CHEMICAL: CARBON and OXYGEN
(read 44-45; 232-239 in Dodson)

BACKGROUND INFORMATION

Types of molecules

- *Organic*: compounds containing Carbon-Hydrogen bonds
- *Inorganic*: everything else.

Photosynthesis

- Primary producers (plants) uses carbon dioxide, water, and light energy to make sugars, releasing oxygen gas as a byproduct.

- $6CO_2 + 6H_2O + \text{light} \rightarrow C_6H_{12}O_6 + 6O_2$

Respiration

- Aerobic respiration uses oxygen to break-down sugars, generating energy (ATP), and releasing CO_2 as a byproduct. This process does NOT require light. Respiration can also occur in the absence of oxygen (anaerobic respiration), but this pathway is less efficient.

- $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_20 + \text{energy}$

OXYGEN

- Oxygen is required by many organisms and controls chemical reactions (redox reactions), so understanding its distribution can inform much about the ecology of a freshwater.

Forms of Oxygen found in freshwaters

- Oxygen gas (0_2)—readily dissolves in water. Remember that solubility is temperature dependent (colder = higher solubility).
- Inorganic molecules—Oxygen comprises a part of many inorganic molecules including H20, Nitrate (NO_3), etc.
- Organic molecules—Oxygen comprises a part of many organic molecules, attaching to carbon chains found on things like amino acids, lipids, sugars; the building blocks of living organisms.

Major reservoirs of Oxygen are:

- Rocks (lithosphere)—however, this oxygen is relatively inaccessible due to the strength of these bonds.
- Atmosphere—O_2 forms 21% of the atmosphere. Oxygen can diffuse into lakes and be mixed down given turbulence.
- Water—Photosynthesis uses water and releases oxygen gas.

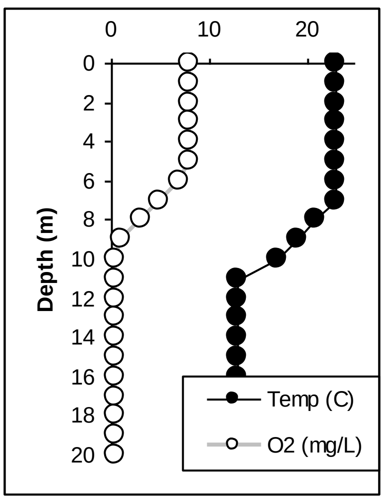
Vertical stratification of oxygen
In stratified lakes, there is often strong vertical stratification of oxygen. The main drivers of the distribution of oxygen are:

- light penetration (driving photosynthesis)
- nutrients (driving photosynthesis)
- organic matter (driving respiration)
- water temperature (lower water temperatures can contain more oxygen)

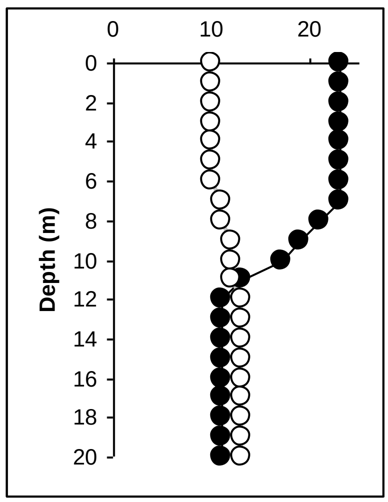
Oxygen profiles in lakes often change throughout the season. Thermal mixing generally mixes oxygen from the surface to deeper water.

Different oxygen curves are referred to as:

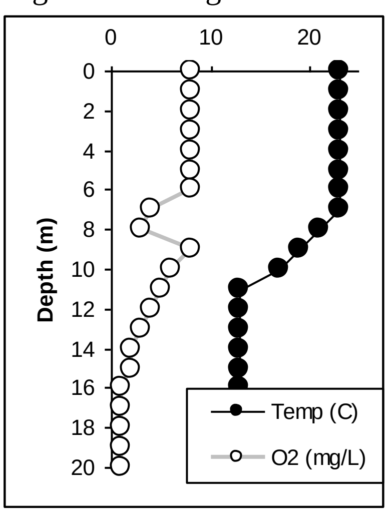
Clinograde



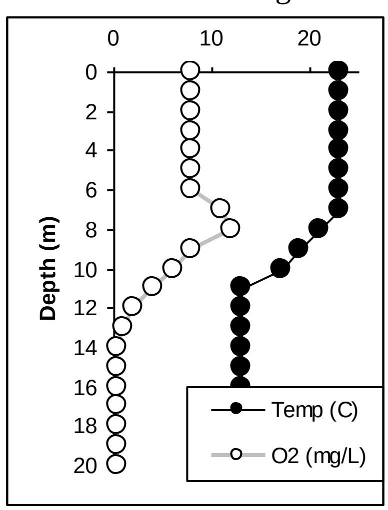
Orthograde



Negative Heterograde



Positive Heterograde



- In general, sediments of lakes are fairly anoxic (without much oxygen).

