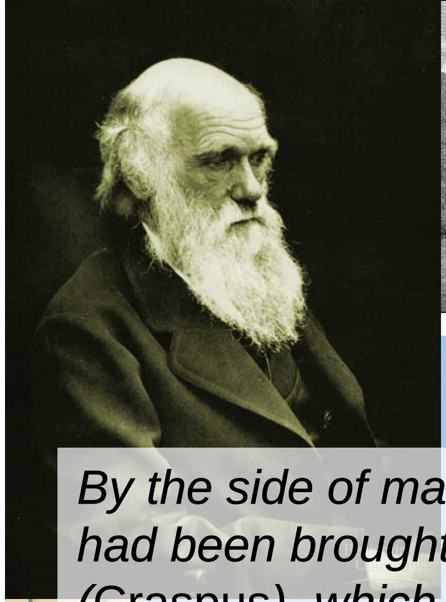
Structure et dynamique des communautés écologiques

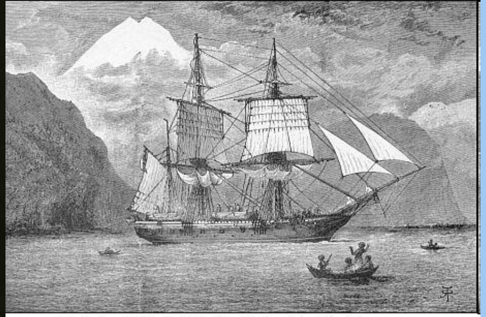
(i)

Structure of interaction networks, indirect interactions and processes shaping networks

Colin Fontaine

Aussois 2021





H.M.S. *Beagle* in Straits of Magellan. Mt. Sarmiento in the distance.

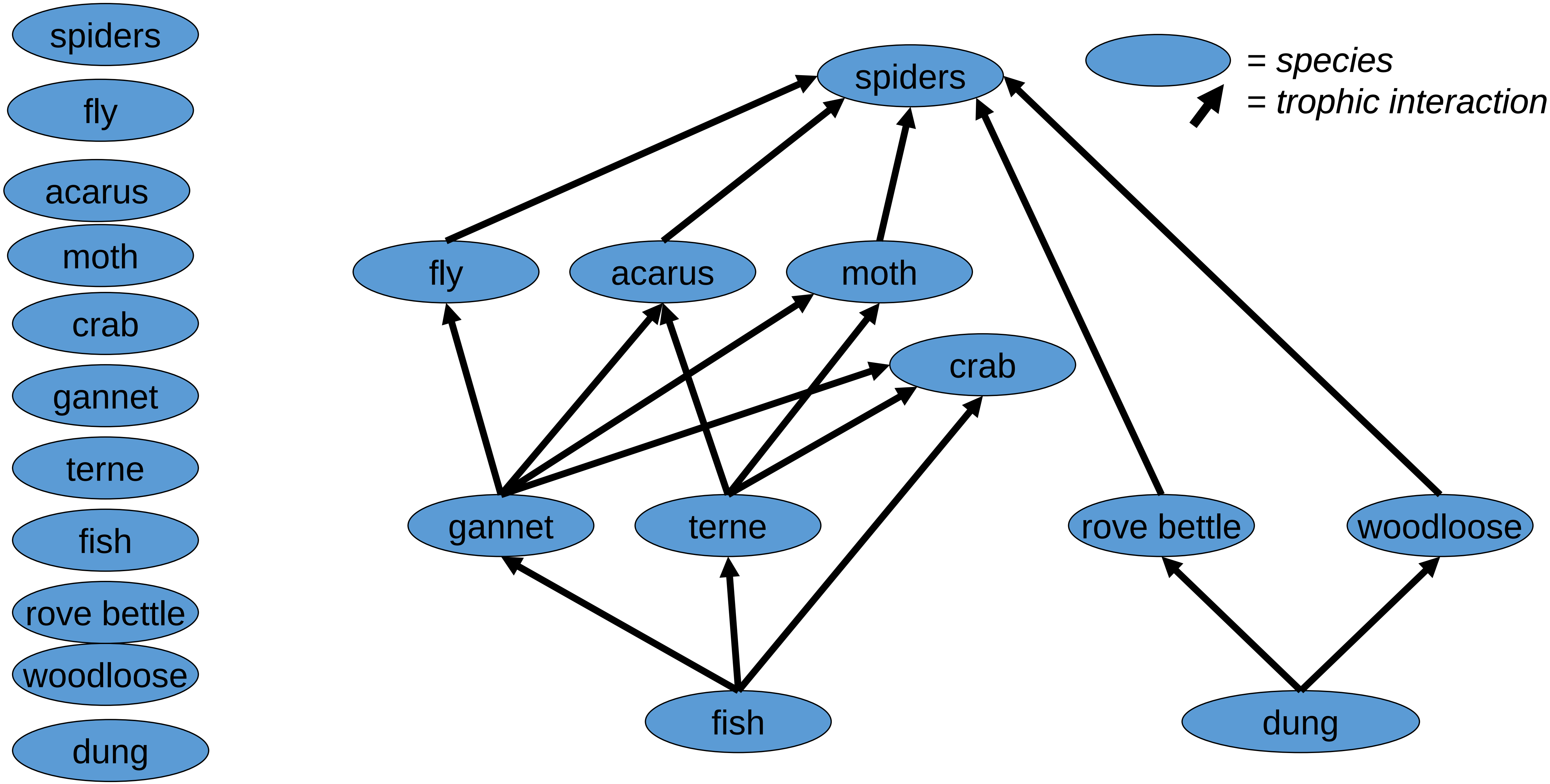
By the side of many of these nests a small flying-fish was placed; which, I suppose, had been brought by the male bird for its partner…quickly a large and active crab (Craspus)*, which inhabits the crevices of the rock, stole the fish from the side of the nest, as soon as we had disturbed the birds. Not a single plant, not even a lichen, grows on this island; yet it is inhabited by several insects and spiders. The following list completes, I believe, the terrestrial fauna: a species of Feronia and an acarus, which must have come here as parasites on the birds; a small brown moth, belonging to a genus that feeds on feathers; a staphylinus* (Quedius) *and a woodlouse from beneath the dung; and lastly, numerous spiders, which I suppose prey on these small attendants on, and scavengers of the waterfowl.*

Darwin, The voyage of the Beagle, 1839

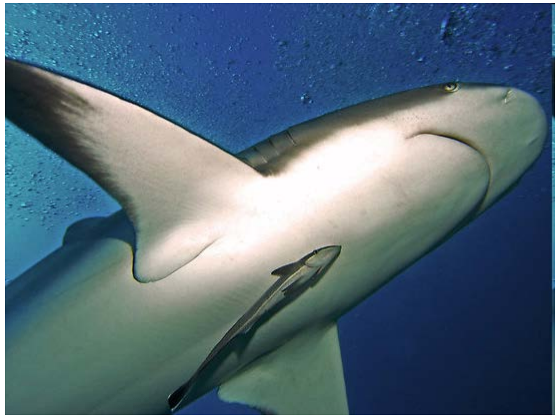
From species list to interaction networks

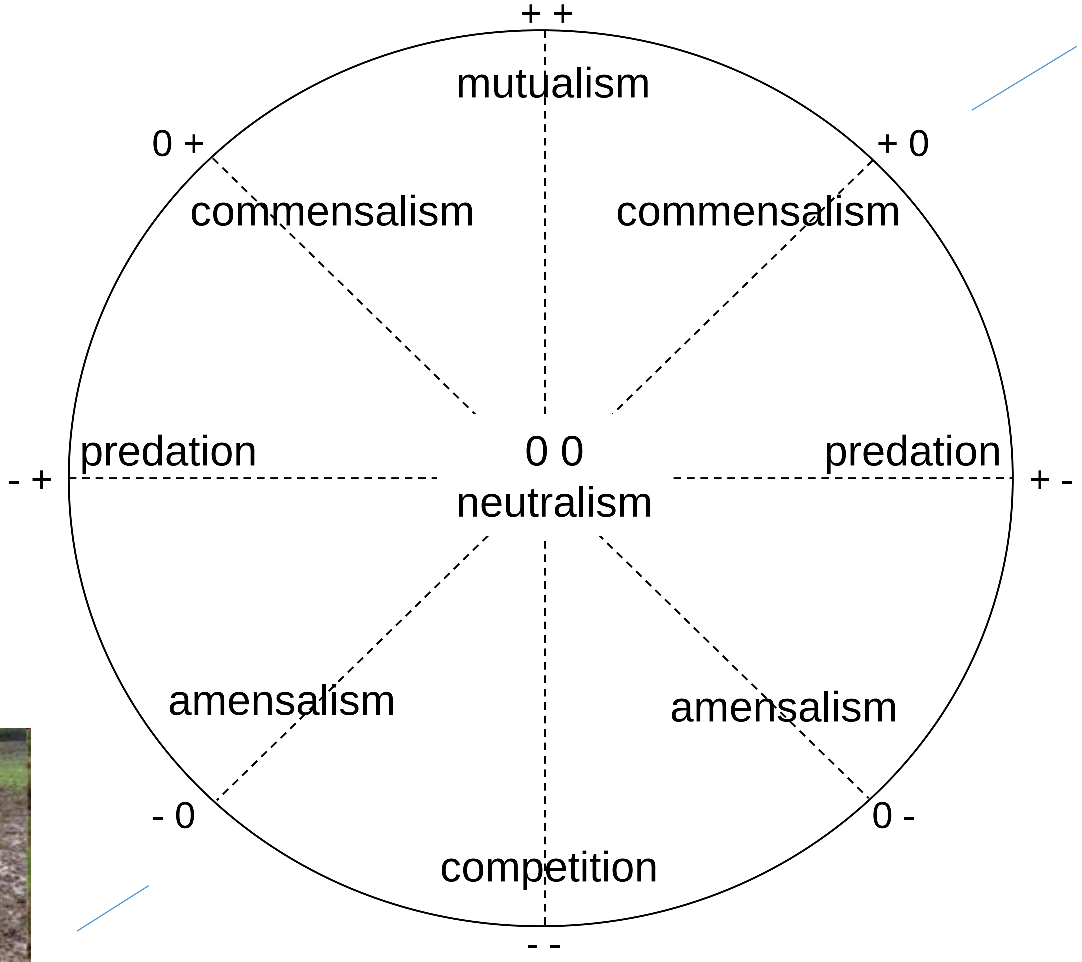
- spiders
- fly
- acarus
- moth
- crab
- gannet
- terne
- fish
- rove bettle
- woodloose
- dung

From species list to interaction networks

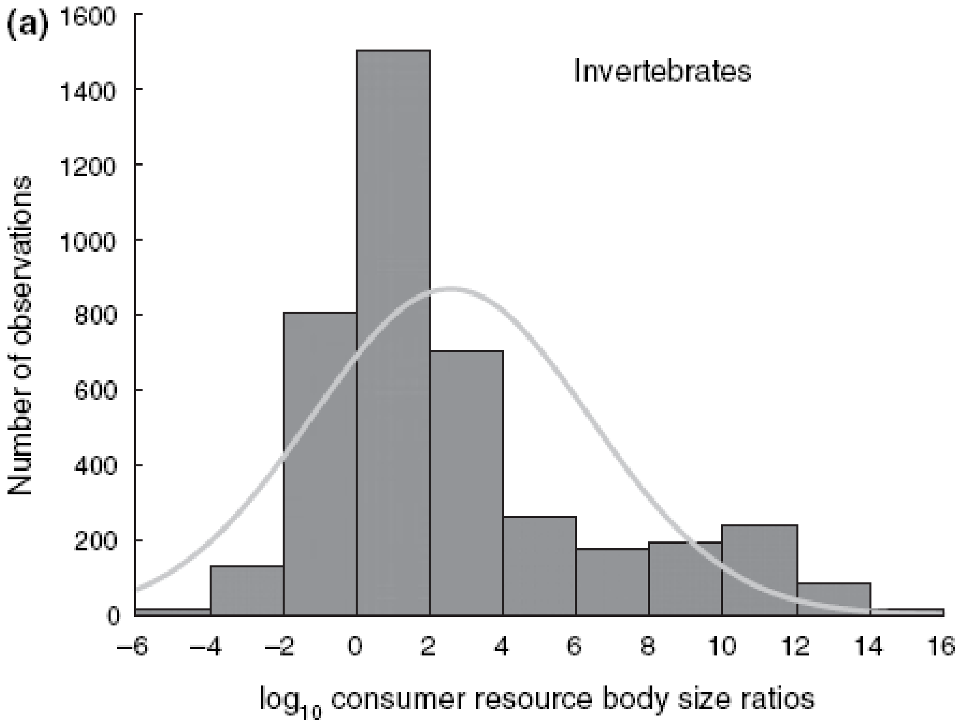


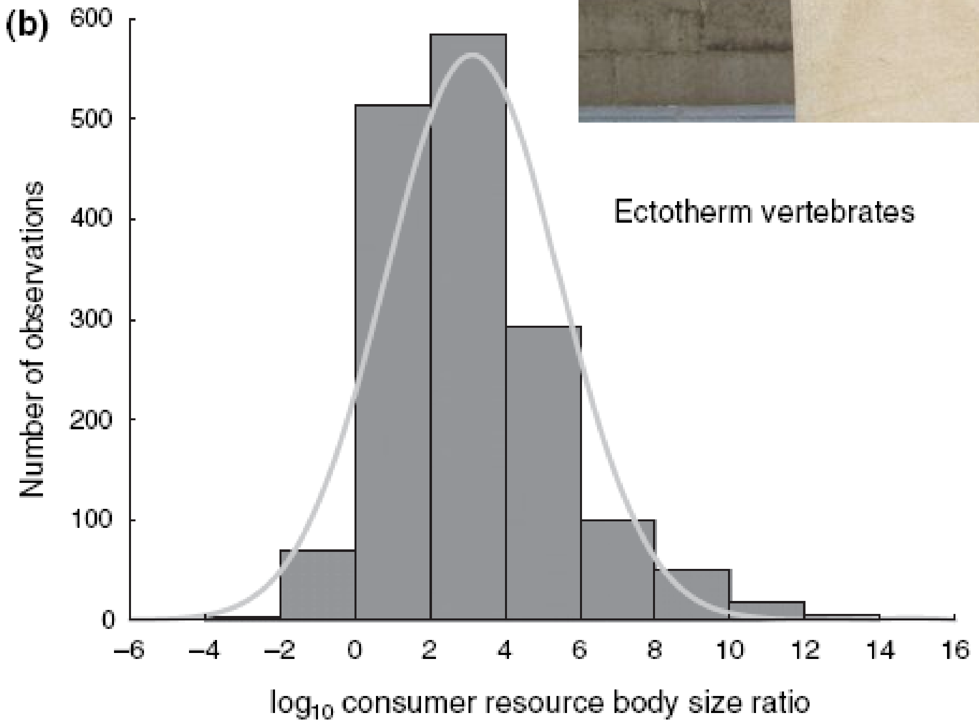
Diversity of ecological interactions





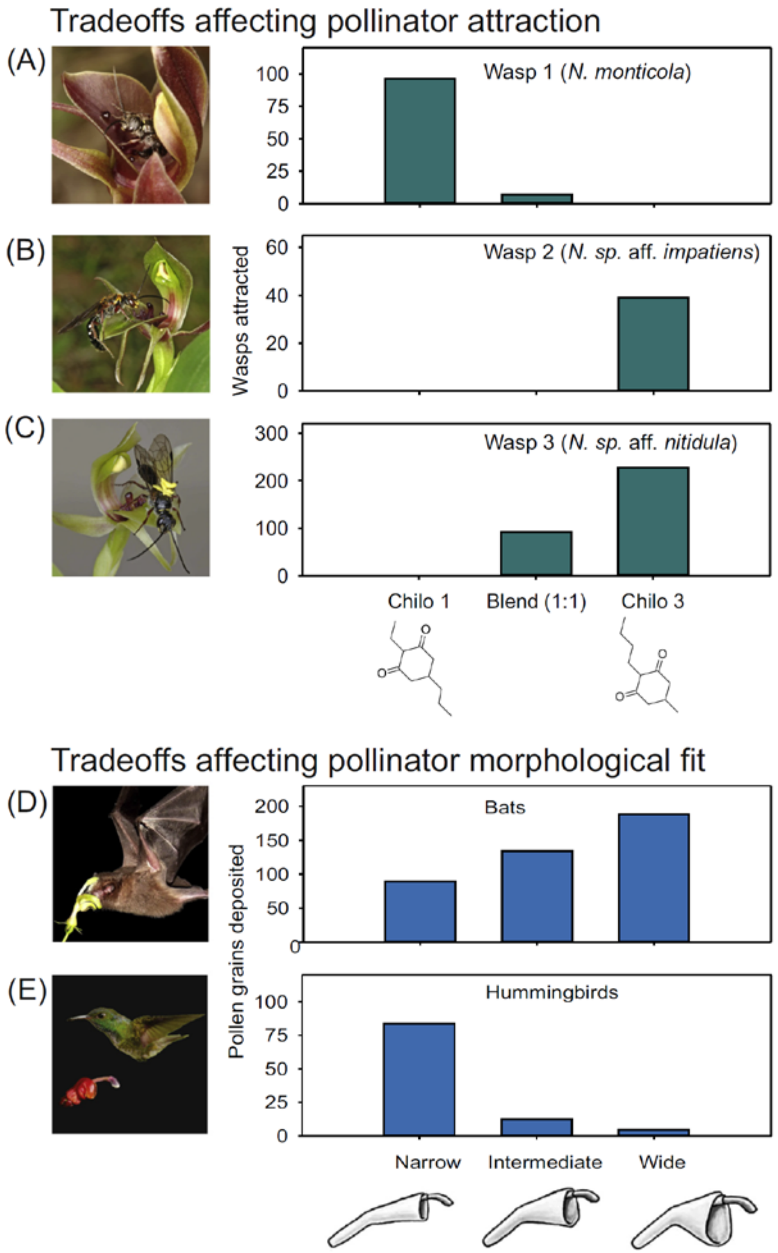
Interaction among species and species traits

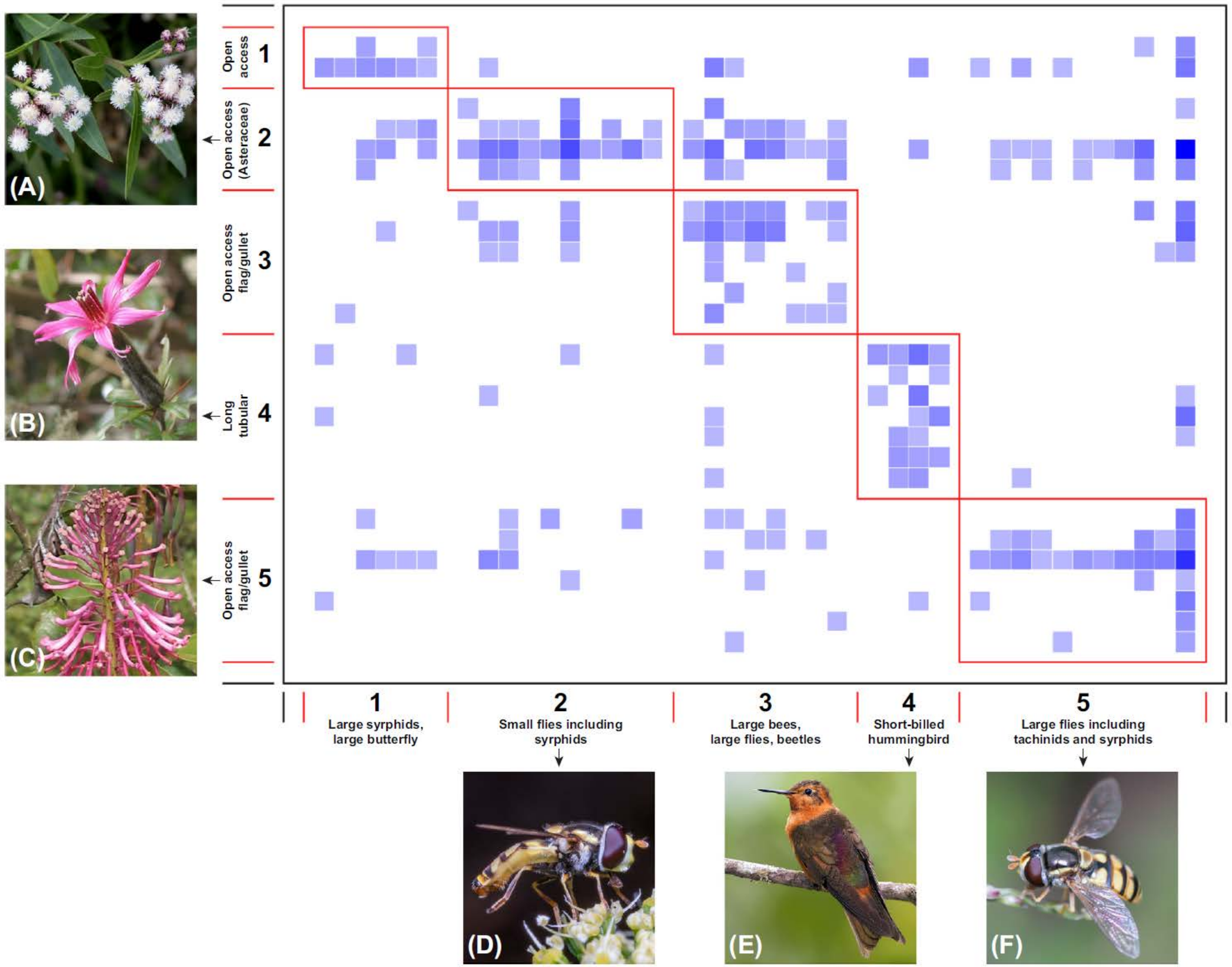




Brose et al. (2006)

