Temperature effect on biomass transfers in coastal marine food webs

Hubert Du Pontavice, William Cheung, Gabriel Reygondeau, Didier Gascuel

PhD title : **Impacts of fisheries and climate change on the trophic functioning of the world ocean : models and forecast**

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Global change disturbed ecosystem at all ecological levels

- Individual level : growth (Lefort et al., 2015), metabolism (Cheung et al. 2017, Lefevre et al., 2017), …

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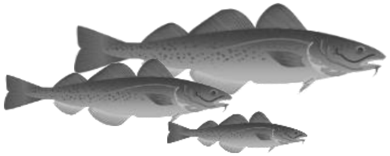

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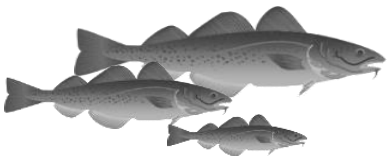
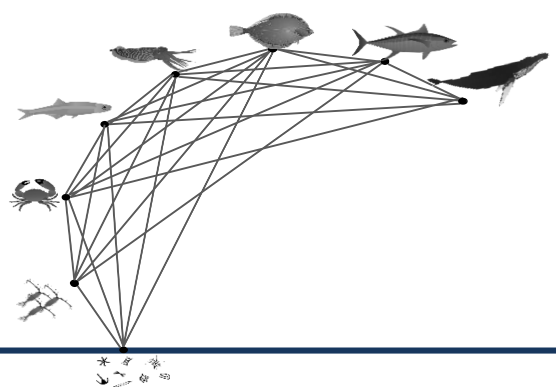


- Community level : composition (Kaufman et al., 2017), distribution (Cheung et al., 2010), interaction (Chivers et al., 2016)…



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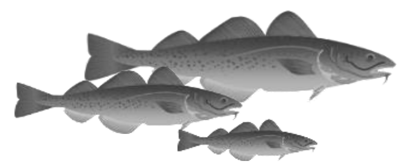
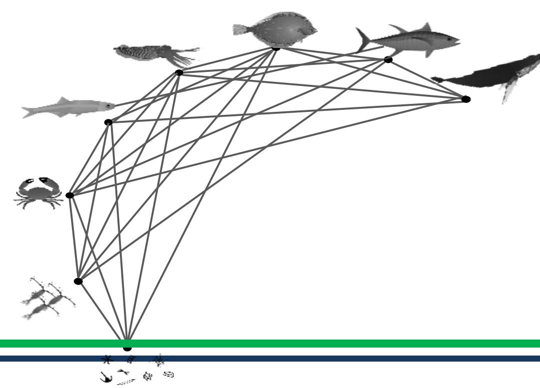


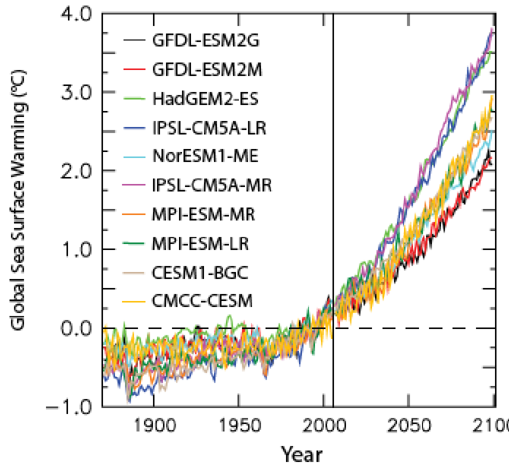
- Community level : **composition** (Kaufman et al., 2017), distribution (Cheung et al., 2010), interaction (Chivers et al., 2016)…

Changes in species assemblages



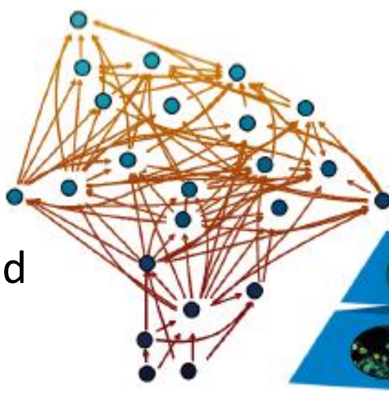
Sea temperature will affect marine communities

- The increase in sea temperature is one of the direct climate change effect
- Increased acceleration of this phenomenon from 2010



Bopp et al, 2013

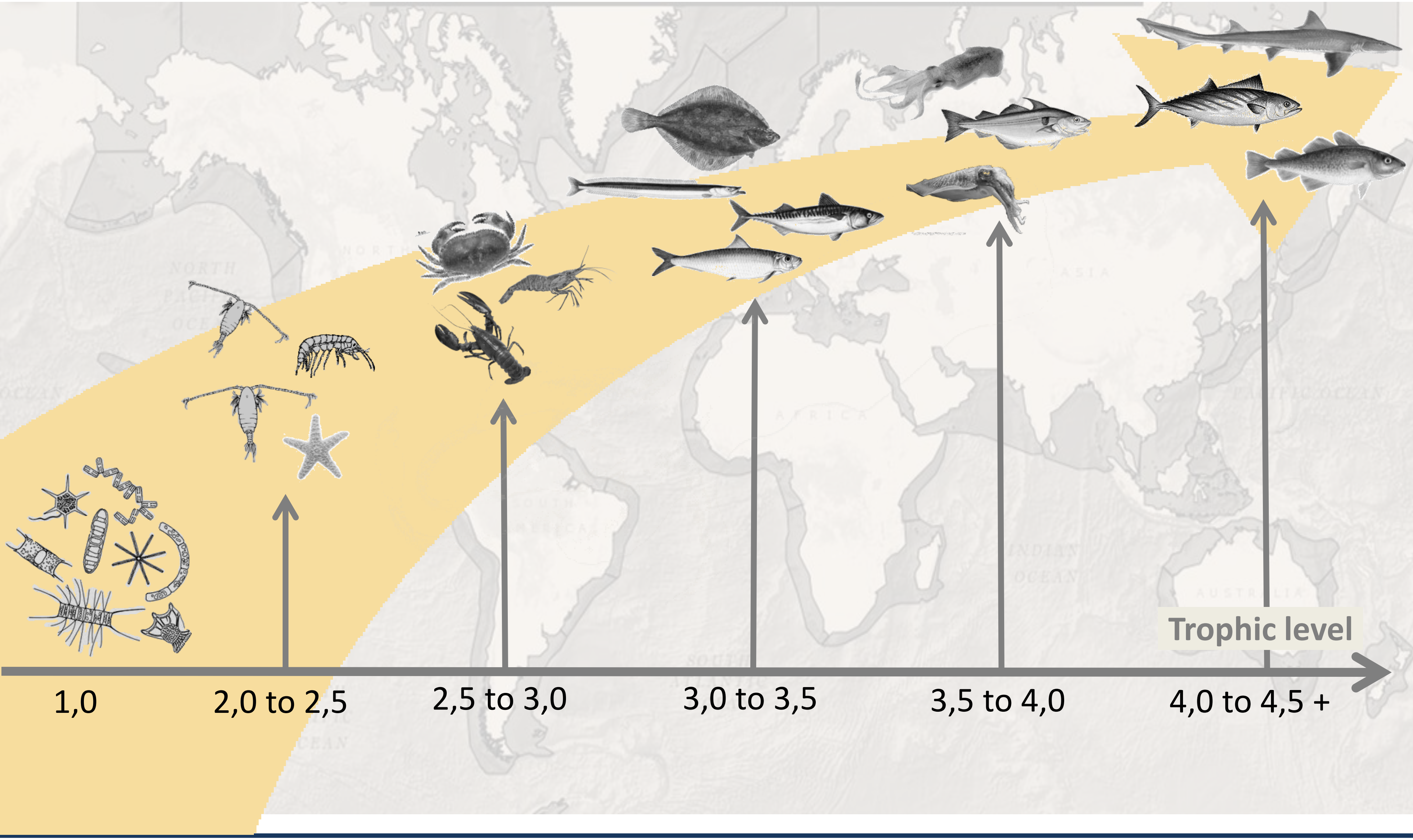
- Community can be simplified / synthesized as a flow



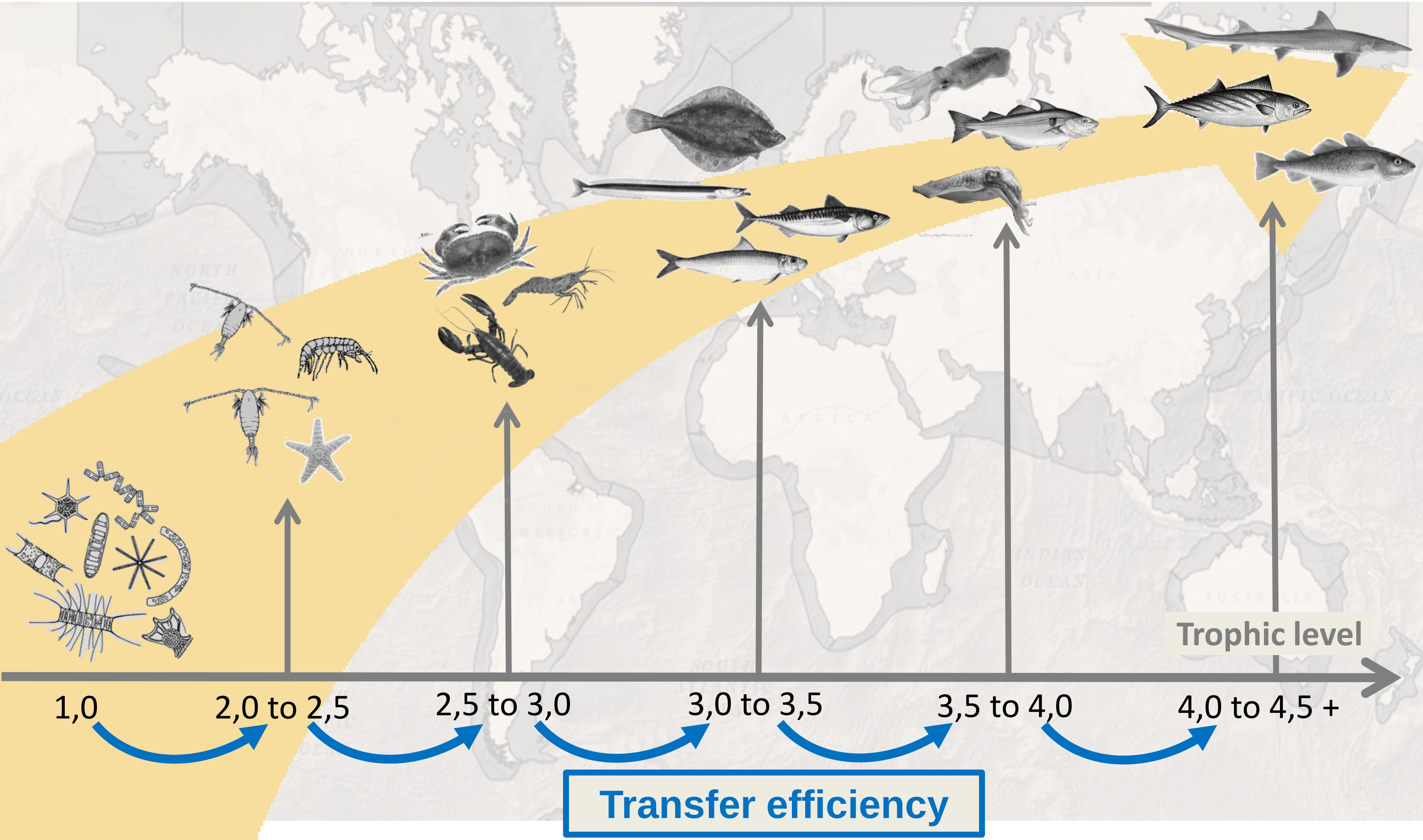
Community representation

How does sea temperature affect biomass flows in marine food web?

