MICROBIAL ECOLOGY

PRINCIPLES OF MICROBIAL ECOLOGY, DEFINITIONS

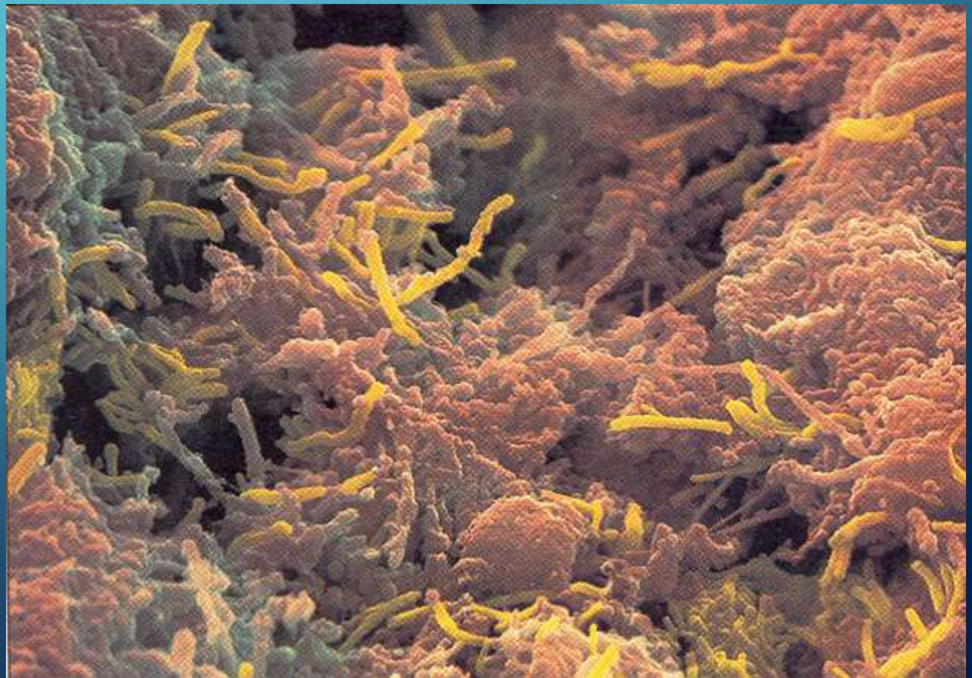
- Ecology
  - The study of relationships among organisms and their environment.
- Ecosystem
  - Includes all of the biotic (living) components and the abiotic (physical and chemical) components of an environment.
- Biosphere
  - That region of the earth that is inhibited by living organisms.

PRINCIPLES OF MICROBIAL ECOLOGY

- Definitions
  - Biodiversity
    - Evenness of distribution of the # of species present
  - Biomass
    - Weight of all organisms present
  - Ecological Community
    - Comprised of a variety of different species in a given environment; more stable than an environment with fewer organisms.

PRINCIPLES OF MICROBIAL ECOLOGY

- Ecological Niche
  - The role that an organism plays in its particular ecosystem as well as the physical space it occupies.
- Microenvironment
  - Environment immediately surrounding an individual cell
  - Biofilm



PRINCIPLES OF MICROBIAL ECOLOGY

- Indigenous
  - Native organisms
- Nonindigenous
  - Temporary inhabitants

PRINCIPLES OF MICROBIAL ECOLOGY

- Nutrient Acquisition
  - Primary Producers
    - Autotrophs
      - Convert CO_2 → organic material
      - Photoautotrophs – plants, algae, cyanobacteria
      - Anoxygenic phototrophs
        - Use sunlight for energy
      - Chemolithoautotrophs
        - Oxidize inorganic compounds for energy
    - Food source for consumers and decomposers

PRINCIPLES OF MICROBIAL ECOLOGY

- Consumers
  - Heterotrophs
    - Utilize organic material
    - Food chain
      - Herbivores – primary consumers
      - Carnivores – secondary consumers
      - Carnivores – tertiary consumers
    - Food web
      - Interacting food chains

