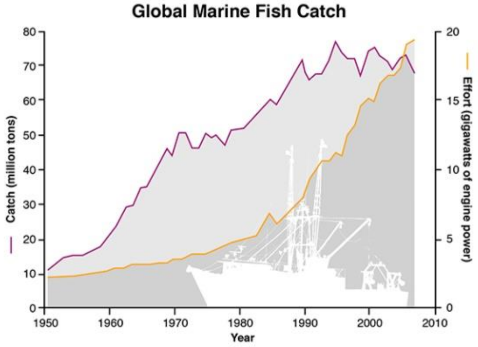
EcoTroph: A tool for simulating unexploited biomass and production at the global scale

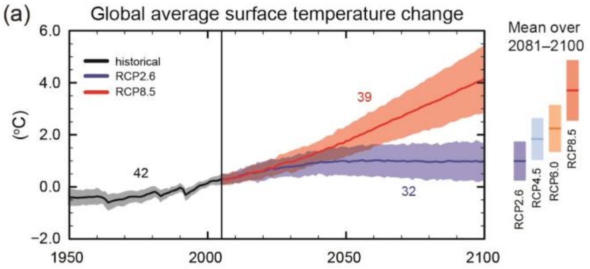
Hubert du Pontavice, Didier Gascuel, Gabriel Reygondeau, William Cheung



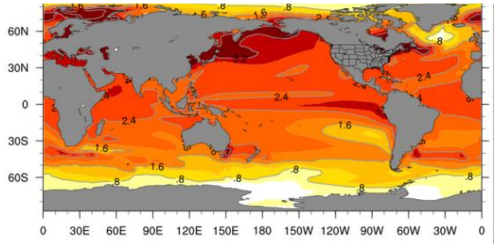
- Over the last century, fishing was main driver of global change

  ➔ Continuous increase in effort and catch since 1950

- Climate change effect on marine ecosystem are increasing since 1980s



Température des eaux de surface entre 2000 et 2100



NOAA

→ **Scientific challenge:** Analyze and quantify on the climate change effects

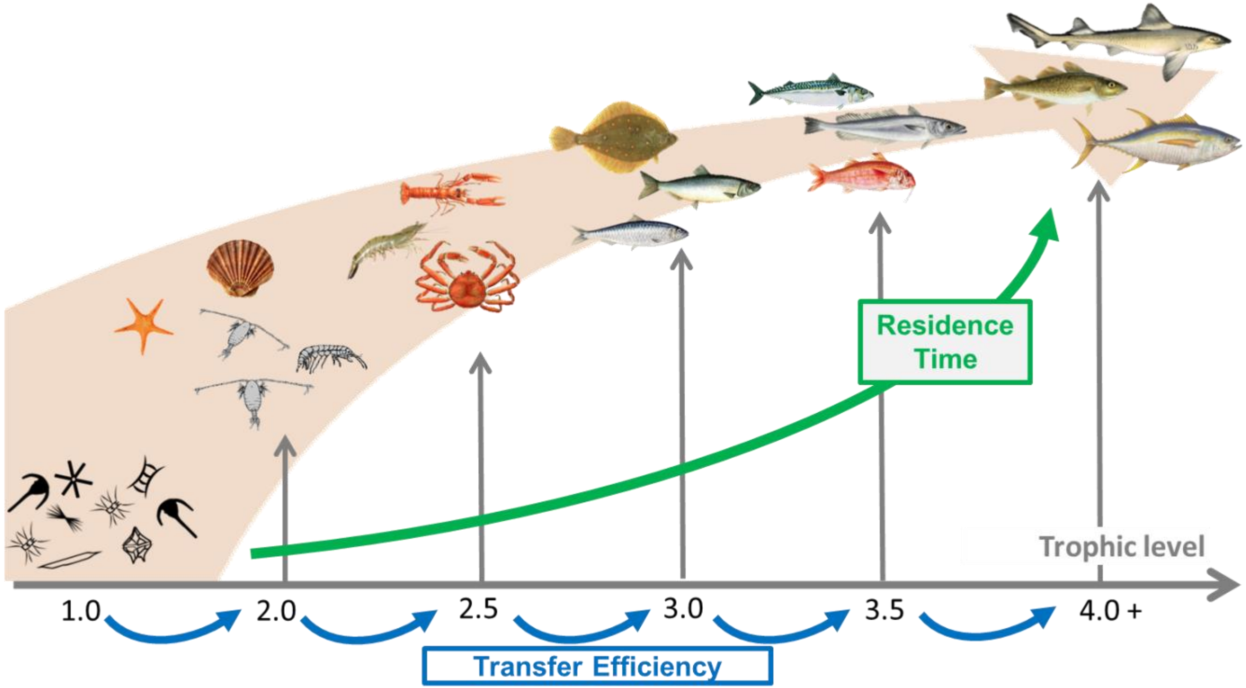
→ **Management challenge:** Manage future of fisheries and marine ecosystems in a changing ocean

- Climate change does affect :
  - all ecological level from species to ecosystem …
  - … But also all compartments in the food web from phytoplankton to top predator

- ultimately the entire ecosystems' trophic networks, and thus the ecosystem functioning are impacted

- Marine ecosystem models are crucial tools to better understand the ecosystem functioning and bring insights into potential changes

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



Ocean warming will affect trophic transfer of biomass (du Pontavice et al., in Prep)

Research questions

What will the sensitivity of unexploited biomass and production to the changes in environmental conditions and transfers of biomass?

1. What are the projected spatial and temporal changes in unexploited biomass and production?

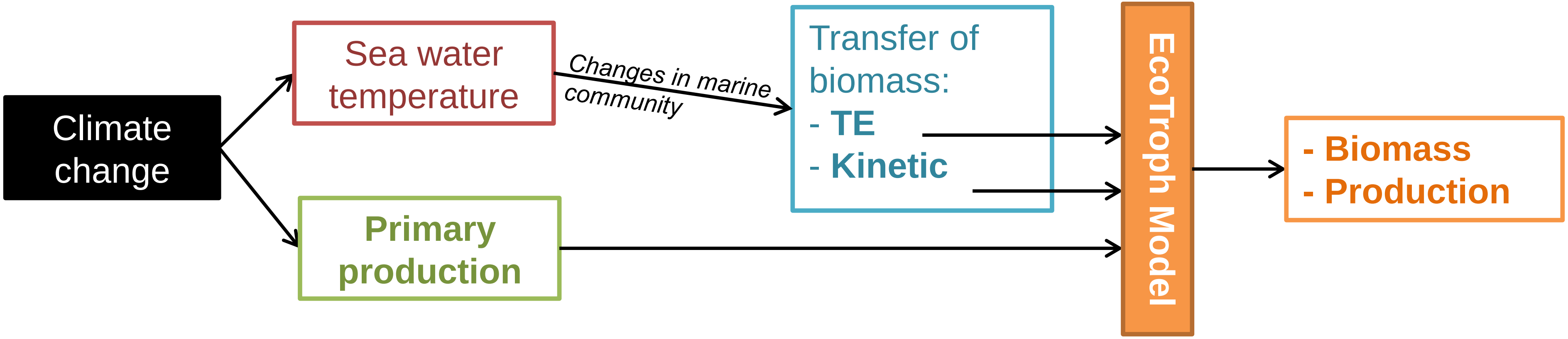
Hypothesis: Marine food webs can be represented as flow – EcoTroph theory

2. What are the ecosystem responses in terms of biomass and production to three biomass transfer processes affected by climate change?

