CHAPTER IV

COASTAL ECOSYSTEMS

In Chapters 1 and 2, we focused on various aspects of the ocean environment–its coverage and extent, features of the ocean floor, physical and chemical properties of the ocean, and the hydrologic cycle. In Chapter 3, we discussed oceanic environments and habitats, as well as some of the physical adaptations that organisms have acquired for continued survival in these areas. In this chapter, we will look at very specialized areas where the land environment meets the oceanic environment–the very fragile interface between humans and the ocean–the coastal zone.

A. Estuaries

Estuaries are semi-enclosed bodies of water, such as harbors, bays, inlets, and sounds, where fresh water and salt water meet. Many estuaries along the East coast of the United States are actually flooded river valleys, as is the case when one considers the Chesapeake Bay. These valleys were made when sea level was lower thousands of years ago. Pamlico Sound, Winyah Bay, Port Royal Sound and the Altamaha Sound are just a few of the estuaries along the Southeastern coast that may be flooded remnants of ancient river valleys.

Estuaries are some of the most productive areas on Earth because they offer an abundance of nutrients, food, and shelter for many of the more common marine plants and animals. Plants in the estuaries photosynthesize, transforming energy from the sun into usable food energy. These plants, as well as other organisms, are eventually broken down by bacteria into detritus. Nutrients from detritus are released back into the system and recycled into the food web, just as we discussed in Chapter 3. Estuaries are extremely productive areas because nutrient-rich water is carried by rivers and land run-off from higher grounds and is added to the nutrient-rich waters of the estuary itself.

Estuaries are not only very productive areas, but they also offer some degree of protection to the young of numerous organisms from predators that might otherwise be encountered in the open ocean. Estuaries can, however, be very stressful places for marine organisms due to extreme variation in temperature, salinity, and water quality caused by cyclic patterns involving tides, currents, precipitation, and seasonal changes. Additionally, human activities, not only in and around coastal areas, but also those which occur far inland, can cause extreme stress to an estuarine system.

B. Wetlands

Wetlands are areas of gradual transition where land meets water. They include swamps, freshwater and saltwater marshes, tidal mud flats, and lagoons. Wetlands are very specialized, dynamic habitats that function in a variety of ways that are important to both wildlife and humans. Some of these functions are described below.

- Wetlands function as buffers against fierce storms. In the fall of 1989, wetlands protected South Carolina's coastal residents from incalculable losses that could have occurred as a result of Hurricane Hugo. In fact, it has been estimated that an acre of wetland, if flooded to a depth of one foot, would hold over 1250 cubic meters (330,000 gallons) of water.

- Coastal wetlands function as nursery grounds for many marine organisms, as they afford an abundance of food, shelter, and protection from potential predators to the young of many species. For example, over 80% of South Carolina's recreational and commercially important species are dependent at some stage of their life cycle on coastal wetlands.
- Wetlands serve as filters for pollutants and traps for sediments and nutrients.
- Wetlands provide resting and/or breeding places for shorebirds and migratory waterfowl. Recent discoveries about neotropical migrant species have demonstrated the importance of coastal freshwater wetlands during migration for these species, as well.
- Coastal wetlands are the final endpoint for watersheds that originate far inland from the ocean. A watershed is the complex system of major rivers and all their tributaries that drain a region, ultimately reaching the ocean (Fig. 4-1). There are eight major watersheds along the Southeastern U.S. coast.
- Wetlands are home to many rare and endangered species. By definition, an endangered species is one that is in immediate danger of extinction.

1. Coastal Marshes

Although there are many different types of wetlands, some of the most familiar wetlands along the Southeastern U.S. coast are saltwater marshes. Many estuaries are bordered on their sides by an abundance of coastal salt marshes. But not all coastal salt marshes are adjacent to estuaries–many are influenced only by the tide, and as such, do not receive large amounts of freshwater input from riverine sources. For example, South Carolina has over 1,351 square kilometers (334,000 acres) of coastal salt marshes, more than occurs in any other state along the Atlantic seaboard.

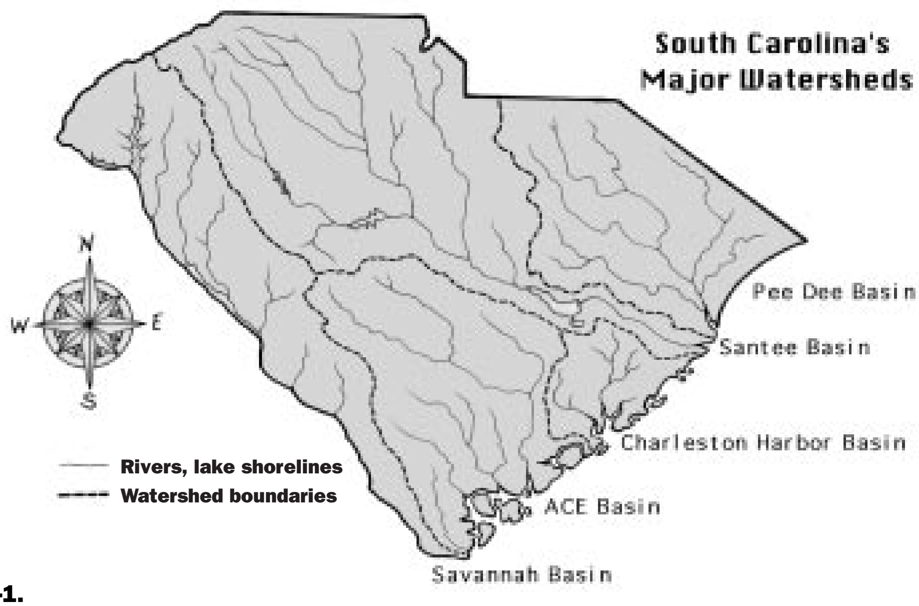

Figure 4-1.
Watersheds of South Carolina.

