

A child-centric microbiology education framework

## Marine bacteria: The Unseen Majority

*Daddy: Are there more trees or mosquitos on earth?*



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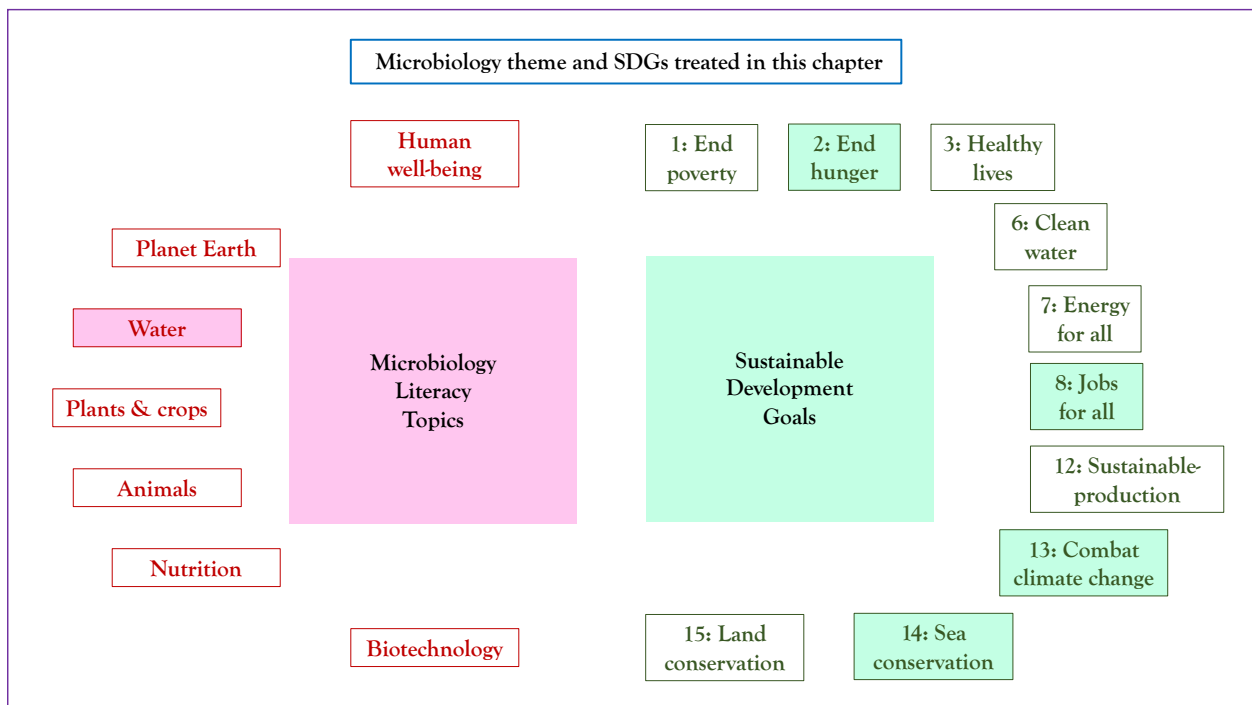
## Marine bacteria

### Storyline

Neither trees nor mosquitos are the most abundant organism on the planet. That title belongs to organisms that cannot be seen with the naked eye: bacteria. They make up the Unseen Majority. Although too many bacteria are pathogens, the vast majority are not, but rather are vital members of natural ecosystems. Bacteria are especially important in the largest ecosystem on the planet, the oceans. Some marine bacteria are major primary producers, like land plants, and others decompose dead organic material and recycle plant nutrients that support primary production. Bacteria and other microbes are at the base of food chains supporting all life in the oceans, including fish and other marine organisms that we value for food or for their beauty.

### The Microbiology and Societal Context

*The Microbiology:* bacterial abundance in natural environments; carbon cycle; food webs; nutrient cycling; marine primary production. *Sustainability issues:* end hunger; employment for all; climate change; conservation of marine resources



### Marine bacteria: the Microbiology

1. *The changing view of microbes.* The oceans are filled with an amazing diversity of life, from small pufferfish and squids to giant mako sharks and blue whales. Some waters sport tuna, halibut, red drum and red porgy, snapper, seabream, flounder, and grouper, to name a few of the countless fish prized by nature and seafood lovers. The list of shellfish, such as snails and scallops, is equally long. All of these organisms depend on what cannot be seen without a microscope: bacteria and other microbes.