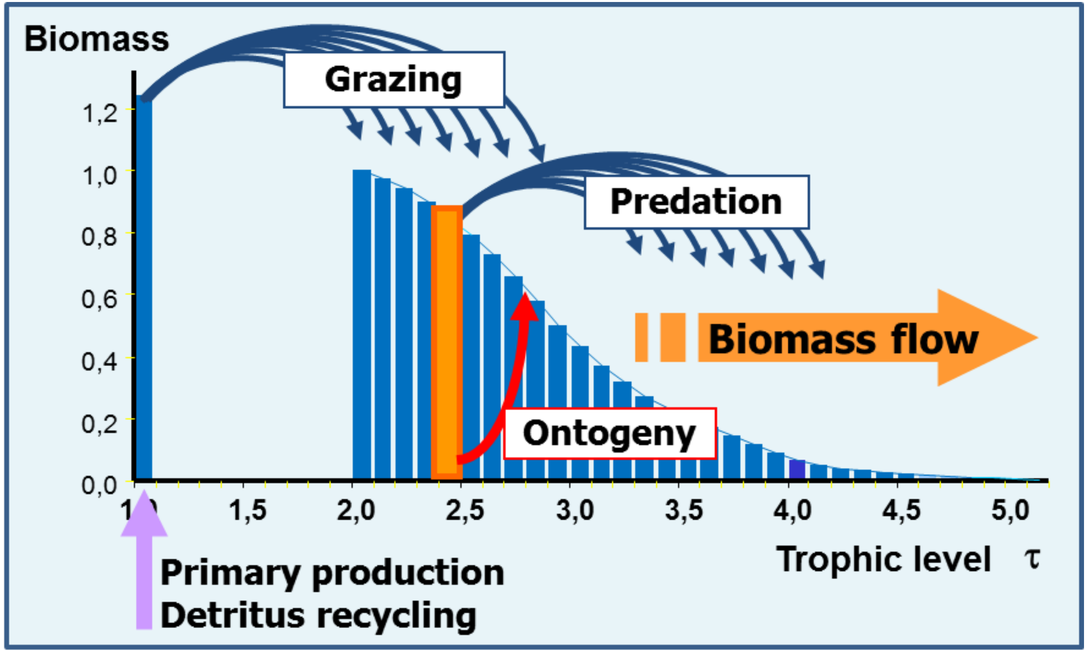
Hypothesis:
Primary production, Transfer efficiency and Kinetic determine the biomass transfers in the food web

Research questions

What will the sensitivity of unexploited biomass and production to the changes in environmental conditions and transfers of biomass?



➢ EcoTroph: how does it work?



Gascuel, 2005 … Gascuel, Pauly, 2009 … Gascuel, Guénette, Pauly, 2011
(*ICES Journal of marine science*, 68: 1403-1416)

- A continuous representation of the biomass distribution, according to trophic level **t**

-> the Biomass Trophic spectrum

- The ecosystem functioning: a flow of biomass trough trophic levels

EcoTroph: Equations and inputs

- The master equation: $\text{Biomass} = \dfrac{Flow}{Kinetic} \times \Delta\tau$

$$at\ each\ trophic\ level: \ B_\tau = \frac{\Phi_\tau}{K_\tau} \times \Delta\tau$$

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- A non-conservative flow: $\Phi_{\tau+\Delta\tau} = \Phi_\tau \times exp(-\mu_\tau \times \Delta\tau)$

$\Phi_1 = \text{NPP}$

(NPP : Net Primary Production)

Natural losses

. Non pred.mort. Mo.B

. Excretion U

. Respiration R

$e^{-\mu}$ =Transfer efficiency

Fishing losses

. Catches Y

Biomass entering the food web

EcoTroph: Equations and inputs

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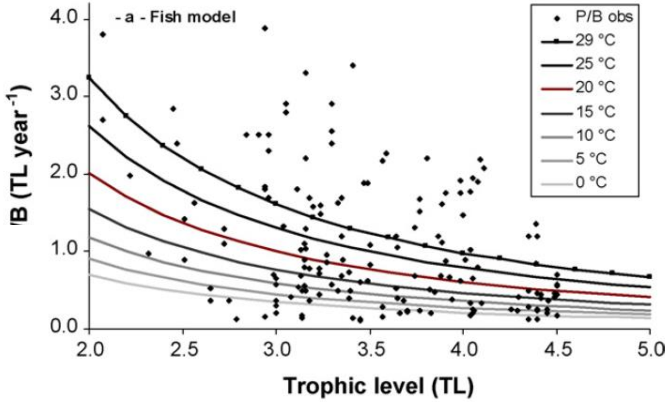
  (NPP : Net Primary Production)
- An empirical model for kinetics: $K_\tau = 20.19 \times \tau^{-3.26} \times exp(0.04 \text{ x } H)$

(Gascuel et al., 2008)   (H : temperature)

55 Ecopath models
- n = 1,718 groups
- $r^2 = 0.54$



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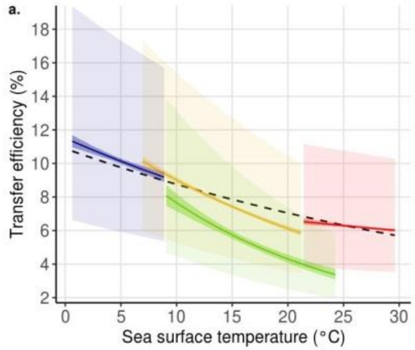
  (Gascuel et al., 2008) (H : temperature)
- An empirical model for Transfer: $TE = exp(-2.162 + H(-0.025 + a) + b)$
  (Du Pontavice, in Prep) (H temperature)



➢ Transfer efficiency

An integrated index : From species level to community level

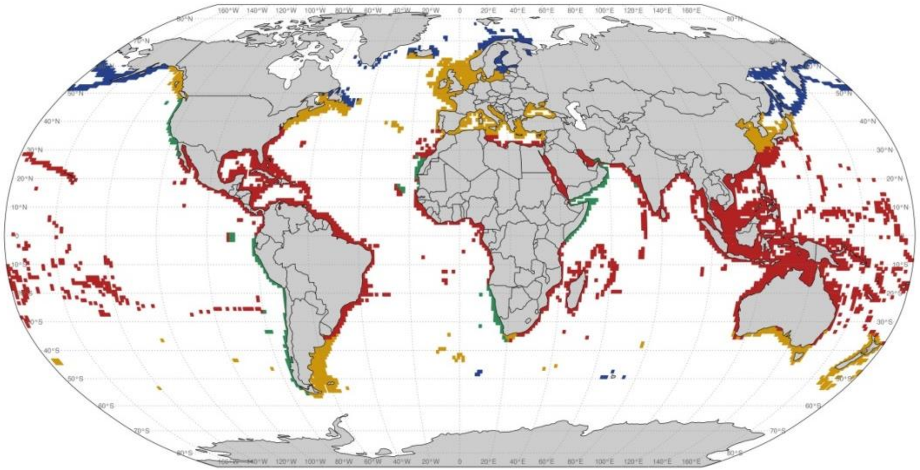
- Calculation of two parameters:
  - ➢ **Transfer efficiency** → Partial transfer efficiency (Maureaud et al., 2017)
    + non-predation losses

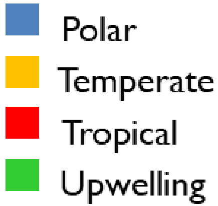
- Multiple data sources: SeaAroundUs, Fishbase, SeaLifeBase and Ecobase

➢ Transfer efficiency

Transfer Efficiency measured:

