

Chapter 30-31

Environmental Microbiology

What is microbial ecology?

The study of...

- the relationships that exist between microorganisms and the environment.
- the relationships that exist between different populations of microorganisms.
- the microbially-mediated processes that sustain life on earth.
- the fate of man-made products in the environment.

Ecological Community

- Indigenous (native) organisms
 - *Spirillum volutans* - stagnant water
 - *Streptomyces* spp. - soil
 - *Escherichia coli* - human digestive tract
- Non-indigenous organisms (temporary)
 - Organisms that appear after an oil spill

Microbial Relationships

- Symbiosis
- Mutualism
- Commensalism
- Antagonism
- Competition
- Parasitism
- Predation

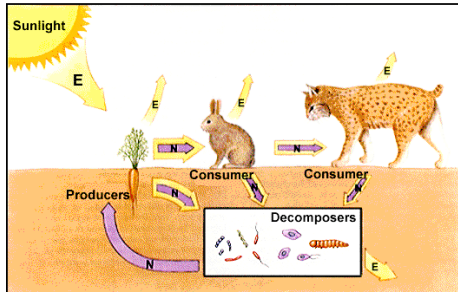
Trophic levels

- Primary producers
 - Autotrophs
- Consumers
 - Heterotrophs
 - 1° consumers
 - 2° consumers
 - 3° consumers
- Decomposers
 - Detritus

Trophic levels & Flow of energy

- The sun - ultimate source of energy
 - Exception - chemolithotrophic (energy - inorganic)
- Primary producers
 - Autotrophs - energy from the sun
 - Photosynthetic bacteria, cyanobacteria, protists and algae
- Consumers
 - Heterotrophs - Heterotrophic bacteria, protists, fungi, and viruses - eat producers or consumers
 - 1° consumers
 - 2° consumers
 - 3° consumers
- Decomposers - eat dead bodies or waste products
 - Numerous fungi and bacteria
 - Detritus

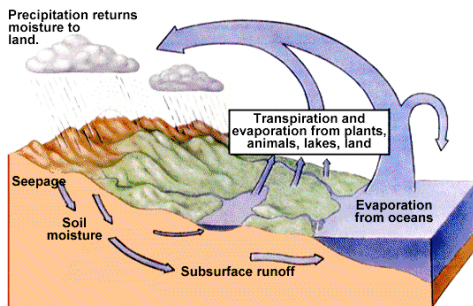
The energy cycle



Biogeochemical Cycles

Bio = living thing
Geo = earth

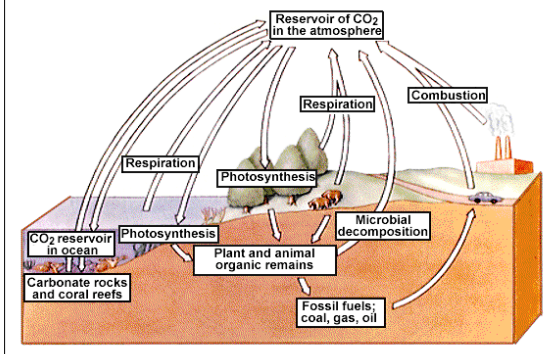
Water cycle or hydrologic cycle



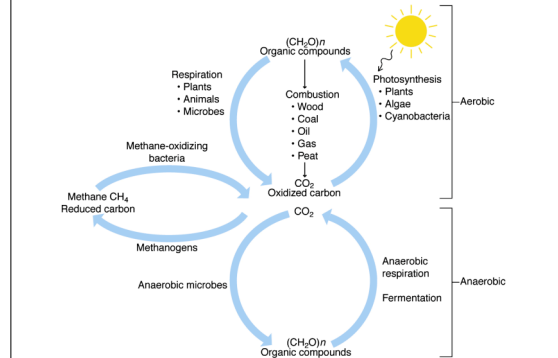
The Carbon Cycle

- Carbon dioxide fixation
 - photosynthesis
 - chemosynthesis
- Forms of carbon in the soil
 - derived from plant material--
 - cellulose and hemicelluloses
 - lignin
 - waxes
 - phenolic compounds

