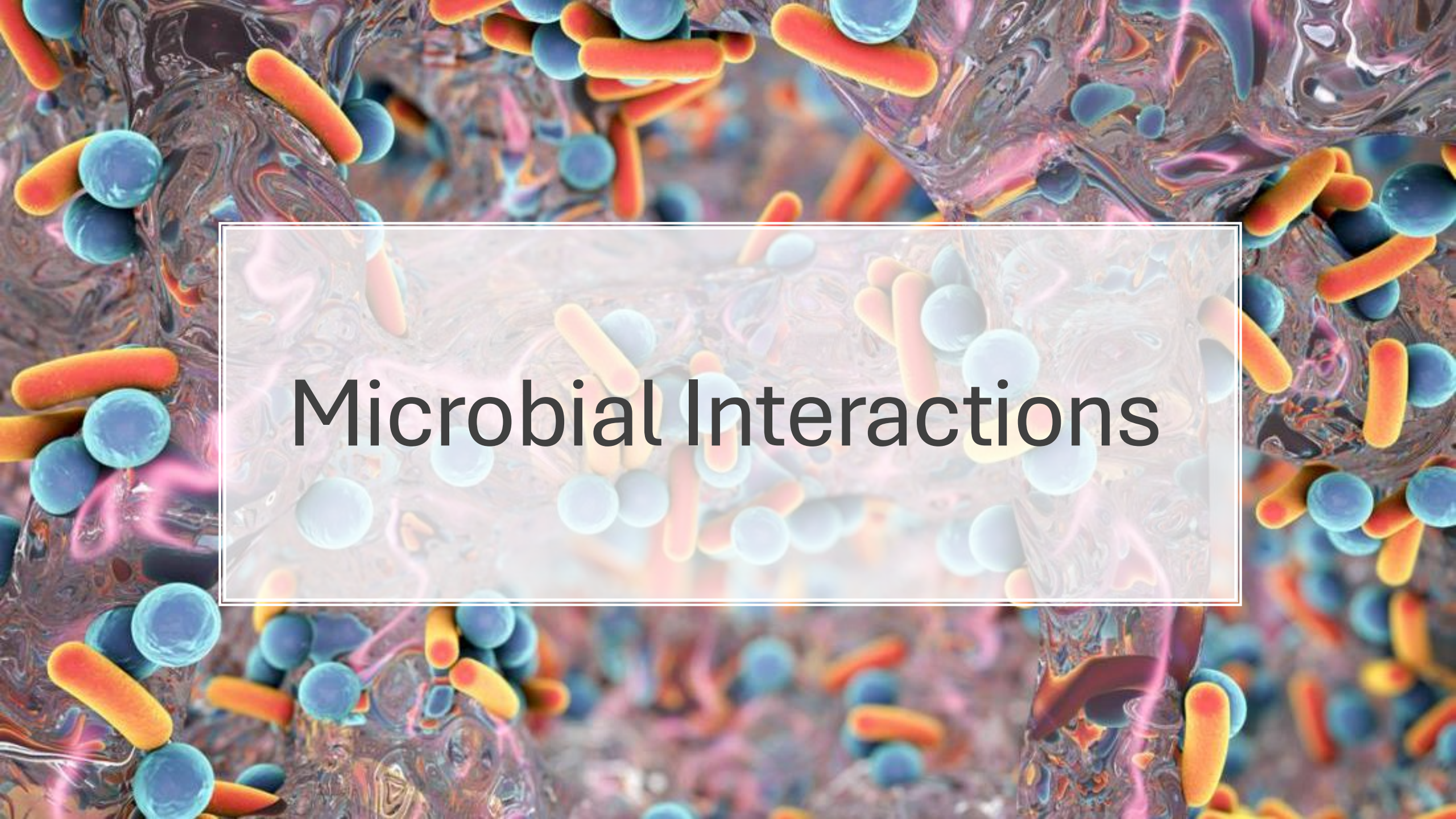
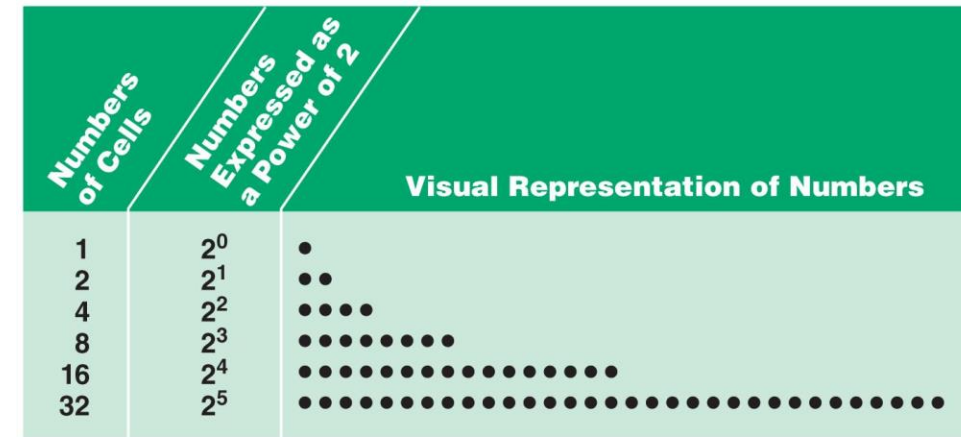


The background of the slide is a vibrant, abstract composition of various shapes and colors, including blue, orange, yellow, and pink, set against a dark, swirling, marbled texture. These elements are scattered across the entire frame, creating a sense of dynamic movement and complexity. A central white rectangular box with a thin black border contains the title text.

Microbial Interactions

Microbial Growth

- **Growth:** increase in the number of cells
- **Generation (doubling) time:** time required for microbial cells to double in number
 - Varies across for microbial species
 - Varies depending on conditions
 - Total number of cells = $2^{\text{number of generations}}$
 - E.g.: **Escherichia coli** = 20 minutes



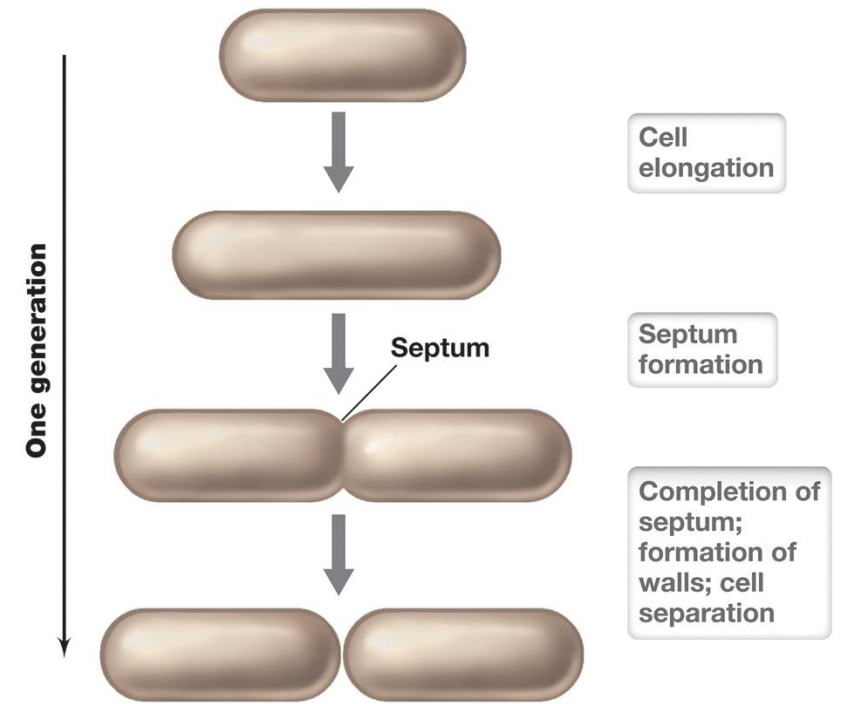
(a) Visual representation of increase in bacterial number over five generations. The number of bacteria doubles in each generation. The superscript indicates the generation; that is, $2^5 = 5$ generations.

Generation Number	Number of Cells	Log ₁₀ of Number of Cells
0	$2^0 = 1$	0
5	$2^5 = 32$	1.51
10	$2^{10} = 1,024$	3.01
15	$2^{15} = 32,768$	4.52
16	$2^{16} = 65,536$	4.82
17	$2^{17} = 131,072$	5.12
18	$2^{18} = 262,144$	5.42
19	$2^{19} = 524,288$	5.72
20	$2^{20} = 1,048,576$	6.02

(b) Conversion of the number of cells in a population into the logarithmic expression of this number. To arrive at the numbers in the center column, use the y^x key on your calculator. Enter 2 on the calculator; press y^x ; enter 5; then press the = sign. The calculator will show the number 32. Thus, the fifth-generation population of bacteria will total 32 cells. To arrive at the numbers in the right-hand column, use the log key on your calculator. Enter the number 32; then press the log key. The calculator will show, rounded off, that the $\log_{10}$ of 32 is 1.51.

Microbial Growth

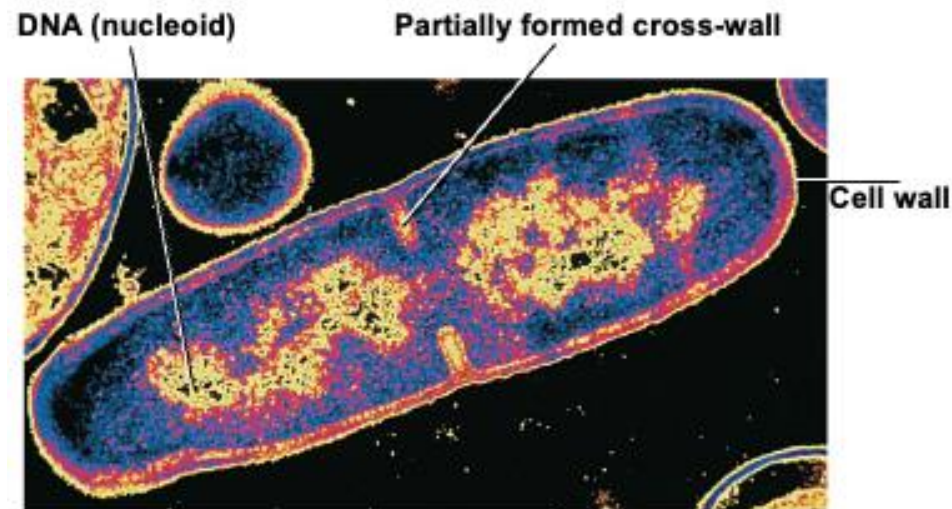
- **Binary fission:** cell division following enlargement of a cell to twice original size
- **Septum:** partition between dividing cells, pinches off between two daughter cells
- Balanced growth - a result of binary fission, producing nearly identical cells



I. Equal products of cell division:

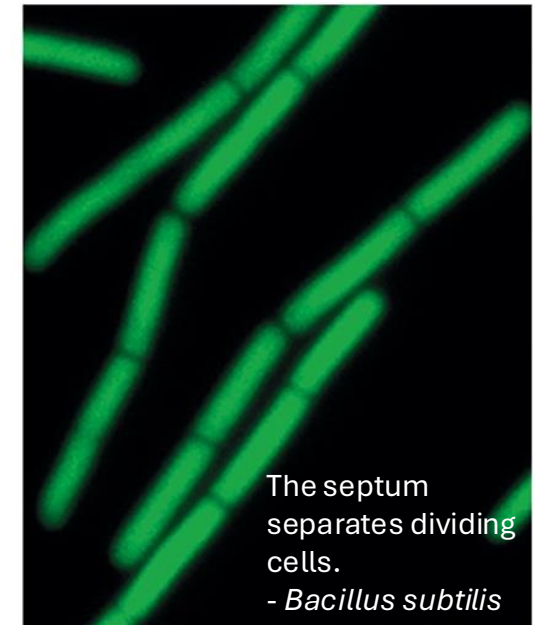


Binary fission: most bacteria



(b) A thin section of a cell of *Bacillus licheniformis* starting to divide

TEM 0.5 μm



Microbial Growth

- Budding cell division
 - Unequal cell growth forming different daughter cells.
 - Some budding bacteria form cytoplasmic extensions
 - stalks (**Caulobacter**)
 - appendages (**Ancalomicrobium**).
- Typical of yeasts (unicellular fungi)

II. Unequal products of cell division:

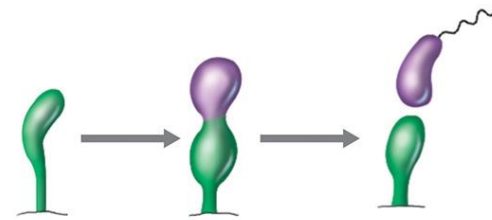
1. Simple budding: *Pirellula*, *Blastobacter*



2. Budding from hyphae: *Hyphomicrobium*, *Rhodomicrobium*, *Pedomicrobium*

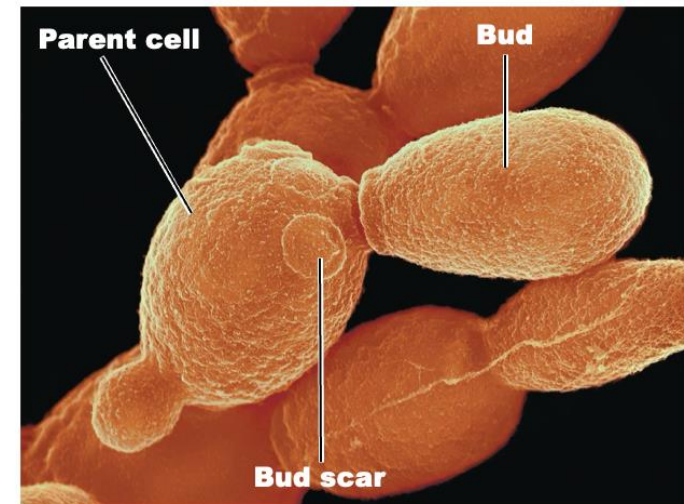


3. Cell division of stalked organism: *Caulobacter*



4. Polar growth without differentiation of cell size:

Rhodopseudomonas, *Nitrobacter*, *Methylosinus*



Microbial Growth

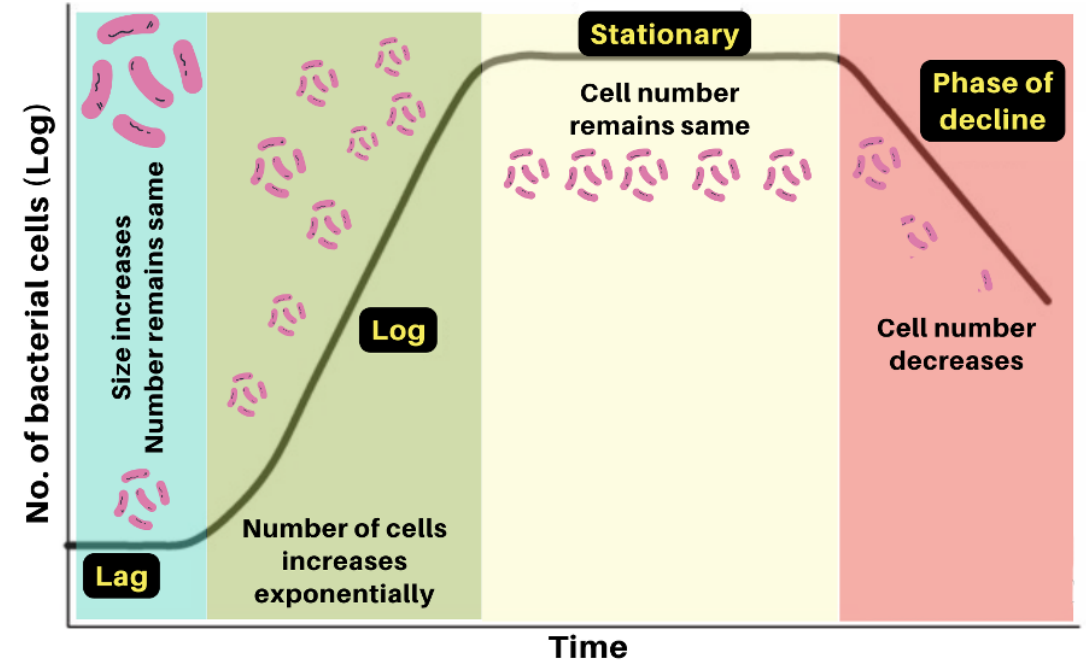
Streptomyces

- Hyphal Growth
 - **Hyphae:** long, thin filaments of actinomycetes (gram-positive filamentous bacteria, **e.g., Streptomyces**)
 - Hyphal growth occurs only at filament tip
 - Cell growth is not linked directly to division (no septa)