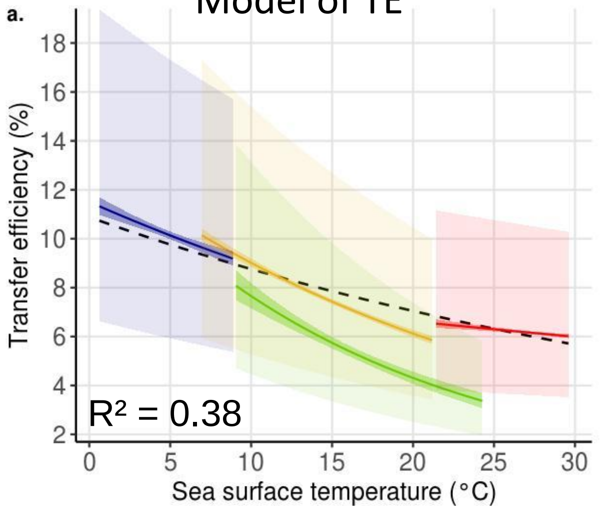
- in **every 1 degree coastal cell (~5500 cells)**
- for **all the years between 1950 and 2010**



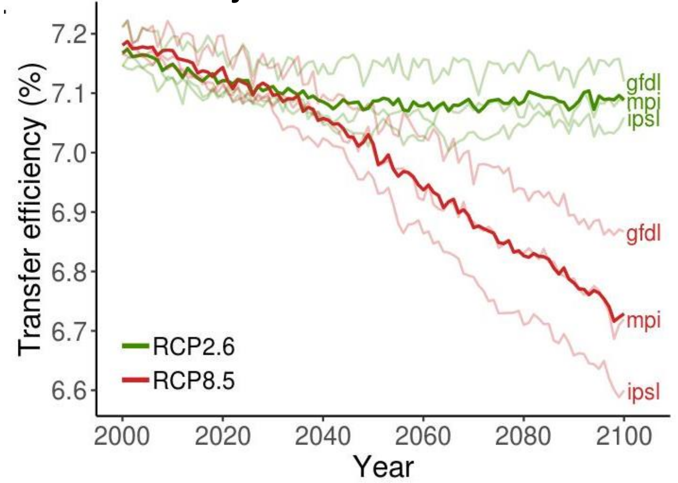


Transfer efficiency

Model of TE



Projections until 2100



Mat & Met

- GLM to analyze the temperature effect on transfer efficiency over the period 2000-2010
- Dependent variables: Transfer efficiency
- Independent variables: Sea surface temperature (SST) & Ecosystem type

Mat & Met

- 2 climate scenarios :
  - RCP2.6 (Increase in global temperature remains below 2°C)
  - RCP8.5 (business as usual)
- 3 general Atmosphere-Ocean circulation models are used

Environnemental conditions in EcoTroph

- The master equation: $\text{Biomass} = \frac{Flow}{Kinetic} \times \Delta\tau$ *at each trophic level* : $B_\tau = \frac{\Phi_\tau}{K_\tau} \times \Delta\tau$
- A non-conservative flow: $\Phi_{\tau+\Delta\tau} = \Phi_\tau \times exp(-\mu_\tau \times \Delta\tau)$ $\Phi_1 = \text{NPP}$ (NPP : Net Primary Production)
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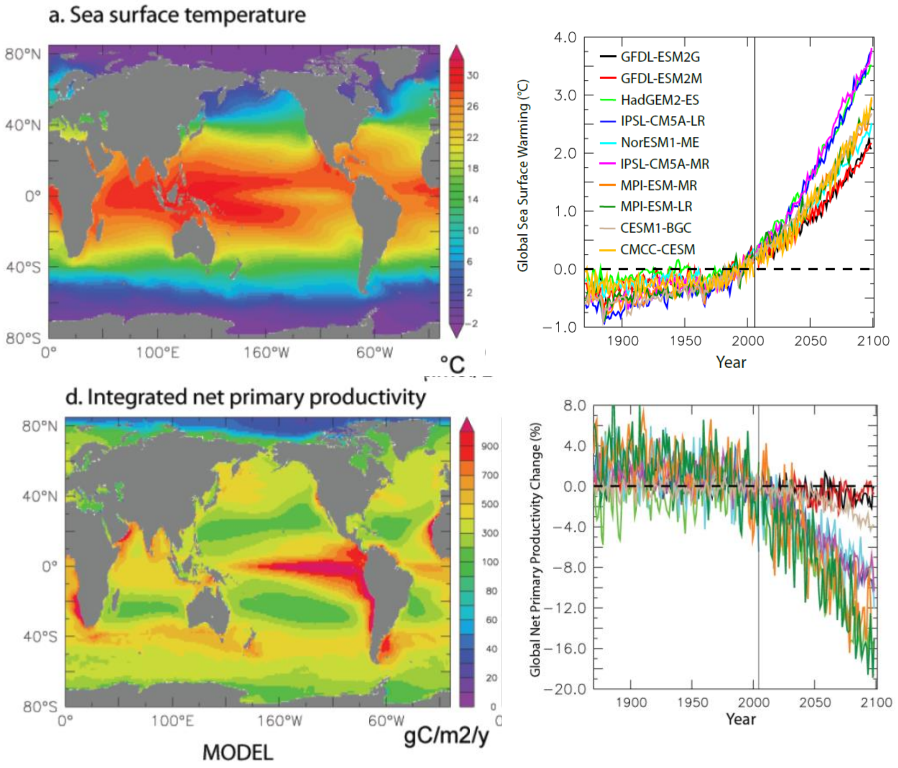
  (Du Pontavice, in Prep)

Environnement affect the food web in EcoTroph

➢ Climate data

- 3 Earth System Models predict changes in environmental changes by 2100 :
  - GDFL
  - IPSL
  - MPI

- Two climate-change forcing's used :
  - Sea Surface Temperature (SST)
  - Net Primary Productivity (NPP)



Bopp et al., 2013

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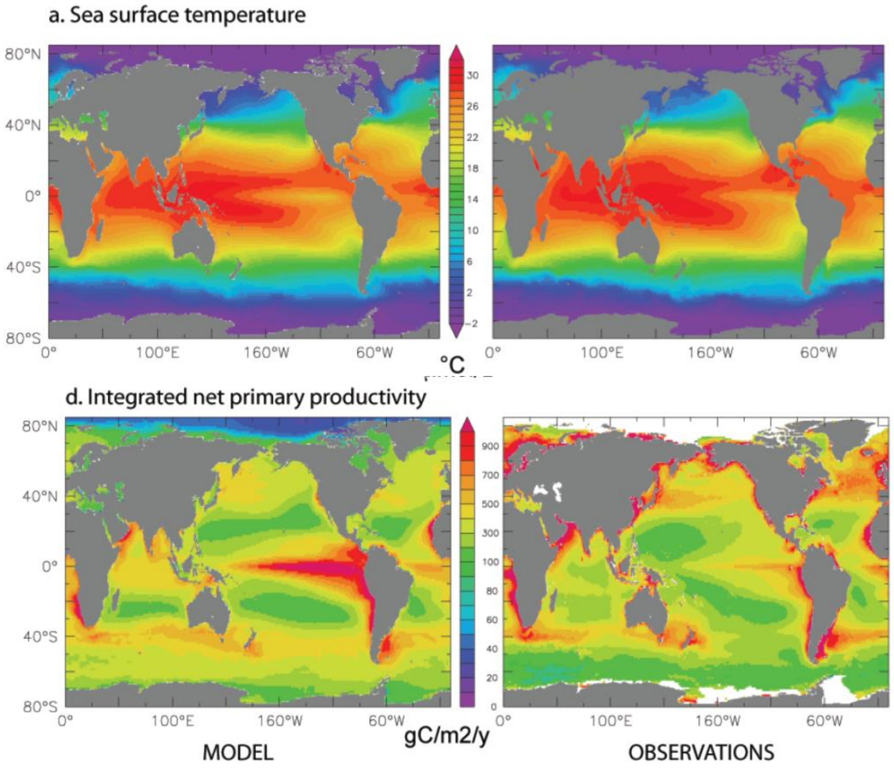
Data bias:

→ substantial spatial and temporal differences between models and observations

❑ How can we reduce this bias?

