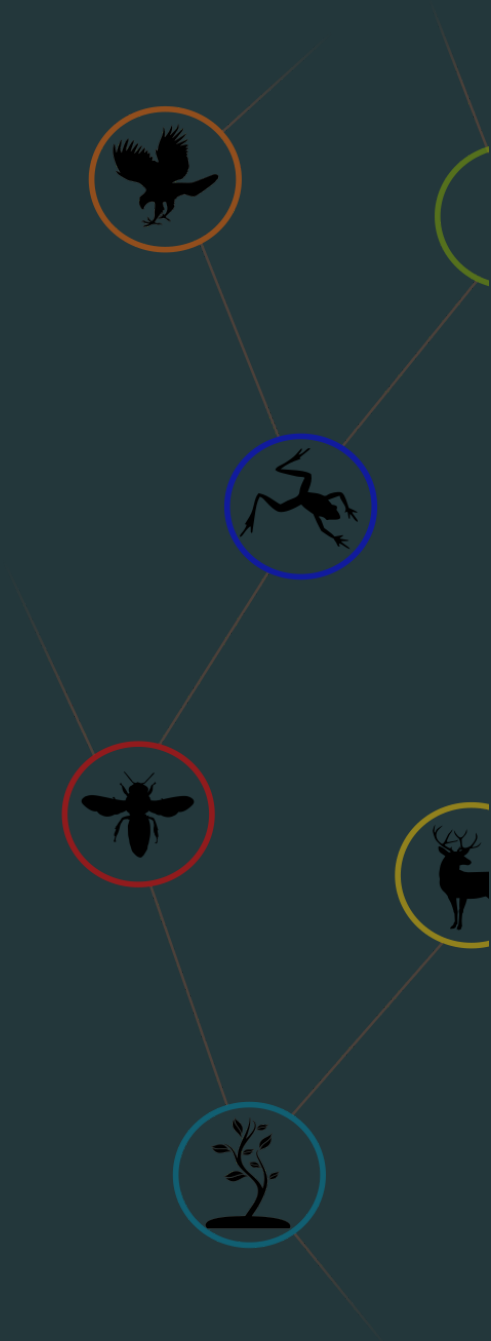
Laboratoire d'écologie intégrative | Integrative Ecology Lab [IE]

Centre for Biodiversity Theory and Modelling

Effects of temperature on species and their trophic interactions

A cross-scales perspective

Azenor Bideault, PhD candidate
Dominique Gravel and Michel Loreau



Azenor/talk_seminar2UdeS

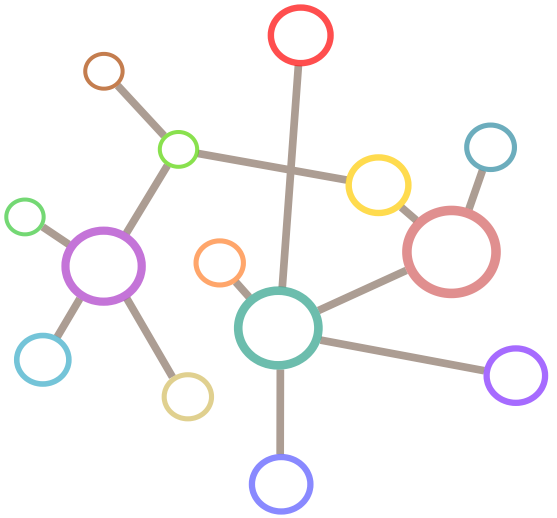
@Azenor_Bideault

How do communities differ from one pole to another ?

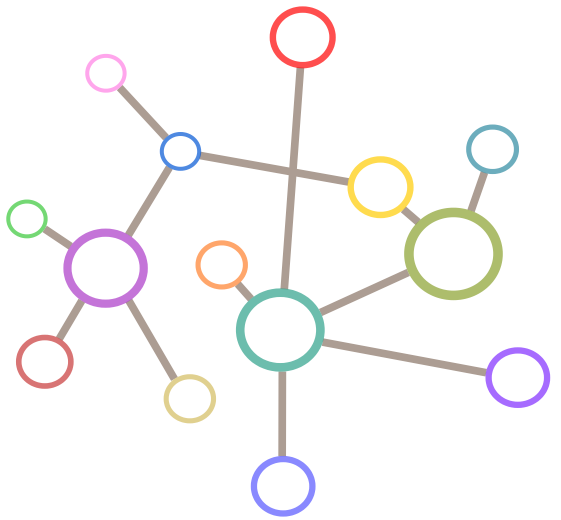
Spot the differences!

- Species identity
- Species richness
- Interactions
- ...

Communities vary across space and time

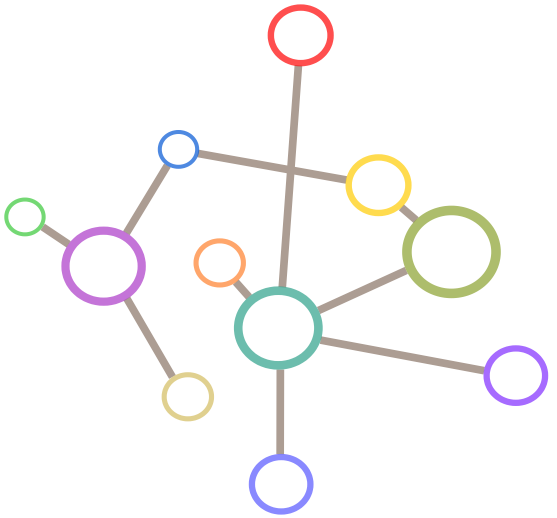


Communities vary across space and time



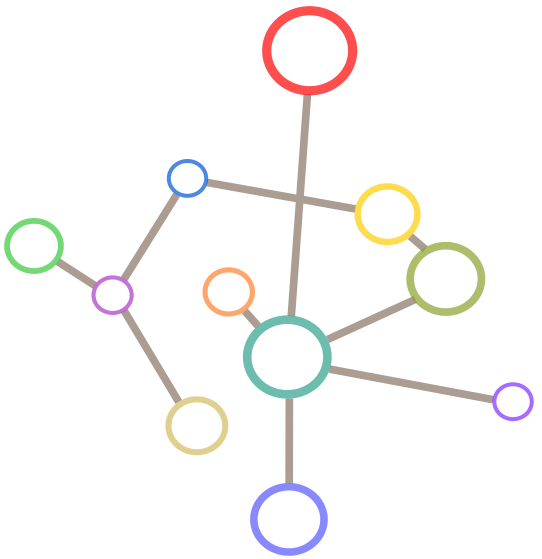
- Identity of species

Communities vary across space and time



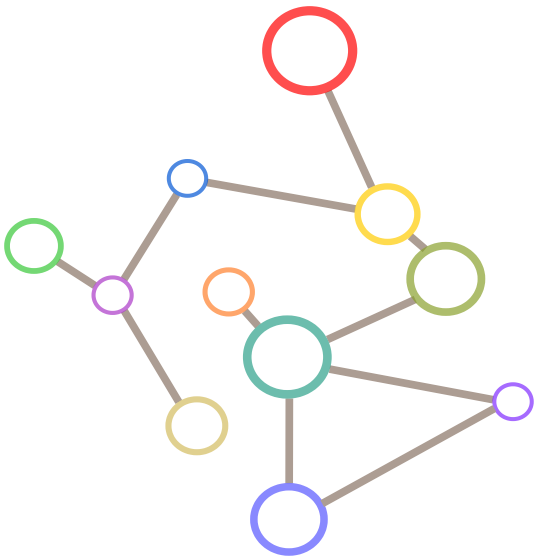
- Identity of species
- Number of species

Communities vary across space and time



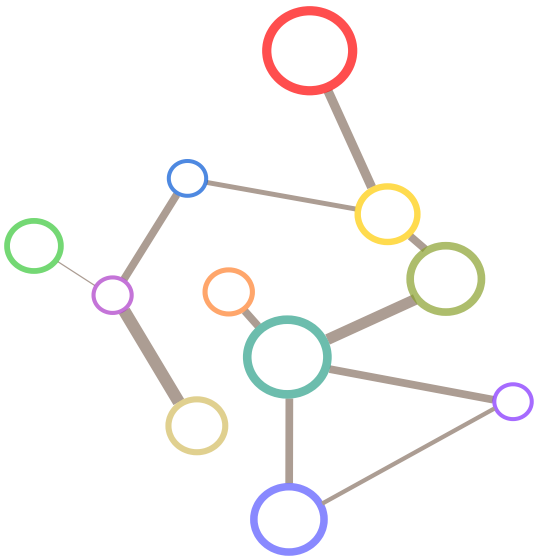
- Identity of species
- Number of species
- Biomass

Communities vary across space and time



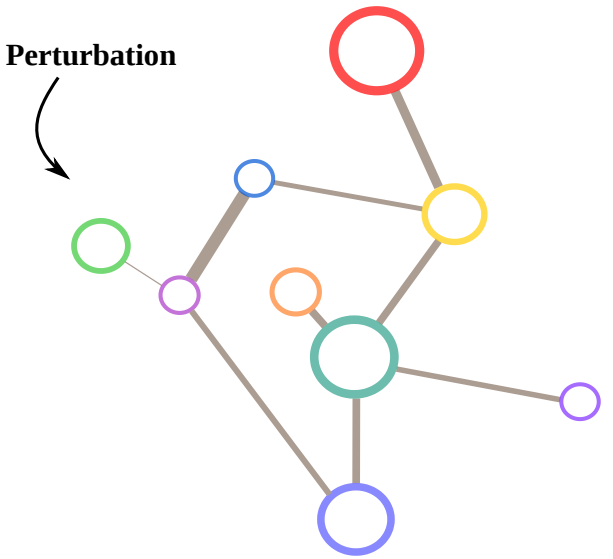
- Identity of species
- Number of species
- Biomass
- Interactions

Communities vary across space and time



- Identity of species
- Number of species
- Biomass
- Interactions
- Interaction strength

Communities vary across space and time



- Identity of species
- Number of species
- Biomass
- Interactions
- Interaction strength
- Stability

How and why ?

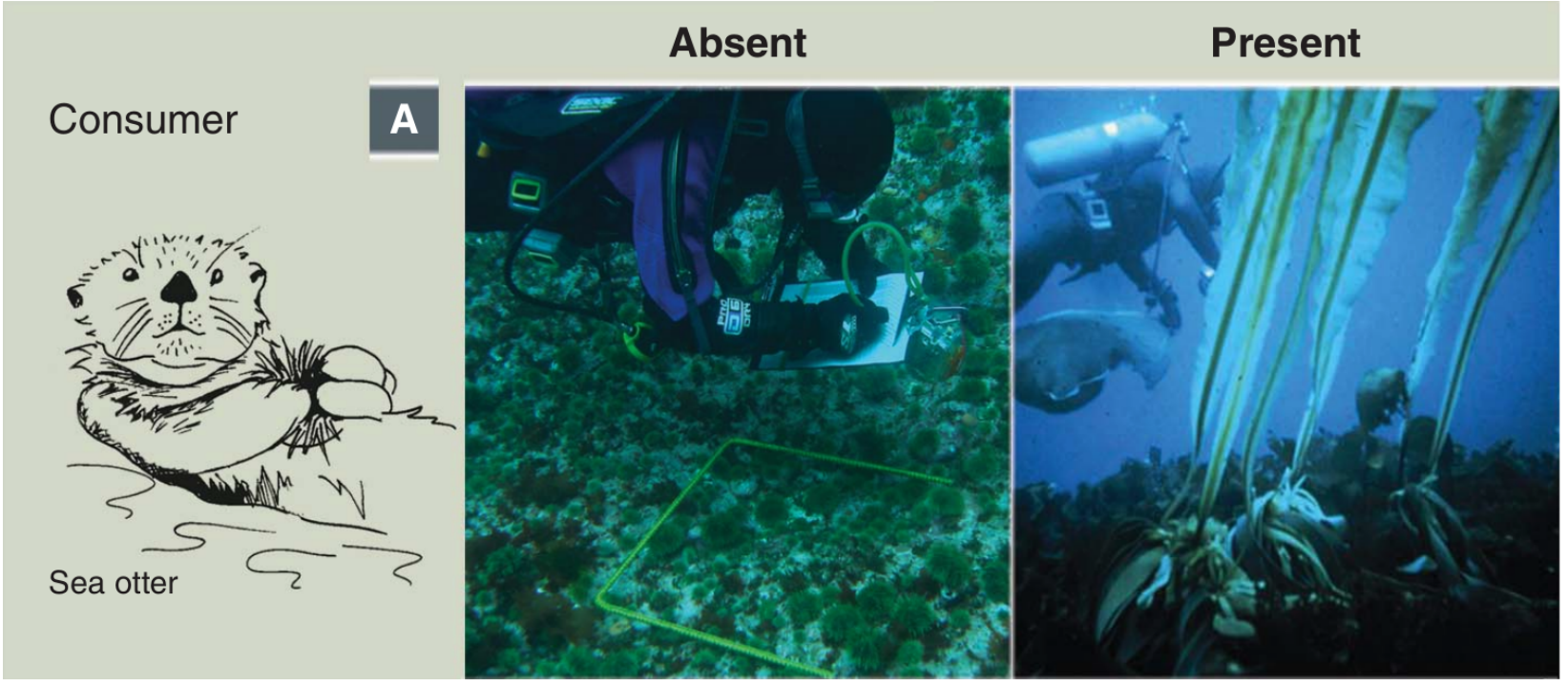
Food webs vary across space and time

Trophic interactions

- Identity of species
- Number of species
- Biomass
- Interactions
- Interaction strength
- Stability

Trophic interactions

Are at the core of ecological systems



Trophic cascade : Sea otters indirectly enhance kelp abundance by consuming herbivorous sea urchins

Estes et al. [2011] Science

What determines food webs structure and dynamics ?

Back to the x differences

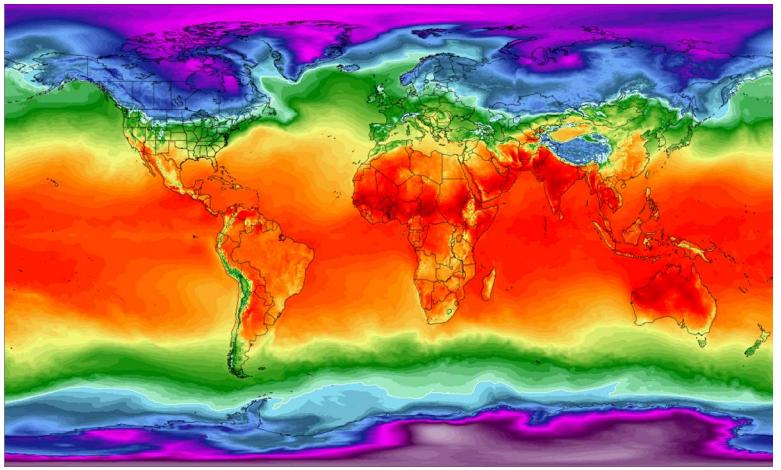
What else is different ?

Environmental drivers :

- Temperature
- Precipitation

Temperature

A major environmental gradient

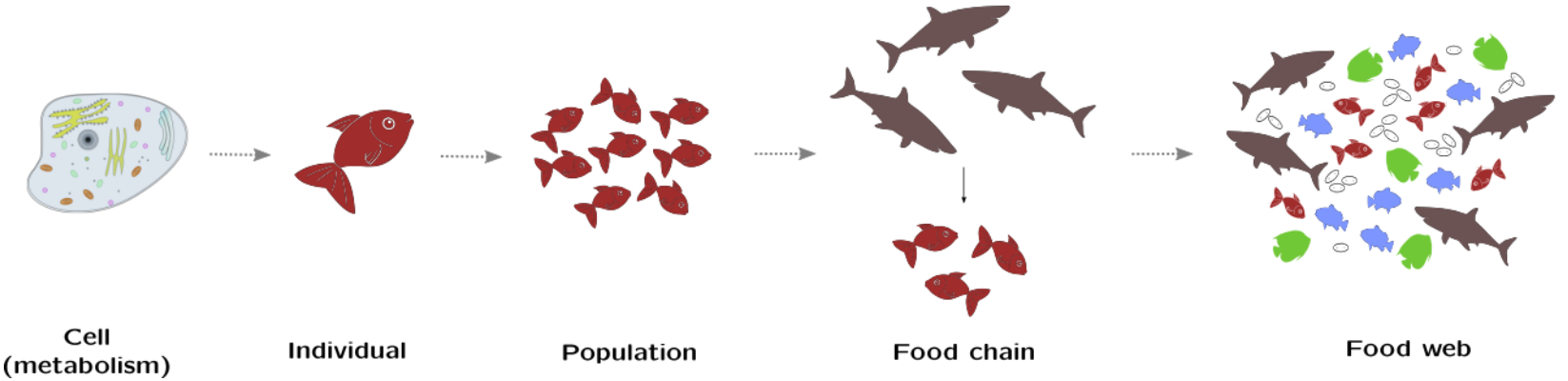


Global warming

What are the effects of temperature ?

