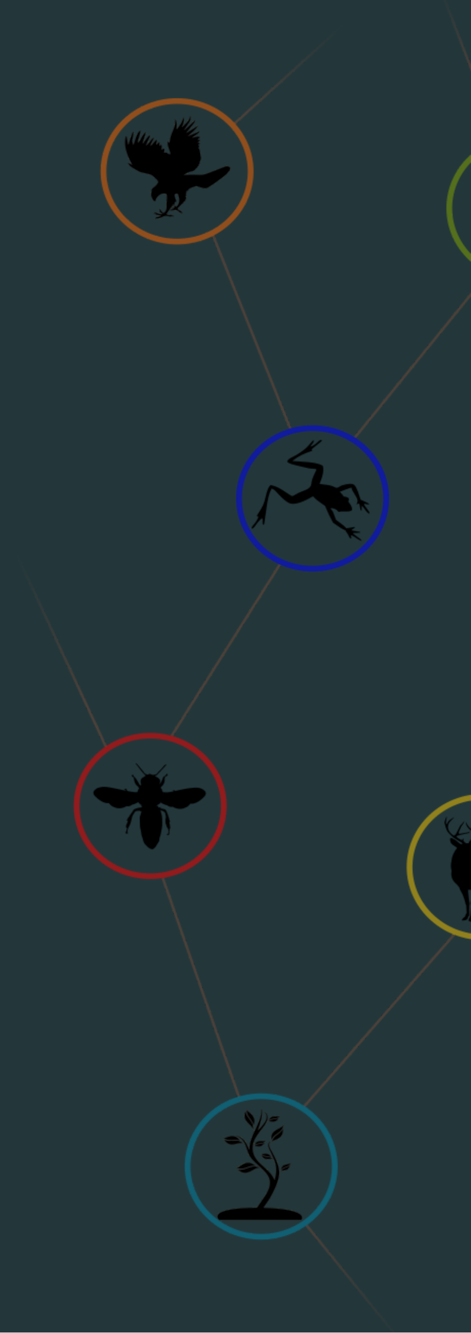
Laboratoire d'écologie intégrative | Integrative Ecology Lab [IE]

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

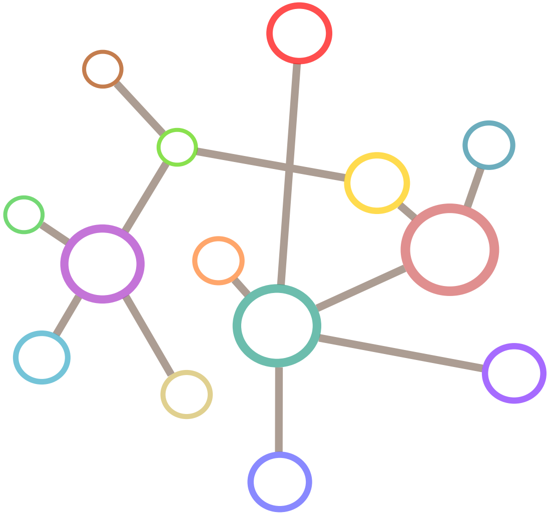
@Azenor_Bideault

How do communities differ from one pole to another ?

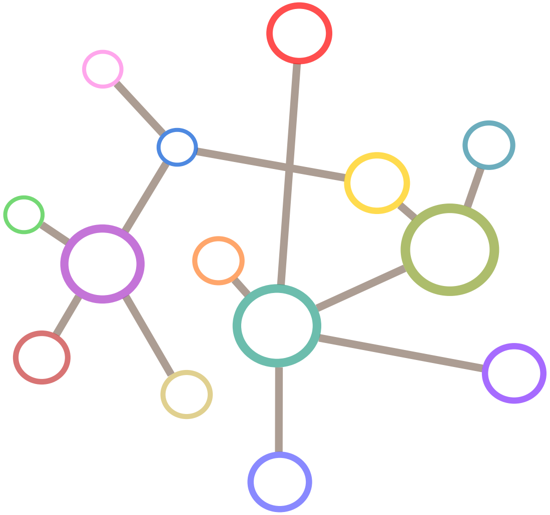
Spot the differences!

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

Communities vary across space and time

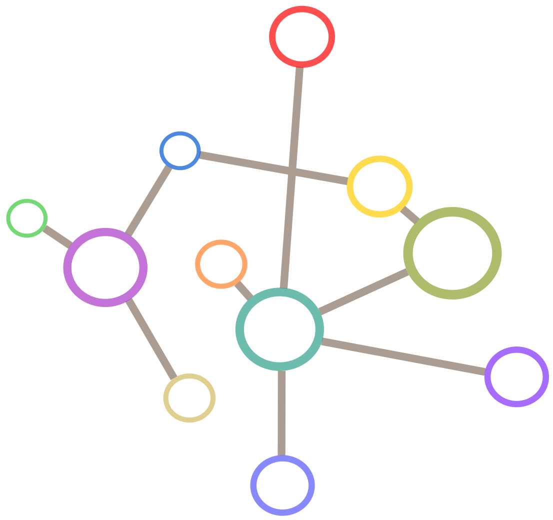


Communities vary across space and time



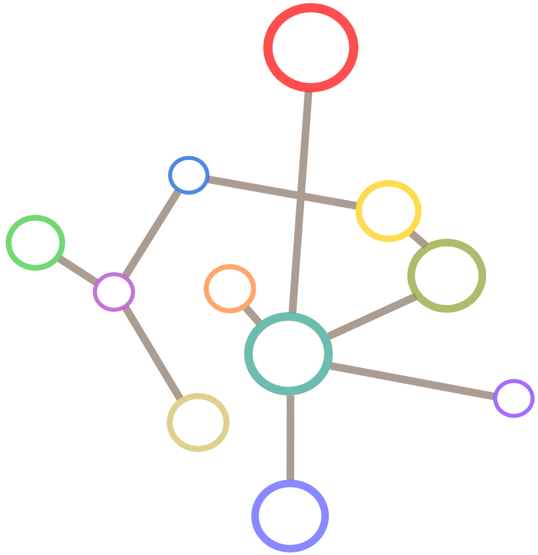
- Identity of species

Communities vary across space and time



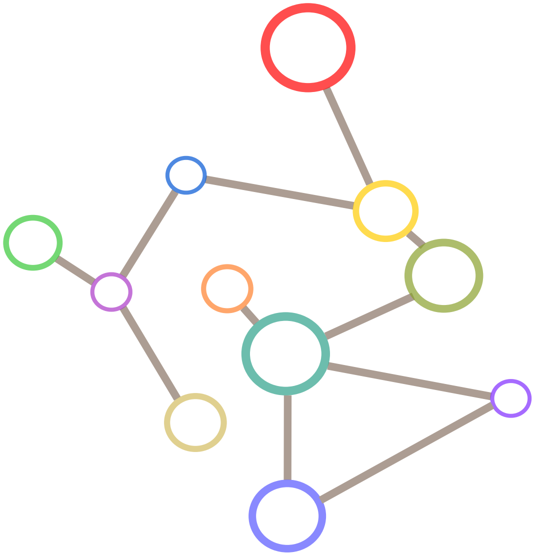
- Identity of species
- Number of species

Communities vary across space and time



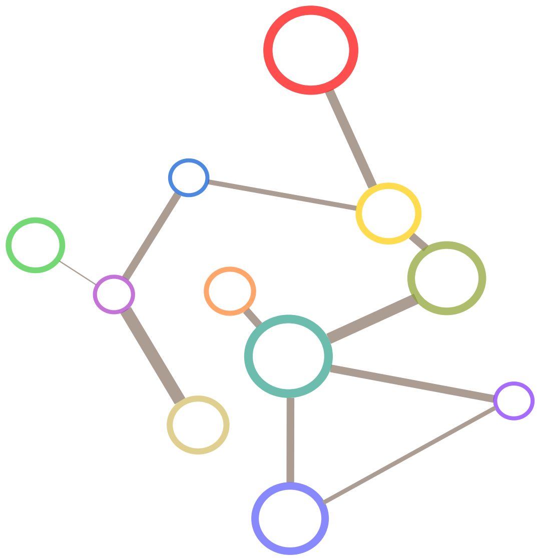
- Identity of species
- Number of species
- Biomass

Communities vary across space and time



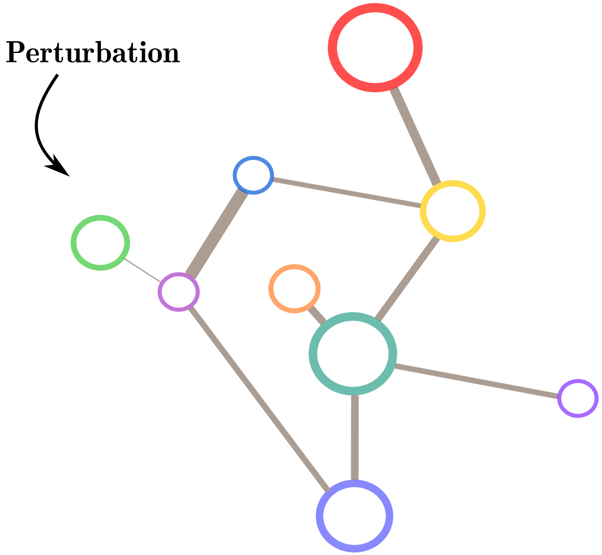
- Identity of species
- Number of species
- Biomass
- Interactions

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

Food webs vary across space and time

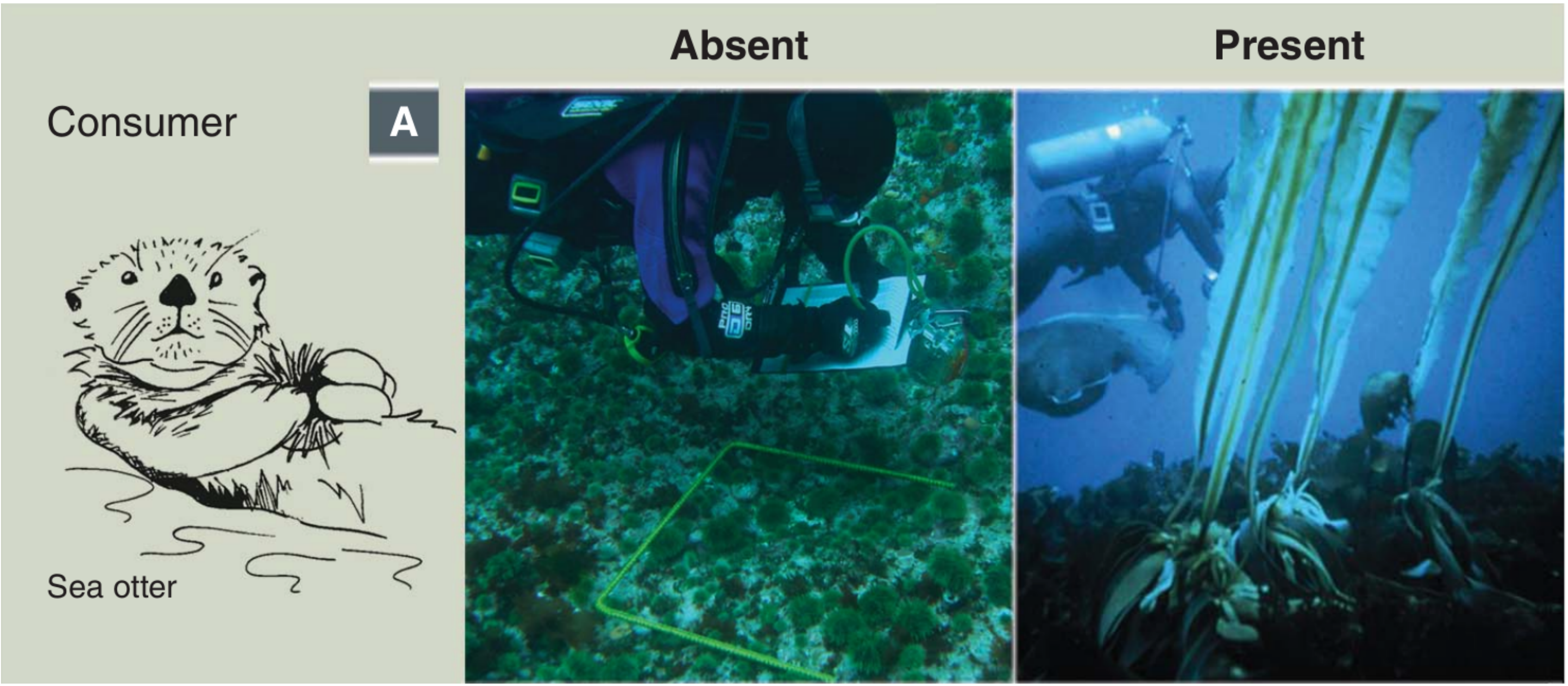
Trophic interactions

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

Variation in structure and dynamics

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

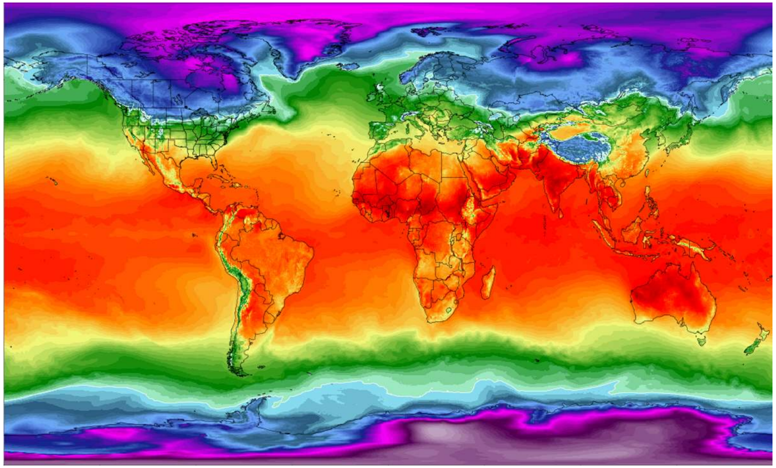
What else is different ?

Environmental drivers :

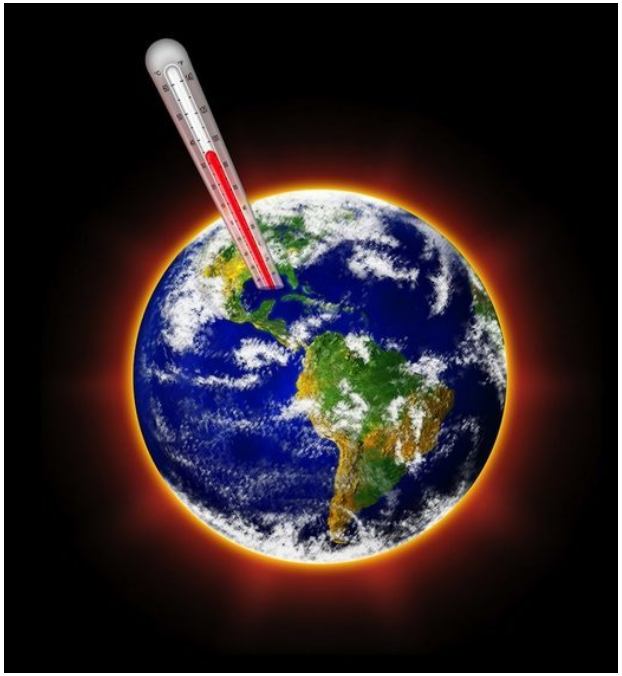
- Temperature
- Precipitation

Temperature

A major environmental gradient



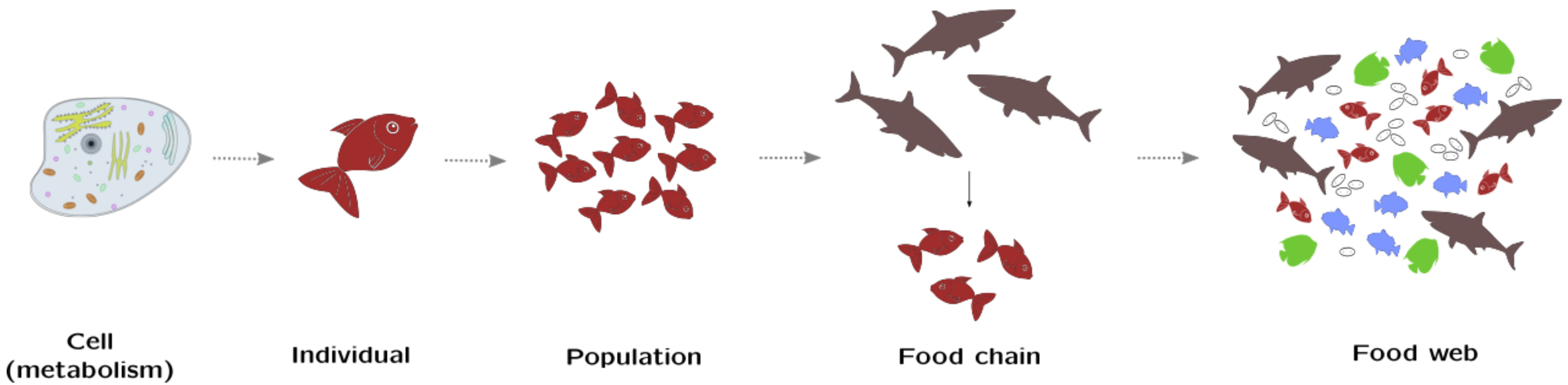
Global warming



What are the effects of temperature ?