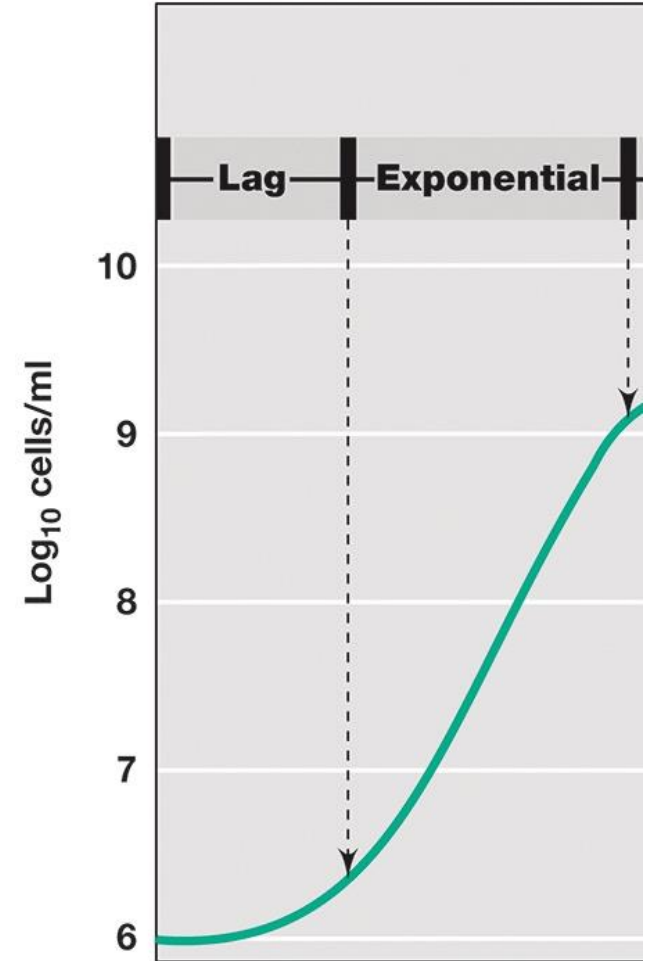
Microbial Growth Cycle

- **Batch culture:** a closed-system microbial culture of fixed volume
- Typical **growth curve** for population of cells grown in a closed system is characterized by four phases.
 - lag phase
 - exponential phase
 - stationary phase
 - death phase



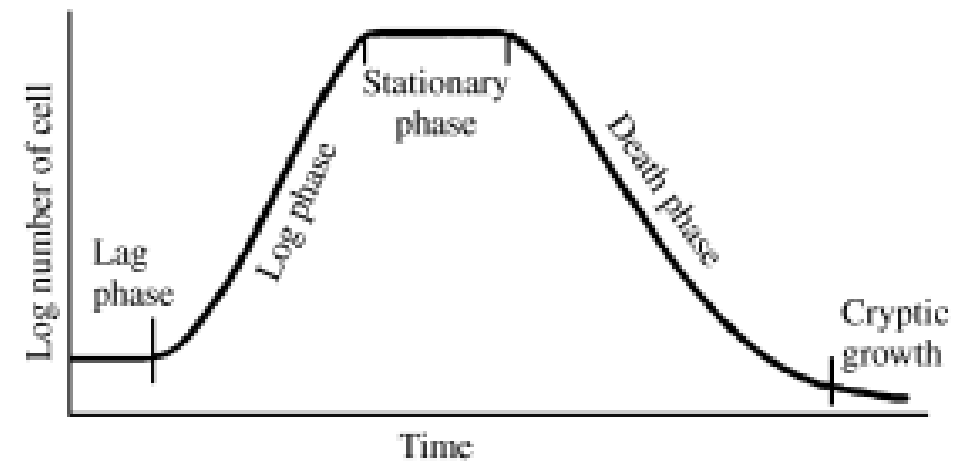
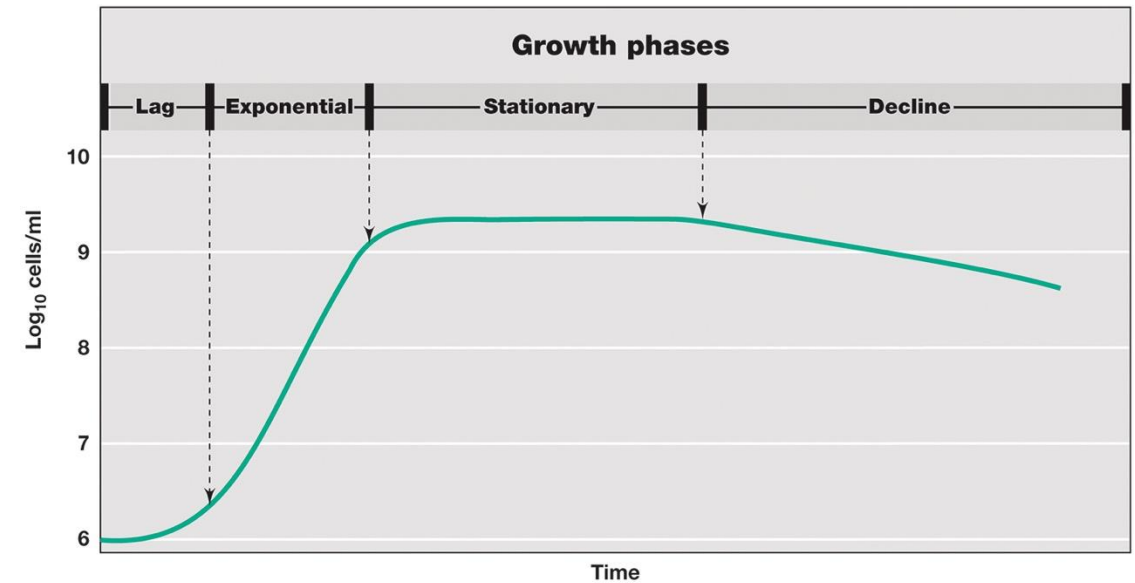
Microbial Growth Cycle

- Lag and Exponential Phases
 - **Lag phase:** interval between inoculation of a culture and beginning of growth
 - new conditions require altering metabolic state
 - time needed for biosynthesis of new enzymes and to produce required metabolites before growth can begin
 - **Exponential phase:** doubling at regular intervals
 - Balanced growth- cells are metabolically identical
 - rates vary greatly
 - influenced by media, conditions, organism itself
 - continues until conditions can no longer sustain growth



Microbial Growth Cycle

- Stationary and Death Phases
 - Growth limited by nutrient depletion or waste accumulation
 - **Stationary phase:** growth rate of population is zero
 - Metabolism continues at greatly reduced rate
 - **Decline phase:** total number decreases due to cell death
 - **Cryptic growth:** subpopulations adapt



Realistic growth rates in the environment

Growth rates of soil bacteria in nature are $<1\%$ of the maximum rate measured in the laboratory



Niche space

- The growth of microorganisms in nature depends on the **growth conditions** and the available **resources (nutrients)**.
- Differences in physicochemical conditions (temperature, pH, water, light, oxygen) and in the type and amount of different resources of an environment define the niche for a particular microorganism.
- Countless niches exist on Earth, which are responsible for the great metabolic diversity of today's microorganisms.

Niche space



Deep mountain lakes

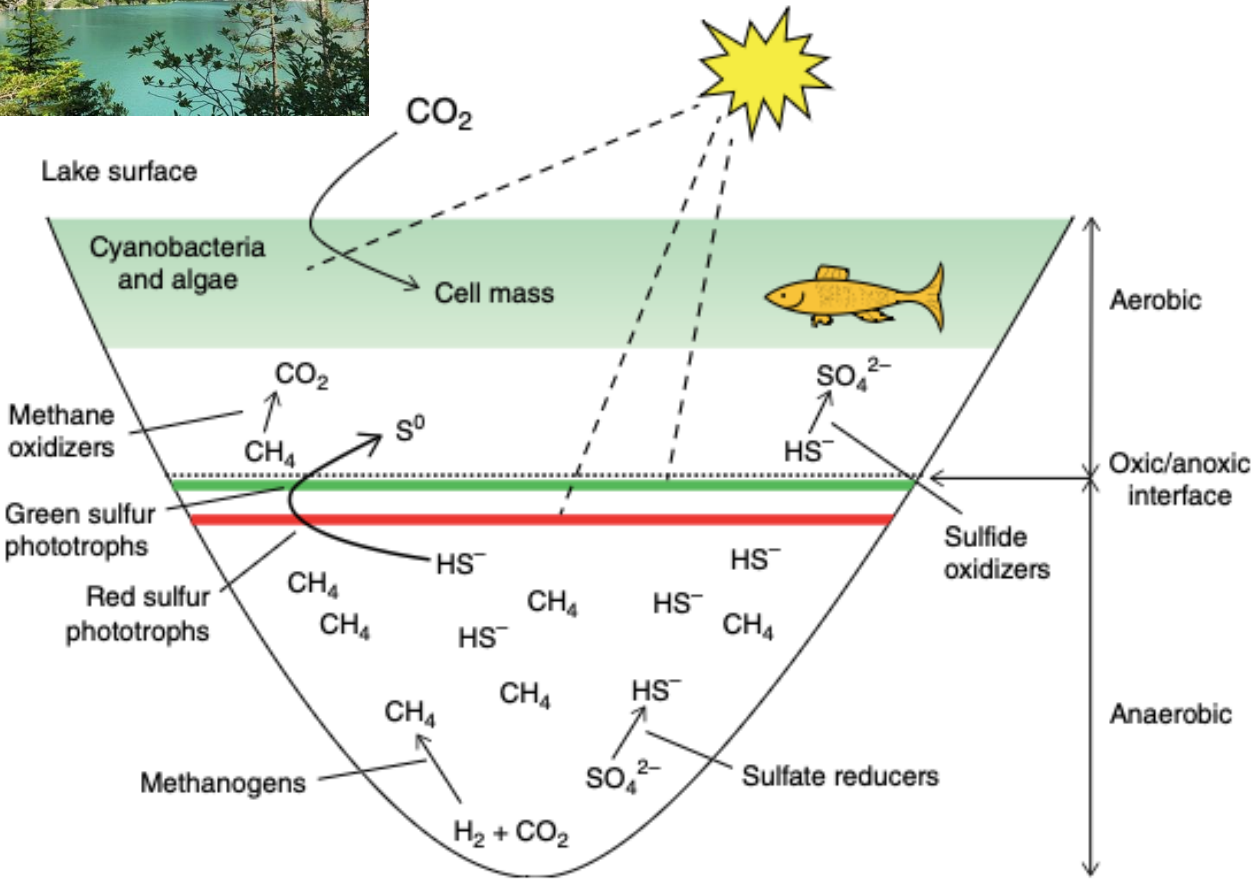


Figure 4.9 A deep lake showing the stratified microbial processes. Cyanobacteria grow on the surface while anaerobic phototrophic bacteria are found in the sulfide rich environment. The position of the red and green photosynthetic bacteria indicates light penetration and the type of bacteriochlorophyll of the phototrophs. Hydrogen sulfide is produced in the anaerobic zone while methane and sulfide oxidation occurs at the oxic/ anoxic interface.

Figure 4.11 Structure of the chlorophyll *a* molecule. Different side groups are added at the encircled regions to produce different bacteriochlorophylls.

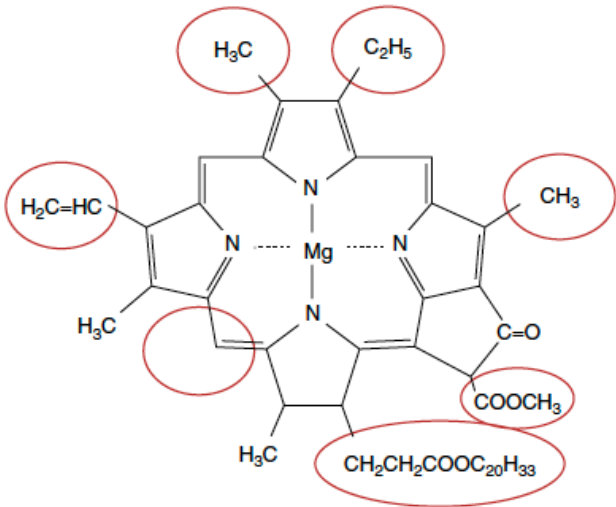


Table 4.8 Selected photosynthetic bacteria and their

Phylum	Genus	Wavelength of adsorption for purified chlorophyll (nm)
Cyanobacteria	Anabaena	680, 700
Chloroflexi	Chloroflexus (green non-sulfur) ^c	800–810
Chlorobi	Chlorobium (green sulfur)	800–810
Betaproteobacteria	Rhodospirillum (purple non-sulfur)	800–810
Alphaproteobacteria	Blastochloris	835–850
Betaproteobacteria	Chromatium (purple sulfur)	800–810
		835–950
Firmicutes	Heliobacterium	670, 788