❑ Should we calculate a correction factor based on observations? If so, how?



Bopp et al., 2013

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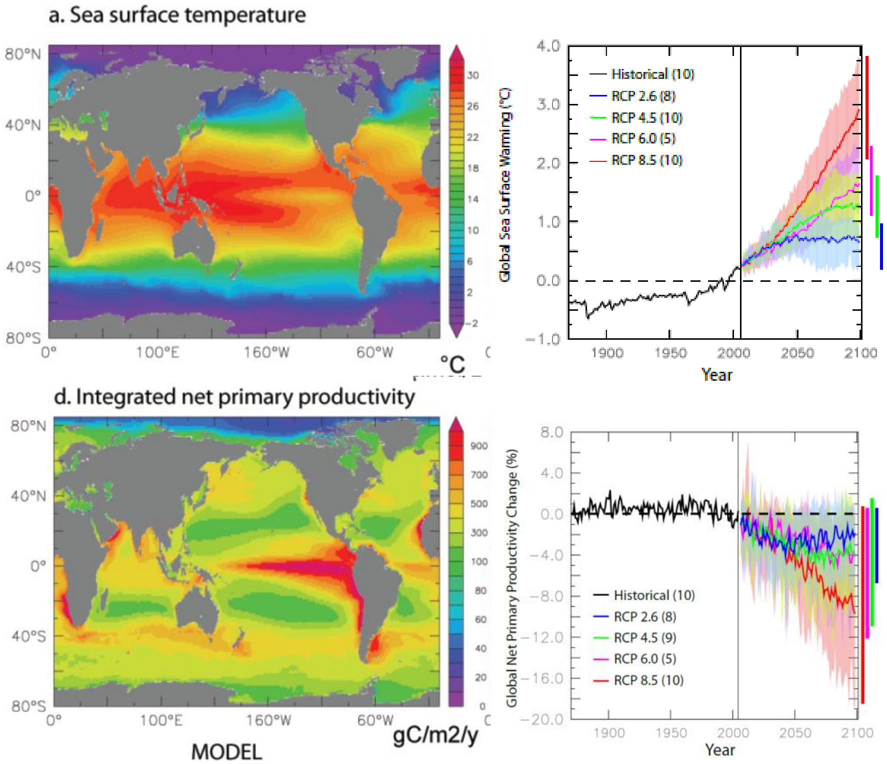
Two climate change scenarios :

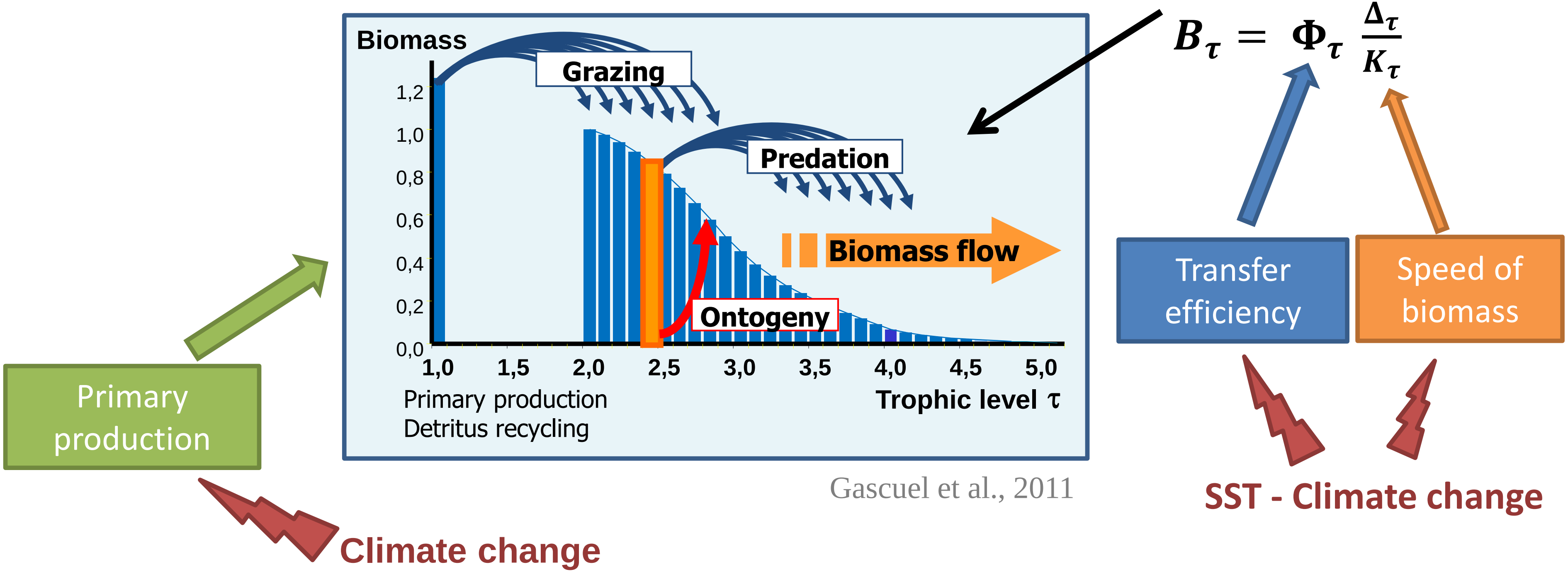
RCP 2.6: Increase in global temperature remains below 2°C

RCP 8.5: Business as usual



Bopp et al., 2013

➢ Climate change forcing in EcoToph



Gascuel et al., 2011

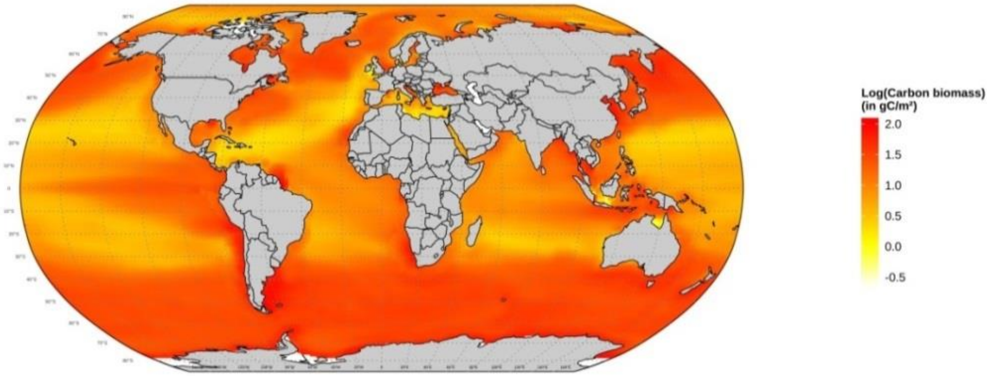
Methods : EcoTroph model applied at the global scale

- Unexploited biomass (TL >= 2) and consumer production (TL>=2)

$$B_\tau = \frac{\Phi_\tau}{K_\tau} \times \Delta\tau$$

- Running EcoTroph model in each cell in 1 degree grid for each year between 1950 and 2100