Effects of temperature

From the individual to the community



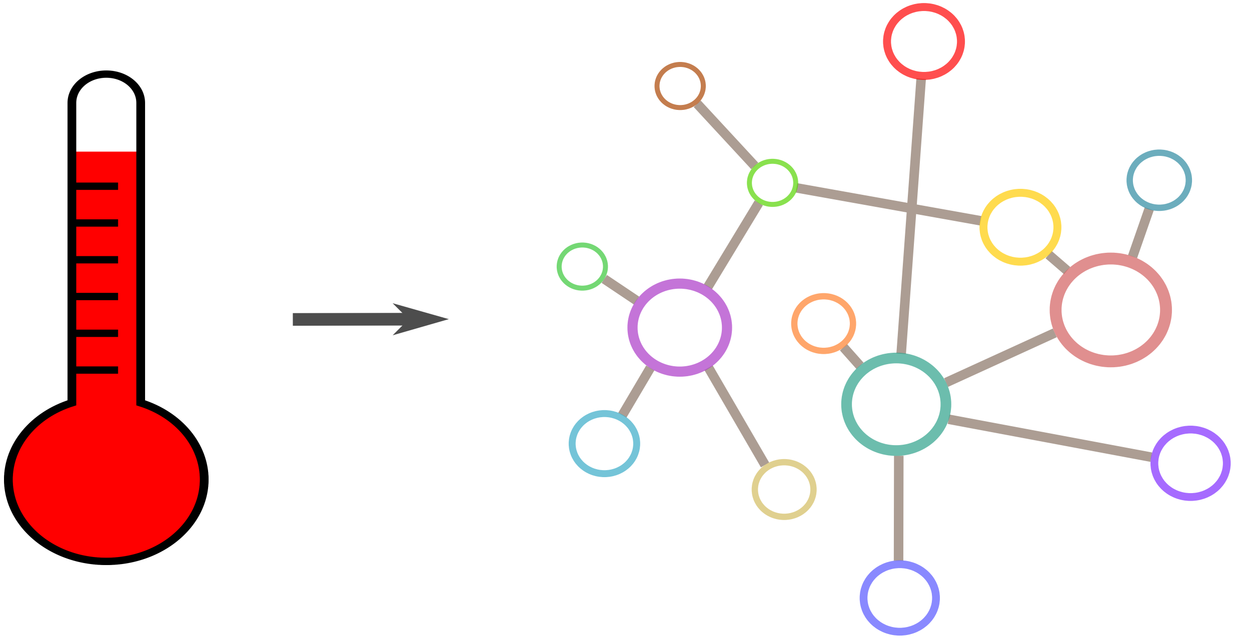
Effects of temperature

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

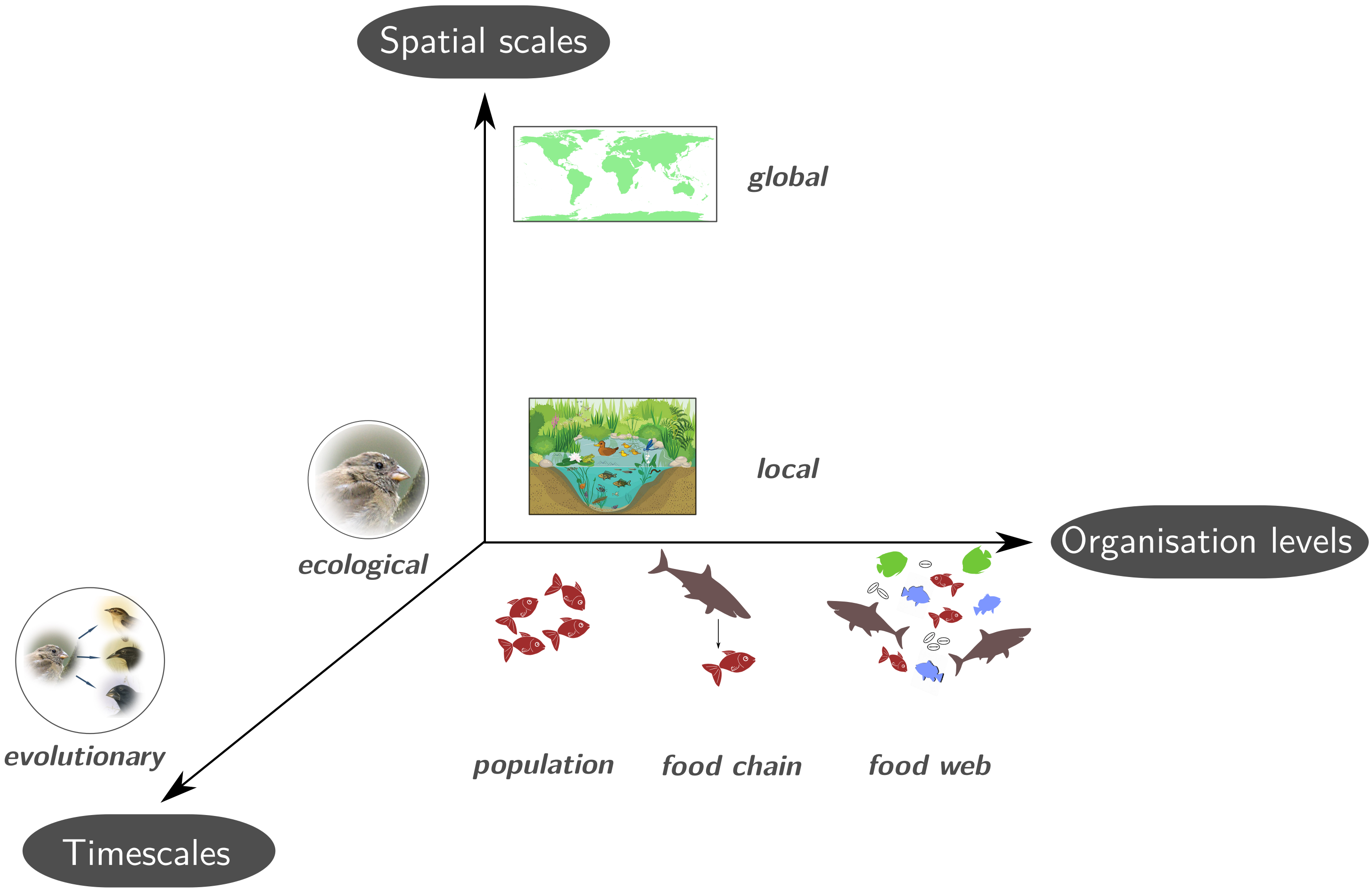
- experimental design
- study system
- theoretical framework
- model assumptions

No synthetic understanding yet

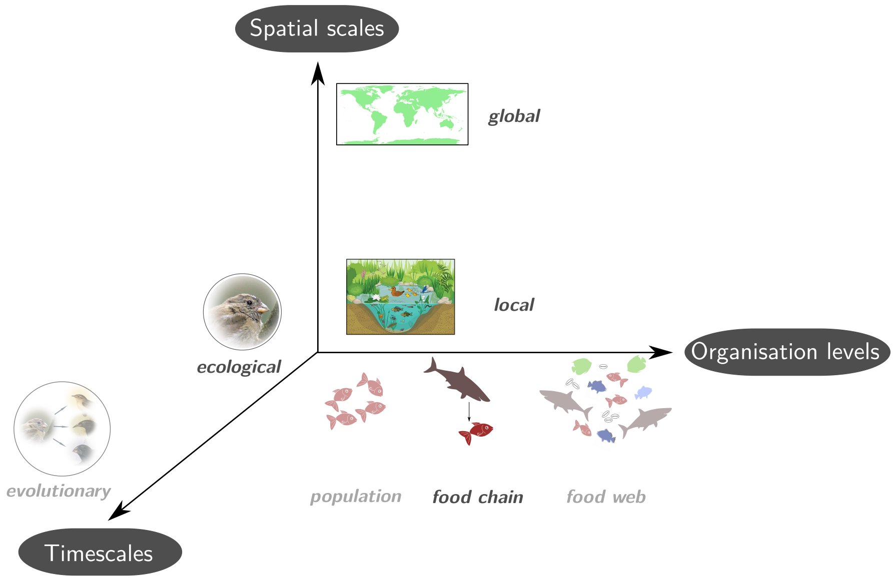
How does temperature affect species and their interactions ?

A cross-scales perspective

A cross-scales perspective

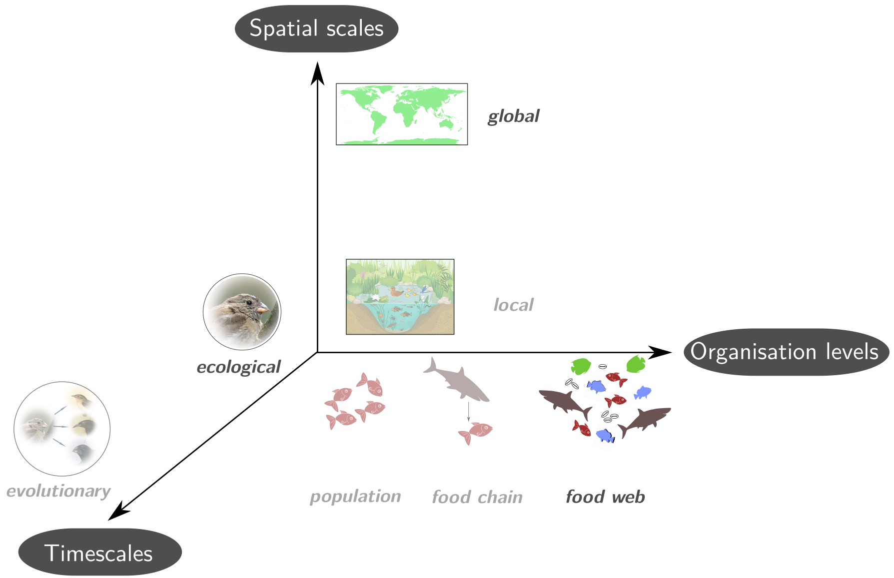


A cross-scale perspective



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

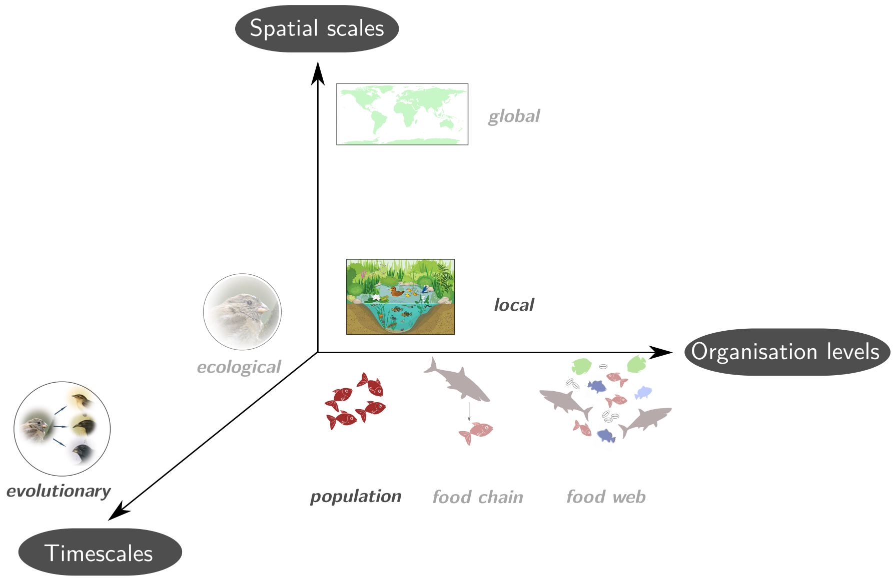
A cross-scale perspective



- 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

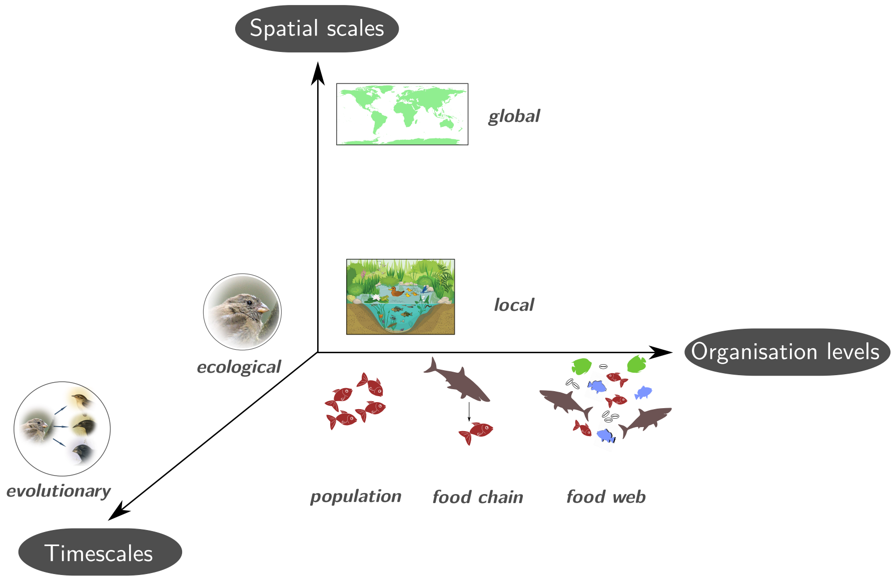
A cross-scale perspective



- 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



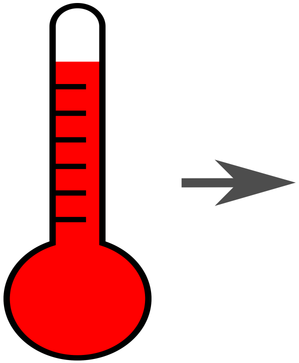
- Thermal mismatches in biological rates determine trophic control and biomass distribution under warming
- Effects of temperature on fish food webs at the global scale
- Short-term thermal adaptation of growth rates in wild bacteria strains

Theoretical approaches

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

A cross-ecosystem comparison

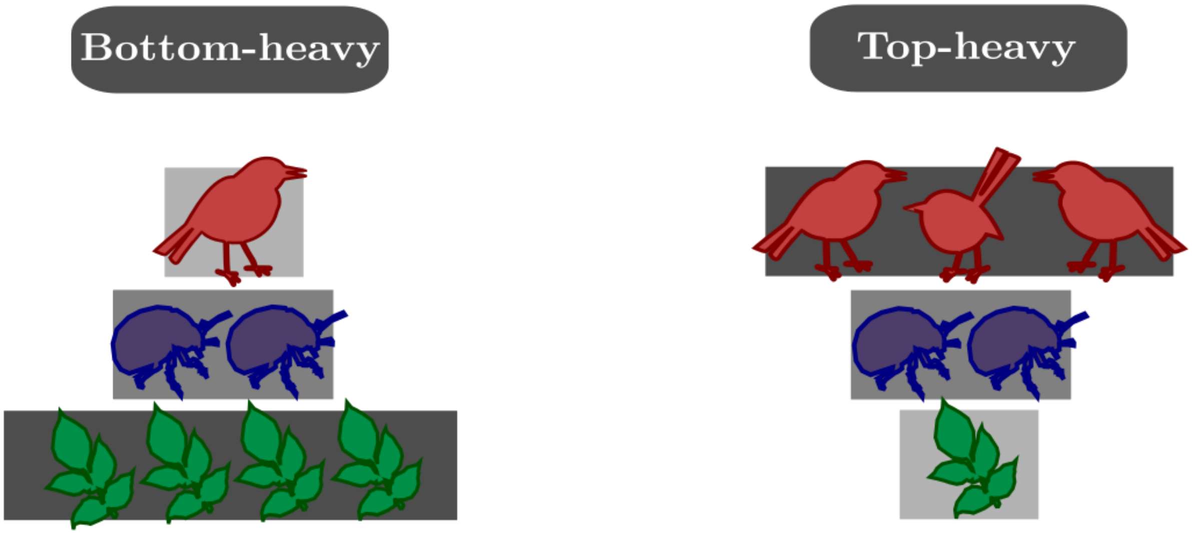
Effects of temperature on trophic interactions