Effects of temperature

From the individual to the community



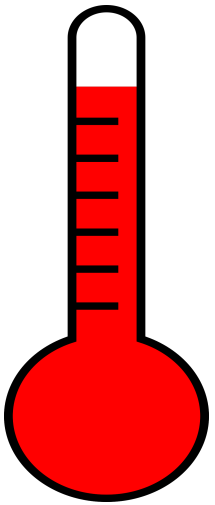
Effects of temperature

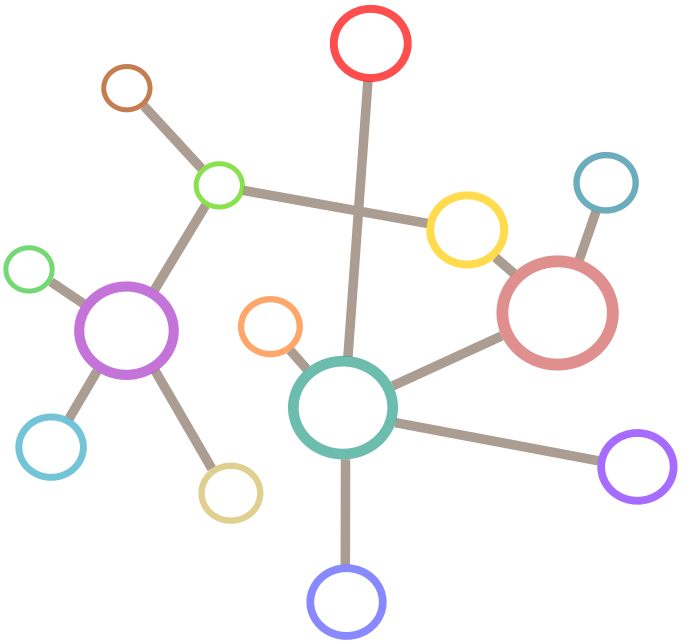
Effects of temperature

Effects of temperature

Effects of temperature

On food webs





- Structure
- Dynamics
- Stability

Lack of consensus

- Hard to disentangle the various effects of temperature
- How do they propagate ?
- Effect of the temperature gradient $\neq$ effect of warming?

Most studies explore :

- One particular ecological system
- One process at a time

with different

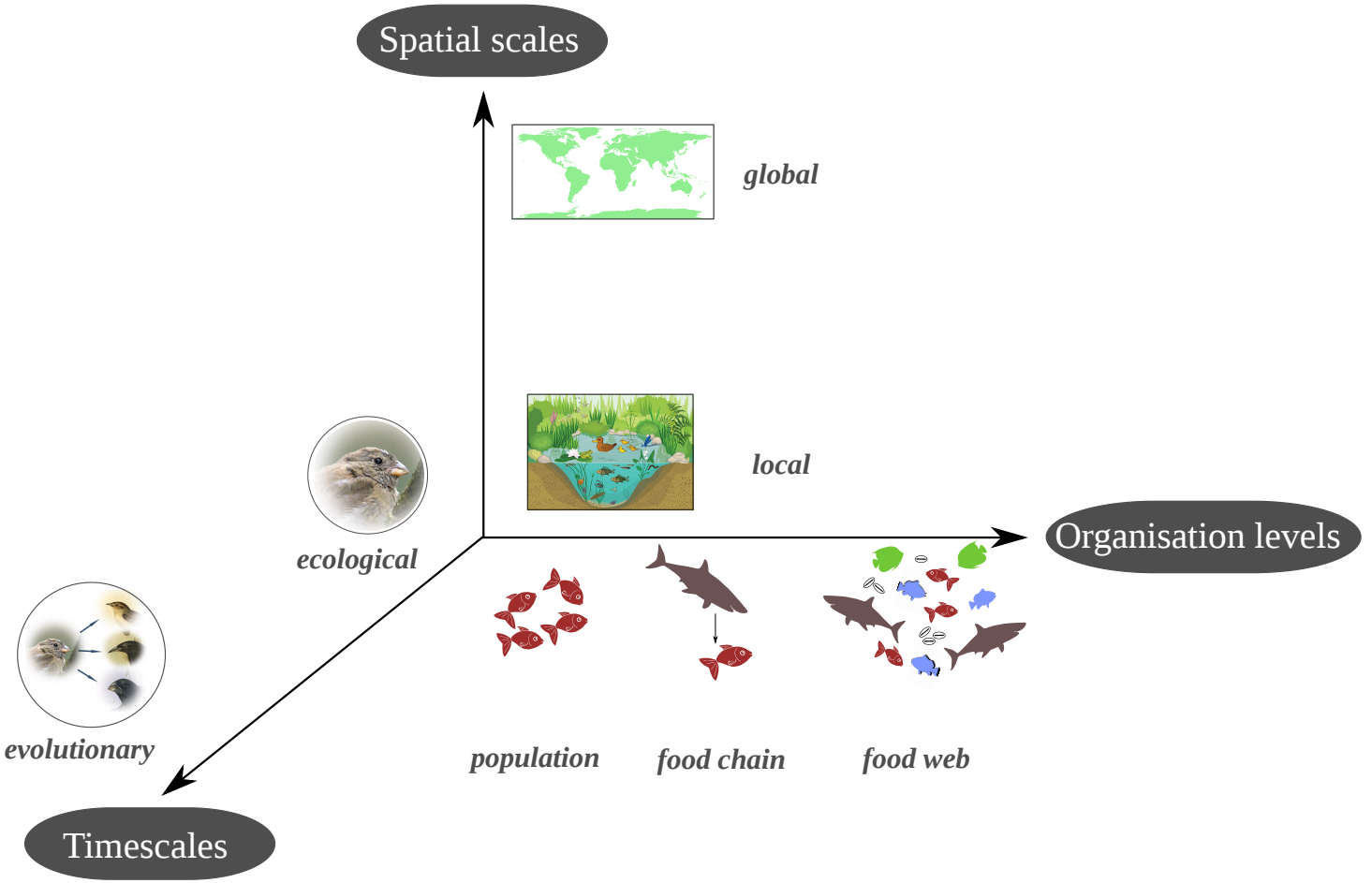
- experimental design
- study system
- theoretical framework
- model assumptions

No synthetic understanding yet

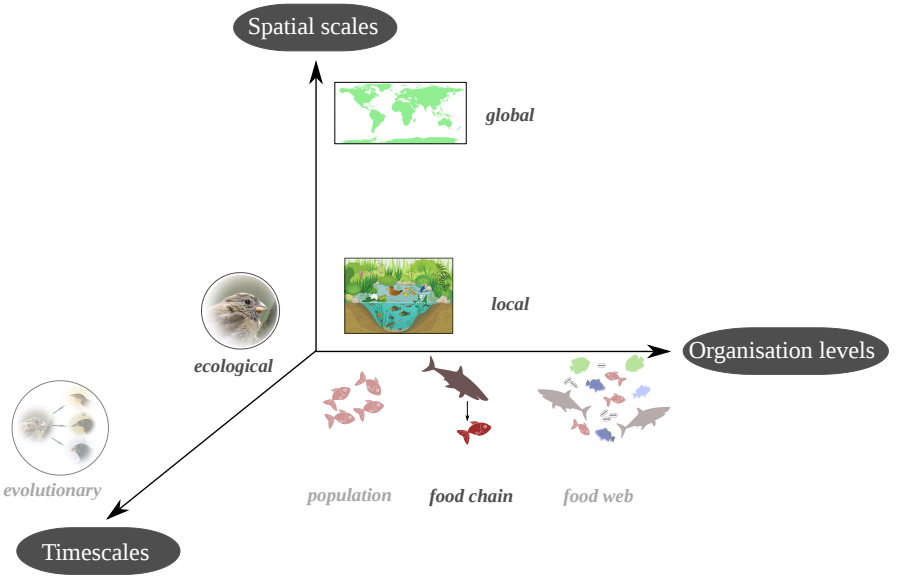
How does temperature affect species and their interactions ?

A cross-scales perspective

A cross-scales perspective

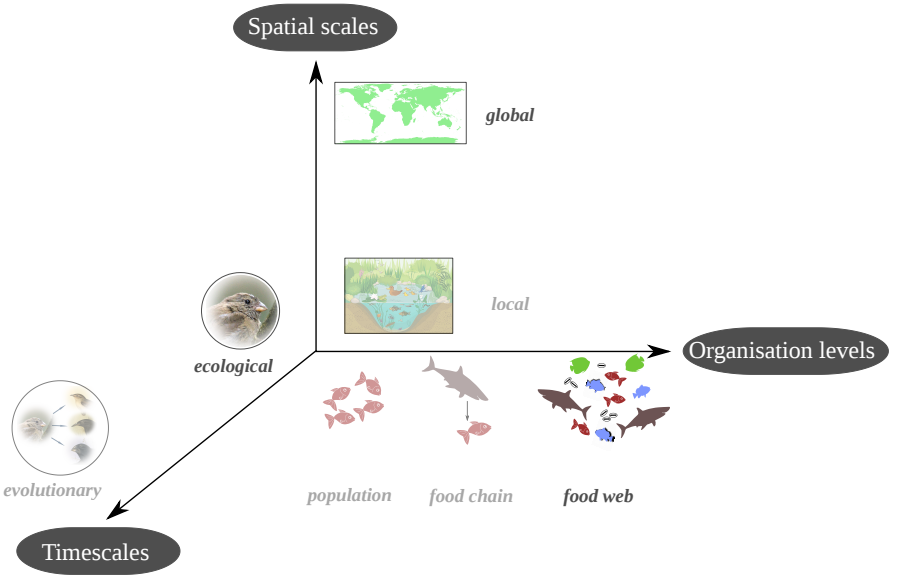


A cross-scale perspective



- Thermal mismatches in biological rates determine trophic control and biomass distribution under warming

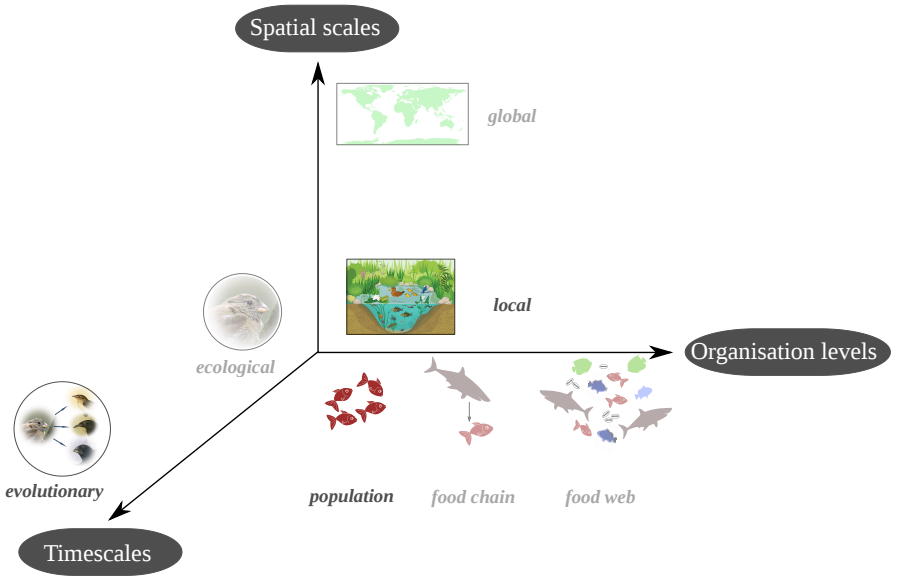
A cross-scale perspective



- Thermal mismatches in biological rates determine trophic control and biomass distribution under warming
- Effects of temperature on fish food webs at the global scale

Using theory

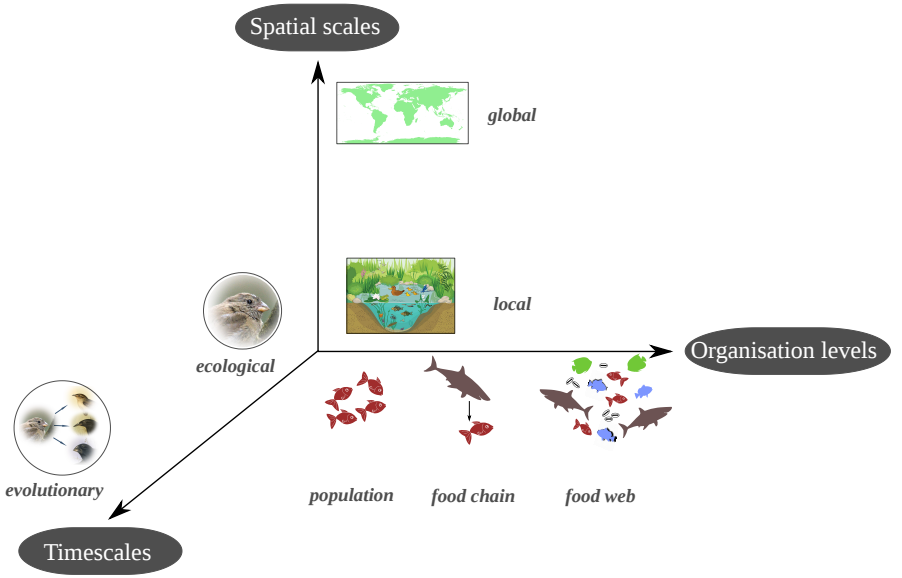
A cross-scale perspective



- Thermal mismatches in biological rates determine trophic control and biomass distribution under warming
- Effects of temperature on fish food webs at the global scale
- Short-term thermal adaptation of growth rates in wild bacteria strains

Using theory and experiments

A cross-scale perspective



- Thermal mismatches in biological rates determine trophic control and biomass distribution under warming
- Effects of temperature on fish food webs at the global scale
- Short-term thermal adaptation of growth rates in wild bacteria strains

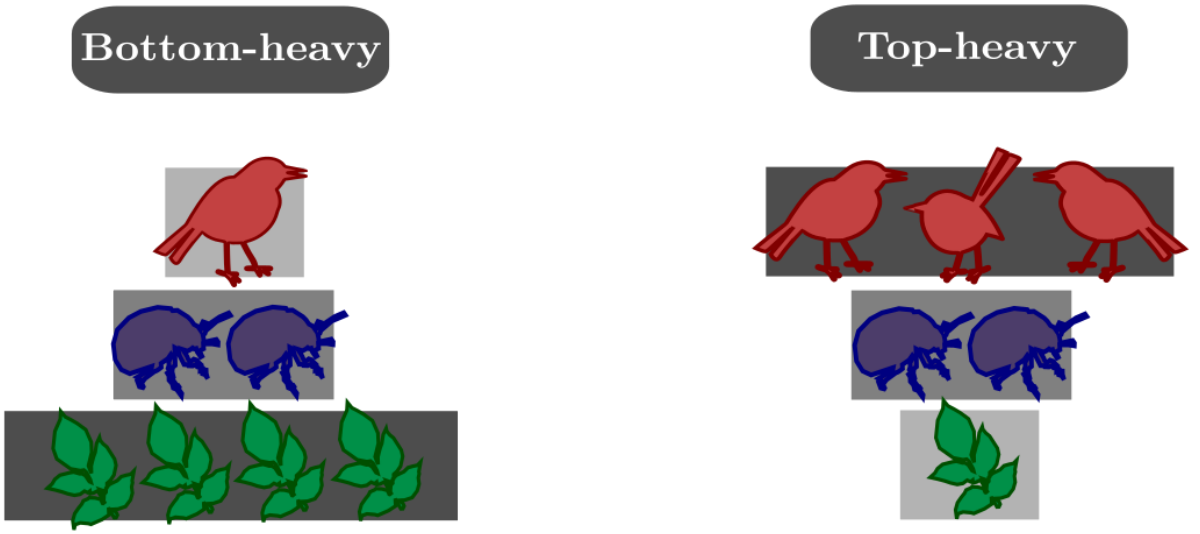
Theoretical approaches

Thermal mismatches in biological rates determine trophic control and biomass distribution under warming

