Environmental Microbiology

Major Microbial Habitats and Diversity

prepared by Prof. Bulent Icgen

Microbial Ecology

- General Ecological Concepts
- Ecosystem Service: Biogeochemistry and Nutrient

Ecosystem = biotic + abiotic

- The sum total of all organisms and abiotic factors in a particular environment

Habitat

- Portion of an ecosystem where a community could reside
- An ecosystem contains many different habitats
- Microbes account for ~50% of all biomass on Earth
- They are ubiquitous on the surface and deep within the earth

Microbial Ecology

- Many microbes establish relationships with other organisms (symbioses)

Parasitism

- One member in the relationship is harmed and the other benefits

Mutualism

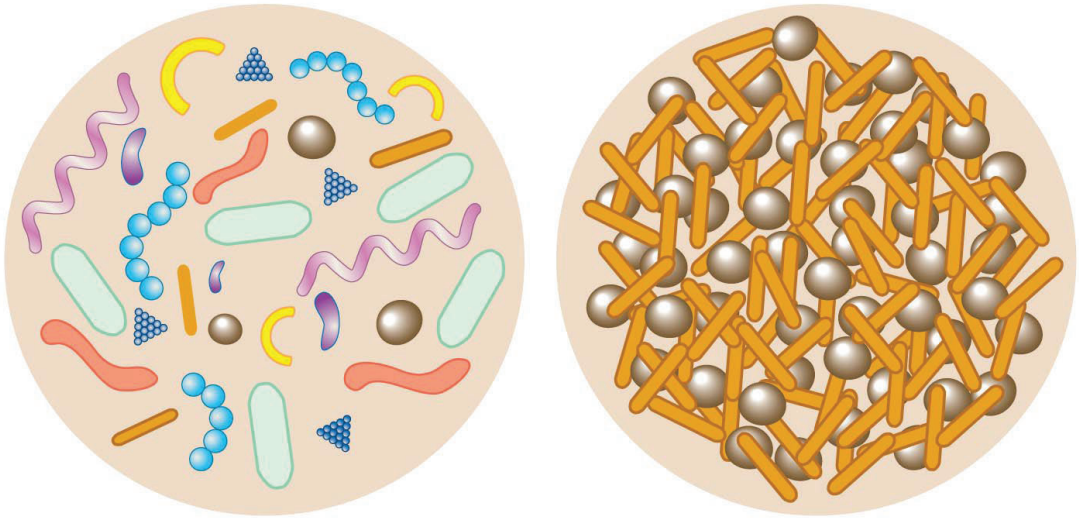
- Both species benefit

Commensalism

- One species benefits and the other is neither harmed nor helped

Microbial Species Diversity

- The diversity of microbial species in an ecosystem can be expressed in two ways
  - Species richness: the total number of different species present
  - Species abundance: the proportion of each species in an ecosystem
- Microbial species richness and abundance is a function of the kinds and amounts of nutrients available in a given habitat



(a) High Species Richness and Low to Moderate Abundance

(b) Low Species Richness and High Abundance

General Ecological Concepts

Table 23.1 ***Resources and conditions that determine microbial growth in nature***

Resources
Carbon (organic, CO_2)
Nitrogen (organic, inorganic)
Other macronutrients (S, P, K, Mg)
Micronutrients (Fe, Mn, Co, Cu, Zn, Mn, Ni)
O_2 and other electron acceptors (NO_3^-, SO_4^{2-}, Fe^{3+})
Inorganic electron donors (H_2, H_2S, Fe^{2+}, NH_4^+, NO_2^-)
Conditions
Temperature: cold → warm → hot
Water potential: dry → moist → wet
pH: 0 → 7 → 14
O_2: oxic → microoxic → anoxic
Light: bright light → dim light → dark
Osmotic conditions: freshwater → marine → hypersaline

Ecosystem Service: Biogeochemistry and Nutrient Cycles

species $\xrightarrow[\text{together}]{\text{come}}$ population $\xrightarrow[\text{metabolism}]{\text{if same}}$ guilds $\xrightarrow[\text{together}]{\text{come}}$ community

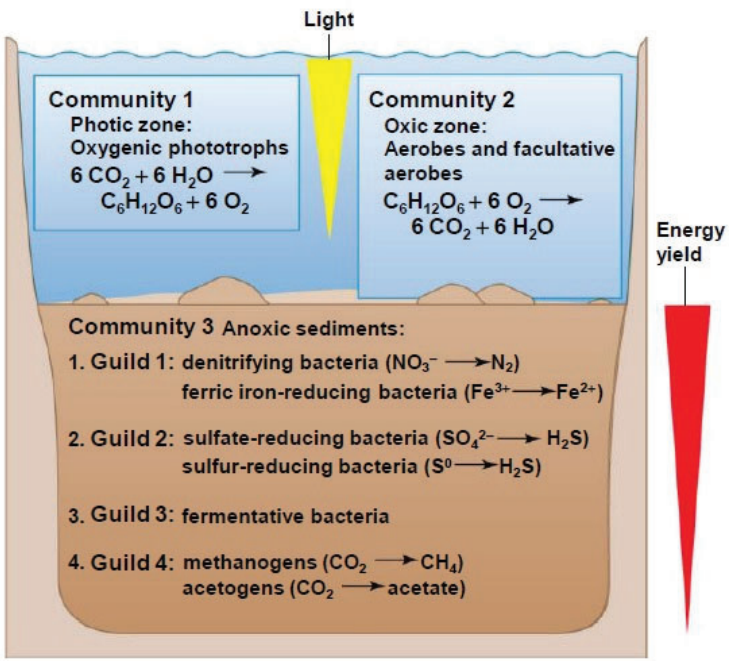
Guilds

- Metabolically related microbial populations
- Sets of guilds form microbial communities that interact with macroorganisms and abiotic factors in the ecosystem

Niche

- Habitat shared by a guild
- Supplies nutrients as well as conditions for growth

Populations, guilds, and communities



- Microbial communities consist of populations of cells of different species.
- The region of greatest activity for each of the different respiratory processes would differ with depth in the sediment.
- As more energetically favorable electron acceptors are depleted by microbial activity near the surface, less favorable reactions occur deeper in the sediment.

