Environmental Microbiology & Ecology Intro

Microbiology
"small life"

The study of microorganisms (microbes) - organisms that cannot be seen by the naked eye: ie. they are microscopic

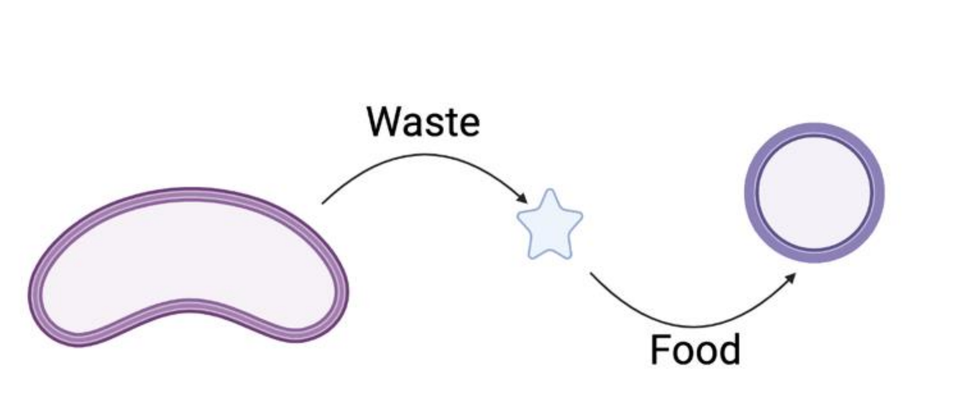
Microbes can exist as single cells (unicellular). They must generate energy and grow independently.

Microbes can also form communities, "talk" to each other, and initiate group behavior.

Microbial diversity on the human tongue

Biofilm in a water pipe

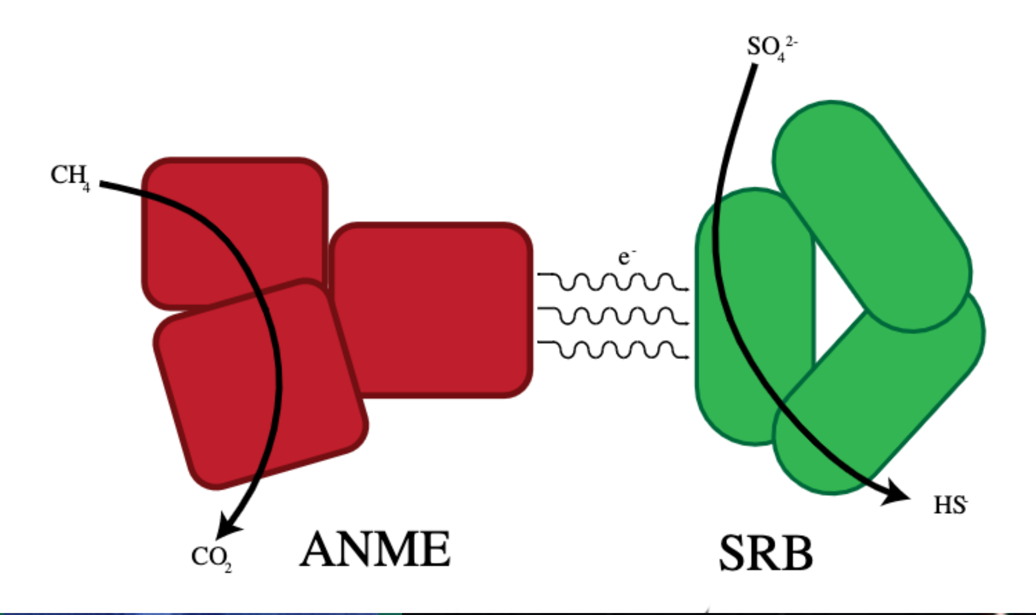
Microbial Interactions

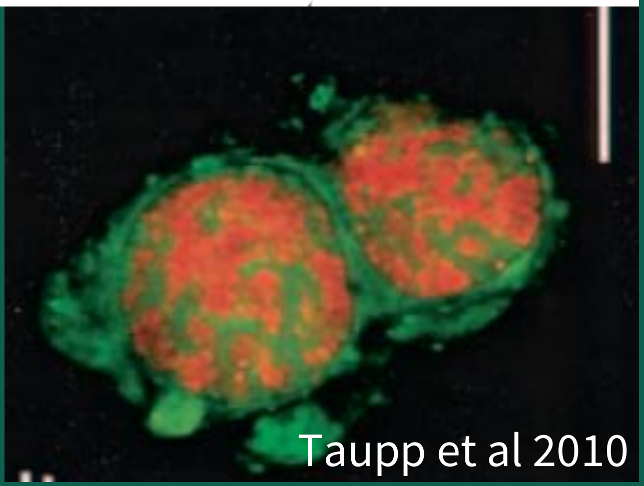


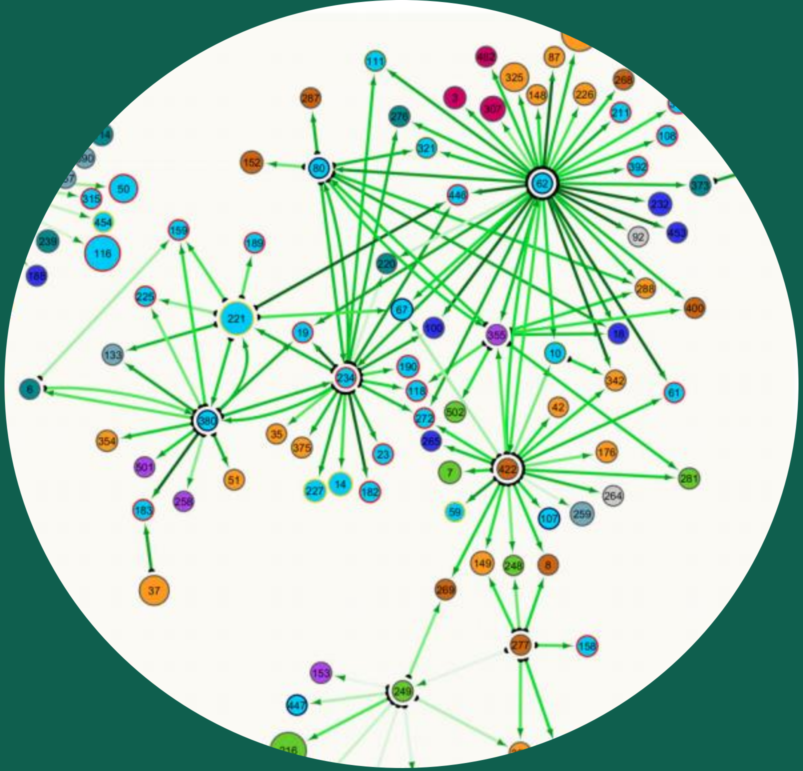
Syntrophy - "Cross feeding"

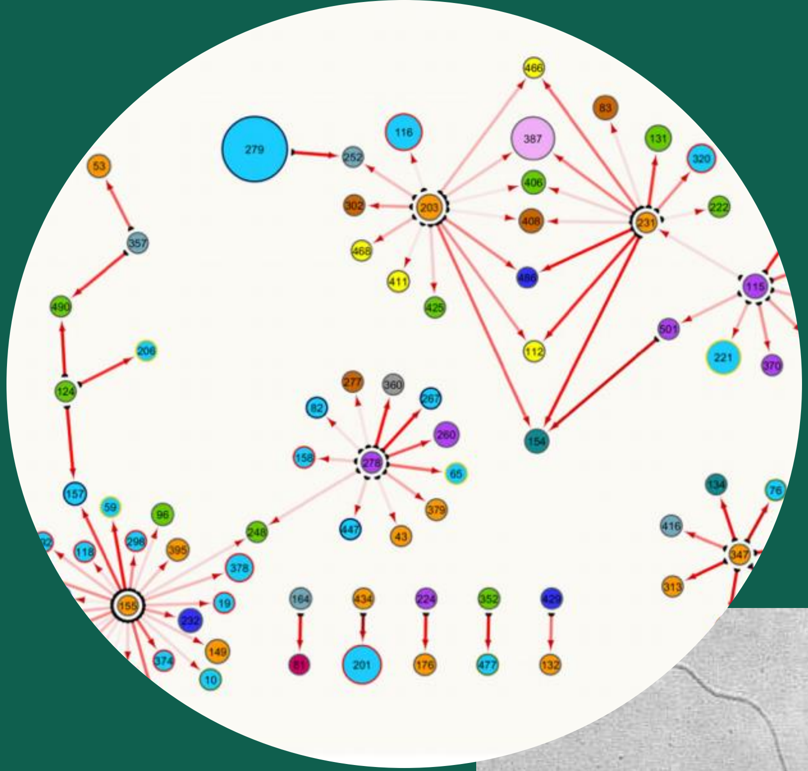
One microbes trash is another microbes treasure.

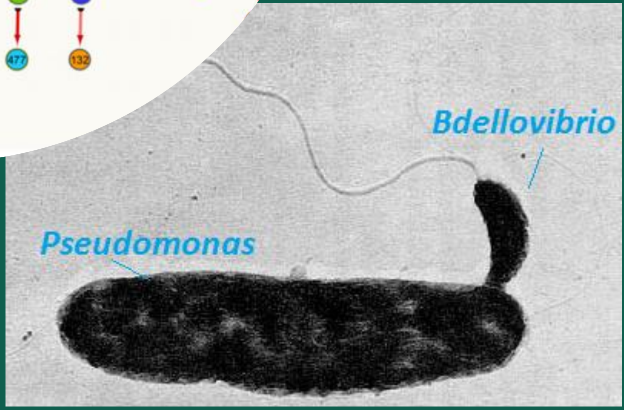
Anaerobic Oxidation of Methane











Positive

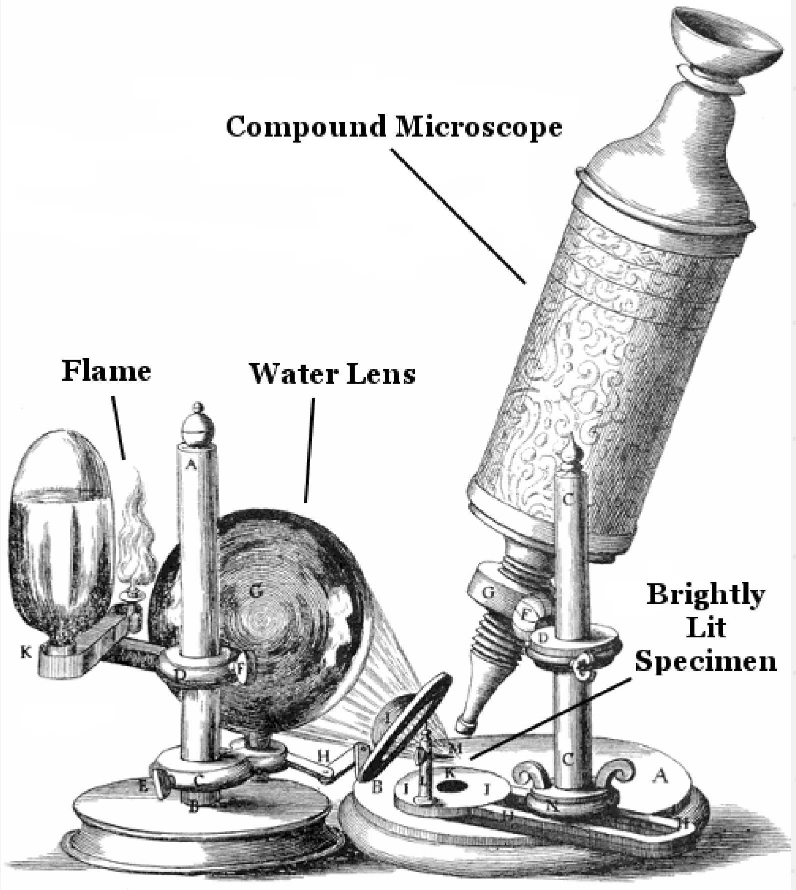
Cooperation - biofilm production
Syntrophy
Symbiosis
Excretion of extracellular enzymes

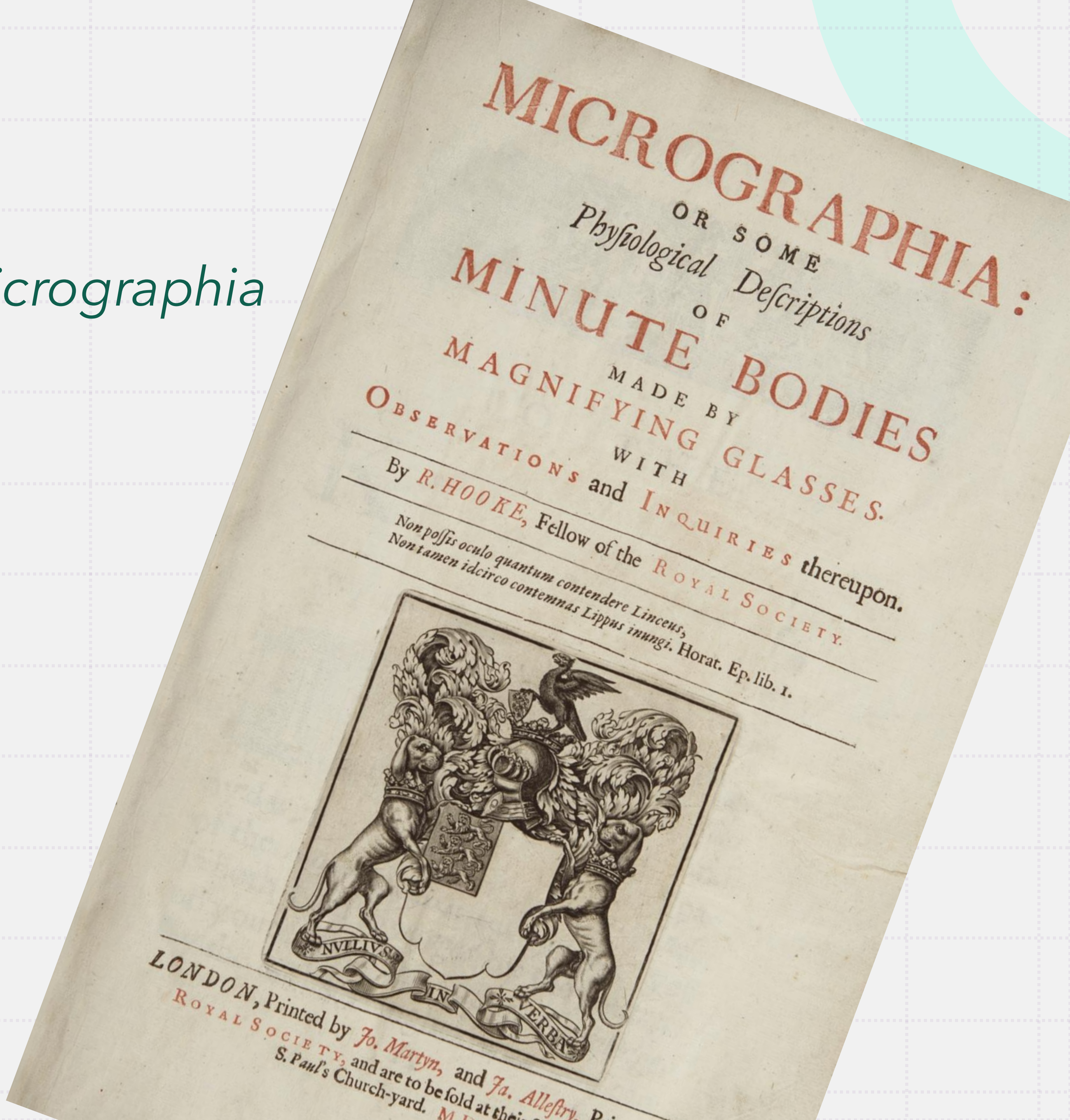
Negative

Predation
Waste- makes inhospitable env.
Antimicrobial substances
Competition for the same niche

