CHAPTER 18 THE BENTHOS: DWELLERS OF THE SEA FLOOR

Objectives

1. To introduce the animals and plants that live either in, or on, the sea floor.
2. To show that benthic plants are closely tied to light intensity and are, therefore, found only in shallow-water environments while benthic animals populate the sea floor at all depths.
3. To learn how distributions of benthic organisms can be broken down into depth and energy zones.
4. To show how we sample the benthos and how we may harvest the benthos for food and other important products.

Key Concepts

Major Concept (I) *The large, benthic, multicellular seaweeds are members of a group called algae.*

Related or supporting concepts:

- Benthic seaweeds are found in coastal intertidal and subtidal communities attached to rocks, shells, or any solid object.
- Seaweeds are not found in areas with unconsolidated sediment, sand or mud, where they can attach themselves firmly to the bottom.
- These organisms contain chlorophyll and photosynthesize. Traditionally, they have been considered members of the plant kingdom, but most biologists only consider them plant-like.
- They do not produce flowers or seeds, and their pigments and storage compounds vary from group to group.
- To remain fixed to the bottom in these high-energy environments, the benthic algae have developed specialized structures that include (see fig. 18.1):
    a. a holdfast, or basal organ, which anchors the plant to the bottom,
    b. a stipe, or stem-like structure connecting the blades to the holdfast, which can be very short or upwards of 35 m (115 ft) in length, and
    c. blades (the photosynthetic organs), which are leaf like structures connected to the stipe.
- Although these structures look very much like those of the flowering plants, most do not serve the same transport functions that they do in true flowering plants. There is no need to transport water up the stipe to the blades.
- Because of the variable absorption of light as a function of wavelength with depth, the dominant color of algae changes with increasing depth. Specifically, algae tend to change from green colors in shallow, rocky shore areas to brown at intermediate depths and finally red at greater depths.
- Seaweeds provide important food and shelter for many animals.

Major Concept (II) *Pigment colors are used to classify algae, or seaweeds, into phyla (see section 18.3 in the text).*

Related or supporting concepts:

- Although algae are commonly classified by color this can be misleading. The visible color of a specific species can be variable. Some red algae appear brown, green, or violet, and some brown algae appear black or greenish.
- Representative algae are illustrated in figure 18.2 in your text.
- Green algae:
    a. are primarily freshwater organisms but a few of them live in the sea,
    b. are moderate in size,

c. may form fine branches or thin, flat sheets, and
d. are most similar to land plants in that they:
    1. have the same green chlorophyll pigments, and
    2. store starch as a food reserve.

- Brown algae:
    a. are marine and range from the microscopic to the giant kelps (the largest of all the algae), and
    b. have a brown pigment, fucoxanthin, that masks the green chlorophyll.
- Red algae:
    a. are almost exclusively marine,
    b. are the most abundant and widespread of the large algae,
    c. are considered the most complex of the algae,
    d. contain the pigments phycoerythin and phycocyanin, which mask the chlorophyll, and
    e. store food reserves in floridean starch.
- There are also benthic diatoms. These are usually pennate diatoms that grow on rocks, muds, and other structures, creating a slippery brown coating.

Major Concept (III) *There are a few marine flowering plants with true roots, stems, and leaves.*

Related or supporting concepts:

- There are a variety of sea grasses that inhabit the marine environment. These include:
    a. eel grass that grows on mud and sand in quiet embayments along the Pacific and Atlantic coasts,
    b. turtle grass along the Gulf Coast, and
    c. surf grass that flourishes in more turbulent habitats exposed to waves and tidal action.
- The decaying leaves of these sea grasses are an important source of nutrients for shorelines and estuaries.
- They also provide a place of attachment for other organisms such as sponges, worms, and tunicates.
- Marine grasses that can tolerate brackish water dominate salt marshes. While some of these grasses are eaten directly by herbivores, much of the vegetation breaks down and is washed into estuaries where bacteria break it down further and release nutrients to the water.
- Mangrove trees are common along humid, tropical coasts. These trees:
    a. are salt-tolerant, woody plants,
    b. can thrive in oxygen-deficient muds,
    c. have waxy leaves to reduce water loss,
    d. expel salt through glands located on their leaves,
    e. help to build the shore seaward by trapping sediments and organic material in their roots.

Major Concept (IV) *Benthic animals, unlike plants, are found at all depths and on all kinds of substrate. There are 50 times more benthic (over 150,000) than pelagic (about 3000) marine animal species.*

Related or supporting concepts:

- There are two basic subdivisions of benthic organisms:
    a. the epifauna, animals that live on or attached to the bottom (80% of benthic organisms), and
    b. the infauna, animals that live buried in the soft sediments of the sea floor such as mud and sand.
- Benthic animals are either classified as being sessile, attached to the sea floor, or motile, moving about the bottom freely.
- Many benthic animals, either sessile or motile, produce motile planktonic larvae.
- The production of motile larvae is particularly important to the ecology of sessile bethos. It allows these species to colonize new areas and reduce population density in regions that might otherwise become overcrowded.
- Sessile benthos have to wait for their food to come to them. Motile benthos can move in search of

prey.

- The distribution of benthic animals is controlled by a complex interaction of several environmental factors and their lifestyles are related to their varied habitats.

Major Concept (V) *A good way to introduce ourselves to the many different types of benthos is to discuss them by the different environments they occupy. This can be done either by depth, substrate type, or by energy level (although these are often intimately related).*

Related or supporting concepts:

- The environments we will use for grouping benthic organisms in this discussion are:
    a. intertidal areas,
        1. rocky shorelines
        2. tidal pools
        3. soft substrates (mud, sand, and gravel)
    b. the deep-sea floor, including deep-sea chemosynthetic communities.
- We will discuss general characteristics of the organisms and their environments in the next sections.

