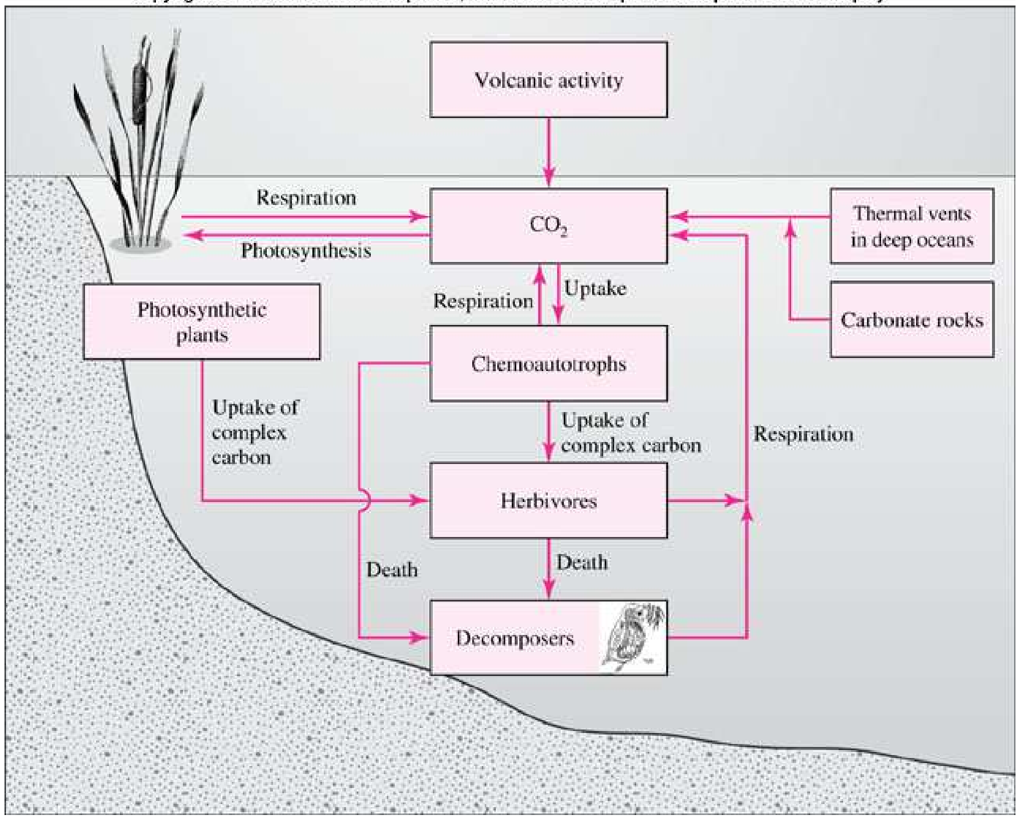
Nutrient cycle: C cycle

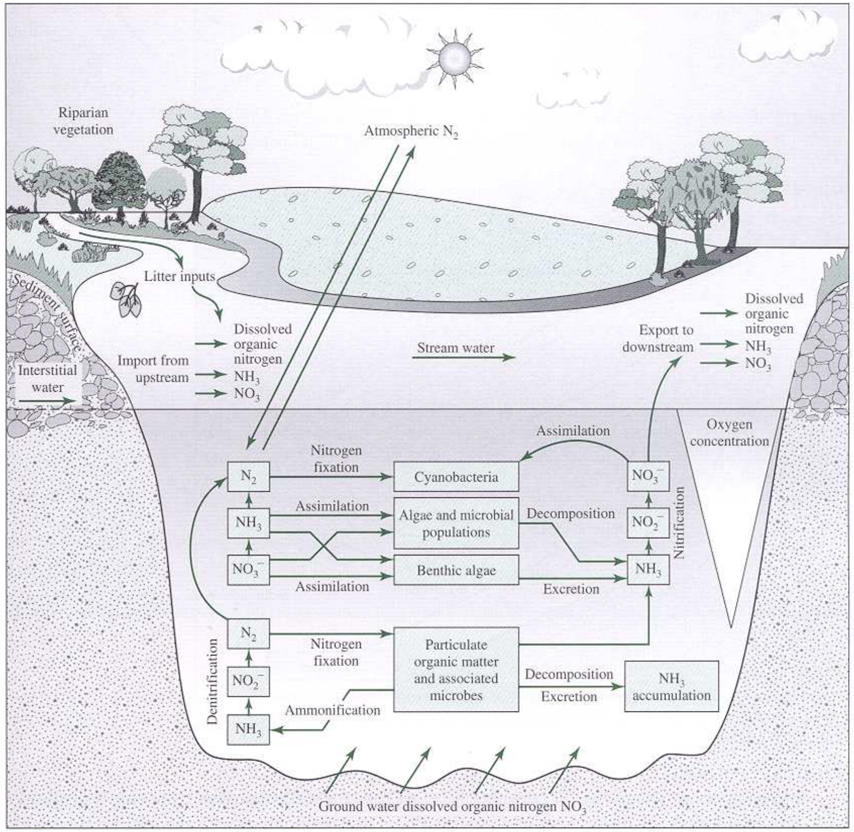
- Essential element: building block of life & life-sustaining chemicals



- Relevant processes
  - carbon cycling in the biosphere: photosynthesis, respiration, predation
  - ocean as a major carbon sink: solubility pump and biological pump
  - fossil fuel combustion: significant input of CO_2 by humans
  - dissolution of carbonate rocks