A cross-ecosystem comparison

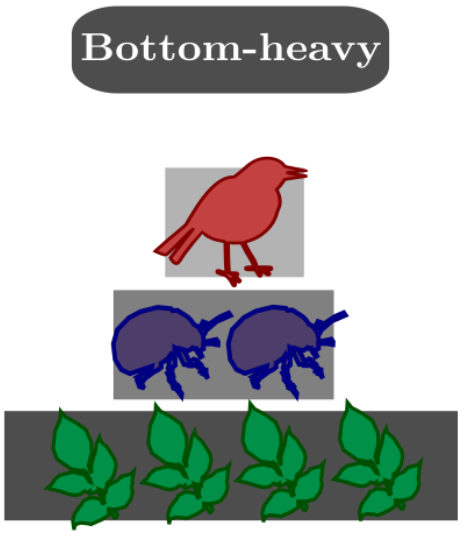
Food chain structural properties

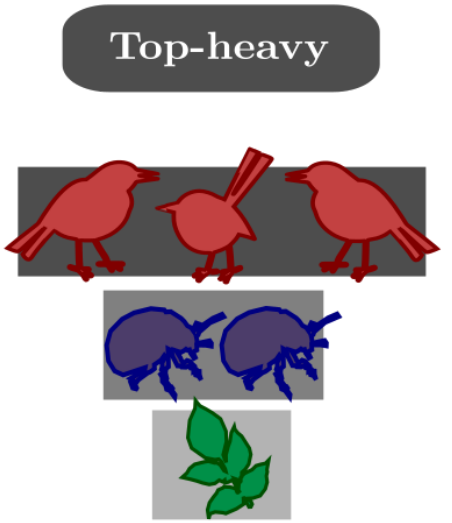
Biomass distribution



Food chain structural properties

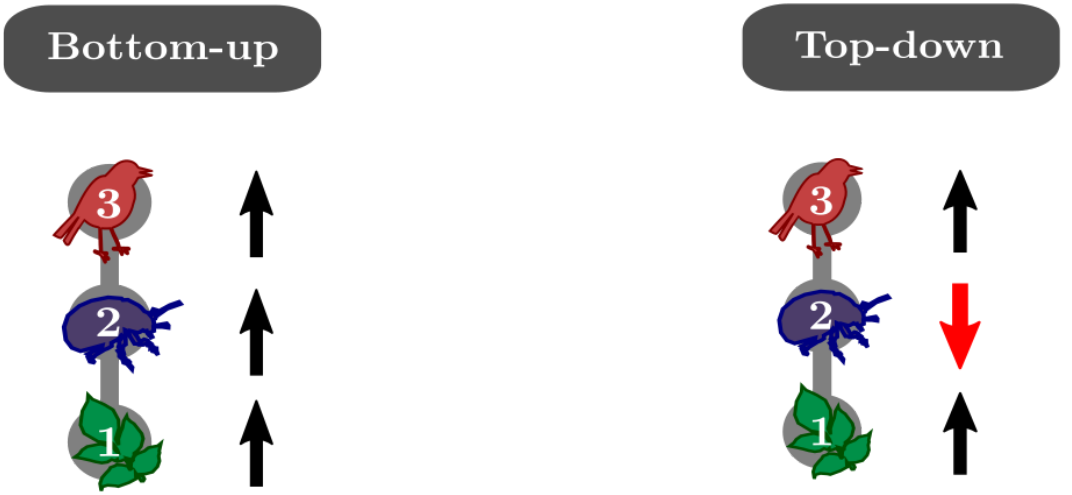
Biomass distribution





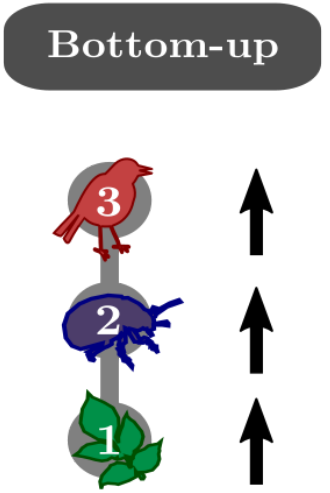
Food chain dynamical features

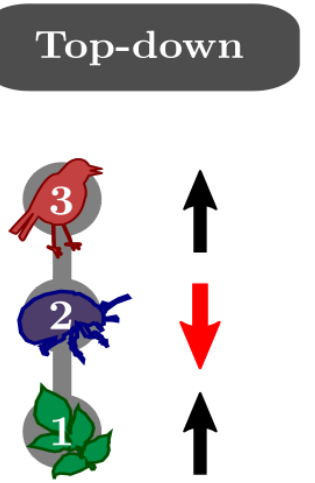
Trophic control



Food chain dynamical features

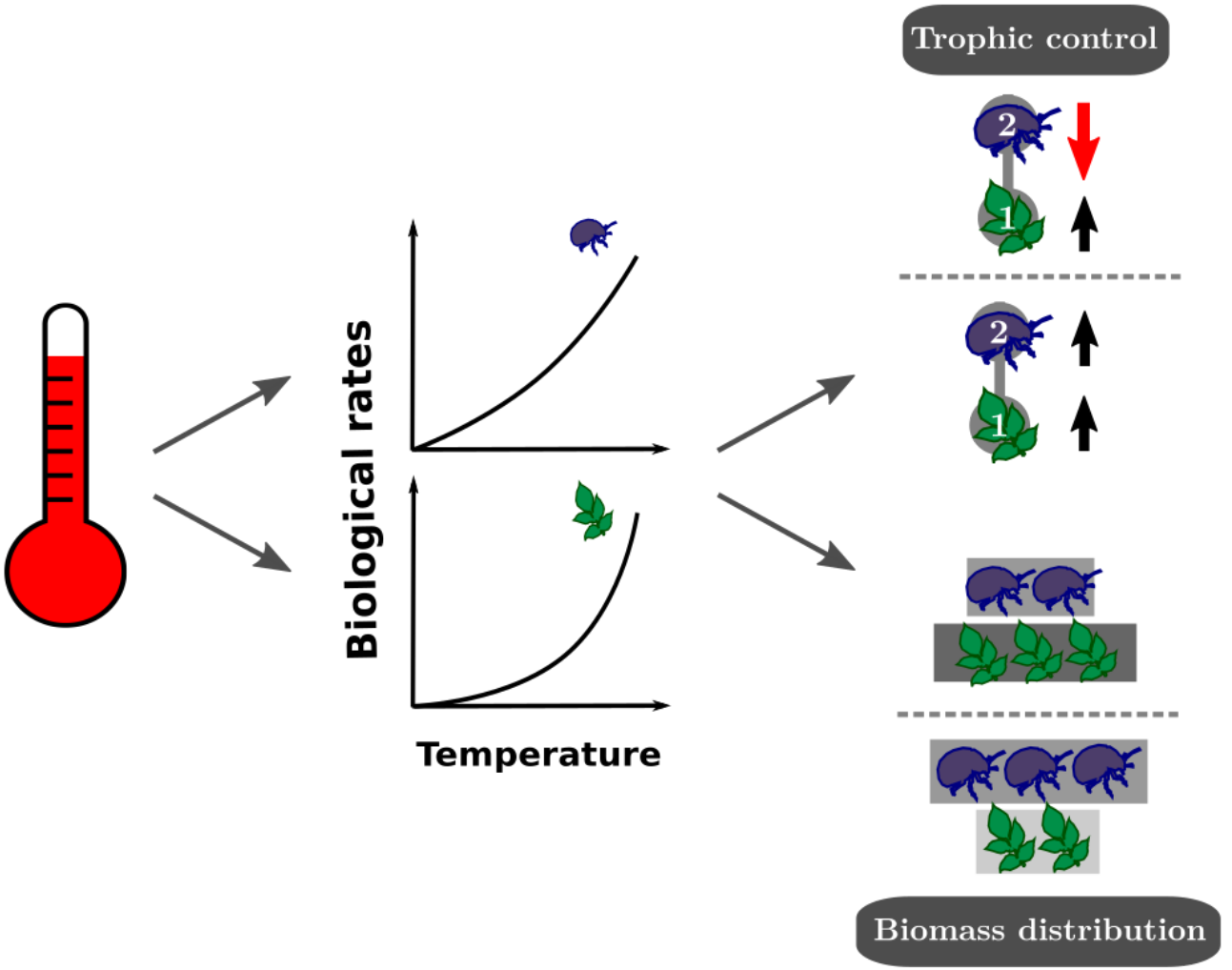
Trophic control





Temperature effects

On food chain structure and dynamics



Method

Method

How to (try to) answer big questions ?

One approach : using **small** models !

Theoretical approach

- simulate consumer-resource interactions
- general overview (go beyond system particularities)
- toward a synthetic understanding

Combined to data

- for various systems

Theoretical framework

Dynamics of consumer-resource systems

$$\frac{dB_i}{dt} = \mathbf{production} - \mathbf{predation\ losses} - \mathbf{internal\ losses}$$

$$\frac{dB_i}{dt} = g_i B_i + \epsilon A_{ji} B_i B_j - A_{ik} B_i B_k - q_i B_i - D_i B_i^2$$

- B_i biomass of species *i*
- g_i growth rate
- ϵ conversion efficiency
- A_{ji} attack rate
- q_i metabolic rate
- D_i self-regulation

Explore some properties of the system

A quick note on self-regulation

An important but not well known parameter

Intraspecific density dependent regulation
A population's growth rate is negatively affected by its own population density

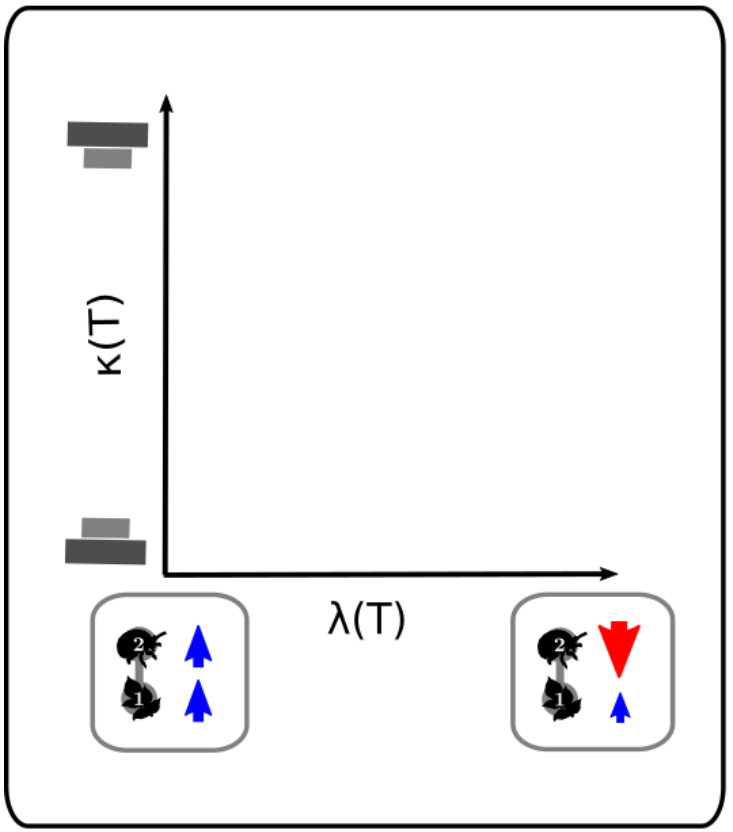
Examples :

- territoriality
- infanticide
- intra-guild predation
- competition for light

Important to match stability levels observed in nature

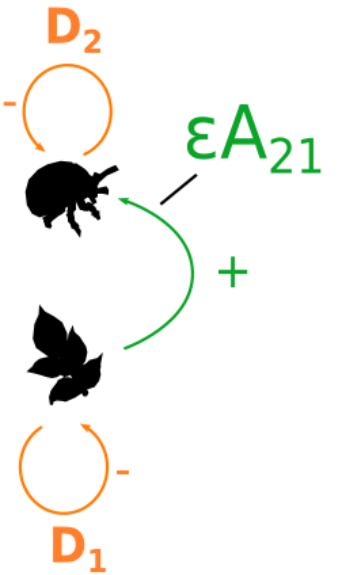
Theoretical framework

Synthetic parameters describing food chain properties



$$\kappa = \frac{\varepsilon D_1}{D_2}$$

$$\lambda = \frac{\varepsilon A_{21}{}^2}{D_1 D_2}$$

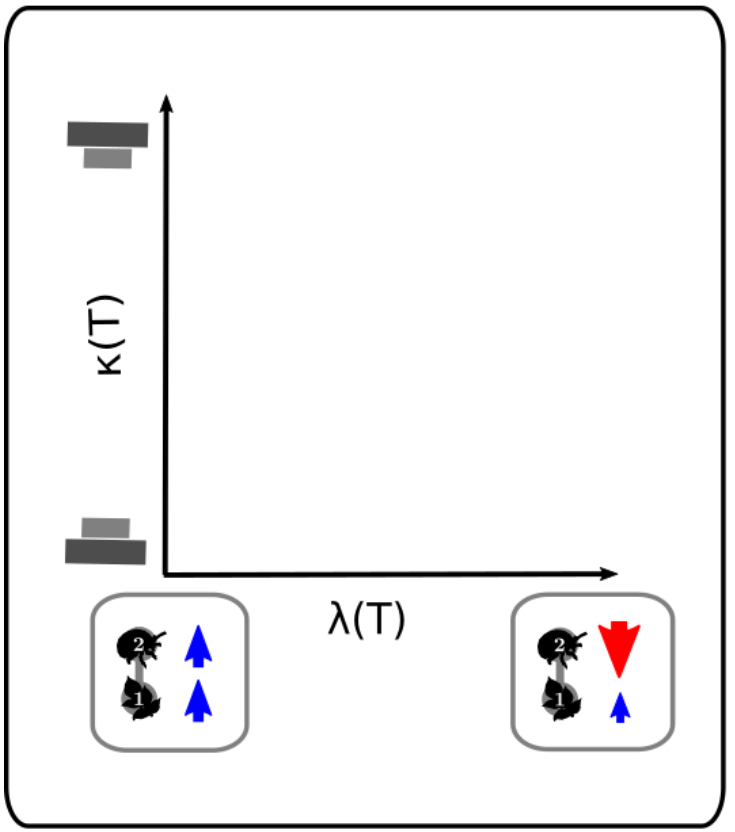


D = self-regulation
ε = biomass conversion efficiency
A = attack rate

κ denotes how much biomass is gained by consumers per unit biomass lost by resources

Theoretical framework

Synthetic parameters describing food chain properties



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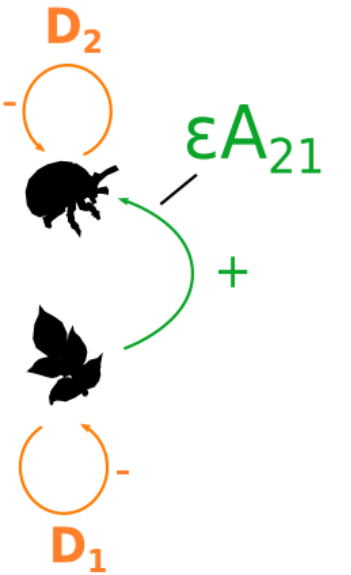
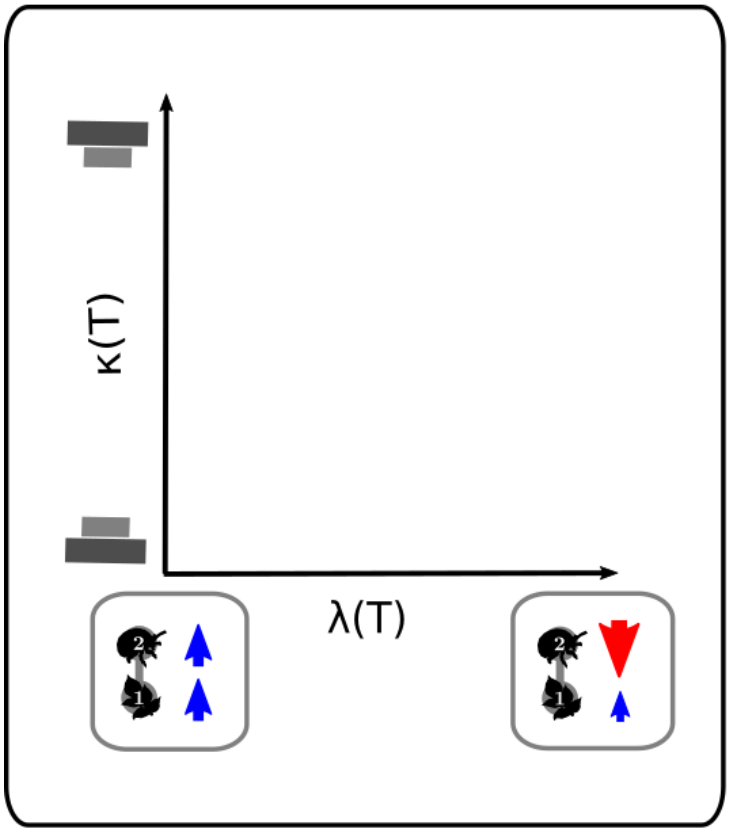


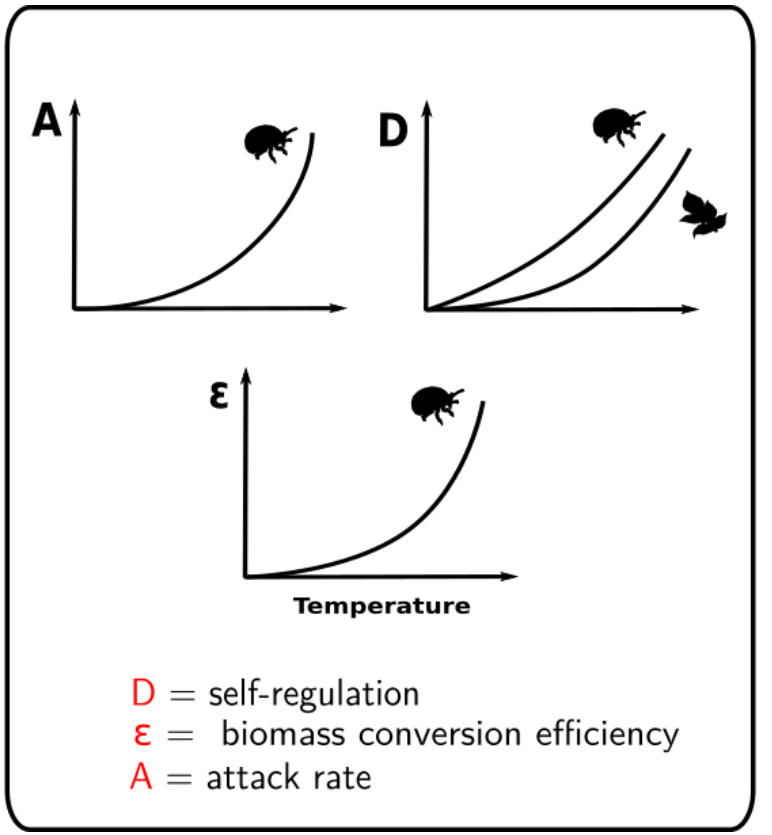
D = self-regulation
ε = biomass conversion efficiency
A = attack rate

