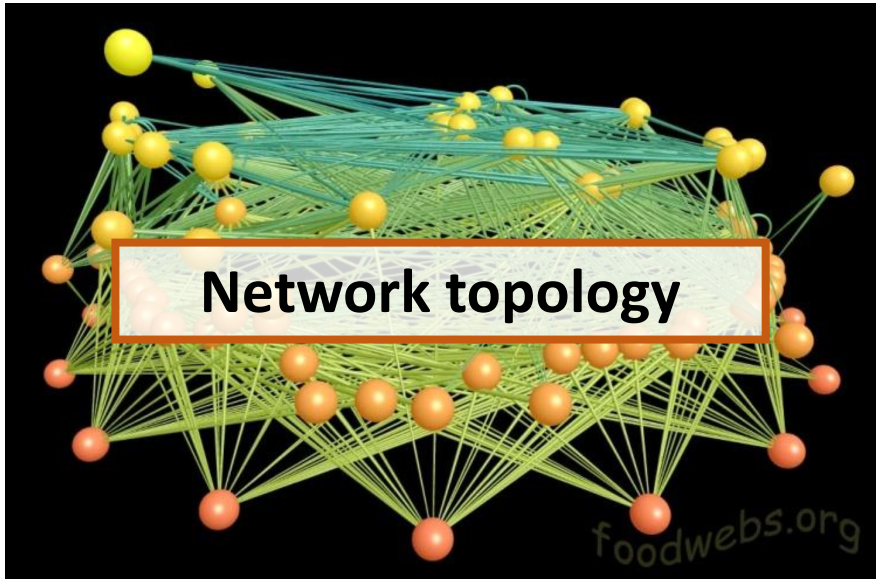
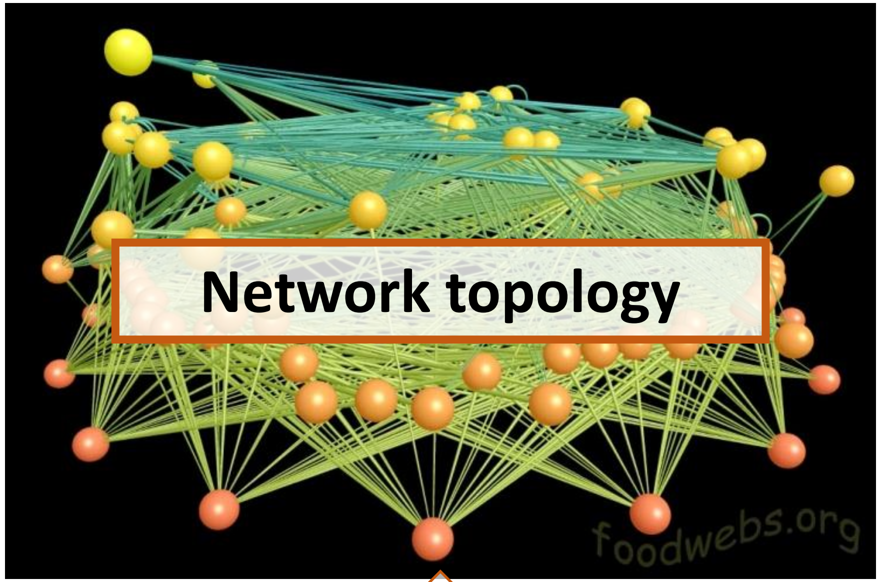
Why study ecological interaction networks?
Which questions?

Elisa Thébault

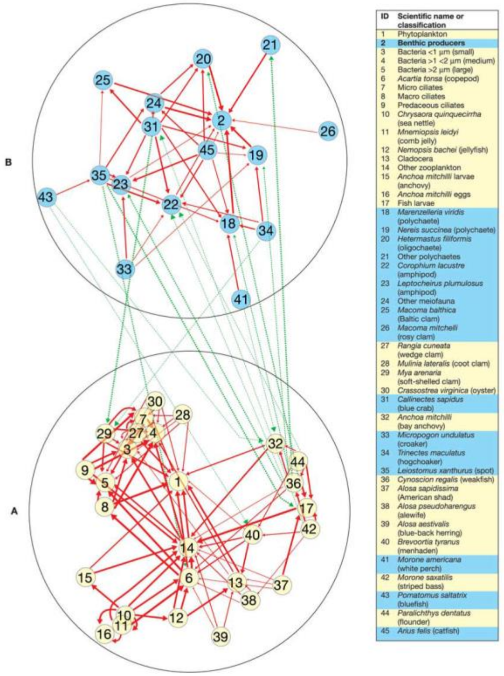
Why study ecological interaction networks?



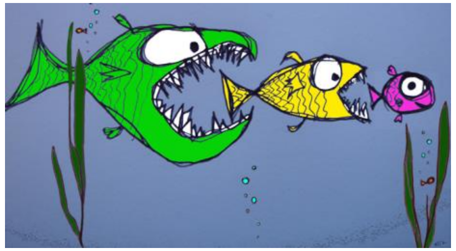
Why study ecological interaction networks?

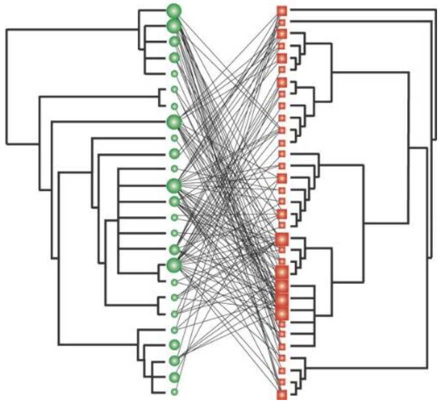


Mechanisms determining interactions between species



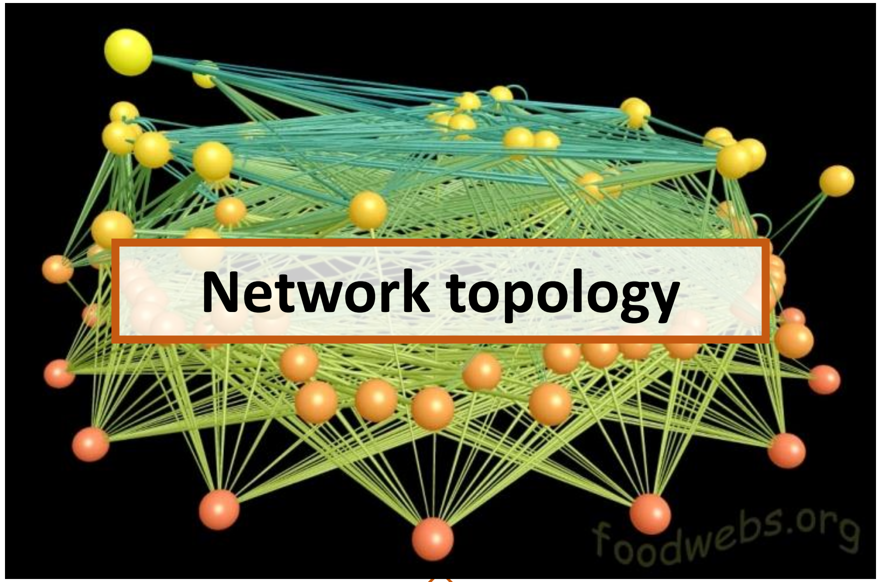
Chesapeake Bay food web
Krause et al. (2003)





Rezende et al. 2007

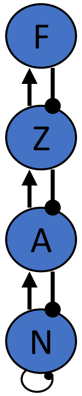
Why study ecological interaction networks?



Network topology

Consequences on community functioning and stability

- ➢ Understand cascading effects in networks

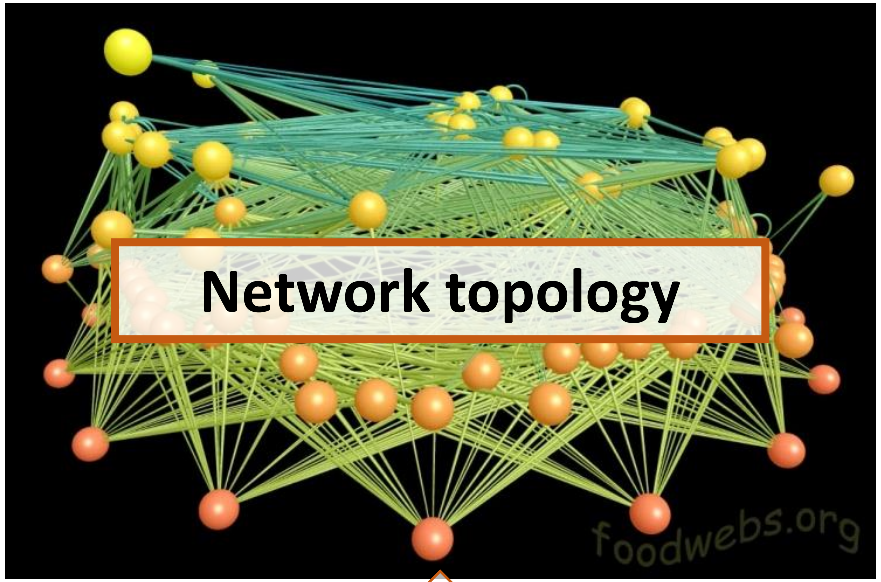


Estes et al. (2011)

Model population dynamics

$$dN_i/dt = N_i\left(r_i + \sum_j^n \alpha_{ij} N_j\right)$$

Why study ecological interaction networks?

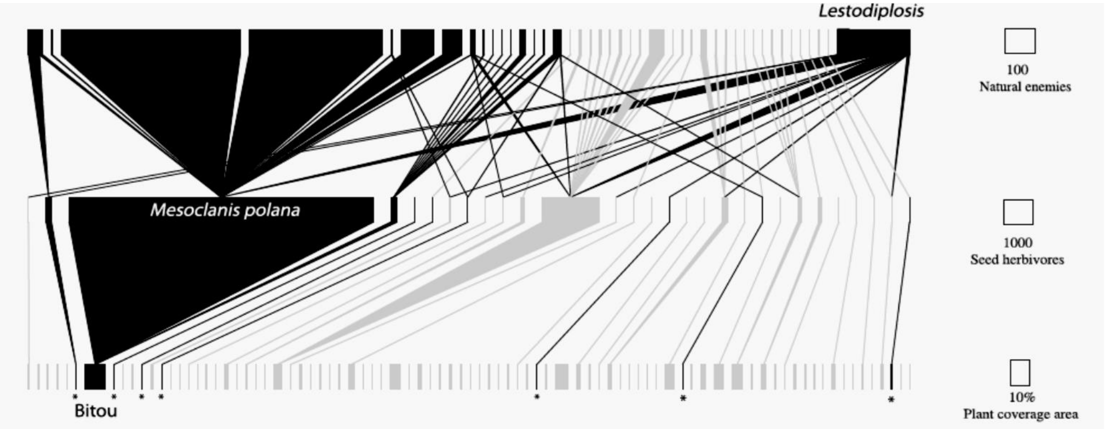


Network topology

⇕

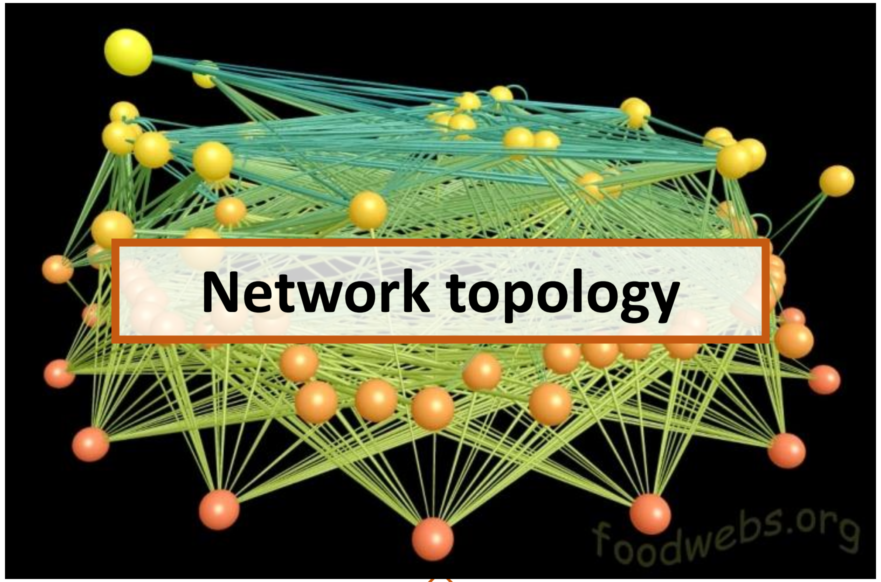
Consequences on community functioning and stability

- Understand cascading effects in networks



Cavalheiro et al. (2008)

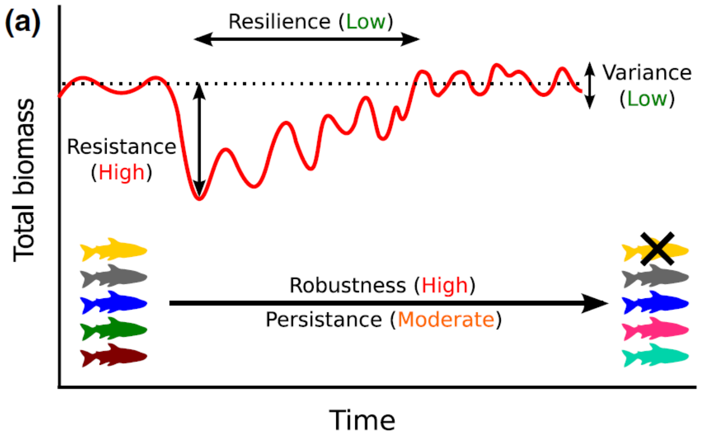
Why study ecological interaction networks?



Network topology

Consequences on community functioning and stability

➢ Study the links between network structure and ecosystem responses to perturbations



Donohue et al. (2016)

Questions

- What determines why there are links?

- What are the links between structure and function?

- What are the links between structure and stability?

- What is the structure of ecological networks? Are there structural generalities?
- How do networks change with environmental conditions?

- What is the role of interaction type?

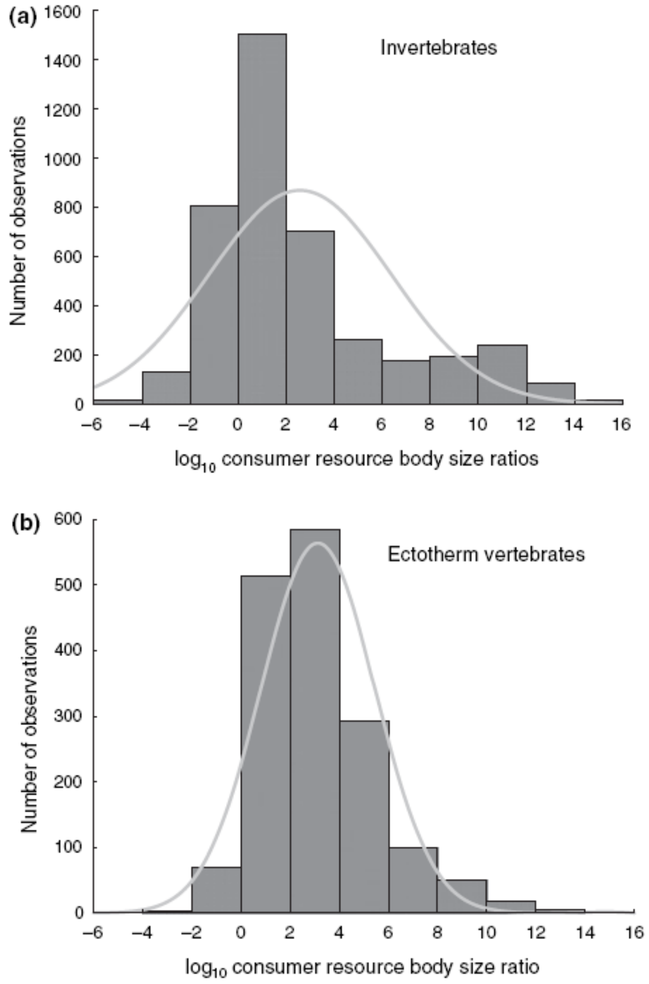
Questions

- What determines why there are links? → Today, example of species traits
- What are the links between structure and function?
  → Today, indirect interactions in networks + links with ecosystem function
- What are the links between structure and stability?
  → Tomorrow
- What is the structure of ecological networks? Are there structural generalities?
- How do networks change with environmental conditions?
  → Tomorrow + maybe Wednesday
- What is the role of interaction type?
  → Thursday

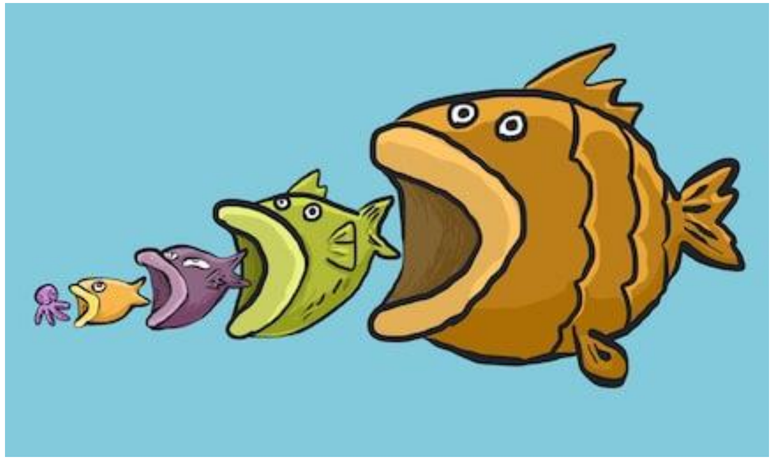
Part I
What determines the links between species?
The role of traits

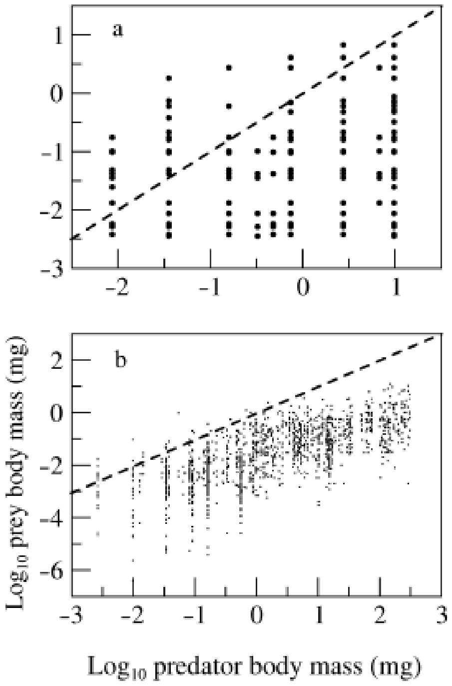
The example of body size in food webs

Trophic interactions and the ratio of body size between prey and predators



Brose et al. (2006)



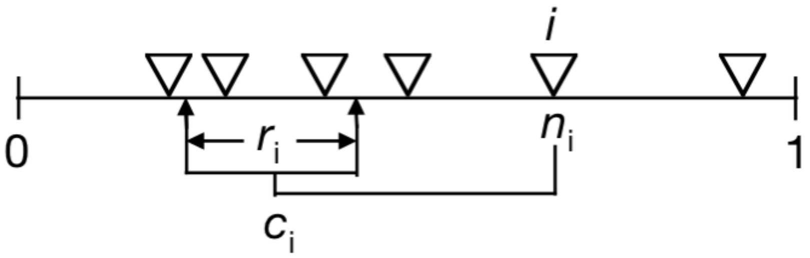


Ings et al. (2009)

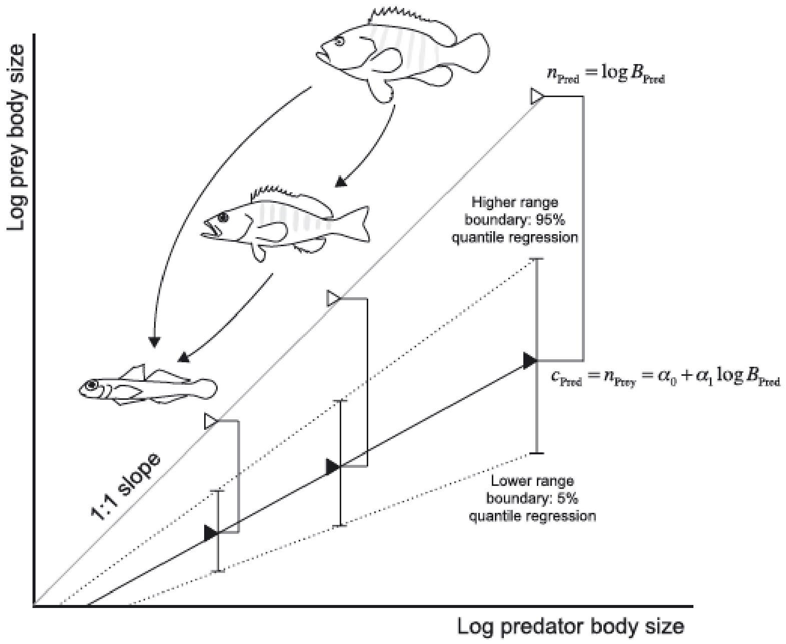
Infering trophic interaction and food web structure from body size

Starting from the niche model

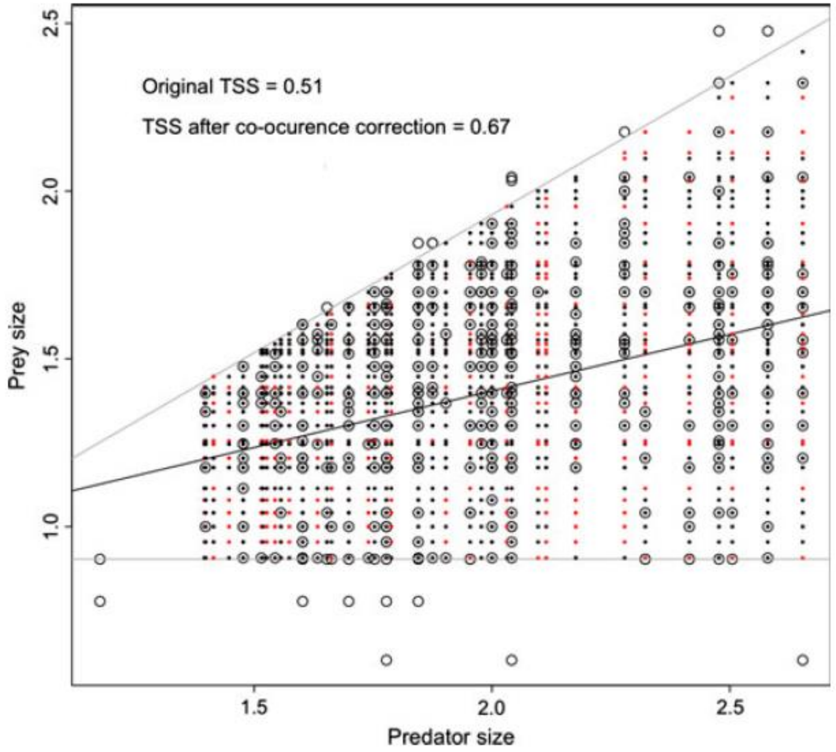
Williams & Martinez (2000)



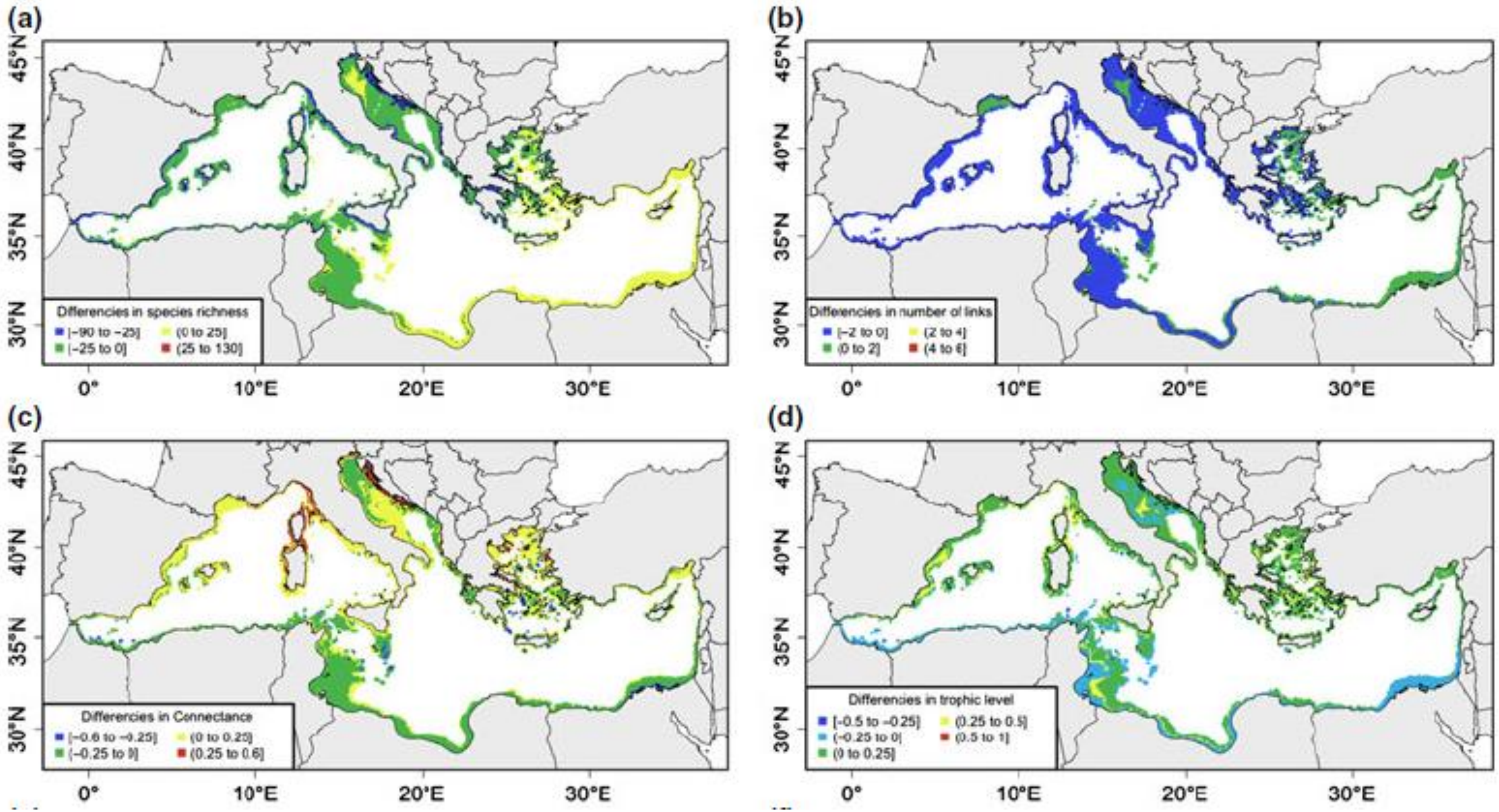
Infer interactions from the niche model and species body size



Gravel et al. (2013)

