Introduction to Environmental Microbiology (& Microbial Ecology)

- **Bacteria**
  - Green non-sulfur bacteria
  - Gram positives
  - Purple bacteria
  - Cyanobacteria
  - Flavobacteria
  - Thermotogales

- **Archaea**
  - Methanobacterium
  - Methanococcus
  - Pyrodictium
  - Thermoproteus T.celer
  - Methanosarcina
  - Entamoebae
  - Slime molds

- **Eucarya**
  - Animals
  - Fungi
  - Plants
  - Ciliates
  - Flagellates
  - Trichomonad
  - Diplomonads
  - Microsporidia
Microbial Ecology & Environmental Microbiology—the study of microbes & their processes in vivo:

- What is an ecosystem?
- Are all ecosystems colonised by microbes?
- What do we know about numbers & diversity of microbes in nature?
- Do they live in isolation and or do they interact?
- How many microbial species are there & can we culture them all in the laboratory

Who, where, what & how
Why Study ecosystems?

To date, much of what we know about the origin, maintenance and distribution of biological diversity stems from research on terrestrial macroorganisms such as birds, plants and insects.
Abundance of aquatic microbes

- Extremely abundant
- High and constant abundances in very different environments
- Bacterial biomass equivalent to phytoplankton and zooplankton
- Key global heterotrophic process at ecosystem level: DOM---→POM
- Key role as primary producers
Microbes

Understanding the distribution and basic ecology of one of the most abundant and diverse groups of organisms on Earth is still a unsolved crucial issue in environmental research.
Microbes are small

but...
... sometimes they have conspicuous colors in pure cultures... and we can see them easily ...

PHOTOSYNTHETIC SULFUR BACTERIA
...making visible the invisible!

LAKE CISO, SPAIN

PURPLE SULFUR BACTERIA
Huge biogeochemical activity...

FIG. 6. Geomicrobiological model of the Tinto River showing the roles of the different microorganisms identified in the ecosystem. Microorganisms are shown associated with their role in the iron and sulfur cycles. The type size of the organism designation is proportional to the respective cell density.
...making visible the invisible!

RIO TINTO, SPAIN
huge cells accumulations...

Hyperhaline Haloquadratum and Salinibacter

ST POLA SOLAR SALTERNS, SPAIN

Up to $10^8$ cells/ml!
Making visible the invisible...

ST POLA SOLAR SALTERNS, SPAIN
... even from 800 km distance!

A “milk sea” of luminescent *Vibrio* detected by satellite
Sometimes we cannot see them, but we can count them

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Population size (cells)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oceans</td>
<td>$1.2 \times 10^{29}$</td>
</tr>
<tr>
<td>Soil</td>
<td>$2.6 \times 10^{29}$</td>
</tr>
<tr>
<td>*Subsurface</td>
<td>$4.9 \times 10^{30}$</td>
</tr>
<tr>
<td>Global</td>
<td>$5 \times 10^{30}$</td>
</tr>
</tbody>
</table>

Whitman et al. PNAS 1998

*terrestrial habitats below 8 m (groundwater included) and marine sediments below 10 cm
<table>
<thead>
<tr>
<th>Habitat</th>
<th>Population size (cells)</th>
<th>Biomass (Pg of C)</th>
<th>Plant Biomass (Pg of C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oceans</td>
<td>$1.2 \times 10^{29}$</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Soil</td>
<td>$2.6 \times 10^{29}$</td>
<td>26</td>
<td>560</td>
</tr>
<tr>
<td>Subsurface</td>
<td>$4.9 \times 10^{30}$</td>
<td>325-520</td>
<td>0</td>
</tr>
<tr>
<td>Global</td>
<td>$5 \times 10^{30}$</td>
<td><strong>350-545</strong></td>
<td><strong>562</strong></td>
</tr>
</tbody>
</table>

1 Pg = $10^{15}$ g

Whitman et al. PNAS 1998
Microbes as a key heterotrophic component...