- Consumer-resource interactions
- Compare marine and terrestrial ecosystem

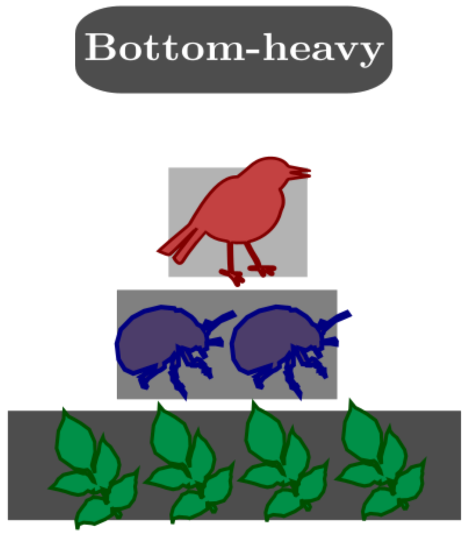
Food chain structural properties

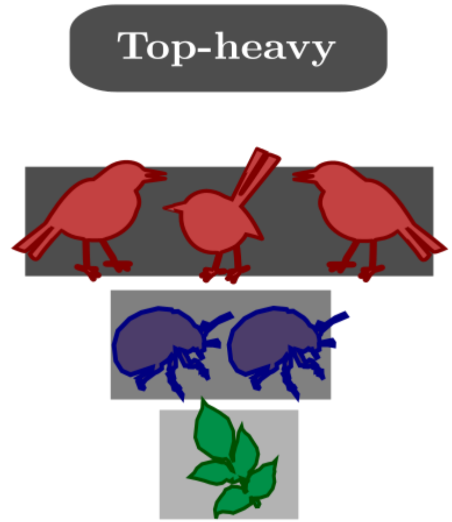
Biomass distribution



Food chain structural properties

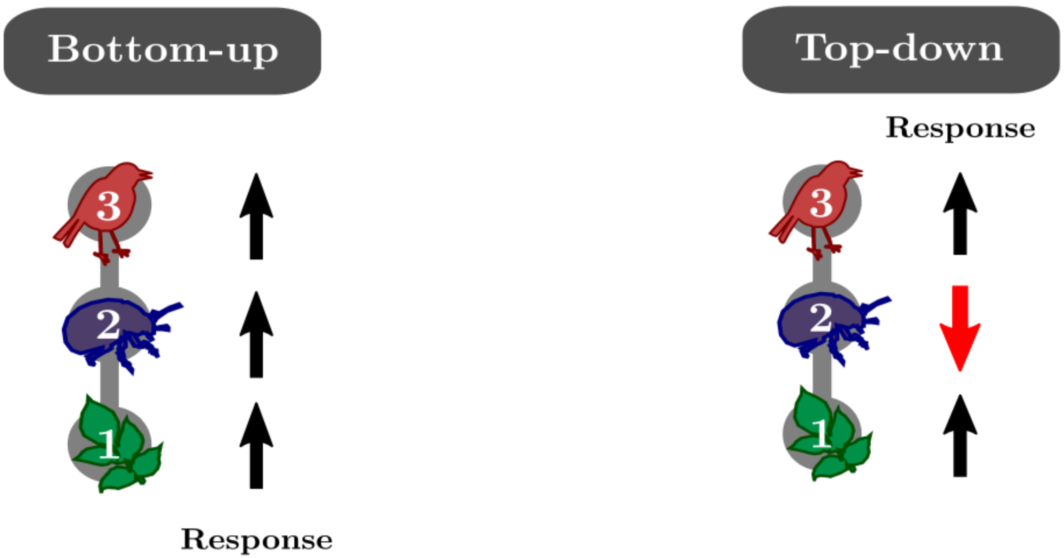
Biomass distribution





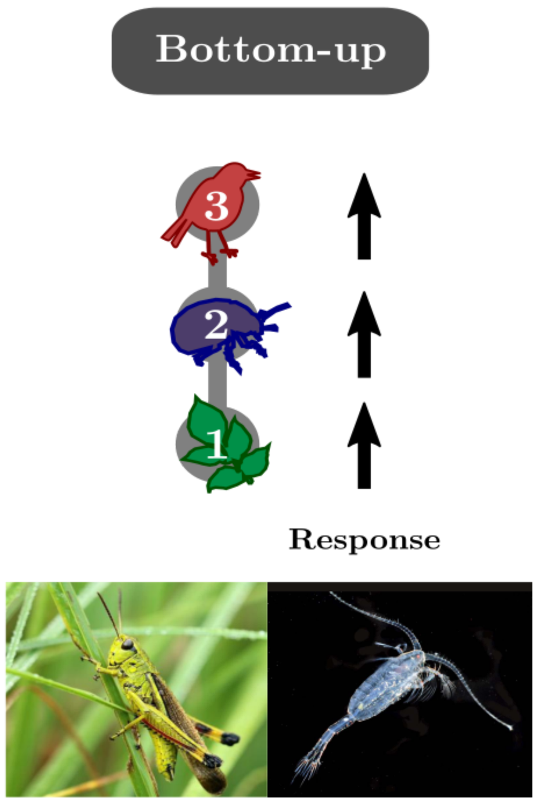
Food chain dynamical features

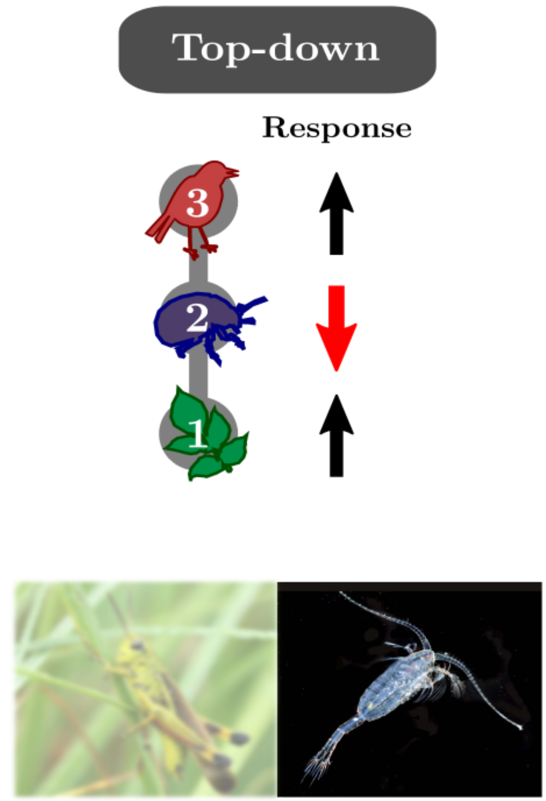
Trophic control



Food chain dynamical features

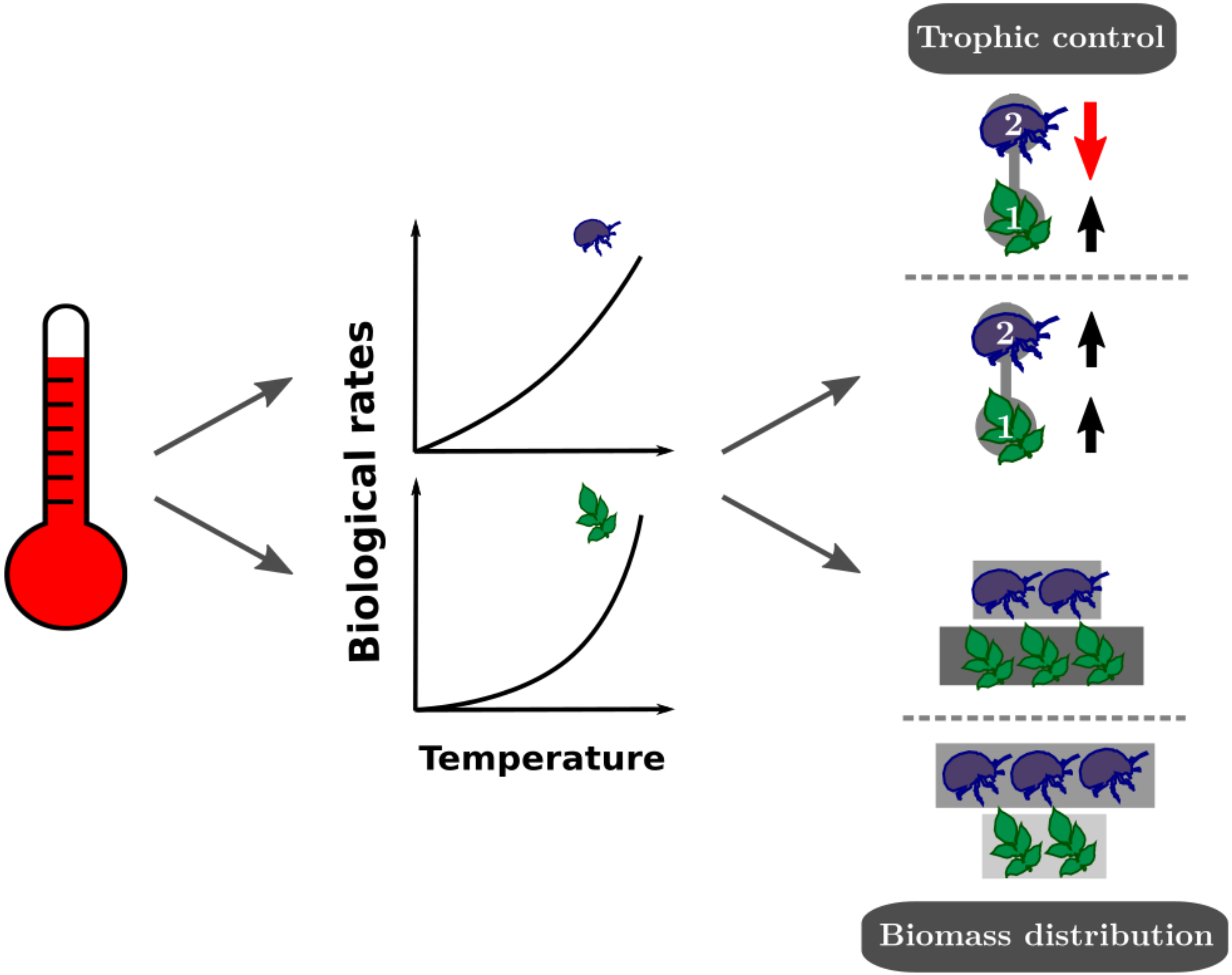
Trophic control





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

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

- 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

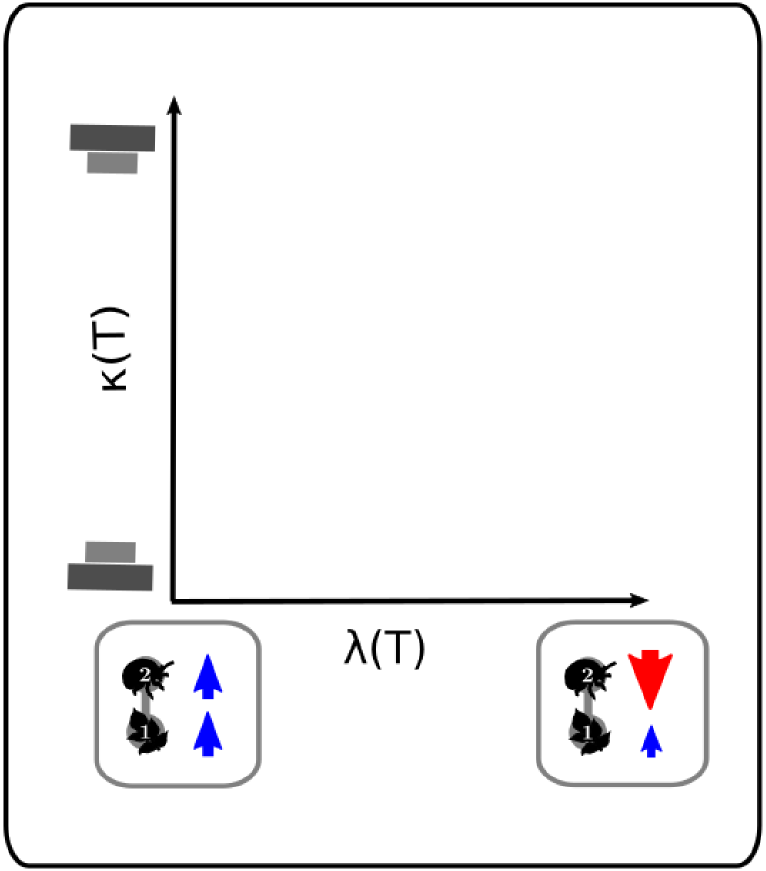
Examples :

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

Important to match stability levels observed in nature

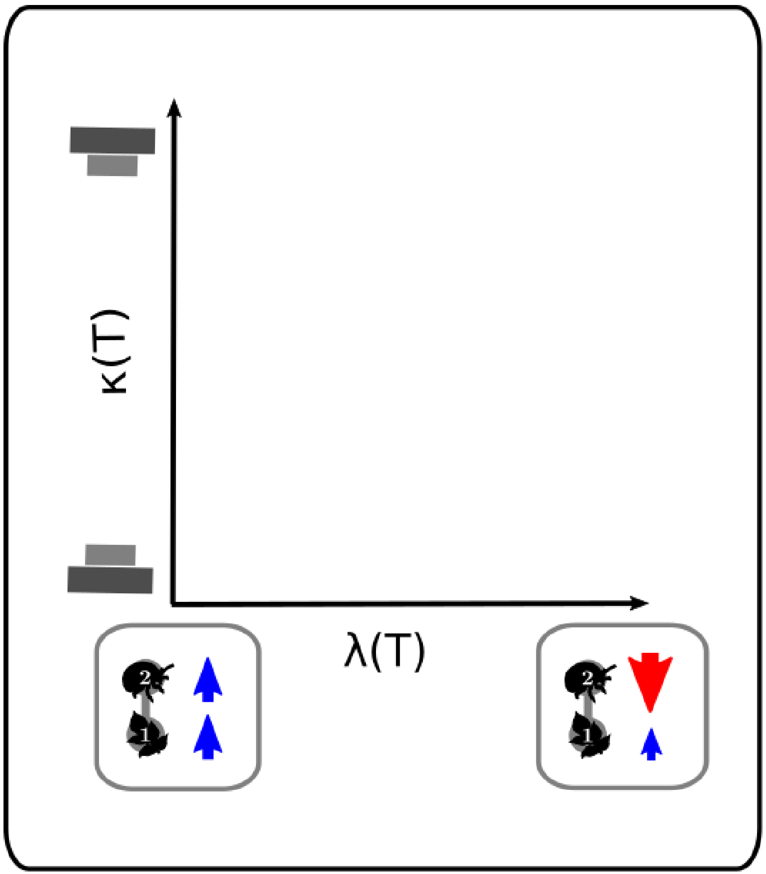
Theoretical framework

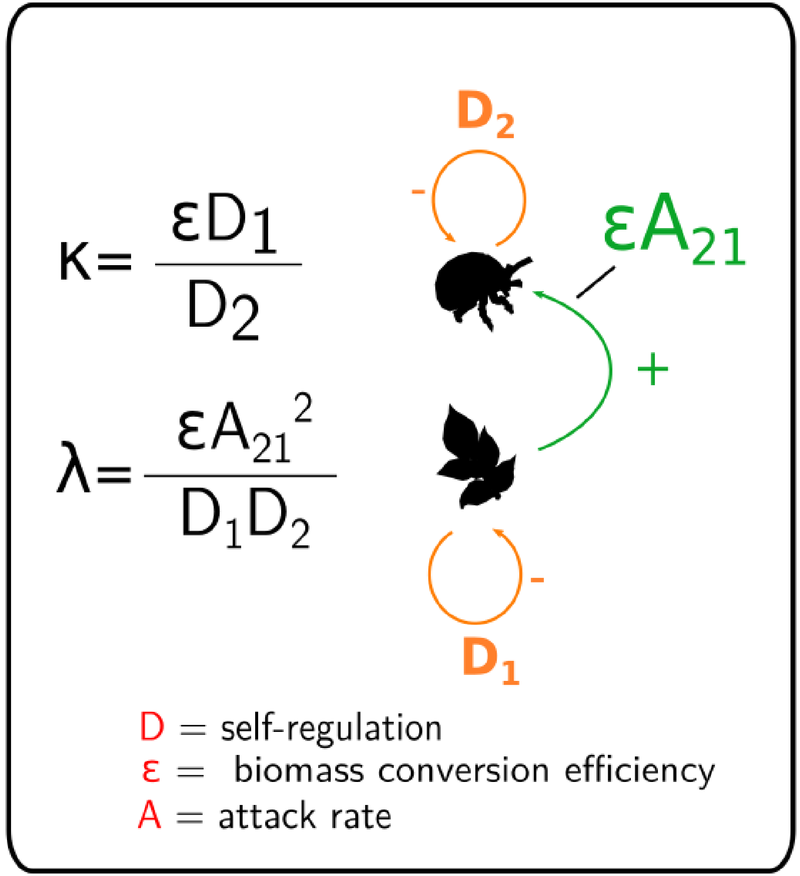
Synthetic parameters describing food chain properties



Theoretical framework

Synthetic parameters describing food chain properties

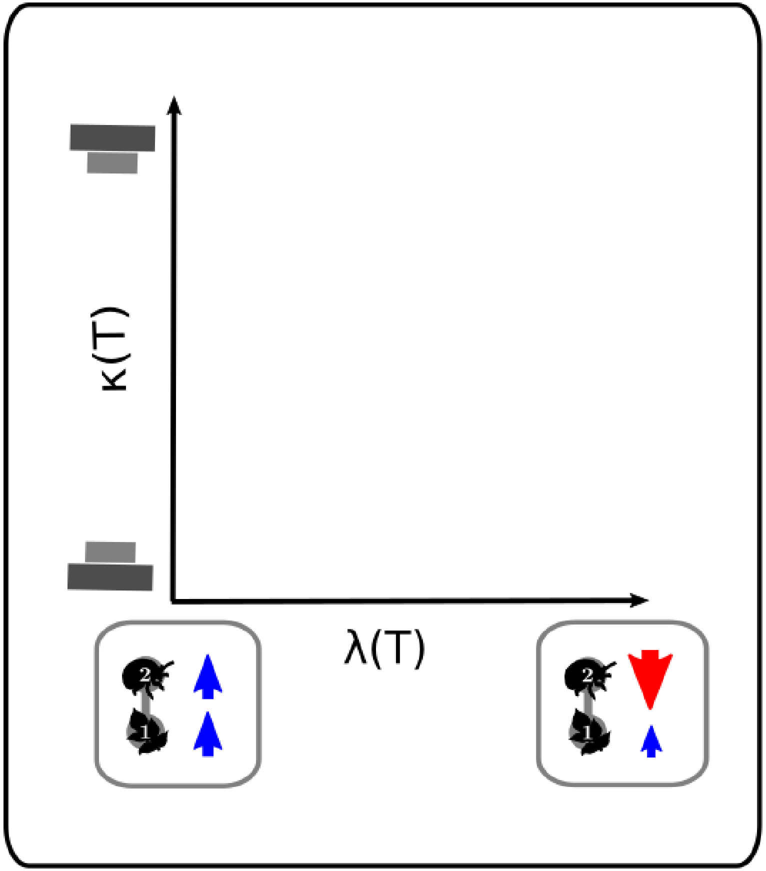




κ denotes how much biomass is gained by consumers per unit biomass lost by resources

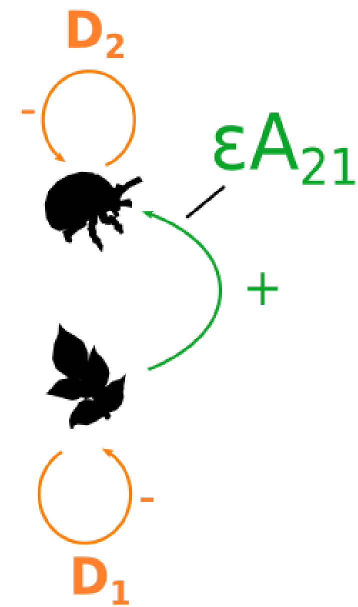
Theoretical framework

Synthetic parameters describing food chain properties



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

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

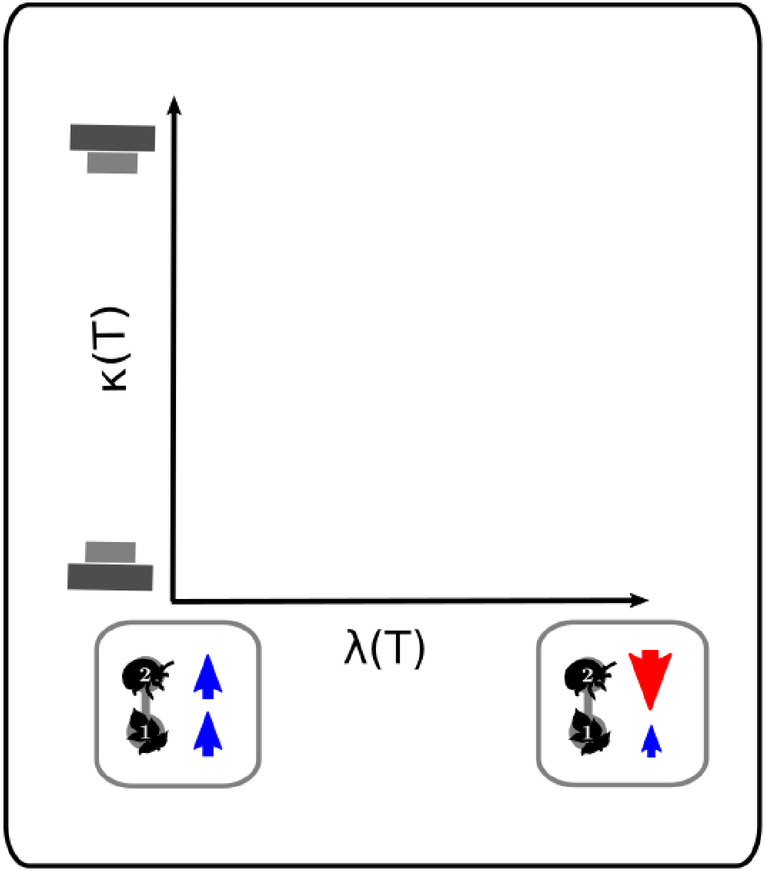


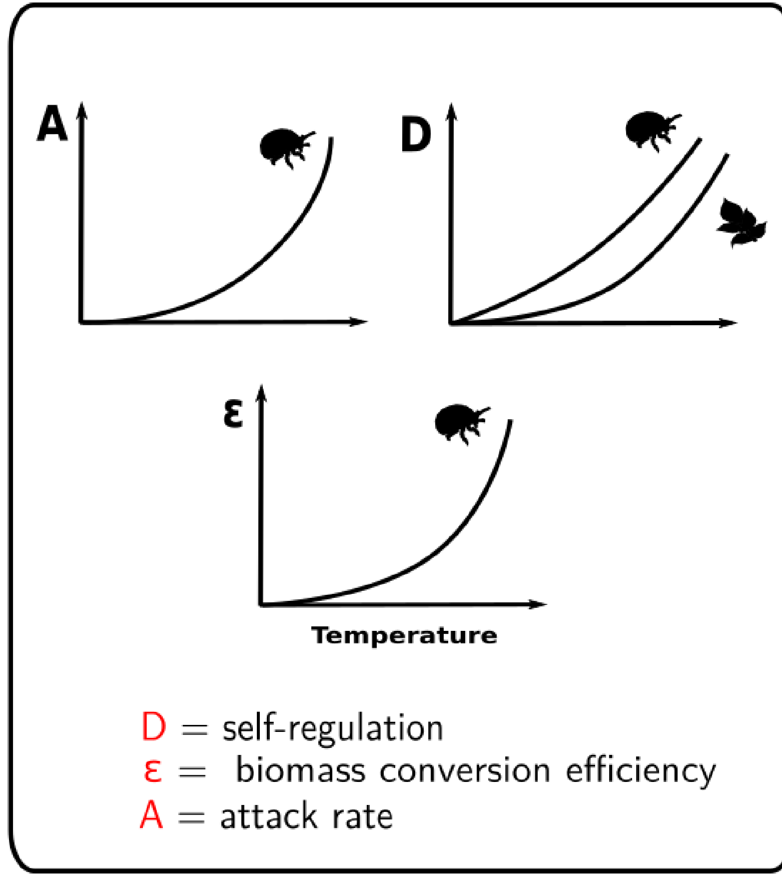
D = self-regulation
ε = biomass conversion efficiency
A = attack rate

