Ecological networks - from individuals to ecosystems

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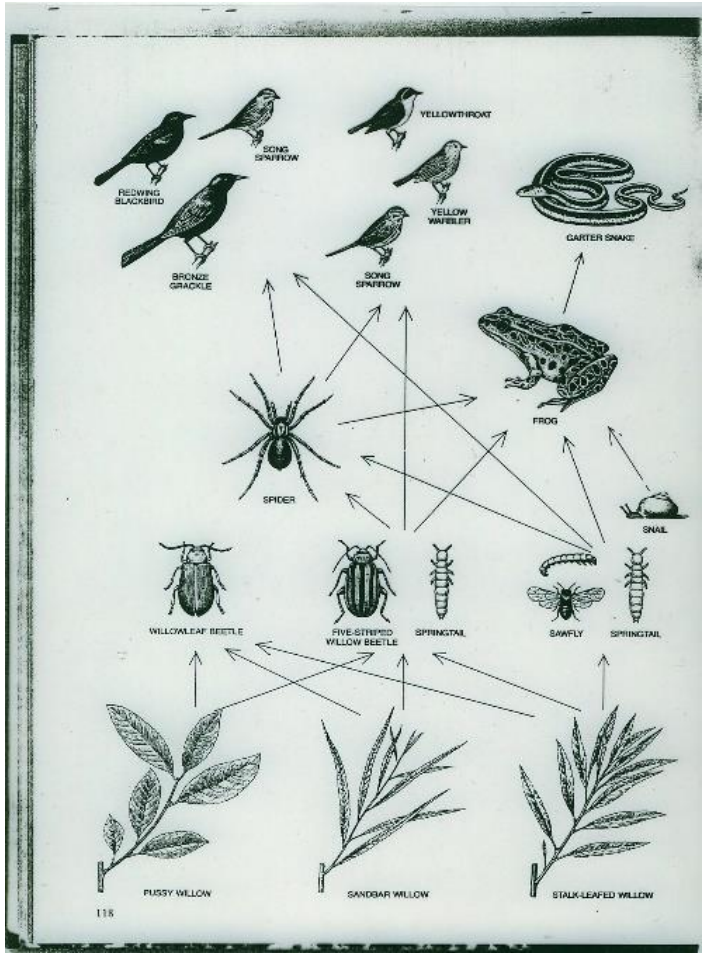
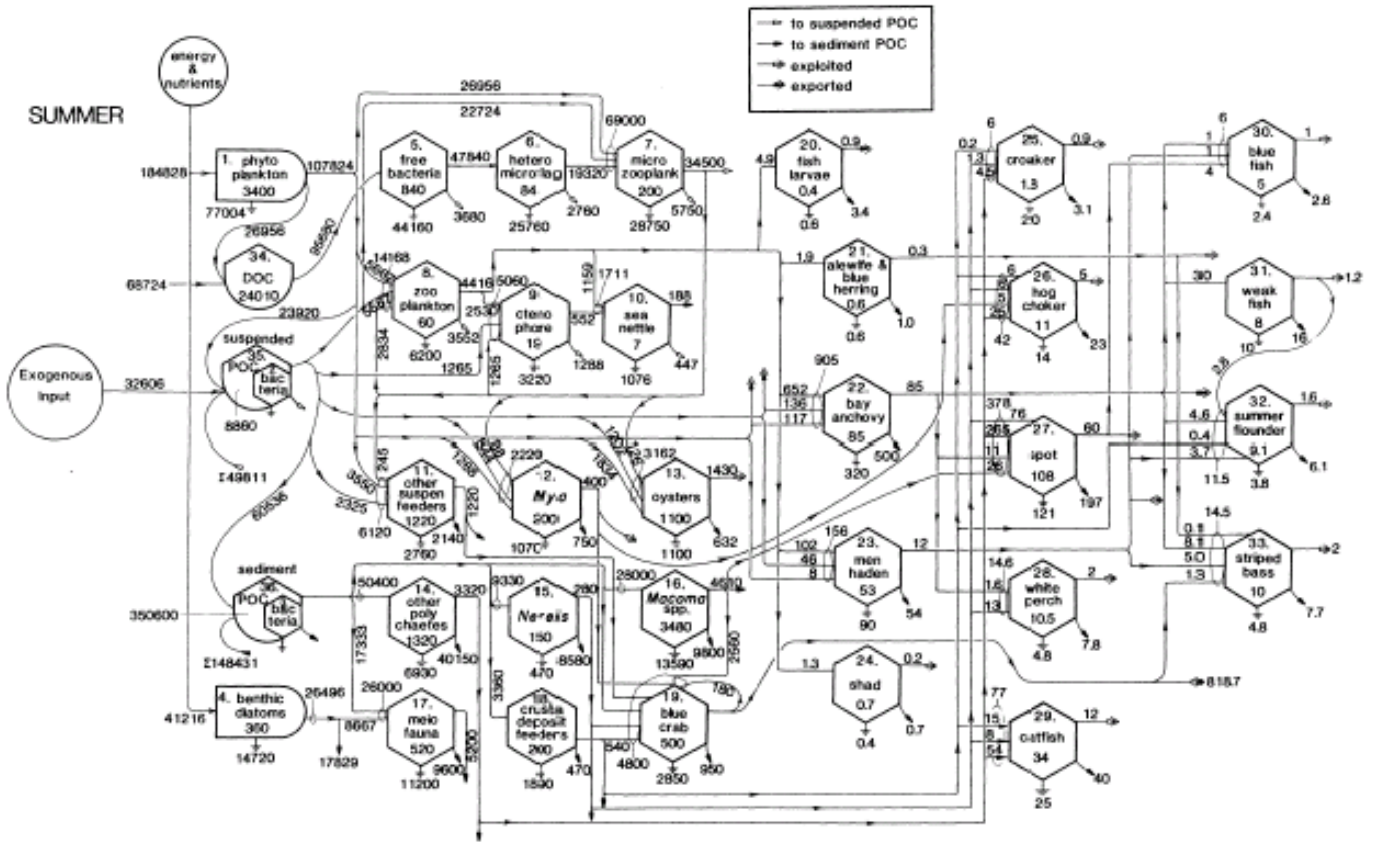
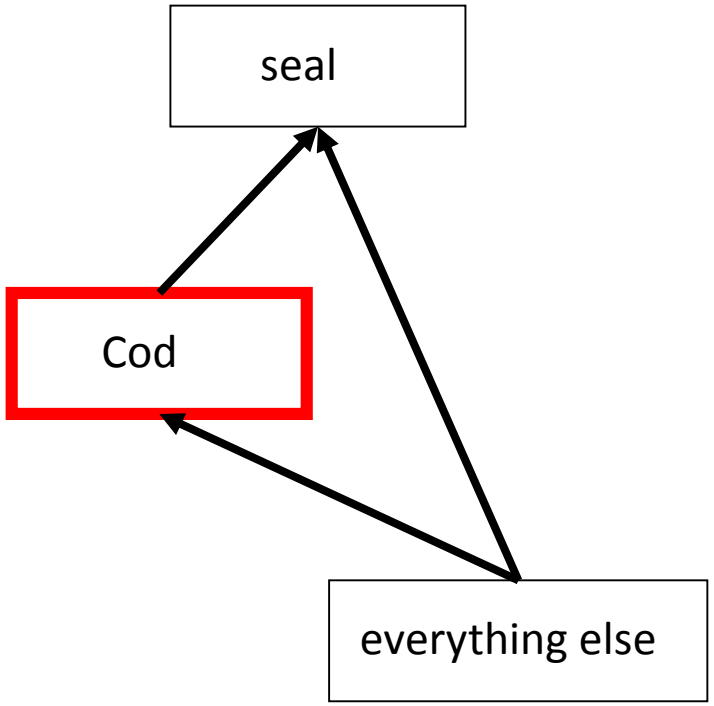
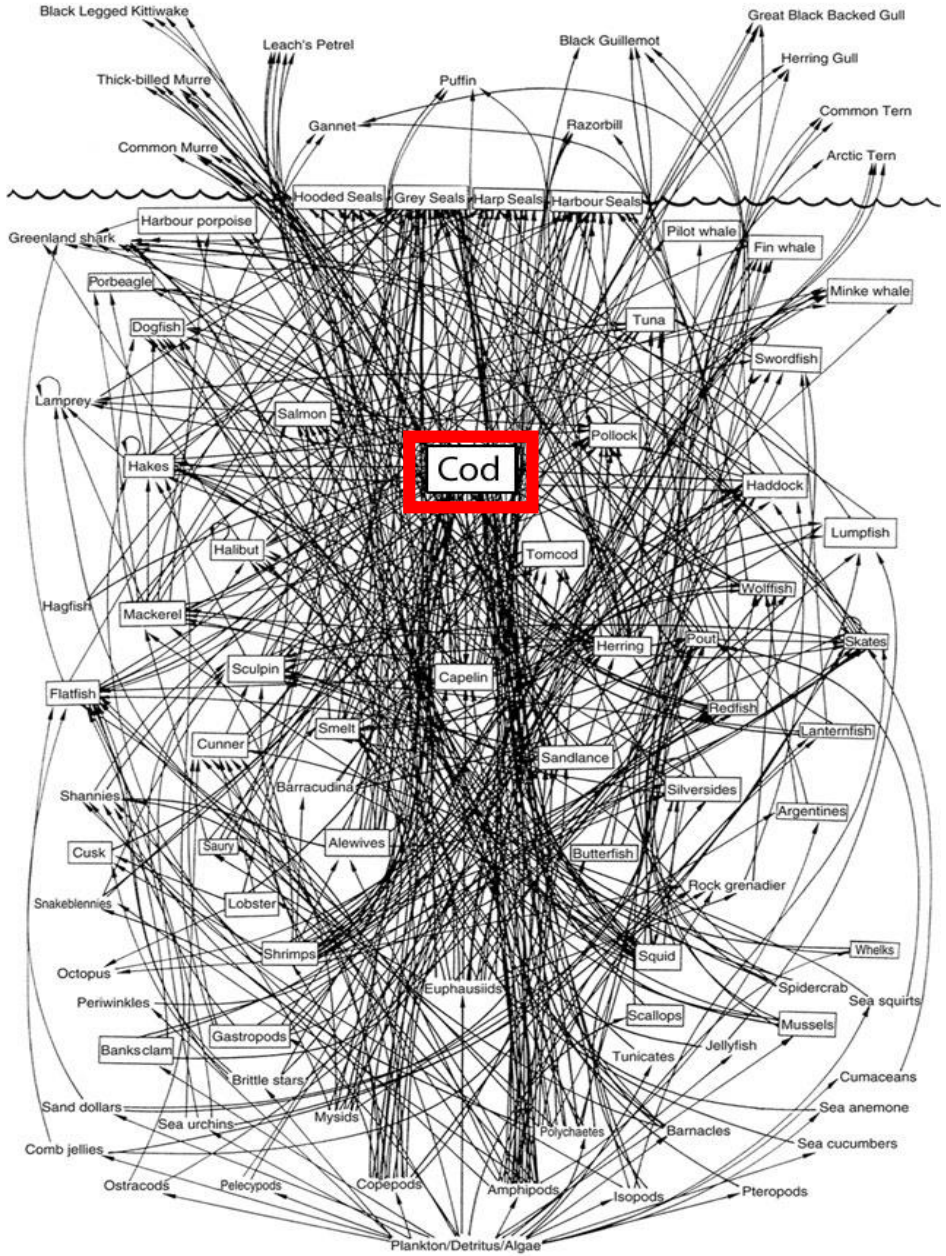
Food webs: the systems view





Food webs: aggregation

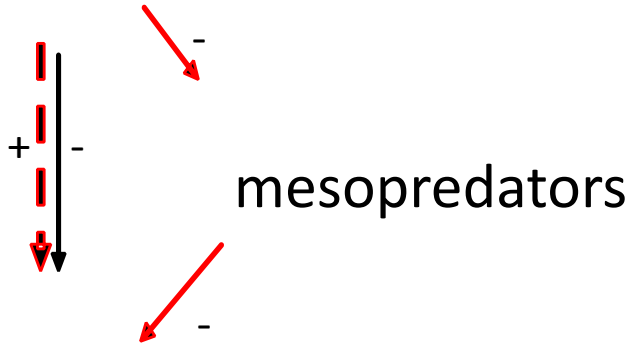




A simplified food web for the Northwest Atlantic. © IMMA

Food webs: indirect effects

Iberian lynx



trophic cascade > predation

Food webs: keystone species

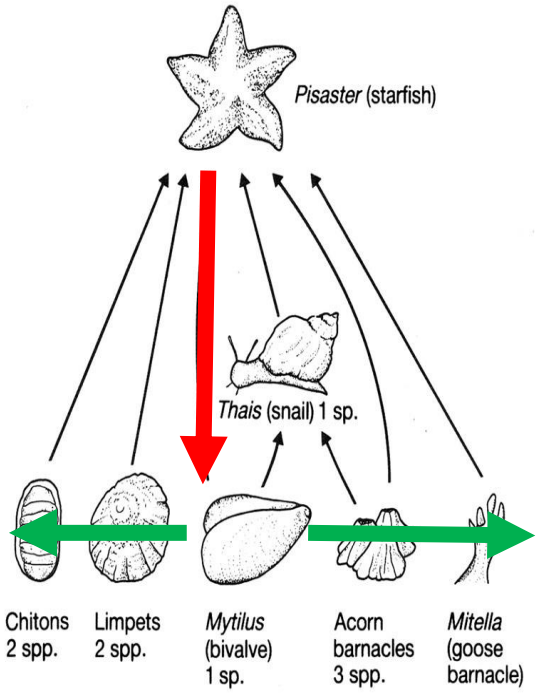
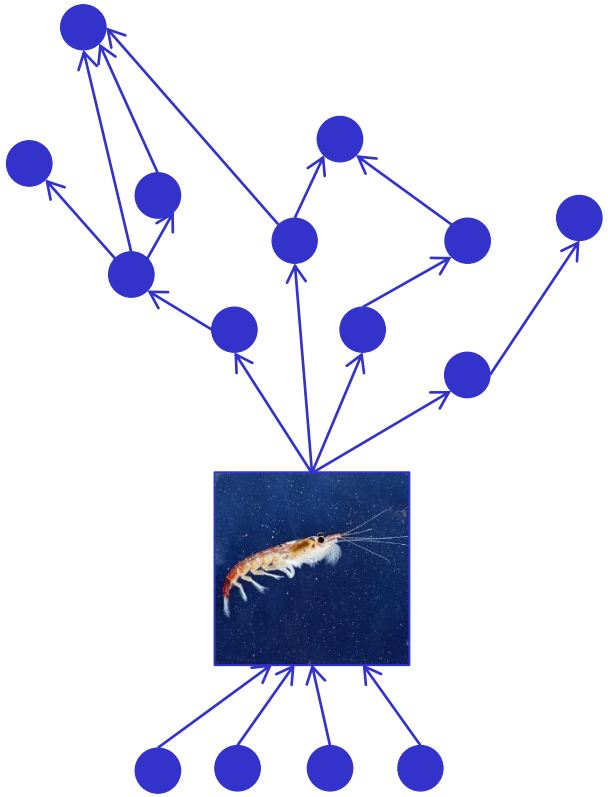


Figure 21.3. Paine's rocky shore community. (After Paine, 1966.)