Consequences of low oxygen

- Fish-kills
  - Summer kill—generally result in super productive lakes when fish are squeezed between water that is too hot and water that is too low of oxygen.
  - Winter kill—generally happens in lakes that get covered with snow, preventing light penetration. Respiration of organic matter over time, and no photosynthesis, can use up all of the oxygen.

- Many aquatic organisms have evolved to deal with low oxygen concentrations.
  - Many bacteria and protists do not use oxygen, and can use anaerobic metabolism/respiration.
  - Hemoglobin
  - Breathing air (e.g., mud minnows)
  - Behavioral adaptations include:
    - Carrying air bubbles as sources of 0_2 (e.g. water boatmen and diving beetles/spiders).

CARBON

Major reservoirs of Carbon:

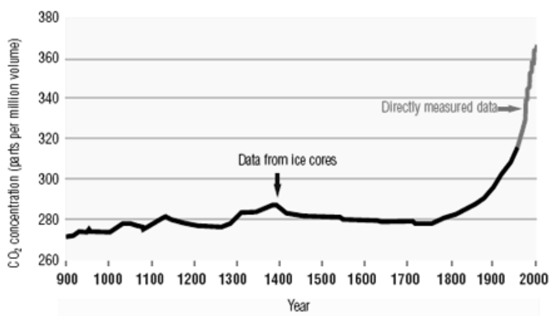
- Rocks (lithosphere)

- Atmosphere—0.035% of atmosphere, but increasing. See graph below.

- Ocean

- Fresh water—e.g., bicarbonate.

- Detritus—organics matter in small particles, often with lots of microbes/bacteria.



(Graph from Health Canada)

- Primary producers—often carbon that comprises primary producers comprises a major proportion of the carbon pools (~40-50%). These primary producers convert inorganic carbon (such as CO_2) to organic carbon.

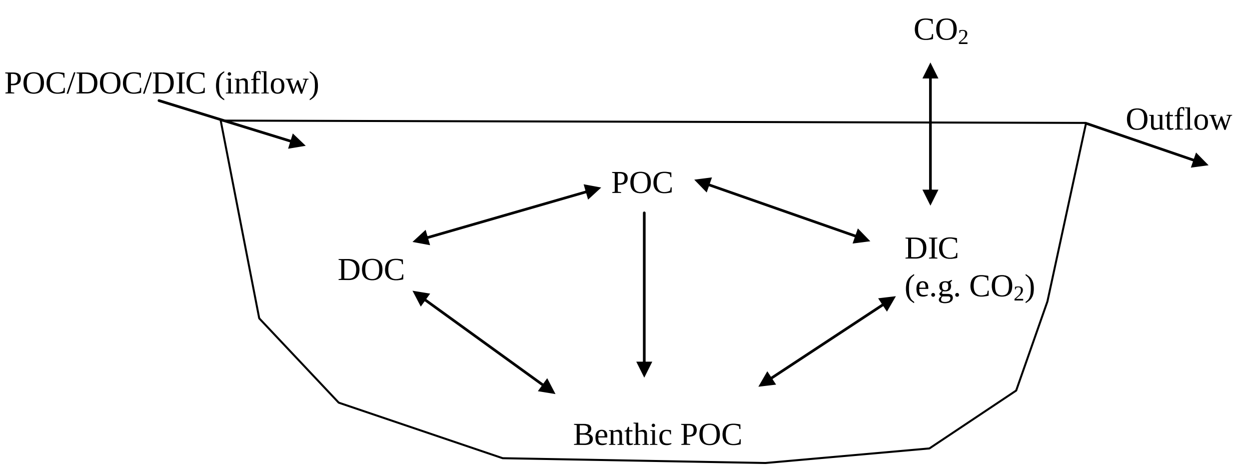
- Consumers—The importance of these depend on the food web structure.

Forms of Carbon found in water:

- Carbon dioxide (CO_2).
    - Diffusing into lakes from the atmosphere. CO_2 is consumed by photosynthesis and produced by respiration.
- Dissolved inorganic (DIC).
    - This includes CO_2 (see above), as well as bicarbonate (CO_3^-), and carbonate (CO_3^{-2}). The pH of the water influences what form dominates. See graph below.
- Dissolved organic carbon (DOC).
    - This includes methane (CH4) and dissolved organic material. Methane is produced during anaerobic decomposition. As we discussed during the light lecture, DOC is extremely good at absorbing light (especially UV wavelengths).
- Particulate Organic Carbon (POC).
    - A lot of carbon in freshwaters is found in the bodies or by-products of organics.

THE CARBON CYCLE.

- You should know the major processes that cause these transformations of Carbon (put labels on those arrows). For example, POC can be created from DIC through photosynthesis while DIC can be created from POC through respiration.



- The form of DIC is determined by the pH of water. For organisms that have shells in the form of carbonate (CO_3^{2-}), what are the implications of increasing acidity (decreasing pH)?

