

The microbial world of sand

Let's go to the beach!



Photo by Quang Nguyen Vinh:
<https://www.pexels.com/photo/boy-playing-on-slide-in-playground-2143761/>



Photo by Renya Sh :
<https://www.pexels.com/photo/children-playing-on-beach-sand-on-shore-10435582/>

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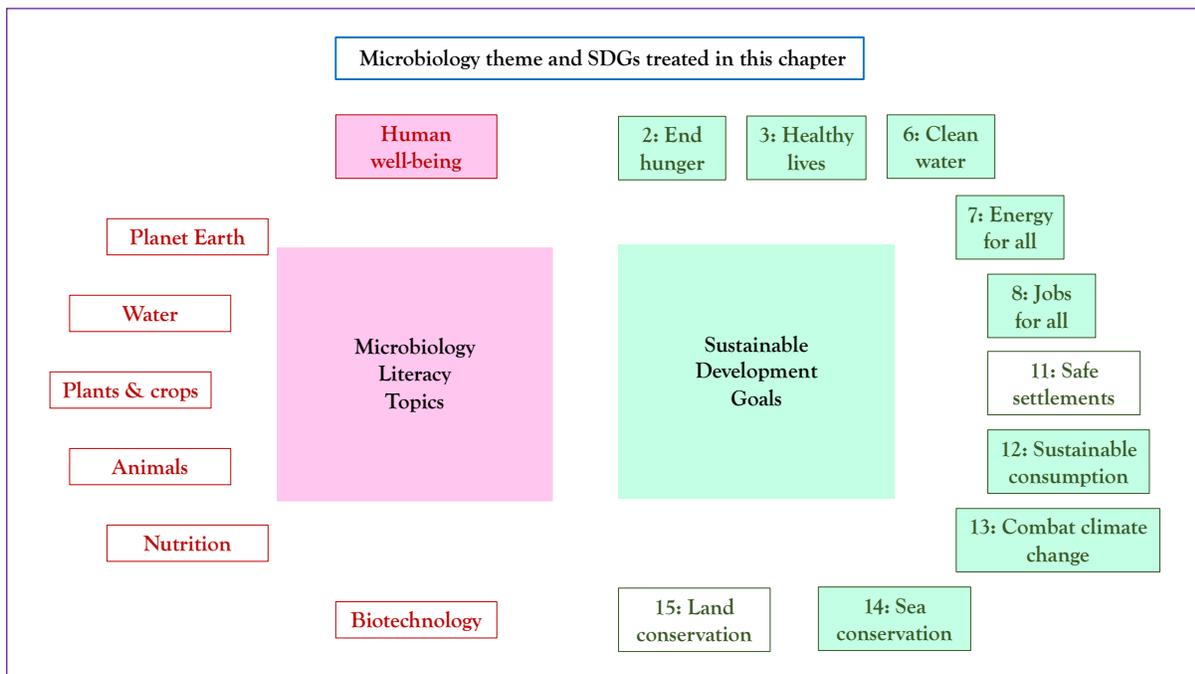
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Storyline

A trip to the beach offers a multitude of opportunities for recreation, ranging from swimming to fishing to near shore boating, surfing and building sandcastles. Trips such as this provide children with a wonderful opportunity to connect with the natural world, and a beach harbors a wide variety of organisms for you to interact with, even though they are hidden in the sand, invisible to the casual viewer. Beaches are what we call edge ecosystems, which are defined as where two different ecosystems meet, in this case, the land and the sea. Because of this, there are a number of different habitats that can be found in a beach, especially with respect to the amount of water and type of water present within the beach sands, resulting in a wide diversity of microorganisms within the sand. These microorganisms work to remove excess dissolved carbon and nitrogen from the waters percolating through the sand as the waves run up and down the beach slope. Through their growth, the microbes not only work to clean the seawater, they serve as the base of the food chain for small animals that live within the beach sediments, animals such as shellfish and crustaceans, which larger animals will feed upon, providing the beach goer with fishing and birding opportunities. Beaches are not static ecosystems and are constantly undergoing change through the actions of storms and sea level rise, which will disturb the underlying community, which will then have to rebalance itself to survive the conditions associated with the beach.

