Singularité des interactions plantes-pollinisateurs

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Lille, 2012

A highly diversified mutualistic interaction

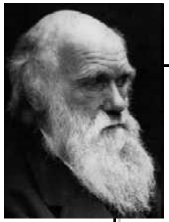
Involved in the reproduction of
~80% of angiosperms (~250 000 sp.)
~70% of crops

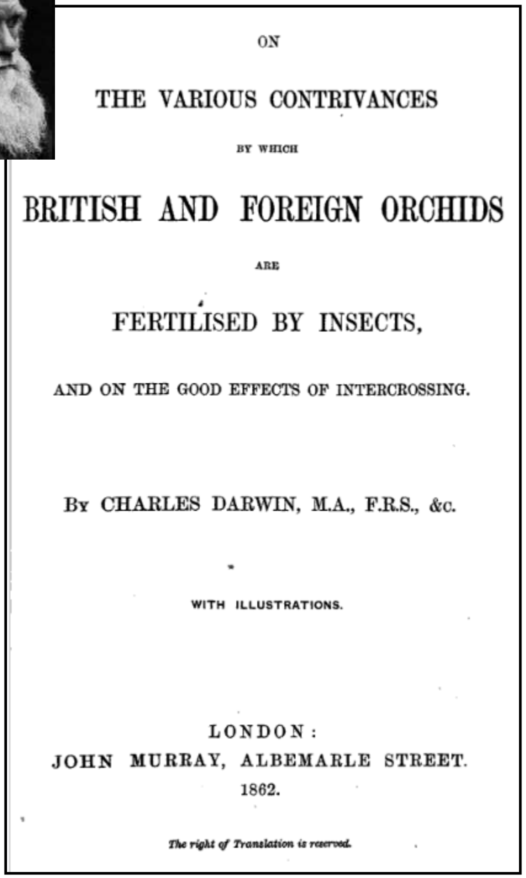
Most pollinators are insects
~43 000 sp. of Hymenoptera
~19 000 sp. of Lepidoptera
~14 000 sp. of Diptera
~210 000 sp. of Coleoptera

But also vertebrates
~900 sp. of birds
~300 sp. of mammals

Nabhan & Buchman 1997

An historical emphasis on specialization





ON

THE VARIOUS CONTRIVANCES

BY WHICH

BRITISH AND FOREIGN ORCHIDS

ARE

FERTILISED BY INSECTS,

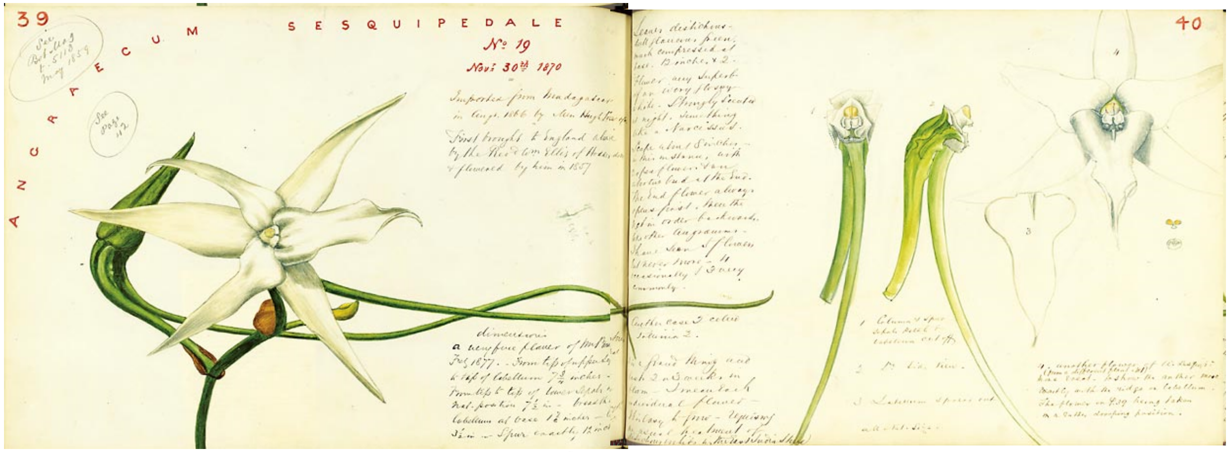
AND ON THE GOOD EFFECTS OF INTERCROSSING.

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

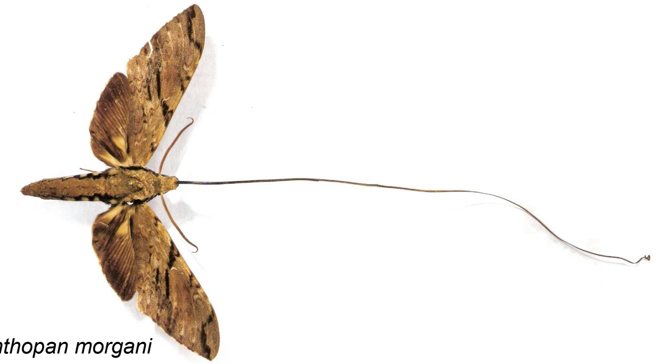
WITH ILLUSTRATIONS.

LONDON:
JOHN MURRAY, ALBEMARLE STREET.
1862.

The right of Translation is reserved.



Angraecum sesquipedale



Xanthopan morgani

Relations between flowers and insect pollinators are archetypes of the results of coevolutionary interactions . . . Constant pollination might allow a maximum number of plant species . . . since . . . each plant species might have an efficient pollinator in spite of relatively high species density.

Crepet 1983:29–30

The flowers of each species are adapted in shape, structure, color, and odor to the particular pollinating agents on which they depend . . . Evolving together, the plants and their pollinators become more finely tuned to each other's peculiarities . . .

Keeton and Gould 1993:476

Generalism and pollination

Ecology, 77(4), 1996, pp. 1043–1060

GENERALIZATION IN POLLINATION SYSTEMS, AND WHY IT MATTERS[1]

Nickolas M. Waser,[2,3] Lars Chittka,[4,5] Mary V. Price,[2,3]
Neal M. Williams,[4] and Jeff Ollerton[6]

Journal of Ecology 1996, **84**, 767–769

FORUM

Reconciling ecological processes with phylogenetic patterns: the apparent paradox of plant–pollinator systems

JEFF OLLERTON

TREE vol. 15, no. 4 April 2000

REVIEWS

Generalization versus specialization in plant pollination systems

Steven D. Johnson and Kim E. Steiner

Generalism and pollination

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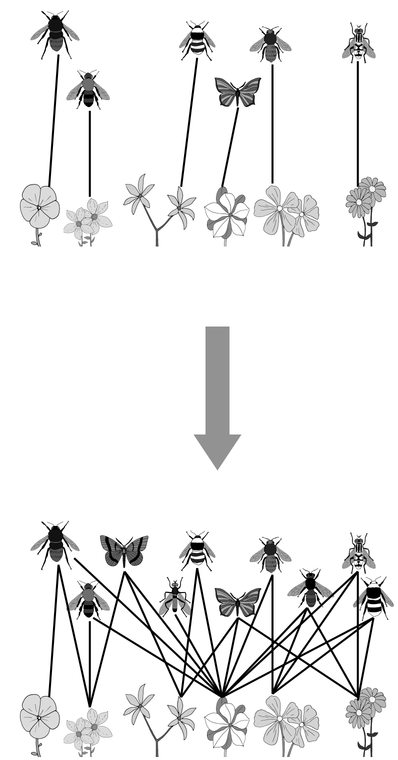
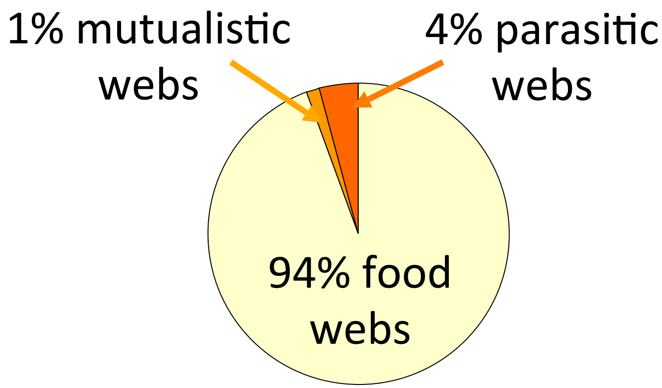
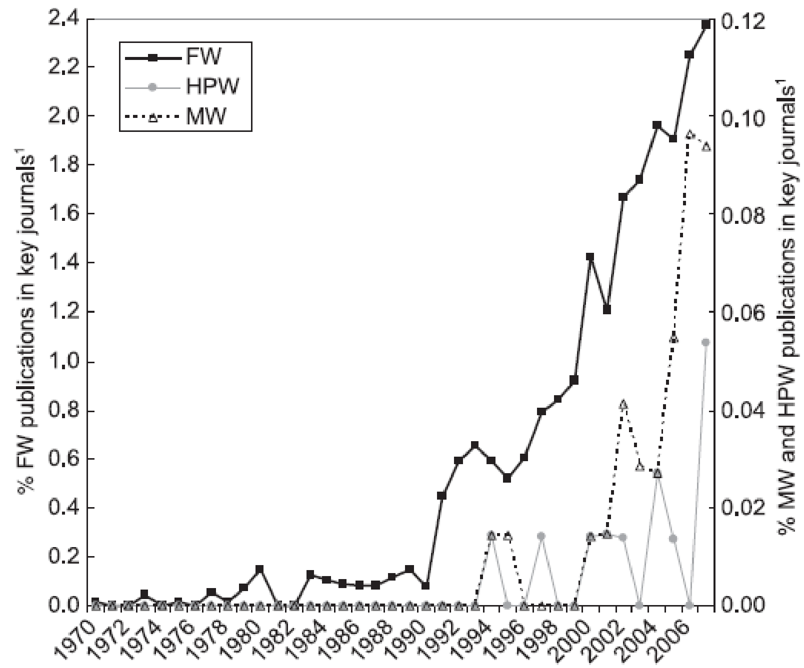


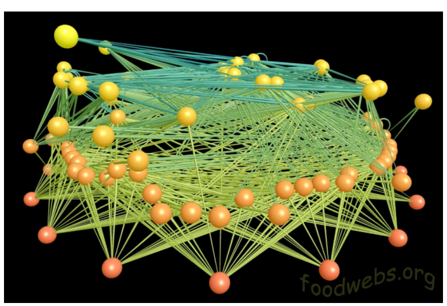
Networks in ecology



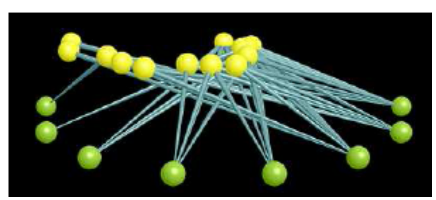


Ings et al. 2009

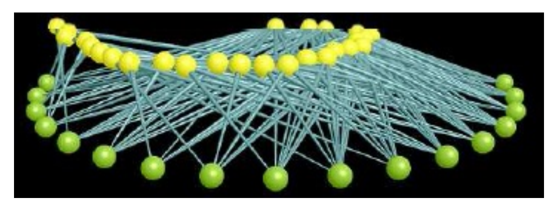
food web



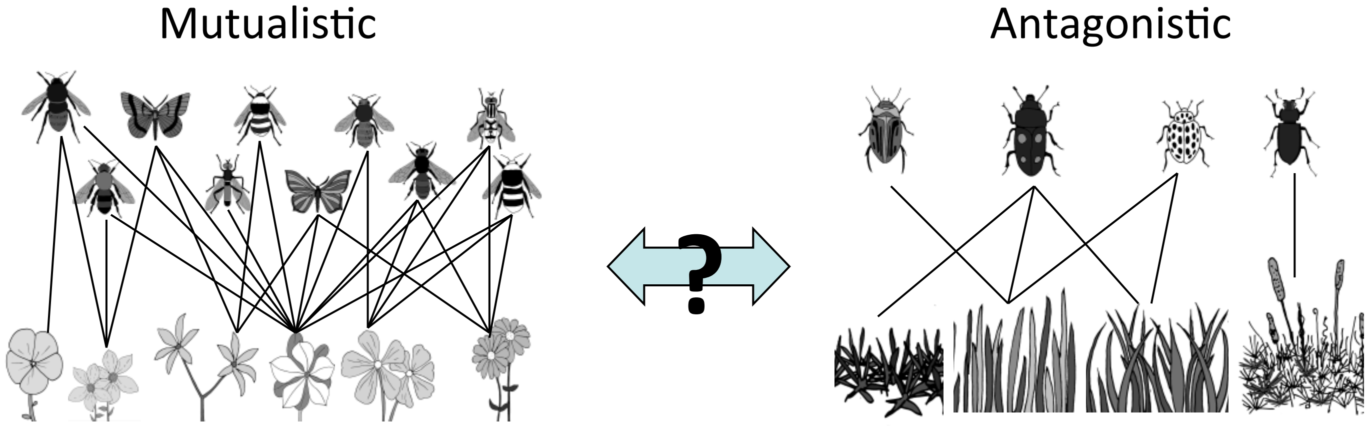
host-parasite web



mutualistic web



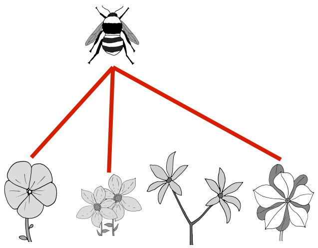
(i)
Do mutualistic and antagonistic networks differ in their architecture?