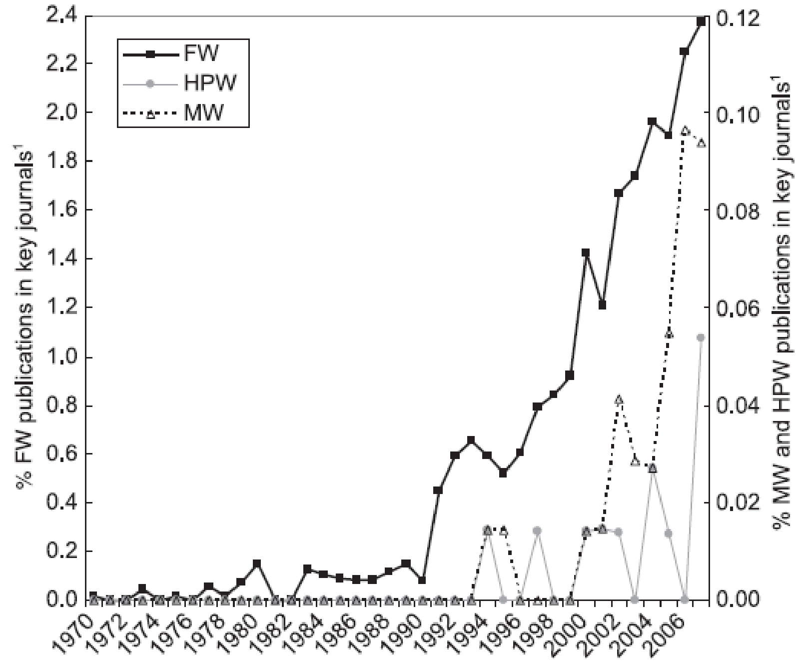
Interaction among species and species traits



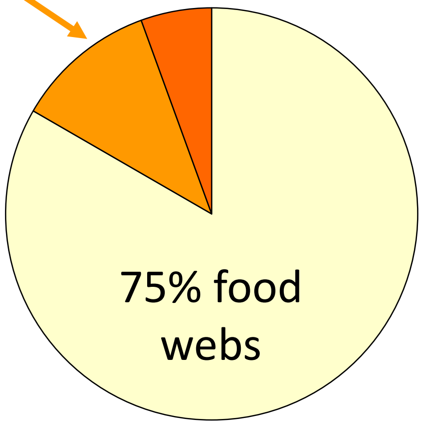


Phillips et al. 2020

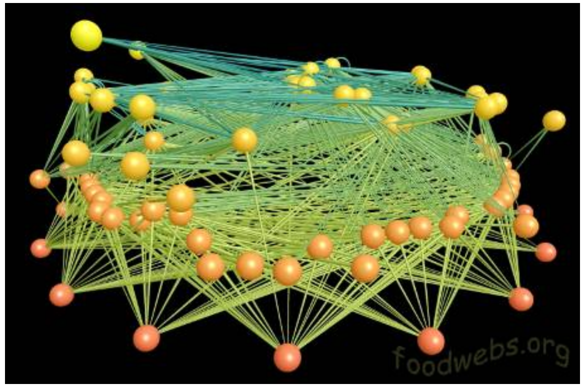
Networks of different interaction types



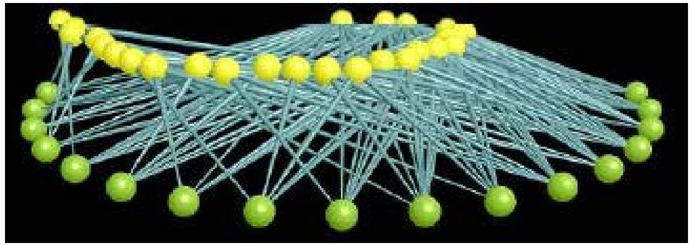
Ings et al. 2009



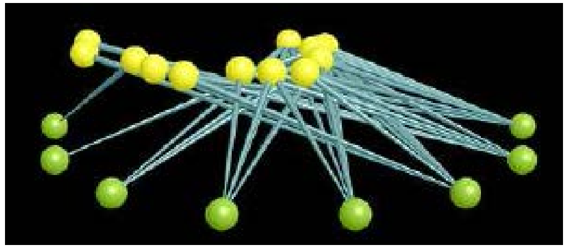
food web



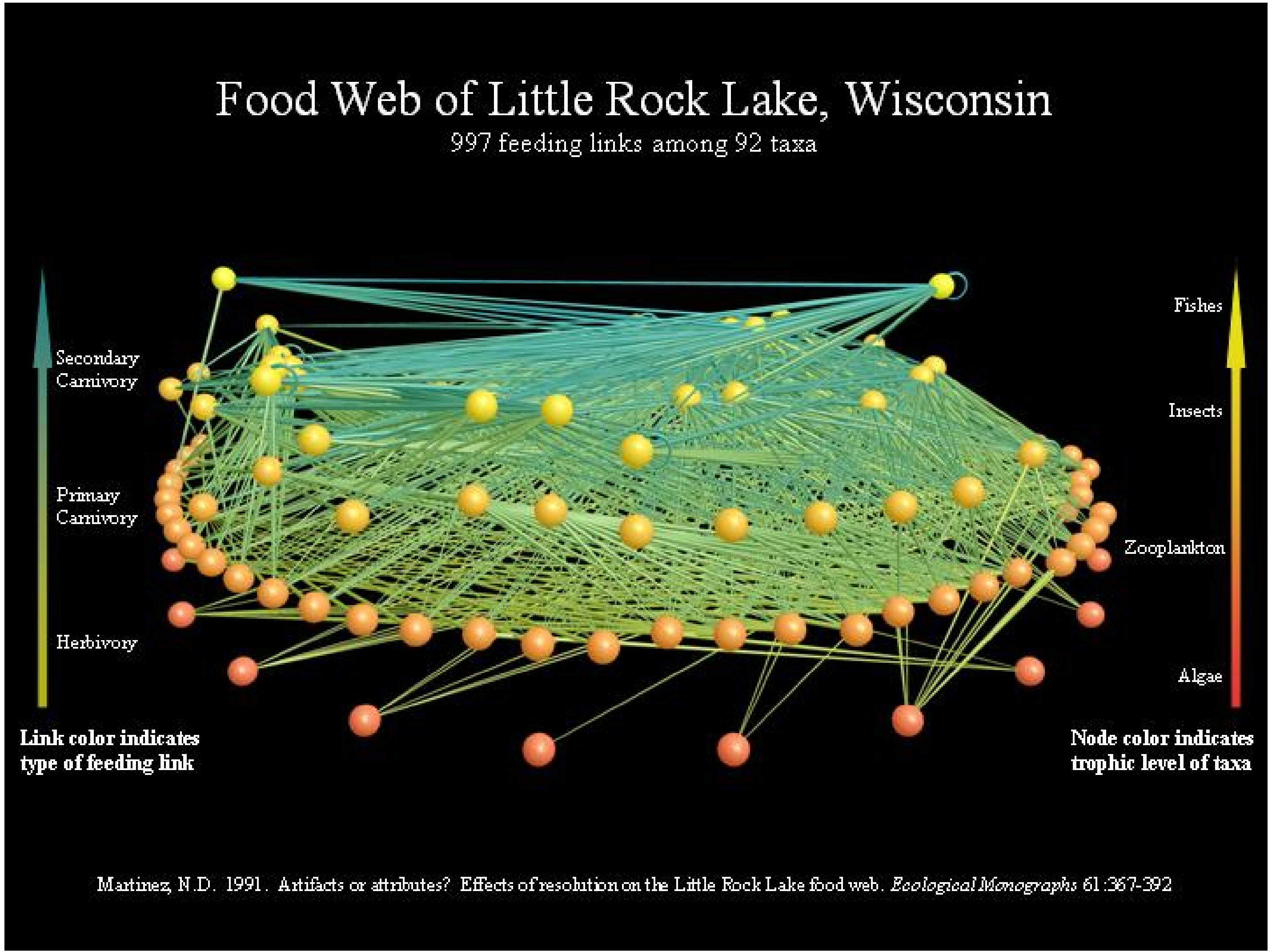
mutualistic web



host-parasite web



(i)
Structure of ecological networks

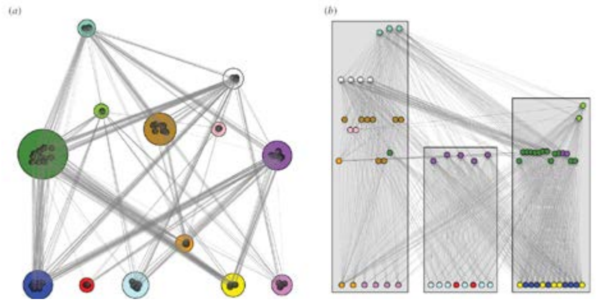


Structure of trophic network and compartments

Trophic groups and modules: two levels of group detection in food webs

Benoit Gauzens[1,2], Elisa Thébault[1], Gérard Lacroix[1,3] and Stéphane Legendre[4]

J. R. Soc. Interface **12**: 20141176



Journal of Animal Ecology 1992,
61, 551–560

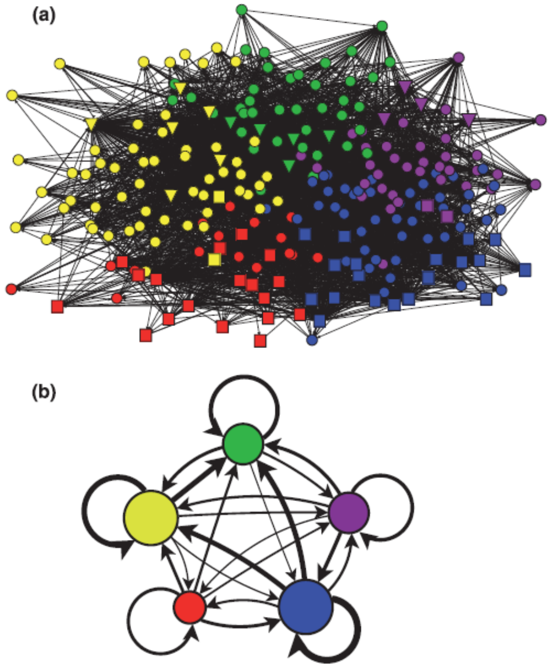
Compartments and predation in an estuarine food web

DAVID RAFFAELLI and STEPHEN J. HALL*
Culterty Field Station, University of Aberdeen, Newburgh, Ellon, Aberdeen AB4 0AA, Scotland; and
**SOAFD Marine Laboratory, P.O. Box 101, Victoria Rd, Aberdeen AB9 8DB, Scotland*

Ecology Letters, (2009) **12**: 779–788 doi: 10.1111/j.1461-0248.2009.01327.x

LETTER

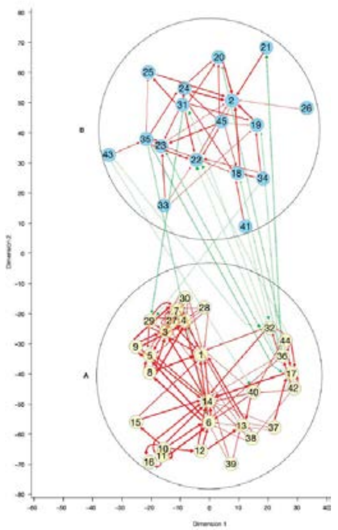
Compartments in a marine food web associated with phylogeny, body mass, and habitat structure



Ecology, 91(10), 2010, pp. 2941–2951

Origin of compartmentalization in food webs

R. Guimerà,[1,2,3,4,11] D. B. Stouffer,[5] M. Sales-Pardo,[1,2,4,6] E. A. Leicht,[7] M. E. J. Newman,[8,9] and L. A. N. Amaral[1,2,10]



letters to nature

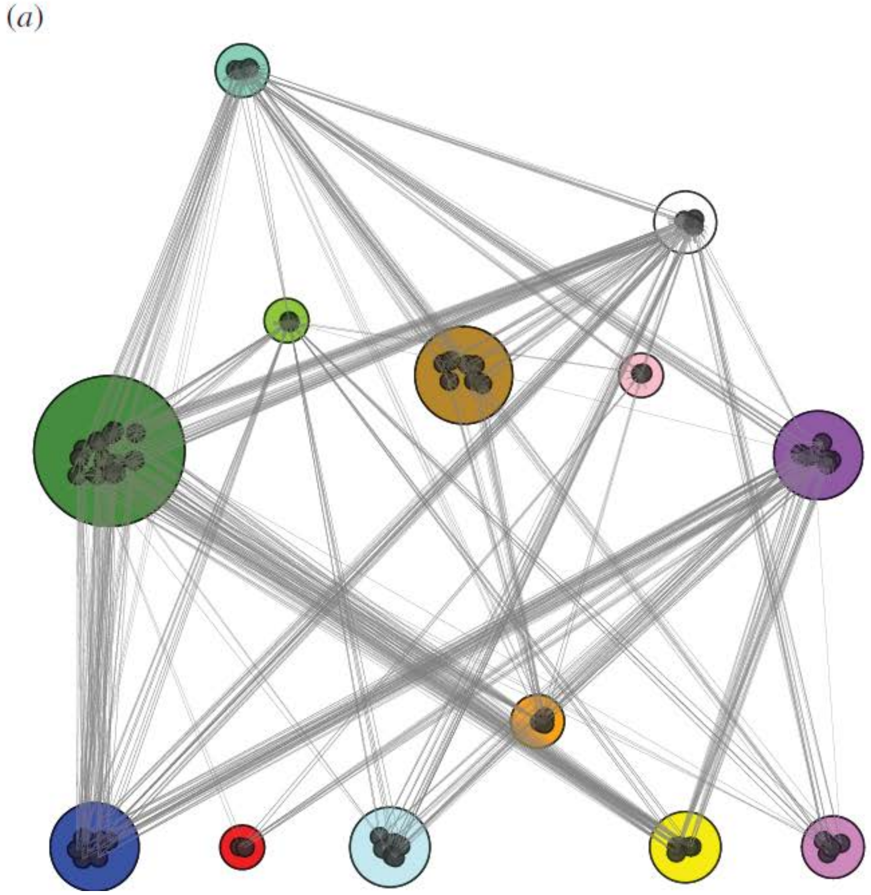
Compartments revealed in food-web structure

Ann E. Krause[1], Kenneth A. Frank[1,2], Doran M. Mason[3], Robert E. Ulanowicz[4] & William W. Taylor[1]

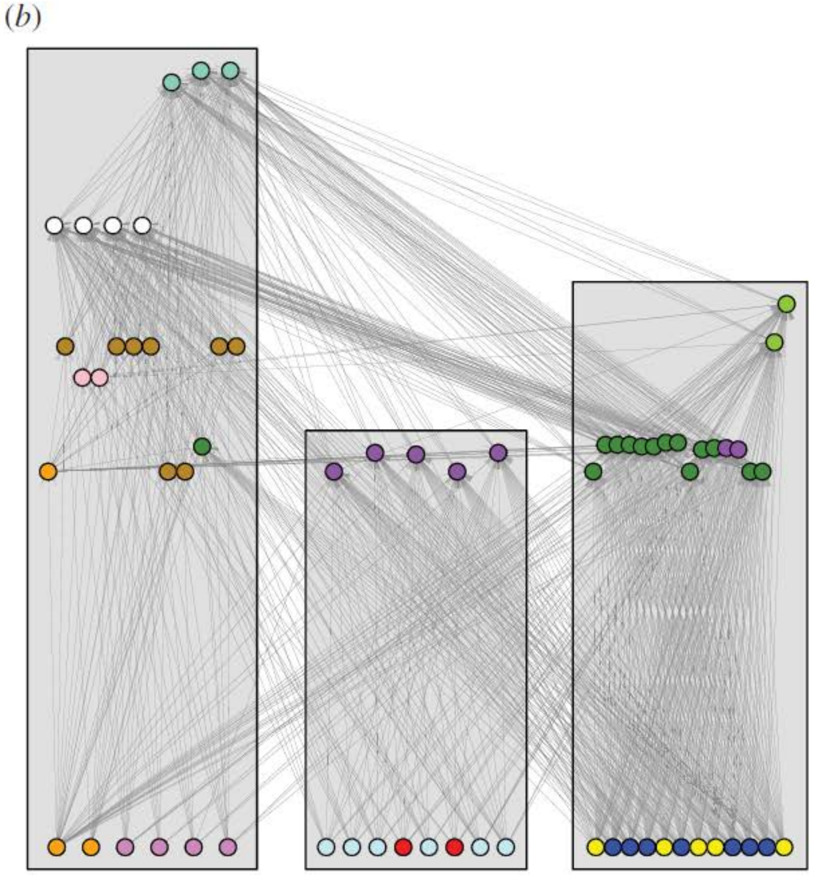
NATURE | VOL 426 | 20 NOVEMBER 2003 | www.nature.com/nature

Different ways of making groups

Trophic groups

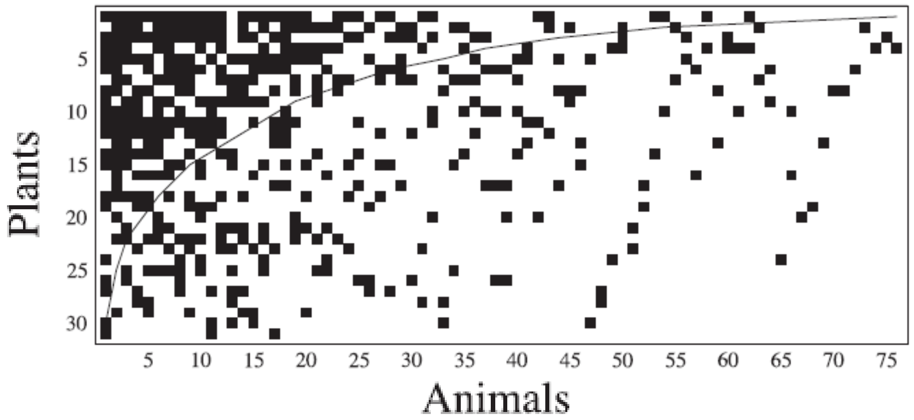


Compartments



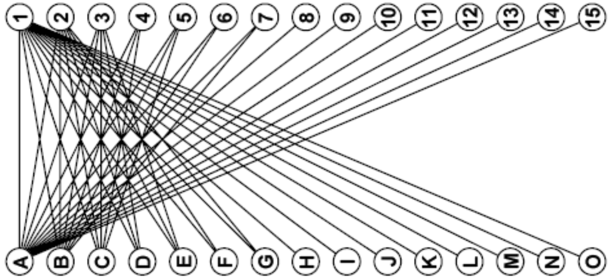
Gauzens et al. 2015

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

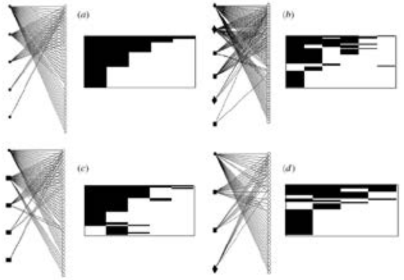
Bascompte et al. 2003

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?