Major Concept (VI) *Intertidal environments are subject to rapid and drastic environmental changes and the distribution of the organisms that live there is governed by their ability to deal with the stresses brought on by periodic exposure, the high energy of wave and tidal turbulence, and other extreme changes in chemical and physical parameters. Even with the harsh nature of this environment it can be as, or more, productive than tropical rain forests.*

Related or supporting concepts:

- Animals in rocky intertidal areas arrange themselves in a vertical or intertidal zonation. Figure 18.4 illustrates some of the organisms that are found here. These zones are:
    a. the splash or supralittoral zone,
    b. the midlittoral zone, and
    c. the lower littoral.
- The supralittoral zone:
    a. This zone is above high water and is only covered by water during storms or extremely high tides.
    b. This environment is as much continental as marine.
    c. Animals in this zone are adapted for long periods of sub-aerial exposure and the possibility of desiccation as well as heat, cold, rain, snow, and predation by land animals and birds.
    d. The width of the zone varies with the slope of the area, as well as variations in sun and shade, exposure to waves and spray, tidal range, and frequency of fog and cool days.
    e. Lichens and blue-green algae are found at the top of the zone. Further down are snails and limpets. Barnacles are found at the bottom of the zone.
    f. Organisms of the supralittoral zone are illustrated in figure 18.5 in your text.
- The midlittoral zone:
    a. In this zone, periods of exposure and the threat of desiccation are minimal, however, living in a prime real estate area has its price, as competition for space and predation may control the distributions of many of these organisms.
    b. Common members of this zone are illustrated in figure 18.6. These include crabs, barnacles, limpets, snails, mussels, and chitons.
    c. Organisms in this zone have different ways of anchoring themselves to the bottom.
        1. Chitons and limpets have a muscular foot,
        2. barnacles secrete a strong cement, and
        3. mussels attach themselves to rocks with strong threads.
    d. Many organisms can prevent themselves from drying out when they are exposed to the air by

closing their shells tightly.

e. These organisms often have shells with rounded, shallow profiles to reduce resistance to wave and currents activity.

f. Seaweeds in this zone typically have strong holdfasts and flexible stipes.

- The lower littoral zone:
  a. Organisms common to this zone are illustrated in figure 18.7.
  b. This area is not subject to severe wave or tidal activity except for minus tides, therefore many delicate sessile forms and motile forms not adapted for high energy live here.
  c. Large anemones are common here. These are flower-like animals that are attached firmly to the rocks. Their tentacles have poisonous darts called nematocysts that are used to stun prey.
  d. A wide variety of starfish are common in the lower littoral zone.
  e. Other organisms include a variety of worms, snails, sponges, and sea slugs (nudibranches).
  f. Familiar inhabitants of this zone are the octopuses. Octopuses:
     1. are eight-armed, soft-bodied mollusks,
     2. feed on crabs and shellfish,
     3. live in caves and crevices,
     4. can flash color changes in their body,
     5. are generally shy and non-aggressive,
     6. have been shown to be capable of learning behaviors through observation, and
     7. can reach in excess of 7 m (23 ft) in diameter and weigh up to 45 kg (100 lb).
- The zonation of animals is narrow where the beach is steep or the tidal range is small, and wide where the beach is flat or the tidal range is large.
- Tidal pools can be thought of as compressed intertidal environments, each one unique and populated with organisms that are able to survive under those specific conditions.
- The bottom of the intertidal zone merges into the sublittoral or subtidal zone that in many cases extends across the continental shelf.
- A special group of organisms that grow profusely in the rocky intertidal, yet can be found on hard substrate anywhere and at any depth in the world oceans, are the fouling or boring organisms. Because they can coat and burrow into docks, pilings, ship hulls, pipelines and water cooling or sewage outfalls, much money and research goes in to understanding the behavior and life habits of these organisms, and ways of preventing their attachment.

Major Concept (VII)

Tide pools provide habitats in the intertidal, or midlittoral zone for organisms that normally inhabit the lower littoral zone.

Related or supporting concepts:

- The zonation of benthic organisms is often dependant on beach slope and tidal range. They tend to be narrow where the slope is steep and the range is small and broad where the slope is gentle and the range is large.
- Benthic zones can be displaced above where they would normally be found under special conditions of beach topography, wave action, and the orientation of the beach face to the sun.
- Tide pools are excellent examples of the displacement of a benthic zone above where it would normally be found.
- Tide pools form in depressions in the rock or other basins where water is trapped during low tide.
- Tide pools can be stressful environments due to variations in salinity, created by evaporation or precipitation, and temperature due to solar heating or night and seasonal cooling.
- The deeper the tide pool and the larger the volume of water it contains, the more stable the environment will be.
- Each tide pool is a specialized environment populated by organisms that can survive the conditions specific to that pool.

Major Concept (VIII)

The animals that live in or on the soft substratum, or unconsolidated sediments, such as mud, sand, or gravel, face very different living conditions than those in intertidal *areas*.