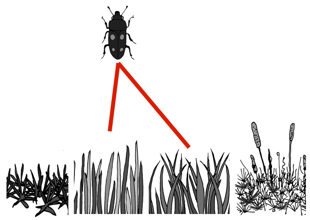


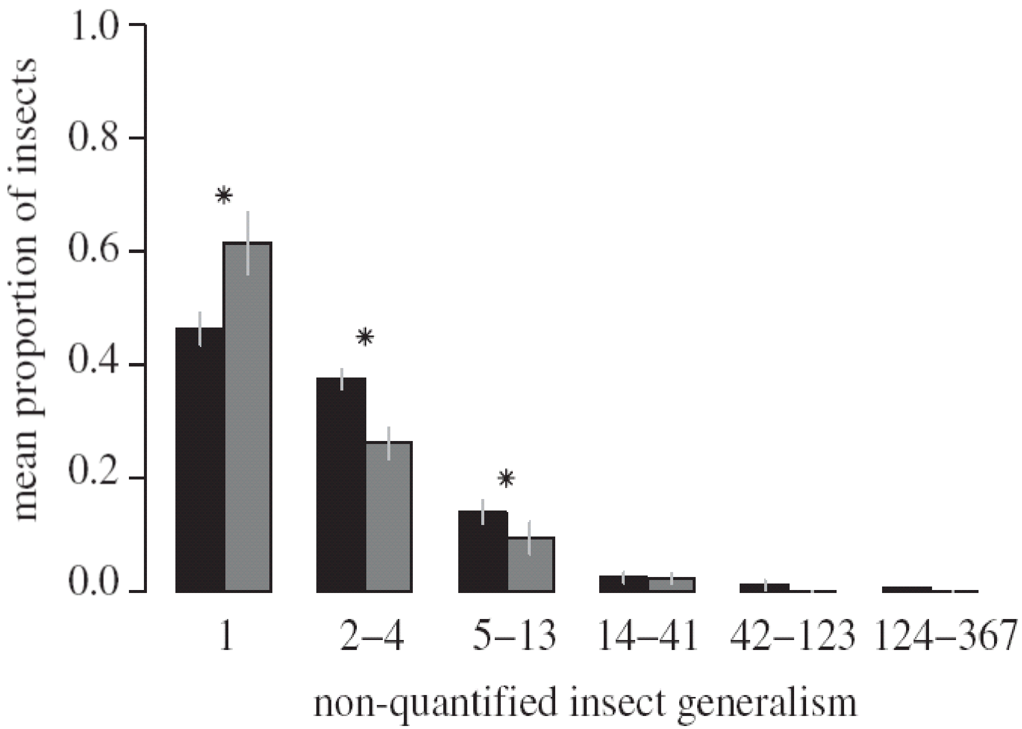
34 plant-pollinator webs

24 plant-phytophagous insect webs

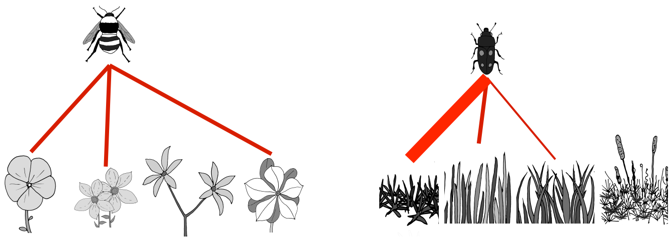
Insect generalism / degree

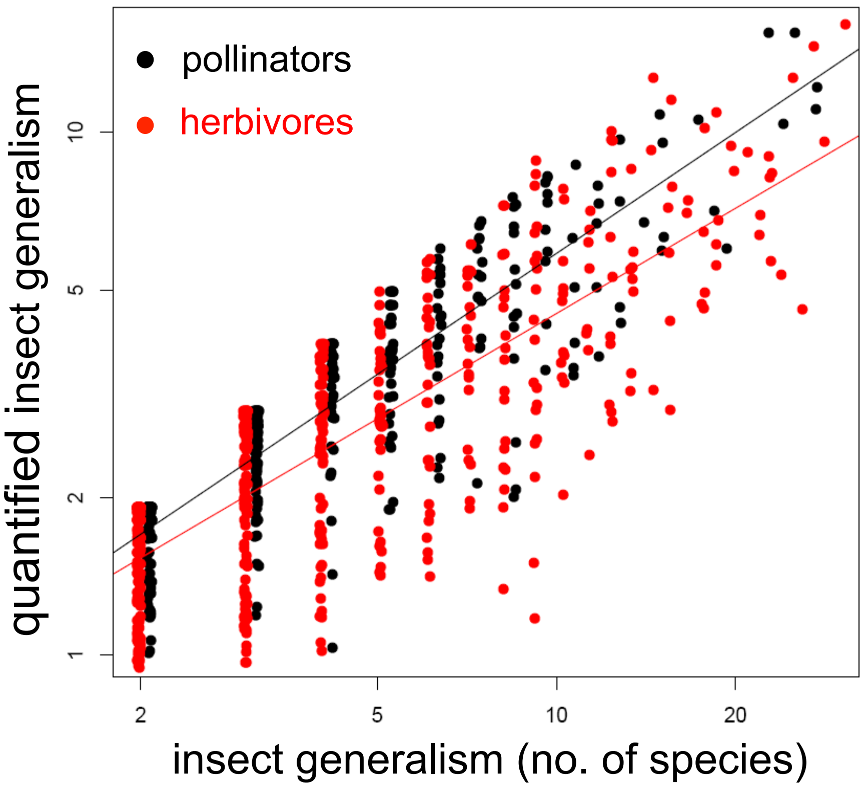






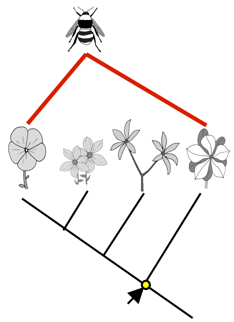
Quantified insect generalism

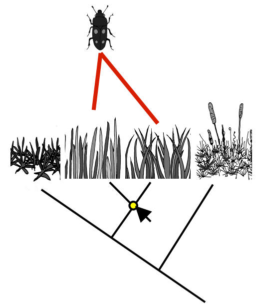


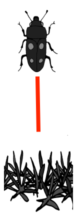


Fontaine & al., Proc. B. 2009

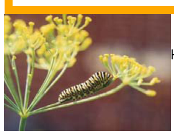
Insect phylogenetic generalism

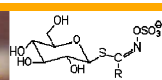


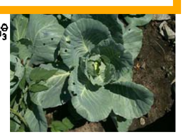


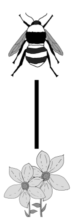


defense and counter-defense co-evolution

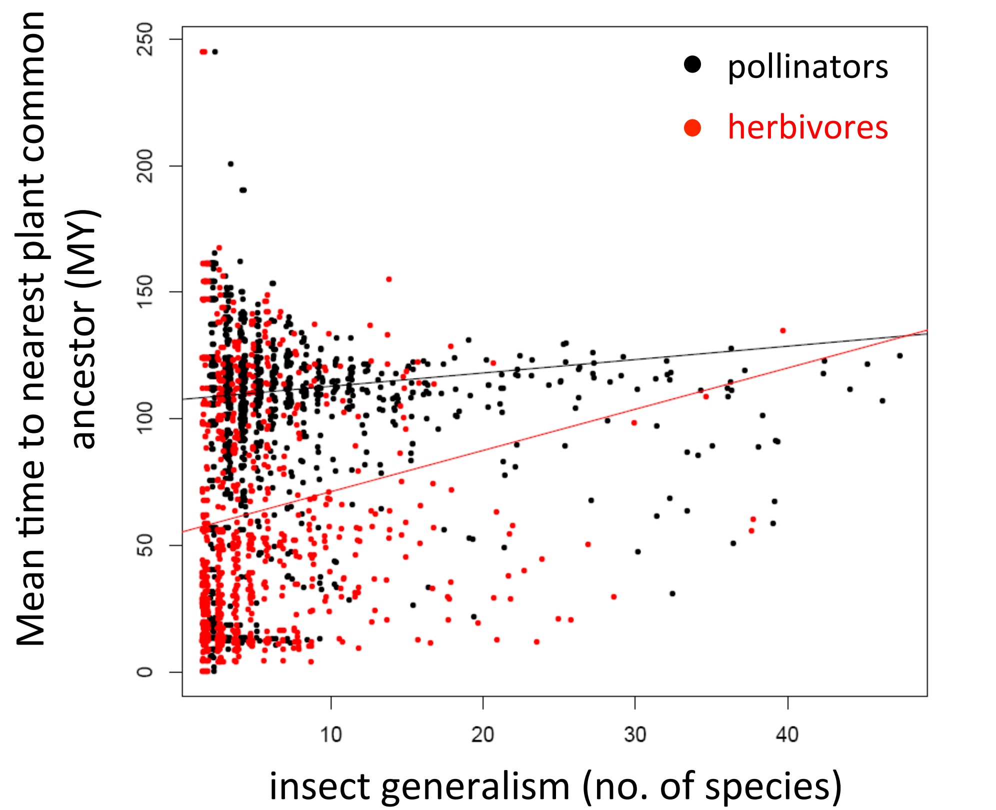






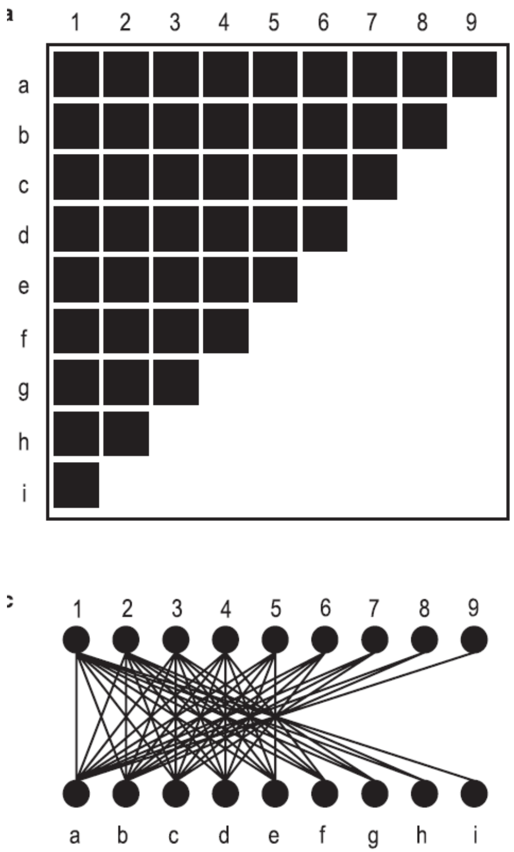


trait convergence and complementarity

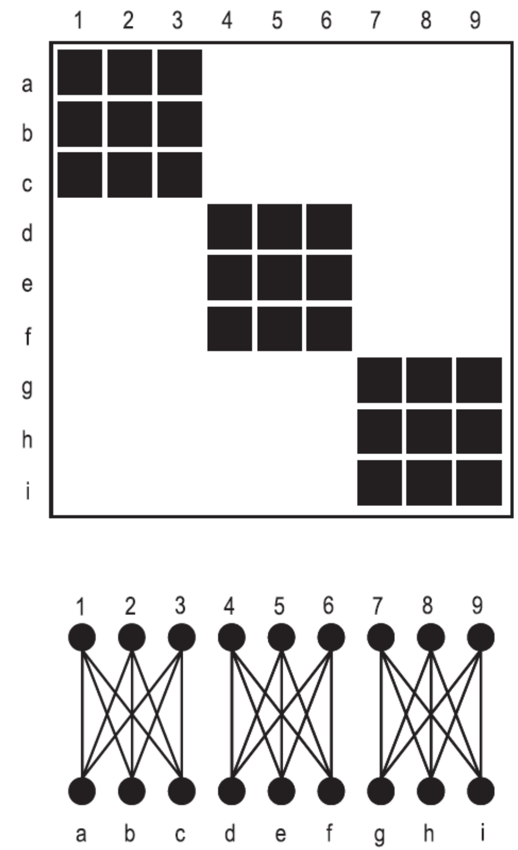


Fontaine & al., Proc. B. 2009

Bipartite networks and fine architectural patterns



Nested

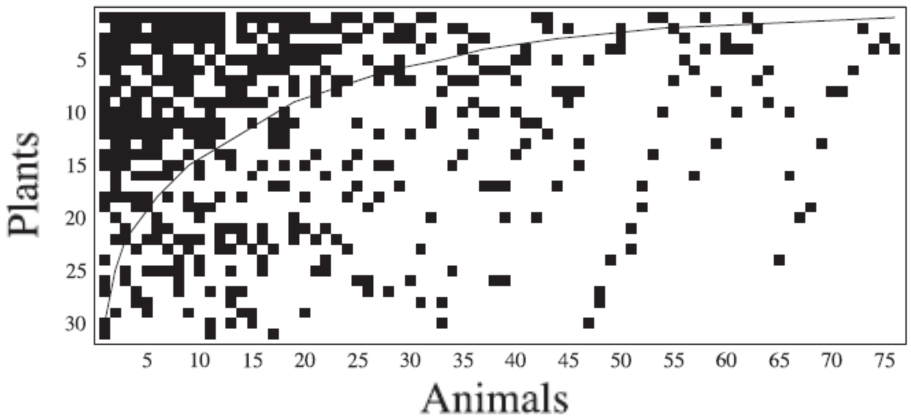


Compartmented

e.g. Bascompte et al. *PNAS* 2003

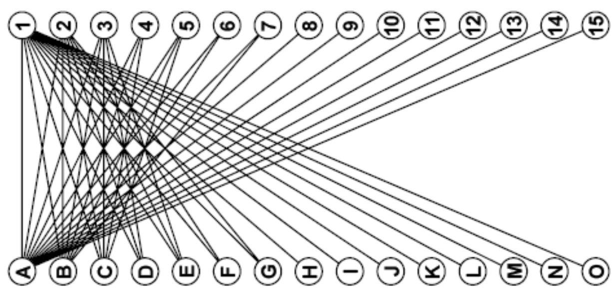
e.g. Lewinsohn et al. *Oikos* 2006

Mutualistic networks and nestedness



Seed dispersal

pollination



Nested structure

- Continuum between specialist and generalist species
- Presence of a core of highly connected species
- Asymmetrical specialization

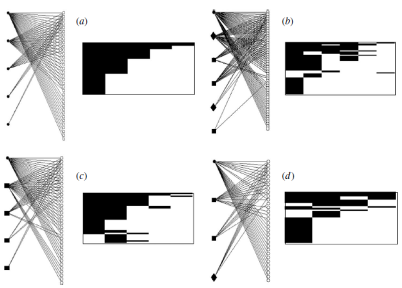
Bascompte et al. 2003

Mutualistic networks and nestedness

biology letters
Biol. Lett.
doi:10.1098/rsbl.2006.0562
Published online

The nested structure of marine cleaning symbiosis: is it like flowers and bees?