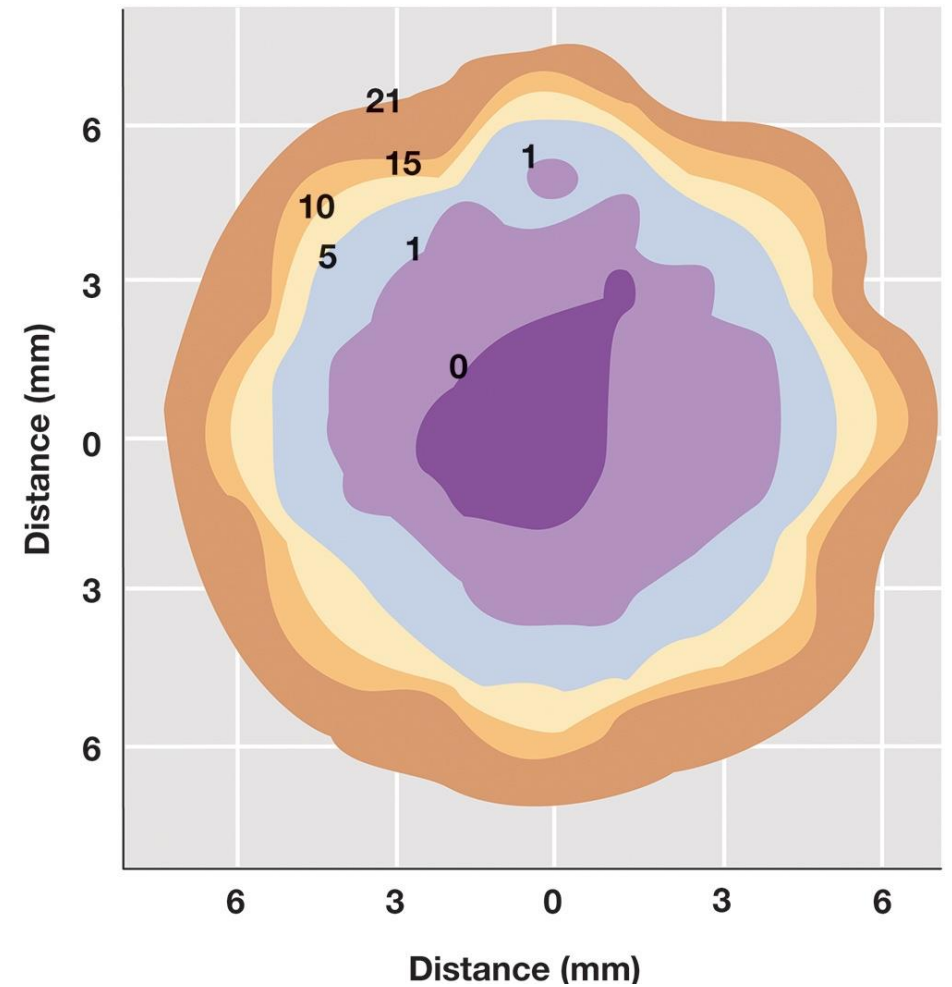
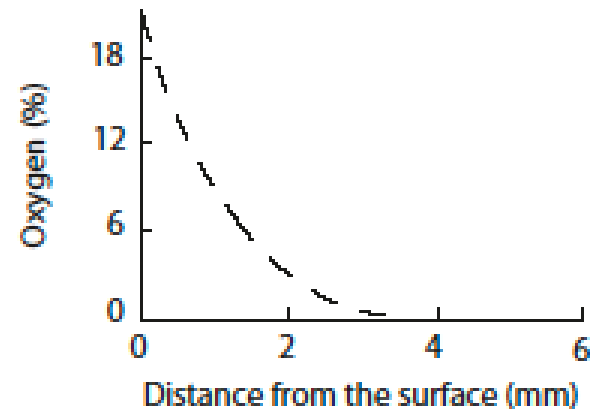
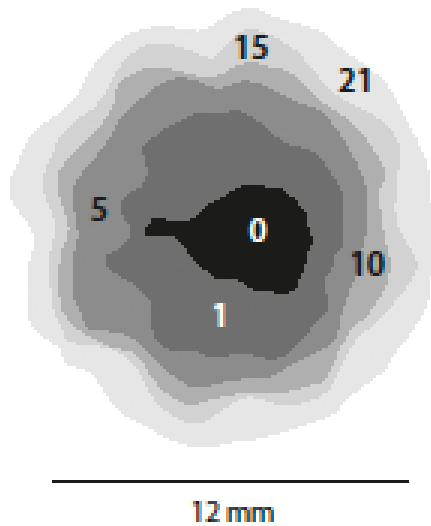
Niche space

- **Physical** and **chemical gradients** can exist within a few millimetres in habitats that strongly influence the microorganisms.
- Microenvironment
 - The immediate environmental surroundings of a microbial cell or group of cells

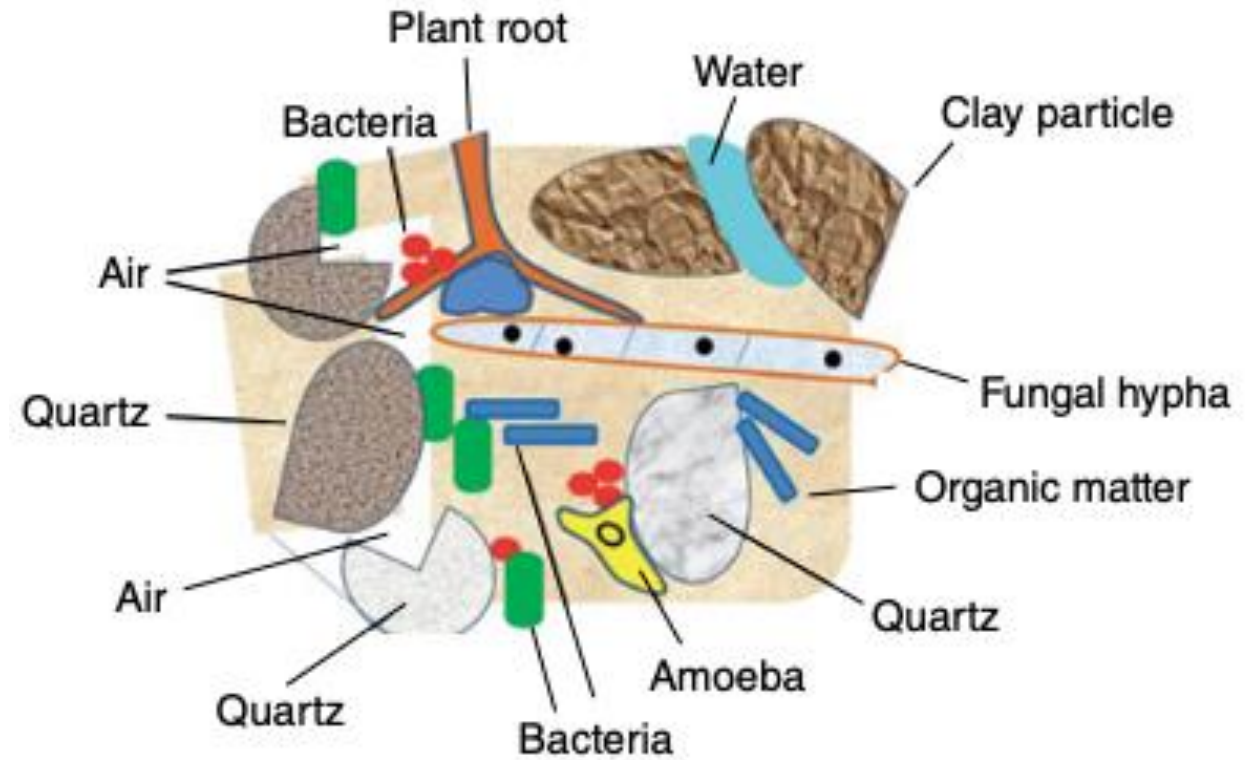
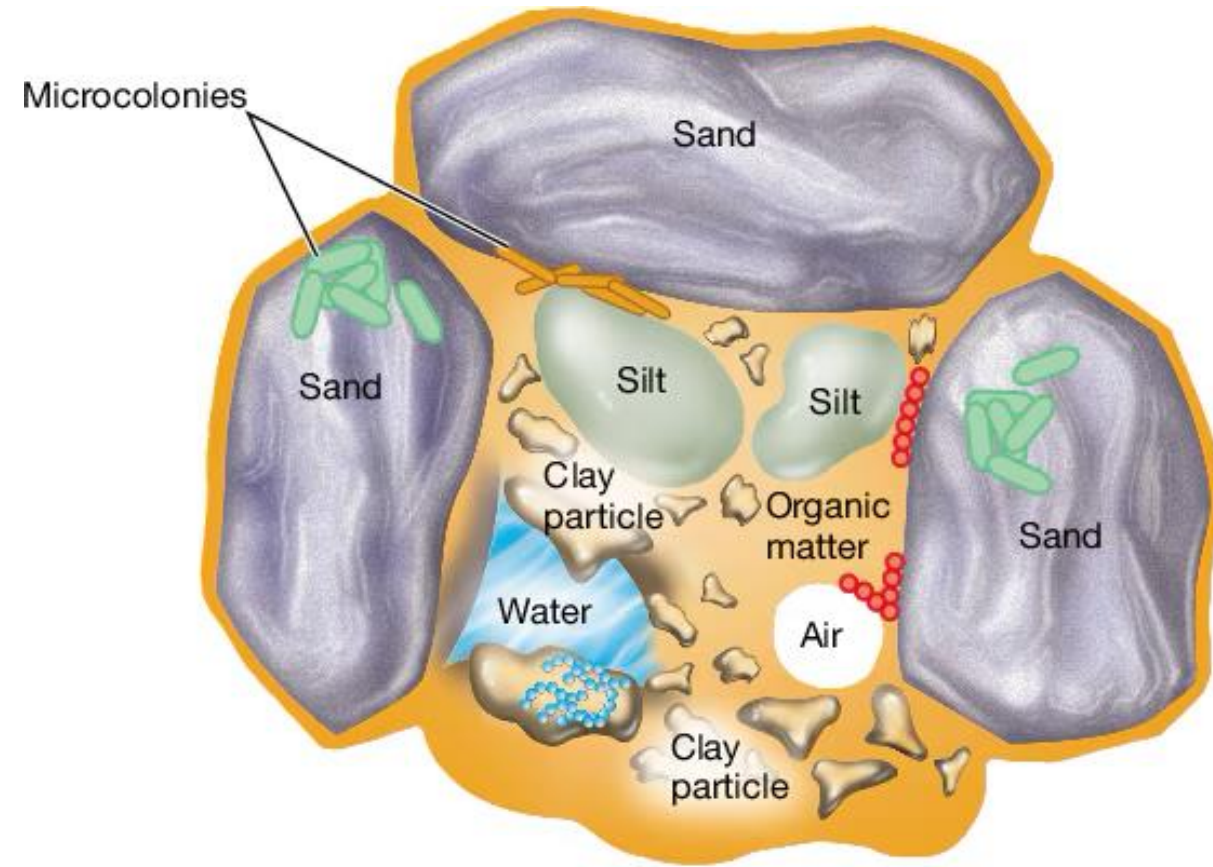
Niche space

Example: Soil particles contain many microenvironments

- Oxygen Microenvironments

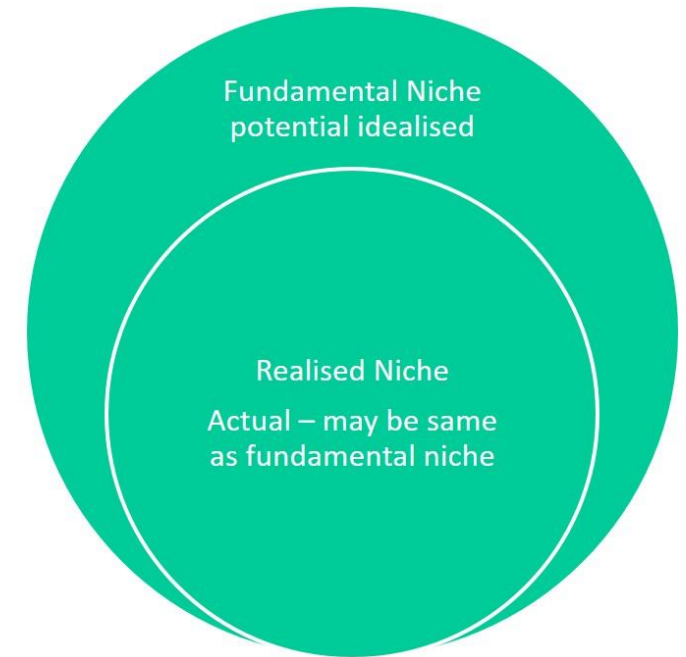


Niche space



Niche space

- Microbes have both a **realized niche** and a **fundamental niche**
 - The fundamental niche indicates where an organism could live,
 - while the realized niche is where an organism does live, given resource limitations and competition



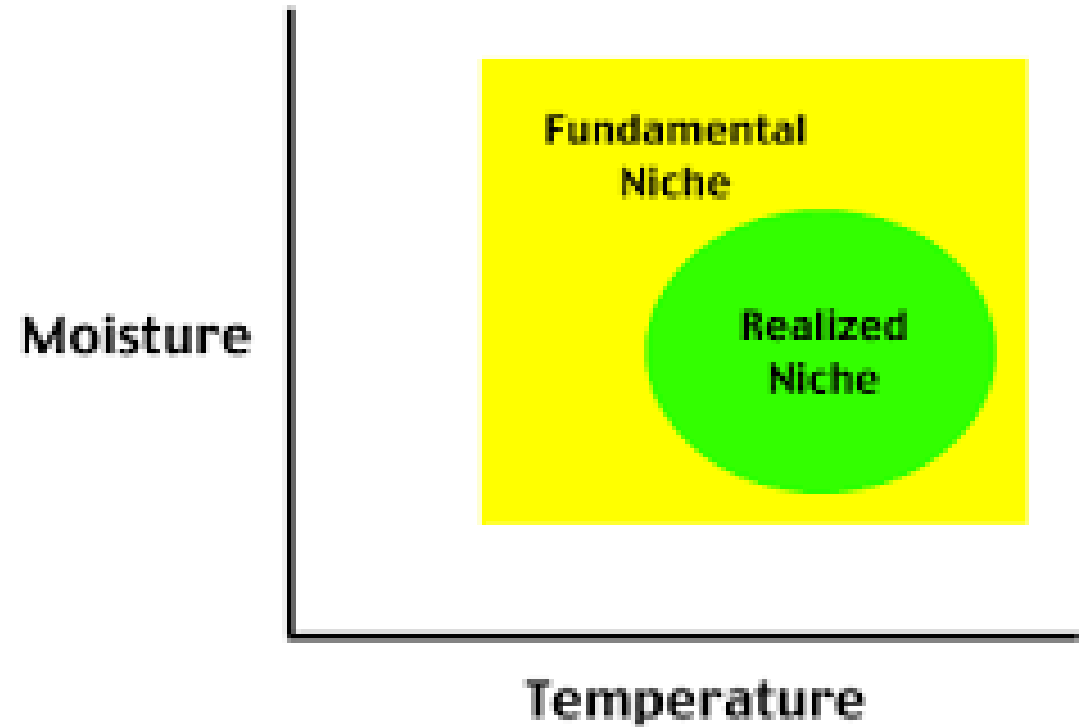
Niche space

The **fundamental environmental niche**

- the set of environmental conditions in which a species can theoretically (i.e., physiologically) live and reproduce in

The **realised environmental niche**

- the restricted set of conditions a species actually occupies *in situ* when accounting for biological interactions (e.g., competition, predation)

