Microbial habitats and nutrient cycles

Lecture 17

Mar 3, 2005

Microbial ecosystems

- Microorganisms play crucial roles in maintaining the biosphere
- Many microbial reactions are absolutely required by other organisms. Example – inorganic nutrient cycles used by plants
- Microorganisms are found EVERYWHERE

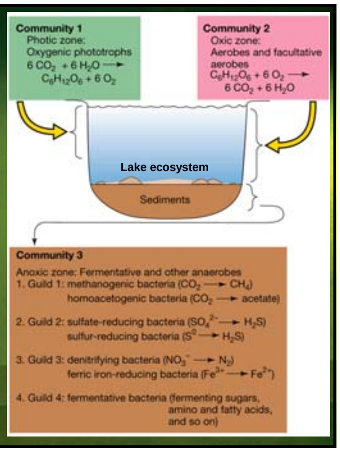
Hierarchy in microbial ecosystems

- Individual cells grow to form *populations*
- Metabolically related populations are *guilds*
- Groups of guild interact to form *communities*
- Communities interact with macroorganisms and the environment to constitute the entire ecosystem

• Microorganisms are involved in the recycling of important elements

Biogeochemical Cycles:

Carbon
Sulfur
Nitrogen
Iron



Microbial growth on surfaces

• Surfaces are importanr microbial habitats because nutrients can adsorb to them – nutrient content on surfaces can be much higher than in the bulk solution

• Microbial cell number is generally much higher on surfaces

• Surface may itself be a nutrient – dead plant material

• Microscope slides are a convenient surface for sampling adherent cells in a microbial habitat

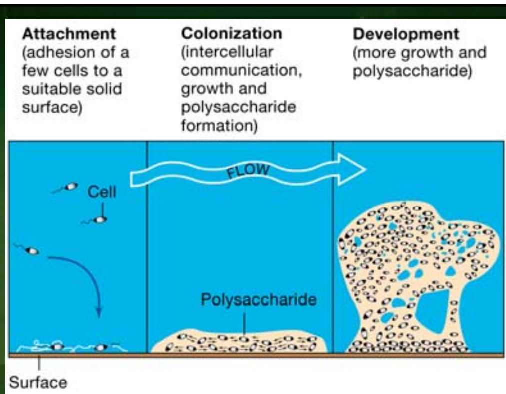
Biofilms - structure

• Microorganisms growing on surfaces are encased in biofilms

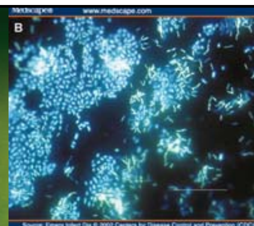
• Biofilms are microcolonies of bacterial cells attached to a surface and encased in adesive polysaccharides secreted by the cells

• Biofilms trap nutrients and prevent detachment in moving ecosystems

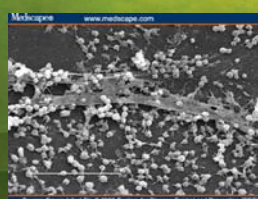
• Attachment of a cell to a surface acts as a signal to commense expression of biofilm synthetic genes. *Pseudomonas aeruginosa* secretes homoserine lactones



• Polymicrobic biofilm growing on stainless steel



Staphylococcal biofilm growing on an implanted medical device



Biofilms – consequence and control

• Formation of biofilms has important medical and economic implications:

• Bacterial pathogens are protected by biofilms impervious to antibiotics or immune defenses

• Biofilms are involved in medical conditions including cystic fibrosis, dental caries, tuberculosis, kidney stones

• Medical implants such as urinary catheters or hip replacements are prone to biofilm development

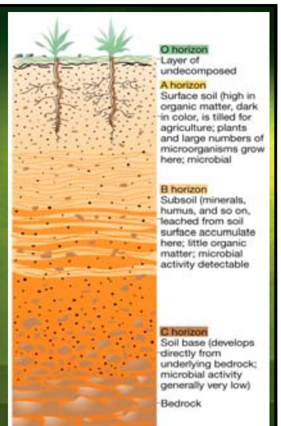
- In industry, biofilms slow the flow of oil, water or other liquids through pipelines
- Biofilms also initiate the degradation of submerged components of oilrigs and boats
- New antibiotics are being developed to either penetrate biofilms, dissolve them, or interfere with intercellular communication
- Chemicals called furanones have antibiofilm properties

Soil habitats

- Soil, particularly the region immediately surrounding plants, is the major terrestrial microbial habitat
- Soil development is a complex geological, climactic and biological process
- Mineral soils predominate in most areas – derived from initial weathering of rock and other inorganic material
- Organic soils – formed from sedimentation processes in marshes and bogs

