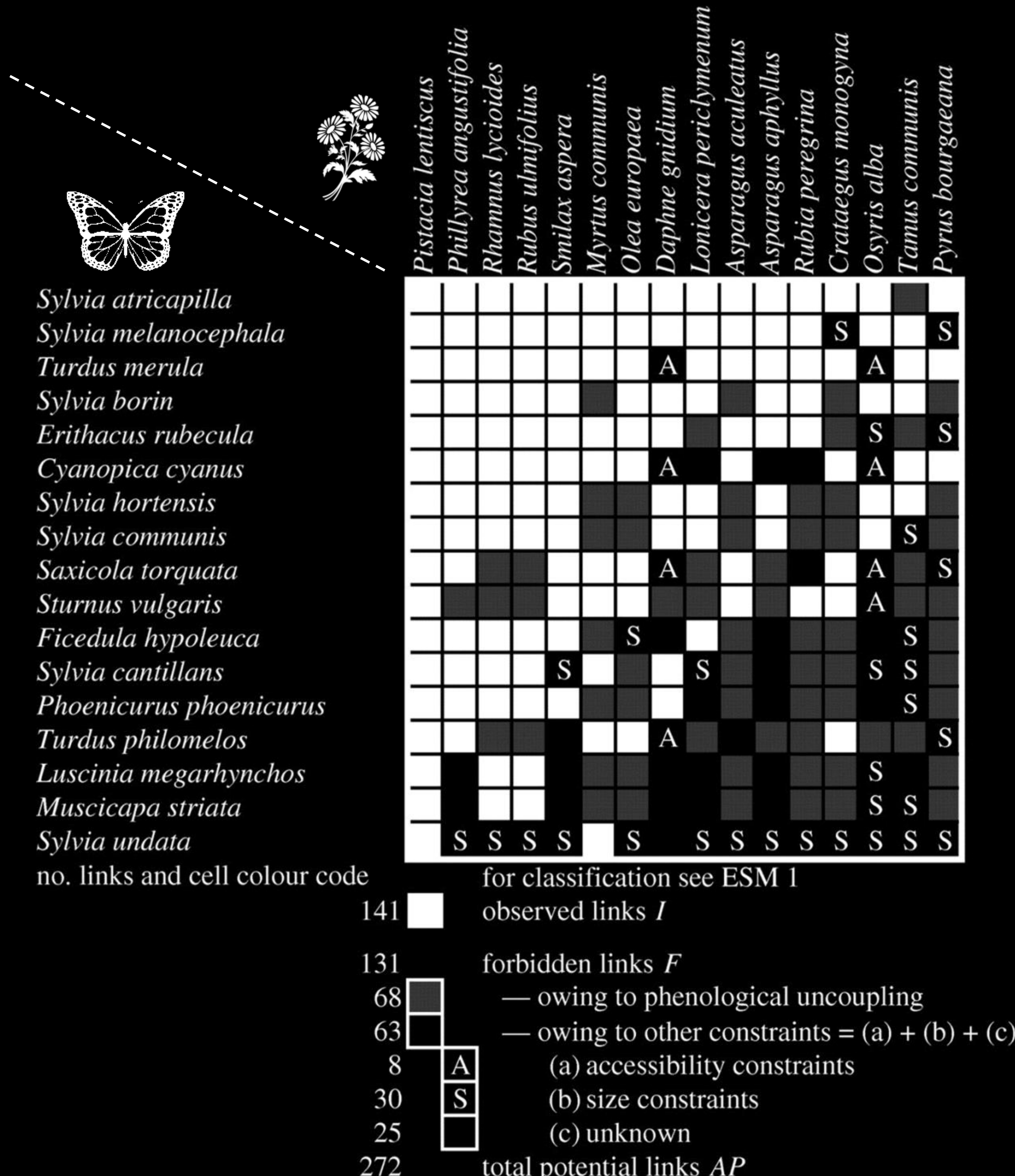
“I have deeply regretted that I did not proceed far enough at least to understand something of the leading principles of mathematics, for men thus endowed seem to have an extra sense.”

(The autobiography of Darwin, p. 13)



Mutualistic Networks



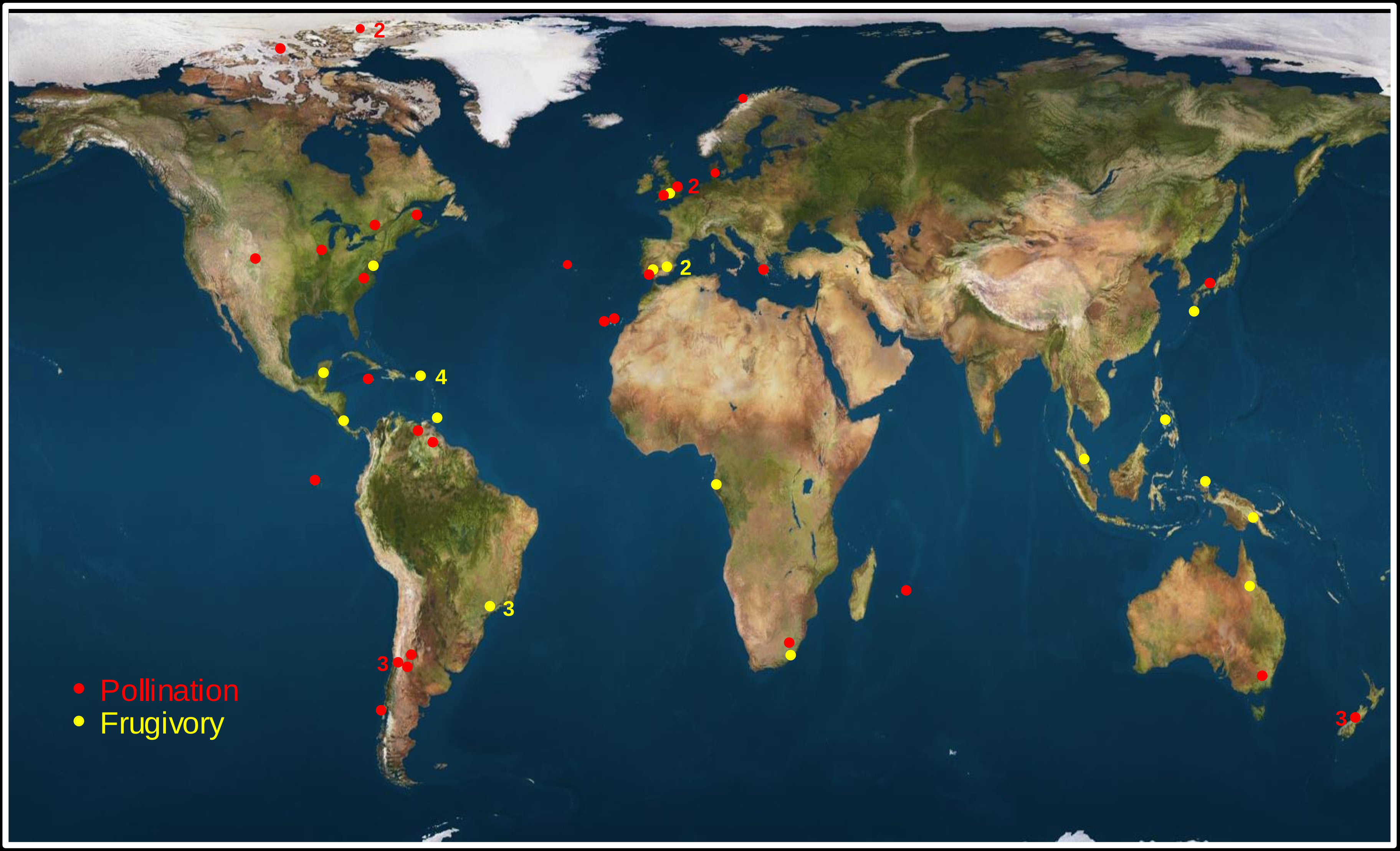


Olesen, et al (2010). *Proc Roy Soc B*

No mathematician left behind

$$A = \begin{pmatrix} 0 & B \\ B' & 0 \end{pmatrix}$$


2
2
2
4
3
3
3
Pollination
Frugivory

Outline

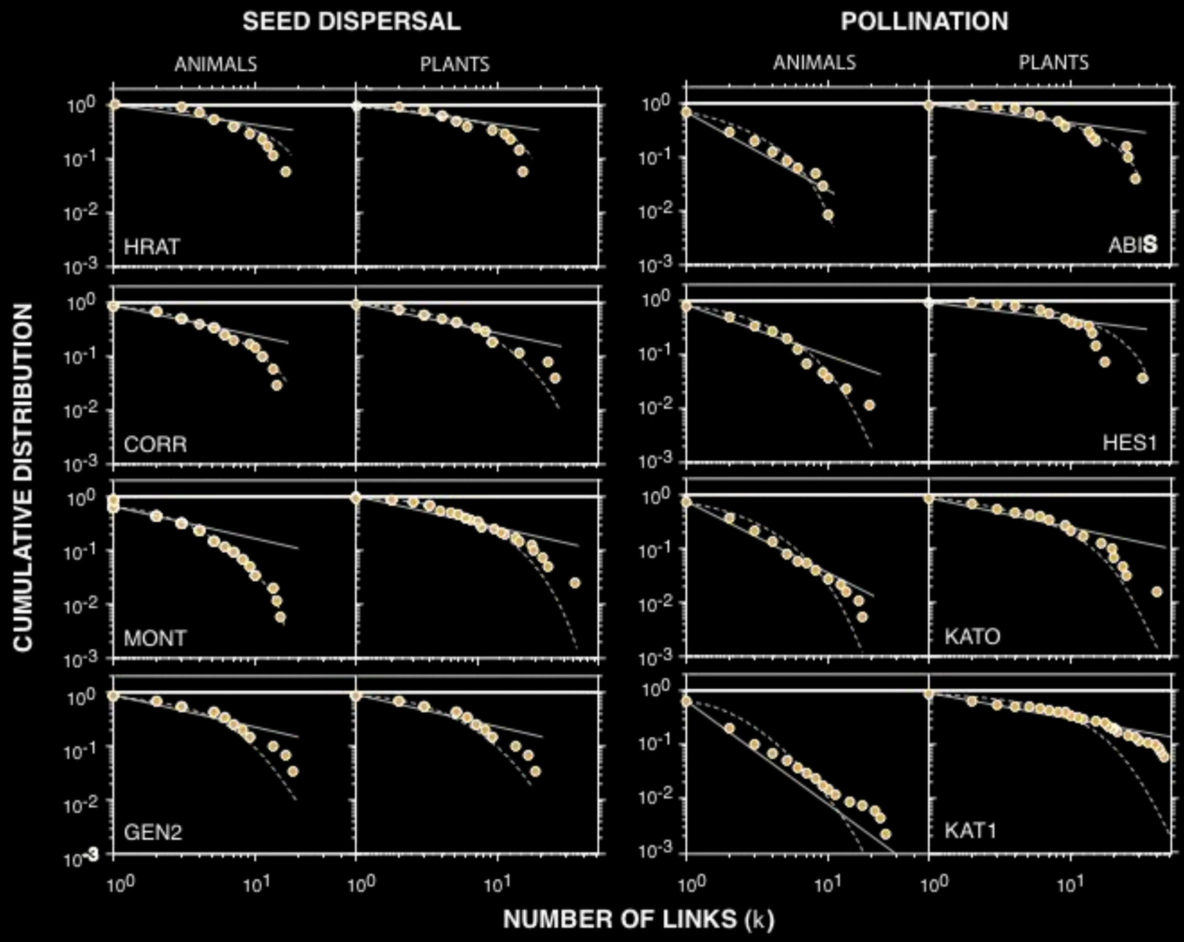
1. Describe network architecture.