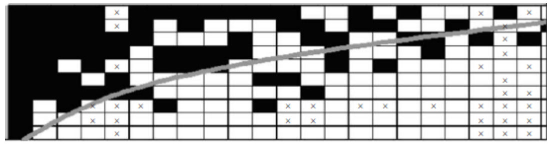
Paulo R. Guimarães Jr[1,2], Cristina Sazima[1], Sérgio Furtado dos Reis[1,*] and Ivan Sazima[1]



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

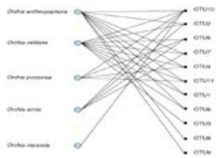
The Nested Assembly of Plant Facilitation Networks Prevents Species Extinctions

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

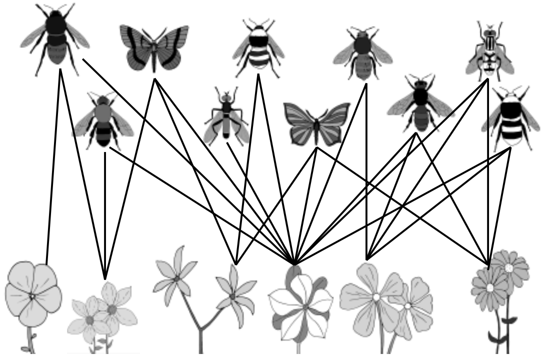
Low specificity and nested subset structure characterize mycorrhizal associations in five closely related species of the genus *Orchis*

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



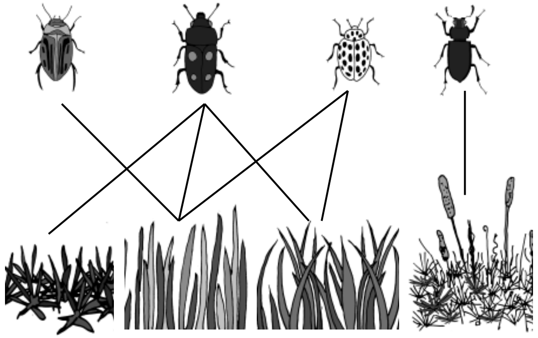
Network architecture and interaction type

Mutualistic

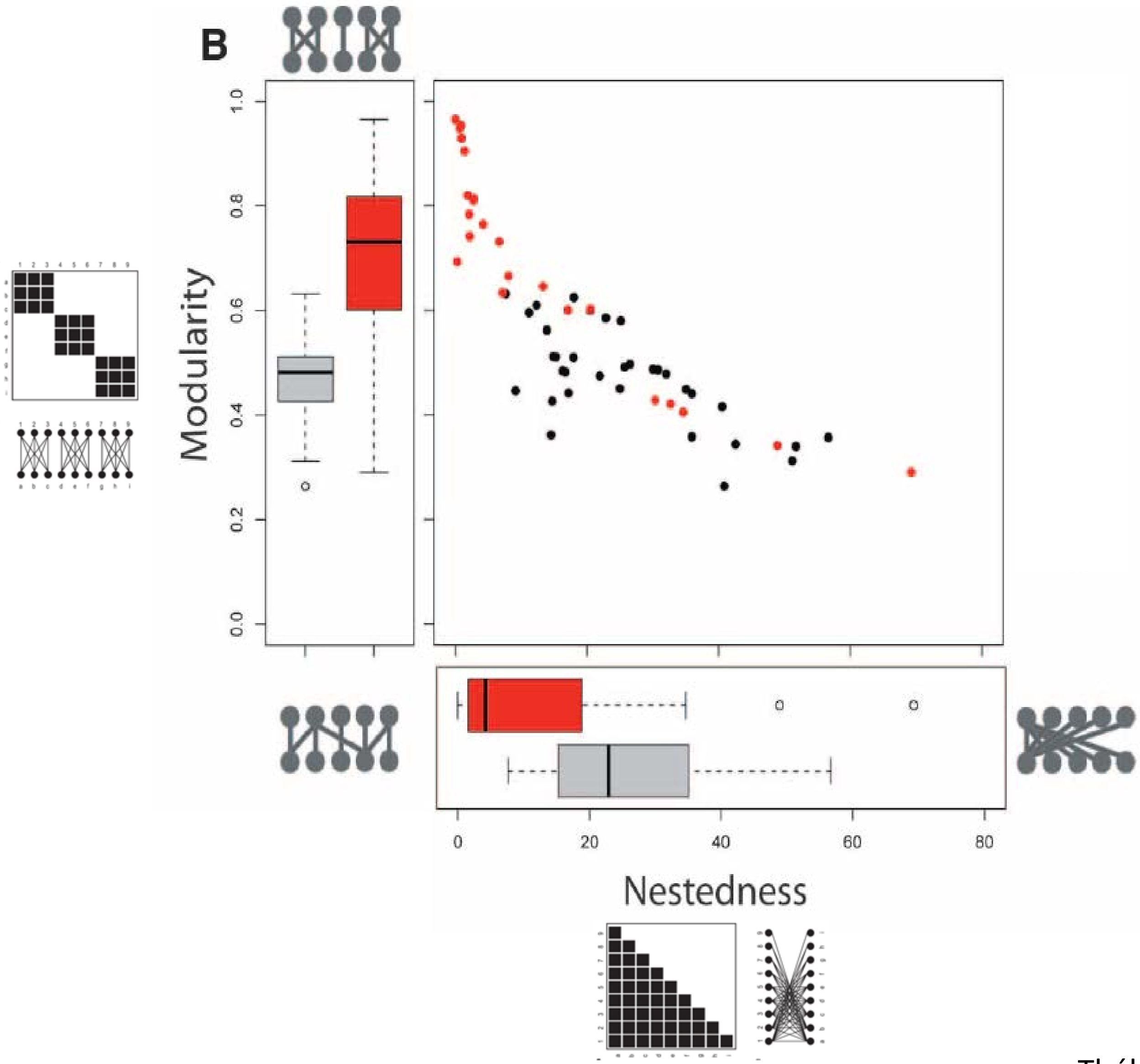


34 plant-pollinator webs

Antagonistic



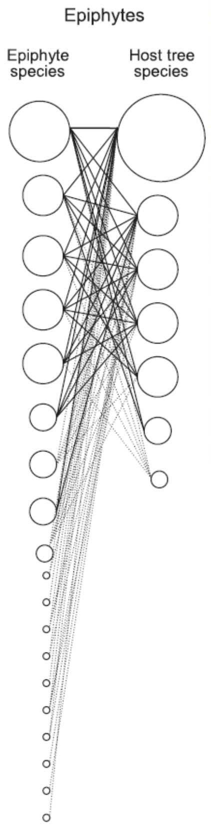
24 plant-phytophagous insect webs



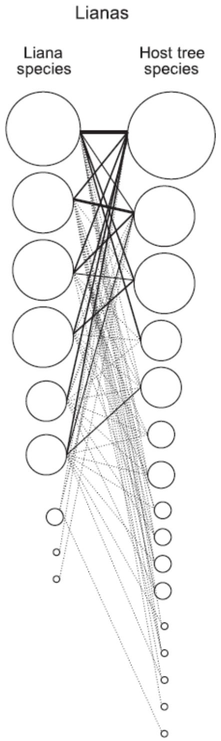
Thébault & Fontaine 2010

Network architecture and interaction type

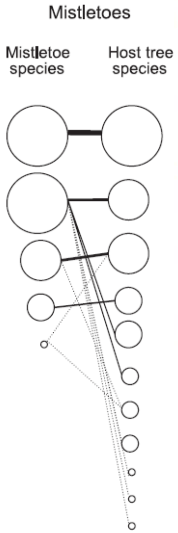
commensal



commensal/parasitic

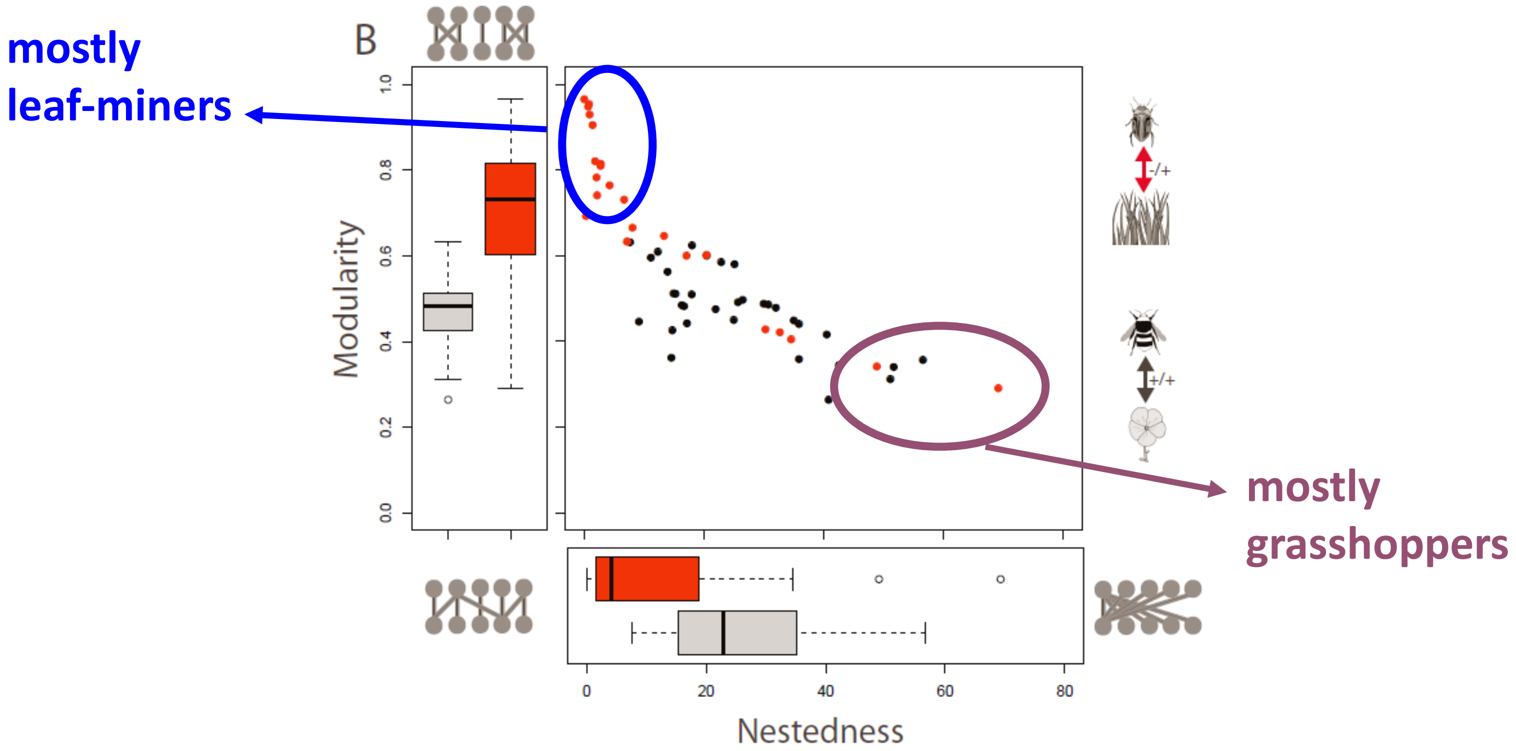


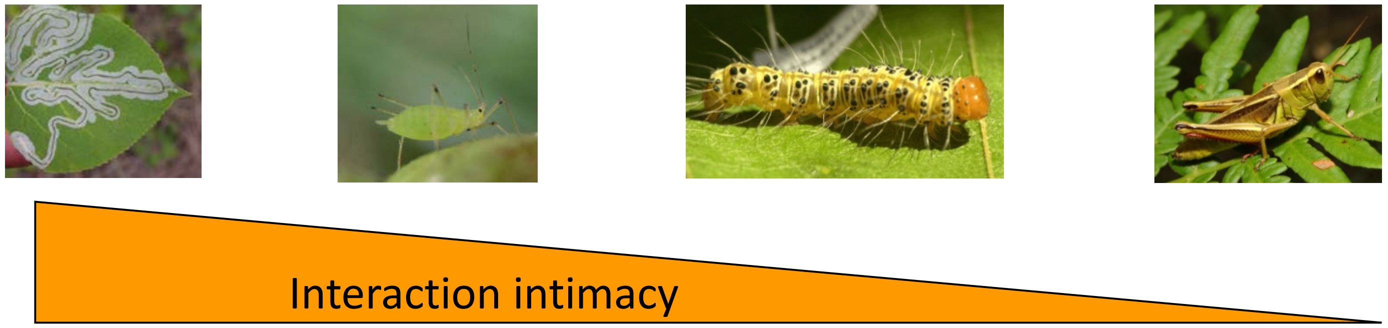
parasitic



Blick & Burns, 2011

and interaction intimacy?

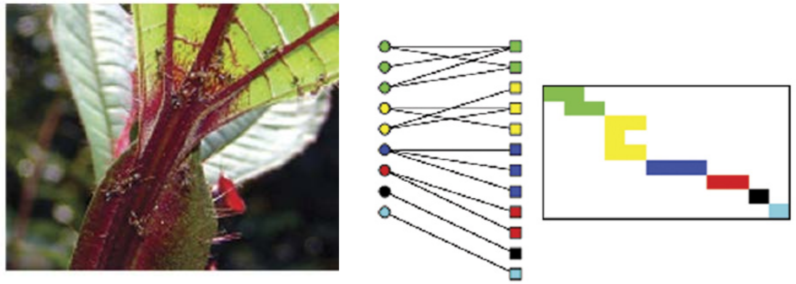




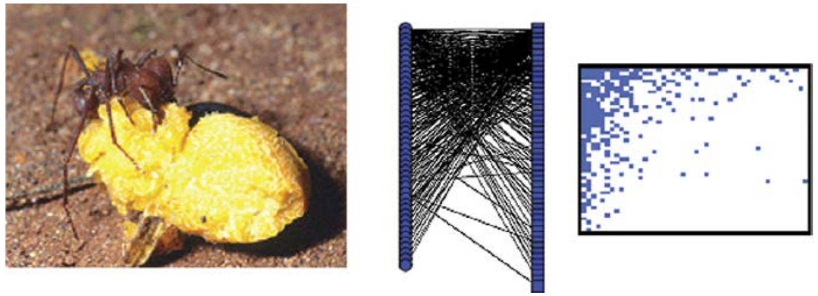
and interaction intimacy?

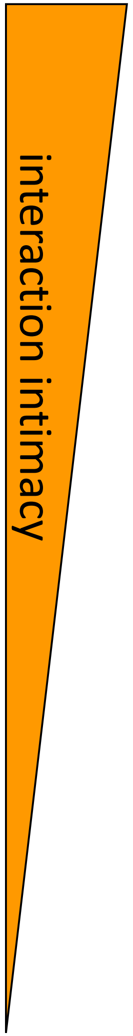
Mutualistic interactions

A

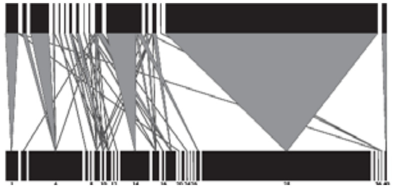


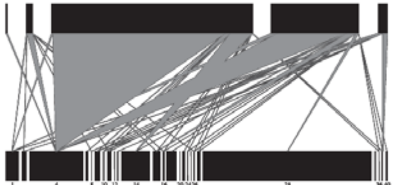
B

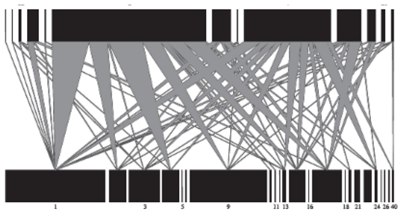




Antagonistic interactions



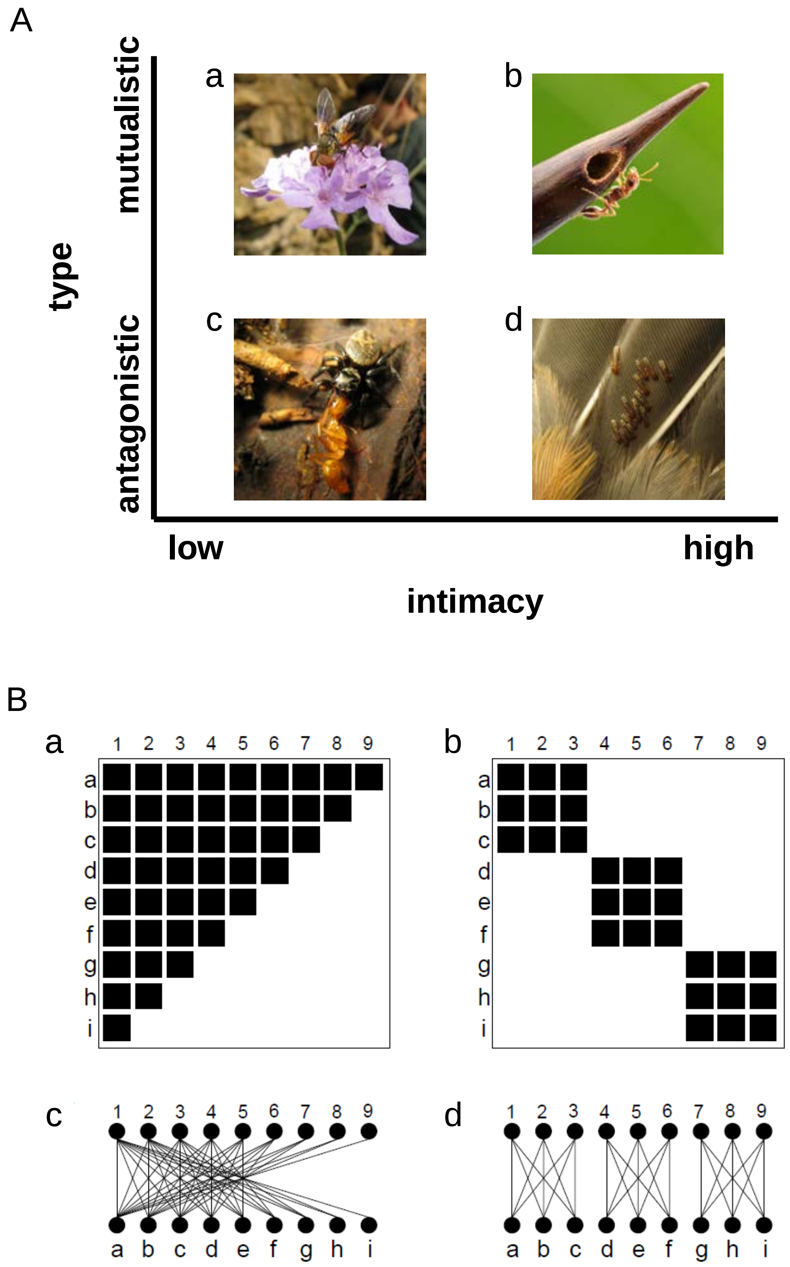


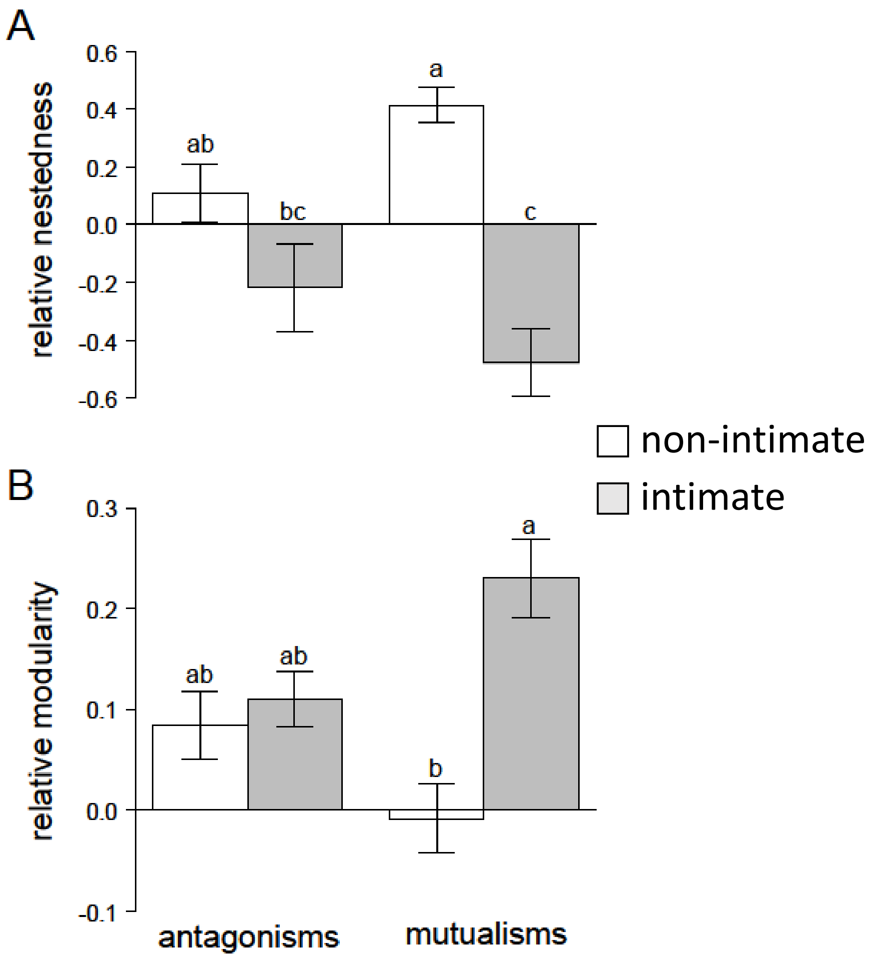


Guimaraes et al. 2007

van Veen et al. 2008

Interaction type and interaction intimacy



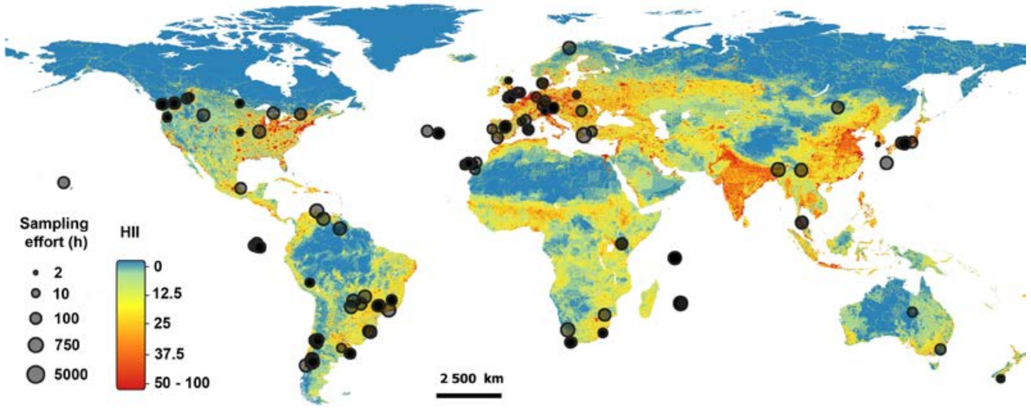


Stronger effect of interaction intimacy on mutualistic web

Fontaine et al., 2011

On the importance of sampling effects when analysing numerous networks from various origins