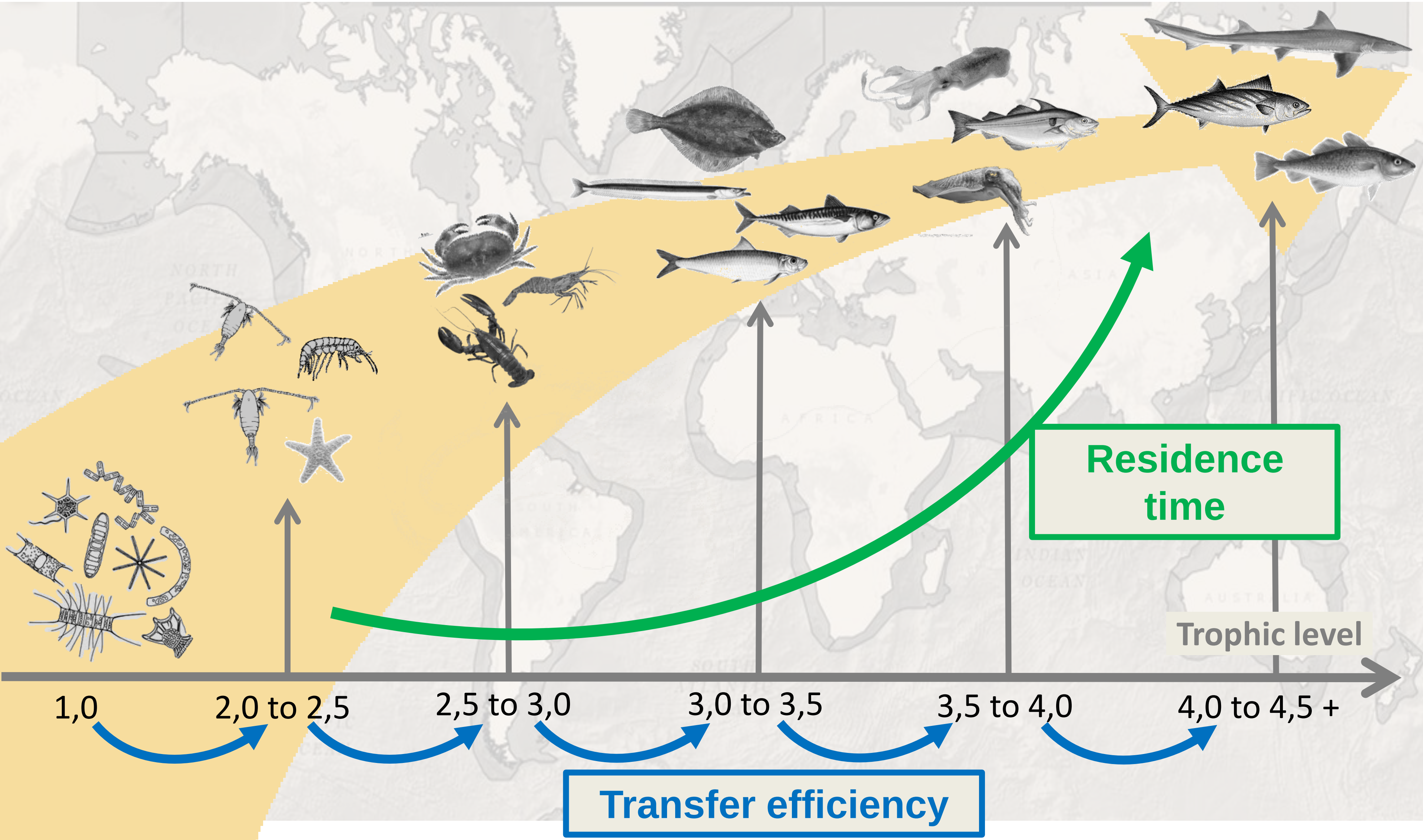
Looking at the functioning of marine food webs as a biomass flow



Looking at the functioning of marine food webs as a biomass flow



Looking at the functioning of marine food webs as a biomass flow

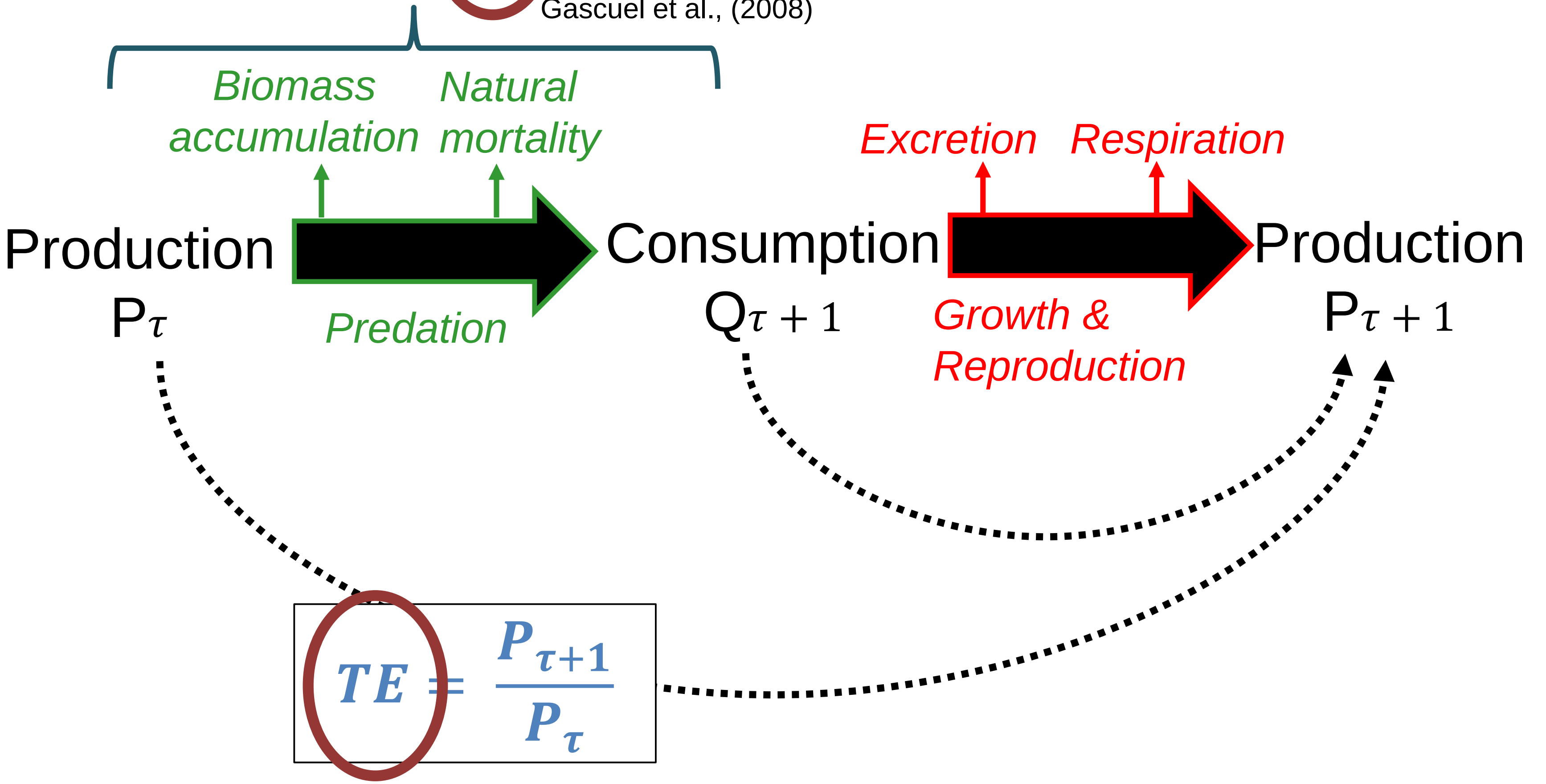


Biomass flow from one trophic level to the next

$$\textit{Speed of flows} = \frac{P_\tau}{B_\tau} = Z = F + M$$

Gascuel et al., (2008)

Transfer times mainly depend on life expectancy of preys



Calculating integrated index : From species level to communities level

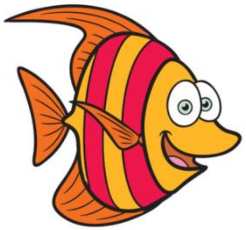
→ Species level : Biomass flow parameters

1) Finfishes

FishBase

Froese & Pauly, 2016

Biological parameters per species



Speed of biomass flow

Transfer Efficiency

Calculating integrated index : From species level to communities level

→ Species level : Biomass flow parameters

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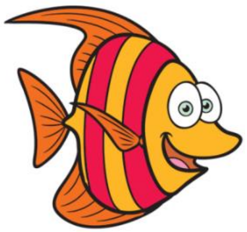

Speed of biomass flow - P/B

Transfer Efficiency

Speed of the biomass flow

$$\frac{P}{B} = 20.19 \times TL^{-1.72} \times e^{0.053 \times T}$$

Gascuel et al., (2008)

TL : Trophic level

T : mean temperature between 1950 - 2010

Calculating integrated index : From species level to communities level

→ Species level : Biomass flow parameters

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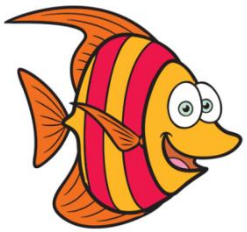

Speed of biomass flow - P/B

Transfer Efficiency

food consumption rate

$$\frac{Q}{B} = 10^{7.964 - 0.204 \times log_{10}(W) - 1.965 \times \frac{1000}{T} + 0.083 \times A + 0.532 \times h + 0.398 \times d}$$

Palomares and Pauly (1998)

T : mean temperature between 1950 - 2010
W : Asymptotic weigth
A : Aspect ratio
h & d : herbivory & detrivory index

