Impacts of Ocean Acidification on Fish

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Oceans are absorbing anthropogenic CO$_2$

The global carbon cycle for the 1990s, showing the main annual fluxes in GtC yr$^{-1}$: pre-industrial ‘natural’ fluxes in black and ‘anthropogenic’ fluxes in red.

(IPCC WG1 AR4 Final Report, 2007)
Dissolved CO$_2$ in seawater

As CO$_2$ dissolves in seawater,

\[
\text{CO}_2 + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{CO}_3 \leftrightarrow \text{HCO}_3^- + \text{H}^+ \leftrightarrow \text{CO}_3^{2-} + 2\text{H}^+
\]

Thus, to increase concentration of proton (H$^+$) \textit{pH} decrease, acidification

carbonic acid (H$_2$CO$_3$) \textit{pCO$_2$} increase

bicarbonate ion (HCO$_3^-$)

while decrease concentration of carbonate ion (CO$_3^{2-}$)
Recent observations show the oceanic $p$CO$_2$ increase and pH decrease

Changes in surface oceanic $p$CO$_2$ (left; in $\mu$atm) and pH (right) from three time series stations: **Blue:** European Station ($29^\circ$ N, 15$^\circ$ W); **green:** Hawaii Ocean ($23^\circ$ N, 158$^\circ$ W); **red:** Bermuda Atlantic ($31/32^\circ$ N, 64$^\circ$ W).  
(IPCC WG1 AR4 Final Report, 2007)
Impact of anthropogenic CO$_2$ on the ocean

• In the past few decades, only half of the CO$_2$ released by human activity has remained in the atmosphere; of the remainder, about 30% has been taken up by the ocean and 20% by the terrestrial biosphere.

• Therefore, ocean would be acidified firstly in surface waters then in deep waters.

• Such dramatic changes of the CO$_2$ system in open-ocean surface waters have probably not occurred for more than 20 million years of Earth’s history.

• If they do occur, they can potentially have significant impacts on the biological systems in the oceans in ways we are only begging to understand.
Impacts of ocean acidification on marine organisms

Direct impacts

• increasing CO$_2$ concentration $\Rightarrow$ fish

• acidification $\Rightarrow$ inhibition of calcification
  \[
  \text{Ca}^{2+} + 2\text{HCO}_3^- \Leftrightarrow \text{CaCO}_3 + \text{H}_2\text{O} + \text{CO}_2
  \]

Indirect impacts

• ecosystem

• complex impacts with global warming
Comparison of lethal effect between CO₂ and acid by mean mortalities of embryos and larvae of fish (*Pagrus major*) at two pH levels. Exposure periods for embryos and larvae were 6 and 24 h, respectively.
Physiological effects of CO$_2$ on fish

Hayashi et al. 2004.

Acid-base change of Japanese flounder during 10,000μatm (●), 30,000μatm (▼) and 50,000μatm (▲) CO$_2$ exposure.
Effects of CO$_2$ on fish growth

Growth of young *Sillago japonica* under sublethal CO$_2$ concentration.

- ●: control (380μatm, pH 8.05), ●: Low CO$_2$(4,000μatm, pH 7.32), ●: Mid CO$_2$ (7,000μatm, pH 7.04),
- ●: High CO$_2$ (12,000μatm, pH 6.82). Bars represent SD.

Kita et al. unpublished
### Standard acute toxicity tests of CO₂ with fish and invertebrate