Illustration by JOHN NORTON

The most common plant in southeastern marshes is *Spartina alterniflora*, or smooth cord grass (Fig. 4-2). Because this plant thrives in estuarine environments, the taller *Spartina* grow closer to the water's edge, while the shorter *Spartina* are found near to the inland edges of the marsh. Although there are a variety of other plants growing within this high marsh zone, including shrubs and a few succulents, *Spartina* has developed specialized adaptations that allow it to withstand constant inundation by salt water. The next time you are in a salt marsh, look closely at the *Spartina* blade. You will see tiny white crystals of salt that have been transpired, or actively transported out through the plant's leaves. Rub your fingers along the blade and taste the salt!

Spartina is an extremely productive plant. In fact, an acre of *Spartina is* more productive than an acre of wheat. Like phytoplankton, *Spartina* photosynthesize and transform energy from the sun into usable food energy. Few animals actually eat living *Spartina*, but bacteria decompose the dead leaves, breaking them down into detritus. As we have seen, the detritus and the bacteria that decompose *Spartina* provide the necessary nutrients to many organisms living in the coastal marsh and estuarine habitat. Not only is *Spartina* an extremely productive plant, but the tall *Spartina* blades also provide protective coverage for larval, juvenile, and adult life cycle stages of numerous marine organisms.

The salt marsh is inundated with salt water twice a day as the tide makes its predictable rise and fall. As these intertidal areas are flushed with the tide, nutrients from the ocean are brought into the estuary, and nutrients from the salt marsh are transported out to sea. The flushing action of the tide also serves as a physical transport mechanism by which larval organisms are brought into–and transported out of–the estuary. Clearly, the abundance of food and protection from predators afforded in the coastal marsh habitat makes it one of the most productive areas on earth.

Photo by CHERIE PITTILLO

Figure 4-2.
Spartina alterniflora*, or smooth cordgrass, in the marsh.*

Daily submergence by the tides is not the only change that takes place in the salt marsh. Seasonal changes also occur, and contribute greatly to the productivity of the salt marsh. If you live along the coast, you have certainly noticed the blades of *Spartina* changing as the seasons change. In the fall, the marsh takes on a golden hue as *Spartina* begins to die and decay. In the winter, most of the *Spartina* turns brown and decays to become the nutrient "soup" that makes coastal saltmarsh areas so productive. As early spring arrives, small green *Spartina* blades arise from beneath the mud and the previous year's decayed *Spartina* that lines the bottom of the salt marsh. These tiny plants will continue to grow into the tall *Spartina* that gently wave in the warm summer breezes, only to turn golden brown in the fall again as they complete their seasonal cycle.

There are many organisms living in the salt marsh. Fiddler crabs , juvenile mullet, shrimp frequent the shallow waters along the edges of the salt marsh. Periwinkle snails slowly make their ascent to the tip of the *Spartina* blades as the tide rolls in, and patiently descend again as the tide falls. Oysters, mussels, and clams are some of the bivalves that can be found in the salt marsh. Many fishes slowly graze along the *Spartina* stems, while crabs and shrimp swim or walk nearby in search of detritus or other decaying matter.

2. Tidal Creeks

Nothing is quite so peaceful as wandering in a small boat in and out of tidal creeks (Fig. 4-3). Terns, skimmers, pelicans, egrets, and herons fly gracefully along the water's still surface. Beds of oysters occasionally squirt small streams of filtered water. Tall bright green stands of *Spartina* line the waterways as fiddler crabs run for their creek-side burrows and juvenile shrimp and mullet skip across the water's surface. These are the quiet places, the places that provide the greatest degree of protection from predation and an abundance of food. They are also the nursery areas. Although tidal creeks seem quiet and somewhat uneventful, closer inspection yields an environment teaming with life. Let's look closely at three habitats commonly found in tidal creeks–the mud flat, the sand flat, and the oyster reef (also known as an oyster bed or bar).

a. The Mud Flat

As we discussed in Chapter 2, freshwater rivers and streams slowly erode or wear away, the rocks and soils over and through which they flow, as they make their descent from mountainous and other inland regions toward the ocean. This erosion produces a wide variety of sediments, ranging in size from coarse sands to silts and fine clays, that are transported toward the coast in rivers and streams. Mud flats are features that form when silts and clays settle out of the water column and are deposited in areas of quieter flow. Some sands may also be found on the mud flat. Mud flats generally occur in quieter areas of creeks, where the water's energy is low enough to allow very fine muds to settle out of the water. Because mud flats are depositional features, they are constantly changing size and shape as current patterns and the availability of sediment from inland sources change (Fig. 4-3).