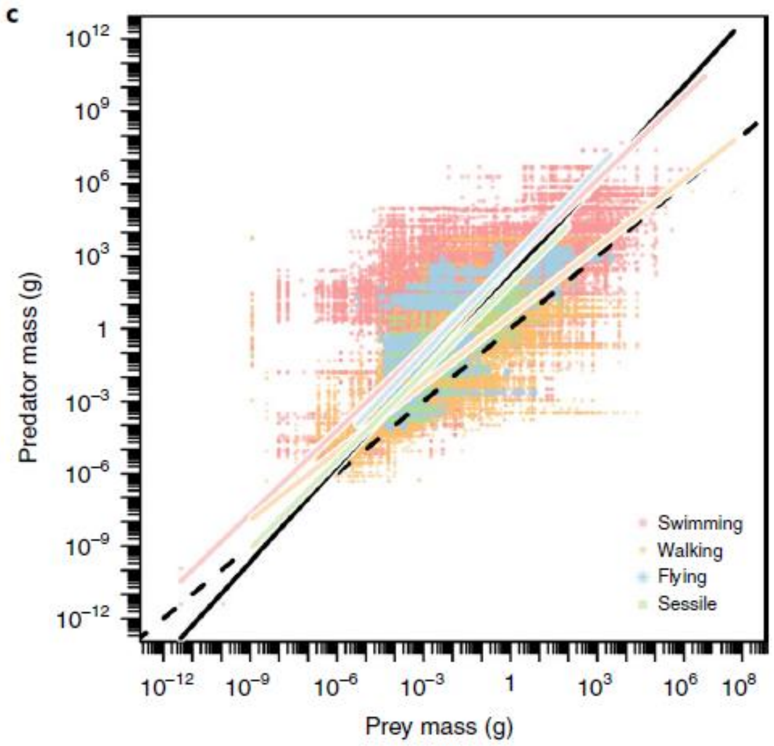


Infering trophic interaction and food web structure from body size



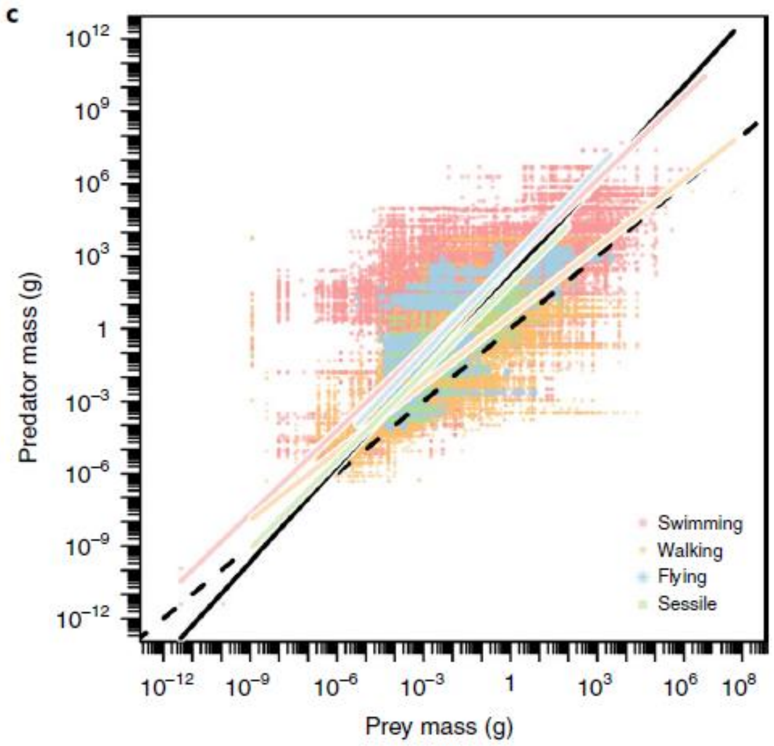
Albouy et al. (2014)

Relations that depend on consumer traits and ecosystem types

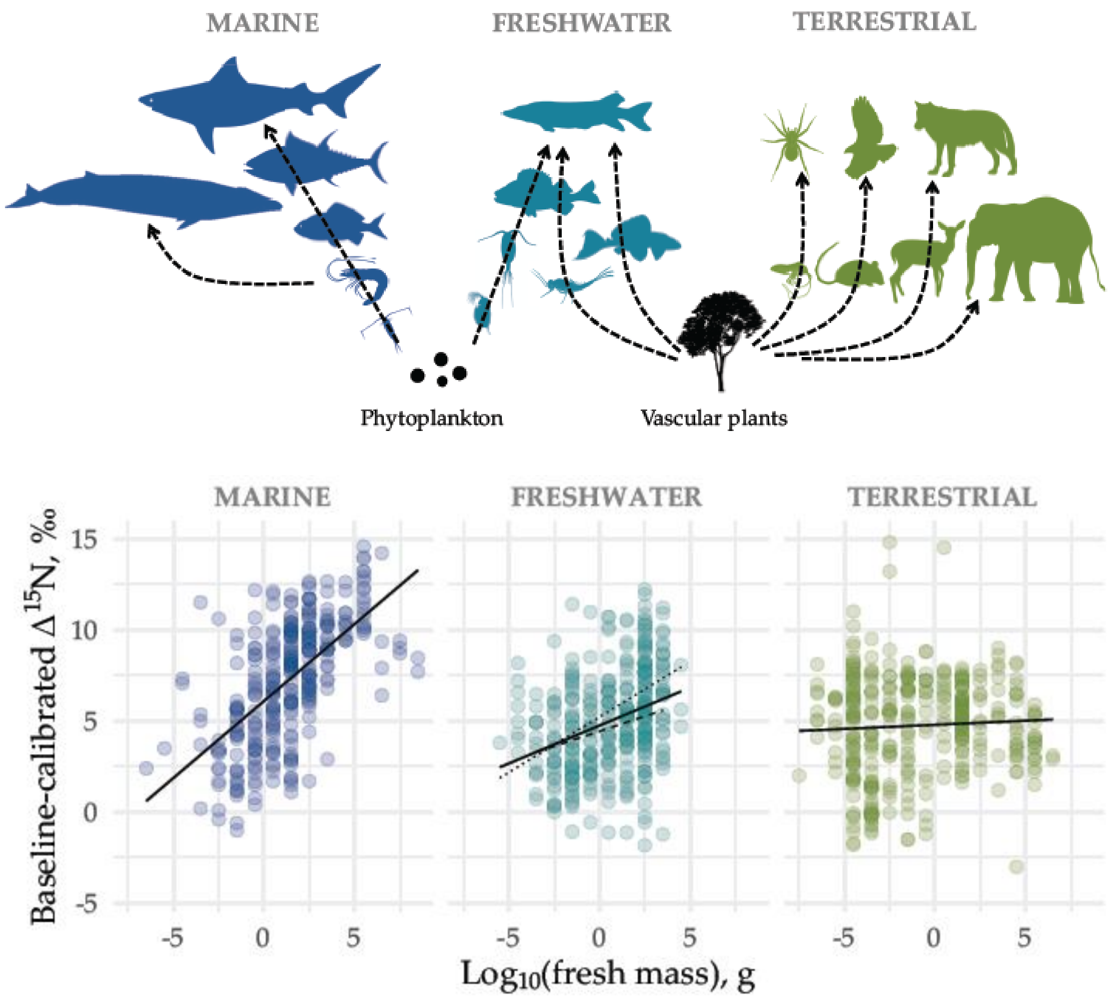


Brose et al. 2019

Relations that depend on consumer traits and ecosystem types

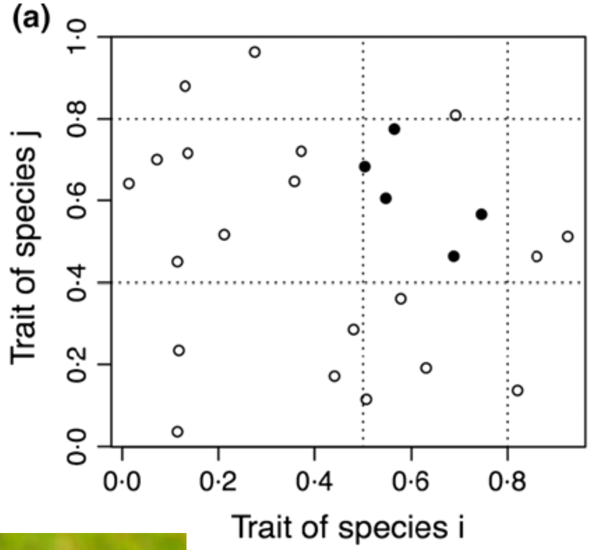


Brose et al. 2019

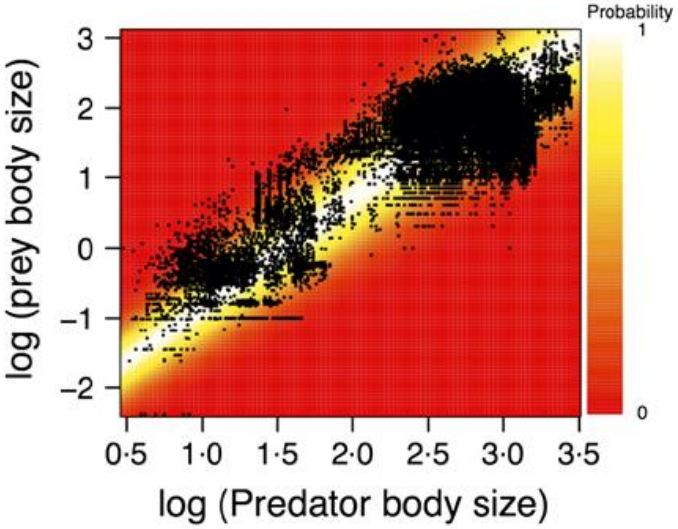


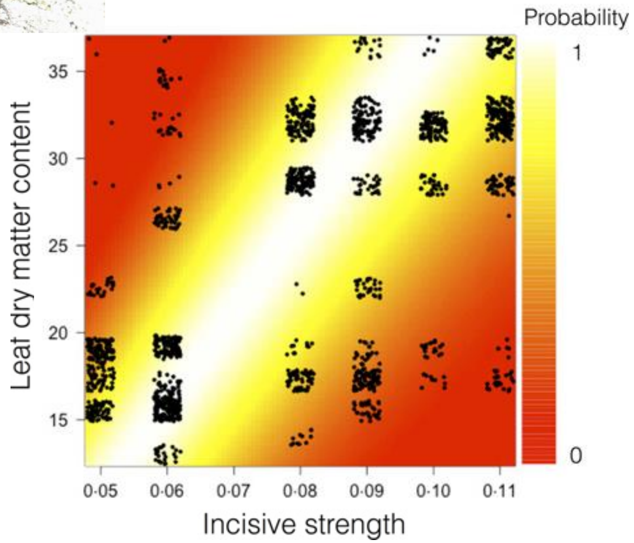
Potapov et al. 2019

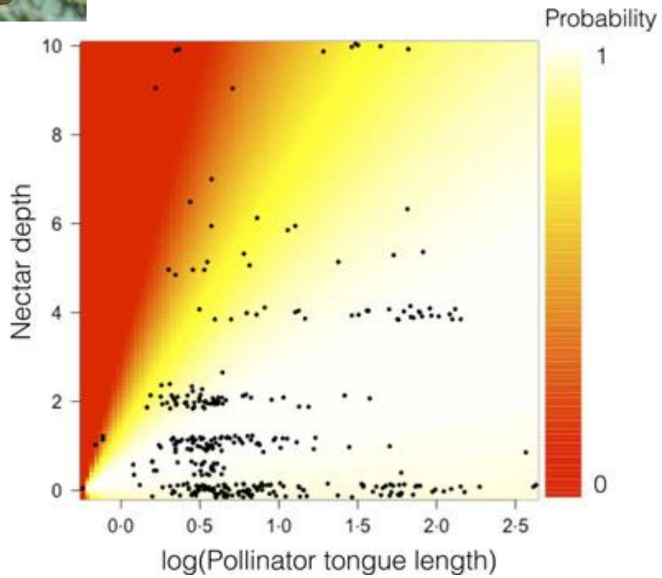
Different traits for different interaction types?



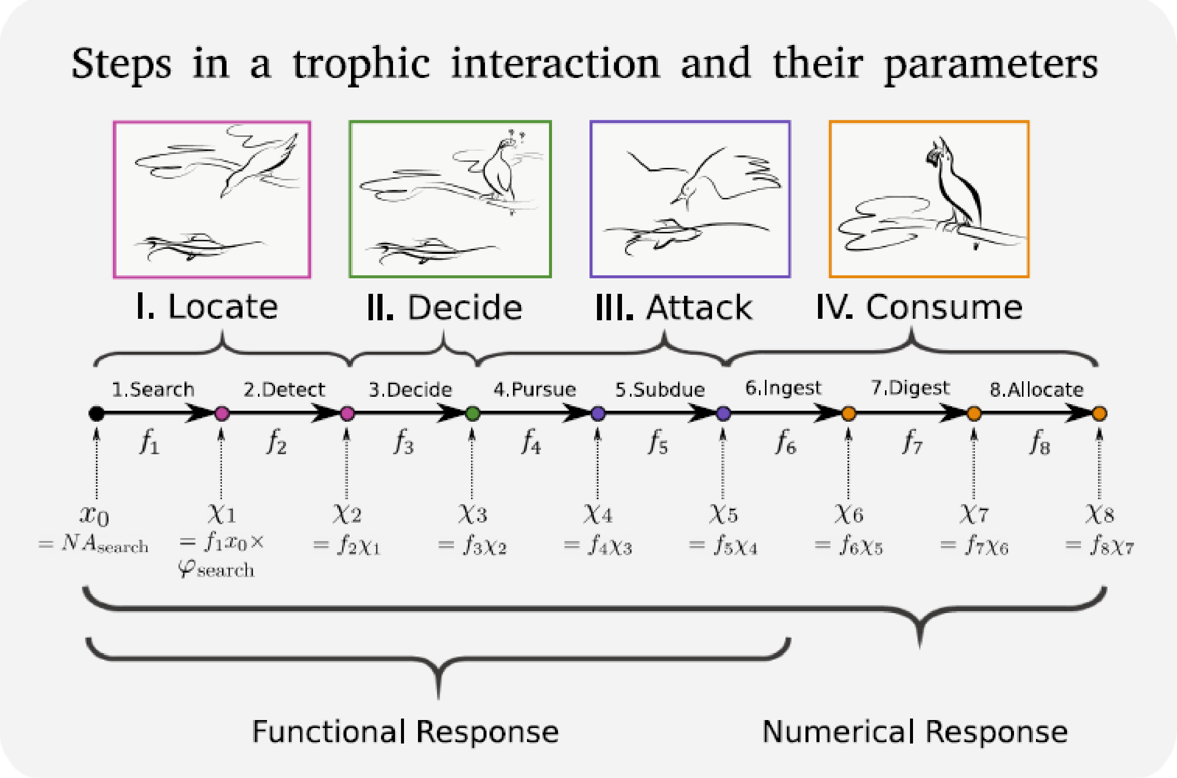
Bartomeus et al. 2016



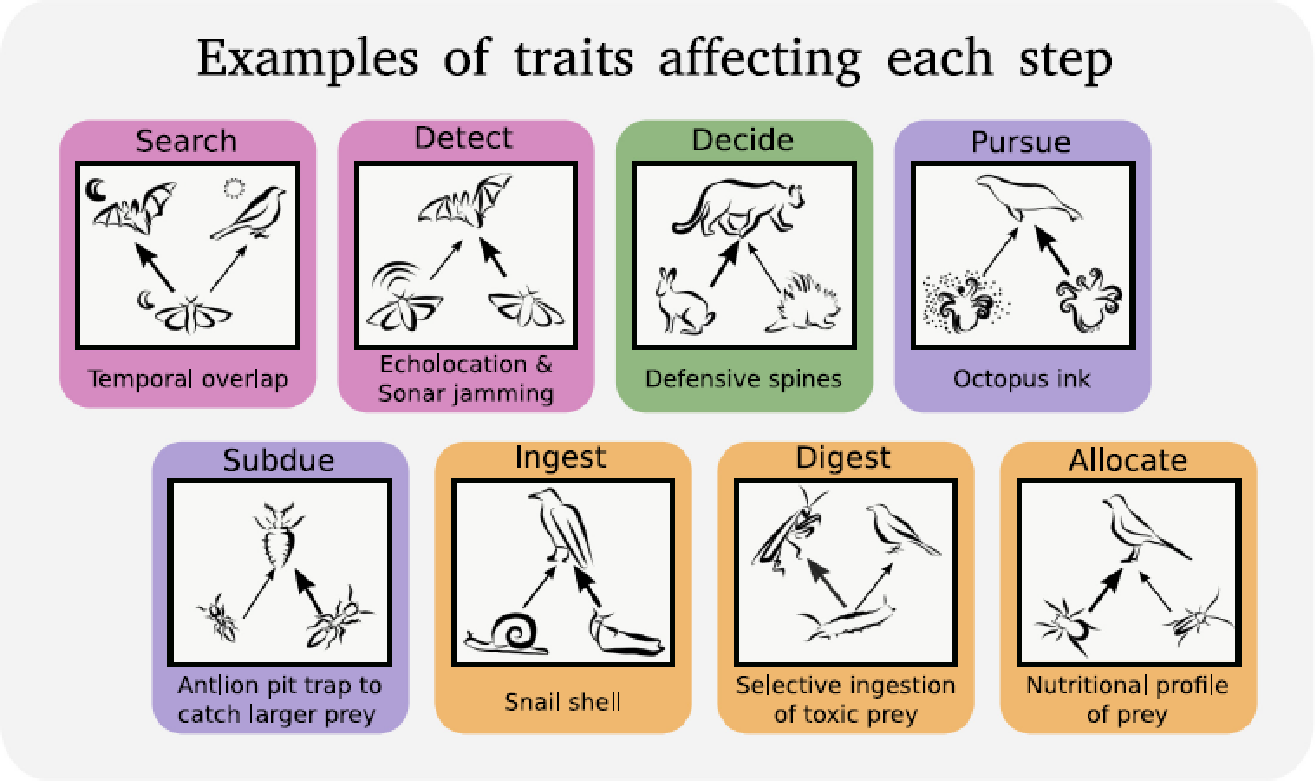




Different traits at different steps of a trophic interaction?



Wootton et al. 2021



How many traits are required to predict an interaction?

ECOLOGY LETTERS

Ecology Letters, (2013) doi: 10.1111/ele.12081

LETTER

The dimensionality of ecological networks

Few trait-axes (dimensions) are required to predict interactions between two species in a given network

Network	type	*S*	*C*	best1	best2	best3	bestAll
Puerto Rico, highland† (Dalsgaard *et al.* 2009)	bim	11 + 2	0.59	1 (BILc/BMc)	1 (BILc/BMc + any)	1 (BILc/BMc + any + any)	1 (9)
NZ landuse*	bim	15 + 16	0.17	0.44 (BWc)	0.79 (BWc + NDr)	0.91 (BWc + NDr + STIr)	0.98 (19)
Santa Genebra (Galetti & Pizo, 1996)	bim	29 + 33	0.14	0.40 (BIGc)	0.58 (BIGc + FSr)	0.65 (BiGc + FSr + BMc)	0.89 (11)
Villavicencio (Chacoff *et al.* 2012)	bim	41 + 80	0.18	0.35 (ORr)	0.46 (ORr + SLr)	0.56 (ORr + SLr + PWc)	0.90 (21)
Garraf (Bosch *et al.* 2009)	bim	19 + 165	0.26	0.62 (FBLr)	0.79 (FBLr + BLDr)	0.87 (FBLr + BLDr + POLr)	0.95 (12)
Ecuador LU-gradient (Tylianakis *et al.* 2007)	bia	29 + 9	0.18	0.58 (BLc)	0.75 (BLc + BLr)	0.75 (BLc + BLr + DPc)	0.75 (8)
NZ alpine grassland*	bia	38 + 31	0.085	0.34 (BMc)	0.74 (BMc + BMr)	0.75 (BMc + BMr + TMPc)	0.75 (6)
Ythan (Cohen *et al.* 2009)	fw	92	0.049	0.32 (BMc)	0.55 (BMc + BMr)	0.61 (BMc + BMr + HBc)	0.74 (12)
StMarks (Christian & Luczkovich, 1999)	fw	143	0.086	0.25 (BMc)	0.45 (BMc + MBr)	0.55 (BMr + MBr + HBc)	0.82 (12)
Caribbean reef (Optiz 1996)	fw	249	0.053	0.17 (BMr)	0.26 (BMr + BMc)	0.33 (BMr + BMc + MBr)	0.42 (12)
Kongsfjorden (Jacob *et al.* 2011)	fw	270	0.023	0.11 (MCr)	0.25 (HBr + BMc)	0.39 (MCr + BMc + MBr)	0.69 (12)
Loughhyne (Riede *et al.* 2010)	fw	349	0.042	0.15 (BMr)	0.24 (BMr + BMc)	0.33 (BMr + BMc + MBr)	0.47 (12)
Weddell (Jacob, 2005)	fw	488	0.067	0.20 (MBr)	0.30 (BMr + MBr)	0.40 (BMr + BMc + MBr)	0.61 (12)

*the data are available in Supporting Information.

†see Supporting Information for additional networks of the same type.

Trait identifiers: BIL, bill length; BM, body mass; BW, body width; ND, amount nectar; STI, flower type; BIG, bill gape; FS, fruit size; OR, orientation; SL, stamen length; PW, proboscis width; FBL, first bloom; BLD, bloom duration; POL, pollen volume per flower; BL, body length; DP, dates present; TMP, temperature envelope; HB, habitat; MB, mobility and MC, metabolic category.

Part I :What determines the links between species?
The role of traits
Some conclusions and perspectives

- ➢ Importance of traits for understanding the structure of interaction networks: can we infer interactions between species?

- ➢ Relative importance of given traits depending on interaction types, ecosystems, environmental conditions?

- ➢ Relative importance of traits vs. abundance? Importance of evolutionary history?

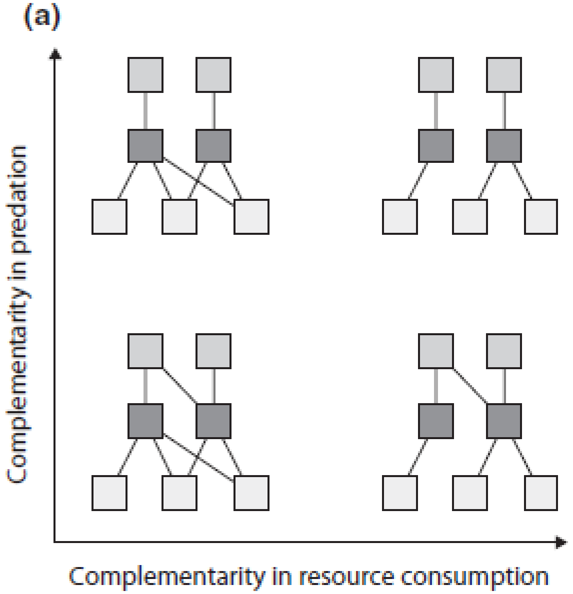
Part II
Network structure and ecosystem functioning

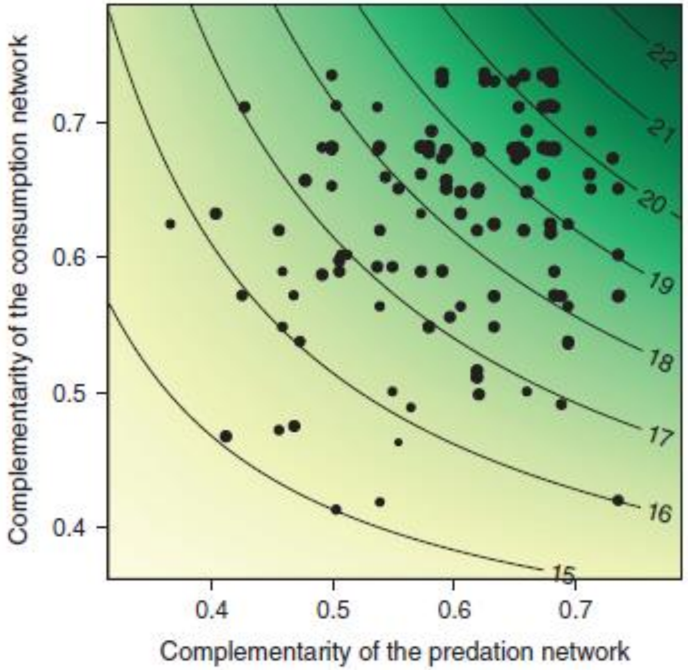
Diversity and ecosystem functioning

Tilman et al. (2006)

Hector et al. (2010)

Diversity and ecosystem functioning in ecological networks





Poisot et al. 2013

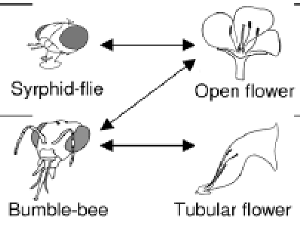
Diversity of pollinators and functioning

PLOS BIOLOGY January 2006 | Volume 4 | Issue 1 | e1

Functional Diversity of Plant–Pollinator Interaction Webs Enhances the Persistence of Plant Communities

Colin Fontaine[1,2*], Isabelle Dajoz[1,2], Jacques Meriguet[1,2], Michel Loreau[2,3]

Pollinators species and groups	Mouthpart length (mm ± S.E.)	Theoretical pollination network	Plants species and groups	Accessibility pollen	Accessibility nectar
Sphaerophoria sp.	2.66 ± 0.35		*M. officinalis*	easy	easy
E. balteatus	2.3 ± 0.20		*E. cicutarium*	easy	easy
E. tenax	5.47 ± 0.29		*R. raphanistrum*	easy	difficult
B. terrestris	9.02 ± 0.19		*M. guttatus*	easy	difficult
B. hortorum	9.21 ± 1.02		*M. sativa*	difficult	difficult
B. lapidarius	8.10 ± 0.86		*L. corniculatus*	difficult	difficult



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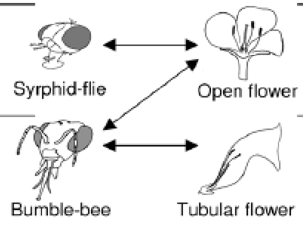
Sphaerophoria sp.	2.66 ± 0.35		*M. officinalis*	easy	easy
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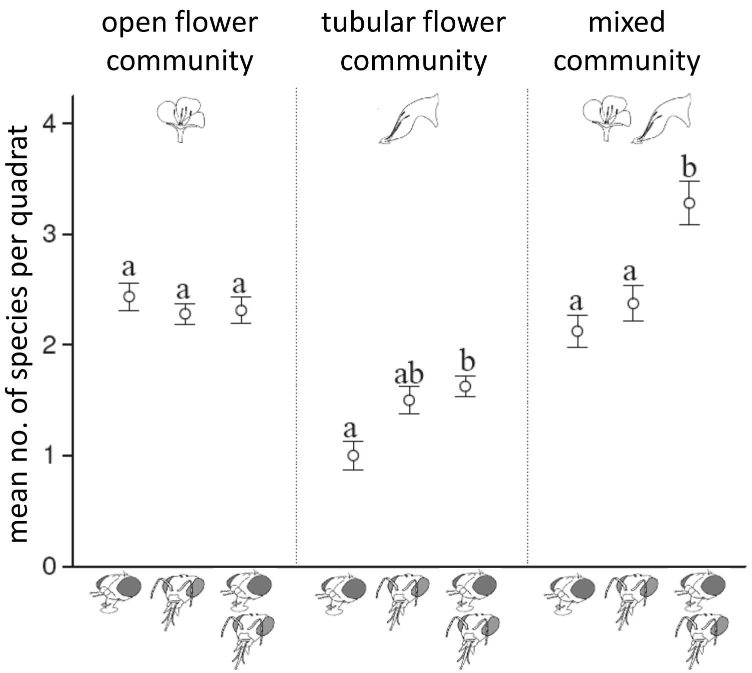