Ecosystem Service: Biogeochemistry and Nutrient Cycles

Biogeochemistry

the study of biologically mediated chemical transformations

- A biogeochemical cycle defines the transformations of a key element by biological or chemical agents. Typically proceed by oxidation–reduction reactions

- Microbes play critical roles in energy transformations and biogeochemical processes that result in the recycling of elements to living systems

The Microbial Environment

- Environments and Microenvironments
- Surfaces and Biofilms (Monolayer) (in solid surface) (if biofilm is thick ⇒ called "mat" (biological mat))
  ↓
  they day be pigmented.
- Microbial Mats

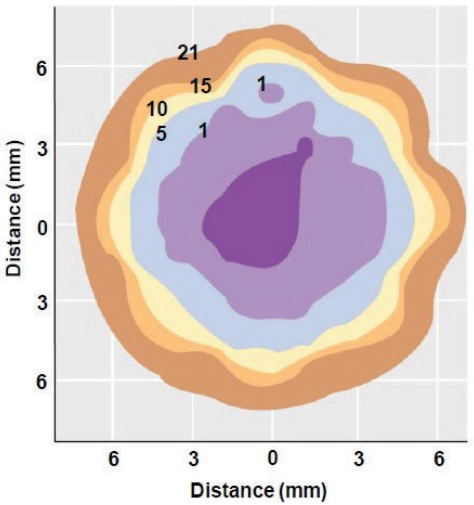
Environments and Microenvironments

- The growth of microbes depends on resources and growth conditions
- Difference in the type and quantity of resources and the physiochemical conditions of a habitat define the niche for each microbe
- For each organism there exists at least one niche in which that organism is most successful (prime niche)

Microenvironment

- The immediate environmental surroundings of a microbial cell or group of cells
- Soil particles contain many microenvironments

Oxygen microenvironments



- Contour map of O_2 concentrations in a small soil particle as determined by a microelectrode.
- The axes show the dimensions of the particle.
- The numbers on the contours are percentages of O_2 concentration (air is 21% O_2).
- Each zone can be considered a different microenvironment.

Environments and Microenvironments

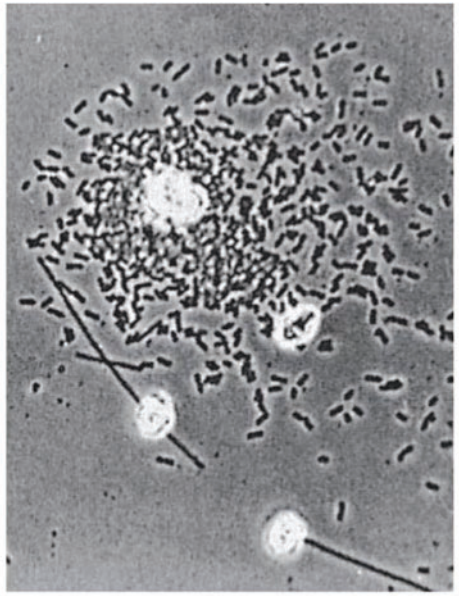
- Physiochemical conditions in a microenvironment are subject to rapid change, both spatially and temporally
- Resources in natural environments are highly variable and many microbes in nature face a feast-or-famine existence
- Growth rates of microbes in nature are usually well below maximum growth rates defined in the laboratory
- Competition and cooperation occur between microbes in natural systems

Surfaces and Biofilms

- Surfaces are important microbial habitats because
- Nutrients adsorb to surfaces
- Microbial cells can attach to surfaces

to get nutrients easy!

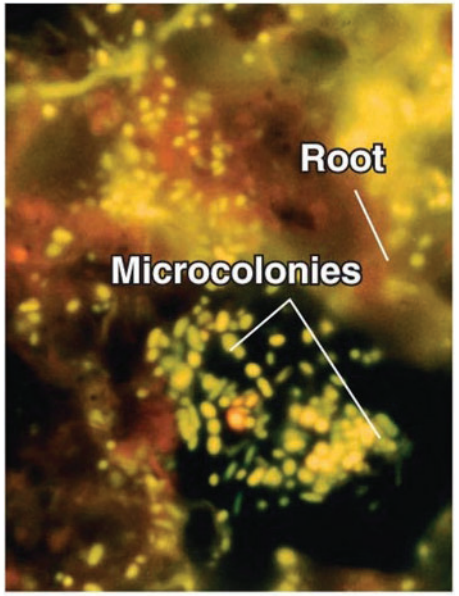
(initial attachment => secrete



T. D. Brock

(a)

Bacterial microcolonies on a microscope slide that was immersed in a river.



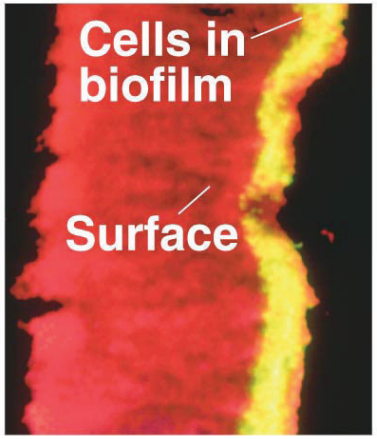
Frank Dazzo

(b)

Fluorescence photomicrograph of a natural microbial community living on a plant roots in soil.