Micro-history

In 1665 Robert Hooke publishes *Micrographia* on his observations through lenses

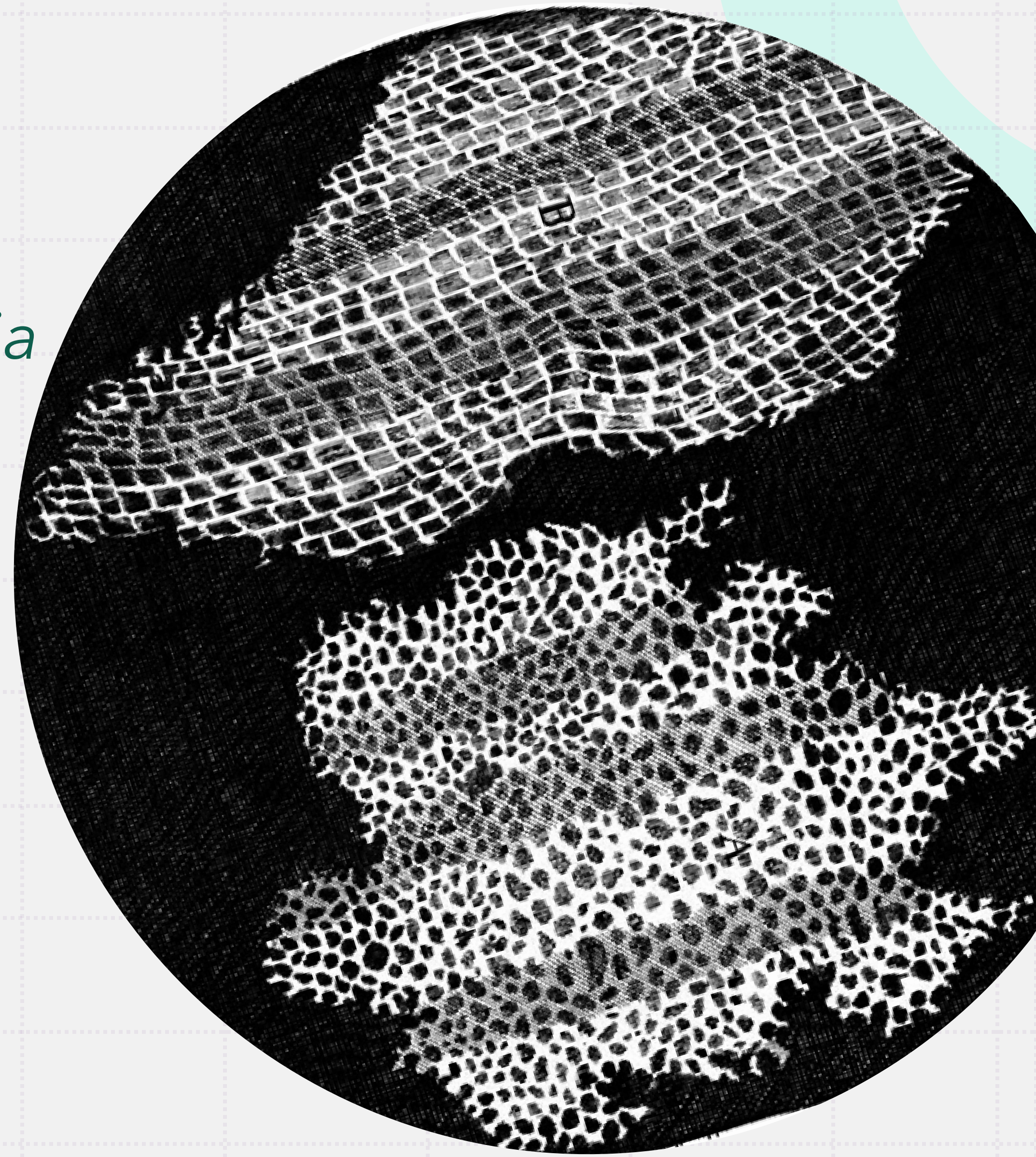



MICROGRAPHIA:
OR SOME
Physiological Descriptions
OF
MINUTE BODIES
MADE BY
MAGNIFYING GLASSES.
WITH
OBSERVATIONS and INQUIRIES thereupon.
By R. HOOKE, Fellow of the ROYAL SOCIETY.
Non possis oculo quantum contendere Linceus,
Non tamen idcirco contemnas Lippus inungi. Horat. Ep. lib. 1.
NVLLIVS IN VERBA
LONDON, Printed by Jo. Martyn, and Ja. Allestry, ...
ROYAL SOCIETY, and are to be sold at their ...
S. Paul's Church-yard. ...

Micro-history

In 1665 Robert Hooke publishes *Micrographia* on his observations through lenses

Blue mold- "Microscopical Mushrooms"

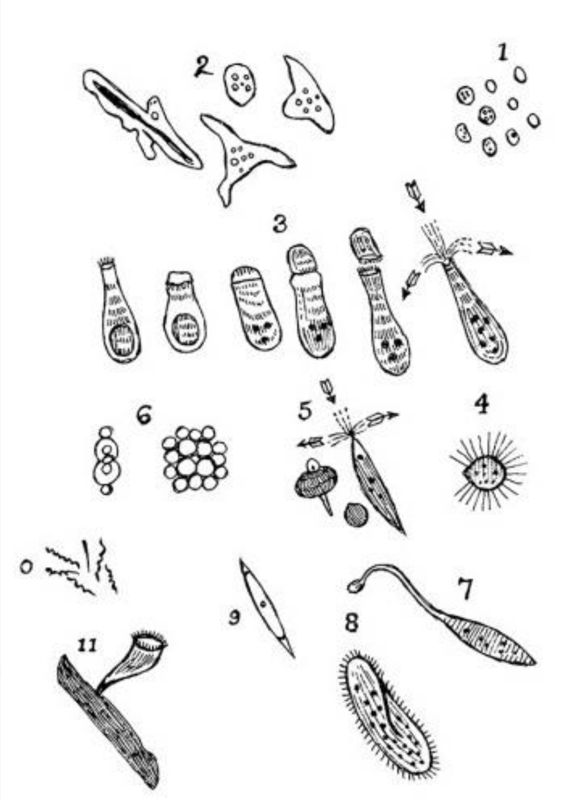


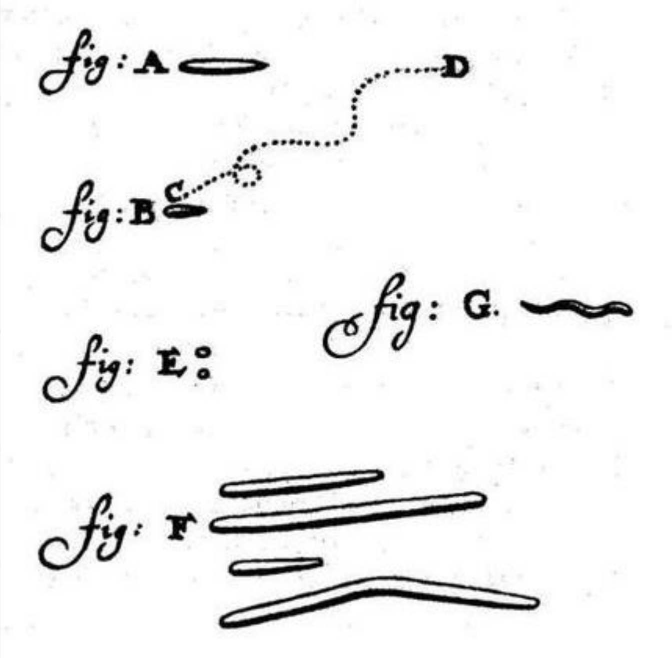
Tiny rooms in a sample of tree bark which Hooke called "cells"

Micro-history

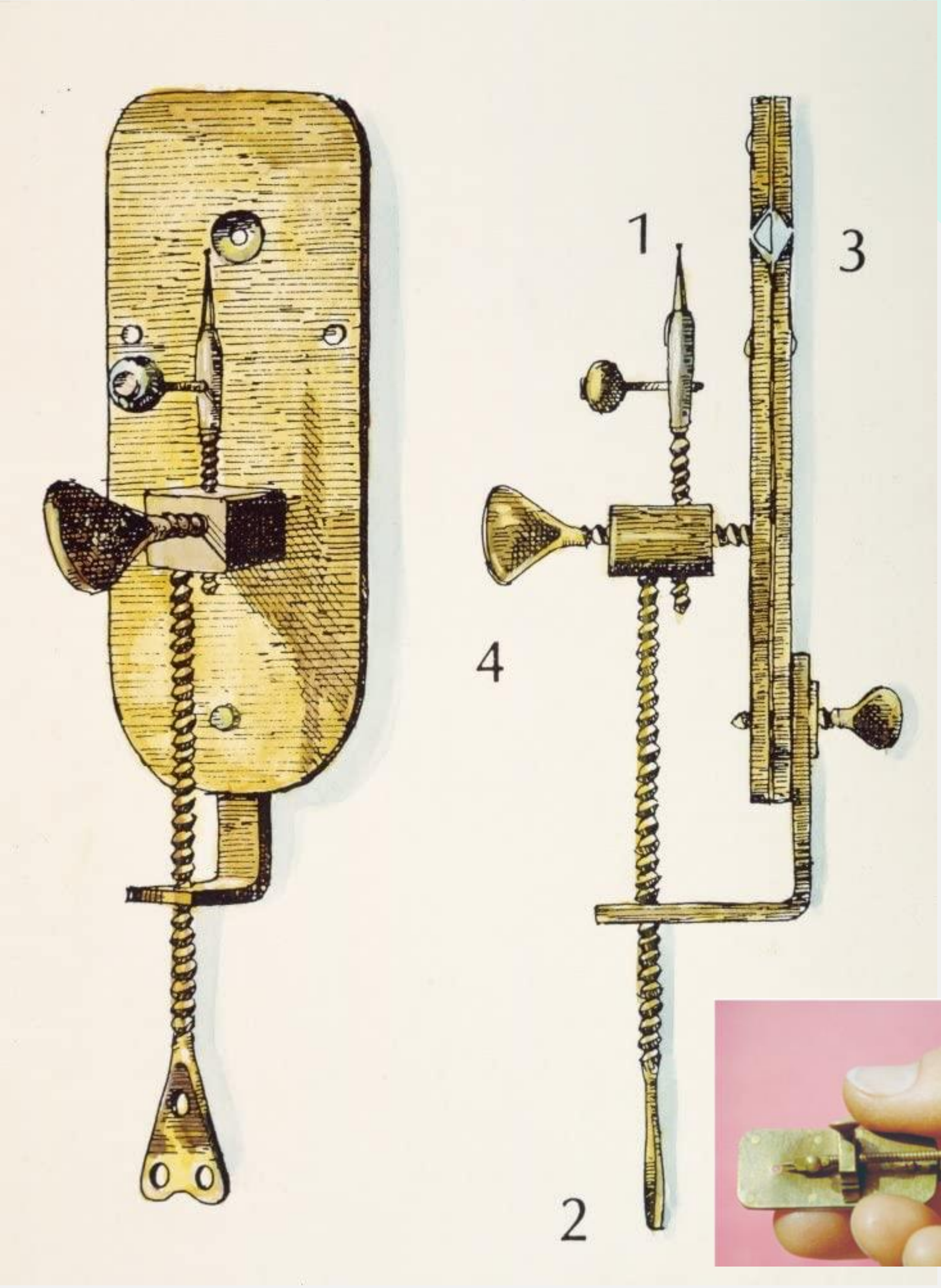
In 1684, Antoni van Leeuwenhoek publishes first drawing of what he called "***wee animalcules***".

Regarded as the "Father of Microbiology."





Bacteria from teeth plaque scrapings



Spontaneous Generation

Hypothesis that some vital force can create living organisms from inanimate objects (without descent from similar organisms). Widely accepted throughout the middle ages and into the 19^{th} century.

Some recipes:

Box + Grain = Mice

Meat + Warmth = Maggots

Spontaneous Generation

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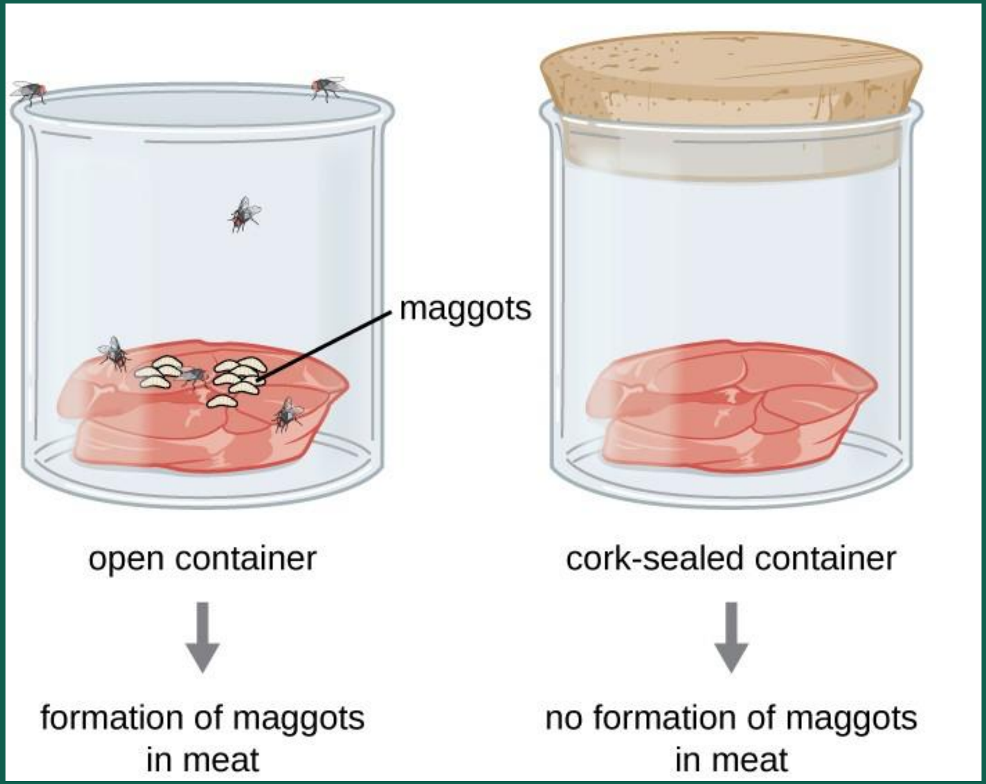
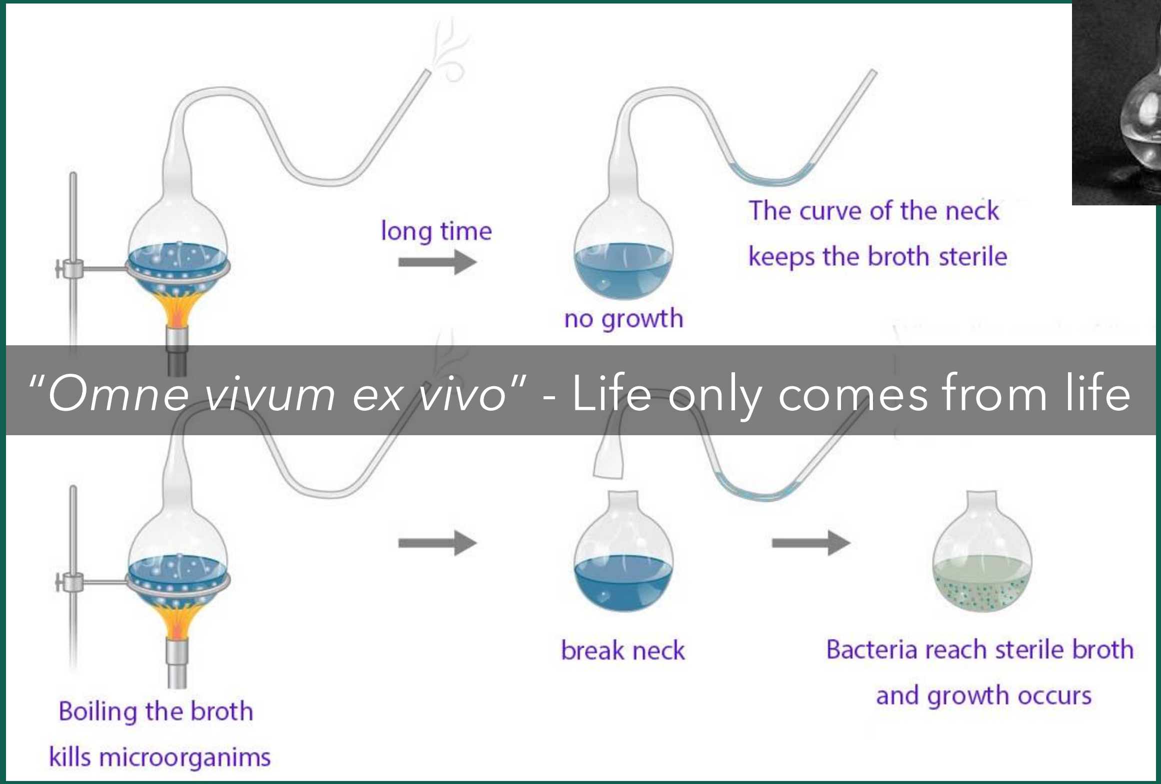
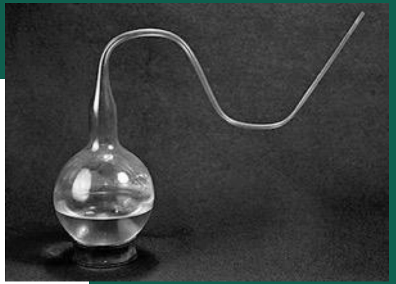