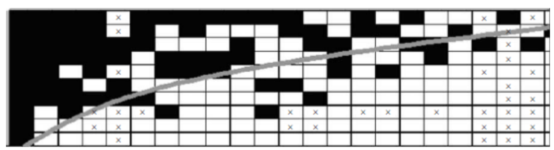
Paulo R. Guimarães Jr[1,2], Cristina Sazima[1], Sérgio Furtado dos Reis[1,*] and Ivan Sazima[1]



PROCEEDINGS OF THE ROYAL SOCIETY B
Proc. R. Soc. B (2007) 274, 591–598
doi:10.1098/rspb.2006.3758
Published online 29 November 2006

Finding NEMO: nestedness engendered by mutualistic organization in anemonefish and their hosts

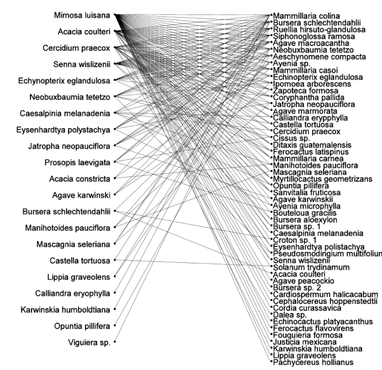
Jeff Ollerton[1,*], Duncan McCollin[1], Daphne G. Fautin[2] and Gerald R. Allen[3]



VOL. 172, NO. 6 THE AMERICAN NATURALIST DECEMBER 2008

The Nested Assembly of Plant Facilitation Networks Prevents Species Extinctions

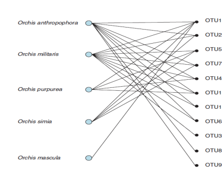
Miguel Verdú[1,*] and Alfonso Valiente-Banuet[2,†]



MOLECULAR ECOLOGY
Molecular Ecology (2010) 19, 4086–4095 doi: 10.1111/j.1365-294X.2010.04785.x

Low specificity and nested subset structure characterize mycorrhizal associations in five closely related species of the genus *Orchis*

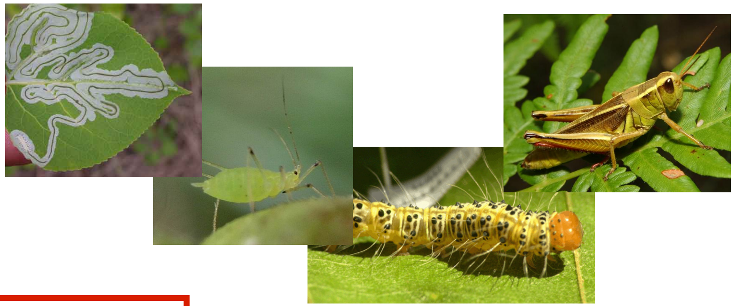
HANS JACQUEMYN,* OLIVIER HONNAY,* BRUNO P. A. CAMMUE,† REIN BRYS‡ and BART



Differences between mutualistic and trophic interaction webs structure?

Mutualistic networks

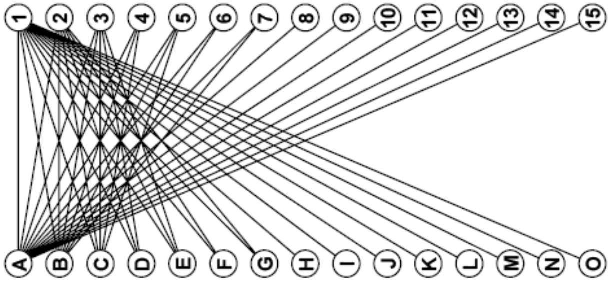
Trophic networks



Hypothesis

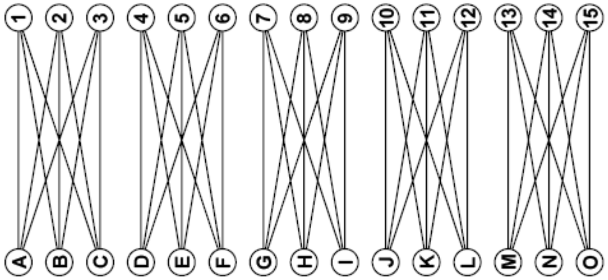
Bascompte et al. *Science* 2006

The structures of mutualistic and trophic networks differ



Nested structure

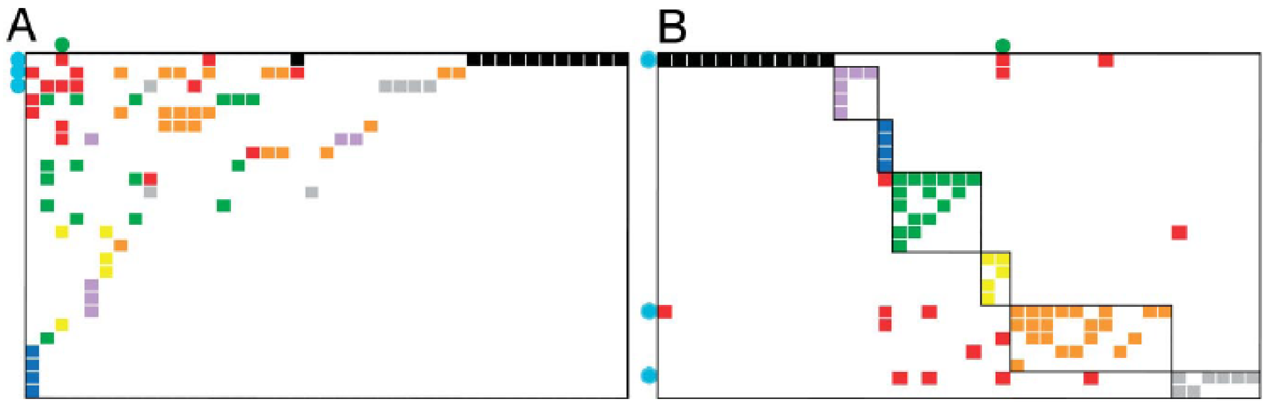
Bascompte et al. *PNAS* 2003

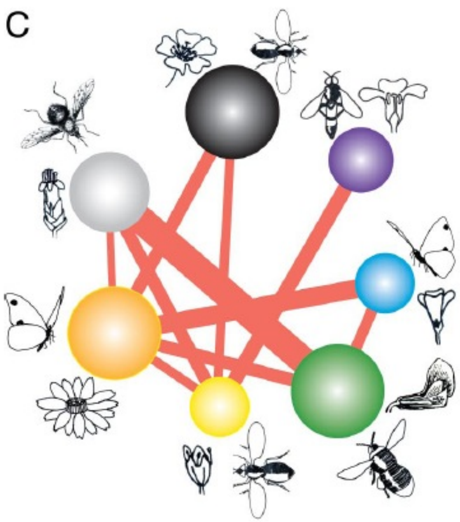


Compartmented structure

Lewinsohn et al. *Oikos* 2006

Mutualistic networks and compartmentation

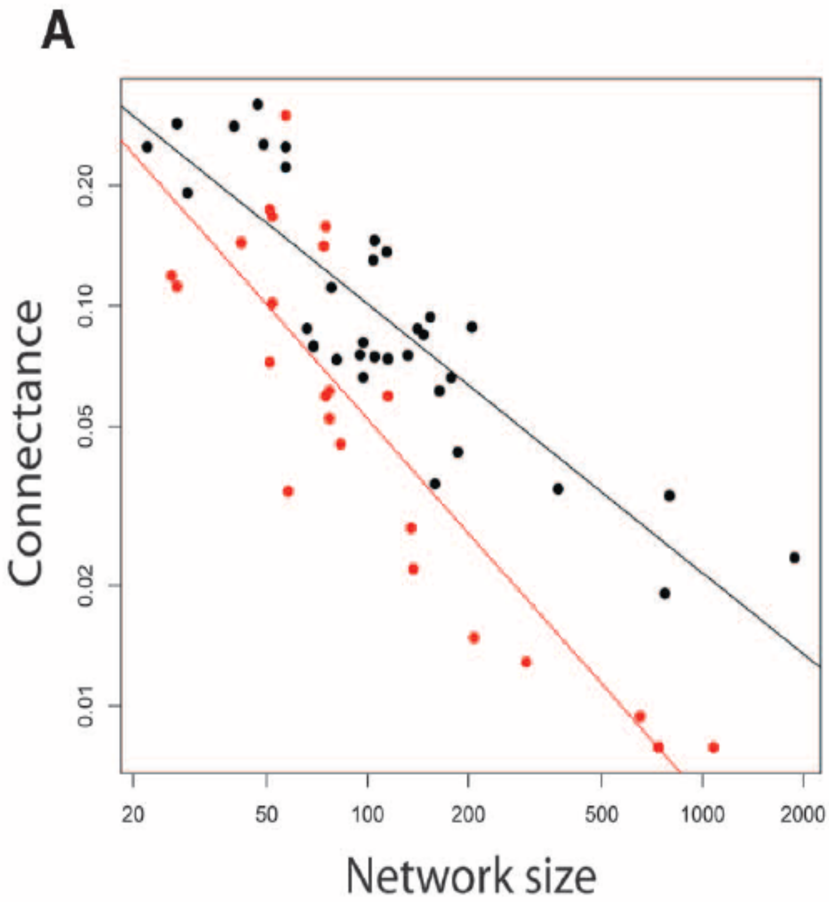


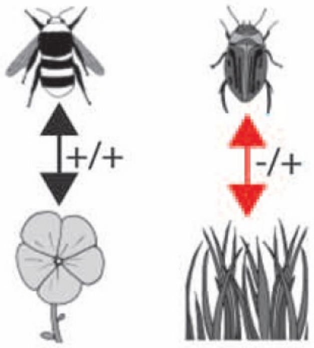


- Compartmented patterns can also be found in plant-pollinator networks

Olesen et al. *PNAS* 2007

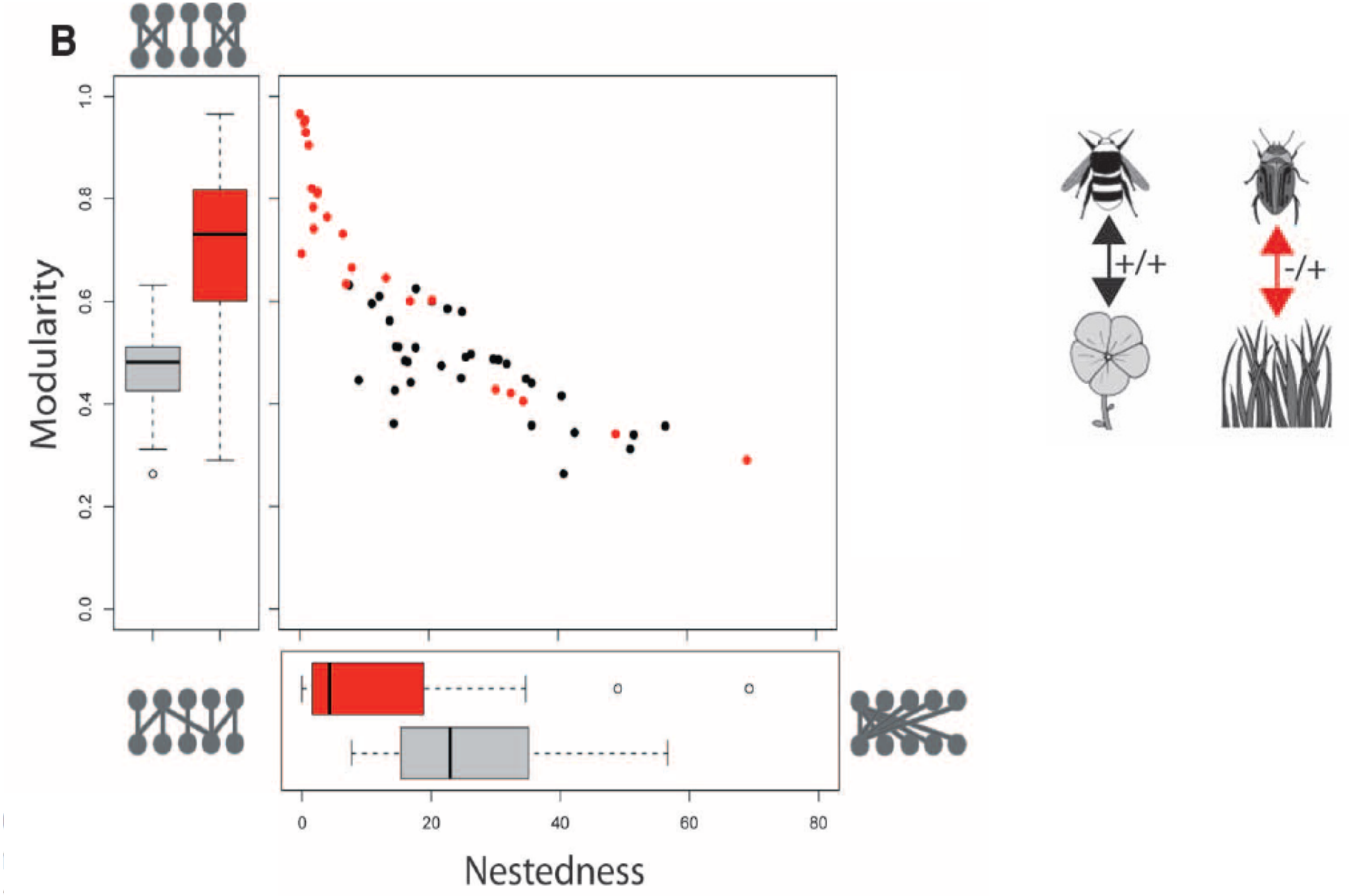
Network architecture and interaction type





Thébault & Fontaine, *Science,* 2010

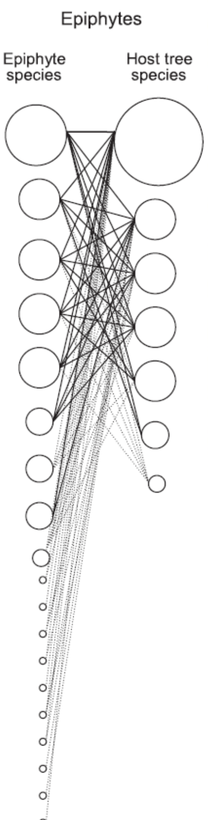
Network architecture and interaction type