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

Theoretical framework

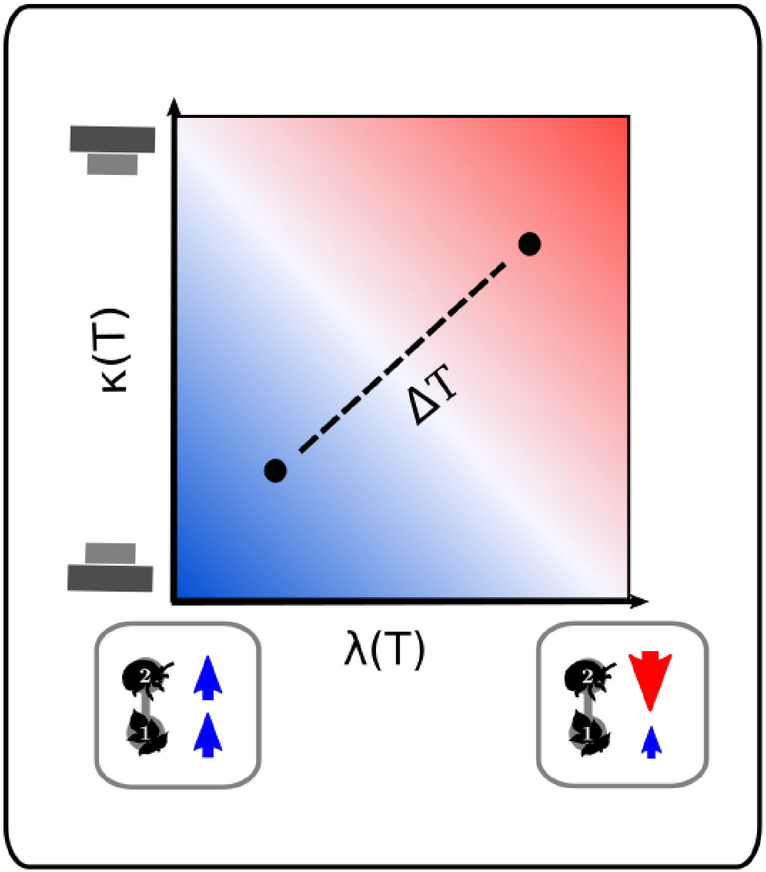
Temperature dependence

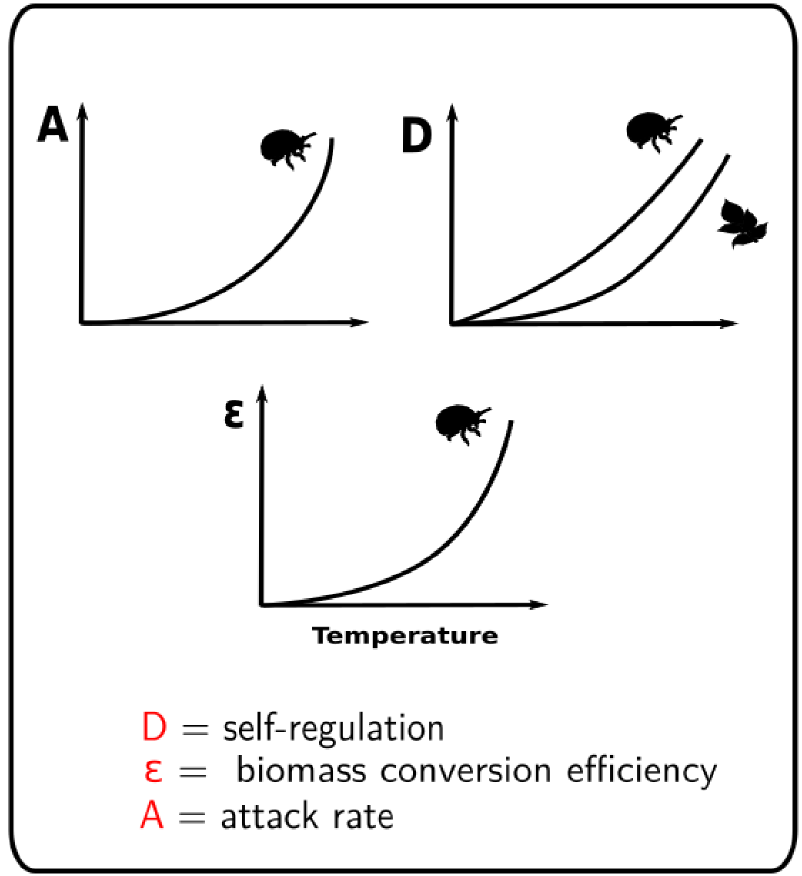




Theoretical framework

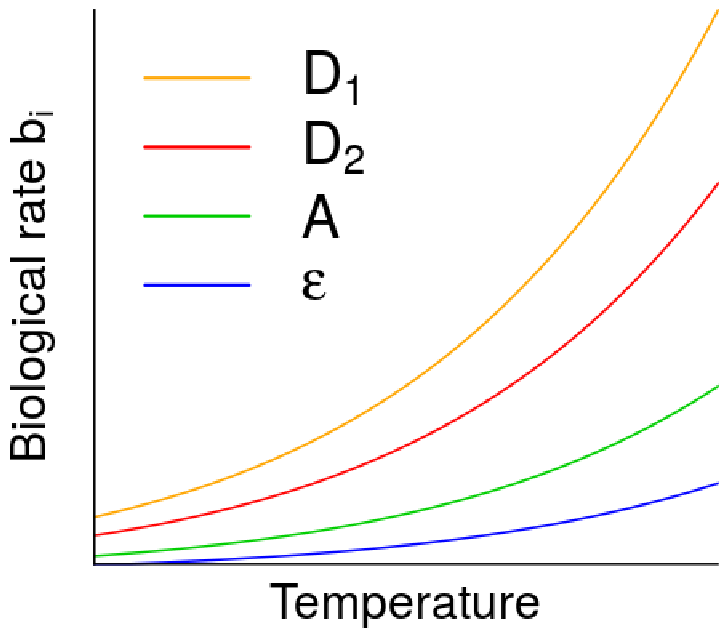
Temperature dependence





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

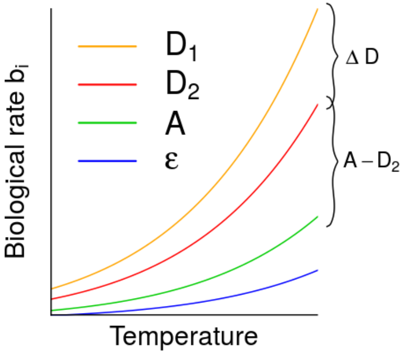
Temperature dependence of the synthetic parameters

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

Their activation energies :

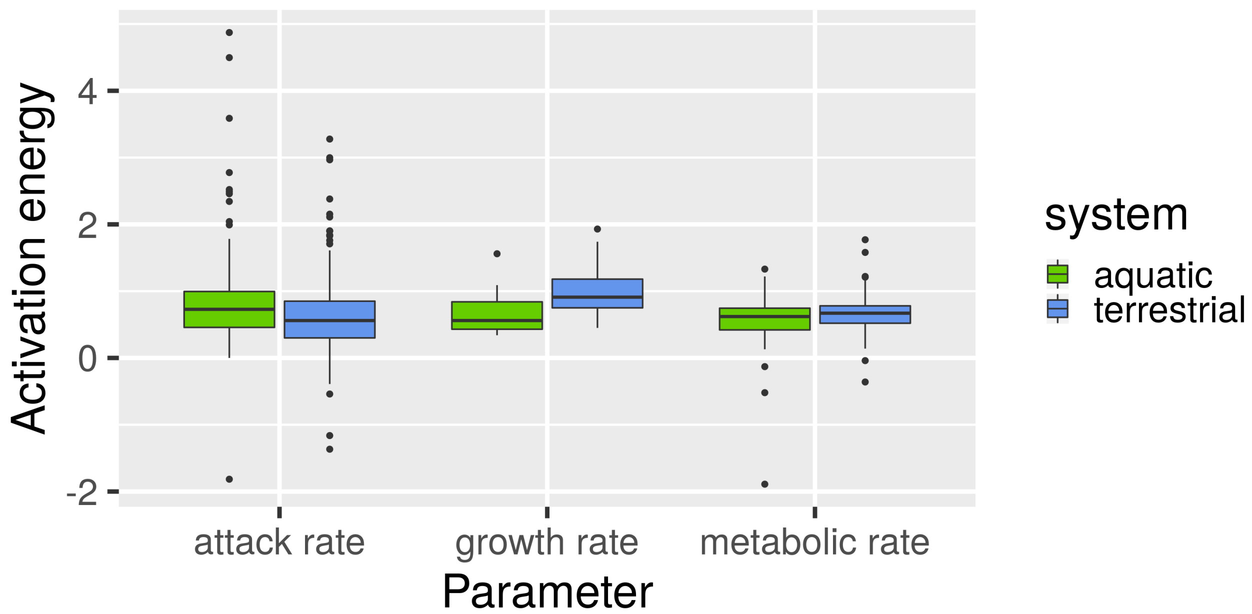
$$E_\kappa = E_\epsilon + E_{D_1} - E_{D_2}$$

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



Mismatches between biological rates

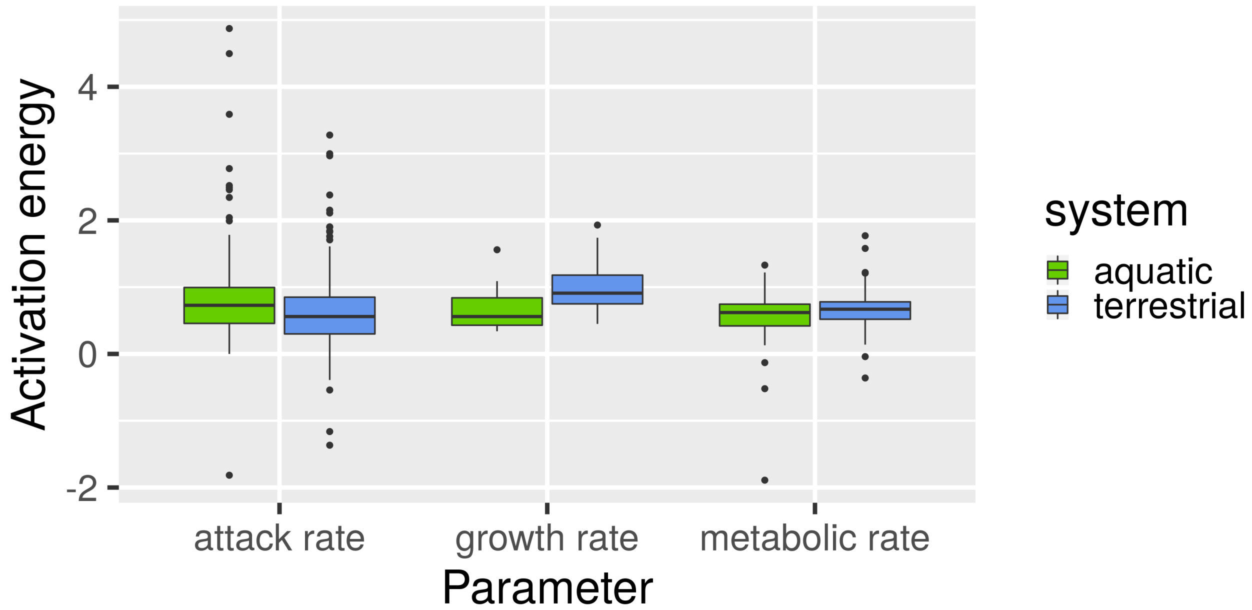
Database of activation energies



- 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

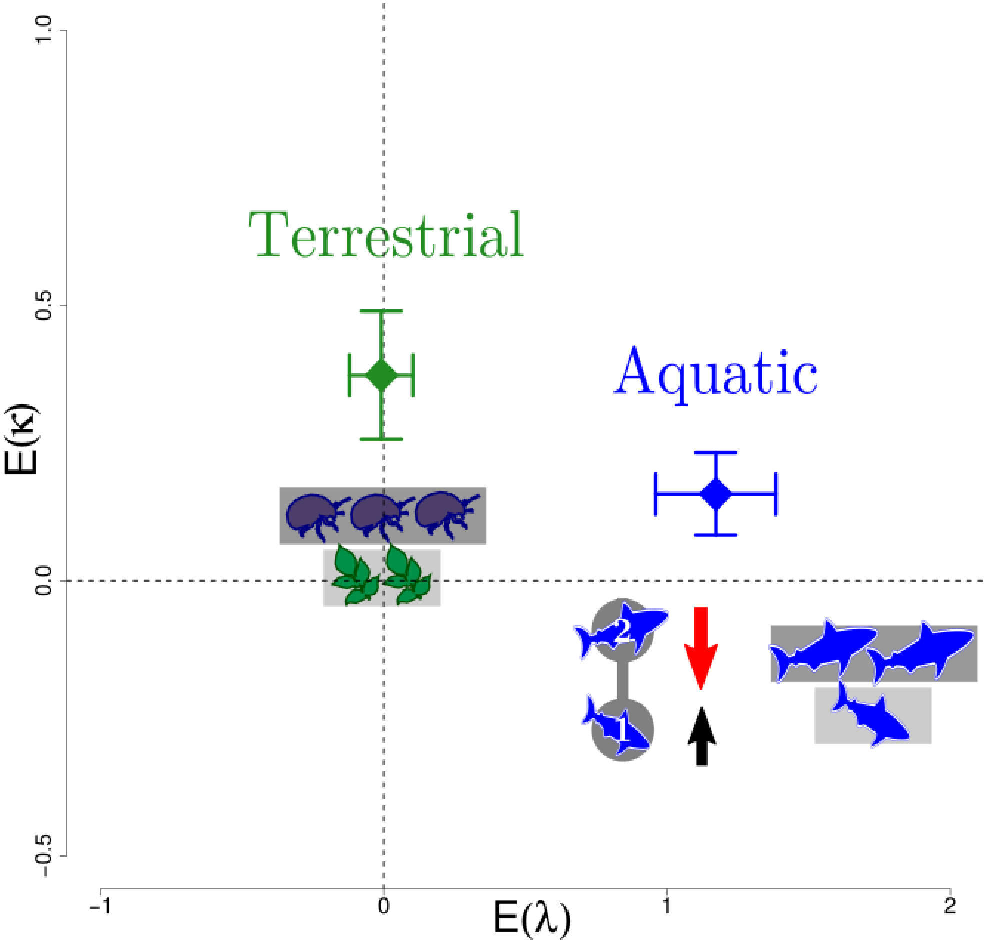
$$D \sim g, A, q$$

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

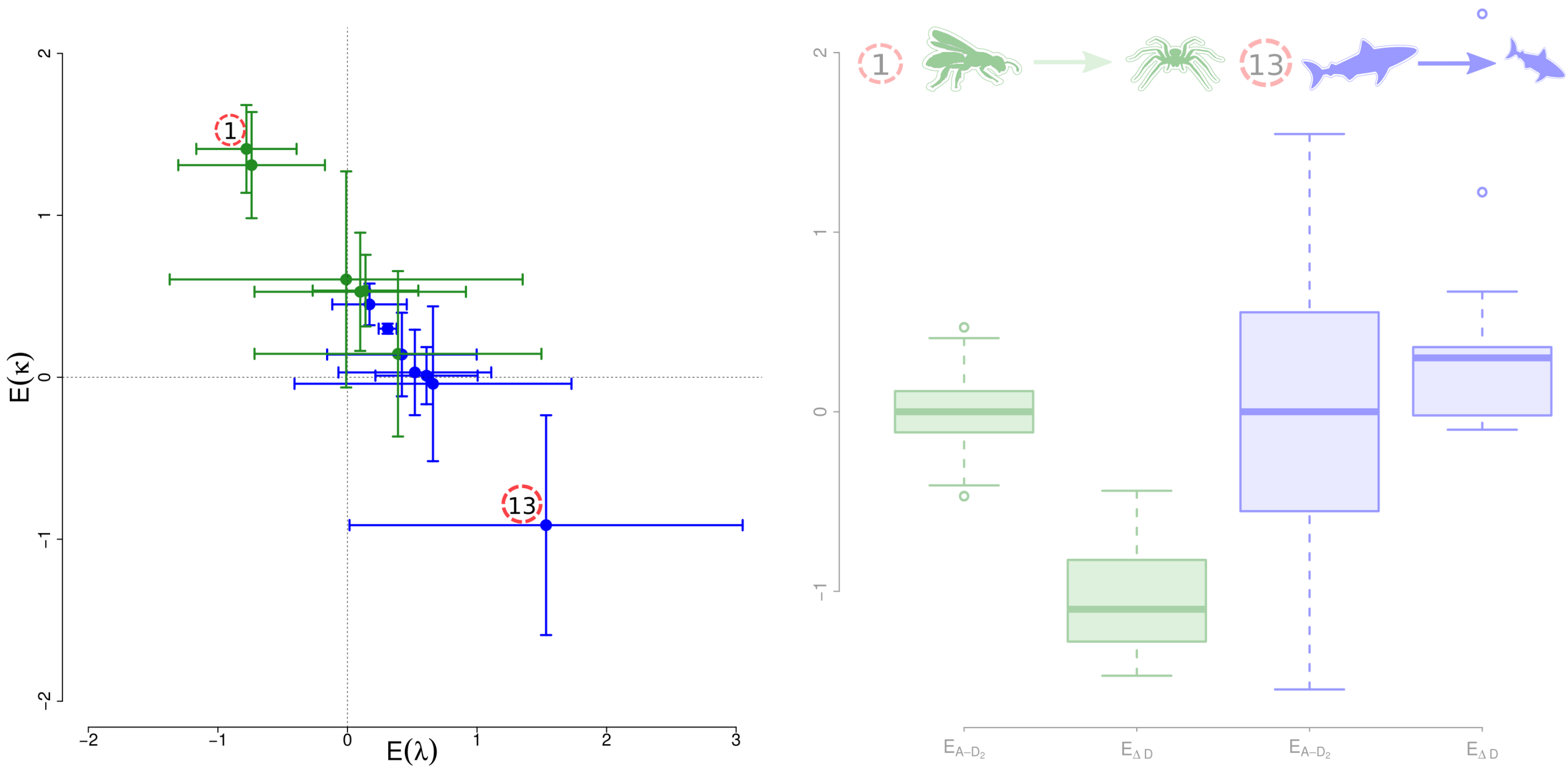
- Temperature dependence of λ and κ
  - Aquatic vs terrestrial organisms
  - Across taxonomic groups
- Shift in λ and κ for herbivores-primary producers at the global scale