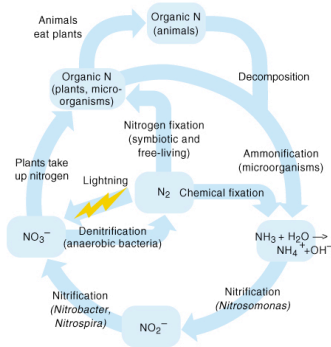
Carbon cycle



Carbon cycle



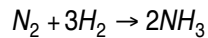
Nitrogen cycle



The Nitrogen Cycle

- Mainly a terrestrial cycle
- Nitrogen is cycled in a series of microbially-mediated oxidation and reduction reactions
- There are 4 main forms of nitrogen
 - dinitrogen gas, organic N, ammonia, and nitrate

Nitrogen Fixation



- Industrial nitrogen fixation
- Lightning nitrogen fixation
- Biological nitrogen fixation

Industrial Nitrogen Fixation

Haber-Bosch Process

- “Fixes” nitrogen under high temperatures and pressures.
- Source of most fertilizer nitrogen.
 - Main forms of fertilizer nitrogen include ammonium, nitrate, urea, and diammonium phosphates.

Lightning fixation

- Energy from lightning
 - sufficient to oxidize dinitrogen to nitrogen oxides.
 - This is a major global contributor of fixed nitrogen.

Biological Nitrogen Fixation

- biological nitrogen fixation requires a lot of energy
 - Like industrial fixation and lightning fixation,.
- It requires 12ATPs per NH_3 fixed:
 - 4 ATPs per bond broken by the enzyme **nitrogenase**

Biological Nitrogen Fixation

- There are 2 types of biological nitrogen fixation
 - Non-symbiotic Nitrogen Fixation
 - Free-living microorganisms
- Symbiotic Nitrogen Fixation
 - Association of a microorganism with another organism, such as a plant.

Nonsymbiotic Nitrogen Fixation

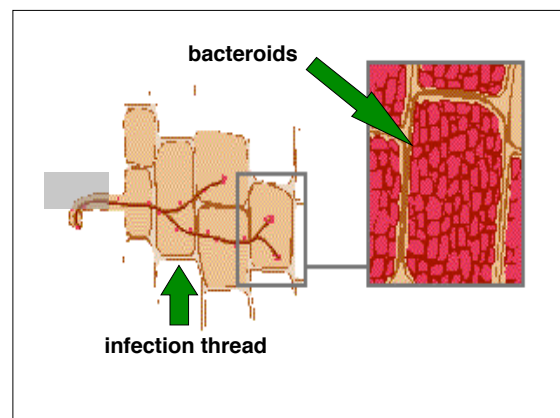
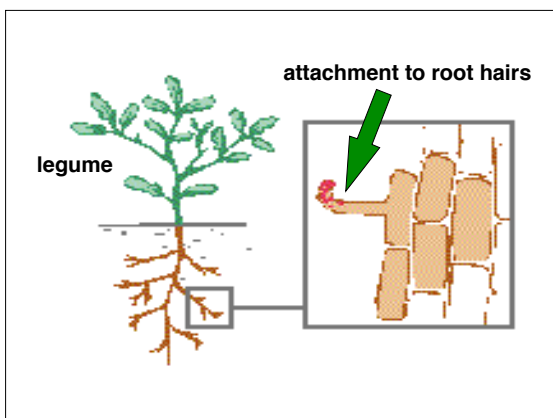
- Important in flooded rice fields, rock surfaces, and nitrogen-deficient soils.
 - Microorganisms include:
 - *Azotobacter*
 - *Clostridium*
 - cyanobacteria

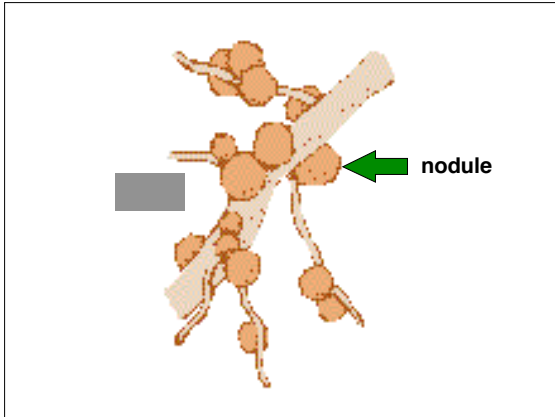
Symbiotic Nitrogen Fixation

- Association - nitrogen-fixing microorganism with a plant
- Important - soils where the fixed nitrogen is insufficient for more than one growing season
- *Rhizobium* - legume
- *Anabaena* (cyanobacteria)- *Azolla* (fern)
- *Frankia* (actinomycetes) - Alder tree

Rhizobium-legume symbiosis

- **Attachment** of rhizobia to surface of root hair.
- **Penetration** of rhizobia into deformed root hair.
- Formation of an **infection thread** of bacteria from root hair to root cortical cells.
- Formation of a **nodule** containing bacteroids.