Most people probably became aware of bacteria when they had an infection – dysentery, or maybe pneumonia. Diseases caused by bacteria once killed millions around the world and are still a problem in poor regions without adequate sanitation and access to modern medicine. Pathogenic bacteria were among the first to be discovered by early microbiologists in the late 19<sup>th</sup> century, and they have been the focus of intensive research ever since.

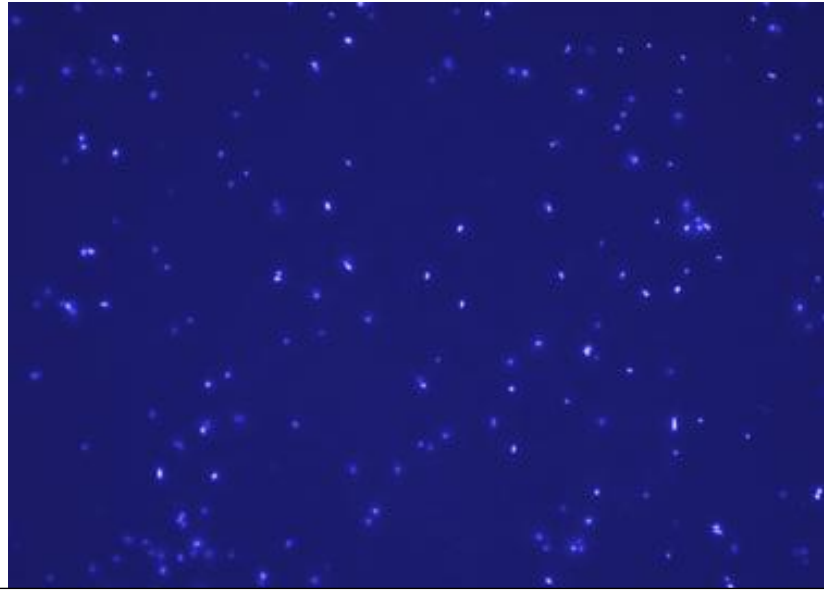
Our picture of bacteria has changed as microbiologists and microbial ecologists have discovered that the vast majority of bacteria are not pathogenic. In fact, they are essential for our health and for the successful functioning of a healthy ecosystem, including the largest one on the planet, the oceans.

2. *Marine bacteria are one of the most abundant organisms on the planet.* Marine microbiologists first thought that each milliliter of seawater had about 1000, or  $10^4$  bacteria. The estimate came from the plate-count method first developed by the German Robert Koch in the 1880s, who effectively used it to discover the bacteria that causes anthrax (*Bacillus anthracis*) and tuberculosis (*Mycobacterium tuberculosis*). In the plate-count method, a sample is spread over solid media on Petri plates, enabling individual bacteria to grow enough to form masses or colonies of cells visible to the naked eye. The number of colonies then reflects the number of bacteria in the original sample. The method is still used, even though studies beginning in the 1950s revealed that it seriously underestimates the number of bacteria in natural habitats.

Another approach to enumerate bacteria relies on staining cells for their nucleic acids and then viewing them by a type of light microscope, called an epifluorescence microscope. The stain makes the bacteria glow, or fluorescence, against a dark background. Although best suited for samples from the oceans, rivers, or lakes, the direct count method can be adapted to soils and other, nonaqueous habitats. Other approaches have confirmed that nearly all particles seen by the direct count method are bacteria.

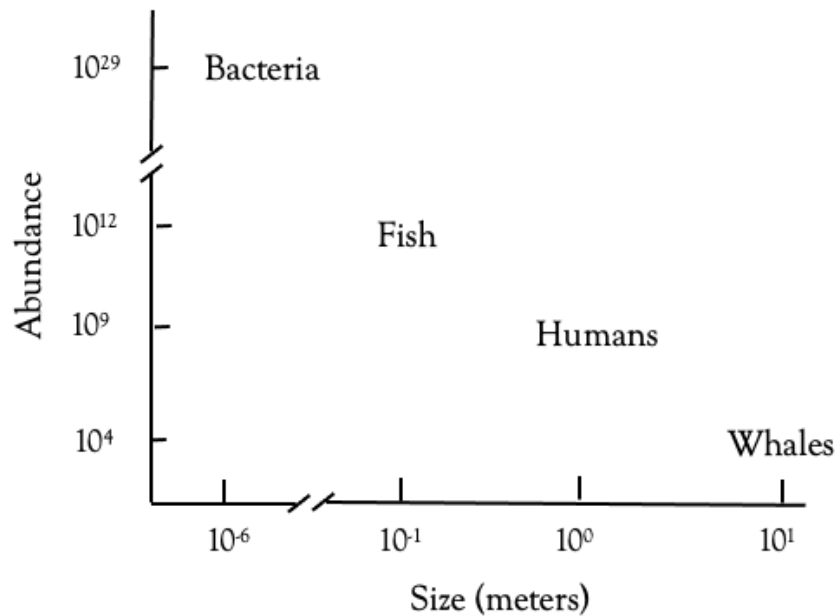
The direct count method reveals that there are roughly a million, or  $10^6$  bacteria in each milliliter of seawater. The number is a bit higher in nutrient-rich estuaries and a bit lower, about 500,000, in the open oceans. At the magnification used in the direct count method (1000x), bacteria are the only organism in the picture. (A few of the stained particles may be viruses, which are about 10 times more abundant than bacteria, but viruses are smaller and need a brighter stain to be visualized by epifluorescence microscopy.) Bacteria are the most abundant organism in the ocean, about 10 times more abundant than the next-most abundant organism, algae. As a rule, the smaller the organism, the bigger its population size.