λ describes the feedback of a trophic level on itself through its predators

Theoretical framework

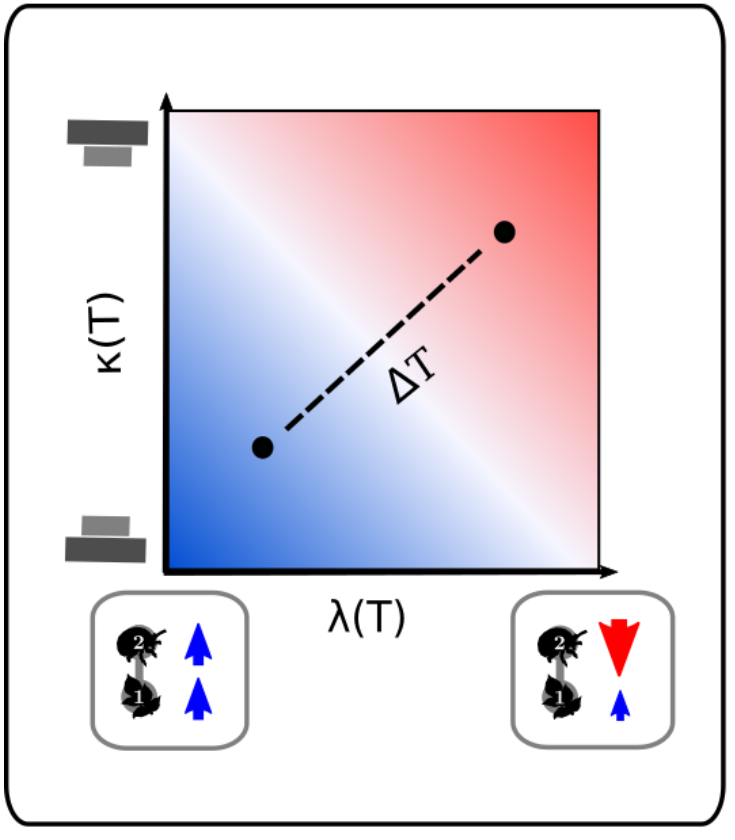
Temperature dependence

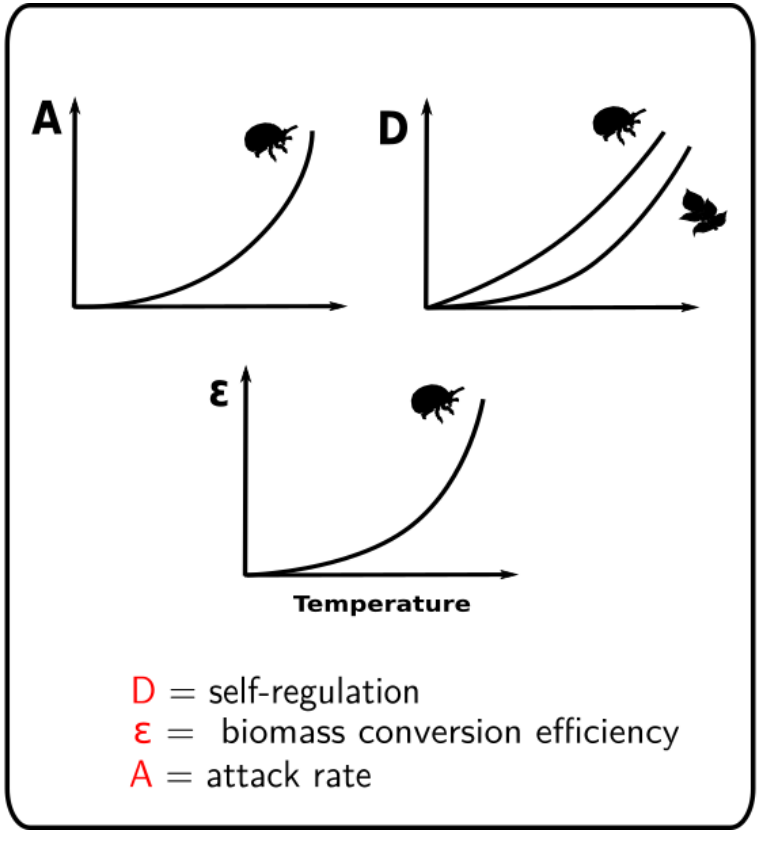




Theoretical framework

Temperature dependence

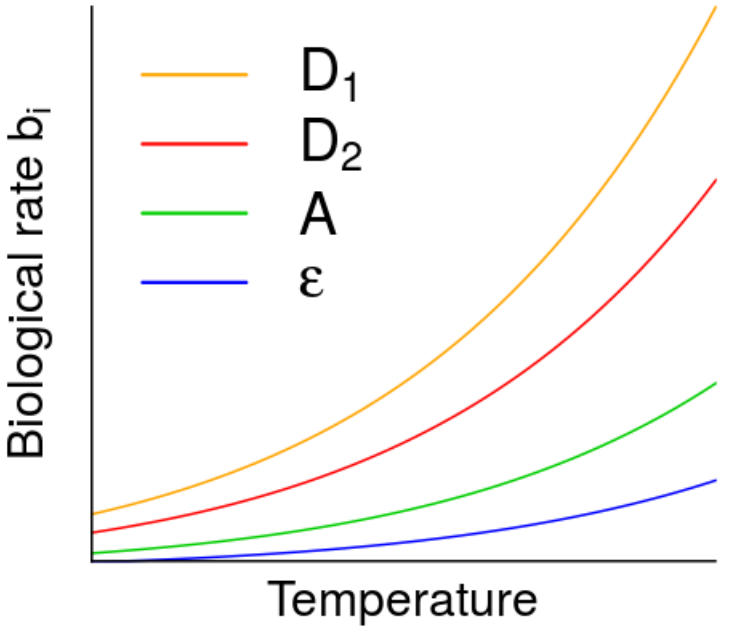




D = self-regulation
ε = biomass conversion efficiency
A = attack rate

Theoretical framework

Temperature dependence of biological rates



$$b_i = b_{0_i} e^{-E_i/kT}$$

- b_0, k constants
- T temperature
- **E activation energy**

The activation energy defines the rate's thermal sensitivity

Theoretical framework

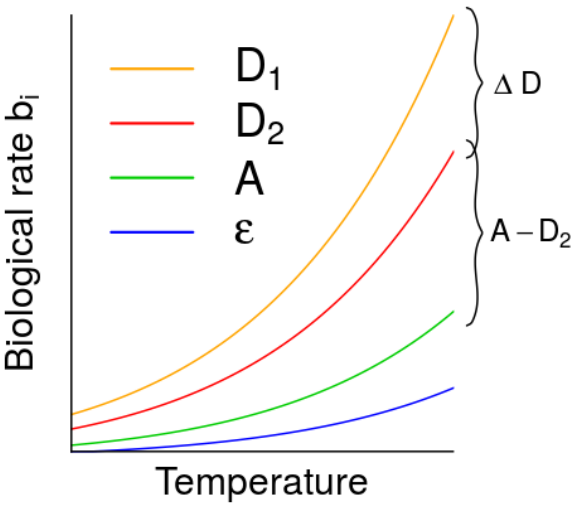
Temperature dependence of the synthetic parameters

Synthetic parameters : $\kappa = \frac{\epsilon D_1}{D_2}, \lambda = \frac{\epsilon A_{21}}{D_1 D_2}$

Their activation energies :

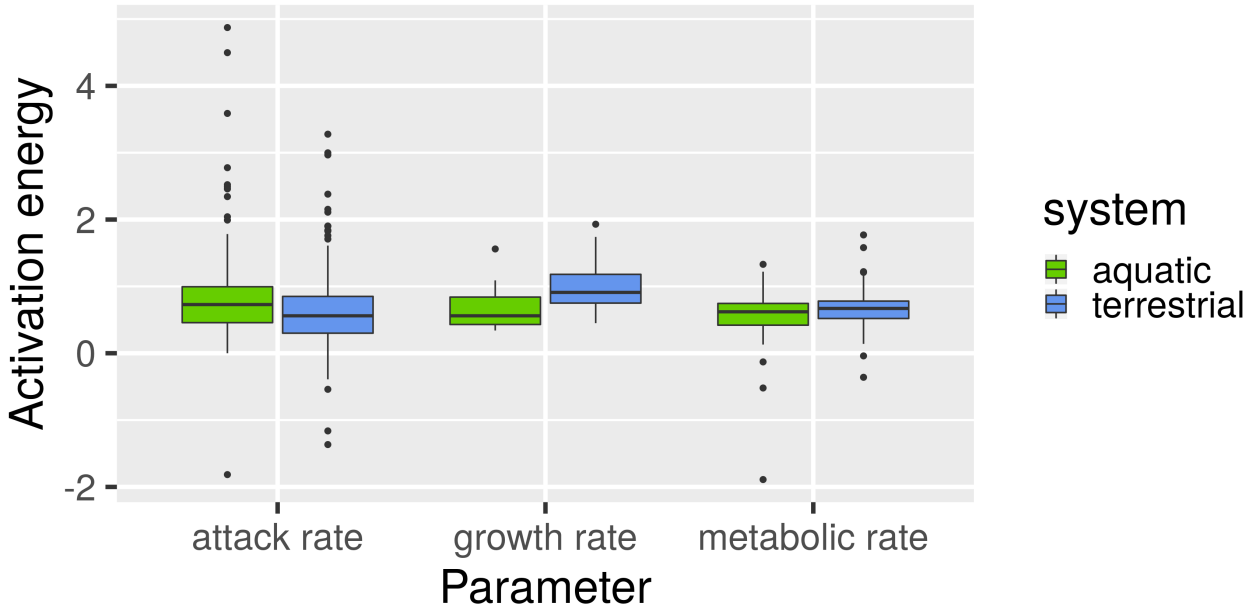
$$E_\kappa = E_\epsilon + E_{D_1} - E_{D_2}$$

$$E_\lambda = E_\epsilon + 2(E_A - E_{D_2}) + E_{D_2} - E_{D_1}$$



Mismatches between biological rates

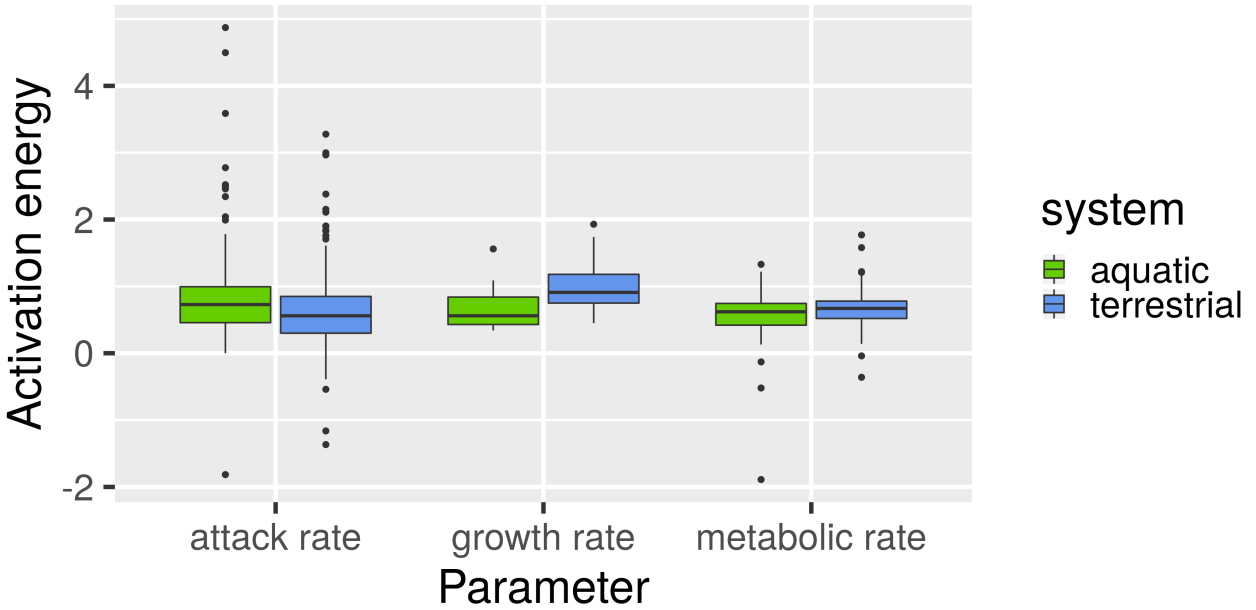
Database of activation energies



- Various species (ectotherm)
- Taxonomic groups
- Habitat
- Diet

Dell et al [2011], Burnside et al [2014], Fussman et al [2014]

Database of activation energies



No information available regarding the temperature dependence of self regulation hence

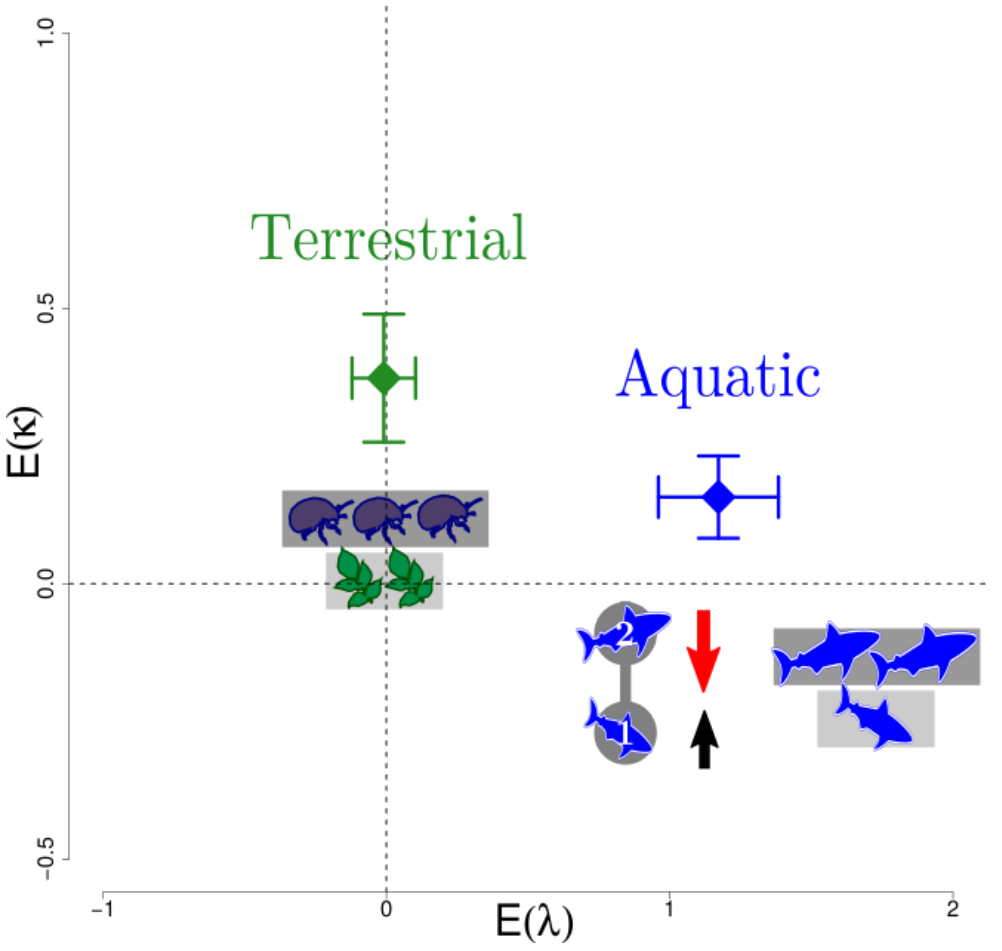
$$D \sim g, A, q$$

Effects of temperature on biomass structure and trophic control in consumer-resource interactions

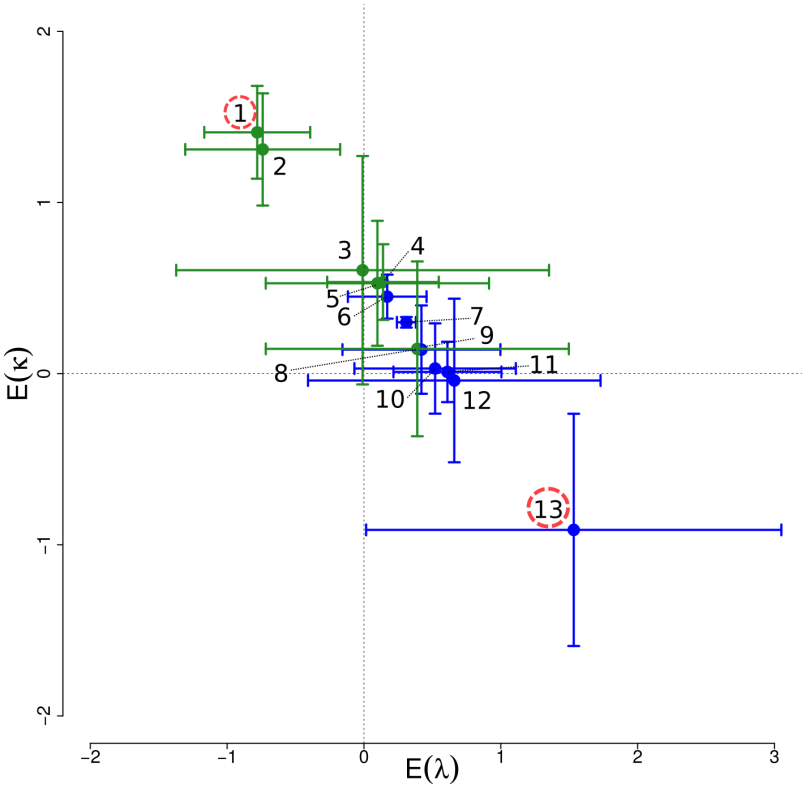
- Temperature dependence of λ and κ
  - Aquatic vs terrestrial organisms
  - Across taxonomic groups
- Shift in λ and κ for herbivores-primary producers at the global scale