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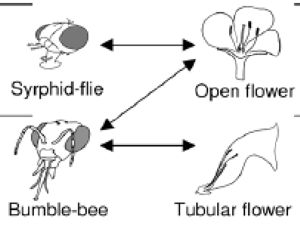
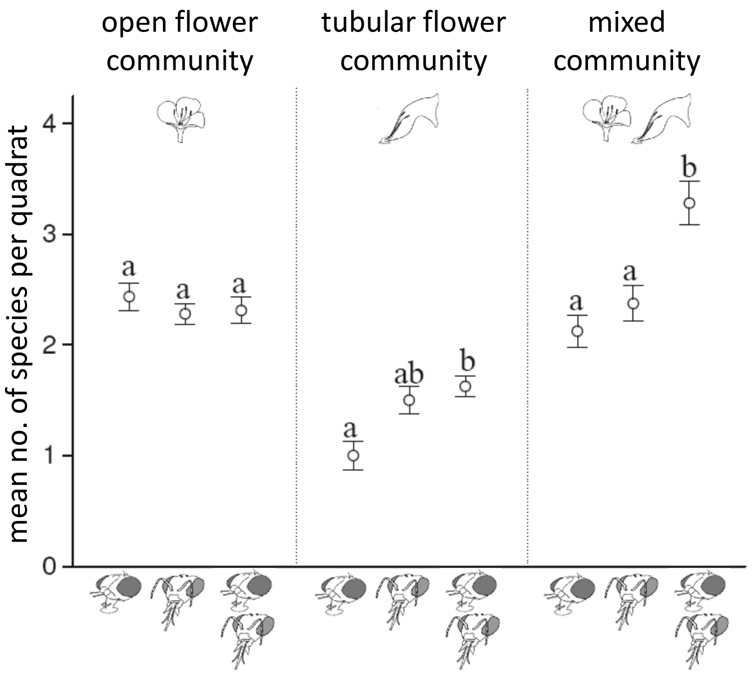
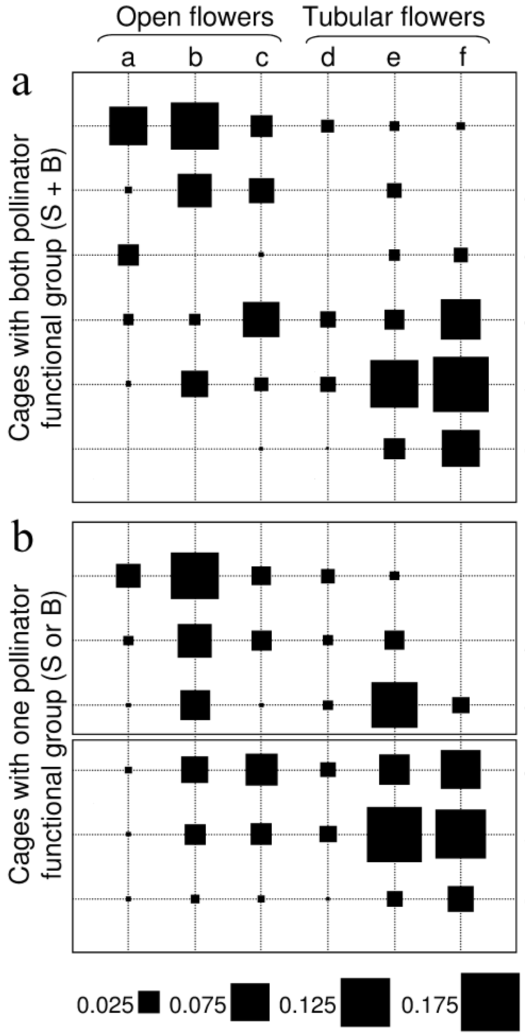




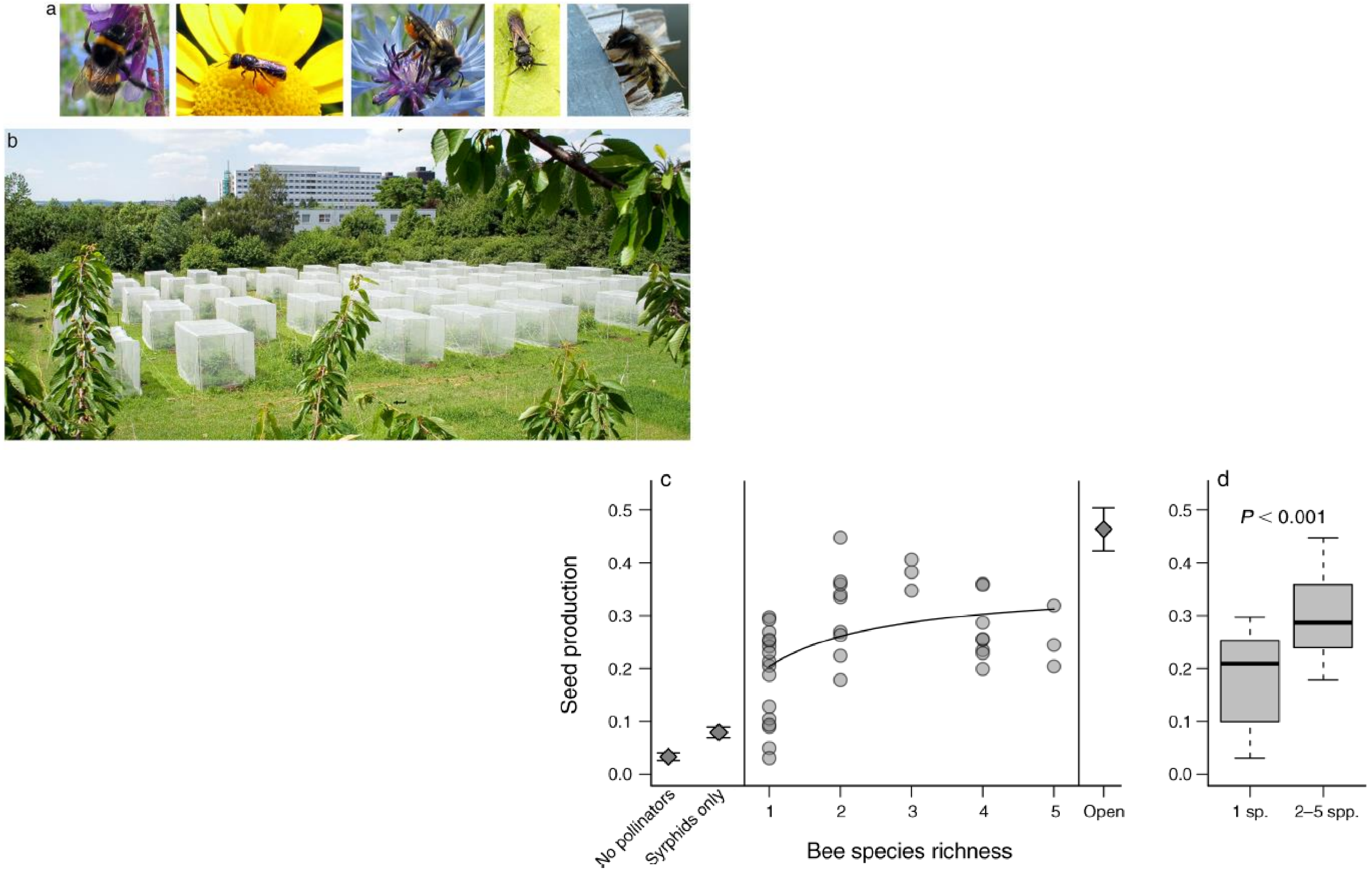


Diversity of pollinators and functioning

Bee diversity effects on pollination depend on functional complementarity and niche shifts

Jochen Fründ,[1,5] Carsten F. Dormann,[2,3] Andrea Holzschuh,[1,4] and Teja Tscharntke[1]

Ecology, 94(9), 2013, pp. 2042–2054



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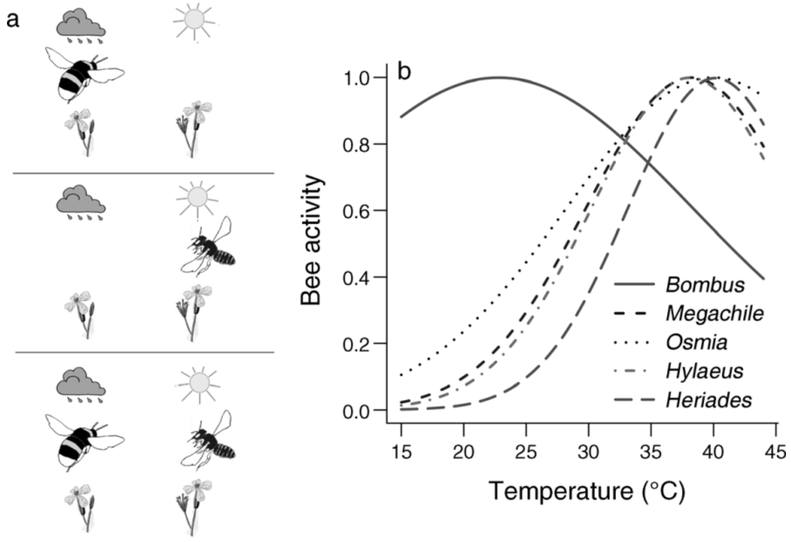
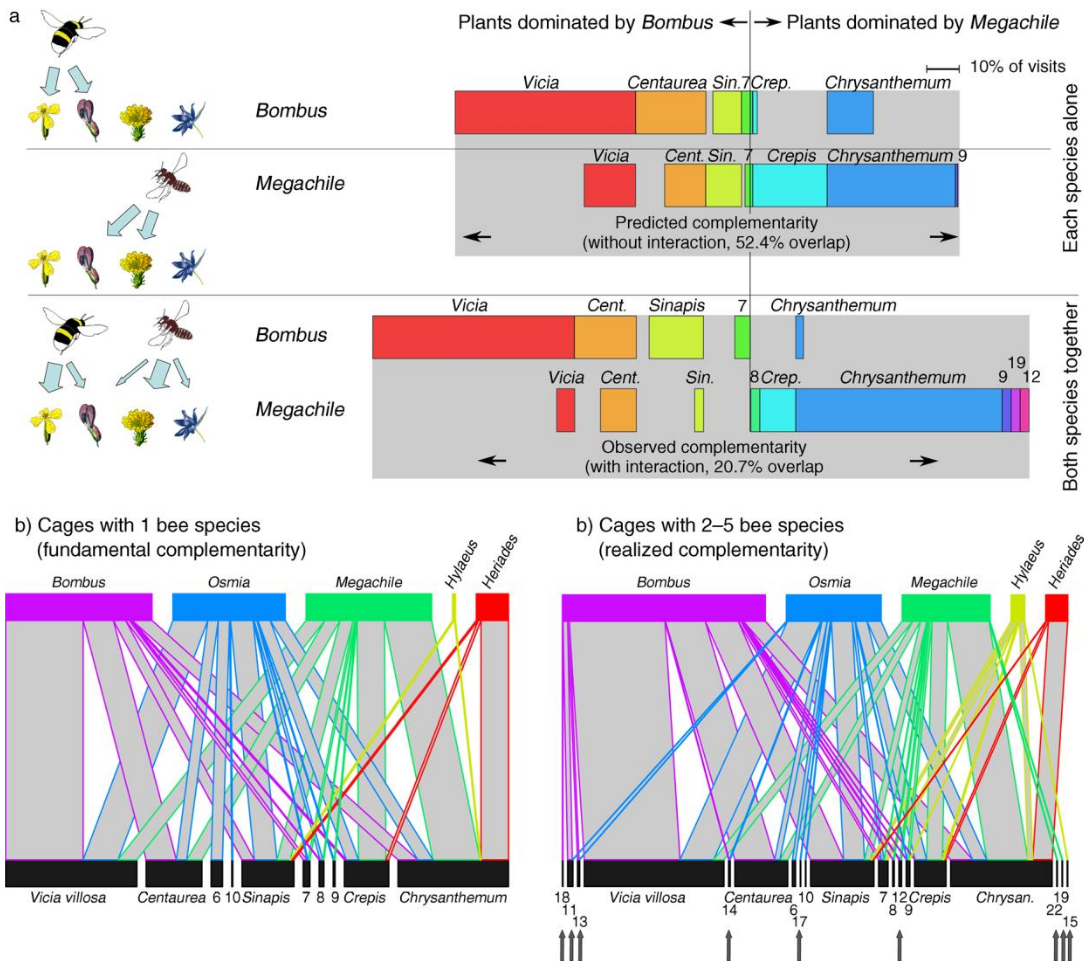


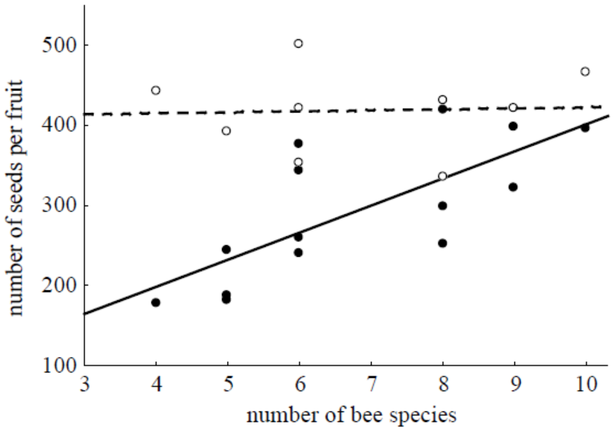


Diversity of pollinators and ecosystem services

Proc. R. Soc. B (2008) **275**, 2283–2291

Functional group diversity of bee pollinators increases crop yield

Patrick Hoehn[1,*], Teja Tscharntke[1], Jason M. Tylianakis[2] and Ingolf Steffan-Dewenter[3]



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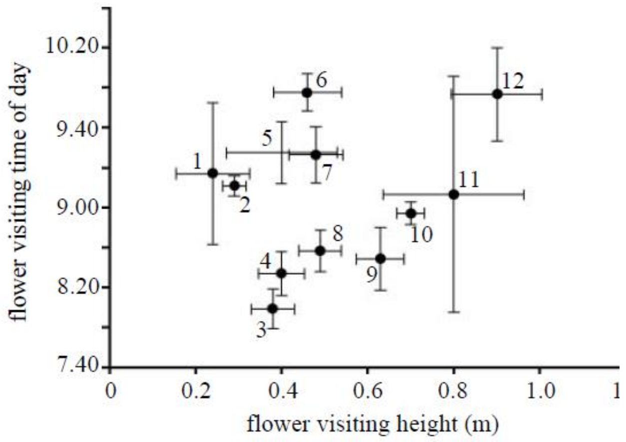

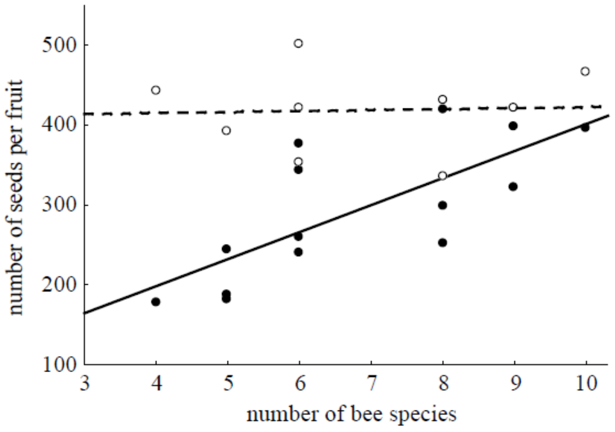

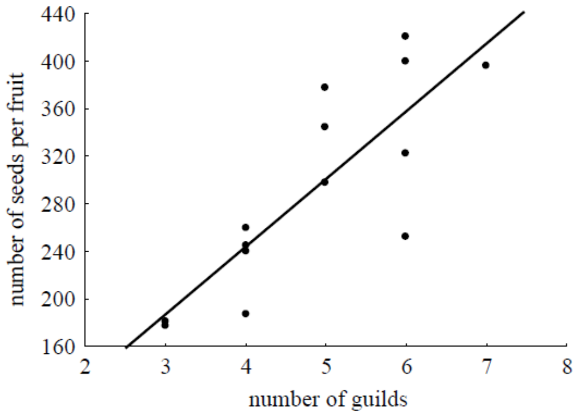

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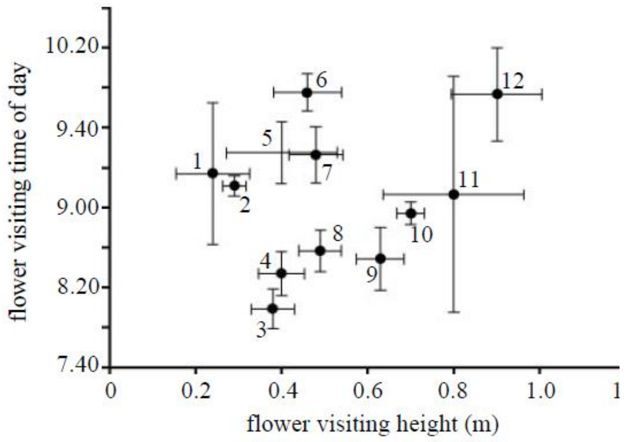
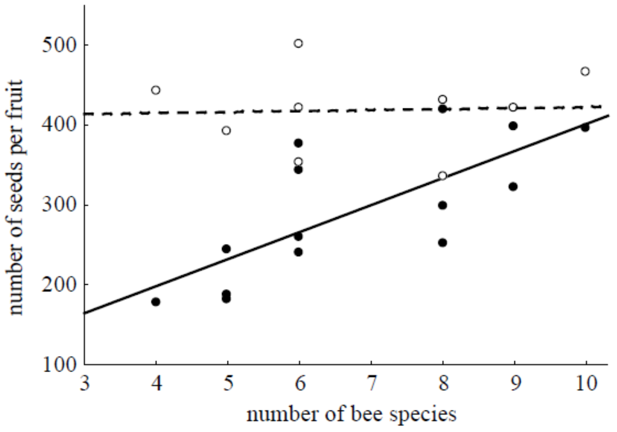




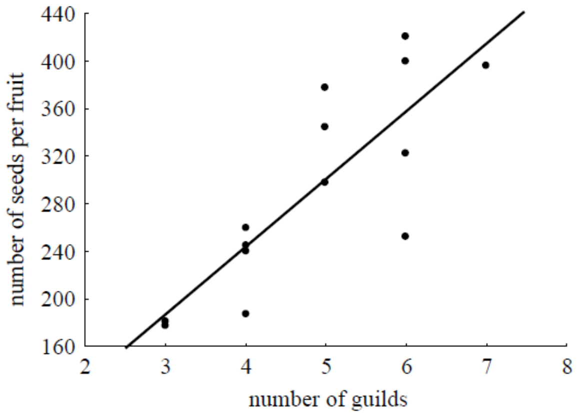


Table 4. Bee species richness and functional guild diversity in relation to the residuals of seed set after correlation with bee abundance. (Italic numbers indicate significant effects.)

	r^2	$F_{1,10}$	p
model 1			
bee species richness	*0.32*	*6.08*	*0.033*
functional guild diversity	0.15	2.87	0.121
model 2			
functional guild diversity	*0.45*	*8.47*	*0.015*
bee species richness	0.02	0.47	0.507

Diversity of pollinators and ecosystem services (stability)

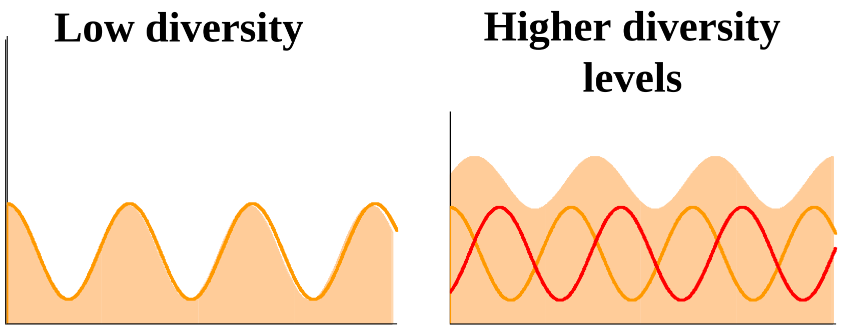
Ecology Letters, (2013) doi: 10.1111/ele.12170

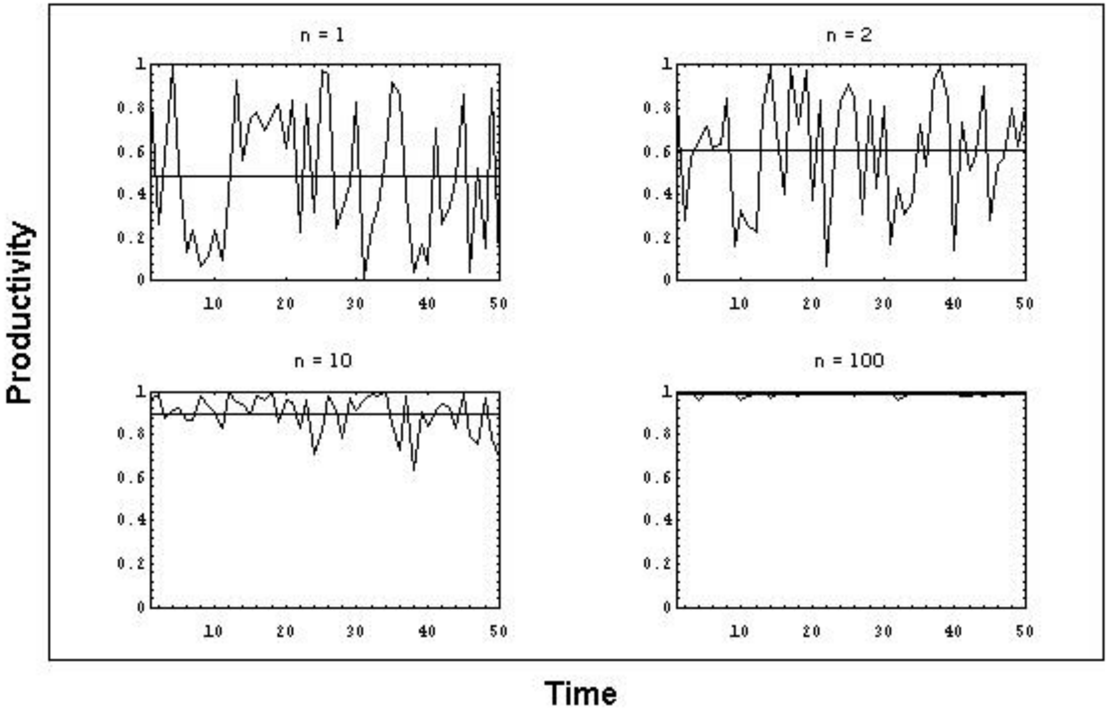
Biodiversity ensures plant–pollinator phenological synchrony against climate change

Ignasi Bartomeus,[1,2]* Mia G. Park,[3] Jason Gibbs,[3,4] Bryan N. Danforth,[3] Alan N. Lakso[5] and Rachael Winfree[1,6]

Insurance hypothesis

Species diversity decreases the variability of ecosystem properties through asynchronous response of species to environmental fluctuations





Yachi & Loreau (1999)

Diversity of pollinators and ecosystem services (stability)

Ecology Letters, (2013) doi: 10.1111/ele.12170

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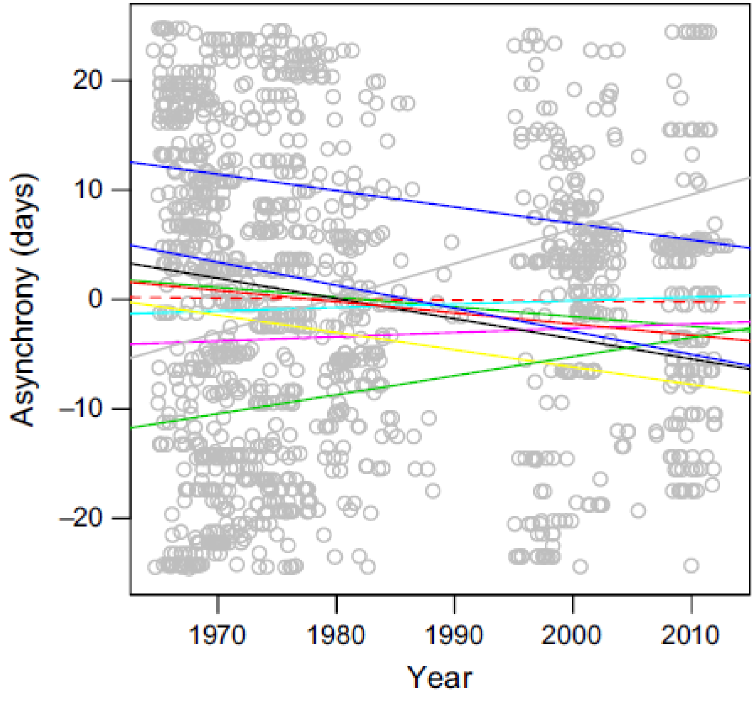

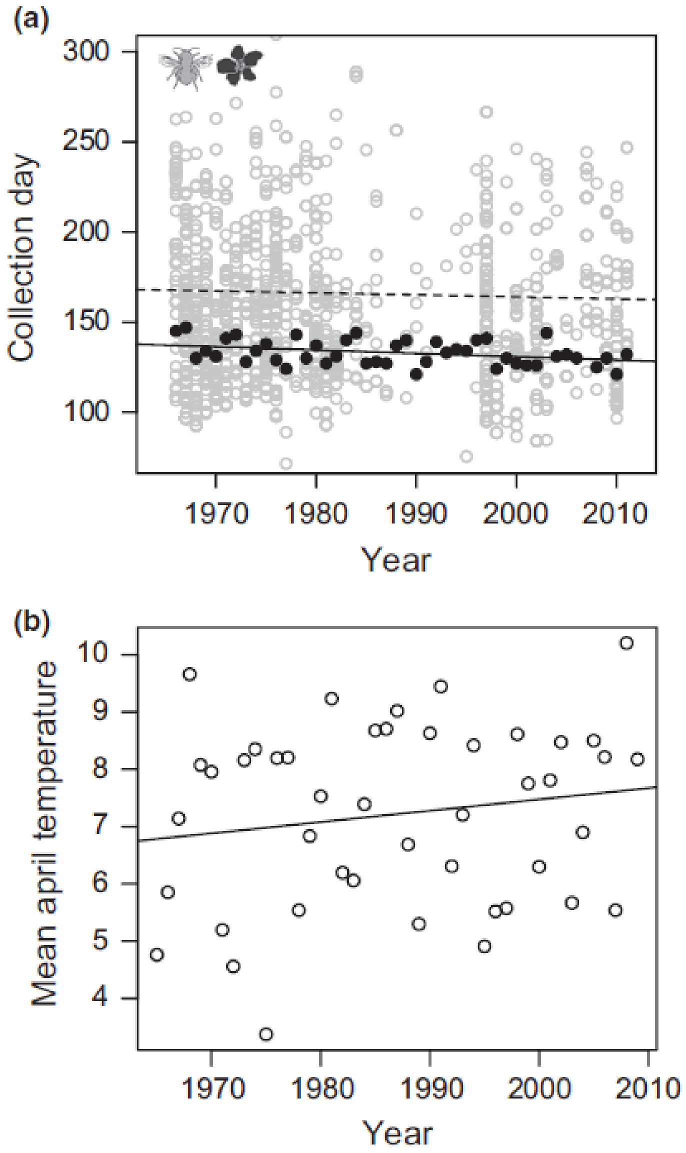

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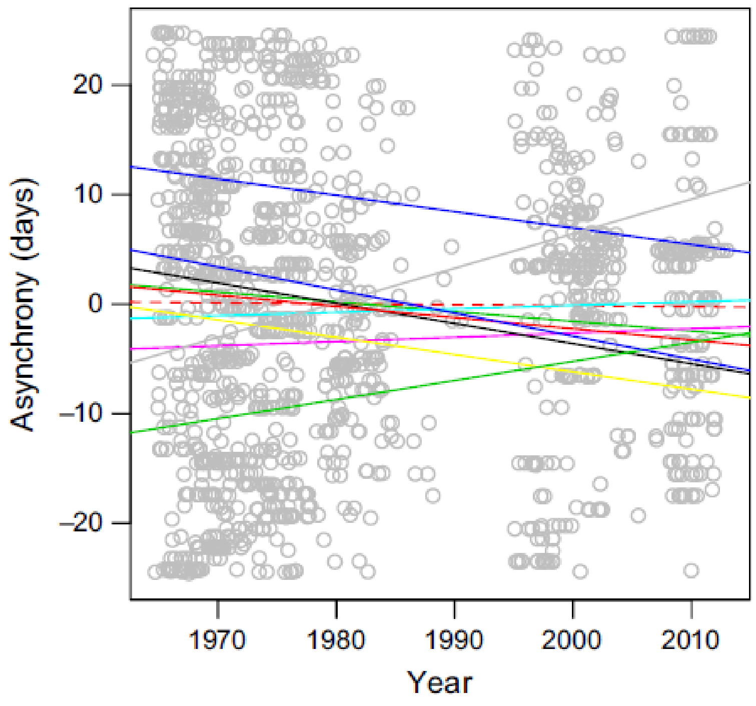
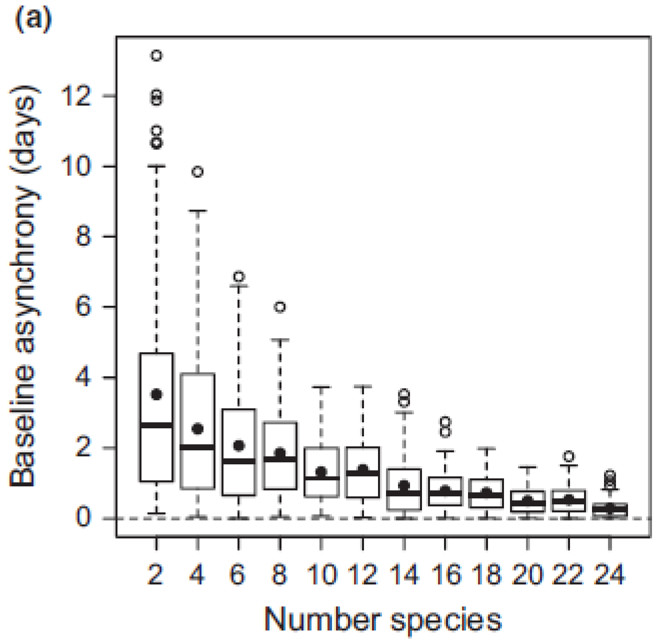


