4. Dune Ecology Chapter: Beaches and Primary Dunes

Dunes are dynamic and constantly changing ecosystems that form a natural buffer between sea and land. Depending on conditions they can either accumulate sand from the beach, growing the dunes and storing sand, or they can form a source of sand to the beach as the dunes erode. The ecology of these ecosystems plays a key role in mediating many of the functions of dunes, including their growth and stabilization. Similarly, the physical environment of this unique habitat strongly shapes the ecology of the organisms living there.

The transition between sea and land creates a zone in which little can live. In the areas covered frequently by water, aquatic organisms thrive. However, in the areas at and just above the high tide zone conditions are particularly harsh. The lack of water makes life near impossible for aquatic or terrestrial organisms, and the dry sand is easy to heat and cool, resulting in strong swings in temperature from too hot to walk on during a sunny summer day, to bitterly cold during winter. The sand in this area is moved by both wind and waves, creating a highly dynamic system in which the sand is in near constant motion. In oceanfront dunes, this high beach area also experiences strong swings in salinity, from highly salty conditions during dry weather caused by salt spray being concentrated by evaporation, to being washed almost free of salt during intense rains. As a consequence, except in specialized habitats (such as the wrack line, where rotting organic materials forms both food and a mechanism for water storage), very few animals, and no true plants can live in this zone.

In the area of beach between the ocean and the dune, the strand line forms a small oasis of life in the otherwise dry and relatively barren sand. Here the debris left by the high tide forms a narrow band along the shore. As many a beachcomber will testify, all kinds of items can be found here, from human garbage to seashells, animal remains and decomposing seaweed, sea grasses and other natural materials. The rich organic content of this area provides a reservoir of water and food for the animals found in this area. One common animal in this zone are talitrid amphipods (*Talorchestia longicornis*) often known as beach fleas or sand hoppers. These animals live in burrows under or near the strandlne. The burrow helps hold water to keep them moist as well as forming a chamber where they can lay their eggs without them being washed away by the tide. These largely nocturnal crustaceans feed on the decomposing organic materials in the strand line. Tiny white worms that are cousins of the earthworm (family Enchytraeidae *Enchytraeus albidus*) are another common resident here. Carrion beetles as well as the larvae of tethinid or carrion flies (*Tethina parvula; Sarcophaga carnaria*) may also often be found under the decaying carcasses of fish, horseshoe crabs and other larger animals found in the strand line. In the past, the brightly metallic colored northeastern beach tiger beetle (*Cicindela dorsalis dorsalis*) would also have been abundant here, especially on the warmest summer days. Unfortunately these animals have become critically endangered in recent years and are either absent or extremely rare on New Jersey's beaches today, despite several attempts to reintroduce them to the beaches and dunes at Sandy Hook. While the diversity of these organisms is low, their abundance can be really high. Attracted by the abundance of food the lycosid spiders (*Arctosa littoralis*) hunt here, their pale color helping to camouflage them in the sand. Robber flies (Alslidae) also patrol this area looking for carrion flies to eat, swooping in

with their characteristically curved attack paths whenever they detect their prey. The rich supply of arthropods and worms make the strand line a favorite foraging area for waders and beach nesting birds like piping plovers. In addition, its common to see swallows swooping low over the strand in search of robber flies and other insects drawn to this area.
http://www.vliz.be/imisdocs/publications/139188.pdf.

Ghost or Sand crabs (Family Ocypodidae) make deep burrows 3-4 feet into the sand toward the top of the beach or into the edges of the dunes, and spend most of the day in these cool, damp hiding spots. Like many beach residents, their shells are sand colored, which combined with their tendency to be seen in moonlight contributes to their ghostly appearance. They can grow to about 2 inches across the shell and can run sideways remarkably fast as they move across the beach in search of clams, insects, detritus and even other crabs to eat. While they spend much of their lives on land, ghost crabs must periodically return to the sea or to the water at the bottom of their tunnels to wet their gills. Females carry their eggs on their undercarriage and these too must be periodically submersed in water to keep them moist and the larvae are also released into ocean when they hatch, spending a brief period as fully aquatic animals before metamorphosing and moving to the land as juveniles
http://barnegatshellfish.org/crab01.htm