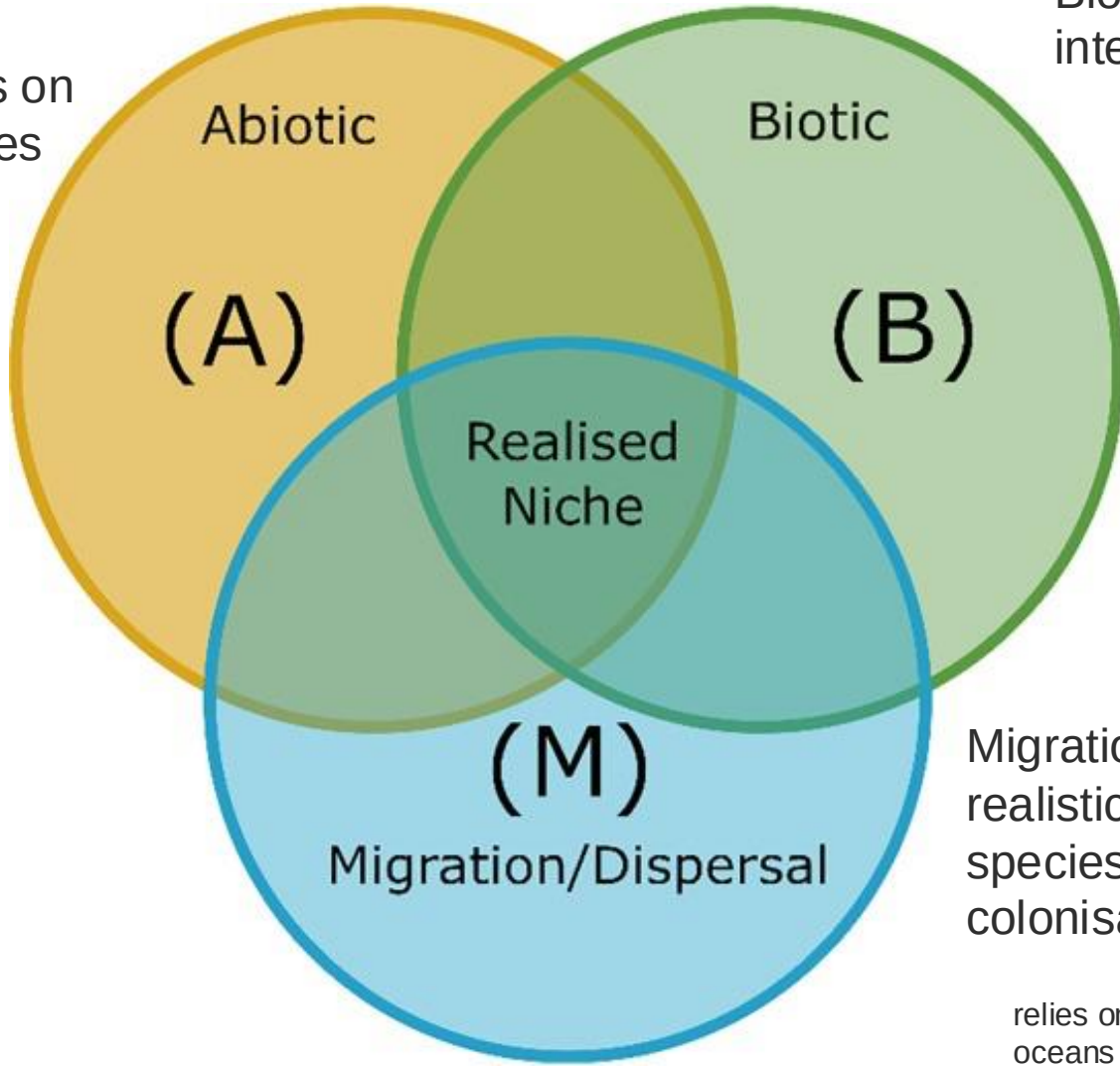


Realised niche is a subset of the fundamental niche

Biotic–Abiotic–Migration (BAM) framework

Abiotic factors impose the physiological limits on the ability of the species to persist in an area.

physicochemical properties of the environment – temperature, O2 availability, N/P availability... etc



Biotic factors include a set of interactions with other species

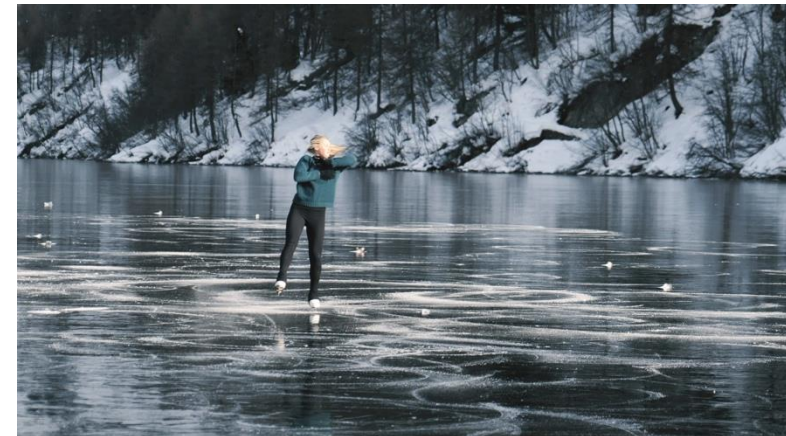
interactions can be either positive (such as mutualism) or negative (such as competition or predation)

Migration/Dispersal is the realistic accessibility of the species to environments for colonisation

relies on land configuration (e.g., oceans or mountains as barriers) and on the dispersal abilities of the species

Environments fluctuate

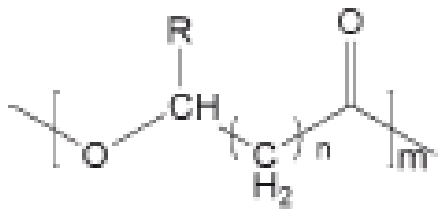
- Physiochemical conditions in an environment are subject to rapid change, both spatially and temporally
 - Nutrients often enter an ecosystem in varying amounts. A large accumulation of nutrients may be followed by a period of severe nutrient deficiency.
- Resources in natural environments are highly 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
 - In nature, extended periods of exponential growth of microorganisms are rare



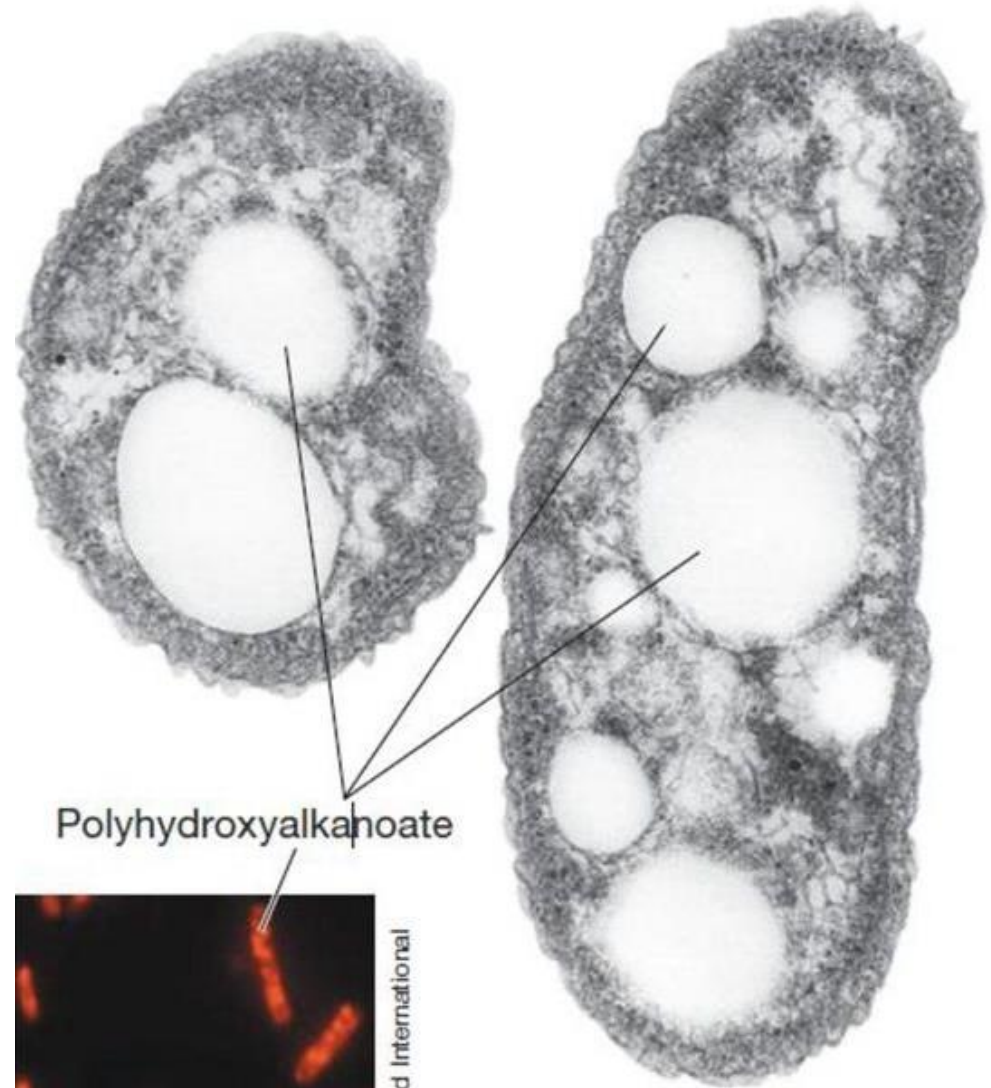
Sidenote

Many microorganisms have evolved biochemical systems that produce storage polymers as reserve materials to store excess nutrients available under favourable growing conditions for use during periods of nutrient scarcity.

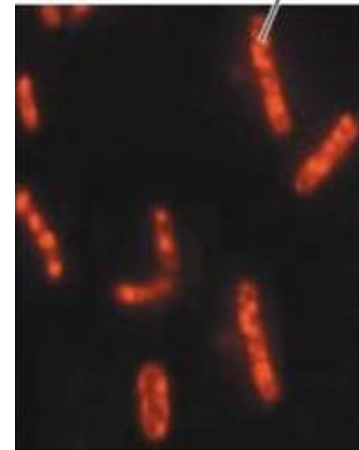
Bioplastics



PHA



Polyhydroxyalkanoate



Mercedes Berlanga and International Microbiology

Competition and cooperation occur between microbes in natural systems

Microbial Interactions

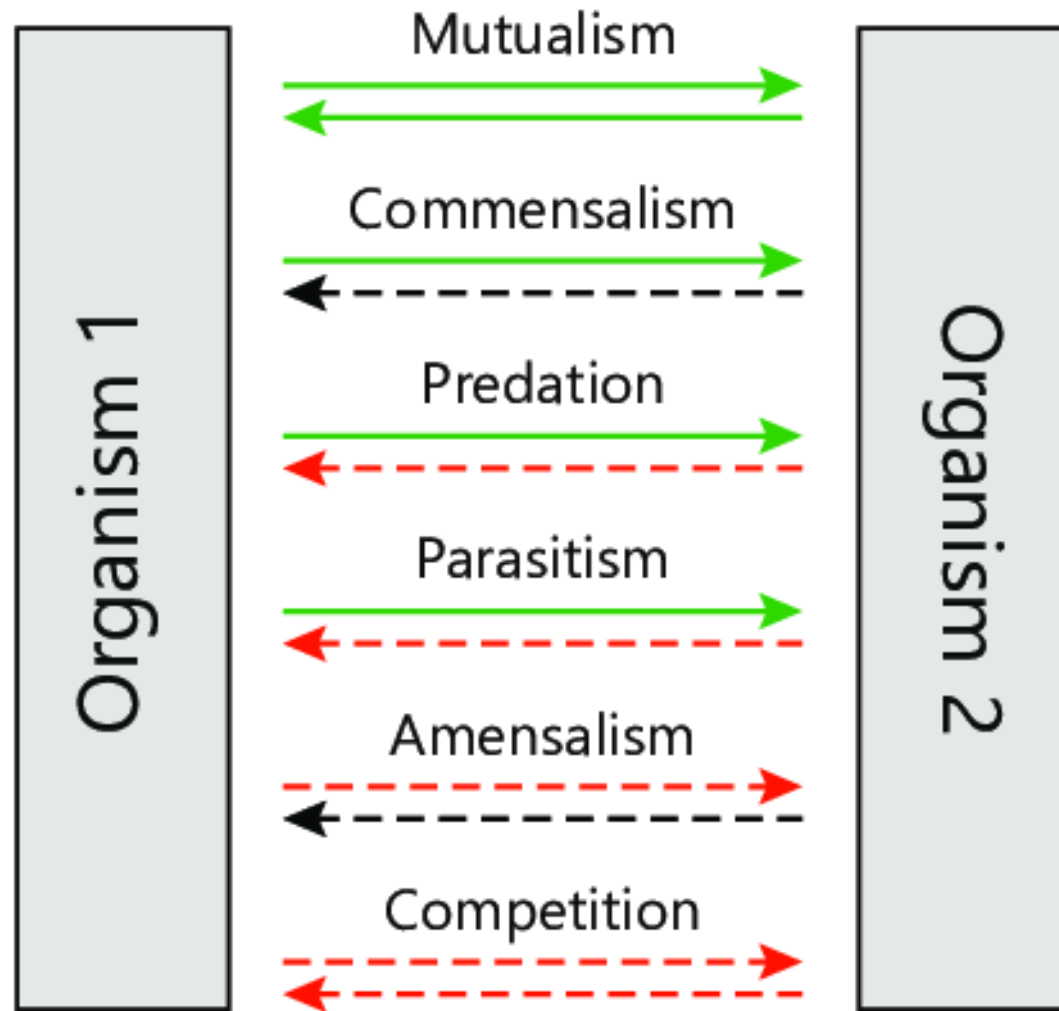
- Neutralism: partners can coexist without interacting with each other
 - Usually when densities is low (marine habitats or oligotrophic lake habitats)
- Competition
 - At higher densities (e.g. competition for food or light)
 - Outcome of competition depends on availability of nutrients and microbial growth rates
- Antagonism
 - One microorganism has a direct negative impact on another (inhibition, killing)
 - Antibiotic production, predation
- Cooperation
 - Mutualism – both microbial species benefit from interaction
 - Commensalism – one microorganism benefits from another
 - Symbiosis – mandatory interaction between organism
 - Syntrophy – two microorganisms complement each other in substrate utilization

Table 2.4 Categories of biological interactions between microorganisms and between microorganisms and other organisms

Categories/types	Characteristics
(a) Neutrallism	The presence of two populations of different microorganisms that do not show any discernible interactions
(b) Mutualism	An interactive association between two populations of different microorganisms from which both derive a small advantage
(c) Synergism	A non-mandatory interactive association between members of two populations or one population that benefits both populations or all members of one population. In synergism, mutualistic coexistence leads to effects that qualitatively and quantitatively exceed the outputs of the partners
(d) Syntrophism	Two organisms complement each other with nutrients or with catabolic enzymes required for the utilization of a substrate (see ► Sect. 10.1.5)
(e) Symbiosis	An obligatory interactive association between members of two populations. Both partners are promoted by living together This is a stable state in which both organisms live in close proximity (ectosymbiosis) or in direct contact (endosymbiosis) to their mutual advantage
(f) Protocooperation	A symbiosis, but not obligatory
(g) Commensalism	One species uses the metabolites of another species without affecting it An interactive association between two populations of different microorganisms in which one population benefits from the association while the other is neither positively nor negatively affected
(h) Kompetition	An interactive association (a struggle) between two populations of different microorganisms that both require a limiting abiotic factor (for example, nutrients, light, oxygen, or space/surface area). If both share this factor, both grow at a suboptimal rate; if the factor is only used/utilized by one population, only that population grows
(i) Amensalism	An interactive association between two populations of different microorganisms by which one is harmed while the other is neither positively nor negatively affected
(j) Antagonism	An interactive association between two populations of different microorganisms in which one exerts a negative effect (inhibition, damage, killing) on the other
(k) Parasitism	An interactive association between two organisms from which the smaller (parasite) benefits and by which the larger (host) is harmed

Extended after Alexander (1977)

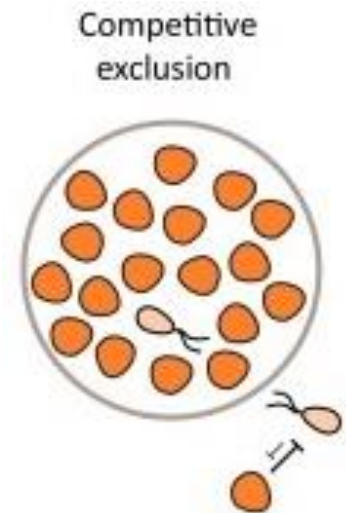
While an interaction listed in (b) to (f) is beneficial for both partners or at least one of them, at least one partner suffers a disadvantage in the case of the interaction characterized in (g) to (k)



- > No effect
- > Positive effect (win)
- > Negative effect (loss)