PRINCIPLES OF MICROBIAL ECOLOGY

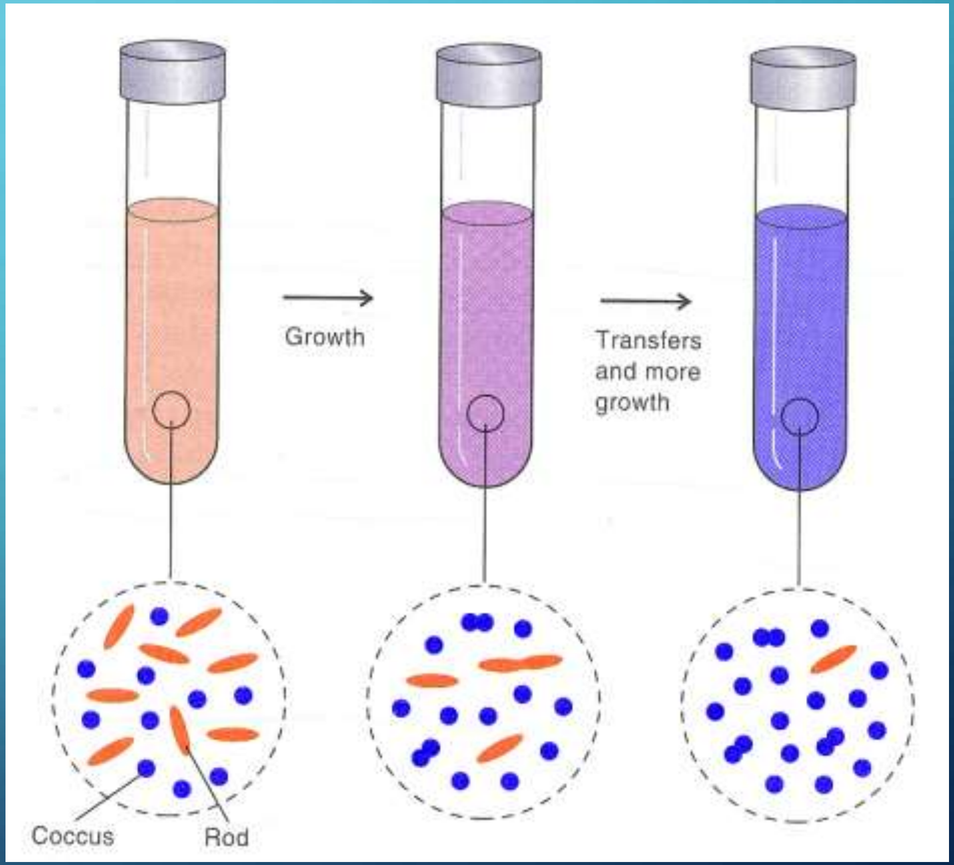
- Decomposers
  - Heterotrophs
    - Primarily bacteria and fungi
    - Digest remains or primary producers and consumers
      - Detritus - Fresh or partially decomposed organic matter
    - Specialize in digesting complex materials
  - Mineralization
    - Complete breakdown of organic matter into inorganic molecules such as ammonia, sulfates, phosphates & CO_2

PRINCIPLES OF MICROBIAL ECOLOGY

- Low Nutrient Environments
  - Common in nature
    - Dilute aqueous solutions
      - Lakes, rivers, streams
      - Distilled water reservoirs
      - Respiratory equipment

PRINCIPLES OF MICROBIAL ECOLOGY

- Microbial Competition
  - Ability of microbes to compete successfully for a habitat generally related to
    - Rate at which organism multiples
    - Ability to withstand adverse environmental conditions