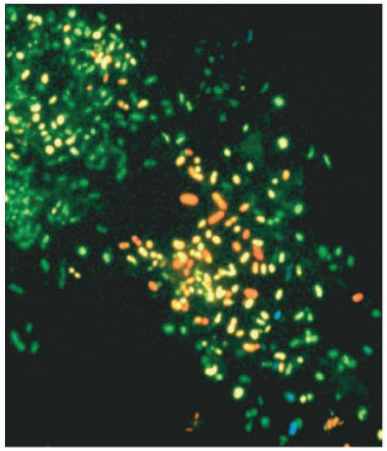
Surfaces and Biofilms

- Assemblages of bacterial cells adhered to a surface and enclosed in an adhesive matrix excreted by the cells
- The matrix is typically a mixture of polysaccharides → to stick to surface
- Biofilms trap nutrients for microbial growth and help prevent detachment of cells in flowing systems



C.-T. Huang, Karen Xu, Gordon McFeters, and Philip S. Stewart

(a) Cross-sectional view of experimental biofilm



Cindy E. Morris

(b) Natural biofilm on a leaf surface (Confocal laser scanning microscopy)

J.M. Sánchez, J.J. deLope, and Ricardo Amils

(c) Biofilm of iron-oxidizing prokaryotes attached to rocks

Biofilm Formation

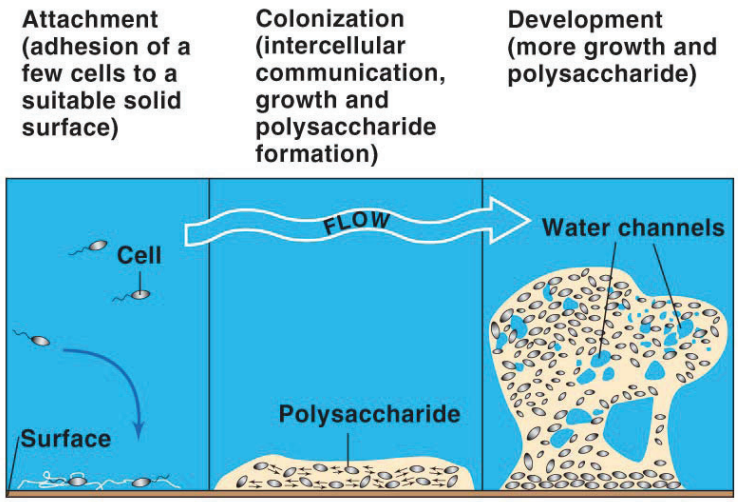
- Biofilm formation is initiated by attachment of a cell to a surface followed by expression of biofilm-specific genes (by chemicals)

  number of the bacteria increases

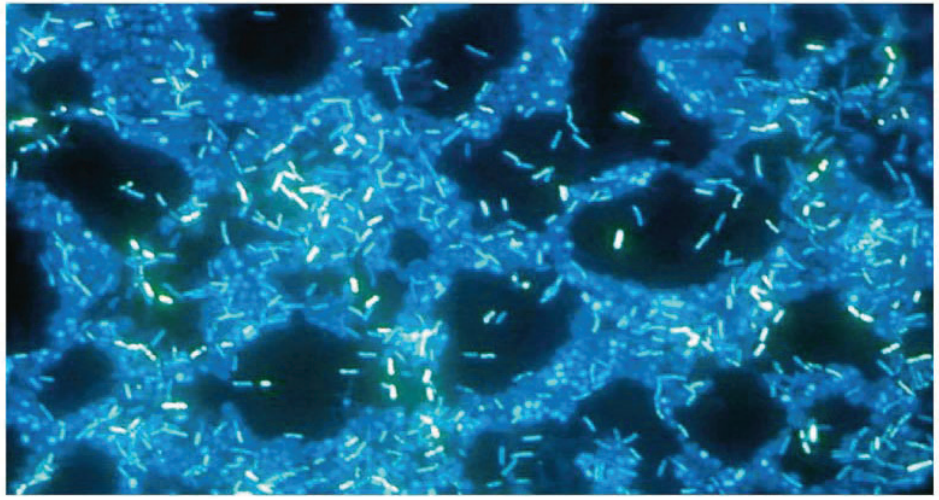
  acylated homoserine lactons ⇒ they communicate without each other

  communication named as "Quorum Sensing"

- Genes encode proteins that synthesize intercellular signaling molecules and initiate matrix formation



(a)



(b)

Rodney M. Donlan and *Emerging Infectious Diseases*

Biofilm Formation

Bacteria form biofilms for several reasons

- Self-defense
- Biofilms resist physical forces that sweep away unattached cells, phagocytosis by
- immune system cells, and penetration of toxins (e.g., antibiotics)
- Allows cells to remain in a favorable niche
- Allows bacterial cells to live in close association with one another
- Biofilms have been implicated in several medical and dental conditions
- In industrial settings, biofilm scan slow the flow of liquids through pipelines and can accelerate corrosion of inert surfaces
- Few highly effective anti biofilm agents are available

Quorum Sensing

Intracellular communication (quorum sensing) is critical in the development and maintenance of a biofilm

Quorum Sensing: The ability of a bacterial colony to sense its size and regulate its activity in response.