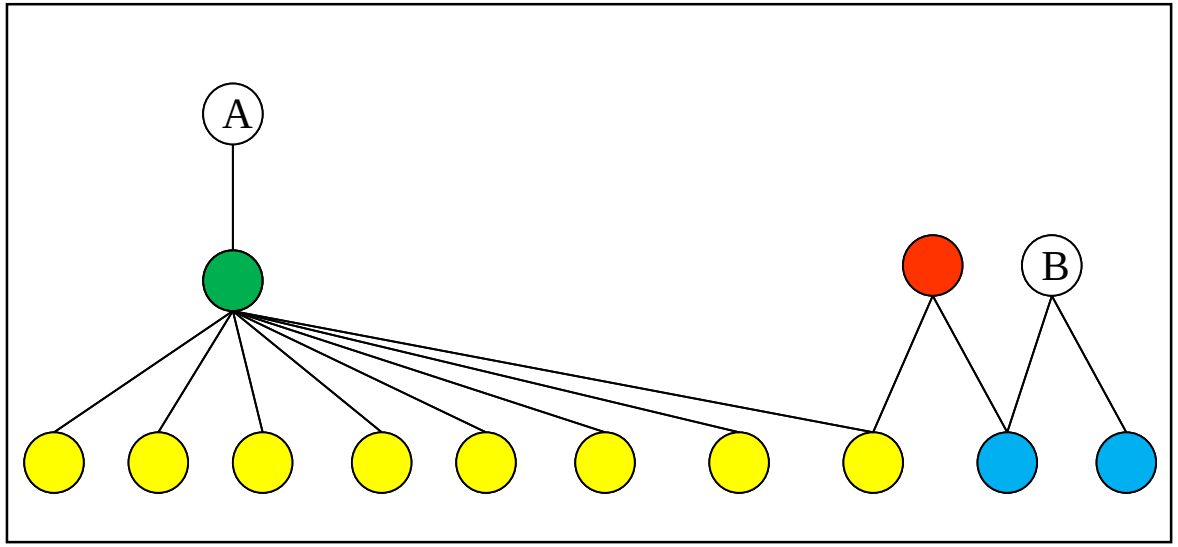
Food webs: network importance



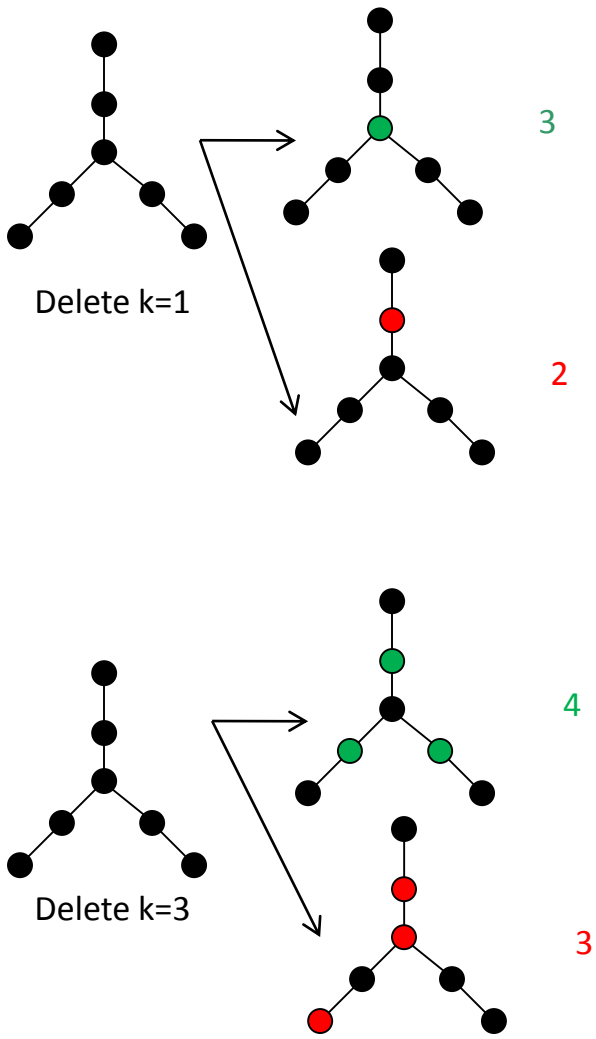
Jordán, F., Liu, W-C. and T. Wyatt, 2005, *Journal of Marine Systems*, 57: 250-263.

Food webs: missing links

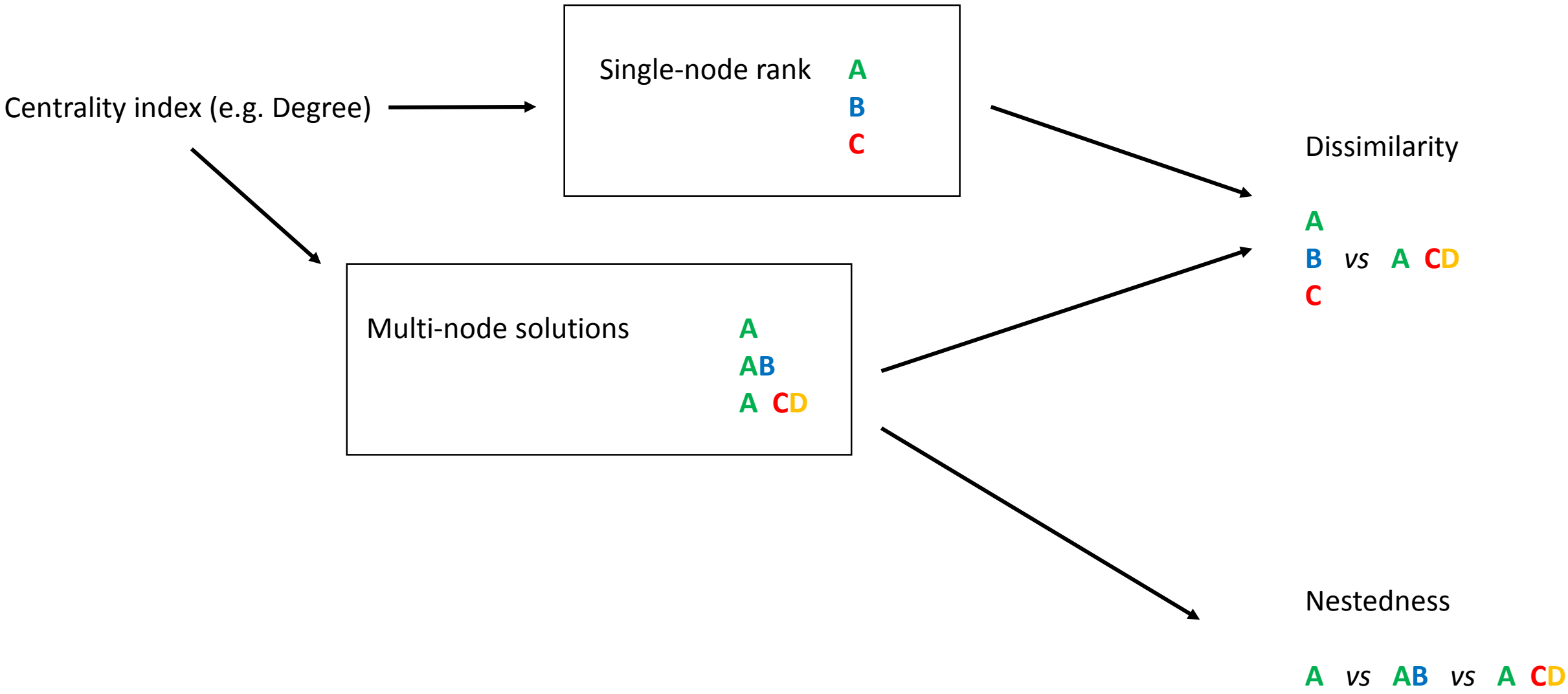
Food webs: central nodes



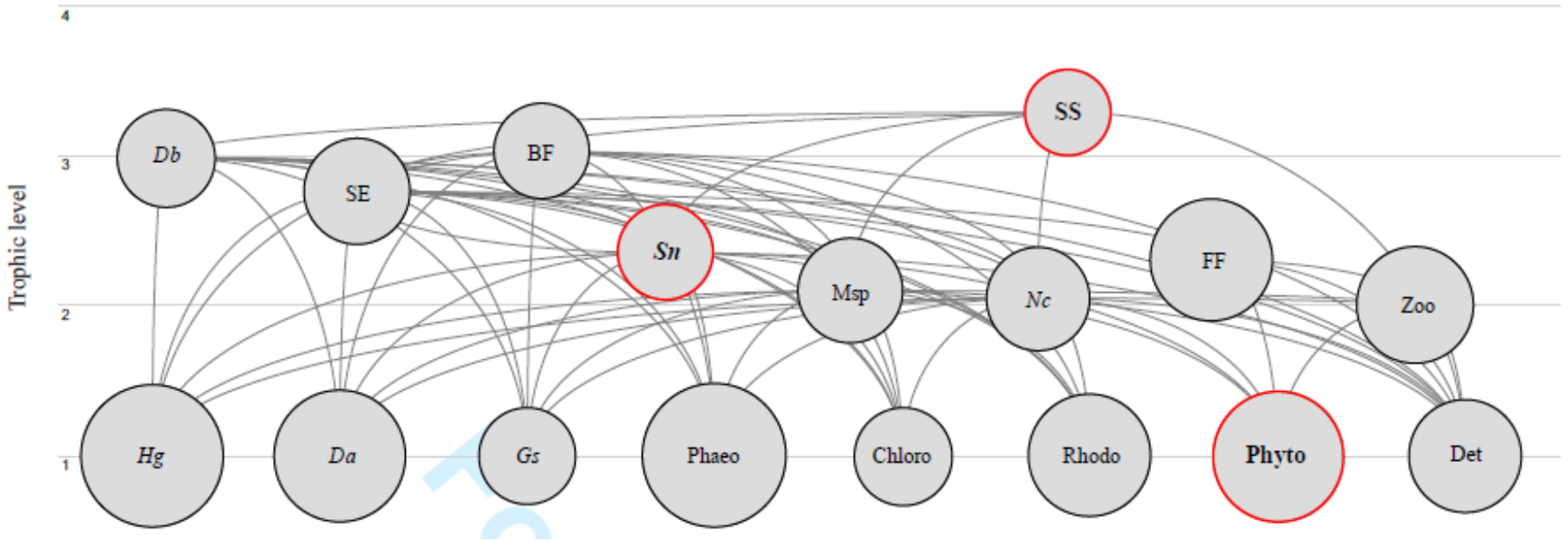
Food webs: KP sets



Food webs: KP sets



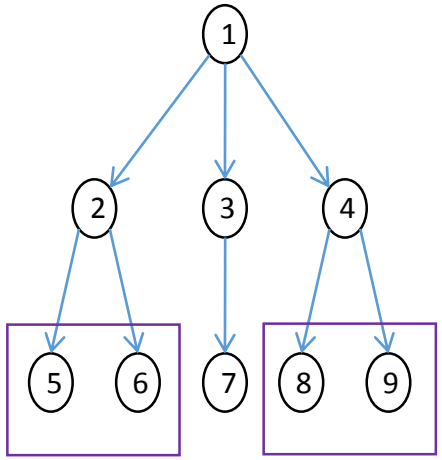
Food webs: keystone complexes



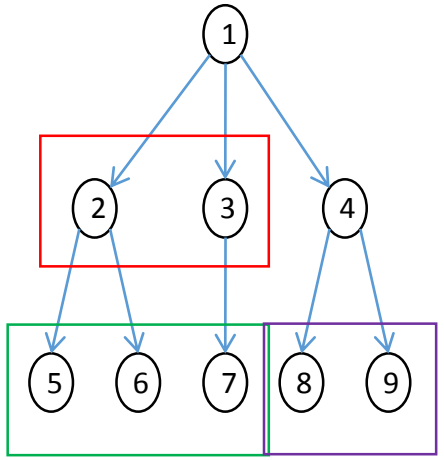
Ortiz, M., Hermosillo-Nuñez, B., González, J., Berrios, F., Rodríguez-Zaragoza, F., Gómez, I., Jordán, F. 2017. *Ecological Indicators*, 81:453–460.