Microbial Competition

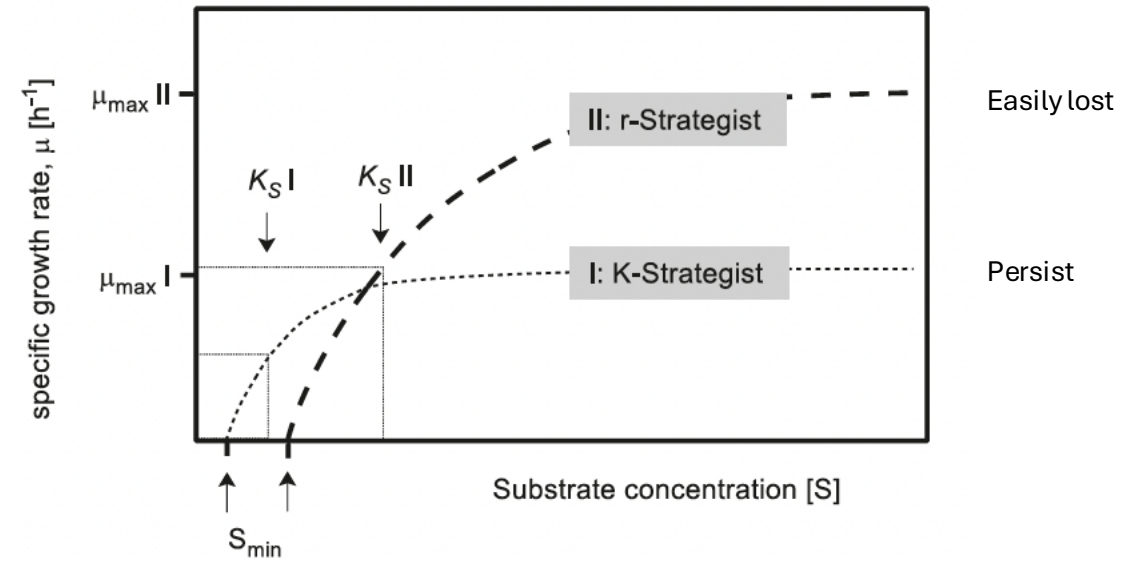
- Energy and nutrient sources are often present in limiting conditions
- Competition for nutrients is one of the major types of interactions among microbial species
- Outcomes depend on growth rates of the species
- Fast-growing organism can generally outcompete slow-growing ones
 - Competitive exclusion



Microbial Competition

- The outcome of a competition between different microorganisms depends on nutrient uptake rates, inherent metabolic rates and ultimately growth rates.
- In nature microorganisms grow with mixtures of substrates

Microbial adaptation strategies to substrate concentration



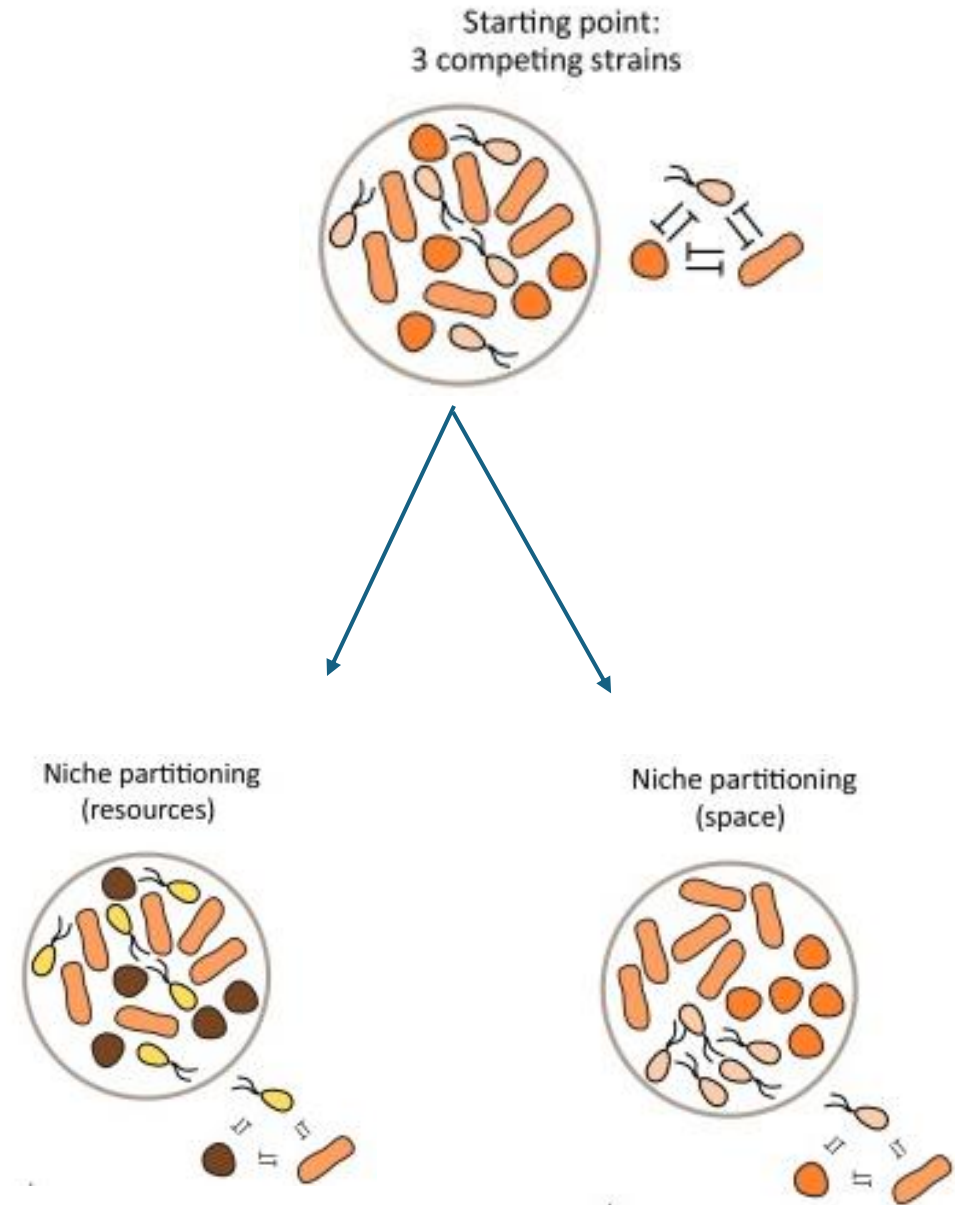
Substrate affinity: K_S

Maximum specific growth rate: μ_{max}

K_S represents the concentration of substrate at which the specific growth rate of microorganisms is half of the maximum rate.

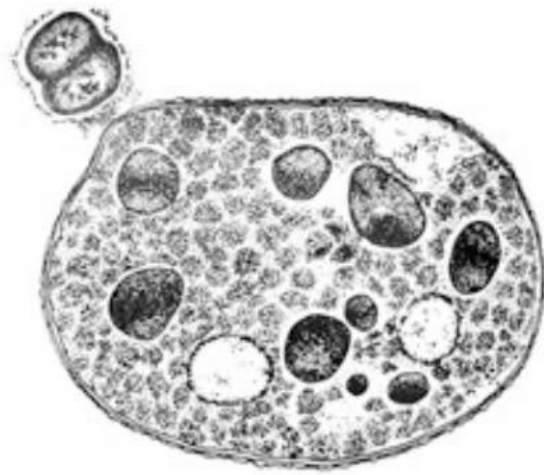
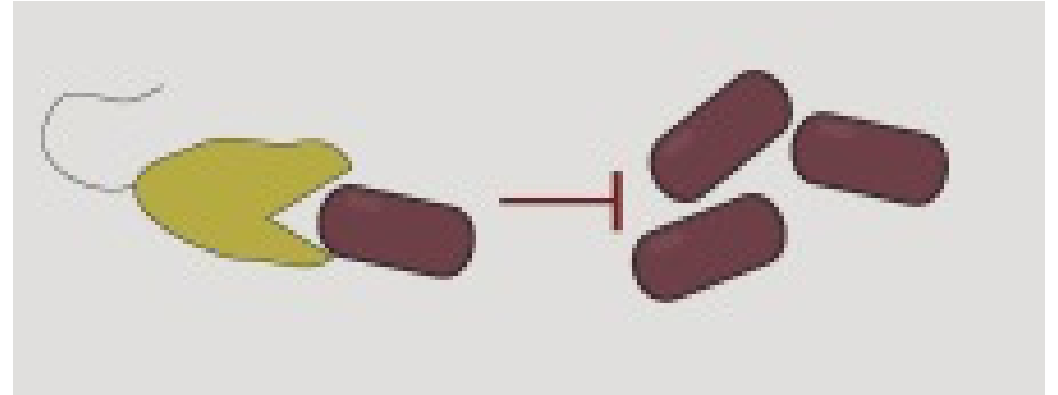
Microbial Competition

- In an ecosystem, fast and slow growing species can live side by side.

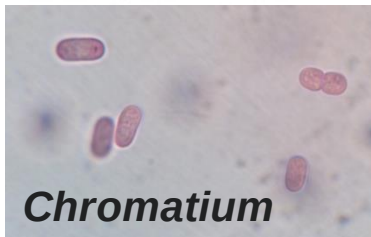


Microbial Antagonism

- Predation

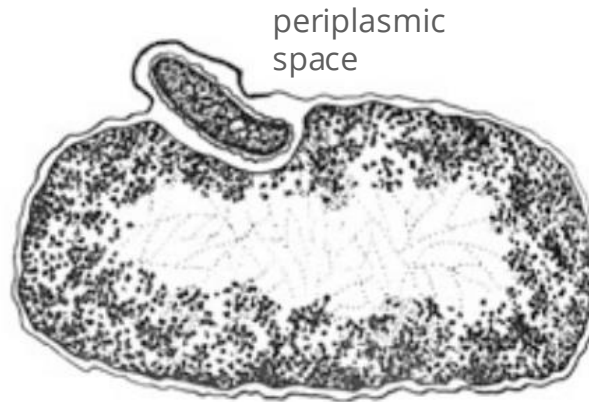


Vampirococcus

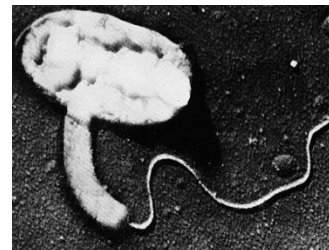


Chromatium

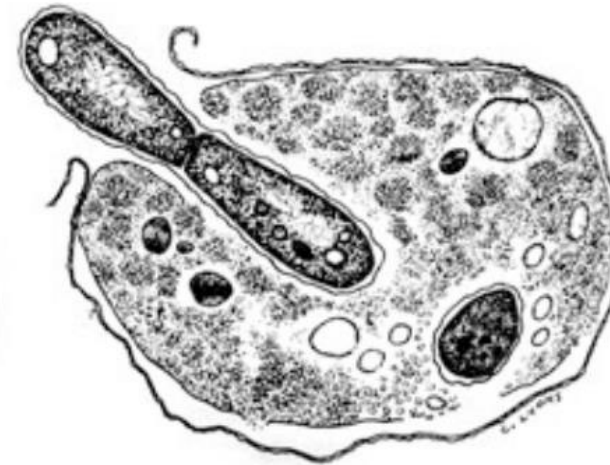
Epibiont: "living on top of"



Bdellovibrio



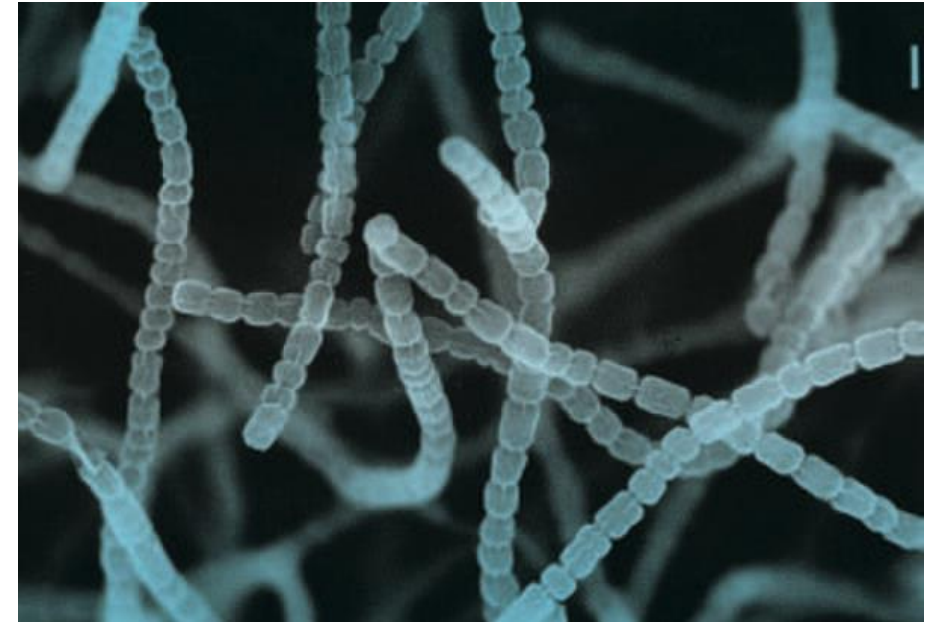
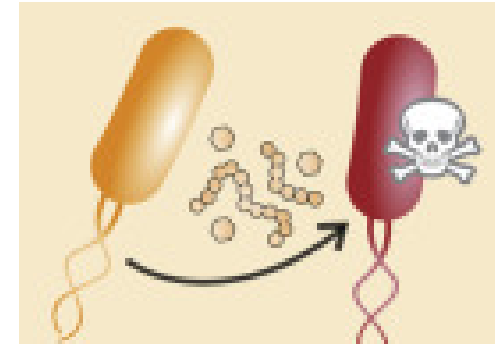
Ectoparasitic



Daptobacter

Microbial Antagonism

- Production of antifungals and antibiotics



80% of antibiotics are sourced from the genus *Streptomyces*
soil-dwelling Gram-positive bacteria

Mutualism

- Interaction is beneficial to both organism, but not mandatory

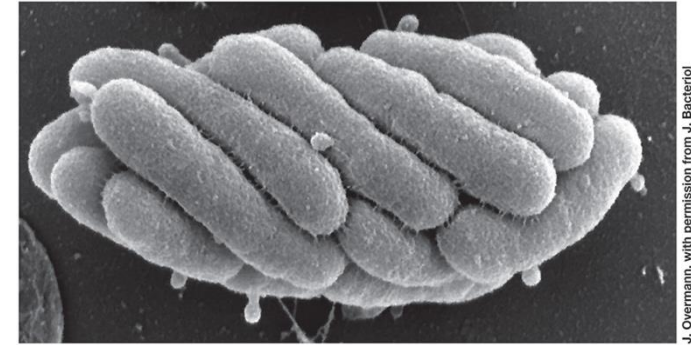
Mutualism



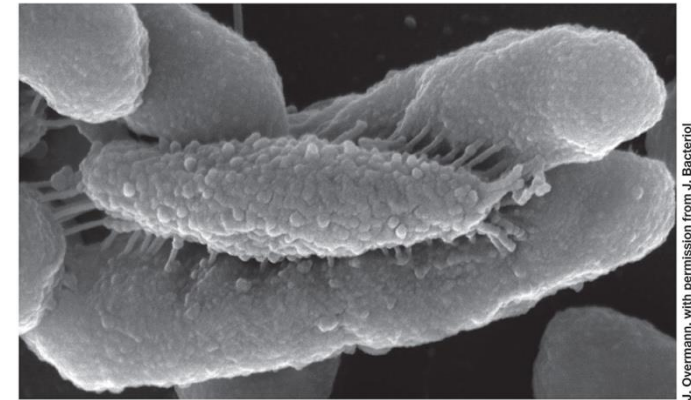
Chlorochromatium Aggregatum

In freshwater there are microbial mutualisms called **consortia**

- nonmotile green sulfur bacteria (epibiont)
 - obligately anaerobic phototrophs
 - *Chlorobium*
- motile, nonphototrophic bacteria
 - flagellated rod-shaped bacterium



(a)



(b)

J. Overmann, with permission from J. Bacteriol

J. Overmann, with permission from J. Bacteriol

Mutualism



Motile consortial

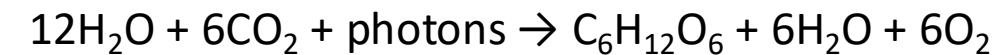
“Chlorochromatium Aggregatum”

These consortia are found in stratified sulfidic lakes

- Light penetrates to layers with H_2S
- Constantly changing gradients of light, oxygen, and H_2S throughout the day.