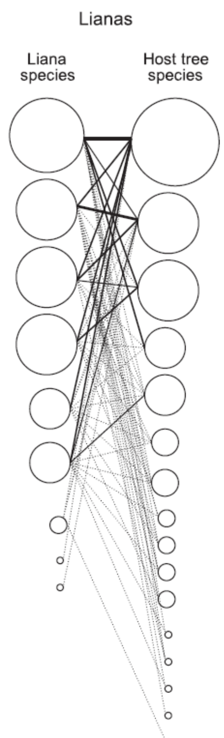
Thébault & Fontaine, *Science,* 2010

Network architecture and interaction type

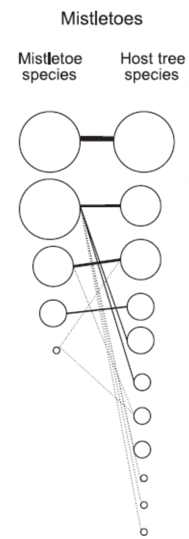
commensal



commensal/parasitic

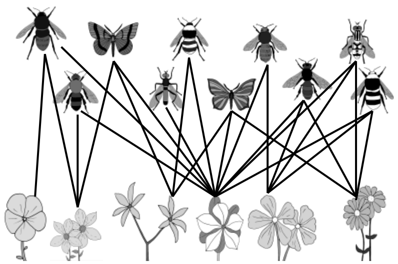


parasitic

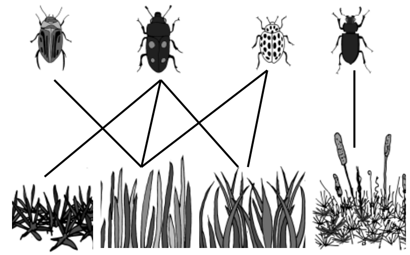


Blick & Burns, *PPEES,* 2011

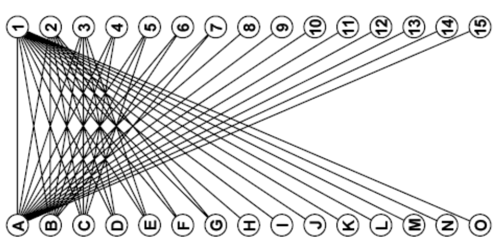
Mutualistic

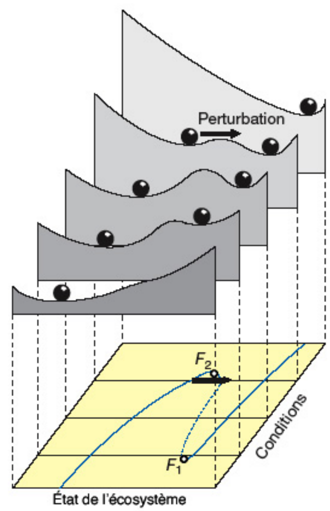


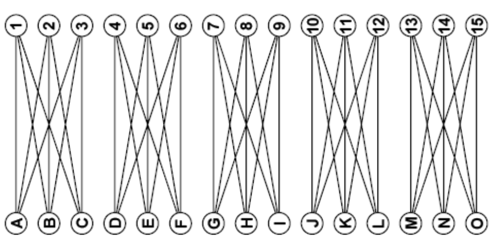
Antagonistic



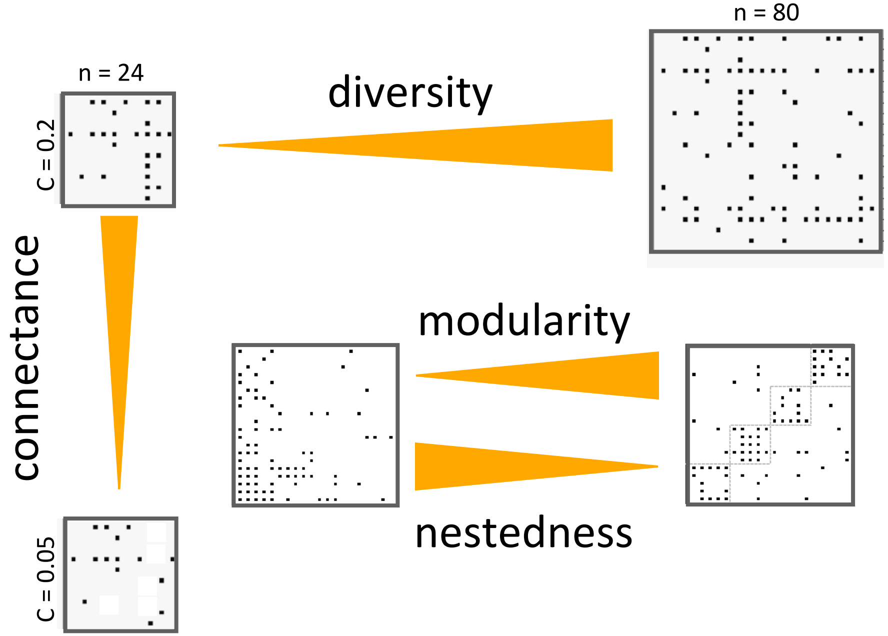
(ii) What are the consequences of the different network architectures on species coexistence and stability?



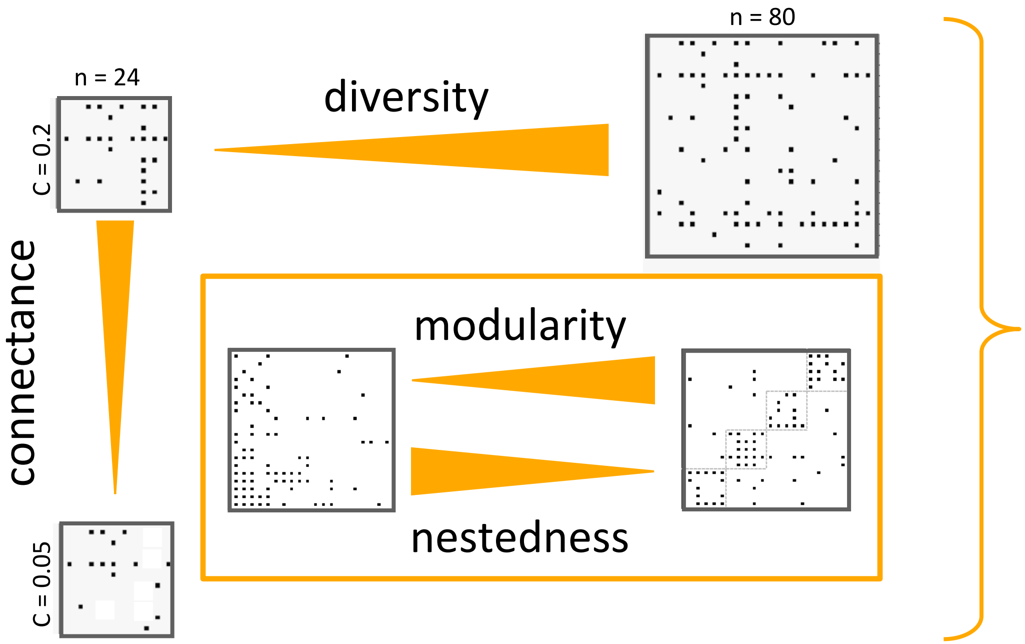




The model: from network architecture to community stability



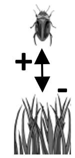
The model:
from network architecture to community stability



Antagonistic

$$\frac{dA_i}{dt} = r_{Ai}A_i - I_{Ai}A_i^2 + \sum_{j=1}^{Np} \frac{c_{ji}A_iP_j}{\alpha_{ji}^{-1} + \sum_{Pk\in prey(Ai)} P_k}$$

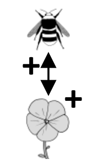
$$\frac{dP_i}{dt} = r_{Pi}P_i - I_{Pi}P_i^2 - \sum_{j=1}^{Na} \frac{c_{ij}A_jP_i}{\alpha_{ij}^{-1} + \sum_{Pk\in prey(Aj)} P_k}$$



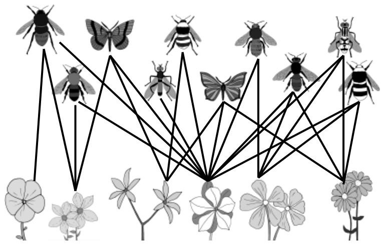
Mutualistic

$$\frac{dA_i}{dt} = r_{Ai}A_i - I_{Ai}A_i^2 + \sum_{j=1}^{Np} \frac{c_{ji}A_iP_j}{\alpha_{ji}^{-1} + \sum_{Pk\in mut(Ai)} P_k}$$

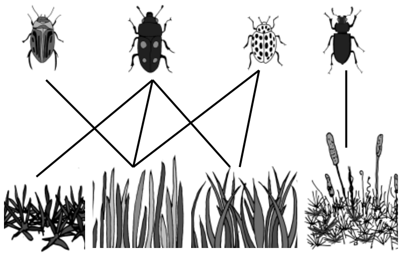
$$\frac{dP_i}{dt} = r_{Pi}P_i - I_{Pi}P_i^2 + \sum_{j=1}^{Na} \frac{c_{ij}A_jP_i}{\alpha_{ij}^{-1} + \sum_{Ak\in mut(Pi)} A_k}$$



The model: dynamics of mutualistic and trophic webs



Mutualistic



Antagonistic

Mutualistic:

$$\frac{dA_i}{dt} = r_{Ai}A_i - I_{Ai}A_i^2 + \sum_{j=1}^{Np} \frac{a_{ji}A_iP_j}{1 + a_{ji}h_{ji} \sum_{Pk \in mut(Ai)} P_k}$$

$$\frac{dP_i}{dt} = r_{Pi}P_i - I_{Pi}P_i^2 + \sum_{j=1}^{Na} \frac{a_{ij}A_jP_i}{1 + a_{ij}h_{ij} \sum_{Ak \in mut(Pi)} A_k}$$

Antagonistic:

$$\frac{dA_i}{dt} = r_{Ai}A_i - I_{Ai}A_i^2 + \sum_{j=1}^{Np} \frac{a_{ji}A_iP_j}{1 + a_{ji}h_{ji} \sum_{Pk \in prey(Ai)} P_k}$$

$$\frac{dP_i}{dt} = r_{Pi}P_i - I_{Pi}P_i^2 - \sum_{j=1}^{Na} \frac{a_{ij}A_jP_i}{1 + a_{ij}h_{ij} \sum_{Pk \in prey(Aj)} P_k}$$

Mutualistic:

-intrinsic growth rates
r_P and $r_A < 0$ ➔ obligate mutualism

-density dependence term

-interaction term
saturates with mutualistic partner densities

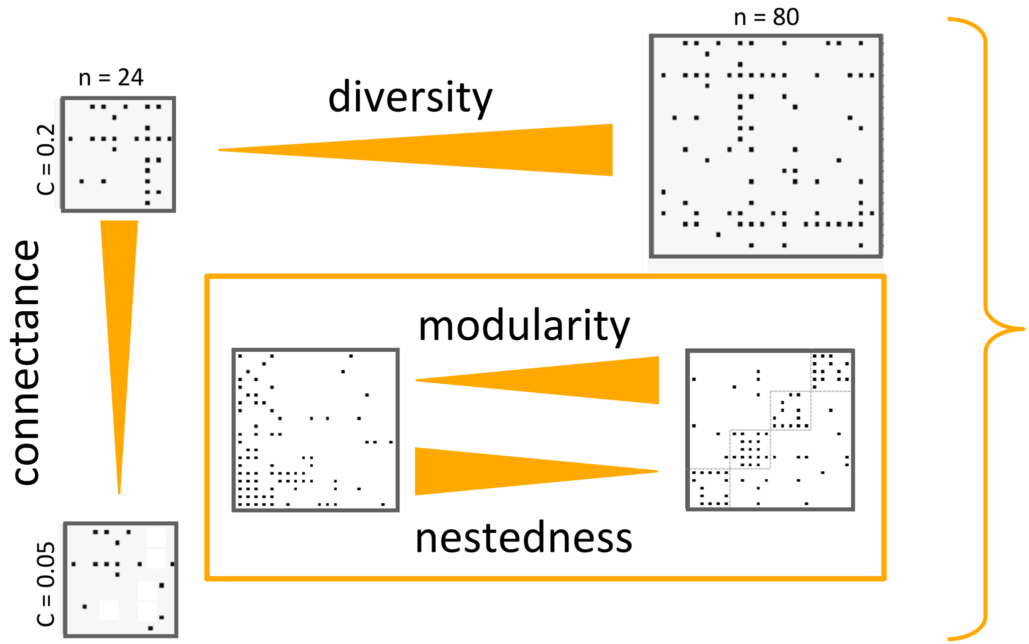
Antagonistic:

-intrinsic growth rates
$r_P > 0$ and $r_A < 0$

-density dependence term

-interaction term
saturates with prey densities

The model:
from network architecture to community stability



Antagonistic

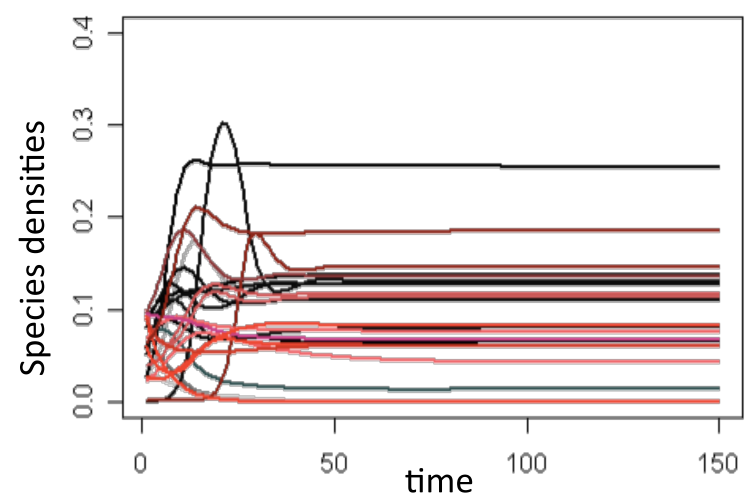
$$\frac{dA_i}{dt} = r_{Ai}A_i - I_{Ai}A_i^2 + \sum_{j=1}^{Np} \frac{c_{ji}A_iP_j}{\alpha_{ji}^{-1} + \sum_{Pk\in prey(Ai)} P_k}$$

$$\frac{dP_i}{dt} = r_{Pi}P_i - I_{Pi}P_i^2 - \sum_{j=1}^{Na} \frac{c_{ij}A_jP_i}{\alpha_{ij}^{-1} + \sum_{Pk\in prey(Aj)} P_k}$$

