Ecosystem

Ecosystem

- Terminologies related to ecosystems
- Human influence on ecosystems
- Energy and mass flow
- Bioaccumulation
- Nutrient cycle
- Population dynamics
- Lake ecosystem

Some terminologies

- **Ecosystems**: communities of organisms that interact with one another and with their physical environment
- **Habitats**: the place where a population of organisms lives
- **Population**: a group of organisms of the same species living in the same place at the same time

Human influence on ecosystems

- Destruction of environment (habitat)
  - deforestration, dam construction, road construction, etc.

- Changes in species population
  - can result in local and global extinction
  - release of toxic chemicals (ex: DDT, petroleum compounds, heavy metals)
  - shifting living conditions: acid rain, global warming, eutrophication, etc.
  - introduction of nonnative (exotic) species
  - excessive hunting

DDT and Silent Spring

1874: DDT first synthesized by O. Zeidler

1939: P. H. Müller discovered the insect killing ability and won Nobel Prize (1948)

1940s: Widely used as an insecticide (especially for lice-Typhus and mosquito-malaria)

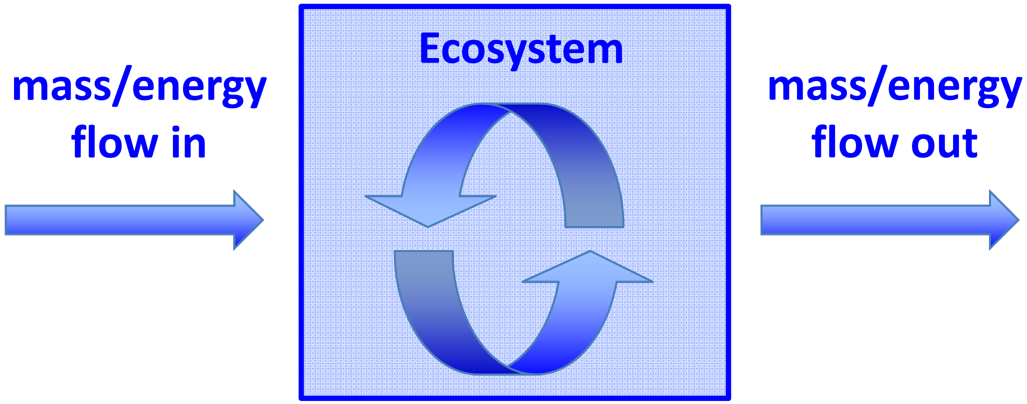
1962: Rachel Carson published “Silent Spring” - described how DDT accumulates in organisms and affect wildlife

1960s: Environmental scientists published researches to support R. Carson’s argument (egg shell thinning by DDT)

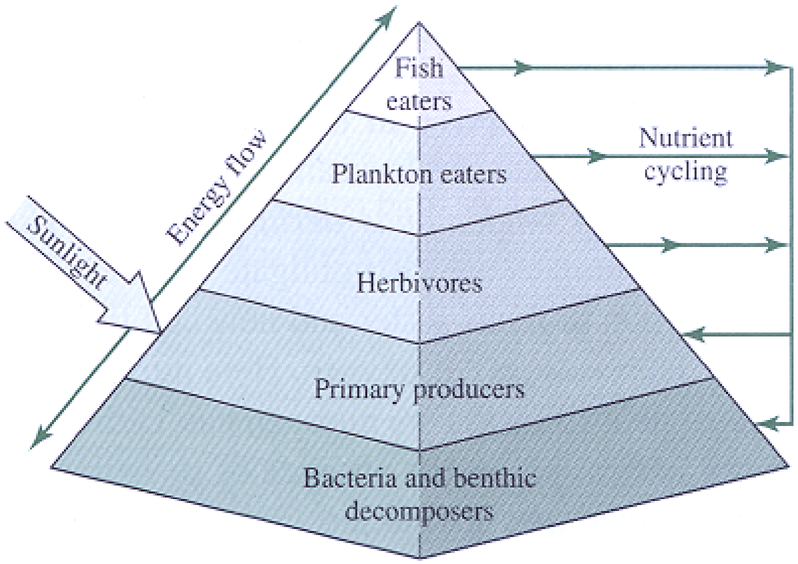
1972: DDT banned in the U.S.