2. Consequences for (i) network robustness to species extinctions and (ii) species richness.

3. Contribution of species to overall network architecture and robustness.

Describe
Network Architecture

1. Connectivity Distribution



Jordano, Bascompte, and Olesen (2003). *Ecol. Lett.* 6: 69-81.

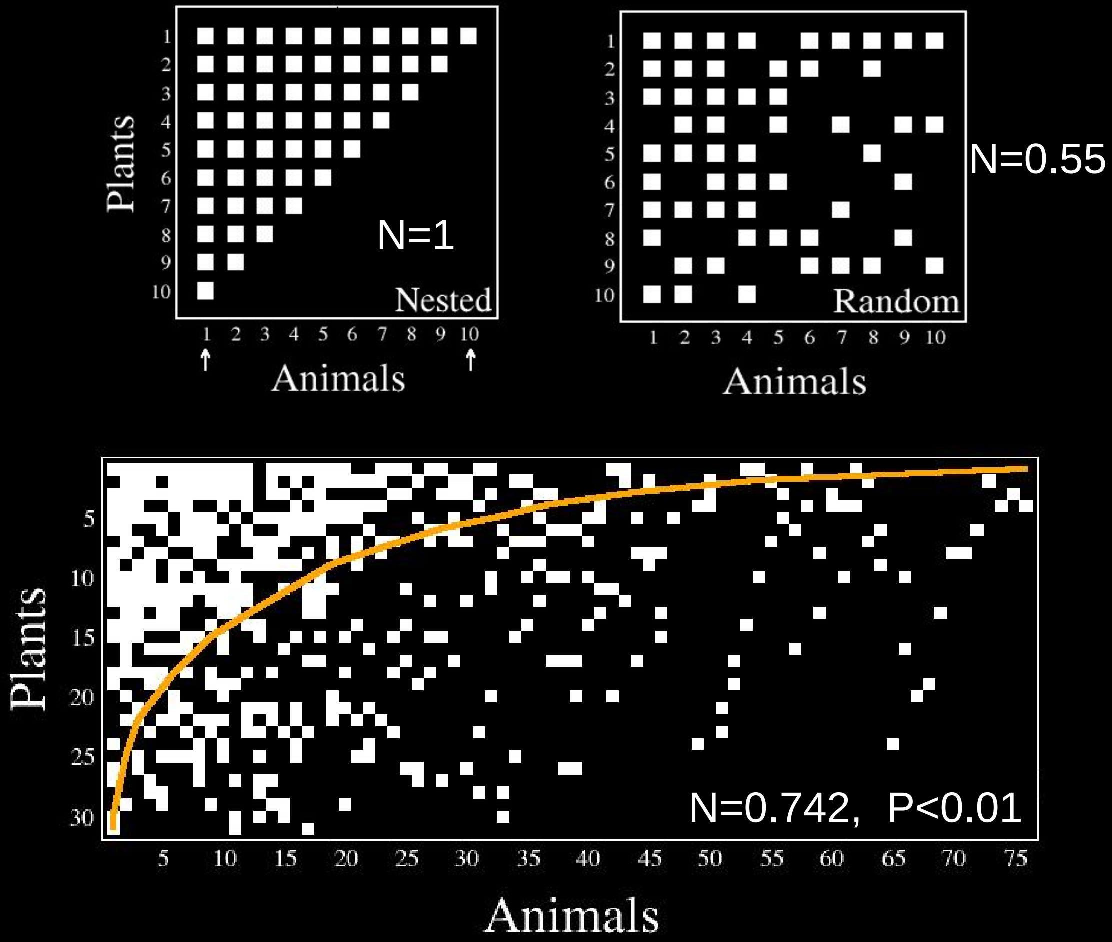
Is degree distribution everything that matters?

Is degree distribution everything that matters?

NO

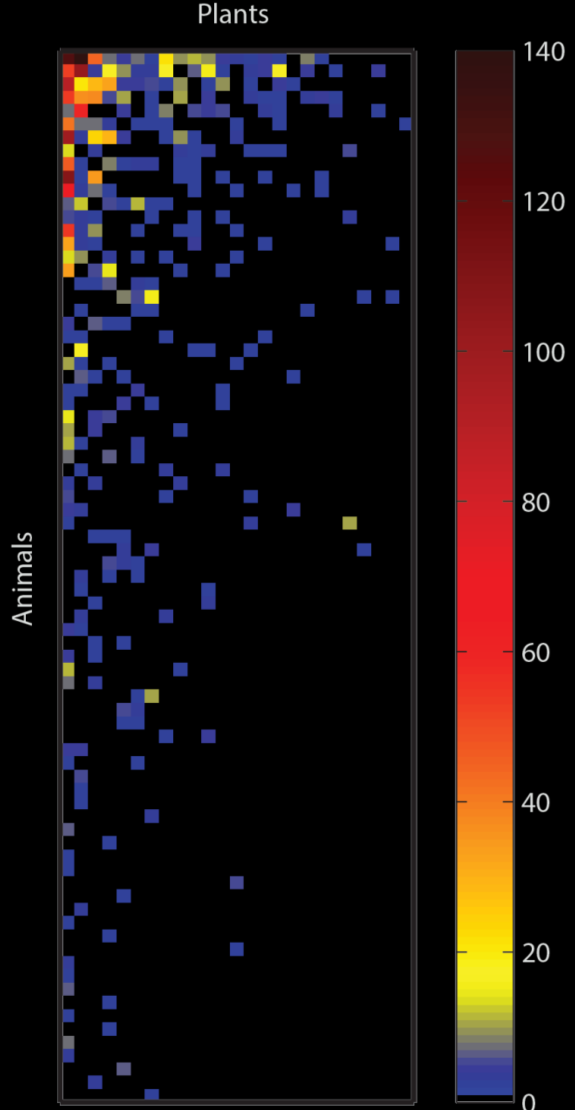
With the correct null model
we can go beyond
degree distribution

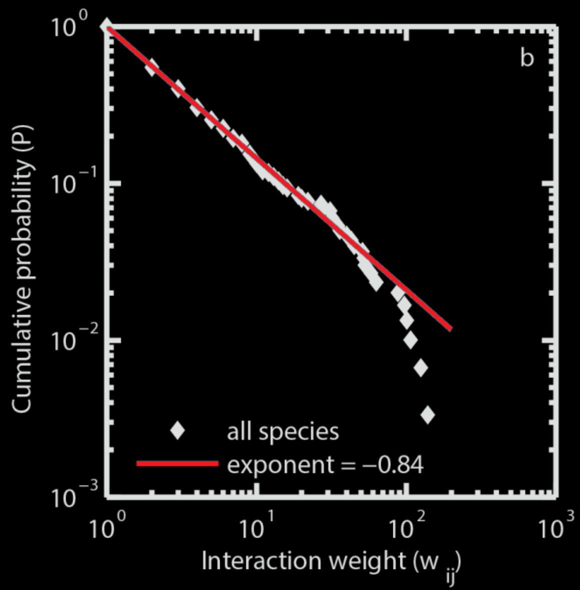
2. Mutualistic networks are Nested



Bascompte, Jordano, Melián, and Olesen (2003). *PNAS* 100: 9383-9387

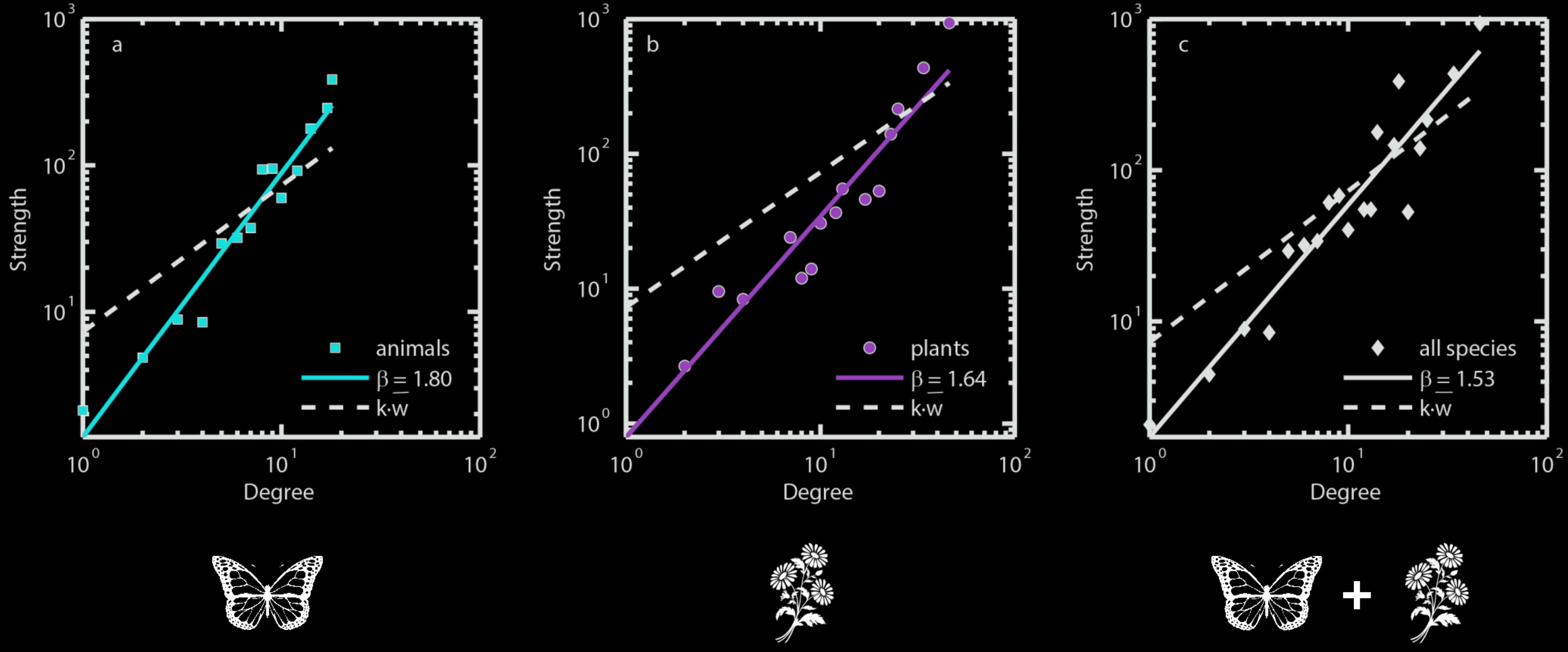
3. Interaction strength is not evenly distributed





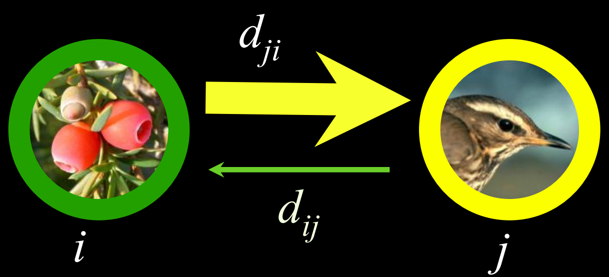
Gilarranz, Pastor, Galeano (2012). Oikos