Rhizobium-legume symbiosis

- Interaction is very specific.

Rhizobium species
Bradyrhizobium japonicum
Rhizobium leguminosarum
Rhizobium meliloti
Rhizobium phaseoli
Rhizobium lupini
Rhizobium trifolii

Legume
 soybeans
 pea, vetch, sweetpea
 alfalfa, sweet clover
 beans
 lupines
 clover

Biologically-fixed nitrogen

<u>Legume</u>	<u>kg N ha⁻¹y⁻¹</u>
Alfalfa	125-335
Red clover	85-190
Pea	80-150
Soybean	65-115
Cowpea	65-130
Vetch	90-155

Decomposition

- Decomposition
 - plant, animal and microbial residues
 - proteins into the soil.
 - Proteins undergo *proteolysis*
 - amino acids.
 - Most nutrients go through living microbial biomass before being accessible to other organisms
 - heterotrophs
 - aerobic conditions decomposition is *faster* and *more complete* than under anaerobic conditions.

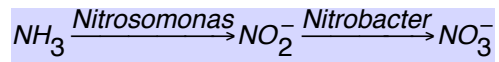
Ammonification

- The degradation of amino acids
 - release of ammonia.
 - another term is *deamination*.

Immobilization or Uptake

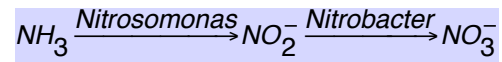
- Plants and microbes use nitrogen
 - Ammonium NH₄
 - Nitrate (most usable to plants) NO₃⁻

Nitrification (ammonia oxidation)



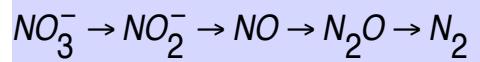
- A two-step process
 - ammonia is converted into nitrite (NO_2^-) toxic to plants
 - then to nitrate.
- Aerobic process

Nitrification



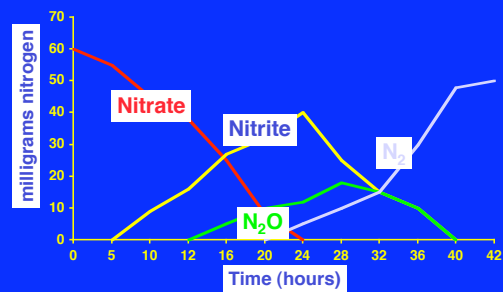
- Oxidation of nitrite is inhibited by ammonium.
- Chemolithotrophic microorganisms or some heterotrophs.

Denitrification (nitrate reduction)



- Mineral nitrogen (NO_3^-) is reduced to dinitrogen gas (N_2)
- Anaerobic process (oxygen poor soils)
- Heterotrophic organisms using nitrate as a terminal electron acceptor: anaerobic respiration (breath Nitrate)

Denitrification products in Melville loam

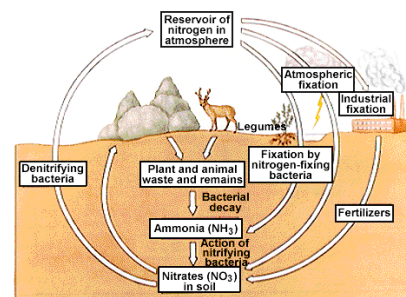


Graph from Alexander, Soil Microbiology

Denitrifying microorganisms

- Organisms are aerobic, but use nitrate as an alternate terminal electron acceptor in anaerobic respiration.
- *Pseudomonas*, *Thiobacillus*, and *Micrococcus* species.
- Removes nitrates and interferes with plant growth