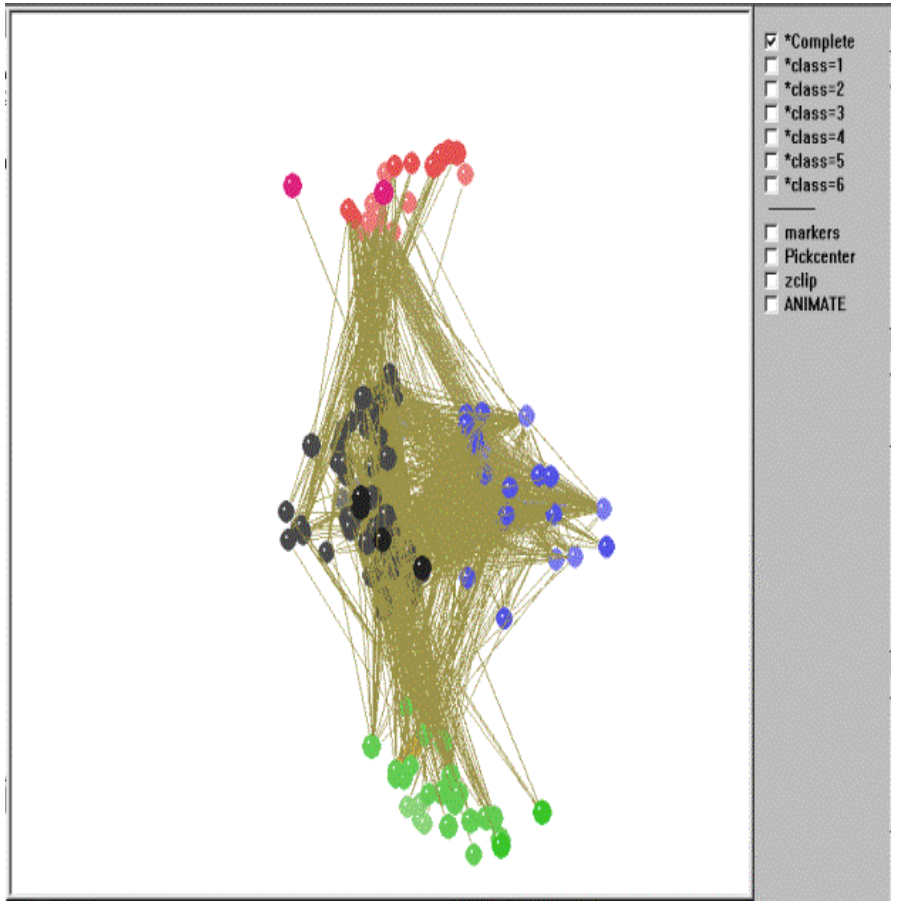
Food webs: roles and positions

Structural equivalence



Regular equivalence





El Verde rainforest, Puerto Rico

Food webs: simulations

„What is noise for the physicist is music for the biologist"
Daniel Simberloff

Stochastic IBM

BlenX process algebra

Number of individuals

Rates of interactions

Kinetics $A + B \xrightarrow{k_1} A$

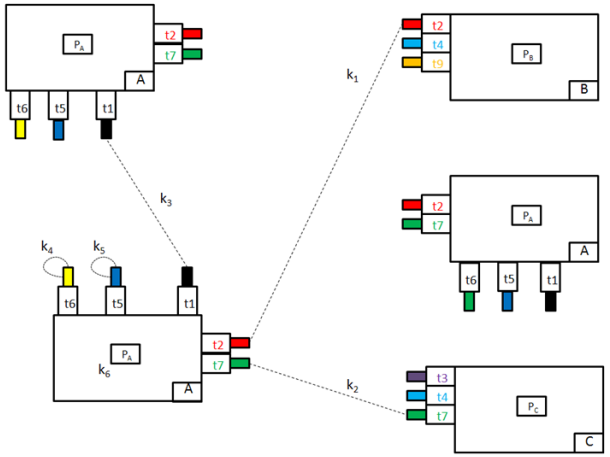
$A + B \xrightarrow{k_2} A^* \xrightarrow{k^*} A + A$

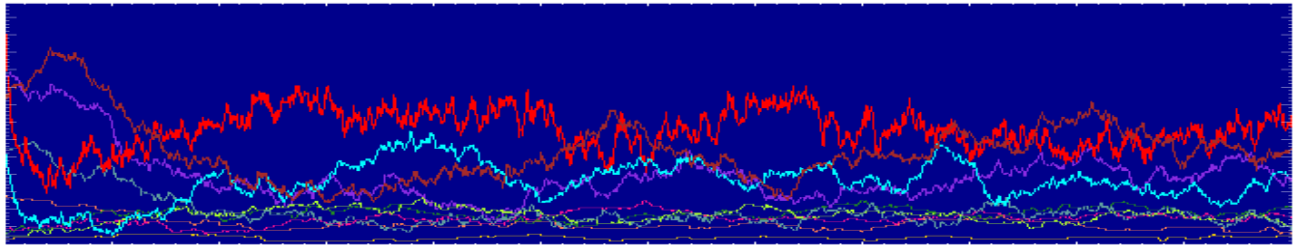
Balancing (genetic algorithm)

Sensitivity analysis

Community response

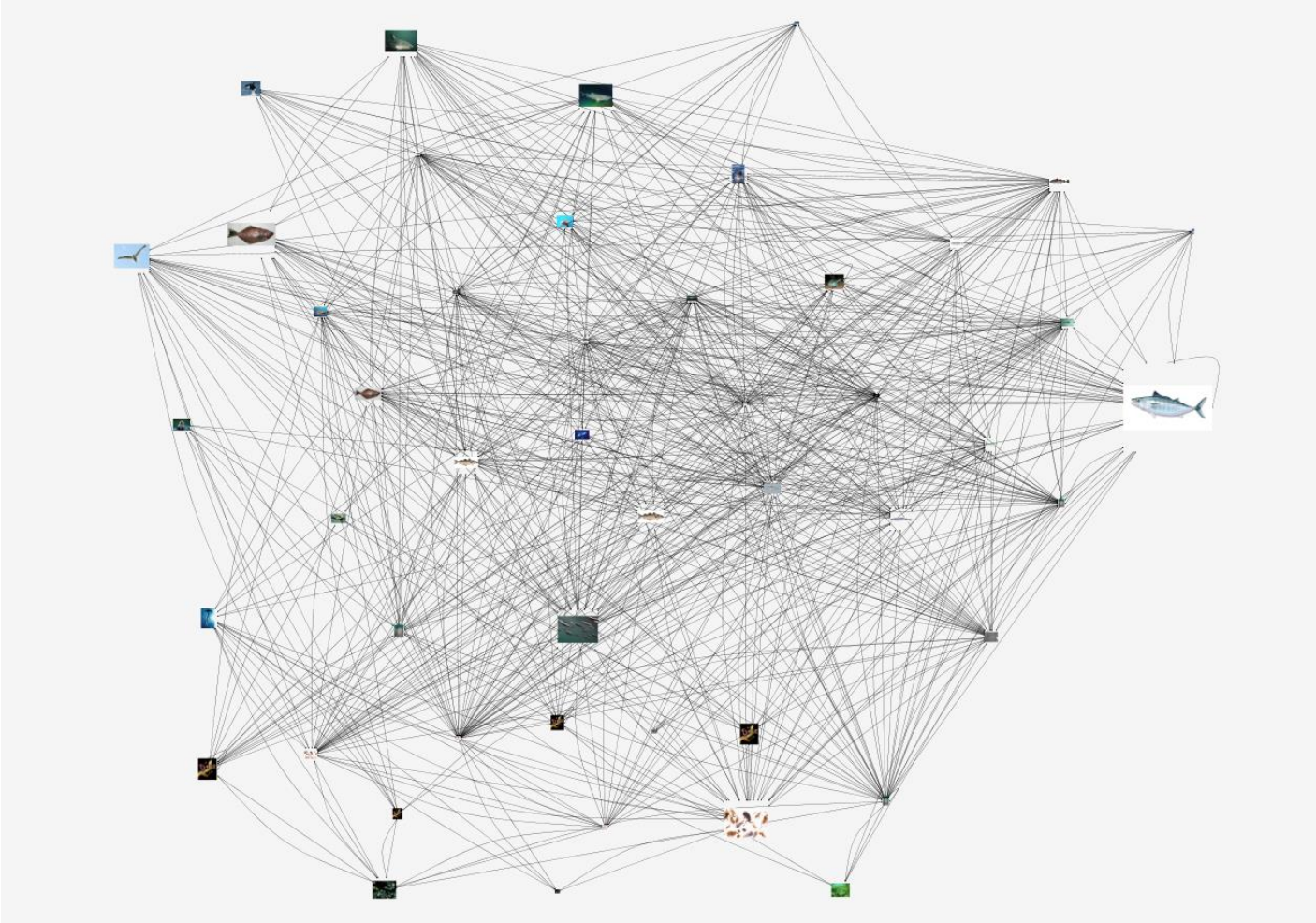
$$A_j = \frac{\sum_{k=1}^{R} a_{k,j}(t)}{R} \qquad A_{ij} = \frac{\sum_{k=1}^{R} a_{ij}(t)}{R} \qquad \mathrm{RR}_{ij} = \frac{|A_j - A_{ij}|}{A_j}$$





Jordán, F., Scotti, M. and Priami, C. 2011. *Ecological Complexity*, 8:357-363.

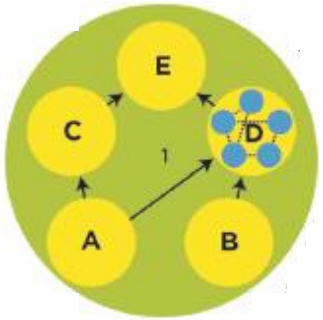
Food webs: marine fisheries



	I_H
Nearshore demersals	231.09
Adult arrowtooth	147.71
Herbivorous zooplank	141.79
Juvenile herring	131.80
Seabirds	121.91
Sleeper shark	117.45
Salmon shark	115.22
Juvenile pollock (0)	103.66
Juv. Arrowtooth	103.21
Adult Pollock (1+)	98.94
Near phytoplankton	98.05
Capelin	94.51
Shallow sm infauna	93.31
Deep lg infauna	92.59
Pacific cod	91.97
Jellies	90.49
Lingcod	88.97
Resident orca	88.75
Pinnipeds	88.75
Macrophytes	87.24
Adult herring	84.56
Sea otter	84.51
Porpoise	82.18
Deep sm infauna	80.51
Invert-eating birds	79.90
Juvenile salmon (0-1)	79.40
Baleen Whales	79.10
Adult salmon	78.41
Sandlance	77.68
Near omnivorous zoops	77.25
Octopods	77.00
Deep demersal fishes	75.17
Shallow lg epibenthos	75.01
Shallow lg infauna	72.59
Spiny dogfish	70.29
Deep epibenthos	66.93
Rockfish	66.83
Shallow sm epibenthos	66.51
Near herbiv zooplank	63.48
Halibut	61.96
Sablefish	61.79
Meiofauna	60.89
Omnivorous zooplank	60.59
Eulachon	57.33
Avian raptors	56.25
Transient orca	53.77
Squid	52.26
Offshore phytoplankton	48.99

Livi, C.M., Jordán, F., Lecca, P. and Okey, T.A. 2011. *Ecological Modelling*, 222:2542-2551.

ZOOM-IN: social networks



Social networks: dominance

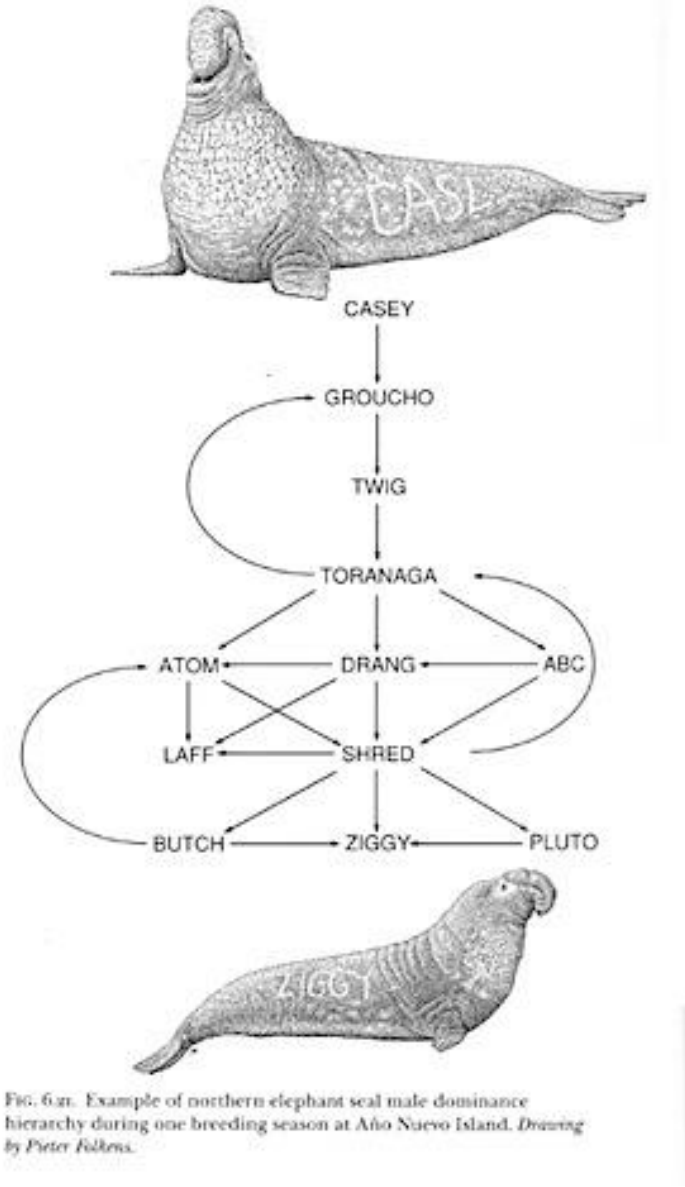
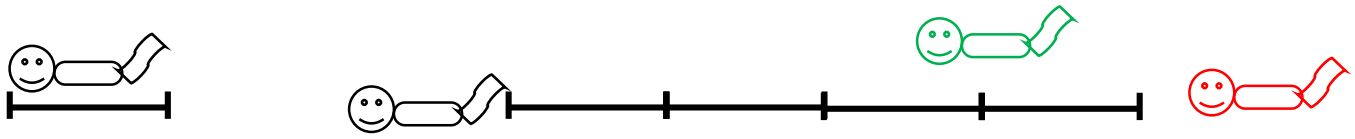
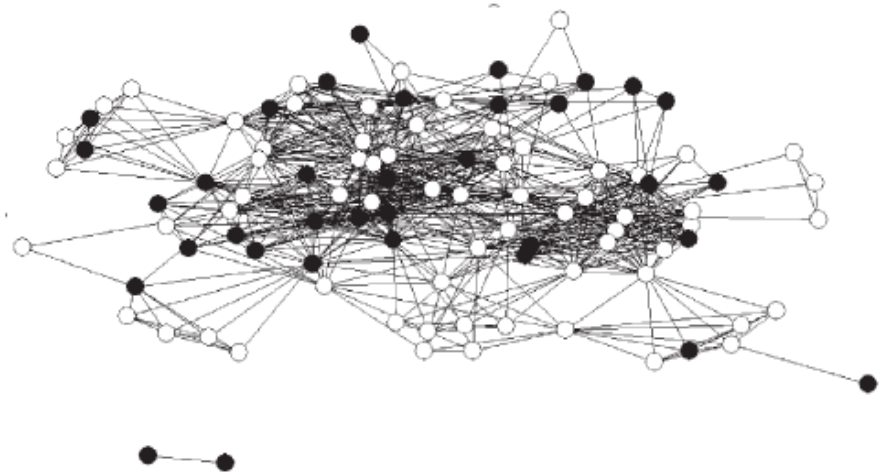


FIG. 6.21. Example of northern elephant seal male dominance hierarchy during one breeding season at Año Nuevo Island. *Drawing by Peter Folkens.*

Social networks: proximity

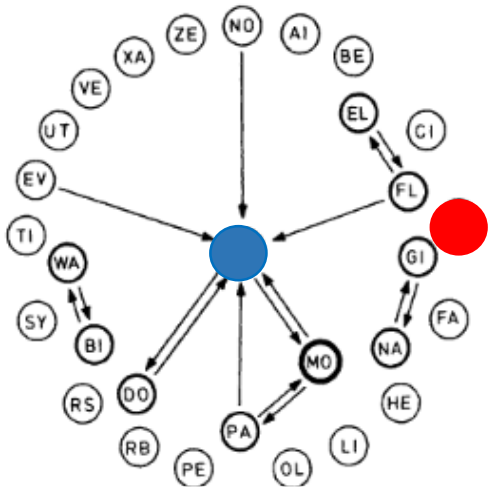




Wey, T., Blumstein, D.T, Shen, W. and Jordán, F. 2008. *Animal Behaviour*, 75: 333-344.