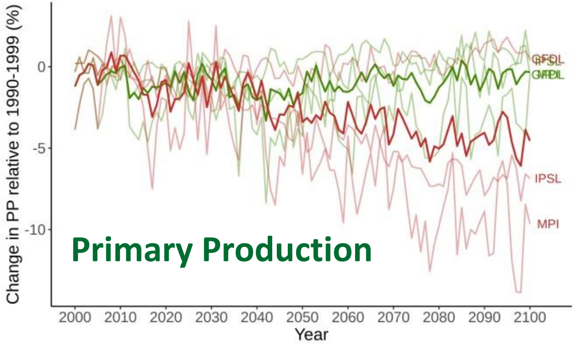
$$P_\tau = \int_\tau^{\tau+\Delta\tau} \Phi(\tau) \times \, d\tau = \Phi_\tau \times \Delta\tau$$

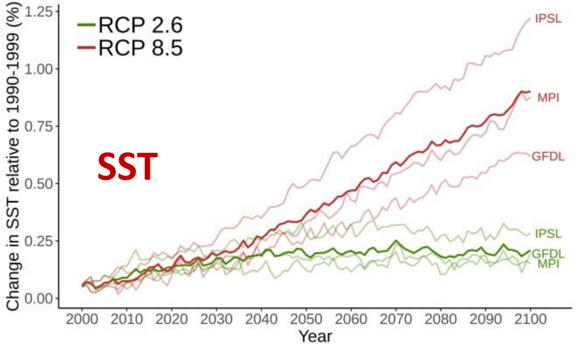


➢ Preliminary results : Simulating biomass and production – Global scale

1) What are the projected spatial and temporal changes in unexploited biomass and production by 2100 depending on two contrasted climate change scenarios?

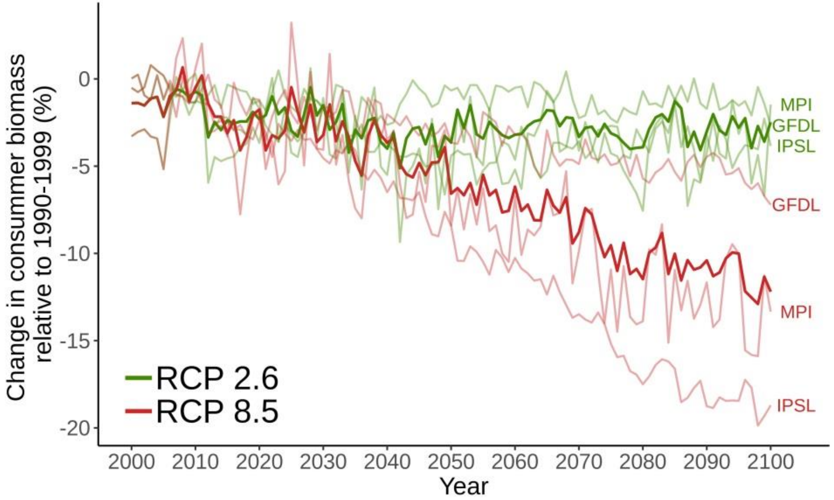
Changes in environnemental conditions





EcoTroph Model

Changes in consumer biomass



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IPSL model & Scenario RCP 8.5 (Pessimistic, Business as usual)

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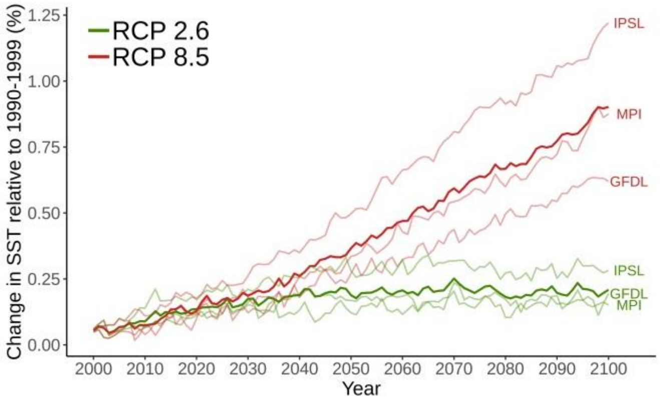
Sciences de l'environnement



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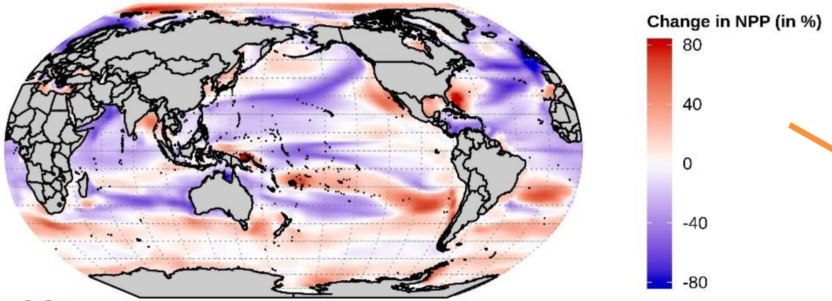
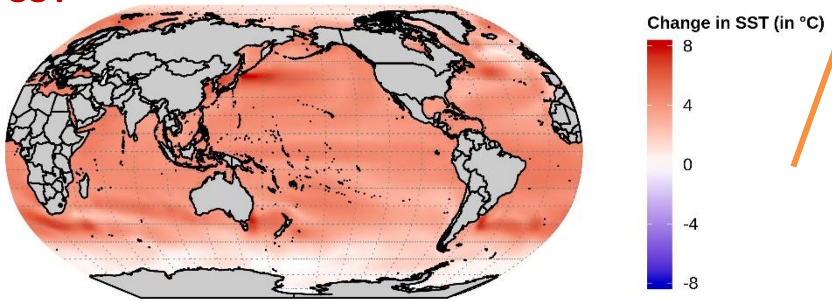
Changes in environnemental conditions

Primary Production



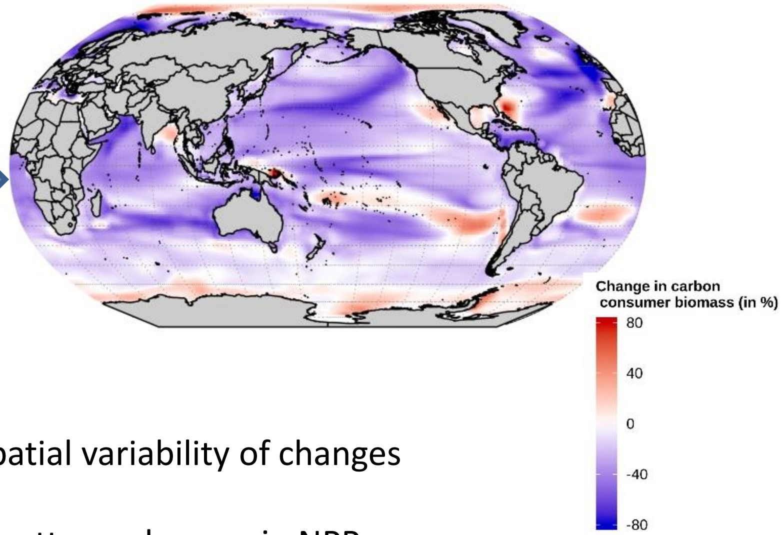
SST



EcoTroph Model

Changes in consumer biomass between 2000 and 2100

IPSL model - Scenarios RCP 8.5

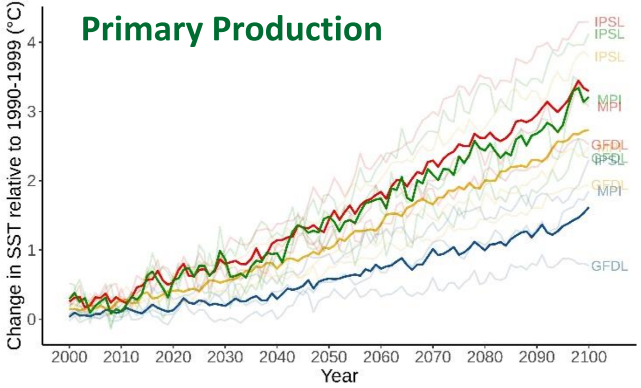


- High spatial variability of changes
- Spatial pattern: changes in NPP
- Magnitude of these changes: changes in SST

