ECCWO Symposium - Session 12: Scenarios and models to explore the future of marine coupled human-natural systems under climate change

EcoTroph, a quasi-physical ecosystem model to analyze the global impact of climate change on marine food-webs

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EcoTroph: an over-simplified ecosystem model

Total ecosystem Biomass (tons/km²)

Trophic level

Producteurs primaires
Détritus
Zooplanc.

TL
Petit
2,0 2,5 3,0 3,5 4,0 4,5 5,0
0.01 .01 1.0 10.0 100.0

Grd. zool.
Crustac.
Dem.in
Ethmal.
Céphal.
Bathy.
Mulets
Capit.
Dem.p.
Bars
Grd.pél.
Req.rai
Daup.
Bal
Artisanal fishery
Indust. fishery
EcoTroph: applications

- to draw diagnostics (Meissa et al., 2015)
- to assess fishing impacts (Gascuel et al., 2005)
- to explore fisheries (Bentorcha et al.)
- to quantify interactions (Gasche et al., 2013)
- to map global fisheries impacts (Tremblay-Boyer et al., 2011)
- to compare ecosystem's structure and dynamics (Moullec et al., 2016)
- to monitor MPA’s benefits (Colleter et al., 2012)
- to compare models (Gasche et al., 2012)

Climate change as the driver?
EcoTroph: how it works?

- A continuous representation of the biomass distribution, according to trophic level $\tau$
  
  -> the Biomass Trophic spectrum

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

Gascuel, 2005 ... Gascuel, Pauly, 2009 ... Gascuel, Guénette, Pauly, 2011
EcoTroph: two key parameters

- **The transfer efficiency TE**: defines the quantity of biomass flow ($\Phi_\tau$), at each trophic level

- **The flow kinetics K**: celerity of biomass transfers through the food web (in TL/y⁻¹)

NB: $1/K$ is the residence time in the food web
EcoTroph: basic equations

- The master equation: \( \text{Biomass} = \frac{\text{flow}}{\text{speed}} \cdot \Delta\tau \)  
  \( B_{\tau} = \Phi_{\tau} \cdot \Delta\tau / K_{\tau} \)

An explicit link between:

- the **biomass** present in the trophic class \([\tau, \tau+\Delta\tau]\) -> \( B_{\tau} \), in tonnes
- the **production**, which results from the biomass flow passing through the trophic class -> \( P_{\tau} = \Phi_{\tau} \cdot \Delta\tau \), in tonnes/year
EcoTroph: basic equations

- The master equation:
  \[ \text{Biomass} = \frac{\text{flow}}{\text{speed}} \cdot \Delta \tau \]
  \[ B_\tau = \Phi_\tau \cdot \Delta \tau / K_\tau \]

- A non-conservative flow:
  \[ \Phi_\tau + \Delta \tau = \Phi_\tau \cdot e^{-\left( \mu_\tau + \phi_\tau \right) \cdot \Delta \tau} \]

- Natural losses:
  - Non pred.mort. Mo.B
  - Excretion U
  - Respiration R

- Fishing losses:
  - Catches Y

\[ e^{-\mu} = \text{Transfer efficiency} \]

\[ \Phi \rightarrow Y = F.B \rightarrow \text{Predator} \rightarrow U \rightarrow \Phi \]

\[ \Phi \rightarrow \text{Prey} \rightarrow M_2.B \rightarrow Q \rightarrow \text{Growth} \rightarrow R \rightarrow \Phi \]
EcoTroph: basic equations

- The master equation: \[ \text{Biomass} = \frac{\text{flow}}{\text{speed}} \cdot \Delta \tau \]
  \[ B_\tau = \Phi_\tau \cdot \Delta \tau / K_\tau \]

- A non-conservative flow: \[ \Phi_\tau + \Delta \tau = \Phi_\tau \cdot e^{-(\mu_\tau + \varphi_\tau) \cdot \Delta \tau} \]

- An empirical model for kinetics: \[ K_{\tau, \text{unexpl.}} = a \cdot \tau^{-b} = 20.2 \cdot e^{0.041 \theta \cdot \tau^{-3.26}} \]

Gascuel et al. (2008, Ecol.Mod)
- 55 Ecopath models
- \( n = 1,718 \) groups
- \( r^2 = 0.54 \)
EcoTroph: additional details

- **Fishing impact on kinetic** (higher mortalities -> shorter life expectancy -> faster transfers)

- **Feedback effects:**
  - Of predators on prey (Top-down control: more predator -> faster transfers)
  - Of the total biomass on detritus recycling (less biomass -> less recycling)