Results

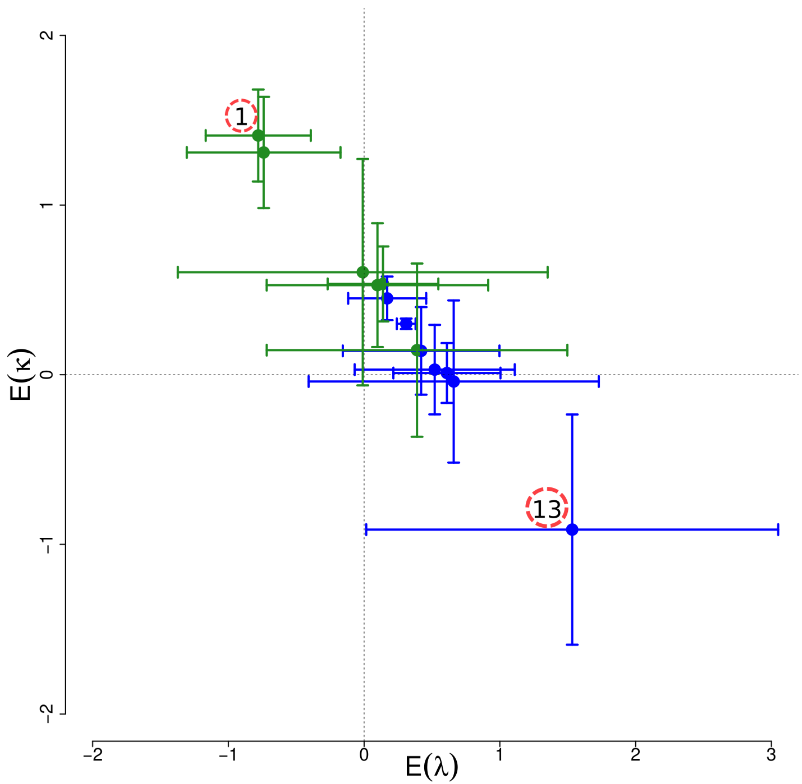
Thermal dependence of λ and κ

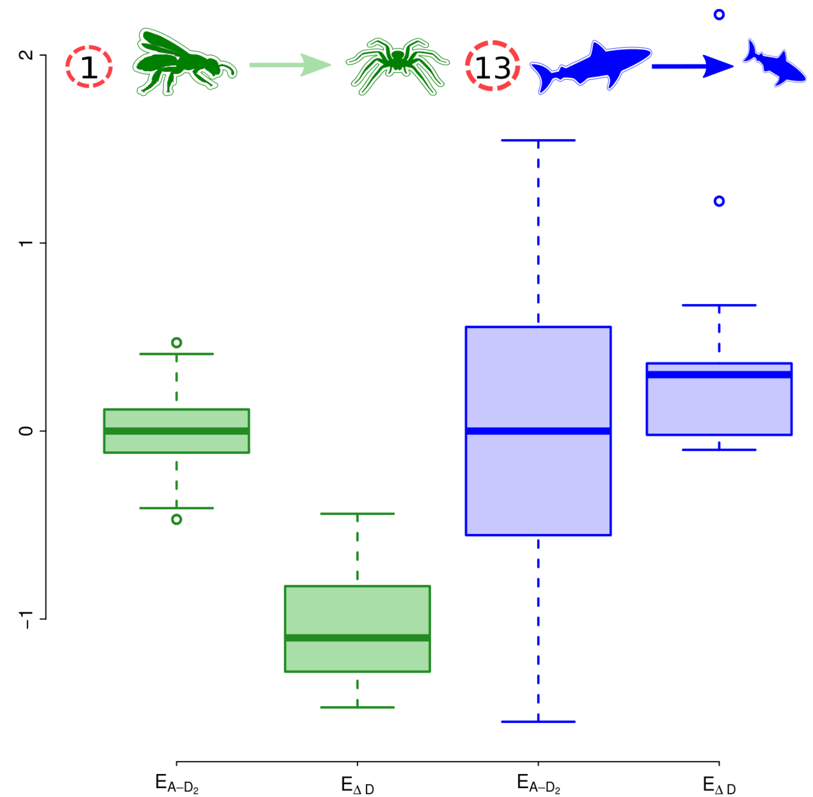


Thermal dependence of λ and κ across taxonomic groups



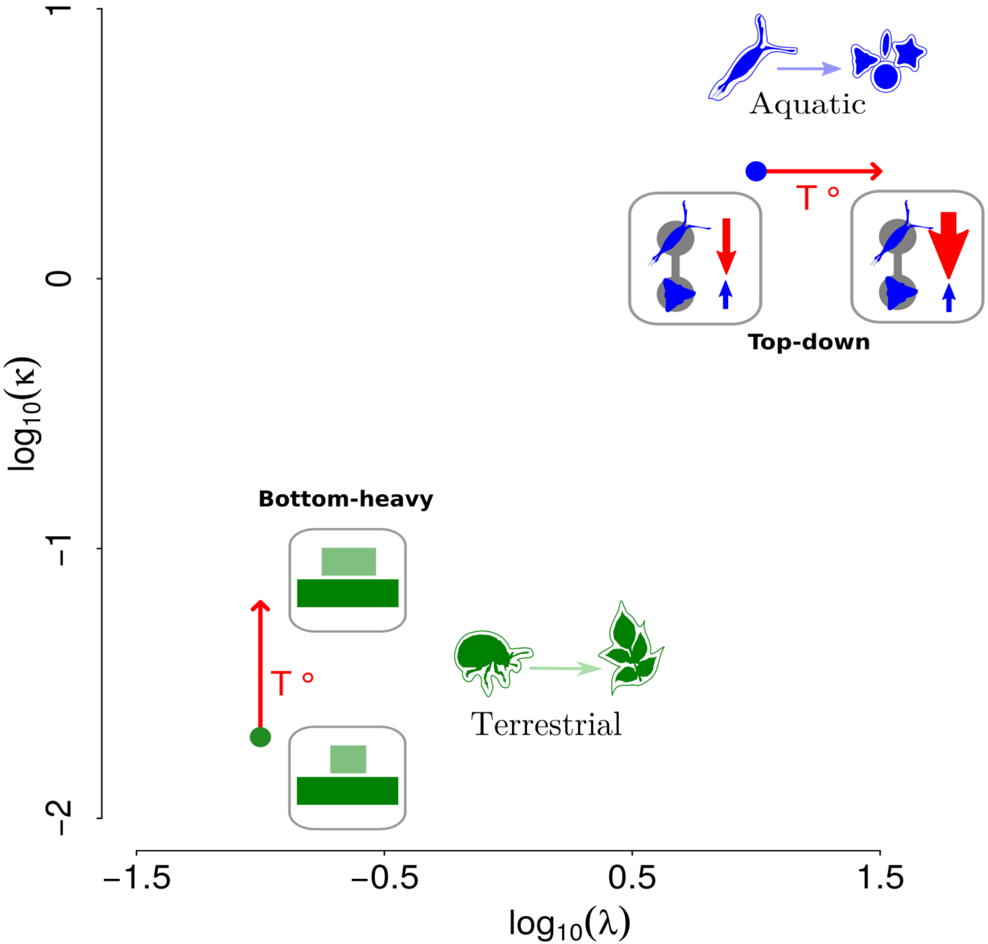
Thermal dependence of λ and κ across taxonomic groups





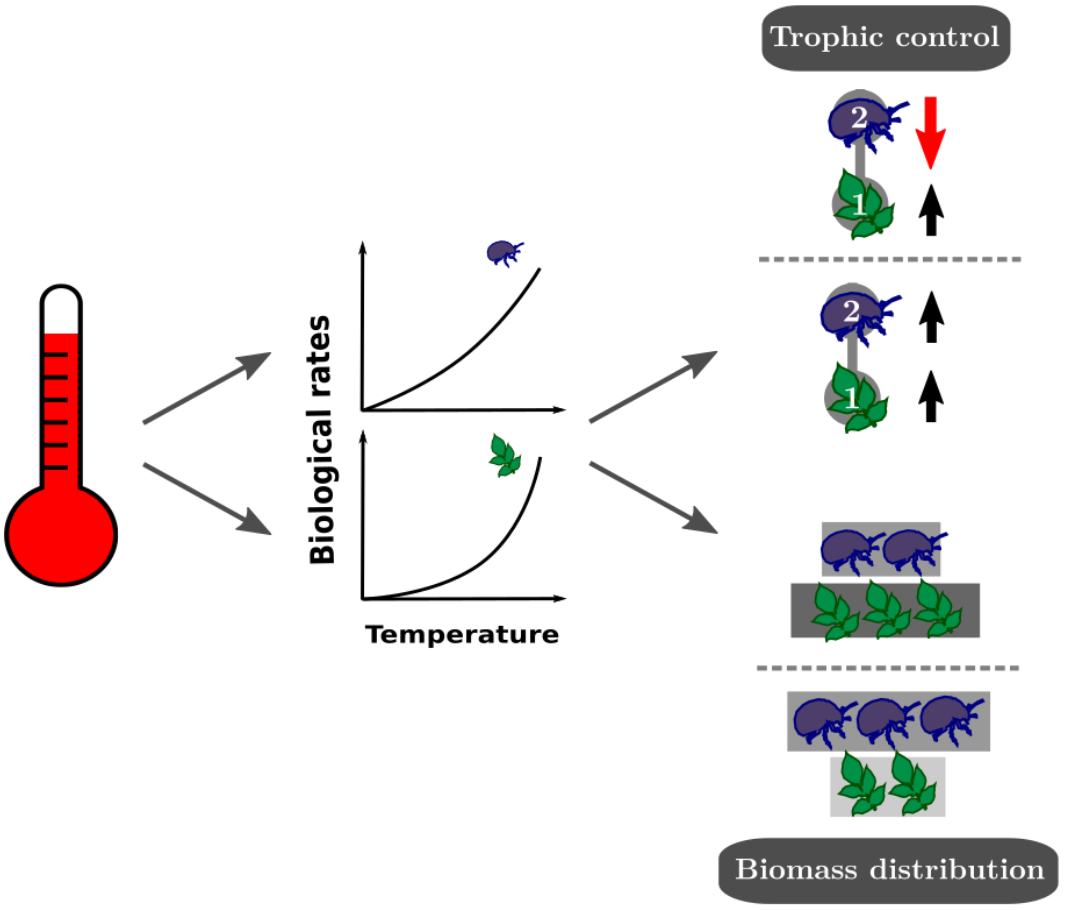
Mismatches between biological rates

Herbivory at the global scale



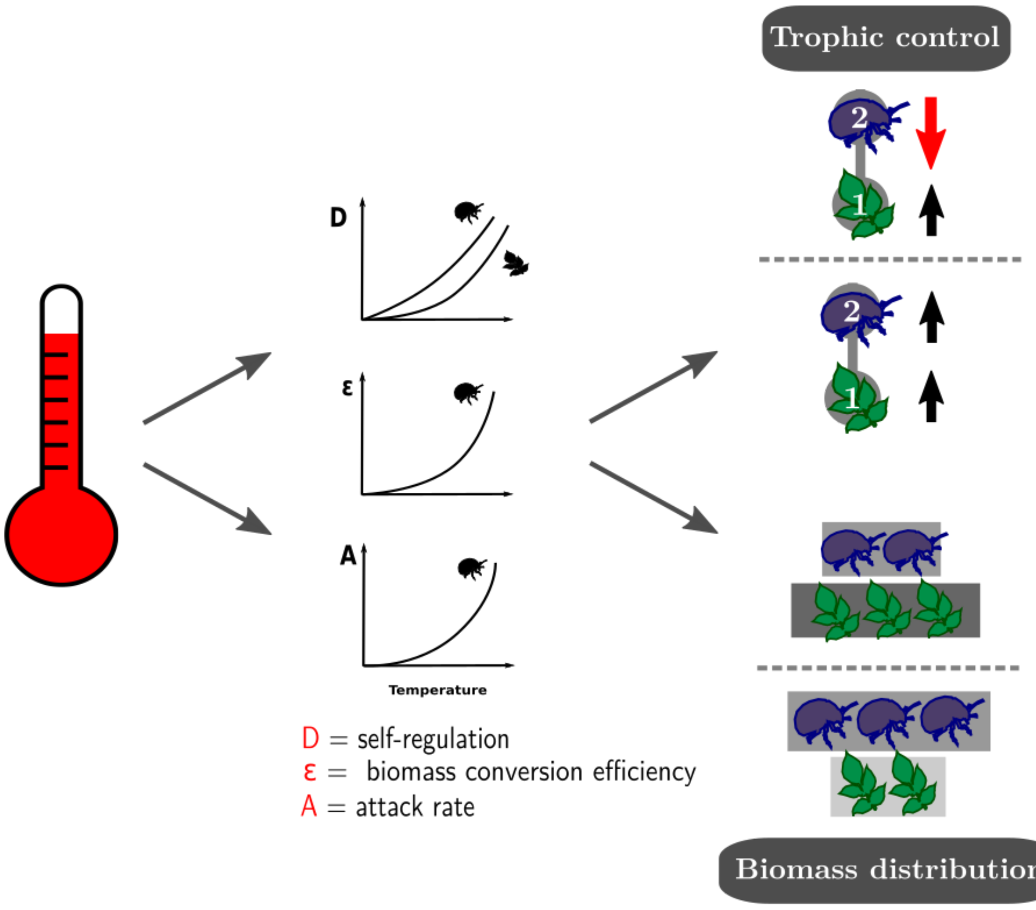
To conclude

To conclude



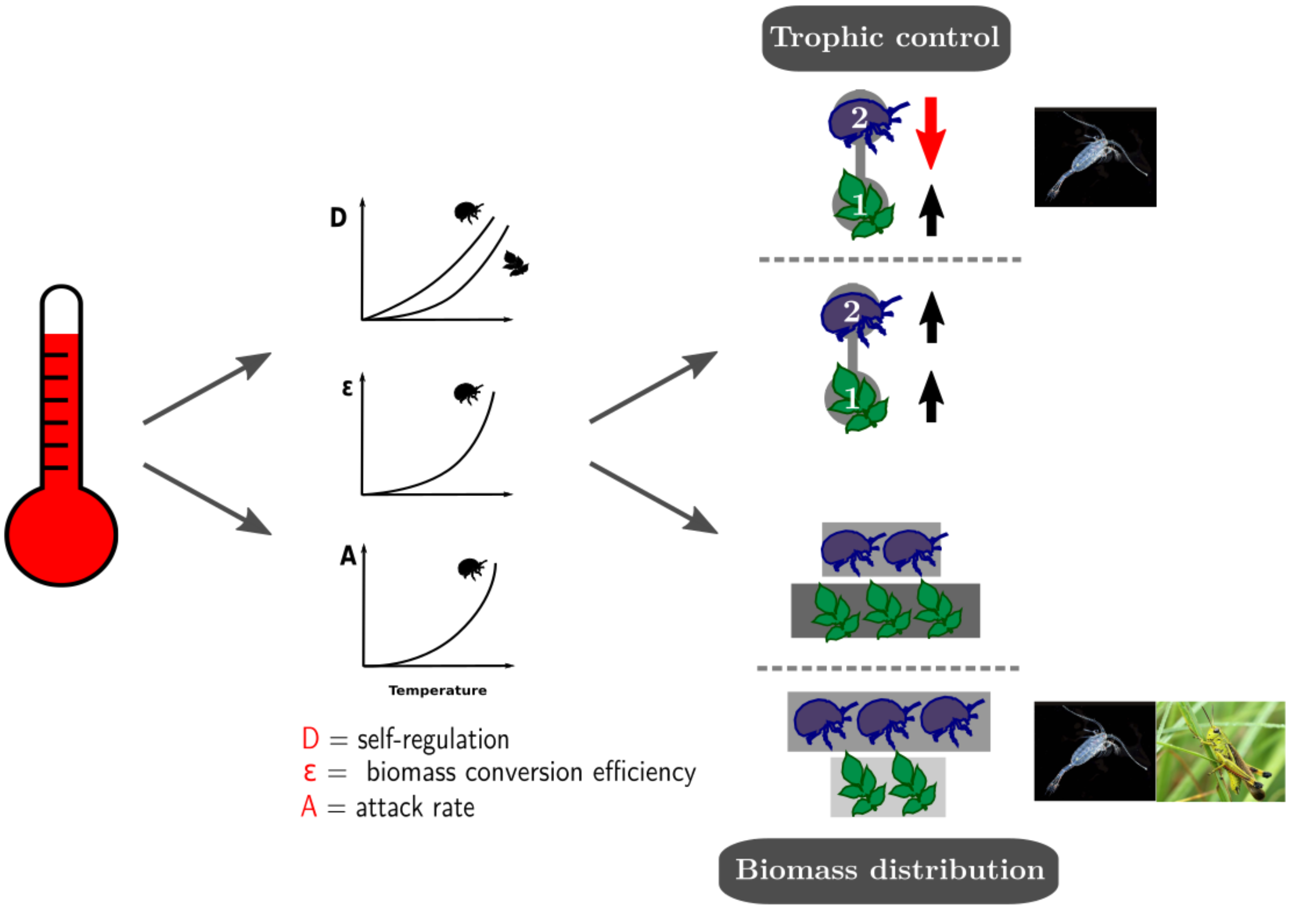
Trophic control
2
1
2
1
Biological rates
Temperature
Biomass distribution

To conclude



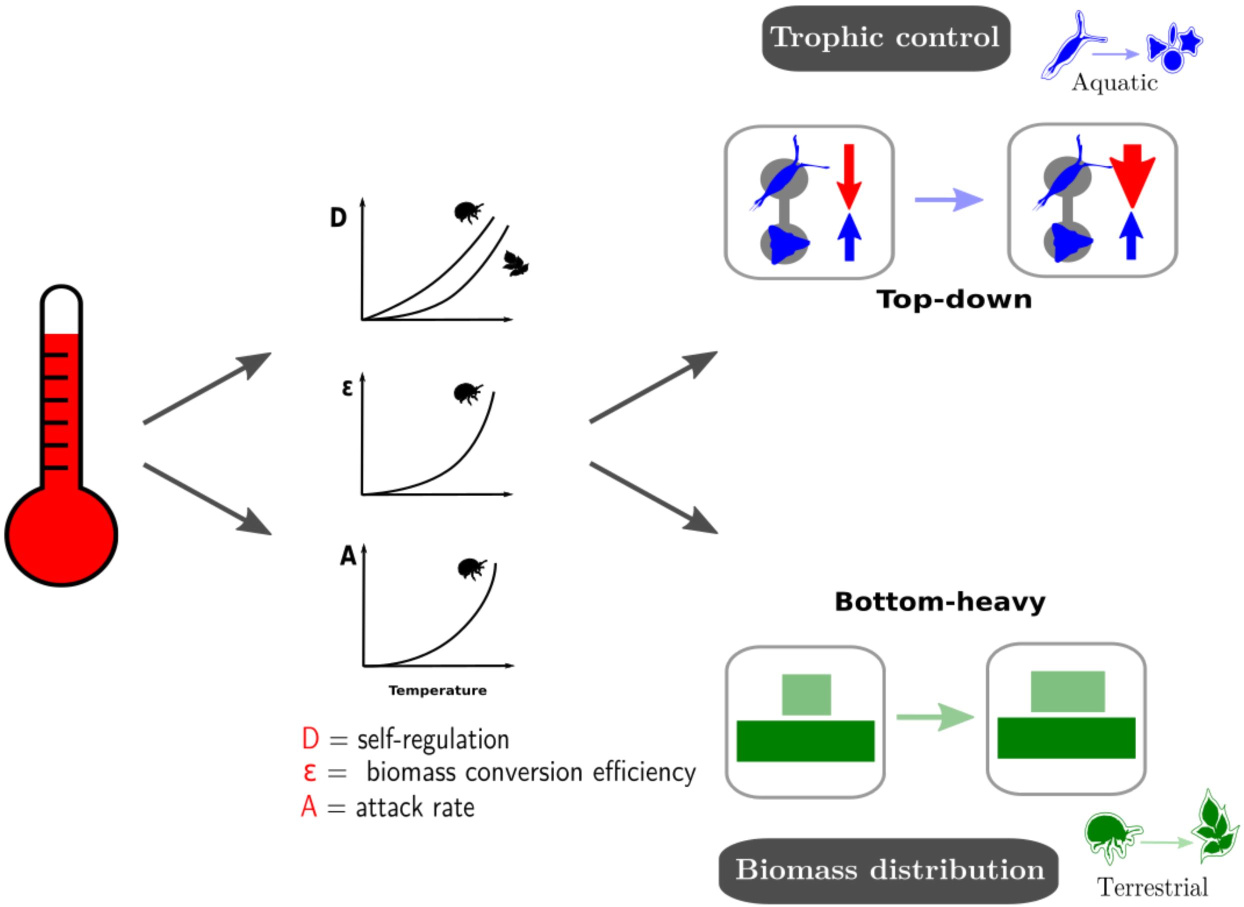
3 fundamental biological rates and their mismatches

To conclude



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

To conclude



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

Herbivory : more top-down control and less bottom-heavy biomass distribution

To conclude

- Mechanistic understanding
- Differences between aquatic and terrestrial communities
- Predictions
- Variation between taxonomic groups