Nutrient cycle: N cycle

- Critical element for all life (protein)
- N_2 in the air: abundant, but not easily available to organisms



- Relevant processes

- nitrification

$NH_4^+ + 2O_2 = NO_3^- + 2H^+ + H_2O$

- denitrification

$2NO_3^- + \text{organic C} = N_2 + CO_2 + H_2O$

- nitrogen fixation

$N_2 + 8e^- + 8H^+ + ATP \rightarrow$

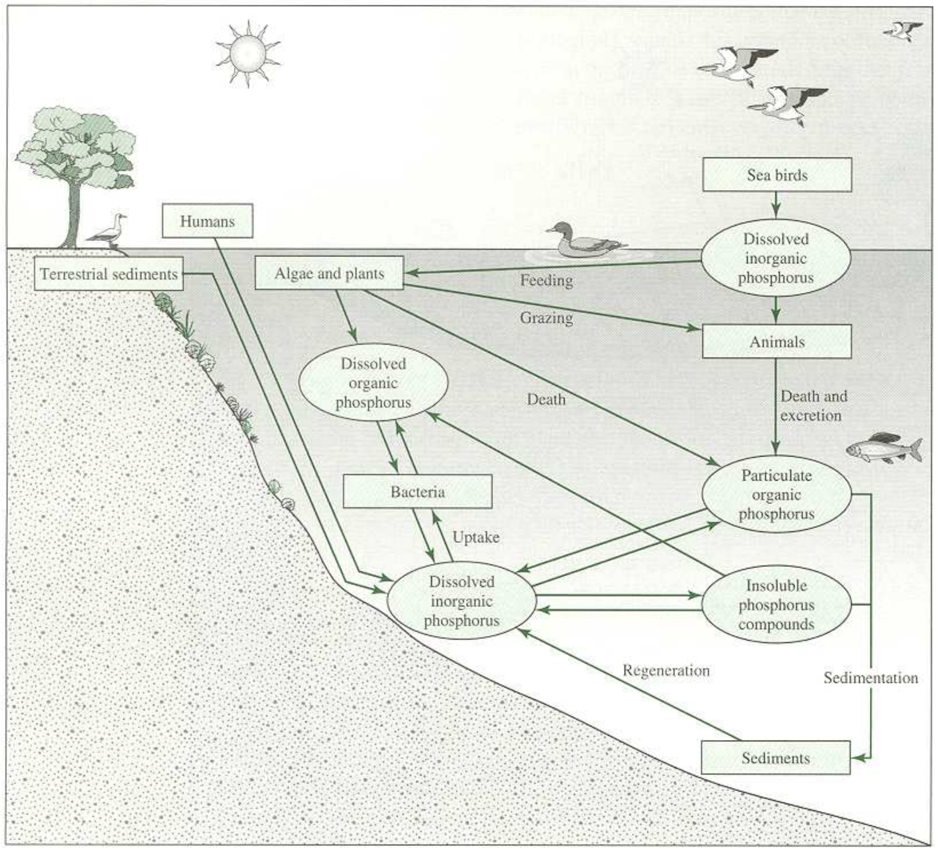
$2NH_3 + H_2 + ADP + \text{inorganic P}$