Anyone who has spent time along the coast during ebb tide has certainly smelled the characteristic odor of mud flats. Fine sediment particles, primarily silts and clays, are packed together so closely on the mud flat that oxygen is lacking between the sediment particles. Detritivores, primarily bacteria and fungi, living in the mud can carry out respiration without oxygen (O_2). This process, known as anaerobic respiration, removes sulfate from the surrounding water and releases hydrogen sulfide into the mud. Hence, the characteristic "rotten egg" smell of "pluff mud" on the mud flat.

A glimpse at a mud flat would lead one to believe that it is relatively devoid of life, with the exception of a few mud snails and wading birds. Closer inspection yields hundreds, or even thousands, of tiny holes in which a variety of animals burrow. The mud flat is home to many burrowing filter feeders. Clams, polychaete worms, amphipods, fiddler crabs (Fig. 4-4), and mantis shrimp are a few of the organisms found living in burrows within the mud flat.

Ulva, or sea lettuce, is an edible marine green alga commonly found on the surface of mud flats. Periwinkle snails, mussels, shrimp, crabs, flounders, stingrays, skates, horseshoe crabs, hermit crabs, and an occasional cluster of oysters are some of the more common inhabitants of the mud flat. A variety of wading shorebirds frequent the mud flat, since these areas are home to such an abundance of marine life upon which they feed.

Photo by CHERIE PITTILLO

Figure 4-3. *Tidal creek with mud flat.*

b. The Sand Flat

Like the mud flat, the sand flat is also a depositional feature. The source of its sediment may be far inland or transported from nearby island beaches by tides, currents, wind, or waves. Like the name indicates, sand flats are primarily composed of sands, with silts and clays being present in sparse quantities when compared to the mud flat. Sand flats are typically composed primarily of grains of the minerals quartz and feldspar, mixed with broken shell. These flats are most often located on the inside bends of swift-current areas, and they shift frequently as current patterns change. Their surface is commonly rippled, due to the flow of currents in the tidal creek during high tides.

The sand flat is home to many of the burrowing organisms that live on or in the mud flat. Fiddler crabs, clams, and amphipods make their homes in the sand flat. Sand dollars, brittle stars, and sea stars are also found on the sand flat.

Figure 4-4. *Fiddler crab.*

Photo by CHERIE PITTILLO

c. The Oyster Reef

Oysters are bivalves that are harvested both recreationally and commercially in many coastal states. The planktonic larvae of oysters settle on a hard substrate within one to three weeks after hatching from the egg. A settling larva must attach its left valve to a hard substrate. If no suitable hard substrate is found upon settlement, the oyster larva dies. A preferred settling structure for many oyster larvae appears to be the shells of adult oysters, both living and dead. Consequently, huge oyster reefs are formed in the intertidal habitat, as oyster larvae continue to settle on the shells of their own kind (Fig. 4-5).

Oyster reefs are not only home to oysters, but are also quite suitable habitats to a host of other marine organisms. Mussels are often found cemented in oyster reefs. Small crabs, tube worms, bryozoans, amphipods, brittle stars, barnacles, sponges, and polychaetes all join the oyster as members of the oyster reef habitat. It is not surprising that juvenile fishes find an abundance of food and safe haven in oyster reefs. Even the juvenile gag grouper, the most common grouper occurring off the South Carolina coast, can be easily captured in estuarine nursery areas for scientific study in plastic milk crates filled with clusters of oysters!

Crassostrea virginica, the Eastern oyster, is the only oyster occurring along the Southeastern U.S. coast. Oysters are filter feeders. They filter detritus, zooplankton, and phytoplankton from the surrounding water, with a single oyster capable of filtering as much as 15 liters (4 gallons) of water in an hour. They also filter pollutants from the surrounding waters, hence these pollutants would likely be ingested by anyone eating an oyster during times when water quality is poor.

Oysters can function as either sex, spawning, or releasing, gametes (eggs or sperm) into the water from April to October in South Carolina.

C. Fouling Communities

Another type of coastal zone habitat with which you may be familiar is the fouling community habitat typically found on the undersides of floating docks and on the hulls

Figure 4-5.
Oyster reefs at low tide.

Photo by CHERIE PITTILLO

of boats moored at marinas. Fouling communities are a very unique assemblage of marine organisms. Although the individual organisms typically found in a fouling community are also found living independently throughout the marine environment, they are only truly closely associated with each other in the fouling community. Most inhabitants of the fouling community live their lives permanently attached to stable structures while other organisms crawl among the attached fouling community inhabitants. Barnacles, sea squirts, worms, isopods, sponges, bryozoans, caridean shrimp, algae, soft corals, and amphipods are among the most common inhabitants of the fouling community.

D. Hard Substrate Intertidal Habitats

Intertidal habitats, like the coastal marshes and tidal creek areas described earlier, are some of the most dynamic and stressful habitats on earth. During flood tides, the intertidal environment and its inhabitants are covered with water. The water brings with it food, cooler surrounding temperatures, changes in salinity, renewed levels of oxygen (O_2), carbon dioxide (CO_2), moisture, and nutrients vital to survival. During ebb tides when the habitat is exposed to the air, organisms must protect themselves from desiccation and heat. Additionally, they must be able to survive with little to no food and avoid predation from other organisms that gain access to them in exposed areas. Many organisms inhabiting the intertidal area have shells that they close to prevent drying out while others burrow down in the sand or mud.


Photo by CHERIE PITTILLO

Figure 4-6.
Intertidal community found on hard substrate of a pier in South Carolina.