- The major intracellular signaling molecules are acylated homoserine lactones
- Both intra- and interspecies signaling likely occurs in biofilms

Importance of Biofilms

Harmful Biofilms

- Biofilms are important in human health and commerce

Biofilms have been implicated in several medical and dental conditions including periodontal disease, kidney stones, tuberculosis, Legionnaire's disease, and *Staphylococcus* infections

- In industrial settings, biofilms can slow the flow of liquids through pipelines and can accelerate corrosion of inert surfaces. Few highly effective antibiofilm agents are available

Beneficial Biofilms

- Used for removal of organic pollutants from wastewaters. Biological treatment is popular due to: low cost, effective in removal of a wide range of organic contaminants, effective in removal of colloidal organics
- can remove toxic non-organic pollutants such as heavy metals

Biological Biofilm Systems

- Trickling Filter
- Fludized Bed
- Packed Bed

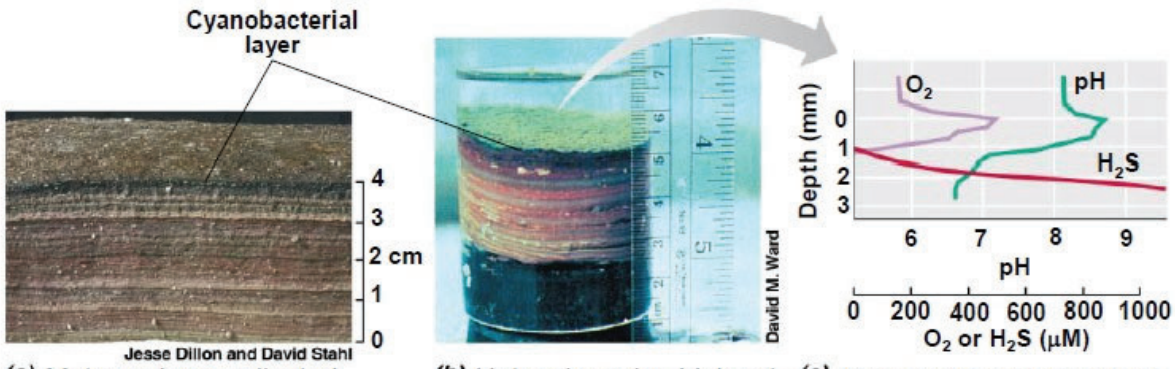
Microbial Mats

- Microbial mats are very thick biofilms
- Built by phototrophic and/or chemolithotrophic bacteria
- Phototrophic mats contain filamentous cyanobacteria

Cyanobacterial mats are complete ecosystem

- Have existed for over 3.5 billion years
- Chemolithotrophic mats contain filamentous sulfur-oxidizing bacteria

Microbial mats



(a) Mat specimen collected from the bottom of a hypersaline pond. Most of the bottom of this shallow pond is covered with mats built by the major primary producer, the filamentous cyanobacterium *Microcoleus hthonoplastes.*

(b) Hot spring microbial mat core from an alkaline hot spring. The upper (green) layer contains mainly cyanobacteria, while the reddish layers contain anoxygenic phototrophic bacteria.

(c) Oxygen (O_2), H_2S and pH profiles through a hot spring mat core such as that shown in 'b'.

Terrestrial Environments

- Soils
- The Subsurface

Soil

- The loose outer material of Earth‟s surface
- Distinct from bedrock

Soil can be divided into two broad groups:

- Mineral soils

Derived from rock weathering and other inorganic materials

- Organic soils

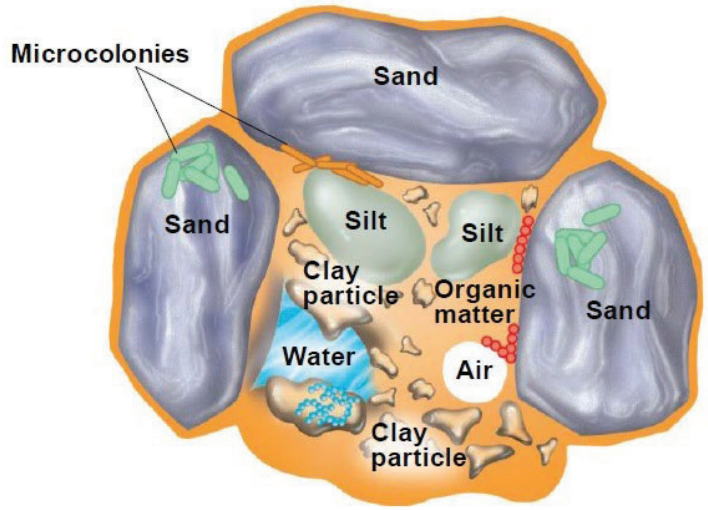
Derived from sedimentation in bogs and marshes

Soil

Soils are composed of

- Inorganic mineral matter (~40% of soil volume)
- Organic matter (~5%)
- Air and water (~50%)
- Living organisms
- Most microbial growth takes place on the surfaces of soil particles
- Soil aggregates can contain many different microenvironments supporting the growth of several types of microbes

A soil microbial habitat



Very few microorganisms are free in the soil solution; most of them reside in microcolonies attached to the soil particles. Note the relative size differences among sand, clay and silt particles.