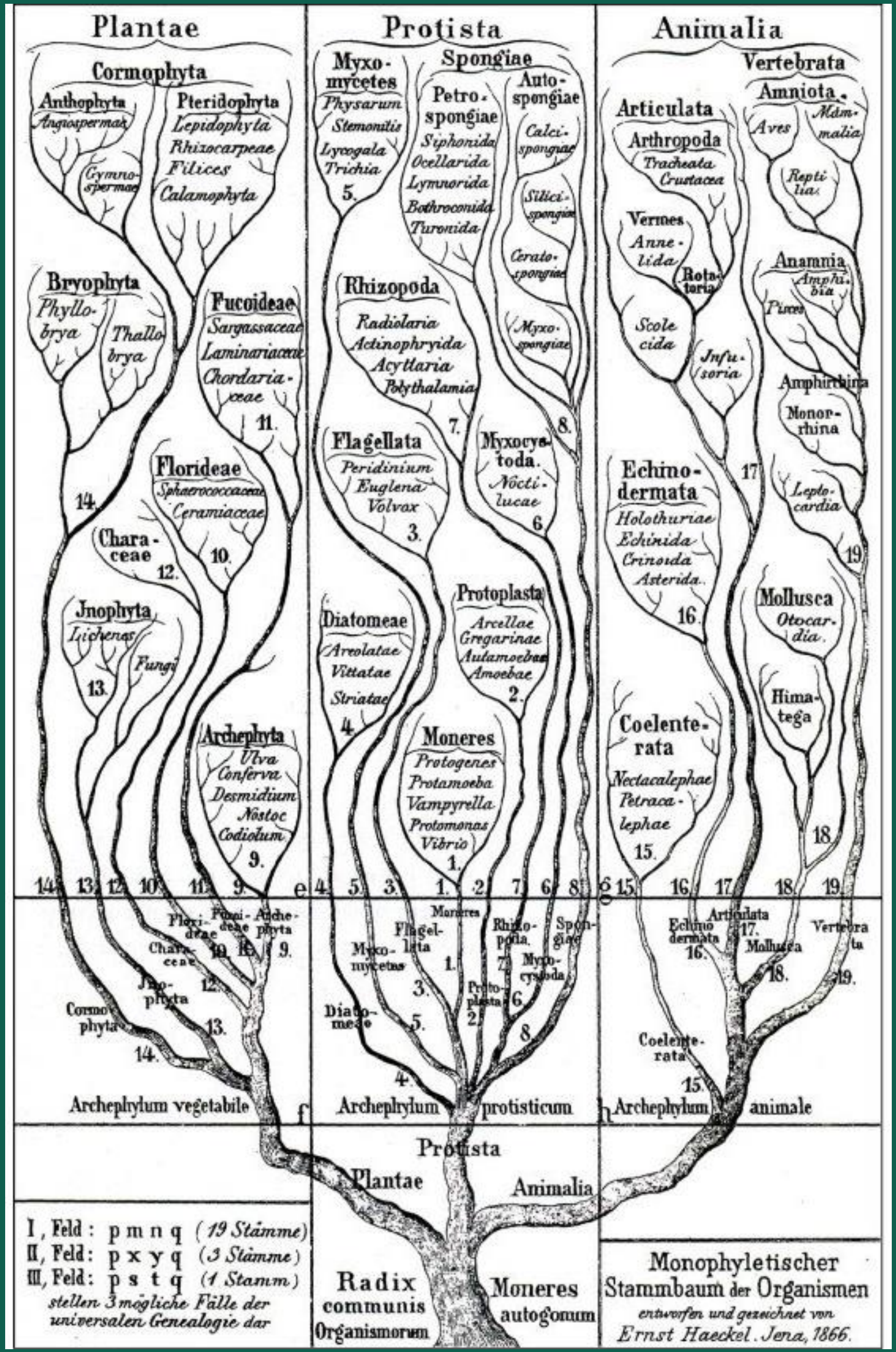
1668, Francesco Redi





"Omne vivum ex vivo" - Life only comes from life

1862, Louis Pasteur



Tree of Life

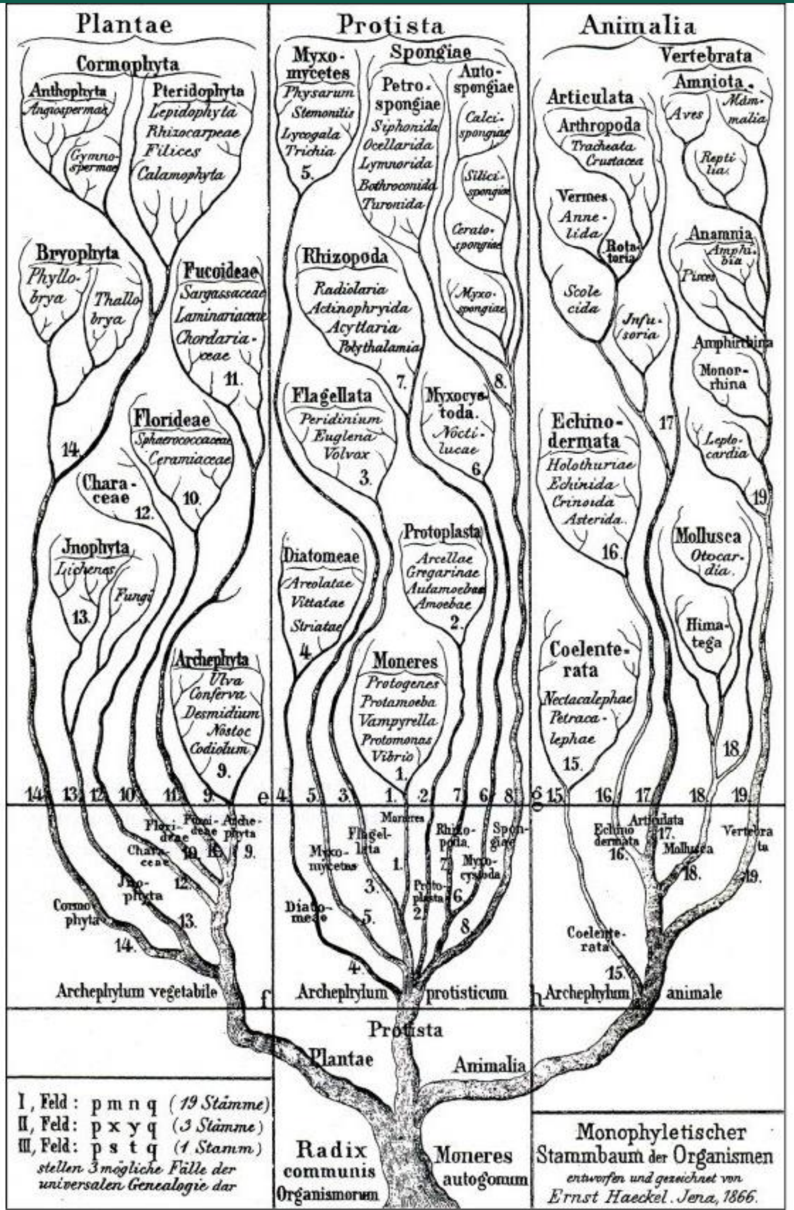
Coined the term ecology ('oecologie')-

"the whole science of the relations of the organism to the environment including, in the broad sense, all the 'conditions of existence'"

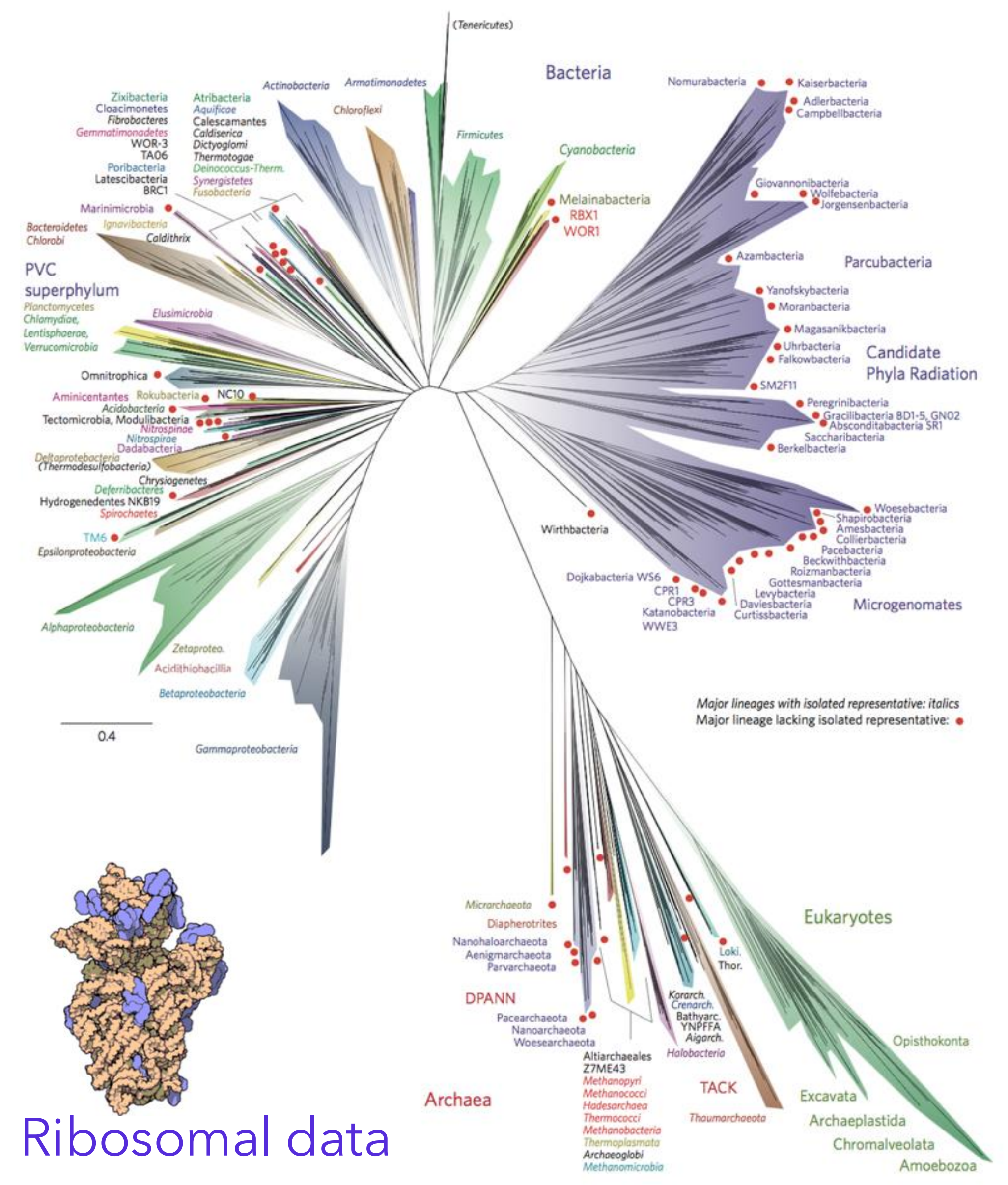
1866, Ernst Haeckel

Tree of Life

1866, Ernst Haeckel



Hug et al. 2016



Microorganisms

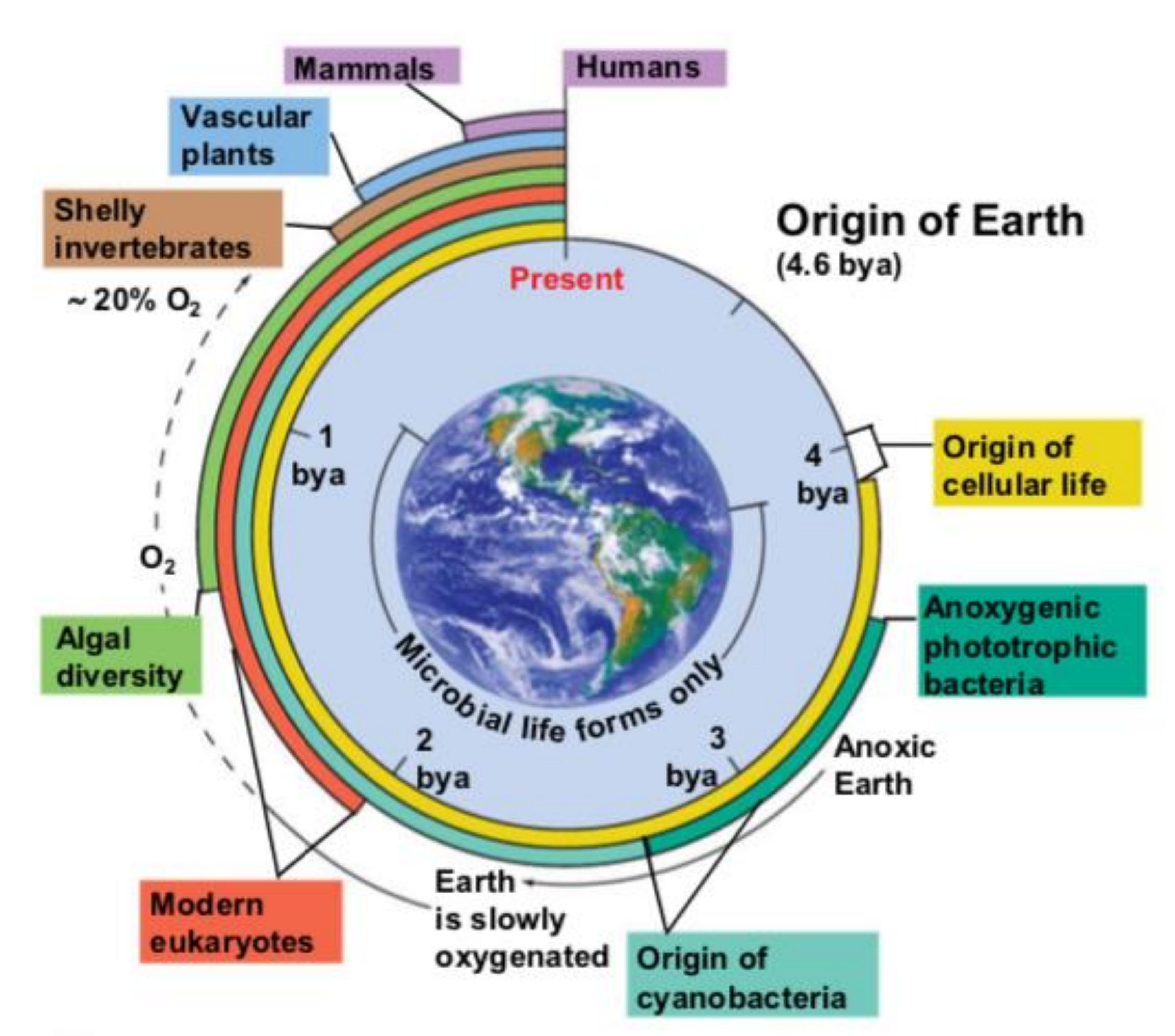
Prokaryotes ("before nucleus")

- Bacteria
- Archaea

Eukaryotes:

- Protozoa (eg: Amoeba)
- Alga (eg: Euglena)
- Fungi (eg: yeasts)

