Introduction to Sandy Beaches and Estuaries

BEACHES:

Storm waves refract, bending toward the rocky headlands, energy focused on the rocky intertidal, rolling rocks and crushing shells. The waves wash storm debris into inlets between the headlands, producing beaches of pebbles and rounded stone. In turn, the pebbles break and fracture into smaller and smaller pieces, finally forming sand grains that pack uniformly along the beach. Sand fills the coves and estuaries, producing long flat sandy beaches, normal to the waves, that are resistant to the power of the swell and breaking surf. During winter, the strong surf erodes these long flat beaches, fine-grained sands are moved offshore into deeper water, and the beach becomes steep and coarse grained. Storms cut vertical berms into the beach, marking the shoreward extent of the highest waves on the highest tide of the strongest storm. In spring, the storms abate and the waves diminish. Gentle swash gradually returns fine sands to the beach. In summer, the beach builds slowly seaward, and the beach slope becomes more gradual. Summer winds blow away the winter berm and smooth the beach. This annual cycle of winter erosion and summer sand replacement is repeated, year after year.

Each year, more sand is carved from rocky headlands and new sand is moved toward the beach, but, also each year water currents transport sand, inexorably and directionally, along the beach until the sand is finally lost far offshore. Waves refract as they approach the beach, bending into lines parallel to the shore, stirring up sand each time a wave crashes onto the beach. But although sand is resuspended each time a wave breaks, this sand quickly settles directly back onto the bottom. Sand does not move directionally along the beach without a directional current. Directional currents parallel to the beach are called longshore currents, and they are caused by the wind. Because each and every beach is uniquely situated topographically with respect to local winds, over the course of any given year these winds summate to produce a grand, long-term average force that drives the water next to the beach either up or down the shore. These longshore currents transport sand sideways along the beach, in step-wise fashion, each time a breaking wave suspends the sand. Each year, therefore, new sand accumulates while old sand is floated away, and although we view the beach as remaining much the same year after year, we do not see the same sand in the same places at the same times of year. The beach is a very slow river of sand, in dynamic balance between the forces of erosion and deposition and the forces of resuspension and longshore transport

Because sandy beaches are always physically in flux, there are no permanent communities of intertidal plants growing on sandy beaches. Energy for the animals that inhabit sandy beaches is all imported, mostly from the sea. Soon after winter storms have ravaged offshore kelp beds, seaweed of all types drifts ashore to molder and rot and enrich the sands. Beach amphipods and isopods accumulate near and below the piles of beach wrack and feed on the windfall, feeding at night but burying deep within the sand during the day to hide from the hoards of shore birds that probe and dig for crustacean prey. On tropical sandy beaches ghost crabs emerge from their burrows at night, racing up and down the beach in search of food. Dead fish and marine mammals wash ashore, to be slowly eaten from below by the scavengers of the beach. Terrestrial nocturnal scavengers, such as coyotes, mink, hyenas, and rats, compete with scavenging birds, the vultures, seagulls and eagles, for carrion.

The ocean also brings live food to the sandy beach in the form of zooplankton and phytoplankton. Plankton is captured in the subtidal by filter feeders and suspension feeding invertebrates, like mole crabs and surf clams. Enormous populations of these animals often occur along the beach, but their populations are tightly zoned in relationship to the height of the tide. This is because they capture food most effectively where the sand and the organic particles trapped within the sand are resuspended by breaking waves. On gently sloping beaches with large tidal ranges, the location where the waves actually break moves toward and away from the shore, twice a day, as the tides rise and fall. In order to maximize feeding effectiveness, the mole crabs and the surf clams must follow the tides, migrating up the beach slope during rising tides and down into deeper water when the tide begins to fall. These tidal migratory movements are so well ingrained physiologically that the animals continue to exhibit incipient rhythmical migratory movements even when they are in laboratory aquariums. When the sounds of breaking waves are played back to surf clams in the laboratory, the clams jump out of the sand, and wait for the next wave!

Decay of beach wrack and entrapment of plankton by shifting sands enriches the interstitial waters around the grains of sand with tiny particles of food. This food is exploited by large numbers of bacteria and protozoa, but it is also exploited by one of the most unusual assemblages of animals in the sea, the meiofauna. This group of animals includes many species of multicellular metazoans from a large number of phyla, all of which are very small, mostly less than 1 mm in length, so they can move about in the interstices among the grains of sand. Meiofaunal animals are not only very small, they are also long, thin, flat, and mobile, with reinforced body walls to resist crushing when the sand moves. They all exhibit reduction of complex organs, including sense organs, but most have suckers or hooks for holding onto the sand when it shifts. Although many meiofaunal animals superficially look alike, there are meiofaunal cnidarians, mollusks, echinoderms, annelids, crustaceans, gastrotrichs, tardigrades, rotifers, nematodes, flatworms, and brachiopods. Meiofauna are not only small, they are also difficult to extract from the sand. Although we do not know much about meiofauna, they are marvelous, miniature creatures.

