Effects of temperature increase and oxygen decrease on behavior and physiology of marine benthic invertebrates

Taewon Kim, Boongho Cho, Eunchong Sin
Department of Ocean Sciences
Inha University
Republic of Korea
Oxygen solubility in water vs. temperature
Physical stressors within estuaries such as Elkhorn Slough vary over multiple time-scales and act upon differing life stages of resident species.

Prætorius et al. (2015) Nature

Cheng et al. (2015) Global Change Biology
Net SST Change in Large Marine Ecosystems

Belkin (2009)
Hypoxic zones around the world

From NASA
What is the effect of increase in temperature and deficiency in DO on behavior and physiology of marine benthic invertebrates?
Temperature & DO controlling experiment (2x2 factorial design)

<table>
<thead>
<tr>
<th></th>
<th>Low DO (3-4 mg/L, 40~50% saturation)</th>
<th>Normoxia (7-8 mg/L, 85~100% saturation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High temp (23-24°C)</td>
<td>High temp. &amp; Low DO</td>
<td>High temp. &amp; Normoxia</td>
</tr>
<tr>
<td>Control temp (18.5-20°C)</td>
<td>Control temp. &amp; Low DO</td>
<td>Control temp. &amp; Normoxia</td>
</tr>
</tbody>
</table>
Regulation of DO and temperature

- N₂ gas
- MFC regulator
- DO control (Witrox Ctrl)
- Temp & DO sensor monitor
- Aquarium (with coolers and heaters)
Temperature and DO change schedule

- Acclimation to the same condition (3-4 days)
- Temperature increase 0.5-1°C per day
- DO decrease

- High Temp
- Low DO
- Normoxia

- High Temp Normoxia
- Low Temp
- Low DO
- Normoxia

- Low Temp Normoxia
Case study 1. Manila clams 바지락 (Venerupis philippinarum)
10cm → 사니질토 3cm

1 2 3
4 5 6 7
8 9 10

10 Replicates
Mortality of juvenile Manila clams

Kim et al. (2018) Ecology and Evolution
Emerging behavior

It's suffocating! I wanna go out !!!

Kim et al. (2018) Ecology and Evolution
Oxygen consumption rates

Loligo systems®
Respirometer

30 min. duration

Kim et al. (2018) Ecology and Evolution
Case study 2.
Pacific abalone 참전복
*Haliotis discus hannai*
Light (predation) avoidance experiment
High temperature had a positive effect on light avoidance but low oxygen had a negative effect.
Foraging experiment

Brown algae
High temperature had a positive effect, but low oxygen had a negative effect on foraging.
Case study 3.
Sea urchins 둥근성게
*Mesocentrotus nudus*
Foraging experiment

Water flow

Food (Laminaria)
Racing to approach food

All $P > 0.05$
Catch me if you can

All $P > 0.05$
Time to get up!

All $P > 0.05$
Feeding experiment
Food intake

### 5 days after exposure

- **18.5 °C**
- **22.5 °C**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Intake (g/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normoxia</td>
<td>0.25</td>
</tr>
<tr>
<td>Low DO</td>
<td>0.10</td>
</tr>
</tbody>
</table>

### 8 days after exposure

<table>
<thead>
<tr>
<th>Condition</th>
<th>Intake (g/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normoxia</td>
<td>0.20</td>
</tr>
<tr>
<td>Low DO</td>
<td>0.10</td>
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</tbody>
</table>

### 15 days after exposure

<table>
<thead>
<tr>
<th>Condition</th>
<th>Intake (g/day)</th>
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</thead>
<tbody>
<tr>
<td>Normoxia</td>
<td>0.15</td>
</tr>
<tr>
<td>Low DO</td>
<td>0.05</td>
</tr>
</tbody>
</table>

### ANOVA Table

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Mean Square</th>
<th>F</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>0.072</td>
<td>7.655</td>
<td>0.012</td>
</tr>
<tr>
<td>DO (Dissolved Oxygen)</td>
<td>0.058</td>
<td>6.246</td>
<td>0.021</td>
</tr>
<tr>
<td>Interaction (Temperature*DO)</td>
<td>0.041</td>
<td>4.384</td>
<td>0.049</td>
</tr>
</tbody>
</table>
Summary

- Responses of benthic invertebrates to increased temperature and decreased DO vary depending on species.
  - Increase in temperature and decrease in DO have additive negative effects on juvenile Manila clams in terms of mortality.
  - Temperature increase is beneficial but low DO is detrimental to juvenile Pacific abalone in terms of foraging and predation avoidance.
  - Adult sea urchins are tolerant to increase in temperature and decrease in DO in terms of foraging behavior and righting ability but their feeding amount was reduced by high temperature and low DO.
Acknowledgements

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• We thank Dr. Wongi Min for collecting sea urchins for the experiment and Gil-Ah Jeong and Dr. Youn Ho Lee for identifying species.

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Coming soon (Next PICES meeting)!

How ocean freshening and acidification influence marine benthic animals in the Antarctica?