- significant human contribution: Haber-Bosch process

$N_2 + 3H_2 \rightarrow 2NH_3$

Nutrient cycle: P cycle

- Another essential nutrient (DNA, RNA, ATP)
- Very slow cycling: moves slowly through the soil and ocean



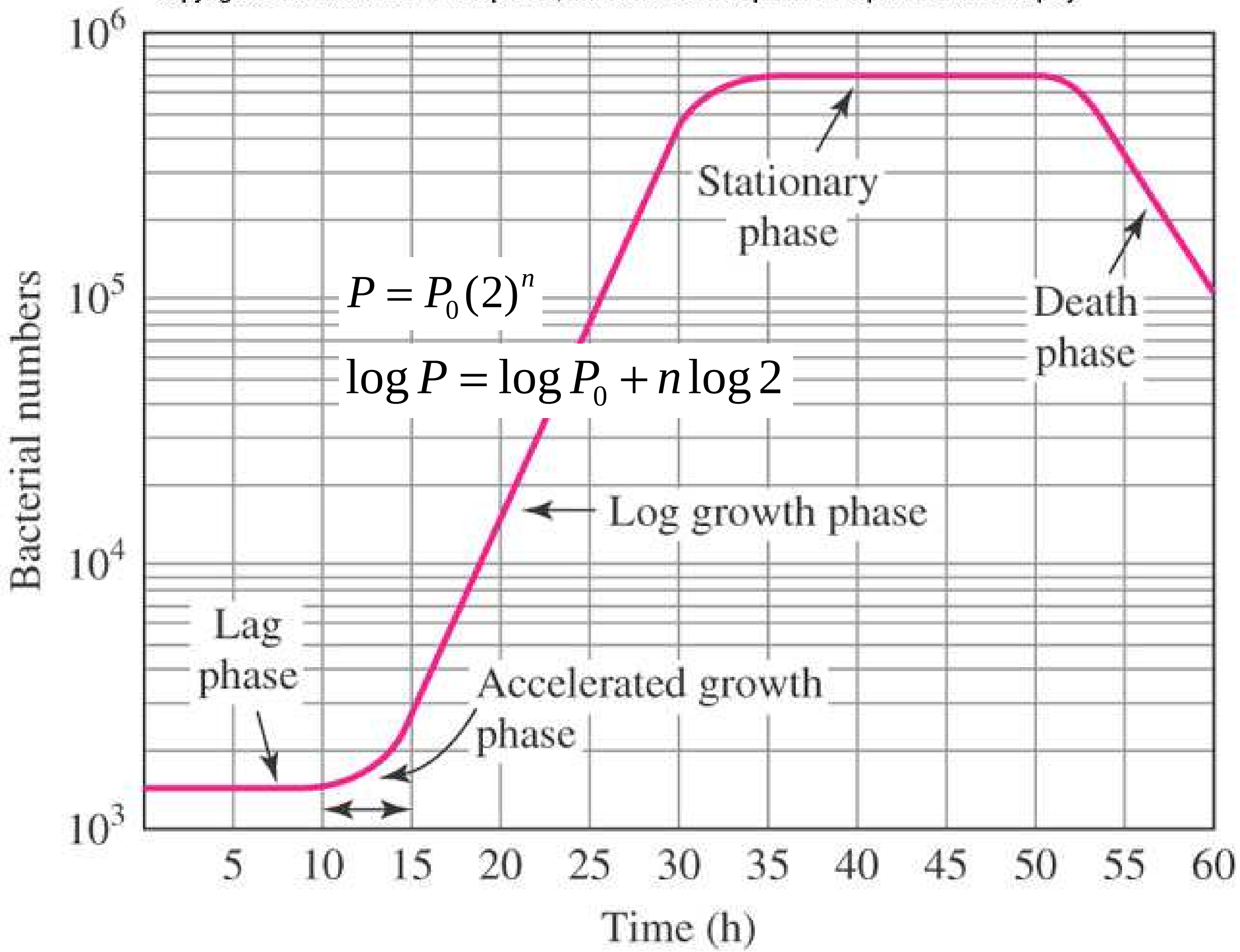
- Relevant processes

- natural source: input from mineral weathering
- human contribution can be significant (fertilizer, detergent, etc.)
- uptake by plants and algae in a soluble inorganic form (HPO_4^{2-}, PO_4^{3-}, etc.)
- loss by sediment burial

Population dynamics

- The study of changes in the numbers and composition of individuals in a population
- Significance for environmental science and engineering
  - Understanding how environmental perturbations affect populations
  - Predicting human populations to determine water resource and waste(water) treatment needs
  - Predicting bacterial populations in engineered systems
