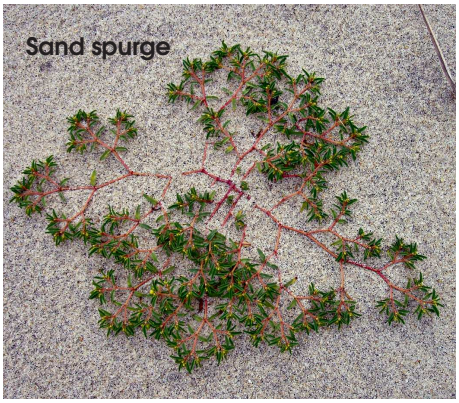
Dune Ecology: Secondary Dunes and Beyond

Secondary Dunes and Dune Swales

Behind the first or primary dune in natural areas are usually a series of additional or secondary dunes. In most coastal areas this and the nearby landward communities have been lost to human developments such as boardwalks, homes, and roads. However, in the few remaining undeveloped areas, such as northern Sandy Hook, Island Beach State Park, Edwin B. Forsythe National Wildlife Refuge, North Brigantine Natural Area, Stone Harbor Point, and Cape May National Wildlife Refuge, this zone is home to a wide variety of communities. Secondary dunes that are relatively close to the dune front tend to have similar vegetation to the primary dunes, although the beach grass tends to be much less dense and healthy in these areas. Seaside goldenrod is common in this habitat, as are sand spurge and even the occasional sea rocket.


Sand spurge

Between the dune crests are low-lying areas called *dune swales*. In these areas, the "lens" effect created by reflection of sunlight from the dune banks surrounding them concentrates the sunlight, creating temperatures that can be 20^0F higher than those of the surrounding areas. This, in combination with the osmotic stress created by salt spray and the lack of a steady supply of fresh sand in these areas, means that dune swales often feature sparse ground cover with many areas of open sand. Scattered in small depressions and other areas where microclimatic features allow life, there is an array of dune plants, including beachgrass, goldenrod, little bluestem, panicgrass, pin-sedge *(Carex grayii)*, lichens *(Cladonia* spp.) (Hosier 2003), the occasional low-growing beach plum or baybush, and Eastern prickly pear cactus *(Opuntia humifussa).*

Little bluestem is a clump-forming grass found in a number of habitats, including dunes. It produces abundant seeds that are an important food source for songbirds, and its leaves form cover for ground birds and small mammals (Tober and Jensen 2013). Coastal panicgrass is a tall grass species that only grows once the sand has been stabilized by American beachgrass or other species. Once established, it creates a fibrous root system that further stabilizes the dune (USDA 2006b). The only cactus species native to New Jersey, the Eastern prickly pear, has virtually no leaves. Instead its stems are swollen into flat, green, fleshy pads that allow this plant to be extremely drought resistant. These pads do have some longer thorns, although it is the tiny bristles that occur in clusters on the pads that are perhaps its greater defense. While tiny, these bristles embed in the tissues of predators and careless humans, creating a painful irritation, and are hard to remove. The bright yellow flowers of the prickly pear cactus form at the margins of the pads, and each lasts only one day, but flowers are produced throughout early summer, forming yellow blooms that are extremely attractive to native, long-tongued bees. When pollinated, these flowers form the "pear"-shaped fruits that give the species its name. The pears turn from green to red when ripe and become quite sweet and juicy. They are an important food source for a number of bird and mammal species and can be eaten raw or made into jams, juices, and other foods by humans. The plant was also used by Native Americans in the preparation of a number of natural remedies.

While dune swales are usually thought of as dry habitats, blowouts and other erosional processes can

actually lower the sand to a level lower than the groundwater surface. In many dune areas a "perched water table" exists in which groundwater is trapped above an impermeable clay layer, forming a lens near the soil surface that is saturated with fresh water. Since the soil is saturated with water, runoff from the surrounding dune areas during rain events can't drain, creating temporarily or semi-permanent wet areas such as dune swale ponds and marshes. Found within the wetland areas is an array of highly specialized, and thus often very rare, plant species. The plants found in these habitats are adapted to flooding and associated anoxic (low or no oxygen) conditions. The amount and salinity of the water in these systems strongly affects the community of plants growing there, but some of the plants found in dune swale wetlands include marsh fern (*Thelypteris palustris)*, rose mallow *(Hibiscus moscheutos)*, cattail *(Typha latifolia),* highbush blueberry, groundsel, large cranberry *(Vaccinium macrocarpon)*, marsh St. Johns-wort, panic grass, tickseed sunflower, sedges and bulrushes *(Carex, Cyperus and Scirpus* spp.), rushes (*Juncus* spp.), and common reed *(Phragmites australis)* (Hosier 2003). Birds, including red-winged blackbirds, golden-crowned kinglets, belted kingfishers (Breininger 1992), and green heron, as well as herpetofauna such as Fowler's toads and snapping turtles, are often found in and around these dune wetlands (NYNHP 2013).