- **All organisms are (currently) not exploited**
  - The accessible biomass
  - A distinct kinetics for the accessible and the not-accessible biomass
EcoTroph: basic equations

- The master equation: \( \text{Biomass} = \frac{\text{flow}}{\text{speed}} \cdot \Delta \tau \)

- A non-conservative flow: \( \Phi_\tau + \Delta = \Phi_\tau \cdot e^{- (\mu_\tau + \varphi_\tau) \cdot \Delta \tau} \)

- An empirical model for kinetics: \( K_{\tau, \text{unexpl.}} = a \cdot \tau^{-b} = 20.2 \cdot e^{0.041 \theta} \cdot \tau^{-3.26} \)

Climate change affects:

- Net Primary Production NPP
- Transfer efficiency TE
- Flow kinetics K
Using EcoTroph to simulate climate change

A global analysis

- Using 1° cells, aggregated by ecosystem type
- And for 2 scenarios: RCP2.6 and RCP8.5 in 2100

- From IPSL
- From Du Pontavice (in prep., See S11-1540)

ECCWO 2018, S12-1420, EcoTroph

Agrocampus Ouest, D. Gascuel - 11 / 17
Using EcoTroph to simulate climate change

- **A global analysis**
  - Using 1° cells, aggregated by ecosystem type
  - And for 2 scenarios: RCP2.6 and RCP8.5 in 2100

- From IPSL
- From Du Pontavice (in prep., See S11-1540)
- From Gascuel et al. (2008)
Climate change effects on the biomass trophic spectra

- Temperate ecosystems, RCP 8.5, biomass in tons/km²

- No change in NPP
- A large effect of changes in Transfer efficiency TE
- An additional effect of change in kinetics K
- A 29% decrease in the total consumer biomass
Effects on Production, Biomass & Accessible biomass

<table>
<thead>
<tr>
<th></th>
<th>Polar</th>
<th>Temperate</th>
<th>Tropical</th>
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<tbody>
<tr>
<td>Production</td>
<td><img src="image1.png" alt="Graph" /></td>
<td><img src="image2.png" alt="Graph" /></td>
<td><img src="image3.png" alt="Graph" /></td>
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<tr>
<td>Biomass</td>
<td><img src="image4.png" alt="Graph" /></td>
<td><img src="image5.png" alt="Graph" /></td>
<td><img src="image6.png" alt="Graph" /></td>
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<tr>
<td>Accessible Biomass</td>
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<td><img src="image8.png" alt="Graph" /></td>
<td><img src="image9.png" alt="Graph" /></td>
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### Loss in total consumer Production

<table>
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<tr>
<th></th>
<th>2010 Base line</th>
<th>2100 RCP 2.6</th>
<th>2100 RCP 8.5</th>
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<tbody>
<tr>
<td>Polar</td>
<td>0%</td>
<td>3%</td>
<td>14%</td>
</tr>
<tr>
<td>Temperate</td>
<td>0%</td>
<td>3%</td>
<td>16%</td>
</tr>
<tr>
<td>Tropical</td>
<td>0%</td>
<td>-1%</td>
<td>12%</td>
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</tbody>
</table>

### Loss in total consumer Biomass

<table>
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<tr>
<td>Polar</td>
<td>0%</td>
<td>12%</td>
</tr>
<tr>
<td>Temperate</td>
<td>0%</td>
<td>16%</td>
</tr>
<tr>
<td>Tropical</td>
<td>0%</td>
<td>2%</td>
</tr>
</tbody>
</table>

- A large impact on production and biomass, especially in temperate ecosystems
- Key role of NPP in tropical ecosystems, TE in temperate and polar, K everywhere
- Highest impacts on accessible and top-predator’s biomass
Global effects

RCP 2.6  -1 %  -5 %
RCP 8.5  -14 %  -25 %

Accessible Biomass  -28 %
Top-predator biomass  -33 %
Discussion & Conclusion

- **Next steps:**
  - Include catches
  - Run the model locally (1° cells)
  - Sensitivity analyses (beyond IPSL)
  - Add changes (in TE and K) occurring at the individual level

- **Take-home messages**
  - Simple model may provide reliable results (TrophMod, as an integrative tool)
  - Climate change will affect food web functioning, through three mechanisms: changing NPP, decreasing Transfer efficiencies, and accelerating the flow kinetics...
  - ... thus leading to a large decrease in total consumer production, biomass and structure

Du Pontavice et al., in prep.
Thank you...