Intertidal habitats are not only stressful places as a result of daily tidal action, but they also bear the brunt of major storms, buffering more fragile coastal areas from extreme flooding, high winds, and waves.

One intertidal community of organisms common to the Southeastern U.S. coast is that found attached to rocky jetties, groins, and concrete pilings (Fig. 4-6). Many of these organisms, like those found in fouling communities, need a substrate on which to attach. Barnacles, amphipods, isopods, sea urchins, algae, tube worms and other polychaetes, oysters, and mussels can all be found living on these structures. Many people fish around these structures, since larger fishes come in to feed on the smaller organisms that feed on the inhabitants of the hard substrate intertidal community.

E. Barrier Islands

Barrier islands are islands that lie parallel to the coast and afford incalculable protection to coastal shorelines around the country (Fig. 4-7). Over 4,344 kilometers (2,700 miles) of our nation's shoreline are bordered by barrier islands. Those of us living on barrier islands during Hurricane Hugo in 1989 clearly understand and remember the wrath that barrier islands endure when faced with the extreme forces of nature.

Photo by RESEARCH PLANNING, INC.

Figure 4-7.
Barrier islands of South Carolina (Bull Island, top; Capers Island, middle; and Dewees Island, bottom).

Barrier islands are known for their beauty, and as such, they have inspired many writers and artists. George Gershwin composed the famous opera, "Porgy and Bess," while residing on Folly Island. Edgar Allen Poe once lived on Sullivan's Island, South Carolina and penned the short story, "The Gold Bug" (hence, the name Gold Bug Island). Books and songs have been written about the tranquillity that these areas offer, and countless canvases have been painted that depict lighthouses, marshes at sunset, and barrier islands during fierce storms.

Because of their beauty, remoteness, and tranquillity, many people seek residence on barrier islands. In fact, some barrier islands along the Southeastern U.S. coast support a population density several times the national average. But barrier islands are always changing due to the movement of sand by waves, winds, tides, currents, and storms. This is evidenced by the fact that most barrier islands are elongate. This elongation is in part the result of the transport of sand parallel to the beach known as longshore drift.

Longshore drift is generated by wave and current action. Along the Southeastern U.S. coast, the longshore drift is generally north to south. This motion occurs because waves most often approach and hit the beach on an angle (Fig. 4-8). As a wave breaks and washes at an angle up onto the beach, particles of sand are carried with it. The next time you have a chance to watch waves breaking on a beach, note how they usually approach at an angle to the beach. The run-up of waves onto the beach is called the swash. The swash of a wave is followed by its inevitable return to the sea, or backwash, down the slope of the beach. A zig-zag pattern of up and down movement results due to the swash and backwash of waves. A particle of sand or silt travels along this zig-zag path, continuously working its way toward the

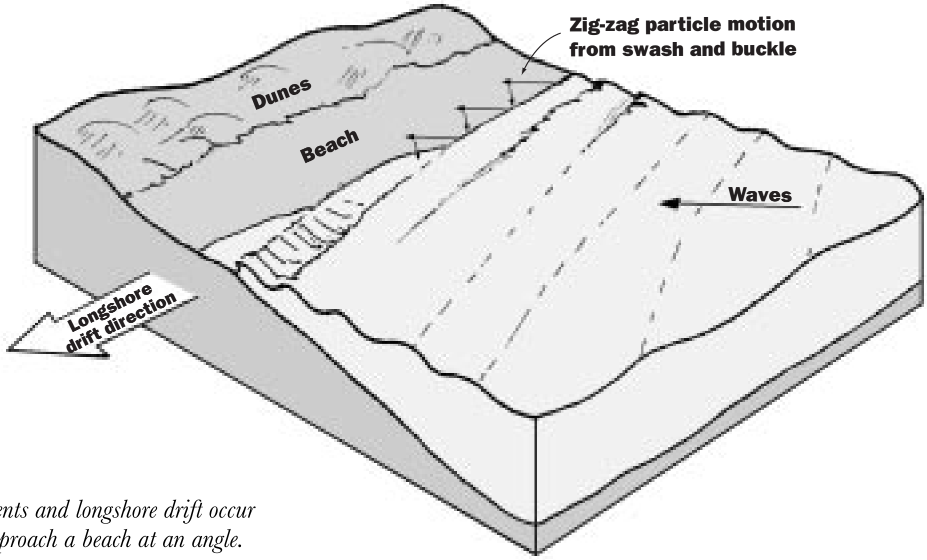

Figure 4-8.
Longshore currents and longshore drift occur when waves approach a beach at an angle.

downdrift end of the beach. This pattern of water movement establishes a longshore current moving parallel to the beach, carrying sediment with it.

Because of the longshore drift of sediments southward, many barrier islands along the Southeastern U.S. coast erode on the north end. The south ends generally "grow," grain by grain, often forming an extended hook-shaped lobe of sand known as a spit. Tremendous volumes of sand are transported along these islands each year.

Along much of the Southeastern U.S. coast, the barrier islands are generally wider on the updrift northern ends. Remnants of older, vegetated dune ridges can be observed from the air on these updrift ends (Fig. 4-9). Hook-shaped spits are characteristic of the downdrift southern ends. This particular type of barrier island typically occurs in areas with a tidal range between 2 and 4 meters (approximately 6 to 9 feet), or a mesotidal tidal range, and is nicknamed a "drumstick" barrier island (Figs. 4-9 and 4-10).