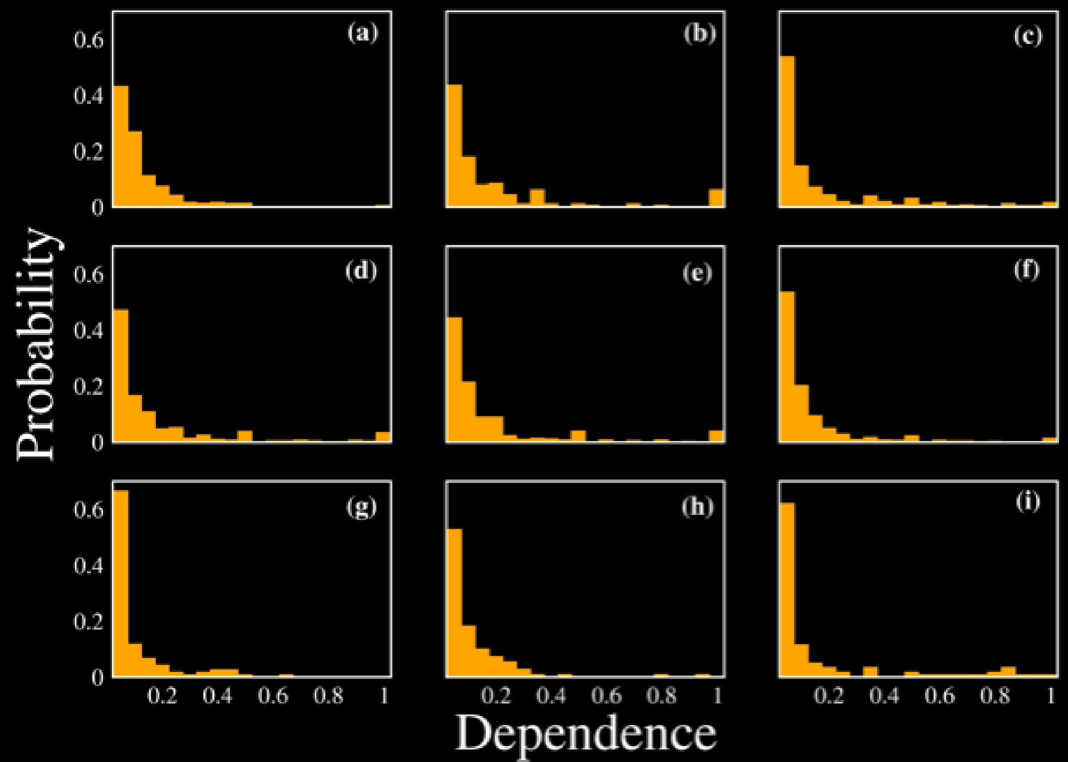
3. Interaction strength is not evenly distributed



Gilarranz, Pastor, Galeano (2012). Oikos

4. Mutualistic dependences are Asymmetric





Bascompte, Jordano, and Olesen (2006). *Science* 312: 431-433.

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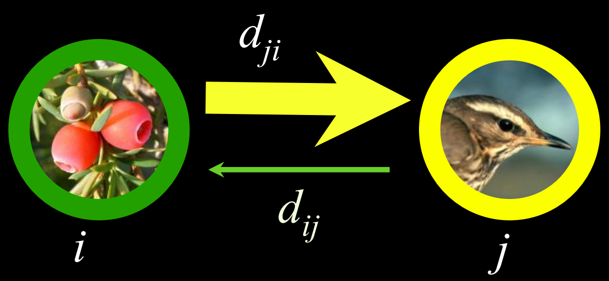
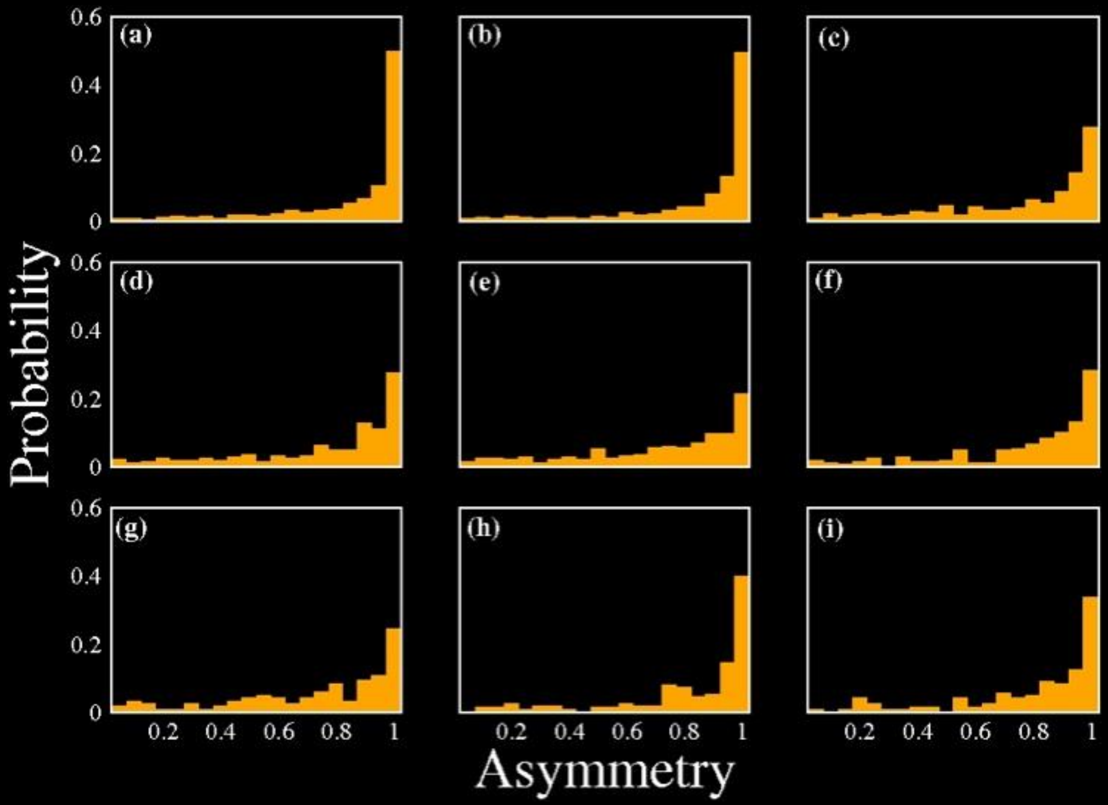
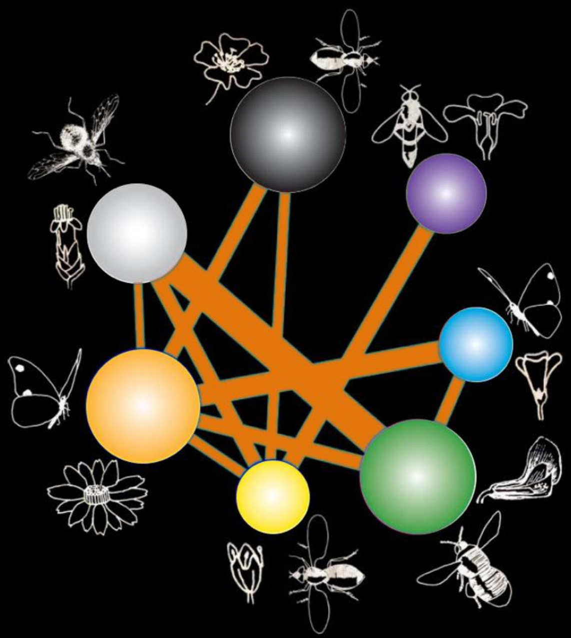


$$AS(i,j) = \frac{|d_{ij} - d_{ji}|}{max(d_{ij}, d_{ji})}$$



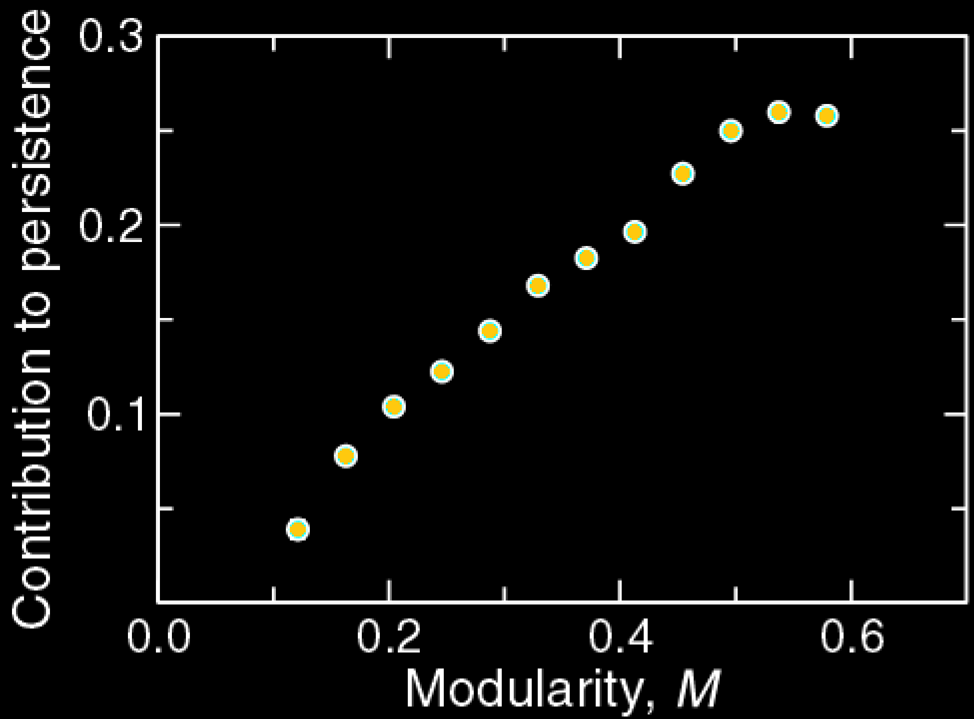
Bascompte, Jordano, and Olesen (2006). *Science* 312: 431-433.