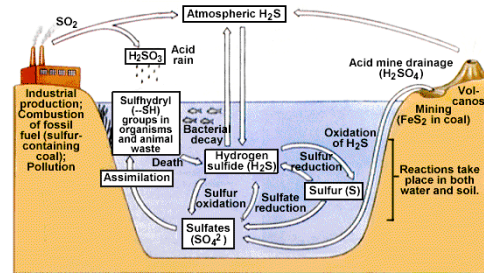
Nitrogen cycle summary



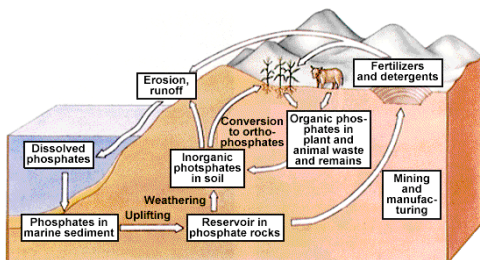
The Sulfur Cycle

- Mainly aquatic
- **Sulfate-reducing** bacteria, *Desulfovibrio*, *Desulfomonas*, *Desulfotomaculum*
 - Reduce SO_4^{2-} to H_2S
 - Anaerobic process - SO_4^{2-} is the final electron acceptor
- **Sulfur-reducing** bacteria, *Desulfonema*
 - reduce sulfate to H_2S
 - Anaerobic process, sulfur is the final electron acceptor
- **Sulfur-oxidizing** bacteria, *Thiobacillus ferrooxidans*
 - Elemental S is oxidized to sulfate
 - Plants use sulfate
 - amino acid biosynthesis.
- Some phototrophic bacteria can oxidize H_2S to elemental sulfur

Sulfur cycle



Phosphorus cycle



Atmosphere Microbiology

Microorganisms in the atmosphere

- Air is very inhospitable for microorganisms
 - dust particles, water, sputum, or aerosol droplets.
 - Some droplets (droplet nuclei) may exist for hours or days
 - Spores - Mold and bacteria, *Bacillus subtilis*

Factors affecting the fate of microorganisms in the atmosphere

- Humidity
- Temperature
- Amount of sunlight
- Size of particles harboring the microorganisms.
- Formation of cysts and spores

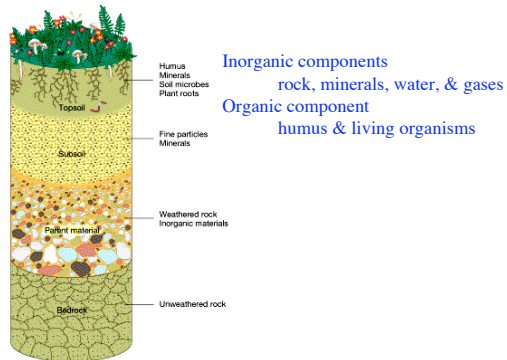
Where do microorganisms in the atmosphere come from?

- Soil (winds pick up dust particles)
- Oceans (winds create sprays)
- Industry, agriculture, municipal facilities can create aerosols
 - water treatment plants
 - irrigation

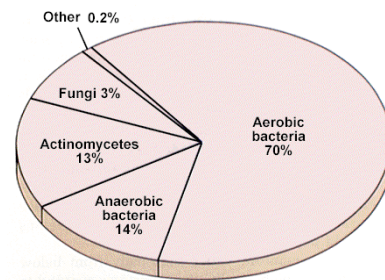
Controlling air-borne microbes

- Triethylene glycol, resorcinol, and lactic acid
- UV radiation
- Filtration (laminar airflow)
 - HEPA filters

Soil horizons



Microorganisms in soil



Factors affecting soil microbes

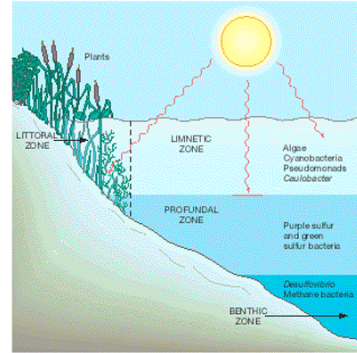
- Moisture
- Oxygen
- pH
 - Optimum 6-8
- Temperature