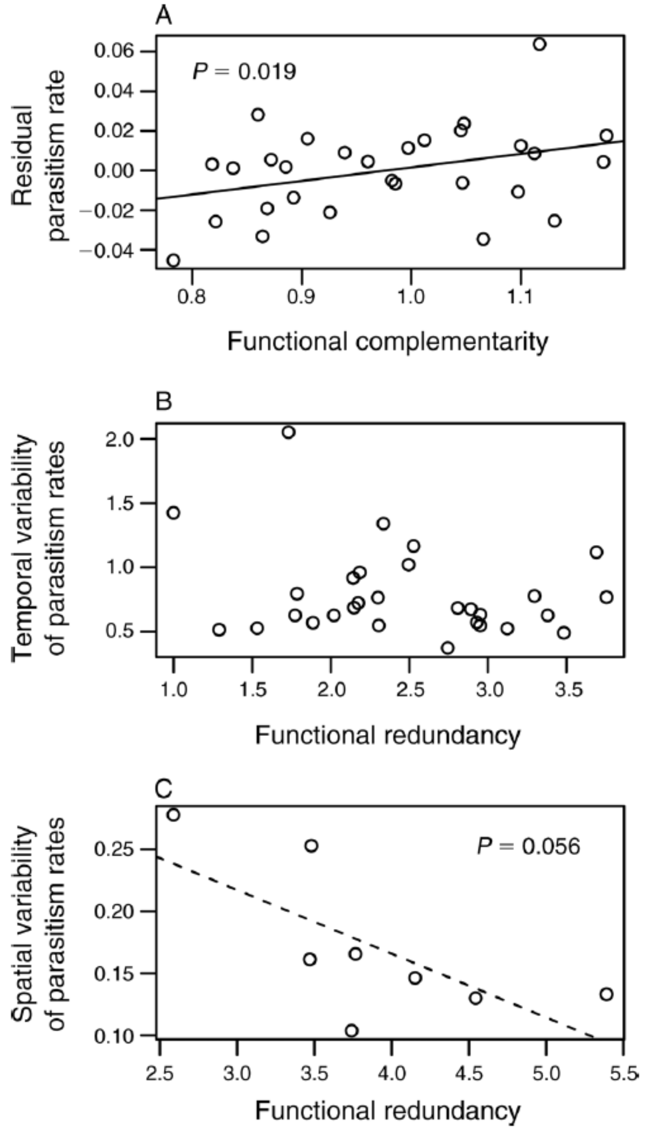


The structure of host-parasitoid networks and functioning

Complementarity and redundancy of interactions enhance attack rates and spatial stability in host–parasitoid food webs

Guadalupe Peralta,[1,6] Carol M. Frost,[1] Tatyana A. Rand,[2] Raphael K. Didham,[3,4] and Jason M. Tylianakis[1,5]

Peralta et al. 2014



Part II: Network structure and ecosystem functioning
Some conclusions and perspectives

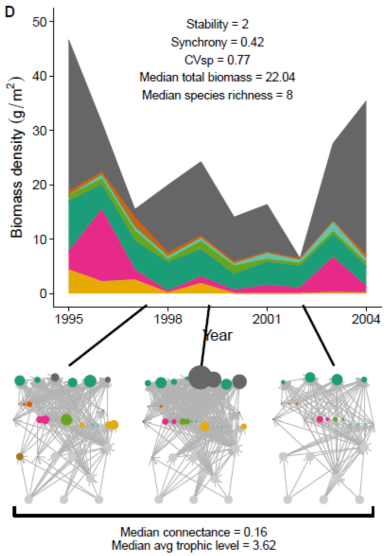
- Network structure allows to describe complementarity and redundancy among species -> direct links with the study of ecosystem functions and stability

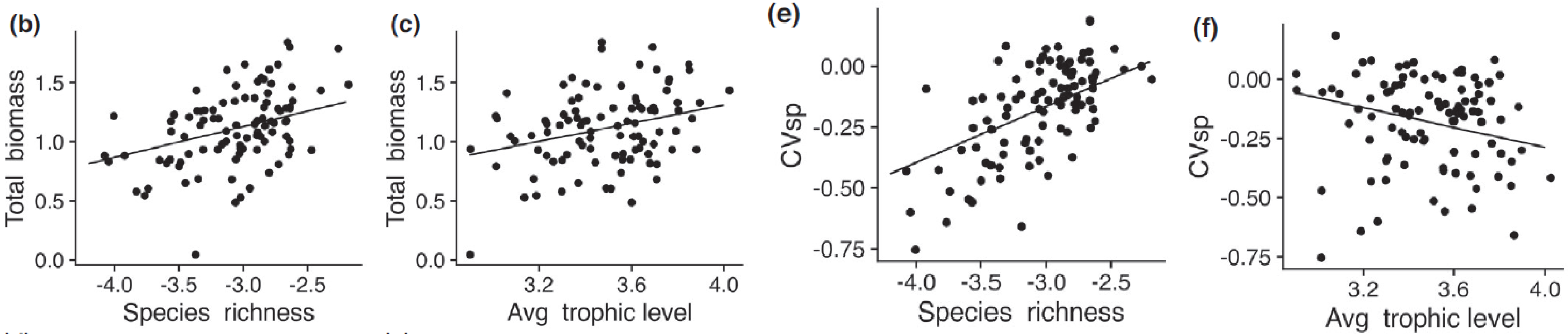
- Studies often focus on one or two trophic levels: need a food web perspective?

Species richness and food-web structure jointly drive community biomass and its temporal stability in fish communities

Alain Danet[1] | Maud Mouchet[1] | Willem Bonnaffé[2] | Elisa Thébault[3] | Colin Fontaine[1]

Danet et al. 2021





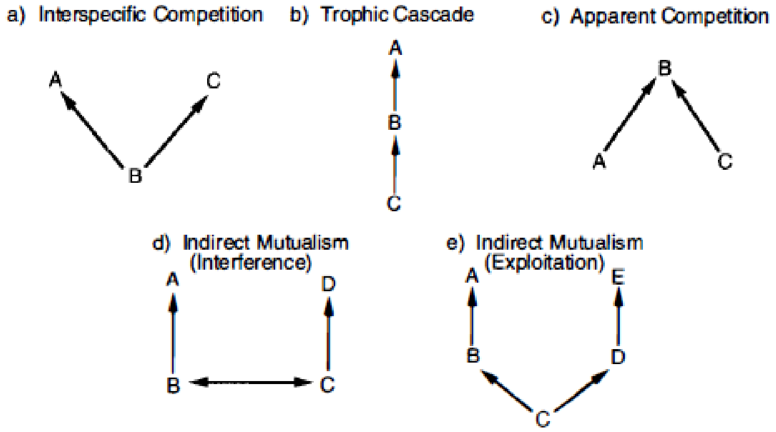
Part III
Cascading effects in networks
Network structure and indirect interactions

Understanding indirect effects: a central issue in ecological networks

Annu. Rev. Ecol. Syst. 1994. 25:443–66

THE NATURE AND CONSEQUENCES OF INDIRECT EFFECTS IN ECOLOGICAL COMMUNITIES

J. Timothy Wootton



Ecology, 101(7), 2020, e03080

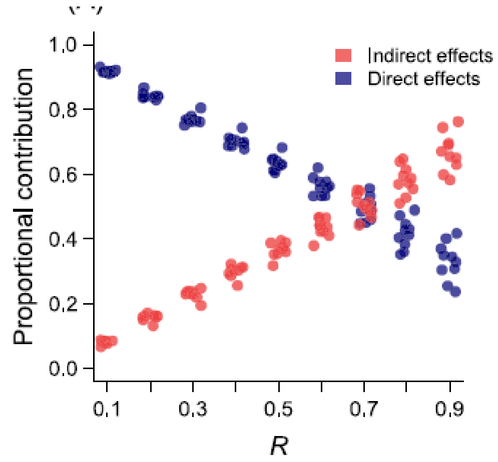
The indirect paths to cascading effects of extinctions in mutualistic networks

Mathias M. Pires,[1,11] James L. O'Donnell,[2] Laura A. Burkle,[3] Cecilia Díaz-Castelazo,[4] David H. Hembry,[5,6] Justin D. Yeakel,[7] Erica A. Newman,[6] Lucas P. Medeiros,[8] Marcus A. M. de Aguiar,[9] and Paulo R. Guimarães Jr.[10]

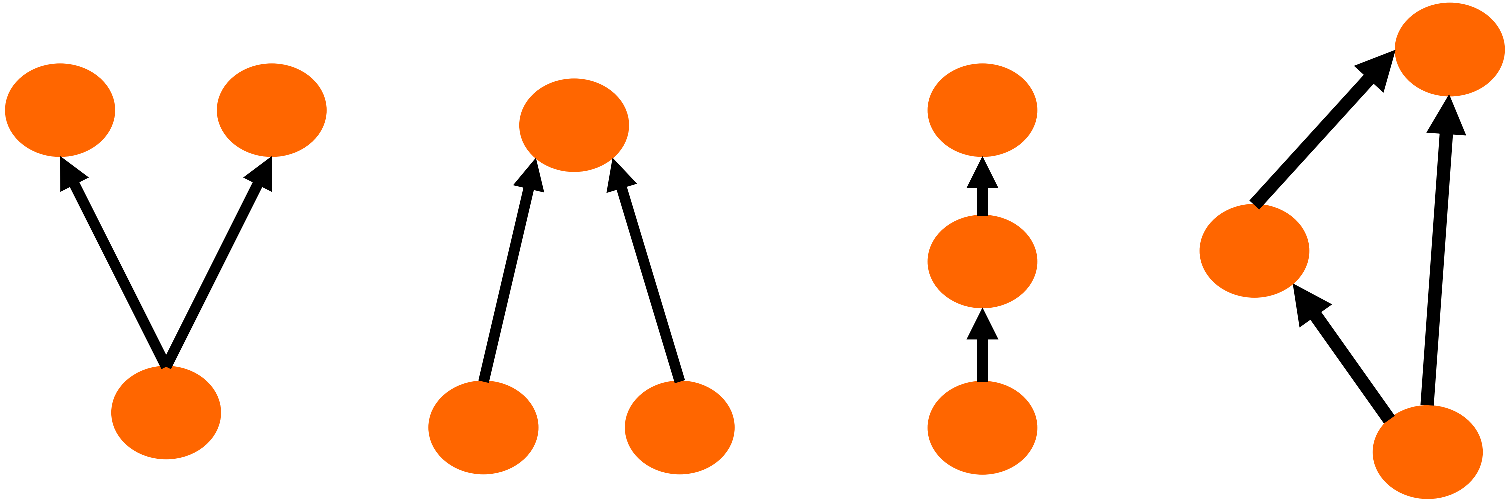
Ecology, 90(9), 2009, pp. 2426–2433

Press perturbations and indirect effects in real food webs

José M. Montoya,[1,2,6] Guy Woodward,[2] Mark C. Emmerson,[3,4] and Ricard V. Solé[5]



Understanding direct and indirect effects: studies on network motifs



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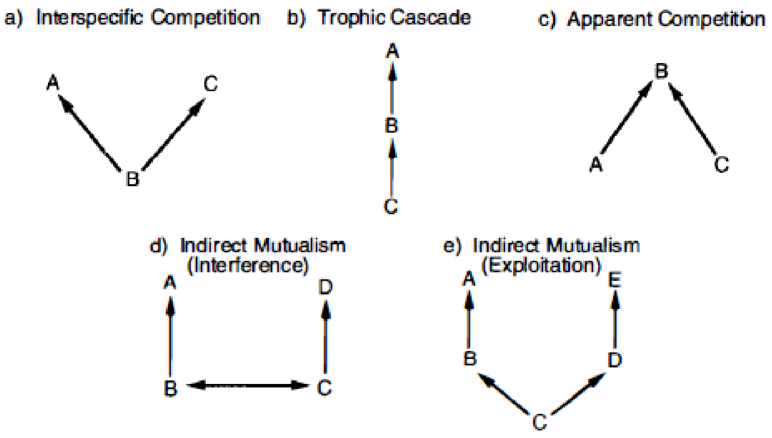

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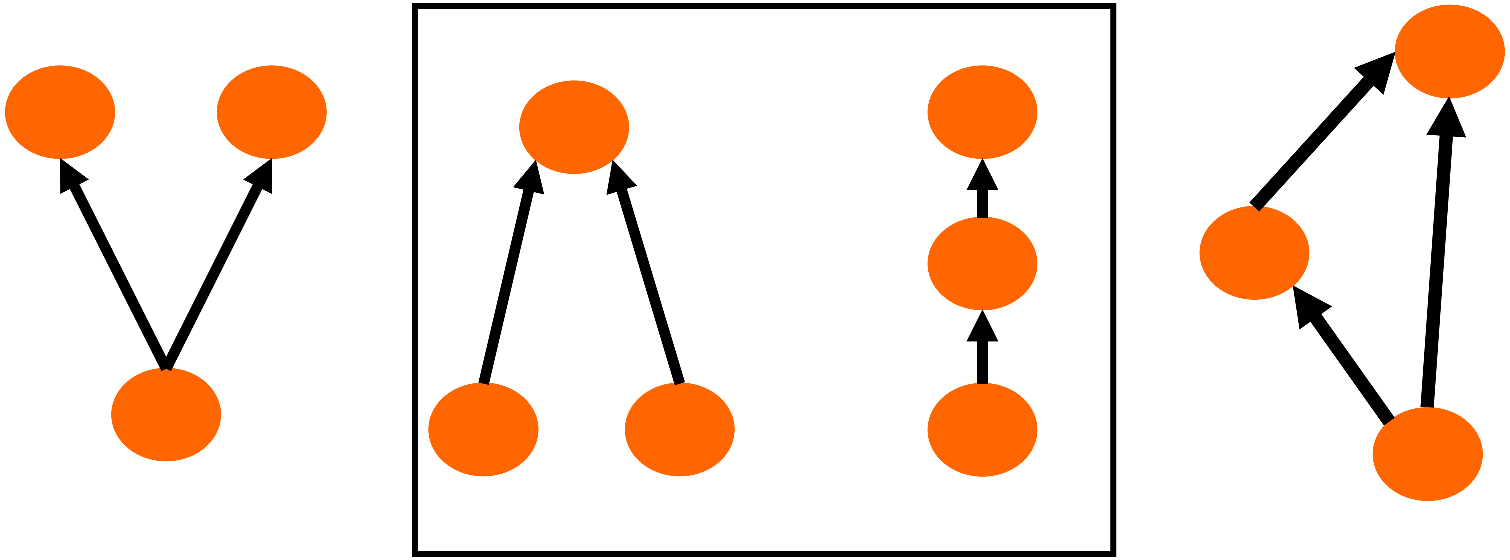

Annu. Rev. Ecol. Syst. 1994. 25:443–66

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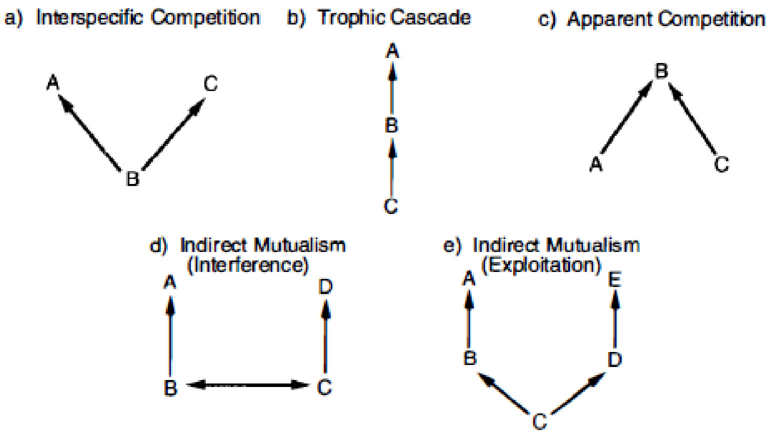
J. Timothy Wootton



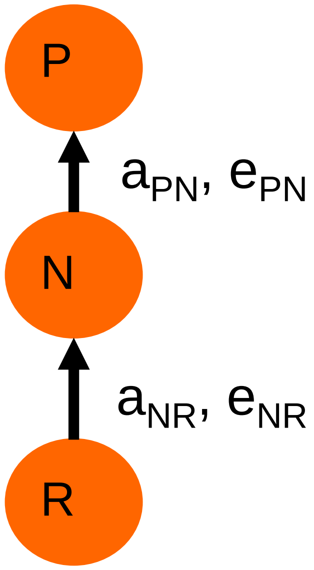
Trophic chain: a first model

- r = intrinsic growth rate of R
- K = carrying capacity of R
- a_{NR} and a_{PN} are the attack rates
- e_{NR} and e_{PN} are the conversion efficiencies
- d_N and d_P are the mortality rates

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

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

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



Trophic chain: a first model

- If there is an equilibrium with all species present, then:

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

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

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

Trophic chain: a first model

- If there is an equilibrium with all species present, then:

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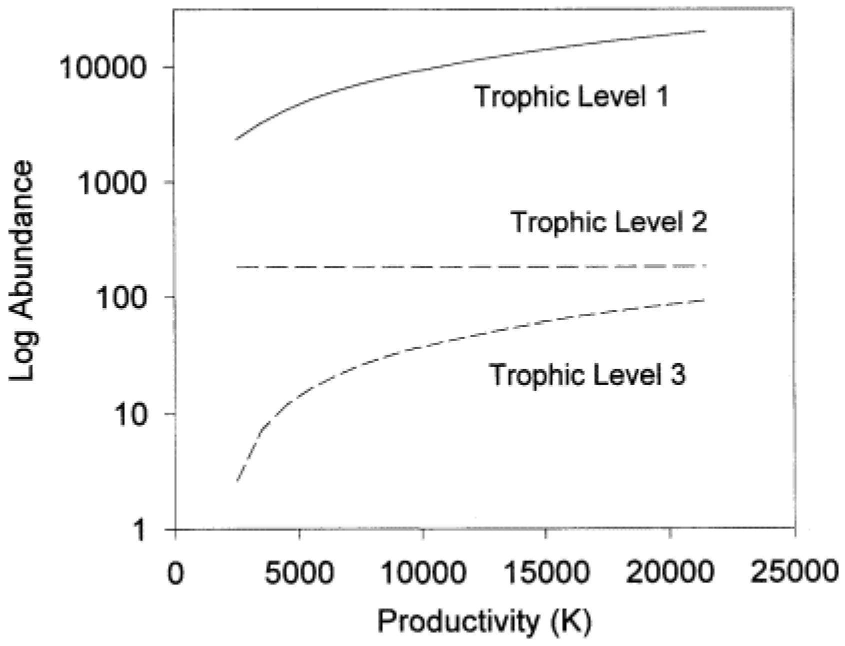


Trophic chain: a first model

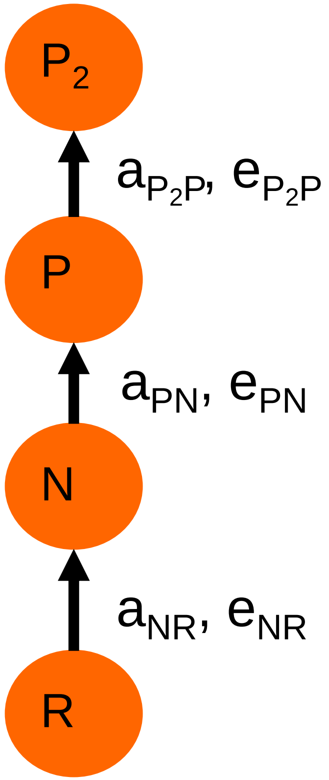
- With 4 species in the food chain:

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

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

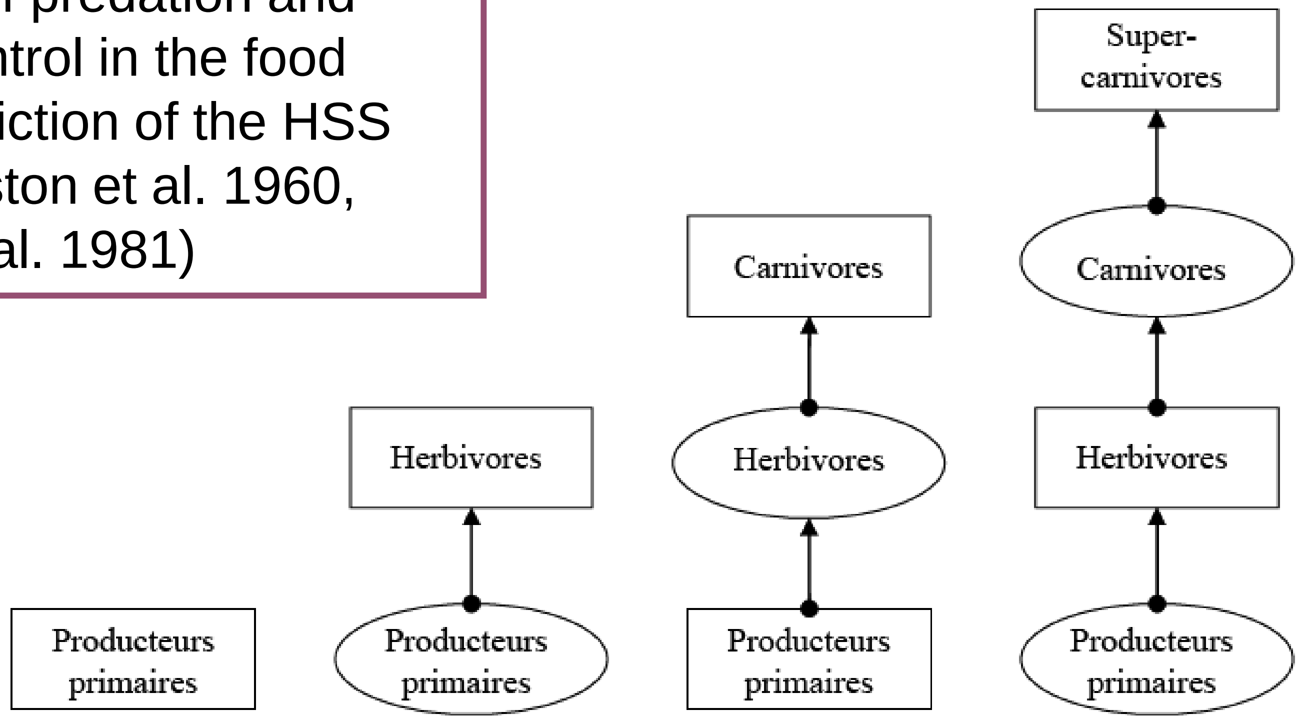
$$N^* = \frac{1}{a_{NR}}\left(1 - \frac{R^*}{K}\right)$$

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



Top-down and bottom-up effects

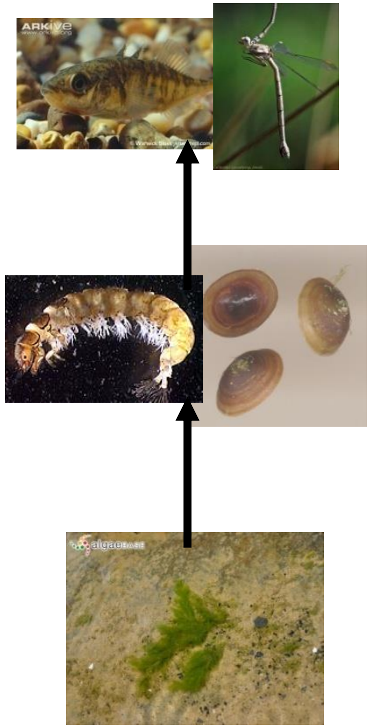
Alternation of predation and resource control in the food chain – prediction of the HSS model (Hairston et al. 1960, Oksanen et al. 1981)