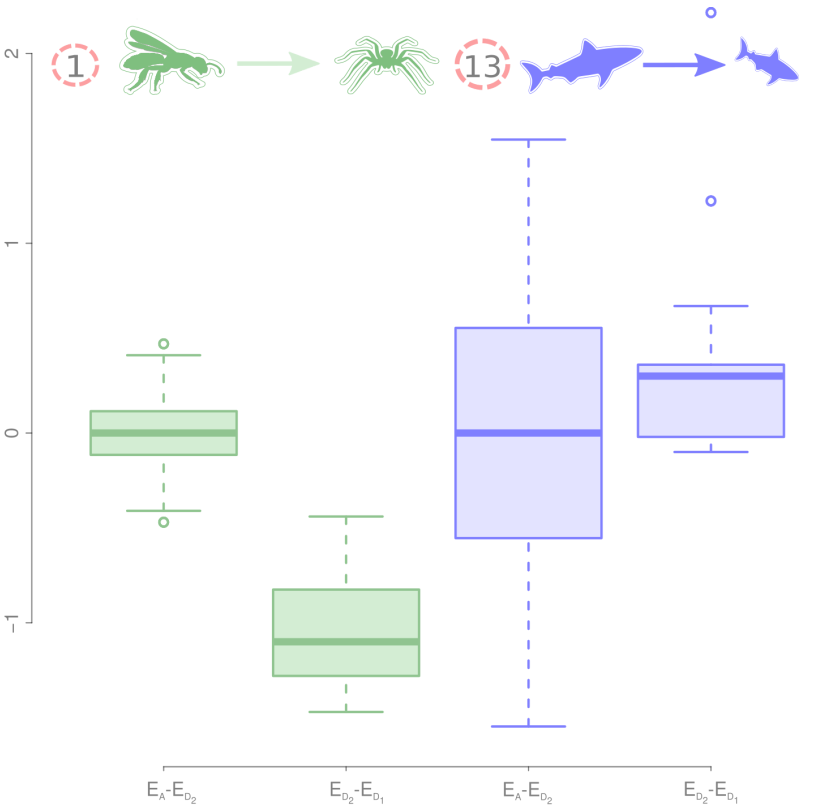
Results

Thermal dependence of λ and κ



Thermal dependence of λ and κ across taxonomic groups





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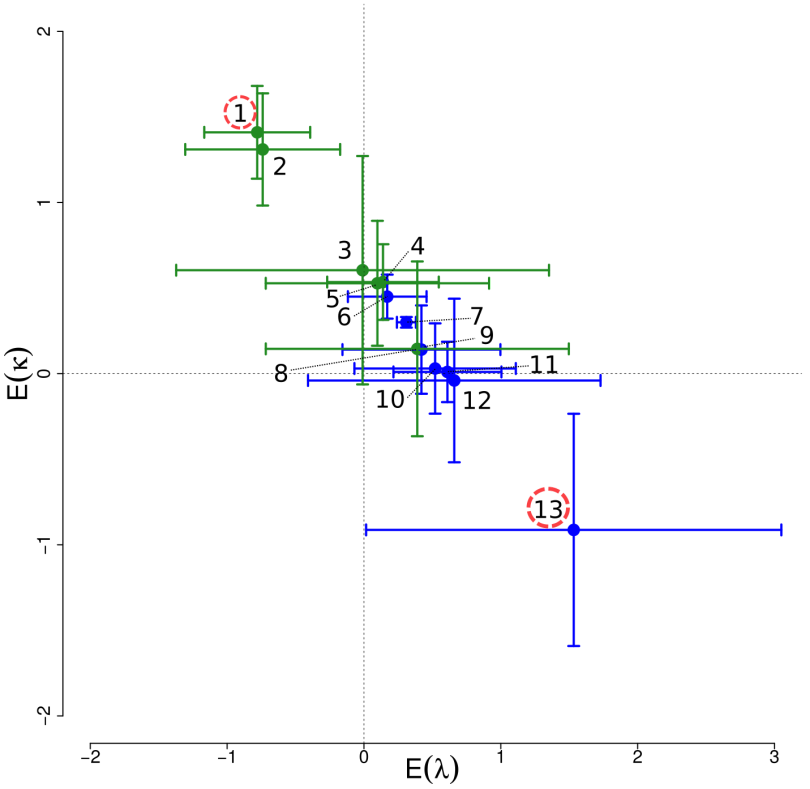
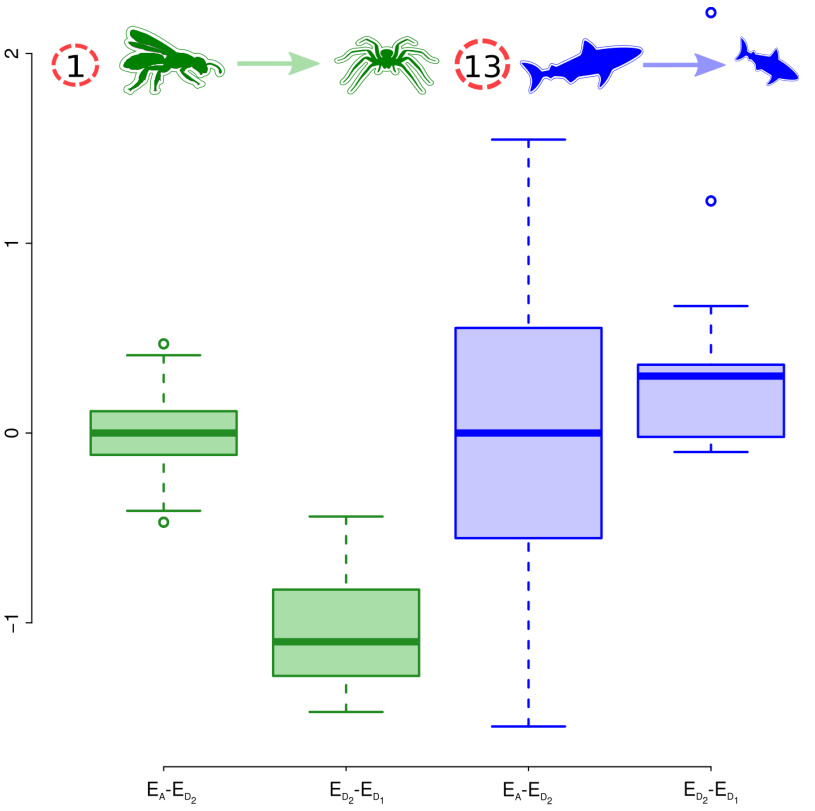
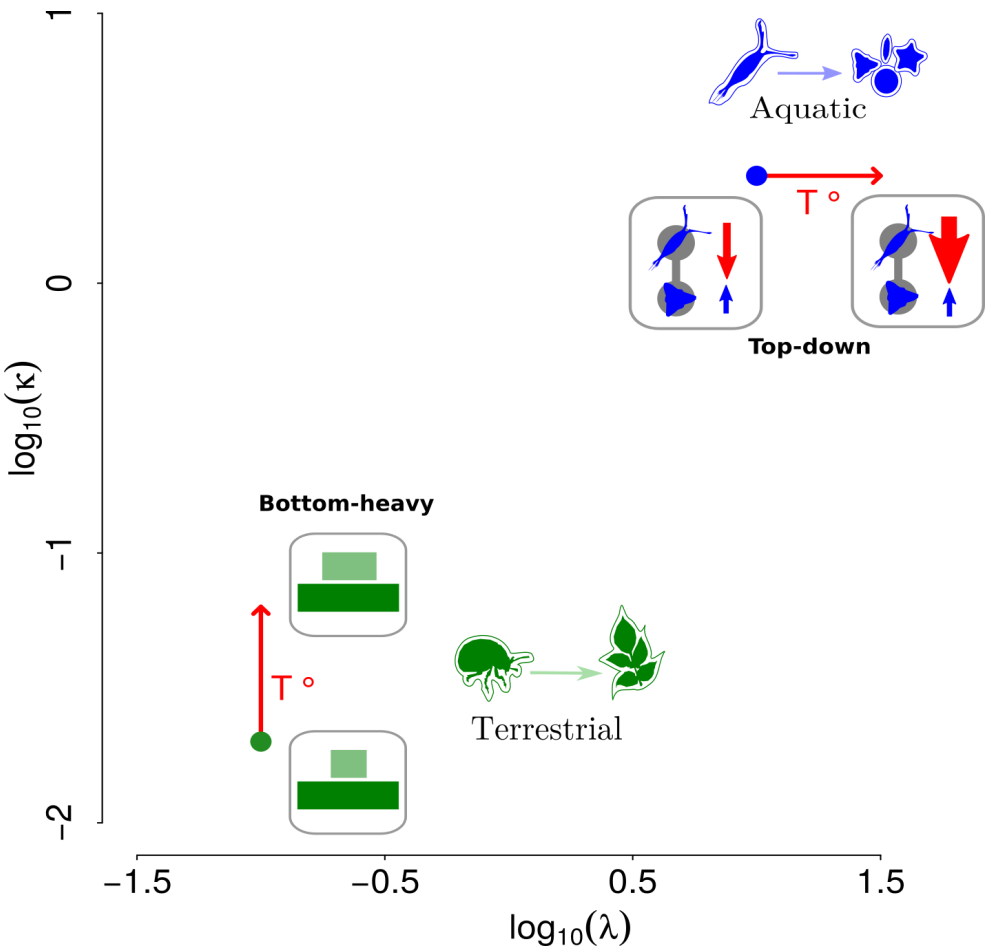




Mismatches between biological rates

Herbivory at the global scale



To conclude

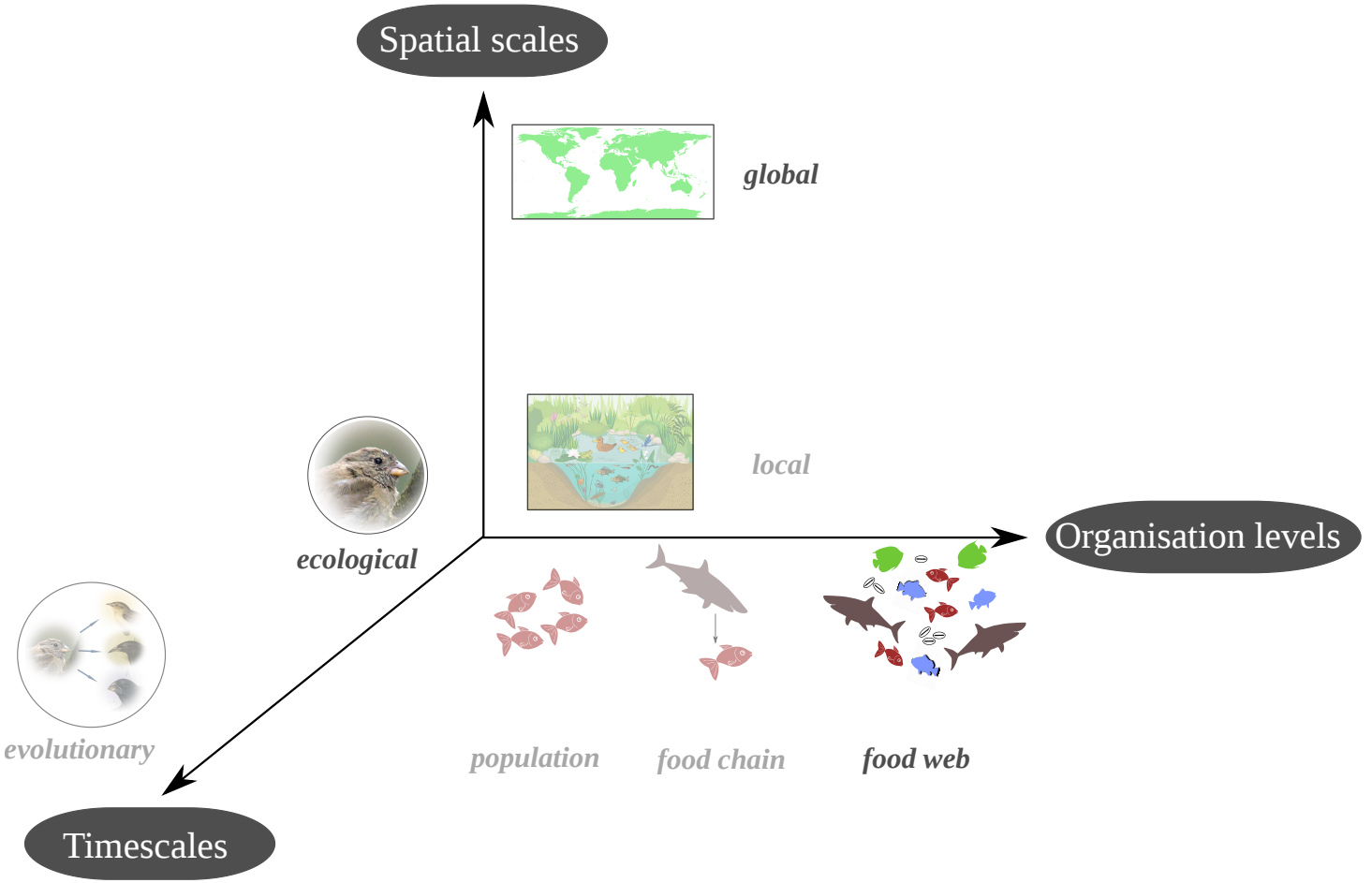
- Mechanistic understanding
  - Importance of 3 parameters and their mismatches in temperature dependence
- Different effects of warming between aquatic and terrestrial communities
  - more top-down control in aquatic systems
  - top-heavier pyramids in aquatic and terrestrial systems
- Variation between taxonomic groups
  - could explain the observed variety of responses
- Estimation for herbivory at the global scale coherent with other studies
  - Predictions

To conclude

But...

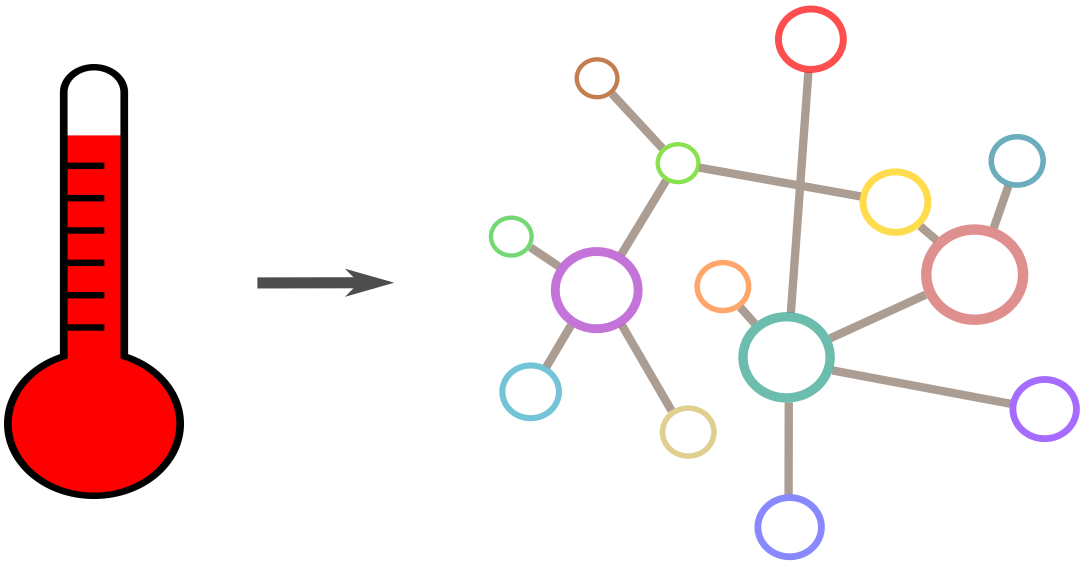
- Lack of data
  - Self-regulation
  - Biomass conversion efficiency
  - Full thermal response
- Consumer-resource interactions

Upscaling to food webs at the global scale



Effects of temperature on fish food webs at the global scale

Effects of temperature on food webs

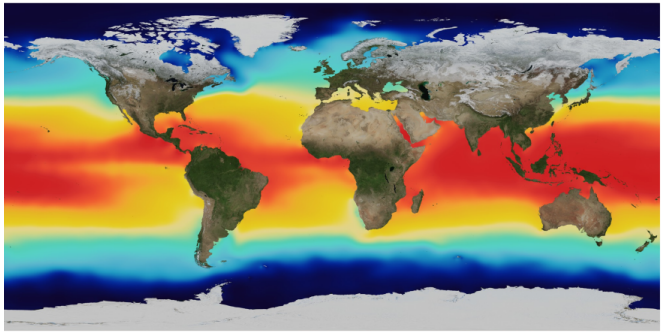


- Warming
- Temperature gradient

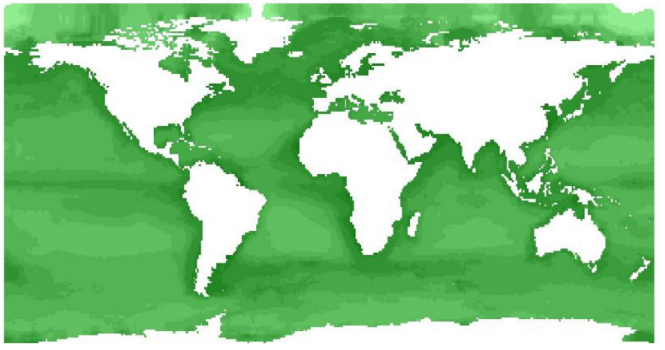
Do they affect community structure and dynamics in a similar way ?