Social networks: multiple links

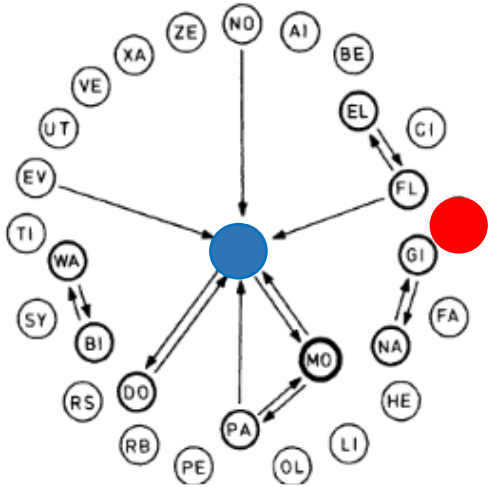
grazing



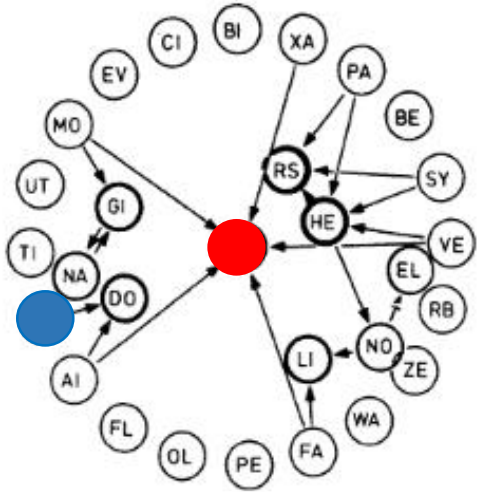
Reinhardt, V. and Reinhardt, A. 1981. *Behaviour*, 77: 121-151.

Social networks: multiple links

grazing

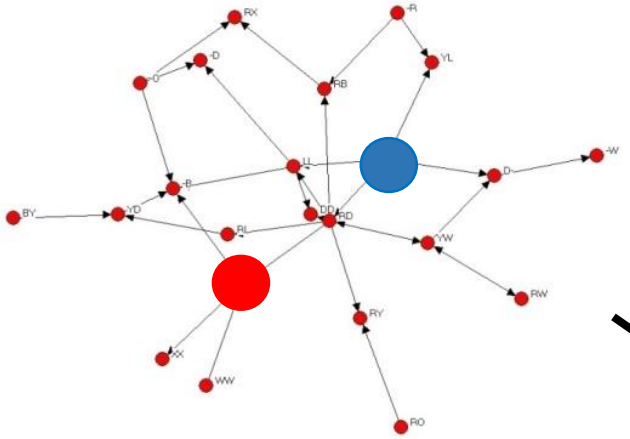


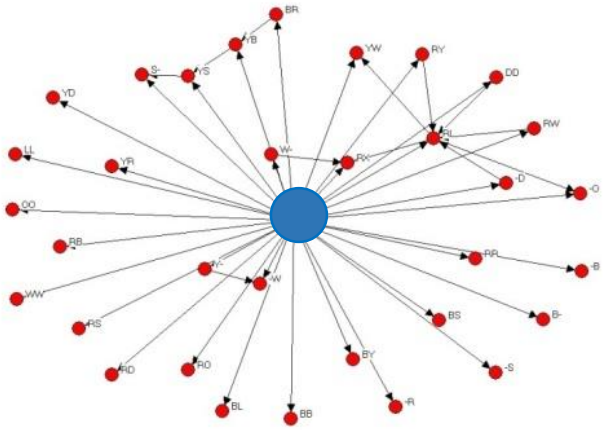
licking



Reinhardt, V. and Reinhardt, A. 1981. *Behaviour*, 77: 121-151.

Social networks: dynamics



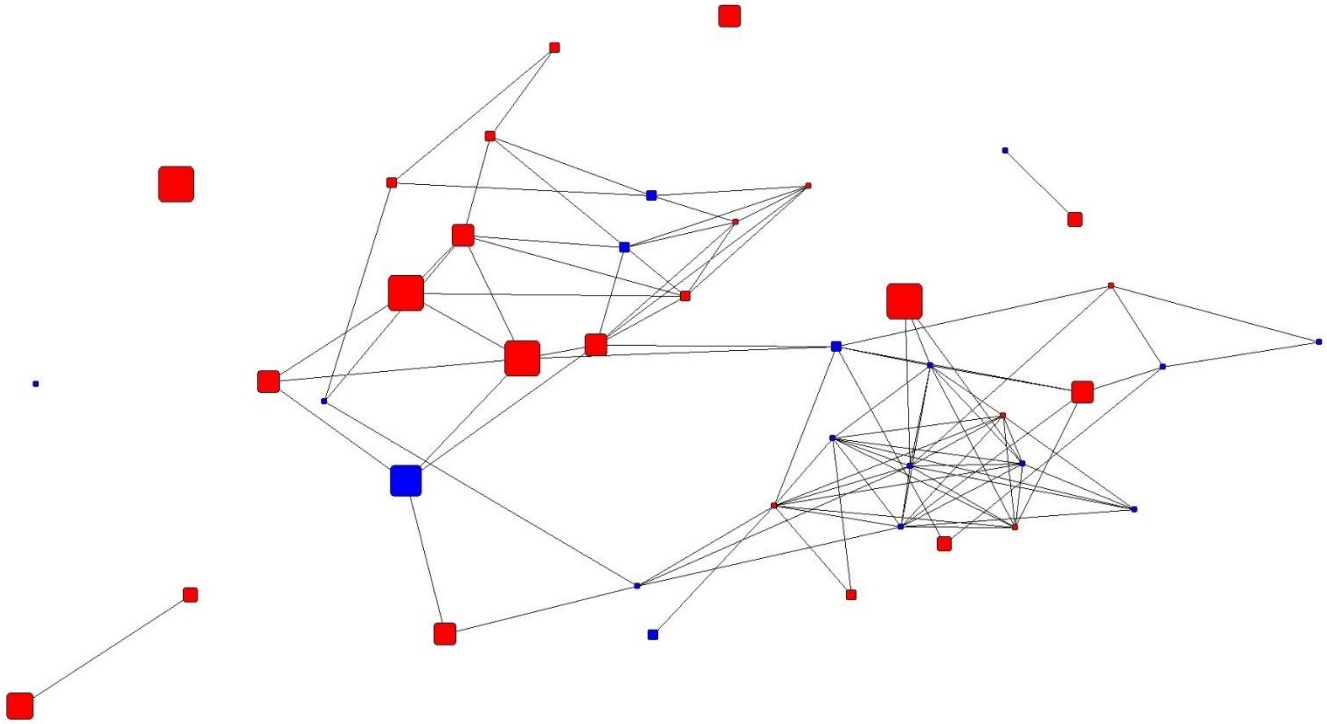


Queens of *Ropalidia marginata*

- Post-queen
- Queen

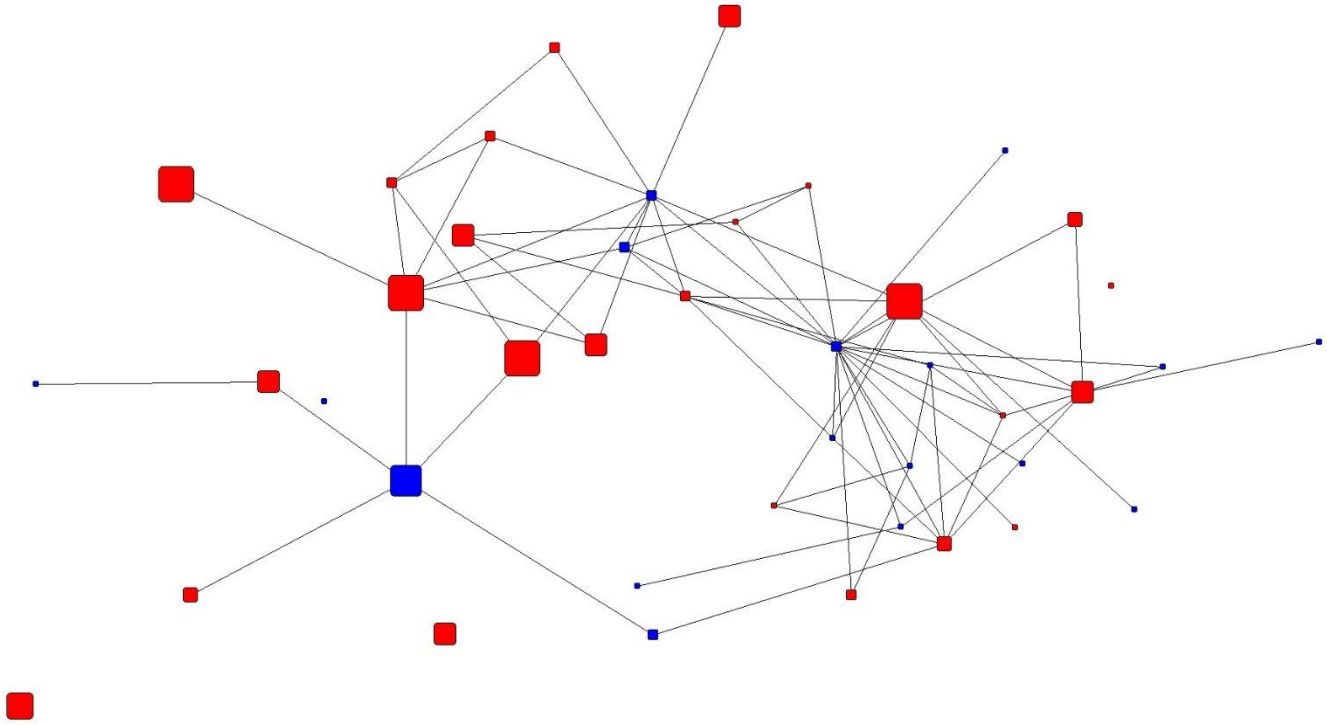
Bhadra, A., Jordán, F., Sumana, A., Deshpande, S. and Gadagkar, R. 2009. *Ecological Complexity*, 6: 48-55.1

Social networks: signed graphs



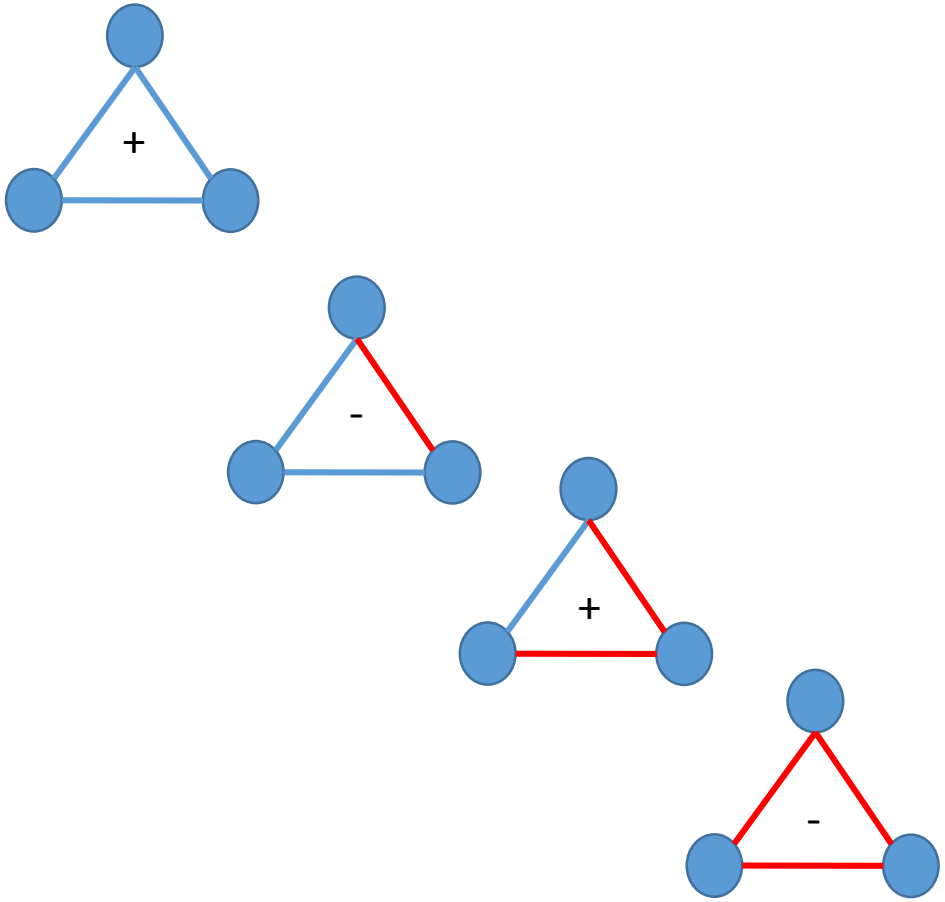
Picnic 2007, **positive** links form two major cliques