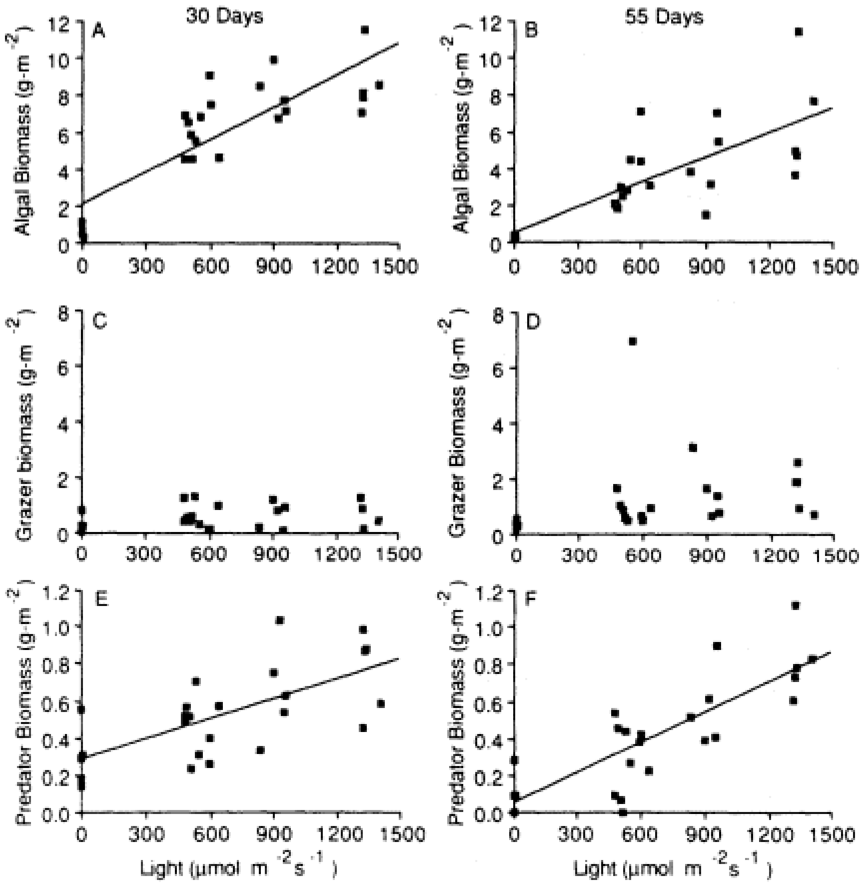


Control by predators

Control by resources

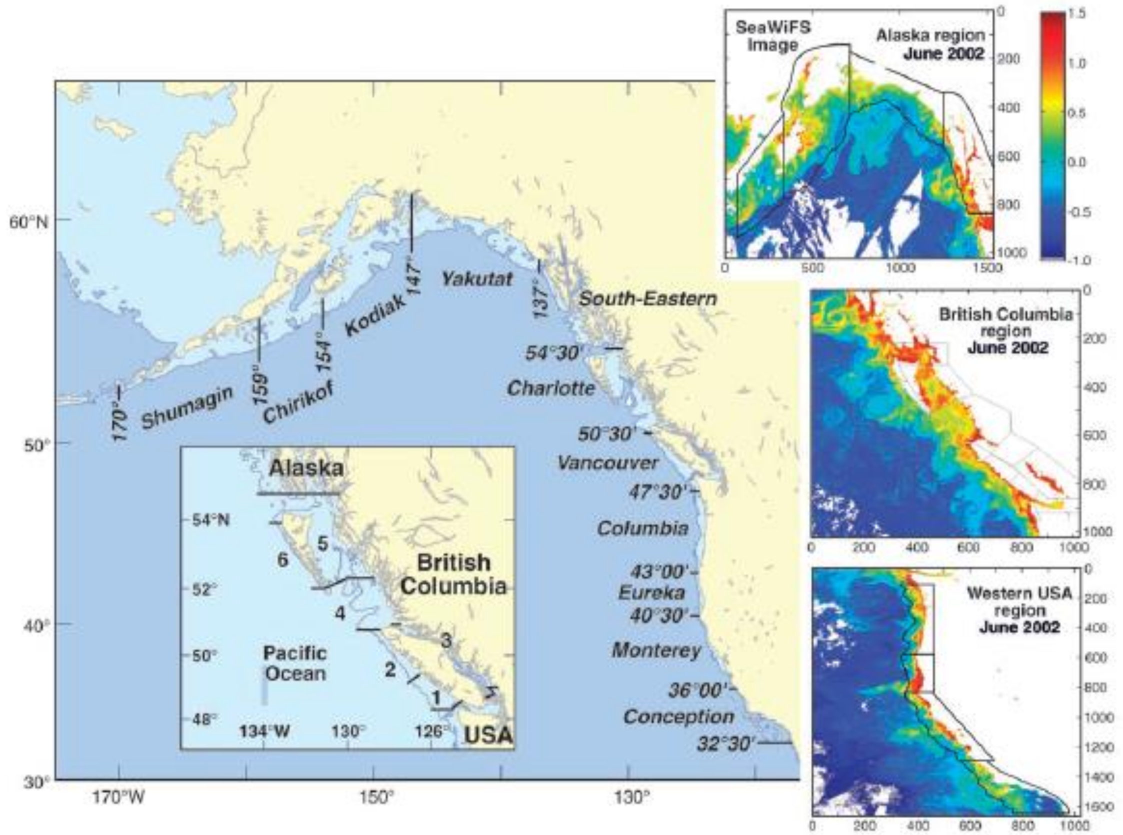
Top-down and bottom-up effects

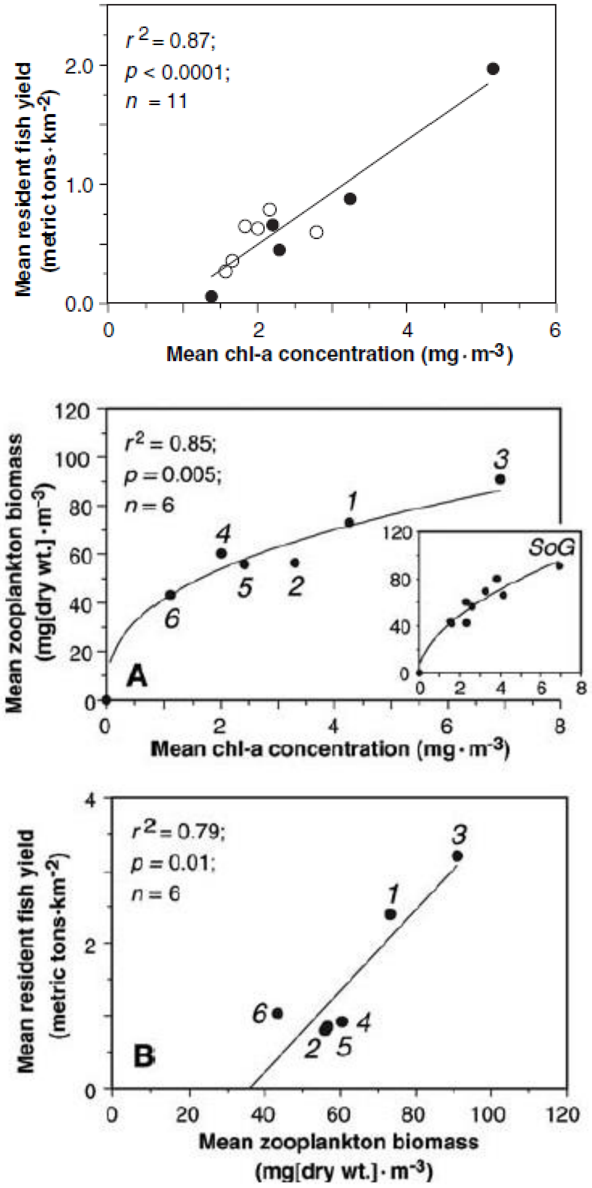




Wootton & Power 1993

Top-down and bottom-up effects





Ware & Thomson Science 2005

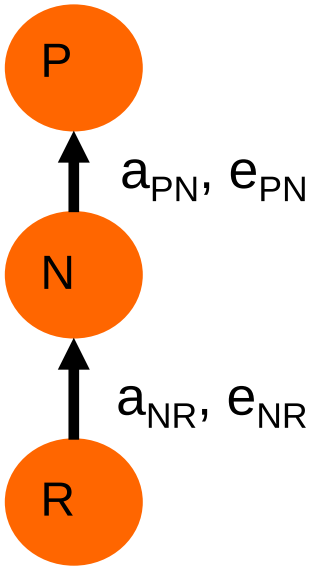
Another example of food chain model

- Consumer functional response is ratio-dependent

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

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

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



Top-down and bottom-up effects

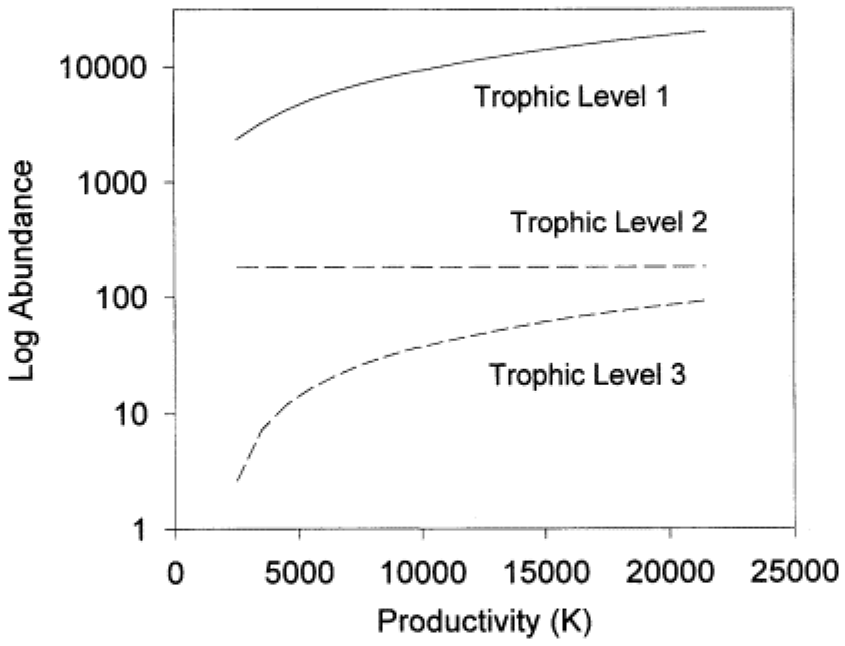
- If there is an equilibrium with all species present, then:

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

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

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

$\neq$



Effects can differ from predictions

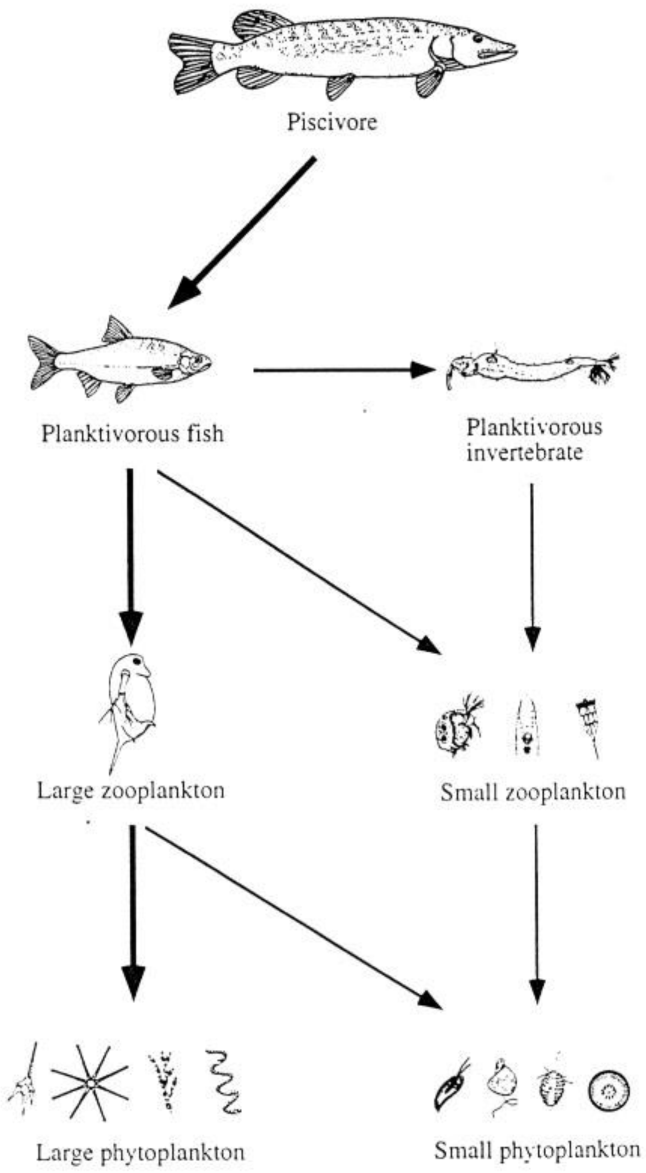
Table 1 Qualitative effects of nutrient enrichment as predicted by two linear food-chain models and corresponding experimental results in mesocosms

	Model predictions		Experimental results	
	Prey dependence	Ratio dependence	Without fish	With fish
Carnivores	+	+	–	§
Herbivores	0	+	ns	ns
Autotrophs	+	+	ns	ns
Phosphorus	0	+	ns	+

Qualitative effects are indicated by their sign: +, 0 and – denote a positive effect, no effect and a negative effect, respectively, of nutrient enrichment on density. Experimental results: + and – denote a significant positive effect and a significant negative effect, respectively ($P \leq 0.05$); brackets, marginally significant effect ($0.05 < P \leq 0.10$); ns, nonsignificant effect ($P > 0.10$); §, no test possible because the sum of invertebrate carnivores density and fish biomass is senseless.

Hulot et al. Nature 2000

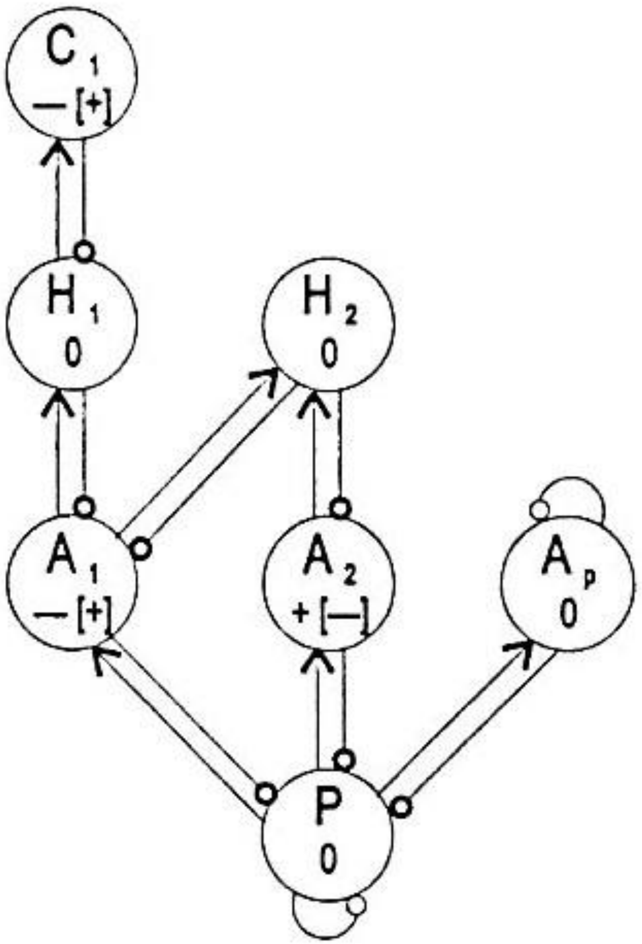
Need to consider food web structure



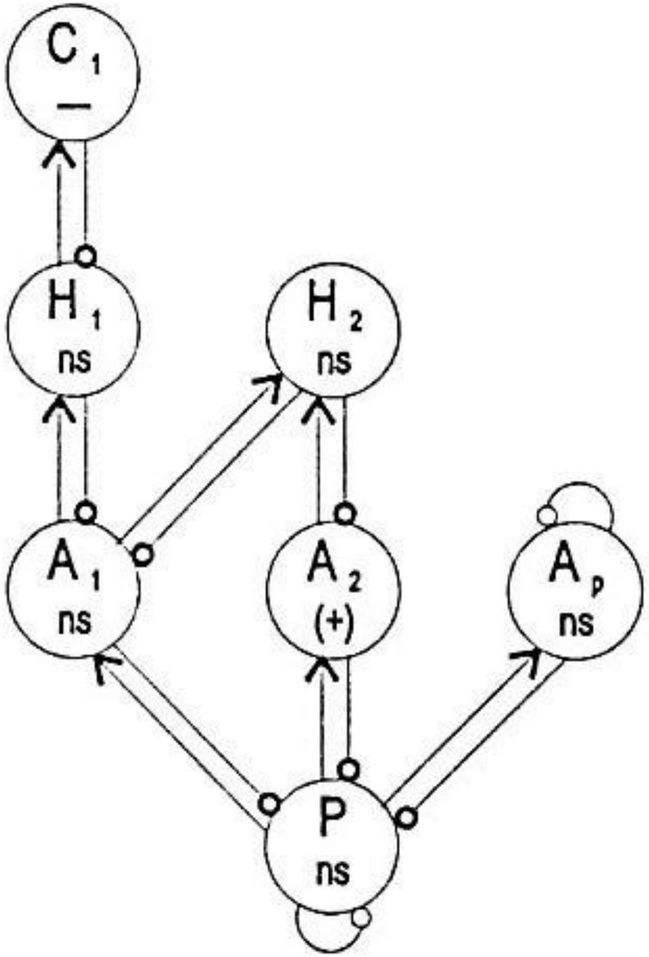
Simplified pelagic food web

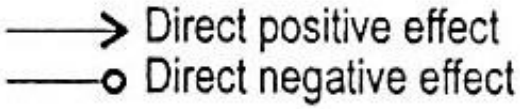
(from Carpenter et Kitchell, 1993, *The trophic cascade in lakes,* Cambridge University Press).

Model



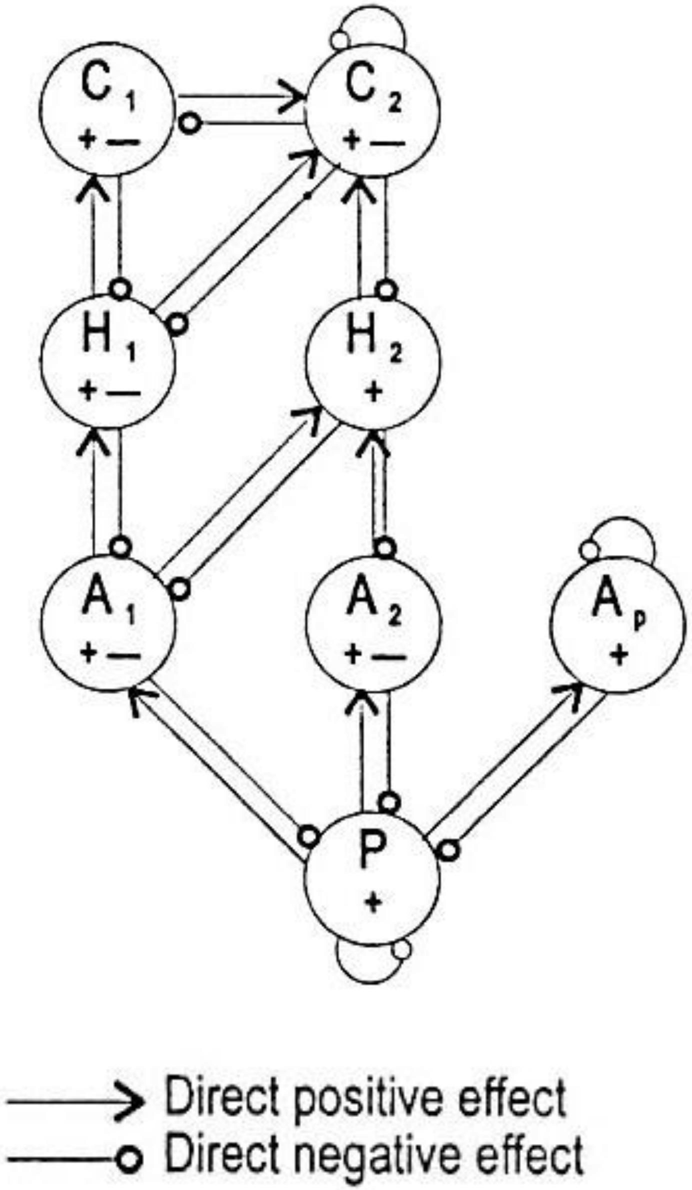
Experimental results



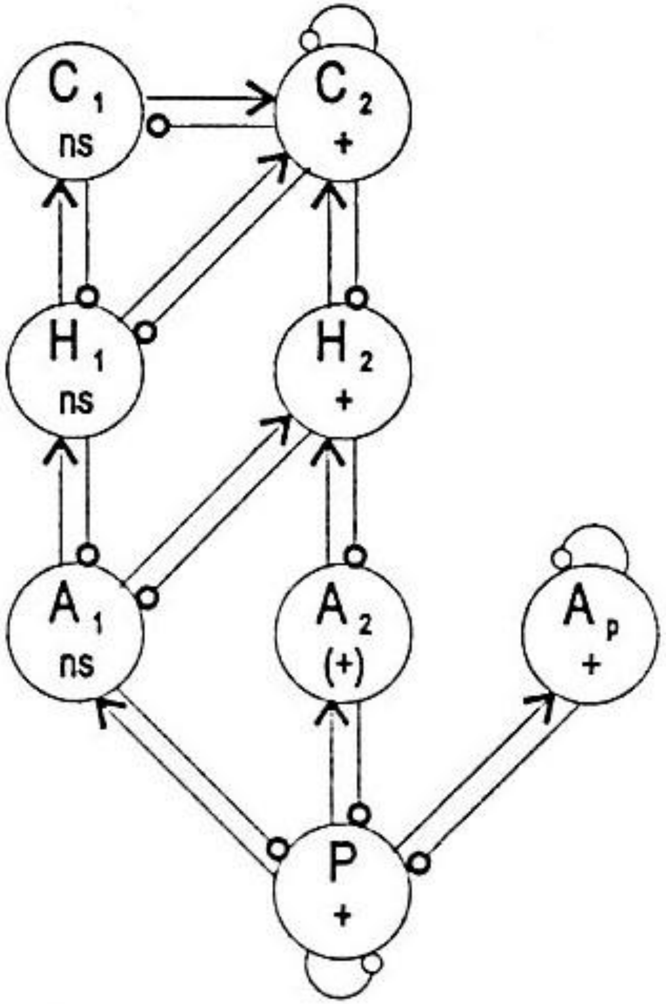


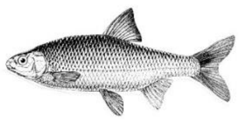
Hulot et al. Nature 2000

Model



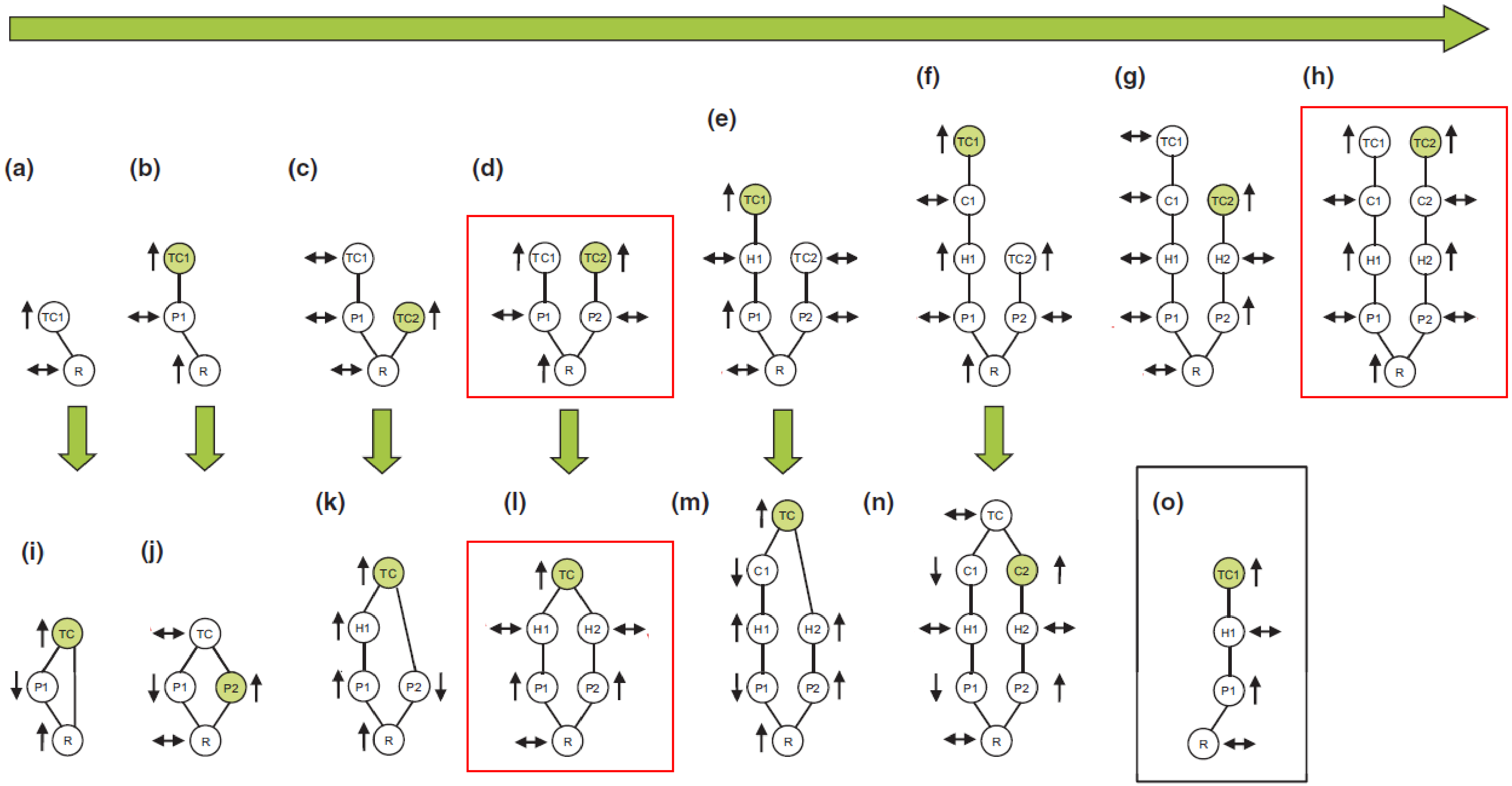
Experimental results





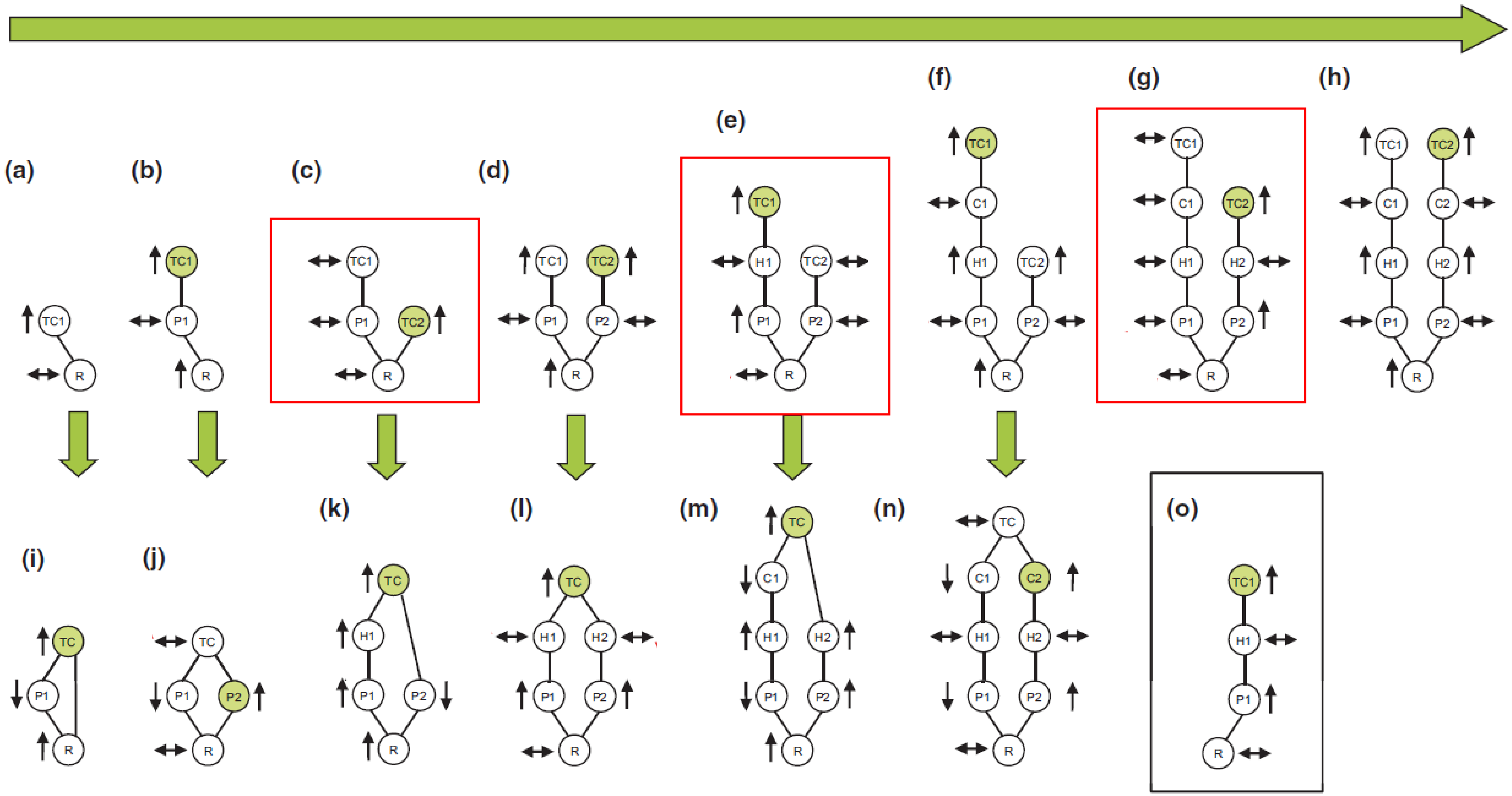
Hulot et al. Nature 2000

Food web structure and bottom-up effects



Wollrab et al. 2012

Food web structure and bottom-up effects



Wollrab et al. 2012

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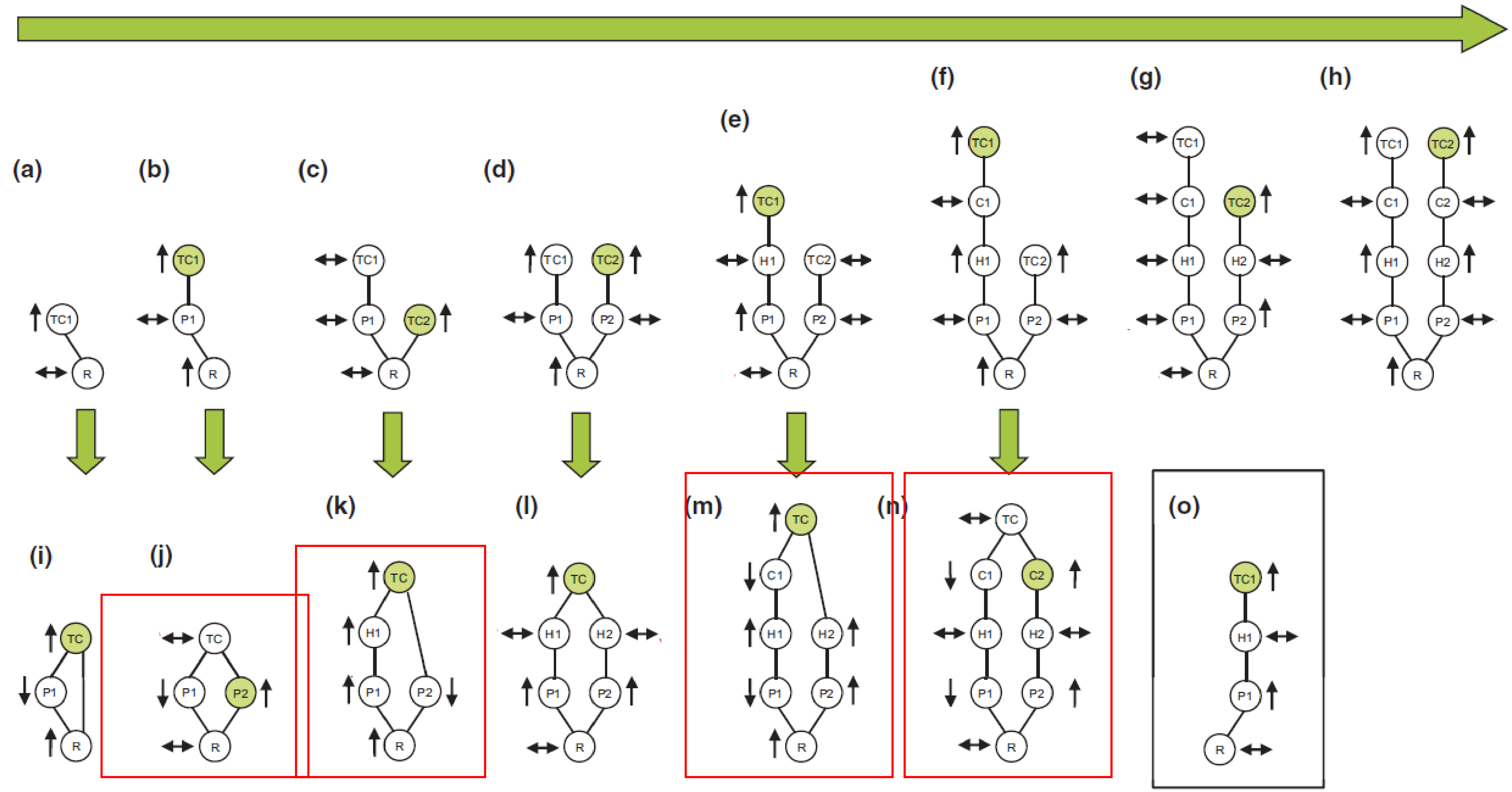