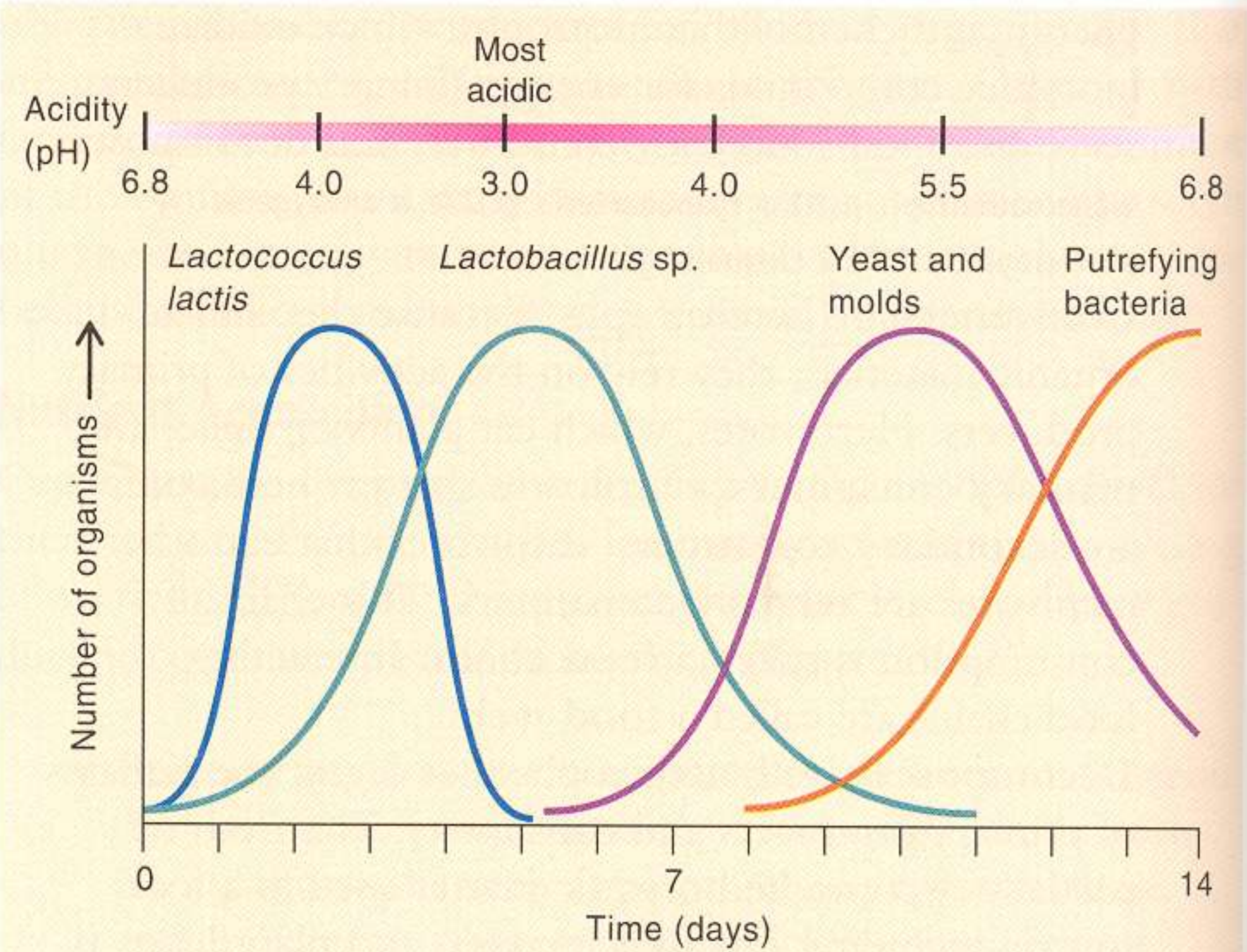


PRINCIPLES OF MICROBIAL ECOLOGY

- Antagonism
  - Promotes biodiversity through competition
    - Bactericins
      - Proteins produced by some soil microbes that kill closely related strains of bacteria

PRINCIPLES OF MICROBIAL ECOLOGY

- Microbes and Environmental Change
  - Examples
    - Enzyme induction
      - Inactivates mercury
      - Only formed when mercury is present
    - Antibiotic resistant bacteria
    - Growth and metabolism of organism can change environment.