<table>
<thead>
<tr>
<th>Test species</th>
<th>24h LC₅₀ (pCO₂ ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fish</strong></td>
<td></td>
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<tr>
<td><em>Pagrus major</em> (Eggs, Larvae, Juveniles)</td>
<td>13,300 - 52,700</td>
</tr>
<tr>
<td><em>Sillago japonica</em> (Larvae, Juveniles)</td>
<td>26,300 - 48,200</td>
</tr>
<tr>
<td><em>Paralichthys olivaceus</em> (Eggs &amp; Juveniles)</td>
<td>28,400 – 50,000</td>
</tr>
<tr>
<td><em>Euthynnus affijis</em> (Eggs)</td>
<td>94,300</td>
</tr>
<tr>
<td><strong>Cephalopod</strong></td>
<td></td>
</tr>
<tr>
<td><em>Sepia lycidas</em> (Juveniles)</td>
<td>83,700</td>
</tr>
<tr>
<td><em>Sepioteuthis lessoniana</em> (Juveniles)</td>
<td>58,700</td>
</tr>
<tr>
<td><strong>Decapod</strong></td>
<td></td>
</tr>
<tr>
<td><em>Penaeus japonica</em> (Juvenile)</td>
<td>&gt; 150,000</td>
</tr>
<tr>
<td><strong>Copepoda</strong></td>
<td></td>
</tr>
<tr>
<td>Subarctic surface species</td>
<td>15,000 (mean value)</td>
</tr>
<tr>
<td>Subarctic deep-sea species</td>
<td>Highly tolerant</td>
</tr>
<tr>
<td>Subtropical surface species</td>
<td>53,000 (mean value)</td>
</tr>
<tr>
<td>Subtropical deep-sea species</td>
<td>86,000 (mean value)</td>
</tr>
</tbody>
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### Sensitivities to CO₂

<table>
<thead>
<tr>
<th>Sensitivities to CO₂</th>
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<tbody>
<tr>
<td>Calanus pacificus</td>
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<tr>
<td>Metridia pacifica</td>
</tr>
<tr>
<td>Neocalanus cristatus</td>
</tr>
<tr>
<td>Paraeuchaeta birostrata</td>
</tr>
<tr>
<td>Heterostylites major</td>
</tr>
<tr>
<td>Gaidius variabilis</td>
</tr>
<tr>
<td>Euchaeta marina</td>
</tr>
<tr>
<td>Deep-living copepods</td>
</tr>
<tr>
<td>Surface copepods (large)</td>
</tr>
<tr>
<td>Surface copepods (small)</td>
</tr>
<tr>
<td>Pleuroomamma spp.</td>
</tr>
</tbody>
</table>

### Exposure time (h) vs. LC₅₀ (pCO₂ ppm)

#### Comparison of mortality (LC₅₀) curve between copepods and fish.

**Copepods:**
- Calanus pacificus
- Metridia pacifica
- Neocalanus cristatus
- Paraeuchaeta birostrata
- Heterostylites major
- Gaidius variabilis
- Euchaeta marina
- Deep-living copepods
- Surface copepods (large)
- Surface copepods (small)
- Pleuroomamma spp.

**Fish:**
- Paralichthys olivaceus (egg)
- Euthynnus affinis (egg)
- Pagrus major (egg-cleavage)
- P. major (egg-embryo)
- P. major (larva-preflexion)
- P. major (larva-flexion)
- P. major (larva-postflexion)
- P. major (juvenile)
- Sillago japonica (egg-cleavage)
- S. japonica (egg-embryo)
- S. japonica (larva-preflexion)
- S. japonica (larva-flexion)
- S. japonica (larva-postflexion)
Otolith formation of fish

- Serves as a sensory organ, playing a role in hearing and balance.
- Composed primarily of aragonite, which is more easily dissolved in acidified seawater than calcite.
- Effect of ocean acidification on process of crystallization is unknown.
Conclusions - 1

Known *lethal* concentrations of CO$_2$ for fish seem to be higher than predicted future concentrations of ocean.

Research emphasis should be placed on long-term *sublethal* effects such as those on growth, reproduction, and behavior.

Almost nothing is known about what happens to fish populations if they are exposed to low but sustained CO$_2$ conditions for long periods of time.

Marine fish are important protein source in many countries around the pacific.
Conclusions - 2

On the basis of current evidence that ocean acidification is an inevitable consequence of continued emissions of CO$_2$ into the atmosphere, and the magnitude of this acidification can be predicted with a high level of confidence.

However, its impacts, particularly on marine organisms, are much less certain and require a substantial research effort.

The socio-economic effects of ocean acidification could be substantial.