Wollrab et al. 2012

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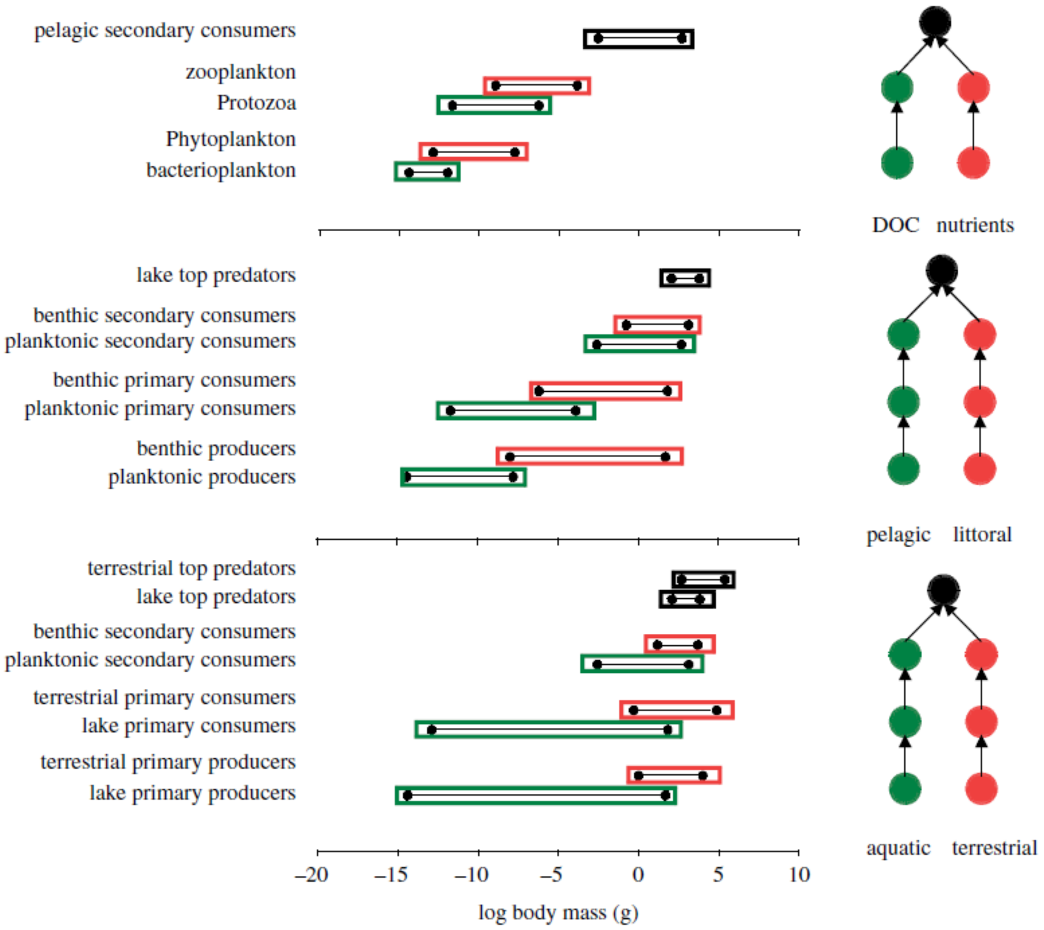
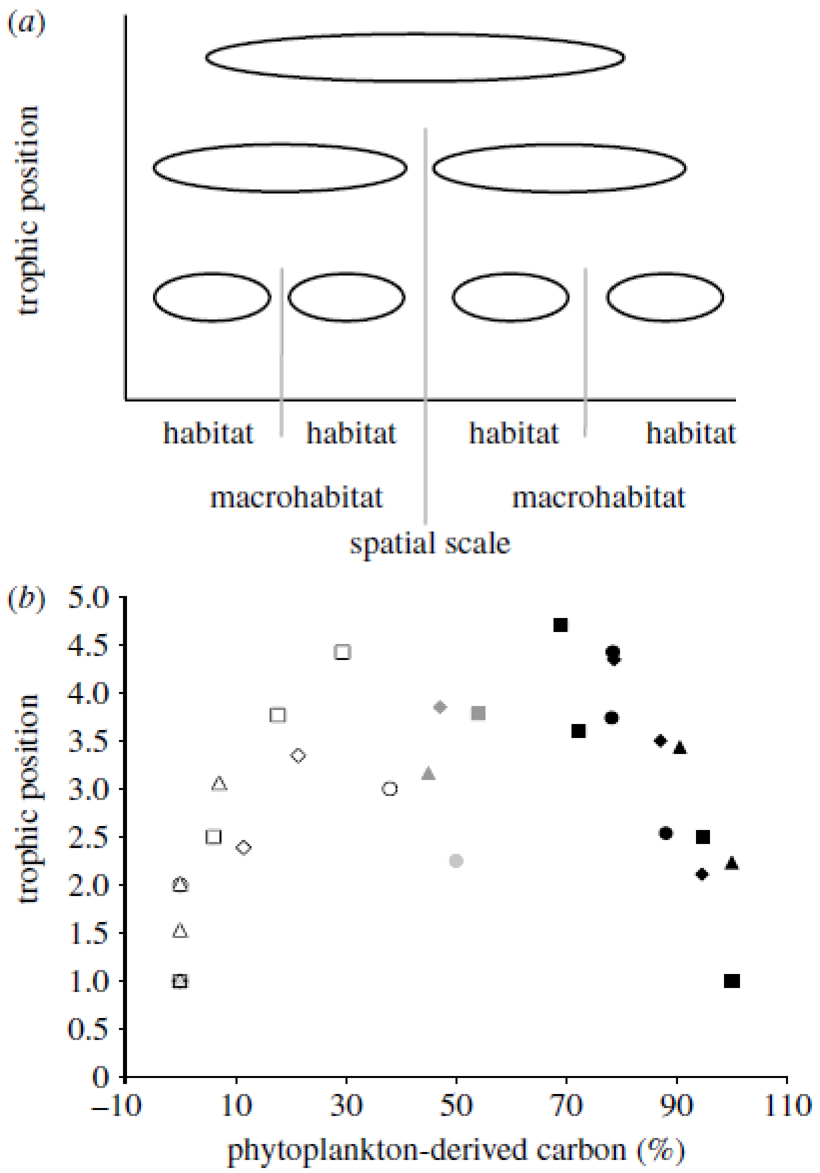
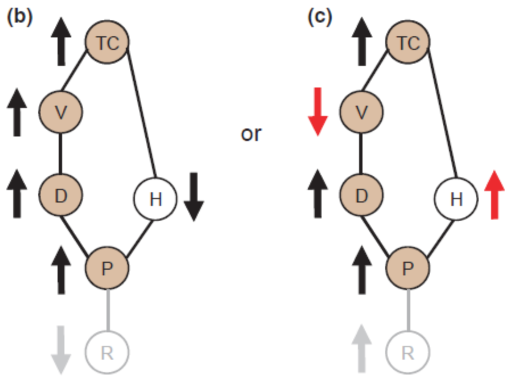


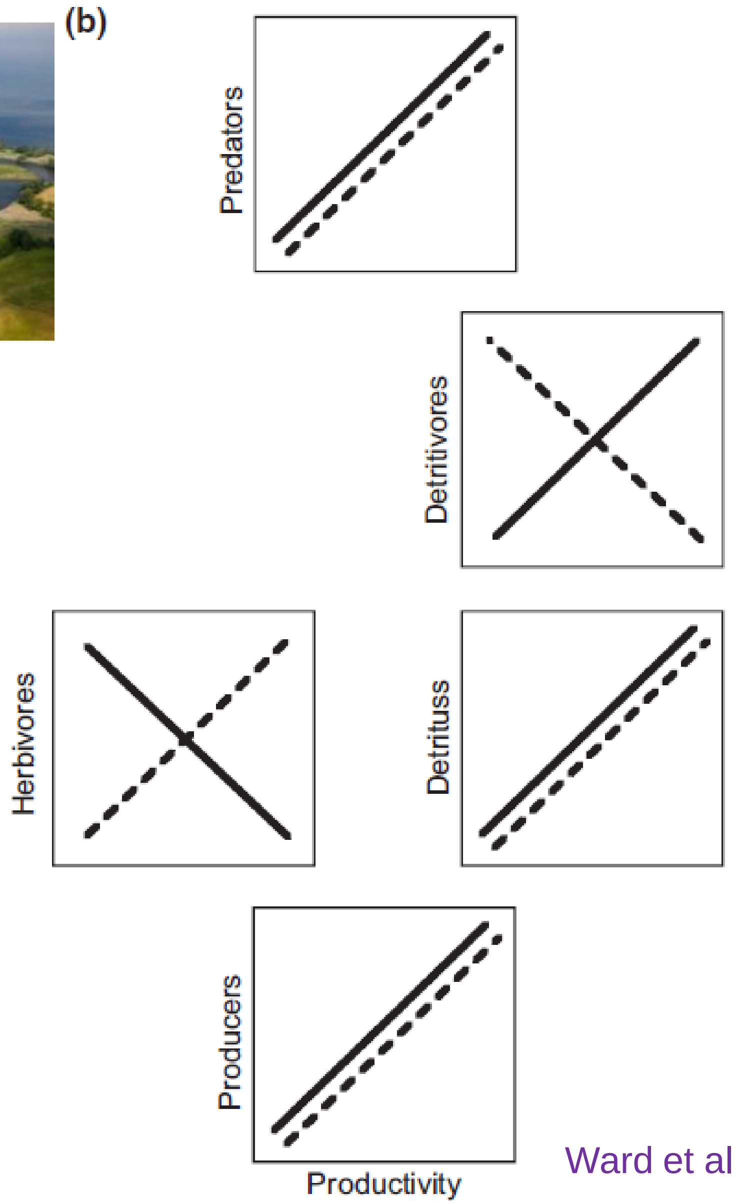


McCann & Rooney 2009

Food web structure and bottom-up effects

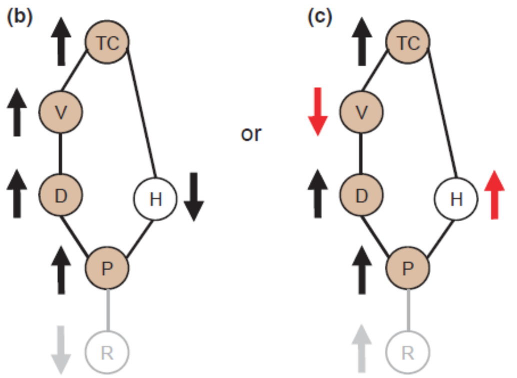


Wollrab et al. 2012

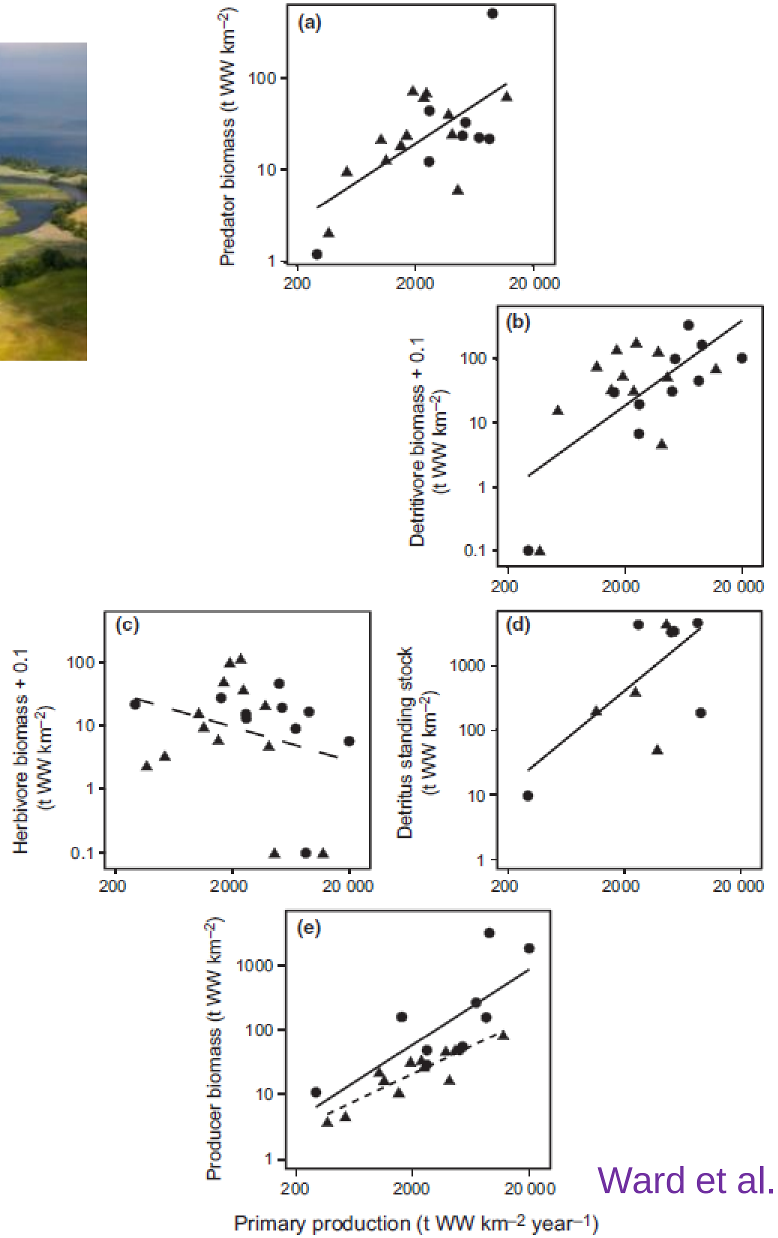


Ward et al. 2015

Food web structure and bottom-up effects

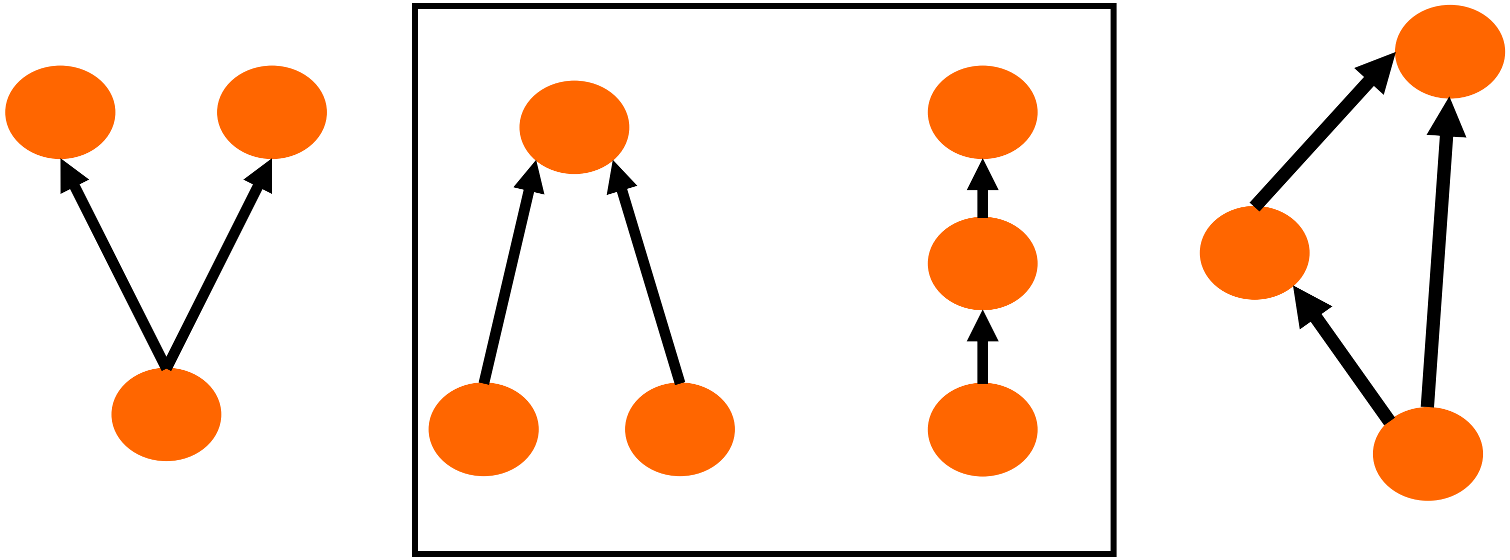


Wollrab et al. 2012



Ward et al. 2015

Understanding direct and indirect effects: studies on network motifs



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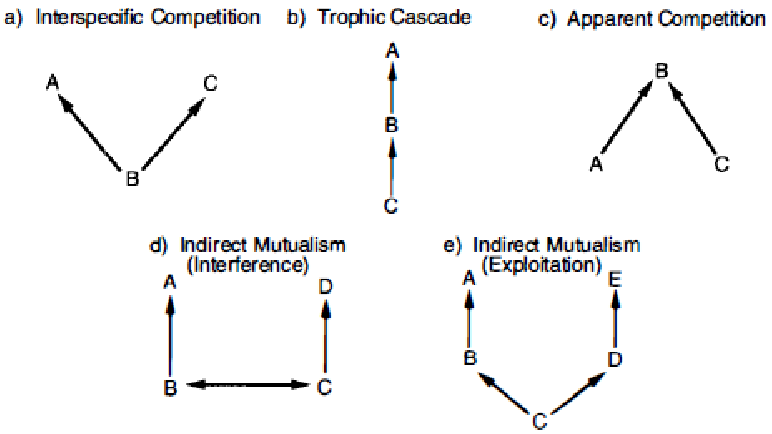
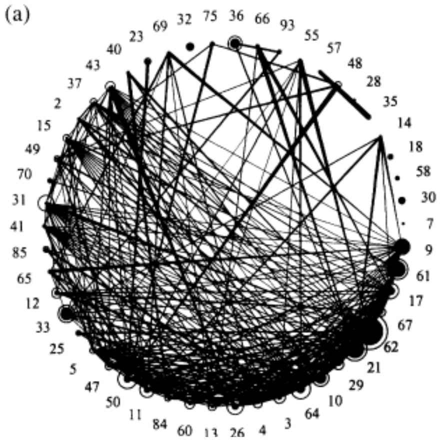
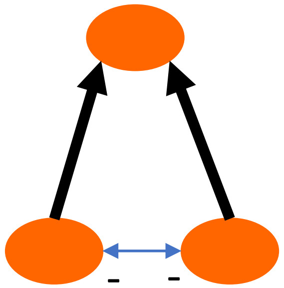
THE NATURE AND CONSEQUENCES OF INDIRECT EFFECTS IN ECOLOGICAL COMMUNITIES

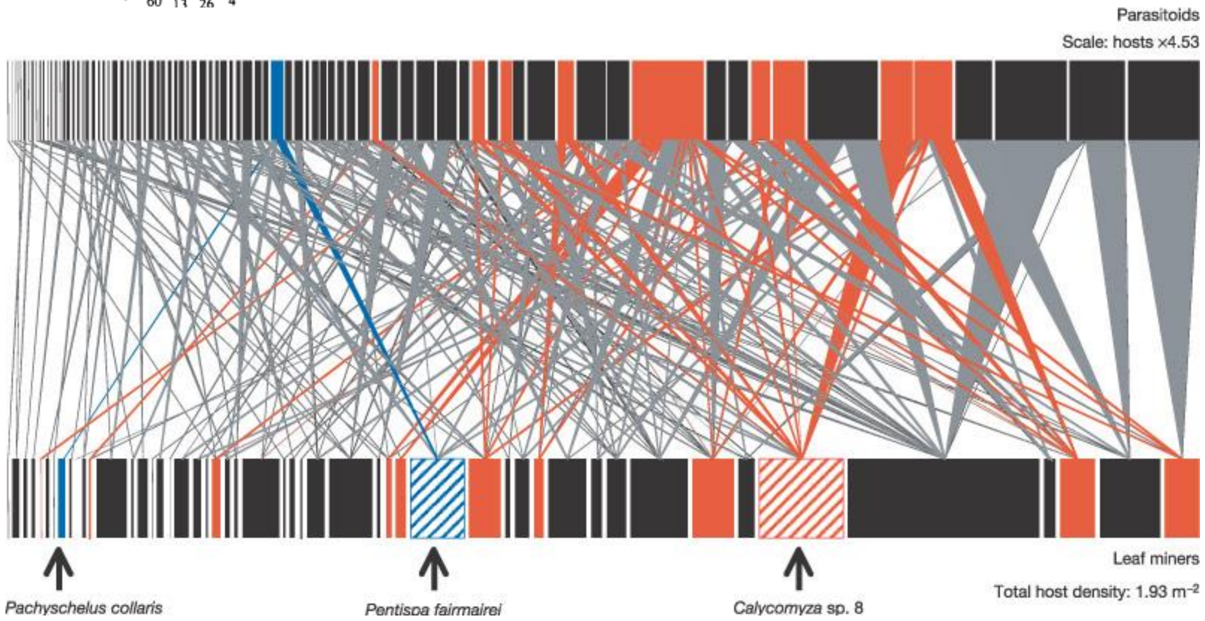
J. Timothy Wootton



Understanding direct and indirect effects
apparent competition

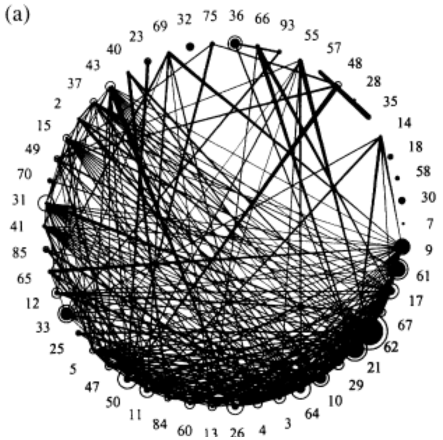


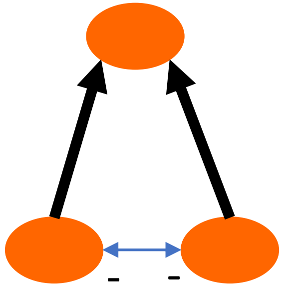


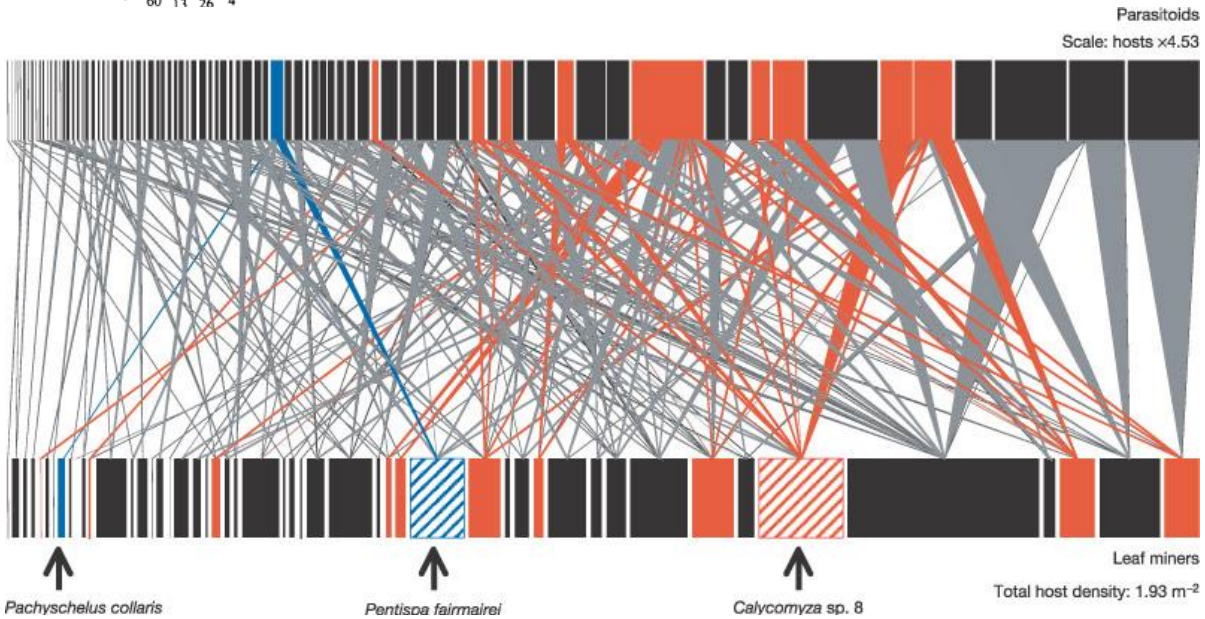


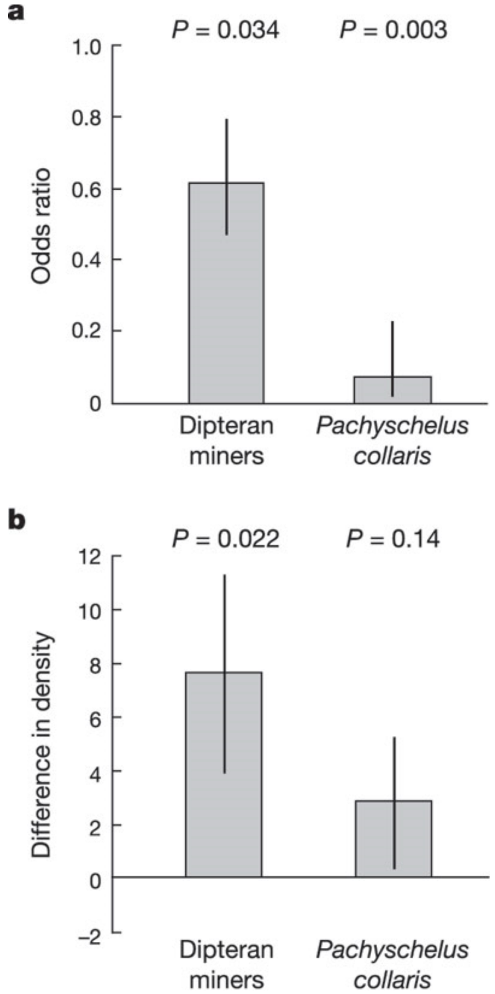
Morris et al. 2004

Understanding direct and indirect effects
apparent competition









Morris et al. 2004

Important applications for management

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Agriculture, Ecosystems and Environment 102 (2004) 205–212

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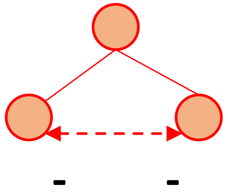


Enhancing parasitism of wheat aphids through apparent competition: a tool for biological control

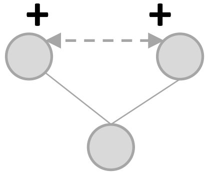
Alain Langer[1], Thierry Hance*

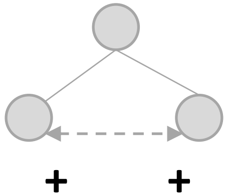
Ecology Letters, (2008) **11**: 690–700 doi: 10.1111/j.1461-0248.2008.01184.x

LETTER

Apparent competition can compromise the safety of highly specific biocontrol agents

Carvalheiro et al. (2008)





ECOLOGY LETTERS

Ecology Letters, (2014) 17: 1389–1399 doi:10.1111/ele.12342

LETTER

The potential for indirect effects between co-flowering plants via shared pollinators depends on resource abundance, accessibility and relatedness

Carvalheiro et al. (2014)

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Basic and Applied Ecology 63 (2022) 36–48

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RESEARCH PAPER

Co-flowering plants support diverse pollinator populations and facilitate pollinator visitation to sweet cherry crops

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Amy-Marie Gilpin[a,*], Corey O'Brien[a], Conrad Kobel[b], Laura E. Brettell[a,c], James M. Cook[a], Sally A. Power[a]

Estimating potential indirect competition among prey
the Muller's index

The Structure of an Aphid-Parasitoid Community

C. B. Muller; I. C. T. Adriaanse; R. Belshaw; H. C. J. Godfray

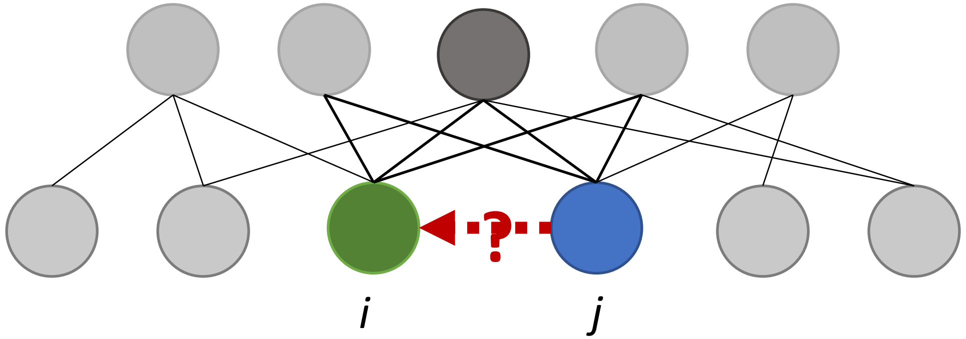
The Journal of Animal Ecology, Vol. 68, No. 2 (Mar., 1999), 346-370.