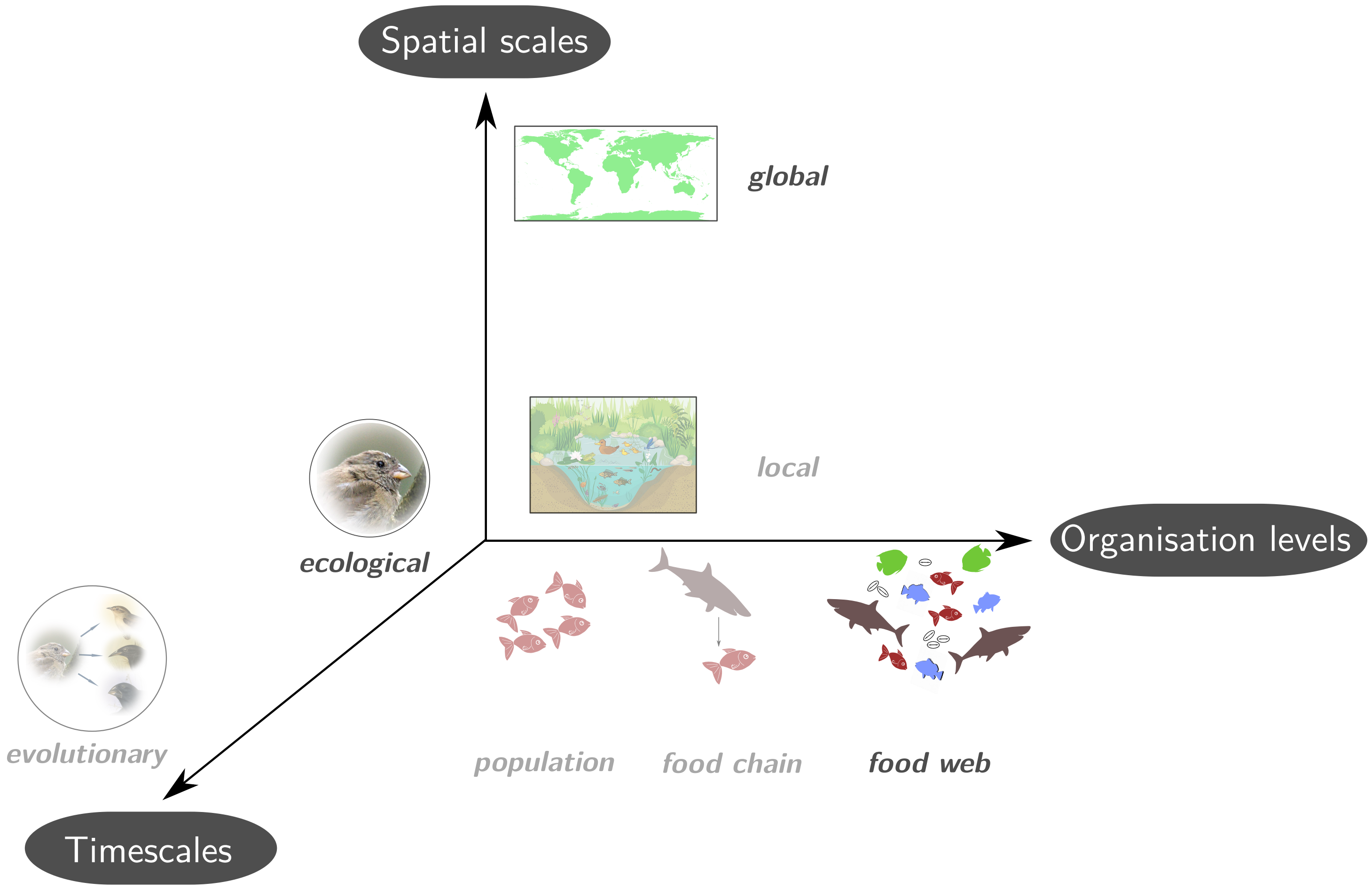
To conclude

- Mechanistic understanding
- Differences between aquatic and terrestrial communities
- Predictions
- Variation between taxonomic groups

But...

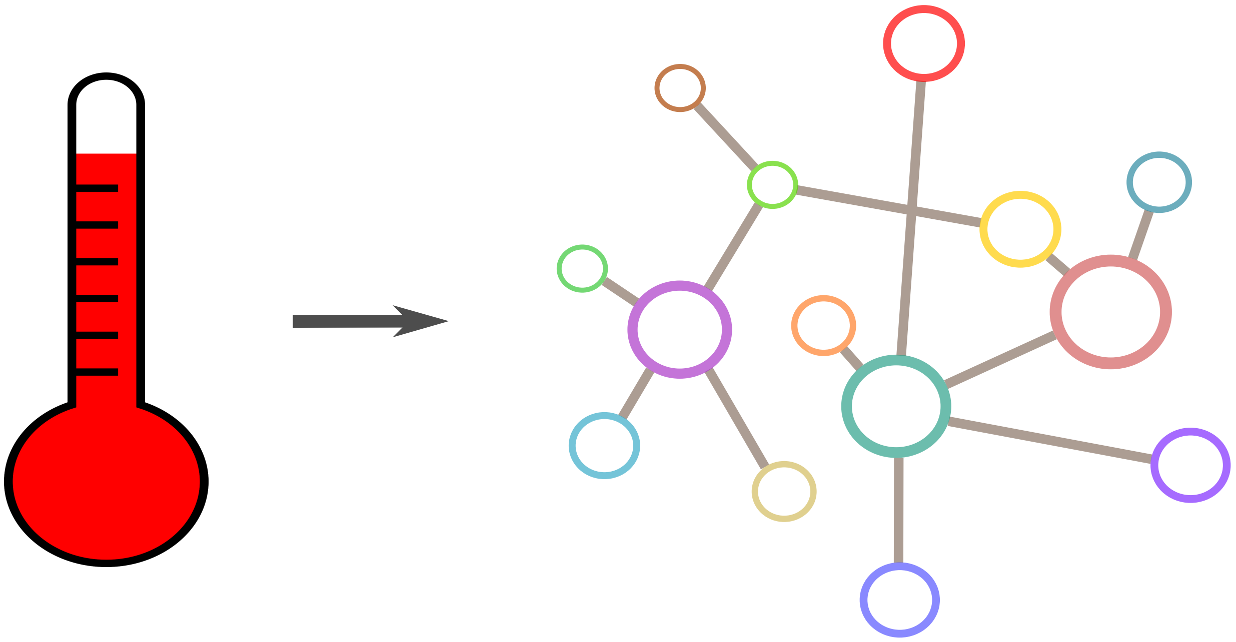
- Lack of data
  - Self-regulation
  - Biomass conversion efficiency
  - Full thermal response
- Consumer-resource interactions

Upscaling to food webs at the global scale

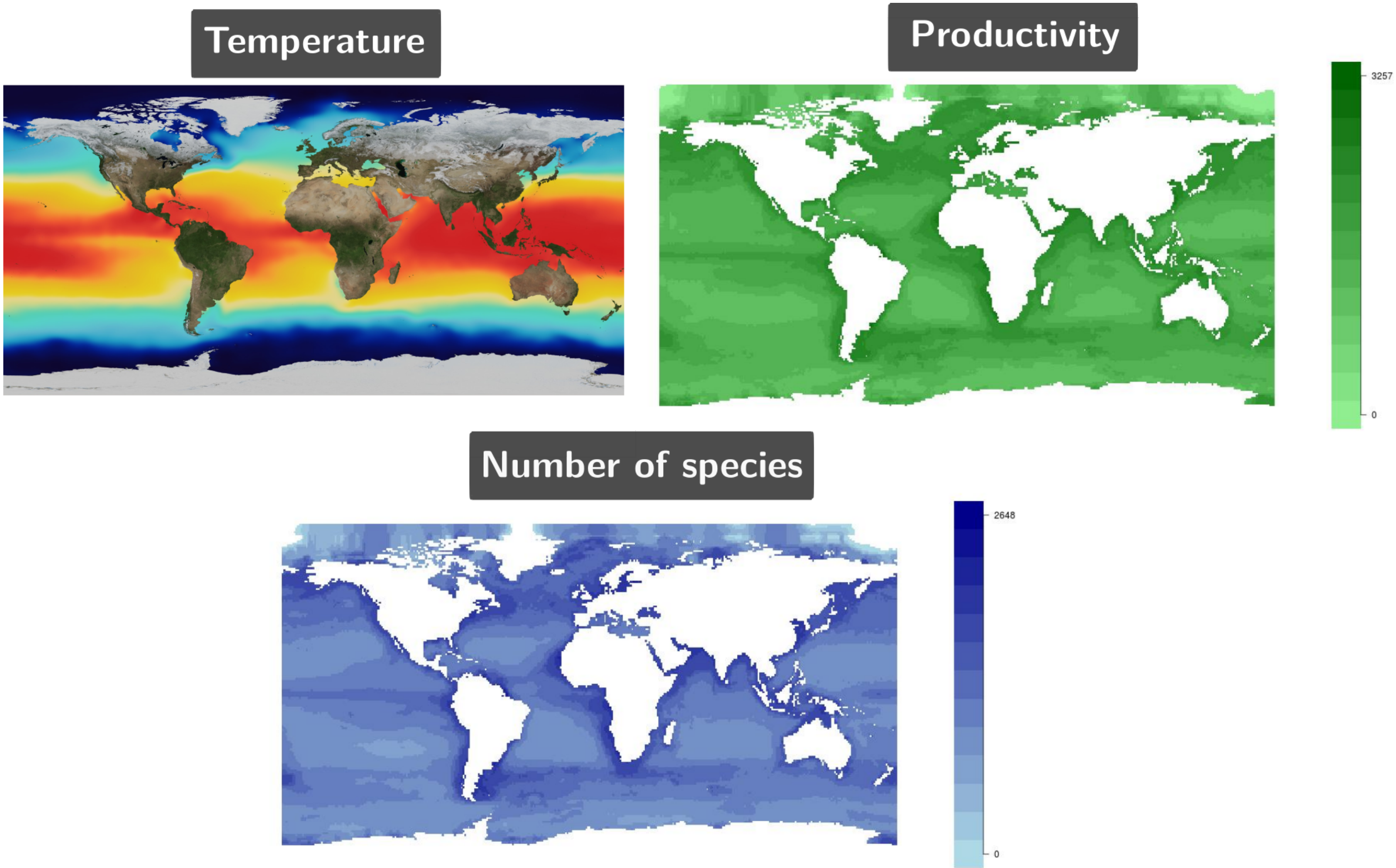


Effects of temperature on fish food webs at the global scale

Effects of temperature on food webs

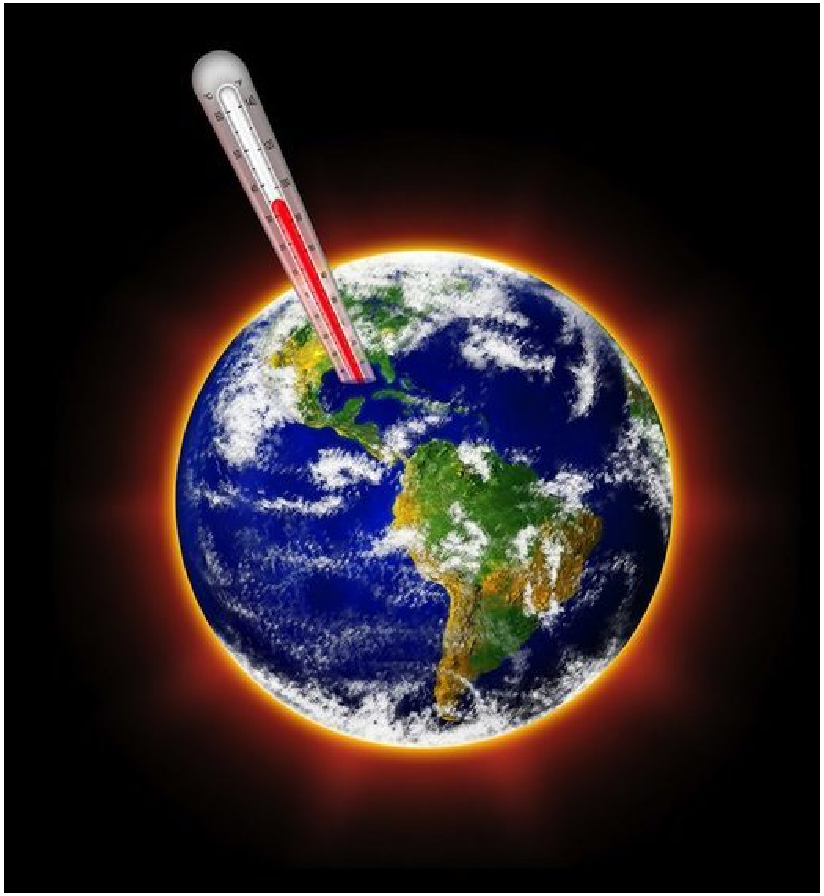


Important gradients across latitudes



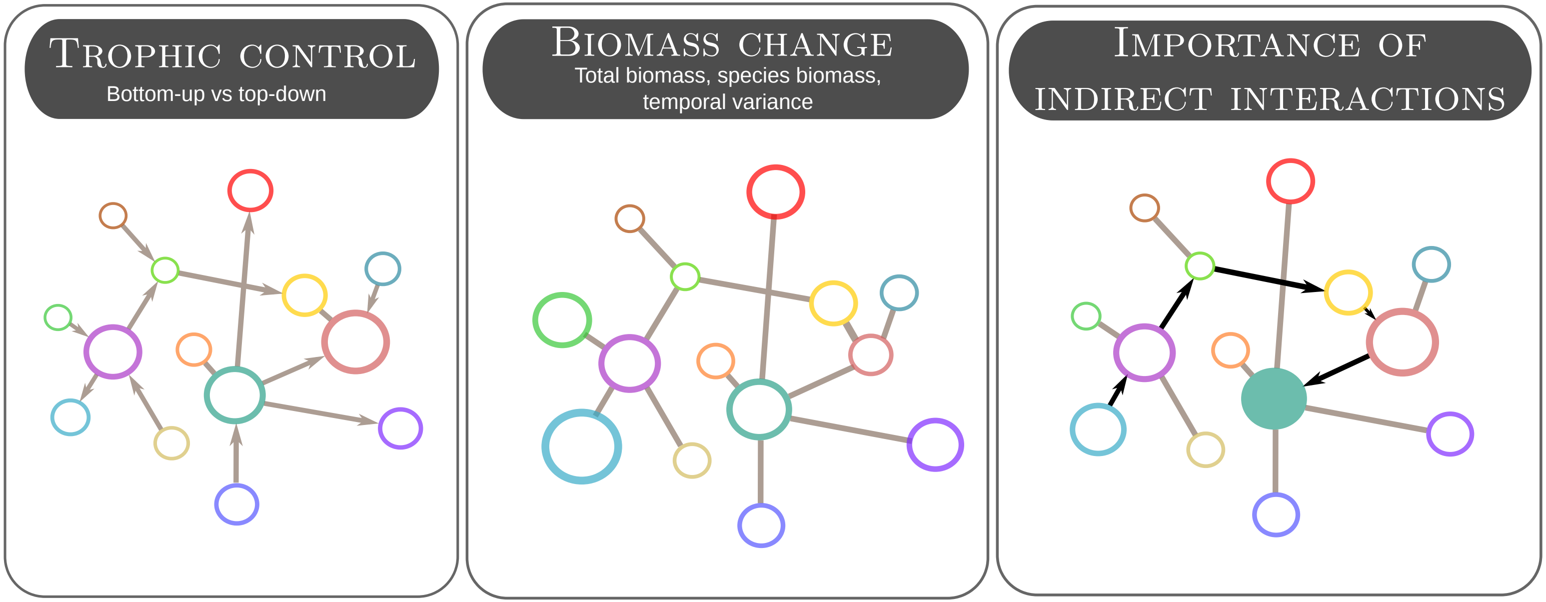
How do they affect food webs dynamics ?

Warming



How does it affect food webs dynamics ?

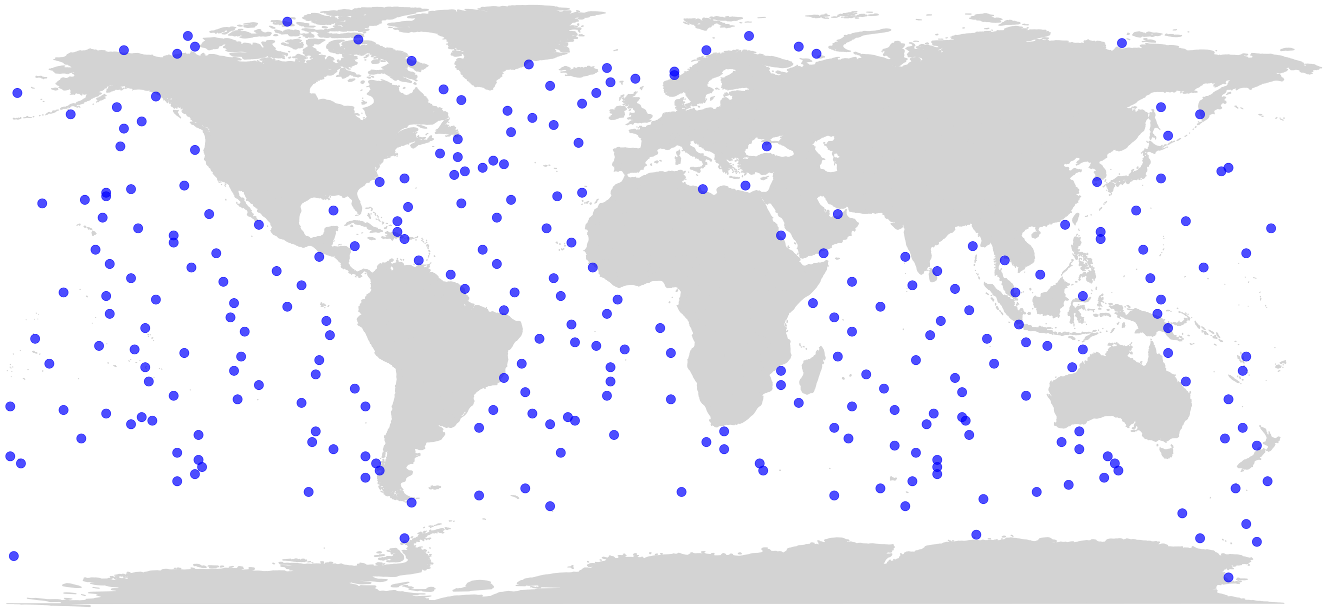
Food webs dynamics



Effects of the latitudinal gradient and warming

Method

Fish communities at large scale



Trophic

interactions

Modelling communities

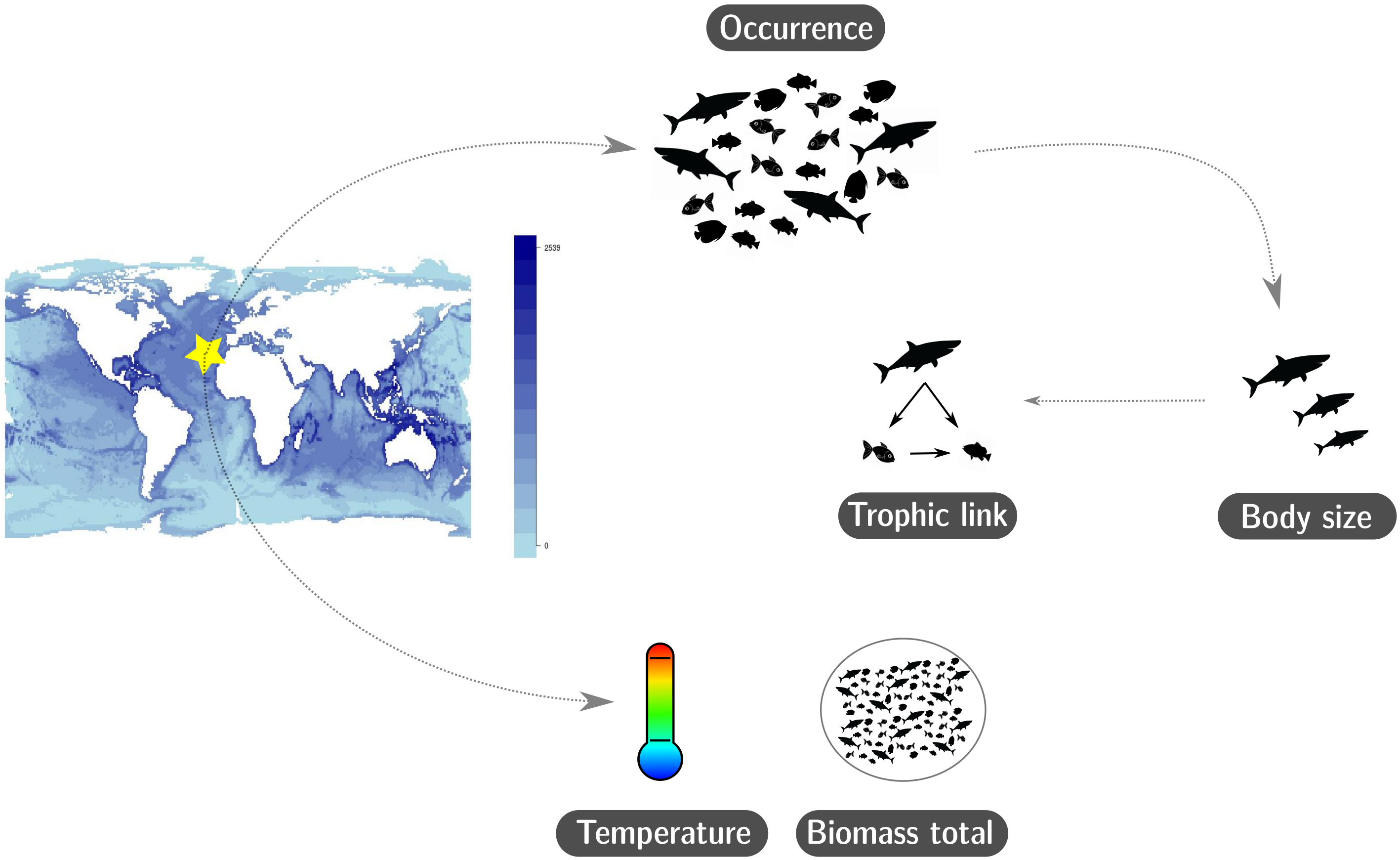
To infer their structural and dynamical properties