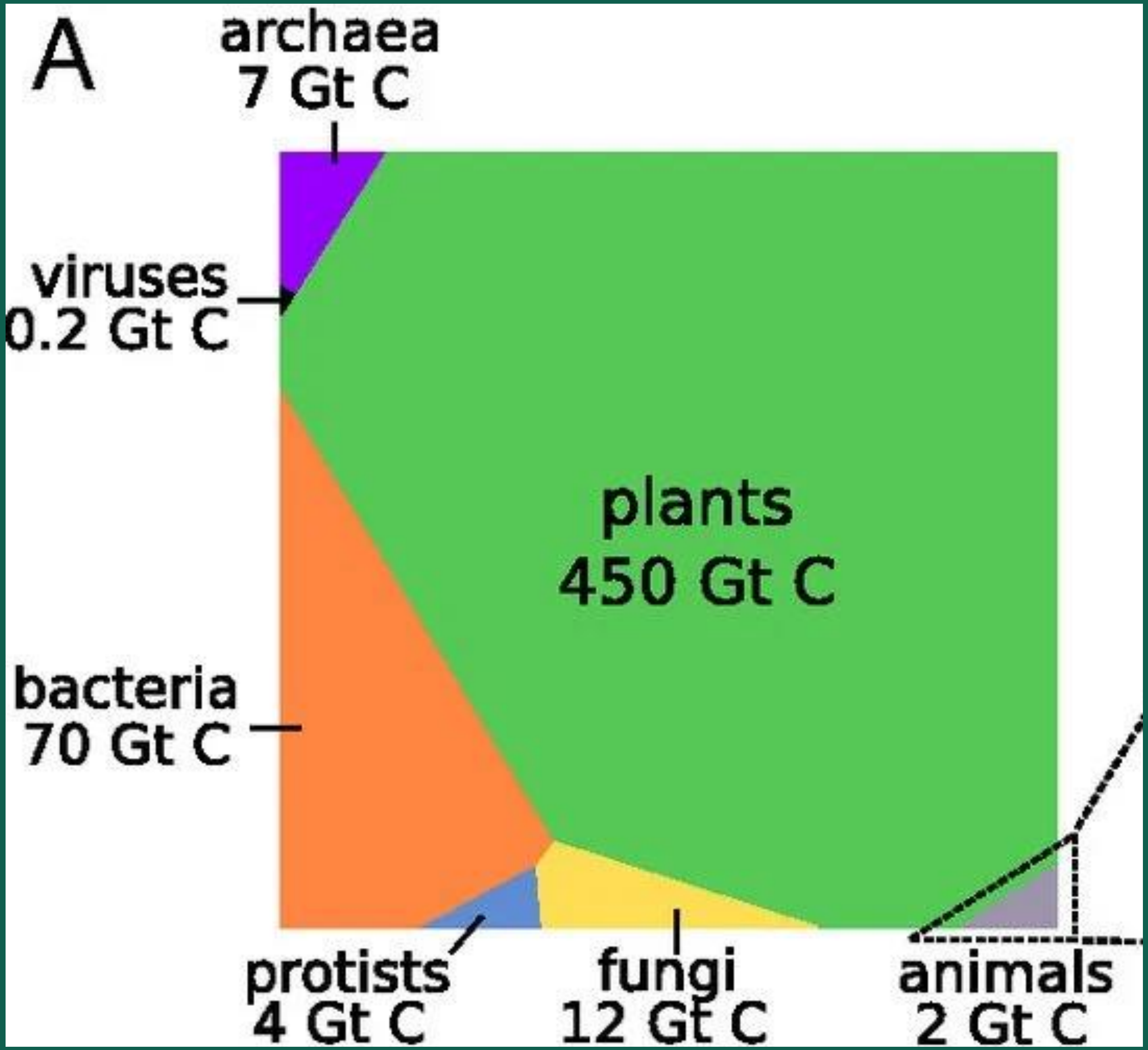
Microorganisms are diverse because they have had a very long time to evolve and differentiate



General Ecological Concepts

- Microbes account for a significant proportion of all biomass on Earth

They are ubiquitous on the surface and deep within Earth



General Ecological Concepts

- Ecosystem: 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

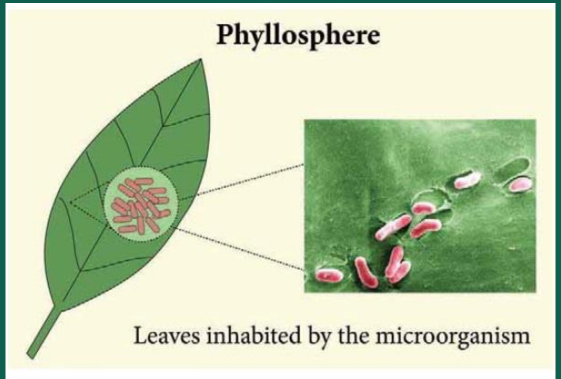


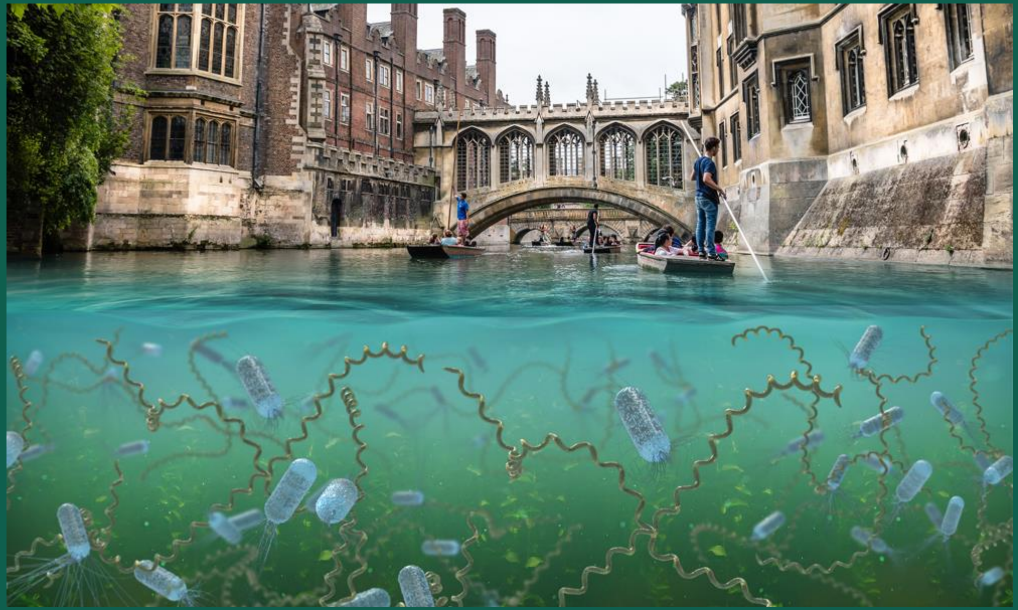
Figure 10.7: Microscopic appearance of Phyllosphere Bacteria

General Ecological Concepts

- Population: a group of microorganisms of the same species that reside in the same place at the same time

    may be descendants of a single cell

- Community: a community consists of populations living in association with other populations



General Ecological Concepts

Diversity of microbial species in an ecosystem is expressed in two ways

- species richness: total number of different species present
- species abundance: proportion of each species in an ecosystem

Microbial species richness and abundance are functions of the types and amounts of nutrients available in a given habitat.

Resources and Conditions That Govern 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

Species richness and abundance can change quickly over a short time.

- change in abundance of cyanobacteria due to nutrient-rich agricultural runoff

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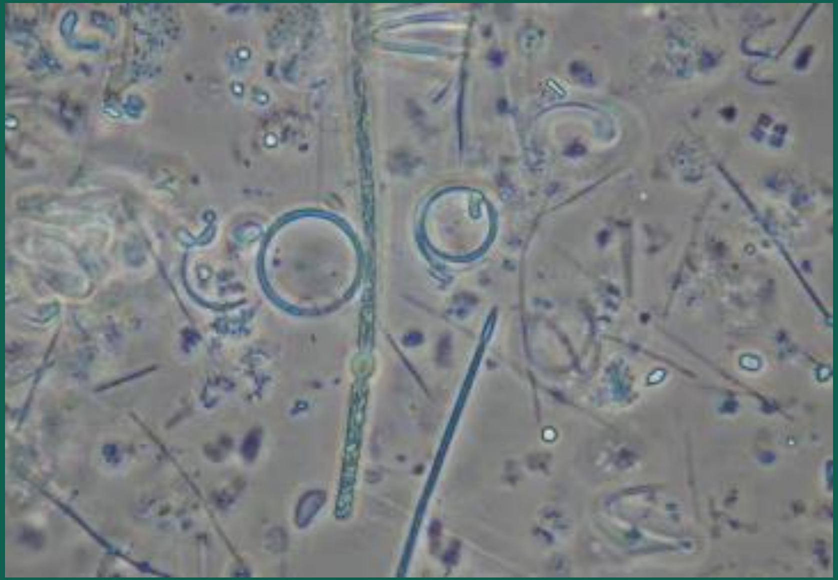
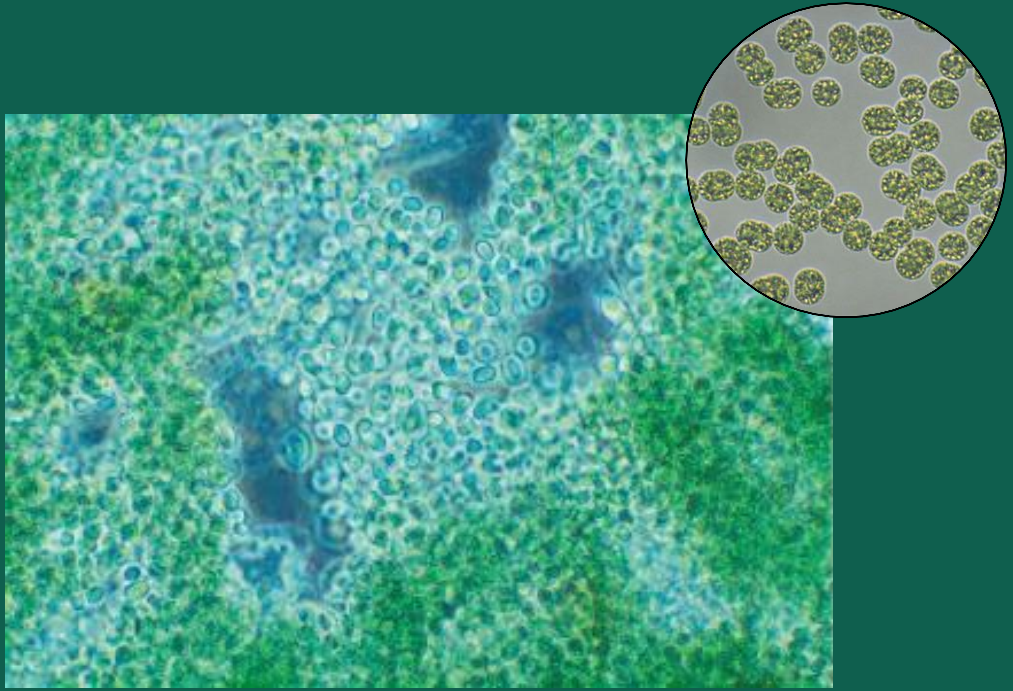


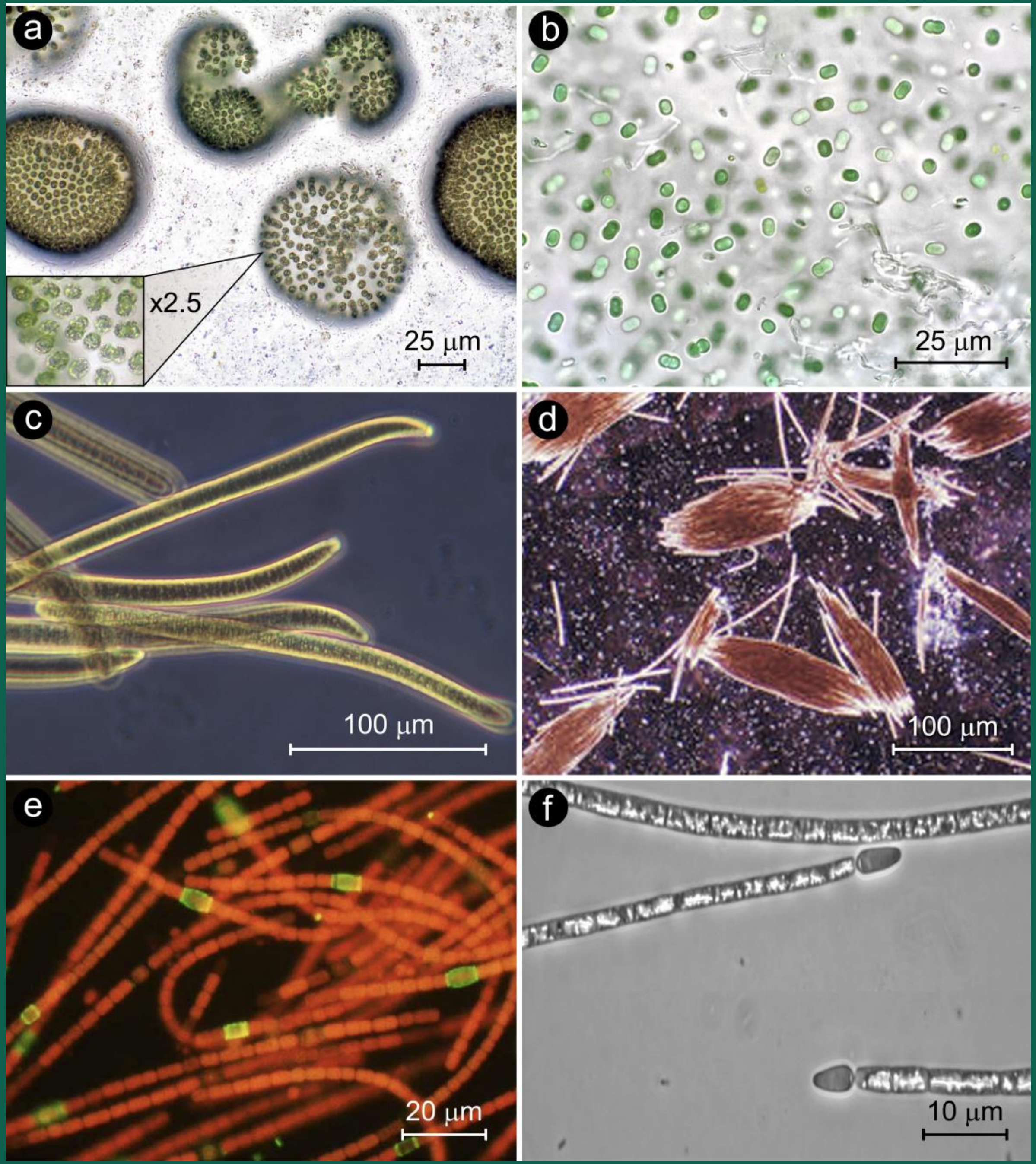
High species richness of planktonic microorganisms: cyanobacteria, diatoms, green algae, flagellates, and bacteria.