Indirect effect of species *j* on species *i*:

$$d_{ij} =$$

Predators or parasitoids

Prey



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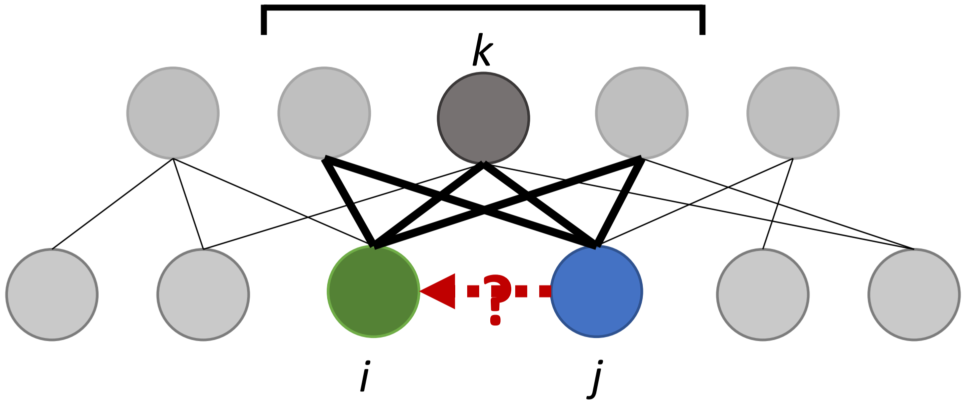
$$d_{ij} = \sum_k \left(\qquad \right)$$

Sum over all shared predators



Estimating potential indirect competition among prey
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Indirect effect of species *j* on species *i*:

$$d_{ij} = \sum_{k} \left(\frac{\alpha_{ik}}{\sum_{l} \alpha_{il}} \times \right)$$

Fraction of predators of species *i* that belong to predator species *k*

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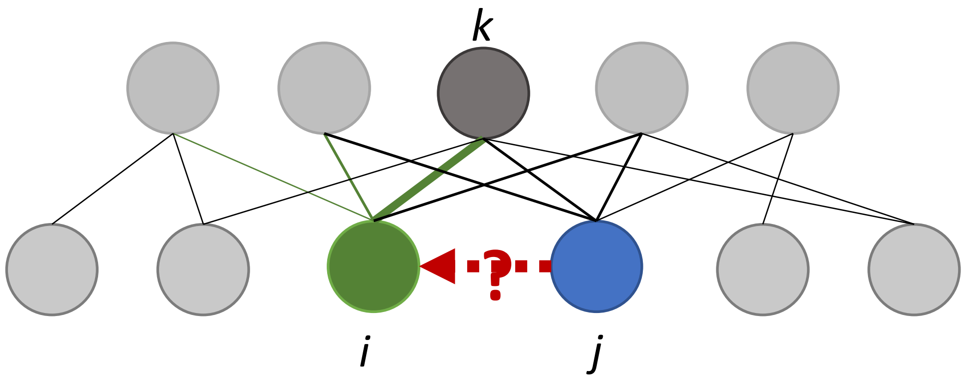

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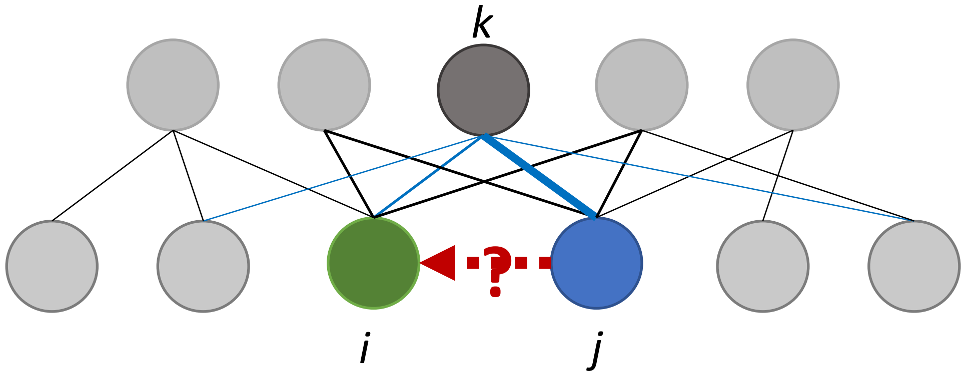
$$d_{ij} = \sum_k \left(\frac{\alpha_{ik}}{\sum_l \alpha_{il}} \times \frac{\alpha_{jk}}{\sum_m \alpha_{mk}} \right)$$

Fraction of predators of species *i* that belong to predator species *k*

Fraction of predator species *k* attacking species *j*

Predators or parasitoids

Prey



Estimating potential indirect competition among prey
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Indirect effect of species *j* on species *i*:

$$d_{ij} = \sum_{k} \left(\frac{\alpha_{ik}}{\sum_{l} \alpha_{il}} \times \frac{\alpha_{jk}}{\sum_{m} \alpha_{mk}} \right)$$

$$d_{ji} \neq d_{ij}$$

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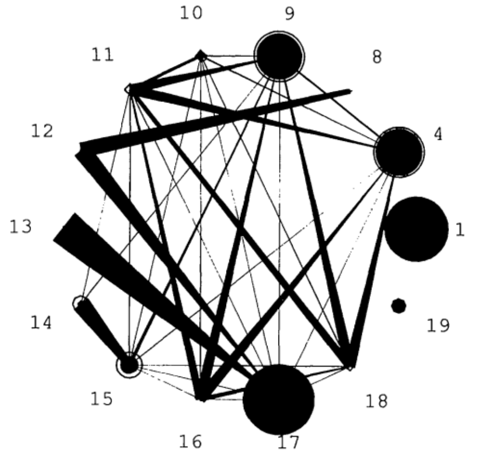

Predators or parasitoids

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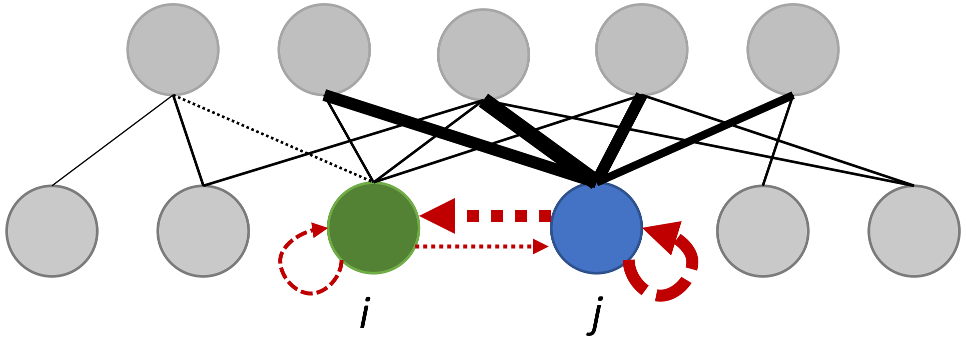
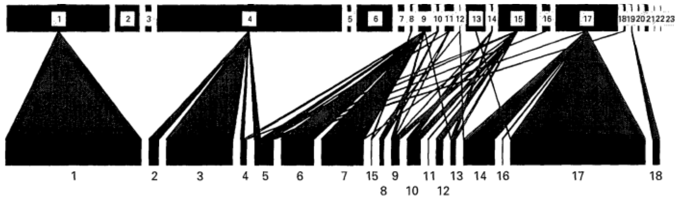


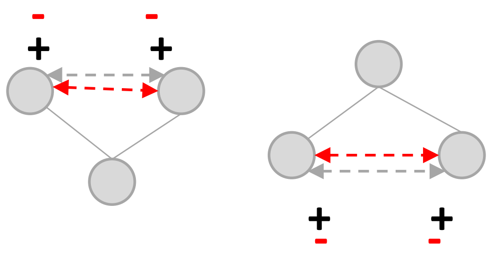


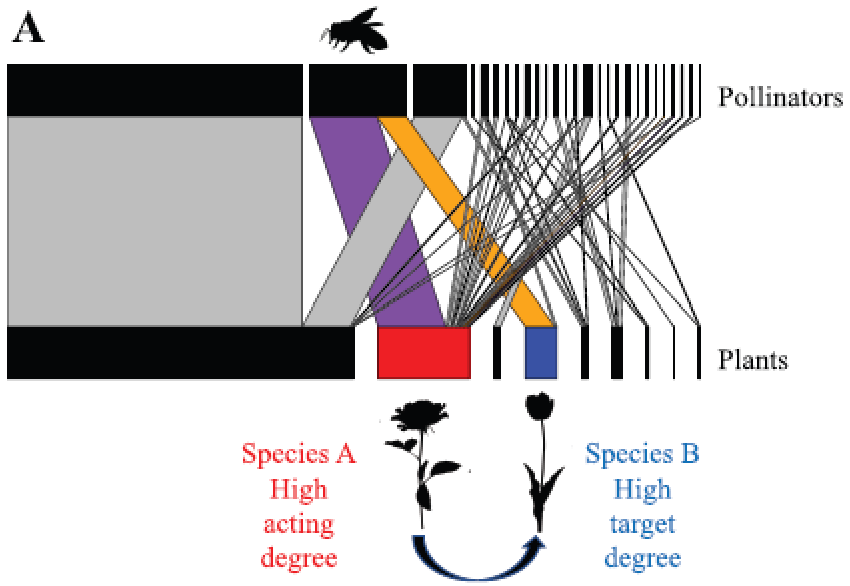
Primary parasitoids (scale: aphids × 58)

Competition or facilitation in plant-pollinator networks?

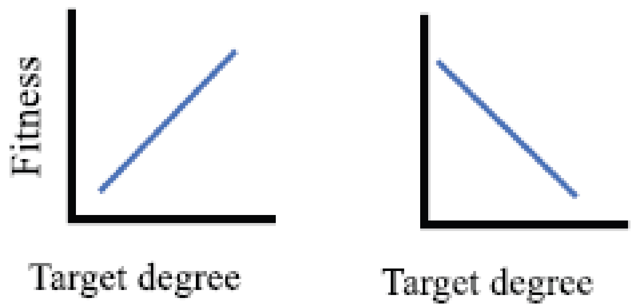
- Complex indirect interactions among plants and among pollinators, importance of the balance between mutualism and competition

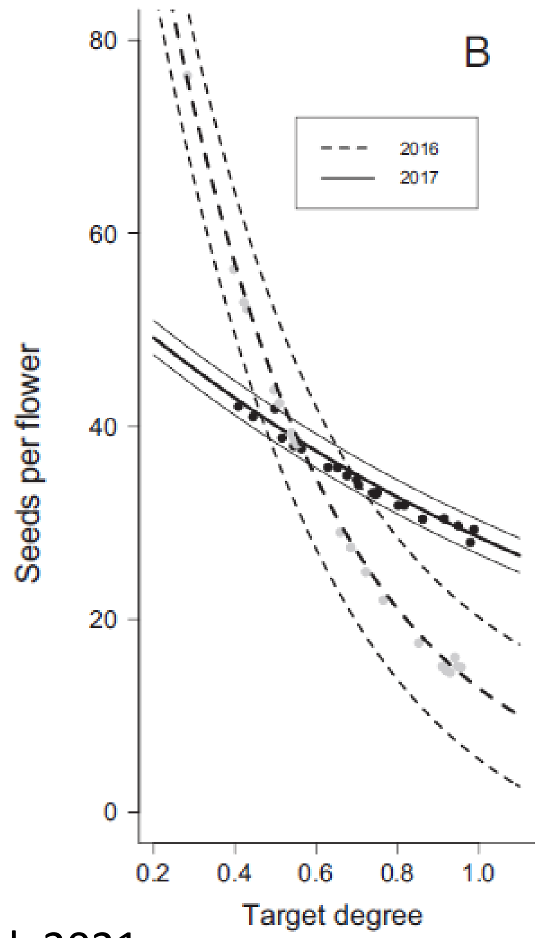
Bastolla et al. (2009)   Valdovinos et al. (2016)





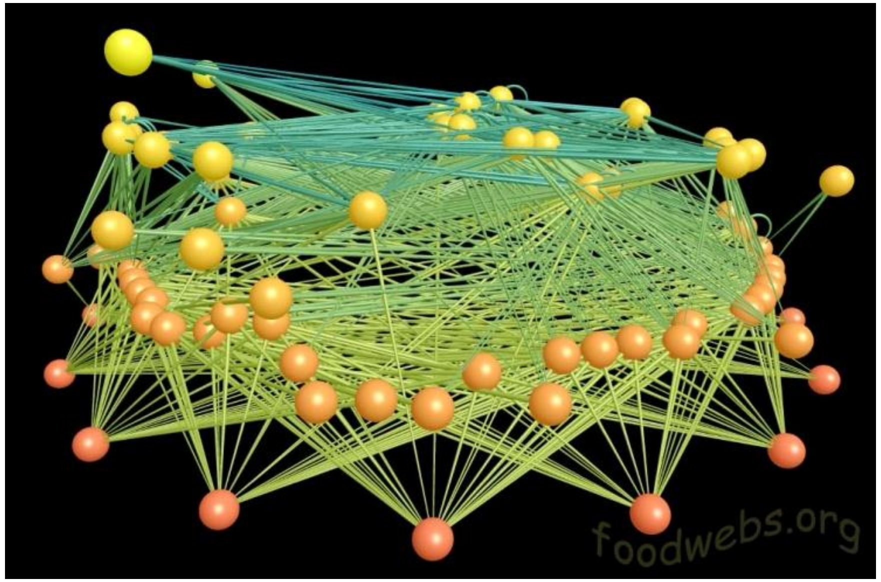
Facilitation   Competition



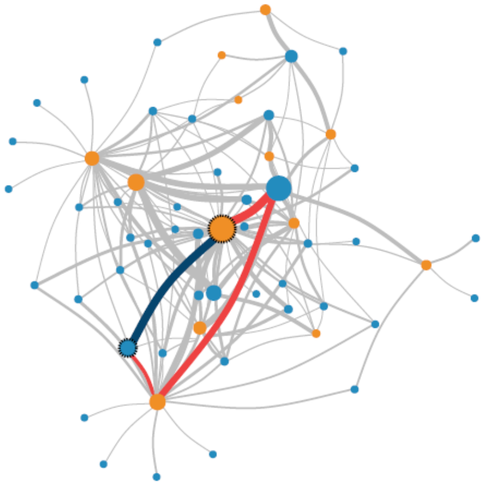


Bergamo et al. 2021

Predicting cascading effects in complex ecological networks?

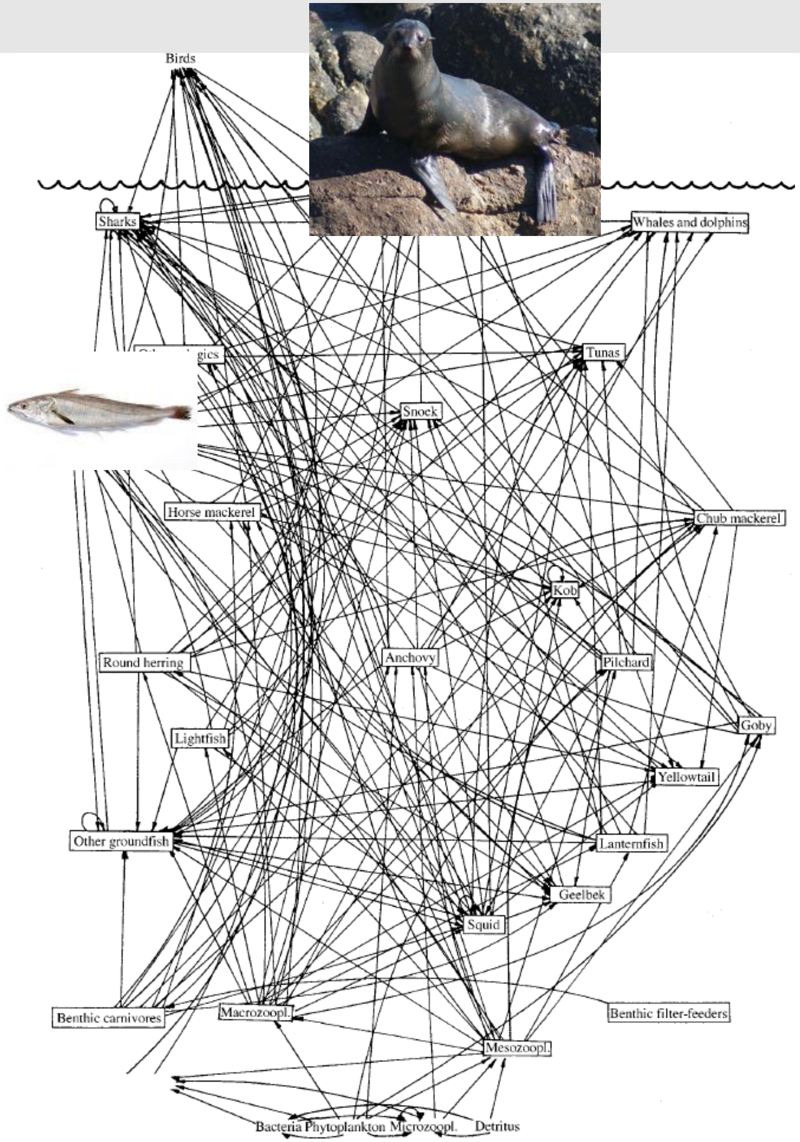


- Need for a dynamical perspective and accounting for long indirect pathways



Pires et al. (2020)

Predicting cascading effects in food webs?
How different species affect the effect of one predator on one prey



Yodzis 2000

Predicting cascading effects in food webs?
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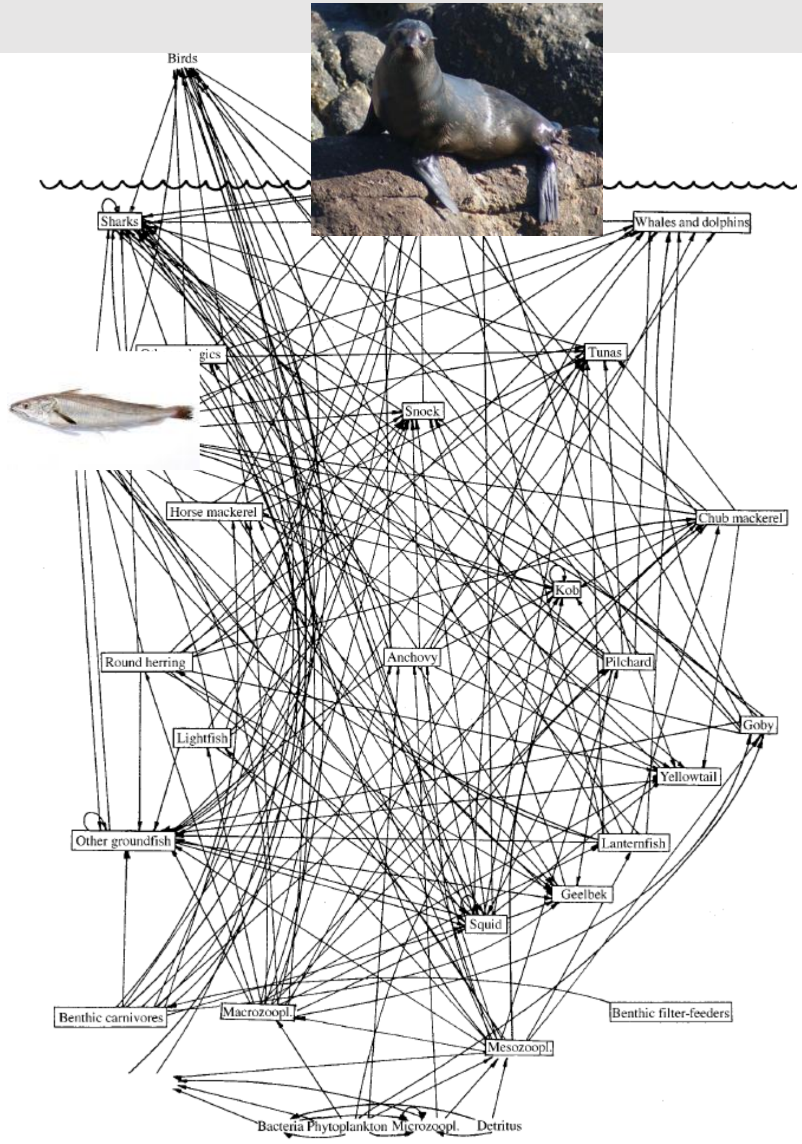

Yodzis 2000

$$\frac{dB_i}{dt} = r_i B_i\left(1 - \frac{B_i}{K_i}\right) - \sum_k F_{ik} B_k - H_i \equiv g_i$$

$$\frac{dB_i}{dt} = \left(-T_i + \sum_k (1 - \delta_k) F_{ki}\right) B_i - \sum_k F_{ik} B_k - I_i B_i^2 - H_i \equiv g_i .$$

Jacobian matrix : $A_{ij} = \left[\frac{\partial g_i}{\partial B_j}\right]_e$

The long-term change in the biomass of species i in response to a change in seal rate of cull is given by

$$R(i,\ s) \equiv \frac{dB_i^e}{dH_s} = (\mathbf{A}^{-1})_{is} \qquad (7)$$

Predicting cascading effects in food webs?
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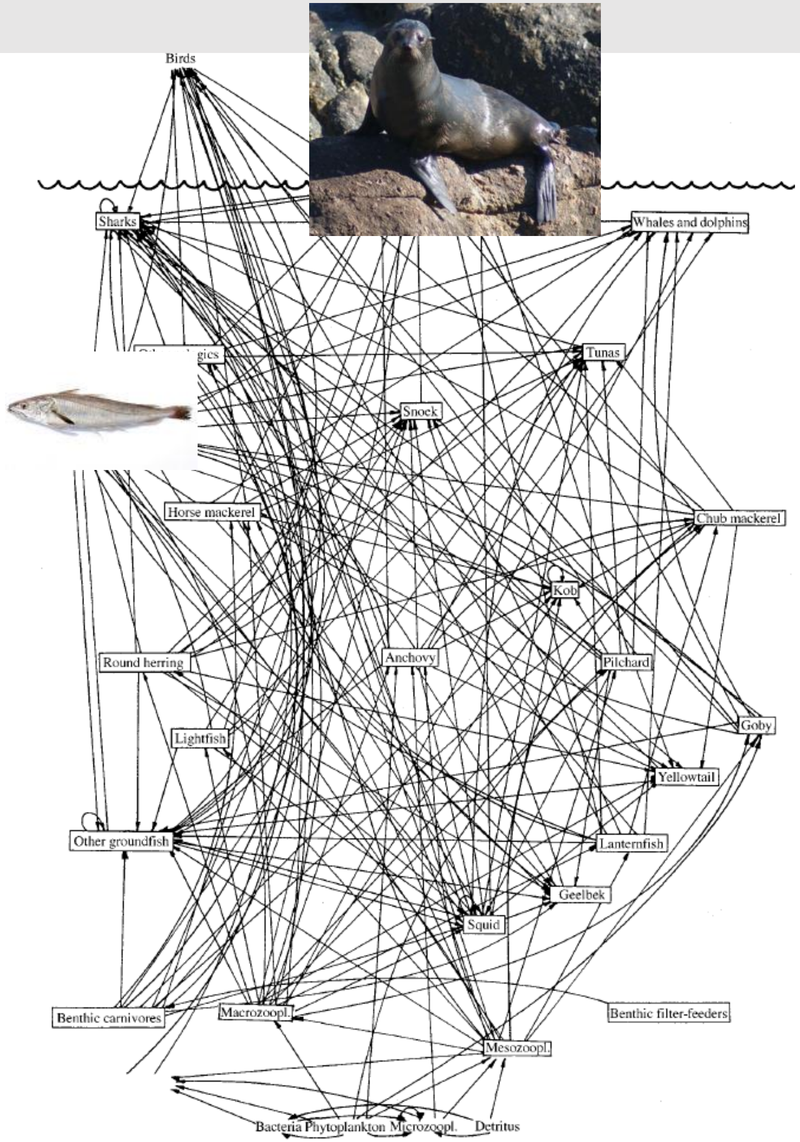

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$$\frac{dB_i}{dt} = r_i B_i\left(l - \frac{B_i}{K_i}\right) - \sum_k F_{ik} B_k - H_i \equiv g_i$$

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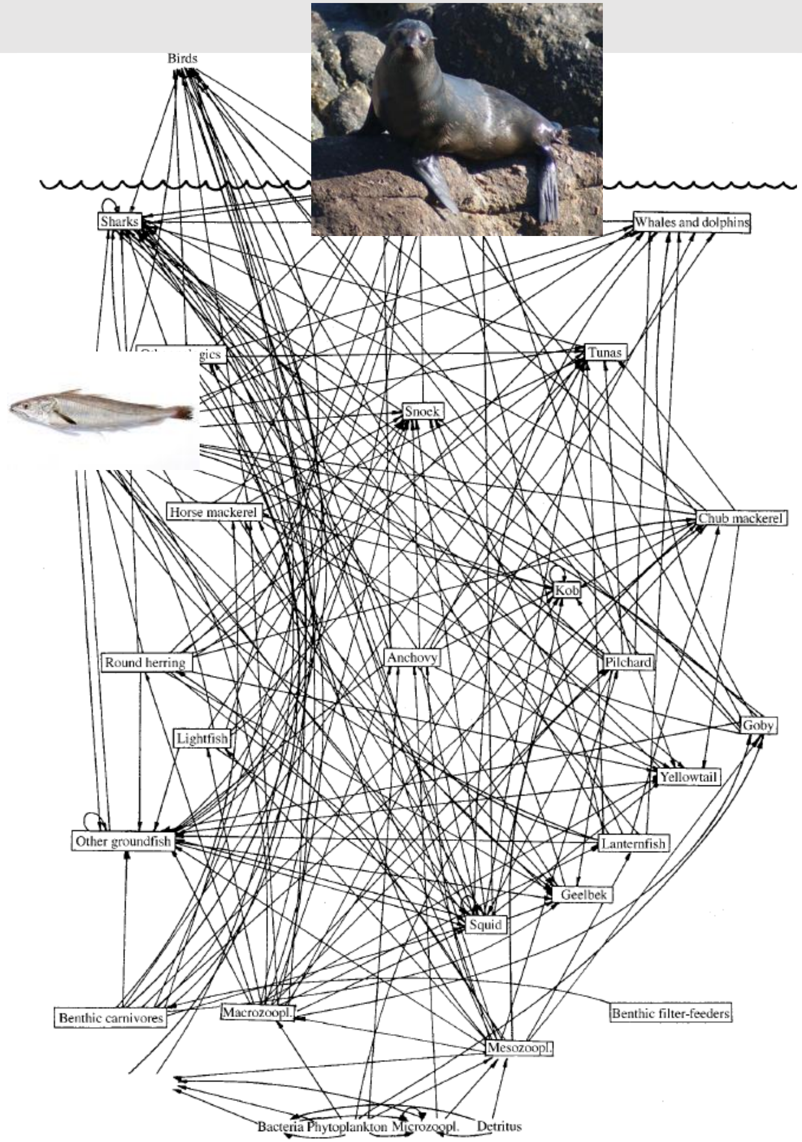
$$R(i,\, s;\, o) \equiv \left[\frac{dB_i^e}{dH_s}\right]_{dB_o^e=0} = (\mathbf{A}^{-1})_{is} - \frac{(\mathbf{A}^{-1})_{io}(\mathbf{A}^{-1})_{os}}{(\mathbf{A}^{-1})_{oo}}.$$

