Ecosystem Modeling & Ocean Acidification

Scott Doney
Woods Hole Oceanographic Institution

Biological Hierarchy
- cell & organism
- population & community
- ecosystem/biogeochemistry
- coupled human-natural systems

Multiple Stressors & Climate
Ecosystem Modeling of Ocean Acidification

Complexity & Trade-offs
- empirical vs. dynamical
- functional form & parameters
- parameterizing across scales & unresolved processes
- data for model evaluation
- physical-chemical framework
- quantifying uncertainty
Plankton Functional Type (PFT) Models

- Aggregate into trophic levels/functional groups/size classes

Rules Governing Plankton Group Responses

Flynn et al.
Royal Soc.
B 2015
Dynamic Energy Budget Models

E. Huxleyi calcification rate per cell

% change calcification rate (IPCC A2)

Muller & Nisbet
Global Change Biology 2014
Potential Biogeochemical Impacts & Feedbacks

Gehlen et al.
Ocean Acidification Book 2011
CO$_3^{2-}$ ion

CaCO$_3$ Cycle Parameterizations

Bopp et al.
Biogeosciences 2013

PIC/POC production ratio

Gangstø et al.
Biogeosciences 2011

Gehlen et al.
Biogeosciences 2007
Acidification Impacts on Biogeochemistry

RCP 8.5, CaCO$_3$ production

Gangstø et al.
Biogeosciences 2011

<table>
<thead>
<tr>
<th></th>
<th>T &amp; CO$_2$</th>
<th>T only</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaCO$_3$ prod.</td>
<td>-56%</td>
<td>-18%</td>
</tr>
<tr>
<td>Export 1000m</td>
<td>-41%</td>
<td>-18%</td>
</tr>
</tbody>
</table>

Yool et al.
Biogeosciences 2013
CaCO$_3$ – Acidification – Carbon Cycle Feedbacks

Gangstø et al.
Biogeosciences 2011

See also:
Heinze Geophys. Res. Lett. 2004
Ridgwell et al. Biogeosciences 2009
Pinsonneault et al. Biogeosciences 2012
CaCO$_3$ production function of light, temp & $\Omega_{\text{aragonite}}$

Need improved estimates of coral cover (coral population models)
Bioclimatic Envelope Models

marine gastropod
Nucella lapillus


Queiros et al.
Global Change Biology 2015

Present

Temp & OA
Dynamic Bioclimates: Warming, Hypoxia & Acidification

Cheung et al.

\[
\frac{dB}{dt} = HW^a - kW,
\]

\[
H \propto f(O_2)f_1(T),
\]

\[
k \propto f_2(T)f([H^+]).
\]

Growth = anabolism – catabolism

\(W\) = body weight

% change in catch potential from 2005 to 2050

- Not sensitive to \(O_2\) and OA
- Medium sensitivity to \(O_2\) and OA
- High sensitivity to \(O_2\) and OA

Osmosis

Maintenance metabolism

Body weight

Growth

Mass-specific \(O_2\) supply

Oxygen supply/demand
Direct and Indirect Food-web Effects

Busch et al. ICES J. Mar. Sci. 2013  Ecopath & Ecosim Foodweb
Vulnerability & Adaptation of Shellfisheries to OA

<table>
<thead>
<tr>
<th>Year threshold hit</th>
<th>Marine ecosystem exposure (water)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006-2030</td>
<td></td>
</tr>
<tr>
<td>2031-2050</td>
<td></td>
</tr>
<tr>
<td>2051-2070</td>
<td></td>
</tr>
<tr>
<td>2071-2099</td>
<td></td>
</tr>
<tr>
<td>After 2099</td>
<td></td>
</tr>
</tbody>
</table>

Social vulnerability (land)

- Highest SV (top 20%)
- Medium high
- Medium SV (middle 20%)
- Medium low
- Lowest SV (bottom 20%)

Exposure
- threshold year $\Omega_{\text{aragonite}} = 1.5$
- eutrophication
- river discharge
- upwelling

Sensitivity
- local societal importance of shellfish

Adaptive capacity
- assets available to help prepare for or avoid impacts of OA

Ekstrom et al. Nature Climate Change 2015
Low pH area ($10^3$ km$^2$)

Low O$_2$ area

Low pH area in response to seasonal eutrophication

Laurent, Fennel, Cai, Huang, Barbero & Wanninkhof (in prep.)
Vulnerability Assessment of California Current Food Webs and Economics to Ocean Acidification

Spatial economic impacts: input-output model.

Kaplan, Busch, Fulton, Leonard, Hermann, Harvey, Essington & McElhany (in prep.)
What Have We Learned in the Past Decade?

June 2005

Ocean acidification due to increasing atmospheric carbon dioxide

Confidence

Clear and “simple”!

Increasingly robust and predictable

More nuanced, conflicting results

Time

Busch et al.
Oceanography
2015 (in press)
Many marine species are sensitive to changes in seawater CO₂ (very high certainty).

Calcification by corals is easier at lower CO₂ levels (high certainty).

Increased atmospheric CO₂ decreases ocean pH and aragonite saturation state (very high certainty).

Species ability to adapt to current change in seawater CO₂ (uncertain).

Shifts in ocean chemistry may harm fishing industries (medium certainty).

Elevated seawater CO₂ impacts marine ecosystems (high certainty).

Marine ecosystems are sensitive to shifts in the physical environment (very high certainty).

Resilience of ecosystems to ocean acidification in concert with other future pressures (uncertain).

Human social and economic systems are altered by shifts in ecosystems (very high certainty).

Busch et al. Oceanography 2015
"I am never content until I have constructed a mechanical model of the subject I am studying. If I succeed in making one, I understand; otherwise I do not."
- Lord Kelvin

"People don't understand the earth, but they want to, so they build a model, and then they have two things they don't understand,"
-Gerard Roe in “The Whale and the Supercomputer” by C. Wohlfirth
Ecosystem Modeling of Ocean Acidification

Data

Complex models

Simple models

Complexity & Trade-offs
- empirical vs. dynamical
- functional form & parameters
- parameterizing across scales & unresolved processes
- data for model evaluation
- physical-chemical framework
- quantifying uncertainty
Extra Slides
Projected Deep pH Trends & Biodiversity Threats

Gehlen et al. Biogeosciences 2014
Other Local Sources of Acidification

Doney et al. PNAS 2007; Doney Science 2010; Kelly et al. Science 2011