Calculating integrated index : From species level to communities level

→ Species level : Biomass flow parameters

FishBase

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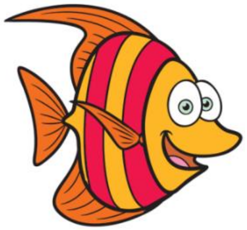
Biological parameters per species



Speed of biomass flow - P/B

Transfer Efficiency – P/Q

$$\boldsymbol{Gross\ food\ conversion\ efficiency}$$

$$\left(\frac{P}{Q}\right) = \frac{({}^{P}/_{B})}{({}^{Q}/_{B})} = \frac{Speed\ of\ the\ biomass\ flow}{food\ consumption\ rate}$$

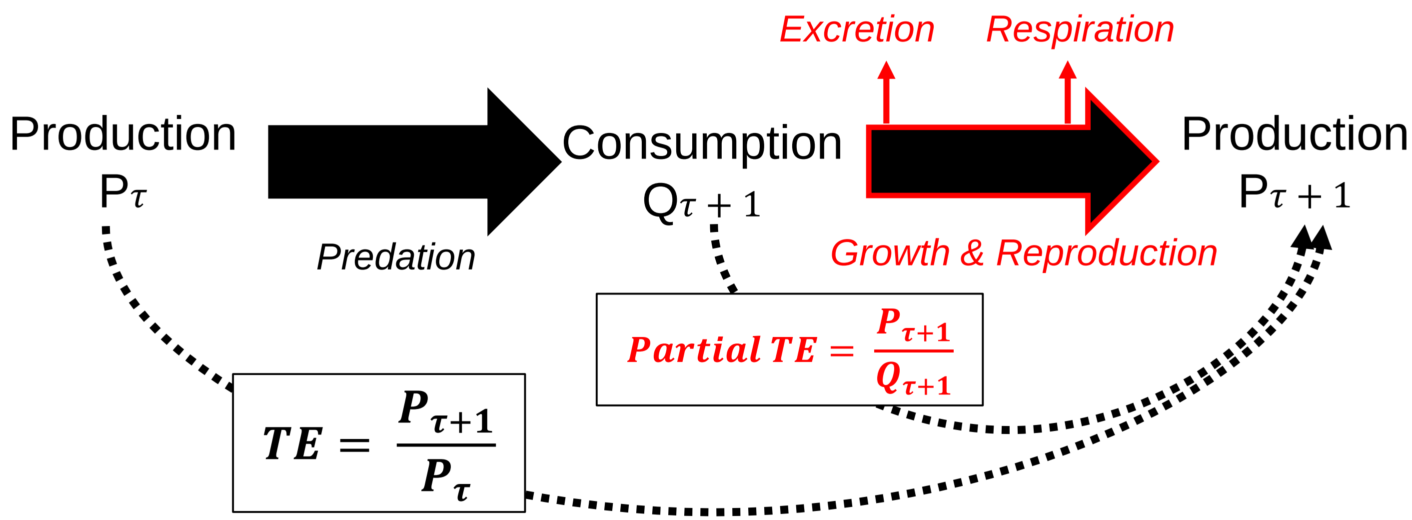
Calculating integrated index : From species level to communities level

→ Species level : Biomass flow parameters

- *From Gross Food Conversion Efficiency* (***P/Q***) *to Transfer Efficiency* (***TE***)

P/Q : Gross Food Conversion Efficiency

Empirical equation



$$\left(\frac{P}{Q}\right)\tau = \frac{({}^{P}/_{B})\tau}{({}^{Q}/_{B})\tau} = \frac{Speed\ of\ the\ biomass\ flow}{food\ consumption\ rate}$$

Calculating integrated index : From species level to communities level

→ Species level : Biomass flow parameters

- *From Gross Food Conversion Efficiency* (***P/Q***) *to Transfer Efficiency* (***TE***)

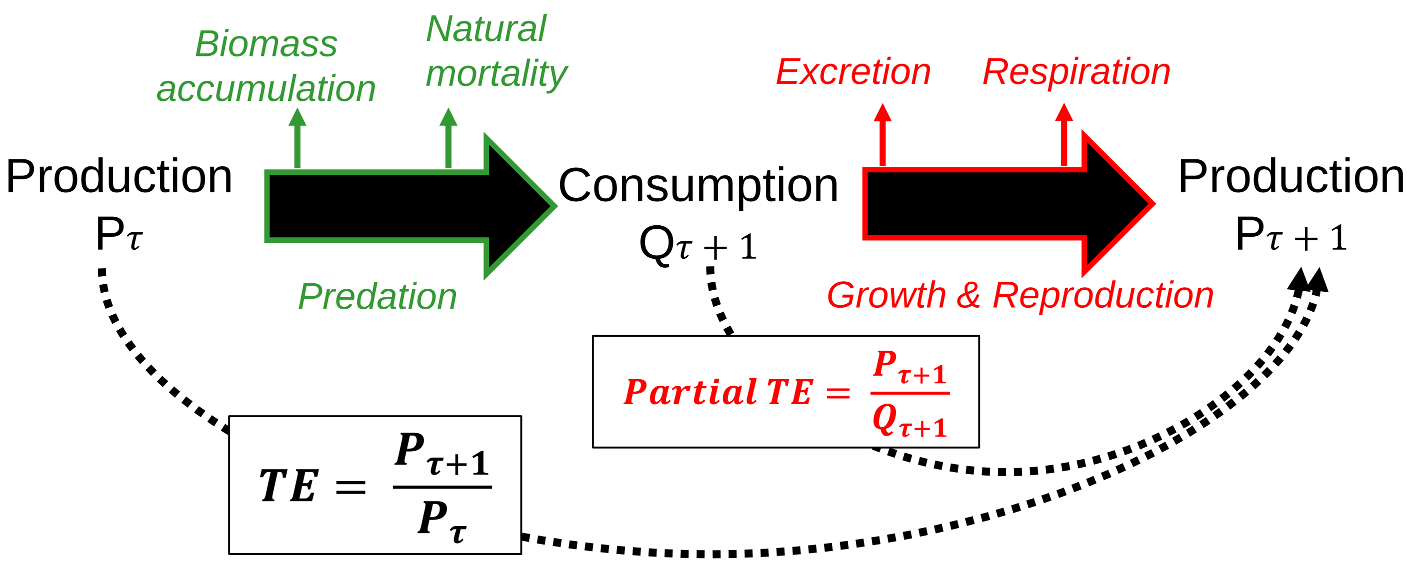
P/Q : Gross Food Conversion Efficiency

Empirical equation

Correction

Ecopath model

(~120 models)



Calculating integrated index : From species level to communities level

→ Species level : Biomass flow parameters

- *From Gross Food Conversion Efficiency* ***(P/Q)*** *to Transfer Efficiency* ***(TE)***

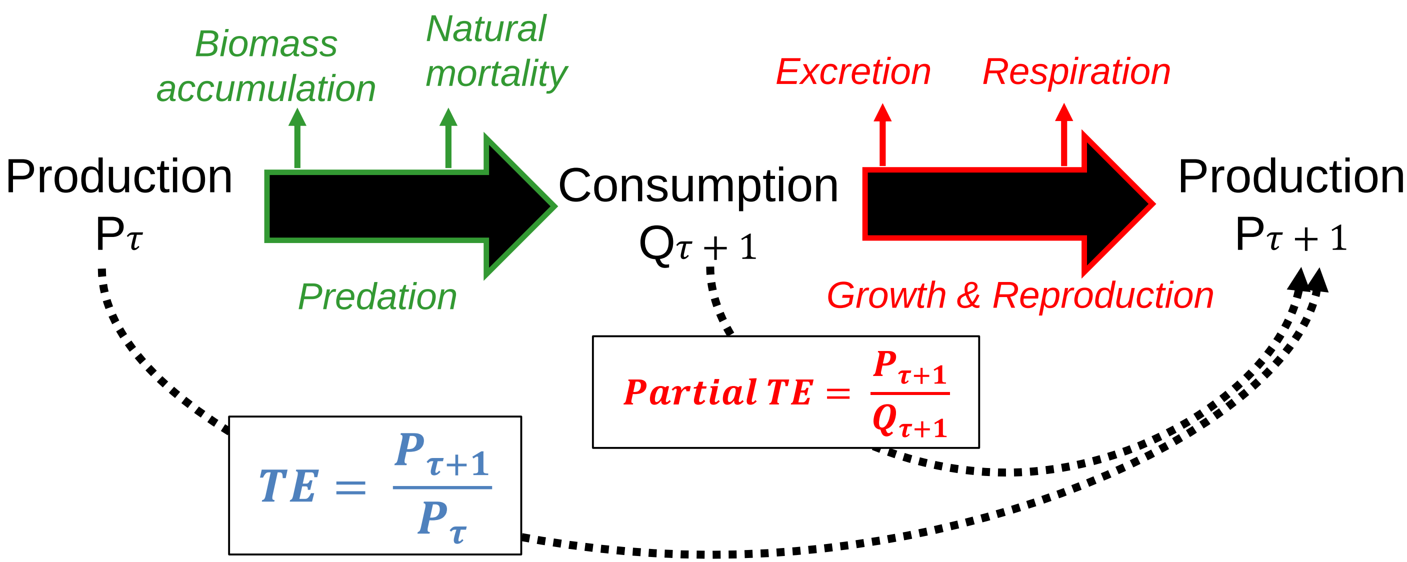
P/Q : Gross Food Conversion Efficiency

Empirical equation

Correction

Ecopath model (~120 models)

TE : Transfer Efficiency



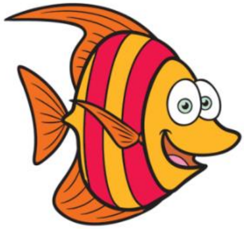
Calculating integrated index : From species level to communities level