Predicting cascading effects in food webs?
How different species affect the effect of one predator on one prey



Yodzis 2000

$$\frac{dB_i}{dt} = r_i B_i \left(l - \frac{B_i}{K_i} \right) - \sum_k F_{ik} B_k - H_i \equiv g_i$$

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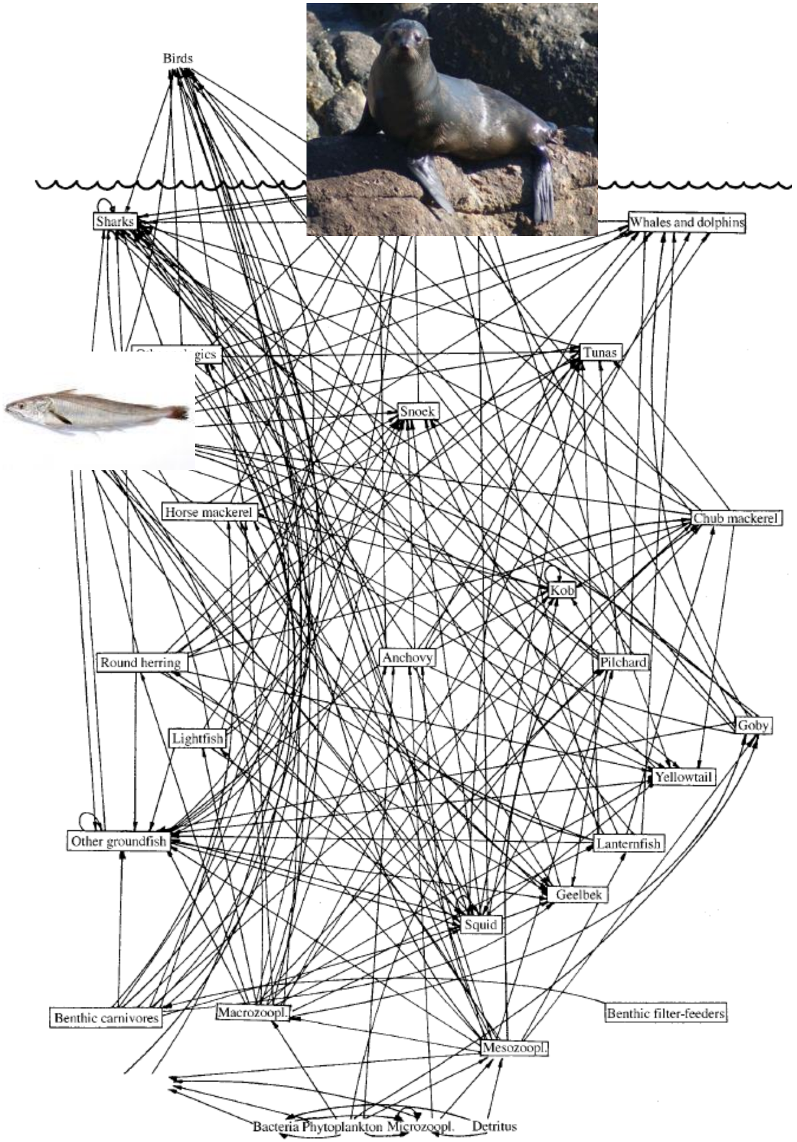
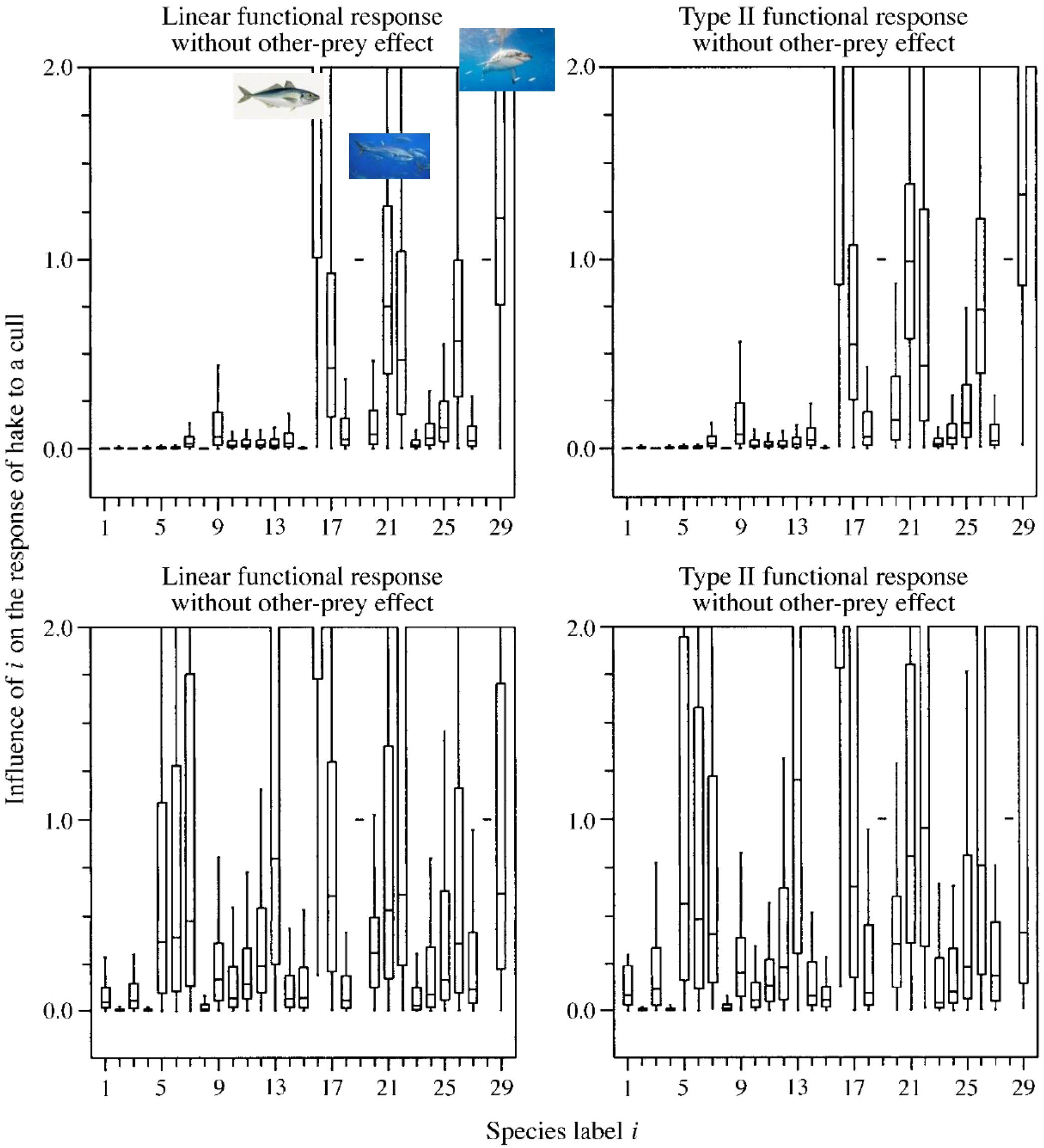
Jacobian matrix : $A_{ij} = \left[\frac{\partial g_i}{\partial B_j} \right]_e$

Influence of a species o on the response of species i to a cull of seals s:

$$I(i, s; o) \equiv \left| \frac{R(i, s; o) - R(i, s)}{R(i, s)} \right| = \left| \frac{(\mathbf{A}^{-1})_{io} (\mathbf{A}^{-1})_{os}}{(\mathbf{A}^{-1})_{oo} (\mathbf{A}^{-1})_{is}} \right| .$$

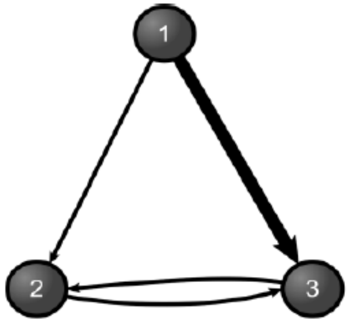
« Diffuse effects in food webs »





Yodzis 2000

« Diffuse effects in food webs »



$$\mathbf{C} = \begin{bmatrix} 0 & - & - \\ + & 0 & - \\ + & - & 0 \end{bmatrix} \qquad \mathbf{C}^{-1} = \begin{bmatrix} \cdots & - & + \\ \cdots & \cdots & - \\ \cdots & \cdots & \cdots \end{bmatrix}$$

(rows and columns numbered 1, 2, 3)

Montoya et al. 2009

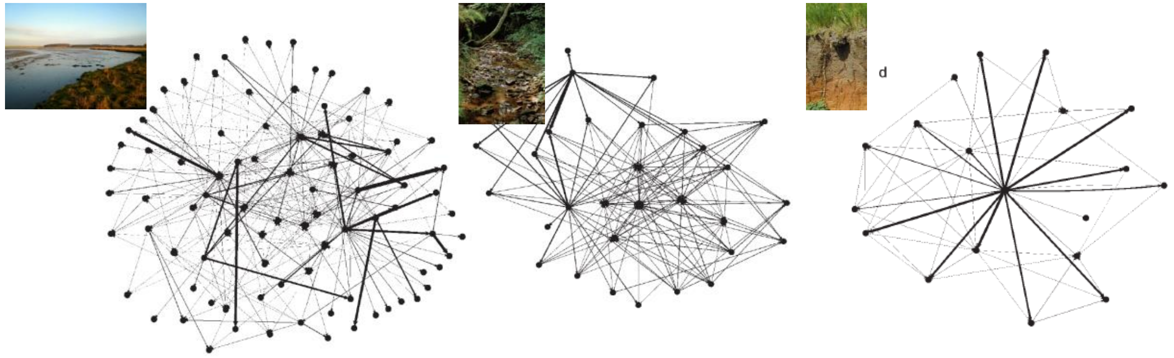


TABLE 3. Sign structure of the Jacobian matrix **C** and of its inverse $\mathbf{C}^{-1}$.

	Same sign		Different sign	
Food web	%	log mean $\lvert c_{ij}\rvert$	%	log mean $\lvert c_{ij}\rvert$
Ythan	54.4	−1.41***	45.6	−1.59***
Broadstone	54	0.16***	46	−0.28***
Soil 1	63.1	0.38	36.9	0.17
Soil 2	53.8	0.12***	46.2	0.46***
Soil 3	63.2	0.45***	36.8	0.3***
Soil 4	57.9	0.44	42.1	0.46
Soil 5	66.7	0.78***	33.3	0.55***
Soil 6	77.8	0.85***	22.2	−0.20***
Soil 7	57.5	0.13***	42.5	−0.04***
Mean	60.93		39.07	

Another approach: food web model based on allometric relations

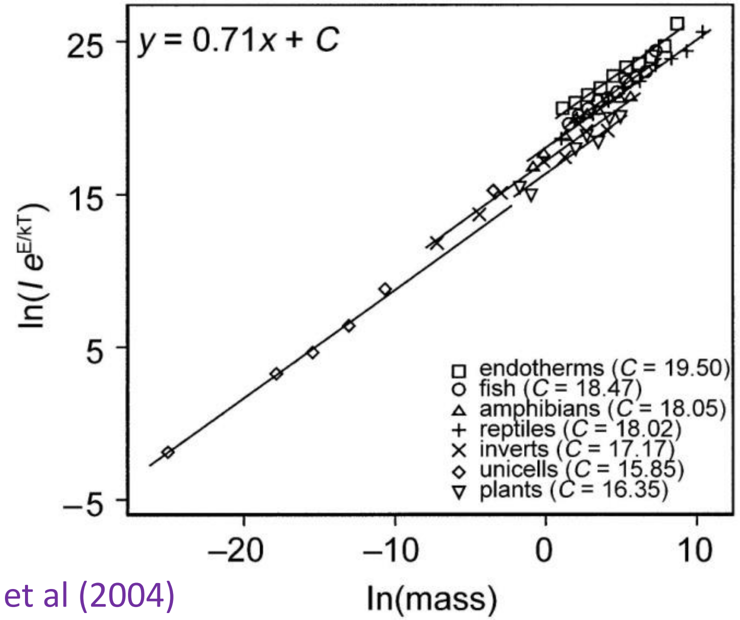
Bioenergetic model of Yodzis and Innes (1992)

$$\frac{dC}{dt} = C\left(-T + (1-\delta)J_{\max}\frac{R^n}{R^n + R_0^n}\right)$$

$$\frac{dR}{dt} = rR\left(1 - \frac{R}{K}\right) - C\frac{J_{\max}}{f_e}\frac{R^n}{R^n + R_0^n}$$

T = mass-specific respiration rate of the population (respiration per unit biomass)

$$T = a_T m_C^{-0.25}$$



Brown et al (2004)

Another approach: food web model based on allometric relations

Bioenergetic model of Yodzis and Innes (1992)

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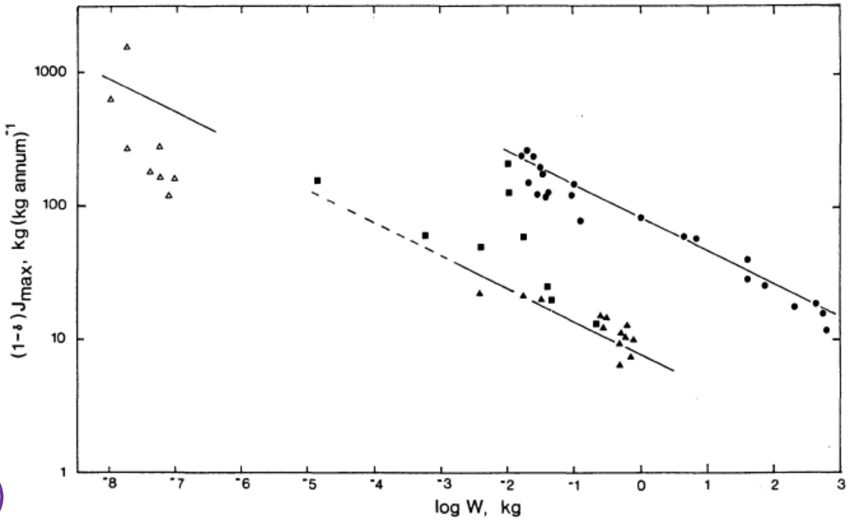
T = mass-specific respiration rate of the population (respiration per unit biomass)

J = mass-specific ingestion rate of the population

$$T = a_T m_C^{-0.25}$$

$$(1-\delta)J_{\max} = f_J a_J m_C^{-0.25}$$

Mass specific maximum feeding rates



Yodzis and Innes (1992)

Another approach: food web model based on allometric relations

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T = mass-specific respiration rate of the population (respiration per unit biomass)
J = mass-specific ingestion rate of the population
r = intrinsic production-biomass ratio

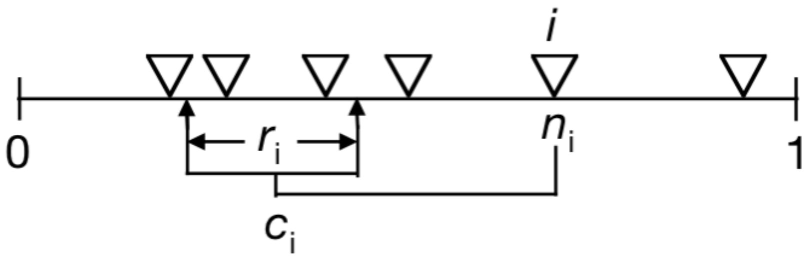
$$T = a_T m_C^{-0.25}$$

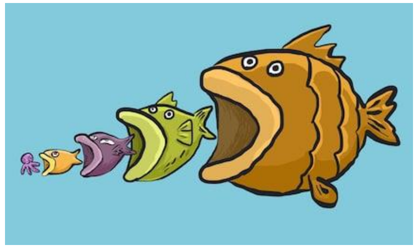
$$(1-\delta)J_{\max} = f_J a_J m_C^{-0.25}$$

$$r = f_r a_r m_R^{-0.25}$$

Another approach: food web model based on allometric relations

Trophic interactions based on the niche model



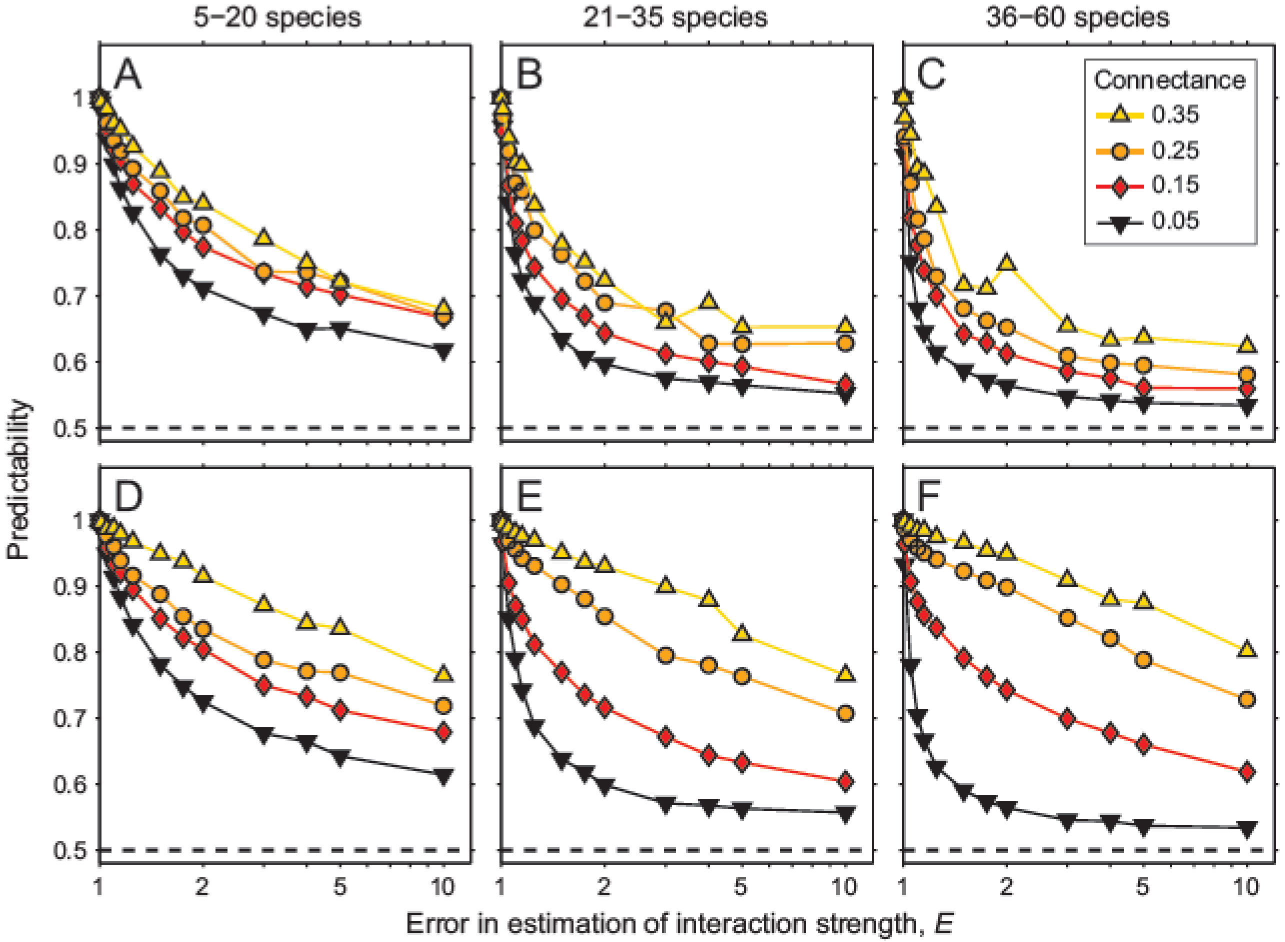


$$\frac{dB_i}{dt} = \overbrace{\sum_{j=1}^{n} x_i y B_i F_{ji}}^{\text{resource gain}} - \overbrace{\sum_{k=1}^{m} x_k \left(\frac{y}{e_i}\right) B_k F_{ik}}^{\text{consumer loss}} - \overbrace{x_i B_i}^{\text{metabolic loss}} \qquad (2a)$$

$$\frac{dB_i}{dt} = \overbrace{\varepsilon x_i B_i G_i}^{\text{production gain}} - \overbrace{\sum_{k=1}^{m} x_k \left(\frac{y}{e_i}\right) B_k F_{ik}}^{\text{consumer loss}} - \overbrace{(1-\varepsilon) x_i B_i}^{\text{metabolic loss}} \qquad (2b)$$

Brose et al. 2006 ; Iles & Novak 2016

Predicting cascading effects in complex food webs?



Iles & Novak 2016

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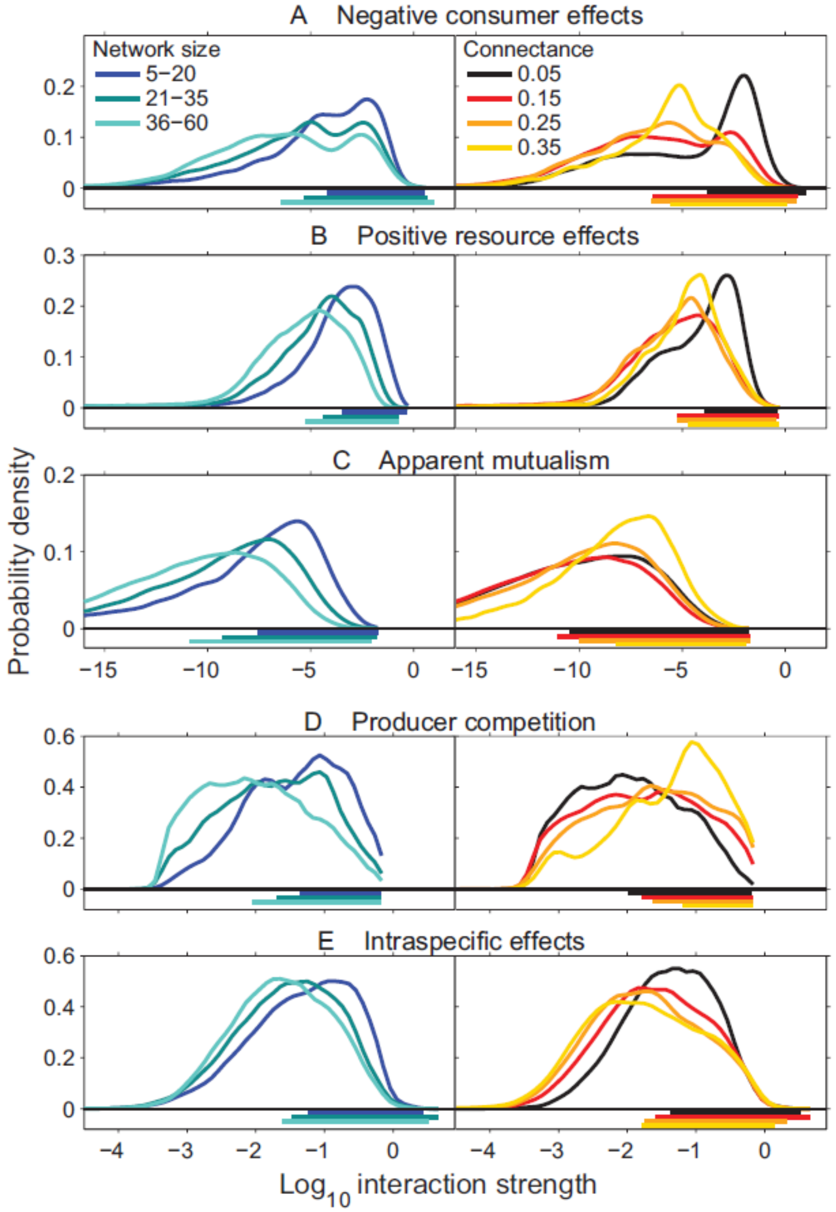

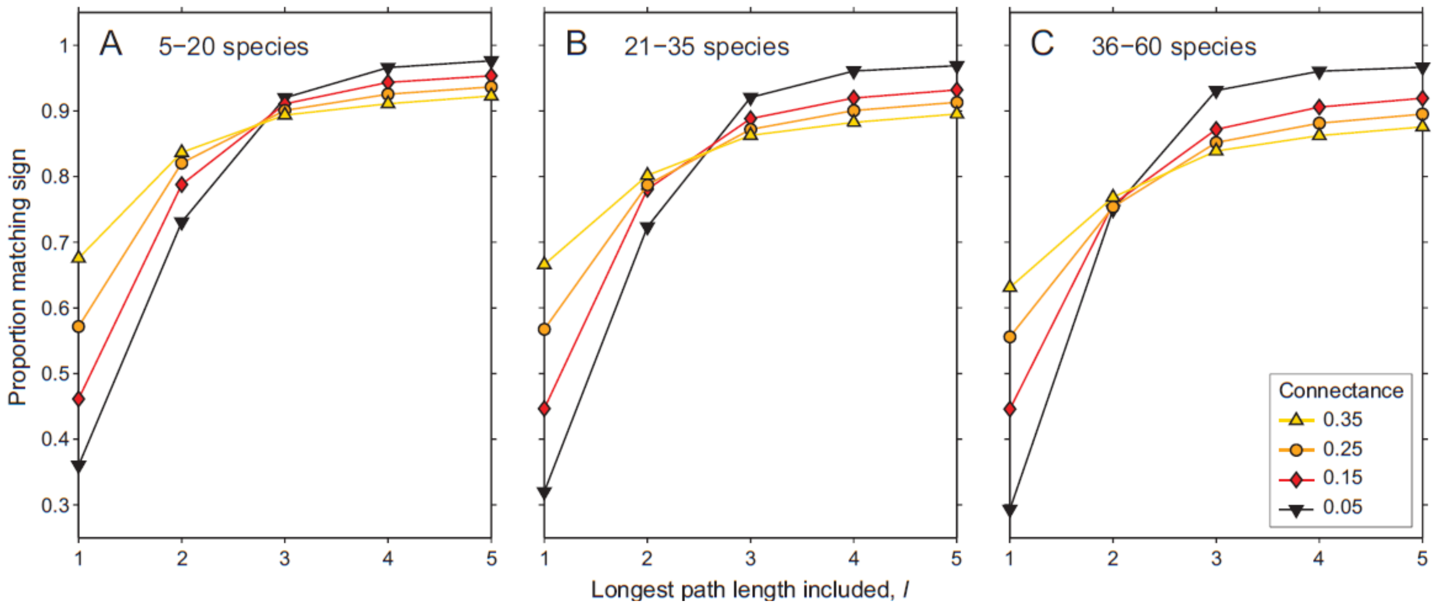

Iles & Novak 2016

Part III: Cascading effects in networks
Network structure and indirect interactions
Some conclusions and perspectives

- Importance of indirect interactions: network structure matters for understanding cascading effects in ecological communities

- Can we predict consequences of perturbations on ecological networks?

- Which network structures limit the spread of cascading effects? See the course tomorrow on structure and stability