  - Using populations as indicators of environmental quality

Bacterial population growth (pure culture)



$$P = P_0(2)^n$$

$$\log P = \log P_0 + n \log 2$$

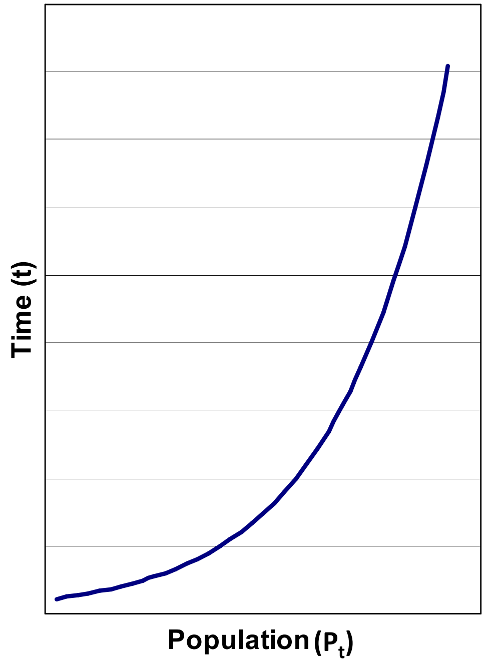
E. coli doubling time: 20-30 mins

Human & animal population models

- **Exponential model**
  - Assumes infinite resources
  - Continuous function

$$\frac{dP}{dt} = rP \quad \Rightarrow \quad P(t) = P(0)e^{rt}$$

P: population
r = specific rate of change



- **Geometric model**
  - Assumes infinite resources
  - Discrete function

$$\frac{P(t+1)}{P(t)} = \lambda$$

P(t): population after t years
P(t+1): population after t+1 years
λ = yearly growth rate

Human & animal population models

Q: Using the following data for the eastern gray wolf population in Wisconsin, USA, compare the population in 2003 predicted by the exponential model and the geometric model.