→ Species level : Biomass flow parameters

1) Finfishes

FishBase
Froese & Pauly, 2016

Biological parameters per species

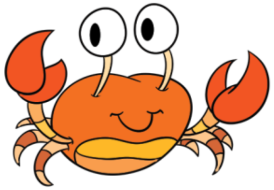


Speed of biomass flow - P/B

Transfer Efficiency - TE = P/Q x Cor

2) Other species

EcoBase
Colléter et al., 2015



Speed of biomass flow - P/B

Transfer Efficiency - TE = P/Q x Cor

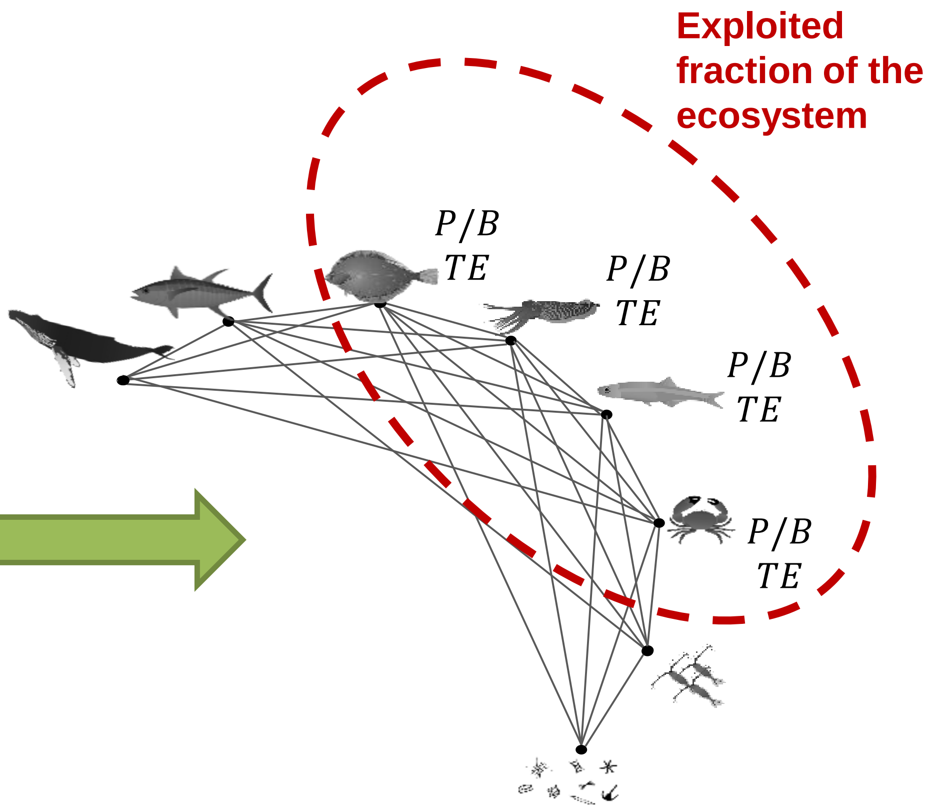
Calculating integrated index : From species level to community level

→ Species level : Catch and trophic level per species

SEA AROUND US
FISHERIES, ECOSYSTEMS & BIODIVERSITY

Pauly & Zeller, 2015

Species Composition of catch 1950-2010

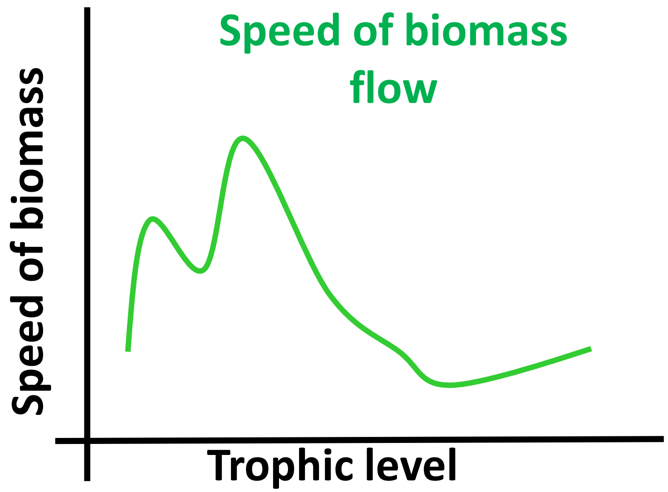


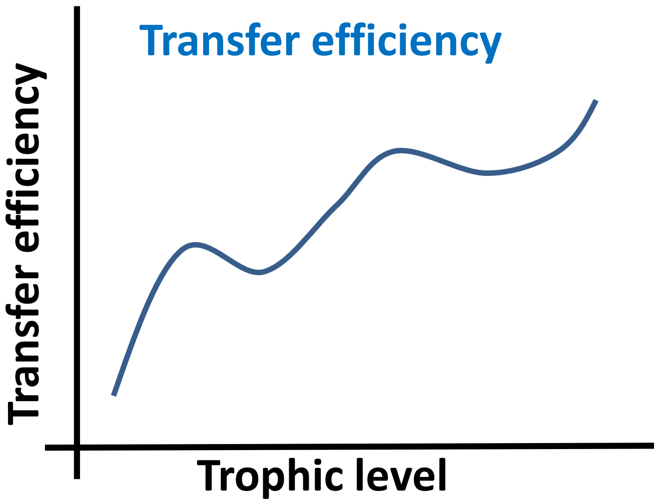
Calculating integrated index : From species level to community level

→ Community level

1 From species to trophic spectra

Maureaud et al., 2017



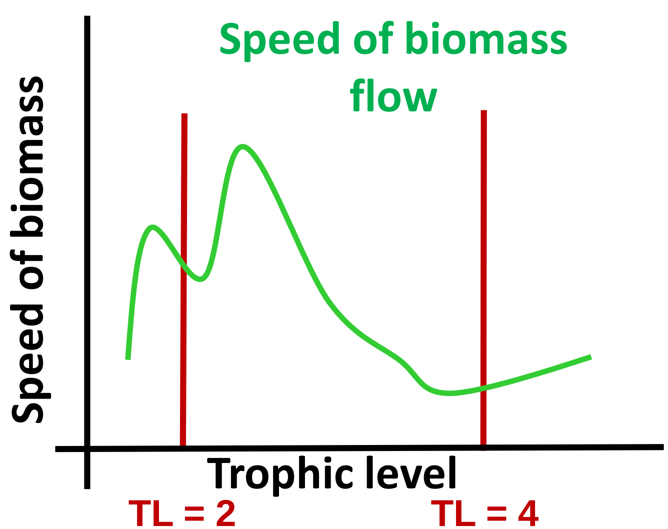


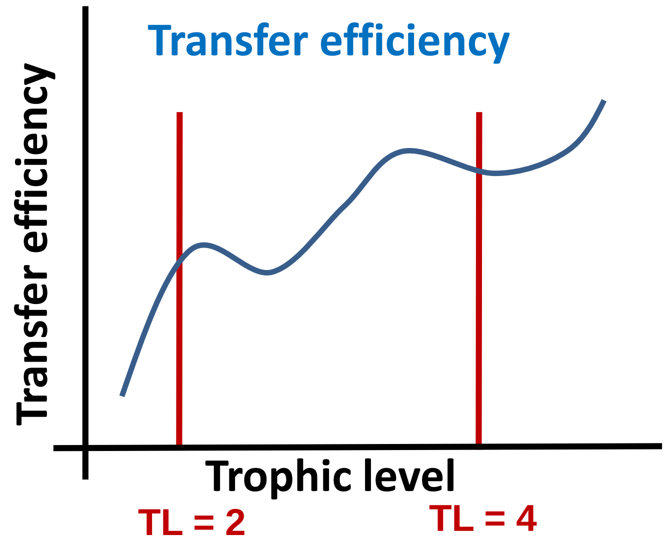
Calculating integrated index : From species level to community level

→ Community level

2 From trophic spectra to ecosystem indicators

Maureaud et al., 2017





Calculating integrated index : From species level to community level

→ Community level

2 From trophic spectra to ecosystem indicators Maureaud et al., 2017

TCI : Time Cumulated Indicator

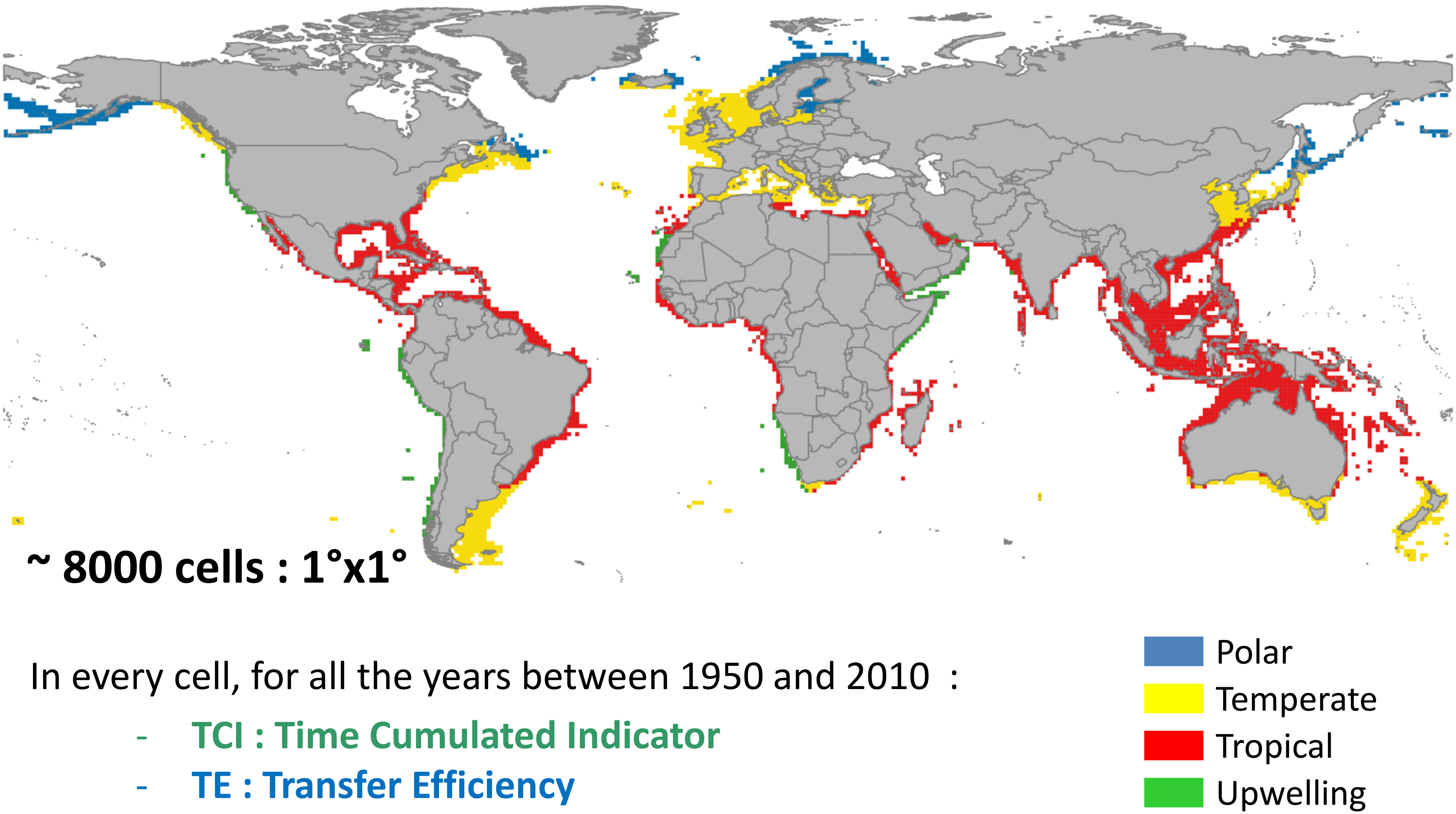
$$TCI_{j,y} = \sum_{\tau=2.0}^{\tau=4.0} \frac{\Delta\tau}{\left(\frac{P}{B}\right)_{\tau,j,y}}$$