Shift of the community to low richness but high abundance following a bloom of the cyanobacterium *Microcystis*

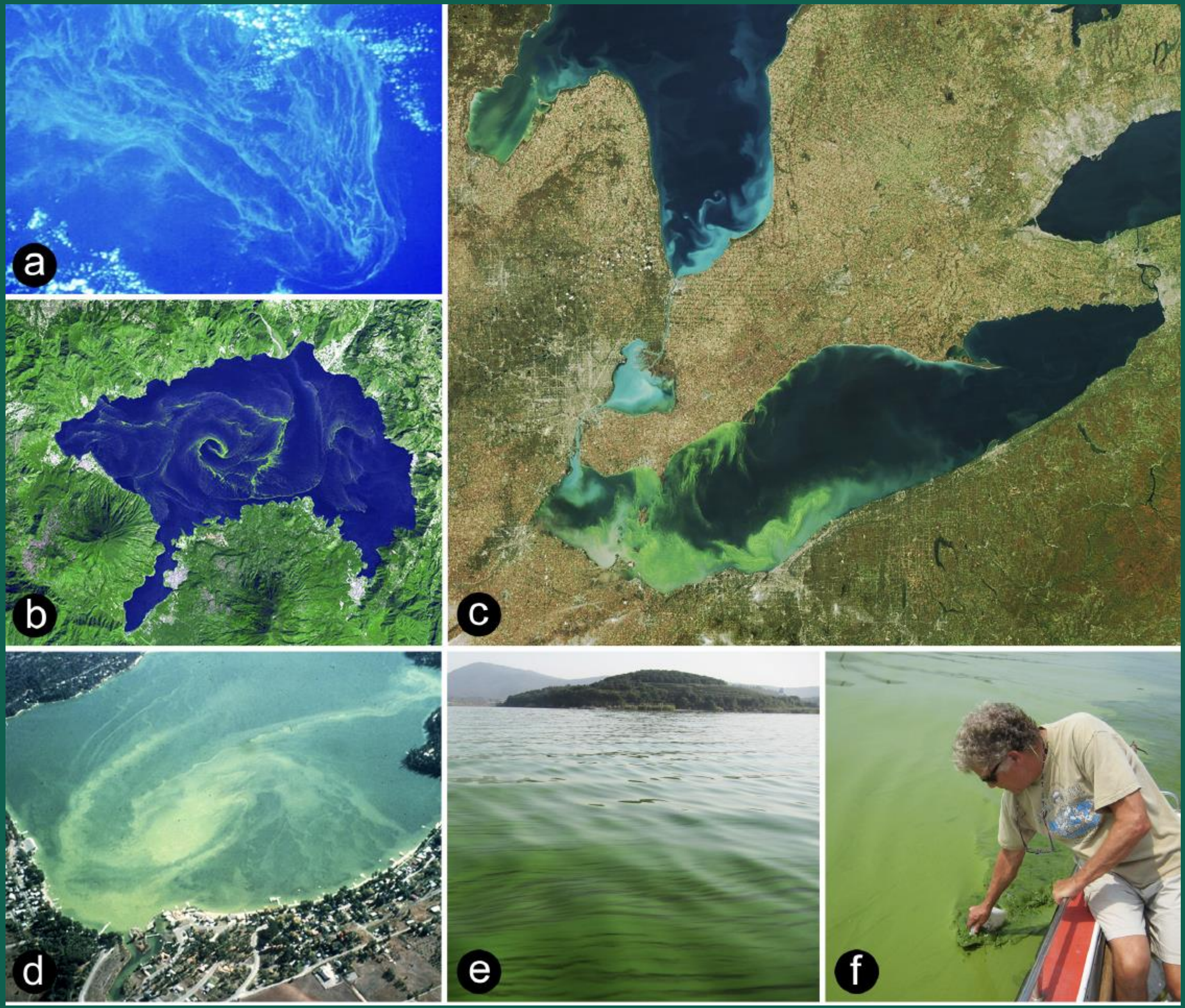
Cyanobacteria

- Earth's oldest oxygenic phototrophs
- Formation of an oxic atmosphere
- >2.5 billion years evolutionary history
    - enabled them to adapt to geochemical and climatic changes
    - widespread adaptations climatic extremes



Cyanobacteria

- Rich “playbook” of ecological strategies aimed at surviving and thriving
- Cyanobacteria to take advantage of human alterations of aquatic environments:
  - eutrophication
  - hydrologic alterations
- Massive growths or “blooms”



Cyanobacteria

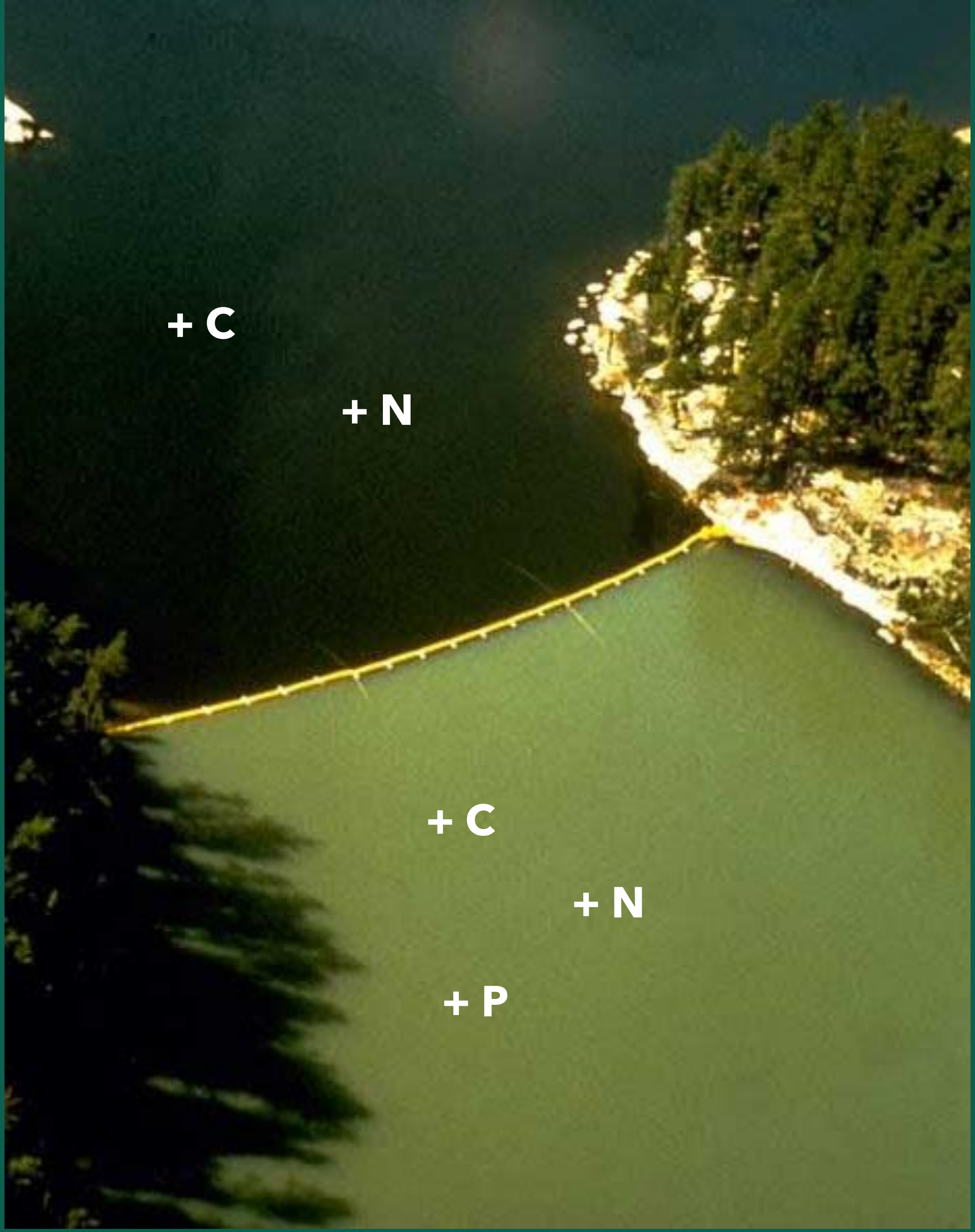
Produce secondary metabolites that are toxic

Lake 226

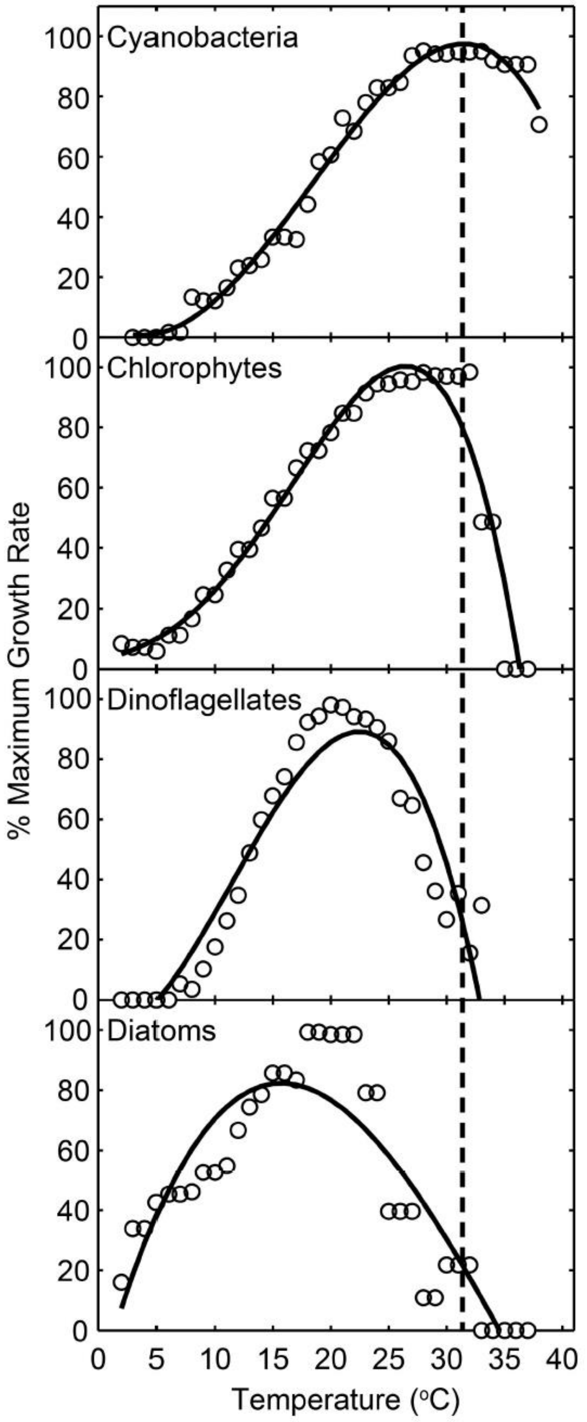
Limited Carbon resulted in eutrophication of lakes rather than Phosphorus

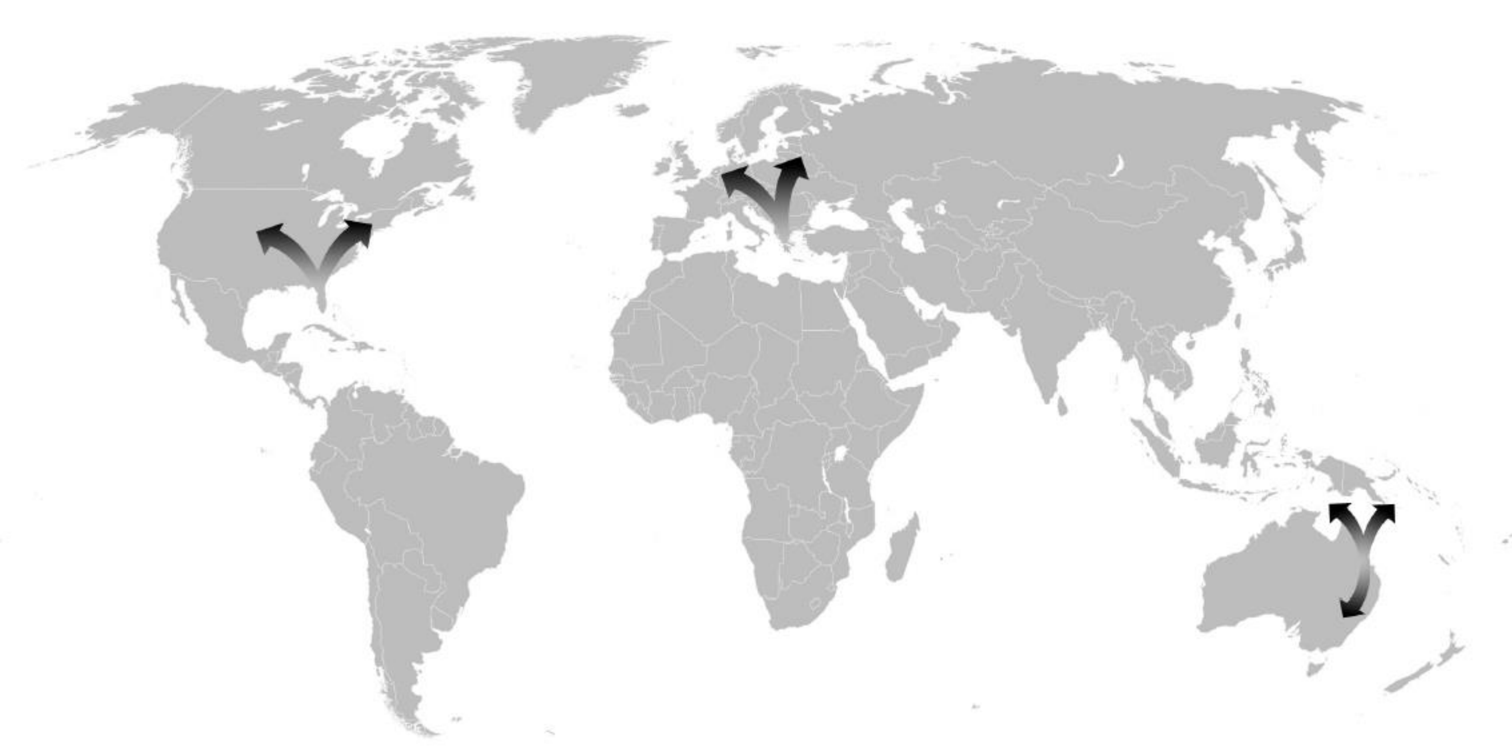
Monitoring P is a "waste of money"

1973–1977 to test eutrophication

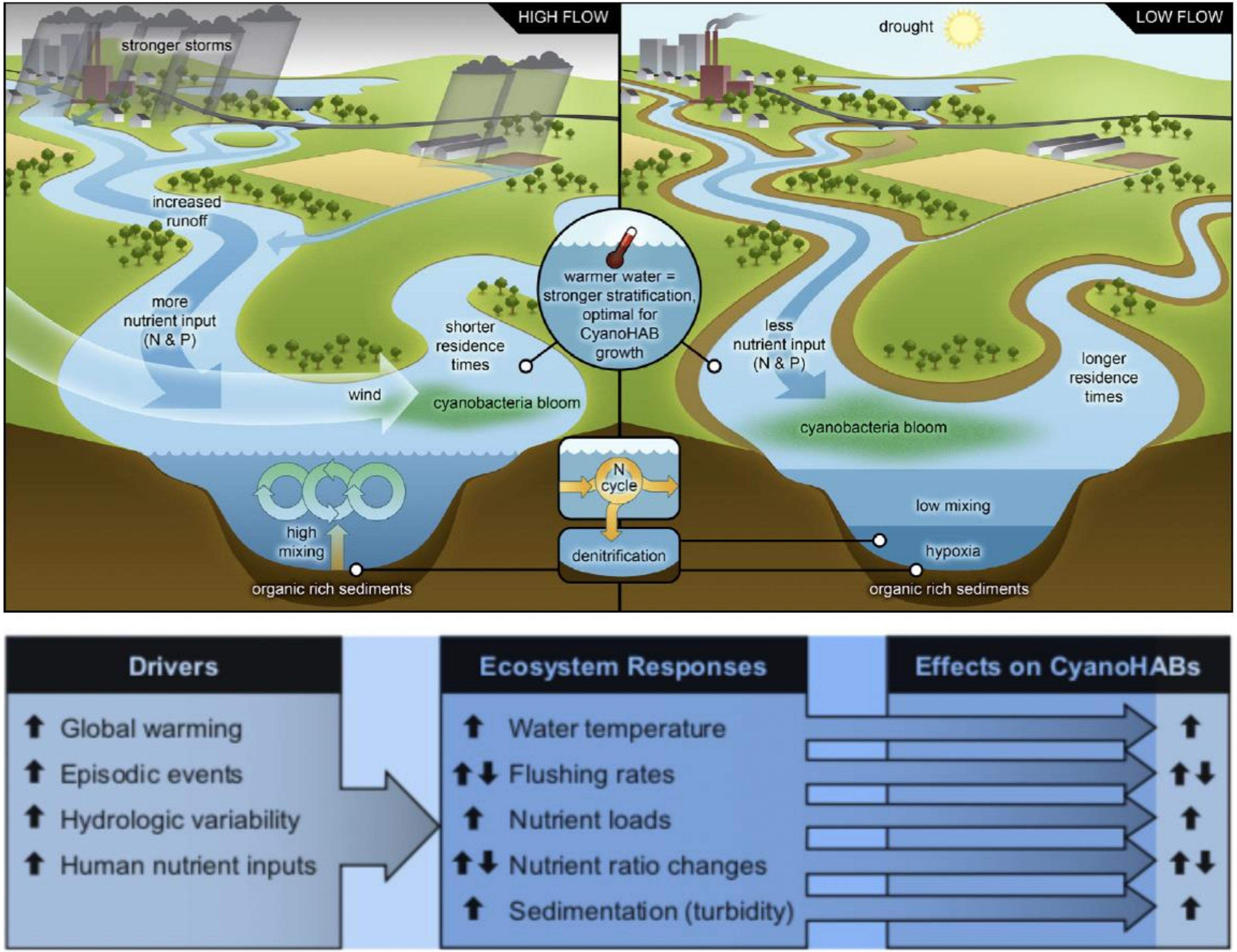


Relationships between temperature and specific growth rates of cyanobacterial species and eukaryotic phytoplankton





geographic expansion of the harmful (toxic) cyanobacterial species *Cylindrospermopsis raciborskii* due to altered hydrologic regimes droughts and warming