Most acidic
Acidity (pH)
6.8
4.0
3.0
4.0
5.5
6.8
Lactococcus lactis
Lactobacillus sp.
Yeast and molds
Putrefying bacteria
Number of organisms
0
7
14
Time (days)

PRINCIPLES OF MICROBIAL ECOLOGY

- Microbial Communities
  - Biofilms
    - Microbial Mat
      - A thick, dense, highly organized structure composed of distinctive layers

PRINCIPLES OF MICROBIAL ECOLOGY

- Microbial Ecology Studies
  - Traditional
    - Cultures
    - Microscopy
  - Molecular Techniques
    - Microscopy
      - Dyes that made are fluorescent by metabolic activities
      - Fluorescence in situ hybridization (FISH)
        - Nucleic acid probes to observe only cells with specific nucleotide sequences

PRINCIPLES OF MICROBIAL ECOLOGY

- Confocal scanning laser microscopes
  - To observe sectional views of a 3-dimensional specimen (biofilm)
- Polymerase chain reaction (PCR)
  - To detect only certain organisms
  - Denaturing gradient gel electrophoresis (DGGE)
  - PCR & DGGE studies conform that standard cultures techniques can be poor indicators of natural microbial population composition
- Genomics
  - Sequence information can apply to more than one group of microbes

AQUATIC HABITATS

- Water
  - Extremely efficient solvent
  - Can absorb various wavelengths of light
    - Important aspect relating to photosynthesis

AQUATIC HABITATS

- Marine Environment
  - Oceans
    - Cover more than 70% of earth's surface
    - Most abundant aquatic habitat
    - Represent 95% of global water
- Fresh Water Environment
  - Lakes, Rivers
    - Fraction of global water source
    - Important source of fresh water

AQUATIC HABITATS

- Oceans and lakes
  - Characteristic zones influence distribution of microbial populations
    - Upper layers
      - Sufficient light penetration - photosynthetic microorganisms
  - Oligotrophic waters
    - Nutrient poor
    - Growth of photosynthetic organisms & autotrophs limited by lack of phosphate, nitrate and iron

AQUATIC HABITATS

- Eutrophic waters
  - Nutrient rich Photosynthetic activities in upper layers produce organic compounds
    - Organic compounds permit growth of heterotrophs in lower layers
    - Heterotrophs consume dissolved O_2 during metabolism
      - O_2 consumption can outpace slow rate of atmospheric O_2 diffusion into water
      - Can create a hypoxic environment

AQUATIC HABITATS

- Potable Water
  - Safe for drinking
- Rainwater
  - Distillate
    - contaminated by air pollutants
- Ground Water
  - aquifers, underground lakes & rivers
- Surface Waters
  - Creeks, rivers, ponds, lakes

AQUATIC HABITATS

- Factors Affecting Presence of Organisms
  - Nutrients
    - Oceans typically oligotrophic
      - Inshore areas not as stable as deep ocean
        - Dramatically affected by run-off
        - Dead zone in Gulf of Mexico every spring

AQUATIC HABITATS

- Oxygen (limiting factor)
  - low solubility in water, quantities limited
  - well mixed cold water ~8-9mg/l
  - warm water ~ 5mg/l
  - Deep marine water is O_2 saturated due to mixing associated with tides, currents and wind
- Temperature - Worldwide 0°C to ~100°C