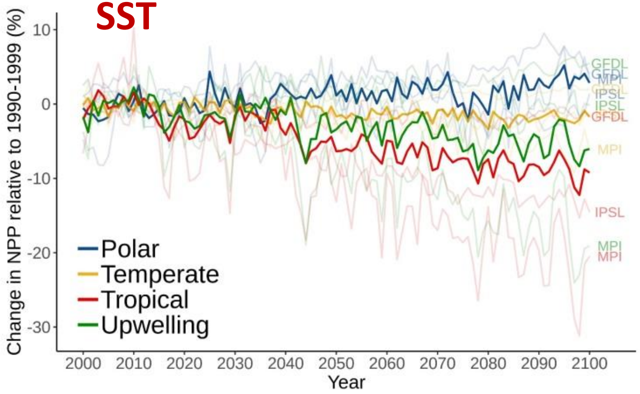
➢ Preliminary results : Simulating biomass and production – Ecosystem type

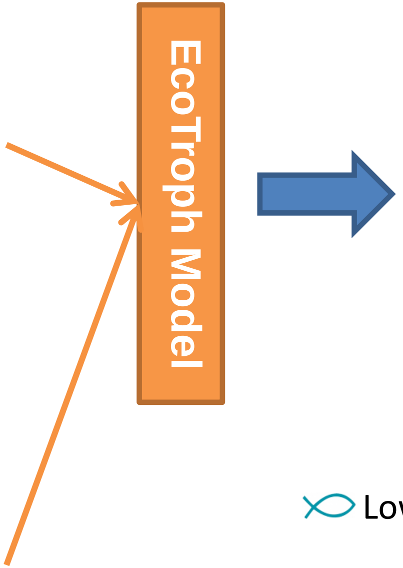
IPSL model & **Scenario RCP 8.5 (Pessimistic, Business as usual)**

Primary Production

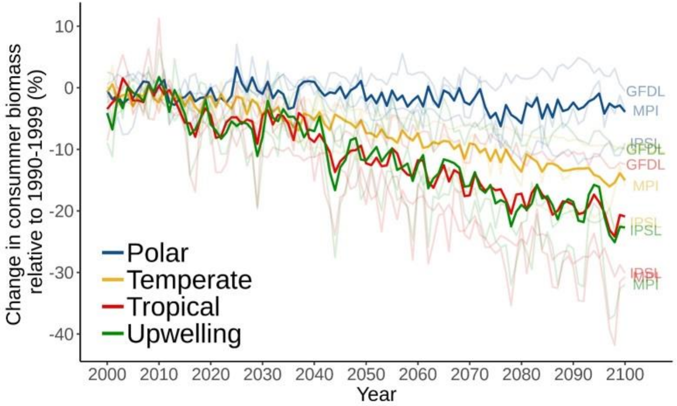


SST





Changes in consumer biomass between 2000 and 2100



- Lowest increase in SST + slight increase in NPP
  ➔ Slight decrease in biomass

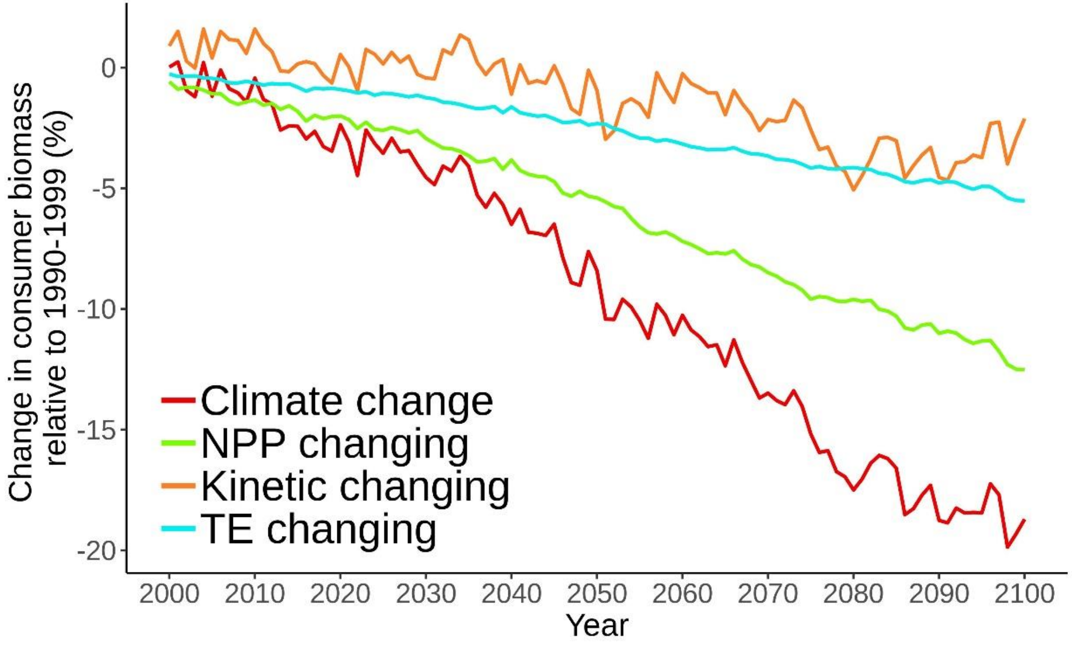
- Strongest decrease in biomass in tropical and upwelling ecosystems

➢ Preliminary results : The processes

2) What are the ecosystem responses in terms of biomass and production to three biomass transfer processes affected by climate change?

➔ Fixed Primary production, transfer efficiency and kinetic (successively) to better understand the effect of each process on the biomass and production estimates

IPSL model & Scenario RCP 8.5 (Pessimistic, Business as usual)