Oxygenic photosynthesis

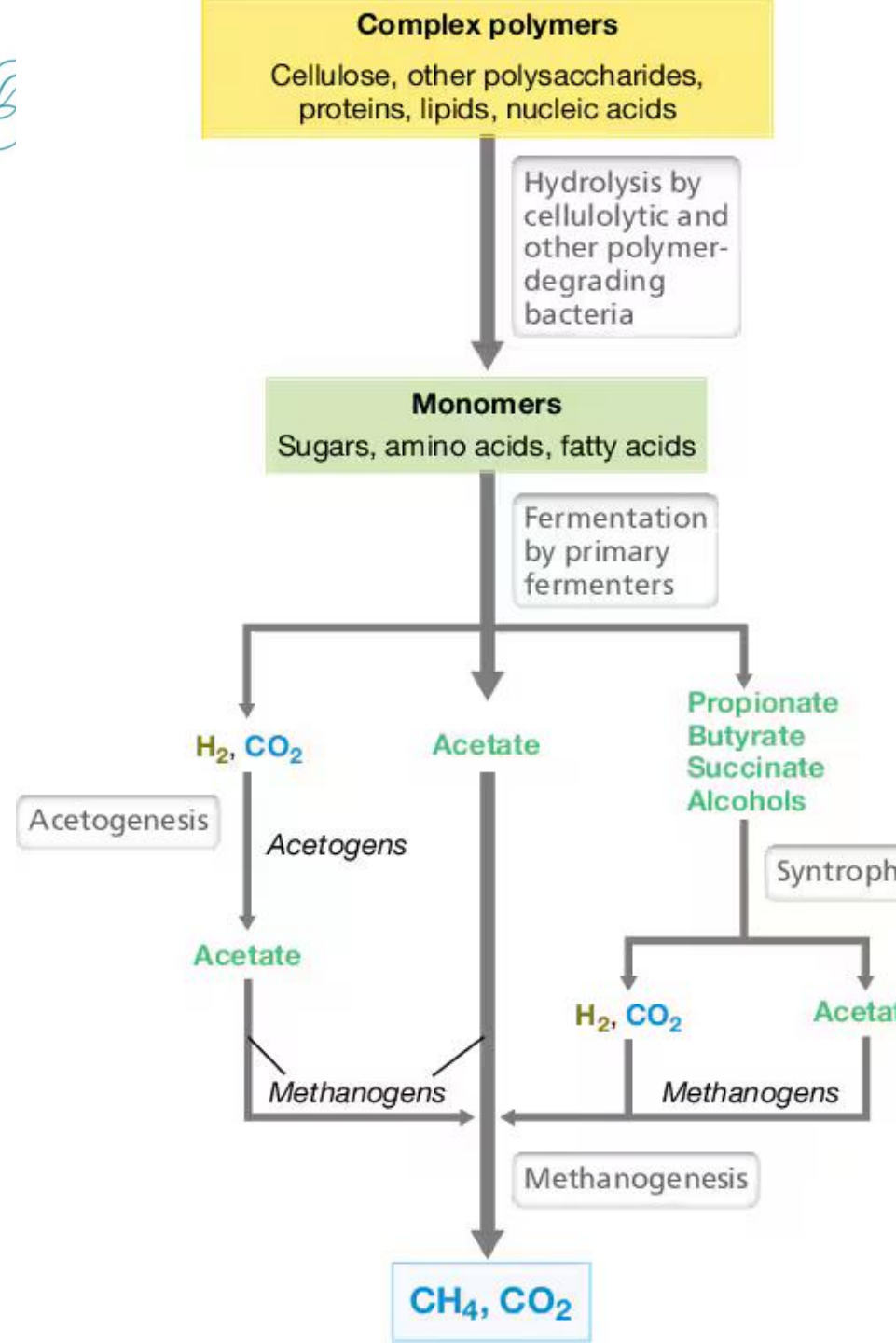
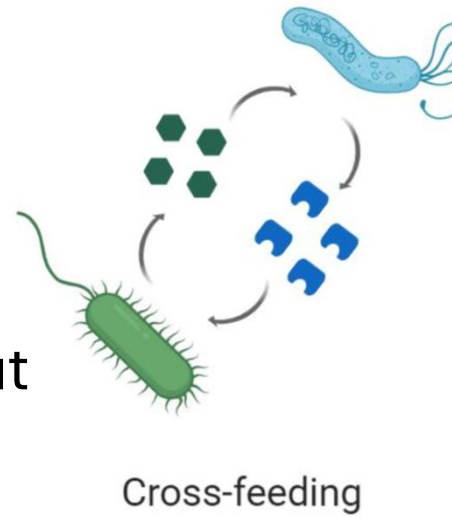


Anoxygenic photosynthesis



Syntrophy

- Microbes work together to carry out transformations that neither can accomplish alone
- Most syntrophic reactions are secondary fermentations in which organisms ferment the fermentation products of other anaerobes
- Metabolic cooperation can also be seen in the activities of organisms that carry out complementary metabolisms



Symbiosis

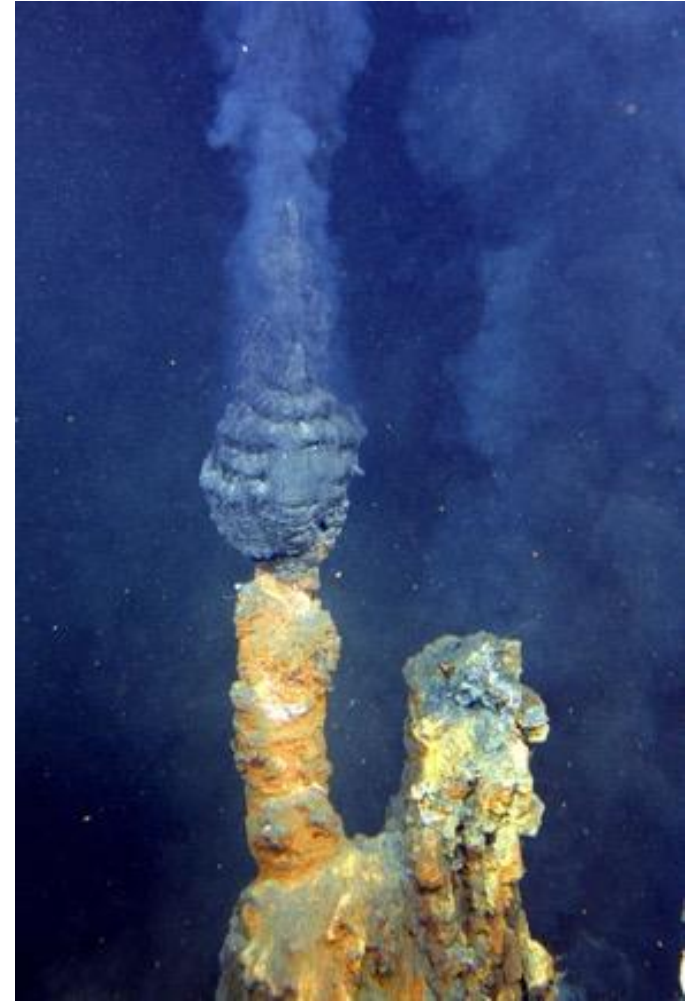
Obligate interactions between the two organisms

- If one partner lives outside the cells of the other partner, it is called **ectosymbiosis**.
- The intracellular settlement of the partner is called **endosymbiosis**.

Symbiosis

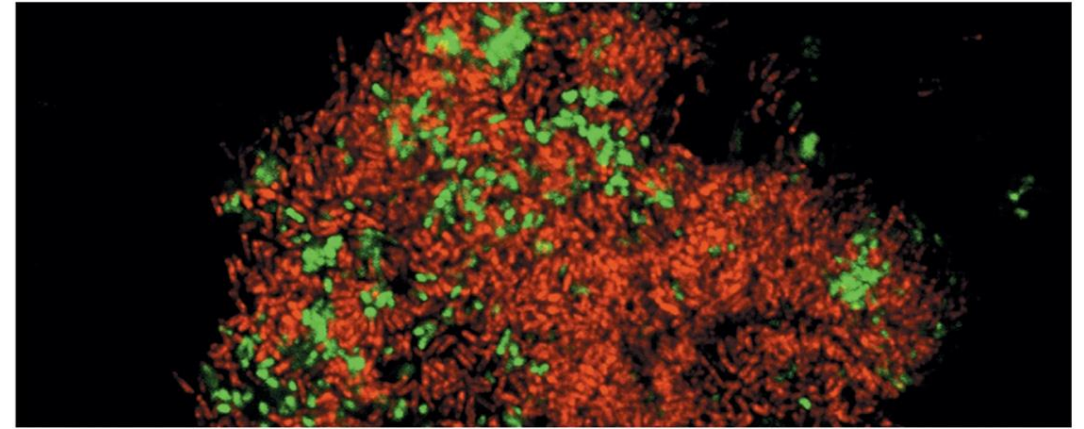
Methanotrophic consortia

- couple the activities of two anaerobic microbes effectively oxidizing methane to CO_2 in anoxic marine sediments
- specific methane-oxidizing (methanotrophic) Archaea form intimate associations with sulfate-reducing bacteria.



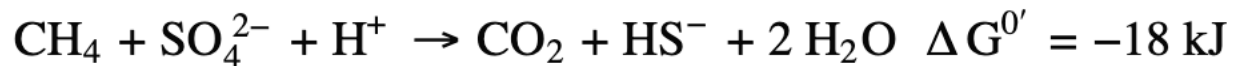
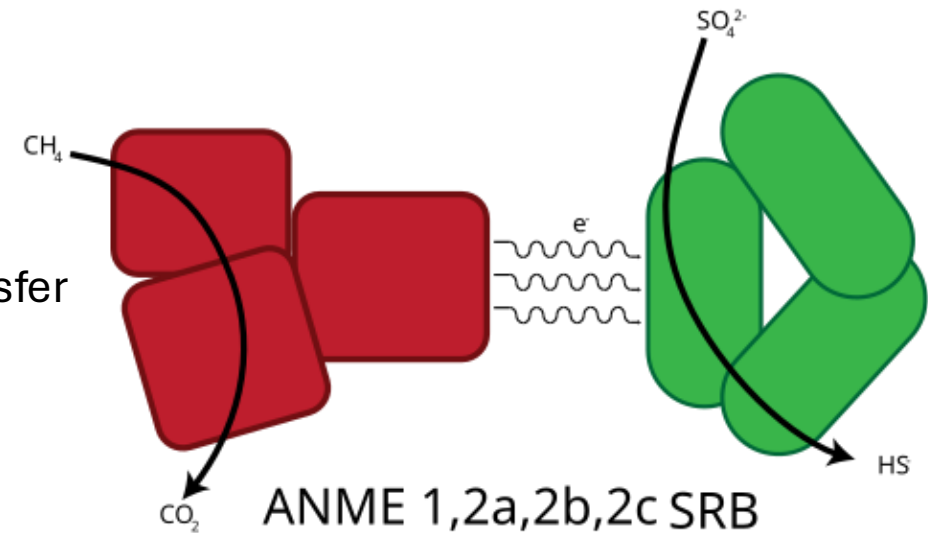
Symbiosis

- A methanotrophic consortia enriched from geothermally heated sediments
- ANME methanotroph (red fluorescence) and its sulfate-reducing bacterial partner (green fluorescence)



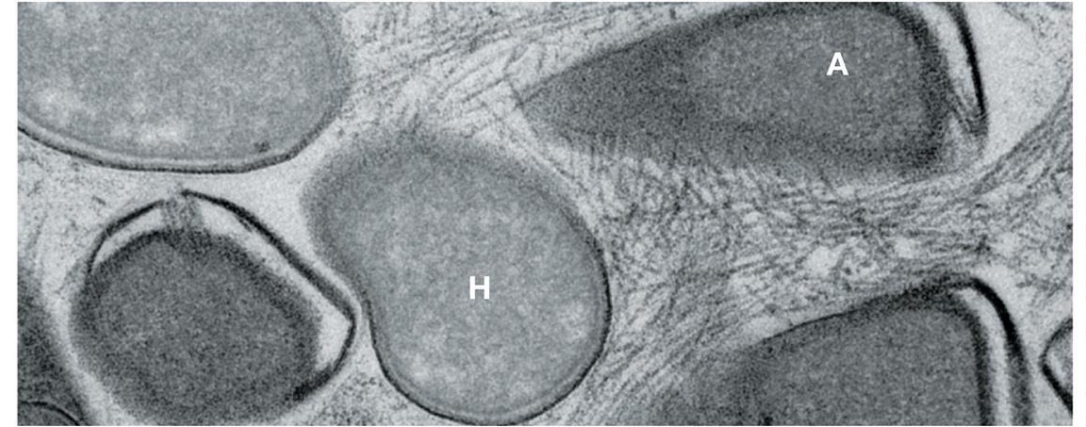
- Anaerobic Methane-Oxidizing Consortia

Direct Interspecies Electron Transfer

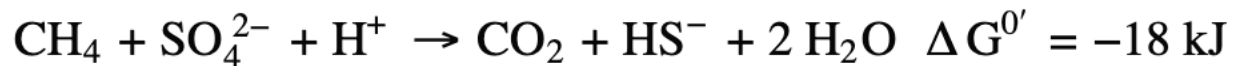
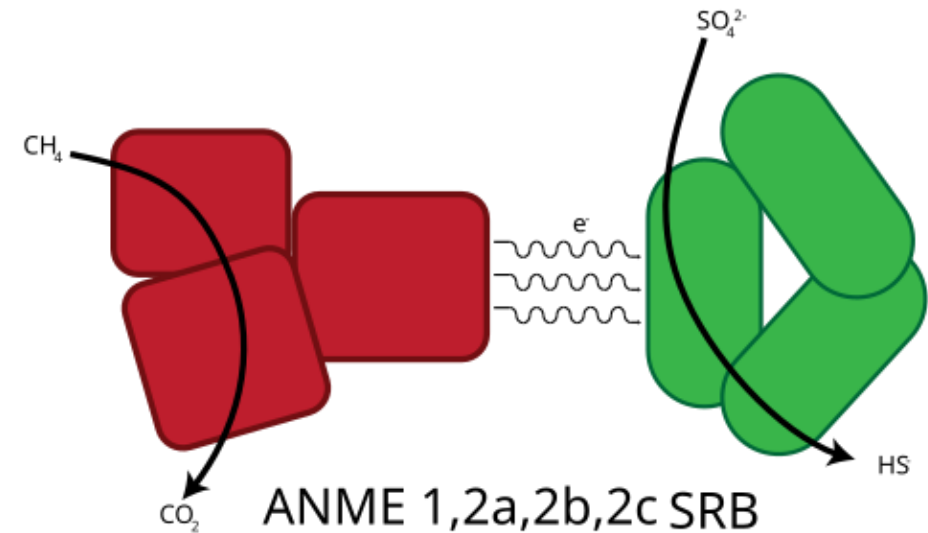