$\text{DOM} \rightarrow \text{POM}$
Microbes as the most versatile primary producers...
Huge metabolic diversity
<table>
<thead>
<tr>
<th><strong>(Reductants)</strong></th>
<th><strong>pE</strong></th>
<th><strong>(Oxidants)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>P870$^-$ → P870$^+$ (hη)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P680$^-$ → P680$^+$ (hη)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CH$_2$O → CO$_2$</td>
<td>-</td>
<td>CO$_2$ → CH$_2$O</td>
</tr>
<tr>
<td>H$_2$ → H$^+$</td>
<td></td>
<td>H$^+$ → H$_2$</td>
</tr>
<tr>
<td>NH$_4^+$ → N$_2$</td>
<td></td>
<td>N$_2$ → NH$_4^+$</td>
</tr>
<tr>
<td>CH$_4$ → CO$_2$</td>
<td></td>
<td>CO$_2$ → CH$_4$</td>
</tr>
<tr>
<td>H$_2$S → S$^0$</td>
<td></td>
<td>S$^0$ → H$_2$S</td>
</tr>
<tr>
<td>H$_2$S → SO$_4^{2-}$</td>
<td></td>
<td>SO$_4^{2-}$ → H$_2$S</td>
</tr>
<tr>
<td>Fe$^{2+}$ → Fe(OH)$_3$</td>
<td></td>
<td>Fe(OH)$_3$ → Fe$^{2+}$</td>
</tr>
<tr>
<td>NH$_4^+$ → NO$_3^-$</td>
<td></td>
<td>NO$_3^-$ → NH$_4^+$</td>
</tr>
<tr>
<td>Mn$^{2+}$ → MnO$_4^-$</td>
<td></td>
<td>P870$^+$ → P870$^-$</td>
</tr>
<tr>
<td>CO → CO$_2$</td>
<td></td>
<td>MnO$_4^-$ → Mn$^{2+}$</td>
</tr>
<tr>
<td>N$_2$ → NO$_3^-$</td>
<td></td>
<td>CO$_2$ → CO</td>
</tr>
<tr>
<td>H$_2$O → O$_2$ (hη)</td>
<td></td>
<td>NO$_3^-$ → N$_2$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>O$_2$ → H$_2$O</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P680$^+$ → P680$^-$</td>
</tr>
</tbody>
</table>

R$_{RED}$ ---→ R$_{OX}$

O$_{OX}$ ---→ O$_{RED}$
Huge genetic diversity

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- Purple bacteria
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- Microsporidia

Woese et al. PNAS 1990
We realized about that only a few years ago!

- Microorganisms play far more important ecological roles in natural environments than their small sizes would suggest (Brock et al. 1988)

Microbial Ecology, a young discipline
Despite their central ecological importance and numerical dominance, the true extent of microbial diversity still remains poorly resolved due to significant **theoretical and practical problems** that have hindered the quantification of bacterial diversity in the past and the disciplinary boundaries that tend to separate **microbiologists from ecologists**.
“We have catalogued and named all the celestial bodies we can detect in the universe but still we do not know how many biological species are living in our planet”

Robert May, 1992

Microbial “black box”
practical problems...

How DAPI stained bacteria looks like through a microscope...

...celestial bodies?

The golden dream of a microbial ecologist would be...
I am a lion

We are zebras

We are trees

We cannot tell them apart
**Culturability**

"the great plate count anomaly"

<table>
<thead>
<tr>
<th>Environment</th>
<th>Culturability (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oceans and seas</td>
<td>0.001 - 0.1</td>
</tr>
<tr>
<td>Continental waters</td>
<td>0.25</td>
</tr>
<tr>
<td>Mesotrophic lake</td>
<td>0.1 - 1</td>
</tr>
<tr>
<td>Estuary</td>
<td>0.1 - 3</td>
</tr>
<tr>
<td>Activated sludges</td>
<td>1 - 15</td>
</tr>
<tr>
<td>Sediments</td>
<td>0.25</td>
</tr>
<tr>
<td>Soil</td>
<td>0.3</td>
</tr>
</tbody>
</table>

and most of the times they are weeds!
The number of microbial species: high or low?

HIGH NUMBER OF SPECIES
• The oldest organisms on Earth
• 3.500 millions years of evolution and diversification
• High number of microniches at their size level

LOW NUMBER OF SPECIES
• High dispersion rates (cosmopolites)
  • Low extinction rates
  • Low speciation rates
  • Lateral gene transfer
Some of the aims of the microbial ecologists are:

- to determine how many different microbial species are out there,
- to find out what they can do,
- and to provide the know-how to identify environments of high and low microbial diversity
Very simple questions for macroorganisms

...but a very hard task for microbial ecologists!
The tools: a key issue

The Tools will be discussed in more details in Module 2