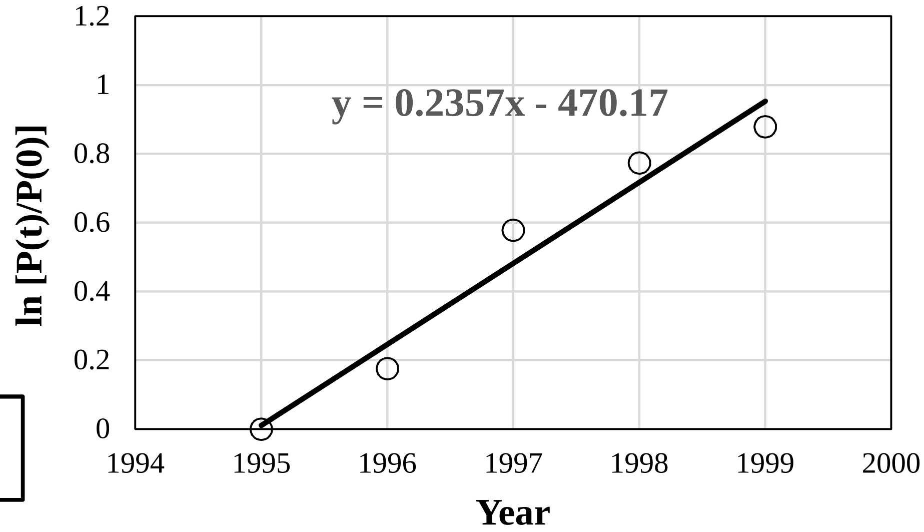
Year	1995	1996	1997	1998	1999
Population	85	99	148	180	200

Human & animal population models

1) Exponential model

$$P(t) = P(0)e^{rt}$$

$$\ln[P(t)/P(0)] = rt$$



***r* = 0.236**

Population in 2003? (t = 8 yrs)

$$P(8) = P(0)e^{r\times 8} = 85e^{0.236\times 8} = \mathbf{562}$$

Human & animal population models

2) Geometric model

$$\frac{P(t+1)}{P(t)} = \lambda$$

Year	Population	λ
1995	83	
1996	99	1.193
1997	148	1.495
1998	180	1.216
1999	200	1.111
Average		**1.254**

Population in 2003?

(t=8 yrs):

use data for y1999 (t=4 yrs)

$$P(8) = P(4) \times \lambda^4$$

$$P(8) = 200 \times 1.254^4 = \mathbf{495}$$

cf) 562 by exponential model

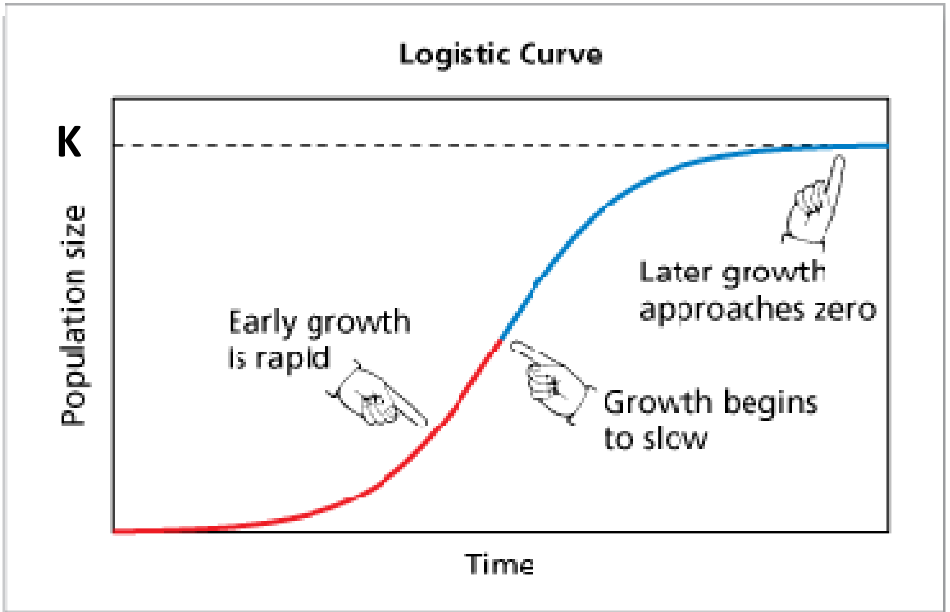
Human & animal population models

- **Logistic model**
  - Assumes resources are limited
  - There is a maximum number of population that an area can support