http://www.nps.gov/pais/learn/nature/ghost_crab.htm

Many beach goers will testify to the fact that the beach often plays host of a variety of biting insects, particularly green heads and stable flies. As may be guessed by its name, the salt marsh greenhead fly, *Tabanus nigrovittatus,* breeds in salt marshes that are often found nearby beaches especially in the Barrier Island and peninsula systems that dominate the New Jersey shoreline. The larval greenflies eat a wide variety of invertebrates found in the decomposing thatch of the salt marsh. They overwinter as pupae and then metamorphose to adults in late spring. Adult flies mate in the marsh areas and the female lays her first batch of eggs without need of a blood meal. However, to fuel additional laying, she needs to obtain energy and protein by biting warm blooded prey. Blown from the marshes to the beaches by the west winds, their strong bite and persistence can make them a serious pest for beach loving humans in the summer. Stable flies, are another familiar bane of summer beachgoers. These flies look similar to house flies but they have a very similar life cycle to greenheads, with the larvae feeding and maturing in the rotting thatch of the salt marsh, and the adults feeding on the blood of warm blooded animals.

http://www.rci.rutgers.edu/~insects/greenheads.htm
http://www.pcbeachmosquito.org/EntGuides/EntGuide4.pdf

The use of off road vehicles can have significant negative effects on this habitat. Vehicles can crush ghost crabs when not in their burrows, and vehicle traffic has also been found to decrease the numbers of invertebrates within the strand lines.
http://www.nps.gov/caco/learn/nature/upload/Steinback-Ginsberg-ORVeffects-DRAFT.pdf

It has also been suggested that off road vehicle use on ocean beaches was a key reason for the precipitous decline in populations of the northeastern beach tiger beetle in the past century

(U.S.F.W.S., 1993). In addition, wrack removal, which is often done via beach raking to increase the esthetics of beaches to bathers strongly lowers the diversity and abundance of beach invertebrates—in both wrack and on open sand (e.g., De la Huz et al., 2005; Dugan et al., 2003; Yaninek, 1980).

High Beach and Embryonic Dunes

Moving up the beach, away from the water, conditions stabilize a little and life becomes possible. Organisms living in this zone must have a high tolerance to being blasted with and buried by the constantly moving sand. This sand has little or no organic material in it, which in turn means that nutrient supplies for plants are low, and without organic materials to absorb water, rain drains rapidly through the coarse sand grains after a storm, so plants must have a strategy for obtaining water rapidly when it is available, and to store it within their tissues for later use. They must also have strategies to deal with the often high amounts of salt in their habitat.

At the very front of the living dune, a small number of highly specialized species with high tolerances to these conditions eke out an existence. Many of the plants and animals in this zone, such as Piping Plover (*Charadrius melodus*), Sea Beach Amaranth (*Amaranthus pumilus)* and seaside knotweed (*Polygonum glaucum*) are endangered since they can't tolerate being trampled or disturbed by the foot or vehicular traffic that commonly occurs there. Making things worse for such species is the increase in flooding frequency resulting from rising sea levels, and the encroachment of the invasive Asiatic sand sedge (*Carex kobomugi*), which grows further down the front of the dune toward the ocean than native dune species. Another distinctive species growing in the high beach at the dune edge is sea rocket (*Cakile edentula*). Its lobed, fleshy leaves help keep it moist in the hot dry sand. It has yellow or white 4-petaled flowers and forms bulbous seed pods that stay on the stem after the leaves drop. Both the flowers and green pods are edible, and are both salty and spicy in flavor (it is a member of the mustard family). The most seaward sea rocket plants tend to grow largest and most vigorously and to make the most seeds. Sea rocket seed pods consist of two sections. The larger, distal area of the pod is designed to break off and its cork-like structure allows it to float well, allowing for long distance dispersal, colonizing new areas and replacing seaward populations. By contrast, the lower part of the pod tends to stay attached to the mother plant, and seeds from it disperse locally. These seeds tend to be blown landward by the prevailing wind, putting them into suboptimal habitats where their growth is lower and herbivore stresses are higher. Such inland sea rocket populations tend not to replace themselves, but instead are replaced by seeds blown inland from plants at the front of the dune. (Davy, A.J., Scott, R., Cordazzo, C.V., 2006. Biological flora of the British Isles: *Cakile maritima* Scop. Journal of Ecology 94, 695-711.).