Important gradients across latitudes

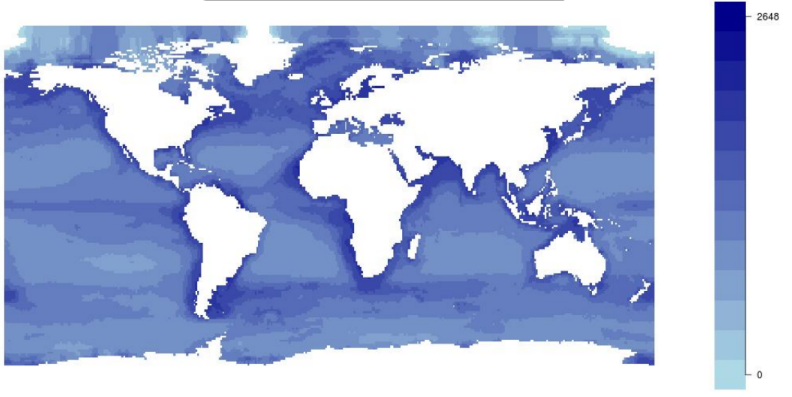
Temperature



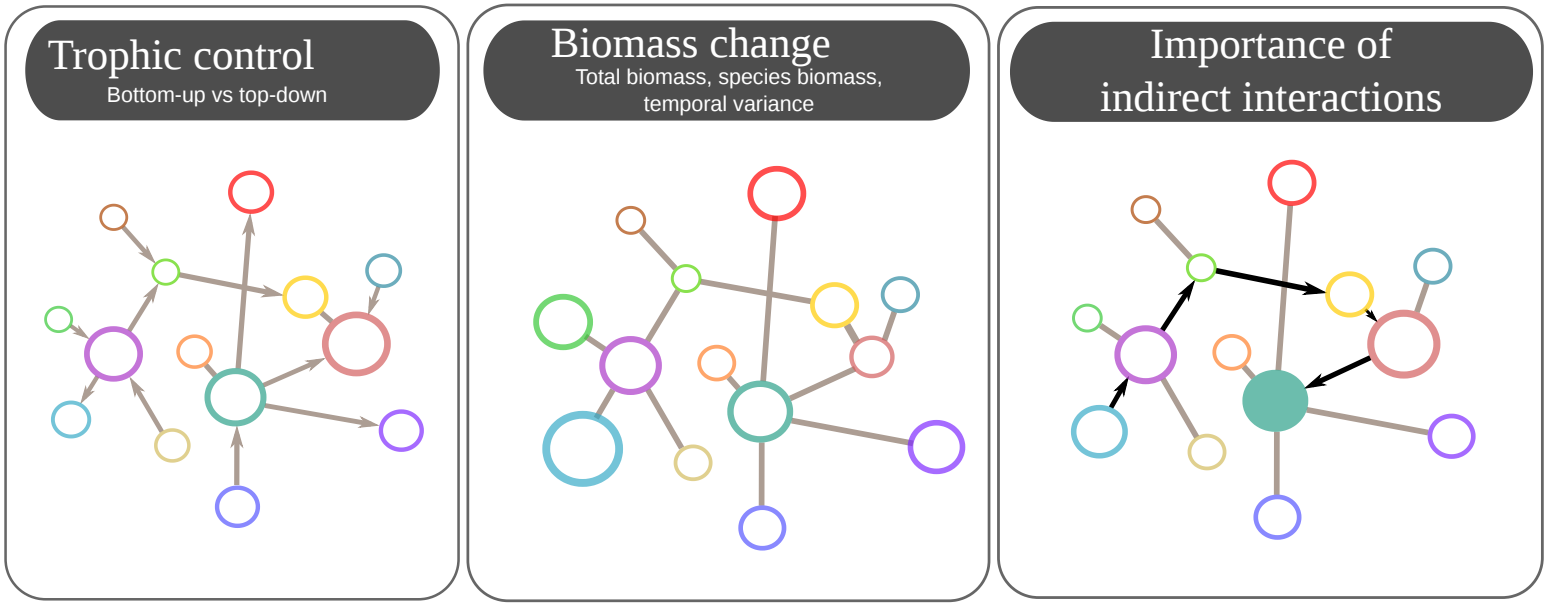
Productivity



Number of species



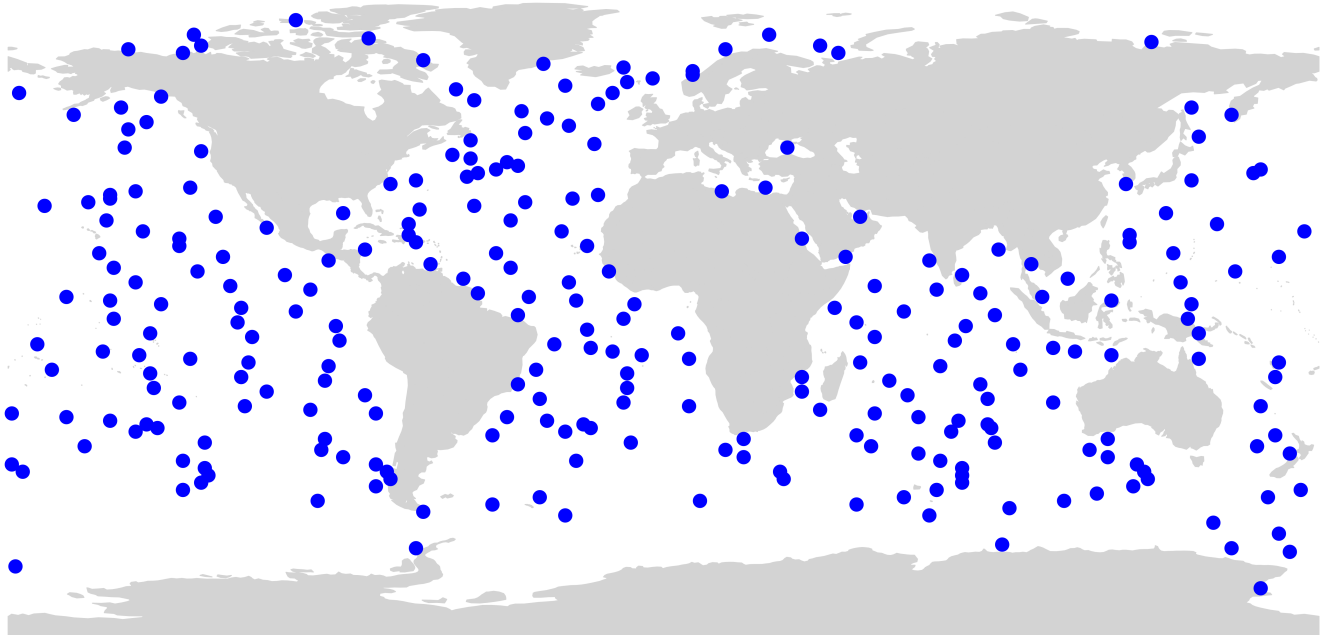
Food webs properties



Effects of the temperature gradient and warming : compare community and species dynamics

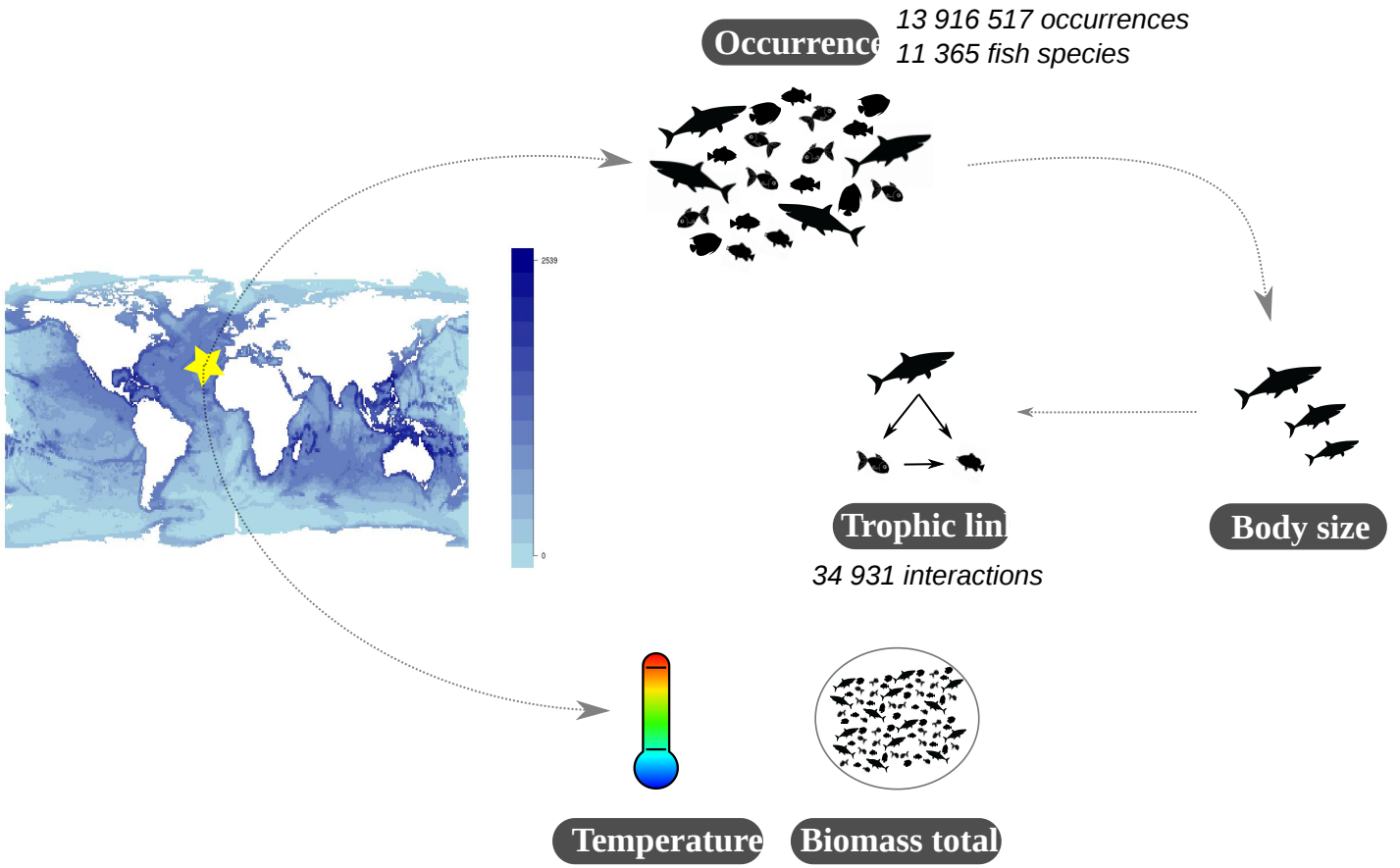
Method

Fish communities at large scale



Trophic interactions

Data


Occurrence
13 916 517 occurrences
11 365 fish species
2539
0
Trophic lin
34 931 interactions
Body size
Temperature
Biomass total

Theoretical approach

Modelling communities to infer their structural and dynamical properties

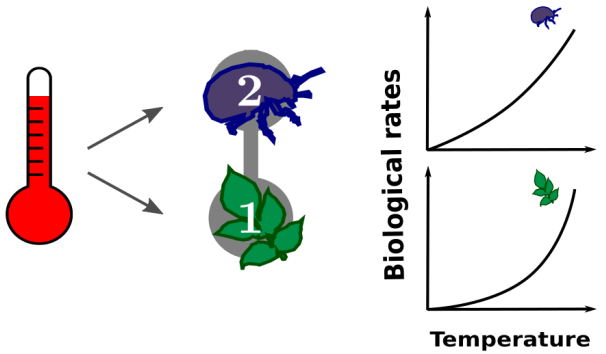
Lotka-Volterra system

$$\frac{dB_i}{dt} = g_i B_i + \sum_j \epsilon M_{ij} B_i B_j - \sum_k M_{ki} B_i B_k - D_i B_i^2$$

- B biomass
- M_{ij} interaction matrix
- g_i net growth rate
- D_i self regulation
- ϵ conversion efficiency

How to parameterize the model?

Temperature and body-mass dependence of biological rates



$$b_i = m_i^{\beta} b_0 e^{-E/kT}$$

- m body mass
- β exponent
- b_0, k constants
- T temperature
- E activation energy

Growth, metabolic and attack rate

Theoretical approach

Modelling communities to infer their structural and dynamical properties

Lotka-Volterra system

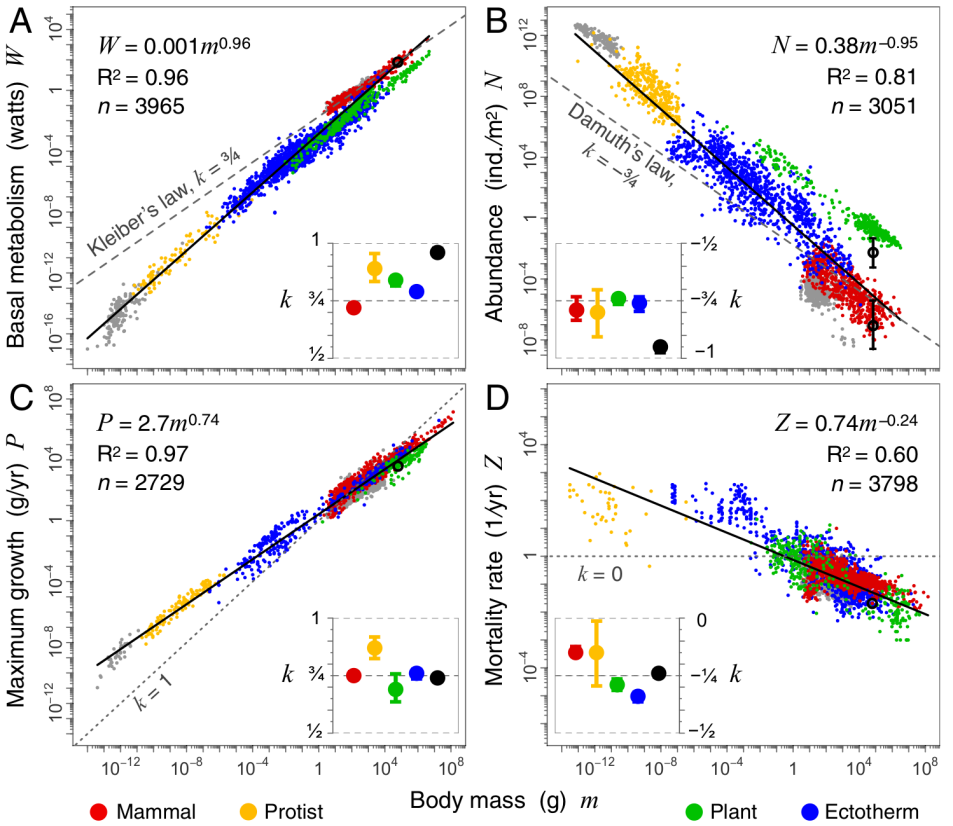
$$\frac{dB_i}{dt} = g_i + \sum_j \epsilon M_{ij} B_j - \sum_k M_{ki} B_k - D_i B_i$$

- **B biomass**
- M interaction matrix
- g net growth rate
- **D self regulation**
- ϵ conversion efficiency

Self-regulation is completely unknown...
Biomass can be inferred from allometric relationship

Estimation of species biomass

Abundance law



Method to estimate self-regulation

From available parameters and

$$\frac{dB_i}{dt} = g_i B_i + \sum_j \epsilon M_{ij} B_i B_j - \sum_k M_{ki} B_i B_k - D_i B_i^2$$

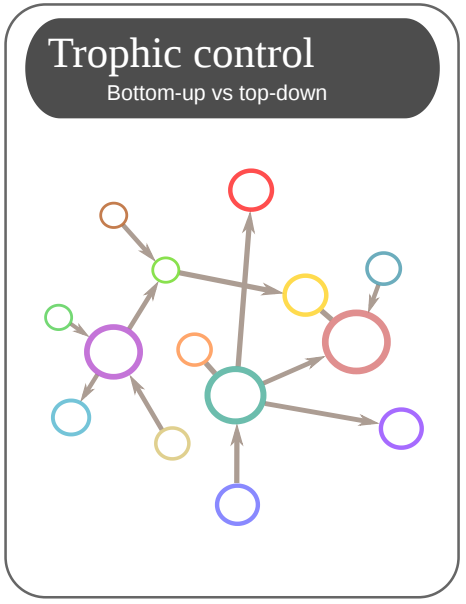
- allow coexistence
- biomass follows allometric laws

Method to estimate self-regulation

A little trick to estimate self-regulation

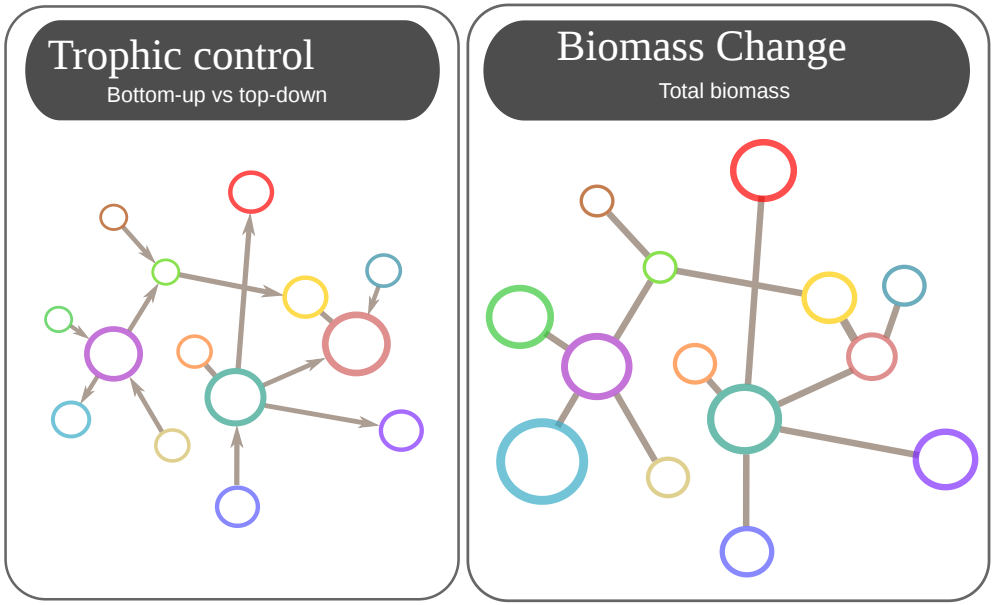
You'll have to believe me (or not) for today...