5. Mutualistic networks are also Modular



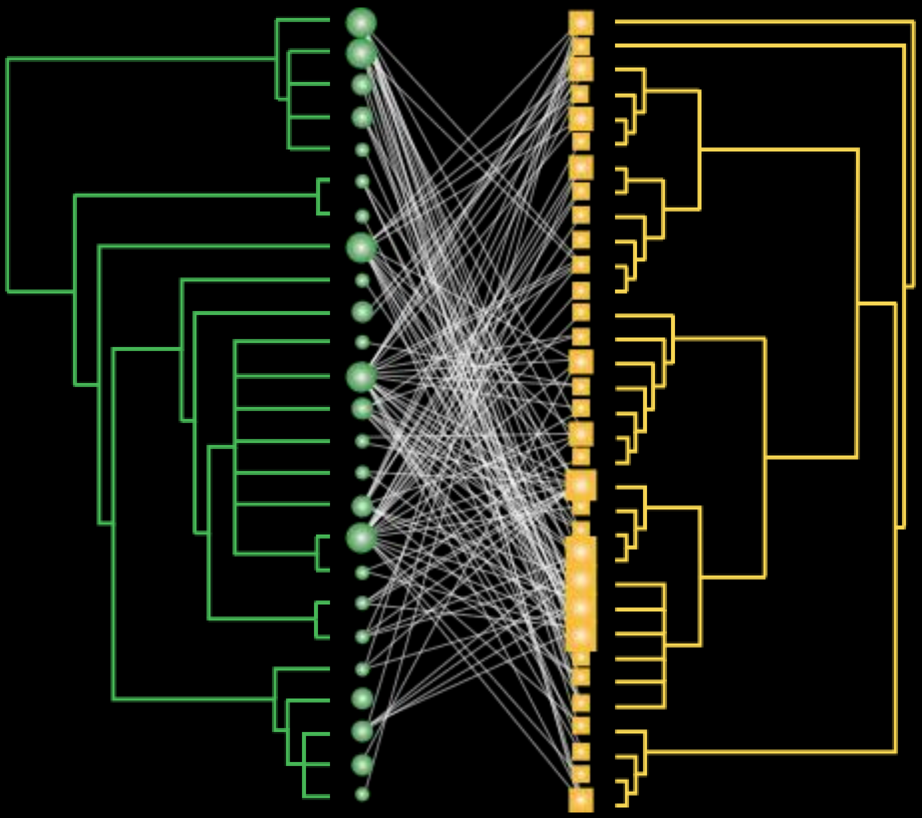
Olesen, Bascompte, Dupont, and Jordano (2007). *PNAS* 104: 19891-19896

5. Mutualistic networks are also Modular



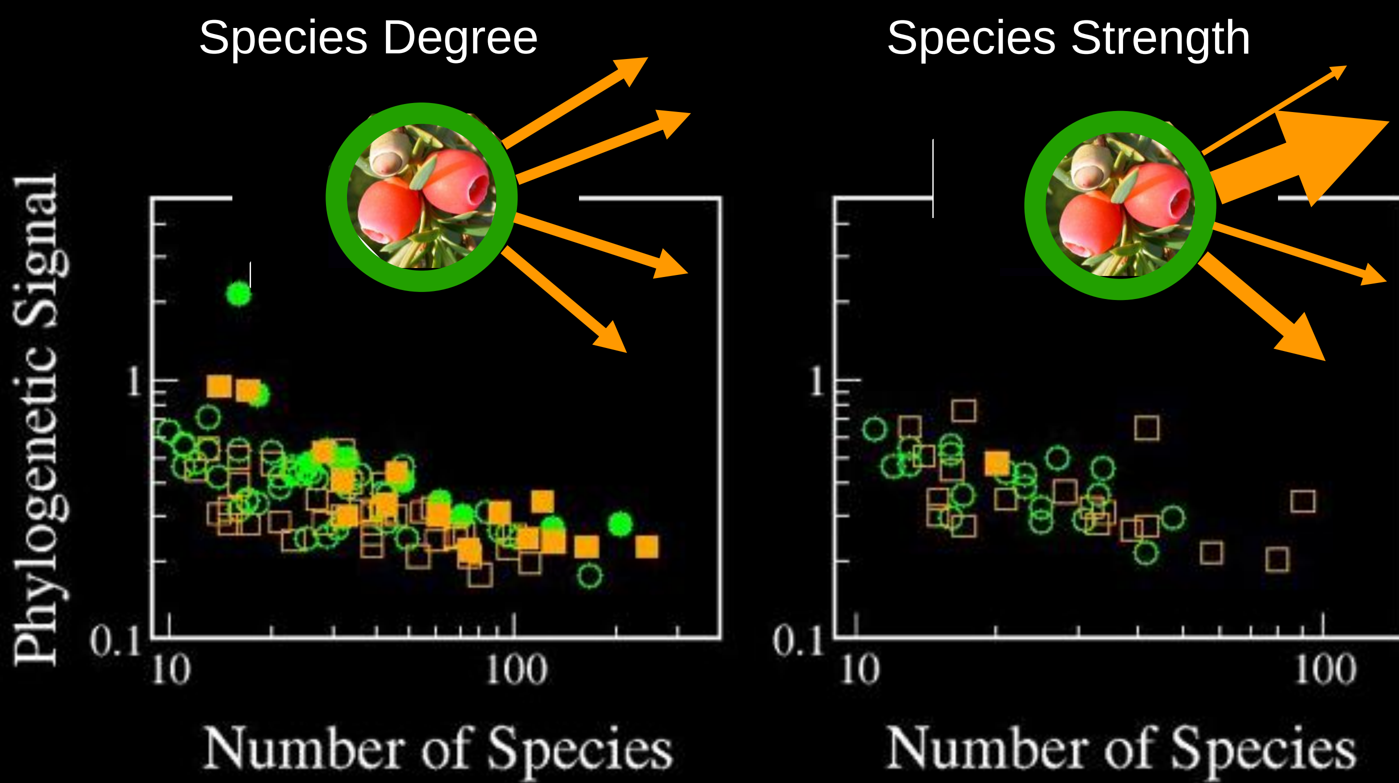
Stouffer, and Bascompte (2011). *PNAS,* 108(9), 3648–3652

6. Evolutionary History



Rezende, Lavabre, Guimaraes, Jordano, and Bascompte (2007). *Nature* 448: 925-928.

7. Phylogenetic Signal



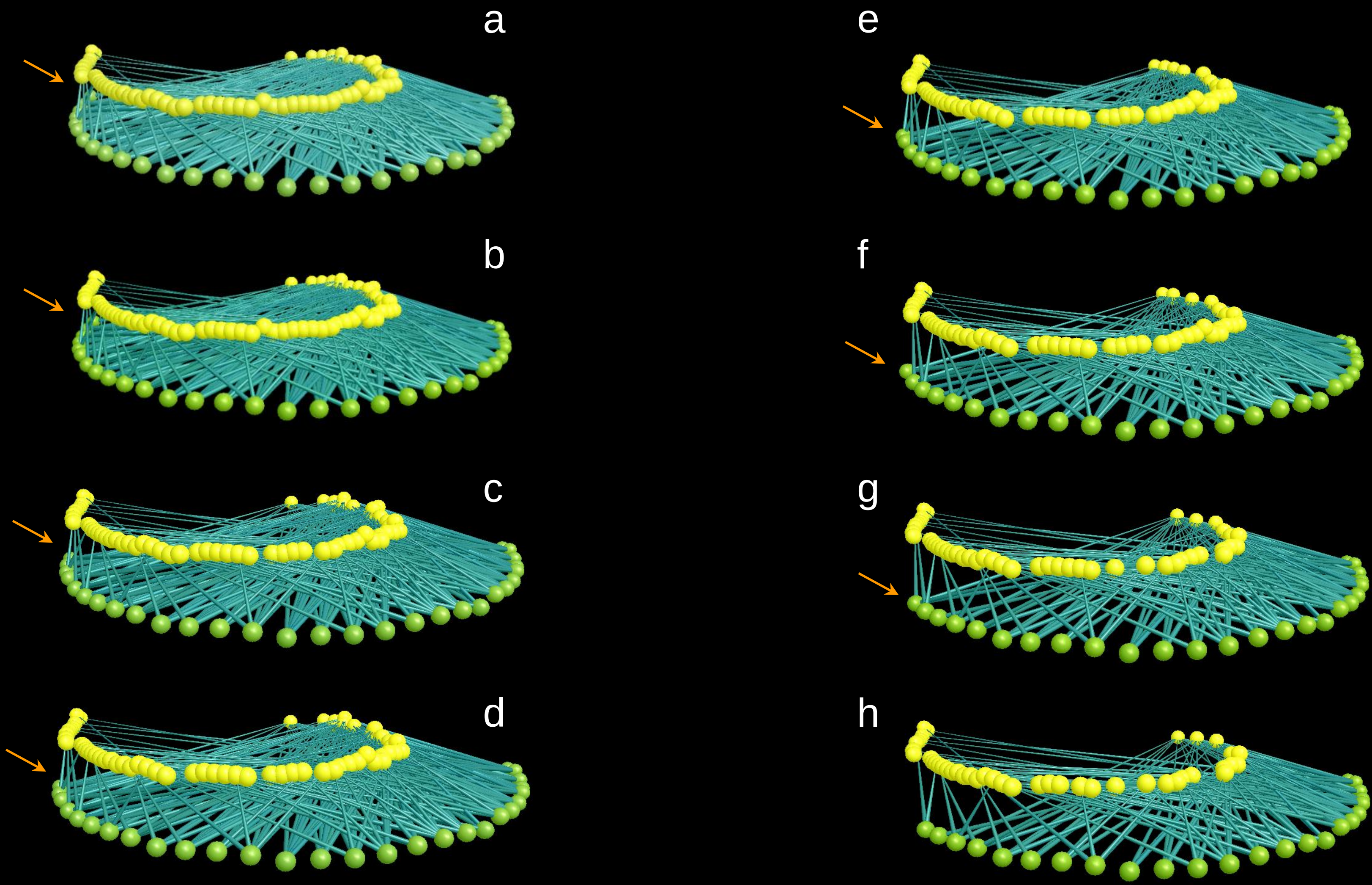
Rezende, Lavabre, Guimaraes, Jordano, and Bascompte (2007). *Nature* 448: 925-928.

Consequences for:

Network robustness to species extinctions.

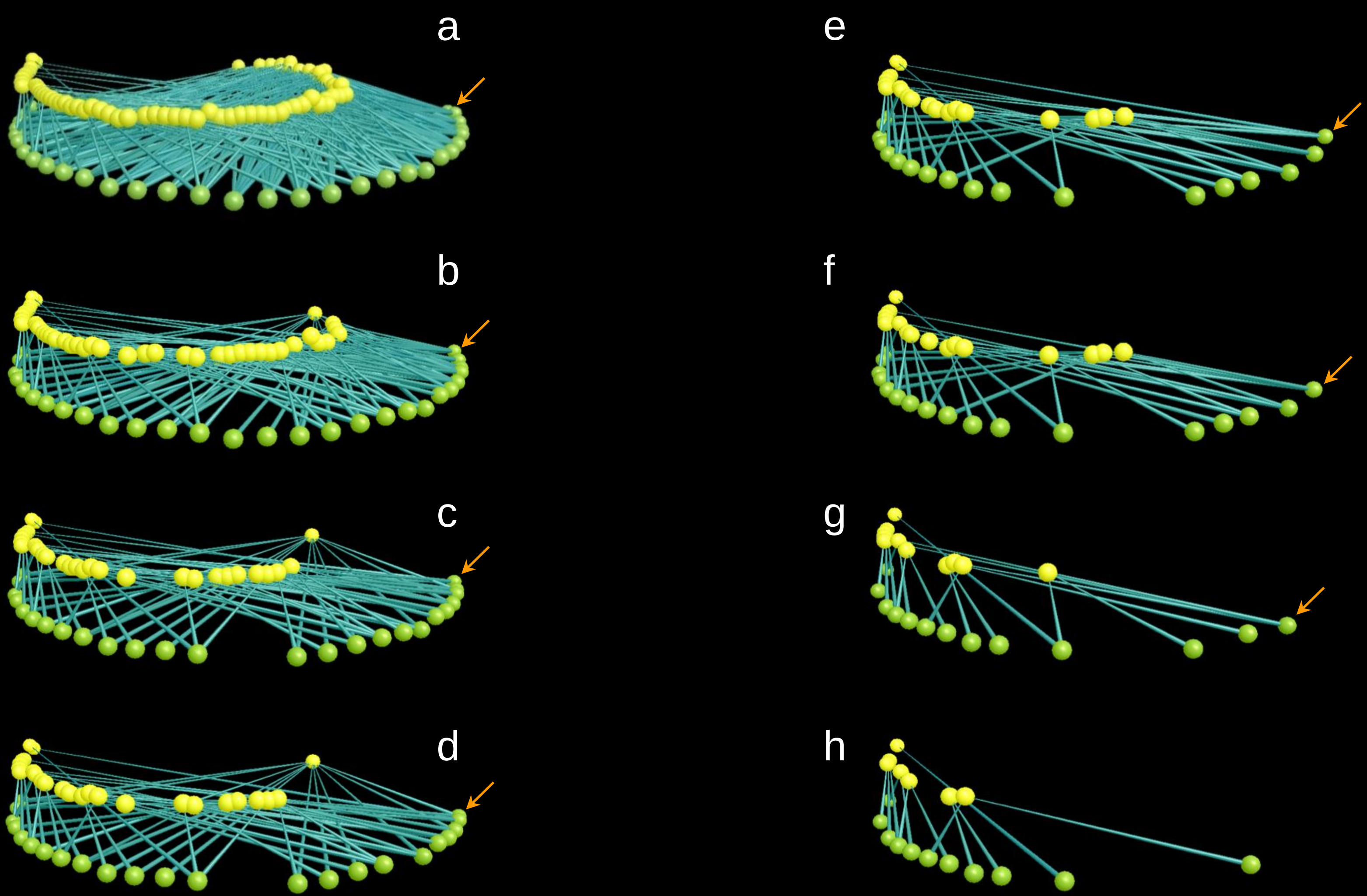
Species richness.