Energy and mass flow

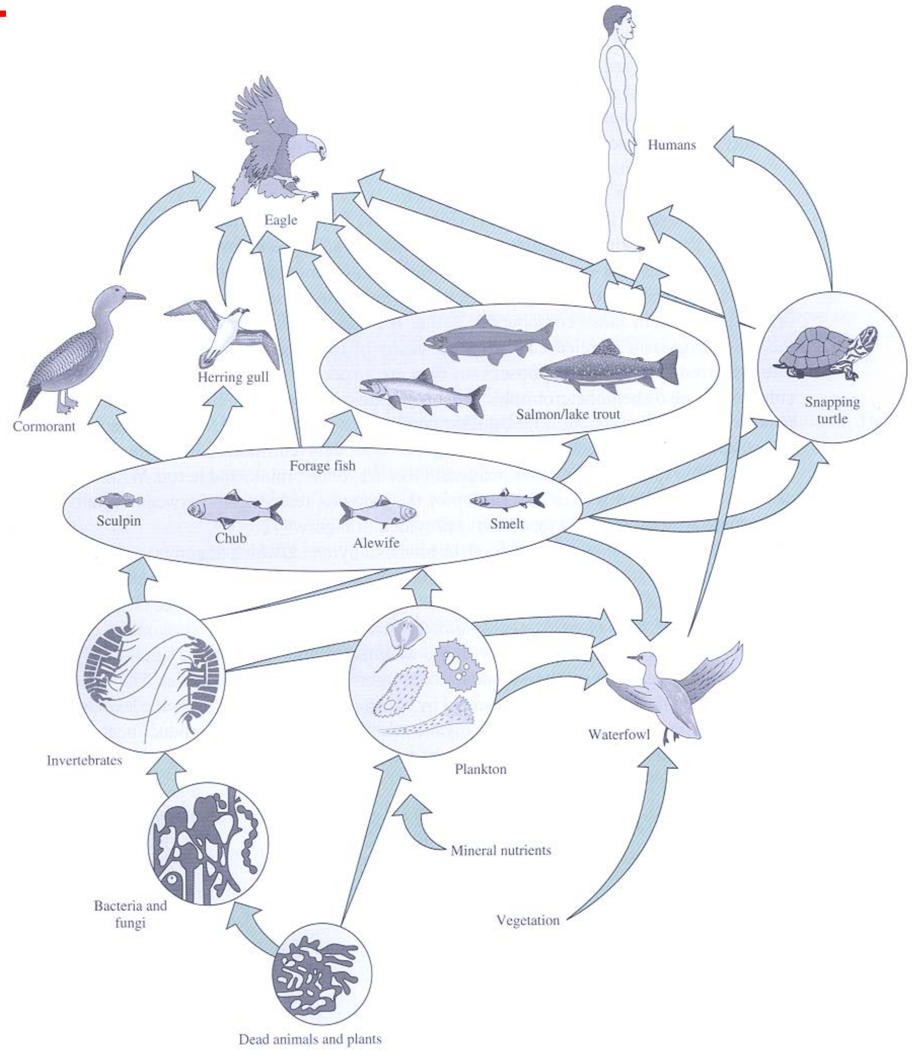
- Important feature of an ecosystem:
  - Flow of matter into, out of, and within the system



Energy and mass flow



<Ecological pyramid example>



<Food web example>

Energy and mass flow

- Primary producers
  - Major source of energy for an ecosystem: sunlight
  - Major source of carbon (essential element for organic matter) for an ecosystem: CO_2
  - Primary producers can use sunlight and CO_2 (or HCO_3^-) to produce organic matter that contains energy in a chemical form:

    <Photosynthesis>

    $$6CO_2 + 6H_2O + \text{sunlight (2800 kJ)} \xrightarrow{\text{chlorophyll}} C_6H_{12}O_6 + 6O_2$$

  - Organisms that obtain carbon from inorganic sources and use sunlight as an energy source is called "*photoautotrophic*"

Energy and mass flow

- Classification of organisms based on energy / carbon source
  - Based on energy source
    - Phototrophs: light
    - Chemotrophs: organic or inorganic compounds
      - Chemolithotrophs: inorganic
      - Chemoorganotrophs: organic
  - Based on carbon source
    - Autotrophs: inorganic C (CO_2 or HCO_3^-)
    - Heterotrophs: organic C

Q: classification of (primary, secondary, tertiary, …) consumers?

A: chemoorganotrophs, heterotrophs

Energy and mass flow

- Respiration
  - A process of oxidizing organic compounds so that the chemical energy stored can be released
  - The energy released is used to derive other reactions (ex: cell metabolism and growth)

<Aerobic respiration>

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{energy}$$

  - Requires an oxidizing agent to oxidize an organic compound by the redox reaction: called "electron acceptors"
  - Some organisms can use electron acceptors other than O_2

Energy and mass flow

- Other electron acceptors: nitrate (NO_3^-), nitrite (NO_2^-), sulfate (SO_4^{2-}), ferric ion (Fe^{3+}), CO_2, organic compounds
- Classification of organisms based on living in the presence/absence of O_2

  : Aerobes / Anaerobes

  – Obligate aerobes: can survive only in the presence of O_2
  – Facultative (an)aerobes: can use O_2 and other electron acceptor(s)
  – Aerotolerant anaerobes: cannot use O_2, but can survive in the presence of O_2
  – Obligate anaerobes: cannot survive in the presence of O_2

Q: classification of human?