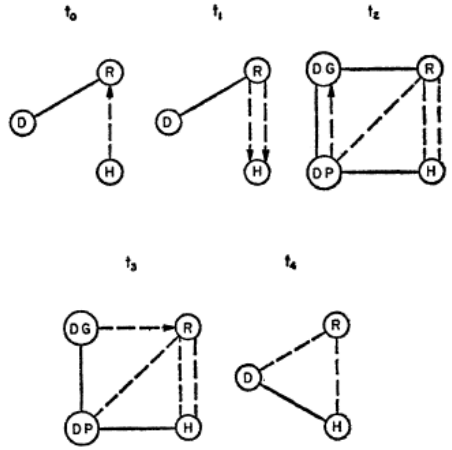
Social networks: signed graphs



Picnic 2007, **negative** links mostly between the two cliques

Social networks: balance

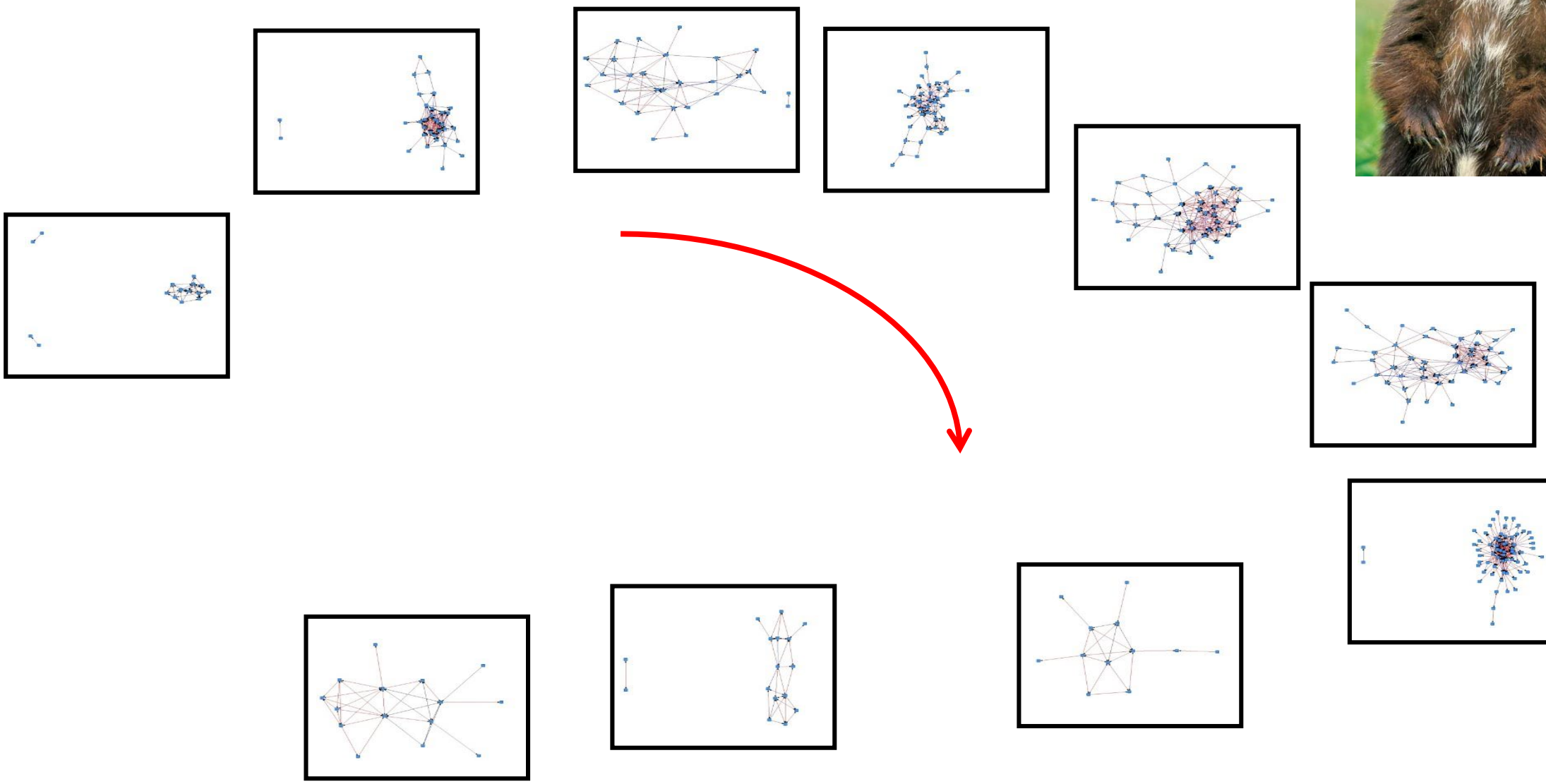




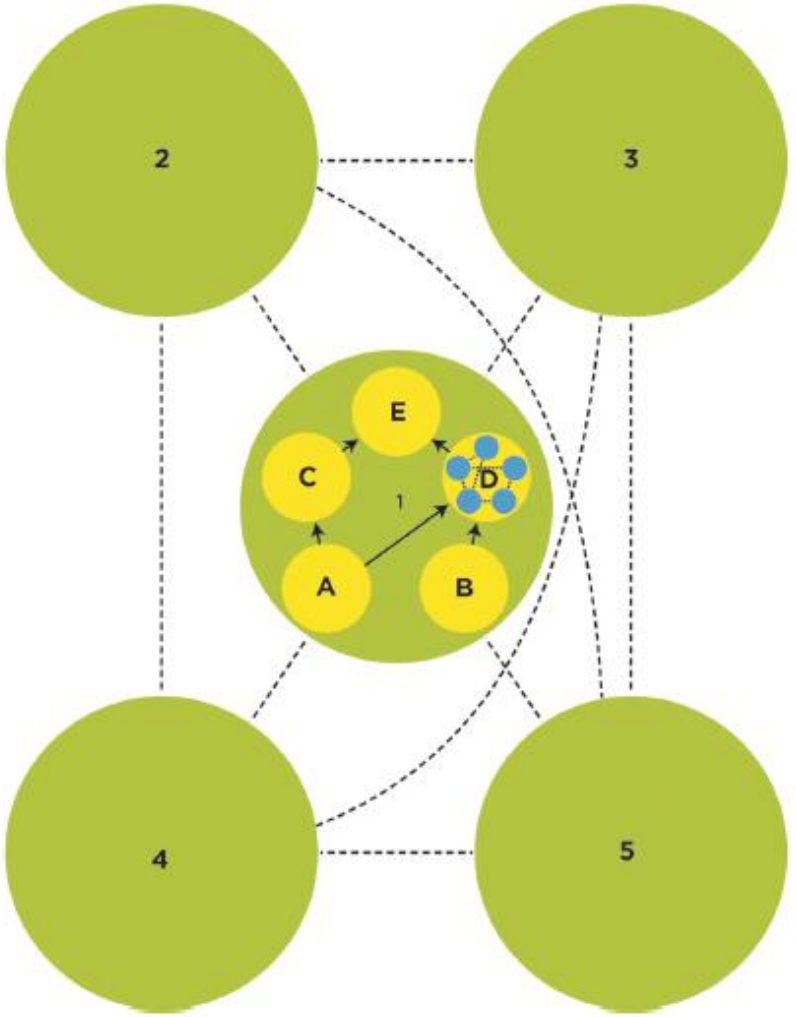
E	Egypt
A	the other Arab countries
B	Great Britain
C	Canada
F	France
I	Israel
D	India
U	U.S.A.
R	U.S.S.R.
H	Hungary

Harary, F. 1961. *The Journal of Conflict Resolution*, 5:167-178.