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Marine bacteria stained with 4',6-diamidino-2-phenylindole (DAPI) and viewed by epifluorescence microscopy. Each white dot is a bacterium, about 0.5 microns in diameter.

Bacteria truly make up the Unseen Majority. That's the case on land as well as in the oceans. The only organisms more abundant on Earth than bacteria in the oceans are bacteria in soils. Although oceans cover much more of the planet than does land, each gram of soil has about 1000 more bacteria than are in a milliliter of seawater. The organisms that we can easily see make up a very small minority of biota on Earth.



Approximate abundance and size of some organisms.

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Perhaps even more surprising, in spite of their small size, collectively bacteria weigh more than nearly all other organisms in the oceans. The biomass of marine bacteria is  $1.3 \times 10^{15}$  grams or 1.3 gigatons of carbon (Gt C), which is nearly twice the biomass of fish (0.7 Gt C) and much more than of whales and other marine mammals (0.004 Gt C). The only marine organisms rivaling bacteria in terms of biomass are other types of microbes such as algae and other protists. (Protists are single-cell eukaryotes such as many algae and protozoa.)

**3. *Marine bacteria are essential for a healthy ocean.*** A few marine bacteria are pathogens and infect other marine organisms and, in rare cases, humans. Although marine bacteria such as *Vibrio vulnificus* are potent pathogens, they can infect people only if ingested in contaminated seafood or via an open wound. However, nearly all bacteria are not pathogens but are essential for the cycling of nutrients and carbon that all other marine organisms depend on.

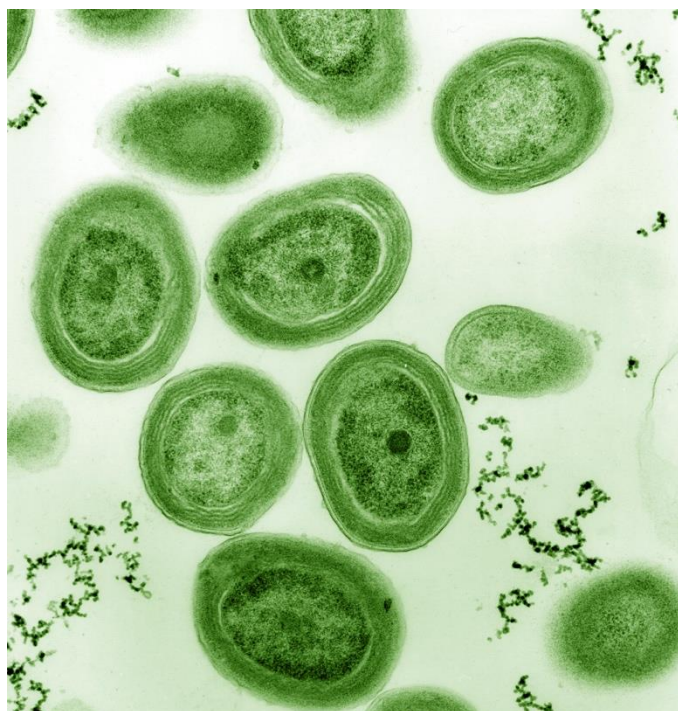
Bacteria are capable of mediating nearly all chemical reactions and pathways making up elemental cycles that keep the biosphere running. Without bacteria, these reactions and pathways would grind to a halt. They include exotic ones, such as the oxidation of hydrogen sulfide or the decomposition of methane, which no other organism can carry out. (The exception is archaea, which are superficially like bacteria.)

Here, however, the focus is on two pathways in the carbon cycle that involve plants and animals. Because they consume or produce carbon dioxide, the most important greenhouse gas, the two pathways and the associated microbes are important in understanding climate change.