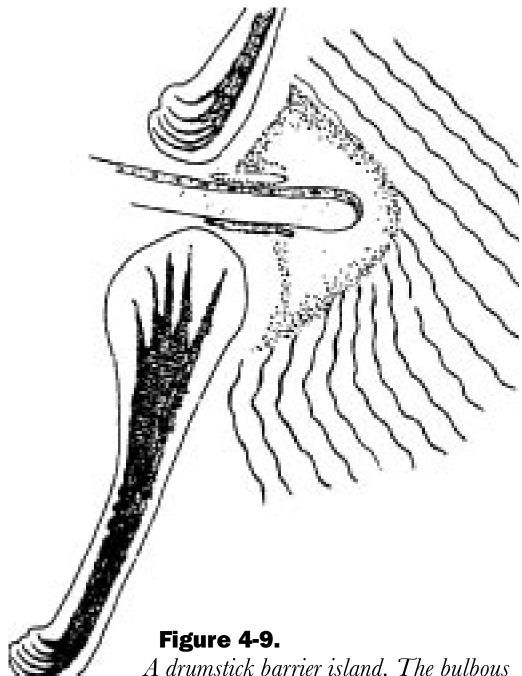

Figure 4-9.
A drumstick barrier island. The bulbous updrift end shows numerous finger-like beach ridges. The downdrift end (bottom) shows the hook-shaped spit formation. (Figure modified from Hayes, 1979).

In many cases, barrier islands also migrate toward the mainland, as storm waves wash over their low-lying areas, removing beach sand and casting it over the dunes to the marsh behind in the form of a washover (Fig. 4-11). This "rolling over" of the beach more often occurs on barrier islands with lower profiles and fewer dune ridges. Low profile barriers are more common in microtidal areas (<2m tidal range). Cape Romain in South Carolina, and the capes of North Carolina (Hatteras, Lookout, and Fear) are located in areas of lower tidal ranges, where storm waves are the major contributors to building washovers.

Photo by RESEARCH PLANNING, INC.

Figure 4-10.
Bull Island in South Carolina is a classic example of a drumstick barrier island. Note the beach ridges at the top of the photo and the recurved spit at the bottom.

Barrier islands have a zonation that is quite unique. Moving horizontally from the ocean toward the mainland, most barrier islands have the following components: offshore sand bars, beach, primary dune system, secondary dune system, and maritime forest (Fig. 4-12). The back marsh lies on the landward of the maritime forest and may also be called the lee or bayside marsh. Mud and/or sand flats may be found in the back marsh. The transition between each of these zones is rapid, within a very short horizontal distance from the ocean to the mainland. Each is unique in the amazing diversity of its habitat and the life which it correspondingly supports. Let's look in detail at the beaches, primary and secondary dune systems, and maritime forests of barrier islands.

1. The Beach

Just as we saw with mud flats and sand flats, beaches are also depositional features formed when sediments, such as sands (primarily quartz and feldspar minerals), silts, and clays, are transported toward the coast by inland rivers and streams. Sediments are redistributed by longshore currents. Beaches occur in coastal areas where waves, tides, and currents are strong enough to wash away the finer silts and clays, yet weak enough so that the sand remains behind. Because beaches form the seaward edge of barrier islands, beach profiles are always changing in response to availability of sand due to longshore drift, tides, and seasonal variations in waves and current patterns.

Figure 4-11.
Cape Romain, South Carolina is an excellent example of a low-profile barrier island that is steadily moving landward. The arrow points to a washover feature that is the result of storm waves.

Not all beaches are eroding. As we discussed above, portions of one barrier island may be eroding, while other portions may be growing, or accreting. Whether a beach erodes or accretes is determined by a combination of several variables, including tidal energy, wave energy, longshore currents, and most importantly, the availability of sediment. If the sediment supply is low, chances are a beach will eventually erode, particularly if wave and longshore current energies are high. In areas with abundant sediment and moderate wave energy, for example, the beach will most likely accrete.

The beach has several zones, extending from the dunes seaward to the outermost region of breaking waves (Fig. 4-13). These zones are defined in part by the high and low tidal water levels, but also by the shape of the shifting sands above and below sea level. In a mesotidal setting, the backshore extends from

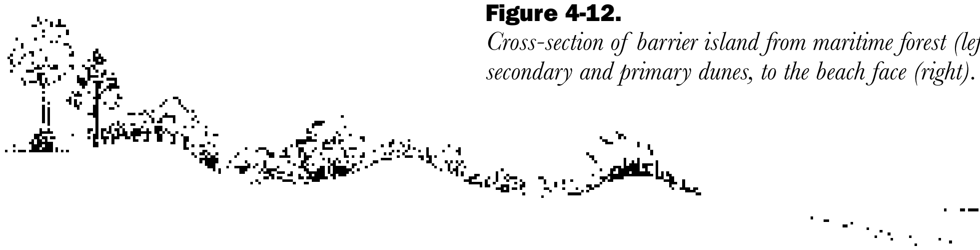

Figure 4-12.
Cross-section of barrier island from maritime forest (left), through secondary and primary dunes, to the beach face (right).