Off road vehicle use, as well as foot traffic, can do significant damage to this ecosystem. Vehicles and pedestrians can crush the delicate and often relatively unobtrustive plants that grow in this area. They can also crush eggs of beach nesting birds, as well as frightening birds from their nests, opening the eggs to predation and lowering hatching success. Thus human activities in these areas is strongly correlated with decreases in abundance of federally endangered species such as piping plover and sea beach amaranth. As they drive or walk on the front of the dunes, pedestrians and drivers alike can also crush the expanding dune grasses

as they spread seaward, preventing the growth of the dunes, and increasing erosion. http://www.nps.gov/caco/learn/nature/upload/Steinback-Ginsberg-ORVeffects-DRAFT.pdf

Because many of the species in this habitat are threatened or endangered, effective management of these areas is particularly important. Activities that affect or change the natural processes of sand accretion and movement, such as sand fencing, installation of jetties or other such practices can have strong impacts on these species and should be avoided when possible. Native or invasive vegetation, such as beach grasses and Asiatic sand sedge compete with T&E species of plant and often make the habitat unsuitable for nesting birds. As a result any fencing or planting activities should be carefully coordinated with wildlife managers and carried out only as prescribed in the approved Beach Management plan for that area. To prevent disturbance to beach nesting birds areas used by them for breeding or foraging are often fenced off to restrict access to foot and vehicular traffic during the nesting season (March 15 through August 31). Similarly, beach raking that removes the wrack materials within the strand line that form an important foraging resource for beach nesting birds should also be avoided. Predators including foxes, raccoons, feral cats and even visiting dogs can be another important source of disturbance and mortality. Predator control plans and restrictions on dog walking may thus also be required in areas where beach nesting birds are active.

http://www.fws.gov/northeast/njfieldoffice/endangered/plover.html

Primary Dunes

Moving inland from the high beach, the soil tends to be made up of smaller sand grains that are easier for the wind to pick up and transport from the beach. The smaller grains help improve the ability of soil to hold water. This, combined with the high humidity of this habitat when winds are blowing onshore and fact that few species can survive the salt, heat and water stresses of this habitat, mean that the few species that can grow there have few competitors and can grow quite abundantly. In New Jersey, one plant species in particular tends to dominate the first fully vegetated areas of the dune (the primary dune). American Beachgrass (*Ammophila breviligulata*) is uniquely suited to life in this habitat in a number of ways. For example, while a burial is usually a negative factor for many typical terrestrial plants, sand burial is actually stimulatory to growth of this and many other primary dune species. The constant rain of fresh sand that characterizes the primary dune brings nutrients (attached to the sediment grains) and is pathogen-free, having been sterilized by the ocean, so it reduces the density of parasites and disease-causing organisms in the soil (Maun 2004 coastal dunes X and Psuty). To save water, the stomata (pores used for gas exchange in plants) are located in deep grooves on the leaf surface, and the long narrow leaves can be rolled or folded and held in such a way to minimize exposure to wind (Plant Fact Sheet: American Beachgrass". United States Department of Agriculture, 2006-05-30). Another adaptation to this habitat is beach grasses' extensive system of roots and rhizomes (underground stems) that form a complex horizontal network that can extend 20 feet deep below the dune and at least as far out horizontally. The horizontal rhizomes connect related plant shoots while the roots allow the plant to access water reserves deep in the sand, as well as accessing moisture near the surface from brief rain events that don't provide enough moisture to infiltrate deep into the dune.

Despite all of these challenges American beachgrass grows rapidly and can grow as much as 6 to 10 feet a year. It can also grow as many as 100 stems per clump each year (Plant Fact Sheet: American Beachgrass", United States Department of Agriculture, 2006-05-30). The leaves of American beachgrass have deep grooves on their top surface, but are smooth underneath. Arising from a relatively short stem, the straight, stiff leaves are relatively narrow (1/4 to 1/3") but can grow to several feet in length, and tend to stand upright rather than drooping. The leaves of American Beach grass act as filters that intercept blowing sand. As the sand grains hit the plant's leaves, the air currents slow and the sand grains fall to the dune surface where the plants' roots and rhizomes help to hold them in place, building and stabilizing the dune.