AQUATIC HABITATS

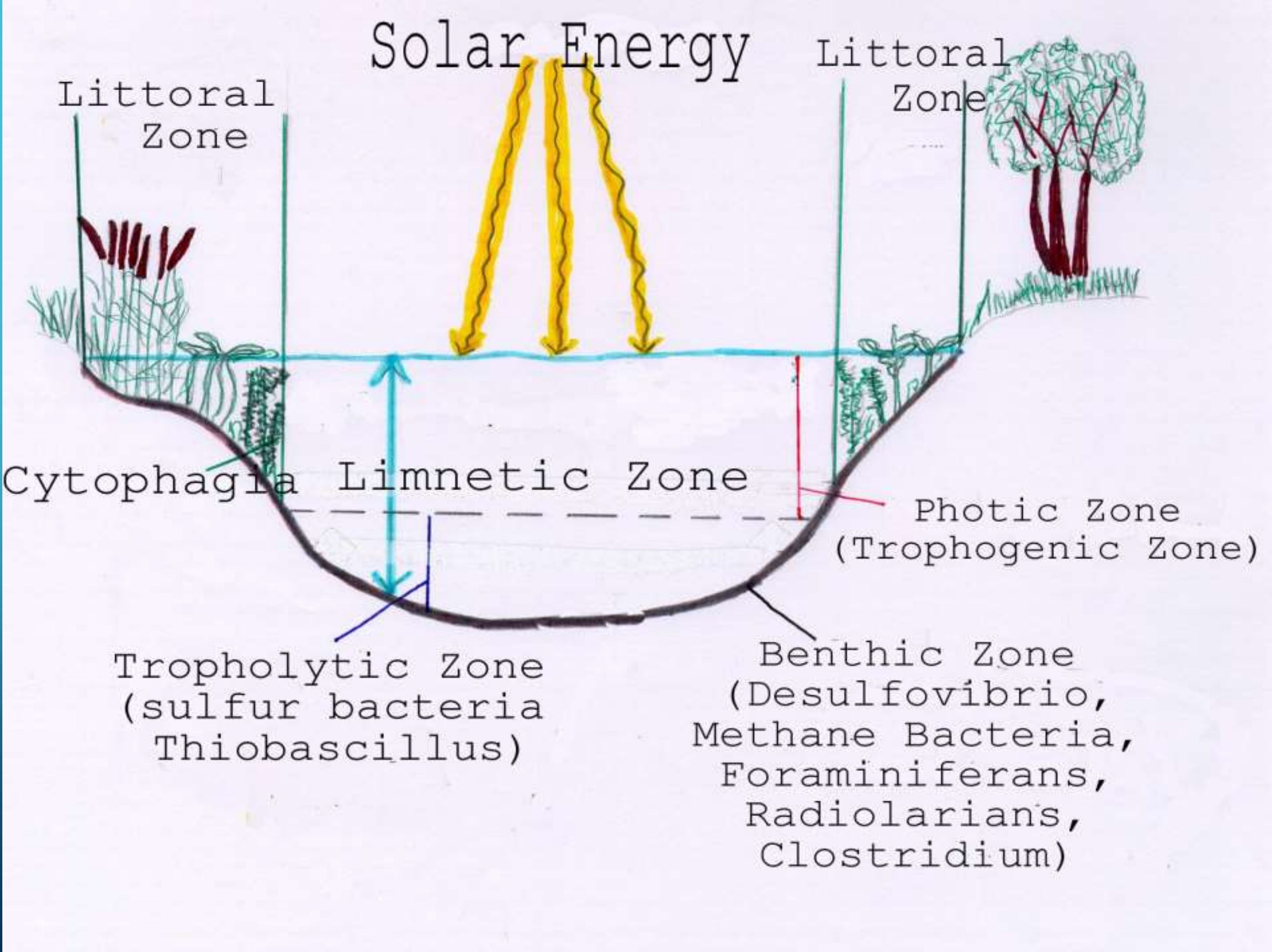
- Freshwater environments
  - Oligotrophic lakes may have anaerobic layers due to thermal stratification
    - Epilimmion
      - Warm upper layer (25°-22°C)
      - Generally oxygen rich due to photosynthetic organisms
      - Generally aerobic
    - Hypolimmion
      - Colder deeper layers (~5°-4°C)
      - May be anaerobic due consumption of O_2 by heterotrophs
      - Water most dense at 4°C (39°F)
    - Thermocline (~20°-10°C)
      - Zone (layer) of rapid temperature change
    - As weather cools, water mixes oxygenating deep water

AQUATIC HABITATS

- Freshwater Environments
  - Rivers and Streams
    - Usually shallow and turbulent
      - Facilitates O_2 circulation
      - Generally aerobic
      - Generally good sunlight penetration for photosynthesis
      - Sheathed bacteria adhere to stable structures to allow utilization of nutrients flowing pass
        - Examples: *Sphaerotilus* & *Leptothrix*

AQUATIC HABITATS

- Factors Affecting Presence of Organisms
  - Sunlight Penetration (Photic Zone)
    - depth of sunlight penetration
    - algae & cyanobacteria
    - photosynthesis provides nutrients & oxygen for other organisms
  - pH Range 2 - 9
    - fish hypersensitive to bacterial parasites at pH 5.5, usually die if pH drops below 4.5