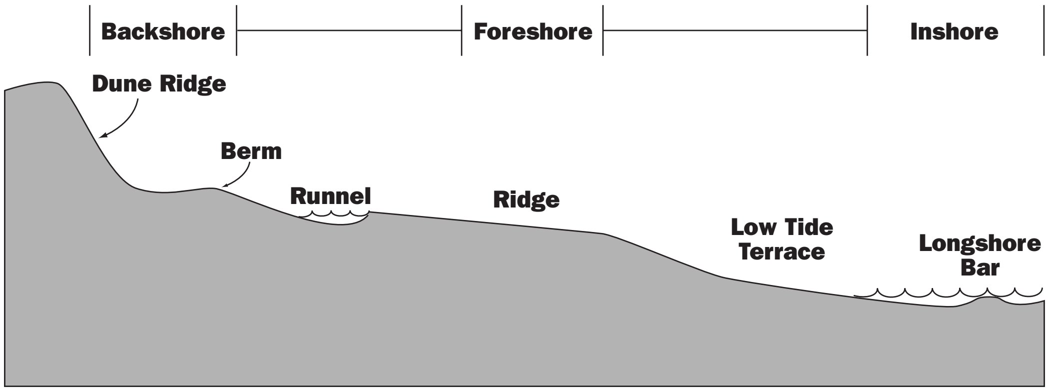

Figure 4-13.
Typical mesotidal beach profile (summer conditions).

the base of the dunes to the mean high tide mark, and is the region affected most by wind and storm activity. The foreshore marks the region between the mean high and mean low water levels. This region is greatly influenced by the swash and backwash of breaking waves and longshore currents. Beyond the foreshore lies the inshore where waves break and surfers roam! Longshore bars, submerged elongate mounds of sediment, may be found in the inshore region.

The beach profile is the shape of the beach across the backshore, foreshore, and inshore zones. It varies from shoreline to shoreline, and from season to season. The profile is a function of several variables including sediment size and amount, tide, wave, and wind energies. However it is wave action that ultimately controls the shape of the beach as a whole, because waves have enough energy to pick up and move the millions of grains of sediment.

Certainly, beaches vary from place to place. Mesotidal beaches, such as those found along parts of the Southeastern U.S. coast, have many characteristic features, as illustrated on Figure 4-13 and described below.

- dune ridge (backshore): consists of fine wind-blown sands; may or may not be vegetated; storm waves may erode the base, creating a large dune scarp.
- berm (backshore): deposits left behind from receding storm waves or spring tide high water levels; often terrace-like with crests defining individual berms; location for wrack lines and the early formation of dunes.
- runnel (foreshore): depression in the beach profile, often filled with seawater throughout tidal cycle; linear and parallel to the shoreline; width is determined by the landward advance of the ridge.
- ridge (foreshore): formed by normal wave action and accretion of sediment to the beach; often advances landward over the existing runnel; broad and gently sloping, but steeper than the low tide terrace; longshore drift occurs here during high tide.
- low tide terrace (foreshore): region of fluctuating cover by water; tidal and wave energy is very significant; location for major portion of longshore transport; smooth and low slope.
- longshore bar (inshore): elongate and parallel to the shoreline; submerged except during

unusually low spring tides; region where waves break; possible sediment supply area for accretion onto beach; possibly formed by deposition of sediments eroded from the beach.

The features just described are most commonly found during the summer when gentle waves tend to accrete, rather than erode, sand to beaches. During winter when winds and waves are stronger, erosional processes dominate. Severe storms may strip the beach, often leaving a flat, featureless, hard-packed sand profile. Dunes may be wave-cut, or scarped. Over time as gentle waves return and roll in, they carry sands landward from offshore and the ridge begins to develop and move landward. A runnel is "born" but only shrinks as the ridge advances. Berms are deposited only during the higher high tides. Usually, by summer the "typical" profile is restored.

As you may guess, beaches are unstable habitats, as the sand that is deposited on them is constantly shifting, making it a difficult place for many organisms to successfully inhabit. It has been estimated that a single grain of sand can move as much as 21 meters (70 feet) a day. In fact, no species of plant has ever adapted to survival at the beach/ocean interface. Nevertheless, the beach is home to a host of marine animals, most of which you cannot see unless you dig for them. Many beach inhabitants burrow in the sand in an attempt to avoid the continual shifting of sand at the surface. Burrowing also serves to prevent desiccation that would otherwise occur if these organisms were left exposed for extended periods of time.

There is a different assemblage of burrowing animals found at the beach than that found in the mud flat, as these areas represent two very different habitats. Mole crabs, coquina clams, razor clams, amphipods, isopods, polychaete worms, and sand dollars are some of the organisms that burrow in beach sand. There is also a marked difference in the diversity and abundance of these organisms at the beach as you move from the dunes to the ocean. Because the upper reaches of the beach are inundated with waves less often than the lower areas, the backshore is relatively dry and food is less abundant than it is closer to the water's edge. The number and diversity of burrowing organisms in the backshore is correspondingly sparse. But as you move closer to the water's edge, organisms become much more abundant due to an increase in the amount of moisture and the availability of food. Many of the burrowing beach inhabitants are filter-feeders, feeding on abundant phytoplankton that are present due to turbulent oceanic water.

Ghost crabs are frequent inhabitants of the backshore region of the beach. As the waves roll in, they scavenge toward the water in search of food and quickly retreat into their burrows to hide as the ocean recedes again. A tremendous variety of shorebirds also feed on the burrowing marine organisms at the water's edge. Terns, sanderlings, ruddy turnstones, gulls, and sandpipers are just a few of the shorebirds frequenting the Southeastern U.S. coast.