American beachgrass flowers are clustered into spikes that grow from a central stem in early summer. Although the plant does set seed, in New Jersey the seeds it forms are not usually fertile, and the plant spreads primarily through vegetative propagation via horizontal rhizomes. In the front of the dune, these rhizomes can be eroded by waves during storms and disperse to other areas via water transport.
(http://www.nrcs.usda.gov/Internet/FSE_PLANTMATERIALS/publications/njpmcrb12116.pdf. Release brochure for American beachgrass 'Cape' (*Ammophila breviligulata*). USDA-Natural Resources Conservation Service, Cape May Plant Materials Center. Cape May, NJ 08210. Published February, 2014).

While American beachgrass seeds may not be fertile, they are still an important food source for birds and small mammals, including snow buntings and the endangered Ipswich sparrow. In addition many other species, including snowy and short-eared owls, piping plovers and a number of gull species, use American beachgrass for habitat (Eastman, J.A. 2003. The book of field and roadside: open-country weeds, trees, and wildflowers of Eastern North America. Stackpole Books. Mechanicsburg, PA. p. 27–30.)

Part of the reason that American beachgrass is able to survive the challenging conditions of the primary dunes is that is usually grows in association with mycorrhizal fungi (Koske et al. 2004 in Coastal Dunes Ecology and Conservation Ecological Studies 171. (Martinez and Psuty 2003)). These fungi obtain water and nutrients from the soil and provide them to plants in return for sugars and other organics from the plant roots. In one study of another dune grass (Sea Oats or *Uniola*) in Florida the ratio of hyphae (the fungus equivalent of roots) to plant root was found to be over 45,000:1. Clearly, then, these fungal extensions massively increase the surface area through which nutrients and water can be absorbed for use in growth by the plant. Not surprisingly, studies show that dune plants with mycorrhizae grow better (get taller, make more leaves, etc.) than those without, especially under drought stress. Mycorrhizal associations can also increase salt tolerance and help plants ward off parasites (Koske et al. 2004 in Coastal Dunes Ecology and Conservation Ecological Studies 171. (Martinez and Psuty 2003)). When plants disperse via rhizomes they actually travel with mycorrhizal spores, so that when they get to their new destination, both plant and its associated fungal partner can sprout together. Typically dune soils contain a variety of different species of mycorrhizal fungi and the more spores there are of those fungi in the soil, the more likely they are to be encountered by a sprouting seed to help with its growth and survival. Not all mycorrhizal fungi work equally well,

in this regard, though:; American beachgrass plants grow better when inoculated with spores from fungi collected from dunes rather than those from other sites.

Compaction, such as that caused by humans driving or trampling on the dunes, can destroy the root-like hyphae of the mycorrhizal fungi, which can impair plant growth (Koske et al. 2004). In addition, coping with the stressful environment of the dunes leaves dune grasses little energy in reserve to dedicate to mounting a response to infection. When humans walk or drive on the dunes, their weight crushes the delicate rhizomes running just below the surface of the sand. Such damage creates a pathway for pathogenic bacteria and fungi to enter the tissues of the plant, sickening or killing it. In addition, since each of the clumps of beachgrass is connected to others through the rhizomal network, once one plant becomes infected, the pathogen can spread rapidly to interconnected clumps, creating a widespread dieoff. This is why it is so important to avoid traveling through dunes in areas where dune grass is growing (NICKERSON, N. H. AND F. R. THIBODEAU. 1983. Destruction of *Ammophila breviligulata* by pedestrian traffic: quantification and control. Biological Conservation 27: 277-287.)