$$\frac{dP}{dt} = rP\left(\frac{K-P}{K}\right)$$

P: population
K = carrying capacity

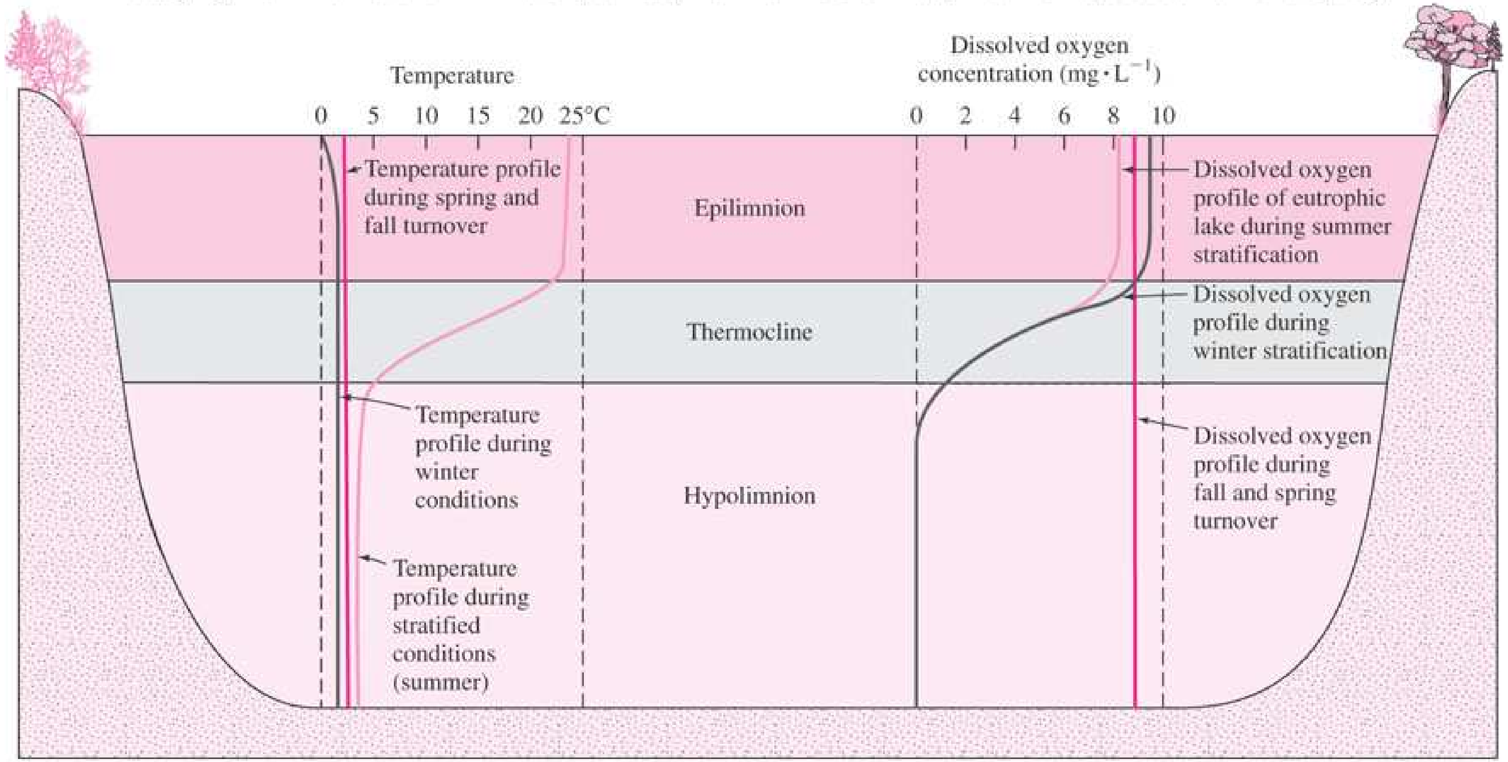
$$P(t) = \frac{K \cdot P(0)}{P(0) + [K - P(0)]e^{-rt}}$$