Lotka-Volterra system

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

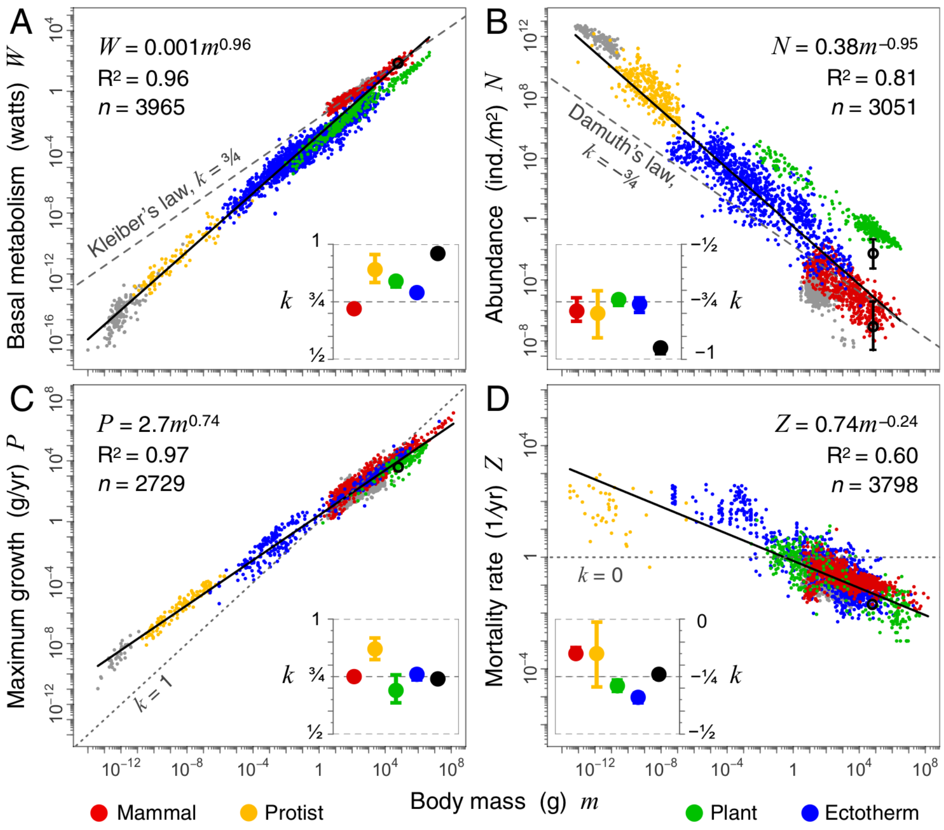
- B biomass
- M_{ij} interaction matrix
- g_i net growth rate
- D_i self regulation
- ϵ conversion efficiency

Data and parameterization

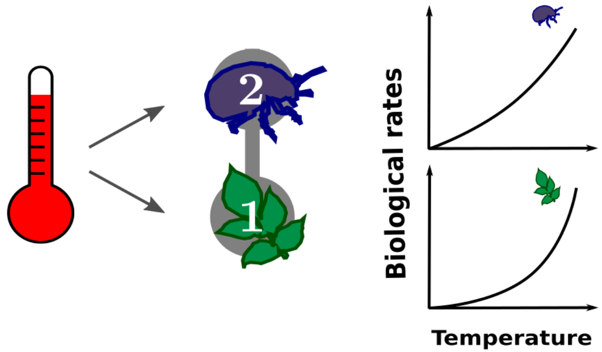


Estimation of species biomass

Abundance law



Temperature 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
What about self-regulation ?

Method to estimate self-regulation

From available parameters and

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

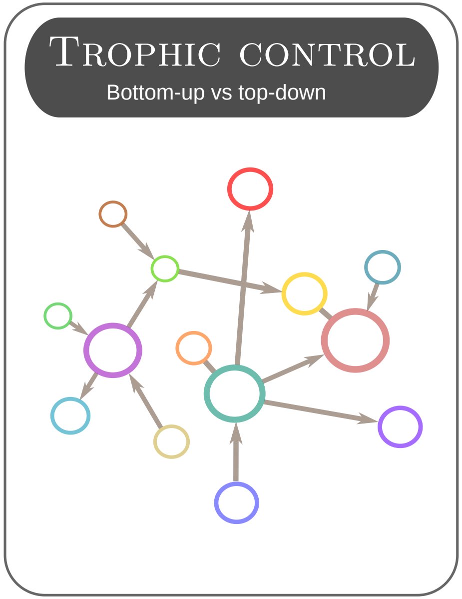
- allow coexistence
- follow abundance laws

Method to estimate self-regulation

A little trick to estimate self-regulation

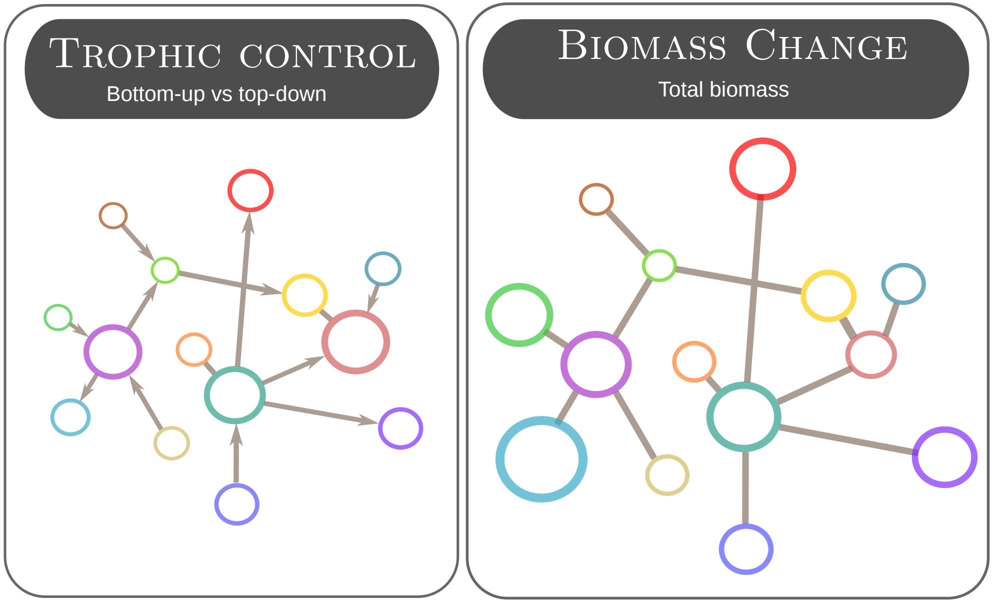
You'll have to believe me (or not) for today...

Measures of community dynamics



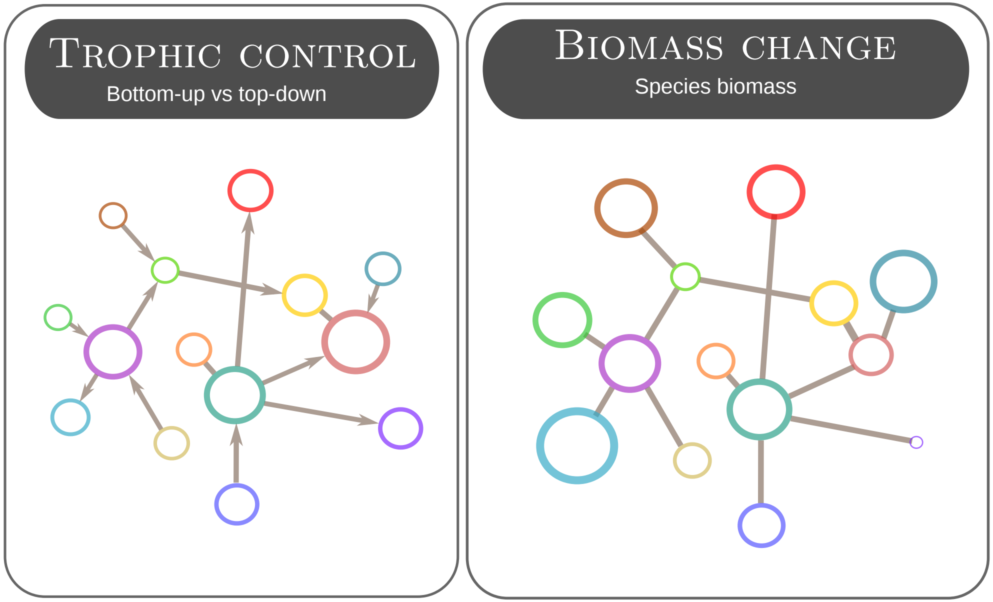
Median λ

Measures of community dynamics



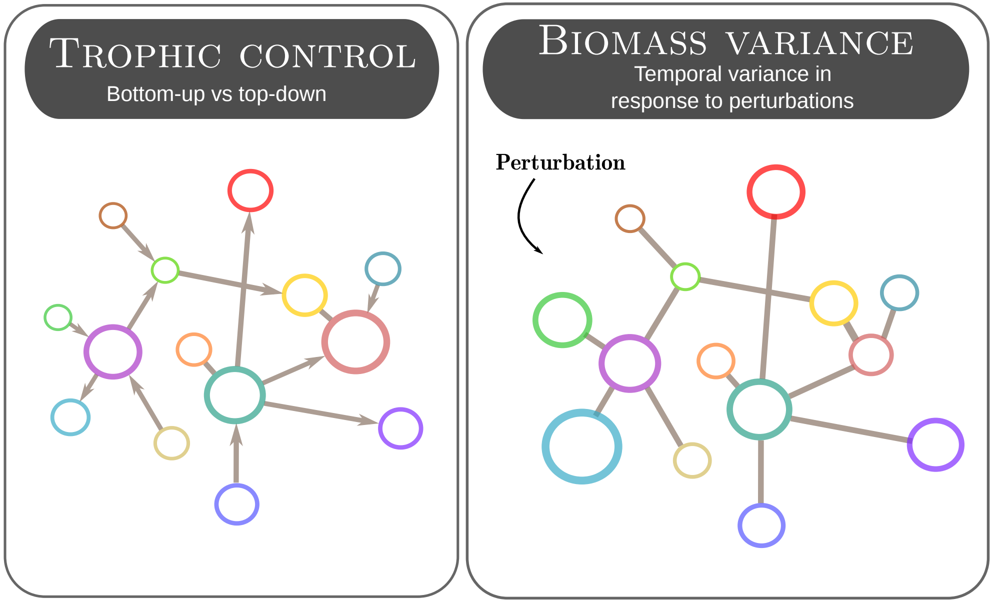
Sum species biomass

Measures of community dynamics



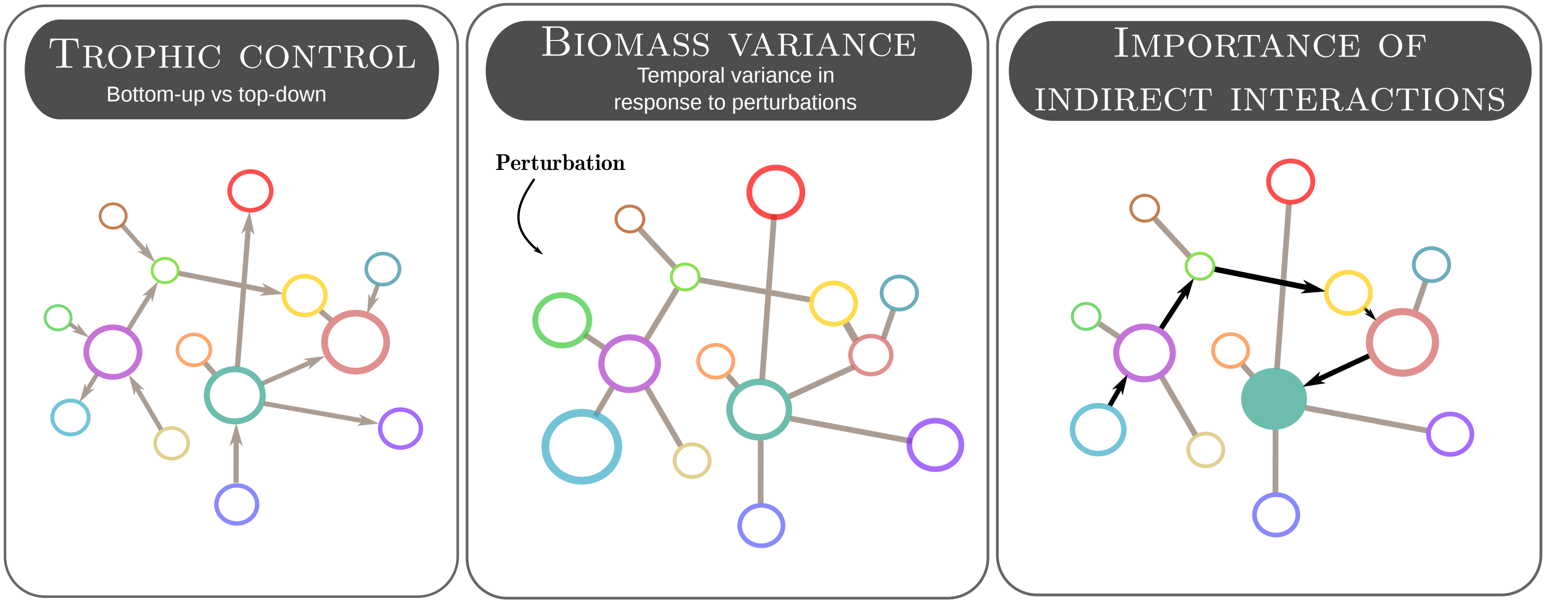
Relative change in species biomass

Measures of community dynamics



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

Measures of community dynamics

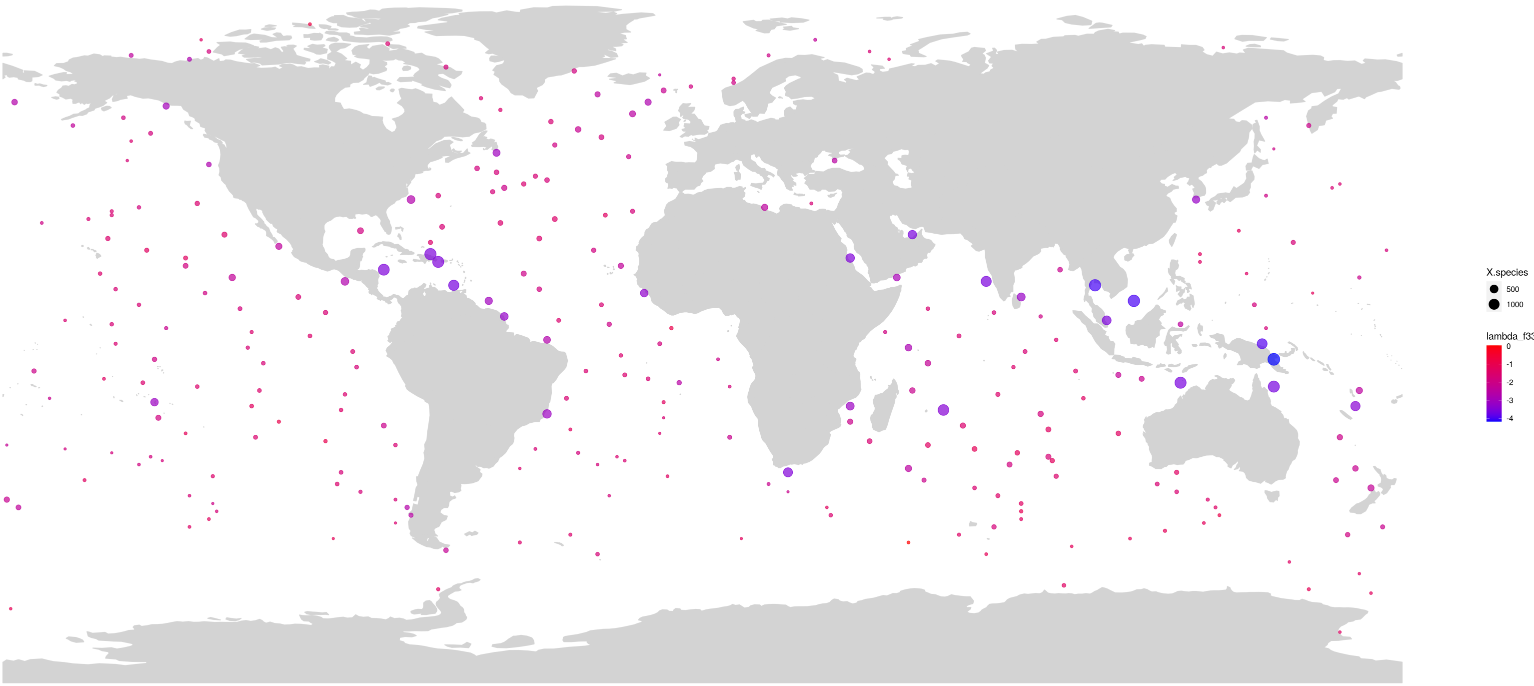


Collectivity : importance of indirect interactions (collectivity = 1, a change in species abundance affect other species far in the network)