Related or supporting concepts:

- High-energy beach areas are unstable, and lack the amount of plant and animal life we see in the rocky intertidal areas. Moreover, zonation is much less defined.
- Low-energy, soft-sediment environments are much more favorable for more diverse and more numerically abundant faunal assemblages.
- Sands and gravels are both porous (have open spaces between grains) and permeable (water and gases can readily move through), and oxygen-rich fluids penetrate deep into these sediments.
- However, due to low permeability, silts, muds, and clay-rich sediments will only be oxidized up to 1–2 cm (0.5–1 in) into the bottom. Many organisms circumvent these problems by vigorously pumping overlying waters through their burrows or by extending their siphons (as in burrowing bivalves) up above the sediment-water interface.
- In areas protected from high wave and current energy, eel grass and surf grass will grow and help stabilize the sediment. These grasses also provide shelter, substrate, and food for many animals.
- Most organisms living in and on sands and muds are detritus feeders, and ingest small bits of organic debris on or in between the sediment grains. Some unique methods are used by certain worms, for example, some ingest large quantities of sediment, strip the bacteria and organics off of the particles in their guts, and before passing the fecal material, inoculate this material with their own intestinal flora and fauna.
- In these soft sediments, bacteria are not only the major decomposers, but also are one of the major suppliers of protein. Between 25% and 50% of the material the bacteria decompose is converted into bacterial cell material which is passed up the food chain through microscopic protozoans, small worms, clams, and crustaceans.
- The intertidal area of a soft-sediment beach exhibits some zonation of benthic organisms but it is not as clearly defined as it is along rocky coasts.
- The process of sediment disruption by feeding or burrowing organisms is known as bioturbation.
- The distribution of organisms in soft sediments is shown in figure 18.8 and figure 18.9 illustrates a selection of animals found in these areas.

Major Concept (IX)

The deep sea floor covers an enormous area dominated by fine-grained sediments in a rather deep, cold, dark environment.

Related or supporting concepts:

- Environments with uniform physical conditions over very long have faunal assemblages with very high diversity where many different kinds of species are competing intensely for the available space, nutrients, etc.
- Deep-sea floor sediments are more uniform and their particle size is smaller than sediments at shallower depths near land. The deep-sea floor is also an environment of constant temperature (cold) and darkness.
- The deep-sea floor is perhaps the most biologically diverse environment on our planet in terms of the numbers of different species.
- The great biological diversity of the deep sea is illustrated in the population of protozoan foraminiferans. Thirty species of planktonic foraminiferans are known while 1000 species of benthic foraminiferans have been described.
- It is also important to note that as diversity has gone up, the number of individuals in any one species population goes down.
    a. Deposit feeders are very abundant in the deep-sea sediments, and are found even in the deepest portions of the sea floor. One important component in the deep-sea sediments are the meiofauna or the meiobenthos, a very diverse group classified primarily by size, less than 2 mm, and that includes nematode worms, burrowing crustaceans, and segmented worms.
        1. Tusk shells are found at depths of 7000 m (23,000 ft).
        2. Acorn worms are common at depths of 4000 m (13,000 ft).
        3. Hagfish burrow into the sediment at depths of 2000 m (6600 ft).

b. Epifaunal organisms are equally diverse in the deep sea, and are found in the deepest of the trenches. Epifauna include protozoans, sponges, sea squirts, anemones, barnacles, tube worms, and snails.
   1. Glass sponges, sea worms, and sea squirts can be found attached to scattered rocks on ocean ridges and seamounts.
   2. Another common organism is the tube worm. It varies in size from a few millimeters to 20 cm (8 in).
   3. Sea spiders with four pairs of long legs that span up to 60 cm (27 in) are found at depths as great as 7000 m (23,000 ft).
   4. Snails are found at the greatest depths in the deepest trenches. Those that inhabit the deepest trenches often lack eyes and eye-stalks.

c. Unique animals occur at great depths.
   1. One of the most interesting groups are the pogonophora or beard worms. They inhabit the deep-sea floor at depths as great as 10,000 m (33,000 ft). They have no mouth or anus and they absorb nutrients and send wastes back out through their skin.
   2. Horny corals, or sea fans, grow at depths of 5000–6000 m (16,000–20,000 ft). They are animals but they resemble plants in appearance.
   3. Stone corals, sea lilies (or crinoids), brittle stars and sea cucumbers are also found in the greatest depths.
   4. Sea cucumbers live in areas where the sediment is rich in organic material. They are a dominant and wide-spread organism on the deep-sea floor.

d. The sedimentation rates in the deep sea are uniformly low enough so that the organisms that live on or in the sediment can mix, or bioturbate, the surface sediments, sometimes rapidly enough that they affect the layering or geologic record in any one location.

Major Concept (X)

Marine organisms sometimes settle and grow on structures. This is called fouling. Other organisms naturally drill or bore their way into the rock and sediment.

Related or supporting concepts:

- Fouling organisms include barnacles, anemones, tube worms, sea squirts, and algae.
- Fouling organisms can have a negative impact on vessels. When attached to the hull they increase drag with the water and decrease speed. This increases the cost of operating a boat both in terms of time, additional fuel, and the need to periodically take the boat out of the water for cleaning.
- Equipment placed in the water can also suffer ill effects from fouling.
- A great deal of research goes into, and money is spent on, antifouling paints and metal alloys.
- Many different animals bore into materials. Some representative examples include:
  a. sponges that bore into scallop and clam shells,
  b. snails that bore into oysters, and
  c. some clams that bore into rock.
- Organisms that bore into wood can produce very costly damage to harbor and port structures as well as wooden-hulled boats. The two organisms responsible for most of the damage are:
  a. the shipworm Teredo,
     1. Teredo is a worm-like mollusk with one end covered by a bivalve shell.
     2. It secretes enzymes that break down and partially digest wood fibers.
     3. It bores deep and very destructive holes in wood.
  b. and the gribble.
     1. The gribble is a crustacean.
     2. It gnaws more superficial and smaller holes but is still very destructive.