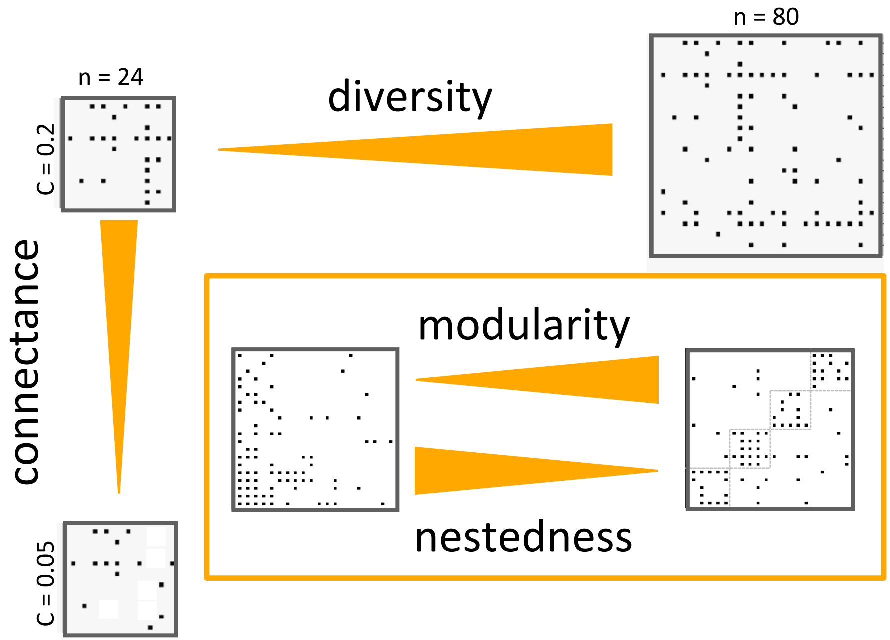
Mutualistic

$$\frac{dA_i}{dt} = r_{Ai}A_i - I_{Ai}A_i^2 + \sum_{j=1}^{Np} \frac{c_{ji}A_iP_j}{\alpha_{ji}^{-1} + \sum_{Pk\in mut(Ai)} P_k}$$

$$\frac{dP_i}{dt} = r_{Pi}P_i - I_{Pi}P_i^2 + \sum_{j=1}^{Na} \frac{c_{ij}A_jP_i}{\alpha_{ij}^{-1} + \sum_{Ak\in mut(Pi)} A_k}$$



The model:
from network architecture to community stability



Antagonistic

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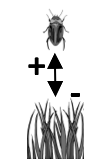

Mutualistic

$$\frac{dA_i}{dt} = r_{Ai}A_i - I_{Ai}A_i^2 + \sum_{j=1}^{Np} \frac{c_{ji}A_iP_j}{\alpha_{ji}^{-1} + \sum_{Pk\in mut(Ai)} P_k}$$

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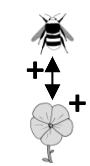
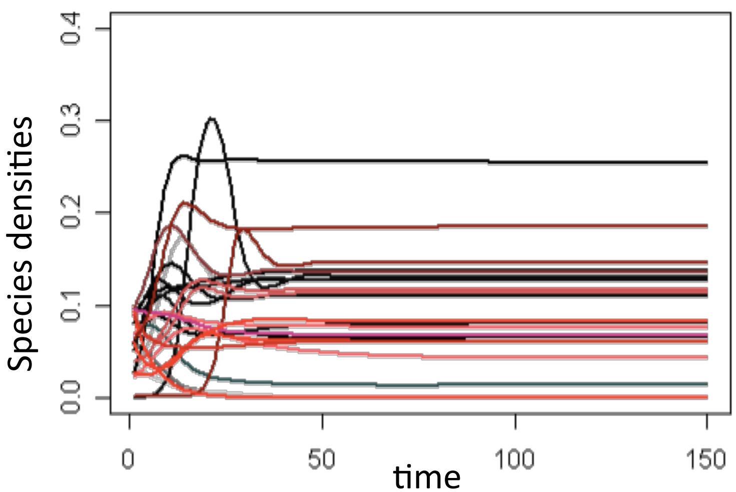


- **Persistence:**

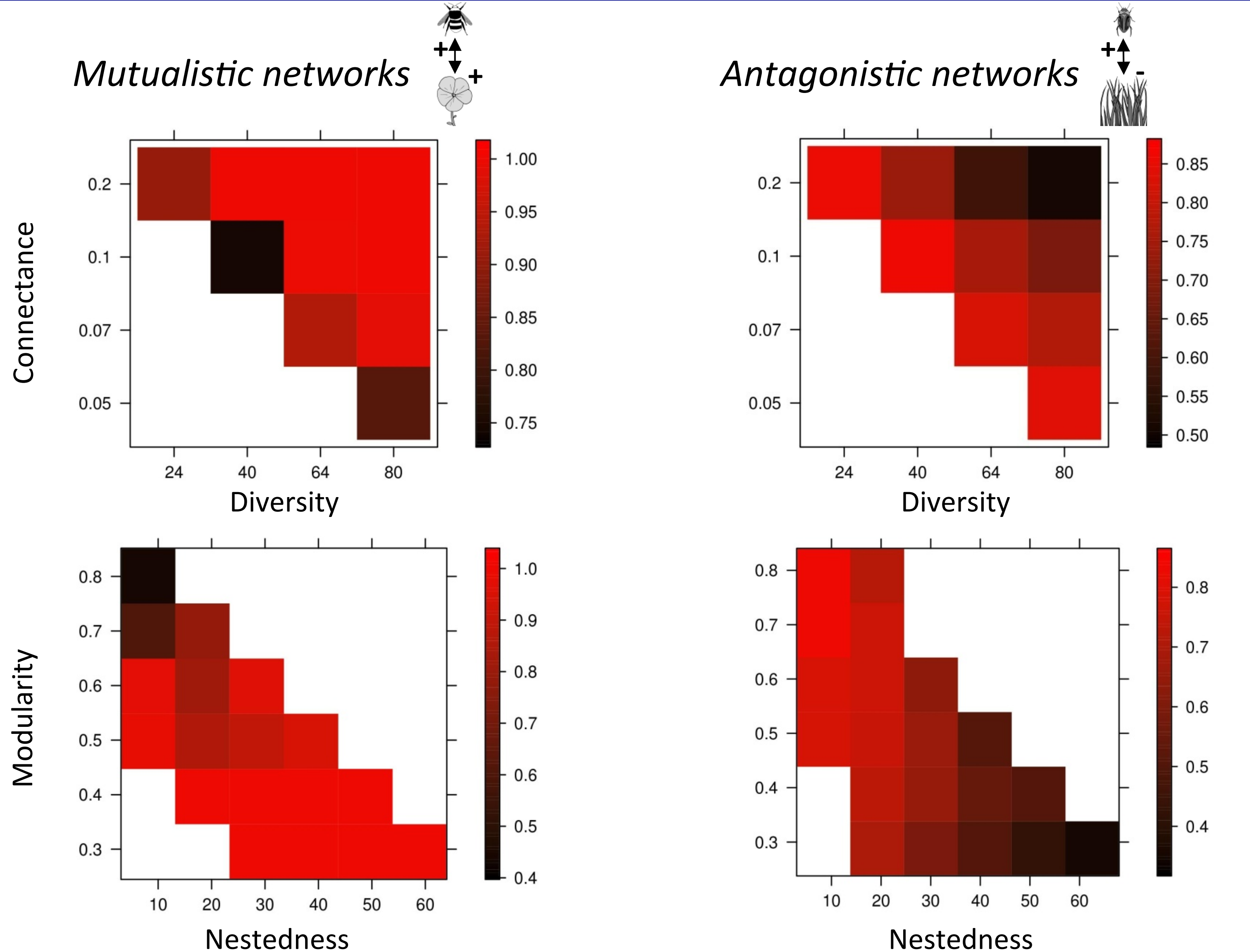
proportion of species persisting at the equilibrium

- **Resilience:**

measure of the speed at which a system returns to its original state after a perturbation

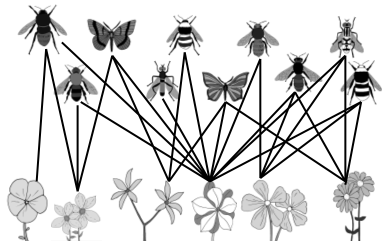


Results: impact of network architecture on species persistence

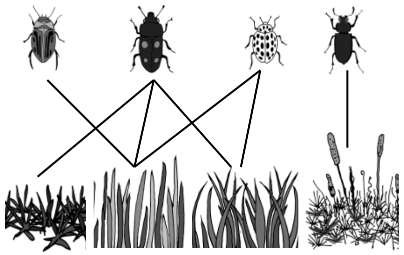


Thébault & Fontaine, *Science,* 2010

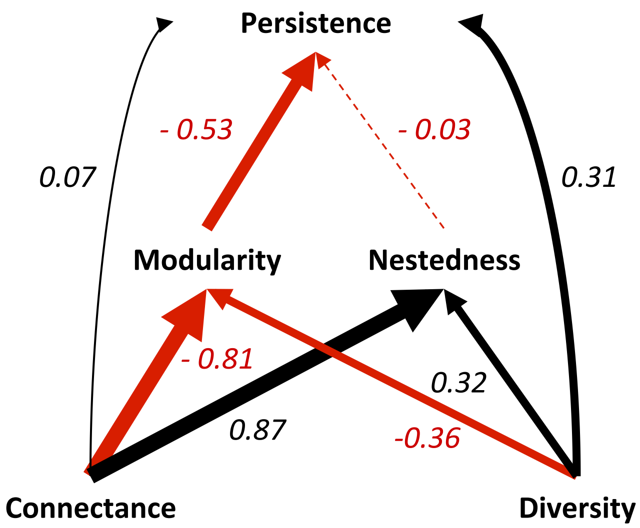
Results: impact of network architecture on species persistence

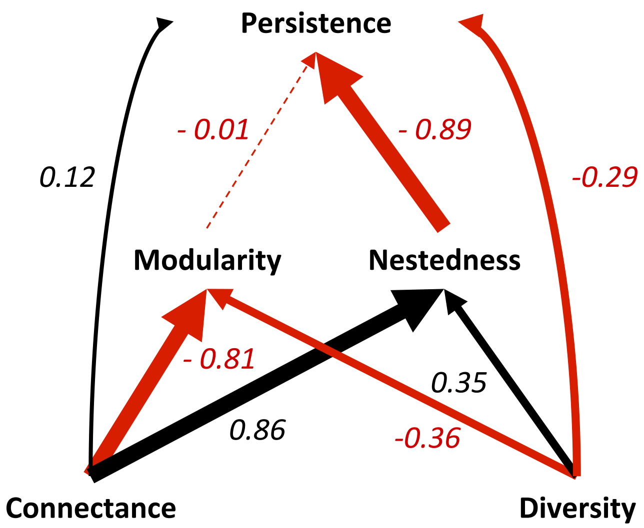


Mutualistic



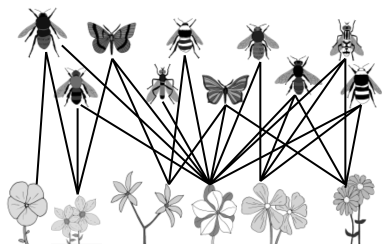
Antagonistic



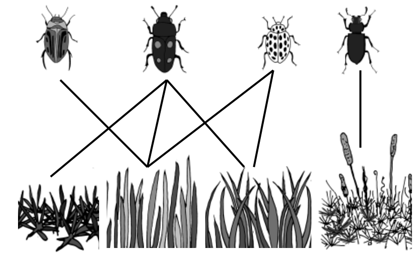


➢ opposite effect of network architecture on the persistence of mutualistic and trophic networks

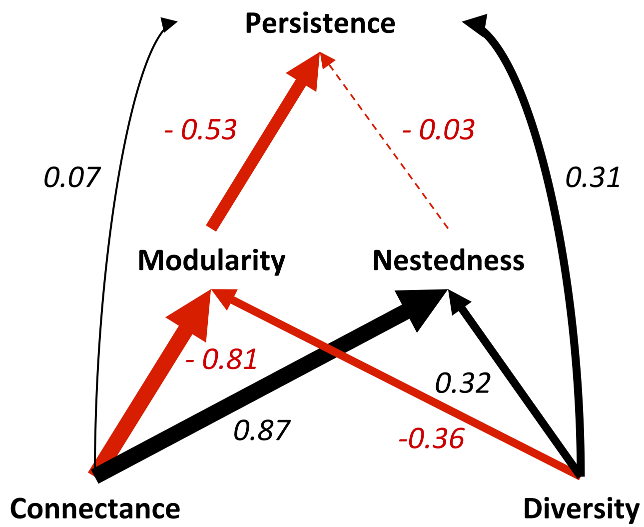
Results: impact of network architecture on species persistence