**4. *Some marine bacteria contribute to primary production.*** All organisms and all food webs depend on primary production, which is the synthesis of organic material by photosynthetic organisms from carbon dioxide. Uptake of carbon dioxide is crucial part of the carbon cycle and is the base of all food chains. Photosynthetic organisms include higher plants, algae, and cyanobacteria. (Other microbes, such as anaerobic anoxygenic photosynthetic bacteria, also contribute to primary production but they are abundant in only a few habitats.) On land, the main primary producers are higher plants while in the oceans, nearly all primary production is by microalgae and cyanobacteria. Primary production by kelp, other macroalgae, and seagrasses is substantial in only a few coastal habitats and contributes only a small part to the global production.

Although microalgae such as diatoms and coccolithophorids are important primary producers in nutrient-rich marine waters, cyanobacteria dominate in the open oceans with low nutrient concentrations. Cyanobacteria were once called blue-green algae because they carry out the same type of photosynthesis seen in algae and higher plants, and they have chlorophyll *a*, the same photosynthetic pigment that gives algae and plants their green color. The blue in blue-green algae comes from another photosynthetic pigment, phycocyanin, found only in cyanobacteria and red algae.

Some marine cyanobacteria, such as *Trichodesmium*, occur as long filaments, but the most abundant form in the oceans is a single round cell, or coccus roughly one micron in diameter. One genus, *Prochlorococcus*, is not only the most abundant cyanobacterium in the ocean but it is the most abundant photoautotroph on the planet. Higher plants, algae and cyanobacteria are all photoautotrophs and use light energy to make their cell components from carbon dioxide and inorganic nutrients.

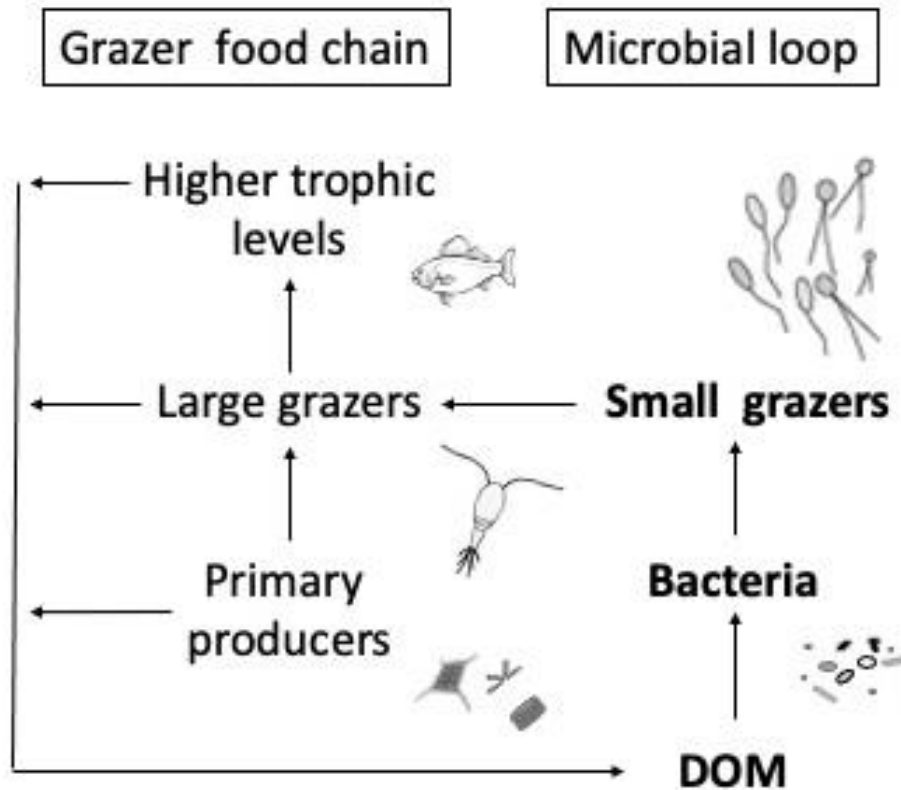


*Prochlorococcus*, the most abundant cyanobacterium and the most abundant photoautotroph on the planet. Picture by Luke Thompson and Nikki Watson, licensed under Creative Commons CC0 1.0.

5. ***Many marine bacteria are decomposers of dead organic material.*** The carbon cycle pathway returning carbon dioxide to the biosphere is the decomposition of organic material by heterotrophic organisms. As seen in animals, heterotrophs use some organic material for energy, releasing carbon dioxide in the process, and some organic material to make their own cellular components. Heterotrophic bacteria are mainly responsible for degrading oil and other organic chemicals polluting the oceans.