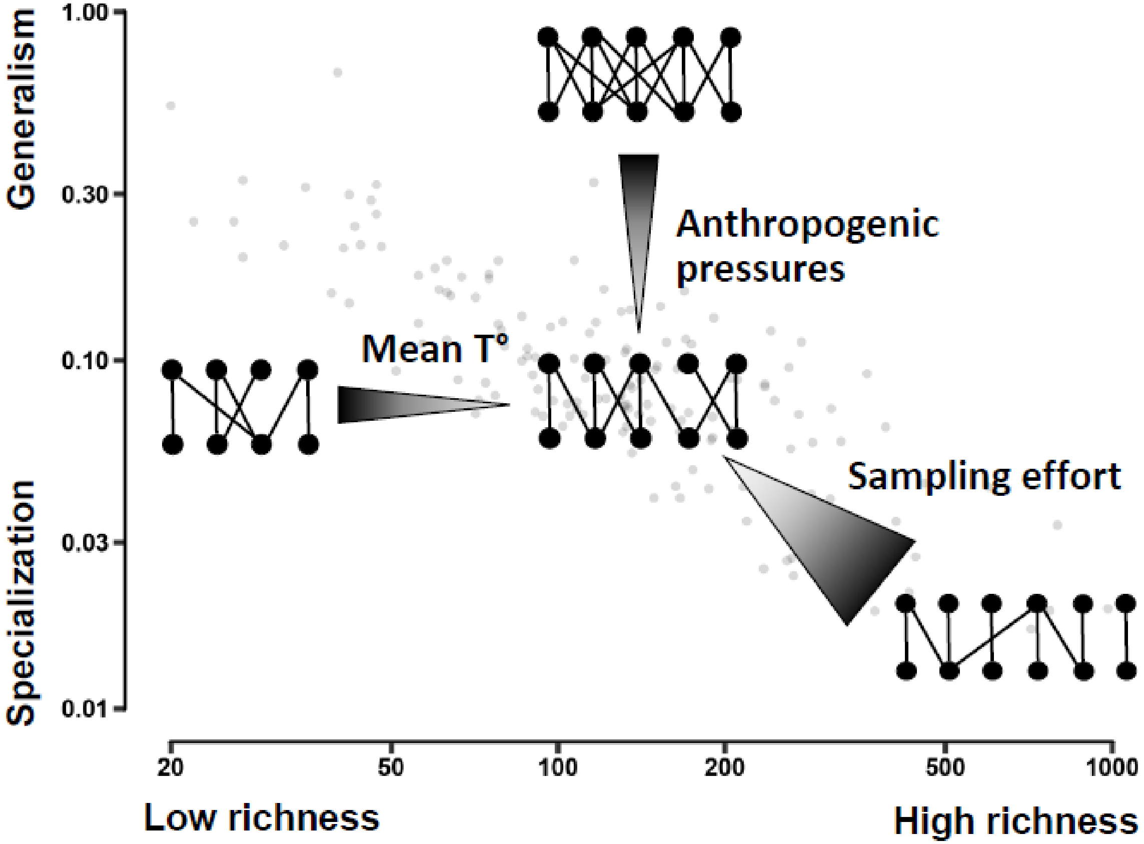
A database of 295 pollination networks



Looking for effects of:

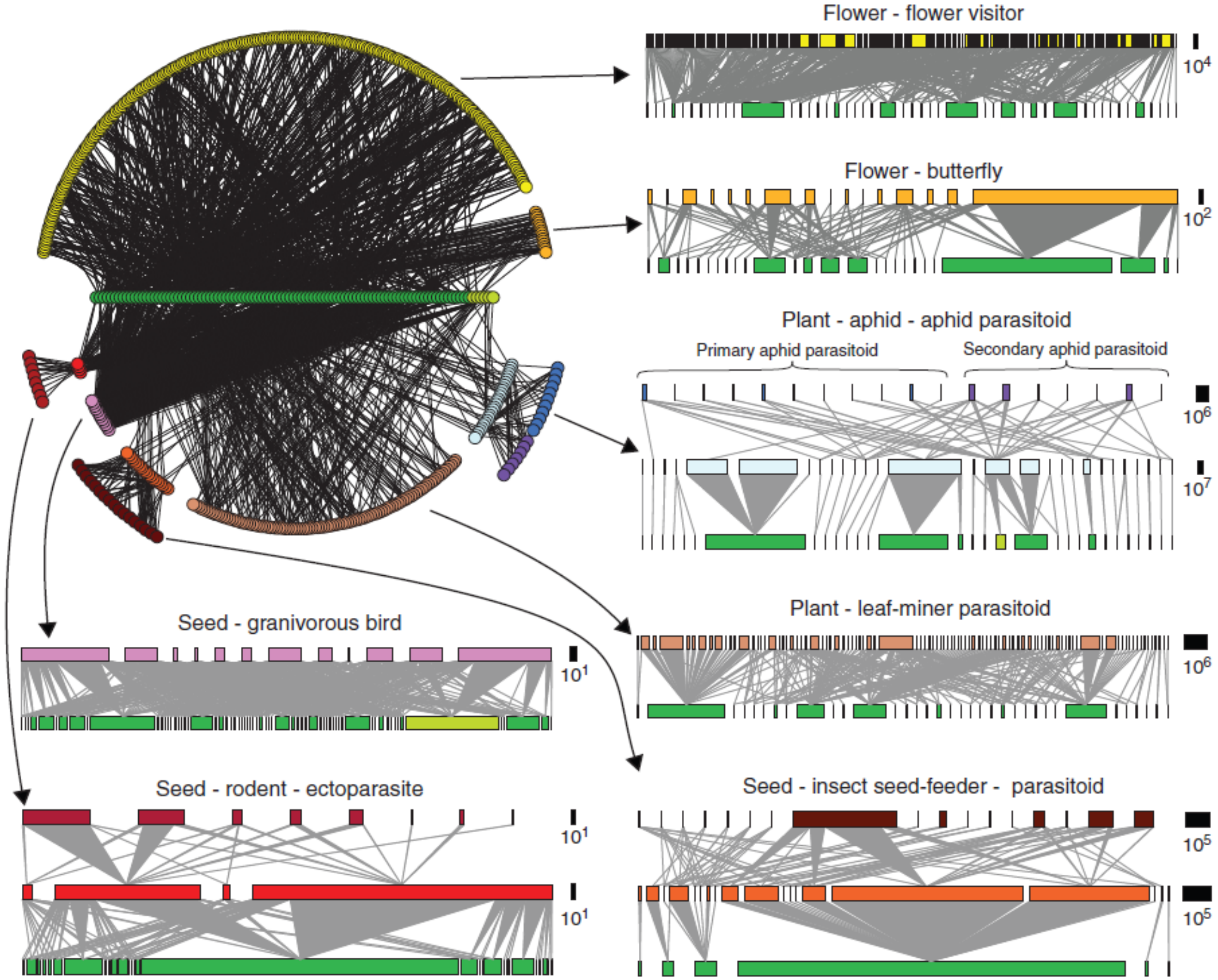
- Anthropogenic disturbances
- Climate
- Sampling effort and protocol

on network richness and species generalism

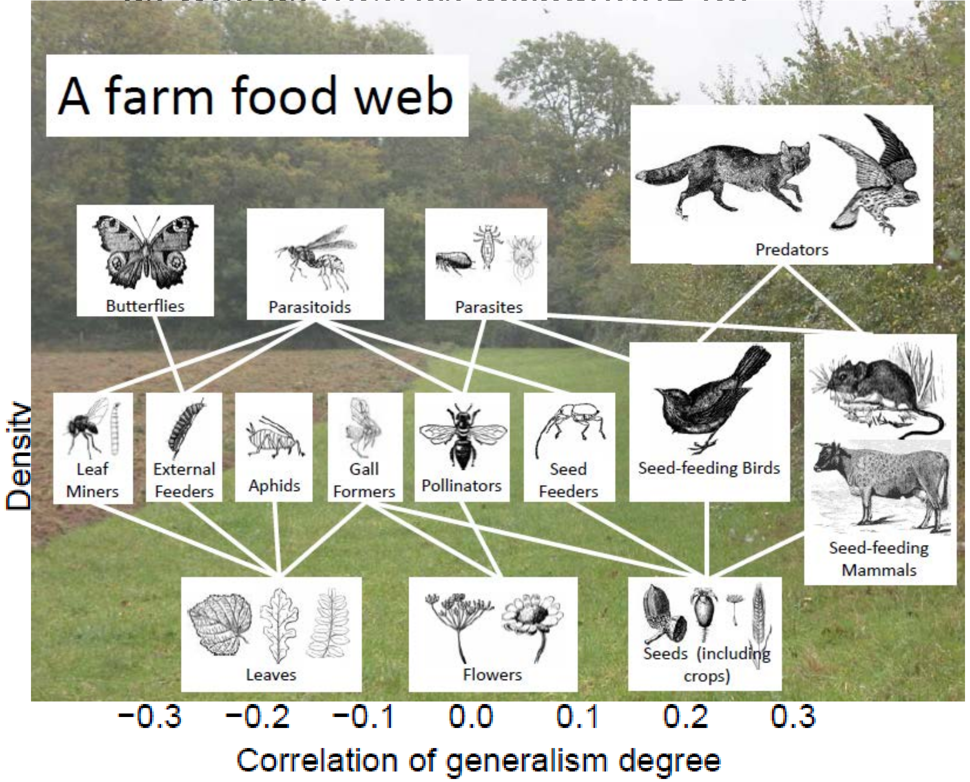


Doré et al. (2020)

Networks combining multiple interaction types



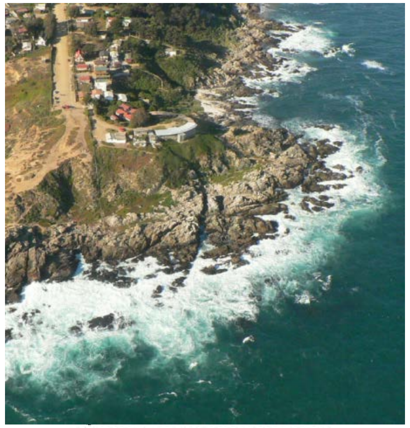
Need for new sampling methods
as well as metrics accounting for

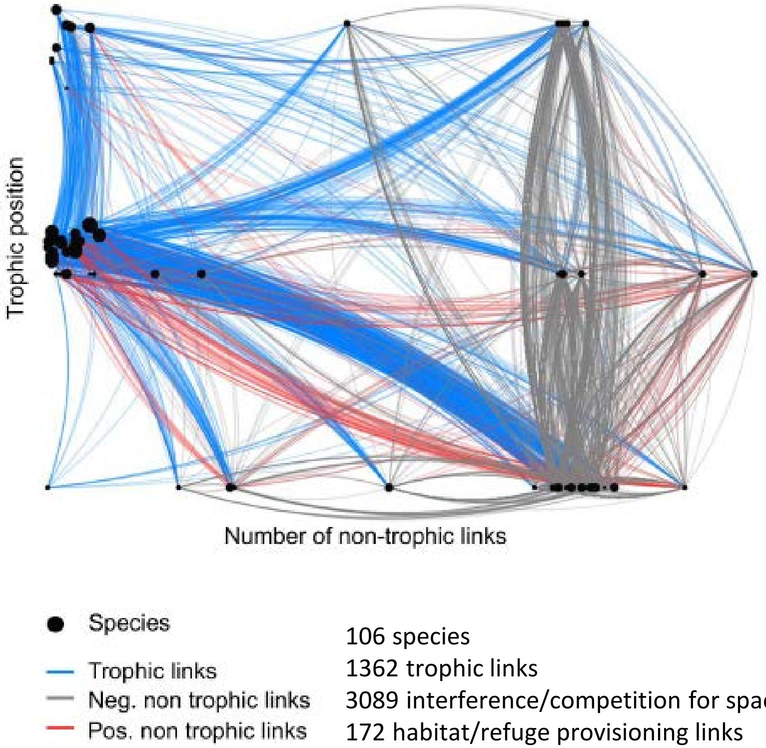


Pocock et al. (2012)

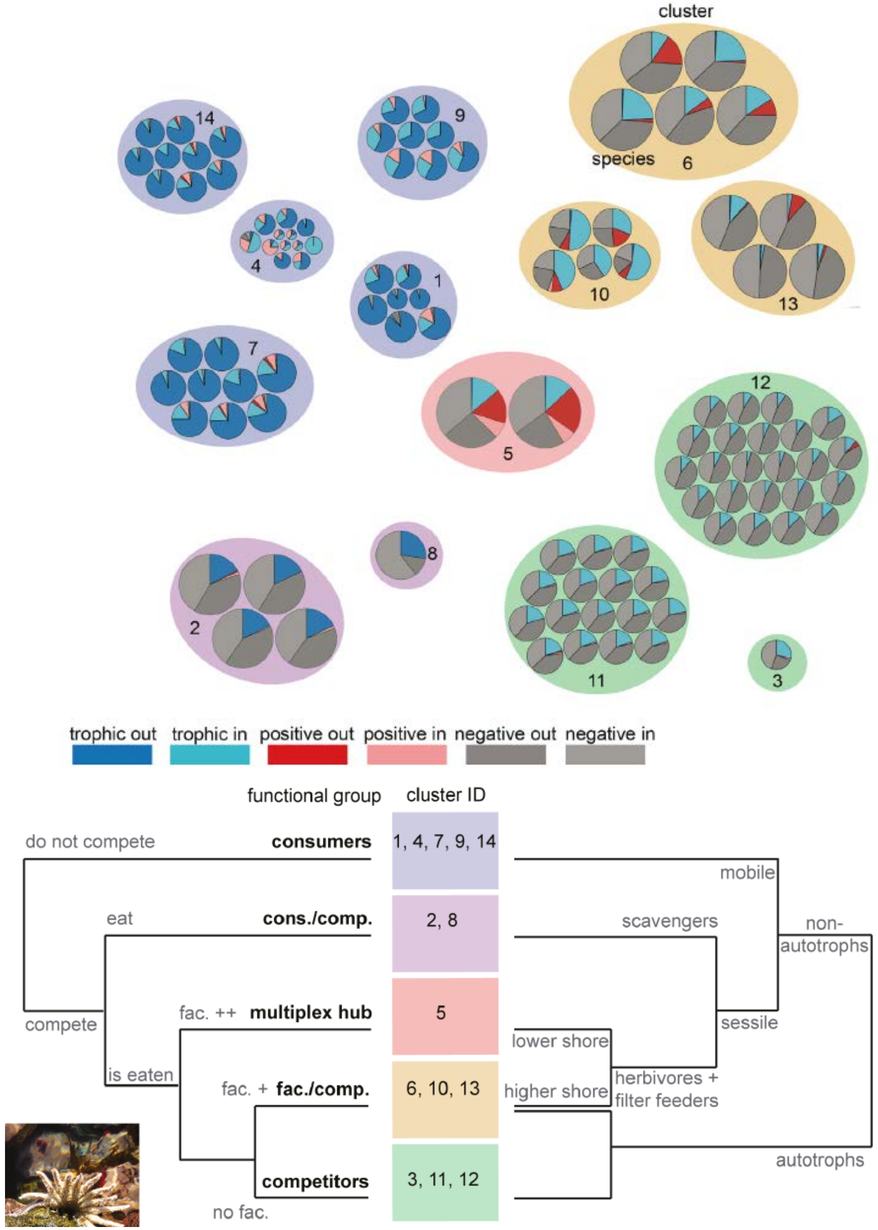
Sauve et al. (2016)

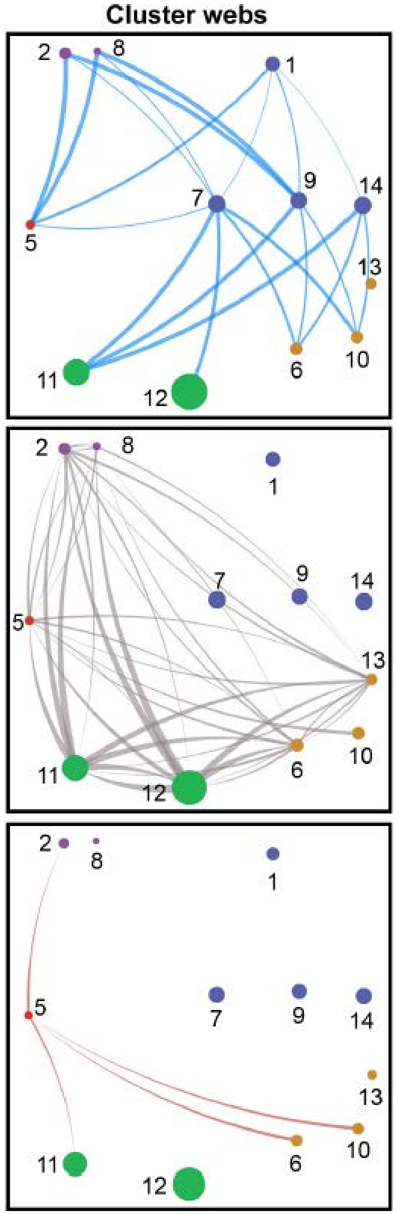
Networks combining multiple interaction types





106 species
1362 trophic links
3089 interference/competition for space links
172 habitat/refuge provisioning links





Kéfi et al. (2016)

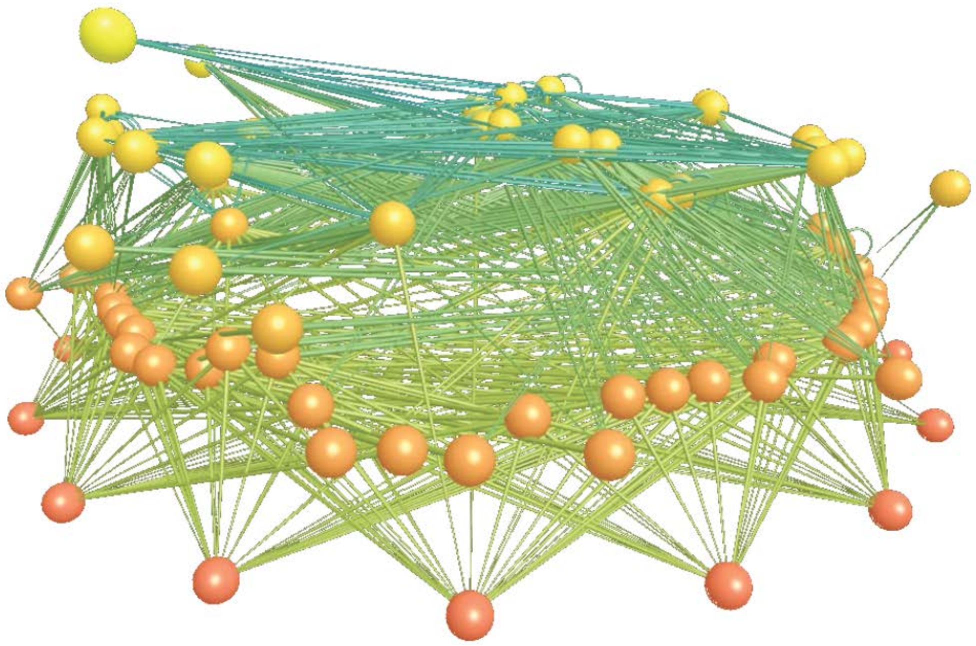
Pairwise interactions are governed by species traits