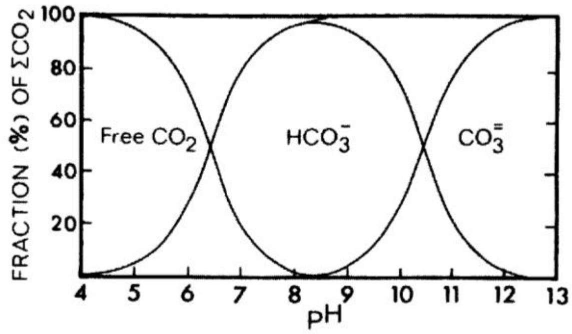
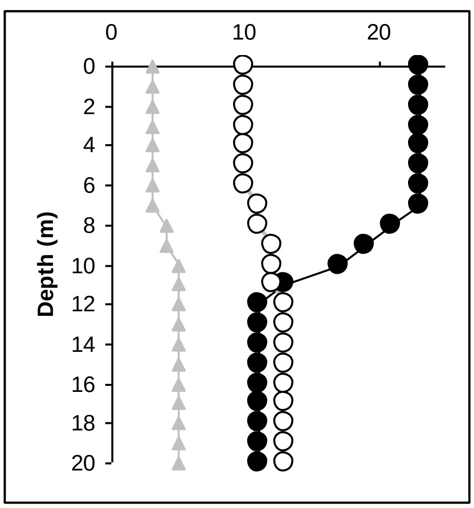
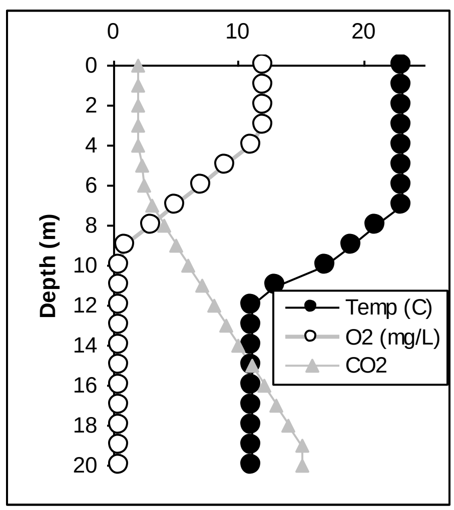


FIGURE 11-1 Relation between pH and the relative proportions of inorganic carbon species of $CO_2(+H_2CO_3)$, HCO_3^-, and CO_3^{2-} in solution. (Slightly modified from Goiterman, H. L. (ed.): *Methods for Chemical Analysis of Fresh Waters,* IBP Handbook No. 8, Oxford England, Blackwell Scientific Publications, 1969.)

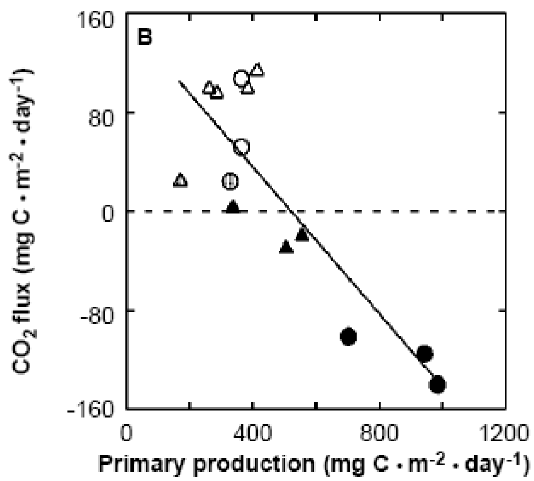
- Industrialization has increased the concentration of CO_2 in the atmosphere. This is globally changing carbon cycling.

- **Vertical stratification**
  - Carbon Dioxide also shows patterns of vertical stratification. [CO2] is controlled by: temperature (colder = higher solubility) and respiration vs. photosynthesis. Compare the two lakes below. Which lake has deeper light penetration?





- Lakes as sources or sinks of CO_2
    - Lakes can be both sinks or sources of CO_2. That is, they can suck up CO2 from the atmosphere due to high levels of primary production, or they can release (source) CO2 to the atmosphere. D.E. Schindler did a series of whole-lake experiments where he showed that the combination of nutrient loading and food web structure controls whether lakes in Wisconsin are sources or sinks of CO_2.



(D.E. Schindler et al. 1997. Science)

- **Lake Nyos tragedy**

Lake Nyos is a volcanic lake in Cameroon. In 1986, a cloud of 80 million m^3 of carbon dioxide (CO2) erupted from the lake. This CO2 blanketed the lake basin, suffocating livestock and more than 1,700 people. This rare event is called a "*limnic eruption*". Researchers discovered that springs at the lake bottom input water with high concentrations of CO2. The pressure of the epilimnion usually keeps the CO2 in solution in the hypolimnion. Some unknown event (landslide, windstorm, etc.) likely triggered lake mixing which allowed the CO2 to reach the surface and off-gas. This event was violent, triggering waves that scoured vegetation from lake shore. Scientists are currently pumping water from the hypolimnion to the surface to promote CO2 off-gassing.