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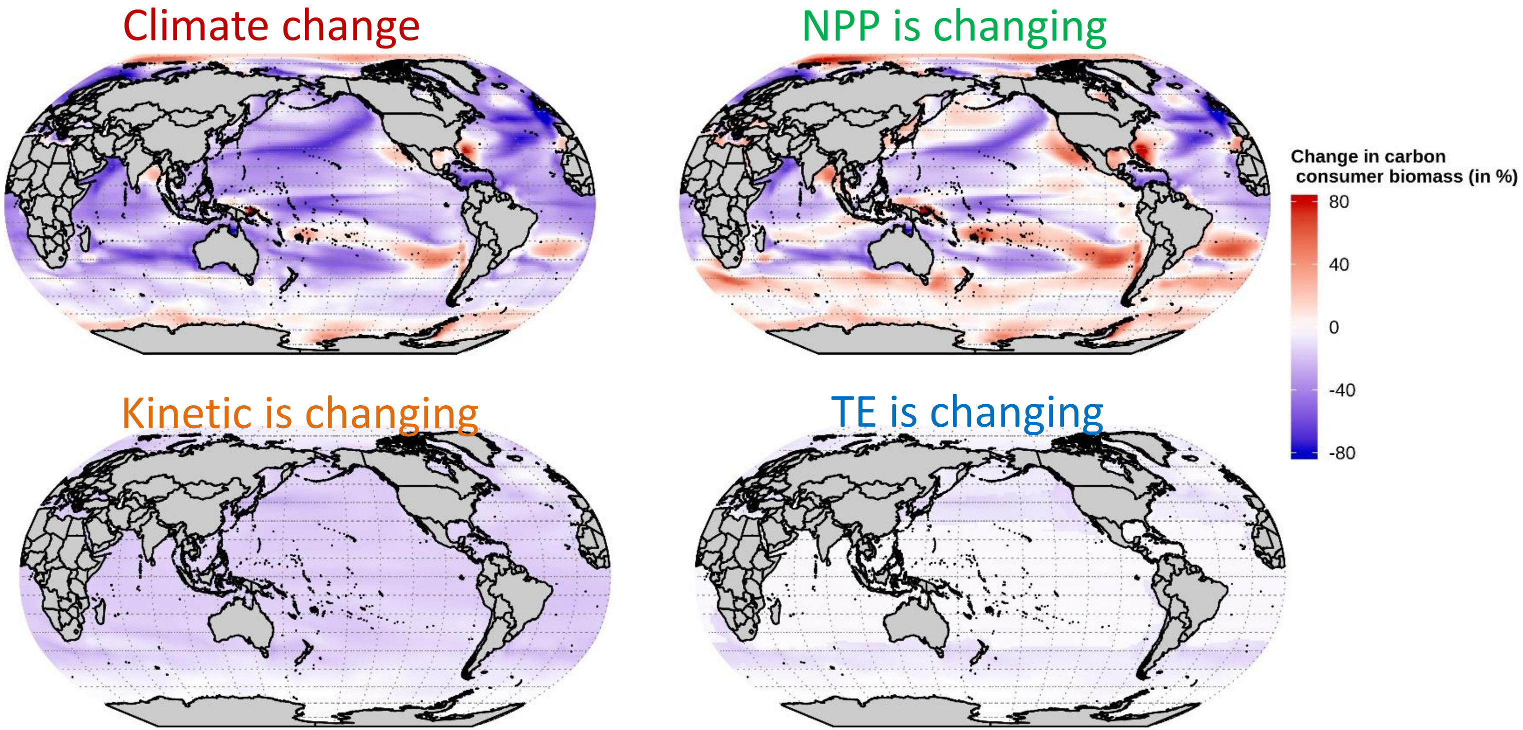


➢ Preliminary results

2) What are the ecosystem responses in terms of biomass and production to three biomass transfer processes affected by climate change?

- Inter model variability
- Changes patterns for each ecosystem types
- Look at the changes by 2030, 2050 and 2100

Work in progress

Preliminary conclusions

- High spatial variability of changes…
- …. with a global decrease in biomass
- Polar regions less affected by climate change in EcoTroph
- PP drive the spatial patterns and trophic transfer (change in SST) drive the magnitude of the changes

Potential issues to solve

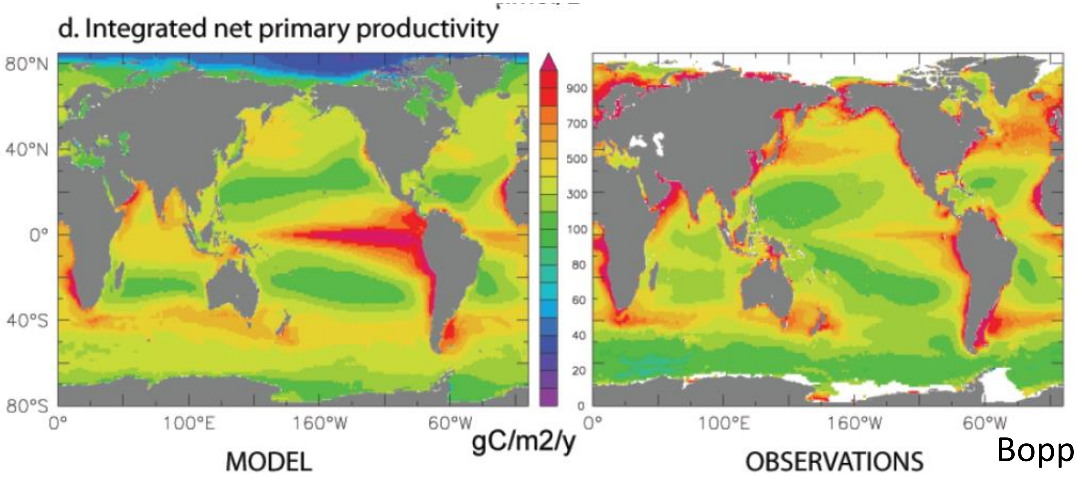
- Biomass transfer from phytoplankton (TL=1) to zooplankton?
- Modelled data does not match with observed data in the coastal areas
- Differences of functioning between open ocean and coastal ecosystem have not been taken into account (same TE and Kinetic)

Next steps

- What will be the consequences of theses changes on fisheries?

➢ Modelled data does not match with observed data in the coastal areas

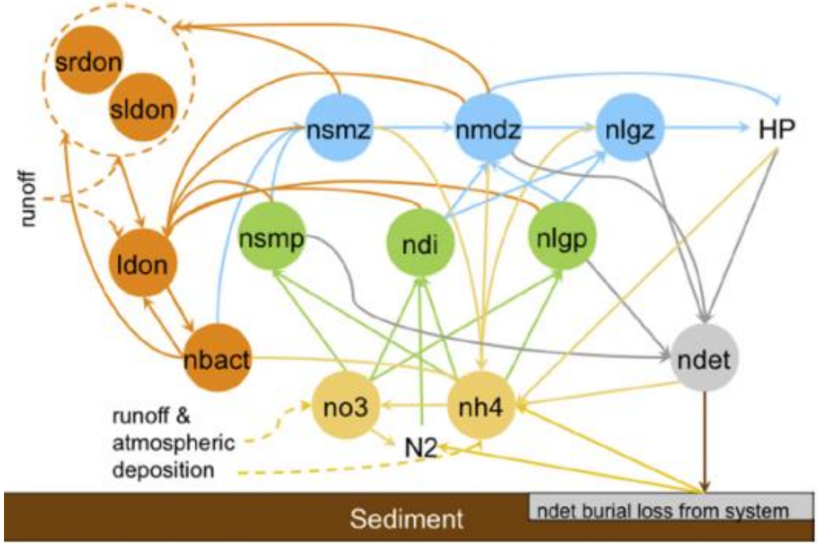
- High difference between modelled and observed data …
- … Spatially and temporally (and especially along the coast)
- A potential solution: Use a correction factor calculated on the year with modelled and observed data



Bopp et al., 2013

➢ Biomass transfer from phytoplankton (TL=1) to zooplankton???

- For now, a 10% values is assigned everywhere



(Stock et al 2014a, b)

➢ Biomass transfer from phytoplankton (TL=1) to zooplankton???