The structure of ecological networks varies depending on the type of interaction (mutualistic vs antagonistic; intimate vs non-intimate)

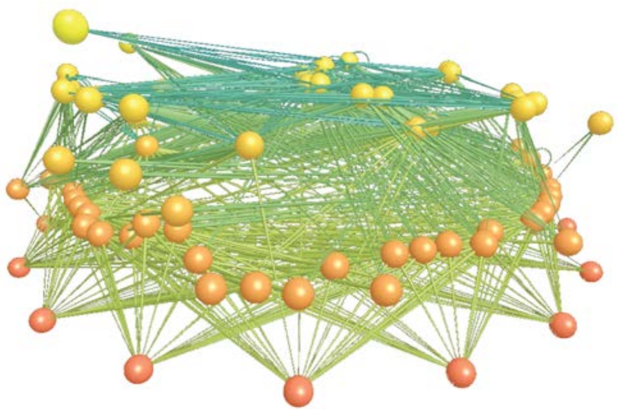
Comparing the structure among networks needs to account for sampling heterogeneity

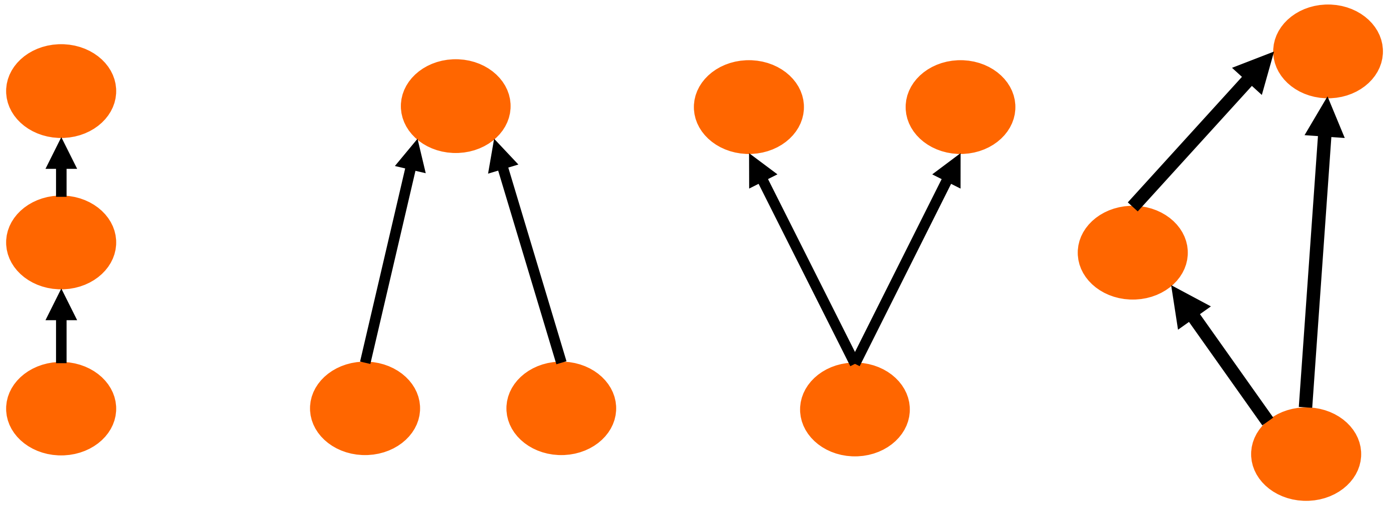
Integrating several interaction types within networks is in its infancy and require new datasets and metrics

(ii)
Indirect interactions and community dynamic

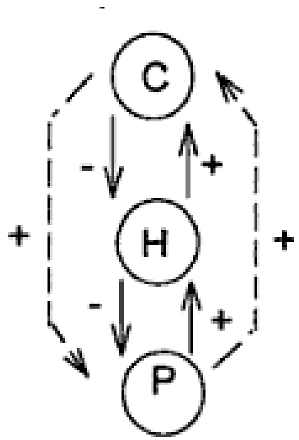


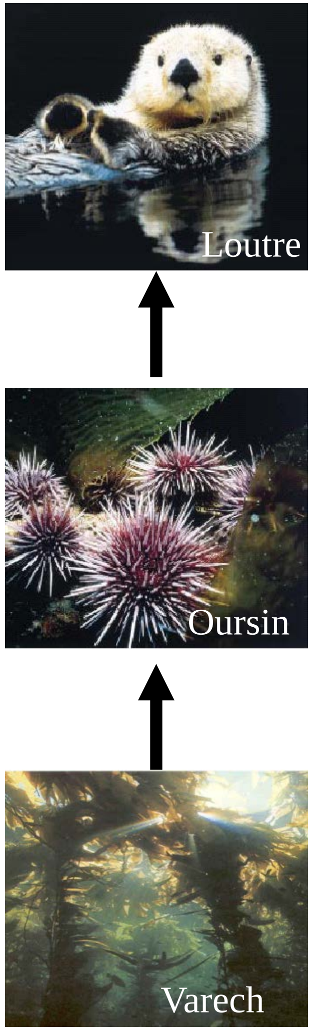
Foodwebs, network motifs and indirect interactions





Foodwebs, trophic chains and trophic cascades





Otter extinction

↓

See urchin explosion

↓

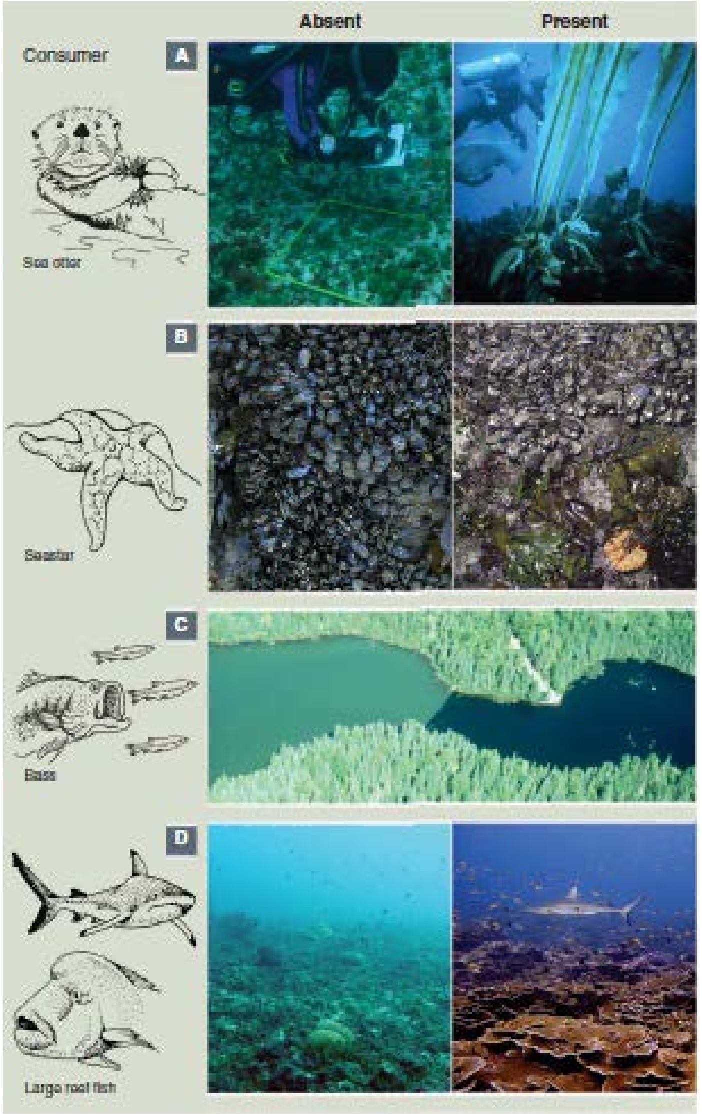
Over-consumption of kelp

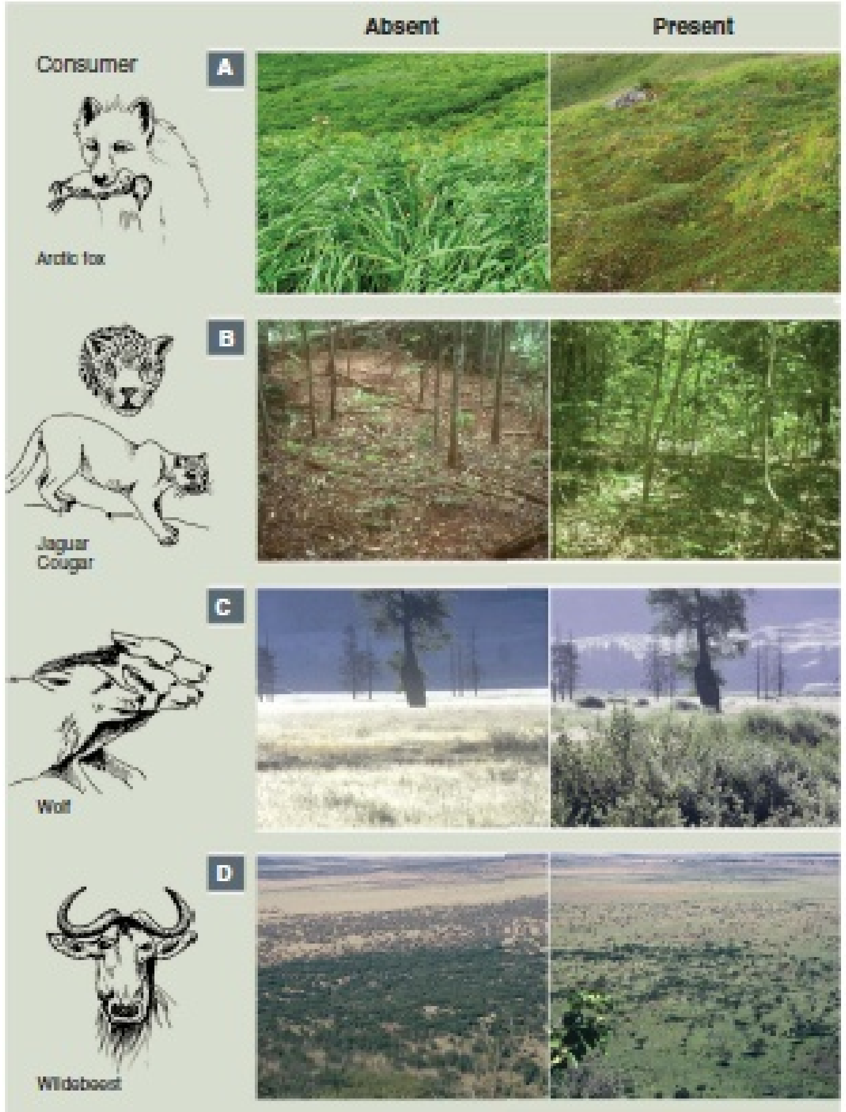
↓

Extinction of species inhabiting kelp forests

Estes & Palmisano 1974

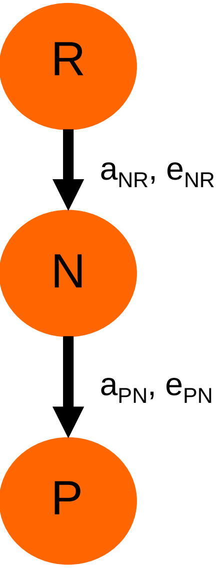
Foodwebs, trophic chains and trophic cascades





Estes et al. 2011

Foodwebs, trophic chains and trophic cascades



$$\frac{dR}{dt} = R(r(1-R/K) - a_{NR}N)$$

$$\frac{dN}{dt} = N(e_{NR}a_{NR}R - d_N - a_{PN}P)$$

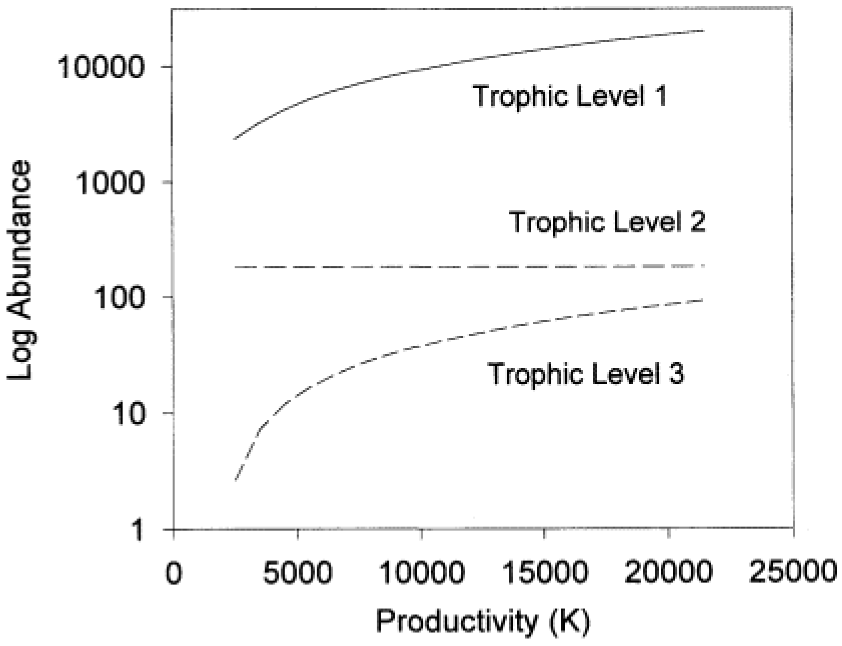
$$\frac{dP}{dt} = P(e_{PN}a_{PN}N - d_P)$$

If an equilibrium exist with three species, then:

$$R^* = K\left(1 - \frac{a_{NR}}{r}N^*\right)$$

$$N^* = \frac{d_P}{e_{PN}a_{PN}}$$

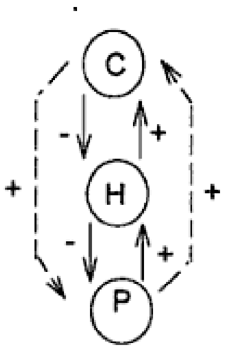
$$P^* = \frac{1}{a_{PN}}\left(e_{NR}a_{NR}R^* - d_N\right)$$

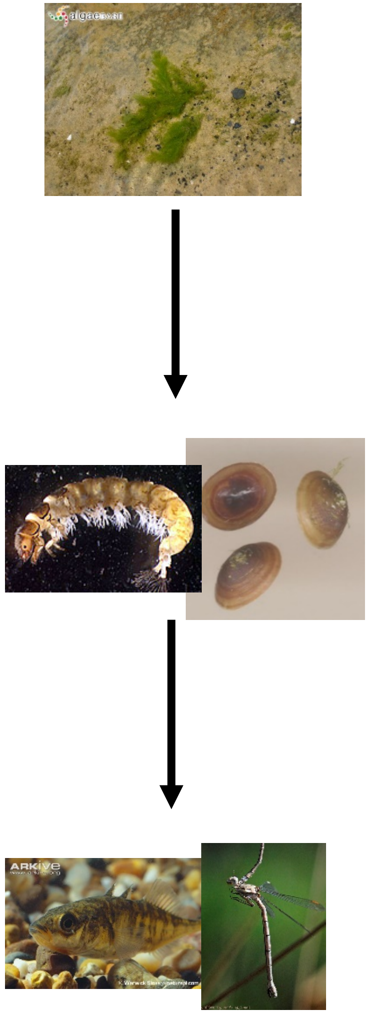


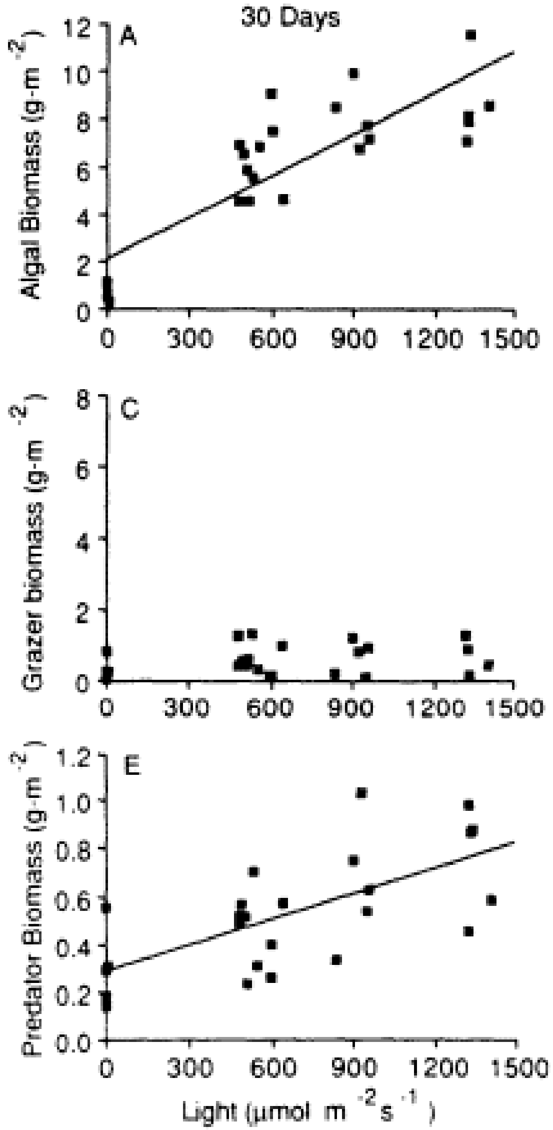
- r = intrinsec groth rate of R
- K = carying capacity of R
- a_{NR} et a_{PN} are atack rates
- e_{NR} et e_{PN} are conversion efficacies
- d_N et d_P are mortality rates

Oksanen 1981

Foodwebs, trophic chains and trophic cascades







Wootton & Power, 1993

Trophic chains: bottom-up and top-down effects

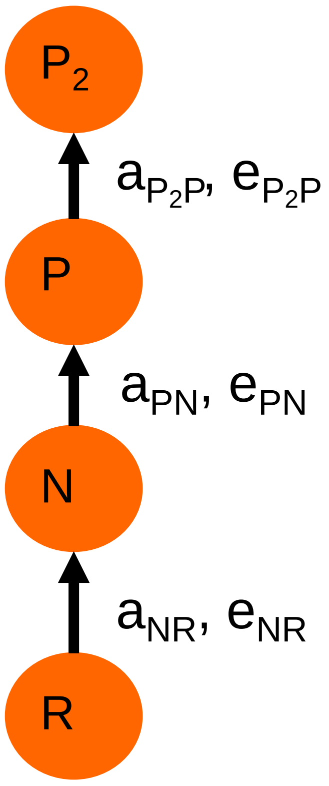
- Trophic chain with four levels:

$$P_2^* = \frac{1}{a_{P2P}}(e_{PN}a_{PN}N^* - d_P)$$

$$P^* = \frac{d_{P2}}{e_{P2P}a_{P2P}}$$

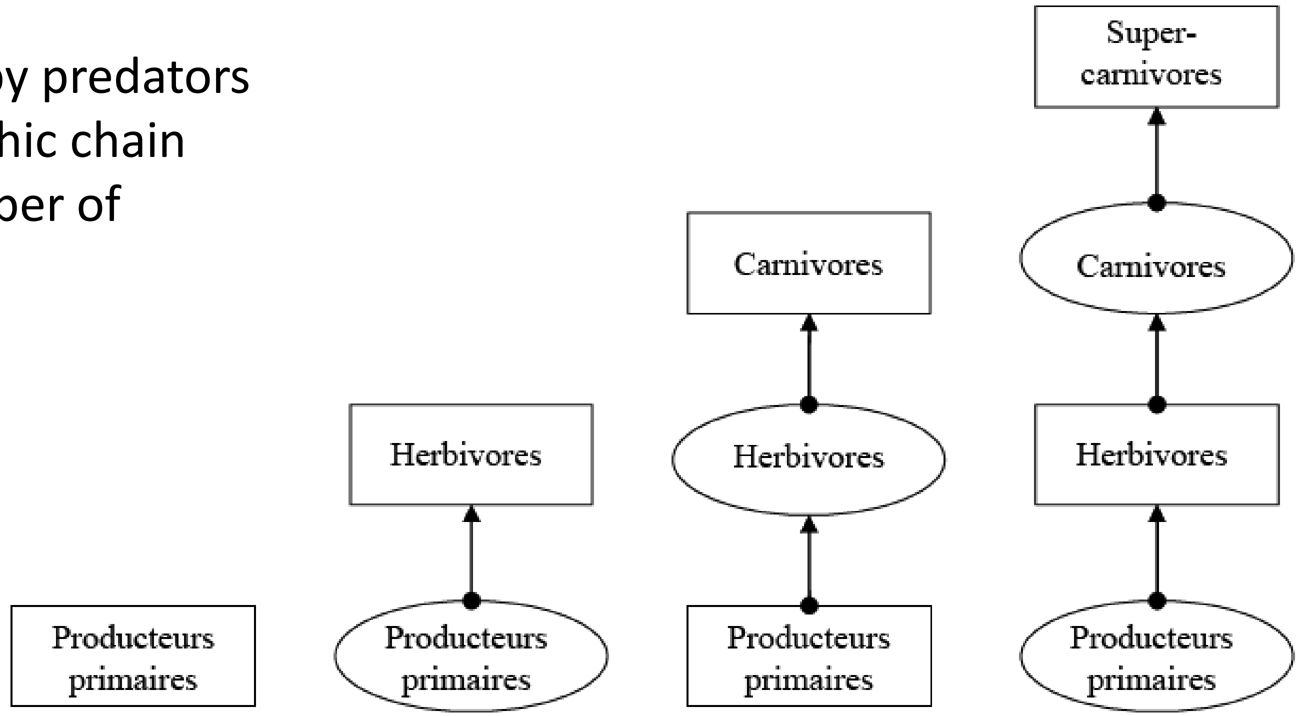
$$N^* = \frac{1}{a_{NR}}\left(1 - \frac{R^*}{K}\right)$$