Solar Energy
Littoral Zone
Littoral Zone
Cytophagia
Limnetic Zone
Photic Zone (Trophogenic Zone)
Tropholytic Zone (sulfur bacteria Thiobascillus)
Benthic Zone (Desulfovibrio, Methane Bacteria, Foraminiferans, Radiolarians, Clostridium)

AQUATIC HABITATS

- Specialized Aquatic Environments
  - Salt lakes – no outlets
    - Water evaporates, concentrates salt
    - Halophilic organisms
  - Iron springs
    - Contain large quantities of ferrous ions
  - Sulfur Springs
    - Support both photosynthetic and non-photosynthetic sulfur bacteria

AQUATIC HABITATS

- Freshwater
  - Composition of the water reflects its source
    - Stagnant ponds to free flowing rivers and lakes
    - Ground water
      - Normally relatively free of nutrients and toxins
    - Surface water
      - Affected by surface runoff of materials
      - Organics, fertilizers, herbicides, pesticides, etc.
  - Inshore Marine
    - Affected by freshwater runoff and pollutants

AQUATIC HABITATS

- Marine Environment
  - Factors affecting presence of miroorganisms
    - Same Factors as Fresh Water plus
    - Barometric pressure (hydrostatic pressure)
      - 1 atm / 33 feet of seawater
      - ocean 35,750 feet (11,000 meters) deep, hydrostatic pressure - 1,083 atm
      - Organisms are **barophilic (barophiles)**
    - Salinity
      - Marine averages 3.5% (fresh averages ~0.5%)
      - Organisms are **halophilic (halophiles) or halotolerant**

AQUATIC HABITATS

- Microbial Flora
  - Dictated by Available Nutrients
    - Bulk of Microbial Mass
      - algae, cyanobacteria & protozoa
    - Aerobic Chemoheterotrophic Bacteria
      - degrade organic materials
      - *Cytophaga*, *Caulobacter*
    - Chemoautotrophic Bacteria
      - obtain energy from aerobic oxidation of reduced inorganic compounds

AQUATIC HABITATS

- Determining Microbial Flora
  - Epifluorescence Counting
    - Stain with acridine orange (stains DNA)
    - view slide under UV light
      - tedious and can be inaccurate, counts DNA from living and dead organisms
  - Luciferin-luciferase Enzyme System
    - Gives estimate of the number of viable organisms in a given volume of water
    - Based on carbon:ATP ratio (~250 for most microbes)

TERRESTRIAL HABITATS

- Characteristics of Soil
  - Composed of
    - Pulverized rocks, decaying organic material, air & water
  - Life
    - Bacteria, fungi, algae, protozoa, worms, insects, and plants roots
    - May contain
      - More than 4,000 different species per gram of soil
      - More than 2 tons of bacteria and fungi per acre
  - Can be a rapidly and dramatically changing environment

TERRESTRIAL HABITATS

- Soil Layers (Horizons)
  - Topsoil (A Horizon)
    - Dark, nutrient-rich
    - Supports plant growth
    - Depth – few inches to several feet
  - Subsoil (B Horizon)
    - Accumulation of clays, salts & various nutrients
  - C Horizon
    - Partially weathered bedrock
  - R Horizon
    - Unweathered bedrock

TERRESTRIAL HABITATS

- Microorganisms in Soil
  - Composition affected by environmental conditions
    - Moisture
      - Finely textured soils (clay) tend to be waterlogged and anaerobic
      - Sandy soils (dry quickly) tend to be aerobic
    - Acidity
      - Suppresses bacterial growth
      - Fungi thrive with less competition for nutrients

TERRESTRIAL HABITATS

- Temperature
  - Mesophiles comprise the bulk of the soil bacteria, they grow best between 20°C and 50°C
  - Thermophiles occur in compost piles where they generate heat
- Available Nutrients
  - The size of the microbial population in soil is limited by on the amount of organic matter available

TERRESTRIAL HABITATS

- Soil Organisms
  - Prokaryotes
    - Most numerous soil inhabitants
    - Most common genera
      - *Nocardia, Arthrobacter, Streptomyces*
      - *Streptomyces*
        - Produce conidia (dessication resistant spore)
        - Produce geosmins (give soil musty odor)
        - Produce many medically useful antibiotics
    - Gram (+) bacteria more abundant than Gram (-) bacteria