TE : Transfer Efficiency

$$ECI_{j,y} = \prod_{\tau=2.0}^{\tau=4.0} \left(\frac{P}{Q}\right)_{\tau,j,y}^{\Delta\tau}$$

τ = 2 : From secondary consummer …
τ = 4 : … to Top predator

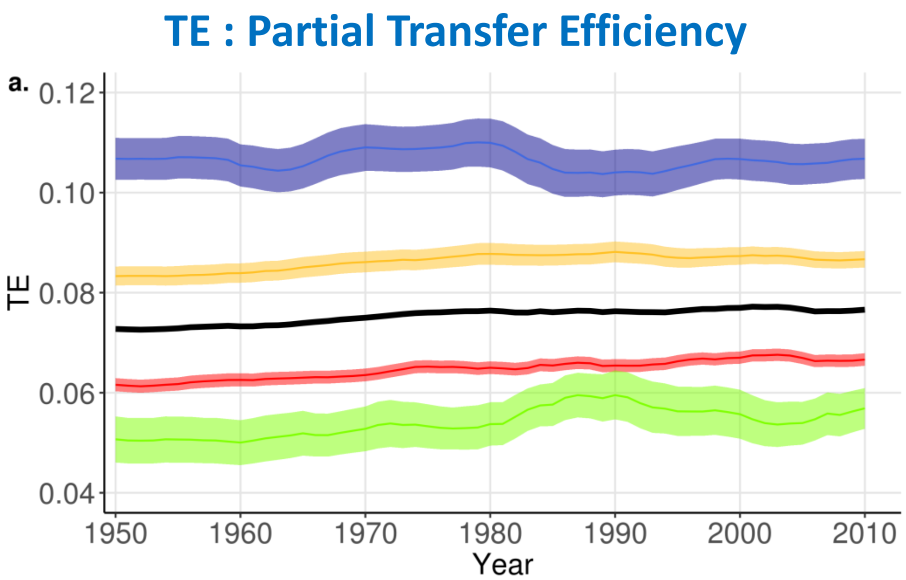
Study area and period: Coastal Ecosystems between 1950 and 2010

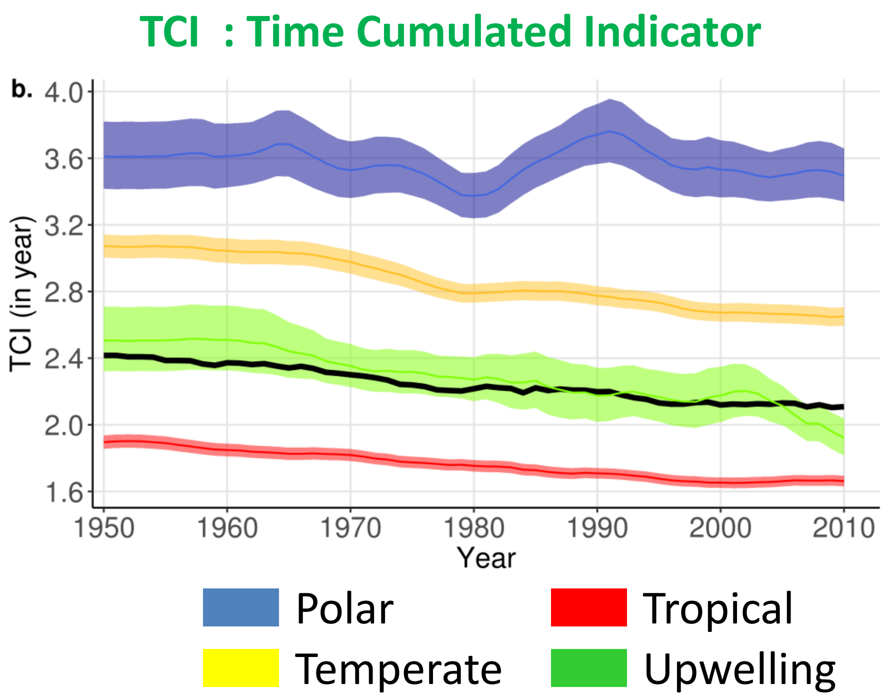


In every cell, for all the years between 1950 and 2010 :

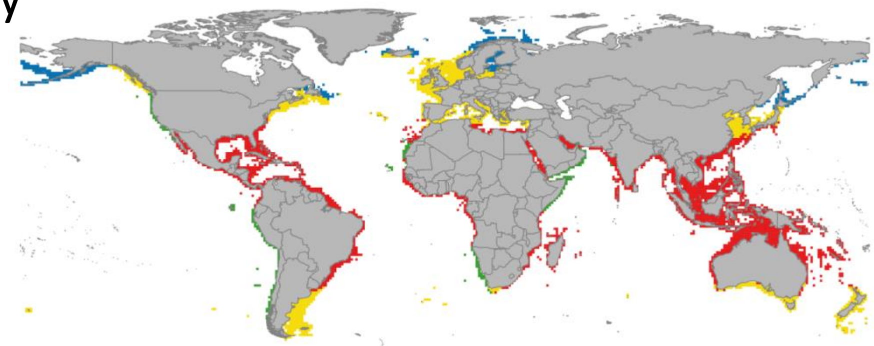
- **TCI : Time Cumulated Indicator**
- **TE : Transfer Efficiency**

Global trends in transfer efficiency and in residence time



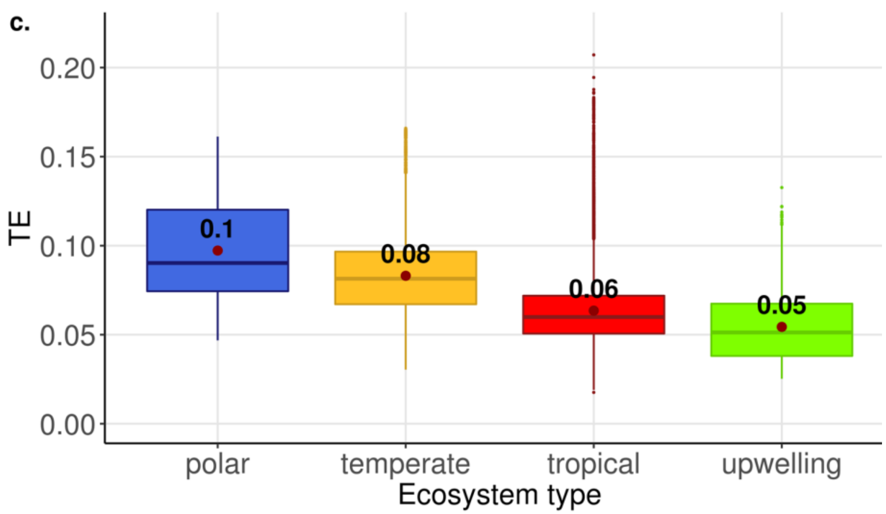


- Slight increase in partial Transfer Efficiency
- Decrease in Residence Time

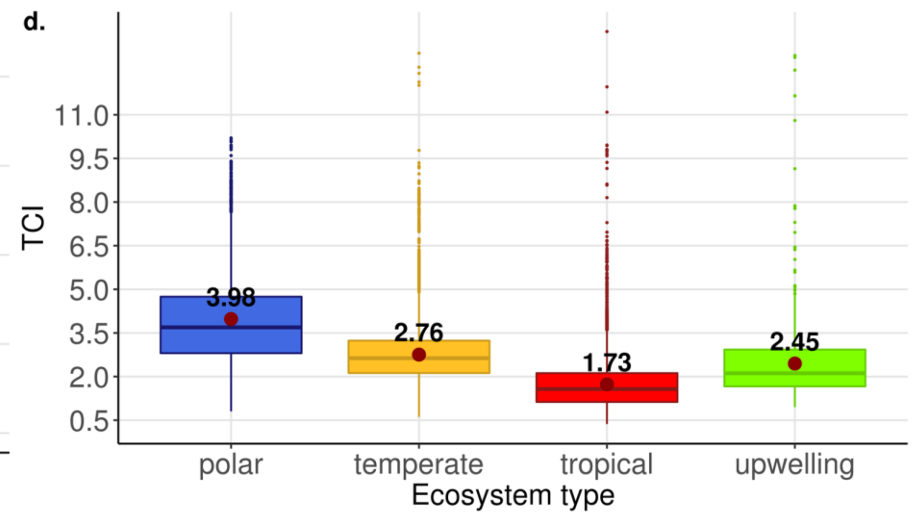


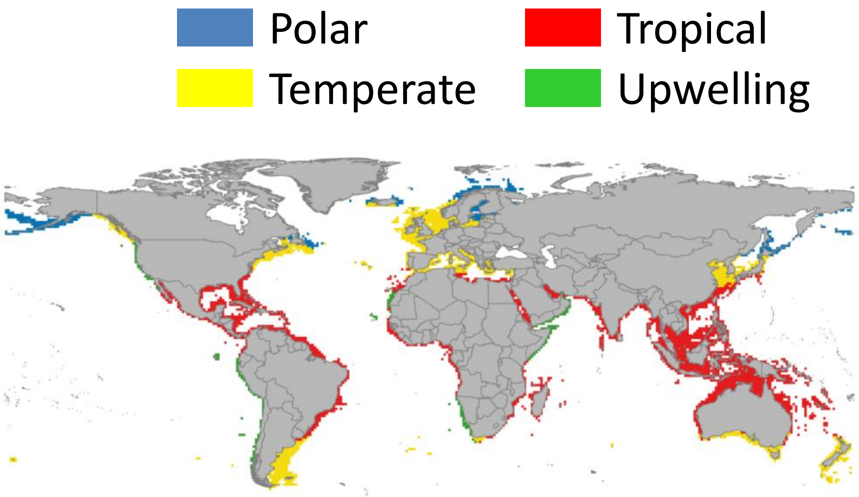
Transfer efficiency and in residence time by ecosystem type