Measures of community dynamics



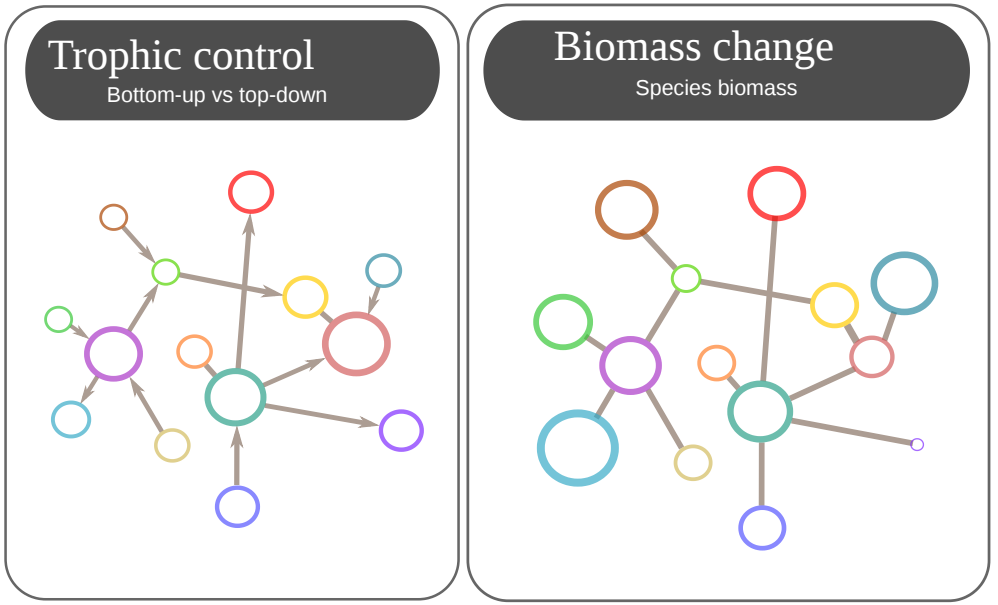
Median λ

Measures of community dynamics



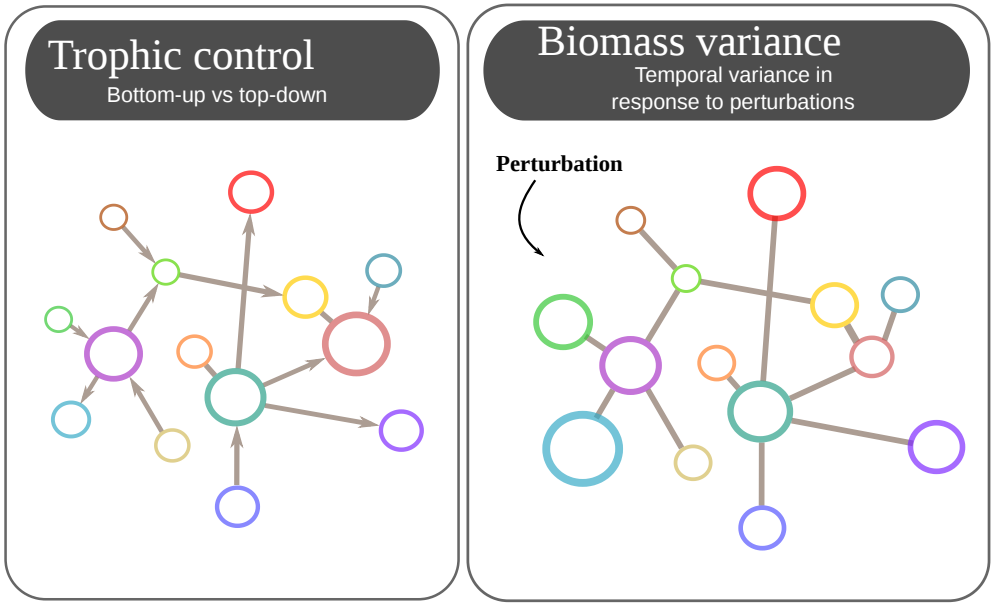
Sum species biomass

Measures of species dynamics



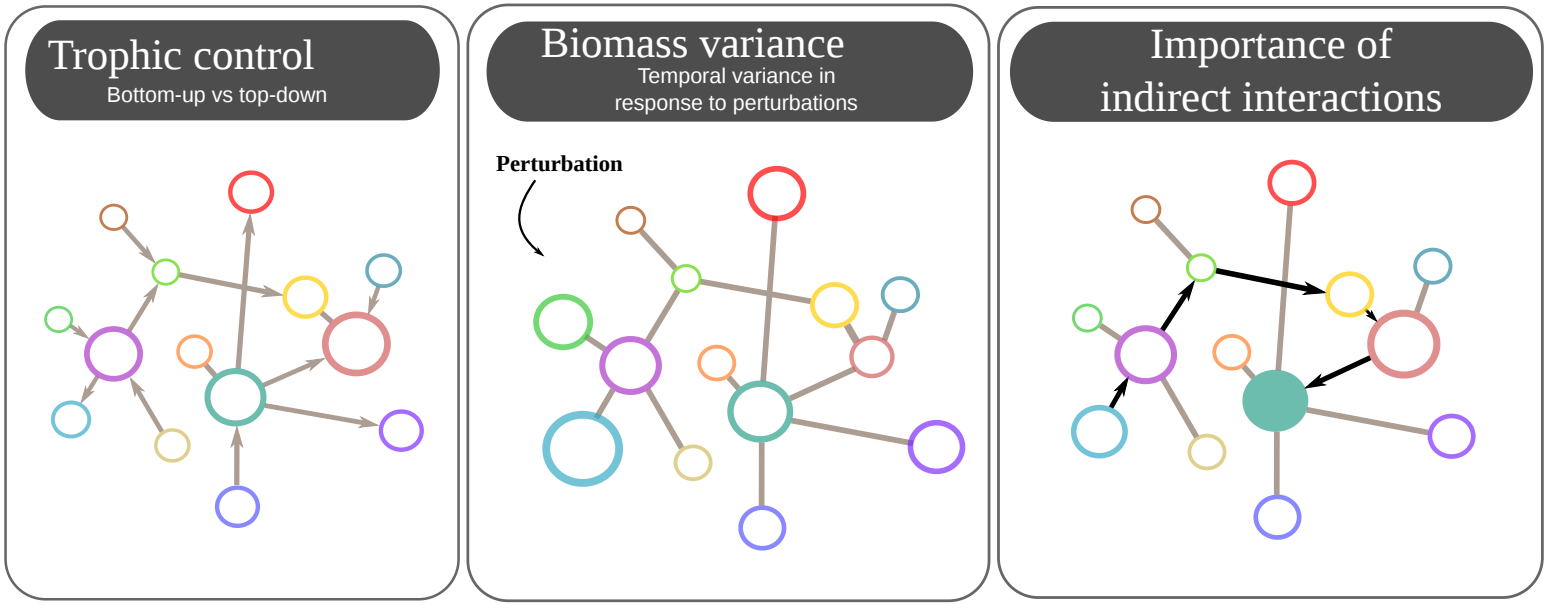
Relative change in species biomass

Measures of community dynamics



Variability : temporal biomass variance in response to stochastic pertubations (community average)

Measures of community dynamics

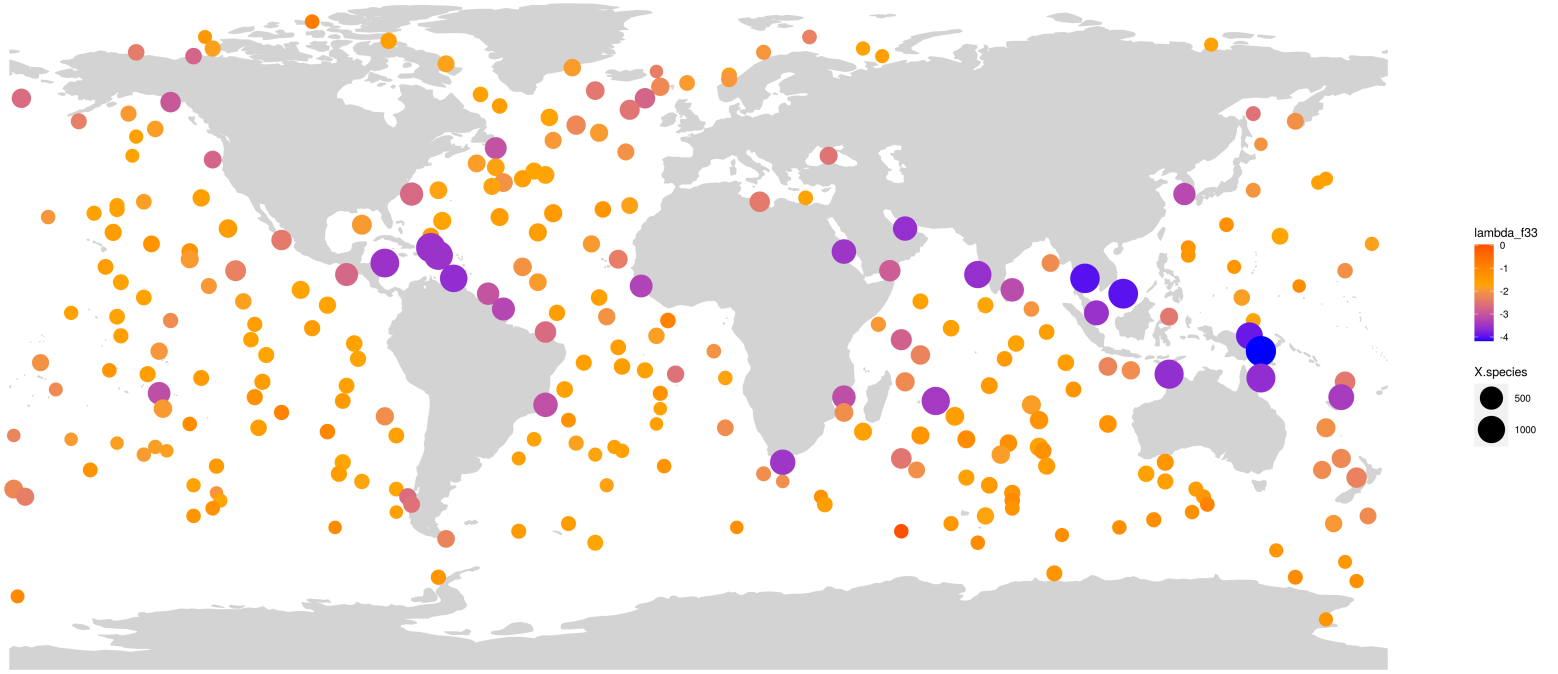


Collectivity : importance of indirect interactions (collectivity = 1, a change in species abundance affect other species far in the network)

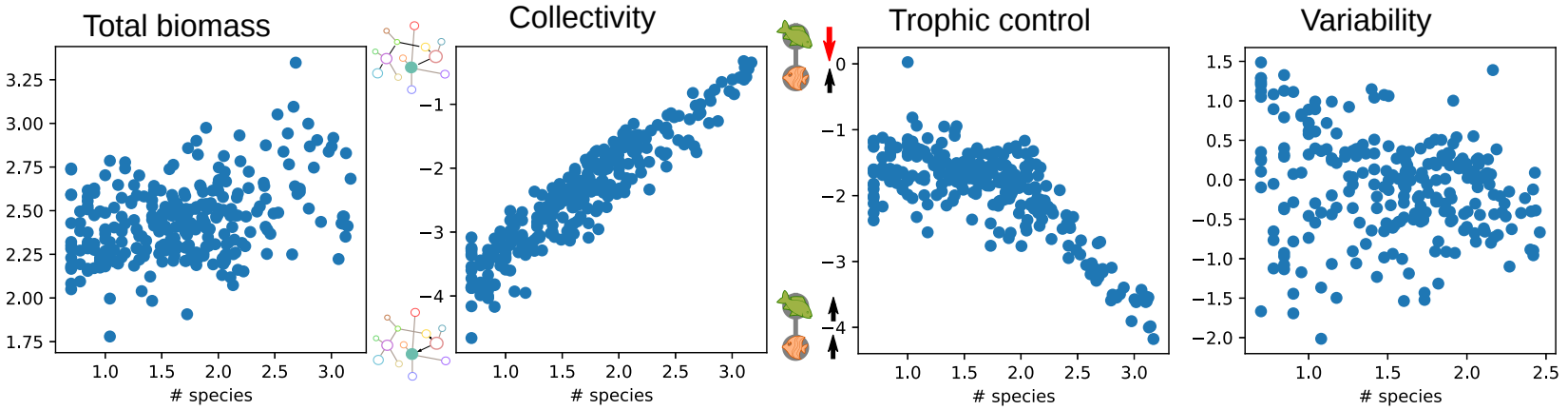
Results

Community properties at large scale

Trophic control

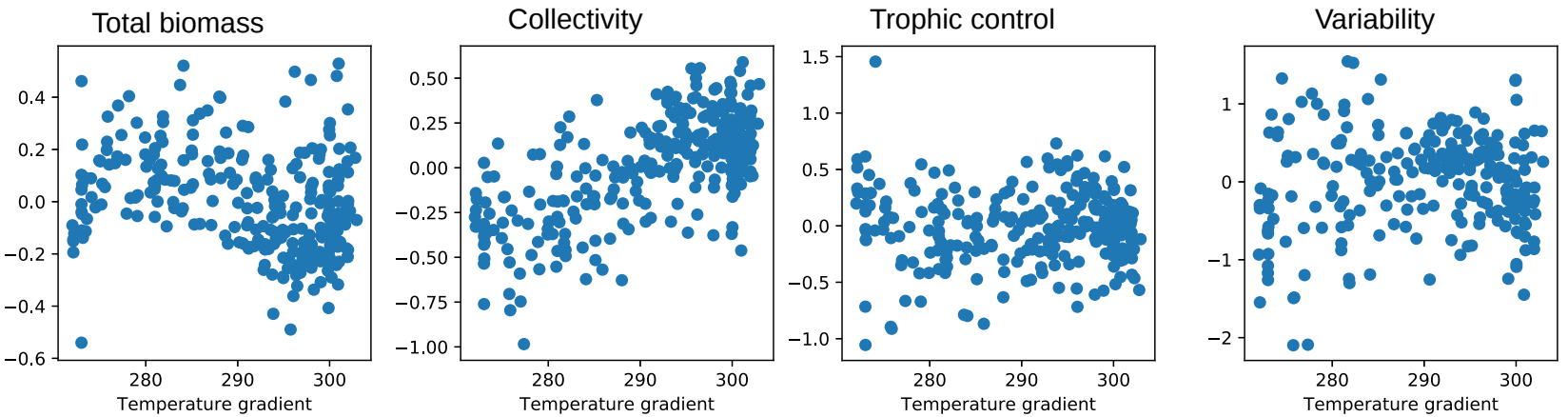


Community properties according to the number of species



Effect of the number of species on λ and collectivity

Residual properties according to temperature



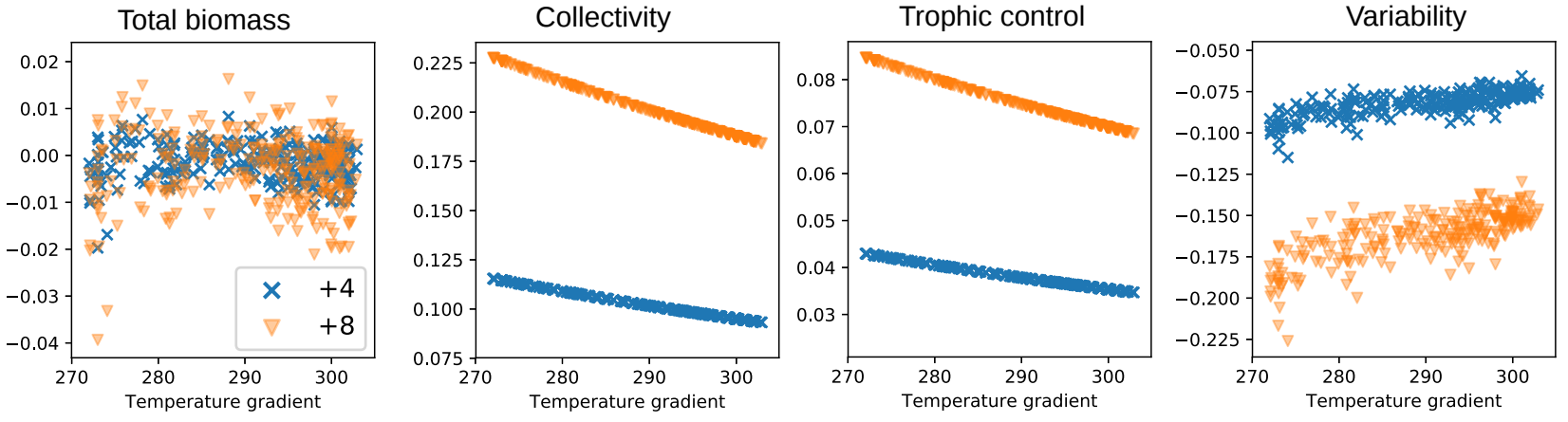
(while controlling for the number of species)

The temperature gradient alone does not seem to strongly affect community properties (except collectivity)

But what about warming ?

