Chapter 6
Marine Microbes
Micro-organisms are the most abundant organisms in the oceans. They include viruses, prokaryotes, protists, and some fungi. Even though they are not visible to the naked eye, they have very important ecological roles. They are the basis of the food chains and play an important role in decomposition and recycling of nutrients.
Marine Viruses

- Virology—the study of viruses
- Viruses are diverse and are more abundant than any other organism in the sea
- Have significance for marine food webs, population biology and diseases of marine organisms
Marine Viruses

- Marine viruses are extremely abundant in the oceans and play an important ecological role.
- Marine viruses are 10 times more abundant than marine prokaryotes, and can be found in densities of up to $10^{10}$ virions/liter in surface water and up to $10^{13}$ virions/liter in sediment.
- Bacteriophages – viruses that infect bacteria
Marine Viruses

- Viruses can use both prokaryotic and eukaryotic organisms as hosts. They are sub-cellular particles that are considered non-living.
Viral Characteristics

- Most authorities do not consider them to be alive
  - Remember you have to be made of at least one cell to be alive, viruses are not cells
- Viruses consist of bits of DNA or RNA surrounded by protein
- 10 and 400 nanometers in length.
- Have no metabolism, and rely entirely on host organism for energy, material and organelles to reproduce themselves
- Viral replication must occur within a host cell
- Viruses infect all groups of living organisms, but may be specialized
  - Infect specific species
  - Infect specific tissues of that species
Viral Characteristics

- **Viral structure**
  - virus particle is called a virion when outside the host cell
  - virion composed of a nucleic acid core surrounded by a coat of protein called a capsid (together called a nucleocapsid)
  - may have a protective envelope, a membrane derived from the host’s nuclear or cell membrane
Ecology of Marine Viruses

- Viruses kill host cells, and thus reduce/control populations of bacteria and other microbes in plankton communities.
- Viruses also responsible for chronic infection and mass mortality of populations of marine animals.
  - For example – problems with shrimp aquaculture.
- Bacterial lysis can alter biogeochemical cycles and planktonic food webs by releasing nutrients back into food webs.
Virus infecting a Bacterium

Figure 4.2. This phage (virus that infects bacteria) causes lysis (breakdown) and death of the cell after it has replicated itself.
Marine Bacteria

- General characteristics
  - simple, prokaryotic organization: no nuclei or membrane-bound organelles, few genes, nonliving cell wall
  - reproduce asexually by binary fission
  - many shapes and sizes
    - bacillus—rod shape
    - coccus—spherical shape
Nutritional Types of Marine Bacteria

- Cyanobacteria are also known blue-green algae
  - They are the only photosynthetic prokaryotes and in fact photosynthesis has evolved only once, in this group.
  - All other photosynthetic organisms have acquired their plastids (photosynthetic organelles) at some point by endosymbiosis with cyanobacteria.
Nutritional Types of bacteria

- Cyanobacteria (blue-green bacteria)
  - photosynthetic bacteria which are found in environments high in dissolved oxygen, and produce free oxygen.
Photosynthesis:

- Carbon dioxide (CO₂)
- Water (H₂O)

Light energy

Carbohydrates (CH₂O)ₓ + Oxygen (O₂)

Cyanobacteria – Free oxygen produced

© 2010 Cengage Learning
Nutritional Types of Marine Bacteria

- Many species of cyanobacteria can use N\textsubscript{2} as a source of nitrogen—allowing them to thrive where low levels of nitrogen nutrients (nitrates (NO\textsubscript{3}- and nitrites NO\textsubscript{2}-) limit the photosynthesis and growth of other photosynthetic organisms.

- They possess unique accessory pigments, which capture different wavelengths of light, enable chromatic adaptation with depth, and protect the cell from damaging wavelengths of light.
Nutritional Types of Marine Bacteria

- The cyanobacteria *Prochlorococcus sp.*, which thrives in nutrient-poor tropical waters, is believed to be the most abundant life form throughout the oceans.