Mutualistic

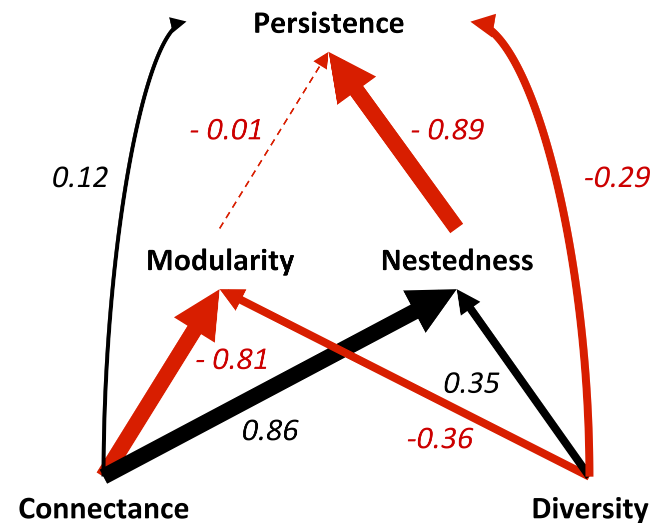


Antagonistic



indirect effect: 0.40

indirect effect: 0.18

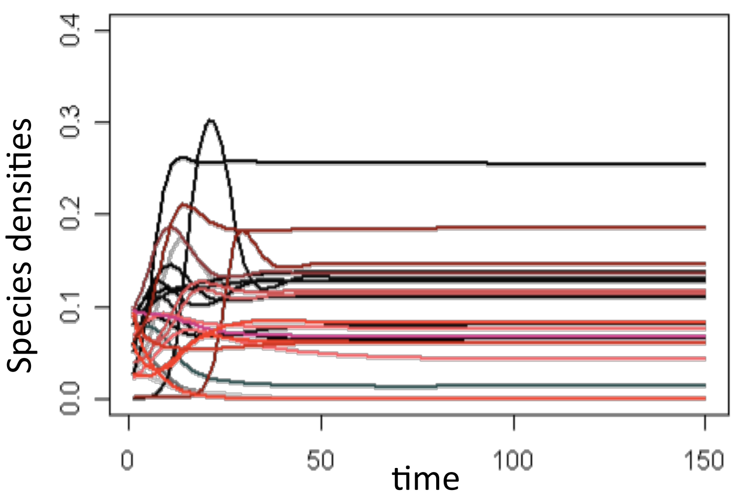


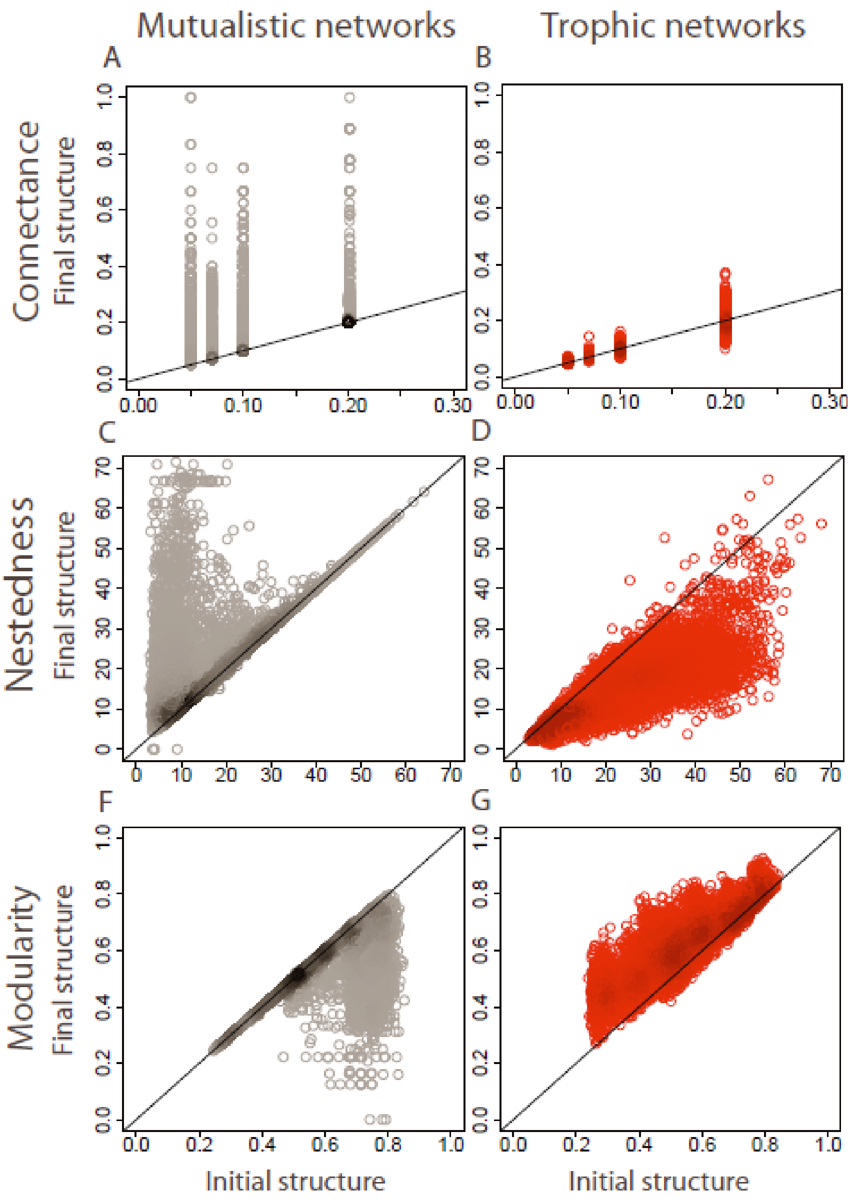
indirect effect: -0.76

indirect effect: -0.31

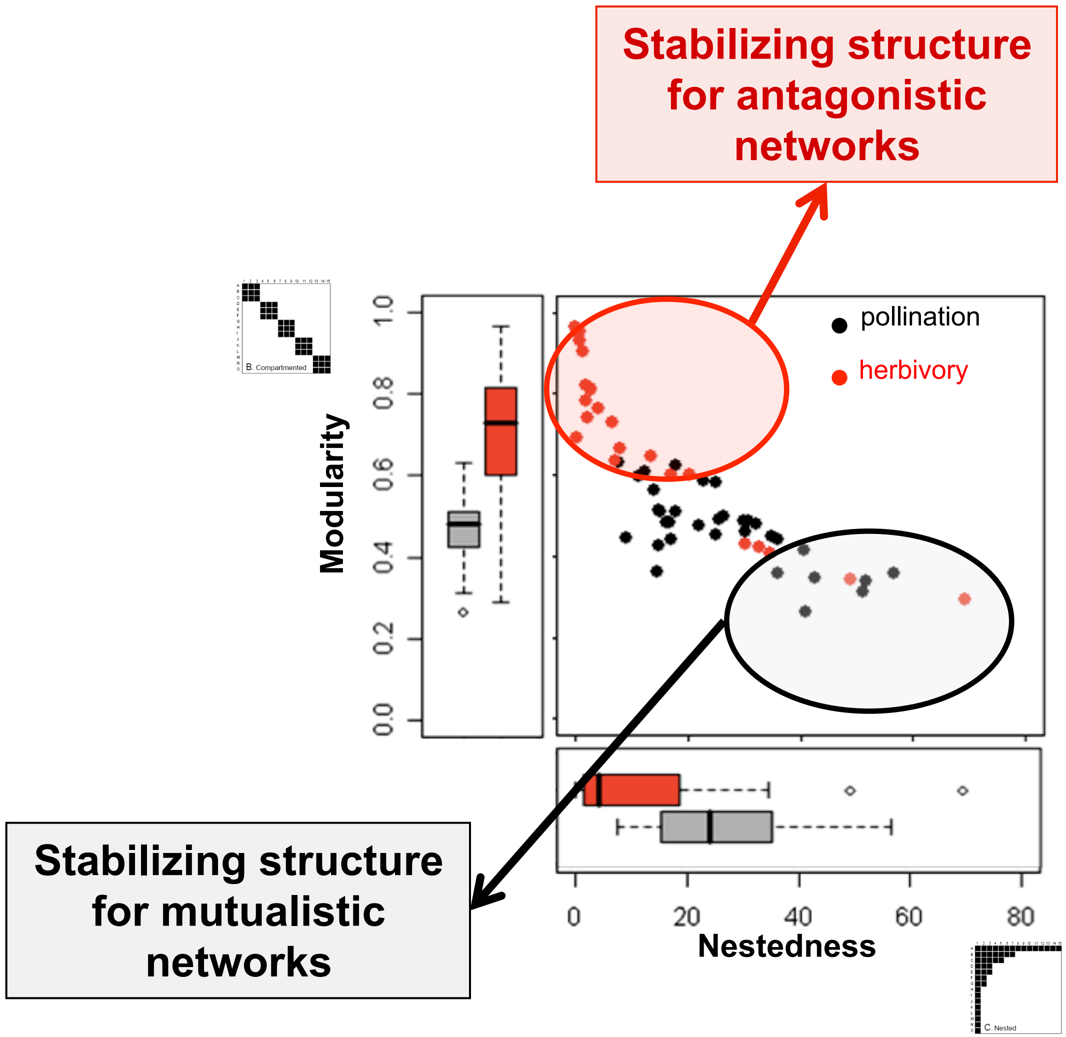
➢ Importance of nestedness and modularity for network stability

Results: network architecture at equilibrium





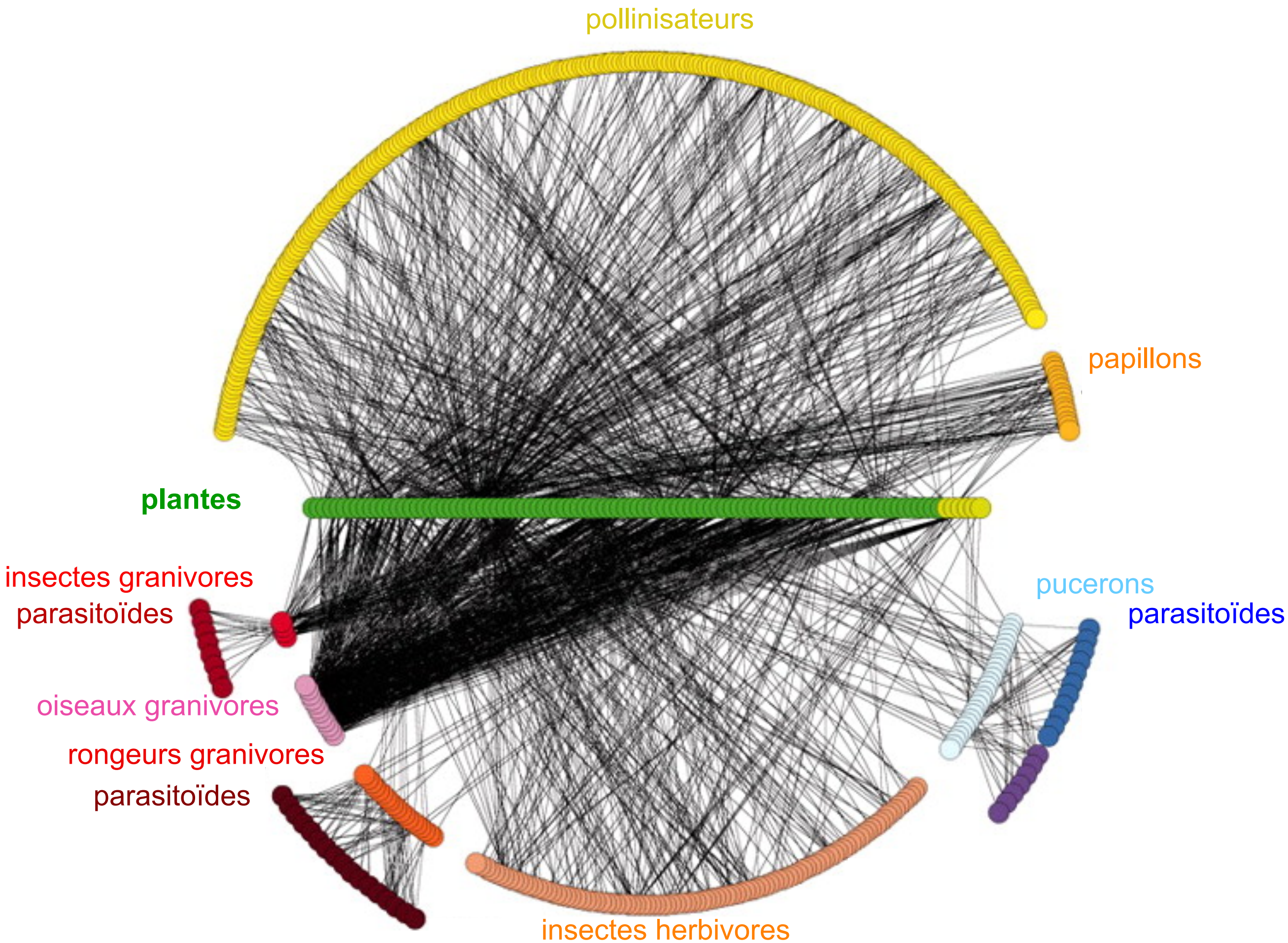
Theoretical predictions fit empirical data



Strong link between stability constraints of dynamical systems and the architecture of ecological interaction networks

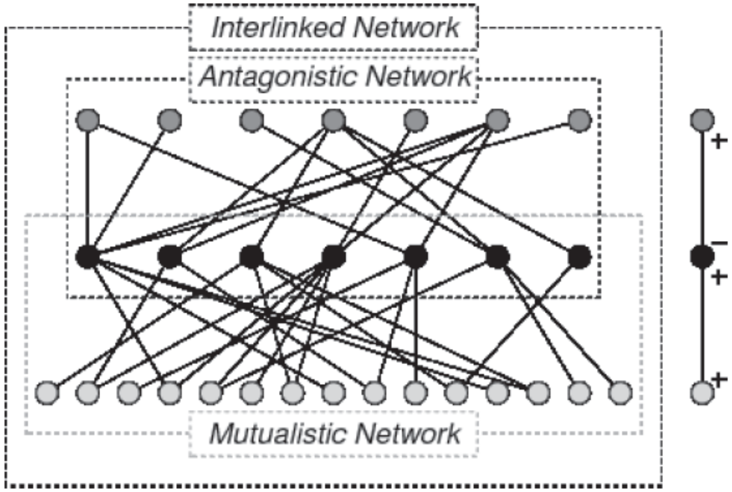
(iii)
Some limits and perspectives

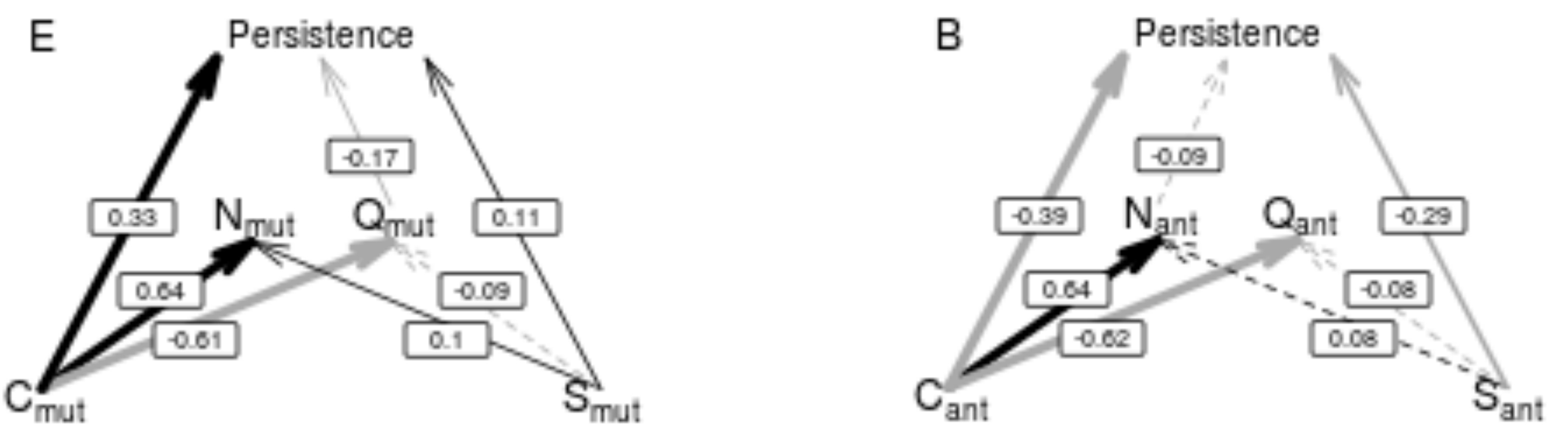
But pollination networks are not isolated…