The Microbiology and Societal Context



The microbiology: biofilms, biofilters, nutrient cycling, ecosystem stability, coastal fisheries and recreation. *Sustainability issues:* tourism, recovery from disaster (manmade and natural), sea level rise

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The microbial world of sand: the Microbiology

1. ***The sand between our toes is home to countless microbes.*** Sandy coastal beaches provide excellent habitats for microbes to grow. The porosity of the sediments allows for the near constant flow of seawater bearing dissolved nutrients through the sediment column. The ebb and flow of the tides adds to the complexity of the system by changing the height of the local water table twice daily. In the seawater just offshore, picoplankton – the invisible floating microbial world – convert carbon dioxide into organic materials via photosynthesis and some of these organisms convert nitrogen gas into ammonia, which is used to form proteins and other organic compounds. These basic processes, coupled with the activities of marine animals, such as fish and birds, provide the basic nutrients that support the microbes living within the beach sediments. At this juncture, we will divide the microbes living within the beach sediments into two categories, chemoorganotrophs (aka heterotrophs) and chemolithotrophs.

Chemoorganotrophs obtain their energy and carbon from preformed organic compounds such as sugars and proteins. They use these materials, originally created by photosynthesis and made available via the excretion of wastes by all types of living organisms, and the lysis of dead cells and organisms, for the energy needed to build and repair their cells. Through the process of growth and reproduction, heterotrophs remove excess dissolved organic material from the water, thereby helping to maintain local water quality.

Chemolithotrophs use certain inorganic chemicals as their energy sources and, in the context of this story, this inorganic chemical is ammonia. To obtain the carbon compounds that are needed for cell growth, these microbes will fix carbon dioxide in a process analogous to the processes found in photosynthesis. These two classes of microbes combine through their metabolic activities to help reduce the eutrophication process by removing excess carbon and nitrogen compounds.

So: next time you are enjoying yourself on and in the sand, think about the microbes on the sand between your toes that carry out such important beach cleaning activities!

2. ***Sand microbes are food for other organisms.*** Microbes growing within the sediments and trapped by beach sediments through the filtration process serve as the food source for many species of invertebrates. These animals graze microbes adhered to sand particles or filter the microbes from the water percolating through the sand column. In turn, these invertebrates are eaten by larger animals such as fish and birds. The beach goer can easily see birds dipping their beaks into the beach sands as they feed on invertebrates. Persons who are fishing will know that some fish will feed on these invertebrates and will even collect their bait from the surf zone as they fish. And while many people enjoy these activities when they go to the beach, very few will understand that these activities are supported by the microbes residing in the sands under their feet and the waters swirling around their knees.

3. ***Not all beach microbes are harmless.*** As you probably know by now, not all microbes are beneficial to our health and safe recreation, and beach systems are not exempt in this regard. Beaches around the world are monitored for the presence of fecal coliforms – typical bacteria that inhabit our intestines – which serve as a proxy for the presence of potentially harmful bacteria and viruses such as *Salmonella* and rotaviruses. Such microbes would enter the water through

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runoff or spills from sewerage treatment facilities. When the levels of these bacteria reach certain levels, the beach is closed to recreational activity until coliform levels drop to a level considered safe.

Other potentially dangerous bacteria, known as *Vibrios* can be found in coastal areas, though they are not common and are generally associated with shellfish. Keep in mind that not all *Vibrios* are harmful to humans, and most are innocuous residents of the sand microbial community that consumes organic carbon, converting it into microbial biomass and carbon dioxide.



In these pictures, you can see bits of plant matter that have washed up onto the beach. While some will go back into the sea due to the actions of the tides, some will be mixed into the beach sands, where it comes into contact with the microbial community and is degraded. Photo by Harry Kurtz at Nags Head Beach, North Carolina, USA



Not all beaches are sandy beaches. Some are mostly rocks and others are a mix of sand and rock. Here we see a rocky beach with some sand present. You also see plant material that was deposited by the tides and like a sandy beach, some of this material will mix into the rocks and sand, where the microbes will work to decompose it. Photo by Harry Kurtz, Brant Rock Massachusetts, USA.