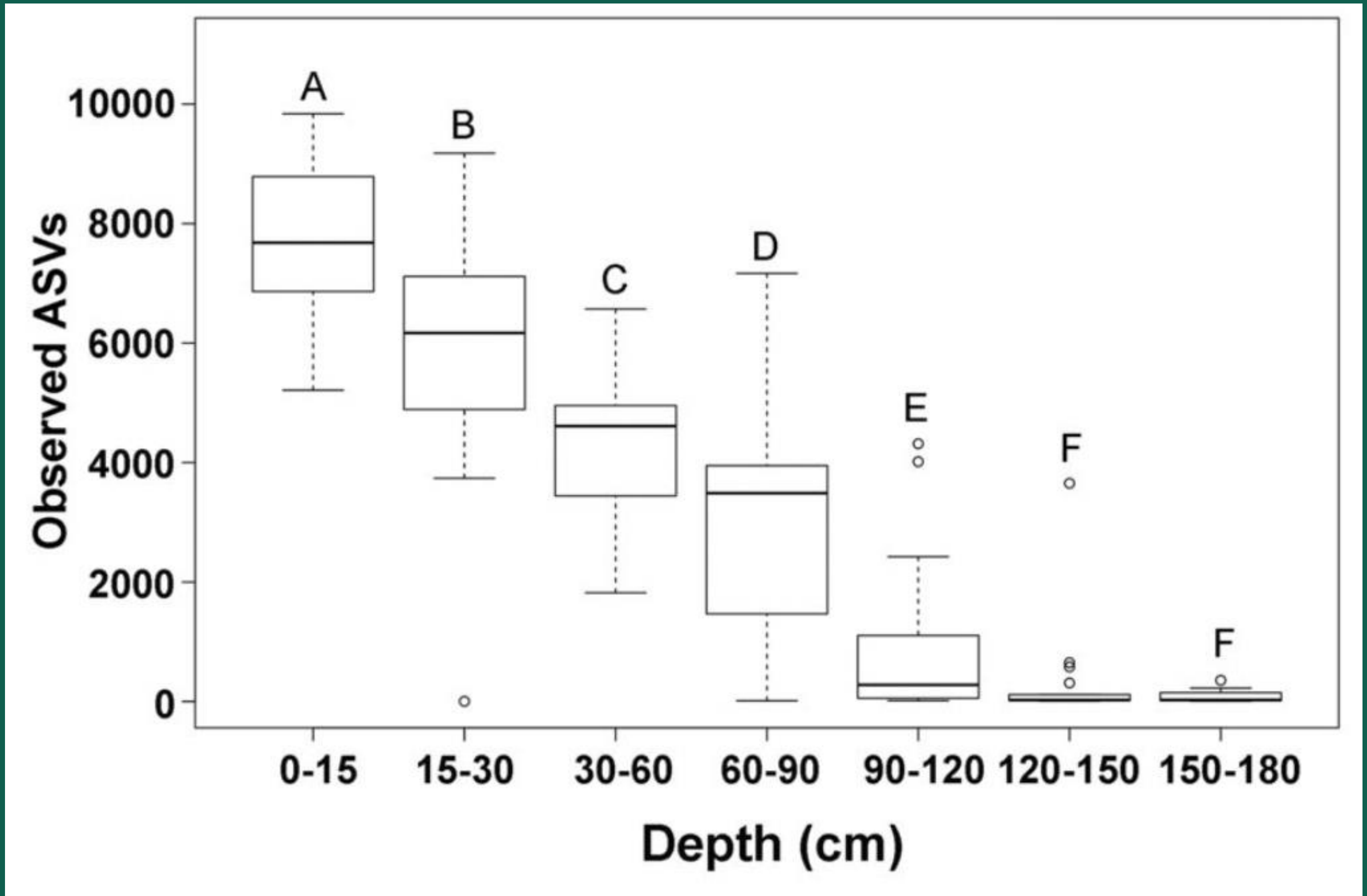
HIGH FLOW
stronger storms
increased runoff
more nutrient input (N & P)
shorter residence times
wind
cyanobacteria bloom
high mixing
organic rich sediments
warmer water = stronger stratification, optimal for CyanoHAB growth
N cycle
denitrification
LOW FLOW
drought
less nutrient input (N & P)
longer residence times
cyanobacteria bloom
low mixing
hypoxia
organic rich sediments
Drivers
↑ Global warming
↑ Episodic events
↑ Hydrologic variability
↑ Human nutrient inputs
Ecosystem Responses
↑ Water temperature
↑↓ Flushing rates
↑ Nutrient loads
↑↓ Nutrient ratio changes
↑ Sedimentation (turbidity)
Effects on CyanoHABs
↑
↑↓
↑
↑↓
↑

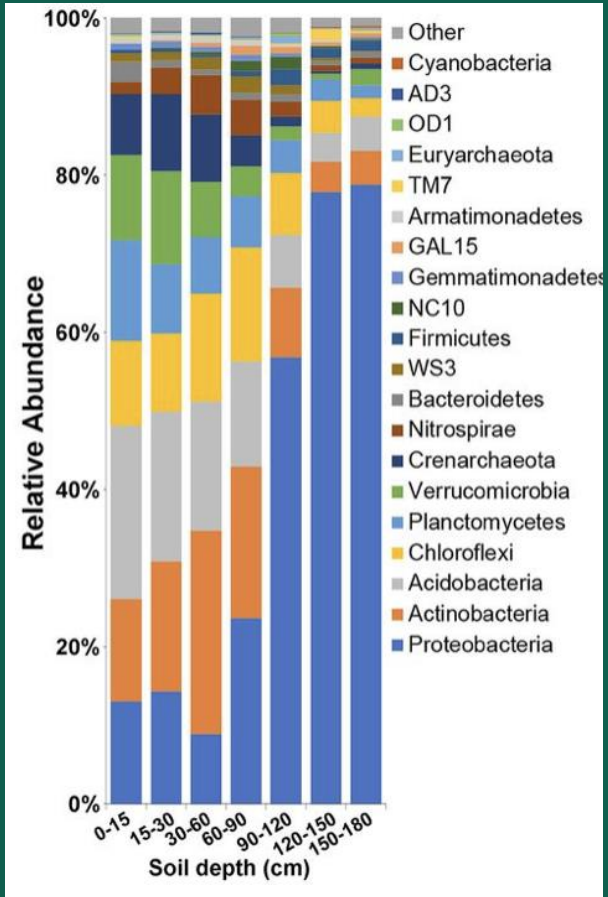
The Effects of Soil Depth on the Structure of Microbial Communities in Agricultural Soils in Iowa (United States)

Authors: Jingjie Hao, Yen Ning Chai, Lucas Dantas Lopes, Raziel A. Ordóñez, Emily E. Wright, Sotirios Archontoulis, Daniel P. Schachtman | AUTHORS INFO & AFFILIATIONS

Species richness and abundance can change quickly over a close spatial distance

- change in diversity of microorganisms across soil depth





Microbial Diversity

Metabolic Capabilities

Structure

Environments

Microbial Diversity

Metabolic Capabilities

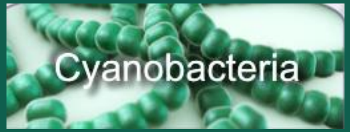
O_2 :
Aerobes: require oxygen for growth
Anaerobe: oxygen is not required for growth

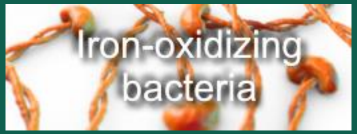
Energy source: (driving ATP synthesis)
Chemicals → **Chem**otroph
Light → **Phot**otroph

Electrons source:
Organic compounds → **Org**anotroph
Inorganic compounds (H_2S) → **Lith**otroph
(litho = rock)

Carbon source:
Organic compounds → Heterotroph
Inorganic compounds (CO_2) → Autotroph

Winogradsky columns





$CO_2 + 2H_2S + light \rightarrow (CH_2O) + H_2O + 2S^0$

Microbial Diversity

Metabolic Capabilities

O_2 :
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Anaerobe: oxygen is not required for growth

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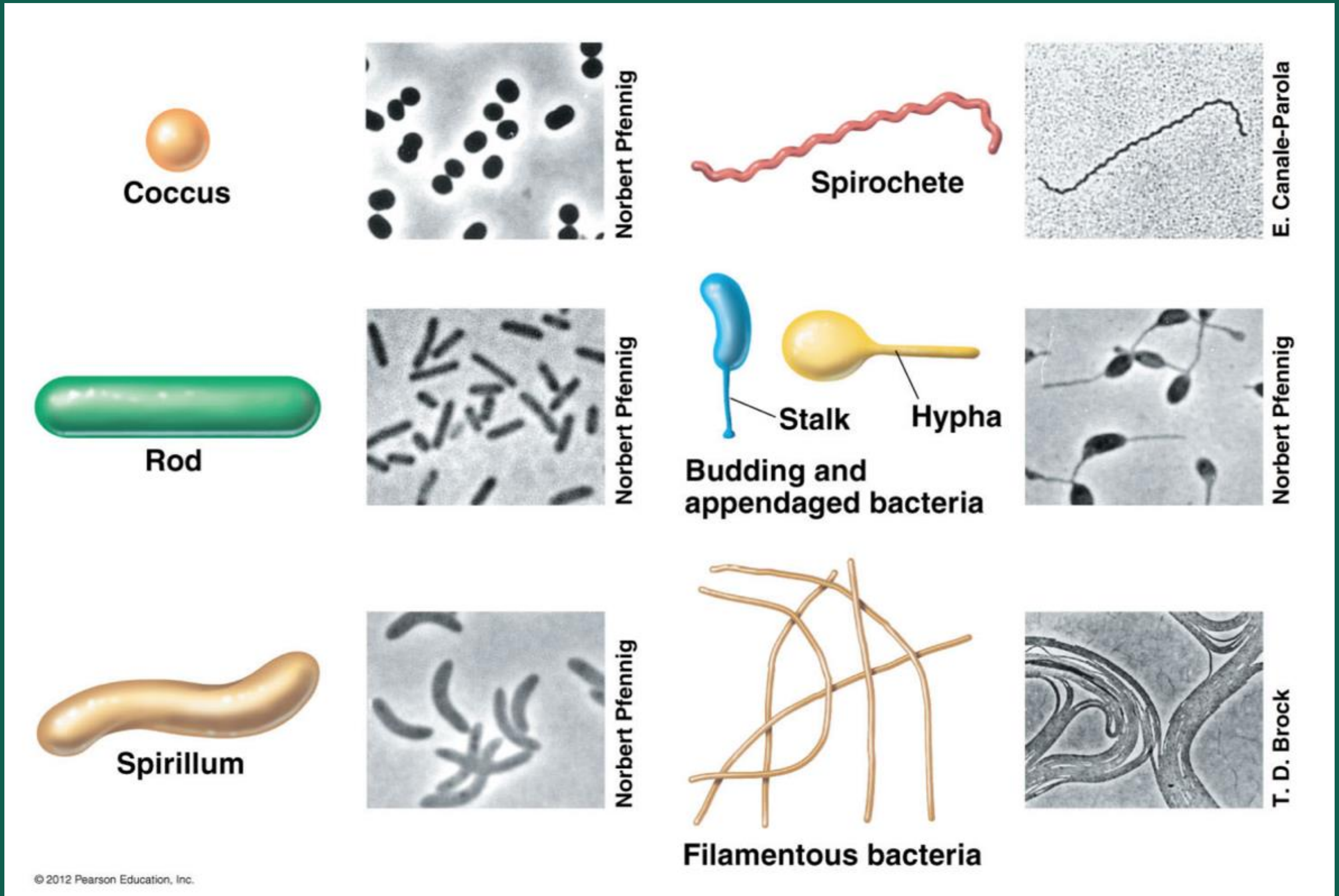
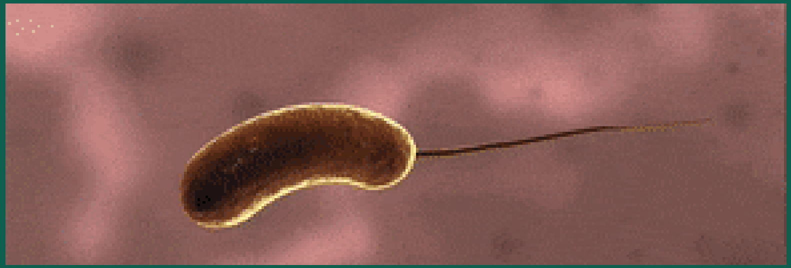
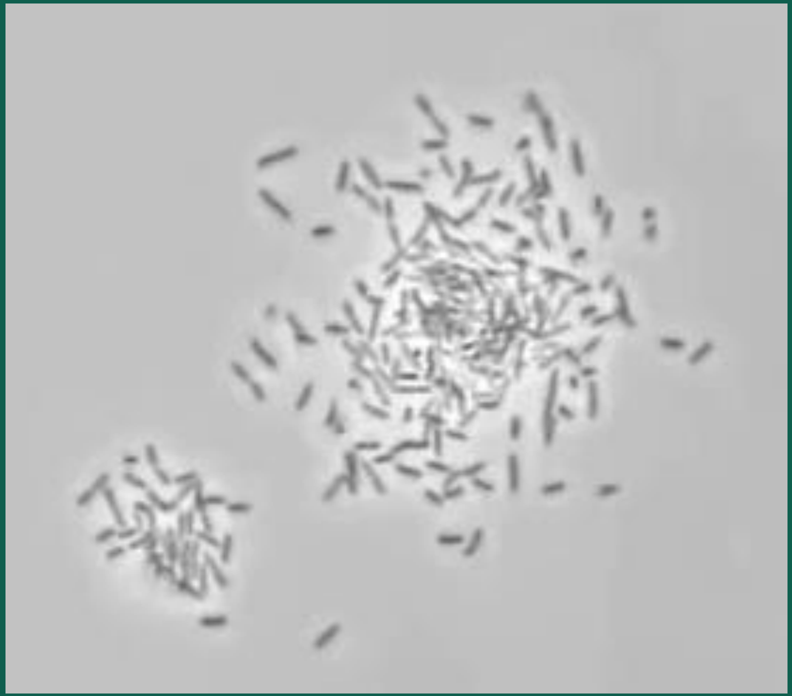
Microbial Diversity

Structure







Microbial Diversity

Environments

Present wherever scientists look

Microbial Diversity

Environments

<u>Present wherever scientists look</u>

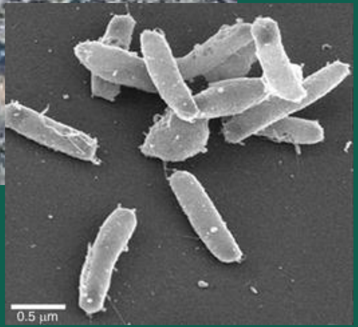
Acidic toxic ponds

Acidophiles
"acid loving"

Isolation and phylogenetic characterization of acidophilic microorganisms indigenous to acidic drainage waters at an abandoned Norwegian copper mine

D. Barrie Johnson, Stewart Rolfe, Kevin B. Hallberg, Eigil Iversen

Microbial Diversity



Halobacterium salinarum

Halophiles
"salt loving"

Environments

Present wherever scientists look

Acidic toxic ponds

Salt flats

Microbial Diversity

Psychrophiles
"cold loving"

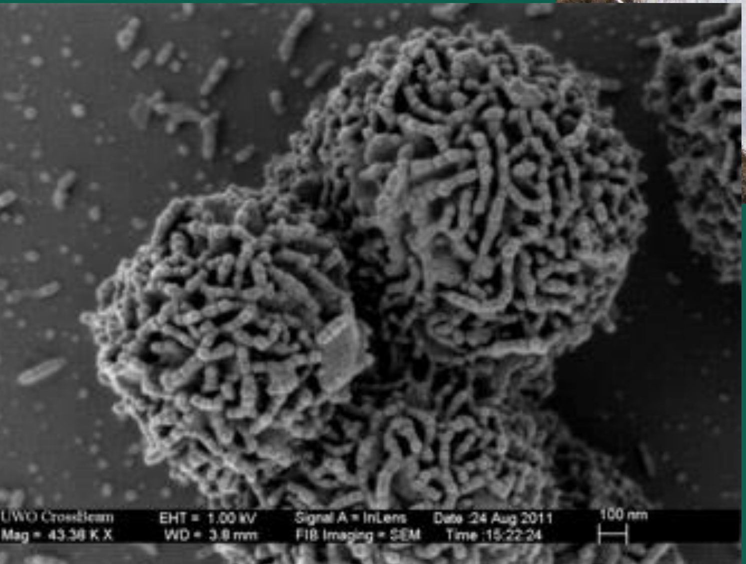
Environments

<u>Present wherever scientists look</u>

Acidic toxic ponds

Salt flats

Glacial ice/permafrost



Planococcus halocryophilus
Isolated from permafrost
and grows at -15C°

Microbial Diversity

Thermophiles
"heat loving"

