Ecological networks for the management of biodiversity in mountain areas

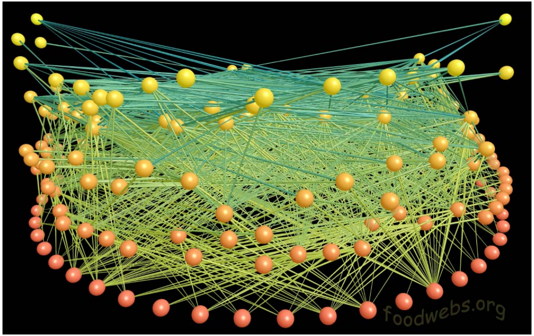
Bernat Claramunt

CREAF - NEMOR

October 28th, 2021

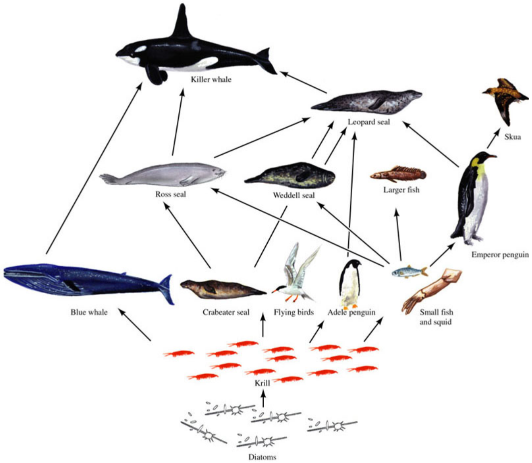
A lot to learn

- Definition of ecological networks
- Trophic levels and energy fluxes
- Characteristics of food webs
- Matrix models



Description of food webs

A trophic network is a real or modeled set of feeding relationships between species or functional groups



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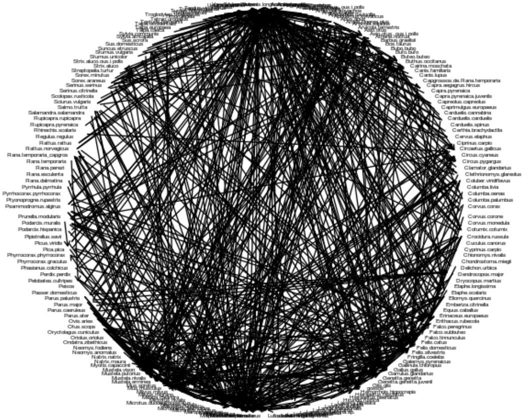
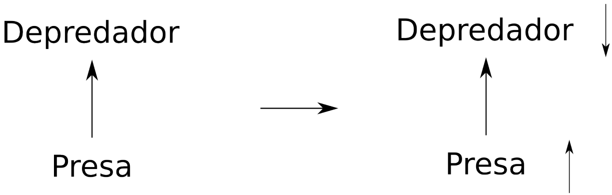


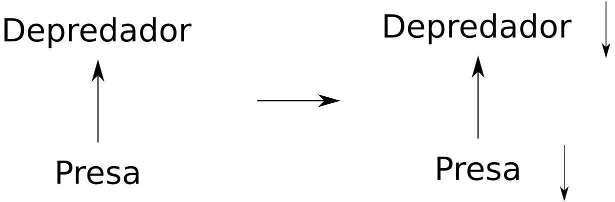
Why studying food webs?

Direct and *indirect* effects



Why studying food webs?

Direct and *indirect* effects

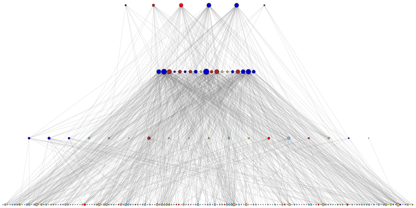


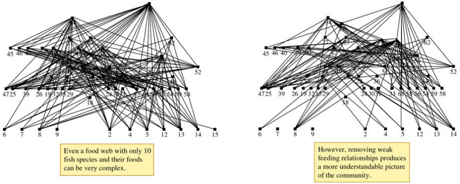
. . . and **in**direct effects are often more important than the direct ones

Trophic levels, is there a limit?