A short essay on why sandy beaches are not all the same:

Sandy beaches occur between the headlands of rocky coasts and also near estuaries and river mouths, but these two types of sandy beaches are quite different because of the presence or absence of mud. Fine grained sediments, mostly silts and clays (mud), are delivered to the sea in huge quantities by large rivers whereas the weathering processes that occur on rocky headlands produce mostly produce gravel and sands and almost no fine grained sediments. Consequently, beaches along the outer coast are composed primarily of large grained sands of quite uniform size, fully oxygenated with depth, whereas coarse grained sands on beaches near river mouths occur only very close to the surface, and the sand grades quickly with depth to anoxic silt and clay.

Sand grains on outer beaches pack together like spheres of uniform size, with a large amount of space, water, oxygen, and meiofaunal animals in the interstices between the sand grains. Meiofauna are found primarily in medium to fine grained sands, with grain sizes of about 0.2 mm diameter supporting the largest biomass of meiofauna. Because the sand grains in the intertidal zone of outer coast beaches are quite uniform, they are constantly, albeit slowly, in motion, stirred by the waves and by the burrowing activities of animals.

Sandy beaches near estuaries, however, are similar to beaches along outer shores only near the surface. When one digs below the surface of these beaches one quickly encounters very fined grained sands composed of silt and clay of mixed grain sizes, packed solidly together with almost no free space between the particles. With little free space between the grains of sediment, there is not much space or water. Instead of oxygen there is hydrogen sulfide gas that smells like rotting eggs.. Sediments with grain sizes smaller than 0.1 mm contain almost no meiofaunal animals. There are large burrowing animals on these beaches, however. Burrowing shrimp, crabs and worms, live in deep permanent burrow systems that are irrigated and oxygenated through permanent connections to the surface. Burrowing clams deep beneath the surface extend their siphons to the overlying water, often through anoxic sediments, to bring down food and oxygen.

Grain sizes for particles and unconsolidated sediments found on beaches:

PARTICLES	SIZE
Boulders	larger than 256 mm
Cobbles	larger than 64 mm
Pebbles	larger than 4 mm
Granules	larger than 2 mm
Coarse Sand	larger than 0.5 mm
Medium Sand	larger than 0.25 mm
Fine Sand	larger than 0.06 mm
Silt	larger than 0.004 mm
Clay	less than 0.004 mm

ESTUARIES:

Estuaries occur in quiet, partly enclosed coastal regions where rivers meet the sea. The unique physical and chemical attributes of estuaries relate primarily to the large volumes of fresh water and sediments delivered to the sea by rivers. The mixing zone for fresh water and seawater within the estuary can be exceptionally complex, affected by the volume and rate of discharge of fresh water from the river, the amount and grain size of sediments in the river, the topography of the coastline, the tidal range, and the strength and direction of prevailing wind and waves. Fortunately, this almost hopelessly bewildering array of factors becomes simplified in reality. There are actually only four major types of estuaries in the world, relating to geological forces that have been operating over thousands of years to produce quiet water coastal habitats.

The 4 types of estuaries are:

1. Drowned River Valleys:
   Drowned river valleys, formed when sea level rose some 120 meters (about 400 feet) at the end of the last ice age, some 18,000 years ago, are common along the east coast. The two largest drowned river valleys in the US are Chesapeake Bay and Delaware Bay.

2. Tectonic Estuaries:
   Tectonic estuaries were created geologically, not by rising sea level, but by subsidence of the land. On the west coast all of San Francisco Bay is now an estuary. The Golden Gate Bridge lies almost exactly on top of the San Andreas fault, marking the boundary between the Pacific Plate and the North American Plate. At this site the Pacific Plate is moving quite rapidly to the north, whereas the North American Plate has subsided somewhat, filling with seawater from the sea and with fresh water from the Sacramento River.