TE : Partial Transfer Efficiency



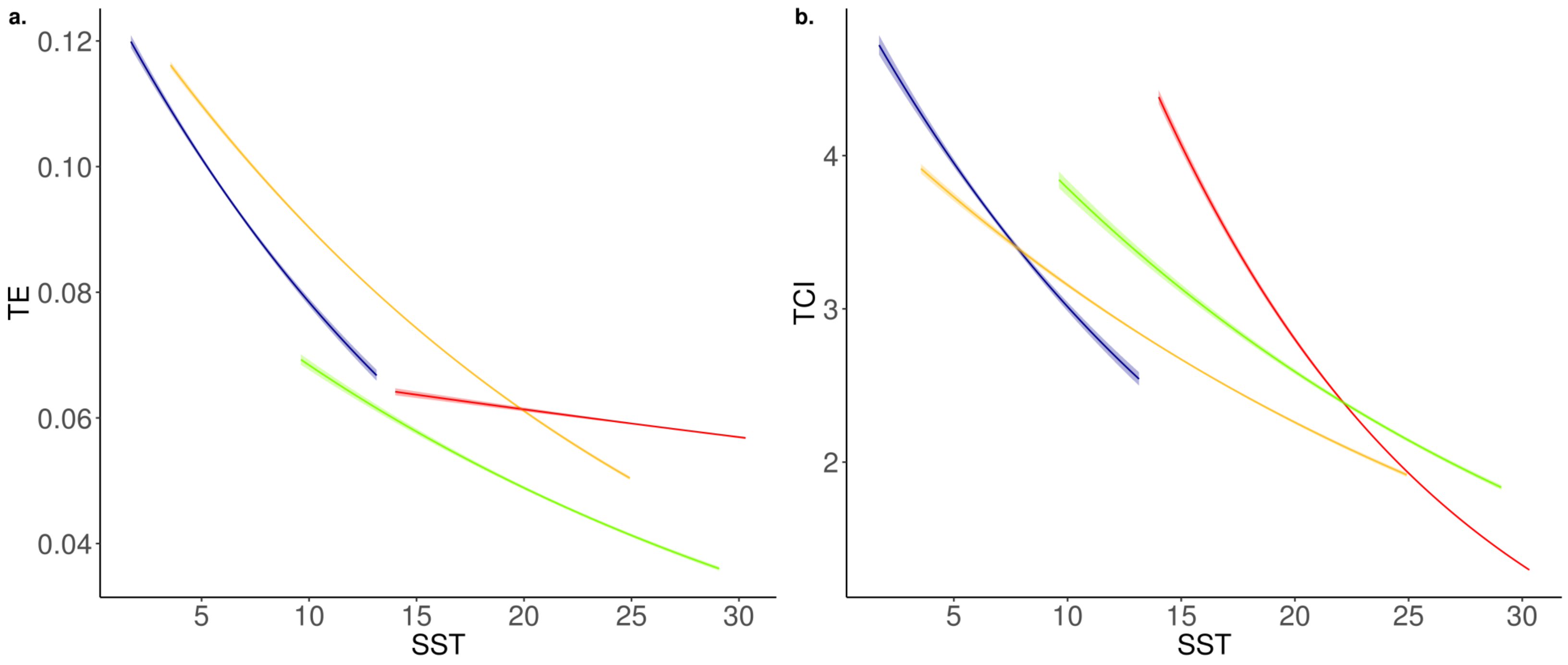
TCI : Time Cumulated Indicator





- Variation in TE and TCI depending on ecosystem type
- High variability in TE and TCI

Temperature effect on transfer efficiency and residence time

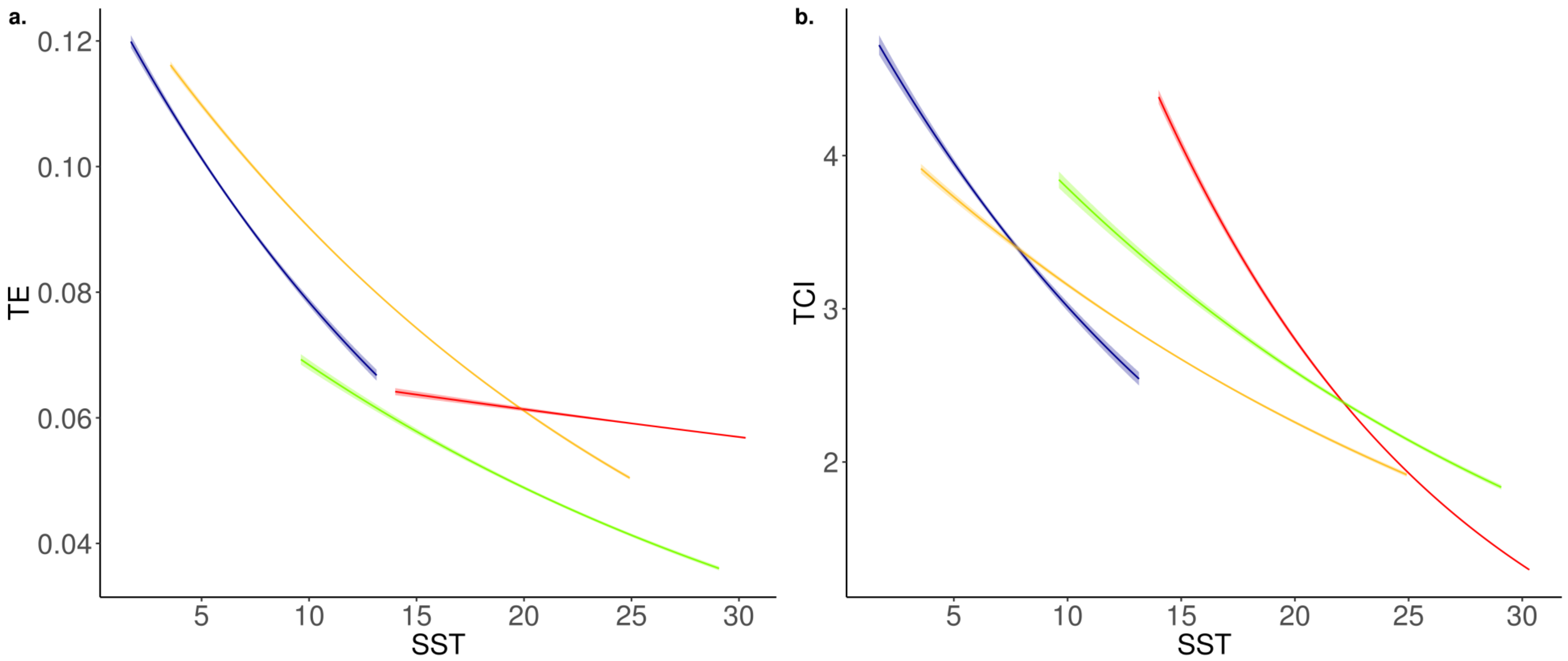


Method : GLM

- Individuals : 1 cell in 1 year
- 3 covariates : SST + Ecosystem type + SST x Ecosystem types

Polar
Temperate
Tropical
Upwelling

Temperature effect on transfer efficiency and residence time



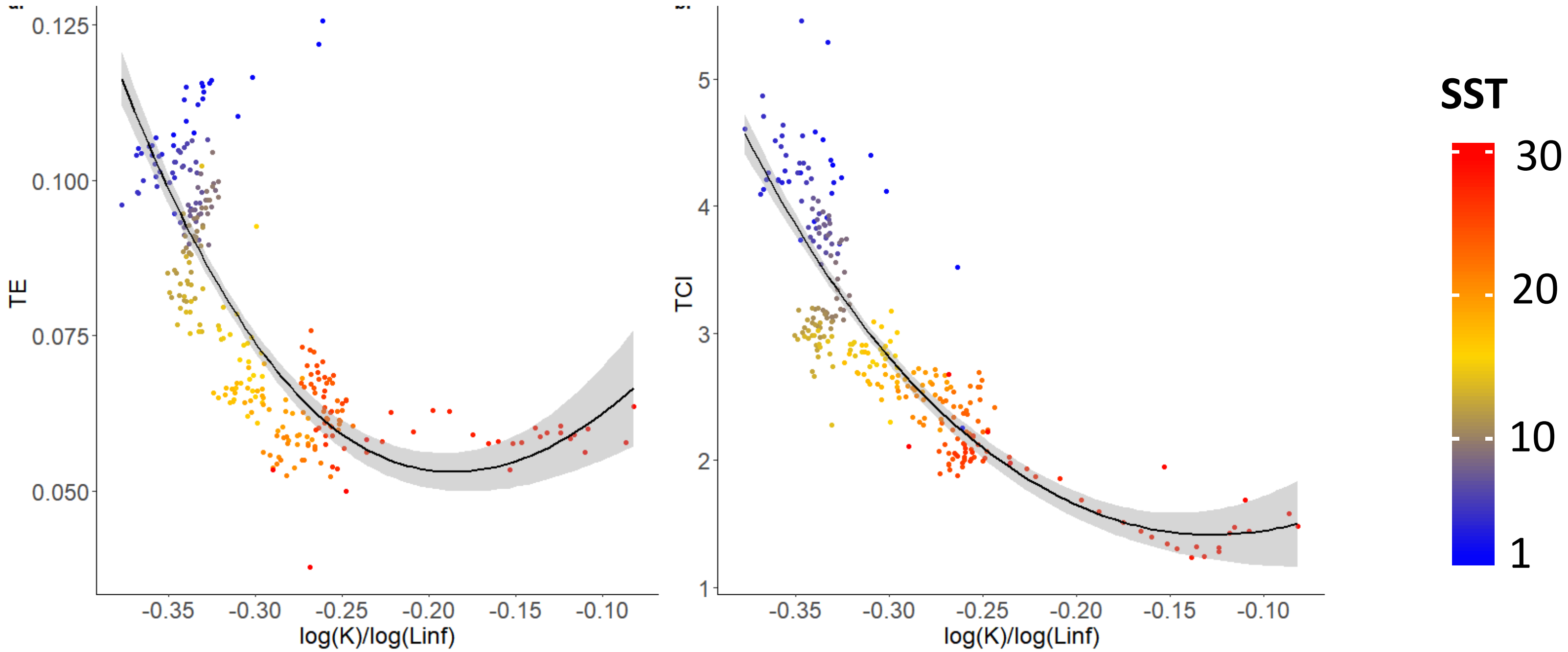
- Decrease in Transfer Efficiency (TE) in all ecosystems
- Decrease in Residence Time (TCI) <-> Increase in the speed of biomass