1. Degree distribution and Network Robustness



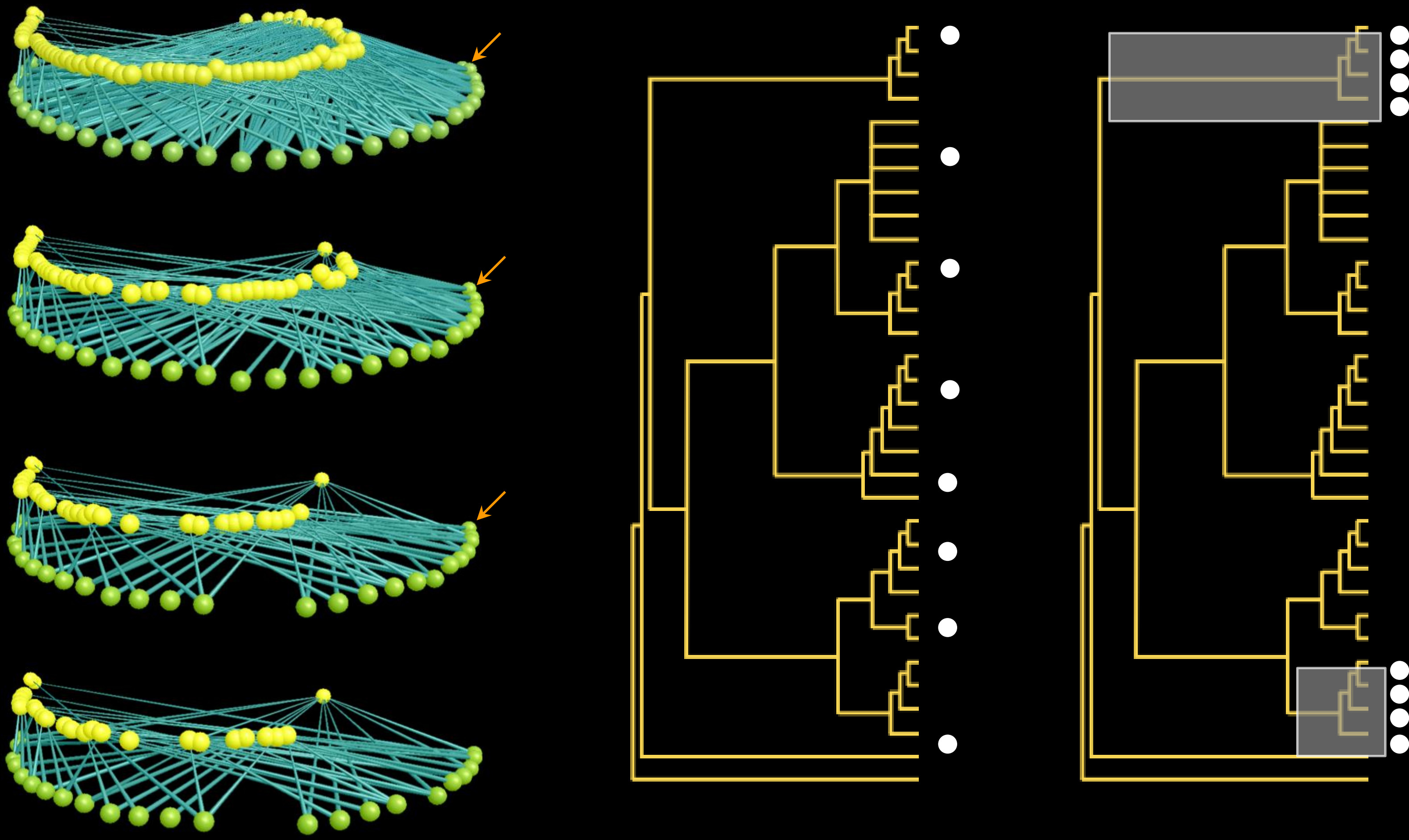
Memmott, Waser, and Price (2004). *Proc. R. Soc. Lond.* 271: 2605-2611

1. Degree distribution and Network Robustness



Memmott, Waser, and Price (2004). *Proc. R. Soc. Lond.* 271: 2605-2611

2. Phylogenetic Signal and Non-random coextinctions



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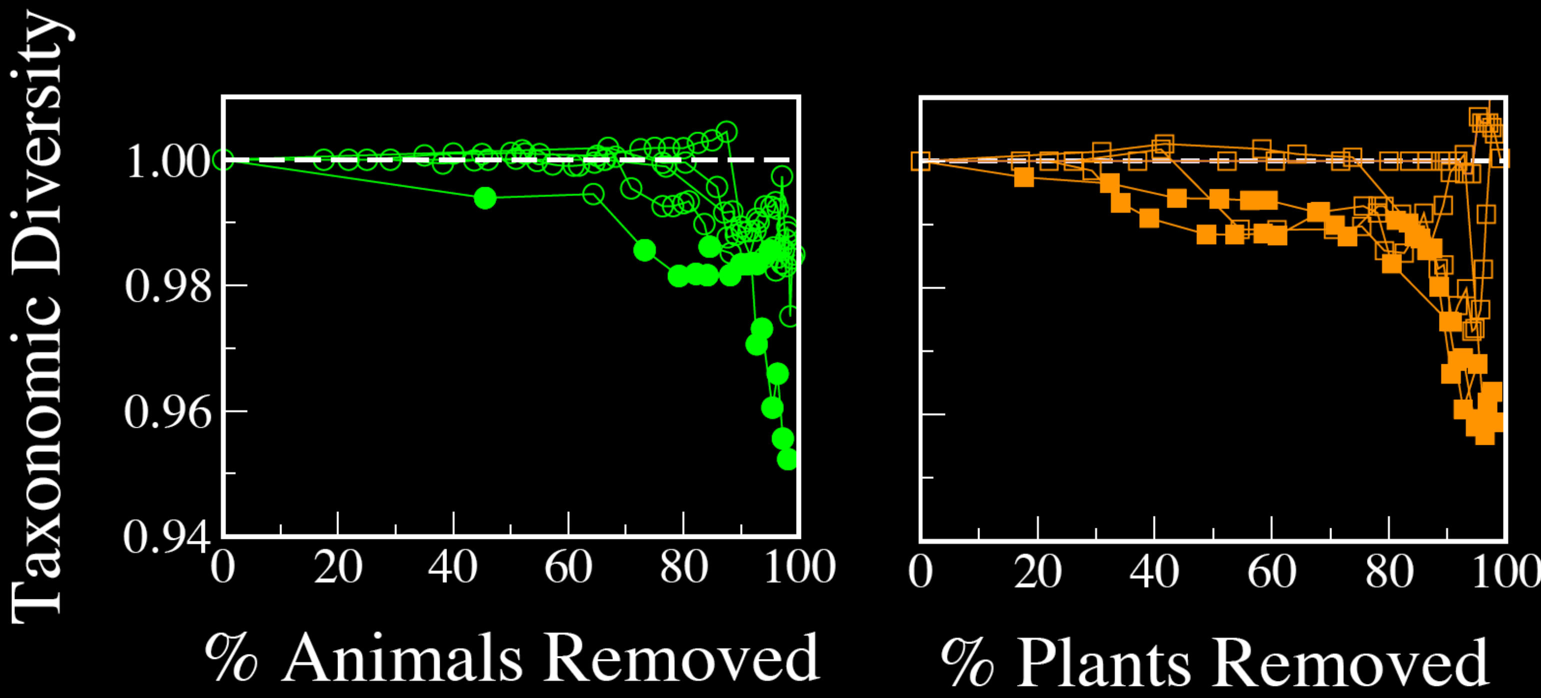


Rezende, Lavabre, Guimaraes, Jordano, and Bascompte (2007). *Nature* 448: 925-928.

Ok, this is very nice but is starting to be kind of boring, and I've spend the last two days wondering…

Why do we observe in nature these patterns?


d
dt

Pollinator Abundance

Interspecific Competition

Intrinsic Growth Rate

Mutualistic Strength

$$\begin{cases} \dfrac{dP_i}{dt} = P_i\left(\alpha_i^{(P)} - \sum_j \beta_{ij}^{(P)} P_j + \dfrac{\sum_j \gamma_{ij}^{(P)} A_j}{1+h\sum_j \gamma_{ij}^{(P)} A_j}\right) \\ \dfrac{dA_i}{dt} = A_i\left(\alpha_i^{(A)} - \sum_j \beta_{ij}^{(A)} A_j + \dfrac{\sum_j \gamma_{ij}^{(A)} P_j}{1+h\sum_j \gamma_{ij}^{(A)} P_j}\right) \end{cases}$$

Plant Abundance

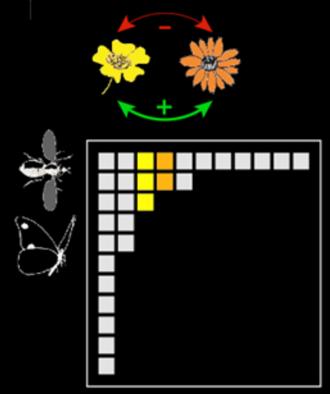
Bastolla, Fortuna, Pascual-García, Ferrera, Luque and Bascompte (2009). *Nature* 458: 1018-1020

3. Network Size, i.e. Biodiversity

effective competition

Number of shared interactions between *i* and *j*

$$c_{ij}^{(P)} = \delta_{ij} + \frac{1}{\overline{S}^{(P)}} + R\left(\frac{1}{S^{(A)} + \overline{S}^{(A)}}\; \underbrace{n_i^{(P)} n_j^{(P)} - n_{ij}^{(P)}}\right)$$