These bacteria are also very important in food webs and the carbon cycle. The traditional grazer food chain starts with primary producers, followed by herbivores that eat primary producers and carnivores that eat herbivores. Heterotrophic bacteria are outside the traditional food chain and were once thought to be important only in releasing nutrients used by algae and other primary producers.

In the oceans and other aquatic habitats, heterotrophic bacteria are at the center of another food chain, called the “microbial loop.” It consists of the uptake by bacteria of dissolved organic material and the grazing on bacteria by other microbes, protists, which in turn are eaten by other organisms in the grazer food chain. Because only bacteria can use dissolved chemicals, they return or loop back carbon to the grazer food chain that otherwise would have been lost. The microbial loop consumes roughly half of all primary production, making it a large part of food webs and the carbon cycle.



The microbial loop and the traditional grazer food chain. The microbial loop, in bold, starts with the release of dissolved organic material (DOM), which is taken up nearly exclusively by bacteria. The carbon in DOM is “looped” back to the grazer food chain when the bacteria are eaten by small grazers which in turn are eaten by larger grazers, eventually ending in fish and other large organisms high in the food chain.

### Relevance for Sustainable Development Goals and Grand Challenges

- **Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture.** Bacteria and other microbes are major players in the marine food web and, as such, contribute significantly to the provision of food sources – finfish, shellfish and algae – harvested for humans and livestock.
- **Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.** Bacteria are not only major contributors to marine food resources, and hence to the industries and sources of employment based upon fishing, but they are the central agents of metabolism and removal of biological, geological (e.g. oil seeps) and anthropogenic wastes, and thus for maintaining marine water quality. This is of crucial importance for many economic activities, especially tourism, which are major employers in coastal regions.

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- **Goal 13. Take urgent action to combat climate change and its impacts.** Bacteria play key roles in the production and consumption of greenhouse gases, including carbon dioxide, methane, and nitrous oxide, which govern earth's climate.
- **Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development.** The metabolic activities of bacteria are responsible for maintaining the water quality of marine systems such as removing pollutants produced by agriculture and industry.

### Exercises

1. Why are bacteria the "Unseen Majority?"
2. How many bacteria would cover a person who has dived into an ocean? Assume the person has an odd shape, a box 1.5 meters by 0.3 meters by 0.2 meters. Assume also that the water on this box-like person is 0.01 meters deep with  $10^6$  bacteria per milliliter (or cubic centimeter).
3. Discuss how a food chain based on bacteria would differ from one based on diatoms which are 50 to 100 microns in diameter. Hint: the ratio of predator to prey size is roughly 10:1 in the oceans.
4. What is the key difference between the microbial loop and the grazer food chain?
5. What would the oceans look like without any heterotrophic bacteria?

### The Evidence Base, Further Reading and Teaching Aids

Bar-On, Y. M., R. Phillips, and R. Milo. 2018. The biomass distribution on Earth. Proceedings of the National Academy of Sciences 115: 6506-6511, <https://www.pnas.org/content/pnas/115/25/6506.full.pdf>  
<https://ocean.si.edu/ocean-life/microbes/marine-microbes>: One of many websites devoted to marine bacteria and other microbes

Pomeroy, L.R., P.J. leB. Williams, F. Azam, and J.E. Hobbie. 2007. The microbial loop. Oceanography 20(2): 28-33, <https://doi.org/10.5670/oceanog.2007.45>.

### Glossary

*biomass*: the weight of living cellular material, usually expressed in terms of carbon.

*cyanobacteria*: bacteria that carries out the type of photosynthesis seen in algae.

*elemental cycles*: the production and consumption of chemicals containing a particular element. In the carbon cycle, for example, plants, algae, and cyanobacteria consume carbon dioxide to produce organic carbon chemicals, which are decomposed by heterotrophs back to carbon dioxide.

*epifluorescence microscopy*: a type of light microscopy that depends on illuminating a sample with light and observing the light, or fluorescence emitted from the stained sample.

*heterotrophy*: the use of organic material to produce energy and for the synthesis of cellular components. Animals are heterotrophs as are many bacteria and other microbes.

*microbe*: any organism that requires a microscope to be seen.

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*microbial loop*: the uptake of dissolved organic chemicals by bacteria, the grazing on those bacteria by protists, and the grazing of protists by other organisms.

*photoautotrophy*: the synthesis of an organism's cellular components from carbon dioxide and inorganic nutrients, fueled by light energy. Plants, algae, and cyanobacteria are all photoautotrophs.

*protist*: single-cell eukaryotes. Many algae are protists as are protozoa.