Thermus Aquaticus

Isolated in 1966 by Thomas Brock

Yellowstone National Park

Its taq polymerase enzyme is used in the PCR

Environments

<u>Present wherever scientists look</u>

Acidic toxic ponds

Salt flats

Glacial ice/permafrost

Hot springs

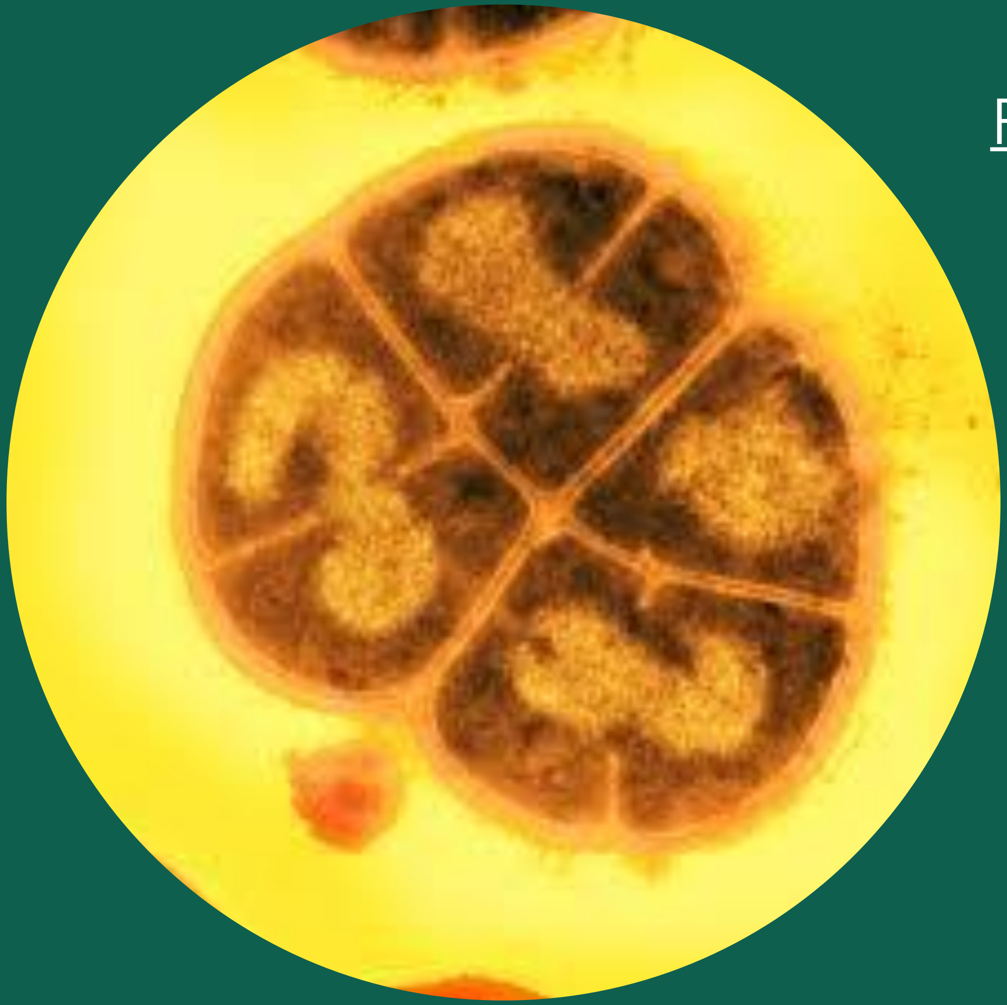
Microbial Diversity

Deinococcus radiodurans

"Radiation surviving terrible berry"

5000-Gy dose of γ radiation without loss of viability or evidence of mutation

Humans die after exposure to 5 Gy



Environments

Present wherever scientists look

Acidic toxic ponds

Salt flats

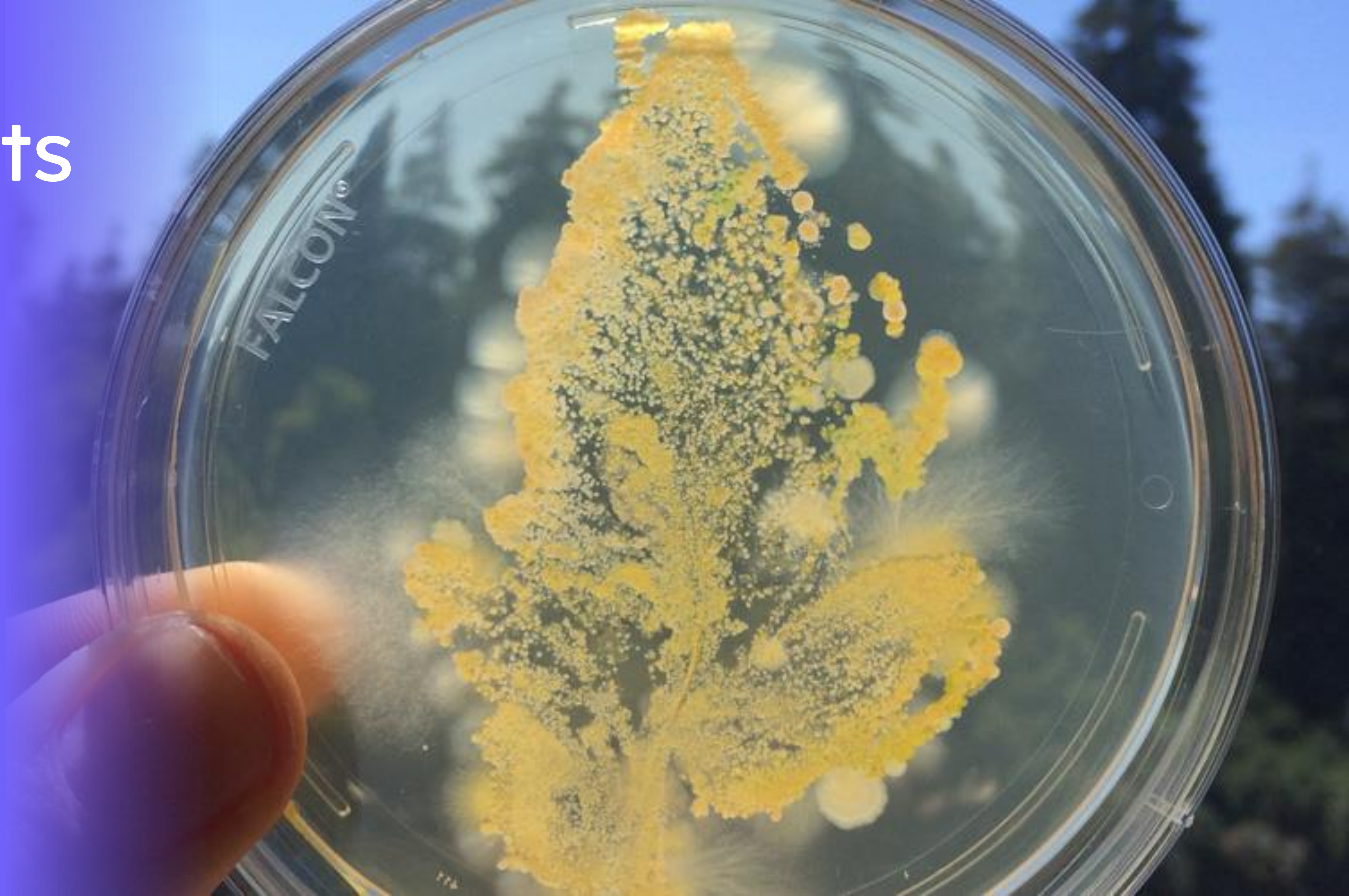
Glacial ice/permafrost

Hot springs

High radiation

Microbial communities do not exist in isolation

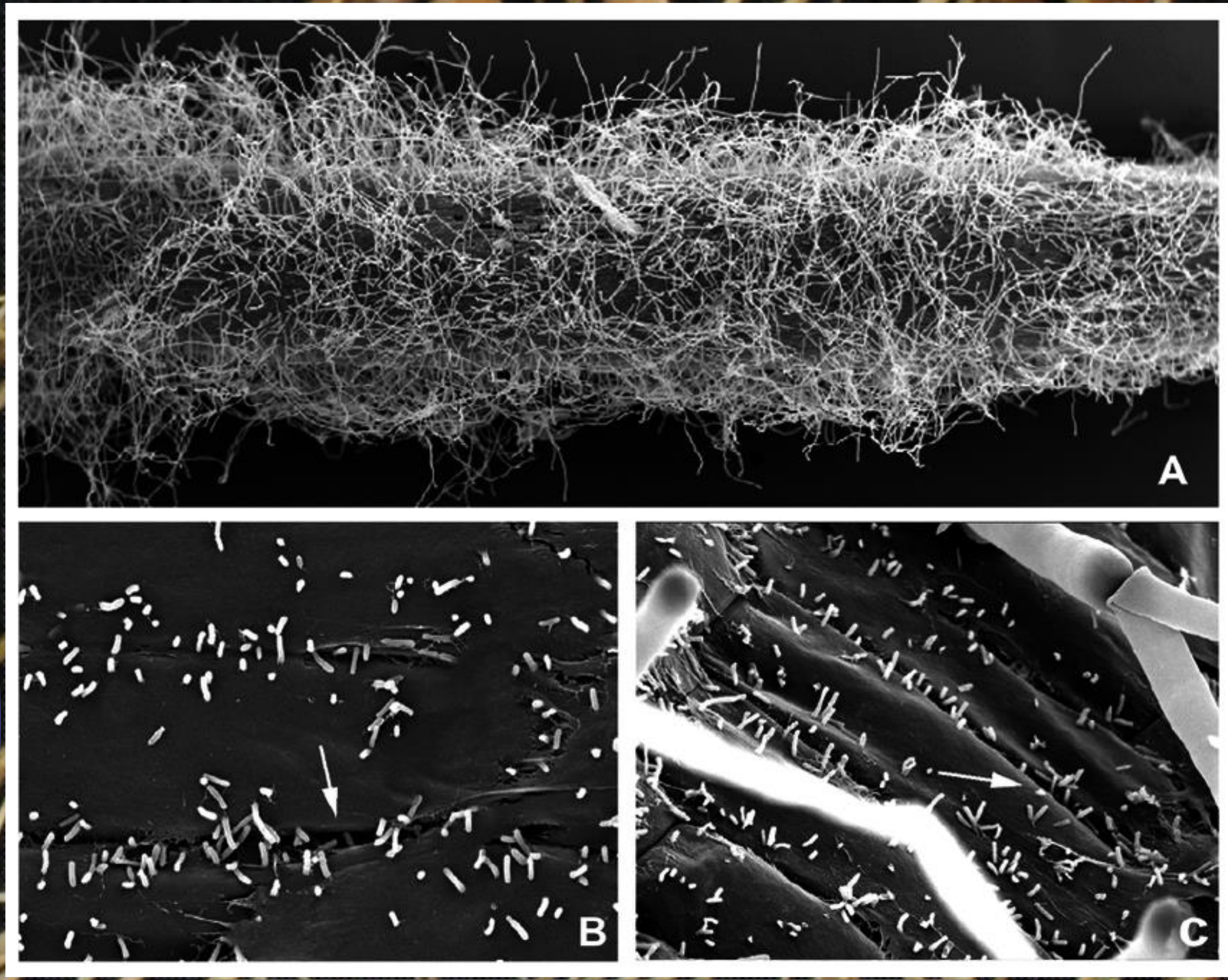
Plants



Yanni et all 2001

Plants

Nitrogen fixing bacteria convert atmospheric nitrogen (N_2) to ammonia (NH_3) that plants can use as a source of nitrogen for growth.



Rhizobium leguminosarum

Ruminants

Rumen is an anaerobic and methanogenic fermentation chamber

High microbial density and diversity including bacteria, archaea, protozoa and fungi

- 10^{11} cells/ml and over 200 species

Responsible for providing nutrients to the host animal

- production of lignocellulolytic enzymes

Microbial Dark Matter

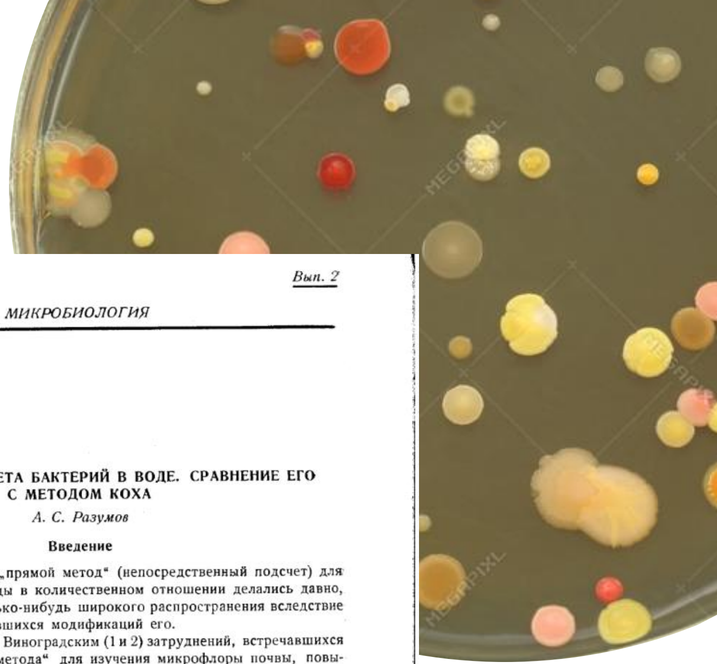
In 1935, Razumov noted a large discrepancy in the number of bacterial cells from aquatic habitats that form colonies on a plate versus the number of cells countable on a microscope.

на агаре согласно стандартным методам (7) (сост. питательной среды, счет через 48 час. при 20—22° С). Такая же методика проводилась и во всех далее изложенных опытах.

ТАБЛИЦА 4

Место взятия пробы	Количество бактерий в 1 $см^3$ прямой счет	Количество бактерий в 1 $см^3$ метод Коха	Отношение
Вода пруда	$1018 \cdot 10^3$	3100	330
„ котлована . . .	$1242 \cdot 10^3$	2630	470
„ из водоп. кр. .	$969 \cdot 10^3$	345	2800

Microscope | Plate | Magnitude difference



ПРЯМОЙ МЕТОД УЧЕТА БАКТЕРИЙ В ВОДЕ. СРАВНЕНИЕ ЕГО С МЕТОДОМ КОХА

А. С. Разумов

Введение

Попытки применить „прямой метод" (непосредственный подсчет) для изучения микрофлоры воды в количественном отношении делались давно, однако, не получили сколько-нибудь широкого распространения вследствие несовершенства предлагавшихся модификаций его.

Удачное разрешение Виноградским (1 и 2) затруднений, встречавшихся в применении „прямого метода" для изучения микрофлоры почвы, повысило интерес к таким исследованиям и в настоящее время почвенные микробиологи широко используют „метод Виноградского". В некоторых же отраслях микробиологи, например, при изучении микрофлоры молока и молочных продуктов (3), „прямой метод" стал общепризнанным и применяется наравне или вместо подсчетов по методу Коха.