The number of trophic levels in networks is never higher than 5 (often between 2 and 4). There are several possible explanations:

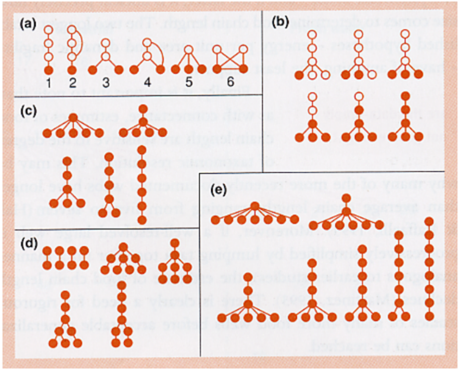
- Productivity (energy fluxes)
- Fragility (from models)
- Design and behavioural limitations of predators





The -dynamic- fragility of networks

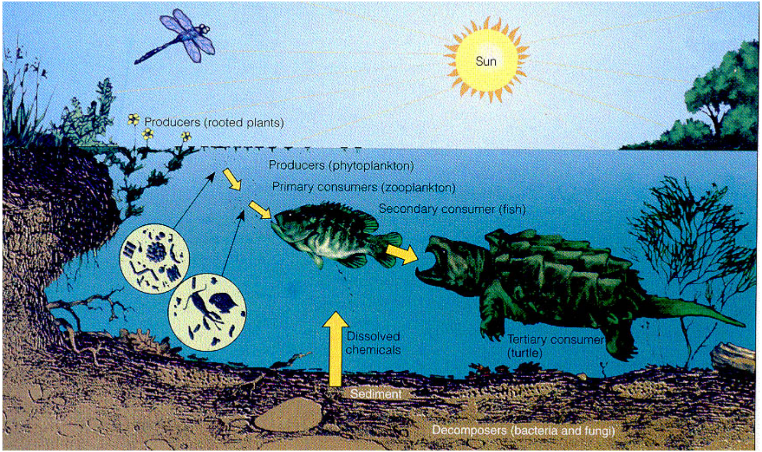
Longer strings are *less* stable (resilient). In frequently disturbed places, we expects the chains to be shorter.



The patterns, however, are not conclusive.

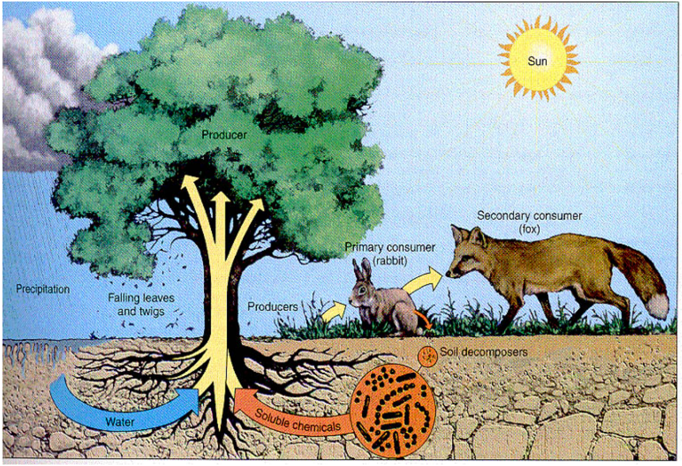
Trophic levels - energy fluxes

Energy fluxes in aquatic systems



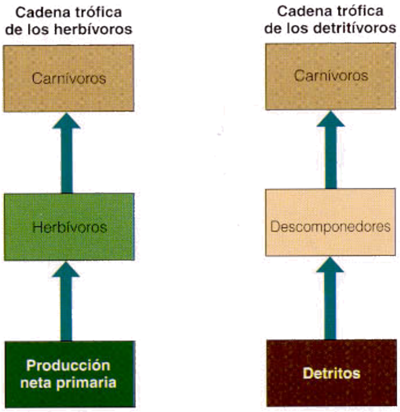
Trophic levels - energy fluxes

Energy fluxes in terrestrial systems



Trophic levels - energy fluxes

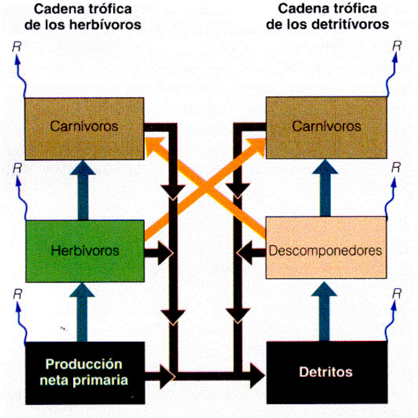
Phytophagous and detritivores paths



Trophic levels - energy fluxes

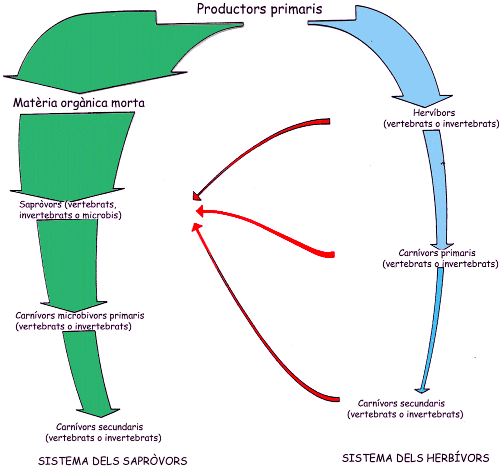
Phytophagous and detritivores paths

Most systems combine both paths!!