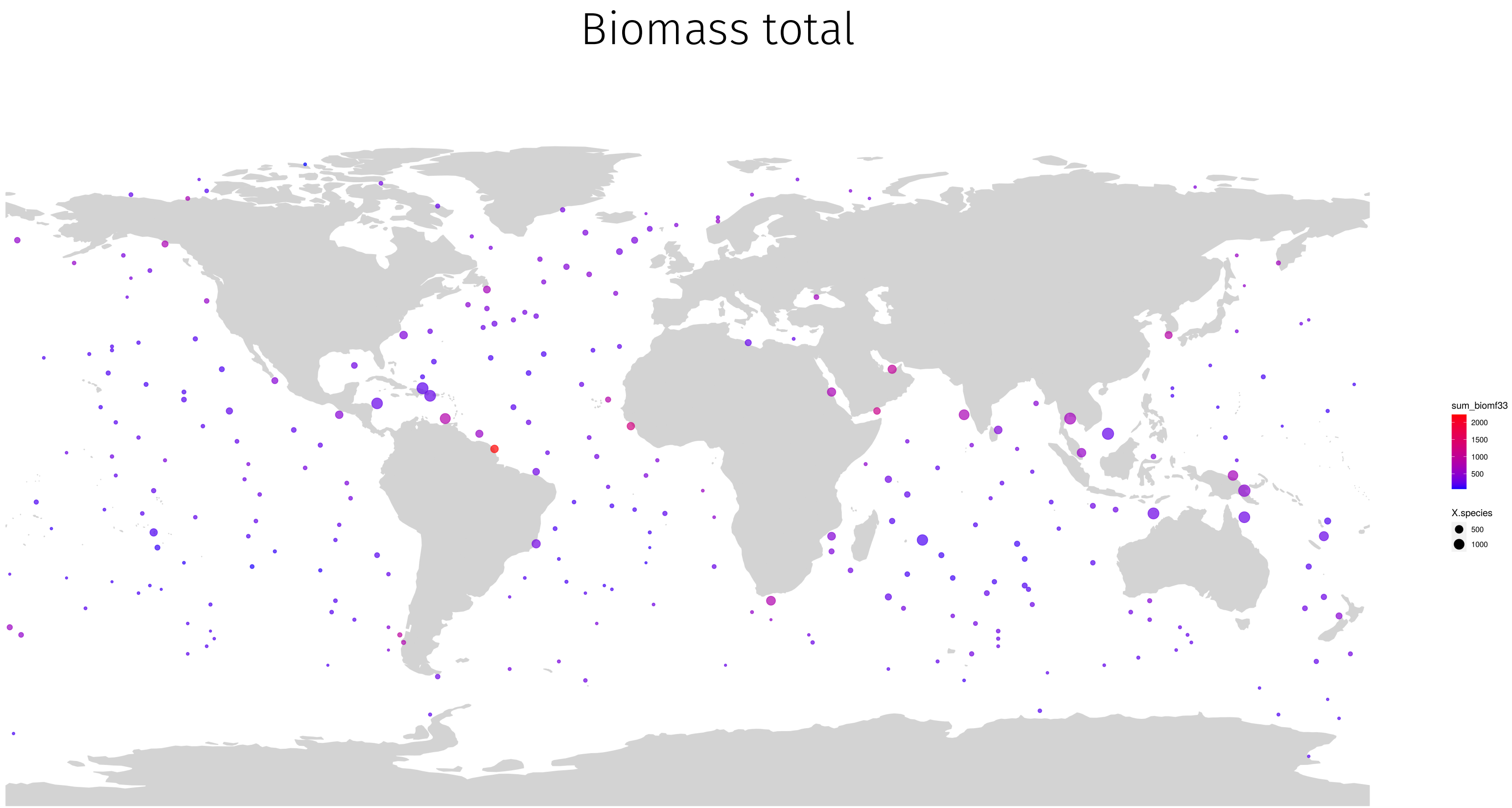
Results

Dynamical properties at large scale

Trophic control

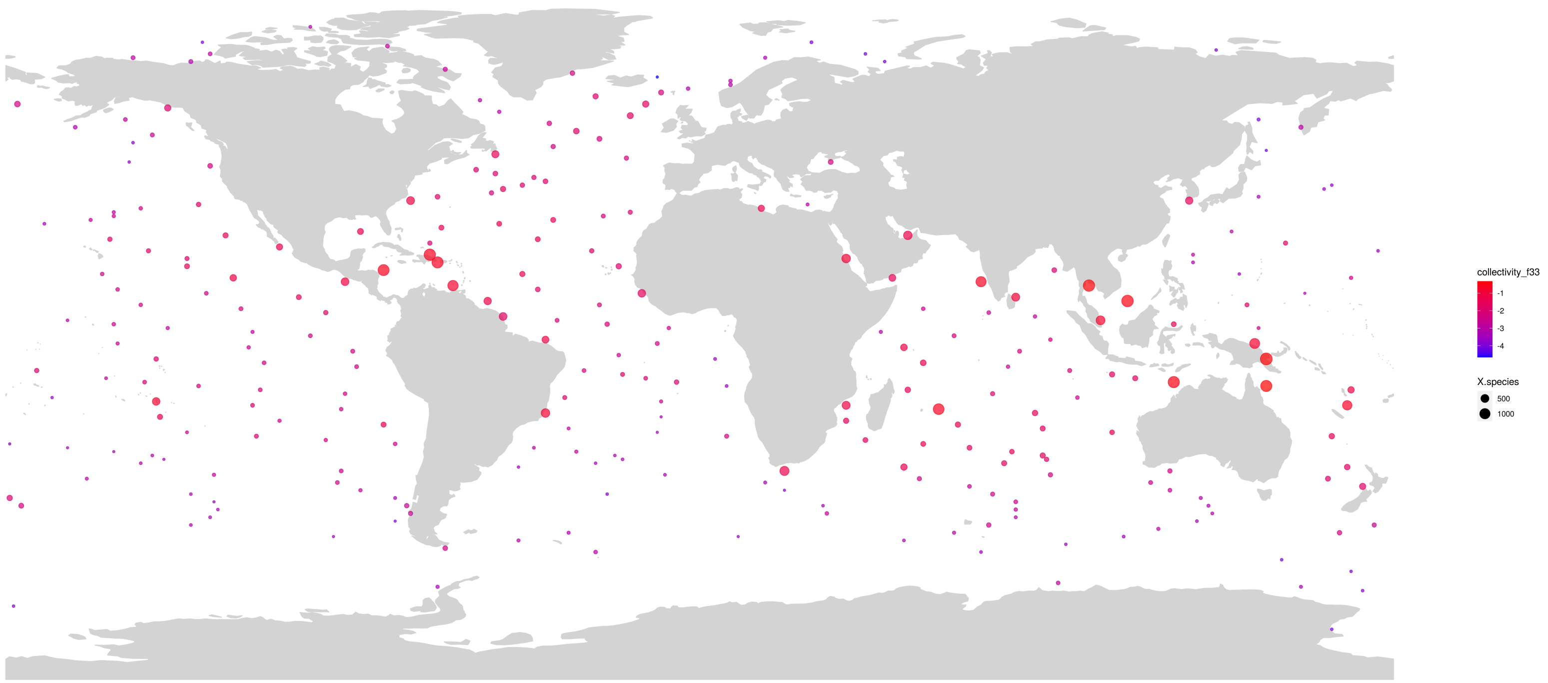


Dynamical properties at large scale

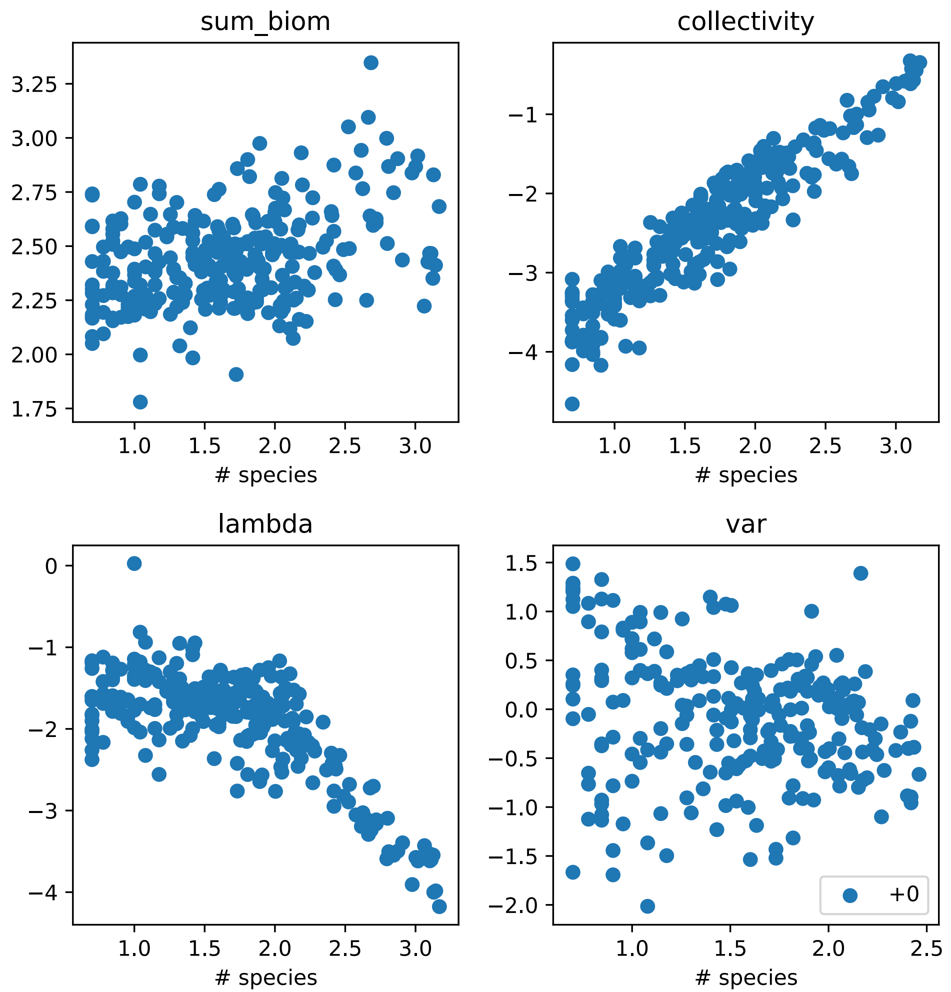


Dynamical properties at large scale

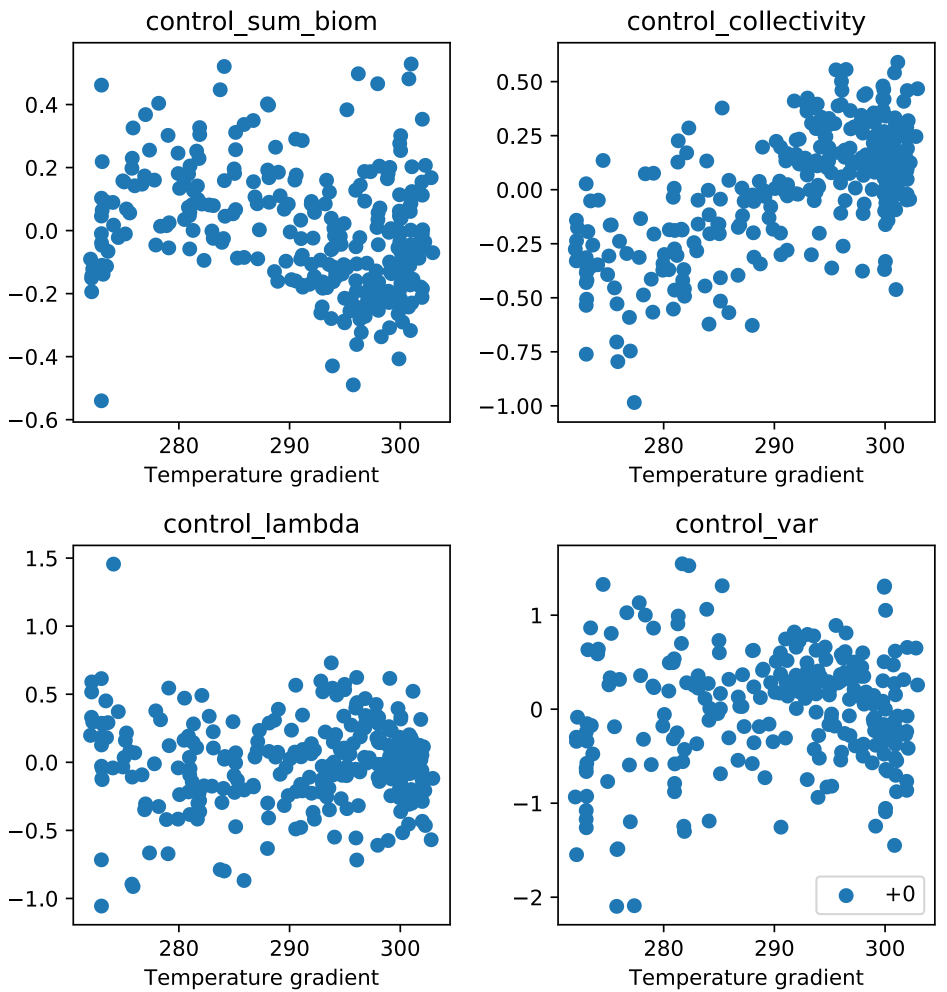
Importance of indirect interactions



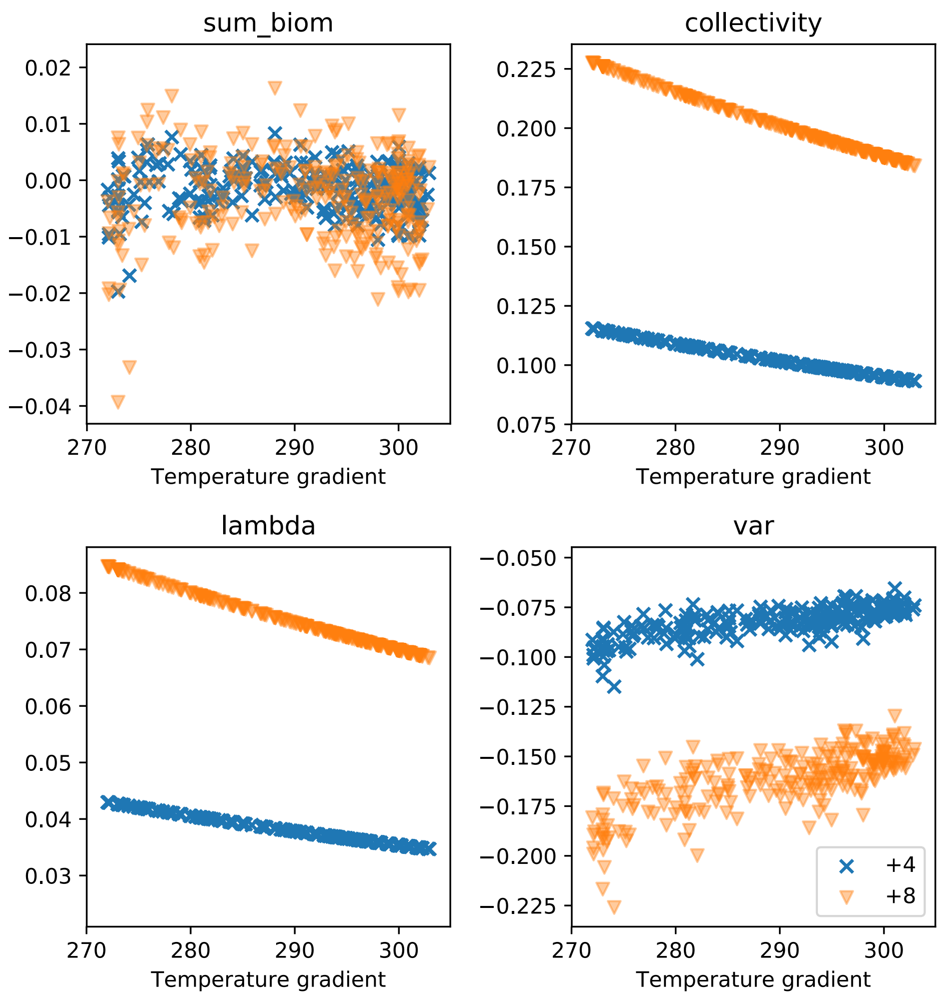
Dynamical properties according to the number of species



Dynamical properties according to temperature

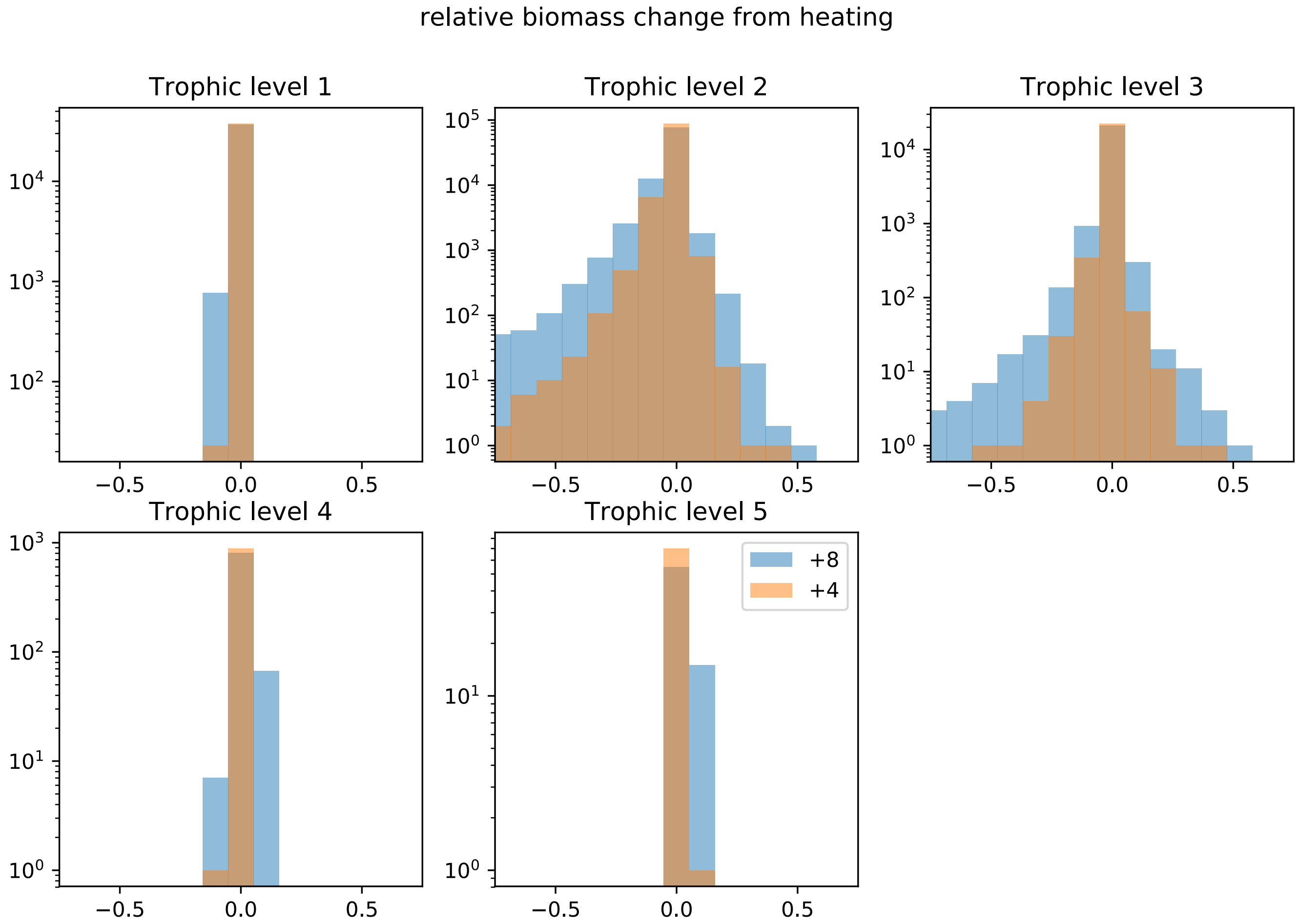


Effect of warming on dynamical properties



Effect of warming on dynamical properties

Difference in species biomass with warming for each trophic level



Conclusion

- Effect of the number of species
- Effect of the temperature gradient on collectivity
- Low impact of warming on community properties
  - except on collectivity
- Warming affects species biomass intra-community
  - especially 2nd and 3rd trophic levels

Limitations :

- Model assumptions and parameters
- Limited data available
- No variation in activation energies

To summarize

blabla

Key message here

QUEBEC CENTRE FOR BIODIVERSITY SCIENCE

NSERC CRSNG

Special thanks to

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