Major Concept (XI)

Coral reefs are one of the most unique, relatively self-contained benthic communities on Earth. It would be hard to find a faunal and floral assemblage with more exotic colors, incredibly luxuriant growth, and the diversity and complexity of animal and *plant interactions in one location (see fig. 18.13).*

Related or supporting concepts:

- Coral reefs are created primarily by colonial coral polyps that secrete a calcium carbonate skeleton.
- Coral polyps are similar to tiny sea anemones with tentacles and stinging cells (see fig. 18.14).
- These organisms are generally restricted to waters warmer than 18°C, with 23–25°C optimal. Therefore, we find these communities primarily between 30°N and S, and in shallow, well-lit, sun-warmed waters away from cold-water currents.
- Corals are filter feeders so they need relatively low-turbidity water to thrive. They are not found where large amounts of terrigenous sediments are shed into the oceanic system.
- The largest coral reef system in the world today is the 2000 km (1200 mi) long Great Barrier Reef that extends from New Guinea southward along the east coast of Australia.
- Warm, shallow water is required by reef-building corals for two reasons.
    a. Many of the polyps live in a symbiotic relationship with the single-celled dinoflagellate algae, zooxanthellae.
        1. The coral polyps provide the algal cells with a secure environment, carbon dioxide, and nitrate and phosphate nutrients.
        2. The zooxanthellae create organic material through photosynthesis, returning oxygen and removing waste.
        3. The polyps receive as much as 60% of their nutrition from the algae.
        4. The algae also make it easier for the coral to extract calcium carbonate from the water and increase their rate of growth.
    b. Water at depths greater than 50–100 m (150–300 ft) is usually too cold for significant secretion of calcium carbonate. The solubility of calcium carbonate increases with decreasing temperature.
        1. Most Caribbean corals are no more than 50 m (150 ft) beneath the surface.
        2. In the more transparent water of the Pacific and Indian oceans corals can be found as much as 150 m (500 ft) beneath the surface.
- Corals extend their tentacles to feed on zooplankton during the night. During the day they retract their tentacles and expose the outer layer of cells that contain zooxanthellae to the light.
- Corals are generally slow-growing. Some species grow less than 1 cm (0.4 in) in a year while others may grow as much as 5 cm (2 in) in a year.
- Corals require a stable, rocky, or volcanic substratum to cement to, therefore, most are found attached to volcanic islands or rocky coastal areas.
- The morphology and design of the corals is related to their position on the reef, probably most related to wave energy distributions.
- Coral reef systems are vertically and horizontally zoned due to their response to wave action (intensity and direction), and water depth (related to waves and light).
    a. On the protected, lagoon side of the reef is a low-energy region called the reef flat. This is usually populated with a large variety of more delicate, branched corals and other organisms. Fine carbonate particles broken off the top of the reef create sand that covers the bottom of the lagoon.
    b. On the windward side is the reef's highest point, the reef crest. This can be exposed during low tide and is generally subjected to high energy pounding from waves. Rounded, sturdy corals inhabit this area.
    c. Below the reef crest is a zone of steep, rugged buttresses and grooves that extend to a depth of about 10–20 m (35–65 ft). Buttresses and grooves dissipate wave energy and allow find sand and debris that could smother the coral to drain off the reef. Masses of large corals and large fish can be found here.
    d. At depths of 20–30 m (65–100 ft), there is little wave energy and the intensity of light is only about 25% of what it is at the surface. The corals at this depth are less massive and more delicately branched.
    e. From 30–40 m (100–130 ft) the slope is relatively gentle and it is quite dark. Sediment accumulates at these depths and corals are patchy.
    f. Below 50 m (165 ft) the slope drops off quickly into deep water.

- The reef exists in a delicate balance between the growth of new organisms on the reef surface and the many physical forces wearing away at the reef (sea level rises, volcanic activity, storms and wave action). In addition, there are biological processes that break down the reef as well.
- Coral reefs are a complex assemblage of many plant and animal species and a refuge for many species passing through. Some estimates indicate that 3000 or more species may coexist in and on a single reef.
- The reef itself can be considered a complete trophic pyramid with the sun's energy driving photosynthesis at its base.
- Physically, reefs are not just corals. They can include many other organisms, including encrusting algae, foraminifera, shells of bivalves, calcareous worm tubes, and spines, plates, spicules, and skeletal parts of hundreds of organisms. Conversely, physical forces are not the only agents that break the reef down; there are many organisms that have specialized in eating parts of the living reef, digesting the organics, and defecating the ground calcium carbonate in the reef environment.

Major Concept (XII) *Coral reefs are delicate ecosystems susceptible to bleaching, predation, and disease.*

Related or supporting concepts:

- Coral bleaching is a process whereby corals expel their zooxanthellae and turn white.
    a. Between 1876 and 1979 there were only three bleaching events but over sixty bleaching events were observed between 1979 and 1990.
    b. In the last two decades episodes of bleaching have become more frequent and more severe.
    c. This process has been related to changes in the temperature of the water caused by El Niño.
    d. Large amounts of bleaching occurred during the 1982–83 ENSO/El Niño event.
        1. Galapagos and Great Barrier Reef corals were damaged.
        2. Shallow reefs in the Java Sea lost 80% to 90% of their coral cover.
    e. The 1997–98 ENSO/El Niño event produced coral bleaching from the Indian Ocean to the coast of Brazil.
    f. Fifteen hundred scientists from over 50 countries met at the International Coral Reef Symposium in 2000 and concluded that coral reefs face a bleak future without immediate and drastic action.
    g. It is estimated that 11% of the world's coral reefs were destroyed by human activity before 1998 (table 18.1), and since that time another 16% have been severely damaged.
    h. In the Indian Ocean 50–95% of the coral reefs have died in the past two years.
- There have been reports from all over the world of reefs in trouble. Problems include infestation with algae, damage from predators, new diseases, recurrent bleaching, and loss of organisms.
- A particularly dangerous predator is the sea star *Acanthaster*, or crown of thorns.
    a. *Acanthaster* feeds on coral polyps.
    b. Fossil evidence indicates that the Great Barrier Reef has been periodically attacked by *Acanthaster* for at least the past 8000 years.
    c. The population of *Acanthaster* periodically increases rapidly. It is thought that these population explosions are related to rainy weather that lowers the salinity and increases nutrients by increasing runoff.
    d. The harvesting of large conches that feed on *Acanthaster* probably also contributes to these population explosions.
    e. There have been three *Acanthaster* population explosions on the Great Barrier Reef since the 1960s.
        1. The most recent outbreak began in 1995 and by 1997 it was affecting 40% of the reef.
        2. It takes 10–15 years for an affected area of the reef to recover.
        3. *Acanthaster* attacks on the reef may open up new areas for slower-growing coral species to expand.
- A recently discovered disease that attacks reef-building algae as well as corals is coralline lethal orange disease (CLOD).
    a. CLOD is caused by a bright orange bacterial pathogen that is lethal to the red algae that deposit calcium carbonate on the reef.
    b. This disease was originally discovered in 1993 in the Cook Islands and Fiji. By 1995 it was

found over a 6000-km (3600-mi) range of the South Pacific.

- Another dangerous disease is black-band disease. Black-band disease increased by 300% between 1996 and 1997 in Florida's reef system. Some people have suggested that this may have been the result of poor water quality and polluted runoff into Florida Bay.
- Scientists are now working on techniques for cultivating corals and introducing them to natural reefs to help the reefs recover. The probability of a cultivated coral being successfully transplanted appears to increase significantly with the size of the coral.
- Human activities have had devastating impacts on reefs all over the world.
    a. Reefs are damaged by careless divers, shell collectors, and boats dragging their anchors.
    b. Clearing of tropical forest areas creates increased runoff that carries sediment, fertilizers, and human and animal waste into coastal waters.
    c. The addition of nutrients can increase the growth of algae. These algae can outcompete the corals for space, smothering existing corals and preventing the growth of new ones.
    d. Some reefs are mined for building materials.
- The NOAA program Coral Reef Watch is developing a long-term coral reef monitoring system for predicting coral bleaching in all U.S. coral reef area. Data from monitoring stations in the Bahamas and the US Virgin islands will be used to provide a Coral Reef Early Warning System (CREWS).
- Not all corals are found in shallow, warm tropical water.
- Deep-water corals (also known as "cool corals") lack zooxanthellae.
- Deep-water corals form large reefs at temperatures down to 4°C and at depths of up to 2000 m.
- These corals are believed to feed on sinking dead plankton or sift food from currents in the water.
- Deep reefs have been found off the coasts of Norway, Scotland, Ireland, Nova Scotia, and Alaska's Aleutian Islands.

Major Concept (XIII) *Intertidal communities in high-energy environments can be more productive than rain forests on land.*

Related or supporting concepts:

- Intertidal communities inhabit a very high-energy environment. On average, waves deliver about 15 times more energy to the coastline than the Sun.
- Kelps inhabiting the rocky intertidal region have 2.5 times more photosynthetic area per square meter of growing area and are 2–10 times more productive than rain forest plants.
- Mussels have also been shown to equal or exceed rain forest productivity.
- High wave energy reduces the number of predators such as starfish and sea urchins. This allows more kelp and mussels to occupy the area.
- The fast moving water also brings nutrients to the organisms and keeps the blades of kelp moving so that they do not remain in the shade.

Major Concept (XIV) *There are unique communities of organisms that are tied to a process of chemosynthesis to generate biomass and energy for life.*

Related or supporting concepts:

- In 1977 we learned that our view of animal trophic systems tied to a large base of sun-driven photosynthetic plant activity was not the only energy source for ecosystems on this planet.
- An expedition to the Galápagos Rift on the East Pacific Rise in March, 1977 discovered densely populated communities of organisms living in the vicinity of hydrothermal vents.
- Dense clouds of hydrogen sulfide or methane metabolizing bacteria seem to be the base of the food chain in what we are now calling chemosynthesis, as they fix carbon and create simple sugars, and other organic building blocks chemically, without photosynthesis.
- Vent communities have been discovered at many other locations throughout the world along the mid-ocean ridge system.
- Nearly 300 new species of organisms have been discovered in these unique communities.
- The animals living in these communities include filter-feeding clams and mussels, anemones, worms,

barnacles, limpets, crabs, and fish.