Profile of a mature soil

- Algae, lichens and mosses photosynthesize on surface of rocks
- Organic material produced is a substrate for other microbes
- Freezing and thawing breaks up rocks enough for hardy plants
- Soil around plant roots constitutes the *rhizosphere*
- Plants die, enriching soil

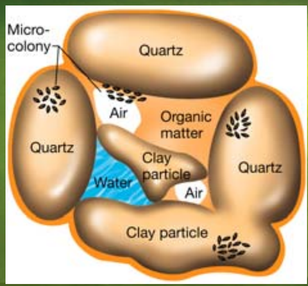


• Small soil aggregates contain several microenvironments

• Water may be present as free liquid or adsorbed onto surfaces

• Soil particles have oxic and anoxic zones

• Nutrient status of soil limits microbial growth



Microorganisms on soil particles
Are easily visualized by microscopy

Freshwater habitats

• Typical environments are lakes, ponds, rivers, springs

• Microorganisms are the predominant phototrophs:

Phytoplankton – floating or suspended algae
Benthic algae – attached to the bottom or sides

Microbiological activity of an ecosystem depends on the rate of primary production via phototrophs whose activities then support other modes of metabolism

• Significant photosynthetic production of oxygen can only occur near the water surface where light is abundant

• Unconsumed organic material sinks where it is consumed by facultative organisms

• Once oxygen is consumed, the depths become anoxic and enriched in anaerobes and fermentors

Biochemical oxygen demand

• BOD is the microbial oxygen-consuming property of a body of water

• Measured by aerating a sample of water, sealing it in a jar under standard conditions (5 days 20C) then measuring residual oxygen

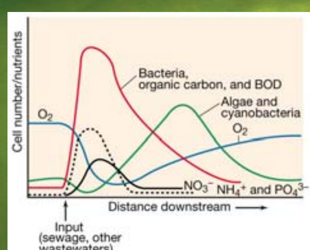
• Gives a measure of the amount of organic material available for oxidation in a sample

• Oxygen and organic carbon are inversely related – high BOD means low oxygen (anoxic)

• Effect of sewage input into aquatic ecosystems:

• Initial depletion of oxygen by bacterial blooms

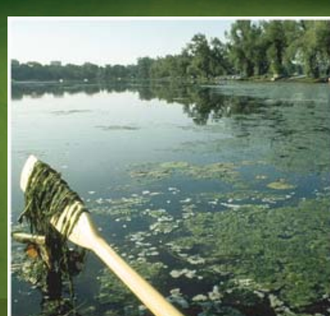
• If ammonia is present, nitrification will proceed



• Algae, cyanobacteria and weeds develop as a result of inorganic nutrients

• Water rapidly becomes anoxic due to agricultural runoff

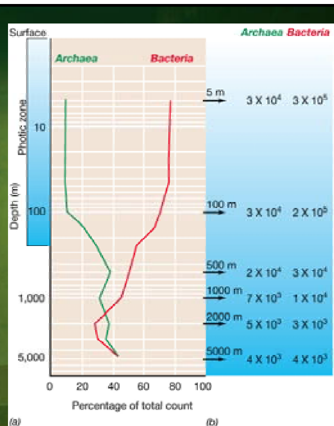
• High or low BOD?



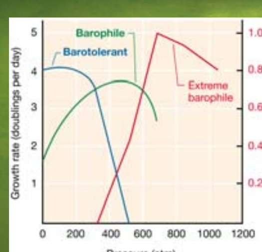
Marine habitats

- Nutrient levels are limiting
- Primary production in open oceans is due to oxygenic prokaryotes called *prochlorophytes*
- Coastal areas support more dense microbial populations
- Numbers of prokaryotes/ml seawater changes with water depth

- Deep sea – no light, low temperature, high pressure, low nutrient levels
- Proportion of *Archae* increases with ocean depth



- At increasing depth = pressure, prokaryotes become increasingly barophilic and psychrophilic
- Molecular adaptations to high pressure – more unsaturated fatty acids in membrane, expression of outer membrane porin proteins such as OmpH



Hydrothermal vents

- Underwater hot springs:
- Warm vents – emit hydrothermal fluid at 6-23C
- Hot vents (black smokers) – emit mineral rich hydrothermal fluid at 270-380C that precipitates in the colder ambient water
- High concentrations of reduced inorganic materials such as H_2S, Mn, H_2 and CO
- Microorganisms at hydrothermal vents are primarily chemolithotrophs that also use dissolved carbon dioxide as a carbon source

