Light and oxygen in lakes

Limnology
Lecture 7
Outline

- Light
- Diffusion
- Oxygen gradients
Vertical Gradients in Lakes

Properties of Water

Properties of Lake Basins

Vertical Gradients

• Light
• Heat
• Dissolved gases
• Dissolved nutrients
Light and Water

- Reflection
- Absorption

\( \text{C}_6\text{H}_{12}\text{O}_6 \)
Light and Water

- **Reflection**
  - Surface
  - Scatter

- **Absorption**
  - Heat
  - Potential Energy
    - Stored in chemical bonds via Photosynthesis

\[ \text{C}_6\text{H}_{12}\text{O}_6 \]
Light and Water

Attenuation equation

\[ I_z = I_0 e^{-kz} \]

where \( e \) = natural logarithm

\( k \) = attenuation coefficient

characteristic for each water body and each wavelength

\[ K = K_{\text{water}} + K_{\text{dissolved organics}} + K_{\text{particulates}} \]
Light Gradients in Water

$K_{\text{dissolved organics}}$ – humic acids absorb short wavelengths (blue, UV)
Dunham Pond
Dunham Pond

\[ y = -3.4936x + 4.198 \]
\[ R^2 = 0.9819 \]
Why is deep water blue?

$K_{\text{water}}$ – pure water absorbs long wavelengths
Blue absorbed the least, scattered the most
Water decreases light and changes colors

$k_{\text{water}}$ – pure water absorbs long low energy wavelengths

Fig. 2.9 Light transmission in distilled water showing that red light (680 nm) is already attenuated at a few metres depth, followed by orange (520 nm) reaching less than 20 nm depth. About 5% of the yellow (580 nm), 46% of the green (520 nm), and almost 70% of the blue (460 nm) light still remains at 70 m depth. Note that violet and UV radiation, which have the shortest wavelengths (400 nm and <350 nm, respectively) do not reach as deep as green and blue radiation.
Solar Radiation as a Spectrum

Electromagnetic Spectrum

[Diagrams showing the electromagnetic spectrum with wavelength and depth in meters]
Light Gradients and aquatic coloration

photonic

twilight

American shad - Alosa sapidissima
Averages 14-39 inches

Red fish

Lobster
Light and habitat

Secchi disk ~ 10% of surface light
Photic zone – light is > 1% of surface value
# Light Gradients in Water

<table>
<thead>
<tr>
<th>Lake</th>
<th>k</th>
<th>Secchi Depth</th>
<th>Euphotic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crater Lake (OR)</td>
<td>0.06—0.12</td>
<td>25—45</td>
<td>&gt;120</td>
</tr>
<tr>
<td>Lake Baikal</td>
<td>0.2</td>
<td>5—40</td>
<td>15—75</td>
</tr>
<tr>
<td>Lake Erie</td>
<td>0.2 — 1.2</td>
<td>2—10</td>
<td>12—26</td>
</tr>
<tr>
<td>Dunham Pond</td>
<td>3.5</td>
<td>?</td>
<td>?</td>
</tr>
</tbody>
</table>
Dunham Pond

**Percent Surface Light**

![Graph](image)

- Depth (m)
- In Percent Light

**Equation:**

\[ y = -3.4936x + 4.198 \]

**R²:** 0.9819
Light and habitat
Light and habitat

Compensation depth – where photosynthesis = respiration in plants

Littoral – From shore to aphotic zone
  - emergent and benthic plants
Limnetic – aphotic zone on benthos
Light Gradients in Water

Pelagic – open water in limnetic zone
Compensation depth – where net photosynthesis = 0
photosynthetic production = respiration
photic or euphotic/aphotic
Light Gradients in Water
Oxygen and temperature

Solubility of oxygen with temperature

- Oxygen (mg/L) vs. Temperature (°C)
  - Oxygen decreases as temperature increases.
Diffusion Equilibrium

Henry’s Law:

\[ C_s = K_H P_t \]

- \( C_s \) = amount of gas dissolved
- \( K_H \) = solubility coefficient for a given temperature
- \( P_t \) = partial pressure of gas in atmosphere
Oxygen in water

Diffusion from atmosphere

\[
\text{O}_2 \text{ partial pressure} = 0.203 \text{ atm} \\
K_H(20\degree C) = 1.39 \text{ mmol O}_2/\text{kg H}_2\text{O} \times \text{atm}
\]

\[
C_s = K_H P_t
\]

\[
\text{O}_2(20\degree C) = 1.39 \times 0.20
\]

\[
= 0.28 \text{ mmol/kg}
\]

\[
= 9.03 \text{ mg/L}
\]
## Oxygen and species survival

<table>
<thead>
<tr>
<th>Species</th>
<th>DO limit (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trout</td>
<td>7-8</td>
</tr>
<tr>
<td>Bass</td>
<td>5</td>
</tr>
<tr>
<td>Sunfish</td>
<td>4.7</td>
</tr>
<tr>
<td>Carp</td>
<td>4</td>
</tr>
<tr>
<td>Amphibian larvae</td>
<td>1-2</td>
</tr>
<tr>
<td>Amphipods</td>
<td>2</td>
</tr>
<tr>
<td>Chironomids</td>
<td>1</td>
</tr>
<tr>
<td>Worms</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Mattson et al. 2007
Oxygen Gradients in Dimictic Lake

- Biological oxygen demand: Rate of oxygen uptake by aquatic organisms

From: Wetzel 1975
Thermocline effects

[Diagram showing dissolved oxygen (O₂) and temperature profiles in Jack's Lake, Ontario, Canada, with layers labeled Epilimnion, Metalimnion, and Hypolimnion, and the thermocline marked by a dashed line.]
Dunham oxygen
Oxygen Gradients in Dimictic Lake

Positive heterograde

Algae sit on density “shelf”
More nutrients

Negative heterograde

Respiration of algae, zoop, decomposition of detritus rain on “shelf”
Fig. NAM-24-5  Seasonal isopleths of dissolved oxygen [mg l$^{-1}$] in Gravenhurst Bay based on weekly measurements, May-October 1969, 1973 and 1974 (10).
Fish Kills (low $\text{O}_2$)

Occur often in small ponds in winter under ice cover – why?
The winterkill process.

Ice forms a barrier between pond water and the atmosphere, preventing the circulation of oxygen.

Heavy snowfall covers the pond and blocks sunlight, which stops the oxygen-creating process of photosynthesis.

Vegetation begins to die, and uses the limited oxygen supply in the decomposition process.

Oxygen depletion becomes critical and fish begin to suffocate, resulting in a winterkill.

Fig. 15. Dissolved oxygen and snow cover, Green Lake, Station 1, 1940-41 and 1942-43.

Fig. 21. Dissolved oxygen, vertical distribution, Green Lake, selected dates, 1942-43. The width of the block diagram at any given depth indicates the amount of oxygen present at that depth.
Fish Kills (low $O_2$)

Also occur often in large lakes in late summer – why?
Late summer

Fig. NAM-24-5  Seasonal isopleths of dissolved oxygen [mg l\(^{-1}\)] in Gravenhurst Bay based on weekly measurements, May-October 1969, 1973 and 1974 (10).
Fish Kills (low $O_2$)

Also occur most often at dawn – why?
At dawn

![Graph showing diurnal oxygen pulse](image)

**Figure 1. Diurnal oxygen pulse**

Eutrophic Timber Ridge Pond in OK• Freimuth and Bass 1994
Fish Kills (low $O_2$)

Also occur often after summer storm – why?
Storm disruption of stratification

Yount, 1961