- Blooms of cyanobacteria can form dense mats that may discolor the water, giving the Red Sea its title.
Nutritional Types of Marine Bacteria

- Other cyanobacteria form mats that trap sediment and precipitate chemicals forming structures known as stromatolites, now only seen in the Bahamas and Australia.
Nutritional Types

- Other photosynthetic bacteria
  - sulfur bacteria are obligate anaerobes (tolerating no oxygen)
  - non-sulfur bacteria are facultative anaerobes (respiring when in low oxygen or in the dark and photosynthesizing anaerobically when in the presence of light)
Purple and green bacteria – No free oxygen produced
Nutritional Types

- Chemosynthetic bacteria are found in areas that are rich in compounds that can be oxidized to release energy, such as hydrothermal vents (where they use hydrogen sulphide, H2S) and cold seeps (use methane, CH4).
- They may be free-living or occur in symbiosis with other organisms.
- Chemosynthetic bacteria are often anaerobic (don’t need oxygen) and do not need sunlight.
Nutritional Types

- Chemosynthesis is less efficient than photosynthesis, so rates of cell growth and division are slower
  - found around hydrothermal vents and some shallower habitats where needed materials are available in abundance
Nutritional Types

- Heterotrophic bacteria
  - decomposers that obtain energy and materials from organic matter in their surroundings
  - return many chemicals to the marine environment through respiration and fermentation
  - populate the surface of organic particles suspended in the water by secreting mucilage (glue-like substance)
Nutritional Types

- Heterotrophic bacteria are decomposers and break down available organic matter to obtain their energy.
- As a result, they release inorganic chemicals back into the water which can then be used again by primary producers.
- Many heterotrophic bacteria may release exoenzymes that can digest cellulose, chitin, keratin and other molecules largely resistant to decay.
Nutritional Types (Heterotrophic Bacteria)

- Heterotrophic bacteria
  - association of heterotrophic bacteria with particles in the water column aids with:
    - consolidation: adjacent particles adhere
    - lithification: formation of mineral cement between particles
    - sedimentation: settling of particles
  - marine snow: large, cobweb-like drifting structures formed by mucus secreted by many kinds of plankton, where particles may accumulate
Black Band Disease
Nitrogen Fixation and Nitrification

Nitrogen fixation is the process by which molecular nitrogen (N2) dissolved in seawater is converted to ammonium (NH4+).

Some cyanobacteria and a few archaeons are capable of fixing nitrogen, allowing them to thrive in low nutrient conditions.

Nitrification is the bacterial conversion of ammonium (NH4+) to nitrite (NO2-) and nitrate (NO3-), forms usable by most plants and algae.
Nitrogen Fixation and Nitrification

- Nitrogen cycle includes nitrogen fixation and nitrification
  - Nitrogen fixation is a major process that adds new usable nitrogen to the sea
  - only some cyanobacteria and a few archaeons with nitrogenase (enzyme) are capable of fixing nitrogen
Nitrogen Fixation and Nitrification

- Nitrification is the process of bacterial conversion of ammonium (NH$_4^+$) to nitrite (NO$_2^-$) and nitrate (NO$_3^-$) ions.
  - bacterial nitrification converts ammonium into a form of nitrogen usable by other primary producers (autotrophs).
Symbiotic Bacteria

- Many bacteria have evolved symbiotic relationships with a variety of marine organisms
- Endosymbiotic theory
  - mitochondria, plastids & hydrogenosomes evolved as symbionts within other cells
- Chemosynthetic bacteria live within tube worms and clams
- Some deep-sea or nocturnal animals host helpful bioluminescent bacteria (light-producing bacteria)
  - Photophores of deep sea fish
  - Embedded in the ink sacs of deep sea squid
The Archaea are also prokaryotes, but they differ from the Bacteria in a few important ways.

- Probably most important is the biochemistry of their cell walls, which in Archaea is more resistant to heat and other extreme environments.
- For this reason, many archcheons inhabit extreme habitats: high or low temperatures, high salinities, low pH or high pressure.
Archaea

- Hyperthermophiles
  - organisms that can survive at temperatures exceeding 100° C, such as near deep-sea vents
  - Potential for biomedical and industrial application
Archaeons are generally smaller than bacteria, measuring 0.1 to 15 micrometers in length.

They may be either autotrophs or heterotrophs.