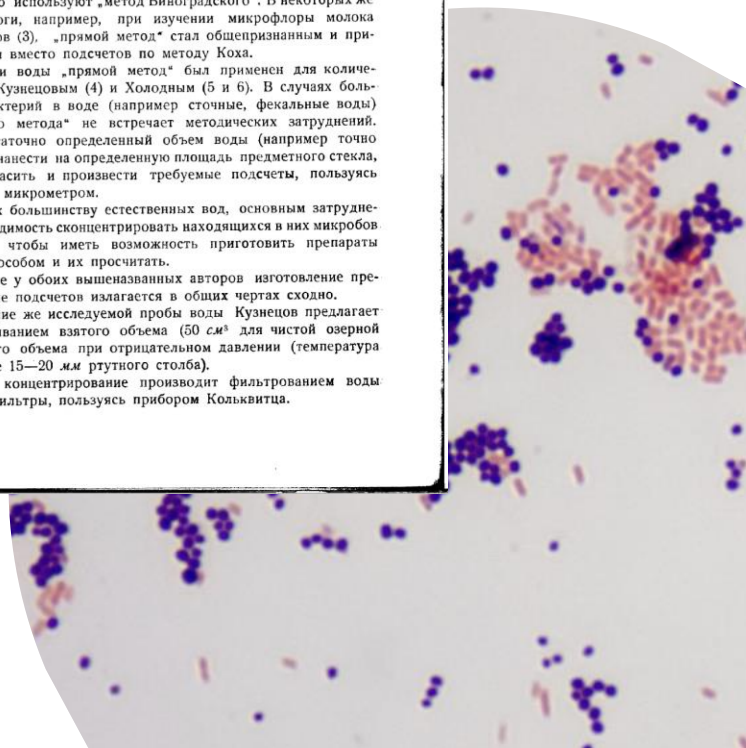
В микробиологии воды „прямой метод" был применен для количественных подсчетов Кузнецовым (4) и Холодным (5 и 6). В случаях большого содержания бактерий в воде (например сточные, фекальные воды) применение „прямого метода" не встречает методических затруднений. Для таких вод достаточно определенный объем воды (например точно измеренную каплю), нанести на определенную площадь предметного стекла, зафиксировать, покрасить и произвести требуемые подсчеты, пользуясь окулярным сетчатым микрометром.

В применении к большинству естественных вод, основным затруднением является необходимость сконцентрировать находящихся в них микробов в меньшем объеме, чтобы иметь возможность приготовить препараты вышеизложенным способом и их просчитать.

По этой причине у обоих вышеназванных авторов изготовление препаратов и проведение подсчетов излагается в общих чертах сходно.

Концентрирование же исследуемой пробы воды Кузнецов предлагает производить выпариванием взятого объема (50 $см^3$ для чистой озерной воды) до небольшого объема при отрицательном давлении (температура 30—50° С и давление 15—20 *мм* ртутного столба).

Холодный это концентрирование производит фильтрованием воды через мембранные фильтры, пользуясь прибором Кольквитца.

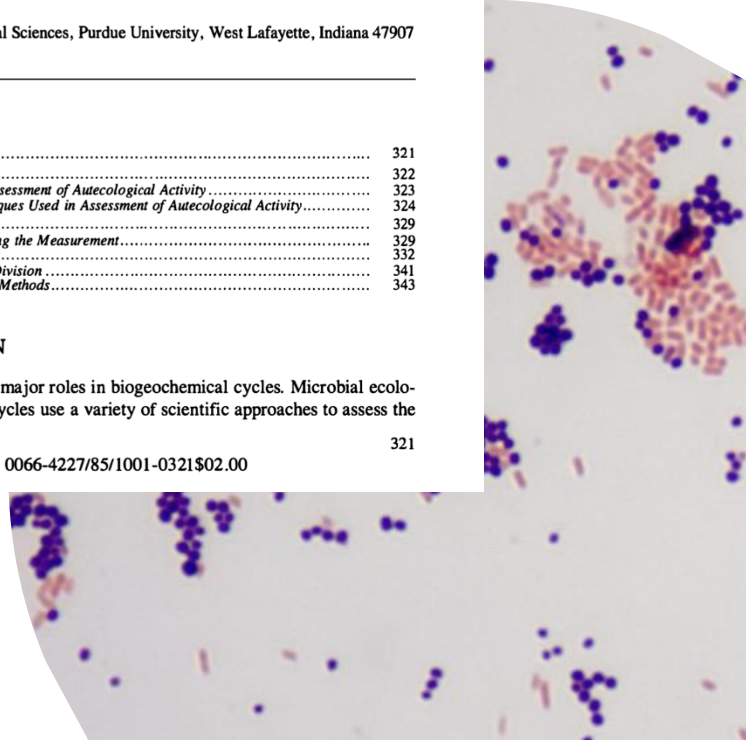


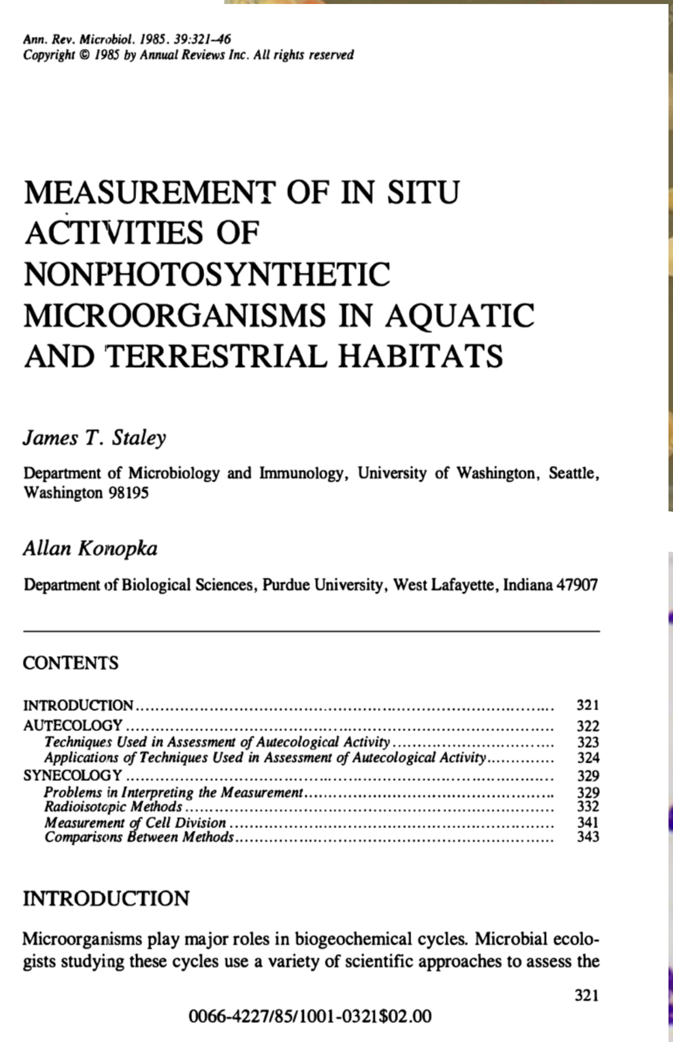
Microbial Dark Matter

In 1935, Razumov noted a large discrepancy in the number of bacterial cells from aquatic habitats that form colonies on a plate versus the number of cells countable on a microscope.

50 years later, Staley & Konopka (1985), describe this phenomenon as the :

“The great plate anomaly”





Ann. Rev. Microbiol. 1985. 39:321–46

MEASUREMENT OF IN SITU ACTIVITIES OF NONPHOTOSYNTHETIC MICROORGANISMS IN AQUATIC AND TERRESTRIAL HABITATS

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CONTENTS

INTRODUCTION

Microorganisms play major roles in biogeochemical cycles. Microbial ecologists studying these cycles use a variety of scientific approaches to assess the

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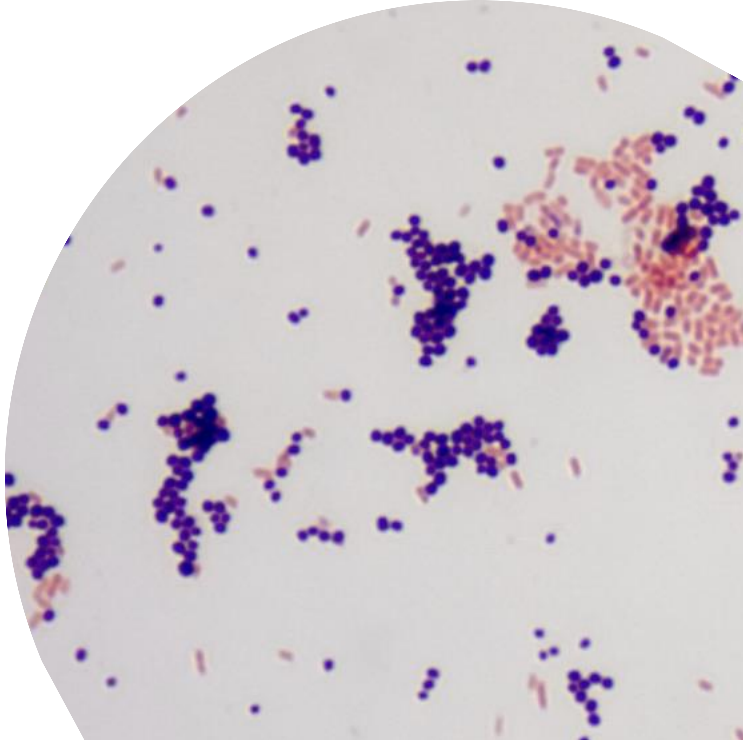
We can culture roughly around 1% of the microbial species.



Microbial Dark Matter

We can culture roughly around 1% of the microbial species.

Habitat	% Culturable
Freshwater	0.25
Lakes	0.1 - 1
Unpolluted waters	0.1 - 3
Activated sludge	1 - 15
Seawater	0.0001 - 0.1
Sediments	0.25
Soil	0.3
Human gut/stool	35 to 65

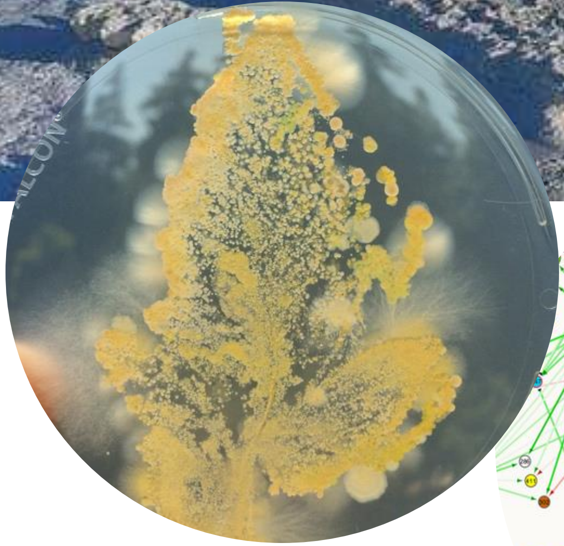
Microbial Dark Matter

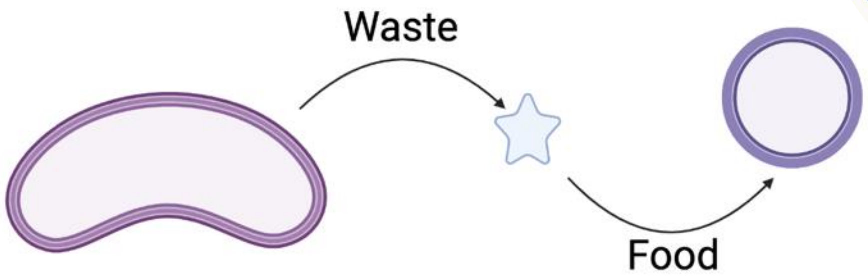
Microbial dark matter constitutes the microorganism that we are not able to culture

Growth conditions – temperature, O_2, light, water availability, salinity, pH…

Substrates – macro & micronutrients, C and N sources…

Obligate symbiotic interactions – cross feeding, secreted extracellular proteins…





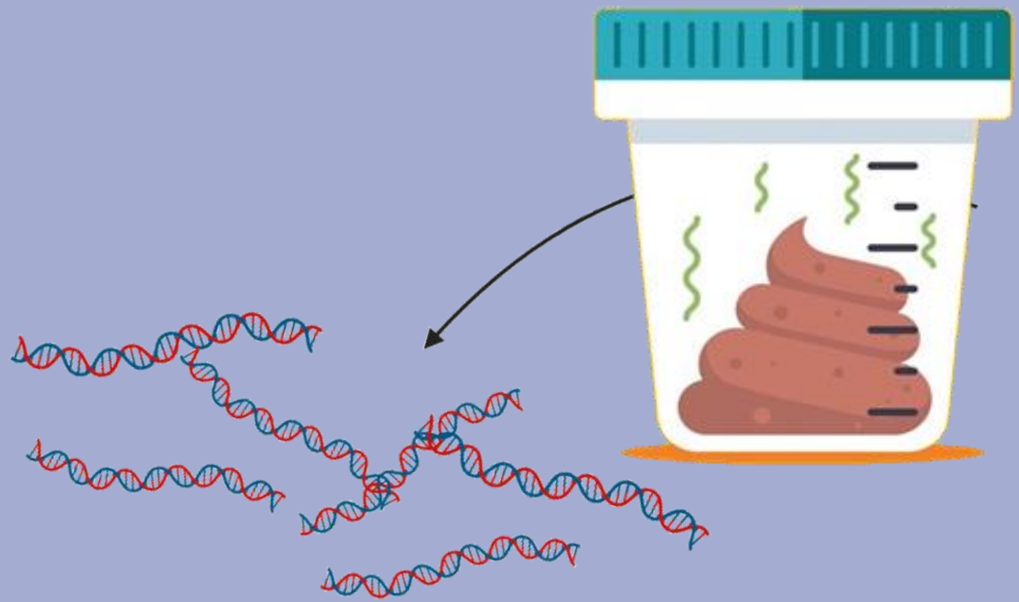
Metagenomics

The study of **all** the genetic material that is extracted from the entire environmental sample

Microbial function and diversity

Cultured Isolates (genomics)

Metagenomics



Microbial function and diversity

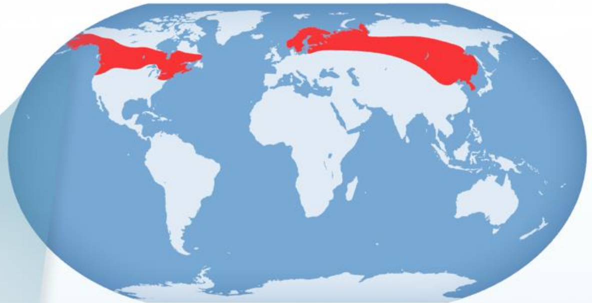
Extra slides:

BIOMES, ECOSYSTEMS, AND HABITATS

WHAT IS THE DIFFERENCE?

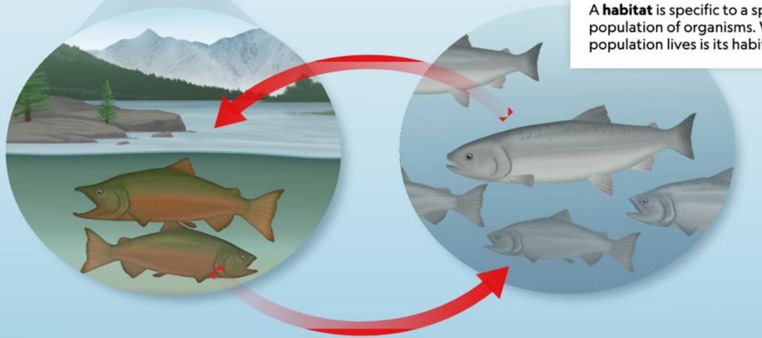
A **biome** refers to a region of the world characterized by its resident life, environment, and climate. Temperature, precipitation, and amount of sunlight all affect what type of life resides in a particular biome and help define each biome. There are a number of biomes around the world, including savanna, rainforest, desert, taiga, and marine biomes.

The taiga, or boreal forest, is the largest terrestrial biome. This northern biome extends from below the Arctic and occupies parts of North America, Europe, and Asia. The region is characterized by high elevation, nutrient-poor soil, and cold temperatures. The taiga is marked by the presence of evergreen trees, such as pines and spruces. There may also be some deciduous trees, such as oak and birch. The animals that reside here are specially adapted to the cold, with features like thick fur. Such animals include snowshoe hares, moose, wolves, and lynxes.



The word **ecosystem** refers to the interaction between organisms living together in a particular environment. This definition encompasses both biotic and abiotic factors, such as water, climate, and soil. Additionally, ecosystems are defined by the flow of energy and nutrients throughout the system.

An example of an ecosystem within the taiga is the Interior Alaska-Yukon lowland taiga. This ecosystem is home to animals like waterfowl, caribou, and black bears, as well as trees like black spruce and alpine fir.



A **habitat** is specific to a species or population of organisms. Wherever that population lives is its habitat.

Consider the habitat of the Chinook salmon. This migratory fish lives in freshwater and marine environments depending on where it is within its life cycle. Chinook salmon inhabit the Interior Alaska-Yukon lowland taiga ecosystem for part of their life, but their habitat extends beyond that. They are born in fresh water, like the Yukon River, and then migrate to the Pacific Ocean as they mature. However, when it is time to spawn, they return to fresh water.

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