Global change and the future of toxic algal blooms in the North Pacific Ocean

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Global warming

Ocean acidification

Harmful algal blooms and toxin production

Hoegh-Guldberg and Bruno 2010
Multiple anthropogenic global change impacts on the surface ocean

By the year 2100:

1. 3-5°C warmer sea surface temperatures.
2. Doubled pCO$_2$ ($\approx$750 ppm), pH decrease of $\approx$0.3.
3. Intensified stratification, shallower mixed layers
   Reduced vertical fluxes of nutrients
   Higher mean light intensities
4. Changes in ocean biogeochemistry
   Nitrogen cycle shifts
   Iron chemical speciation
5. Major changes in biological communities
   Competition
   Grazing
Effects of a warming-induced extended growing season on *Alexandrium catenella*

Moore et al. 2008, Environmental Health 7

Fig. 7. Scenarios for warmer sea surface temperature conditions in Puget Sound by 2, 4, and 6°C would widen the >13°C window (in gray) of accelerated growth for the PSP dinoflagellate *Alexandrium catenella*. After Moore et al. (2008b). PSP, paralytic shellfish poisoning.
Karlodinium veneficum blooms

Massive Australian *K. veneficum* bloom, Swan River estuary
(Alice Gedaria, UWA)

Recent mid-Atlantic blooms *Karlodinium veneficum*

2009 Maryland *K. veneficum* fish kill
(Maryland DOE)

*Karlodinium veneficum* in Korea

![Abundance of Karlodinium veneficum over months](chart)
Methods

1. *Karlodinium veneficum* cultures isolated from the DIB were grown in semi-continuous cultures

2. Treatments: Three pCO$_2$ levels: 230, 430, and 745 ppm: each under both P-limited and P-replete growth conditions

3. Measurements of growth rates, physiological parameters, karlotoxin production
LC-MS measurements of karlotoxin congeners (by Al Place, UM)

Fu et al. 2010 AME
Karlodinium growth rates

Fu et al. 2010 Aquatic Microbial Ecology
pCO$_2$ and P availability together control *Karlodinium* toxin production and congener composition

(Fu et al. 2010 AME)
**Karlodinium**: Cellular potency increases under higher pCO$_2$ and reduced P availability

![Graph showing relative cellular toxicity](image)

Relative cellular toxicity

(picosaponin equivalents cell$^{-1}$)

Fu et al. 2010 AME
Complex interactions between pCO$_2$, light and karlotoxin production

Fu, Place and Hutchins, unpubl. data
Conclusions

• Higher pCO₂ could greatly increase the cell-specific toxicity of *Karlodinium* blooms, through changes in the relative production rates of differentially potent karlotoxin congeners.

• Interactions between cellular toxicity and pCO₂ are likely to be especially significant in P-limited and high light conditions.

• The effects of pCO₂ on cellular karlotoxin are also dependent on light intensities.

• More work is needed to determine the interactions of global change variables with pCO₂ in other toxic dinoflagellates e.g. *Alexandrium*, *Pyrodinium bahamense*, and *Gymnodinium catenatum* in the Pacific region.
Pseudo-nitzschia blooms

Pseudo-nitzschia bloom, Juan de Fuca eddy

Domoic Acid

www.whoi.edu/redtide/
Methods

- Toxic *Pseudo-nitzschia multiseries* culture from eastern Canada
- Grown at three pCO$_2$ levels (220, 400 and 730 ppm)
- Each pCO$_2$ treatment under P-limited and P-replete conditions
- Measurements of domoic acid production (ELISA), physiological and biogeochemical parameters

**Effects of changing pCO$_2$ and phosphate availability on domoic acid production and physiology of the marine harmful bloom diatom *Pseudo-nitzschia multiseries***

Jun Sun, David A. Hutchins, Yuanyuan Feng, Erica L. Seubert, David A. Caron, and Fei-Xue Fu

*Limnology and Oceanography* 56 (2011)
**Pseudo-nitzschia multiseries**
growth and carbon fixation rates