TERRESTRIAL HABITATS

- Not all Soil Organisms are Beneficial
  - Human Bacterial Pathogens
    - *Clostridium* and *Norcardia*
  - Human Fungal Pathogens
    - *Coccidioides*, *Histoplasma*, and *Blastomyces*

TERRESTRIAL HABITATS

- Fungi
  - Make up bulk of soil biomass
  - Most are aerobic
    - Usually found in top 10 cm of soil
    - Crucial in decomposing plant matter
  - Some are free-living
  - Some occur in symbiotic relationship with plant roots
    - *Mycorrhizae*
- Algae
  - Live mostly on or near surface

TERRESTRIAL HABITATS

- Algae
  - Dependent on sunlight and photosynthesis to provide energy needs.
  - Sensitive to environmental conditions of drought and low temperature
  - Major nutrient source for
    - Earthworms and nematodes
- Protozoa
  - Aerobic - generally found near the surface
  - Found in moist soils at a density of ~10^4 to 10^5 organisms per gram of soil
  - Predators of soil bacteria and algae

TERRESTRIAL HABITATS

- Rhizosphere
  - Zone of soil that adheres to plant roots
  - Roots cells extract organic molecules
    - Sugars, amino acids and vitamins
  - Fosters growth of microorganisms
    - Gram (-) more prevalent than surrounding soil
    - Certain grasses – enriched with *Azospirillum* species

BIOCHEMICAL CYCLING & ENERGY FLOW

- Biochemical Cycles
  - Cyclical paths elements take as they flow through living (biotic) and non-living (abiotic) components of ecosystem
  - Fixed and limited amount of elements available
    - Carbon and nitrogen particularly important
      - Stable gaseous forms CO_2 and N gas enter atmosphere
      - Global impacts
  - Elements continually cycle in ecosystem
    - Energy does not, must be continually added to fuel life