- The clams are large and exhibit one of the fastest growth rate of any known deep-sea animal, up to 4 cm (2 in) per year.
- Giant tube worms as long as 3 m (10 ft) are also commonly found (see fig. 18.17).
    a. These worms have no mouths and no digestive systems.
    b. The tissue of their internal body cavity is filled with bacteria.
    c. The worms are able to transfer sulfide that has been rendered non-toxic by combining it with a binding protein, oxygen, and carbon dioxide, to the bacteria.
    d. The bacteria then synthesize the organic molecules the worm uses for nutrition.
    e. Tube worms are known to grow at rates in excess of 1 m (3.3 ft) per year, making them another extremely fast growing marine invertebrate.
- The clams and mussels in these communities have bacteria in their gills.
- Vent plankton are believed to feed on the bacteria. The plankton then serve as a source of nutrition for a variety of filter-feeders.
- There are also extensive bacterial mats surrounding the vents that serve as food for snails and other grazers.
- Vent communities have biomass density that is 500 to 1000 times greater than commonly found on the deep-sea floor.
- These communities can be completely destroyed in volcanic eruptions on the ridge.
    a. In 1991, a submersible encountered a recently destroyed vent community on the East Pacific Rise.
    b. A volcanic eruption had killed all of the larger organisms and only bacteria were left.
    c. In 1992, the area was revisited and the bacterial mats were being grazed upon by fish, crabs, and other organisms.
    d. In 1993, tube worms up to a meter and more in length were observed.
    e. During the 1993 visit researchers also found metal-rich sulfide chimneys 10 m (33 ft) high.
    f. Between 1995 and 1997 the number of species observed at the site more than doubled from 12 to 29. At this time there were still no giant clams observed.
- Chemosynthetic communities have also been found near cold seeps off the coasts of Florida, Oregon, and Japan.
- The primary producers at these cold seeps are bacteria that utilize methane and hydrogen sulfide.
- In areas of the Gulf Coast there are communities that are found in association with oil and gas seeps.
- In some places on the floor of the Gulf of Mexico there are large depressions on the sea floor created by the escape of gas at salt seeps. These depressions are filled with salt brine more than 3.5 times the salinity of normal sea water. Large communities of mussels can be found surrounding them.
- In December of 2000, researchers discovered a new type of hydrothermal vent field that they called the Lost City. Lost City is located just off the axis of the Mid-Atlantic Ridge.
- Lost City does not have black smokers. Instead it has steep sided white, carbonate pinnacles 10–30 m (33–99 ft) tall. These carbonate chimneys support dense bacterial populations but there are no large populations of larger organisms surrounding the vents.

Major Concept (XV)

To understand these complex ecosystems, and to better manage and protect their resources, we must sample the benthos from the rocky intertidal area to the deepest of the deep-sea trenches.

Related or supporting concepts:

- Sampling intertidal areas is the easiest job, as armed with buckets and shovels at low tide, biologists can decipher ecosystems at leisure. From this area on, however, down to the deep sea, sampling the benthos becomes more and more difficult and costly.
- Two common techniques in nearshore areas are:
    a. To establish a sampling line, or beach transect line that can be readily laid out and resampled at time intervals for comparative study, and
    b. recolonization experiments, where an area of native sea floor is marked off as a control and another area is denuded of fauna and flora. In this way we can look at the nature and timing of

recovery of the benthic community experimentally after disturbances, such as dredging, disposal, or severe oil spills.

- Subtidal to deep-sea environments have traditionally been sampled with a bottom dredge consisting of a frame and heavy net or bag of chains with a collecting bag at the end (see fig. 18.19). This device is lowered to the sea floor and dragged behind the boat, scraping off the organisms on the bottom. Unfortunately this is very qualitative, and tells us little about how, and exactly where the benthic organisms live. Much of the data on deep-sea faunas was obtained this way from the time of the *Challenger* expedition up to the early 1960s.
- Bottom grabs, box cores, piston and gravity corers, etc., can all be used to get a more quantitative view of a small portion of the sea floor in areas with soft sediments. Animals and sediments can be washed through different sized screens to ascertain their size, number, and depth of occurrence. Many replicates and a spread of samples are necessary to tell with any certainty the nature of the bottom community. These samples are both labor and cost intensive.
- Today, divers, manned and unmanned submersibles, and remotely operated vehicles, have been to almost every depth in the world's oceans and can take samples, photographs, and videos of the bottom, including setting up long-term experiments and bottom-sampling stations for yearly sampling.

Major Concept (XVI) *There is now a concerted effort to harvest and effectively manage benthic plants and animals for food, energy, and pharmaceuticals.*

Related or supporting concepts:

- Benthic plants and animals are increasingly sought after for their food resources and other by- products. We will briefly cover four main categories:
  a. Food from benthic animals
  b. Food and by-products from benthic plants
  c. Bioconversion efforts, and
  d. Pharmaceuticals from the benthos.
- Benthic animals are currently one of the more important food resources from the sea. Their life histories and behavior make crustaceans (crabs, shrimp, prawns, and lobsters) and mollusks (bivalve clams, mussels, and oysters) the dominant areas of concentration.
  a. The world's harvests in 2000 were 7.2 million metric tons of shellfish (including squid) and another 6 million metric tons of crustaceans.
  b. Benthic fishery techniques have mirrored the mistakes and problems common in the finfish industry. Many species have been over harvested, and their populations and recent catch levels have crashed.
  c. Between 1975 and 1980 more and more boats entered the king crab fishery of the Bering Sea. The catch of 70,000 metric tons in 1979 dwindled to just 5000 metric tons in 1994.
  d. Aquaculture is becoming increasingly important. Oysters, mussels, and clams are some of the most important groups. The combined harvest of marine crustaceans and mollusks in 2000 was more than 10 million metric tons. World shrimp and prawn production was over 1 million metric tons in 1999 and 2000.
  e. Crustaceans account for 5% of the world's aquaculture production by weight but they account for 25% of the total value.
  f. Multi-use aquaculture projects are in the experimental stages, where many levels in the trophic pyramid may benefit or be harvested.
- Benthic algae are another important component of worldwide aquaculture.
- In 1999 the world's wild and aquaculture harvests of seaweed totaled 9 million metric tons, with most coming from aquaculture. The 1999 and 2000 algal mariculture harvests in metric tons were:

	aquaculture harvest
green algae	less than1,000,000
red algae	1,900,000
brown algae	5,000,000