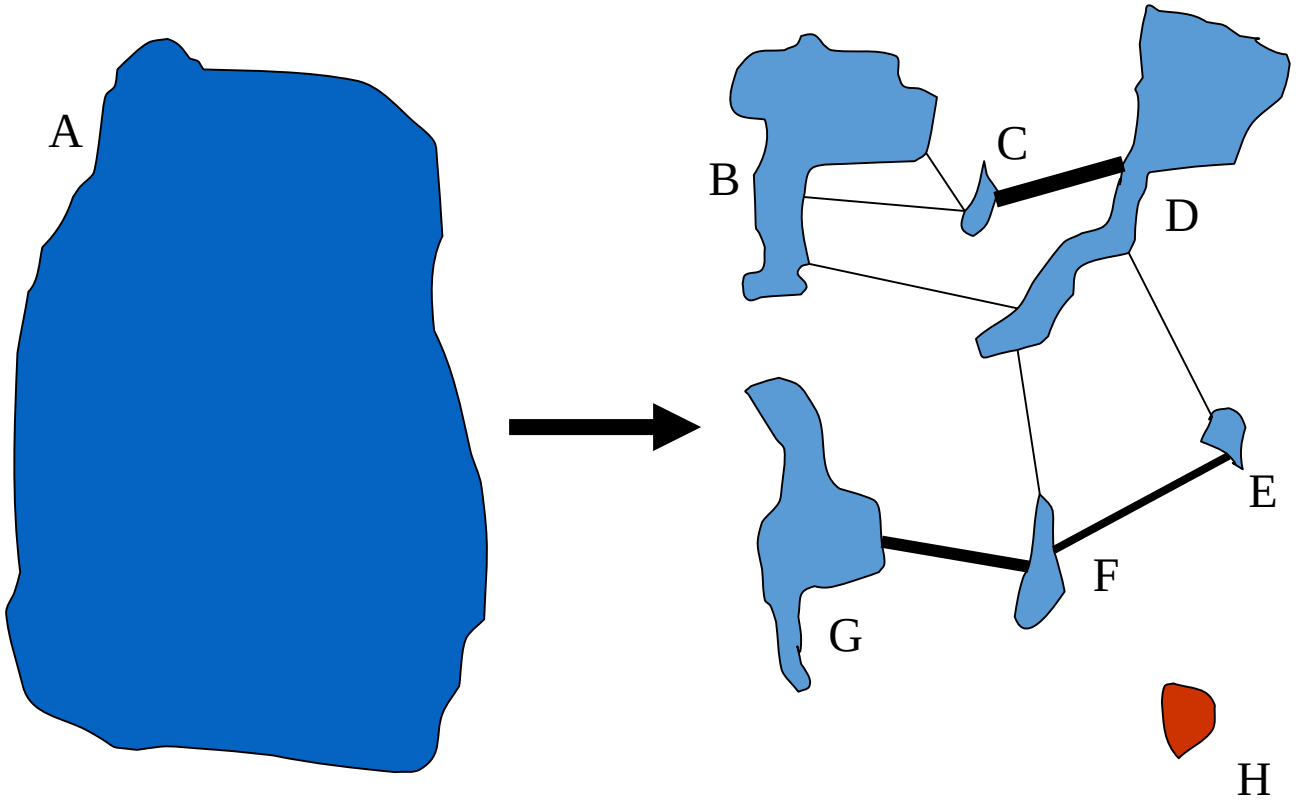
Social networks: time series



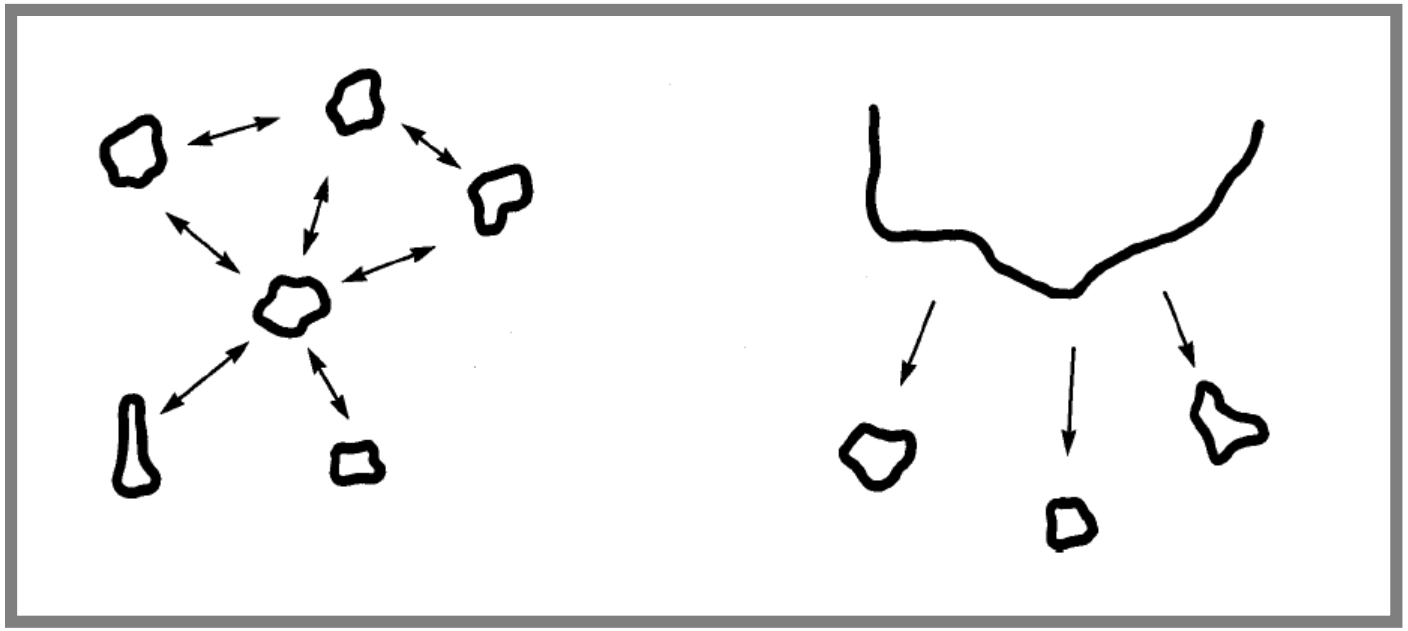
ZOOM-OUT: landscape graphs



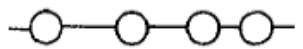
Landscape graphs: isolation



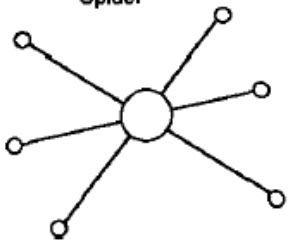
Landscape graphs: topology



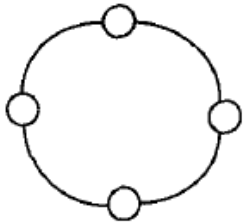
Necklace



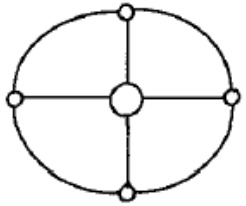
Spider



Graph Cell

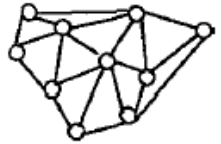


Cross

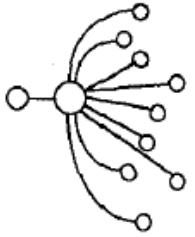


Satellite

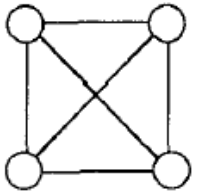
Mesh



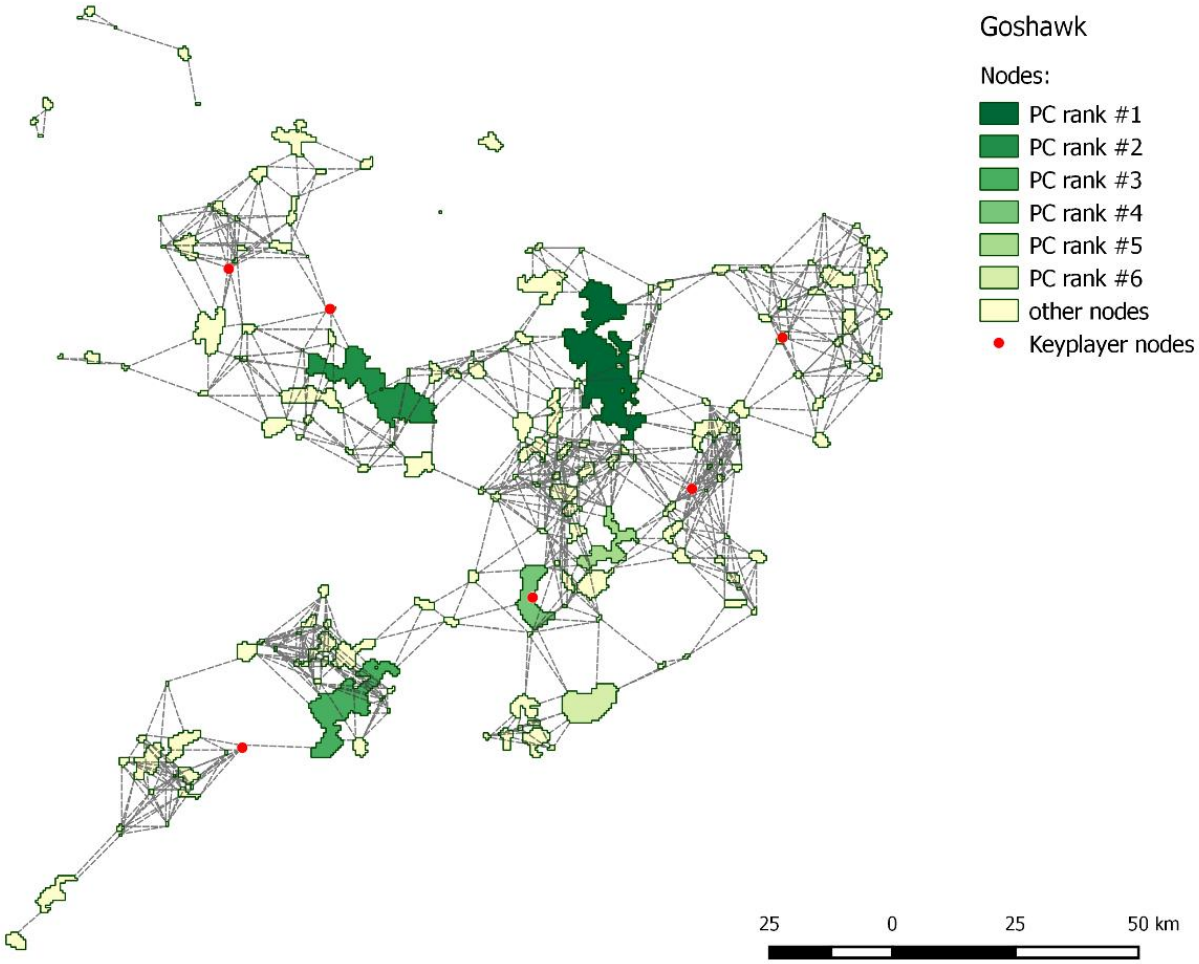
Candelabra



Rigid Polygon

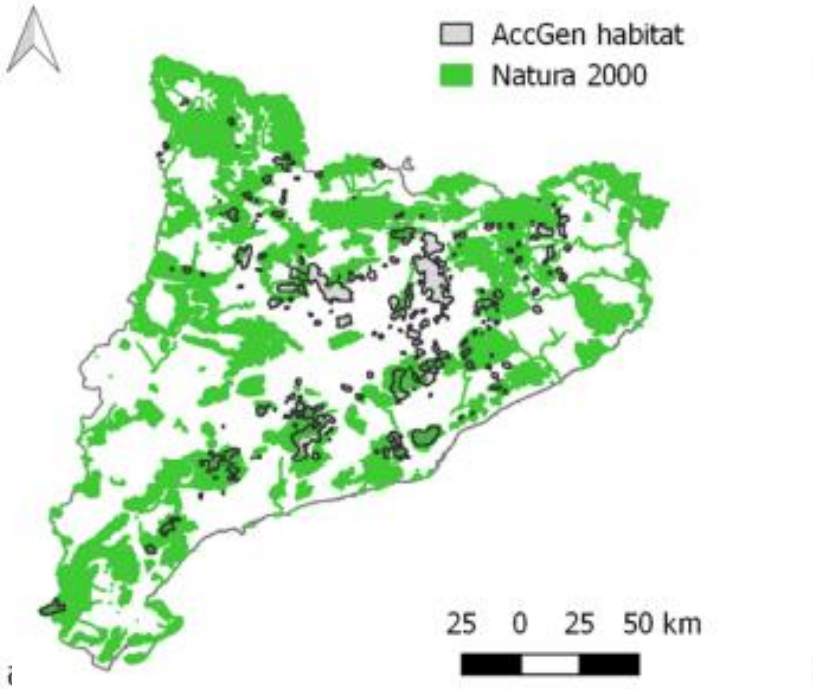


Landscape graphs: critical nodes



Pereira, J., Saura, S. and Jordán, F. 2017. *Methods in Ecology and Evolution*, doi: 10.1111/2041-210X.12783.

Landscape graphs: conservation



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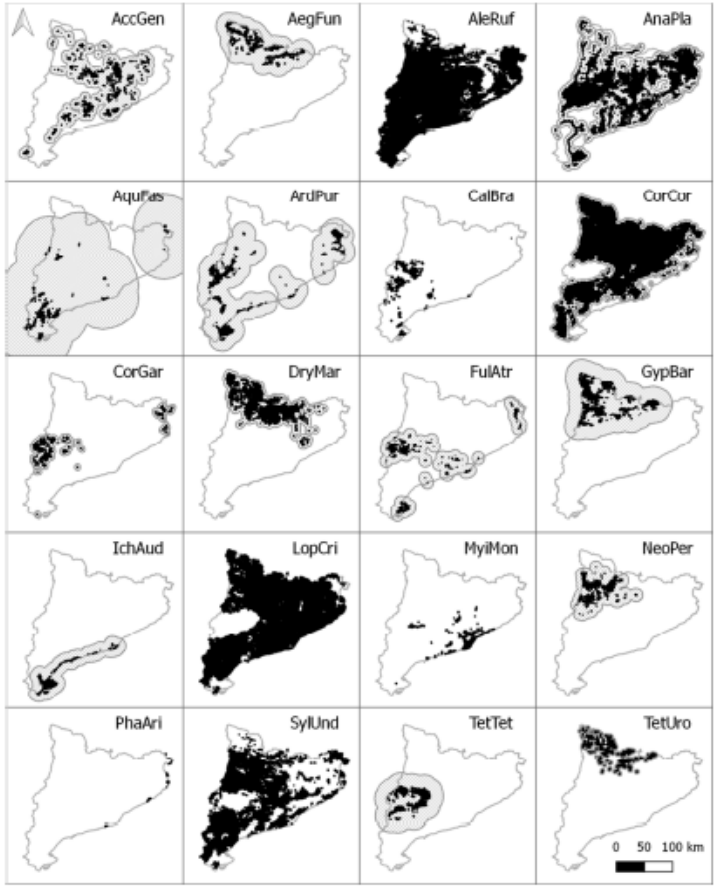
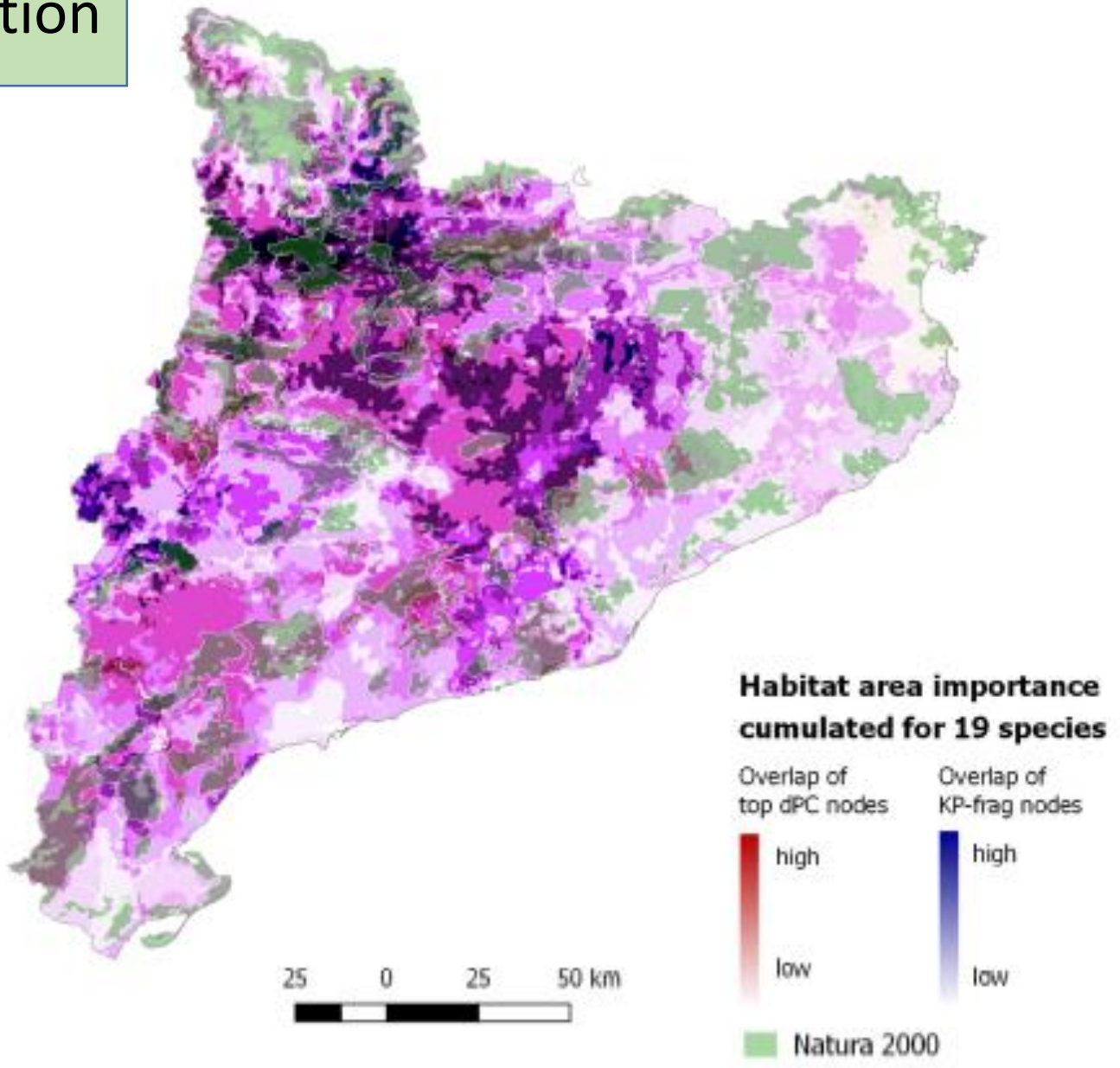
Landscape graphs: conservation