http://www.math.andyou.com

Lakes

- Seasonal changes

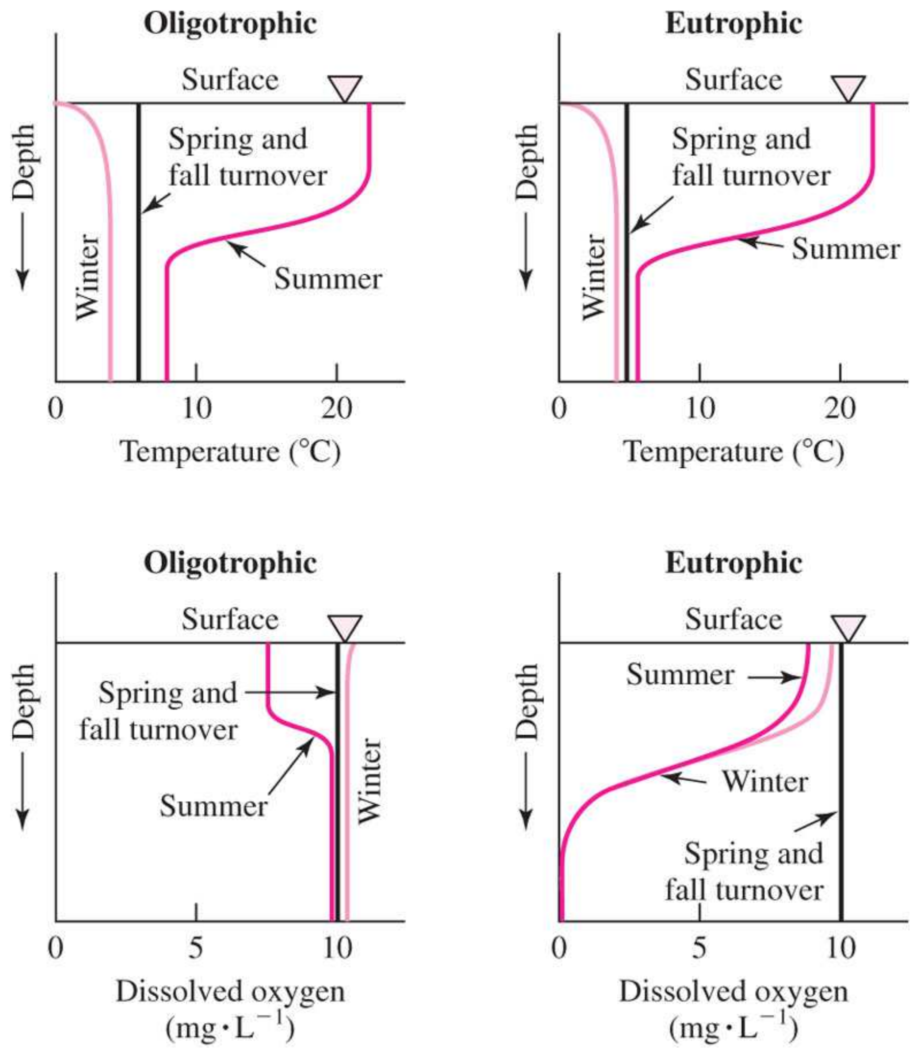


(a) Temperature profile (b) Dissolved oxygen profile

Lake productivity

- **Oligotrophic lakes**: low productivity due to limited supply of nutrients, clear water

- **Eutrophic lakes**: high productivity due to abundance supply of nutrients, turbid water



Lake productivity

- Lake productivity: a measure of a lake's ability to support aquatic life (a more productive lake has a higher biomass concentration)
- Controlled by the limiting factor ("Liebig's law of the minimum"*)

* *Liebig's law of the minimum*: growth is controlled not by the total amount of the resources available, but by the scarcest resource (limiting factor).