Symbiosis

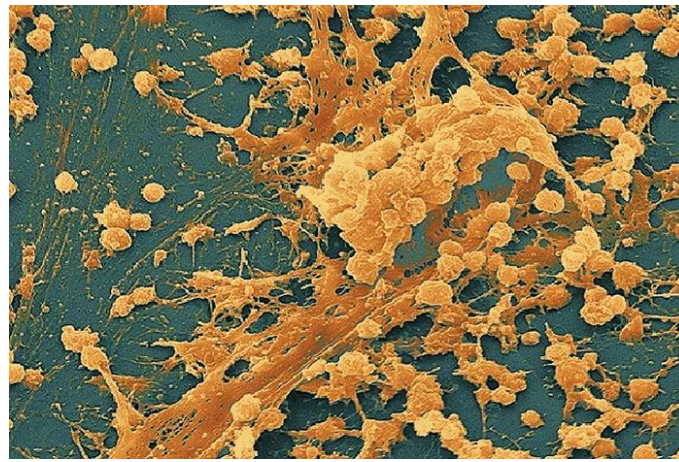
- A methanotrophic consortia enriched from geothermally heated sediments
- ANME methanotroph (red fluorescence) and its sulfate-reducing bacterial partner (green fluorescence)
- Electron micrograph of a thin section through the consortia, showing the electrically conductive “nanowires” produced by the sulfate reducer (H), connecting it electrically to cytochrome-rich proteins on the surface of the ANME methanotroph (A)



Viola Krukenberg, Karin Knittel, and Gunther Wegener



Biofilms



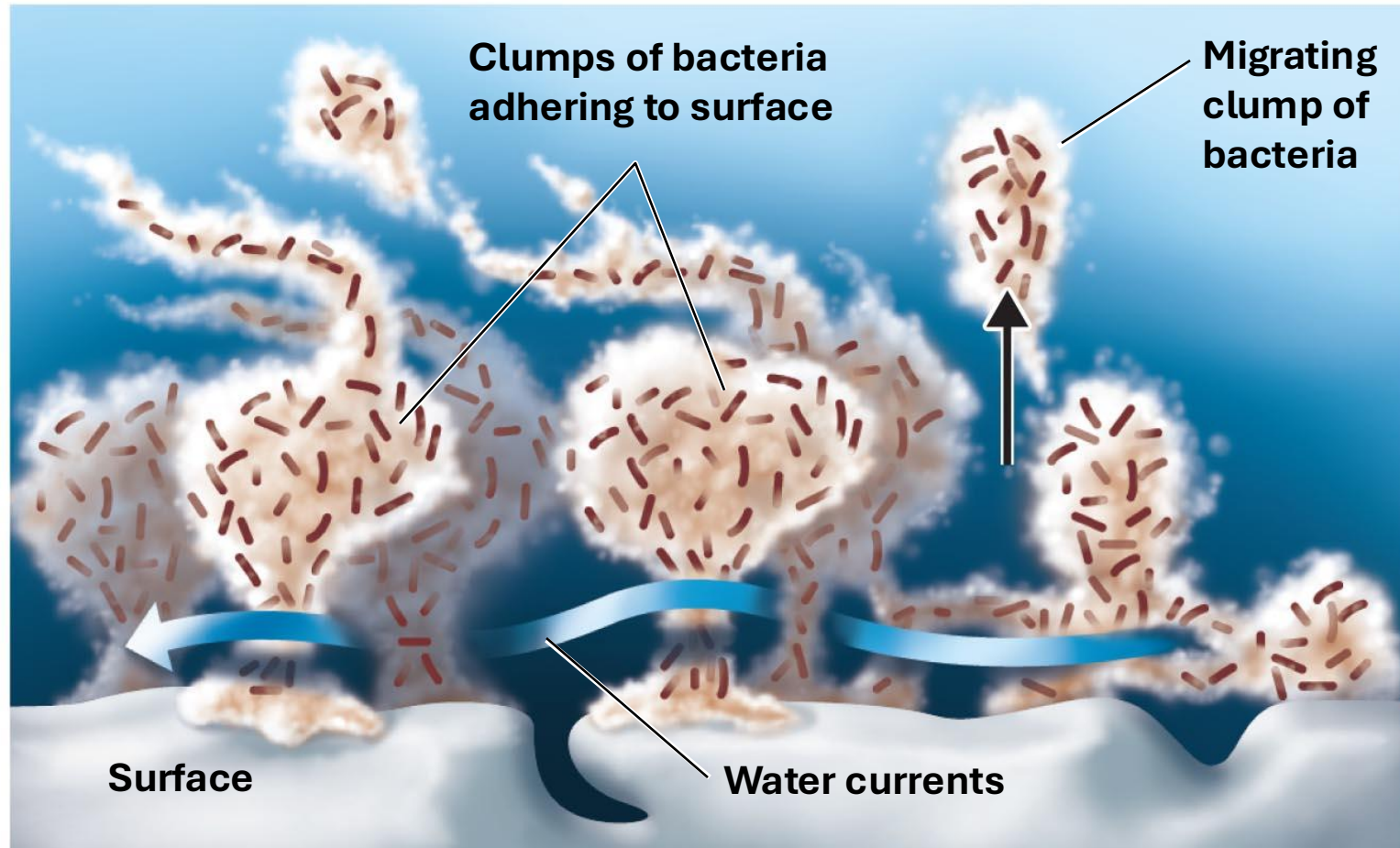
Complex colonies of microorganisms
Offer protective coatings for microbes to shield them from unfavourable environments



The chemical structure shows a central glucose molecule in its cyclic form, linked to several other sugar units. A galactose unit is attached to the C2 position of the central glucose. A mannose unit is attached to the C4 position. A sialic acid unit is attached to the C6 position. The structure also includes a long chain of glucose units extending from the C4 position, and a side chain containing a glucose unit and a sialic acid unit attached to the C2 position of the central glucose. The structure is highly branched and complex, representing a typical polysaccharide structure.



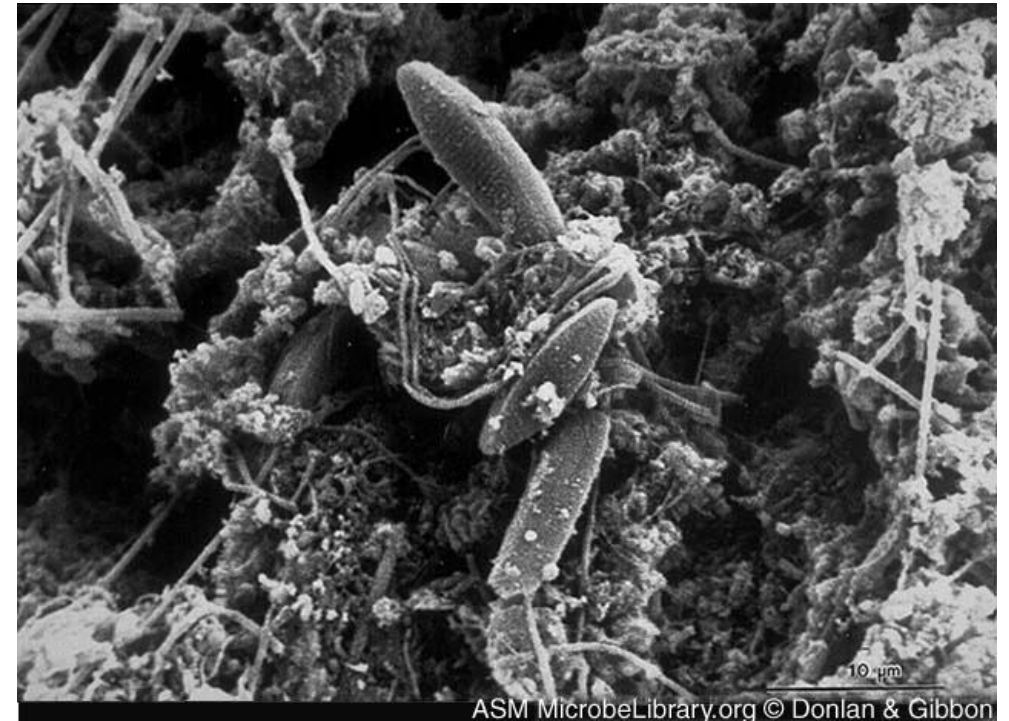
- Extracellular polymeric substance (EPS) matrix is made by microorganism
- Cells entangled in a polysaccharide matrix attached to surface



Water currents move, as shown by the blue arrow, among pillars of slime formed by the growth of bacteria attached to solid surfaces. This allows efficient access to nutrients and removal of bacterial waste products. Individual slime-forming bacteria or bacteria in clumps of slime detach and move to new locations.

Biofilms

- Multiple species or single species
 - Organised communities of microorganisms (e.g. bacteria, protozoa, algae, fungi)
- Predominant form of microbial life that is ubiquitous in natural ecosystems
- Exchange of nutrients
 - Syntrophic interactions
- Exchange of genetic material



Akin to multicellular organisms?

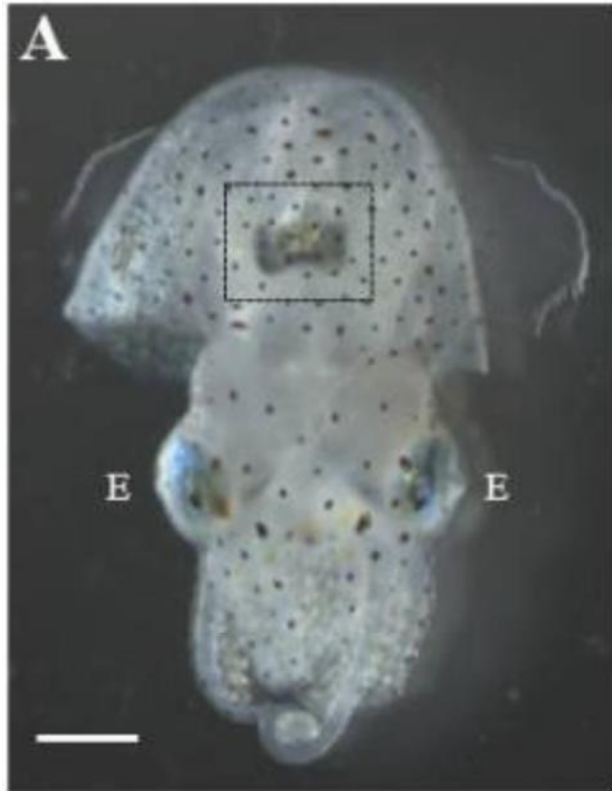
- division of labour among specialised cell types (same species)
- the division of labour via the interaction of different taxonomic groups (multiple species)

Quorum Sensing

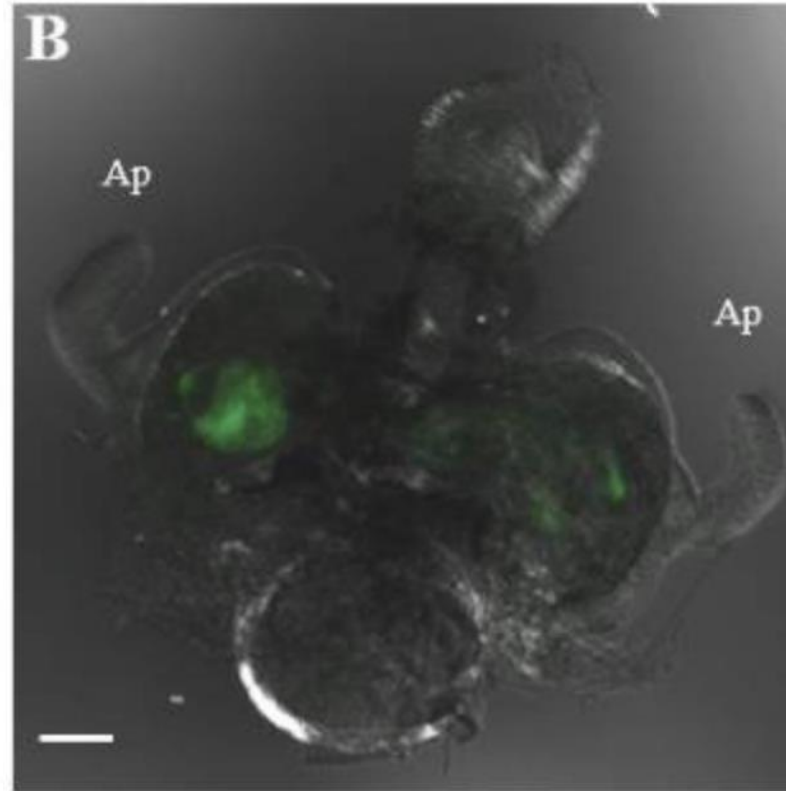
- The ability of bacteria to communicate with each other is called **quorum sensing**
 - Intercellular form of communication
 - Produce and secrete signalling molecules
 - Measurement of the cell density
- Initiate coordinated group behaviour
 - Luminescence
 - Spore formation
 - Antibiotic production
 - Biofilm production



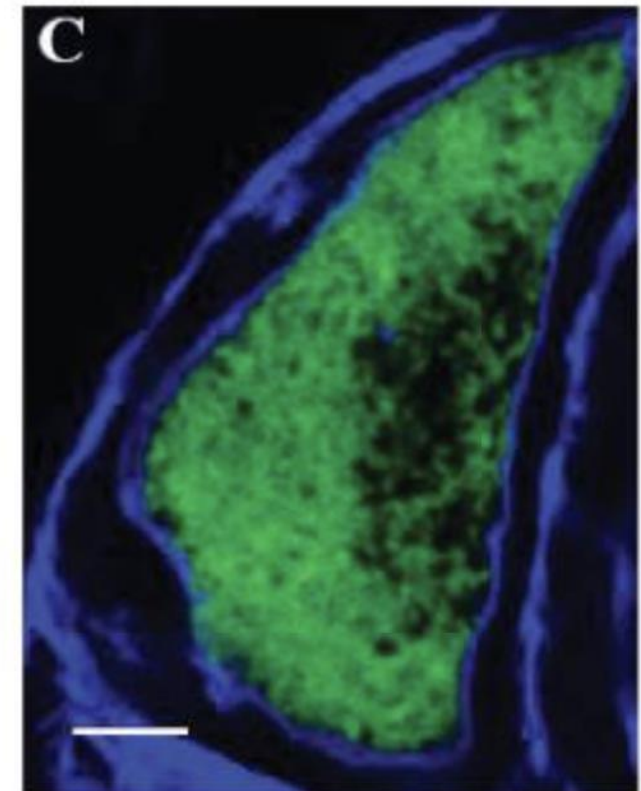
Quorum Sensing



E. scolopes



light organ



V. fischeri

Lichens

- Lichens are a mutualistic relationship between:
 - Mycobiont: fungus
 - Photobiont: alga or cyanobacterium
- Often found on rocks, tree bark, house roofs, and the surfaces of bare soils



Pierre Philippe Laisue

(a)



T.D. Brock

(b)

