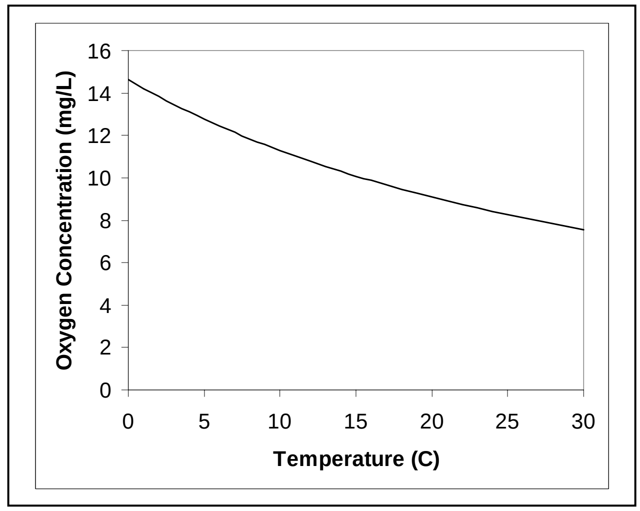
Oxygen

(read: pp 115 – 132 in H+G)

Oxygen is essential to the metabolism of many bacteria, plants and animals. Oxygen concentrations also affect the solubility of many nutrients and the oxidation-reduction (REDOX) conditions in lakes. Understanding the processes that control the spatial and temporal dynamics of oxygen is crucial to understanding the biological and chemical processes in lakes.

1) Solubility of oxygen (O_2) in water is affected by:



   a) *Temperature* – increasing temperature decreases solubility

   b) *Pressure* – increasing pressure increases solubility. The concentration of a gas in water is described by **Henry's Law** that states that at a constant temperature the amount of gas absorbed by a given volume of liquid is proportional to the pressure in atmospheres that the gas exerts. ($c = K \times p$), where *c* is the concentration, *p* is the partial pressure of the gas, and *K* is a solubility factor.

   c) *Salinity* – increasing salinity decreases solubility

2) Sources of oxygen in aquatic ecosystems

   a) Atmosphere – oxygen can enter water bodies through diffusion from the atmosphere. This process is enhanced by turbulence at the air water interface. The atmosphere is about 20.95% oxygen (the rest is mostly nitrogen).

   b) Photosynthesis – produces oxygen from water. In lakes, algae and macrophytes are important sources of oxygen for animals.

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

3) Losses of oxygen in aquatic ecosystems

a) Atmosphere – if a water body is supersaturated with oxygen, some will diffuse to the atmosphere.

b) Respiration – oxidation of organic matter by organisms consumes oxygen. In most lakes, the majority of respiration is done by bacteria and other microorganisms. The **term biological oxygen demand (BOD)** refers the rate at which a volume of water consumes oxygen through respiration. Respiration rate (and BOD) are positively affected by temperature and the amount of organic substrate available to organisms (especially bacteria). Oxygen consumption also may be augmented by inputs of material from outside the lake (termed **allochthonous** material, e.g. sewage)

c) Chemical oxidation processes often consume oxygen. For example, chemical oxidation of dissolved organic carbon (DOC) can be an important sink for dissolved oxygen in lakes with high DOC concentrations.

4) Vertical distribution of oxygen in lakes

The vertical distribution of oxygen in lakes reflects the balance of sources and losses at various depths in the water column. In most lakes, the effects of respiration and photosynthesis dominate this balance. The vertical distribution of most animals is constrained by oxygen concentrations. Therefore, the balance of respiration and photosynthesis throughout the water column affects where organisms can live in lakes.

a) The shapes of vertical oxygen profiles can be described as *orthograde*, *clinograde*, *positive heterograde*, and *negative heterograde*.

From Cole (1983). Oxygen profiles in thermally stratified lakes.