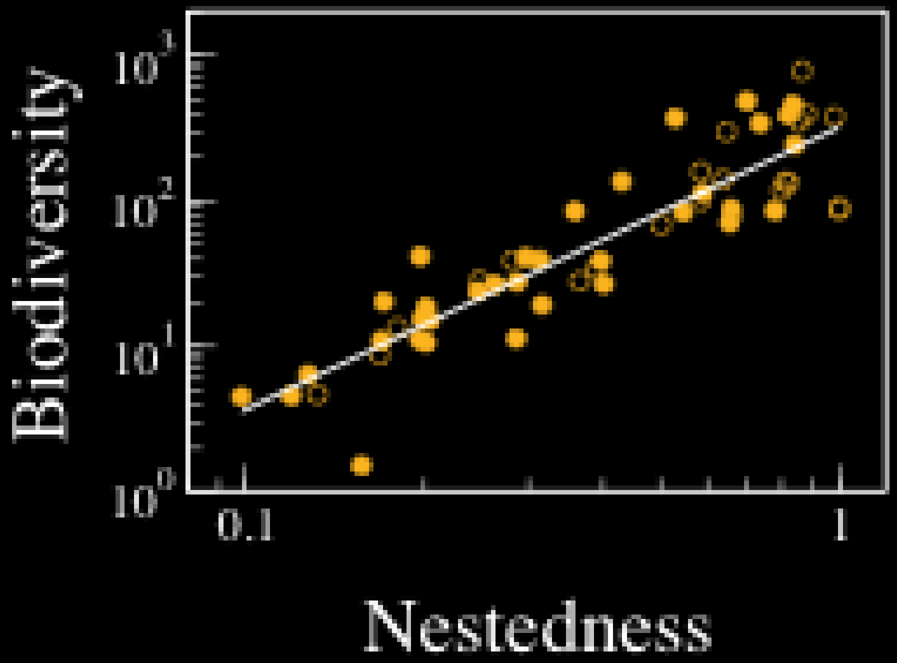
$$\rho^{(P)} = f(\lambda_1)$$

$$\overline{S}^{(P)} = \frac{1-\rho^{(P)}}{\rho^{(P)}}$$

The higher nestedness, the lower the effective interspecific competition, and the higher the maximum biodiversity

Bastolla, Fortuna, Pascual-García, Ferrera, Luque and Bascompte (2009). *Nature* 458: 1018-1020

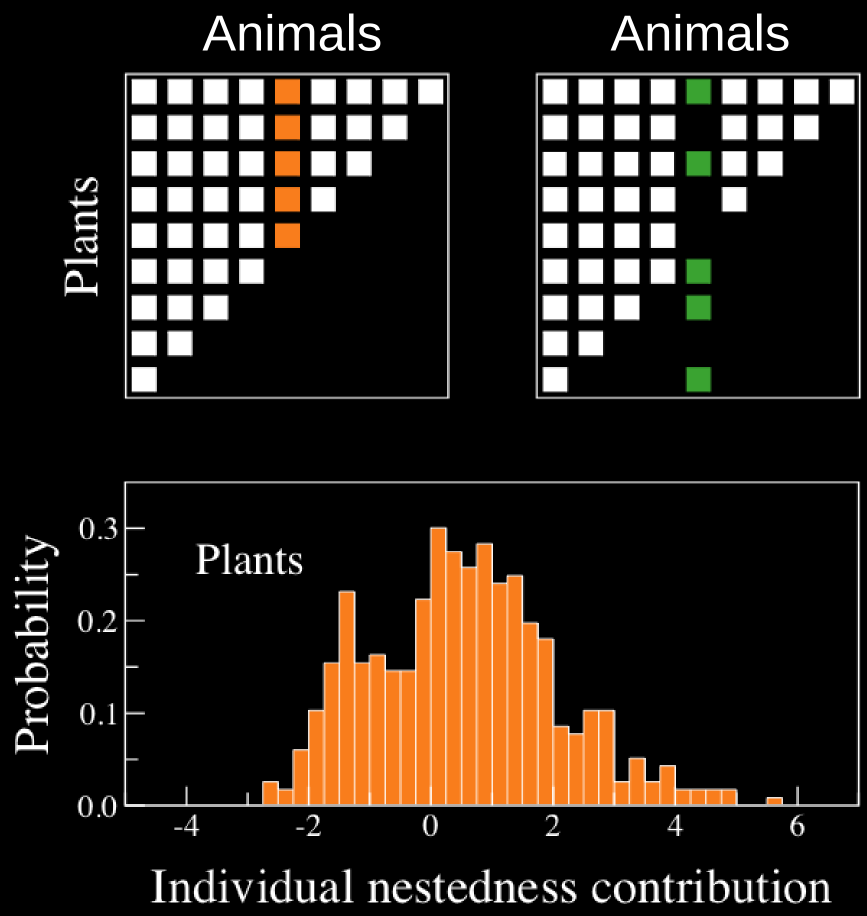
3. Network Size, i.e. Biodiversity



Bastolla, Fortuna, Pascual-García, Ferrera, Luque and Bascompte (2009). *Nature* 458: 1018-1020

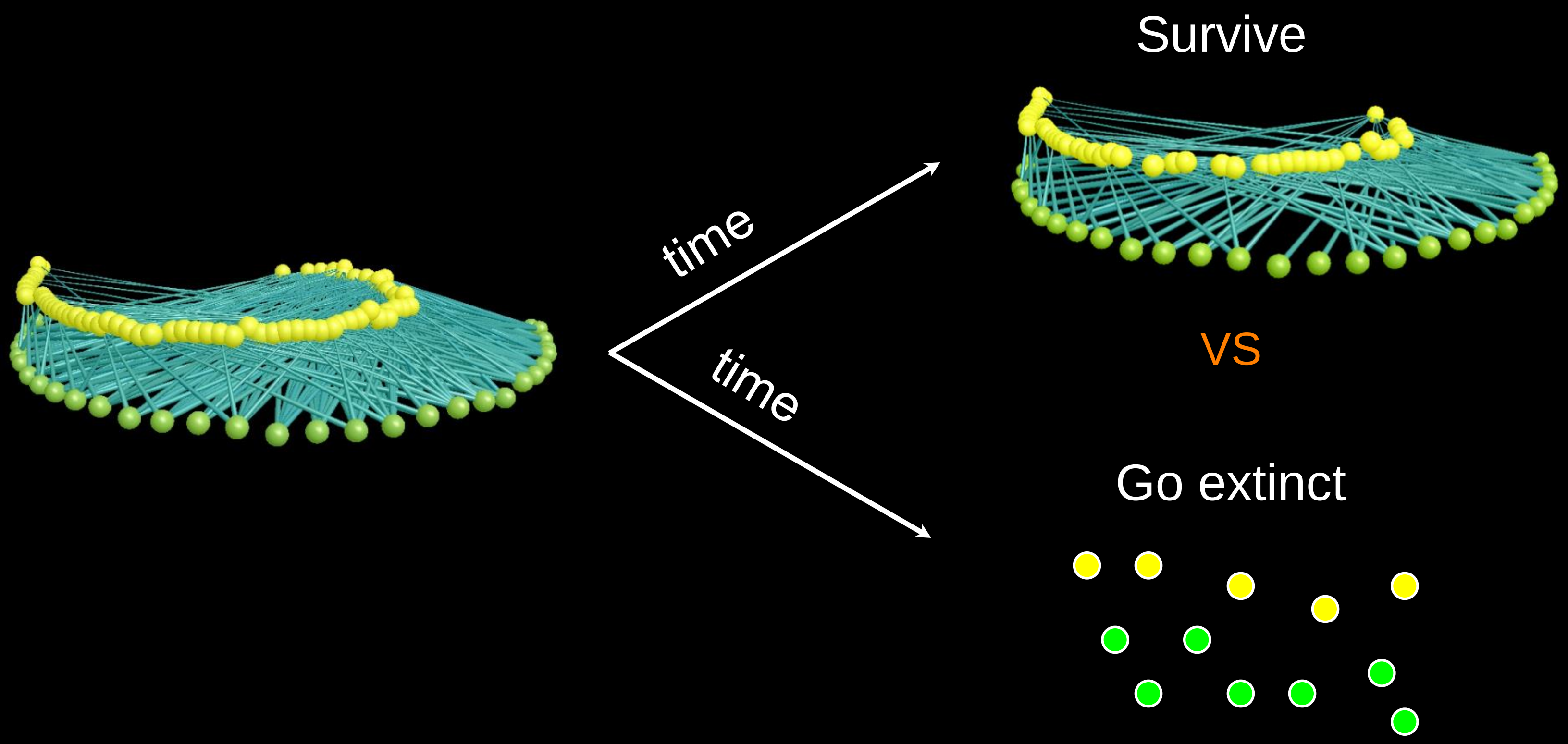
Contribution of species to overall network architecture and robustness

1. Species Contribution

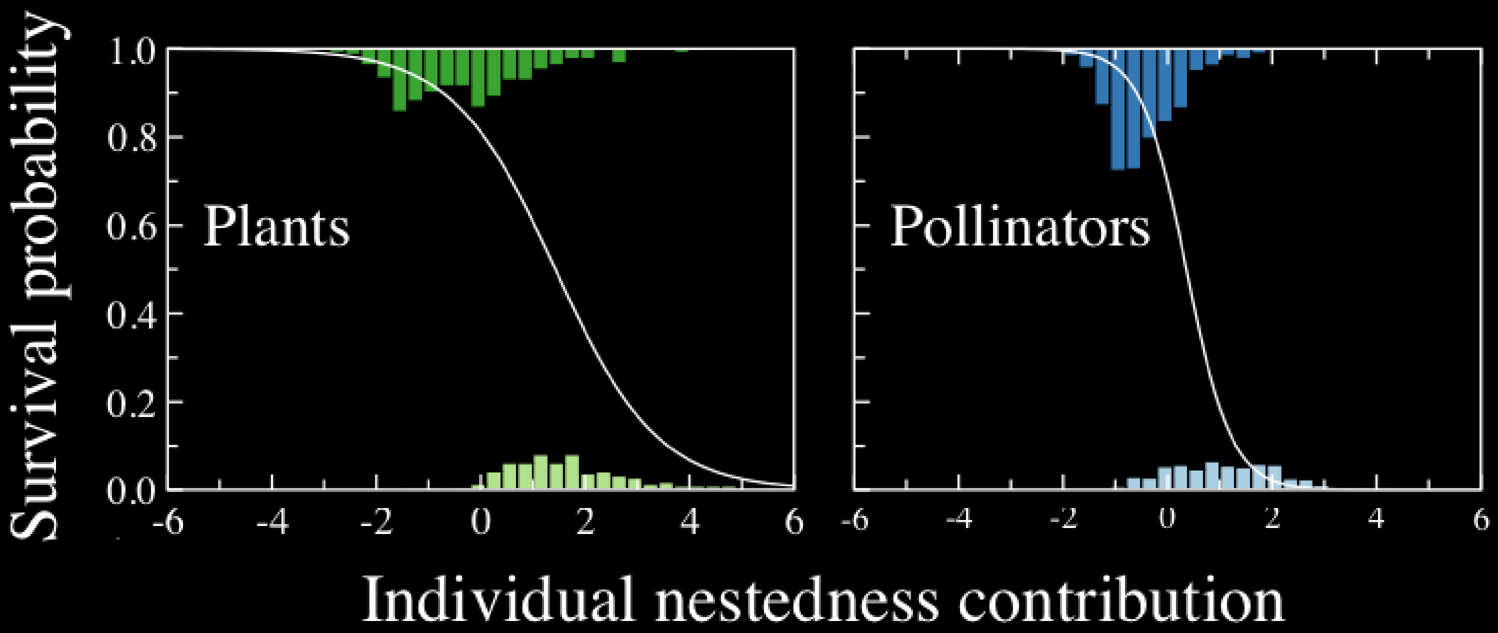


Saavedra, Stouffer, Uzzi, and Bascompte (2011). *Nature* 478: 233-235.