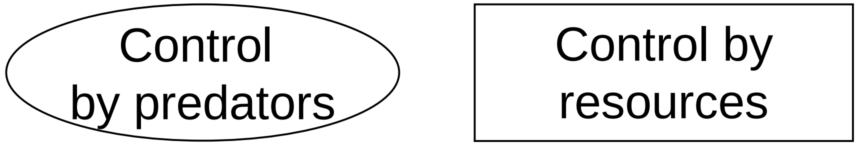
$$R^* = \frac{d_N + a_{PN}P^*}{e_{NR}a_{NR}}$$



Trophic chains: bottom-up and top-down effects

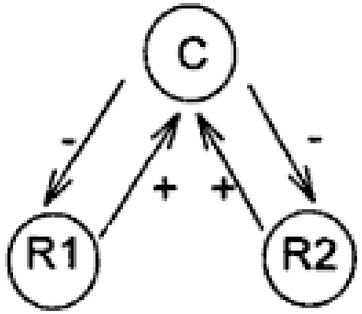
Alternation of control by predators and resources in a trophic chain depending on the number of trophic levels



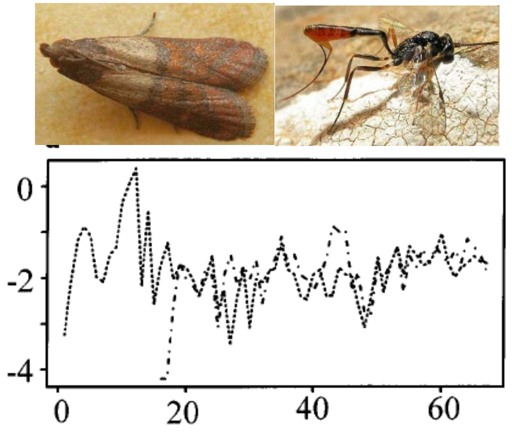


Hairston et al. 1960

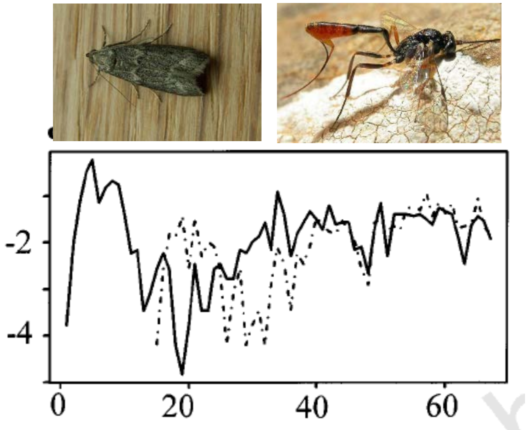
Foodwebs, sharing of predator and apparent competition

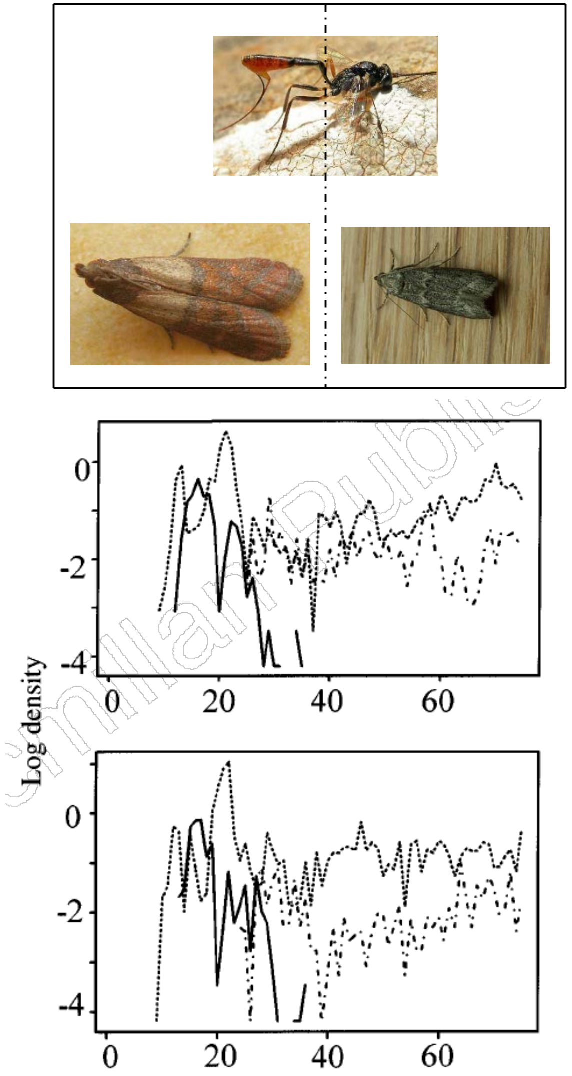


Plodia interpunctella Venturia canescens



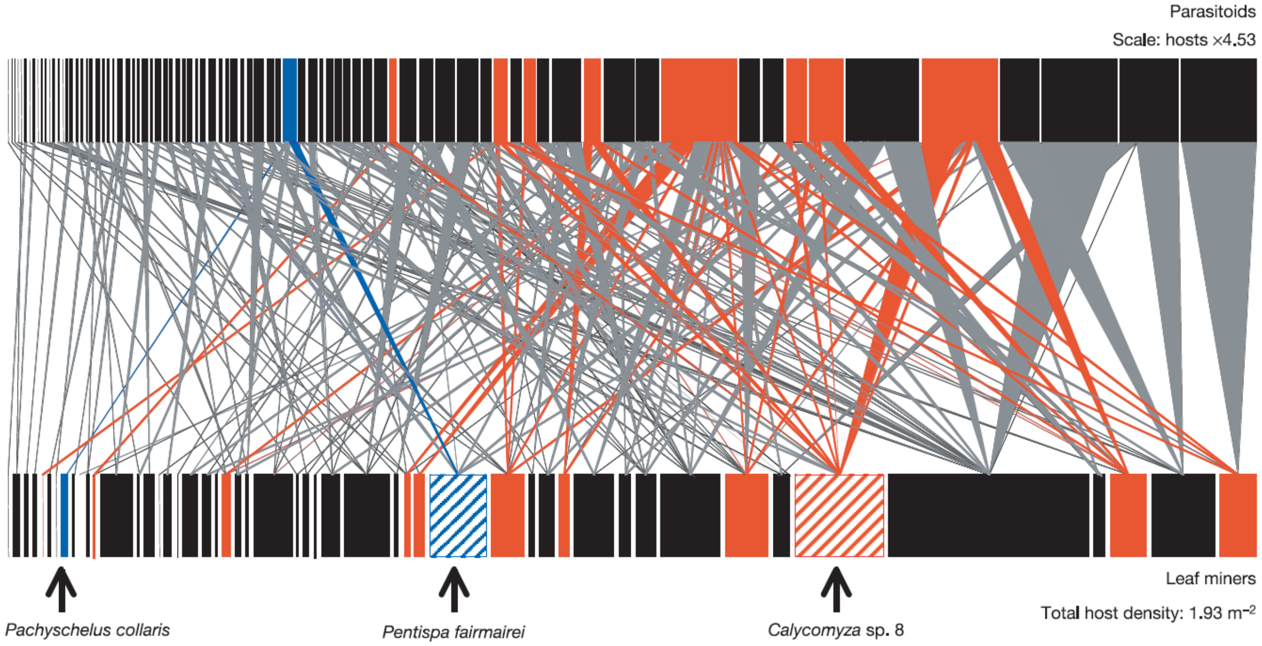
Ephestia kuehniella Venturia canescens

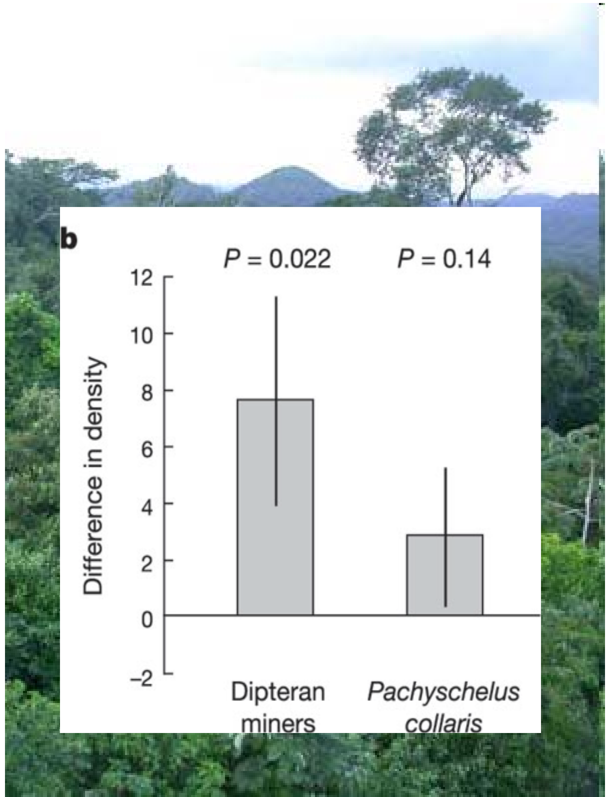




Bonsall & Hassell, 1997

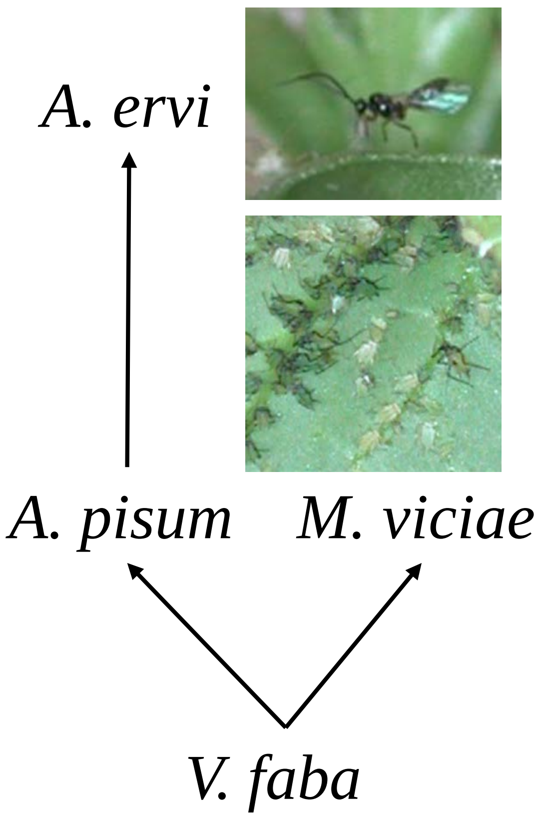
Foodwebs, sharing of predator and apparent competition

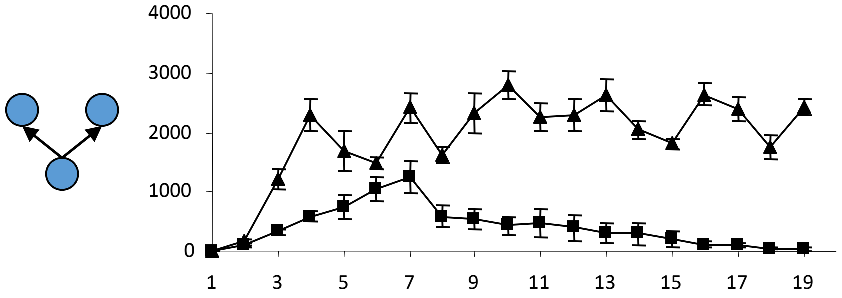




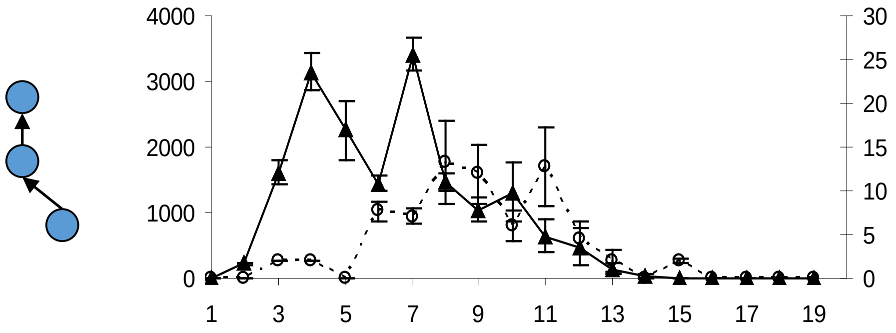
Morris et al., 2004

Foodwebs, interference and coexistence

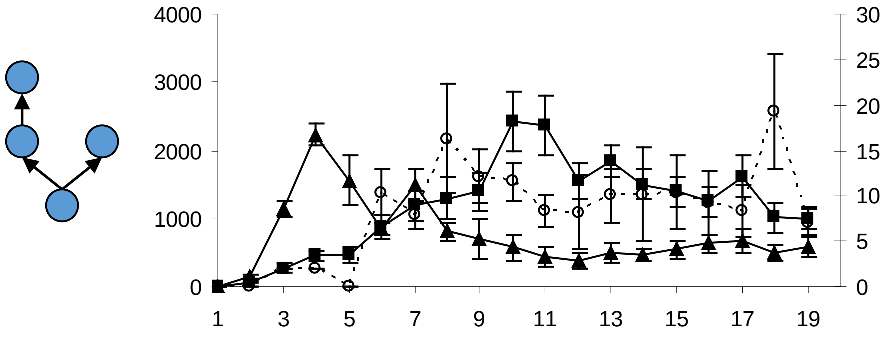




competitive exclusion



extinction

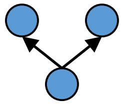


coexistence

van Veen & al. Ecology, 2005

Foodwebs, interference and coexistence

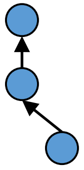
Lotka-Volterra competition model



$$\frac{dN_1}{dt} = r_1 N_1 (1 - \alpha_{11} N_1 - \alpha_{12} N_2)$$

$$\frac{dN_2}{dt} = r_2 N_2 (1 - \alpha_{12} N_2 - \alpha_{21} N_1)$$

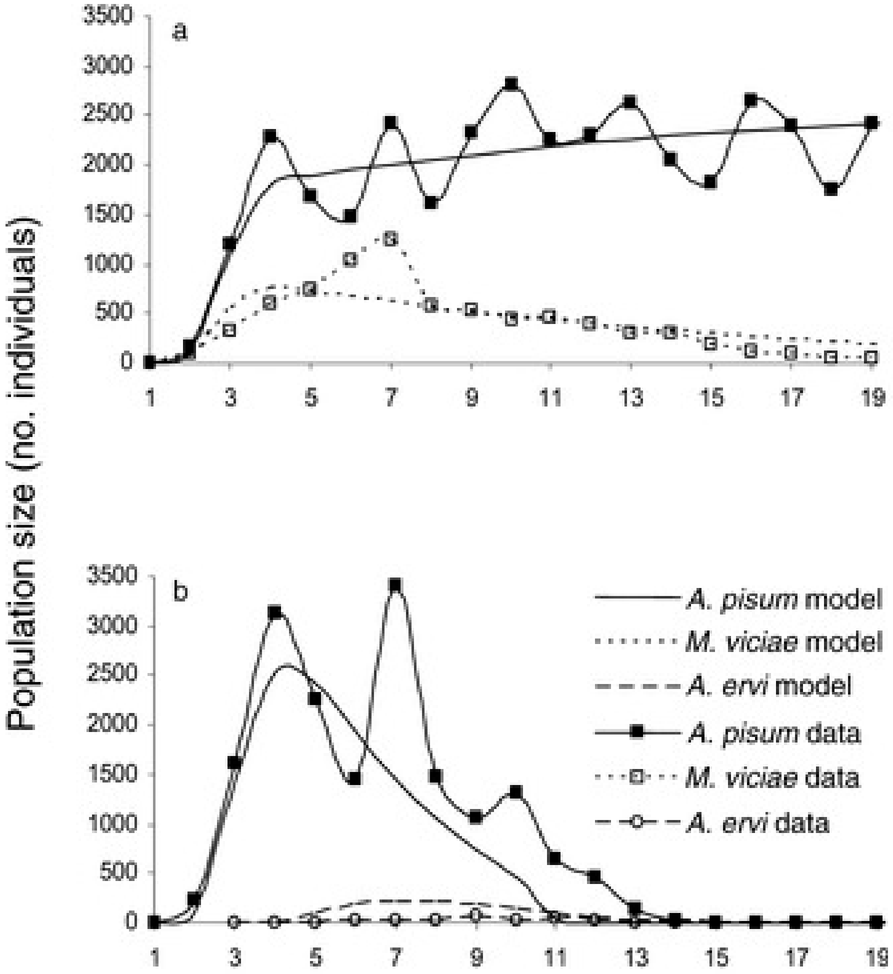
Lotka-Volterra predator-prey model



$$\frac{dN_1}{dt} = r_1 N_1 (1 - \alpha_{11} N_1) - N_1 \frac{\alpha_{1P} P}{1 + bN_1}$$

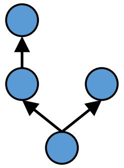
$$\frac{dP}{dt} = N_1 \frac{\alpha_{1P} P}{1 + bN_1 + cP} - \mu P$$

(i) Intra and interspecific competition for hosts
(ii) hyperbolic (Type II) functional response
(iii) density dependent parasitoid recruitment



van Veen & al. Ecology, 2005

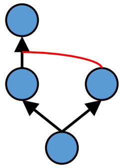
Foodwebs, interference and coexistence



$$\frac{dN_1}{dt} = r_1 N_1 (1 - \alpha_{11} N_1 - \alpha_{12} N_2) - N_1 \frac{\alpha_{1P} P}{1 + bN_1}$$

$$\frac{dN_2}{dt} = r_2 N_2 (1 - \alpha_{22} N_2 - \alpha_{21} N_1)$$

$$\frac{dP}{dt} = N_1 \frac{\alpha_{1P} P}{1 + bN_1 + cP} - \mu P$$

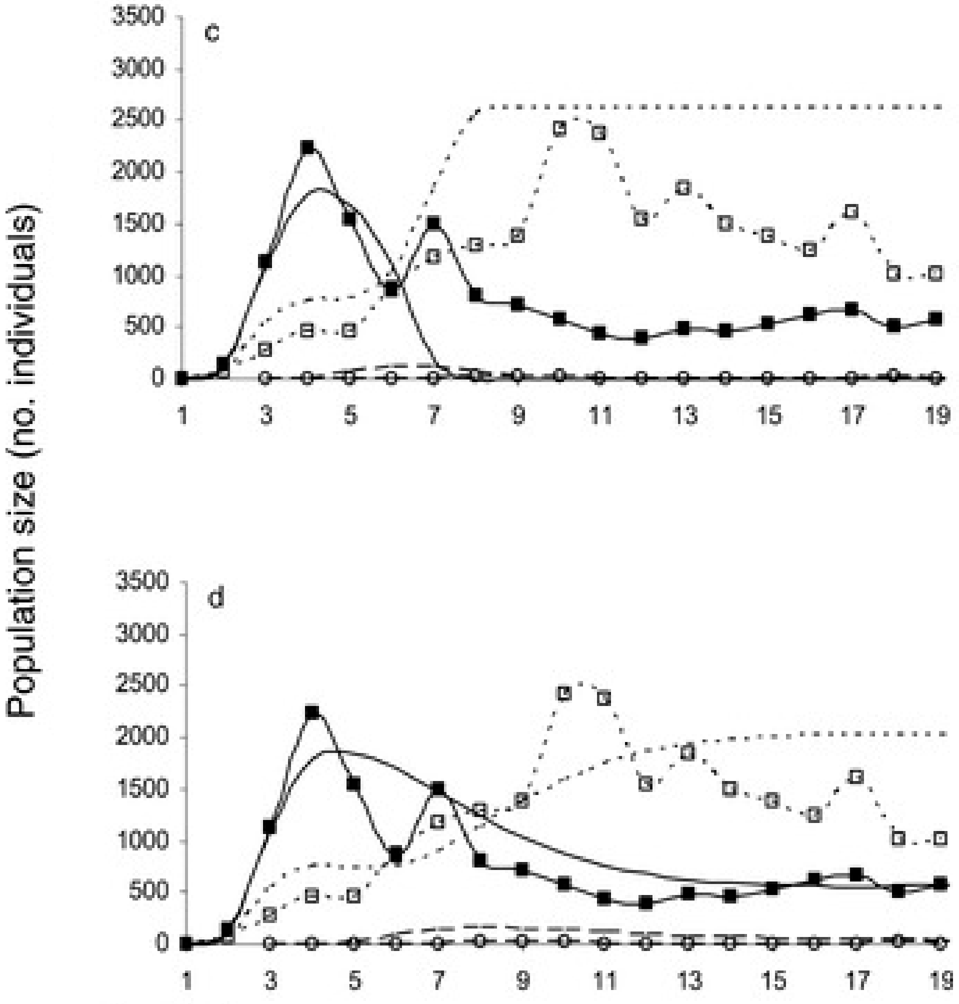


$$\frac{dN_1}{dt} = r_1 N_1 (1 - \alpha_{11} N_1 - \alpha_{12} N_2) - N_1 \frac{\alpha_{1P} P}{1 + bN_1 + \underline{\varpi N_2}}$$

$$\frac{dN_2}{dt} = r_2 N_2 (1 - \alpha_{22} N_2 - \alpha_{21} N_1)$$

$$\frac{dP}{dt} = N_1 \frac{\alpha_{1P} P}{1 + bN_1 + \underline{\varpi N_2} + cP} - \mu P$$

Trait mediated indirect effect: Interference of *M. viciae* with searching behaviour of the parasitoid.