- Algae are a good source of vitamins and minerals but not of food calories. Most of the plant material is indigestible.
- Algae or seaweeds have historically been harvested from the wild in many coastal communities. In Northern Europe, Japan, China, and South East Asia seaweeds have been used as fodder for animals, in soups, pickled, and in many salads and fried dishes.
- Industrial uses for algal by-products continue to expand. Algin is extracted from brown algae for stabilizers in everything from ice cream to paints. Agar and carrageenan are both refined from red algae and used for bacterial growth media and as a stabilizer and emulsifier respectively.
- About 1 million pounds of agar and 10 million pounds of carrageenan are used in the United States annually.
- Many organisms contain toxins and other exotic chemicals for protection and carrying out their existence in the sea. Most of these chemicals are presently not well understood. Since the mid-1980s over 5000 such compounds have been reported.
    a. Anti-inflammatory and antibiotic substances have been extracted from some sponges.
    b. An anticoagulant has been found in red algae.
    c. Some corals produce antimicrobial compounds.
    d. One species of sea anemone has been found to produce a substance that acts as a cardiac stimulant.
    e. Extracts of abalone and oyster can be used as antibacterial agents.
    f. A muscle relaxant has been derived from one species of snail.
    g. The adhesive secreted by mussels is used to secure dental fillings and crowns, and it has also been used to repair the cornea and retina of the eye.
    h. An anti-cancer drug has been derived from one species of marine sponge.

Matching Key Terms with Major Concepts

At the end of the chapter in the textbook is a list of key terms. You should be able to match each of these with one of the previously listed major concepts. To test your ability, try to match the following key terms with the number (I–XVI) of the appropriate major concept identified in this section:

holdfast	stipe	blade
alga/algae	mutualism	meiobenthos
epifauna	symbiosis	bioturbation
infauna	commensalism	zooxanthellae
sessile	parasitism	agar
vertical zonation	detritus	carrageenan
chemosynthesis	algin	polyp
kelp	intertidal zonation	boring
fouling	reef flat	reef crest
beach transect line		

Test Your Recall

Answer the following questions to test your understanding

FILL IN THE BLANK

1. The use of a plant crop to harness the sun's energy for conversion to energy sources is termed

   ______________________________________.

2. _____________ is used to culture bacteria in laboratories.

3. John Ryther developed a model aquaculture farm at the Woods Hole Oceanographic Institution that obtained

nutrients from ___________________.

4. _____________ culture is perhaps the most successful technique for raising shellfish in Japan and Spain.
5. A ___________________ is a metal frame to which a heavy net bag and/or chain bag is used to scrape and collect organisms off the bottom.
6. ____ describes the ability of deep-sea bacteria to fix carbon from CO_2 into sugars and other organic molecules without photosynthesis.
7. Intertidal communities that are constantly battered by the waves may be as, or more, productive than the world's _____________ ______________________.
8. ___________________ and their activities are the greatest threat to the health of coral reefs today.
9. The _____________ ________________ is exposed at low tide and pounded by the breaking waves of the surf zone.
10. Corals require a _____________ to which they can cement their skeletons.
11. Single-celled algae living within the tissues of corals are called ____.
12. Large numbers of coral ___________________ grow together in colonial forms as the dominant reef building organisms.
13. The _________________________ is a wood-boring mollusk.
14. The mixing of sediment by benthic organisms is termed ______________________________________.
15. Animals less than 2 mm in size are called the ___________________________________.
16. Animals that live by eating small bits of organic material on the bottom are _________________________ ______________________.
17. Both ____________________________ and ______________________________________ are forms of symbiosis.
18. ________________________________ is a relationship where one partner is harmed by the other.
19. The spacing out of organisms with depth in the intertidal area is called _________________________ _________________________.
20. _________________________ live on or attached to the bottom, while ______________________ live in the bottom sediments.

TRUE - FALSE

1. Animals and plants that float free in the world's oceans are called the benthos.
2. Kelps have morphological similarities to flowering plants, in that they possess root like holdfasts, stem like stipes, and leaflike blades.
3. Benthic algae are confined to shallow sunlit areas of the oceans.
4. Algae are classified by size.
5. There are true flowering plants in the sea.
6. Sessile organisms are usually very mobile predators.
7. The splash, or supratidal, zone is above the high water level and is covered with water only during extreme storms and high water.

8. Mutualism is a form of symbiosis where neither partner gains any benefit from the other.
9. Soft substrates, such as muds and clays, usually indicate deeper waters and a lower energy environment.
10. Bacteria are an insignificant food source for benthic organisms.
11. Intertidal soft-sediment areas are not as clearly zoned as the rocky intertidal.
12. The deep sea is less diverse than the intertidal rocky shoreline.
13. Benthic organisms are found in the bottom of the deepest parts of the ocean.
14. Coral reefs are restricted to areas north of 30°N and south of 30°S.
15. Corals that have zooxanthellae can remove calcium carbonate from seawater more easily to produce skeletal material.
16. The largest coral reef system in the world is located in Lake Michigan, just south of Milwaukee.
17. Some 3000 different species may be found together on a single reef tract.
18. Deep-sea vent communities still have primary producers that depend on sunlight for photosynthesis.
19. Sampling the benthos in the deep sea takes high-tech equipment, and lots of time and money.
20. Harvesting and efficiently managing benthic populations will be one of the goals of the future aquaculturist.