As mentioned earlier, American beachgrass needs a constant supply of sand accumulation to remain healthy. Away from the dune front, the species starts to lose vigor and becomes susceptible to infection by diseases such as *Marasimus* blight caused by a fungal infection. This disease creates characteristic circular dead patches in the grass (http://www.nrcs.usda.gov/Internet/FSE_PLANTMATERIALS/publications/njpmcrb12116.pdf TERIALS/publications/njpmcrb12116.pdf. Release brochure for American beachgrass 'Cape' (*Ammophila breviligulata*). USDA-Natural Resources Conservation Service, Cape May Plant Materials Center. Cape May, NJ 08210. Published February, 2014). Insects are the primary herbivores in dunes, with grasshoppers, aphids and the soft-scale insect (Ericoccus carolinae) becoming increasingly common with distance from the ocean feasting on the plant's tissues. Similarly , rabbits, deer and other herbivores that graze on the beach grass leaves become increasingly common with distance from the water, as do the nematode worms like the root-knot nematode (*Meloidogyne sasseri),* which attack its roots (dune book http://www.seagrant.umaine.edu/files/chg/RogersNashdune_booklet.pdf) . As a result of all this, growth of American beachgrass becomes increasingly sparse behind the dune crest.

An increasingly common sight in the primary dunes in New Jersey is Asiatic sand sedge (*Carex kobomugi*), an invasive species that, as its name suggests, has its origins in coastal areas around the Sea of Japan. Like American beachgrass, this species has a high tolerance for salt spray and heavy winds. Typically it grows to about a foot tall in large, dense beds. Its usual color is bright to yellowish green, with yellow and brown leaves being more common in the spring and fall. The relatively stiff, grass-like leaves curl over the plant, giving it a low profile. On the edges of the leaves are small, spiny ridges, which make the leaf edge feel like a serrated steak knife. The plant forms many flowers on a single stem. Each stem contains either male or female flowers. The male flowers form distinctive white pollen tubes during the early spring, but die back after pollen production ends. The female flowers are relatively unobtrusive in spring but by fall they develop into a large seed head characterized by a triangular set of spikes attached to a long stem with distinctive brown scales. Below the ground, *Asiatic sand sedge* forms spike-tipped rhizomes which spread out quickly from the plant. It also builds long roots that can grow

several feet into the sand. While the species does produce numerous seeds each fall, the viability of those seeds seems to be low, and the plant is believed to spread largely through creation of new clumps along its rhizomes, some of which can break off and be transported to new habitats by wind or erosion and transport by ocean waves and currents. Unlike American beach grass, this species is relatively resistant to damage from trampling. Being non-native, few species recognize it as a potential prey, so few animals eat it and it tends to be resistant to pathogens. Indeed it was these characteristics, along with its sharp seeds and rhizomes, that form a natural deterrent to pedestrian traffic that caused this species to be planted in New Jersey's dunes for several decades. However, the species' tendency to form a monoculture, outcompeting the native species and significantly changing the biology and geomorphology of the dunes, resulted in discontinuation of its use for dune restoration by the late 1980s. However, the species is still spreading through natural propagation and it is rapidly becoming the dominant species within many primary dunes in New Jersey and beyond.

Moving up the dune and away from the ocean, the improving soil quality and decreasing stress from salt spray and sand scour mean that other species are able to thrive in these areas. One of these is seaside goldenrod (*Solidago sempervirens*). Seaside goldenrod is a perennial (the same plant grows back year after year). Its broad leaves are arranged alternately on the stem, which grows as much as 3' tall. The fleshy leaves store water and have a shiny wax coating to protect the leaf from evaporative water loss and the drying effects of the salt spray. In late summer and early autumn seaside goldenrod produces large clusters of bright yellow flowers at the top of its stems. The individual flowers in these clusters are larger than those of other New Jersey goldenrods. Seaside goldenrod pollen grains are heavy and sticky, so the species is largely insect-pollinated. (The heavy pollen also means that, contrary to common perceptions, this plant is not responsible for the misery of allergy sufferers in the fall. Ragweed, a plant with unobtrusive flowers that create pollen designed for air dispersal, is the real villain in this regard). Its sugary nectar is an important food source for migrating monarch and the common buckeye butterflies as well as for other butterflies such the silver bordered fritillary. Each flower cluster gives rise to seeds that look similar to the fuzzy parachuted seeds of a dandelion. These seeds are food for mice and songbirds, and the plant hosts a number of gall producing insects, which in turn are an important winter food resource for birds like chickadees. Deer and rabbits will also occasionally graze its leaves. Release brochure for seaside goldenrod Monarch Germplasm (*Solidago sempervirens*). USDA-Natural Resources Conservation Service, Cape May Plant Materials Center. Cape May, NJ 08210. Published July, 2012 http://www.nrcs.usda.gov/Internet/FSE_PLANTMATERIALS/publications/njpmcrb12132.pdf. As well as increasing species diversity of the dunes, goldenrod, like American beachgrass, helps create habitat for foraging and nesting for a number of bird species including killdeer (*Charadrius vociferous*), piping plovers, and black skimmers (*Rynchops niger*)(Safina and Burger, 1983).