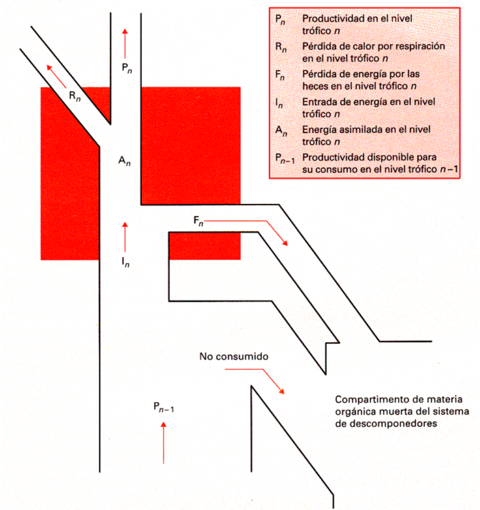
Trophic levels - energy fluxes

The importance of decomposers/detritivores path is always higher than that of phytophagous



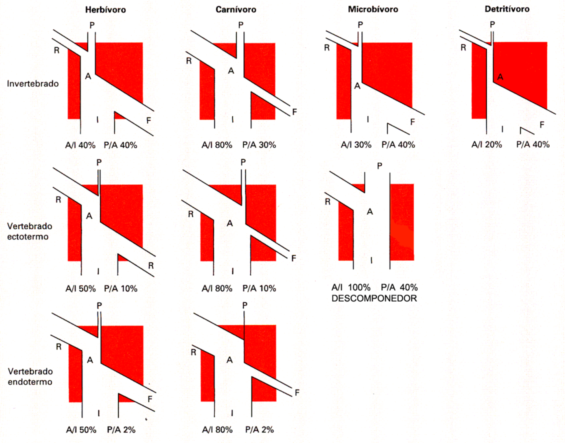
Energy fluxes

General scheme of energy flow through a trophic compartment



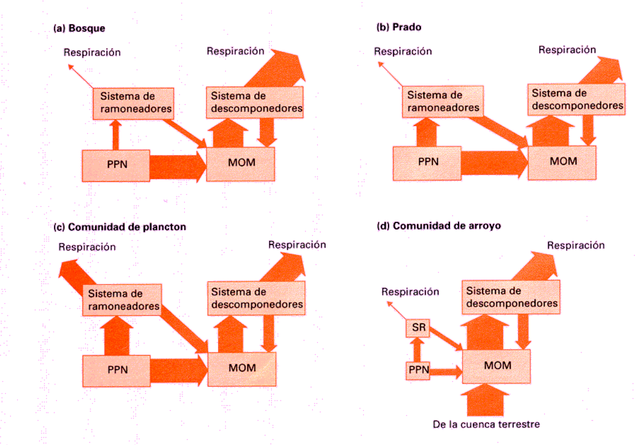
Energy fluxes

Scheme of energy flow in different compartments and groups of animals, indicating average values of assimilation (A/I) and production (P/A) rates



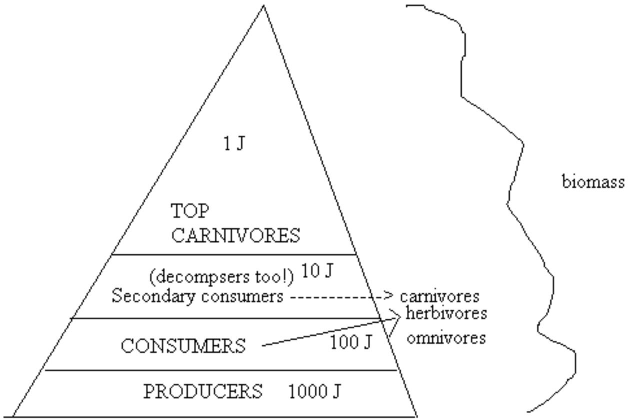
Energy fluxes

Energy flows vary by ecosystem



Energy fluxes

There is, therefore, a clear limitation



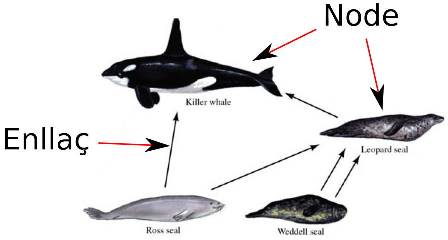
Attributes of trophic networks

A special language is needed to describe the components of trophic networks, also needed to describe the properties of the network as a whole. Networks have a series of *emerging properties*, understood as features that do not exist at lower levels of organization. Some of these descriptors and properties are:

- Node
- Link
- Trophic position
- Connectance
- Link density
- Food chain lenght
- Compartmentation
- Trophic level
- Omnivory
- Biomass relationships
- Generalism and vulnerability

Emerging attributes and properties

- **Node**
  Connection point between two links. Each node can be any group of sufficiently similar organisms
- **Link (L)**
  It is the trophic relationship. It can be direct or indirect.



Emerging attributes and properties

- **Trophic position** of a species
  It can be *basal*, *intermediate*, or *culminal* (upper predator). The basal species do not feed on any other species (on the net), the intermediate ones serve as food and feed on other species, and the culminating ones do not serve as food on any other species.
- **Connectance**
  How many of the possible links are present on the network. It can be calculated from direct (C_D) or indirect (C_I) links:

$$C_D = \frac{L}{S^2} \qquad (1)$$

where S is the number of species or nodes

Connectance

Table 1. Values of network properties of the 9 original food webs (by elevations and seasons; ALL: all year season, SS: spring–summer season, AW: autumn–winter). *S*: number of species; *L*: number of links; *L/S:* number of links per species; *C:* connectance; *GenSD:* standard deviation of generality; *VulSD:* standard deviation of vulnerability; *MFCL:* mean food chain length; *M:* modularity.

	Low elevation			Intermediate elevation			High elevation		
Season	ALL	SS	AW	ALL	SS	AW	ALL	SS	AW
S	223	214	125	202	199	125	82	82	51
L	875	851	506	799	791	506	179	179	119
L/S	3.924	3.977	4.048	3.955	3.975	4.048	2.183	2.183	2.333
C	0.018	0.019	0.032	0.02	0.02	0.032	0.027	0.027	0.046
VulSD	0.951	0.952	0.87	0.955	0.956	0.87	0.656	0.656	0.616
GenSD	3.224	3.124	2.736	3.067	3.03	2.736	2.845	2.845	2.43
MFCL	2.731	2.738	2.521	2.793	2.793	2.521	2.171	2.171	2.115
M	0.307	0.304	0.265	0.302	0.303	0.265	0.361	0.361	0.304

Emerging attributes and properties

- **Link length or density**
  Average number of trophic links per species.

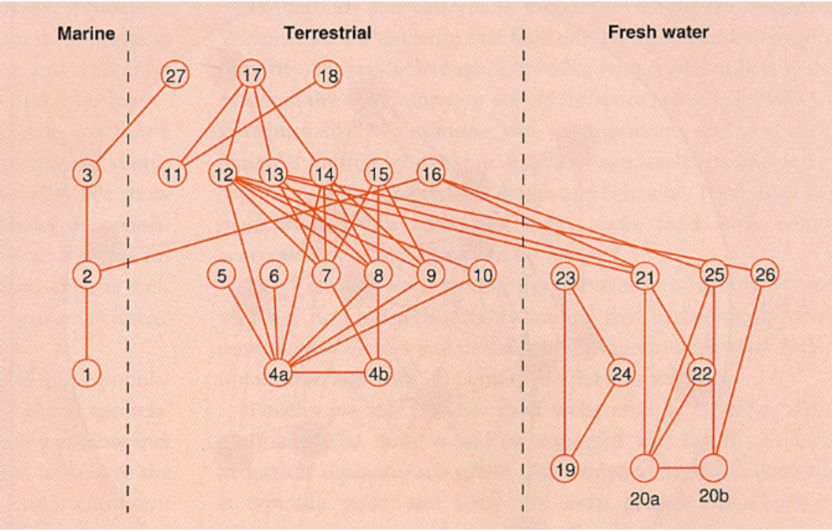
$$\text{Link length or density} = \frac{L}{S} \qquad (2)$$

- **Compartmentation**
  Extent to which a network contains relatively isolated subnets, more richly connected within them and with few connections between them.

$$C_1 = \frac{1}{s(s-1)} \sum_{i=1}^{s} \sum_{j=1}^{s} p_{ij} \qquad (3)$$

where species i is not equal to species j, s is the number of species, and p_{ij} is the number of species interacting with the two species, divided by the number of species that interact with either one or the other