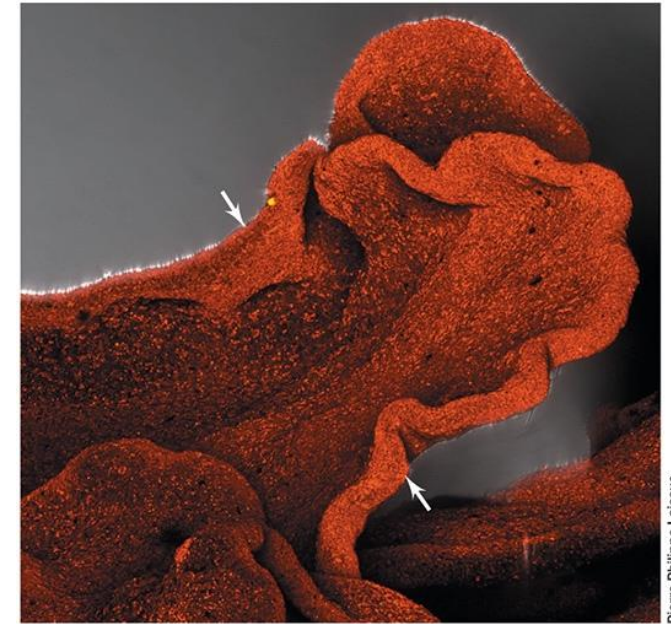


M.T. Madigan

(c)

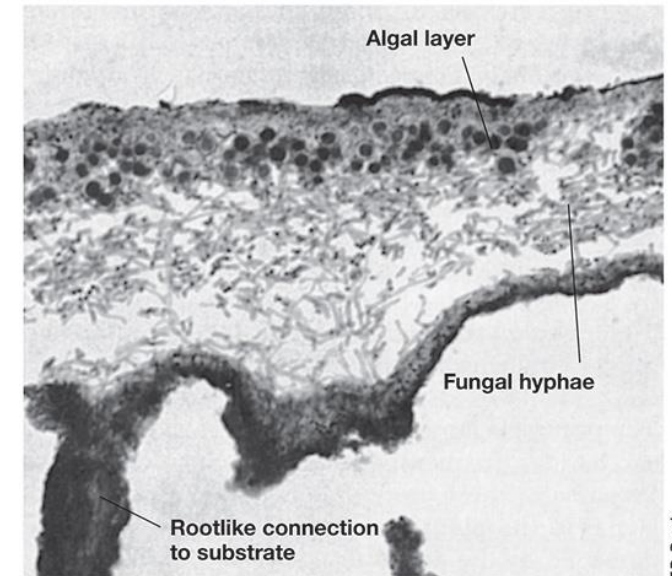
Lichens

- The photobiont is photosynthetic and produces organic matter and often nitrogen-fixing
- The fungus provides a structure within which the phototrophic partner can grow protected
- Lichens are more complex than previously considered as they contain bacterial and archaeal microbiota



Pierre Philippe Laissue

(a)

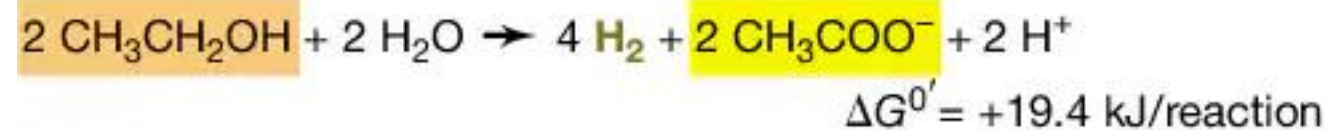


T.O. Brock

(b)

Extra slides

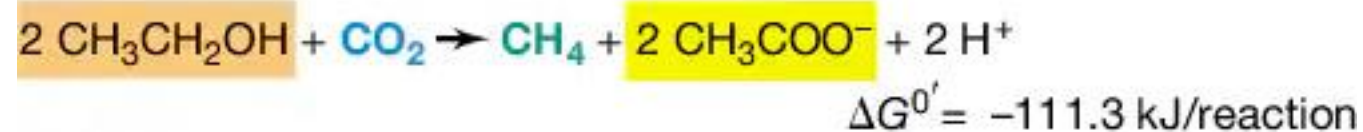
Ethanol fermentation carried out by the syntroph:



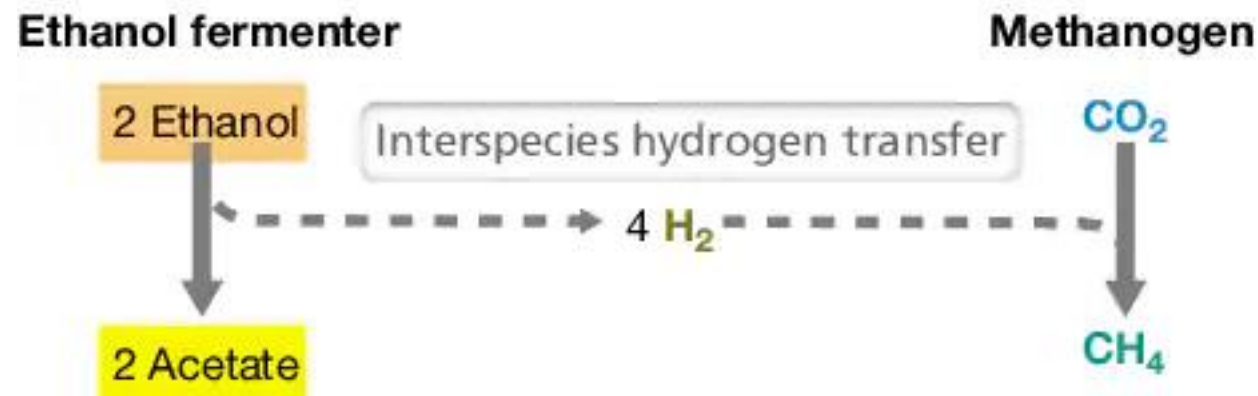
Methanogenesis carried out by the methanogen:



Coupled reaction in coculture of syntroph and methanogen:

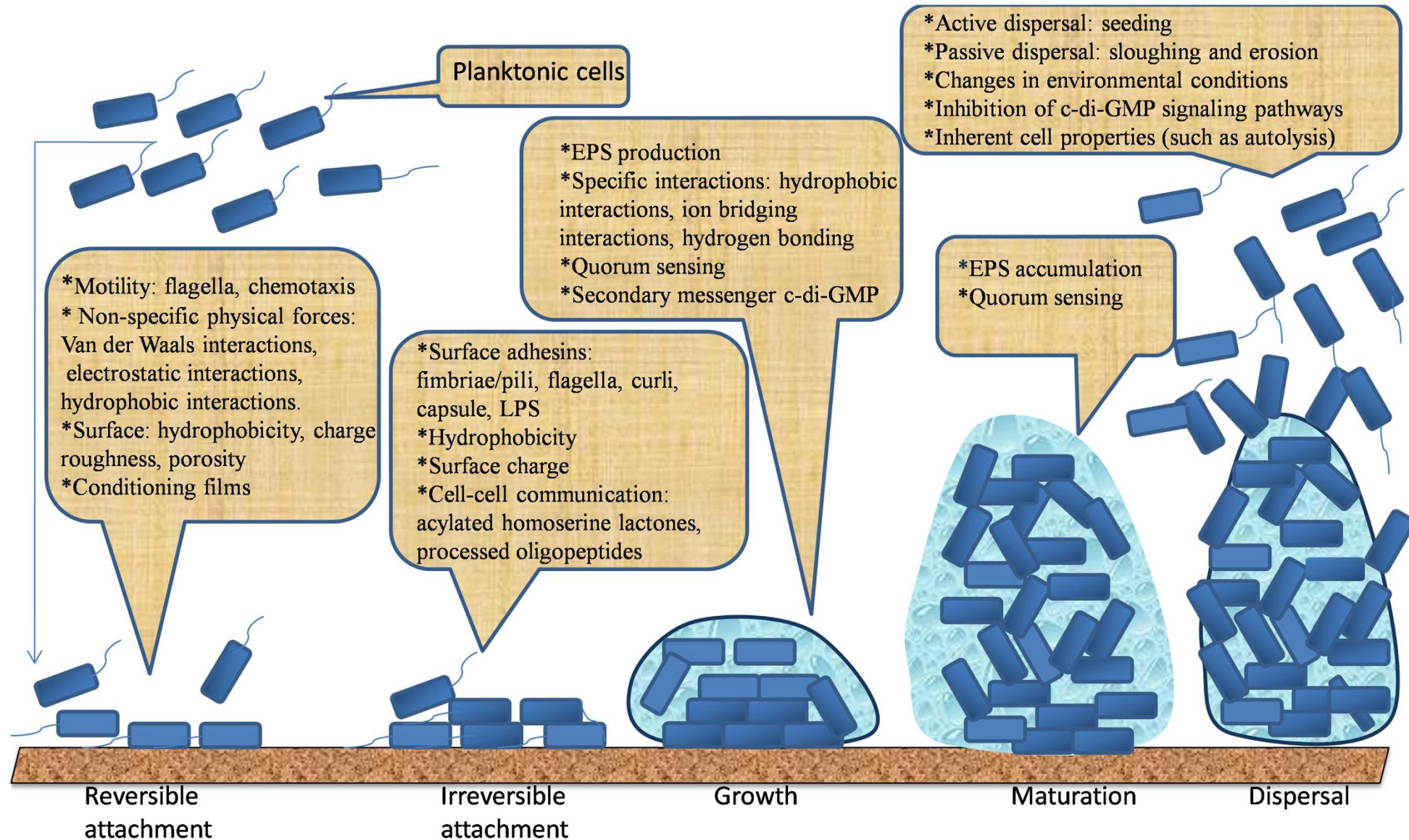


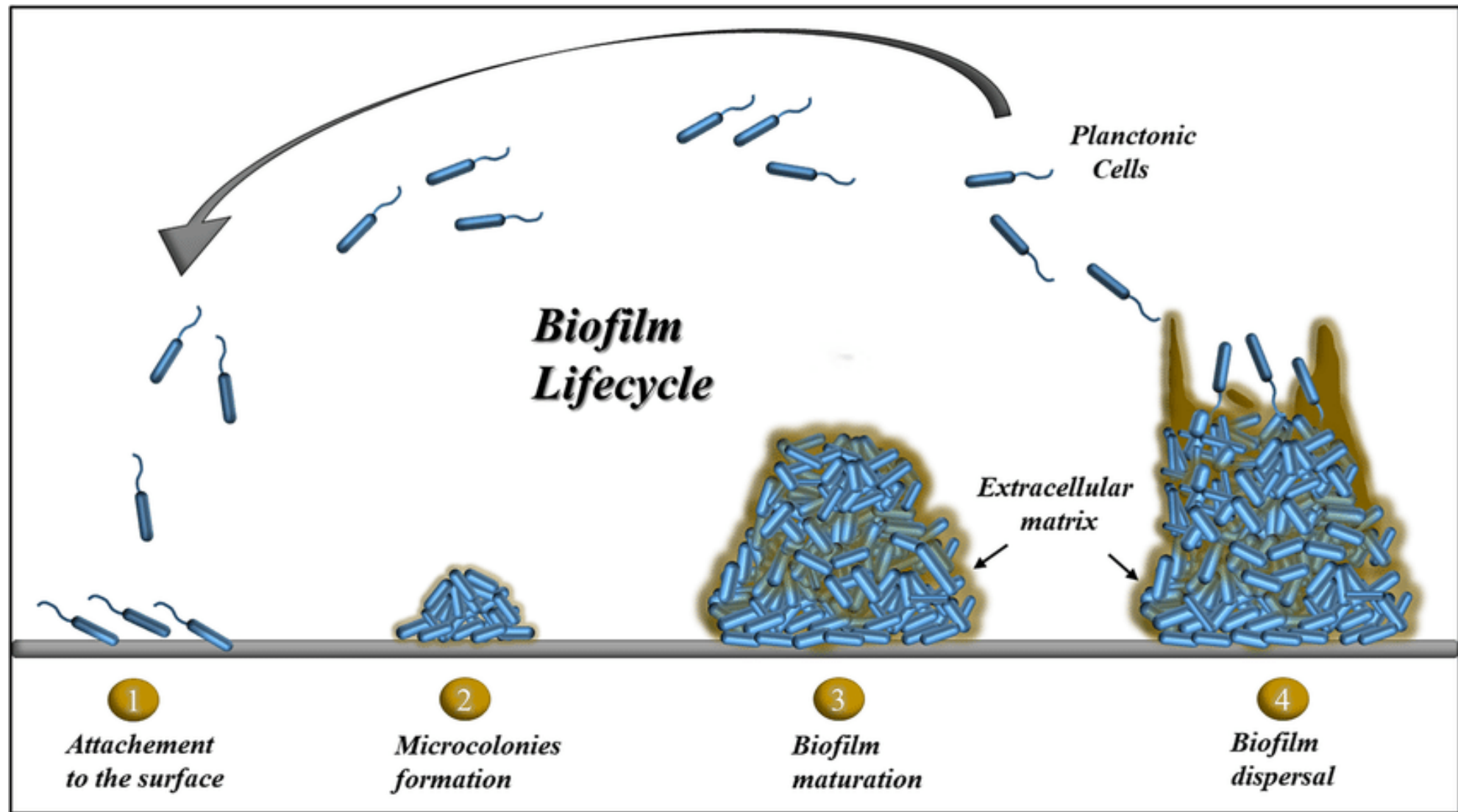
(a) **Reactions**



(b) **Overview of syntrophic transfer of H₂**

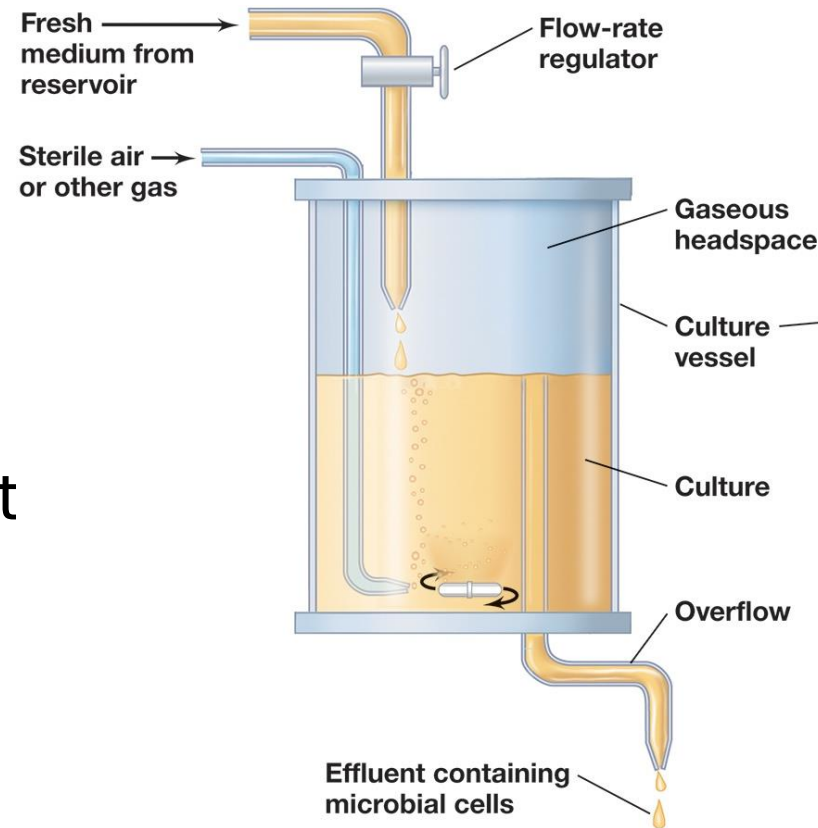
The five main phases leading to the development and dispersal of biofilm





Microbial Growth Cycle

- **Continuous culture:** an open system
- **Chemostat:** most common type of continuous culture device; known volume added while spent medium is removed at same rate
- **Steady state:** cell density and substrate concentration do not change over time



(a)



(b)