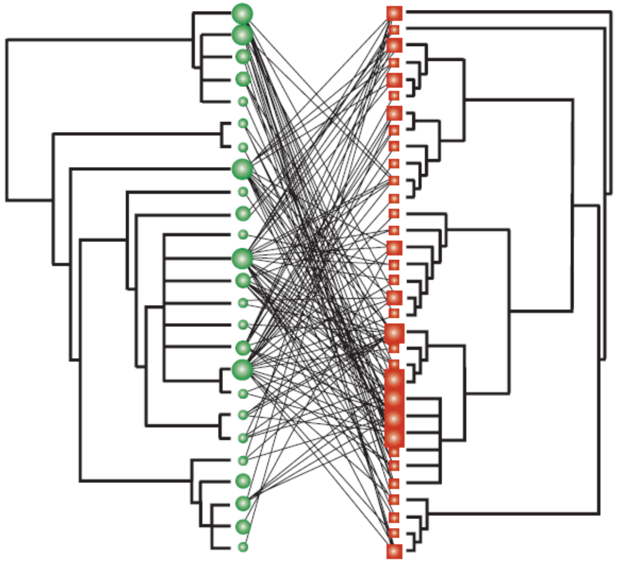


van Veen & al. Ecology, 2005

Indirect interactions have strong effects on species abundances and coexistence

Network approaches allow understanding cascading effects within communities which are pervasive

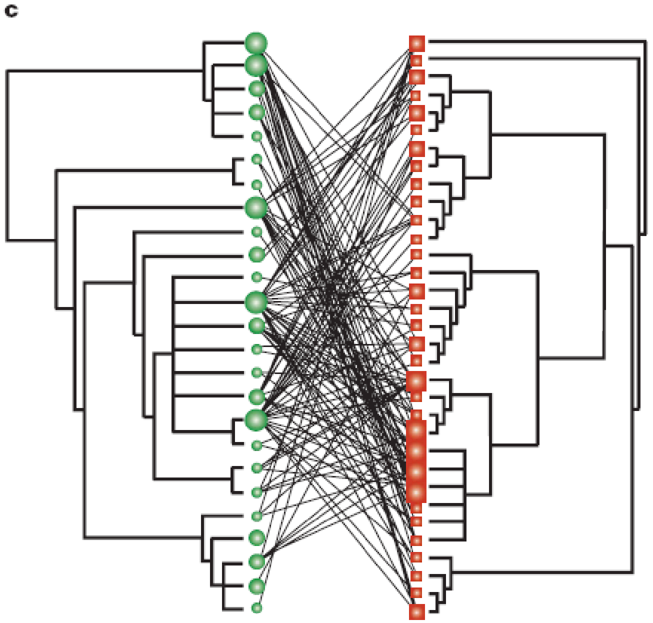
(iii)
Processes shaping the network architecture of a multilevel antagonistic network



From Rezende et al. 2007

What are the processes shaping network architecture?

Phylogenetic constraints

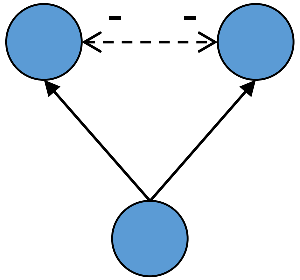


From Rezende et al., *Nature* 2007

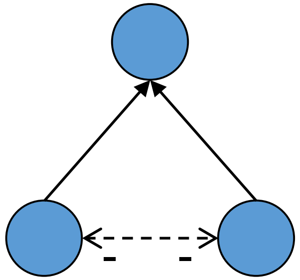
Closely related species should interact with the same species

Indirect interactions

From the consumer side:
exploitative competition

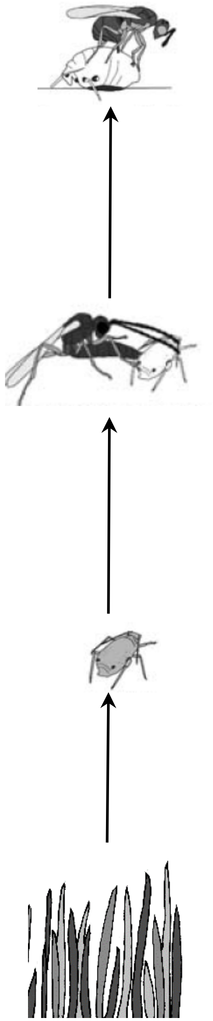


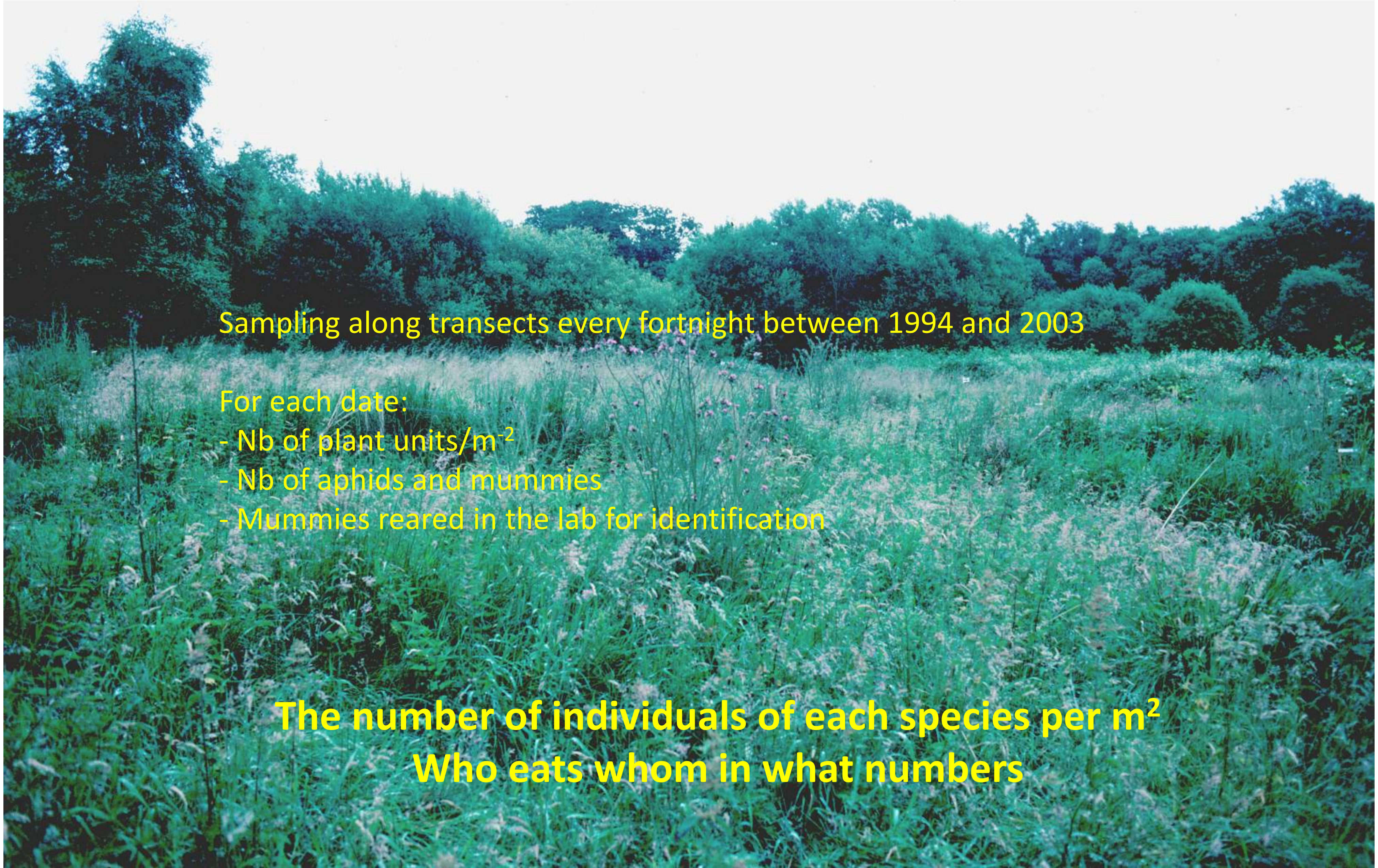
From the resource side:
apparent competition



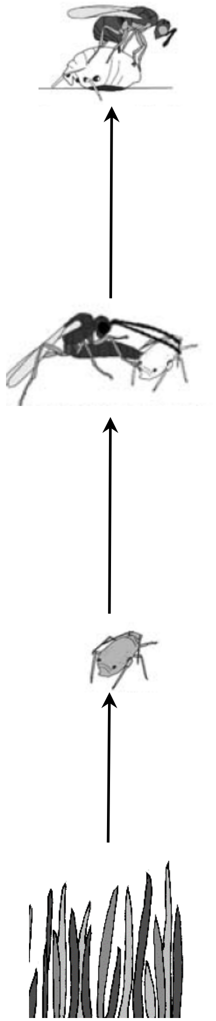
Species should interact with different partner to minimise competition

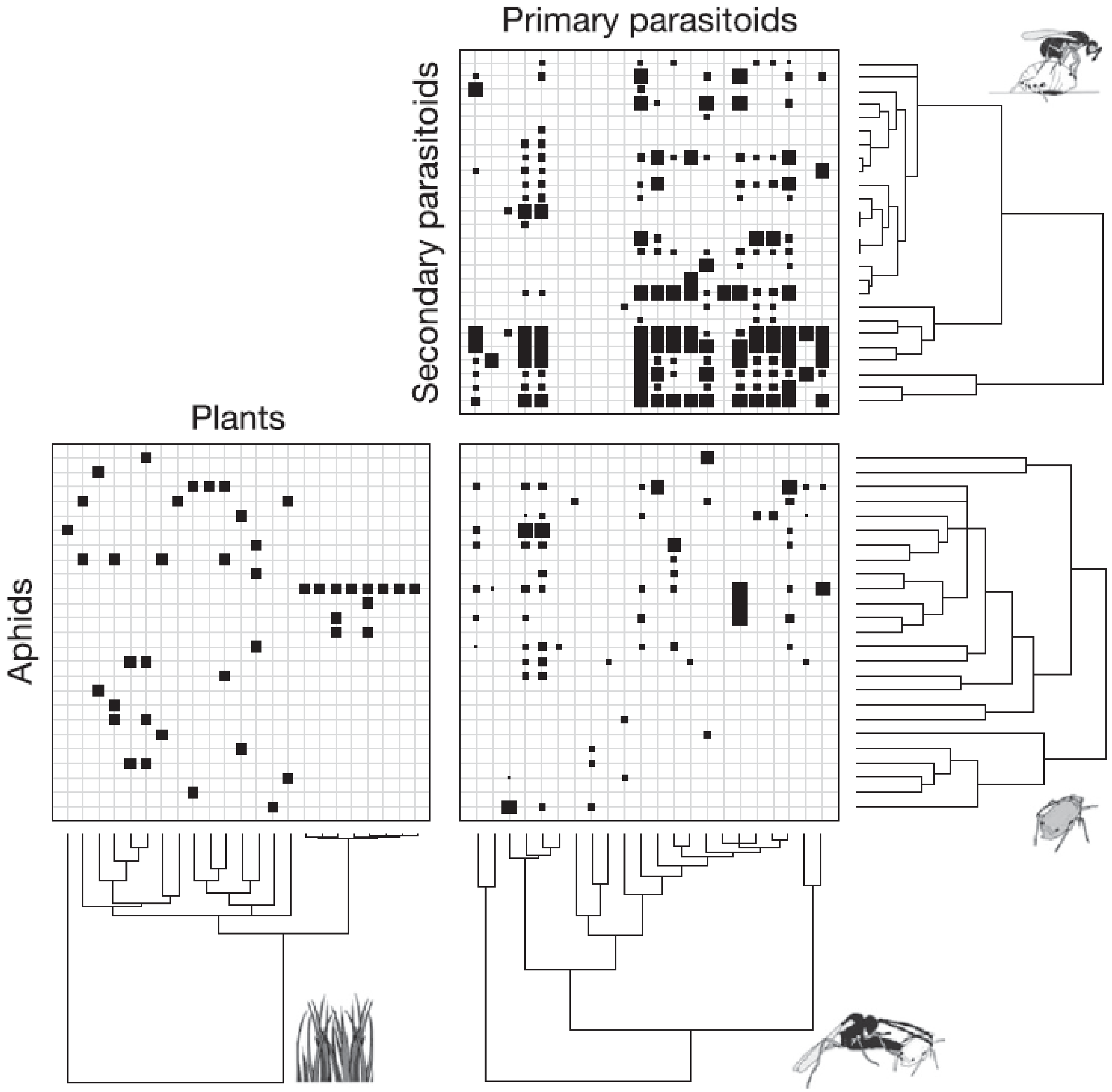
The Rush Meadow dataset





The Rush Meadow dataset

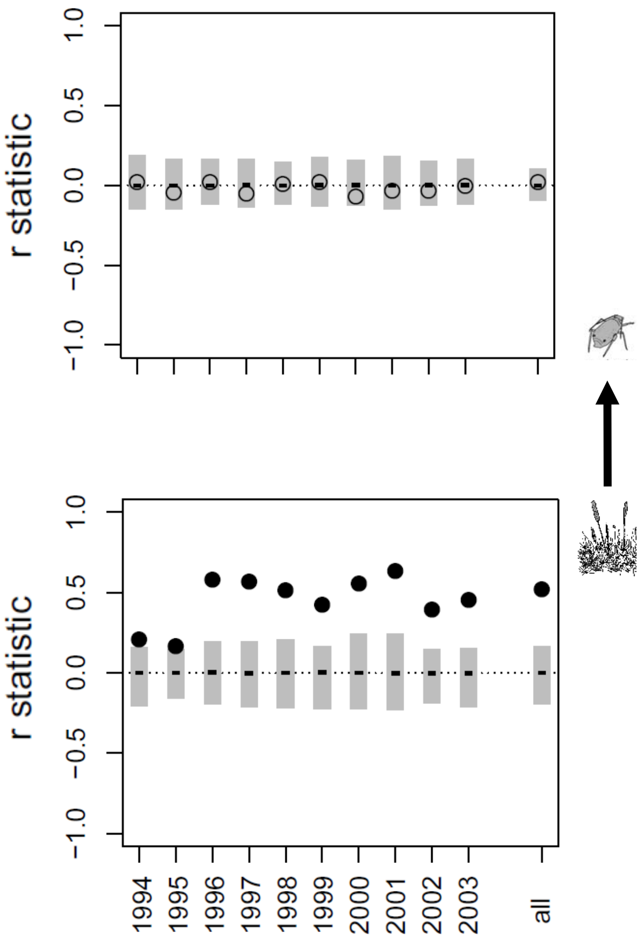




Phylogenetic signal estimated as the correlation between ecological and phylogenetic distances

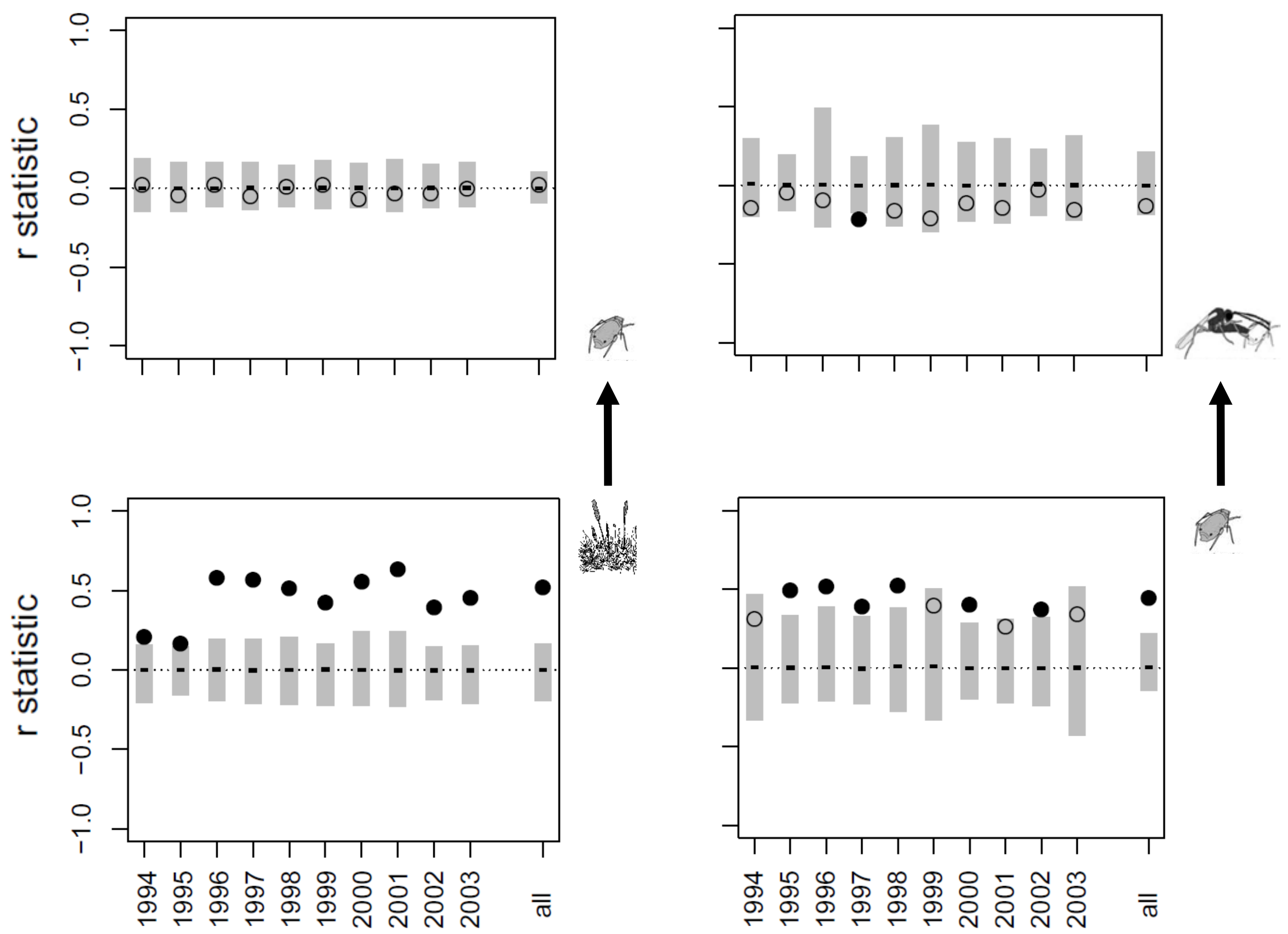
Elias & al., 2014

Phylogenetic signal and anti-signal within a network



Elias & al., 2014

Phylogenetic signal and anti-signal within a network

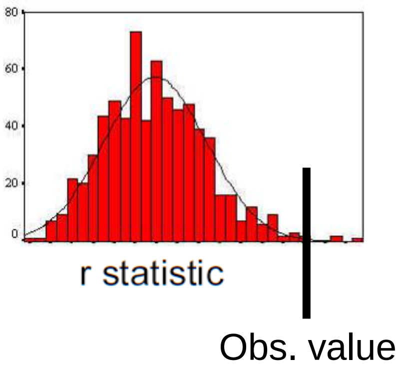


Strong **phylogenetic signal** for prey levels ⇨ Vulnerability traits are **phylogenetically constrained**