Soil

- The availability of water is the most important factor influencing microbial activity in surface soils
- Nutrient availability is the most important factor in subsurface environments

Phylogenetic sampling

- Molecular sampling indicates thousands of different microbial species
- Phylotype: a “species” defined by a 16S rRNA sequence that differs from all other sequences by 3%
- Microbial diversity varies with soil type and geographical location

The Subsurface

- The deep soil subsurface can extend for several hundred meters below the soil surface
- Archaea and Bacteria believed to exist in deep subsurface
- Microorganisms in the deep subsurface have access to nutrients because groundwater flows through their habitats

Aquatic Environments

- Freshwaters (Lakes, River)
- Coastal and Ocean Waters

Phototrophic Microorganisms, Pelagic Bacteria, Archaea and Viruses

- The Deep Sea and Deep-Sea Sediments
- Hydrothermal Vents

Freshwaters

- Freshwater environments are highly variable in the resources and conditions available for microbial growth
- The balance between photosynthesis and respiration controls the oxygen and carbon cycles
- Phytoplankton: oxygenic phototrophs suspended freely in water; include algae and cyanobacteria
- Benthic species are attached to the bottom or sides of a lake or stream
- The activity of heterotrophic microbes in aquatic systems is highly dependent upon activity of primary producers; oxygenic phototrophs produce organic material and oxygen
- Oxygen has limited solubility in water; the deep layers of freshwater lakes can become anoxic once the oxygen is consumed
- Oxygen concentrations in aquatic systems are dependent on the amount of organic matter present and the physical mixing of the system

Freshwater Zonation

- Littoral zone: Along shore → kıyıya yakın

Producers: Plants

- Limnetic zone: Surface of open water along shore (O_2 ve light) ↳ bolgede ışık.

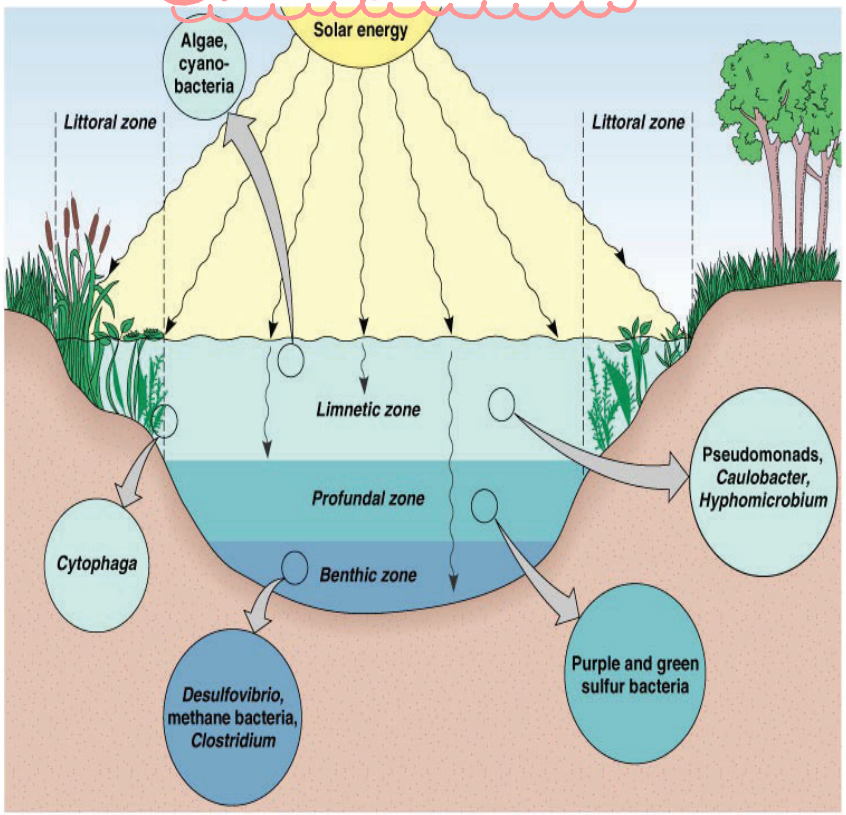
Producers: Algae and cyanobacteria !