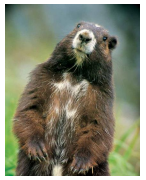
Hierarchy: the vertical links

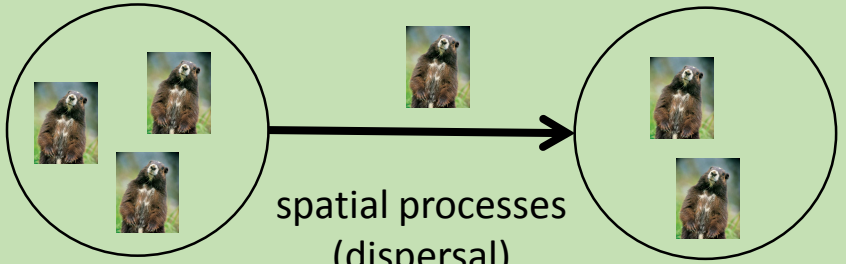
Landscape graphs: isolation

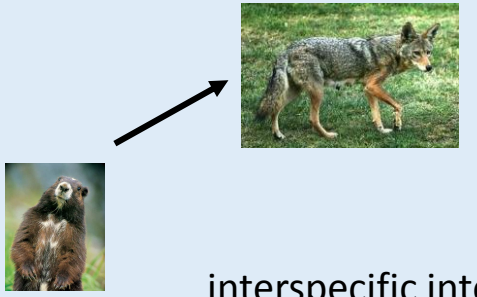
Food webs: the systems view

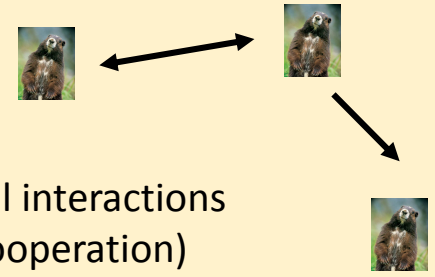
Social networks: dominance

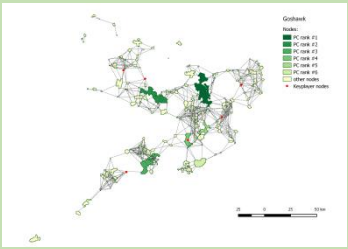
Hierarchy: the vertical links

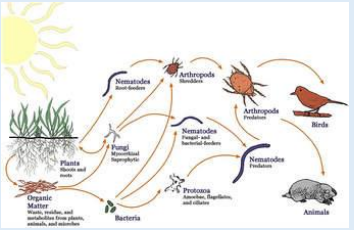




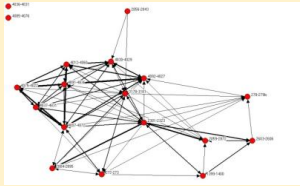





landscape graph

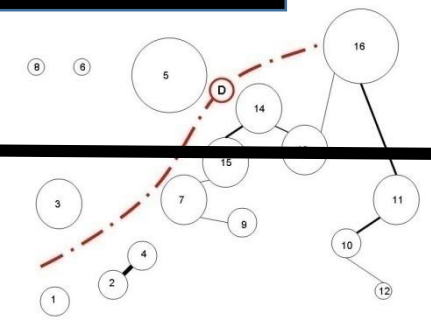


food web


social network

Scotti, M. et al. 2013. *Journal of Complex Networks*, 1: 1-23.

Hierarchy: the vertical links

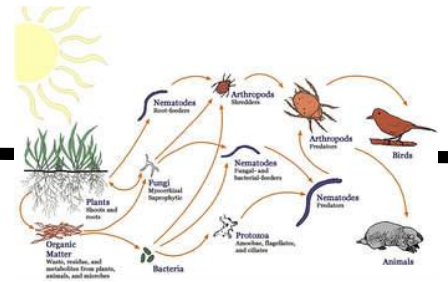


$$mr_{i,t+1} = pop_{i,t} \cdot m_i.$$

$$rrPP_{i,t+1} = popPP_{i,t} \cdot b_i,$$

$$rrC_{i,t+1} = popC_{i,t} \cdot popR_{j,t} \cdot er_{ji} \cdot \frac{D_{i,t}}{D_{j,t}}.$$

$$C = \frac{l}{S^2} = \frac{5}{5^2} = 0.2.$$



$$mort_{j,t+1} = popC_{i,t} \cdot popR_{j,t} \cdot e_{ji} \cdot \frac{D_{i,t}}{D_{j,t}},$$

$$mort_{j,t+1} = popC_{i,t} \cdot popR_{j,t} \cdot er_{ji} \cdot \frac{D_{i,t}}{D_{j,t}},$$

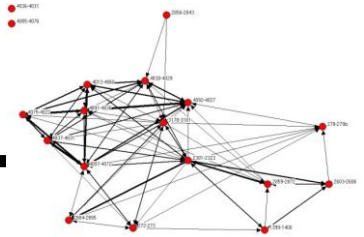
$$mortPP_{i,t+1} = popPP_{i,t}^2, \cdot d_i,$$

$$mortC_{i,t+1} = popC_{i,t} \cdot dC_i.$$

$$eat_{j,t+1} = popC_{j,t} \cdot popR_{i,t} \cdot e_{ij} \cdot \frac{D_{j,t}}{D_{i,t}},$$

$$eat_repr_{j,t+1} = popC_{j,t} \cdot popR_{i,t} \cdot er_{ij} \cdot \frac{D_{j,t}}{D_{i,t}}.$$

$$D_{i,t} = \frac{2 \cdot links_{i,t}}{[pop_{i,t} \cdot (pop_{i,t} - 1) + 0.001]}.$$

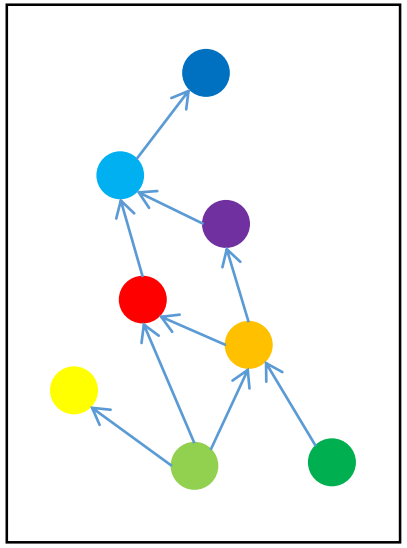


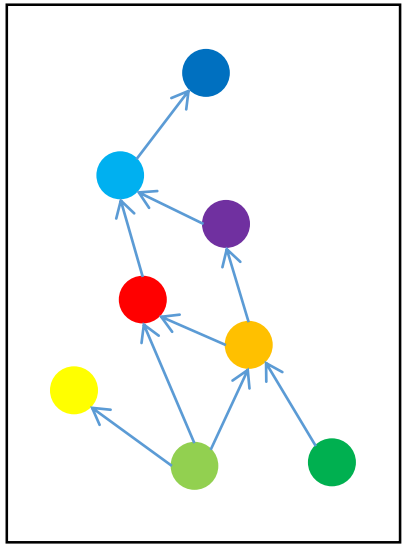
$$linkF_{i,t+1} = p_i \cdot non_links_{i,t},$$

$$linkR_{i,t+1} = q_i \cdot links_{i,t}.$$

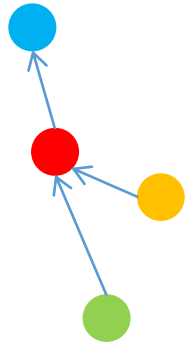
Scotti, M. et al. 2013. *Journal of Complex Networks*, 1: 1-23.

Methods





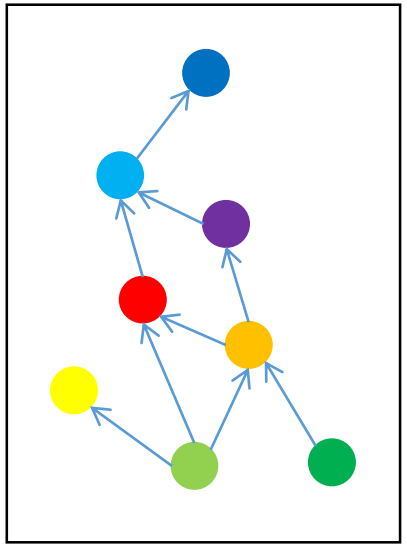
Degree: D



D_{in} (in-degree) = 2

D_{out} (out-degree) = 1

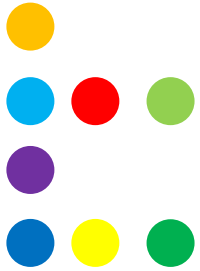
D (degree) = D_{in} + D_{out} = 3

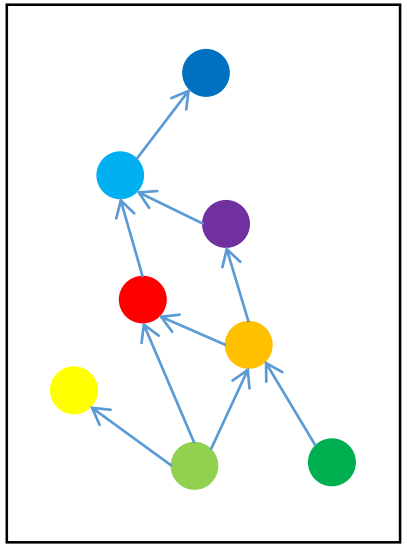


Degree: D

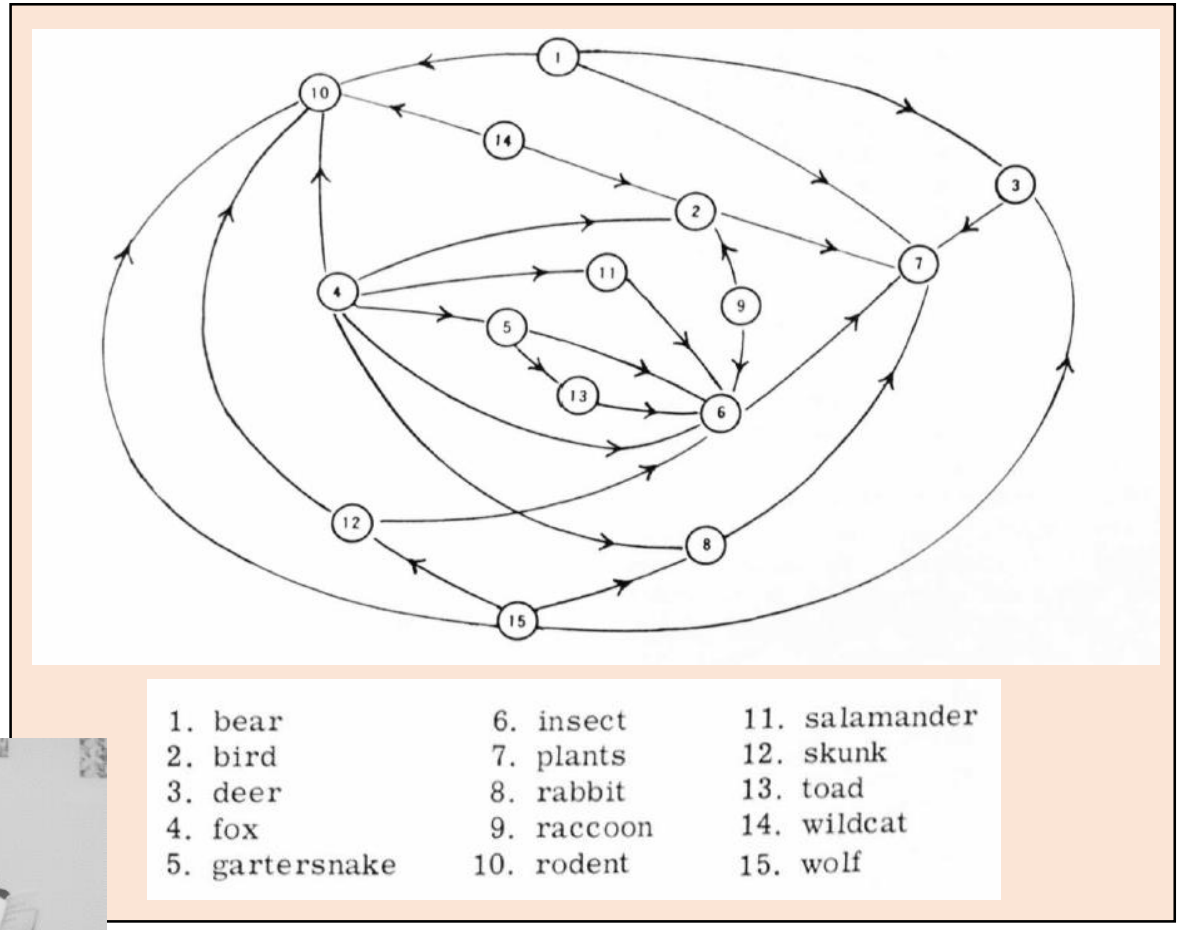
	D_{in}	D_{out}	D
	1	0	1
	2	1	3
	1	1	2
	2	1	3
	2	2	4
	1	0	1
	0	1	1
	0	3	3

Importance rank:

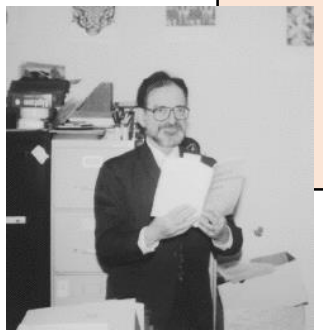




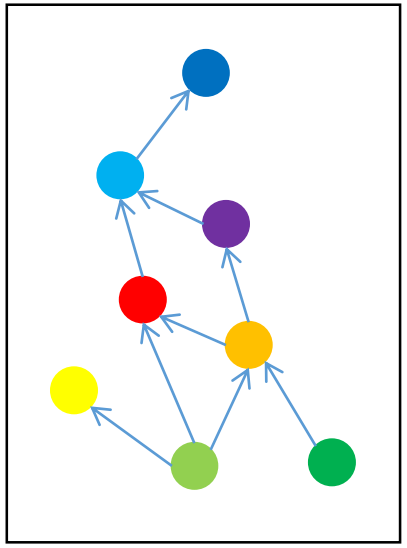
Net status: Δs



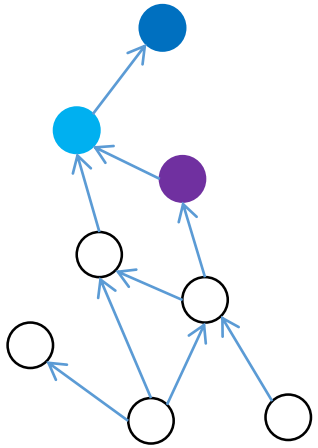
1. bear
2. bird
3. deer
4. fox
5. gartersnake
6. insect
7. plants
8. rabbit
9. raccoon
10. rodent
11. salamander
12. skunk
13. toad
14. wildcat
15. wolf



Harary, F. 1961. Who eats whom? *General Systems* 6: 41-44.