Pocock et al. *Science* 2012

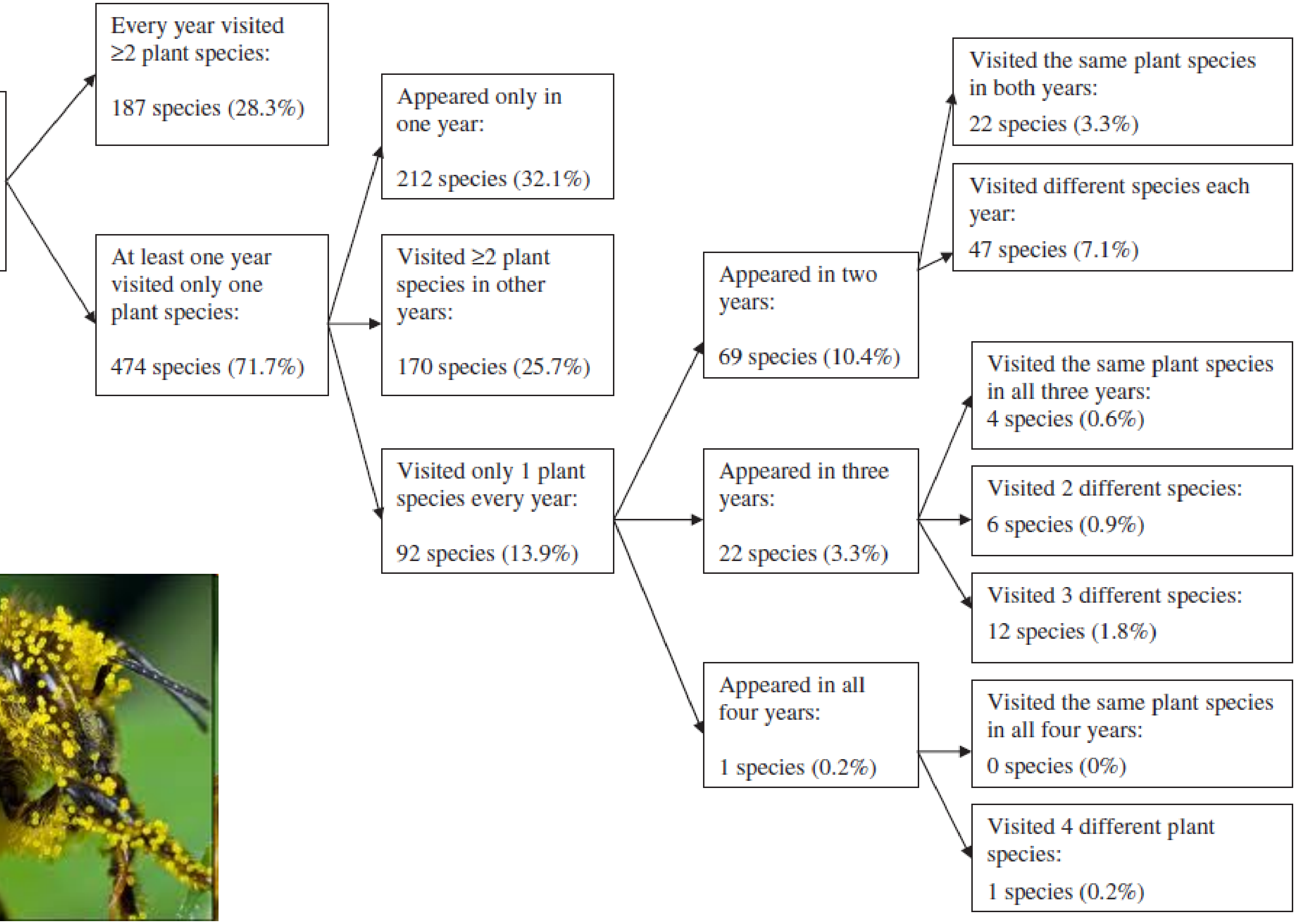
But pollination networks are not isolated…





Sauve et al. submitted

Plasticity in pollination networks



Petanidou et al. Eco. Let. 2008

Plasticity in pollination networks

	1983 and 1984	1984 and 1985	1985 and 1986	1983 and 1985	1984 and 1986	1983 and 1986
Jaccard similarity index						
Plants	0.721	0.841	0.742	0.714	0.722	0.661
Insects	0.429	0.447	0.438	0.420	0.426	0.389
Interactions	0.179	0.196	0.171	0.163	0.176	0.158

Loss of interactions due to:

70% → Partners are missing

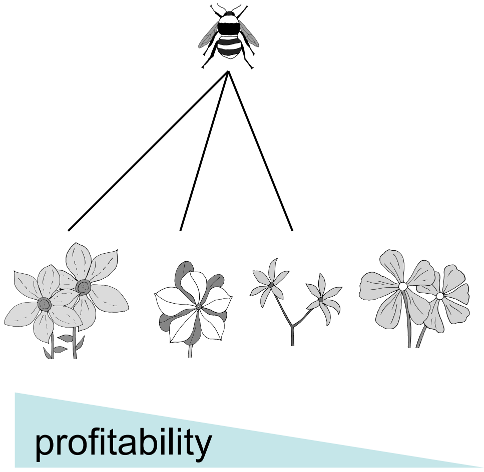
30% → Partners are present

Petanidou et al. Eco. Let. 2008

Plasticity in interaction networks and optimal foraging theory

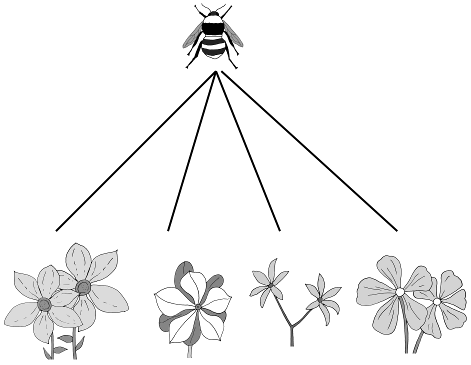
Optimal foraging (McArthur & Pianka 1966)

fitness of animal is a function of the efficiency of foraging measured in terms of some currency – usually energy – and natural selection has resulted in animals that forage so as to maximize this fitness



if

$$\mathbf{E/T} < E_{new}/(h_{new})$$



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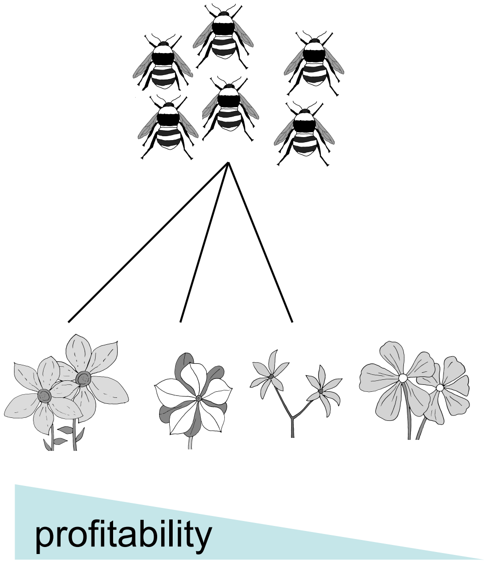

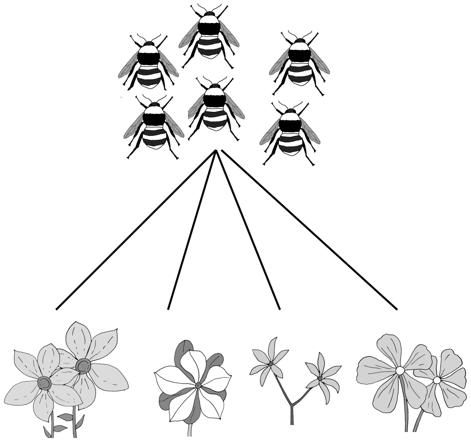

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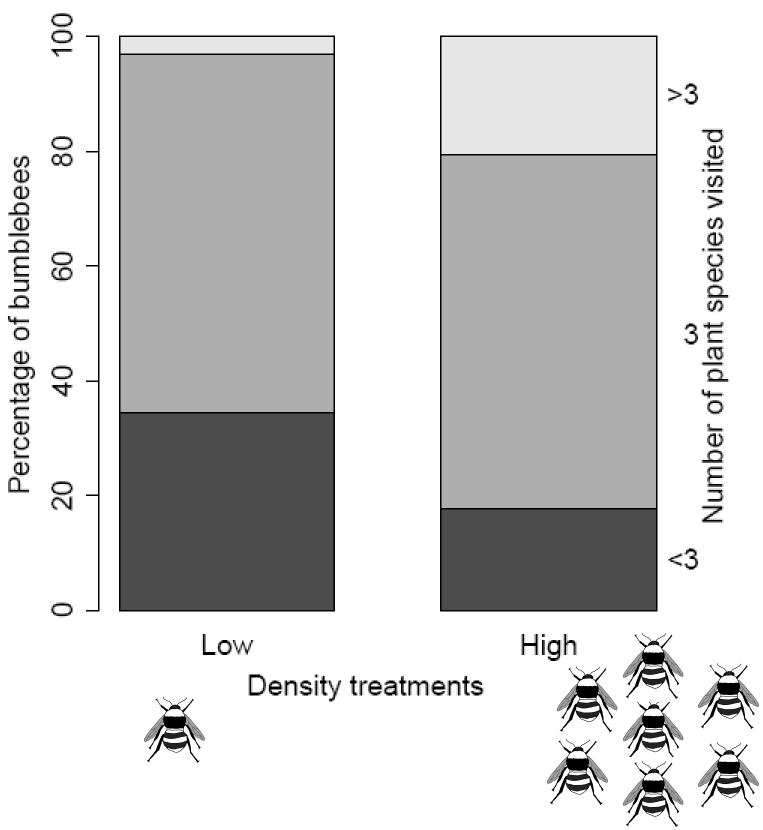
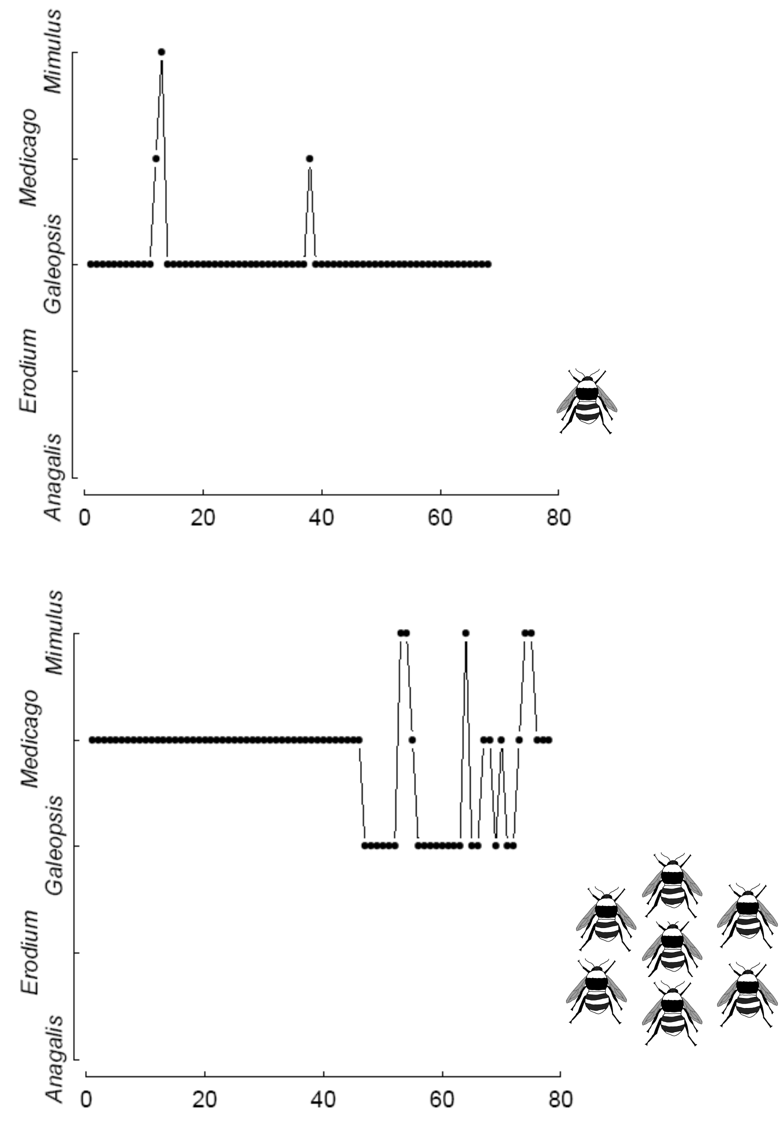
Optimal diet, effect of intraspecific competition