Soil pathogens

- *Clostridium tetani*
 - tetanus
- *Clostridium botulinum*
 - botulism
- *Clostridium perfringens*
 - Gas gangrene
- *Bacillus anthracis*
 - anthrax

Water and Wastewater Microbiology

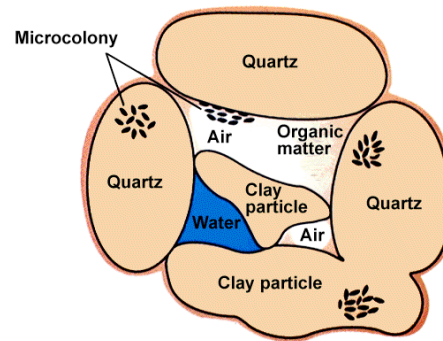
Zonation in a lake



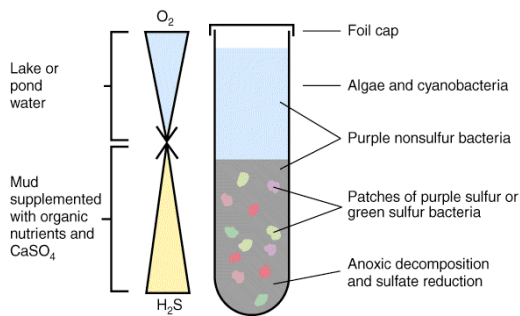
Factors affecting microorganisms in aquatic environments

- Temperature
- Hydrostatic Pressure
- Light
- Salinity
- Turbidity
- pH
 - Fresh 2-9
 - Ocean 6.5-8.3
- Nutrients

Oxygen and water relationship



Oxygen vs hydrogen sulfide



Freshwater environments

- **Limnology**--the study of freshwater environments.
- Freshwater environments include:
 - lakes
 - ponds
 - streams
 - rivers
 - estuaries

Marine environments

- phytoplankton, cyanobacteria, algae, diatoms, dinoflagellates
- Gram negative bacteria
 - *Pseudomonas, Vibrio, Achromobacter, Flavobacterium*
- Marine fungi and protozoa
- The ocean environment is oligotrophic.

“Oligotrophic” means that there are few nutrients available for organisms to use for growth.

Drinking Water

- Rivers, streams, and lakes
- Groundwater
- All of these water sources can become chemically and biologically polluted.

Water purification

- Alum (aluminum potassium sulfate)
 - Flocculation
- Filtration
 - Beds of sand or charcoal
- Chlorination
 - Kills bacteria, some viruses

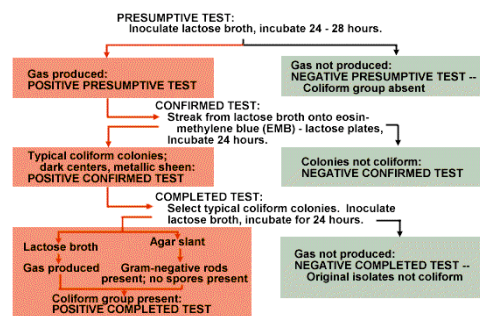
Testing water for potential pathogens

- ✓ Use “indicator microorganisms”
- ✓ Present in polluted water
- ✓ Present when pathogens are present
- ✓ Quantity correlates with number of pathogens
- ✓ Survives better than pathogens
- ✓ Has uniform and stable properties
- ✓ Generally harmless to humans
- ✓ Present in greater numbers than pathogen
- ✓ Easily detected in the lab

Human pathogen transmitted in water

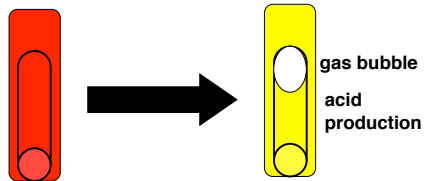
ORGANISMS	DISEASES CAUSED
<i>Salmonella typhi</i>	Typhoid fever
Other <i>Salmonella</i> species	Salmonellosis (gastroenteritis)
<i>Shigella</i> species	Shigellosis (bacillary dysentery)
<i>Vibrio cholerae</i>	Asiatic cholera
<i>Vibrio parahaemolyticus</i>	Gastroenteritis
<i>Escherichia coli</i>	Gastroenteritis
<i>Yersinia enterocolitica</i>	Gastroenteritis
<i>Campylobacter fetus</i>	Gastroenteritis
Hepatitis A virus	Hepatitis
Poliovirus	Polio
<i>Giardia intestinalis</i>	Giardiasis
<i>Balantidium coli</i>	Balantidiasis
<i>Entamoeba hist</i>	Amoebic dysentery

Multiple tube fermentation test



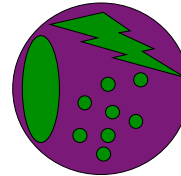
Multiple-tube test, Part 1

- Presumptive test
- + gas production in lactose broth.



