Ocean Acidification, Warming and the Biological Carbon Pump

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Global Change

**Some direct and indirect changes to the abiotic environment of the surface ocean:**

- temperature
- ocean acidification
- allochthonous inputs (N, Fe)
  - stratification/ turbulence
    - light climate
    - nutrient availability & stoichiometry
  - sea level rise
  - deoxygenation, OMZ
- trace element availability
- exoenzyme activity
- saturation state of CaCO$_3$

<table>
<thead>
<tr>
<th></th>
<th>today</th>
<th>Year 2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>pCO$_2$</td>
<td>370</td>
<td>~750 µatm</td>
</tr>
<tr>
<td>pH</td>
<td>~8.1</td>
<td>~7.8</td>
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</tbody>
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Adapted Rost et al. 2008
Carbon Sequestration by the Biological Pump

Passow & Carlson 2012
The Problem: An Analysis of Relevant Scales

Introduction
Hypothesis on TEP, aggregation and carbon flux

TEP = Transparent Exopolymer Particles: Sticky exopolysaccharides that form the matrix of most sinking marine snow

Adapted Arrigo 2007
POC & TEP production as a function of $pCO_2$ (exp. 1)

**POC in ug L$^{-1}$**

- Present: [3000, 4000]
- Future: [3500, 4500]

**TEP in ug Xeq. L$^{-1}$**

- Present: [1000, 1800]
- Future: [2000, 2800]

**Note:**

Population level:
- Higher $pCO_2$
  - Has no impact on POC
  - Leads to increased TEP

Batch growth till nutrient limitation

Rossi et al. in prep.
POC & TEP production as a function of $pCO_2$ & temperature (exp. 3)

**POC**

*Temp. effect*

**TEP**

*Temp. & $pCO_2$ effect*

**Note:**

Population level:
- Higher $pCO_2$
  - no impact on POC
  - increased TEP
- Higher temperature
  - increased POC
  - Increased TEP

Batch growth after N-limitation

T. weissflogii: (CCMP 1336)

Taucher *et al.* L&O 2015
POC & TEP production as a function of $pCO_2$ & temperature (exp. 3)

**POC**

$pCO_2$ effect

![Bar chart showing POC production at different $pCO_2$ levels: ambient, high CO2, high Temp, greenhouse.](image)

- ambient
- high CO2
- high Temp
- greenhouse

**TEP**

Temp. & $pCO_2$ effect

![Bar chart showing TEP production at different temperatures and $pCO_2$ levels: ambient, high CO2, high Temp, greenhouse.](image)

- ambient
- high CO2
- high Temp
- greenhouse

**Note:**

Population level:

- Higher $pCO_2$
  - increased POC !!!
  - increased TEP

- Higher temperature
  - unchanged POC !!!
  - decreased TEP !!!

Batch growth after N-limitation

*Taucher et al. L&O 2015*
TEP Production as a function of $pCO_2$ & temperature (exp. 6)

Note:
Population level:
Higher $pCO_2$:
• No consistent effect on TEP!!!

Higher temperature:
• increased TEP

Sebah et al. PLOS ONE 2014
Why is there no consistent response pattern of POC and TEP to increased temperature and $pCO_2$?

Three coastal diatoms, all bloom forming

- *Skeletonema costatum*
- *T. weissflogii:*
- *Dactyliosolen fragilissimus*
1. Keeping Perspective

*Single abiotic stressor experiments: A fixed change in stressor may result in three different answers*  
- Performance, e.g. growth
- Environmental parameter, e.g. temperature, irradiance, $pCO_2$
- Carbon Fixation

**POC & TEP production seemingly unpredictable:**  
1. Response direction and magnitude depends on parameter position on response curve
2. Interactive effects of multiple stressors (exp. 2)

POC & TEP production seemingly unpredictable:

2. Multi-stressor effects are not the sum of the individual stressors. (Cellular response to $pCO_2$ depends on light climate or temperature)

3. Physiological responses complex and species specific
Partitioning: POC, DOC & TEP:

1. Response direction and magnitude depends on parameter position on response curve
2. And on interactive effects between potential stressors (light, temp, nutrients,...)
3. Species specific physiology
Future Temp., $p\text{CO}_2$

Hypothesis on POC and TEP production

No *a priori* predictions on the net effect of increased temperature and $p\text{CO}_2$ for POC & TEP productions can be made at this time.

However, a predictive understanding may be possible.
Aggregation & sinking velocity as a function of $pCO_2$ (& TEP)(exp. 1)

Aggregation & Sinking:

Higher $pCO_2$:
- Decreased aggregation (more TEP)
- no impact on sinking

Ross et al. in prep.
Aggregation as a function of \( pCO_2 \) & temperature (and TEP) (exp. 6)

Aggregation:
- Higher \( pCO_2 \):
  - decreased aggregation (independent of TEP)
- Higher temperature:
  - decreased aggregation (increased TEP)

Seebah et al. PLOS ONE 2014
Sinking velocity as a function of $pCO_2$ & temperature (exp. 6)

- No $pCO_2$ effect
- 15°C: Higher $pCO_2$:
  - no impact on sinking velocity
- 20°C; more TEP: Higher temperature:
  - decreased sinking velocity
Hypothesis on aggregation and sinking velocity

Future Temp., $pCO_2$

Note:
Higher TEP concentration did NOT result in more aggregation or in faster sinking.

This evidence gives no reason to believe that BCP will be more efficient.
Carbon Sequestration by the Biological Pump

- **CO₂**
- **DIC**
- **POM**
- **TEP (DOM)**

Surface layer
~ 100 m

Euphotic zone

Mesopelagic zone

Deep Ocean
~ 1000 m

Allochthonous nutrient input

↑ pCO₂ & ↑ temperature

DIC & Nutrients

Conclusions
Summary & Conclusions

Carbon Fixation
- No *a priori* predictions with regards to carbon partitioning (between TEP and POC and DOC) as a function of increased temperature or $pCO_2$ currently possible. The response is a
  - function of stressor in relation to response curve of that species
  - function of species physiology
  - function of interactive effects of multiple environmental stressors

Aggregation & Sinking
- Aggregation rate decreased at high $pCO_2$ or high temperature
- Sinking velocity decreased at high temperature (more TEP), but no $pCO_2$ effect *per se* (or maybe a high TEP effect).

BCP
- Diatom aggregation section of the Biological Carbon Pump would suggest a weakening of carbon flux under high $pCO_2$ and high temperature conditions
Thank you!