- Profundal zone: Deeper water, under limnetic zone

Producrs: Anaerobic purple and green photosynthetic bacteria

- Benthic zone: Bottom sediment

SINAVDA SORDU



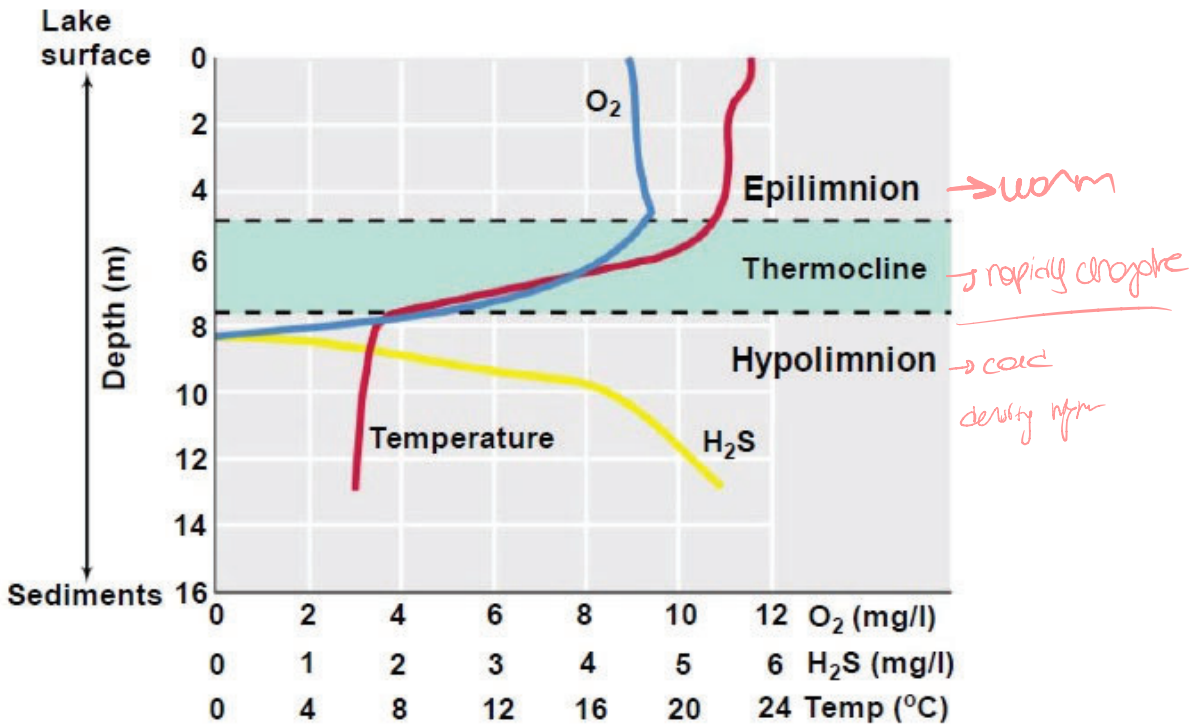
Lakes

- In many temperate lakes the water column becomes stratified during the summer

Stratification: the formation of water layers based on temperature

hypolimnion and epilimnion changing.

Development of anoxic conditions in a temperate lake due to summer stratification



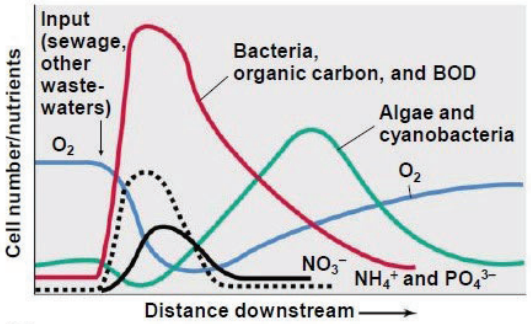
The colder bottom waters are more dense and contain H_2S from bacterial sulfate reduction. The thermocline is the zone of rapid temperature change. As surface waters cool in the fall and early winter, they reach the temperature and density of hypolimnetic waters and sink, displacing bottom waters and effecting lake turnover.

Rivers

- May be well mixed because of rapid water flow
- Can still suffer from oxygen deficiencies due to high inputs of
- Organic matter from sewage
- Agricultural and industrial pollution
- Biochemical oxygen demand (BOD)

The microbial oxygen-consuming capacity of a body of water

Effect of the input of organic-rich wastewaters into aquatic systems



(a)

In a river, bacterial numbers increase and O_2 levels decrease with a spike of organic matter. The rise in numbers of algae and cyanobacteria is primarily a response to inorganic nutrients, especially phosphate (PO_4^{3-}).

T. D. Brock

(b)

Photo of a eutrophic (nutrient-rich) lake, showing algae, cyanobacteria and aquatic plants that bloom in response to nutrient pollution from agricultural runoff.

eutrophication means

algal bloom

beware of too much organic input. (phosphate) ↳ detergents ↳ soften the detergent.

Coastal and Ocean Waters: Phototrophic Microorganisms

Compared with most freshwater environments, the open ocean environment is

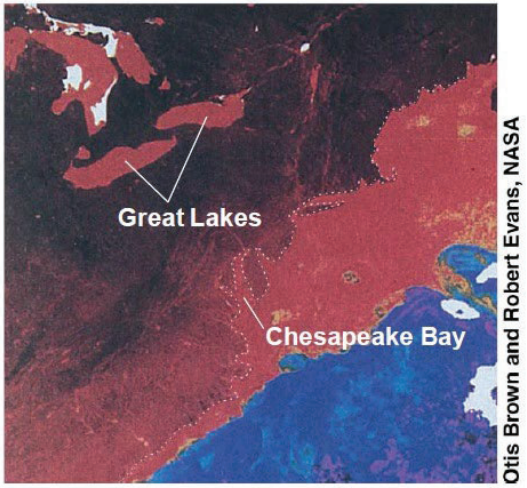
- Saline
- Low in nutrients, especially with respect to nitrogen, phosphorus and iron
- Cooler (especially ocean is very cold.)
- Due to the size of the oceans, the microbial activities taking place in them are major factors in Earth's carbon balance
- Near-shore (→ coastal part) marine waters typically contain higher microbial numbers than the open ocean because of higher nutrient levels

pelagic → oligotrophs → they don't need to much nutrients

most of the ocean they have.

↳ pigment → (rhodopsin) → they trap the light → sentence ATP.

Distribution of chlorophyll in the western North Atlantic Ocean as recorded by satellite



Otis Brown and Robert Evans, NASA

The northeast coast of the United States is shown in dotted outline. Areas rich in phototrophic plankton are shown in red (1 mg chlorophyll/m^3); blue and purple areas have lower chlorophyll concentrations (0.01 mg/m^3). Note the high primary productivity of coastal areas and the Great Lakes.

Coastal and Ocean Waters: Phototrophic Microorganisms

Coastal and Ocean Waters: Phototrophic Microorganisms

- Most of the primary productivity in the open oceans is due to photosynthesis by prochlorophytes. *Prochlorococcus* is the most abundant oxygenic phototrophin the oceans and accounts for

↳ different type of cyanobacteria.