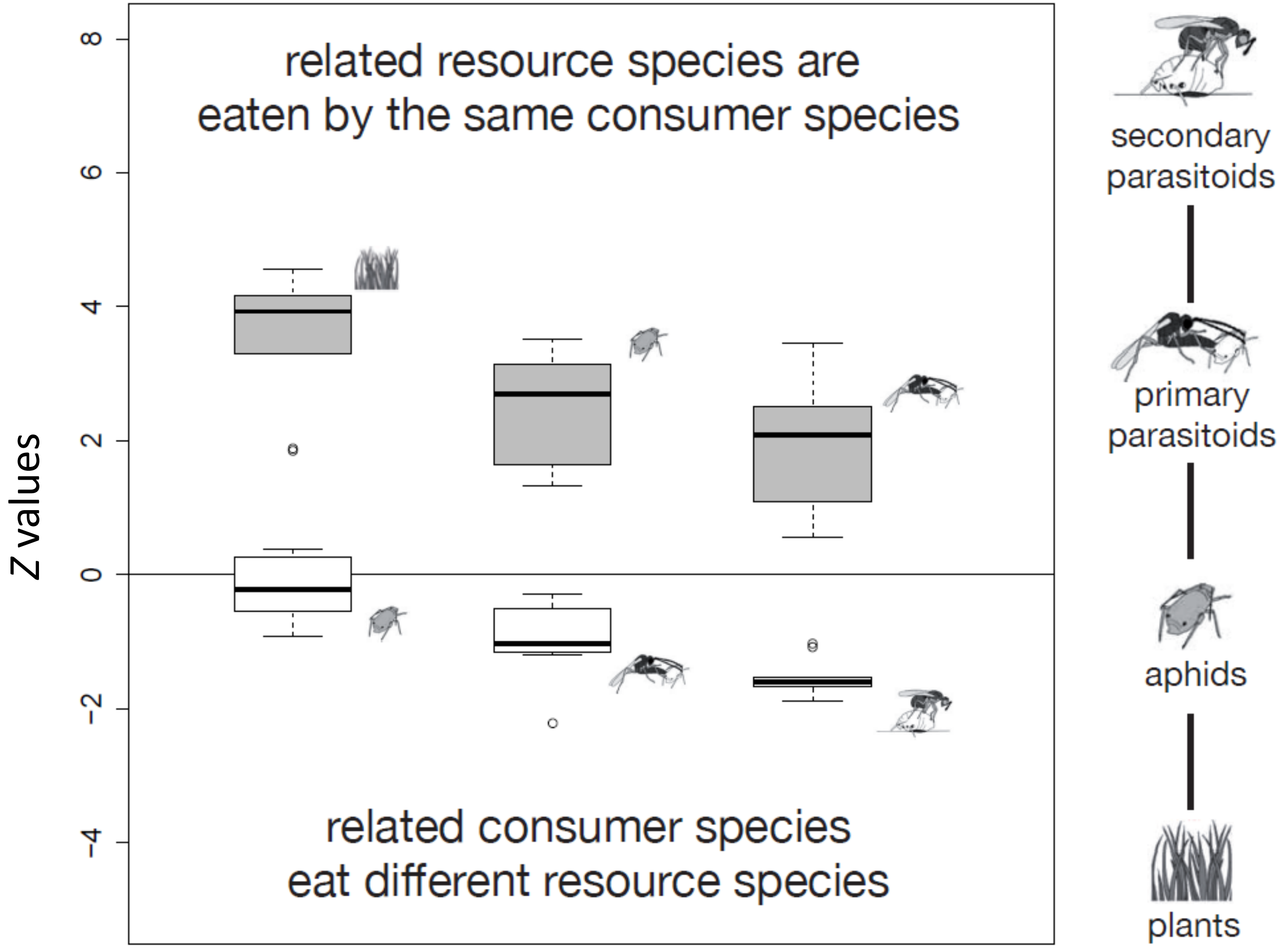
Phylogenetic anti-signal for predator levels ⇨ Foraging traits are phylogenetically labile and **ecologically contrained**

Elias & al., 2014

Variation of signal strength with trophic levels



$$z = \frac{x - \mu}{\sigma}$$



Lower phylogenetic signal with increasing trophic level for resource species ⇨ plant phylogeny and chemical cues ?

Stronger phylogenetic anti-signal with increasing trophic level for consumer species ⇨ biomass pyramid ?

Phylogenetic signal and anti-signal within a network

Phylogenetic signal varies within network

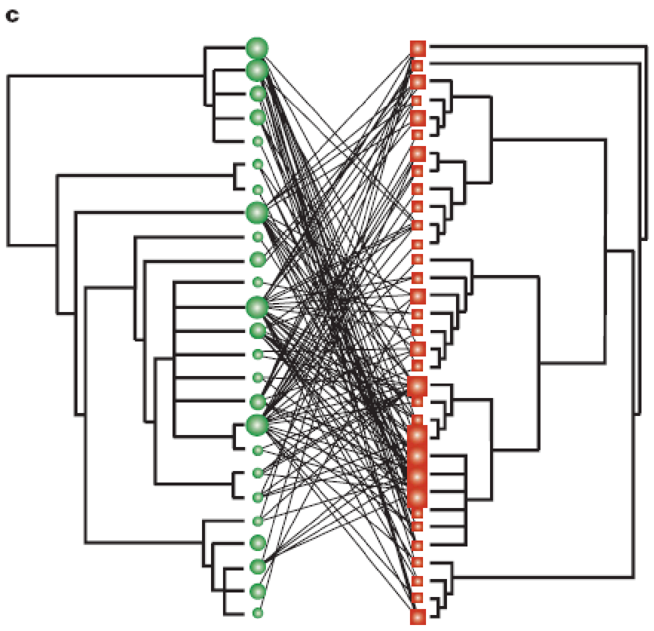
Interaction as resources are phylogenetically constrained ➔ evolutionary history of species
Interaction as consumer are not ➔ exploitative competition

	Interactions as consumer		Interaction as resource	
	r (S.E.)	*P*	*r* (S.E.)	*P*
Chesapeake Bay	0.231 (0.057)	<0.001	0.330 (0.092)	0.002
Coachella*	0.159 (0.057)	0.040	0.635 (0.036)	<0.001
Skipwith Pond*	0.101 (0.050)	0.077	0.459 (0.046)	<0.001
St-Martin Island	0.270 (0.067)	<0.001	0.131 (0.073)	0.051
Ythan estuary*	0.099 (0.027)	<0.001	0.206 (0.035)	<0.001

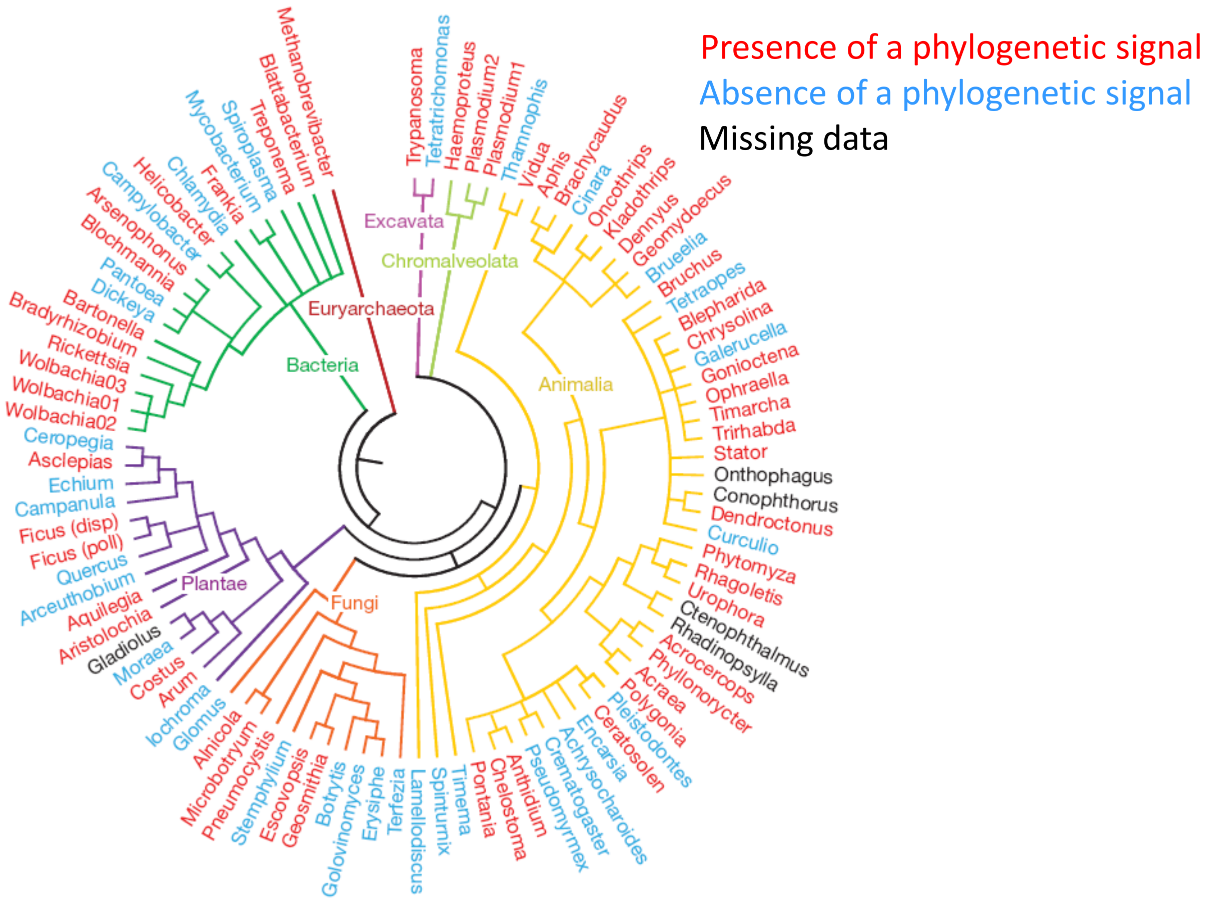
Bersier & Kehrly, Ecol. Complex. 2008

What are the processes shaping network architecture?

Phylogenetic constraints



From Rezende et al., *Nature* 2007

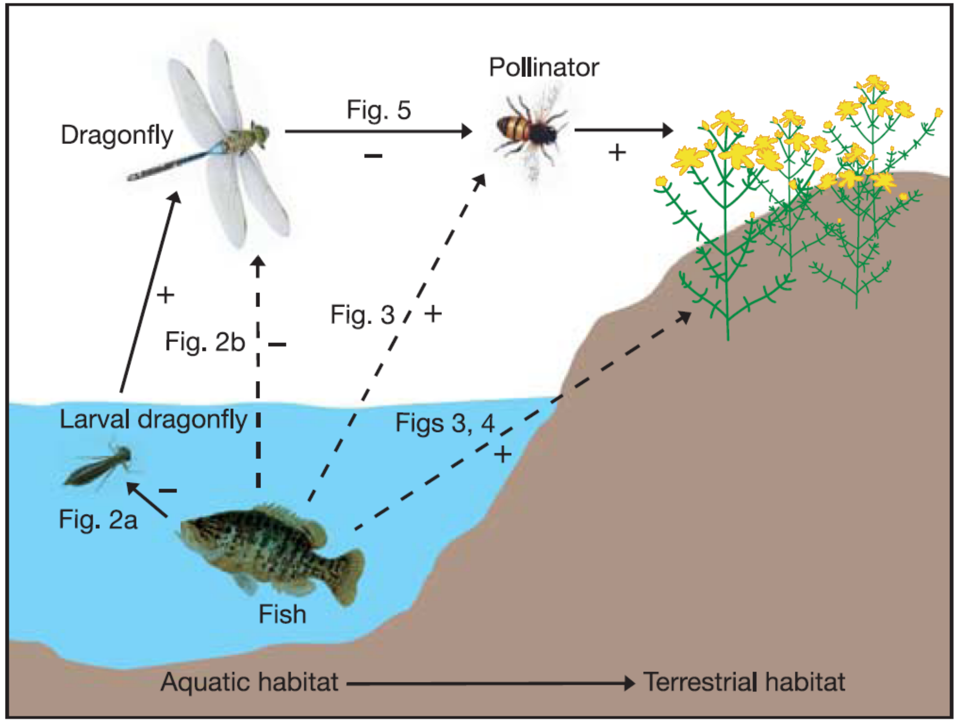


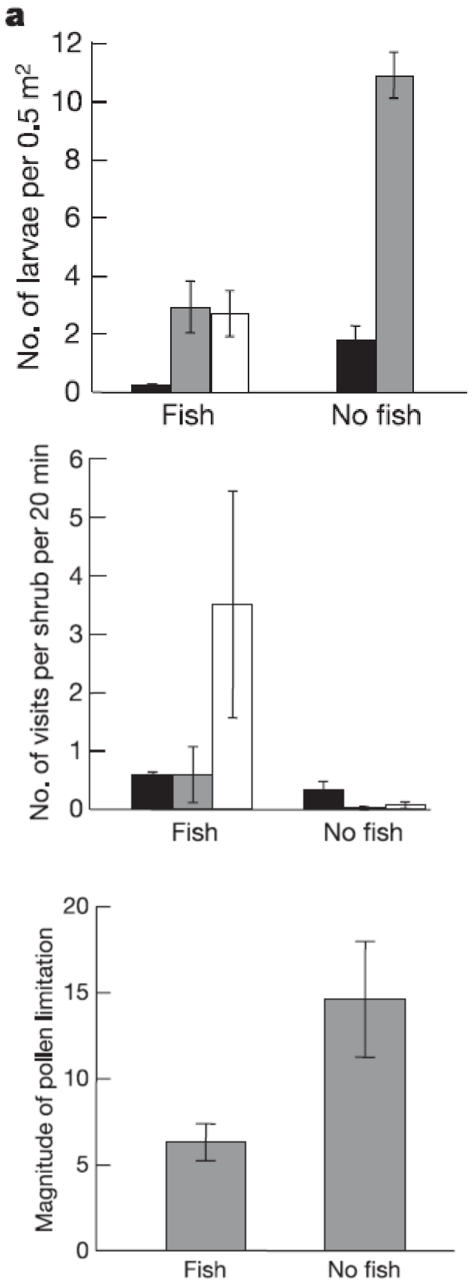
Closely related species should interact with the same species

70% of the 116 genus analysed present conserved interactions

Gomez, Verdu & Perfectti, Nature 2010

Indirect interactions and effect spread through antagonistic and mutualistic interactions





Knight et al. 2005

Trophic chains: bottom-up and top-down effects

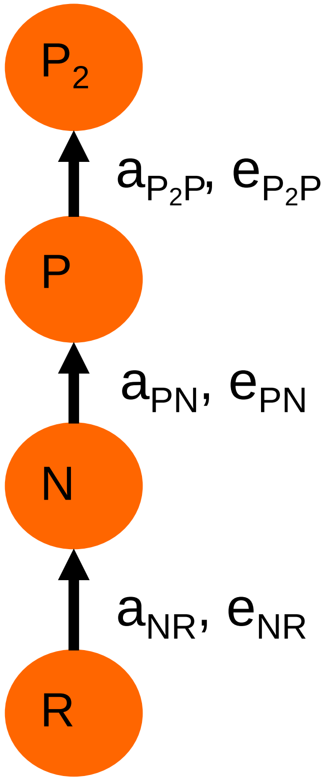
- Trophic chain with four levels:

$$P_2^* = \frac{1}{a_{P2P}}\left(e_{PN} a_{PN} N^* - d_P\right)$$

$$P^* = \frac{d_{P2}}{e_{P2P} a_{P2P}}$$

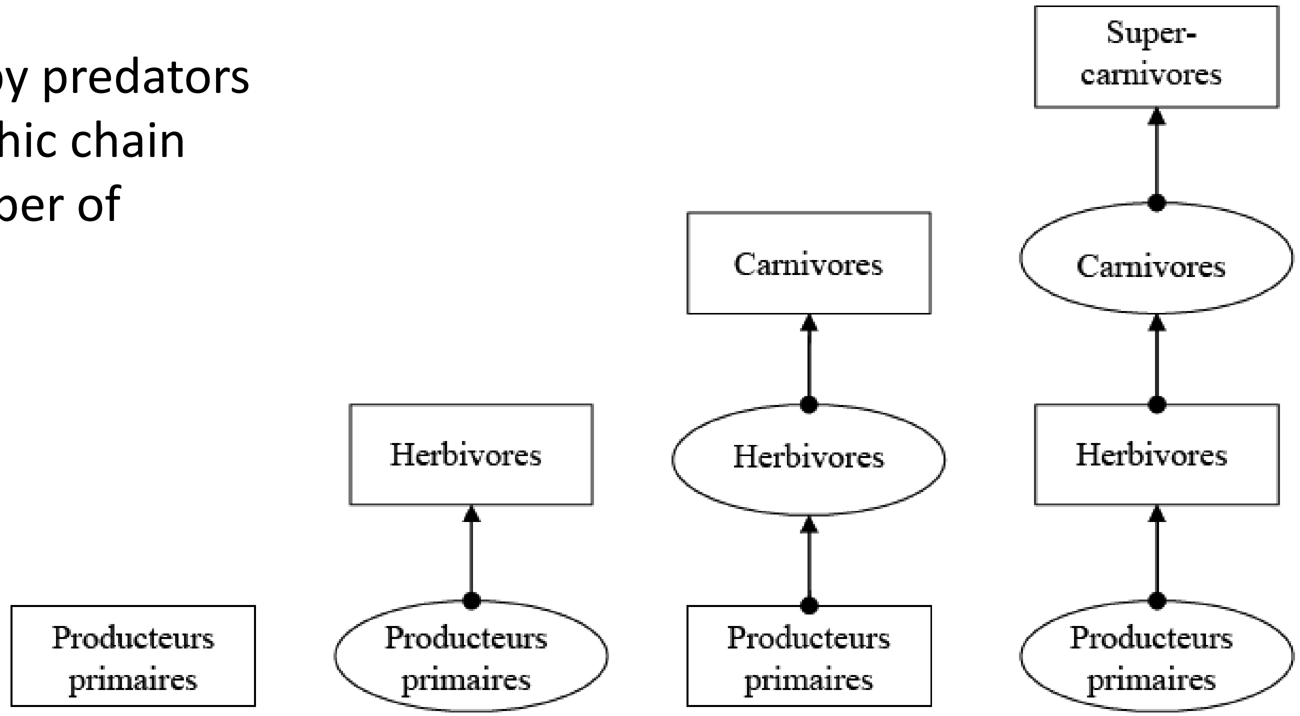
$$N^* = \frac{1}{a_{NR}}\left(1 - \frac{R^*}{K}\right)$$

$$R^* = \frac{d_N + a_{PN} P^*}{e_{NR} a_{NR}}$$



Trophic chains: bottom-up and top-down effects

Alternation of control by predators and resources in a trophic chain depending on the number of trophic levels



Control by predators

Control by resources

Hairston et al. 1960