A: obligate aerobe

Bioaccumulation

- Some chemicals have significantly higher affinity to some part of organisms than to the environment (water, air, soil, etc.)

  ex) hydrophobic compounds have very high affinity to lipids than to water

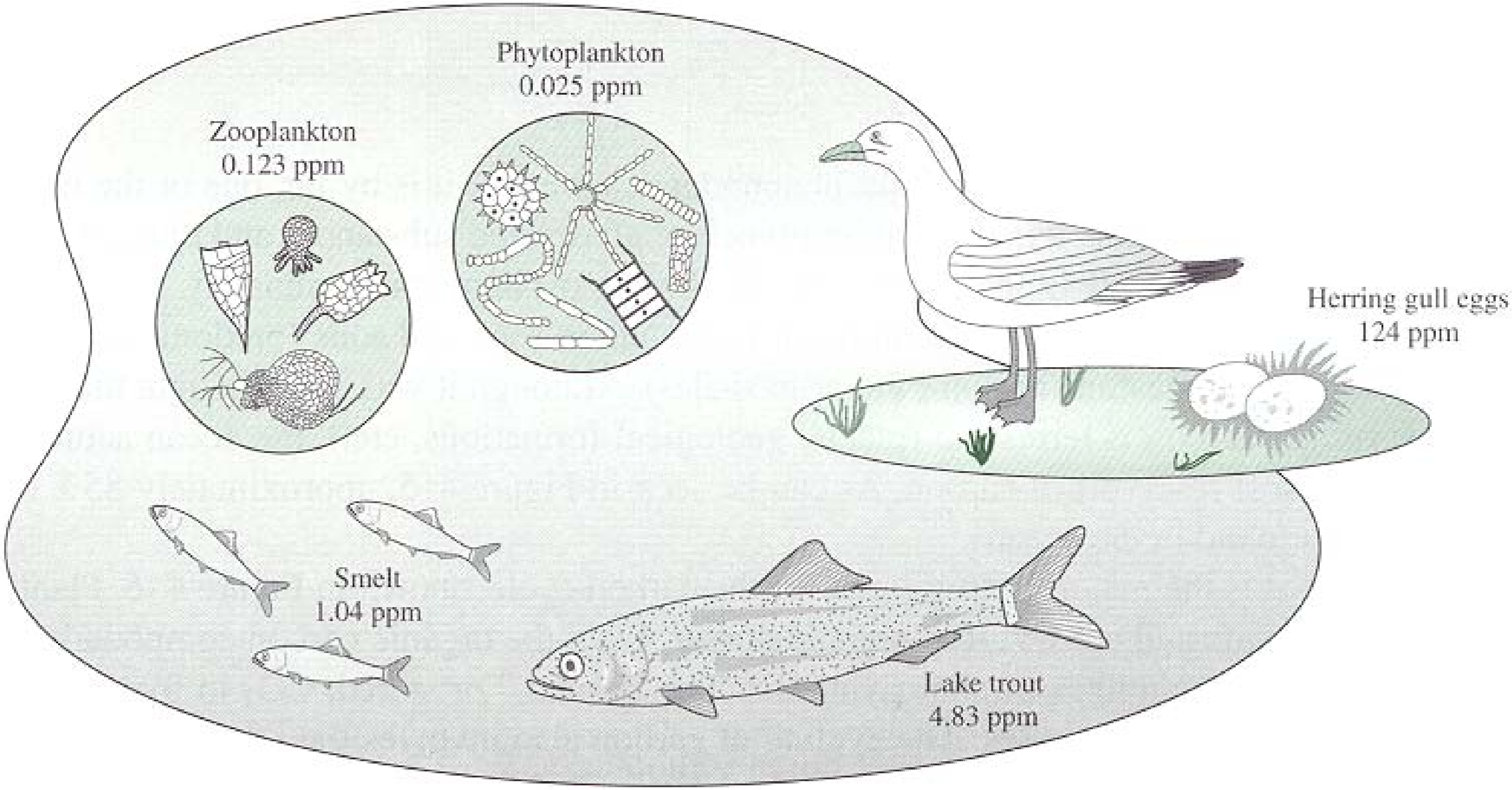
- If chemical gain > loss for an organism, then the chemical may be accumulated within the body
- The chemical accumulation may occur more significantly for higher trophic level organisms

Terminologies related to bioaccumulation

- **Bioaccumulation**: total uptake of chemicals by an organism from either water or food
- **Biomagnification**: a process that results in accumulation of a chemical in an organism at higher levels than are found in its own food
- **Bioconcentration**: the uptake of chemicals from the dissolved phase