2. Primary and Secondary Dunes

The continual shifting of sand on the beaches makes the beach a difficult place for many organisms to survive. Although no plants have adapted to survival at the beach/ocean interface, plants do exist and are well adapted for certain zones on barrier islands. These zones are slightly more stable than the beach/ocean interface. The first of these zones that you encounter as you move inland from the water's edge are the primary and secondary dune zones (Fig. 4-12). Let's look at how dunes are formed.

Although much decaying plant matter, such as *Spartina*, remains in the estuary, some decaying *Spartina* and other plant matter are washed out to sea through inlets. Wind, waves, and tides wash some of this plant matter back onto the beaches, where it remains and forms a

Figure 4-14.
Formation of a dune from a wrack line over time.

"wrack" line that runs up and down the beach at the places where the tide reaches its highest point (Fig. 4-14). Windblown sand hits the wrack, falls out of the air, and begins to accumulate around the wrack line. Plant seeds carried by the wind also settle in the wrack and have a perfect mulch of decaying matter on which to begin deriving moisture and nutrients.

As the plants begin to grow, their roots provide an anchor that keeps them stationary in the shifting sand. As sand continues to accumulate around the base of the plants, a more stable zone is produced, enabling these plants to continue their growth. This stable zone has now become a sand dune. In fact, if undisturbed by severe wave action, a wrack line may someday become a primary dune. Primary dunes include the line of dunes closest to the water's edge. Primary dunes can be washed away during extremely high tides that are accompanied with high winds and storms. Secondary dunes are farther inland than primary dunes and are thus more protected. Secondary dunes are formed by the same process as just described, but over the years they have escaped destruction, being protected by newer sets of dunes–the primary dunes built on their seaward side.

Dune habitats are similar to deserts–the wind blows frequently, shifting the sand, and water is scarce. Plants living in the dunes have developed special features enabling them to survive this desert-like habitat. Sea oats, one of the most commonly occurring plants in dune systems along the Southeastern U.S. coast, have developed long stems and leaves that are very flexible in high winds. Narrow leaves also aid in surviving frequent salt spray and retaining water. Sea oats have extensive root systems that reach deep into the sand for fresh water. Sea oats are protected by federal law and it is illegal to disturb their growth in any way. Fines for picking sea oats can be as high as $200 per oat! *Spartina* also inhabits the primary dune system.

Secondary dunes are also colonized by sea oats, but because they are more protected from battering winds off the ocean, they are more stable than primary dunes and are able to support a greater diversity of plants. Many species of succulents, such as cacti, can be found in secondary dunes. These plants have thick, waxy leaves resistant to desiccation. Additionally, their leaves are capable of storing relatively large volumes of water. Saltwort, pennywort (dollar weed), butterfly peas, sea oxeye, yucca plants, greenbrier, sandspur, broom sedge, and camphorweed are just a few species of plants occupying secondary dunes.

Plants are not the only organisms surviving in primary and secondary dune systems. Ghost crabs build their burrows there and many shorebirds nest in the dunes. Raccoons, mice, rats, opossums, rabbits, snakes, lizards, and foxes forage in the primary and secondary dunes. The loggerhead turtle, a threatened species on the state and Federal Threatened and Endangered Species List, crawls onto barrier island beaches at night from May through August to lay its eggs in the dunes. It is also interesting to note that barrier islands and their dune systems probably support more species of birds than any other ecosystem in the continental United States. Clearly, they are habitats well worth protecting.

3. The Maritime Forest

Many barrier islands have maritime forests located landward from their primary and secondary dune zones. Maritime forests are frequently found in the interiors or back sides of larger barrier islands. These areas are buffered from the full force of winds by the dune zone. Nevertheless, they are affected to a lesser degree by salt spray, high winds, and sandy soils. Many maritime forests are located on what once was a secondary dune. As new dunes become established seaward of the primary and secondary dunes, these areas become more stable, eventually transforming into mature maritime forests. As one moves from the water's edge toward the maritime forest, it is easy to see: 1) the wrack line and its embryonic dune, 2) the primary dune with its sea oats, 3) the secondary dune with its sea oxeye and broom sedge, and 4) the maritime forest with its mature saw palmettos and live oaks–the entire sequence, or stepwise progression of the growth and establishment, of a stable coastal terrestrial supratidal environment. In fact, maritime forests often appear as a linear beach ridge if seen from the air.

The seaward edge of the maritime forest abuts the landward edge of the secondary dune zone. Trees and shrubs are dwarfed by winds that blow sand and salt spray, essentially "pruning" these plants on a continual basis. Many tree tops and shrubs at the edge of the maritime forest have flattened top branches as a result of this salt pruning process.

Maritime forests absorb much of the heat on barrier islands and offer protection from extreme temperatures, an abundance of food, and nesting areas to a variety of organisms. Low-lying areas of the maritime forest trap and hold rainwater and are thus a source of fresh water for many inhabitants. Because they are located so close to the mainland, maritime forests support similar species that the mainland areas support. Live oak, American holly, yaupon holly, sweetgum, wax myrtle, red cedar, cabbage palm, saw palmetto, pines, dogwoods, and magnolias are a few of the trees that occupy the maritime forest habitat. Deer, raccoons, snakes, lizards, rabbits, eagles, ospreys, hawks, bobcats, and foxes are some of the larger animals living in the maritime forest.