**A**
Specific growth rate (d⁻¹)

<table>
<thead>
<tr>
<th>Concentration</th>
<th>Growth Rate</th>
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</thead>
<tbody>
<tr>
<td>190 ppm</td>
<td>0.0</td>
</tr>
<tr>
<td>380 ppm</td>
<td>0.2</td>
</tr>
<tr>
<td>750 ppm</td>
<td>0.4</td>
</tr>
<tr>
<td>190 ppm</td>
<td>0.6</td>
</tr>
<tr>
<td>380 ppm</td>
<td>0.8</td>
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<tr>
<td>750 ppm</td>
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</table>

**B**
Carbon fixation

<table>
<thead>
<tr>
<th>Concentration</th>
<th>Carbon Fixation (mg C mg Chl a h⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>190 ppm</td>
<td>0.2</td>
</tr>
<tr>
<td>380 ppm</td>
<td>0.4</td>
</tr>
<tr>
<td>750 ppm</td>
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</tr>
</tbody>
</table>

Sun et al. 2011
L&O 56
Domoic acid production is regulated by both $pCO_2$ and P availability.
Si and CO₂ effects on a coastal Southern California *Pseudo-nitzschia fraudulenta* isolate

Three CO₂ levels (210 ppm, 380 ppm, 770 ppm)

Silicate-limited and Silicate-replete

Measurements of domoic acid production (HPLC), growth rates, elemental ratios

http://www.smhi.se/oceanografi/oce
Domoic acid production increases dramatically at lower pH (higher pCO$_2$), especially during Si-limited growth

Tatters, Fu and Hutchins in preparation
Growth rate is positively correlated with toxin production in both Si-limited and Si-replete diatom cultures.

Tatters, Fu and Hutchins
In preparation
Supporting evidence from field studies

MacIntyre et al. 2011.

Environmental correlates of community composition and toxicity during a bloom of *Pseudo-nitzschia* spp. in the northern Gulf of Mexico. *J. Plank. Res.* 33
Gene expression and domoic acid/CO$_2$/Si interactions

- Transcriptome samples from this *Pseudo-nitzschia fradulenta* CO$_2$/Si experiment have just been Illumina-sequenced through a small grant from the Moore Foundation Marine Microbial Eukaryote Transcriptome Project, in collaboration with Bethany Jenkins (URI)

- Gene expression patterns are currently being analyzed, with an eye towards identifying CO$_2$- and toxin-responsive genes for future followup work
The interactive effects of CO$_2$ & light on Fe uptake and cellular Chl in *Pseudo-nitzschia fraudulenta*.

- **Graph 1:** 55Fe uptake vs pCO$_2$ for High Light (black) and Low Light (green).
  - X-axis: pCO$_2$ levels (190 ppm, 380 ppm, 800 ppm).
  - Y-axis: 55Fe uptake (fmol cell$^{-1}$ h$^{-1}$).

- **Graph 2:** Cellular Chl (μg Chl cell$^{-1}$) under Low Light.
  - X-axis: pCO$_2$ levels (190 ppm, 380 ppm, 800 ppm).
  - Y-axis: Chl concentration (μg Chl cell$^{-1}$).
Conclusions

• Like the dinoflagellate, the toxicity of *Pseudo-nitzschia* spp. diatoms is greatly increased by the combination of nutrient limitation and elevated pCO$_2$.

• Effects on domoic acid production of interactions between pCO$_2$ and other global change variables, such as temperature, light and iron, are unknown and still need to be determined.

• There is a potential for greatly increased toxicity of *Pseudo-nitzschia* blooms in the future acidified ocean.
Overall conclusions

In some HAB dinoflagellates and diatoms, cellular toxicity can increase dramatically as pCO$_2$ goes up.

Interactions of global change variables with other key environmental variables like nutrients and light are critical and need to be considered.

The potential for adaptation of HAB species to long-term ecosystem changes also needs to be considered.
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