>40% of the biomass of marine phototrophs

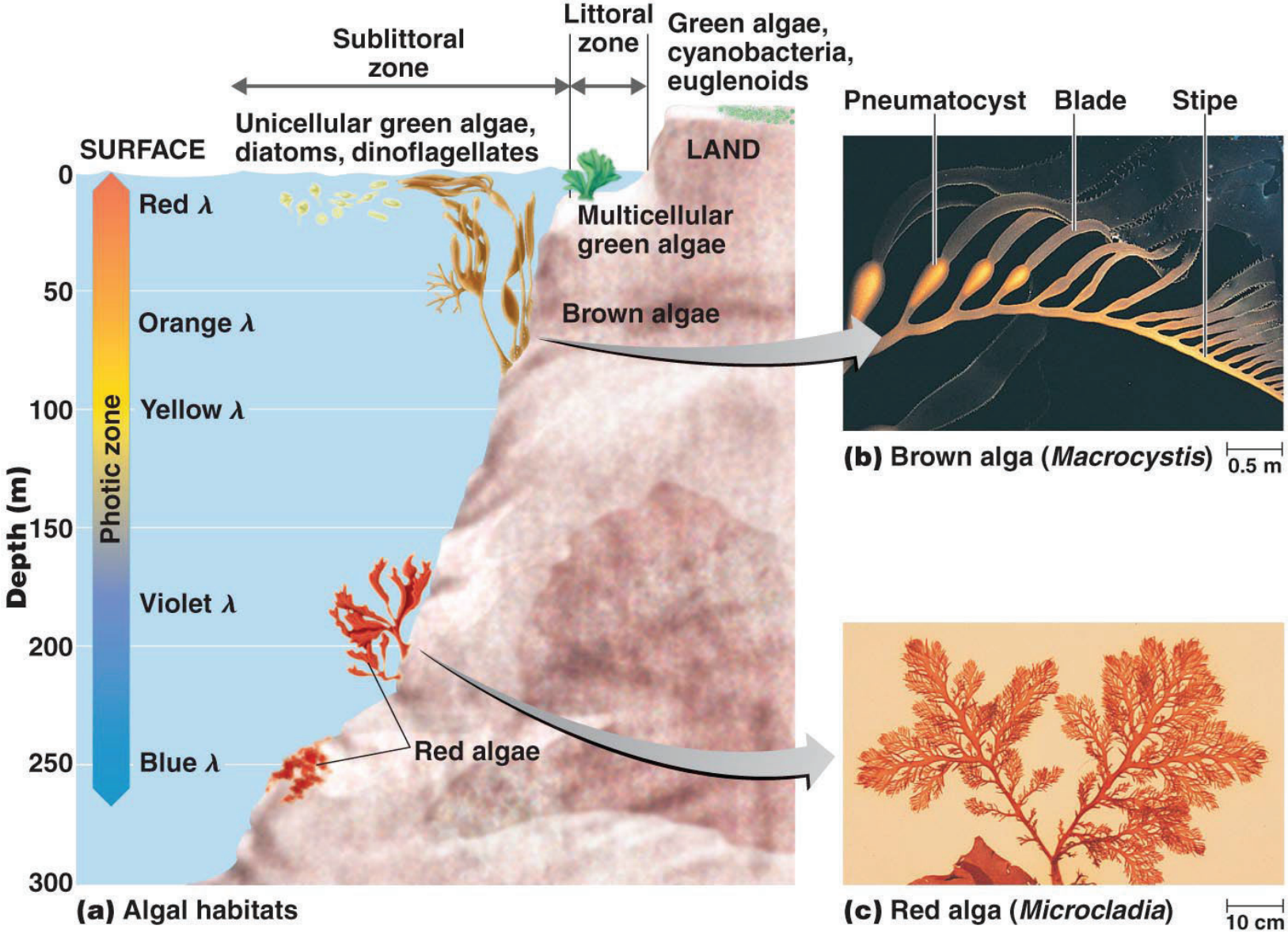
~50% of the net primary production

- The planktonic filamentous cyanobacterium *Trichodesmium* is an abundant phototrophin tropical and subtropical oceans
- Small phototrophic eukaryotes, such as *Ostreococcus*, inhabit coastal and marine waters and are likely important primary producers.

Aerobic anoxygenic phototrophs

- Another class of marine microbes that use light energy but do not fix carbon dioxide
- Light is used for ATP synthesis via photophosphorylation

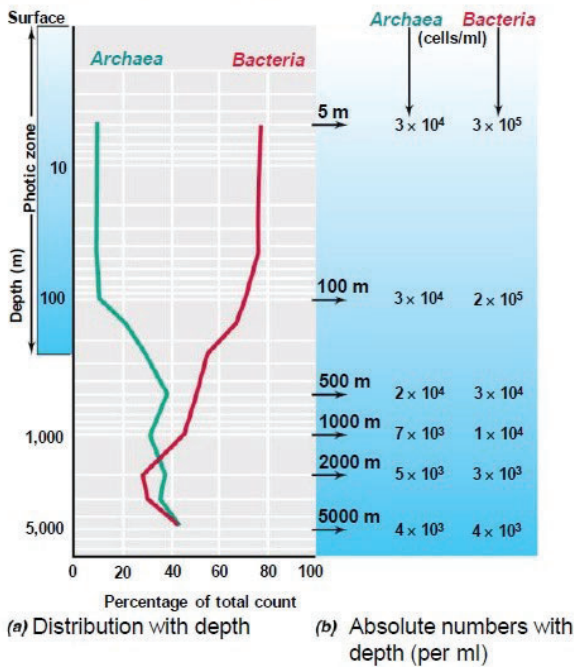
Seawater Microbiota



Pelagic Bacteria, Archaea, and Viruses

- Pelagic Bacteria: living or growing at or near the surface of the ocean, far from land.
- Small planktonicheterotrophic prokaryotes are abundant (10^5-10^6 cells/ml) in pelagic marine waters
- Prokaryote densities in the open ocean decrease with depth
- Surface waters contain ~10^6 cells/ml; cell numbers drop to 10^3-10^5/ml below 1,000 m in depth
- Bacterial species tend to dominate in surface waters, and archaeal species dominate in deeper waters