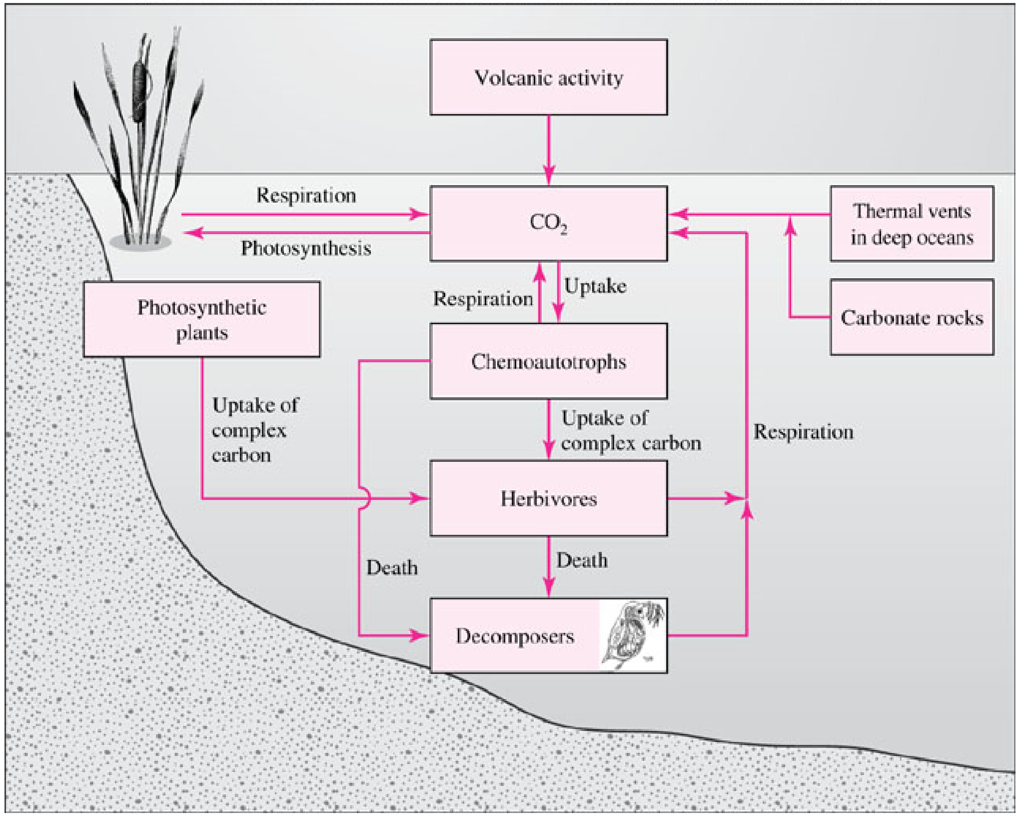
Biomagnification in aquatic food web

<PCBs in Great Lakes aquatic food web>



Nutrient cycle: C cycle

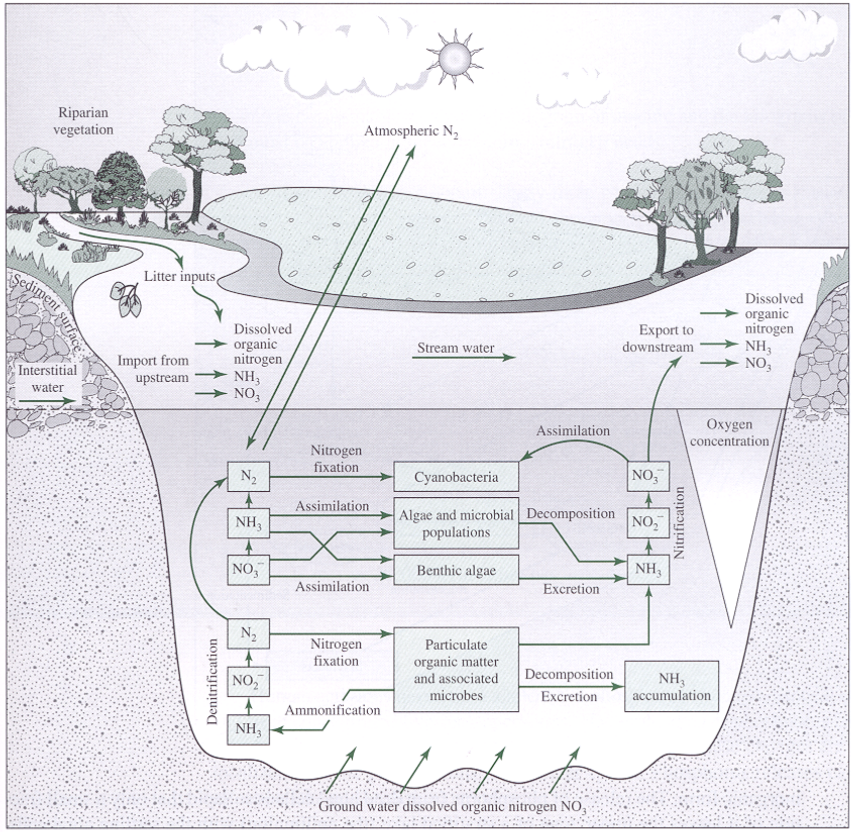
- Essential element: building block of life & life-sustaining chemicals



- Relevant processes
  - carbon cycling in the biosphere: photosynthesis, respiration, predation
  - <u>ocean as a major carbon sink</u>: 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