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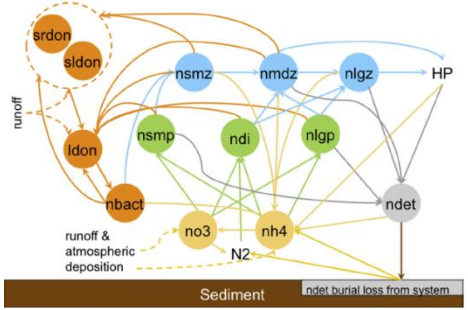
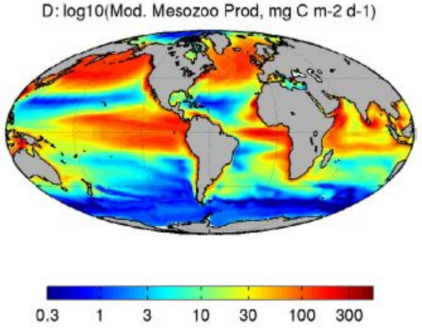
- Gradient of TE between highly productive area (high TE) and oligotrophic gyres (low TE) (Stock et al 2014a, b)?
  - Lower TE's in the oligotrophic gyres
  - Higher TE highly productive region

- Magnitude of these changes: changes in SST

- One solution to improve the TE estimates in this compartment :
  - Use estimates from **planktonic food webs model** developed at global scale

    ex: PISCES (ipsl) or COBALT (gfdl)





$$TE_{1\to2} = \frac{Mesozooplankton\ production}{Net\ Primary\ Production}^{(Mesozooplankton\ TL-1)}$$

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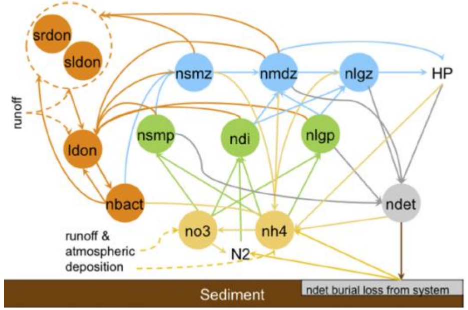
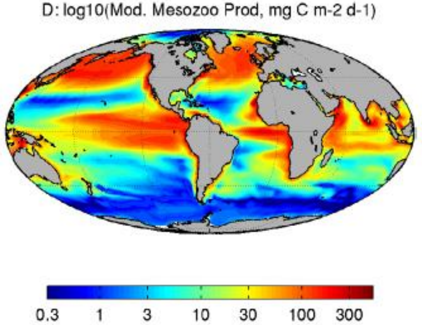




➢ What will be the consequences of theses changes on fisheries?

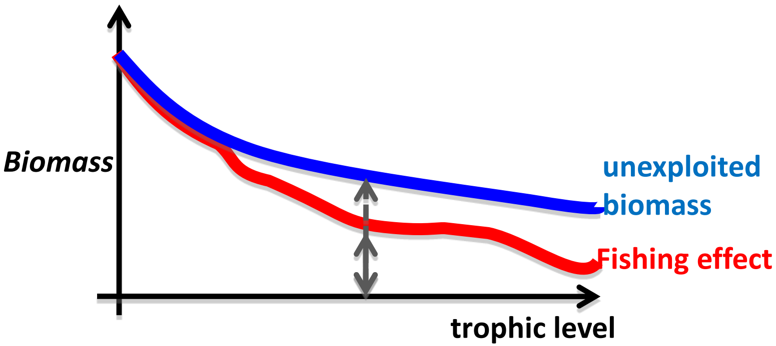
Status Quo Scenario:

- Apply the current fishing mortalities on unexploited biomass

Data: SeaAroundUs

Various fishing scenarios:

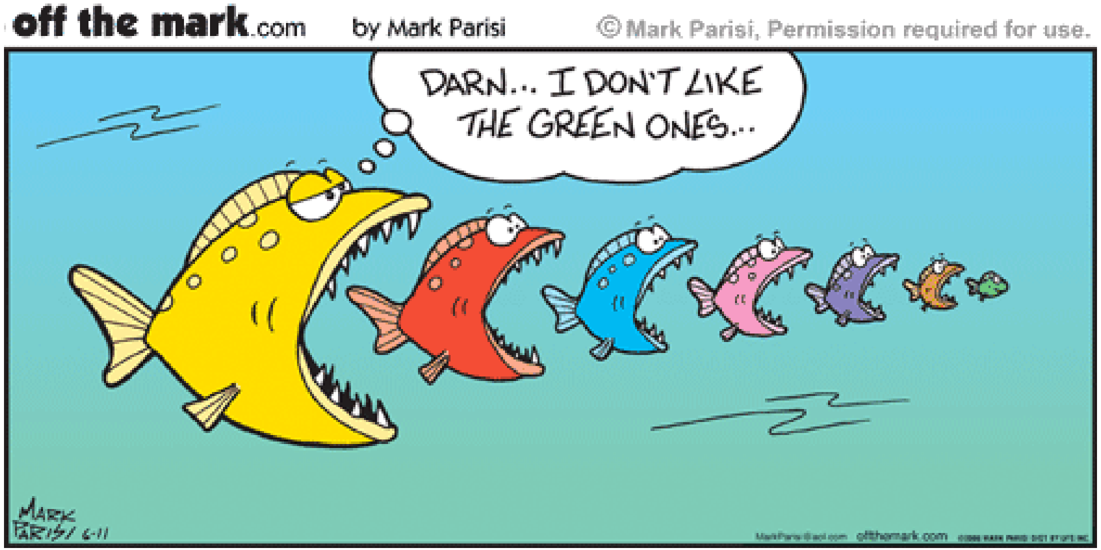
- The same F everywhere
- MSY Scenarios
- Mass Balanced Harvest



Aim:

- Bring insights on the future catch potential
- Highlight potential temporal and spatial changes

MERCI DE VOTRE ATTENTION



➢ Preliminary results

2) What are the ecosystem responses in terms of biomass and production to three biomass transfer processes affected by climate change?

FISH-MIP outputs

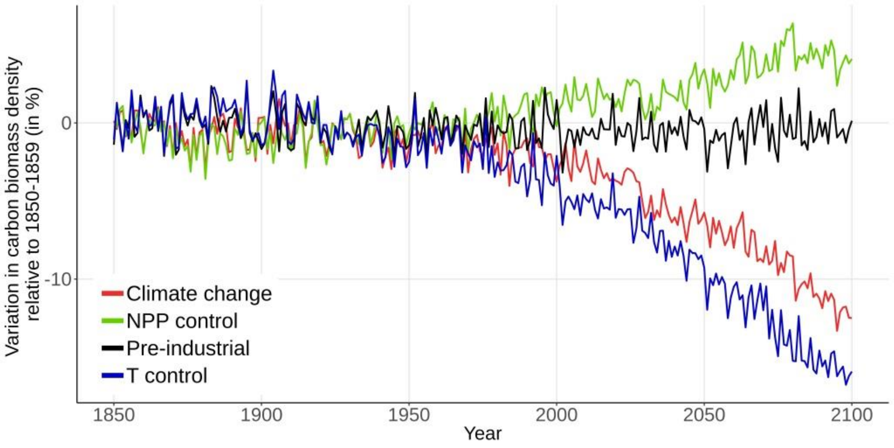
Fixed Primary production and temperature (successively) to better understand the effect of each climate forcing's on the biomass and production estimates

- at global scale: NPP and SST affect differently biomass :
  - Changes in NPP and SST antagonist effects
  - NPP ➔ biomass ↗
  - SST ➔ biomass ↘ ↘

- Unexpected NPP effect :

Hypothesis: the model predict strong increase in NPP in the pole

Global temporal variation of consummer biomass for the 4 runs (in %, 1850/59 vs 2090/99)



➢ Preliminary results

2) What are the ecosystem responses in terms of biomass and production to three biomass transfer processes affected by climate change?

FISH-MIP outputs

- High spatial variability of changes
- Spatial pattern: changes in NPP
- Magnitude of these changes: changes in SST = Changes in transfer of biomass
- Strong increase in biomass toward the poles

Spatial variation of biomass for the 4 runs (in %, 1850/59 vs 2090/99)