Fontaine & al., *J. Ani. Eco.*, 2009

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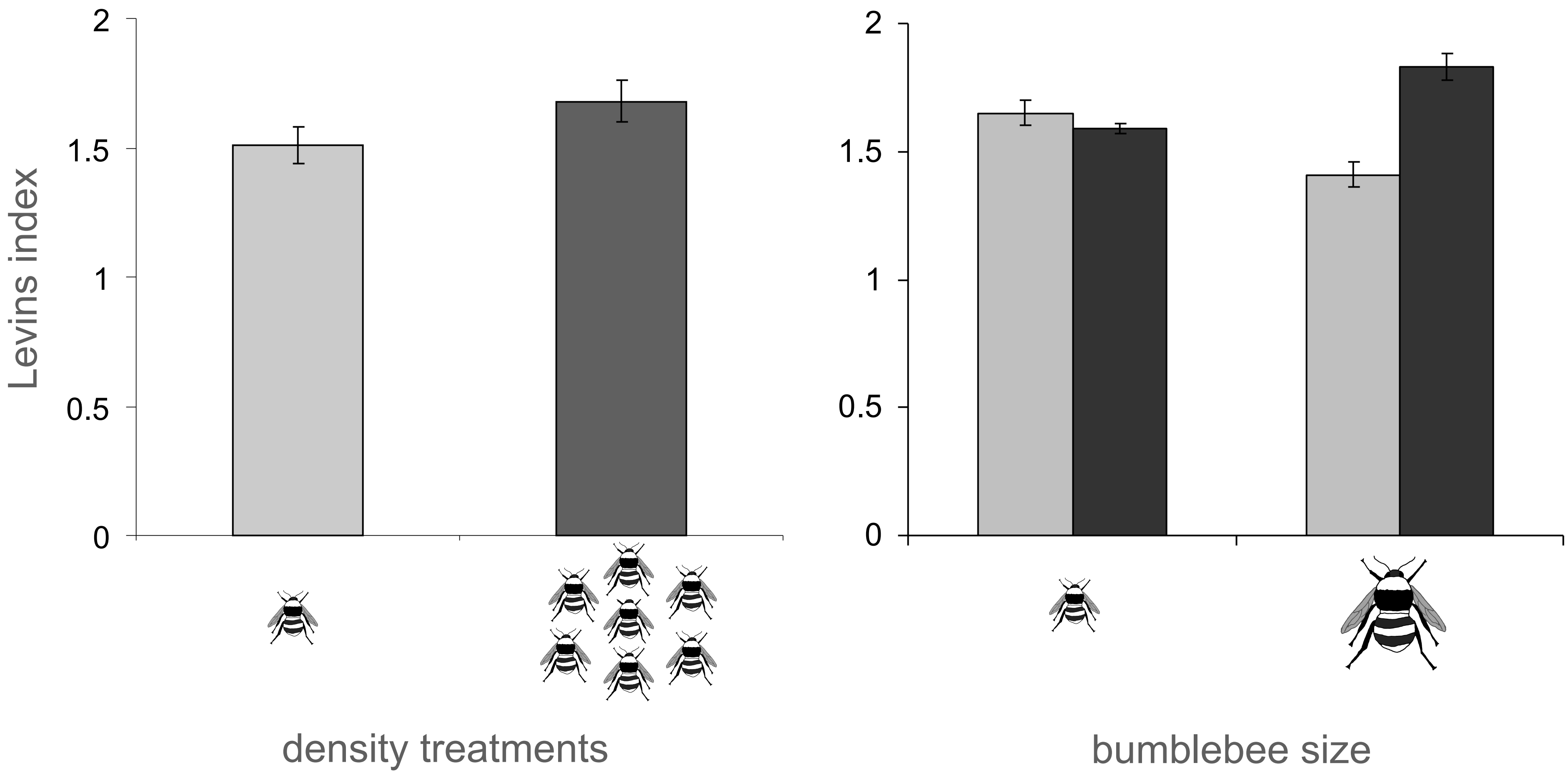


Fontaine & al., *J. Ani. Eco.*, 2009

Introducing adaptive foraging in pollination models

Adaptive foraging allows the maintenance of biodiversity of pollination networks

Oikos 000: 001–011, 2012
doi: 10.1111/j.1600-0706.2012.20830.x

Subject Editor: Stefano Allesina. Accepted 20 July 2012

Fernanda S. Valdovinos, Pablo Moisset de Espanés, José D. Flores and Rodrigo Ramos-Jiliberto

$$\frac{dp_i}{dt} = \gamma_i \sum_{j \in A} e_{ij}\sigma_{ij}V_{ij} - \mu_i^P p_i$$

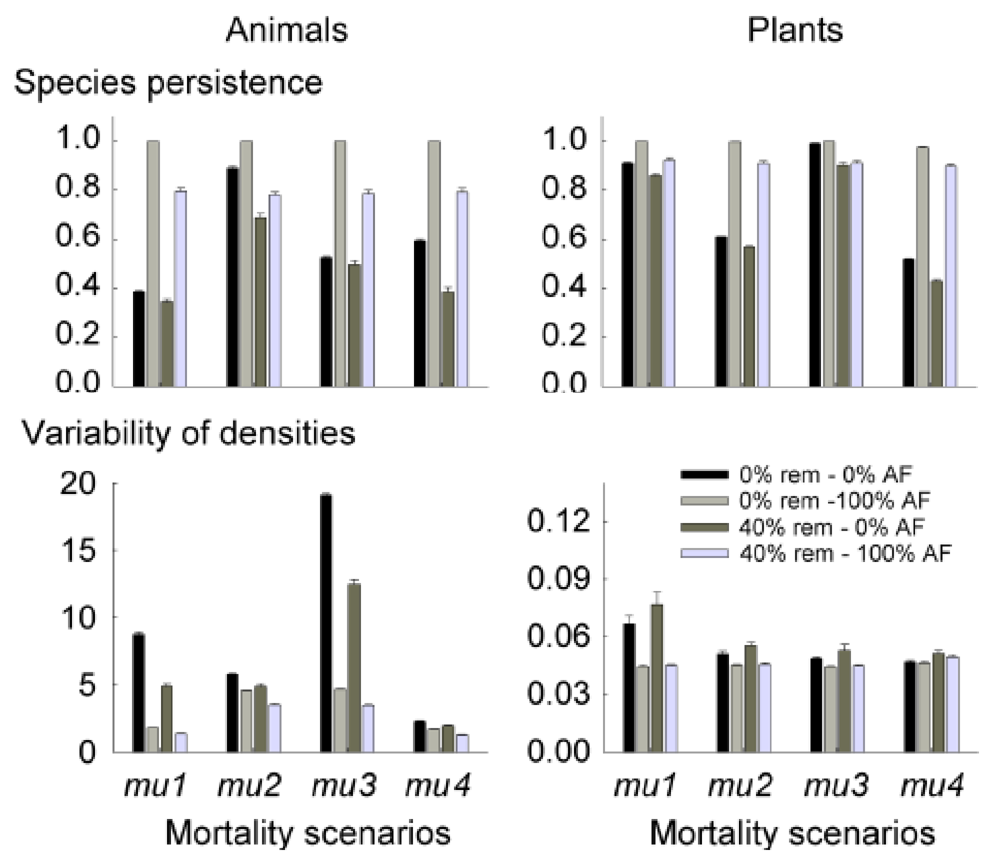
$$V_{ij} = \alpha_{ij}\tau_{ij}a_j p_i$$

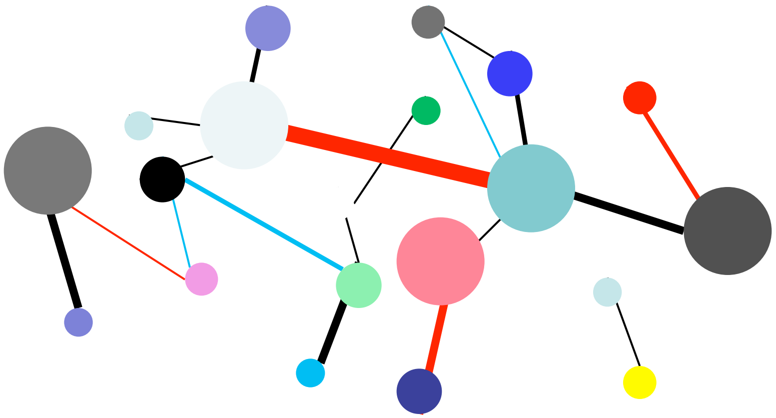
$$V_{ij} = 0$$

$$\frac{da_j}{dt} = \sum_{i \in P} c_{ij}V_{ij}f_{ij}(R_i, p_i) - \mu_j^A a_j$$

$$\frac{dR_i}{dt} = \beta_i p_i - \phi_i R_i - \sum_{j \in A} V_{ij}f_{ij}(R_i, p_i)$$

$$\frac{d\alpha_{ij}}{dt} = G_j\alpha_{ij}\left(c_{ij}\tau_{ij}p_i f_{ij}(R_i, p_i) - \sum_{k \in P}\alpha_{kj}c_{kj}\tau_{ij}p_i f_{kj}(R_k, p_k)\right)$$





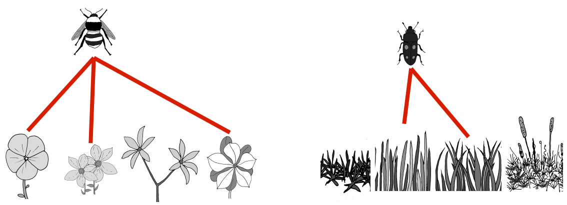
Thank you!

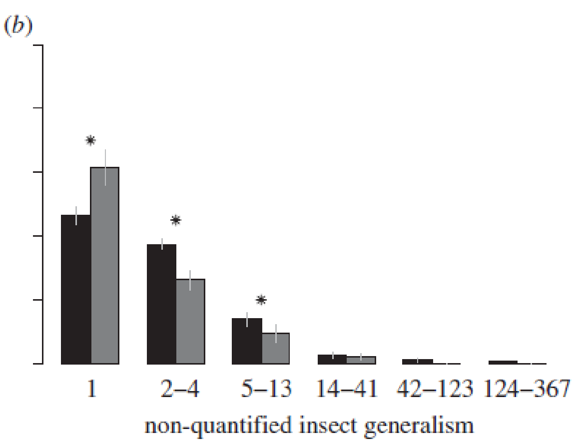
And thanks to:

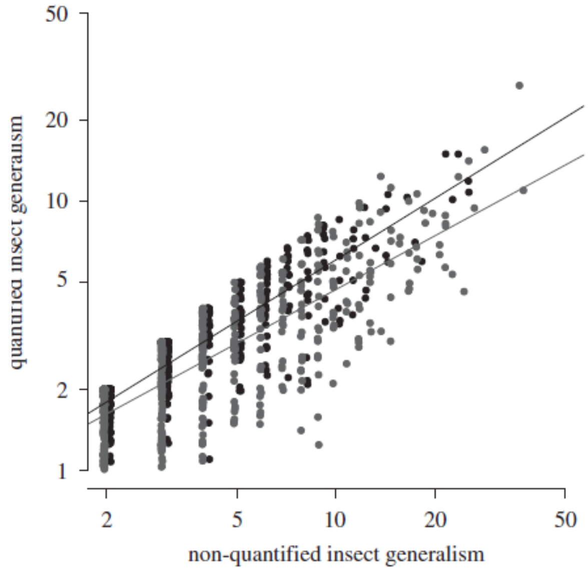
Elisa Thébault

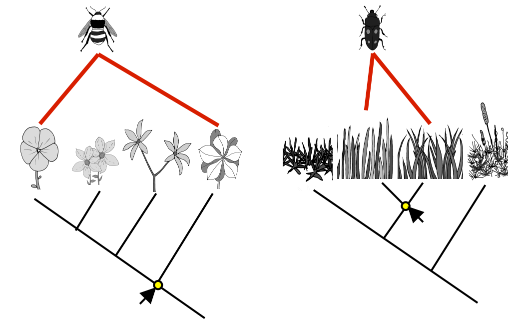
Alix Sauve

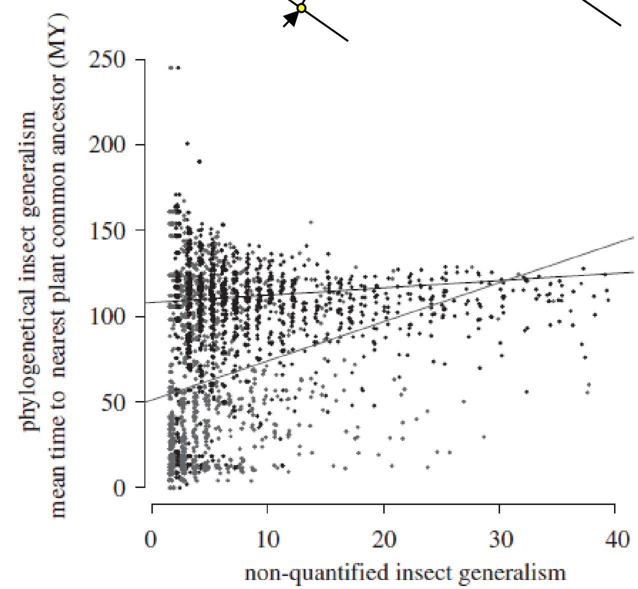
Generalism and interaction type

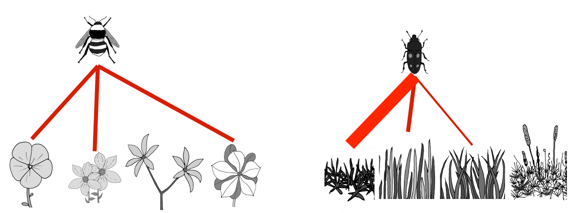












Fontaine et al., Proc. B., 2009

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Généralisme et pollinisation

Ecology, 77(4), 1996, pp. 1043–1060

GENERALIZATION IN POLLINATION SYSTEMS, AND WHY IT MATTERS[1]

Nickolas M. Waser,[2,3] Lars Chittka,[4,5] Mary V. Price,[2,3]
Neal M. Williams,[4] and Jeff Ollerton[6]

Annu. Rev. Ecol. Syst. 1990. 21:243–73

HOST SPECIALIZATION IN PHYTOPHAGOUS INSECTS

John Jaenike

Journal of Ecology 1996, **84**, 767–769

FORUM

Reconciling ecological processes with phylogenetic patterns: the apparent paradox of plant–pollinator systems

JEFF OLLERTON

Journal of Animal Ecology 2002
71, 400–412

Host specialization of leaf-chewing insects in a New Guinea rainforest

VOJTECH NOVOTNY*, YVES BASSET†, SCOTT E. MILLER‡, PAVEL DROZD§ and LUKAS CIZEK*

TREE vol. 15, no. 4 April 2000

REVIEWS

Generalization versus specialization in plant pollination systems

Steven D. Johnson and Kim E. Steiner

PROCEEDINGS OF THE ROYAL SOCIETY B

Proc. R. Soc. B (2005) **272**, 1083–1090
doi:10.1098/rspb.2004.3023
Published online 1 June 2005

Review

Host specificity of insect herbivores in tropical forests

Vojtech Novotny[1,*] and Yves Basset[2]