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

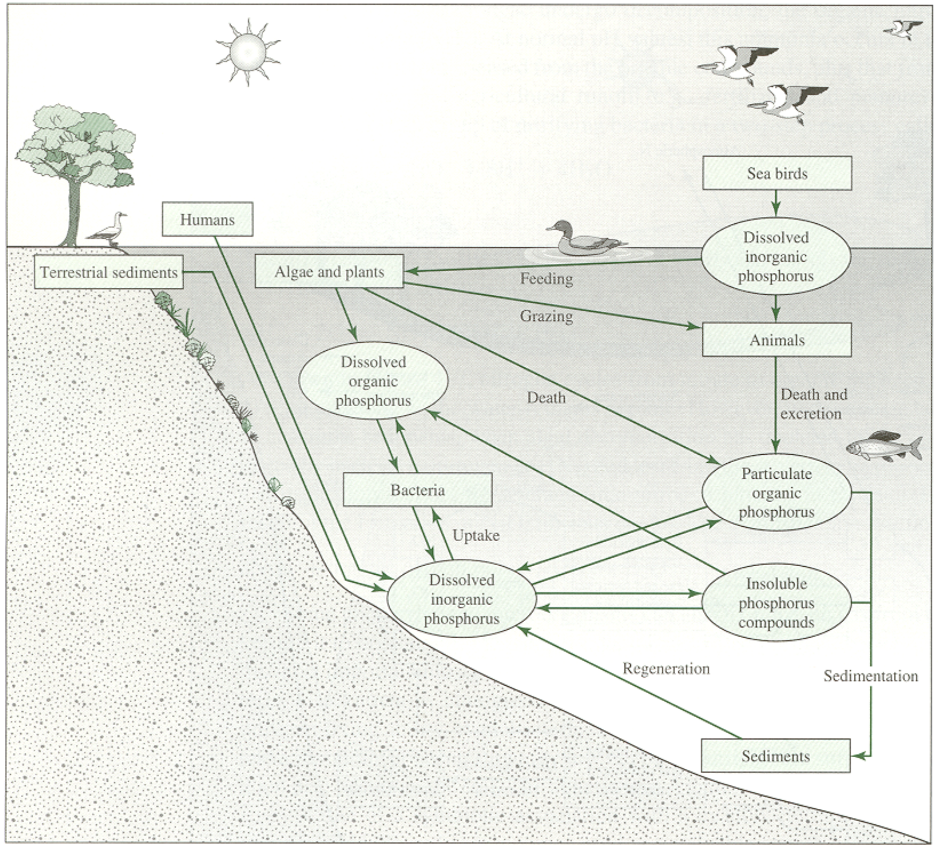
    $2NH_3 + H_2 + ADP + \text{inorganic P}$
  - significant human contribution:

    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.)

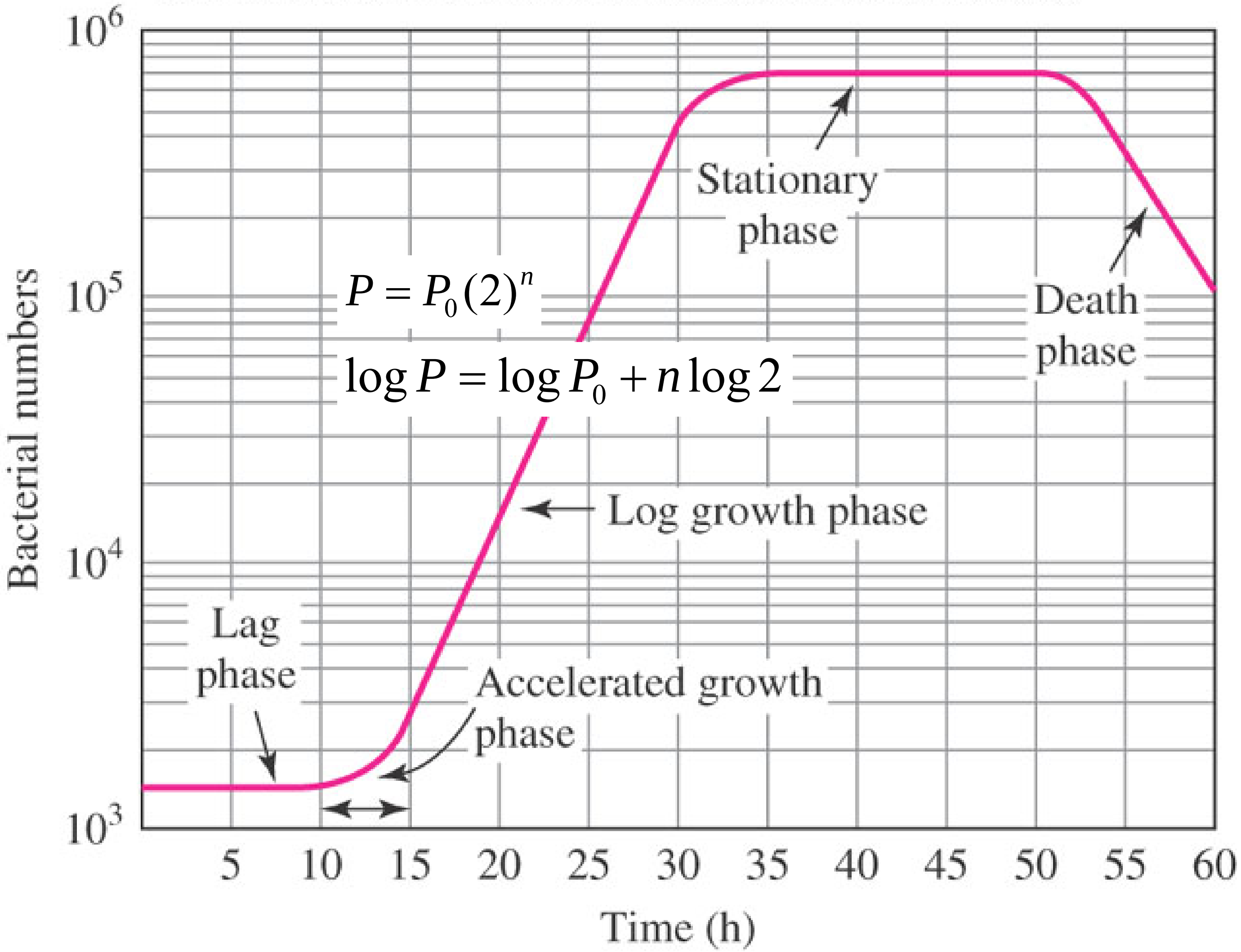
- uptake by plants and algae in a soluble inorganic form (HPO_4^{2-}, PO_4^{3-}, etc.)