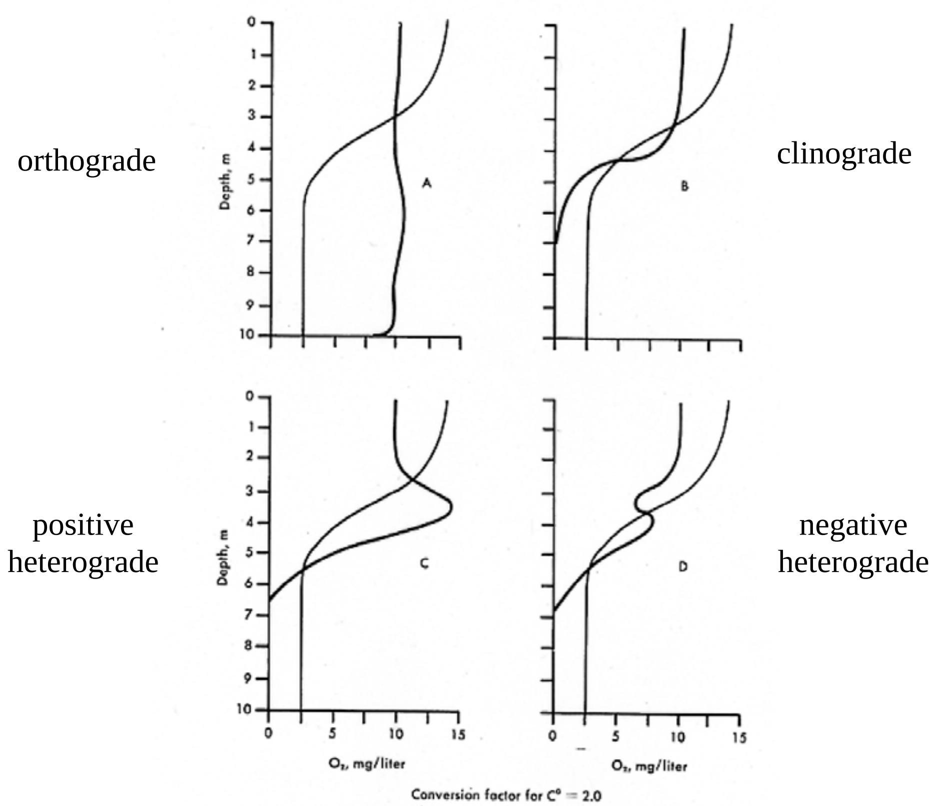
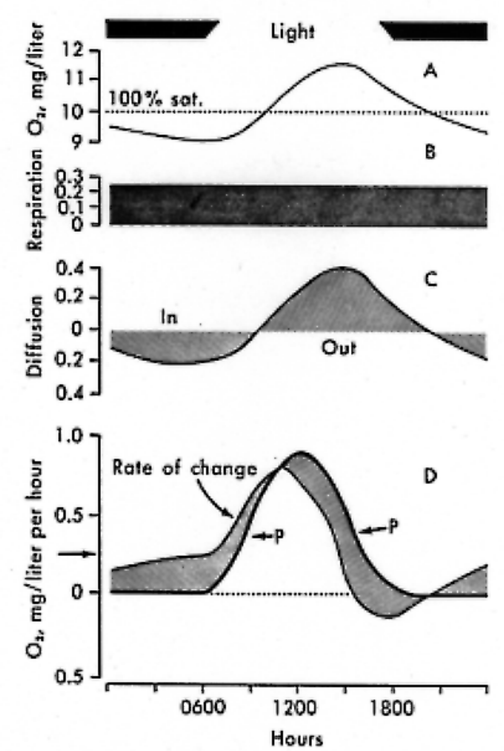


Figure 11-1
Oxygen profiles in thermally stratified lakes. *A*, Orthograde oxygen profile; *B*, clinograde oxygen profile; *C*, positive heterograde oxygen profile; *D*, negative heterograde oxygen profile. Oxygen plotted with thicker lines; temperature plotted uniformly and with thinner lines; figures on *x* axis times 2.0 = °C.

5) Daily changes in oxygen concentrations throughout the water column are largely driven by the changes in light conditions that drive photosynthesis.

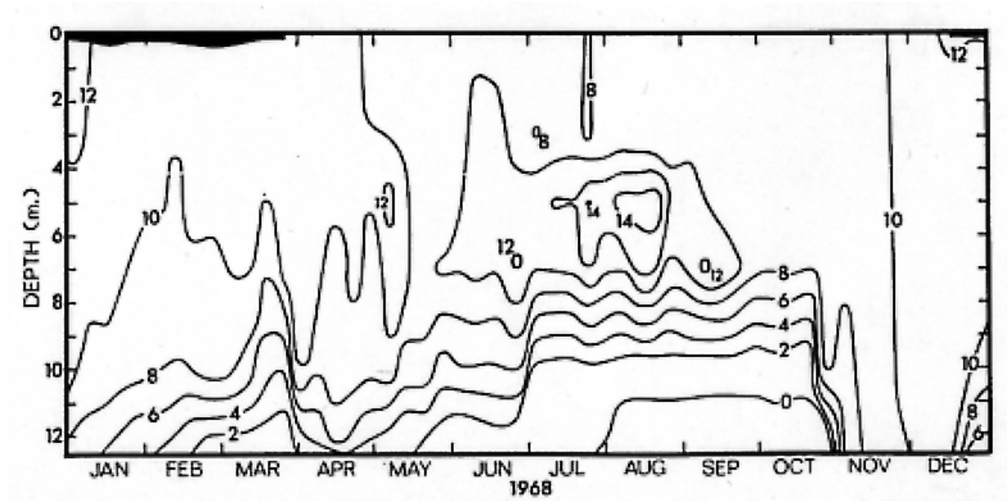
By monitoring the daily changes in oxygen concentrations in a water body, we can estimate the rate of gross primary productivity (the rate at which the plants in the system are fixing carbon through photosynthesis).