Some archaeons are methanogens: anaerobic organisms that live in environments rich in organic matter, releasing methane as a waste product of metabolism.
Eukarya

- The domain Eukarya includes all organisms with eukaryotic cells, such as plants, animals, fungi and protists.
- There is an incredible diversity of micro-organisms in the domain Eukarya in the ocean.
- We will only cover some of the most important groups.
Fungi

- Fungi are eukaryotes with cell walls made of chitin (the same compound used in the exoskeleton of crustaceans).
- They are heterotrophic decomposers that use exoenzymes to recycle organic matter.
- Fungi are strict aerobes; anaerobic decomposition is carried out by bacteria.
Fungi

- General features of fungi
  - eukaryotes with cell walls of chitin
  - many are unicellular yeasts
  - filamentous fungi grow into long, multi-cellular filaments called hyphae that can branch to produce a tangled mass called a mycelium
  - heterotrophic decomposers that recycle organic material
    - can digest lignin (major component of wood)
Fungi

- General features of fungi (con’t)
  - Kingdom Fungi is divided into 4 phyla:
    - Chytridiomycota (motile cells)
    - Zygomycota (e.g. black bread mold)
    - Basidiomycota (club fungi, e.g. mushrooms)
    - Ascomycota (sac fungi)
  - In marine systems, ascomycotes are the most diverse and abundant fungi
Fungi

- Marine fungi are not very abundant (less than 1% of fungi are marine), and they
- are mostly microscopic.
- Marine fungi can be classified on the basis of where they live.
  - By far the most diverse group of marine fungi can be found on decomposing wood of terrestrial origin although others types may inhabit coastal salt marshes, mangroves, sand or the planktonic communities of the open ocean.
Fungi

- Fungi are also important as disease agents, for example aspergillosis, a disease found in Caribbean sea fans, is caused by the fungus *Aspergillus sydowii*.

- Lichens are mutualistic associations of fungus and algae.

- The fungus provides the attachment, general structure, minerals, and moisture, while the alga produces organic matter through photosynthesis.
Fungi

- This association allows lichens to inhabit inhospitable environments, for example high up in the intertidal zone.
Stramenophiles

- The stramenopiles are a diverse group of protists with two flagella of unequal length.
- They are named for one of their flagella which has hair-like filaments stramen=straw; pilos=hair
- Some stramenopiles are photosynthetic, others are not.
  - Those that photosynthesize have acquired their plastids (photosynthetic organelles) through secondary endosymbiosis.
This means that stramenopiles acquired through endosymbiosis a photosynthetic eukaryotic organism which itself had acquired its plastics from endosymbiosis with cyanobacteria.

The stramenopiles are a varied group which includes the brown algae, diatoms, other ochrophytes and labyrinthomorphs.

Of the microscopic stramenopiles, only diatoms will be discussed.
Flagellum with mastigonemes

STRAMENOPILES

WITH STRAW HAIRS

Chrysophytes

Diatoms

Cafeteria

macrophytic brown algae

opalines

© 2010 Cengage Learning
Diatoms

- Diatoms are important members of both planktonic and benthic communities.
- They are photosynthetic primary producers and have a cell wall made of silicon dioxide (SiO$_2$; a major constituent of glass).
- This cell wall, called a frustule, is composed of two halves, or valves, with one fitting over the other like a shoe box.
Diatoms

- They exhibit either radial symmetry (centric), usually seen in planktonic species, or bilateral symmetry (pinnate), more typical in benthic diatoms.

- They are most abundant at high latitudes and in areas of upwelling where nutrient levels are relatively high, as they are large phytoplankton and require silica as well as nitrates and phosphates in order to thrive.
Diatoms

- Some diatoms can produce a toxin called domoic acid, which when present in high concentrations can kill other organisms.
- Diatoms reproduce both asexually and sexually.
- They reproduce asexually by fission, where the valves separate and each secretes a new valve inside the old valve.
Diatoms

- This asexual reproduction leads to progressively smaller individuals and when a diatom has reached 50% of its original size, it reproduces sexually through the formation of an auxospore.