- 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)



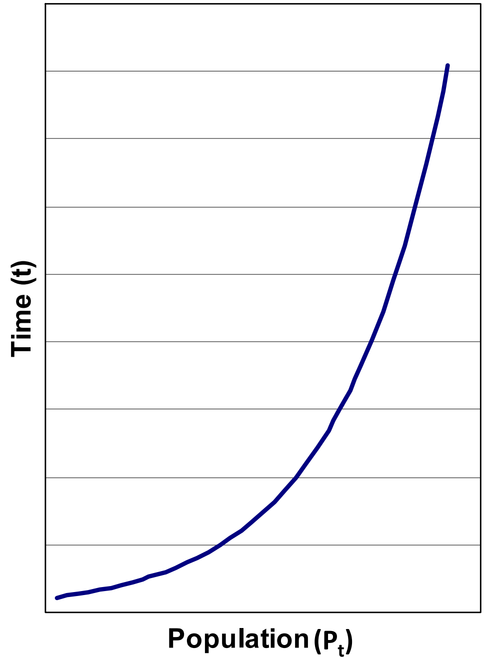
E. coli doubling time: 20-30 mins

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

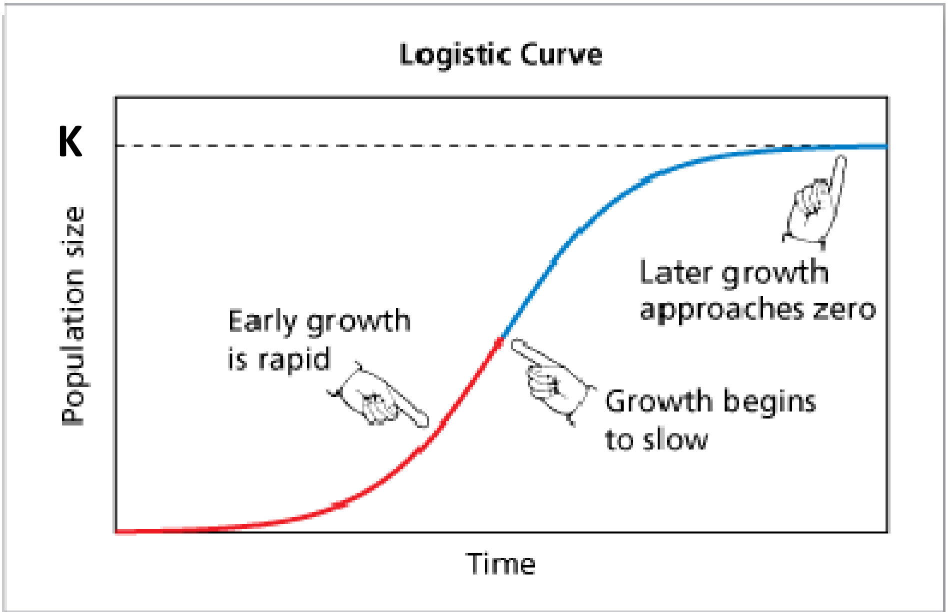
Human & animal population models