3. Sand Bar or Barrier Island Estuaries:
   Barrier islands are a conspicuous feature along the east coast and the Gulf coast but not the west coast of the continental United States. Barrier islands were originally ancient beaches on the wide, gentle sloping continental shelves of the Atlantic and Caribbean when sea level began to rise 18,000 years ago. Pounding waves piled sand onto these shorelines, and, as sea level continued to rise, more sand was heaped on top of the dunes until a relatively stable barrier island was formed. But sea level continued to rise, year after year for 18,000 years. Each year a bit more of the front of the barrier island was eroded away by waves and each year more sand blew across the dunes to be deposited in the lagoon behind the island. These processes continue today, and each year barrier islands move a bit closer to the mainland. Barrier islands isolate barrier lagoons from the sea. Rivers discharge into these lagoons, and near the

river mouths barrier lagoons are true estuaries, full of brackish water, mud and silt. Similar sorts of barrier islands were not formed on the Pacific Coast because the continental shelf there is too narrow and steep for sand bar beaches.

4. Fjords:

Fjords are deep valleys that were cut by glaciers during the last glaciation, but that now are supplied with sea water from one end and fresh water at the other. There are no fjords in the continental United States, but fjords are common in Alaska, Canada, Chile, New Zealand, and Norway. A fjord is often separated from the sea by a shallow sill at the mouth, formed of rocks that were pushed ahead of the actively moving glacier. Now the only remnant of the glacier is a wall of mostly submerged rocks across the mouth of the water-filled valley.

Estuaries are physically structured by the geological processes that produced the estuary, but they are also structured by forces that affect the delta at the mouth of the estuary, forces generated by waves, tides, and the river itself.

1. Wave dominated estuaries often have a sand bar or sand spit across the mouth of the estuary. This sand bar breaks the force of the waves and physically protects the estuarine lagoon from wind and waves. These sand bars form even if the wave regimen is exceptionally strong because waves are wind driven and because the wind almost never blows directly at right angles, or normal, to the shore. Consequently, once breaking waves have suspended the sand, the longshore current driven by the wind moves the sand in stepwise fashion down the beach and across the mouth of the river. Tidal currents and river discharge maintain an opening to the estuarine lagoon, but this opening is always downwind of the river, never directly opposite the river mouth.

2. Tide dominated estuaries are open directly to the ocean; they have no sand bar across the river mouth. Tide dominated estuaries occur where there is an exceptionally high tidal range so that during flood and ebb tides large amounts of sea water race up and down the mouth of the river. These strong tidal currents prevent the development of a protective sand bar across the mouth of the river.

3. River dominated deltas are river systems little influenced by the ocean. Here the river is so strong that freshwater discharge creates a huge fan-shaped offshore delta of muddy deposits, with relatively little incursion of sea water. The Mississippi River delta is such a system. When upstream dams restrict the flow of water and sediments out of these rivers, however, then saltwater incursions do occur, often with unexpected consequences.

These hydrodynamic distinctions among types of estuaries are exceptionally important. Wave dominated estuaries are protected by an offshore sand bar, so they accumulate sediments and exhibit strong water stratification because of the absence of waves in the lagoon. Most storms do not have a major impact wave on these estuaries because the sand bar in front of the river protects the estuary from all but the strongest waves. Tide dominated estuaries, on the other hand, are always exposed to waves, sediment accumulation is low, and tidal currents force the sea far inland. During storms, storm surges as high as 5 m (16.5 ft) above normal high water race inland, unimpeded by a protective sand bar, and inland damage from storm surge waters is often disastrous. For example, the nation of Bangladesh is dominated by the Ganges-Brahmaputra River delta, a tide dominated delta. Tropical cyclones in the Bay of Bengal regularly produce storm surges that cause catastrophic damage to the delta. In 1970, 300,000 people in Bangladesh were killed by storm damage, and another 140,000 were killed in 1991.

The dynamic forces within estuaries of waves, tides, and rivers and the shifting substrate of silts and clays produce an exceptionally difficult set of environmental conditions for the establishment of plant and animal populations. Animals and plants that inhabit estuaries must be able to live in an aquatic environment where they might be adjusted physiologically to fresh water, only to be abruptly immersed in full strength seawater. Very few aquatic organisms can tolerate such extreme rapid changes in salinity. The result is that the number of species of plants and animals that inhabit estuaries is low. However, populations of the species that can live in estuaries are often exceptionally large because rivers wash huge quantities of nutrients (such as nitrogen, phosphorous, silicate, and iron) out of terrestrial soils. The rivers quickly transport these nutrients to the estuary, where they are intercepted primarily by marsh grasses and sea grasses, promoting rapid and high primary productivity along the shore. In turn, this new production of plant tissue supports large populations of estuarine invertebrates, zooplankton, and fish. Estuaries are particularly important locations for the development of coastal fish populations because of the high productivity. In addition, the shallow water, the structural complexity of the benthic plants and the high turbidity produced by muddy water provides protection for larval fish from predators.