Compartmentation

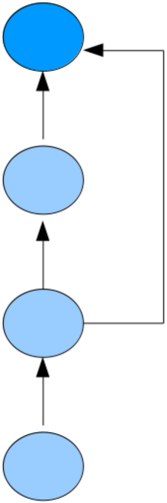


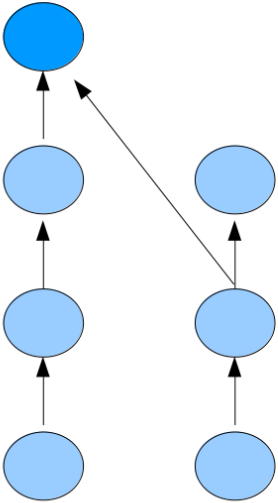
Emerging attributes and properties

- **Trophic level**
  Trophic level refers to the number of links + 1 between a basal species and the species we are interested in. For most non-basal species, the trophic level can vary depending on the path followed. To fix this is one must average the number of links + 1 of all possible paths from the basal species to the species of interest.
- **Omnivory**
  Omnivory occurs when species feed on more than one trophic level. The degree of omnivory of a network is calculated from the *closed omnivorous links*.

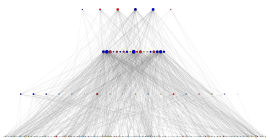
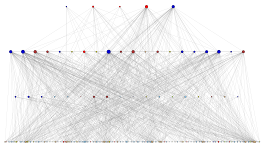
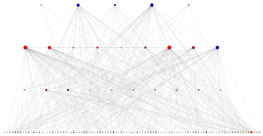
$$\text{Omnivory degree} = \frac{\text{Number of closed omnivory links}}{\text{Number of culminal species}} \tag{4}$$

Omnivory





Biomass relationships

A case study: the vertebrate community of the Pyrenees



Biomass relationships

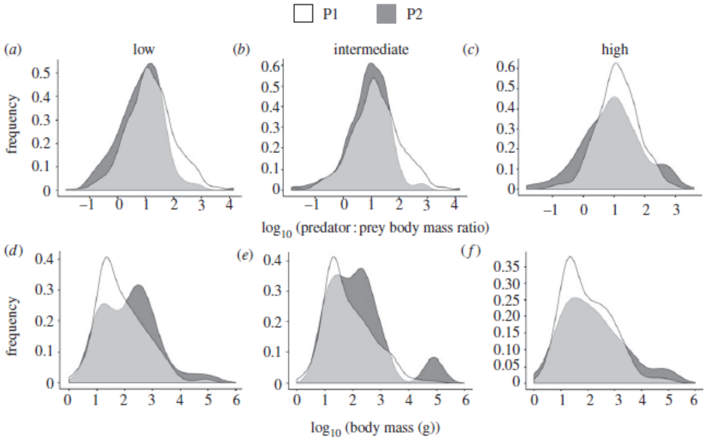
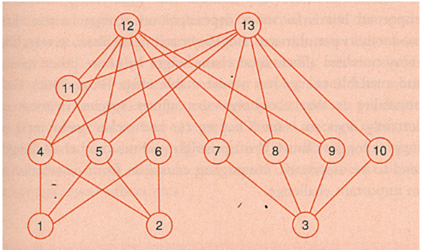


Figure 3. (*a–c*) Comparison of PPMR probability distribution of the food webs from P1 (1984–1990) and the food webs from P2 (1991–2001) at each elevation range; (*d–f*) Comparison of body mass probability distribution of new prey incomers in the period P2 (1991–2001) and native prey species already present in P1 (1984–1990) at each elevation range.

Emerging attributes and properties

- **Trophic chain length**
  Number of trophic links in the pathways from all basal species to all higher predators



Maximal food chains

1 4 11 12	2 4 11 12	3 7 12
1 4 11 13	2 4 11 13	3 7 13
1 4 12	2 4 12	3 8 12
1 4 13	2 4 13	3 8 13
1 5 11 12	2 5 11 12	3 9 12
1 5 11 13	2 5 11 13	3 9 13
1 5 12	2 5 12	3 10 13
1 5 13	2 5 13	
1 6 12	2 6 12	

The stability of food webs

Complexity and Stability

Imagine that we have...