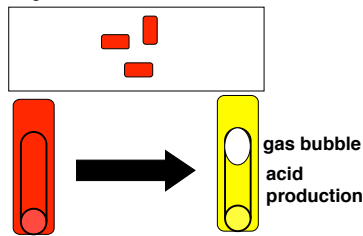
Multiple-tube test, Part 2

- Confirmed test
- metallic green colonies on EMB agar.



Multiple-tube test, Part 3

- Completed test
- growth of Gram negative, non-spore forming rods on agar slant
- Acid & Gas production



Testing water purity

- Multiple-tube fermentation method
- Membrane filter method
- 1 cfu/100 ml of water
- ONPG and MUG test
- Enzyme that convert reduce dyes

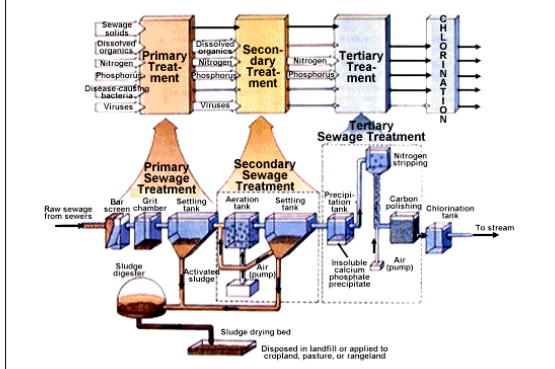
Municipal Wastewater

- Where does it originate?
- domestic sources (human wastes, and wash water)
 - industrial sources
 - ground, surface, and atmospheric water

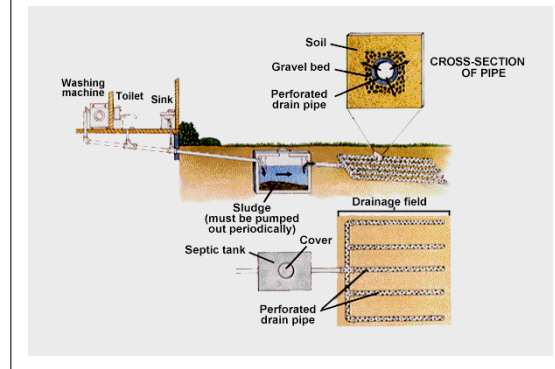
Municipal Wastewater

- Three main steps:
1. sedimentation
 2. filtration
 3. chlorination

Sewage treatment



Septic tank



Pesticide and Pollutant Degradation

What are pesticides?

– Natural and man-made substances used to control pests.

- They include:
 - herbicides--control of weeds
 - insecticides--control of insects
 - fungicides--control of fungi
 - nematicides--control of nematodes

The Fate of Pesticides in the Environment

Bioremediation

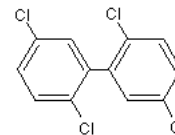
Depends on:

- Complexity of the molecule
- Presence of halogens, such as chlorine atoms in the molecule
- Presence and number of microorganisms capable of degrading the pesticide
- Presence of other nutrients
- Concentration of the pesticide

Pollutants we might be concerned about...

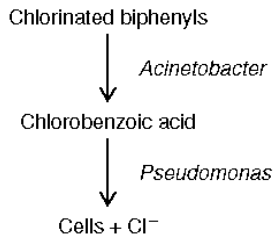
- polychlorinated biphenyls (PCBs)
- pesticide residues in foods and drinking water.
- ozone, nitrogen and sulfur oxides.
- heavy metals
- *Phanerochaete chrysosporium*
 - White rot fungus

An example of a polychlorinated biphenyl



2,2',5,5'-tetrachlorobiphenyl

Degradation of PCBs by microorganisms



Some pesticides