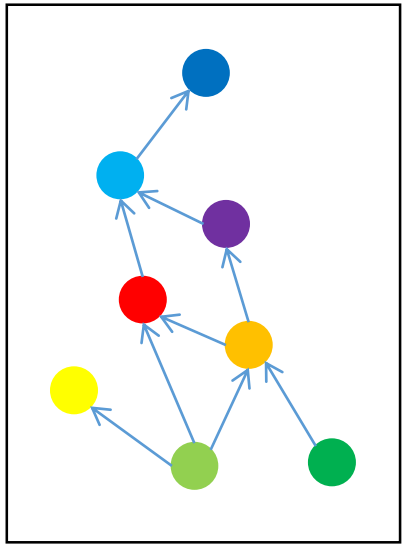


Net status: Δs

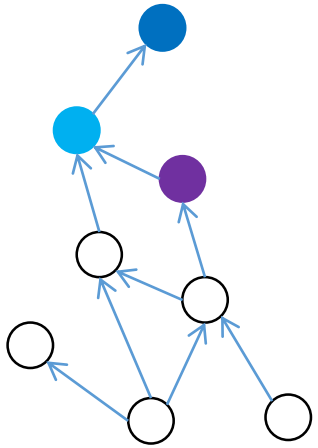


s (status) = 1 + 2 = 3

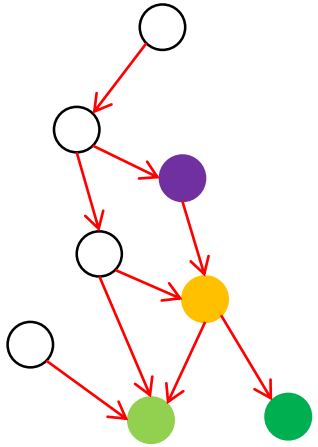
$s = \sum d_{ix}$



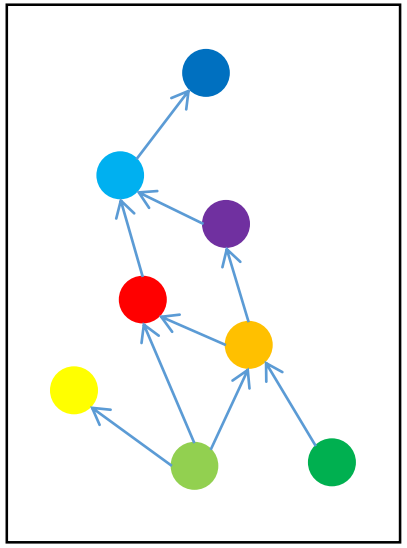
Net status: Δs



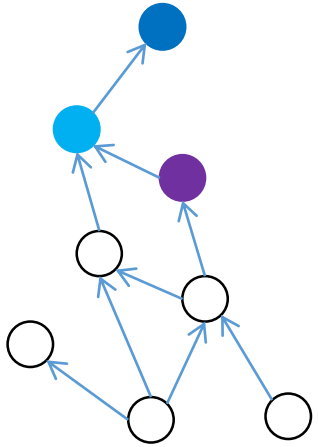
s (status) = 1 + 2 = 3



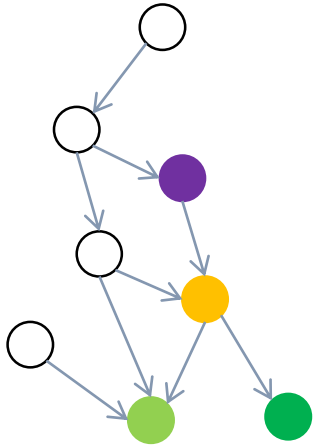
s’ (contra-status) = 1 + 2 + 2 = 5



Net status: Δs

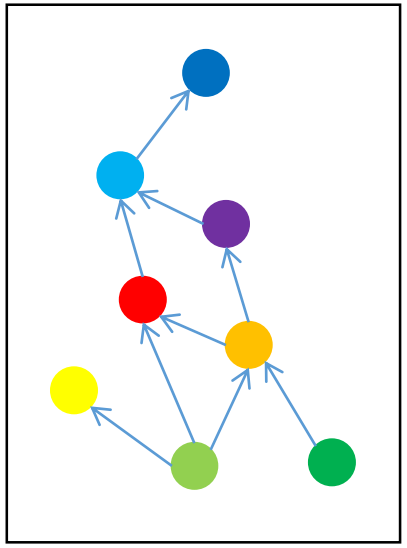


● s (status) = 1 + 2 = 3



● s’ (contra-status) = 1 + 2 + 2 = 5

● Δs (net status) = s – s’ = -2

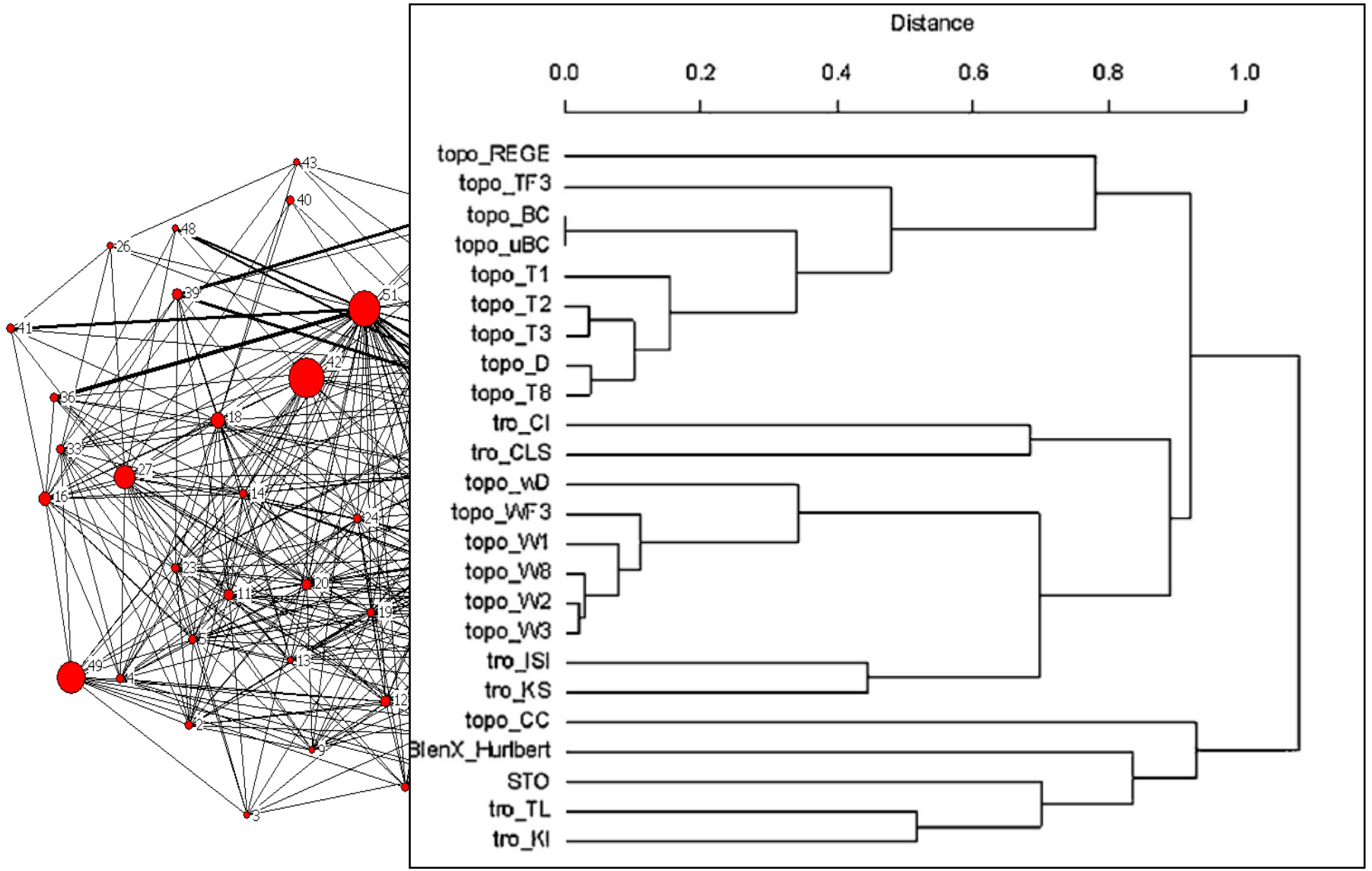


Net status: Δs

s	s’	Δs
0	15	-15
1	9	-8
3	5	-2
3	4	-1
7	2	5
0	1	-1
12	0	12
10	0	10

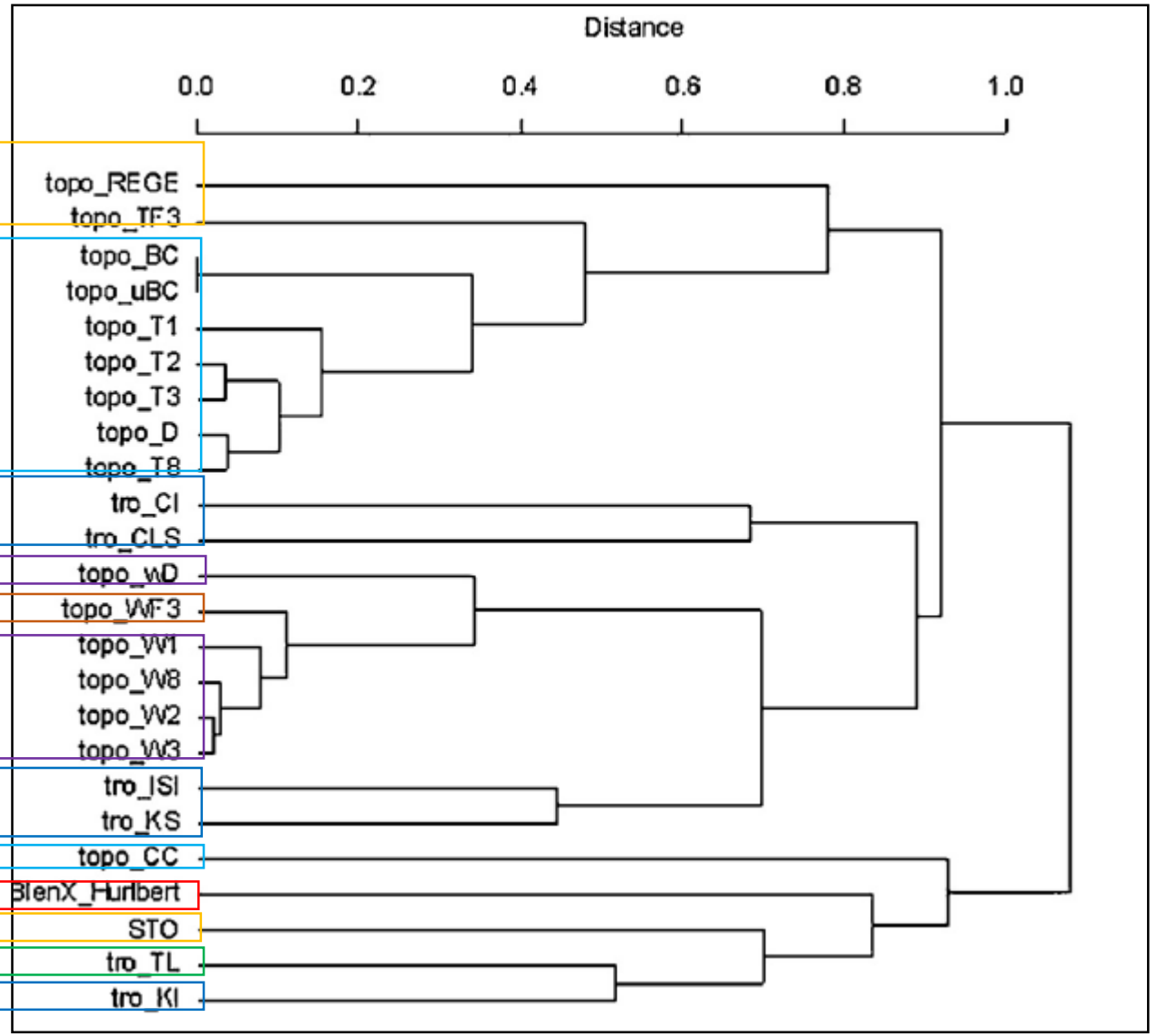
Importance rank:

Positional *vs* dynamical importance of network nodes



Lai, S.M., Liu, W.C., and Jordán, F. 2015. *Ecological Modelling*, 299: 95-101.

Positional *vs* dynamical importance of network nodes



24:

1 trophic level

8 topology (binary)

5 topology (weighted)

3 similarity (binary)

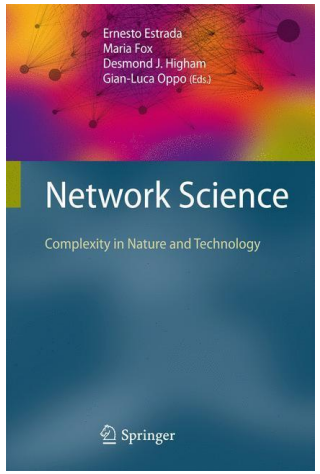
1 similarity (weighted)

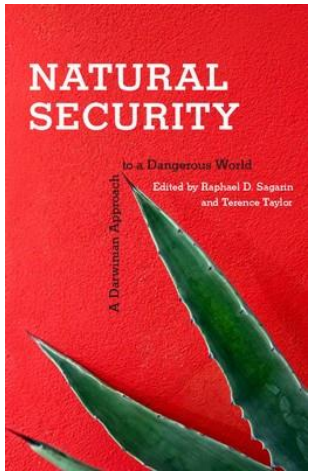
5 dynamics (deterministic)

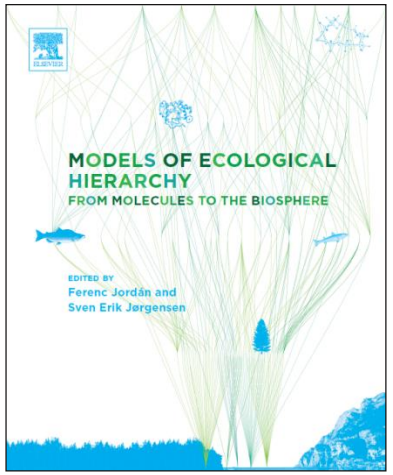
1 dynamics (stochastic)

Lai, S.M., Liu, W.C., and Jordán, F. 2015. *Ecological Modelling*, 299: 95-101.

Thank you







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