Percentage of total prokaryotes belonging to *Archaea* and *Bacteria* in North Pacific Ocean water



(a) Distribution with depth (b) Absolute numbers with depth (per ml)

Pelagic Bacteria, Archaea, and Viruses

- The most abundant marine heterotroph is Pelagibacter, an oligotroph

Oligotroph: an organism that grows best at very low nutrient concentrations

- Pelagibacter and other marine heterotrophs contain proteorhodopsin, a form of rhodopsin that allows cells to use light energy to drive ATP synthesis

Viruses are the most abundant microorganisms in the oceans

- Viral concentration believed to be as high as 10^8 virion particles/ml
- Viruses affect prokaryotic populations and are highly diverse

The Deep Sea and Deep-Sea Sediments

>75% of all ocean water is deep sea, lying primarily between 1,000 and 6,000 m

Organisms that inhabit the deep sea must deal with

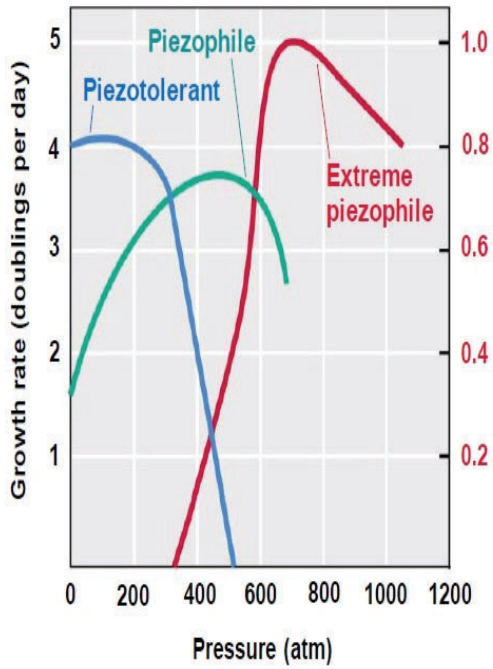
- Low temperature
- High pressure
- Low nutrient levels
- Absence of light energy

Deep-sea microbes are

- Psychrophilic (cold-loving) or psychrotolerant
- Piezophilic (pressure-loving) or piezotolerant

Adaptations for growth under high pressure are likely only seen for a few key proteins

Growth of piezotolerant, piezophilic, and extremely piezophilic bacteria



Compare the slower growth rate of the extreme piezophile (right ordinate) with the growth rate of the piezotolerant and piezophilic bacteria (left ordinate), and note the inability of the extreme piezophile to grow at low pressures.

Hydrothermal Vents

Thriving animal and microbial communities associated with deep-sea hydrothermal vents. Two types of vents:

- Warm diffuse or very hot

Chemolithotrophic bacteria predominate at vent

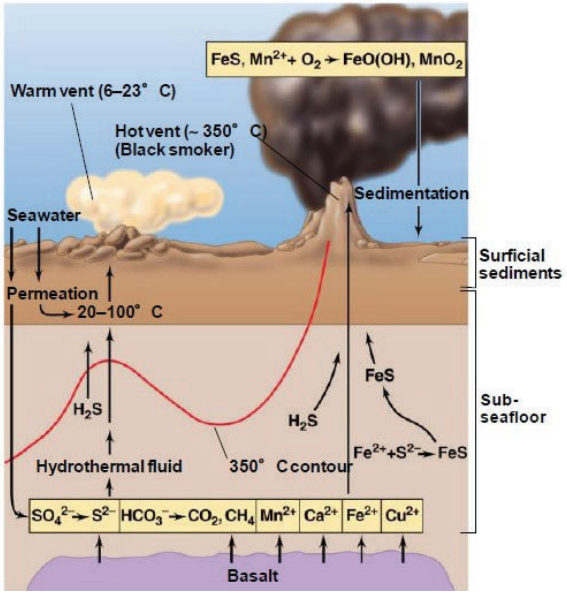
- Thermophiles and hyperthermophiles present

Chemolithotrophic prokaryotes utilize inorganic materials from the vents

permanent → smoke
↳ they cause warm vent.

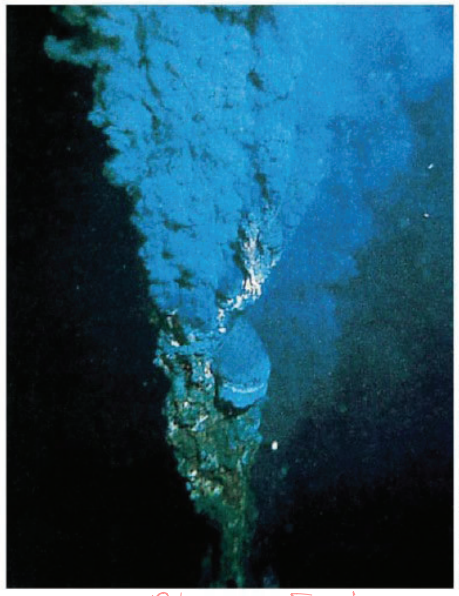
bottom of the of the beam 20°

Hydrothermal vents



Schematic showing geological formations and major chemical species at warm vents and black smokers. In warm vents, the hot hydrothermal fluid is cooled by cold 2-3 °C seawater permeating the sediments. In black smokers, hot hydrothermal fluid near 350 °C reaches the seafloor directly.

A hydrothermal vent black smoker emitting sulfide- and mineral-rich water at 350 °C



Robert D. Ballard

The walls of the black smoker chimneys display a steep temperature gradient and contain several types of prokaryotes.

if they just come out very quickly ⇒ hot vent Black Smokers (350°C Also called