- ... N espècies
- ... β_{ij} = effect of species j on the increment rate of species i
- ... we build a network of N species, so:
  - β_{ii}, β_{jj}...are all = 1
  - and the rest of β are all random, including some 0s

To escribe the network, we have:

- S = number of species
- C = connectance, with values of $\beta <> 0$
- β = average of all values of $\beta <> 0$, without sign

The stability of food webs

Complexity and stability

May (1972) found that the network was only stable when:

$$\beta(SC)^{1/2} < 1 \tag{5}$$

So, if:

- the number of species (S) increases, and/or
- connectance (C) increases, and/or
- interaction strength (β) increase

...the community becomes more *un*stable

What does the model say?

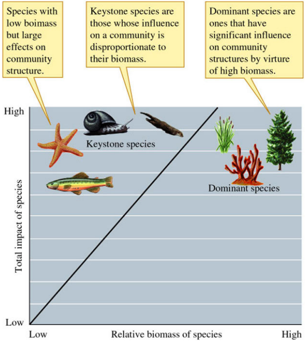
The higher the complexity, the lower the stability

but there are, **a lot of** exceptions

The stability of food webs

Keystone species

Not all species are equally important. We differentiate between *keystone species* and *strong interactors*



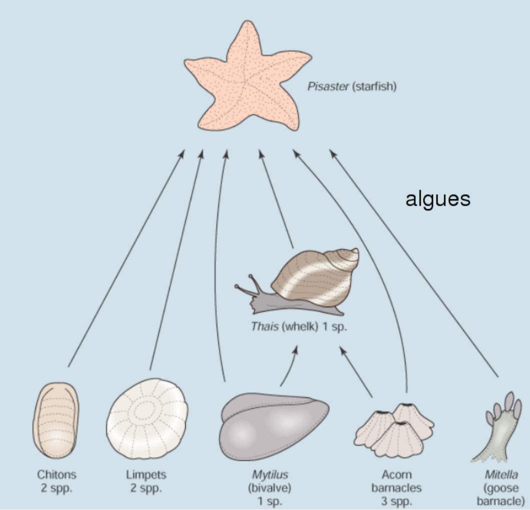
The stability of food webs

Keystone species

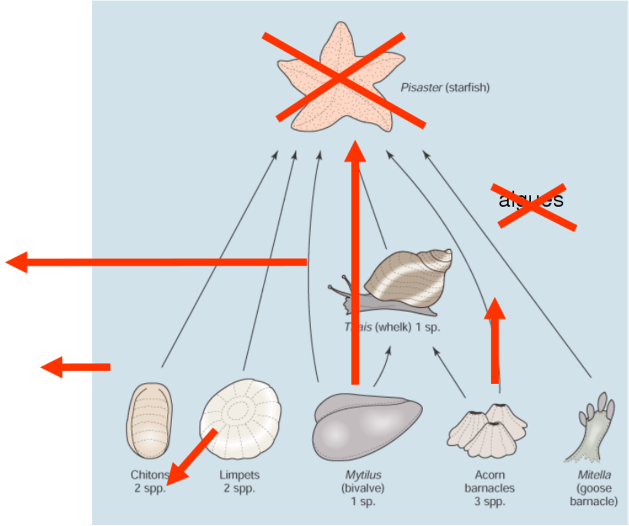
Species can be keystone species because of:

- their trophic role
- other reasons

The stability of food webs



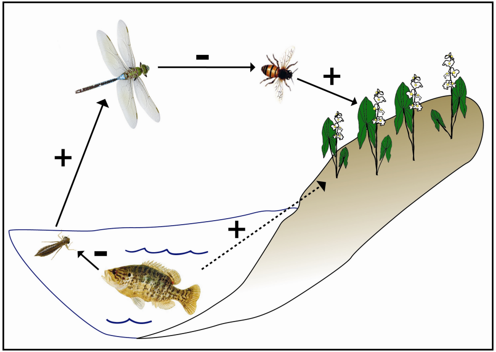
The stability of food webs



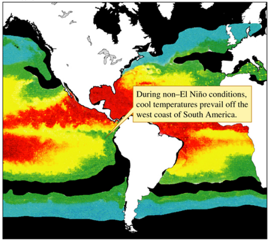
15 spp → 8 spp

Trophic cascades

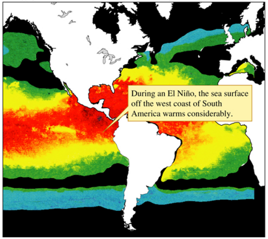
A **trophic cascades** occurs when a predator reduces the abundance of its prey and this effect ”moves” along the cascade to the lower trophic level, so that the resources of the prey increase their abundance.