Together, American beachgrass and goldenrod make up 90 to 95% of the plants in the foredune. A small number of other species are also present including sea rocket, seaside spurge, panic grass, purple sandgrass, saltmeadow hay, beach pea, trailing wild-bean and the non-native dusty miller (http://people.uncw.edu/hosier/BIE/bieclschd/present/pltanimla.htm). Beach pea and trailing sand bean plants, like other legumes, have a symbiotic relationship with

nitrogen-fixing bacteria within swollen "nodules" in their roots. These bacteria are able to take atmospheric nitrogen (which is not usually available to plants) and turn it into ammonia (the same ingredient found in store-bought fertilizers). This is particularly important in the nutrient-poor soils found in sand dunes. Beach peas have pretty pink or purple flowers reminiscent of those of cultivated sweet peas. The flowers are popular foods for bees and butterflies, and once pollinated form seed pods filled with small peas which are eaten by deer, mice, birds and a number of insects. http://www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/coastal-landscaping/plant-highlights.html . Burrowing under the roots of the grass to escape the heat, and foraging for plant material and any carrion they can find are a variety of ant species. Similarly, the dunes are home to numerous burrowing wolf spiders. This spider's deep burrows (up to 3 feet deep) create a refuge from the daytime heat. The wolf spider hunts mostly at night, and preys on other dune insects. Another common dune species, the seaside grasshopper, is exquisitely camouflaged to look like sand. These animals are one of the few insects that prey on American beach grass, which forms their major food source. This warmth-loving insect sometimes buries itself under the sand at night with just its head exposed in order to make use of the heat stored in the sand grains of the dune. On a warm day the chirps made by the males by rubbing their legs against their wings in order to attract females may be heard throughout the primary and secondary dune systems.
(http://animaldiversity.org/accounts/Trimerotropis_maritima/)

The fact that there seems to be sand everywhere on a dune makes it look like a very uniform habitat to the casual observer. However, the direction and strength of the wind and the supply of sand from the beach make for strong differences between sites. The height of the dune also varies, and this in turn can affect the temperature by varying the timing and amount of shade experienced by plants on the dune surface, as well as affecting access to water supply from ground water. Even small depressions in the dune can make an important difference to the plants growing there by collecting organic material (which holds water and forms a nutrient source as it decomposes), as well as providing a shaded area that may be an important nursery area (Garcia Novo et al 2004). Similarly, the shade provided by beachgrass and goldenrod can help promote germination and establishment of seeds in the sand below. Consequently, beachgrass may be planted along with other species in areas behind the dune crest, even though it is unlikely to persist there on the long term, because its presence can help promote the establishment of the other plants sown along with it.

Coastal dunes form sand reservoirs that can play an important role in maintaining sand for the beaches in front of them as well as in protecting the communities behind them. In storms, wave erosion can become focused on one area of dune and can overwhelm the stabilizing effects of the dune vegetation. The sand released helps replace sand lost from the beach, but allows the ocean waters to flood landward, creating areas of flat sand known as blowouts. While blowouts can be problematic for the human infrastructure because they provide pathways for flood waters to move landward behind the dunes' defenses, they form a critical habitat for many threatened and endangered species. In particular they create safe nesting and foraging areas for beach nesting birds, being well above the usual high tide mark but lacking in vegetation that may provide habitat and cover for their predators.