Effect of warming on community properties

Relative change with warming



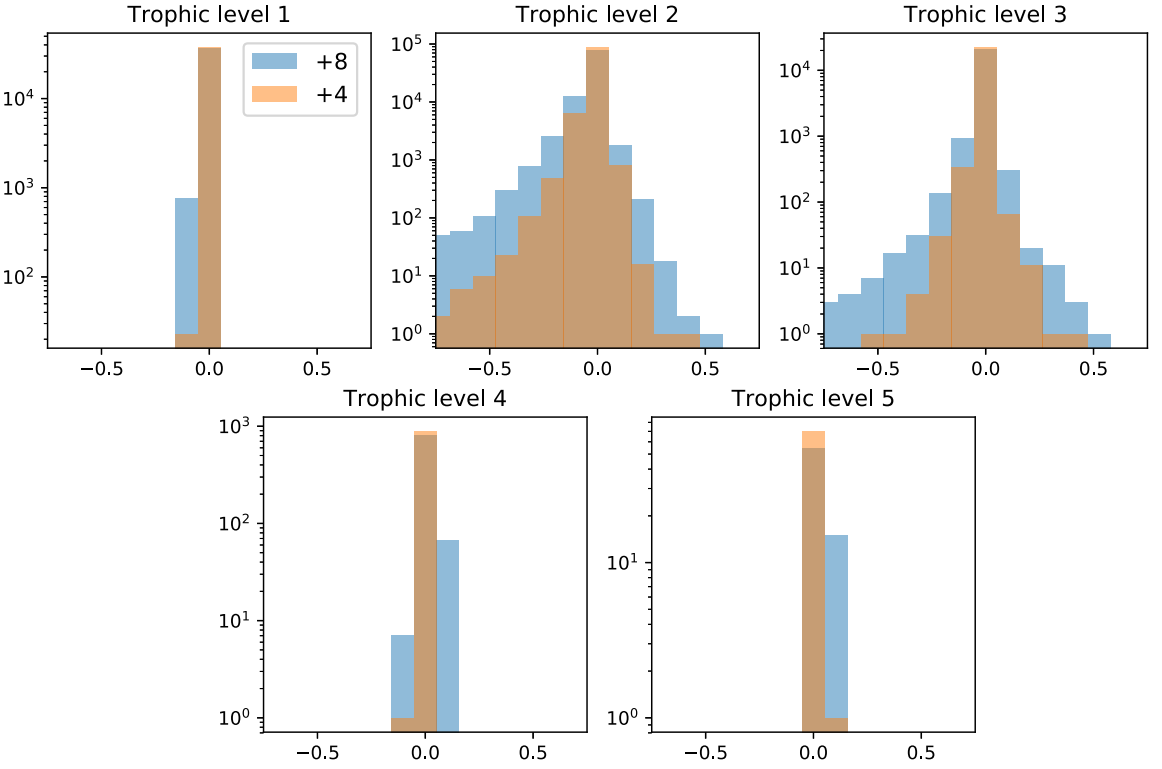
Warming affects collectivity and variability but not other community properties

Interactive effect of warming and the temperature gradient

Effect of warming on species biomass

If warming does not affect some properties of the community as a whole, does it affect single species in the community ?

Relative change in species biomass with warming for each trophic level



To conclude

- Latitudinal variation mostly driven by number of species
- λ decreases and collectivity increases with the number of species
  - Latitudinal variation in trophic control
- Temperature gradient and warming affects collectivity, warming affects variability, but not significantly other community properties

Warming seems to affect individual species more significantly than communities as an entity

Especially species from trophic levels 2 and 3

To conclude

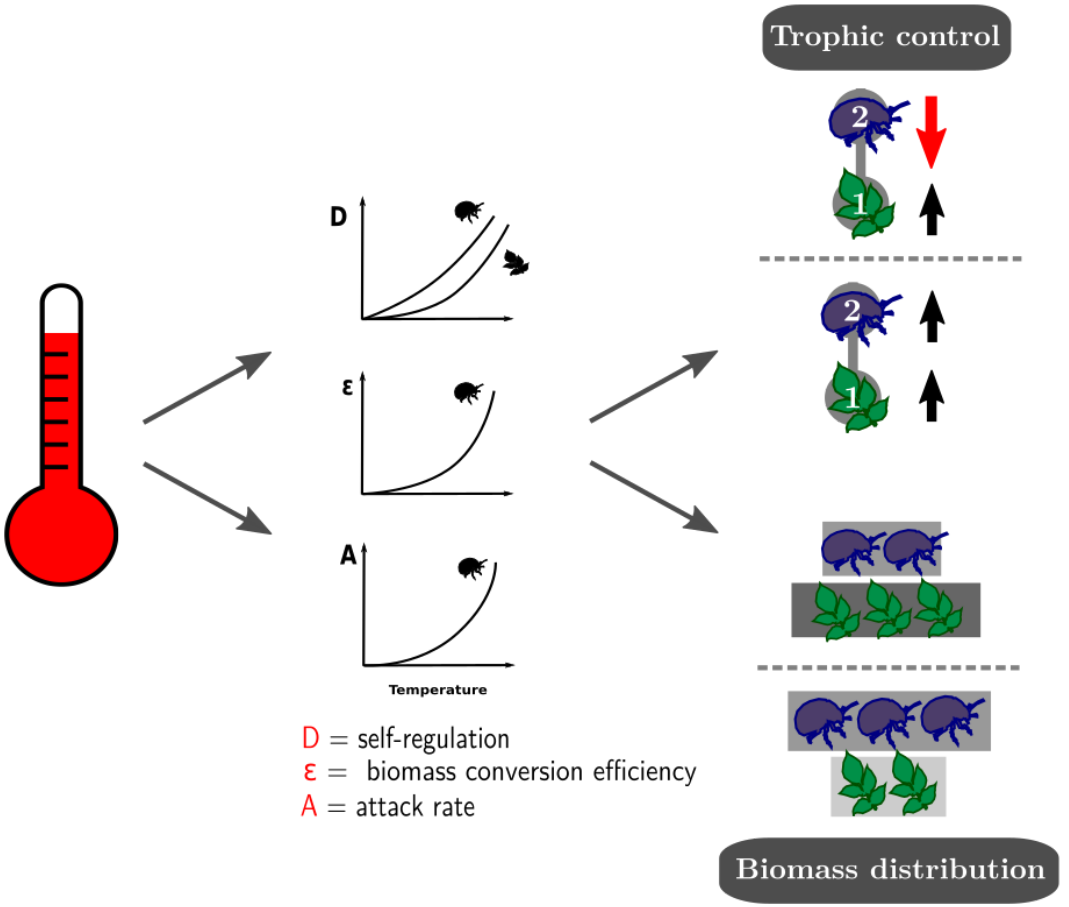
Limitations :

- Limited data available
- No variation in activation energies (but same taxonomic group)
- Model assumptions and parameters

The model is right but it might be wrong

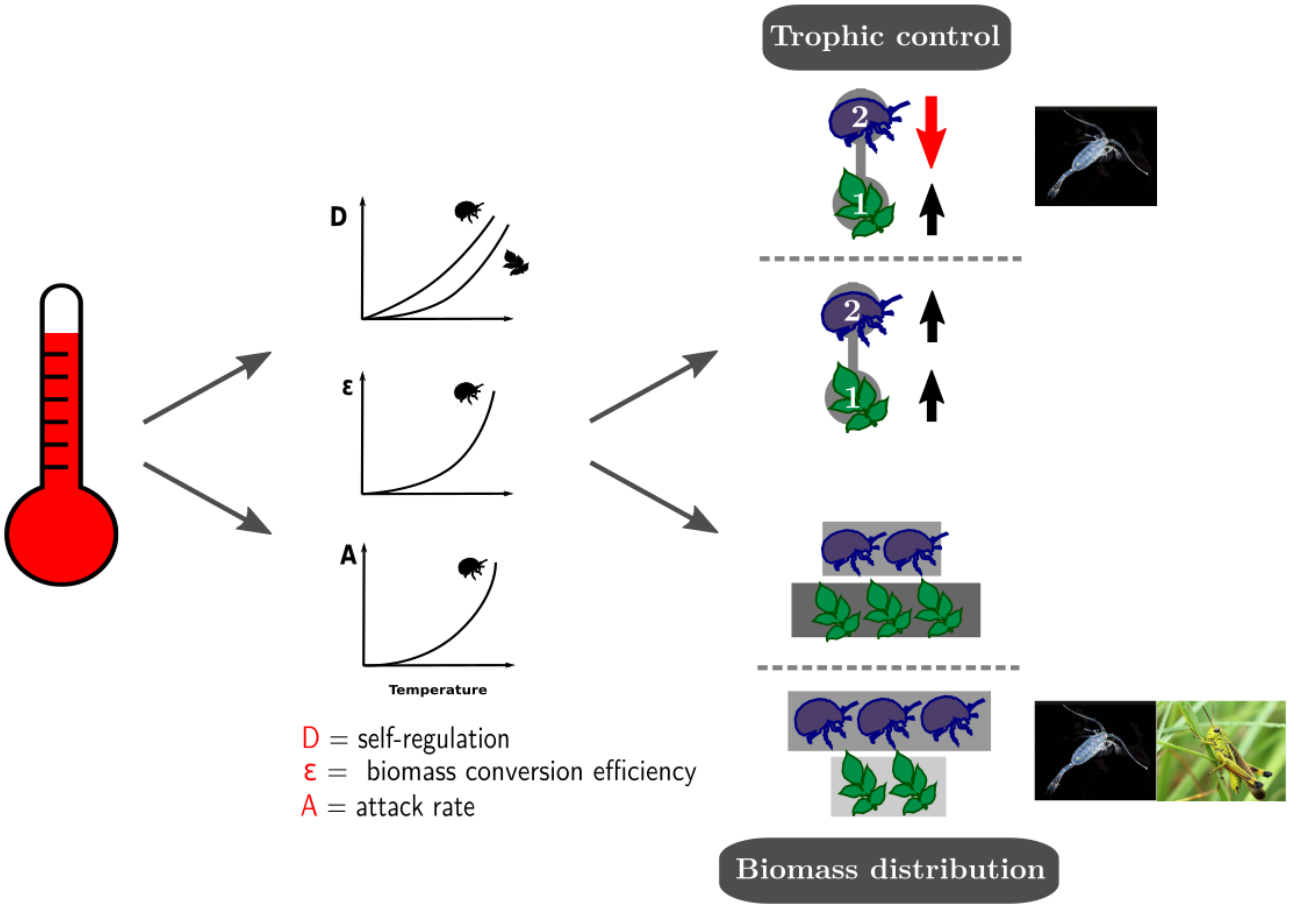
General conclusion

To conclude - First part



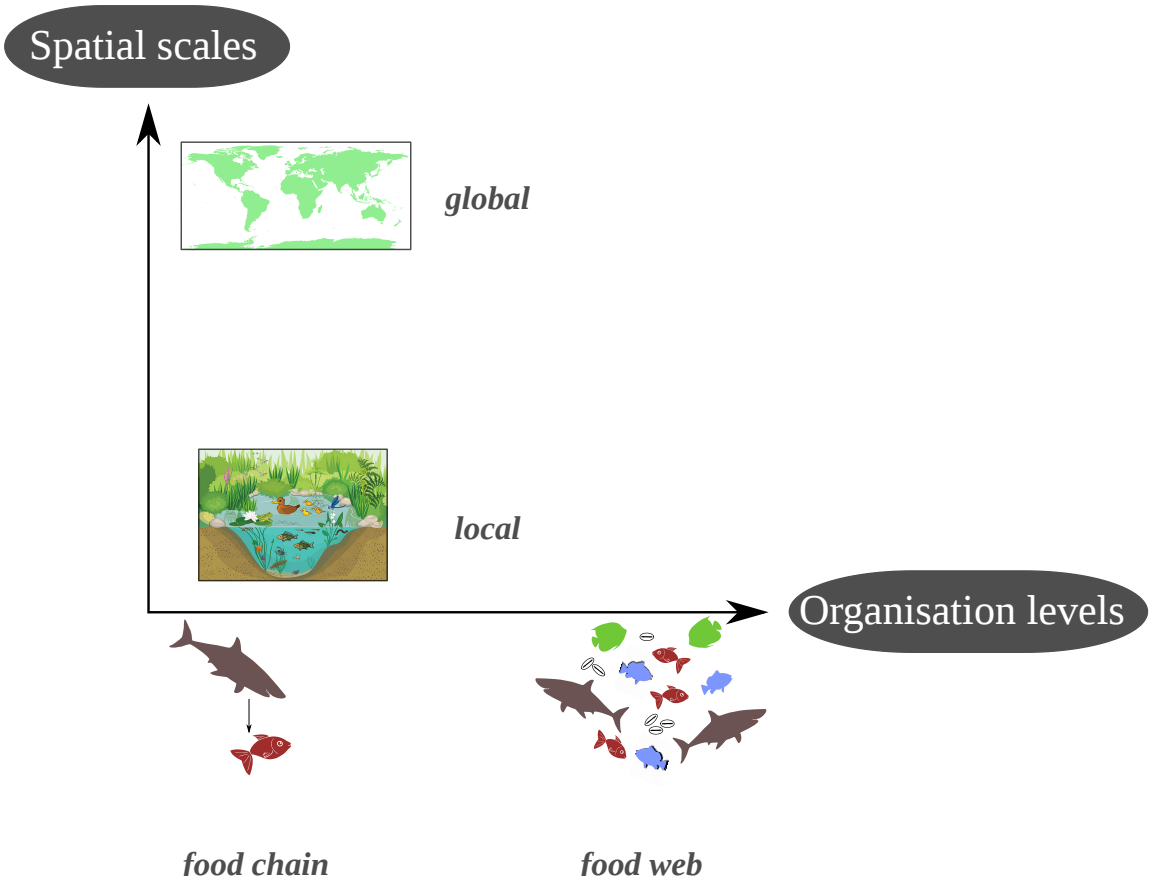
3 fundamental biological rates and their mismatches

To conclude - First part



General trend : more top-down control in aquatic systems and top-heavier biomass distribution in terrestrial and aquatic ones

To conclude - Second part



Temperature effects seem to vary from one scale to another !

To conclude - Second part

- Latitudinal gradient mostly driven by number of species
- Community properties seem robust to warming
- But individual species much less !
  - Which could explain why strong effects are observed at lower scales
  - Warming effect on λ for a pair of species $\neq \lambda$ at the community level

Theoretical exploration of the direct effect of warming to better understand mechanisms

Of course in nature ... things can be different !

- Warming has interactive effects
- Habitat loss
- Fishing
- Increase in human populations
- Pollution
- ...

So this is not an excuse to take the plane too often ;)

QUEBEC CENTRE FOR BIODIVERSITY SCIENCE

NSERC CRSNG

Special thanks to

- You for listening
- My supervisors Dominique and Michel
- Matthieu, Jeff and Ben
- Lab mates in Sherbrooke and Moulis
- Will for the (beautiful right?) template