F. Inlets

Salt water from the ocean enters estuaries and backmarshes through inlets. Inlets are waterways between islands. They are the passages through which sediments are transported by tidal flow. Sediments deposited adjacent to inlets serve as sediment reservoirs that feed many barrier islands along the Southeastern U.S. coast.

Depending on the relative strengths of the local tidal currents and waves, lobes of sand and silt may accumulate on either the landward or seaward side of the inlet. Along most of the South Carolina and Georgia coastline, the tidal range is great enough (i.e., mesotidal tidal range) to create a significant flow of water, or tidal current, during ebb tide. Wave action is less significant and, therefore the tidal currents pass through the inlets and extend seaward. These ebb tidal currents decrease in velocity as they enter the coastal ocean, allowing sands and silts to settle out. Ebb tidal deltas and bars of sand called shoals are formed by these deposits seaward of the inlet (Fig. 4-15). In microtidal regions, such as the northernmost stretch of the South Carolina coast on up into North Carolina, tidal currents are diminished. Wave action in these regions is quite significant and serves to prevent the weaker tidal currents from carrying their sediment load seaward of the inlets. Instead, flat areas of silt and sand are deposited on the landward side of the inlets as flood tidal deltas.

The numerous ebb tidal deltas along mesotidal sections of the coastline may contain nearly as much sand and silt as is found exposed on the beaches! It has been estimated that 30% to 40% of the total sediment deposited on barrier islands along the Southeastern U.S. coast originates from sand shoals and ebb tidal deltas.

Shifting sediment and tidal action cause many inlets to constantly change position. Sediments are moved by the combined effects of wave action and longshore currents. Sands carried along the length of a barrier island eventually encounter an inlet. Some particles remain as dune or spit deposits, described earlier, while others become part of the inlet-tidal delta system. An enormous "package" of sand accumulates at the island's downdrift end and slowly works its way around the lobe of the ebb tidal delta itself. This process is called inlet bypassing and allows for the continued flow of the enormous volume of sediments southward along the Southeastern U.S. coast. When the sand package completes its trek around the delta lobe, waves continue to push it toward the adjacent barrier island, "welding" the bar to that island's updrift end. This welding of huge packages of sand is in part the reason for the greater widths of barrier islands on their updrift end. Some of these welded beaches eventually become vegetated, forming anchored beach ridges.

Areas of land located on either side of inlets are thus very unstable as their profiles change in response to different phases of the inlet bypassing process. A single inlet bypass may take between 5 and 100 years, depending on the size of the delta and the strength of the longshore currents and waves.

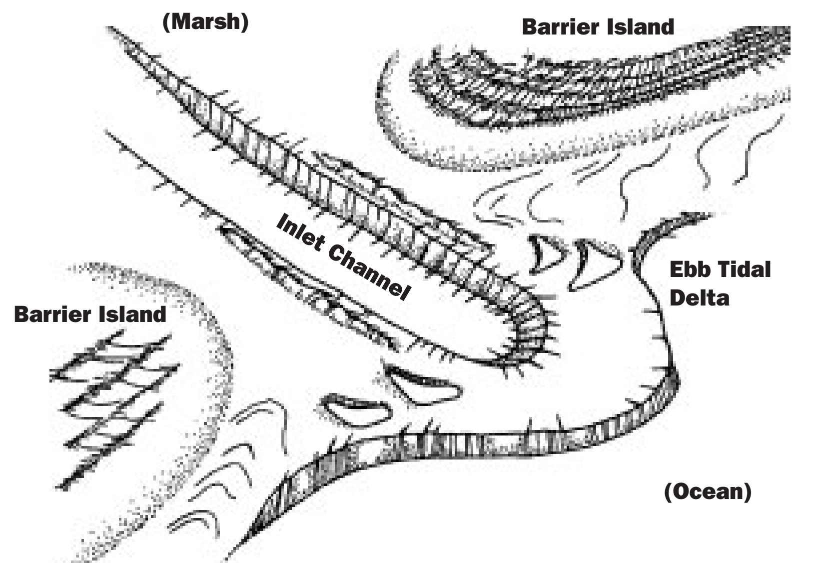

Figure 4-15.
Inlet and ebb tidal delta. (Figure modified from Hayes, 1980).

Fierce storms can cause inlets to form in low-lying, unvegetated, or narrow areas of islands located along the coast, particularly in the microtidal sections. Flows during maximum tidal stages can be quite rapid, as inlets function as "garden hoses" funneling large volumes of water through narrow openings. Flows through inlets can be particularly dangerous during ebb tides and many people have drowned while swimming and wading in these inlets.

Inlets not only are conduits for sediments, but they are also pathways through which nutrients, gases, salts, food, and pollution enter the ocean. Tidal inlets enable salty ocean water to mix with the less saline water of estuaries during high tides. They also allow for the twice-daily flushing of estuarine areas along the coast.

Organisms that are spawned offshore, but are dependent on estuaries as nursery grounds, enter estuaries through inlets. Larvae of shrimp, crabs, certain types of groupers, and many other commercial and recreational species enter estuarine areas riding the flood tide currents. Once inside, they settle out from their planktonic habitat and take up a benthic existence in their new estuarine nursery grounds. Organisms that are dependent on estuarine nursery grounds find an abundance of food and shelter in inlets and the smaller tidal creeks which meander throughout saltwater marshes.