Polar
Temperate
Tropical
Upwelling

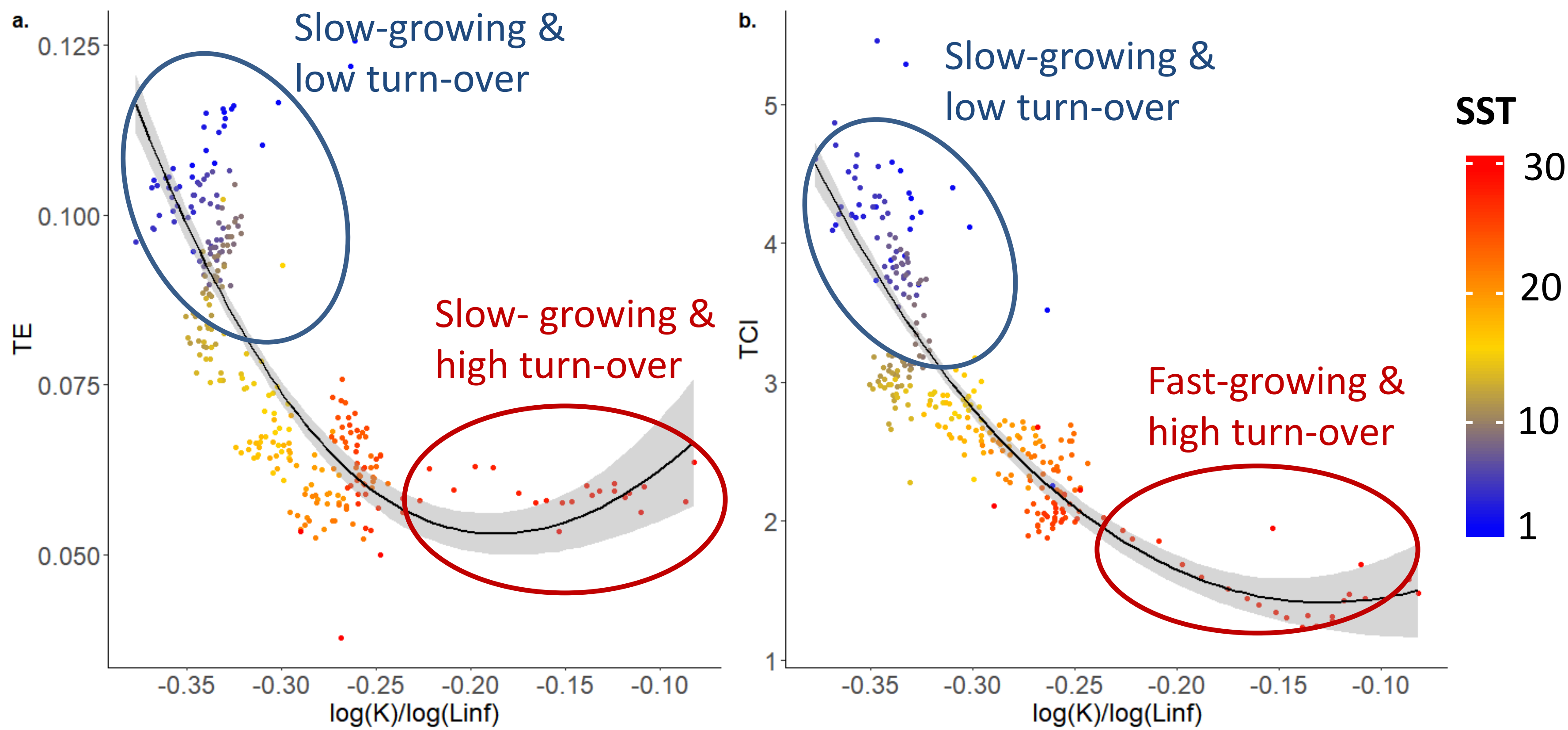
Relation between biomass flows and species life history characteristics

Method :

- Ratio log(K)/log(Linf) for finfishes using Fishbase
- 1 dot = 1 range of SST
- Combinations of log(K) and log(Linf) to explore the growth performance (Cury and Pauly, 2000; Silva *et al.*, 2008)



Relation between biomass flows and species life history characteristics



→ Strong negative correlation between the TE / TCI and Growth characteristics

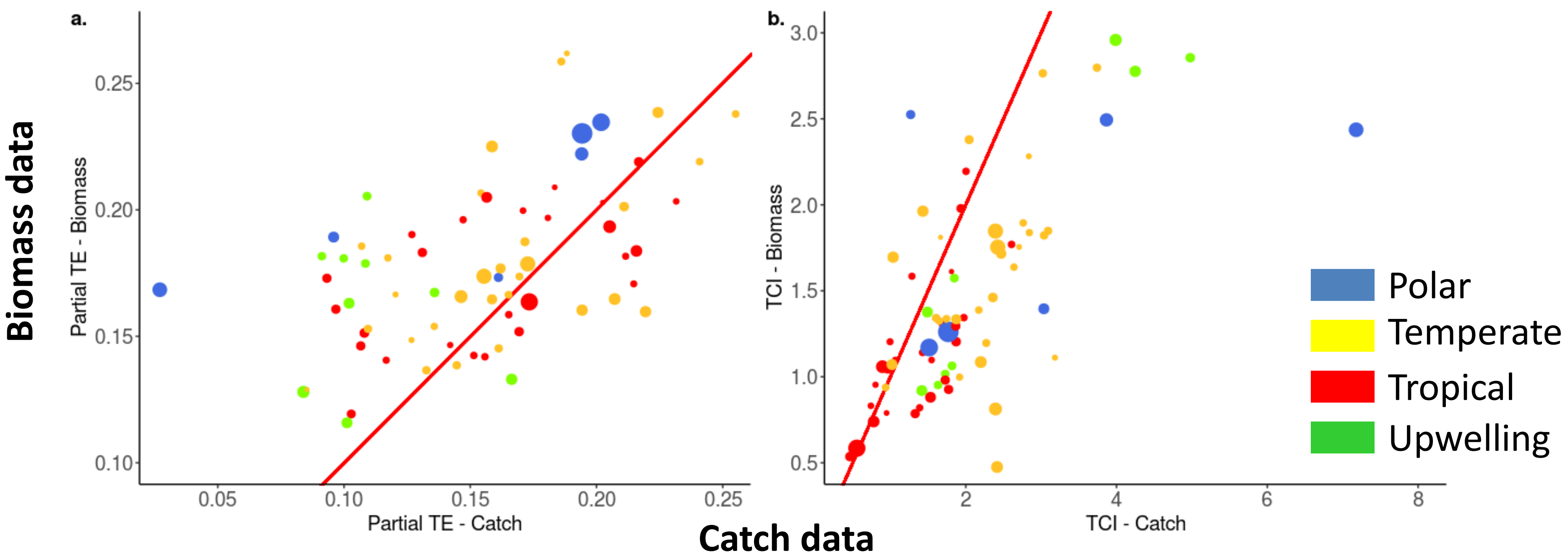
- Fast growing & high turn-over species where biomass transfers are fast and less efficient
- Slow growing & low turn-over species where biomass transfers are slow and efficient

Potential bias due to the use of catch data

→ Comparison Transfer Efficiency and Time Residence based on Biomass and Catch using 71 published ecosystem models (Ecopath)

TE : Partial Transfer Efficiency

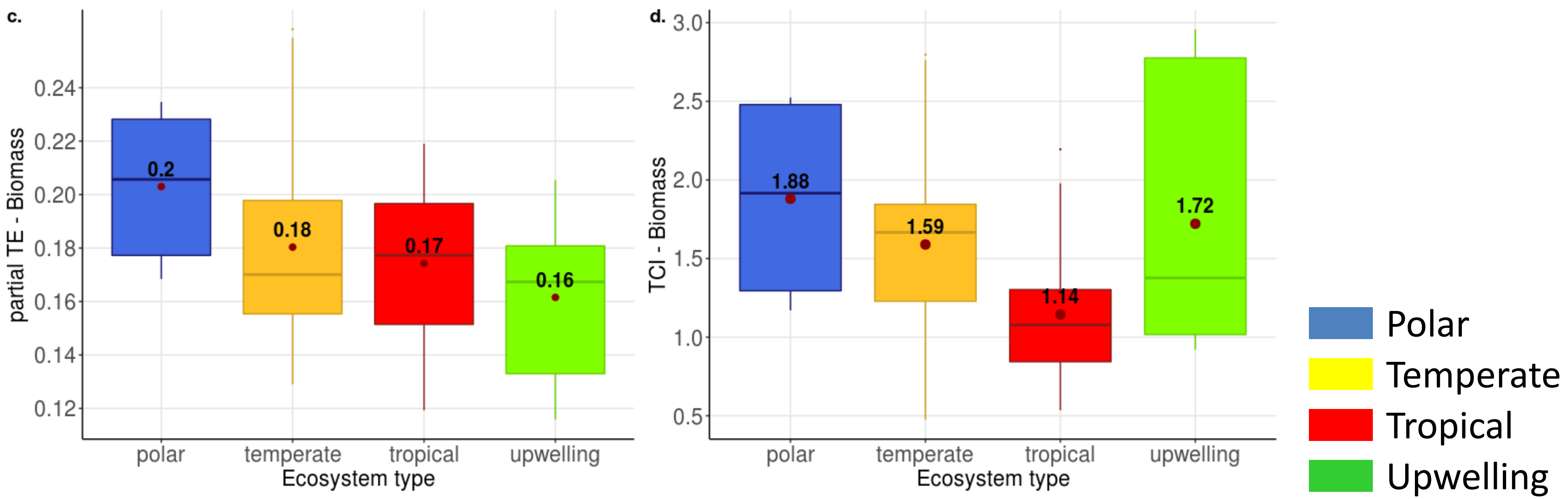
TCI : Time Cumulated Indicator



- ➢ TE from Catch < TE from Biomass
- ➢ TCI from catch > TCI from biomass

Potential bias due to the use of catch data

→ Comparison : biomass flow patterns based on biomass and catch regarding the ecosystem types



- Same global patterns regarding the types of ecosystems using the biomass data from Ecopath
- Residence time much shorter using Ecopath data – especially in polar ecosystem

Global discussion

- **Multiple sources of uncertainty :**
  - Species history traits
  - Global catch from SeaAroundUs despite the data cleansing
  - Quality of Ecopath models

- **Indirect calculation of Transfer Efficiency** based on empirical equation and parameters from Ecopath

- **Very simple modelling – glm including only fixed effect**
  → Autocorrelation spatial and temporal :
  - add random effects to include this variability ?
  - Subsample the data ?

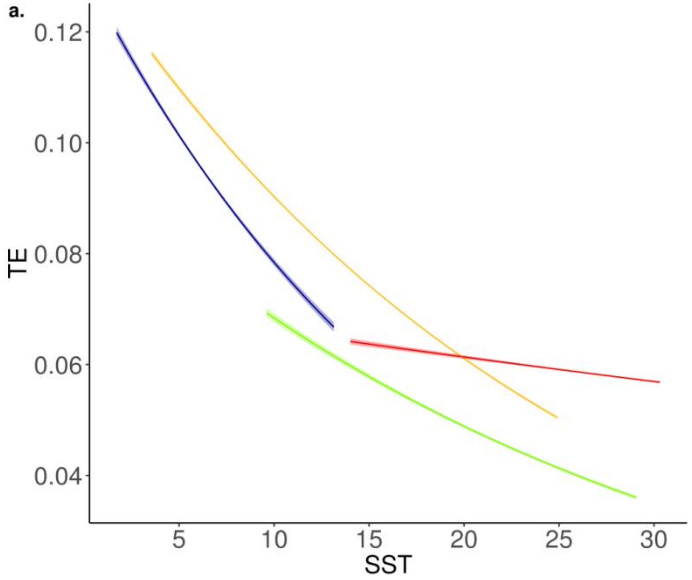
- **Circularity of the analysis :**
  - Biomass flow parameters P/B and P/Q calculated from Temperature

- **Changes likely underestimated** : Only the community level considered

Global discussion

- **Tropical Ecosystems : TE less sensitive to temperature and more diversity in terms of growth characteristics**

  Tropical Ecosystems more resilient ?