From Cole (1983)



6) Seasonal changes in oxygen concentrations are largely driven by the seasonal changes in the rates of photosynthesis and respiration, and the seasonal changes in the thermal stratification of lakes.

From Wetzel (1983)



Seasonal changes in respiration and photosynthesis can lead to very low oxygen concentrations in the water column. In some lakes, the oxygen concentration can drop to levels that some organisms (especially fishes) cannot tolerate.

Winterkill – is seen in very productive but shallow lakes during ice cover. Snow-covered ice does not allow light to penetrate the water column and planktonic respiration can greatly deplete oxygen concentrations that lead to fish kills.

Summerkill – is seen in very productive stratified lakes during the summer. After thermal stratification in spring, the hypolimnion of productive (eutrophic) lakes will slowly lose oxygen due to respiration of sediments and the organic "rain" from the epilimnion. By late in the summer, all of the hypolimnetic oxygen can be consumed, that can lead mortality of fishes that require the cold water habitat of the hypolimnion or metalimnion.

7) Oxygen deficit – quantifies the difference between the expected oxygen and the actual oxygen concentration.

Actual oxygen deficit = saturated [oxygen] - observed [oxygen]

Absolute oxygen deficit = saturated at 4°C[oxygen] - observed [oxygen]

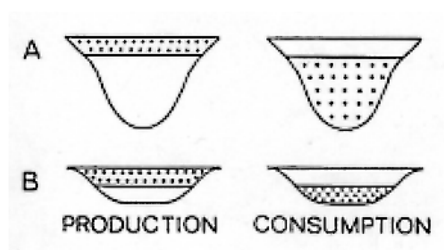
Relative oxygen deficit = spring turnover [oxygen] - observed [oxygen]

8) Morphometric effects on oxygen deficit

The hypolimnetic oxygen deficit has been shown to be a function of the relative volumes in the **trophogenic zone** (i.e. where organic matter is produced and photosynthesis > respiration) and

tropholytic zone (usually the hypolimnion, where respiration > photosynthesis) where no oxygen is produced but respiration consumes oxygen.

From Wetzel (1983)



From Cornett and Rigler (1980). AHOD refers to the areal hypolimnetic oxygen deficit. VOD refers to the volumetric oxygen deficit.

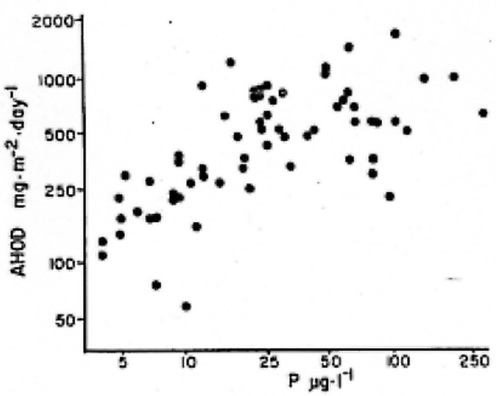


Fig. 1. Relationship between measured lake phosphorus concentration and AHOD ($N = 65$; $r^2 = 0.43$, $P < 0.001$).

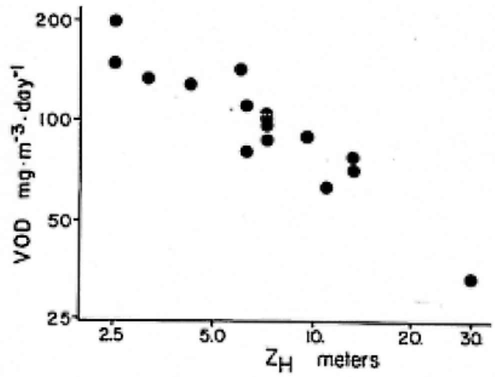


Fig. 6. Average rates of oxygen depletion per cubic meter in 10 Wisconsin lakes plotted vs. mean thickness of hypolimnion.

Cornett, R.J., and F.H. Rigler. 1980. The areal hypolimnetic oxygen deficit: an empirical test of the model. *Limnology and Oceanography* 25:672-679.

9) Oxygen measurement

a) The traditional technique for measuring the oxygen concentration in water is with a **Winkler titration.** This technique involves the reaction of manganese sulphate with potassium hydroxide that forms insoluble manganese hydroxide. As the manganese hydroxide settles out of solution is absorbs all of the oxygen from solution and settles it to the bottom of the titration flask. When this solution is then acidified in the presence of potassium iodine, iodine is released in a quantity equivalent to the amount of oxygen in the original water. This iodine turns the sample dark blue in the presence of starch. The liberated iodine can then be titrated quantitatively with sodium thiosulphate. When all of the iodine is consumed from titration, the solution loses its blue colour. This technique is very precise.

b) An alternative technique to measure oxygen in solution is with an electronic oxygen meter with a potassium chloride electrode. This technique is much easier than the Winkler titration, but is often not as precise.