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4. ***Beach microbes recycle seaweed and other plant materials.*** Microbes within the beach ecosystem not only consume dissolved organic materials, they also break down larger particulate matter such as seaweed. If you've been to a beach, especially after a storm or even just a gusty day, you likely saw plant matter. This plant matter comes from the local marshes that may be near the beach, or from the sea grass beds that can be found just beyond the zone of cresting waves. When wave action increases in intensity, it has the potential to break off or uproot sea grasses, allowing the action of the waves to bring the material onto the beach. Marsh grasses arrive in a similar fashion, though here, it is the tides that move the grasses from the estuary into the near coastal waters where the actions of currents and waves move the material along and onto the beach. You can see this plant matter, especially along the high tide mark.

These deposits of plant matter are the source of food for a wide variety of microbes, who will produce enzymes that break down the cellulose and other components of the plant, releasing smaller organic compounds. Much of this material is used by the microbes degrading the plant material, though a portion of it simply washes away and feeds the larger microbial community within the beach. A similar process happens to animals that die on the beach, though it is a much faster process, comparatively speaking.

5. ***Beach restoration activities temporarily perturb the microbial ecology of beach sand.*** Through the action of waves and wind, beach sediments can be formed into coastal dunes that provide some protection against damage from storm and sea level rise. At times this protection is not enough, and the beach becomes severely eroded. Such coastal erosion can be repaired through dredging of nearby sediment deposits and using that material to renourish the damaged beach. Microbiologically, this process brings a subtidal community of microbes onto the beach, which is a different environment for them, resulting in a temporary instability in the new beach community as it adjusts to the new conditions. Once the renourishment of the beach is completed, the action of the waves and tides slowly change the chemistry of the beach sands by percolating seawater through them. Over time, the composition of the microbial community resembles what was there prior to the damage.

Relevance for Sustainable Development Goals and Grand Challenges

The microbial dimension of coastal beaches relates to several SDGs (*microbial aspects in italics*), including

- **Goal 3. Healthy Lives** (*safe recreation, improved health*). Recreational opportunities contribute to healthy lives. Maintaining a healthy beach ecosystem provides for safe opportunities for people to connect with nature. It also contributes to the health and well being of birds, sea turtles and many other animals, providing us with opportunities to observe them. Healthy beaches help protect us from pollutants that may impinge on and affect the beach. Low levels of petroleum products that come from recreational vehicles such as boats and cars are rapidly degraded and removed by the indigenous microbes found in the beach sands and gravels.

- **Goal 6. Clean Water** (*reduce pollution, improve water quality*). While salt water is not drinkable, it is important that the water remain clean so that you and others can recreate in it. The microbes in the beach ecosystem remove excess nutrients from the water filtering

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through it, helping to prevent eutrophication of the near shore waters. This process supports a healthy fishery and helps to keep recreational opportunities safe.

- **Goal 8. Jobs** (*promote economic growth*). Coastal recreation and tourism provides many jobs to people on an annual and a seasonal basis. Residents who live near the coast depend on clean beaches to draw the tourists in all year long. In the northern hemisphere, the off season on the coast will see tourists who come to fish as well as the local populace coming to fish on the beaches. During the summer tourist season, people will come to the beach communities for recreation and employment. Whenever the local beaches are compromised, whether through erosion or pollution, tourism drops precipitously, resulting in fewer dollars coming into the community.

- **Goal 12. Sustainable Consumption** (*maintain local fishery, reduce beach maintenance and clean up*). There are many different ecosystems that contribute to maintaining a healthy fishery; beaches are one of these ecosystems. Microbial growth in the beach sands provides food to some of the invertebrates and protozoans, which then become food for larger animals. This source of food helps to support the growth of numerous fishes, which may become part of your dinner someday. Thus, it is important that we keep our beaches healthy as they, along with other ecosystems such as tidal marshes, help to keep our food supply healthy.