- **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

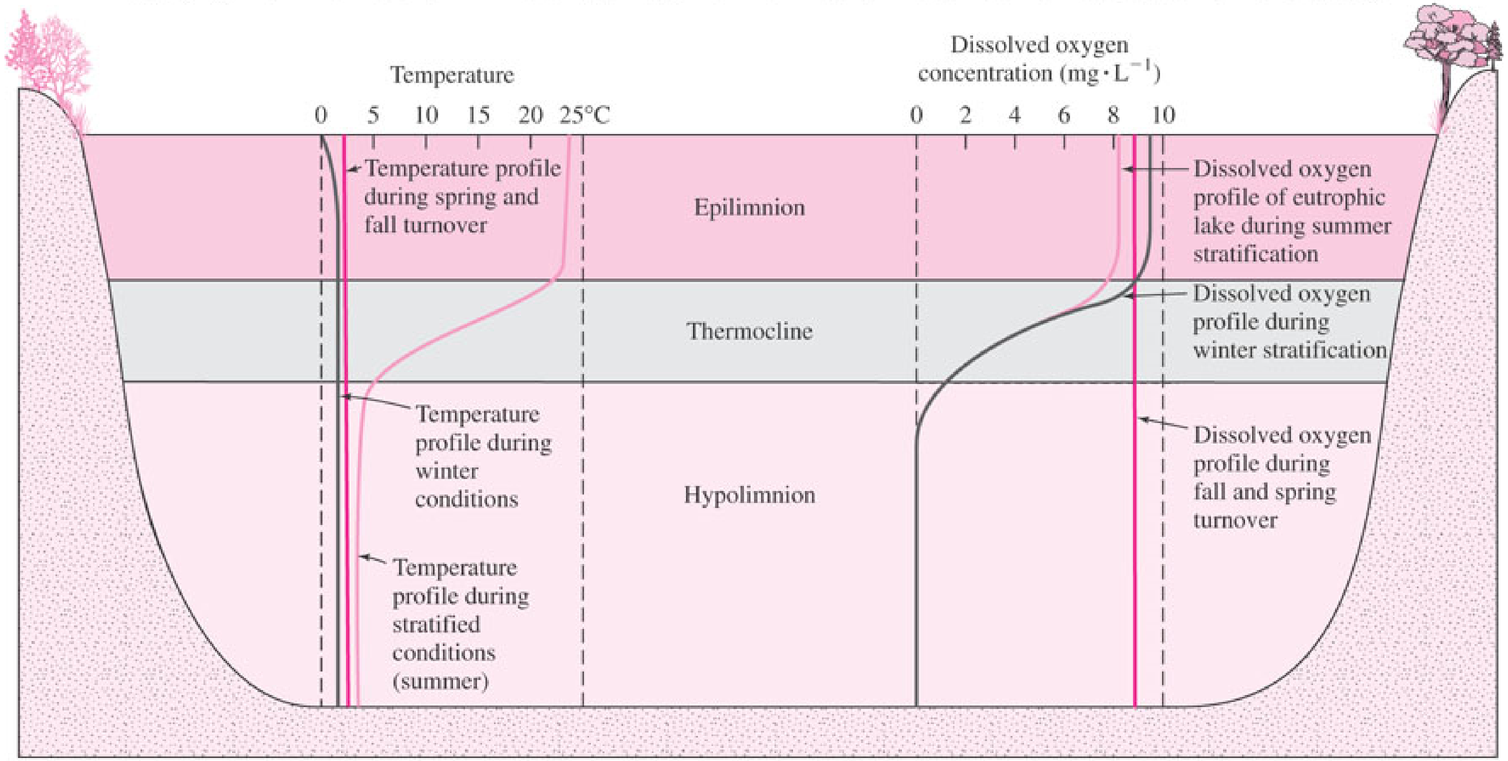
$$P(t) = \frac{K \cdot P(0)}{P(0) + [K - P(0)]e^{-rt}}$$



http://www.math.andyou.com

Lakes

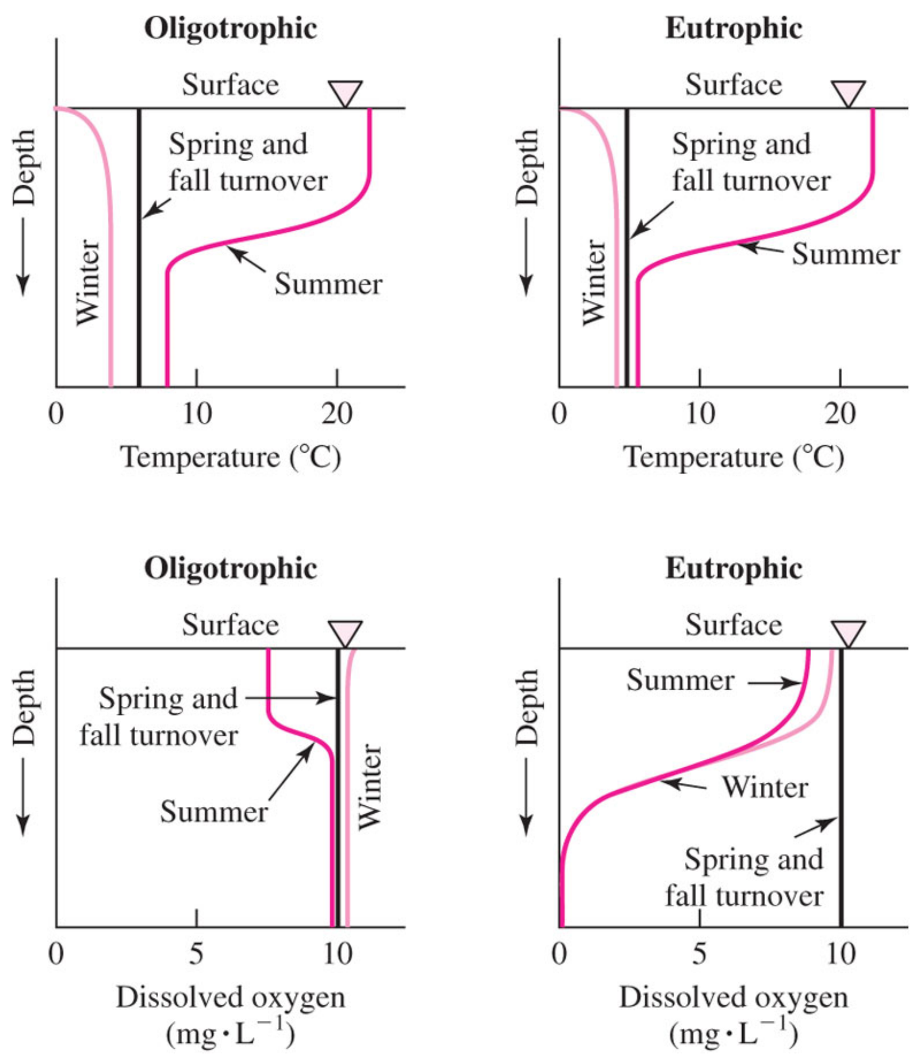
- Seasonal changes



(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).