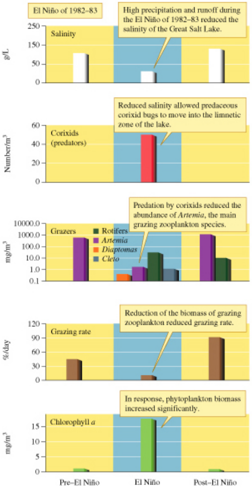
Trophic cascades



(b)



(a)

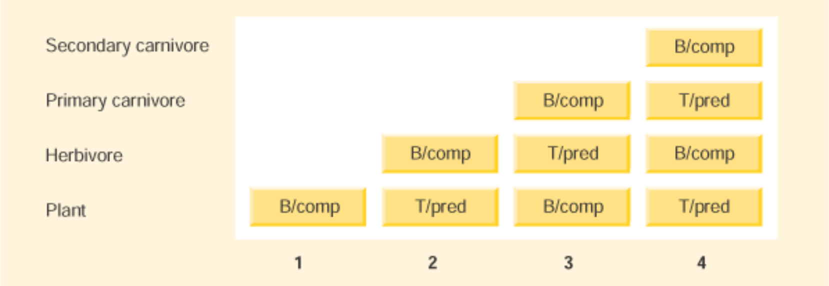


Top-down or bottom-up control?

Control by resources recursos (“bottom-up”)

vs.

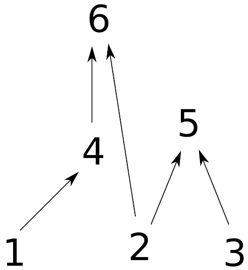
Control by predators (“top-down”)



Matrix models for food webs

	1	2	3
1	0	1	0
2	0	0	1
3	0	0	0

Matrix models for food webs



	1	2	3	4	5	6
1	0	0	0	1	0	0
2	0	0	0	0	1	1
3	0	0	0	0	1	0
4	0	0	0	0	0	1
5	0	0	0	0	0	0
6	0	0	0	0	0	0

Climate change effects in the Pyrenees

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B

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Phil. Trans. R. Soc. B (2012) **367**, 3050–3057
doi:10.1098/rstb.2012.0239

Research

Climate change impacts on body size and food web structure on mountain ecosystems

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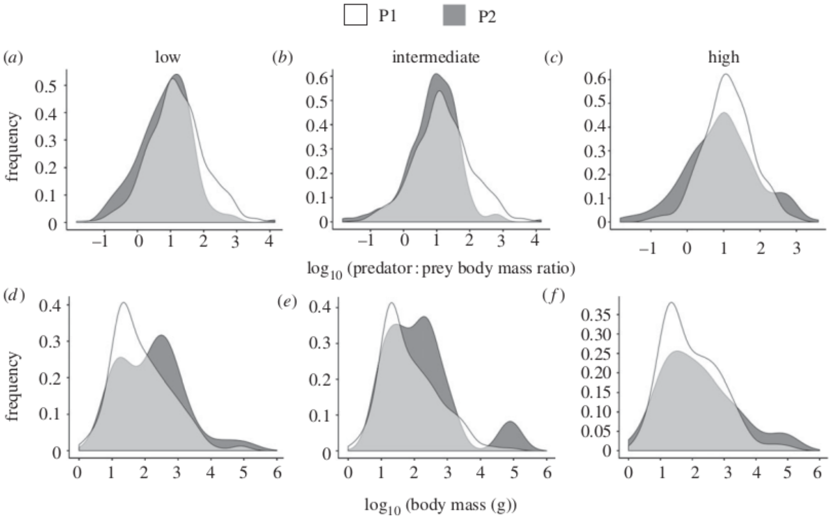
The current distribution of climatic conditions will be rearranged on the globe. To survive, species will have to keep pace with climates as they move. Mountains are among the most affected regions owing to both climate and land-use change. Here, we explore the effects of climate change in the vertebrate food web of the Pyrenees. We investigate elevation range expansions between two time-periods illustrative of warming conditions, to assess: (i) the taxonomic composition of range expanders; (ii) changes in food web properties such as the distribution of links per species and community size-struc-

Climate change effects in the Pyrenees



Invasive species in the Pyrenees

Oikos 123: 721–728, 2014
doi: 10.1111/j.1600-0706.2013.00859.x

Subject Editor: Ulrich Brose. Accepted 15 November 2013

Invasions cause biodiversity loss and community simplification in vertebrate food webs