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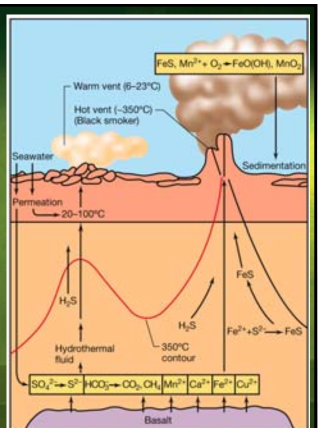
- Vents are found typically at about 2000 m depth
- Sulfur-, iron-, hydrogen-oxidizing bacteria provide nourishment for a diverse array of unusual animal life



Carbon and Oxygen cycles

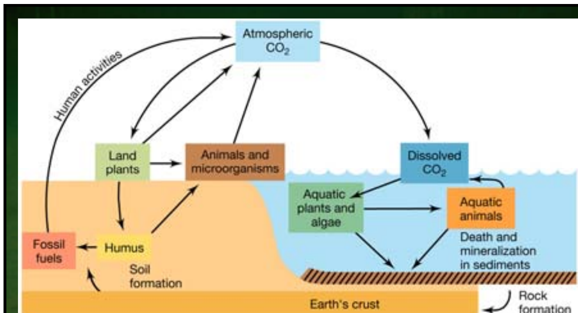
• Global cycling of C and O depends on activities of macroorganisms and microorganisms

• These cycles are inter-related:

$CO_2 + H_2O > CH_2O + O_2$ photosynthesis

$CH_2O + O_2 > CO_2 + H_2O$ respiration

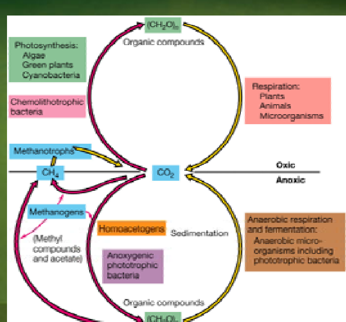
• Carbon reservoirs include rocks and other sediments, oceans, land plants, and *humus* – partially decomposed organic matter



• Human activities have radically altered carbon inputs into the atmosphere – 12% increase in CO_2 levels in the last 40 years

• Fixed carbon is eventually degraded to methane by methanogens or to carbon dioxide by respiration.

•Methanotrophs return carbon from methane to carbon dioxide



Sulfur cycle

- More complex than the carbon cycle because of the number of S oxidation states. Also, some transformations occur by strictly chemical means

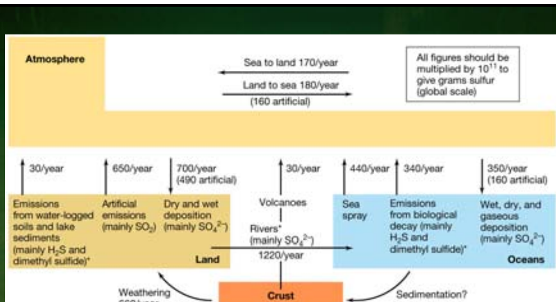
- Sulfur oxidation states in nature:

R-SH, SH, S, SO_4

- The most abundant organic sulfur compound in nature is dimethyl sulfide:

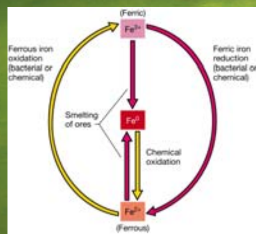
$H_3C\text{-}S\text{-}CH_3$

Process	Organisms
Sulfide/sulfur oxidation ($H_2S \rightarrow S^0 \rightarrow SO_4^{2-}$)	
Aerobic	Sulfur chemolithotrophs (*Thiobacillus*, *Beggiatoa*, many others)
Anaerobic	Purple and green phototrophic bacteria, some chemolithotrophs
Sulfate reduction (anaerobic) ($SO_4^{2-} \rightarrow H_2S$)	*Desulfovibrio*, *Desulfobacter*,
Sulfur reduction (anaerobic) ($S^0 \rightarrow H_2S$)	*Desulfuromonas*, many hyperthermophilic *Archaea*
Sulfur disproportionation ($S_2O_3^{2-} \rightarrow H_2S + SO_4^{2-}$)	*Desulfovibrio*, and others
Organic sulfur compound oxidation or reduction ($CH_3SH \rightarrow CO_2 + H_2S$) (DMSO → DMS)	
Desulfurylation (organic–S → H_2S)	Many organisms can do this



Iron cycle

- Cycling of ferric and ferrous forms occurs by both bacterial and chemical means
- *Thiobacillus ferrooxidans* oxidizes ferrous iron to ferric iron in acidic conditiions
- This process is common in coal-mining regions



- Pyrite (FeS_2) is an abundant form of iron in nature
- $FeS_2 + 14Fe^{3+} + 8H_2O$
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  $15Fe^{2+} + 2SO_4^{2+} + 16H^+$
- Bacterial oxidation of pyrite is a major contributor to acidification of waterways downstream of iron mines