- Under poor environmental conditions, diatoms can form resting spores which sink to the bottom and stay dormant until such time when favorable conditions persist before developing.
Diatoms

- Because silica is insoluble and does not decompose, when diatoms die their frustules sink to the benthos and accumulate in the sediment, creating siliceous oozes prolific at high latitudes.
- When brought to the surface, diatomaceous earth can be harvested as commercial filters (used in swimming pools, and beer and champagne production) or abrasives (used in silver polish and toothpaste).
Diatoms

- Diatomaceous sediments
  - Frustules of dead diatoms sink and collect on the seafloor to form siliceous oozes
  - Accumulations form sedimentary rock
  - These deposits, called diatomaceous earth, are mined for use as filtering material, a mild abrasive, and for soundproofing and insulation products
  - Nutrient reserves, stored as lipids, accumulate in siliceous oozes accounting for most of the world's petroleum reserves
    - Ancient diatoms sank to the bottom of the ocean, were covered by sediment before they decomposed, were subjected to pressure and heat and turned into petroleum
Diatoms
Haptophytes

- The haptophytes are a group of mostly photosynthetic organisms that are closely related to the stramenopiles but have simple flagella (without hair) and a unique structure called the haptonema.

- The haptonema is used to capture food in heterotrophic haptophytes but is also present (if usually shorter) in photosynthetic ones.
Haptophytes

- The largest group of haptophytes are the coccolithophores.
- Coccolithophores are exclusively marine and photosynthetic.
- They have a calcium carbonate shells made of coccolith plates, which may account for up to 40% of modern carbonate production in the oceans forming sediment known as calcareous oozes.
Haptophytes

- In some areas these sediments have been uplifted and form chalk cliffs, e.g. the White Cliffs of Dover.
Alveolates

- Alveolates have membranous sacs under their cell membranes.
- They include several closely-related groups; by far the most important in the marine environment are the dinoflagellates.
- Dinoflagellates are globular, single-celled organisms which have two flagella that lie in grooves on the cell’s surface.
Alveolates

- One of the flagella creates forward propulsion while the other makes the dinoflagellate spin.
- Armored dinoflagellates are covered in cellulose plates which give protection and aid in species identification.
Dinoflagellates mostly reproduce asexually by fission, yet many species may also reproduce sexually.

Dinoflagellates also occasionally produce dormant cysts which are resistant to decay and environmental stress, and can mature when environmental conditions are favorable.
Dinoflagellates

- Dinoflagellates, unlike diatoms, do not require silica as a nutrient.
- Moreover, they can be autotrophic, heterotrophic, or mixotrophic (capable of both autotrophy and heterotrophy).
- These characteristics allow dinoflagellates to be more abundant than diatoms in nutrient-poor tropical waters.
Dinoflagellates

- Some dinoflagellates are parasitic, while others occur in mutualistic symbioses such as the zooxanthellae that live in the tissues of corals and other cnidarians.

- Some dinoflagellates are bioluminescent, e.g. *Noctiluca*, and light up the wake of boats and waves on the beach.
Dinoflagellates

- Dinoflagellates are one of the most important groups responsible for harmful algal blooms, also known as red tides.
- Some species produce toxins that may be concentrated by filter feeders but are harmful to humans and other organisms that consume them.
Red Tides
Choanoflagellates

- Choanoflagellates are the protists most closely-related to the animal kingdom.
- They occur as single cells or in colonies, and their cells closely resemble the feeding cells of sponges.
Amoeboid Protozoans

- Foraminiferans and radiolarians are heterotrophic protists grouped together as amoeboid protozoans.
- They all have organelles called pseudopods which are extensions of the cell surface that can change shape and are used for propulsion or to catch prey.
- Amoeboid protozoans are heterotrophs and consume bacteria and other small organisms by phagocytosis.
Amoeboid Protozoans

- Most have a shell or test (externally secreted organic membrane covered in foreign particles or strengthened with mineral secretions) which form a thick ooze over vast areas of the deep sea floor.
- Foraminiferans have branched pseudopods that form netlike structures used to catch prey, reduce sinking rate or crawl on the benthos.
Amoeboid Protozoans

- They produce a multi-chambered calcium carbonate test and are a major constituent of deep-sea sediment, in areas shallower than 5000m.

- Foraminiferans also contribute to the pink sands of many Caribbean islands.
Radiolarians

- Radiolarians have an external organic membrane called a capsule, which bears pores that allow pseudopods to pass through.
- They also secrete an internal shell of silica, which doesn’t decompose and accumulates as a siliceous ooze at low latitudes.