2. Species Survival



3. Trade-offs in Persistence



Saavedra, Stouffer, Uzzi, and Bascompte (2011). *Nature* 478: 233-235.

doi:10.1038/nature07532 nature

LETTERS

A simple model of bipartite cooperation for ecological and organizational networks

Serguei Saavedra[1,2,3], Felix Reed-Tsochas[2,4] & Brian Uzzi[5,6]

Vol 451|21 February 2008 nature

NEWS & VIEWS

COMPLEX SYSTEMS

Ecology for bankers

Robert M. May, Simon A. Levin and George Sugihara

PERSPECTIVE

doi:10.1038/nature09659

Systemic risk in banking ecosystems

Andrew G. Haldane[1] & Robert M. May[2]

In the run-up to the recent financial crisis, an increasingly elaborate set of financial instruments emerged, intended to optimize returns to individual institutions with seemingly minimal risk. Essentially no attention was given to their possible effects on the stability of the system as a whole. Drawing analogies with the dynamics of ecological food webs and with networks within which infectious diseases spread, we explore the interplay between complexity and stability in deliberately simplified models of financial networks. We suggest some policy lessons that can be drawn from such models, with the explicit aim of minimizing systemic risk.

In the 1960s, the notion of the 'balance of nature' played a significant part as ecologists sought a conceptual foundation for their subject. In particular, Evelyn Hutchinson[1], following Elton[2], suggested that "oscillations observed in arctic and boreal fauna may be due in part to the communities not being sufficiently complex to damp out oscillations". He went on to state, based on a misunderstanding of MacArthur's[3] paper, that there was now a "formal proof of the increase in stability of a community as the number of links in its food web increases".

To the direct contrary, however, a closer examination of model ecosystems showed that a random assembly of N species, each of which had feedback mechanisms that would ensure the population's stability were it alone, showed a sharp transition from overall stability to instability as the number and strength of interactions among species increased. More explicitly, for $N \gg 1$ this transition occurs once $m\alpha^2 > 1$, where m is the average number of links per species, and $(\pm)\ \alpha$ their average strength[4].

In ecology this has, since the 1970s, prompted a search for special food-web structures that may help reconcile complexity with persistence or stability[5–8]. Along these lines there is, for example, tentative evidence for modularity[9] (particularly in plant–pollinator associations, where linkages tend to be overdispersed or disassociative), and more generally for nested hierarchies in food webs[10]. The fact that some features of the network structure of interactions (such as predator/prey ratios) inferred from the Burgess Shale communities are similar to those in present day ones[11] reinforces hopes that this is a meaningful area of research.

In the wake of the global financial crisis that began in 2007, there is increasing recognition of the need to address risk at the systemic level, as distinct from focusing on individual banks[12,13]. This quest to understand the network dynamics of what might be called 'financial ecosystems' has interesting parallels with ecology in the 1970s. Implicit in much economic thinking in general, and financial mathematics in particular, is the notion of a 'general equilibrium'. Elements of this belief underpin, for example, the pricing of complex derivatives. But, as shown below, deeper analysis of such systems reveals explicit analogies with the concept that too much complexity implies instability, which was found earlier in model ecosystems.

There are, of course, major differences between ecosystems and financial systems. For one thing, today's ecosystems are the winnowed survivors of long-lasting evolutionary processes, whereas the evolution of financial systems is a relatively recent phenomenon[14]. Nor have selective pressures been entirely dispassionate, with the hand of government a constant presence shaping financial structures, especially among institutions deemed "too big to fail"[15]. In financial ecosystems, evolutionary forces have often been survival of the fattest rather than the fittest.

In what follows, we first consider the role of the growth in intrafinancial system claims in generating bank failure and instability, focusing on the problems inherent in prevailing methods of pricing complex derivatives, or arbitrage pricing theory (APT). Second, we sketch various ways in which such an initial bank failure, or 'shock', may propagate to cause cascades of subsequent failure. Third, we outline some tentative policy lessons that might be drawn from these deliberately oversimplified models. Last, we ask how we might reshape the financial system to realize the economic benefits individual banks can deliver, while at the same time paying deliberate and explicit attention to their system-wide stability.

Potential causes of an initial shock

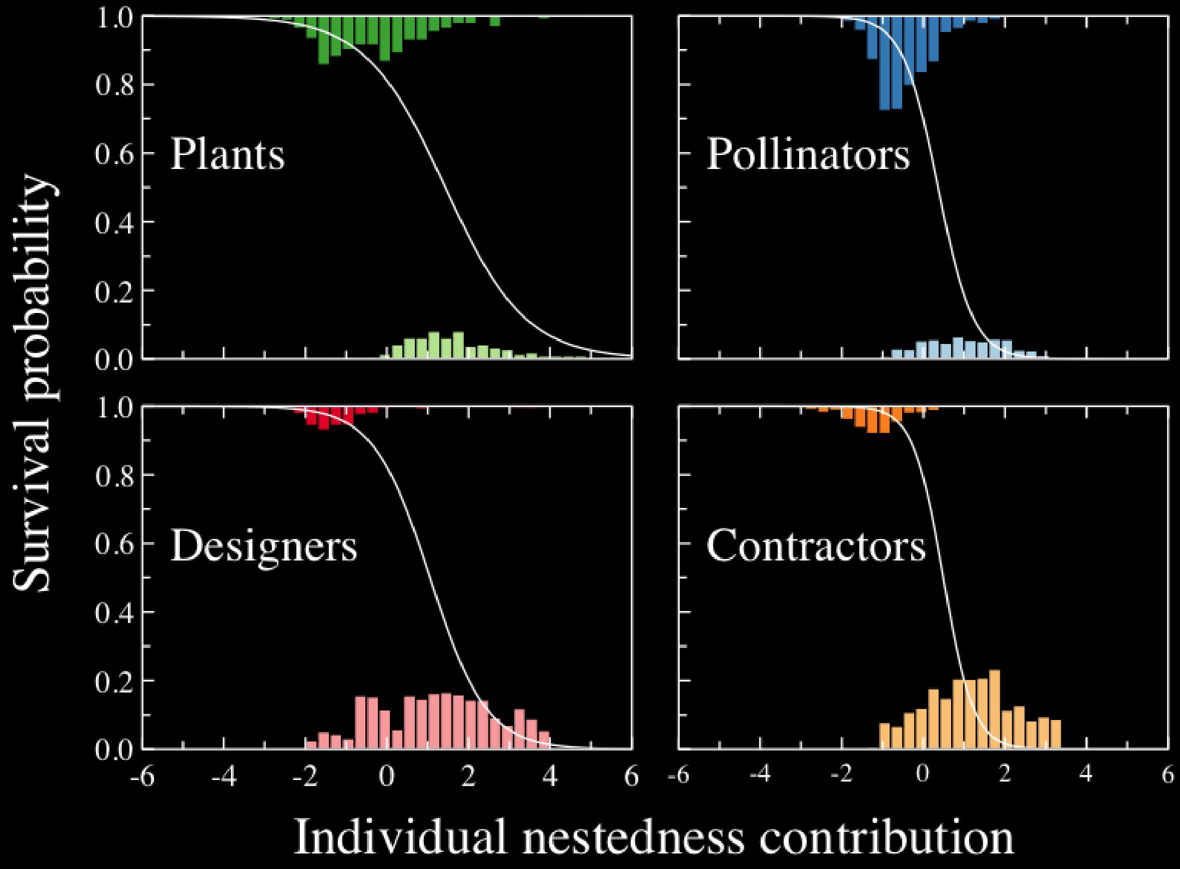
Events external to the banking system, such as recessions, major wars, civil unrest or environmental catastrophes, clearly have the potential to depress the value of a bank's assets so severely that the system fails. Although probably exacerbated by such events, including global imbalances (China as producer and saver, the United States as consumer and debtor), the present crisis seems more akin to self-harm caused by overexuberance within the financial sector itself. Perhaps as much as two-thirds of the spectacular growth in banks' balance sheet over recent decades reflected increasing claims within the financial system, rather than with non-financial agents. One key driver of this explosive intrasystem activity came from the growth in derivative markets.

In 2002, when Warren Buffet first expressed his view that "derivatives are financial weapons of mass destruction"[16], markets—although booming—seemed remarkably stable. Their subsequent growth, illustrated in Fig. 1, has been extraordinary, outpacing the growth in world gross domestic product (GDP) by a factor of three. In some derivatives markets, such as credit default swaps (CDS), growth has outpaced Moore's Law. These developments contributed significantly towards an unprecedented influx of mathematically skilled people (quantitative analysts) into the financial/banking industry. These people produced very sophisticated techniques (including APT), which seemingly allowed you to put a price on future risks, and thus to trade increasingly complex derivative contracts—bundles of assets—with risks apparently decreasing as the bundles grew.

However, recent empirical and theoretical studies have indicated that the trading activity associated with derivatives can have significant effects on markets[17–19]. More specifically, Brock and colleagues[20] have shown that proliferation of hedging instruments can destabilize markets. Building on this, Caccioli and colleagues[21] note that APT makes several conventional assumptions upon which everything else depends: "perfect competition, market liquidity, no-arbitrage and market completeness". Crucially, this adds up to the implicit assumption that trading activity has no feedback on the dynamical behaviour of markets. And indeed, in the APT-fuelled

[1]Bank of England, Threadneedle Street, London EC2R 8AH, UK. [2]Zoology Department, Oxford University, Oxford OX1 3PS, UK.

3. Trade-offs in Persistence



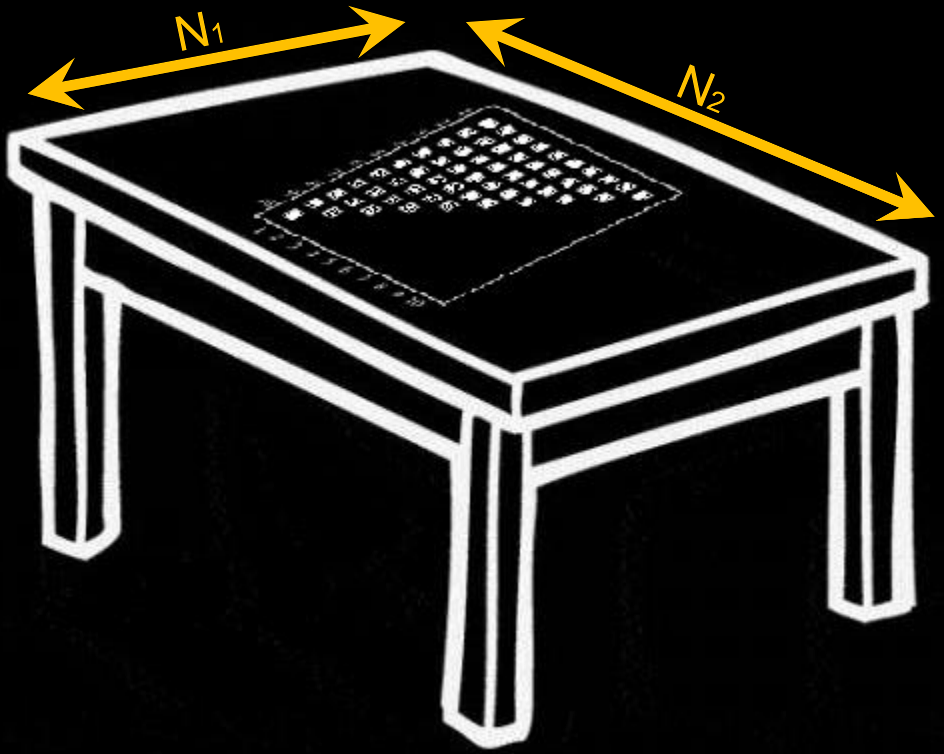
Saavedra, Stouffer, Uzzi, and Bascompte (2011). *Nature* 478: 233-235.

The species that contribute
the most to the nested pattern
are more likely going to go extinct!