Núria Galiana, Miguel Lurgi, José M. Montoya and Bernat C. López

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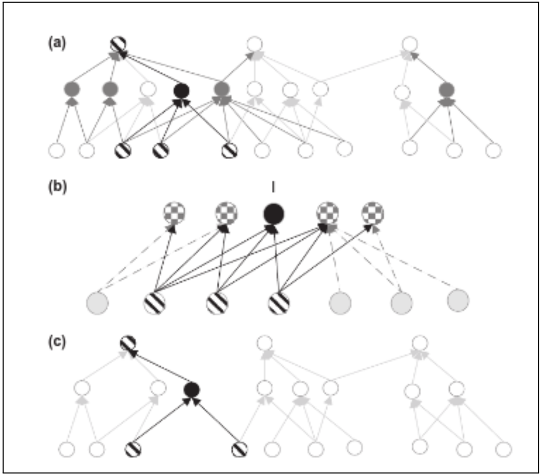
Invasive species in the Pyrenees



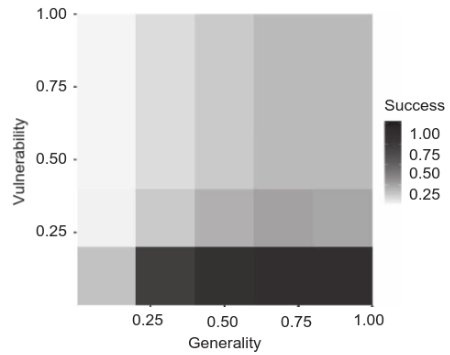
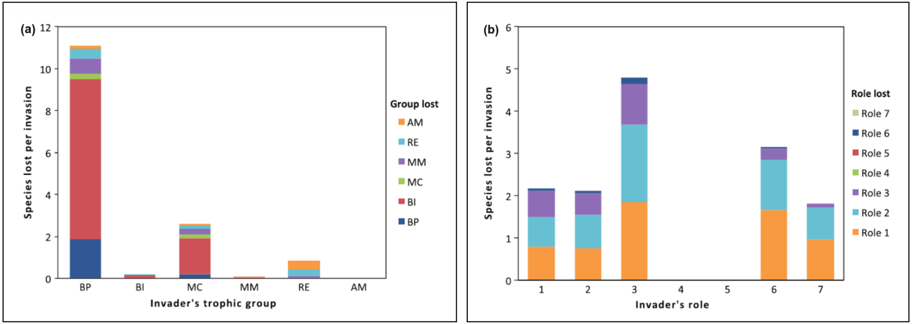


Figure 2. Heatmap for invasion success rate of the possible combinations between the fraction of vulnerability and the fraction of generality of the invader species. Higher success rates occur at low values of vulnerability and high values of generality.

Invasive species in the Pyrenees



Arctic wildlife populations

Advance View
https://doi.org/10.3354/cr01638

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May 27, 2021

Contribution to CR Special 'Sustainable management of renewable resources in a changing environment: an integrated approach across terrestrial, freshwater and marine ecosystems'

OPINION PIECE

Food web approach for managing Arctic wildlife populations in an era of rapid environmental change

Jarad Pope Mellard[1,*,#], John-André Henden[1,#], Åshild Ønvik Pedersen[2], Filippo Marolla[1], Sandra Hamel[3], Nigel Gilles Yoccoz[1], Rolf Anker Ims[1]

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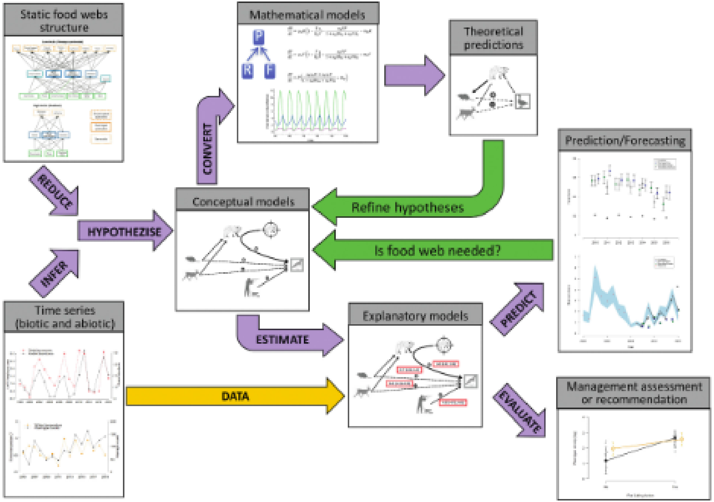
Arctic wildlife populations



Ecological networks for the management of biodiversity in mountain areas

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CREAF - NEMOR

October 28th, 2021