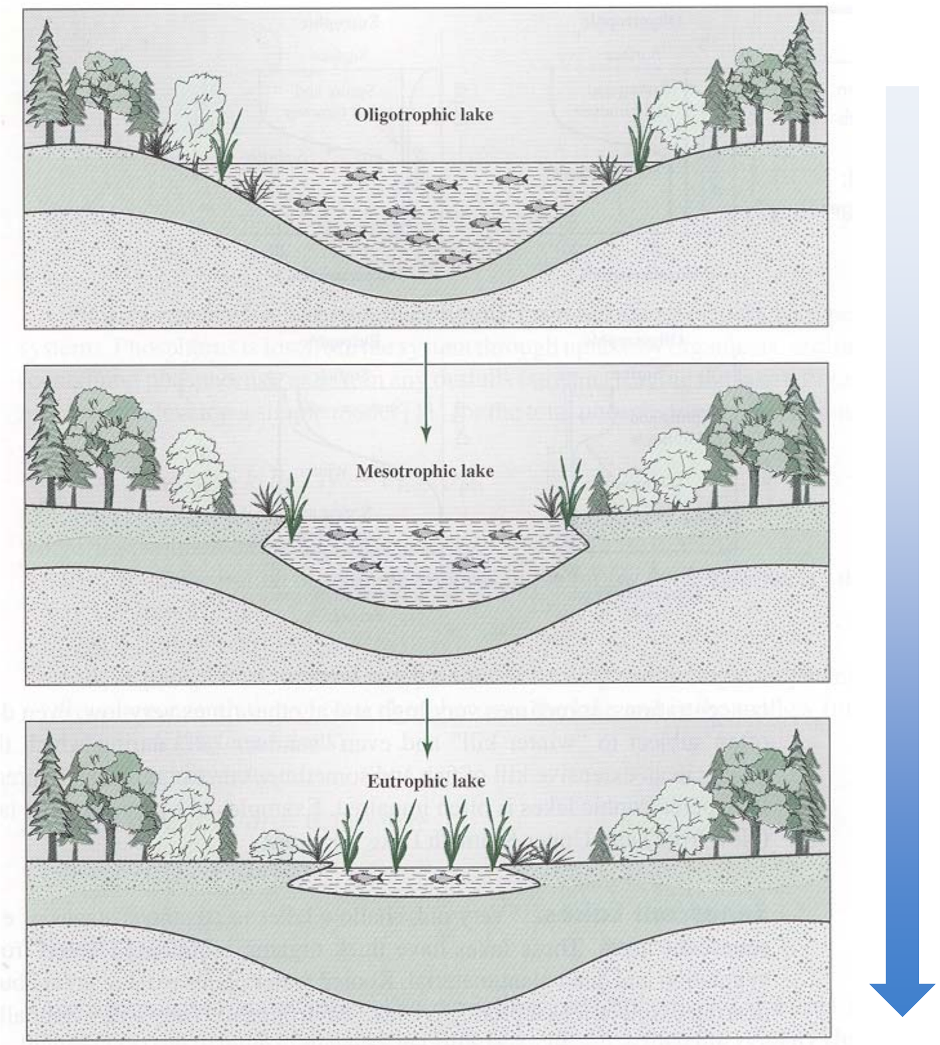
  Recall: C, H, O, N, S, P, K, Ca, Mg, Fe

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 p. 190-225

Human & animal population models

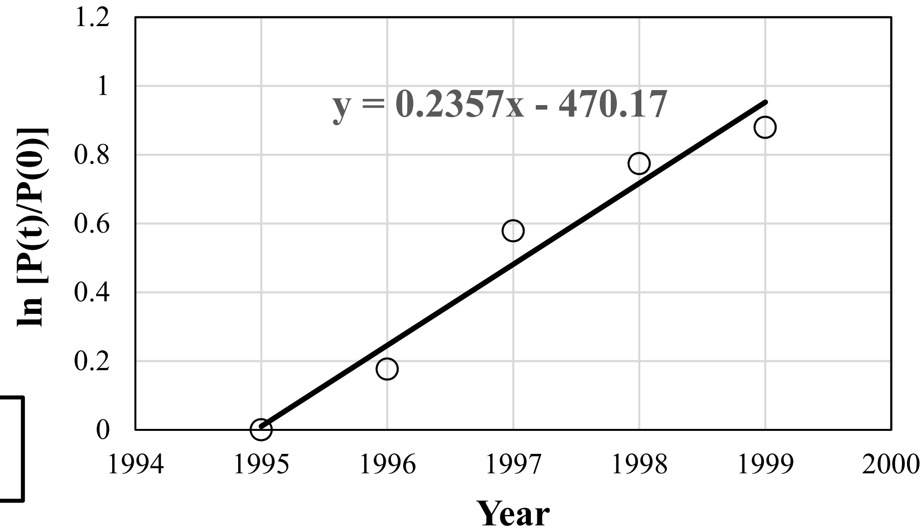
Slide#21 solution)

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