- **Goal 15. Land Conservation** (*reduce detritus on beach, develop healthy dune soil, stabilization of coastal landscape, harden beach to storm damage, reduce pollution, provide for diverse animal and plant life*). Beaches as places where the land and sea meet, represent an edge ecosystem. The conservation of these ecosystems not only conserves our sea resources, but also conserves our land. Beaches are highly dynamic systems with water levels rising and dropping roughly every 13 hours as the tide comes in and out. While this is an obvious example of the dynamics present on the beach, wind also plays a large role in the dynamics of a beach. Here we look to the wind driven movement of sand, which will form the coastal dune systems. Sand dunes start off as eolian sediment deposits, that if left undisturbed long enough, will develop a plant community, changing the dune sand into a soil. This process can take years to occur, but the development of a plant community on the dunes makes the sand dunes more stable, and thus more resilient to storms. Ultimately, this process will bring sandy sediments from the sea and form islands and peninsulas that can be used by humans and other animals. Unfortunately, sea level rise is affecting this process adversely at this time, causing these land structures to either shift to different locations, or disappear into the sea.

Potential Implications for Decisions

1. *Individual*

- a. Do the benefits of recreating on a beach outweigh the potential negative impacts on yourself?
- b. What about your impact on the beach? Does building a sand castle affect the beach in a negative or positive fashion? If you fish from the beach, what are the potential impacts from that activity?
- c. If you drive onto the beach, what are things that your vehicle might do to the beach and how might your vehicle affect the microbiota?

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d. *Non-microbial parameters: How will your trip to the beach affect the resident wildlife? Do you require a permit or license to conduct that activity?*

2. *Community policies*

- a. What are the regulations associated with the beach you are visiting and how are they implemented?
- b. Pollution of public spaces is always a concern, especially when many people use that space at the same time. What would be some of the ways that a community could reduce pollution by tourists (and locals) to a bare minimum?
- c. Health costs associated with infections and injuries that happen at times.
- d. *Non-microbial parameters: support of local economy.*

3. *National policies relating to seashore (beach) activities*

- a. Environmental pollution
- b. Endangered species protection (turtles and birds)
- c. Coastal erosion and recovery
- d. Fisheries management
- e. *Non-microbial parameters: policies relating to beach recreation: licensing and permits. town beach versus National Seashore off road vehicle permits, resident or non-resident fishing license.*

Pupil participation

1. *Have students who have recently been to a beach talk about what they observed.*

2. *Pupil stakeholder awareness*

- a. Beaches and dunes are beautiful yet fragile ecosystems: what activities increase their fragility and what can we do to protect them better?
- b. Beach use has positive and negative consequences for the SDGs. Which of these are most important to you personally/as a class?
- c. Beaches are great for parties: what should we avoid doing to protect them?

3. *Exercises*

- a. Beaches change constantly with wave and wind action. See if you can find historical records/images of a beach and draw the changes it has experienced over time.
- b. Find out what restoration activities are planned for a beach and draw its outline now and how it is planned.
- c. Look for images of how major hurricanes or other storms have affected beaches.

The Evidence Base, Further Reading and Teaching Aids

Environmental Protection Agency's Beach Information Website: <https://www.epa.gov/beaches>

Beach Renourishment and Restoration: <https://www.nps.gov/articles/beach-nourishment.htm>

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Figure 5 shows the basic physical structure of a coastal beach. <https://www.nature.com/scitable/knowledge/library/coastal-processes-and-beaches-26276621/>

Figure 1 shows water movement, fresh and salt, within the beach system <https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2015WR017395>

Glossary

Chemoorganotrophs (heterotrophs): Microbes that use organic compounds as a source of energy and carbon for metabolic processes.

Chemolithotrophs: Microbes that use inorganic compounds as a source of energy to fuel metabolic processes. In most cases, these organisms also fix carbon that is used to build cell structures.

Eolian deposits: Wind deposited sediments that are often seen in the form of dunes, though could also be depressions in the landscape that have been filled with sand and dust by the wind.

Fecal coliforms: These are bacteria associated with the intestinal tract of mammals and are used to assess the level of contamination by human waste.

Salmonella: This is a genus of bacteria related to fecal coliforms that can cause intestinal illness if ingested.

Rotaviruses: These viruses can cause diarrhea if ingested.

Vibrios: This is a large group of bacteria that have a curved cellular morphology that makes them look like a comma when viewed under the microscope. Most are innocuous to humans, though several can cause severe disease if a person becomes infected.

Saprophytes: A plant, fungus, or microorganism that lives on dead or decaying organic matter.