BIOCHEMICAL CYCLING

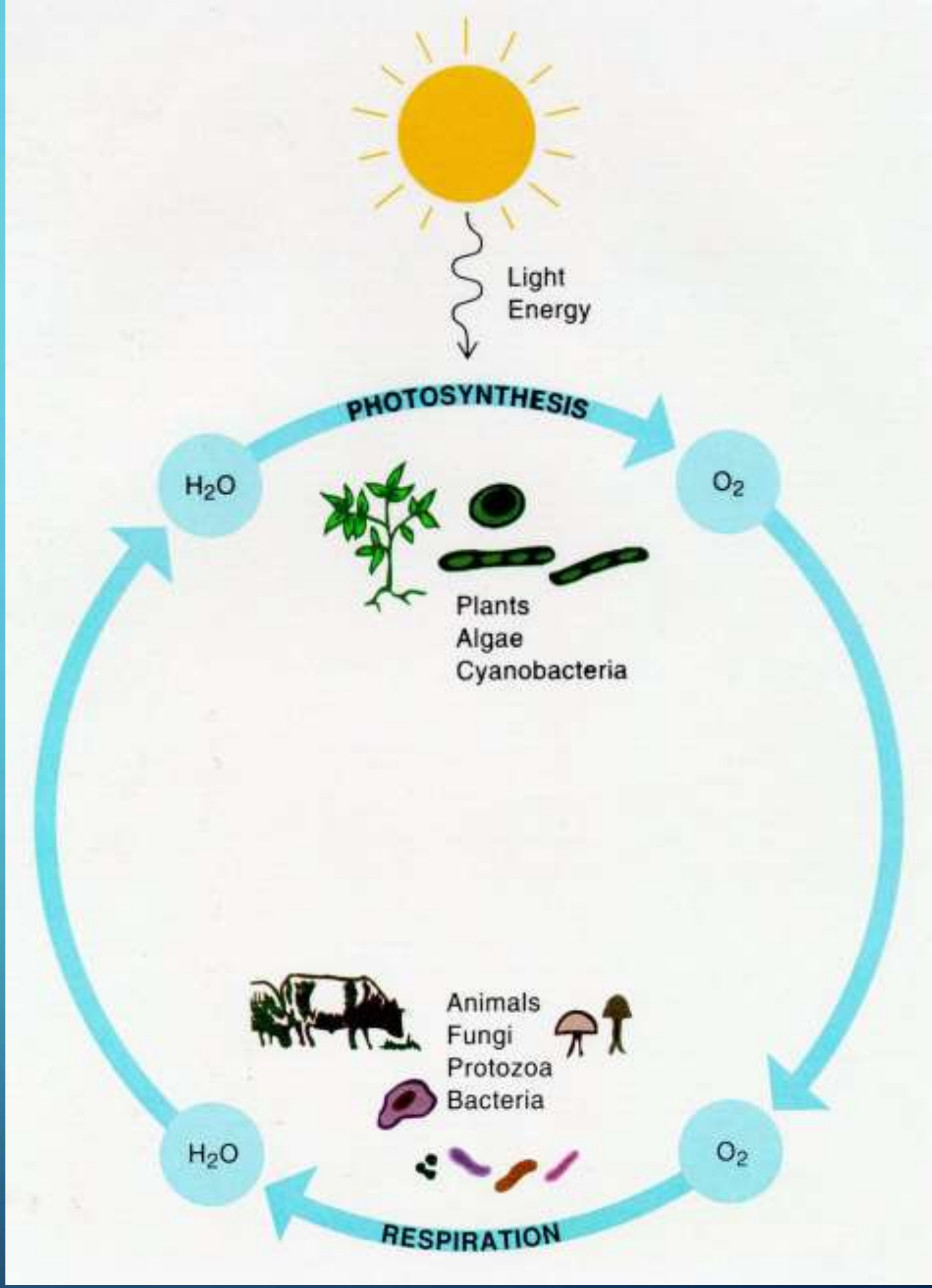
- Elements - three general purposes
  - Biomass production
    - Incorporated into cell material
      - All organisms require nitrogen to produce amino acids
  - Energy source
    - Reduced form of element is used to generate energy – ATP
    - Energy yielding reactions oxidize the energy source
      - Chemoorganotrophs use reduced carbon compounds – sugar, lipids and amino acids
      - Chemolithotrophs use reduced inorganic molecules – H_2S, ammonia (NH_3) and hydrogen gas (H_4)

BIOCHEMICAL CYCLING

- Terminal electron acceptor
  - Electrons from energy source transferred to an oxidized form of element during respiration
    - Aerobic conditions
      - O_2 is terminal electron acceptor
    - Anaerobic conditions some prokaryotes use
      - Nitrate (NO_3), nitrite (NO_2), sulfate (SO_4)and CO_2
- The following pages will review cycling processes for oxygen, carbon, nitrogen, phosphorus and sulfur

OXYGEN CYCLE

- During photosynthesis cyanobacteria, algae and green plants produce oxygen from water. The oxygen is utilized via respiration.
  - The level of oxygen in the atmosphere is maintained by chemical reactions in the upper atmosphere, aerobic respiration and photosynthesis



CARBON CYCLE

- Carbon
  - Carbon enters producers during photosynthesis or chemosynthesis
  - In turn enters consumers via consumption of the producers.
  - Carbon returned to the atmosphere in the form of CO_2 by respiration and the actions of decomposers consuming dead or decaying waste.
    - Oxygen has profound influence on cycle
      - Allows degradation of certain compounds
      - Helps determine the types of carbon containing gases produced
      - Aerobic decomposition
      - Great deal of OC2 formed through aerobic respiration
      - $(CH_2O)n + (O_2)n \longrightarrow CO_2 + H_2O$

CARBON CYCLE

- Low oxygen (wet soils, marshes, swamps, etc.)
  - Degradation is incomplete
  - Generate CO_2 and other gases
  - Some CO_2 used by methanogens (ex: *Archaea*) as terminal electron acceptor generating methane (CH_4)
  - $4H_2 + CO_2 \longrightarrow CH_4 + H_2O$
  - Methane entering atmosphere is oxidized by UV light and chemical ions to CO and CO_2