MULTIPLE CHOICE

1. Algae and algal by-products are used for
    a. soups, pickles, and salads.
    b. bacterial growth media.
    c. emulsifiers.
    d. stabilizers.
    e. all of the above.
2. Raft aquaculture of oysters in Japan in 1984 raised
    a. 2500 metric tons.
    b. 25,000 metric tons.
    c. 250,000 metric tons.
    d. 2,500,000 metric tons.
    e. none of the above.
3. Our knowledge of the deep-sea benthos is
    a. excellent, we are aware of all the forms.
    b. very incomplete, as the area of sea floor is immense and costs are high.
    c. not a valid concern of taxpayers or oceanographers.
    d. none of the above.
    e. all of the above.
4. A dredge is used to
    a. collect intertidal samples.
    b. remove barnacles from oceanographic vessels.
    c. collect samples from subtidal to the deep sea.
    d. corral fish.
    e. none of the above.
5. Deep-sea vent communities are among the most productive in the world. They are based on
    a. photosynthesis.
    b. chemosynthesis.
    c. bacteria that metabolize methane and hydrogen sulfides.
    d. b and c above.
    e. a and c above.
6. On the average, waves deliver to each square cm of exposed coastline
    a. 2 times more energy than the sun's input.
    b. equal energy to that of the sun's input.
    c. 5 times that of the sun's input.
    d. 10 times that of the sun's input.
    e. 15 times that of the sun's input.
7. Animals that break down coral reefs include
    a. sponges.

b. worms.
c. clams.
d. *Acanthaster* sea stars.
e. all of the above.

8. Tropical coral reefs show a vertical zonation that is largely the product of
a. wave action and water depth.
b. wave action and animal color.
c. water depth and sunlight penetration.
d. water depth and compass orientation.
e. all of the above.

9. Tropical coral reefs grow best at water temperatures between
a. 10–15°C.
b. 13–15°C.
c. 18–21°C.
d. 23–25°C.
e. all of the above.

10. The two organisms responsible for most marine wood-boring are
a. the powder-post clam and the gribble.
b. the toredo and the gribble.
c. the toredo and the shipworm.
d. none of the above.
e. all of the above.

11. The mixing of sediments by benthic organisms is
a. bioconversion.
b. bioenergetics.
c. biosynthesis.
d. bioturbation.
e. none of the above.

12. Meiobenthos are
a. $>$ 2 cm long.
b. $>$ 2 mm.
c. $<$ 2 mm.
d. $\leq$ 2 m.

13. Most sand- and mud-dwelling benthos are
a. mobile predators.
b. filter feeders.
c. nekton.
d. detritus feeders.
e. picky eaters.

14. Sandy sediments are
a. porous and permeable.
b. porous and very fine-grained.
c. permeable but not porous.
d. porous but not permeable.
e. none of the above.

15. Zonation on a soft sediment beach compared to the rocky intertidal is
a. much more rigidly defined.
b. much less distinct.
c. there is no difference!
d. there is no zonation.
e. all of the above.

16. Which of the following is not a mollusk?
a. oyster
b. abalone
c. octopus

d. squid
e. barnacle

17. Which of the following relationships benefits both participants?
    a. intellectualism
    b. pessimism
    c. mutualism
    d. commensalism
    e. parasitism
18. Benthic marine animals are
    a. only found on rocky substrates.
    b. only found on sandy substrates.
    c. not found below depths of 6000 meters.
    d. found on all substrates and at all depths.
    e. only found above depths of 4000 meters.
19. It has been estimated that there are many more benthic than pelagic species. Your text says there are more than __________ benthic species.
    a. 1500
    b. 15,000
    c. 150,000
    d. 3000
    e. 30,000
20. The longest stipe of a giant kelp is estimated at up to
    a. 3.5 m.
    b. 35 m.
    c. 350 m.
    d. kelp have stems, not stipes.
    e. kelp have stripes, not stipes or stems.

Visual Aids: Test Your Understanding of the Figures

1. Examine figure 18.2 carefully. Which is the giant kelp? What algal group is it in? How do you think it got its name?
2. This is such a brief introduction to these complex ecosystems and their associated organisms, try to take a good look at all of the figures. See if you can identify any the next time you skim through the chapter.

Study Problem

1. Use the graph in figure 18.3 to determine the approximate percent of daily exposure for mean sea level, mean high water (MHW), and mean low water (MLW).

Answer Key for Key Terms and Test Your Recall

KEY TERMS

holdfast (I)	stipe (I)	blade (I)
alga/algae (I)	mutualism (VI)	meiobenthos (IX)
epifauna (IV)	symbiosis (VI)	bioturbation (VIII)
infauna (IV)	commensalism (VI)	zooxanthellae (XII)
sessile (IV)	parasitism (VI)	agar (XVI)
vertical zonation (VI)	detritus (VIII)	carrageenan (XVI)
chemosynthesis (IX)	algin (XVI)	polyp (XII)
kelp (II)	intertidal zonation (VI)	boring (X)
fouling (X)	reef flat (XII)	reef crest (XII)
beach transect line (XV)		

FILL IN THE BLANK

1. bioconversion	2. agar	3. sewage
4. raft	5. dredge	6. chemosynthesis
7. rain forests	8. humans	9. reef crest
10. base	11. zooxanthellae	12. polyps
13. shipworm	14. bioturbation	15. meiobenthos
16. detritus feeders	17. mutualism, commensalism	18. parasitism
19. vertical zonation	20. epifauna, infauna	

TRUE - FALSE

1.F 2.T 3.T 4.F 5.T 6.F 7.T 8.F 9.T 10.F 11.T 12.F 13.T 14.F 15.T 16.F 17.T 18.F 19.T 20.T

MULTIPLE CHOICE

1.e 2.c 3.b 4.c 5.d 6.e 7.e 8.a 9.d 10.b 11.d 12.c 13.d 14.a 15.b 16.e 17.c 18.d 19.c 20.b

STUDY PROBLEM

1. 88%, 10%