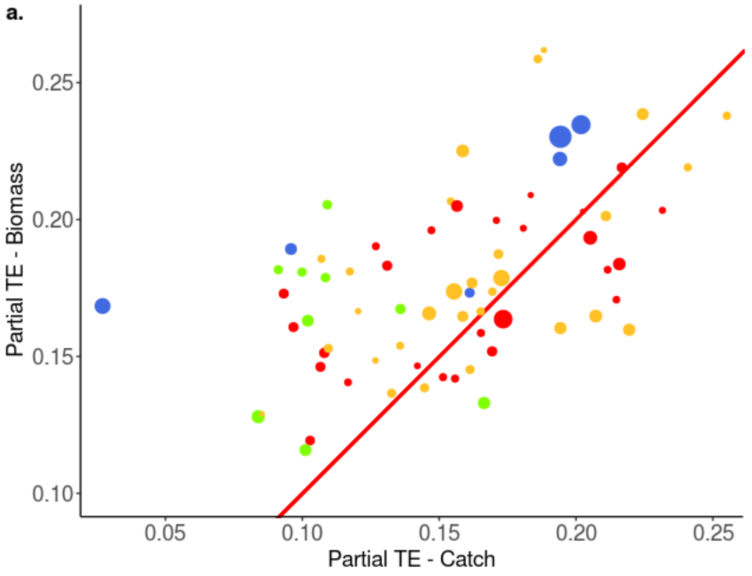
Global discussion

- **Tropical Ecosystems : TE less sensitive to temperature and more diversity in terms of growth characteristics**

  Tropical Ecosystems more resilient ?

- **TE from Catch < TE from Biomass** and **TCI from Catch > TCI from Catch**

  Fishing selects the least efficient species?



Global discussion

- ➢ **Tropical Ecosystems : TE less sensitive to temperature and more diversity in terms of growth characteristics**
  - Tropical Ecosystems more resilient ?

- ➢ **TE from Catch < TE from Biomass** and **TCI from Catch > TCI from Catch**
  - Fishing selects the least efficient species?

Conclusion

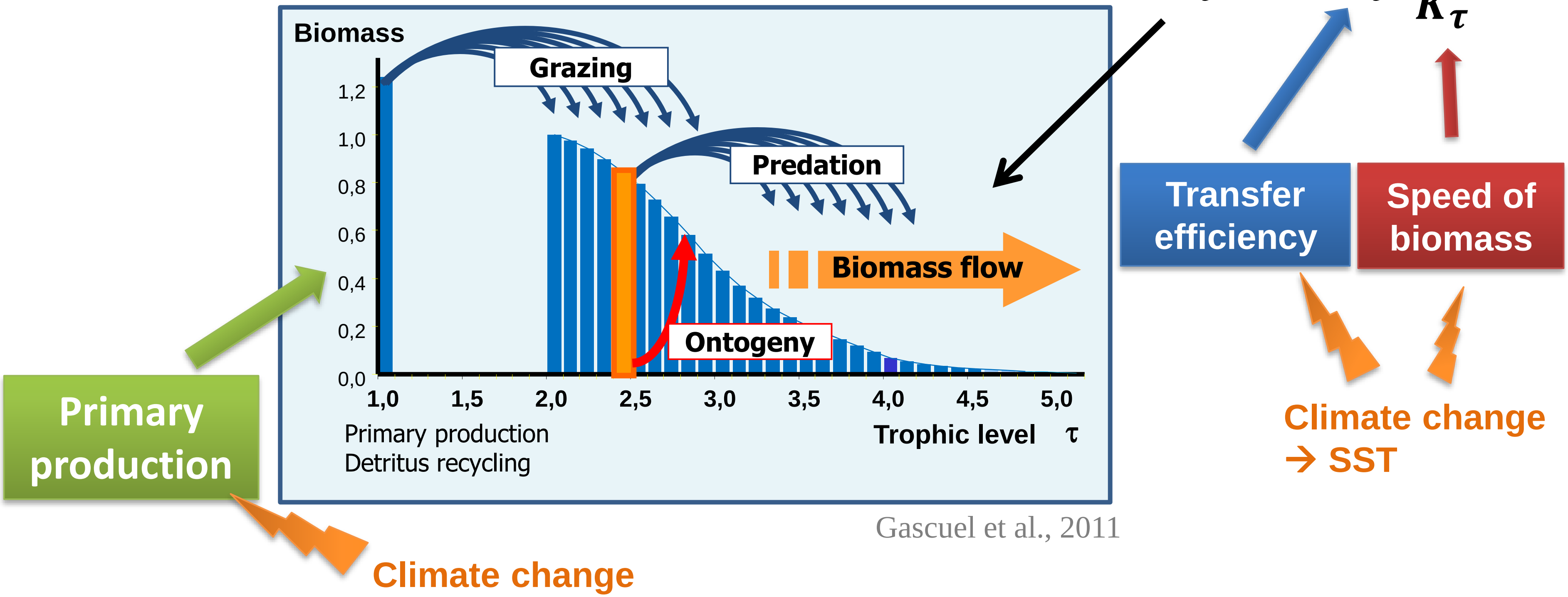
- At the global scale, **biomass transfers are faster and more efficient**

- **Cold Ecosystems : slow and more efficient biomass transfers**
  - With slow growing & low turn-over species

  Warn Ecosystems : Fast and less efficient biomass transfers
  - With fast growing & high turn-over species

Simulation of unexploited biomass and production using the trophodynamic model : EcoTroph

$$B_\tau = \Phi_\tau \frac{\Delta_\tau}{K_\tau}$$

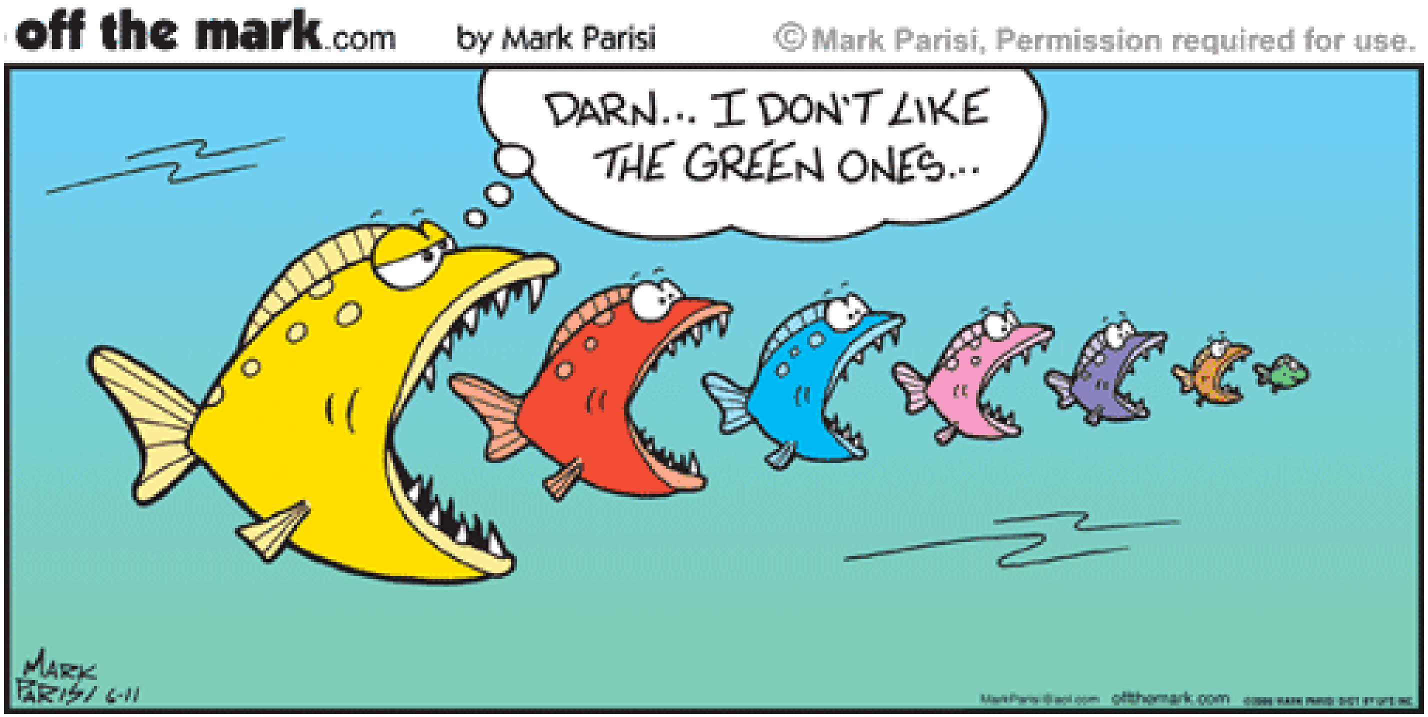


Gascuel et al., 2011

Purpose : Inform the sensitivity unexploited production and biomass to climate change

-->Various climate change models and scenarios will be tested

Thank you for your attention!



Any questions?

Speed of flows and partial trophic efficiency

- TCI : Time cumulated indicators

$$\frac{P}{B} = 20.19 \times TL^{-1.72} \times e^{0.053 \times T}$$

$$TCI_{j,y} = \sum_{\tau=2.0}^{\tau=4.0} \frac{\Delta\tau}{\left(\frac{P}{B}\right)_{\tau,j,y}}$$

τ = 2 : From secondary consummer ...

τ = 4 : ... to Top predator

- ECI : Efficiency cumulated indicators

$$\left(\frac{Q}{B}\right)_{i,j} = 10^{7.964 - 0.204 \times log_{10}(W_{i,j}) - 1.965 \times \frac{1000}{T_j} + 0.083 \times A_i + 0.532 \times h + 0.398 \times d}$$

$$\left(\frac{P}{Q}\right)\tau = \frac{(^P/_B)\tau}{(^Q/_B)\tau} = \frac{Speed\ of\ the\ biomass\ flow}{food\ consumption\ rate}$$

$$ECI_{j,y} = \prod_{\tau=2.0}^{\tau=4.0} \left(\frac{P}{Q}\right)_{\tau,j,y}^{\Delta\tau}$$

T : Temperature
TE: Transfer Efficiency
τ & TL : Trophic level
W : Asymptotic weigth
A : Aspect ratio
h & d : herbivory & detrivory index

Adapted from Gascuel et al., 2008

Speed of flows

Indeed, *P*/*B* is a rate of regeneration of the biomass; it relates to the proportion of tissue which is elaborated (whether it survives or not) over a unit of time (Christensen et al., 2005). Each animal or group can be regarded as a ‘unit’ which transfers the biomass of prey into biomass of a predator, on average from TL = to TL = + 1. And logically the regeneration rate defines the speed at which the production crosses through a given organism or a given trophic level. Assuming equilibrium, the *P*/*B* ratio is equal to the total mortality rate *Z* (Allen, 1971). This means that the total mortality rate *Z*, which may be considered a measure of the biomass turn-over (Paloheimo and Dickie, 1970), is also a measure of the speed of the trophic flow, passing through a given trophic level in steady-state conditions.