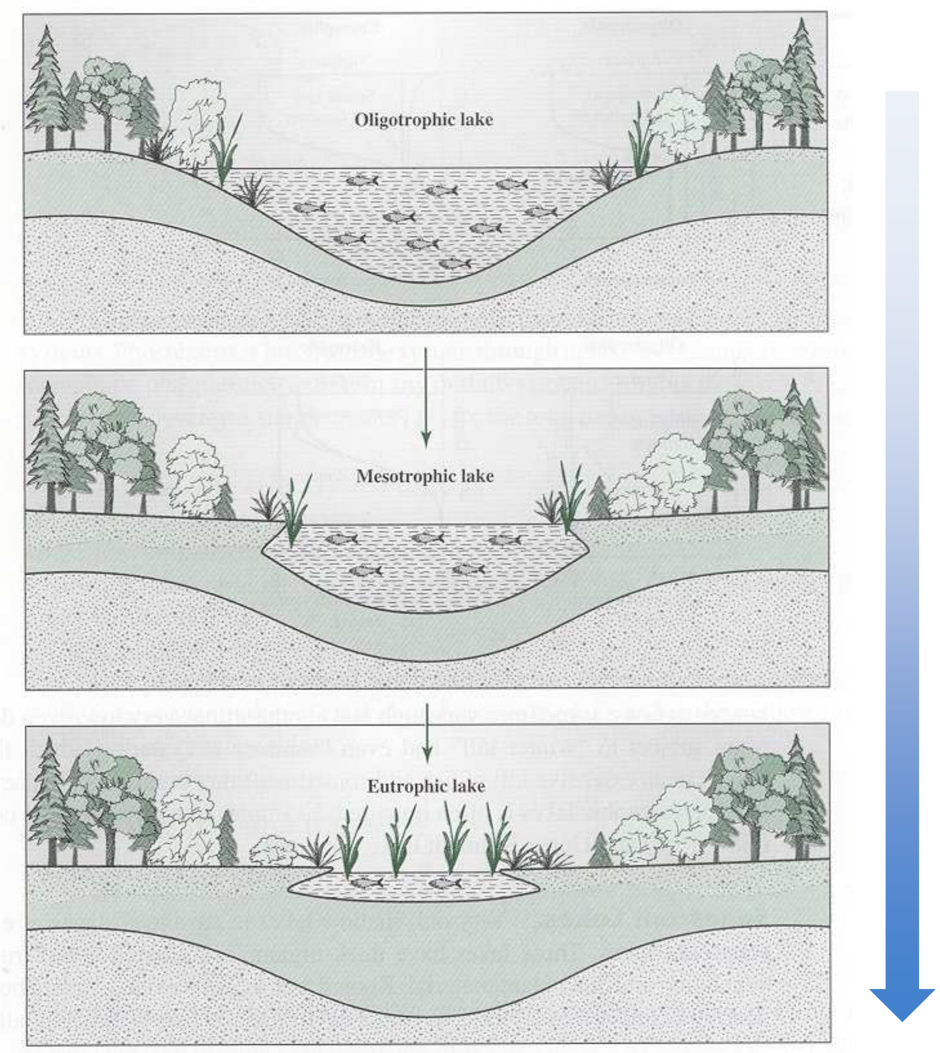
Recall: C, H, O, N, S, P, K, Ca, Mg, Fe

Eutrophication of lakes

- **Natural eutrophication**: A natural aging process of a lake; may take over thousands of years (an unpolluted lake)

- **Cultural eutrophication**: accelerated eutrophication through the introduction of high levels of nutrients (a polluted lake)

Natural eutrophication



lake productivity increases over time

Cultural eutrophication

- Caused by the introduction of high levels of N and P (usually P for lakes and N for coastal waters)
- Sources of nutrients
  - human waste (sewage)
  - animal waste
  - agricultural sites

Cultural eutrophication

- Effect of eutrophication: algal bloom
  - high algae biomass: taste and odor problems, aesthetic problem
  - deposition of dead algae: oxygen depletion in the bottom
  - harmful algal bloom: some algal species produce toxic materials (ex: microcystin by cyanobacteria)
  - fish kills by O_2 depletion and toxic compounds, and clogging by algae

Reading assignment

- Textbook Ch5 199-225