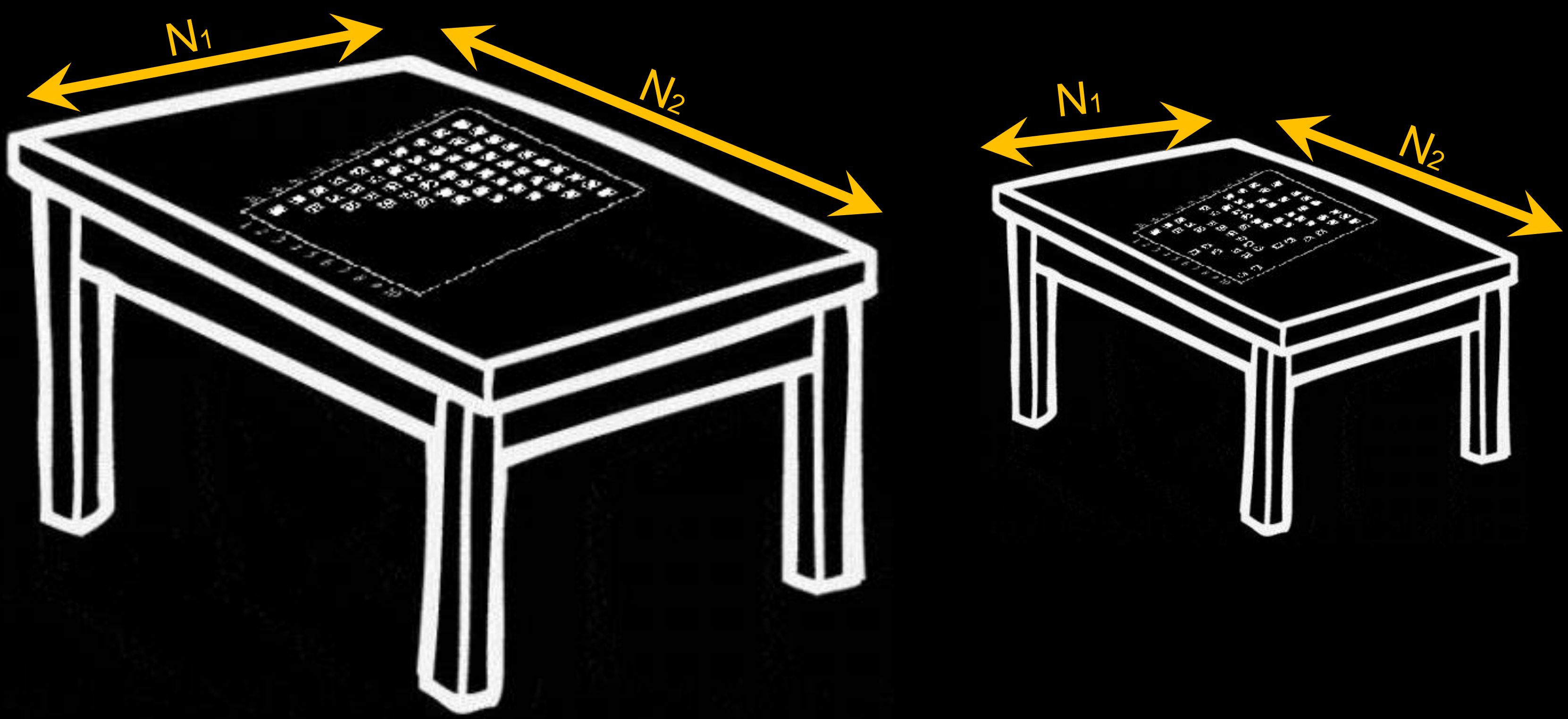
Bonus track 1

Structural Stability

1. Range of Feasibility

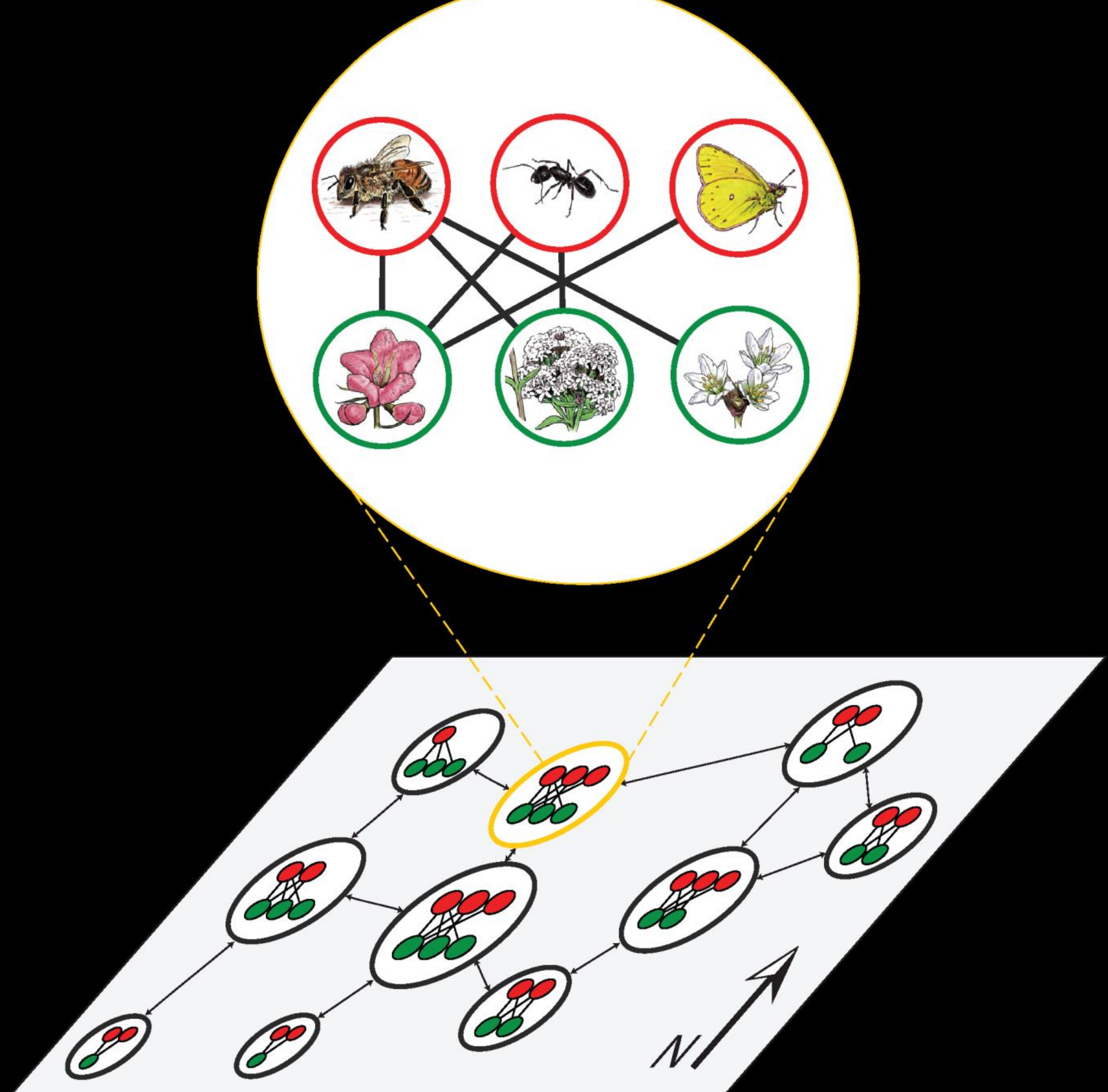


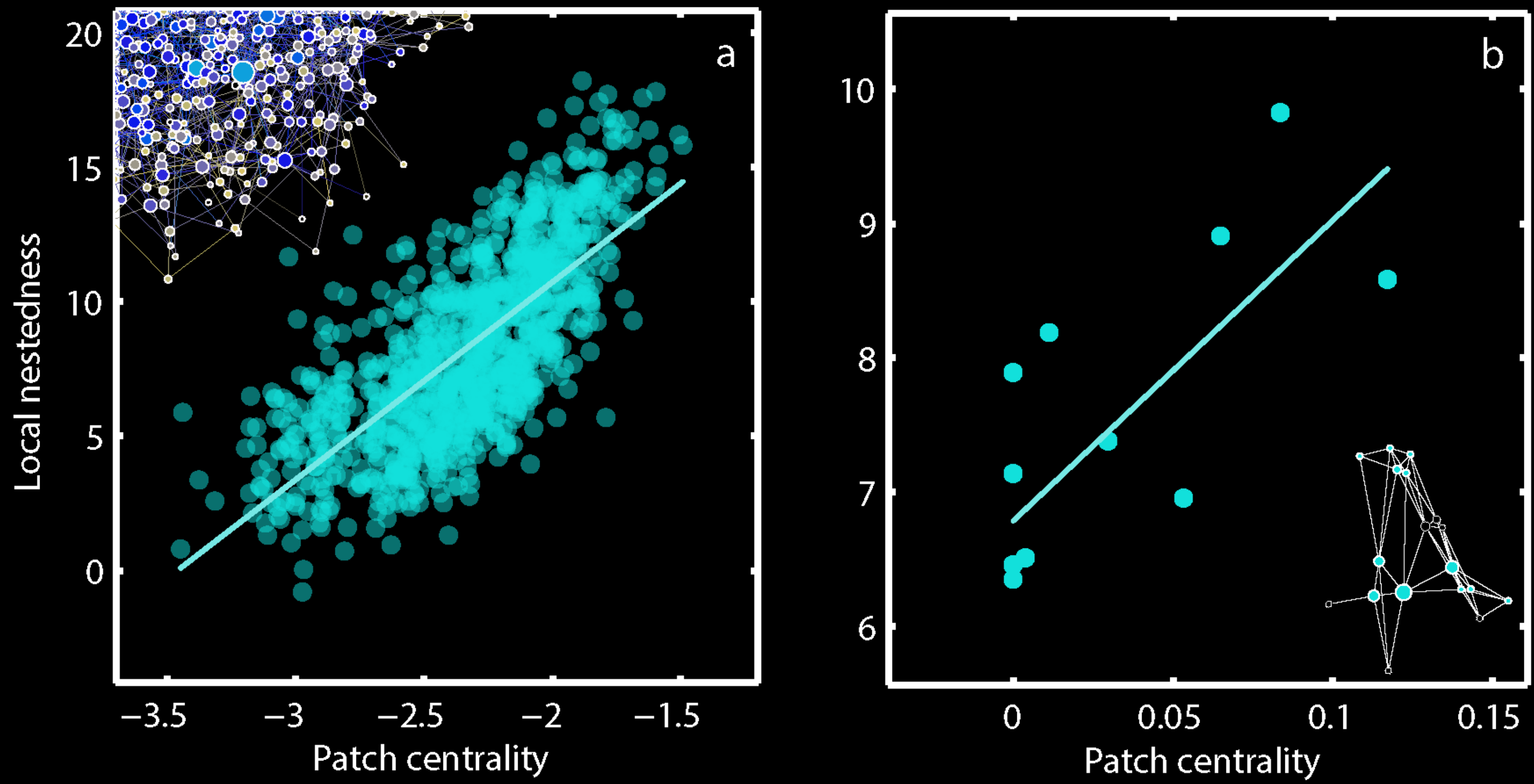
2. Nested networks can allocate more noise → will resist better changing conditions



Bonus track 2

Spatial Distribution


N



a
b
Local nestedness
Patch centrality
Patch centrality
20
15
10
5
0
−3.5
−3
−2.5
−2
−1.5
10
9
8
7
6
0
0.05
0.1
0.15