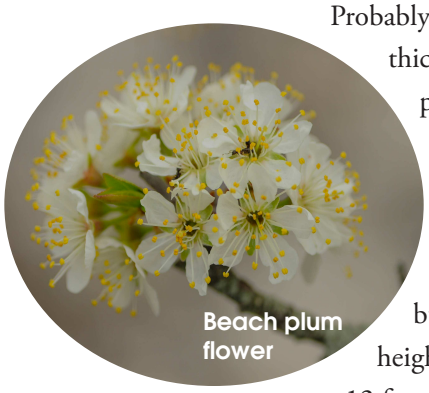
Dune wetlands also provide habitat for the larvae of mosquitos, dragonflies, and other insects. An unusual, and increasingly rare, inhabitant of dunes and dune wetlands is the eastern hognose snake. This thick-bodied snake prefers to feed on Fowler's toads and other amphibians, though it will also eat small mammals, birds, insects, and even carrion when amphibians are scarce. Hognose snakes are completely harmless to humans, but when threatened they will hiss loudly, which can be mistaken for the rattling sound of the venomous timber rattlesnake. They will also flatten and spread out their heads like cobras and make a series of fake strikes to try to scare off the animal creating the perceived threat. If this doesn't work, the hognose will go through an elaborate "fake death scene" in which it will throw up its last meal and proceed to seemingly writhe in agony with its mouth open and tongue sticking out. The snake will then defecate, flip over on its back, and play dead until the threat goes away. This death scene can be quite convincing. However, if you return the snake to its right side it will proceed to flip back over and continue to play dead, which rather ruins the effect (Vanek 2014)!

Beach heather *Louise Wootton photo*

In some higher-elevation backdune areas farther back from the ocean, woolly beach heather *(Hudsonia tomentosa)* commonly forms large patches. This plant gets its name from the white furry hairs on its leaves that help reflect light to prevent heat stress in the hot, dry backdune habitat. The leaves are also small and tend to be curled, and the plant grows close to the ground, all of which are adaptations to prevent water loss. Like some other dune species, dune heather's roots make associations with nitrogen-fixing bacteria in the soil, which provide the plant with much needed nitrogen-containing nutrients in return for sugars from the plant. For most of the year, wooly beach heather's low-growing pattern and dull grey-green leaves make it an unobtrusive plant. However, for a brief few weeks between late May and early July it creates a brilliant display with abundant bright yellow flowers being produced at the tips of each stem. Beach heather is extremely sensitive to trampling, so walking or driving on or near this plant should always be avoided.

Shrub Thicket

Moving away from the ocean, behind the secondary dune crests, a diverse community of shrubs and vines can be found that forms increasingly dense thickets as growing conditions improve. A few of the plants found in the thickets also grow in the swale between primary and secondary dunes, but their growth is usually stunted by exposure to wind-borne salt spray, so these plants have lower vitality in the dune swale than those growing further back from the ocean.



Kevin Knutsen hoto

Probably the most familiar thicket plant is beach plum *(Prunus maritima).* In most areas of the dune, this plant grows to only 4-6 feet tall, but it can grow to a height of as much as 10-12 feet in inland, nutrient-rich soils. Before the leaves form each spring, beach plums produce an abundance of snow-white flowers that develop and ripen into purple-black fruits in late summer and fall. It can also reproduce asexually, with extensive colonies developing from a single plant when conditions for growth are favorable (USDA 2002). The fleshy, sweet fruits are an important food resource for many birds and dune animals as well as humans, and its branches form nesting habitat and refuge for many birds and mammals.

Another common plant of the shrub thicket is Northern bayberry (*Myrica pensylvanica).* This woody shrub is technically deciduous, but its fragrant leaves may stay attached to its branches for much of the winter. The flowers and fruits of this species are both inconspicuous, but its waxy berries are an important food resource for a variety of dune animals. As with many other dune species, the bayberry plant is host to nitrogen-fixing bacteria that help it to survive on soils which, though richer than those of the primary dunes, are still relatively nutrient poor (USDA 2002).

Poison ivy *(Toxicodendrum radicans)* is much hated by humans who, nearly unique among animals, react to some of the oils in these plants by forming a nasty, itchy rash. Most children learn to identify the plant from its leaves ("Leaves of three, let it be!") and hairy stems ("Stem like a rope, don't be a dope!"). In the spring, poison ivy leaves start out small and bright red, but enlarge and become a shiny, dark-green color. Then in fall, the leaves again change color to bright red before being shed for the winter. Poison ivy produces numerous grey berries that are eaten by a wide variety of birds (more than 40 species of bird have been observed to eat the seeds of this plant). The tangled branches of the poison ivy also form great nesting and hiding places for a variety of animals, and the plants' dense and tough roots help to stabilize the dunes. Thus, though people may not like this species, from a wildlife point of view this species is a highly desirable part of the dune plant community.

Often mistaken for poison ivy, Virginia creeper *(Parthenocissus quinquefolia)* is a woody, deciduous vine that has 5-part leaves rather than that the 3-part leaves of poison ivy. On dunes this plant can be found growing prostrate over the sand, but it will also climb any shrubs or trees in the habitat, using tendrils that have disks that can attach to whatever they are climbing. Like poison ivy, the leaves start out small and deep red, change to green during the growing season, and change back to red or yellow before being


L Peragino photo

shed in the fall. This plant also helps stabilize dunes, both through its roots and through the dense network of stems that it spreads across the dune surface. In the fall it produces numerous blue berries that are a popular food for songbirds. Its leaves and branches also provide cover and nesting habitat for a variety of small birds and mammals (King and Henson 2005)

Eastern red cedar trees can grow as high as 40 feet, but usually they are much stunted when growing on dunes, rarely exceeding 10 feet tall. Its pyramid shaped branches and evergreen leaves form an important protective habitat, and its pale blue berries are eaten by a number of birds and mammals. The leaves, roots, and berries of the red cedar were used by Native Americans as a source for a number of natural remedies (USDA FS n.d.).

Maritime Forest

As the distance from the ocean increases, the influence of salt spray lessens and soil quality increases, improving access to both water and nutrients. As this happens the dune thicket community transitions to maritime forest. Trees here tend to be smaller than their inland counterparts and often display a distinctive shape with a flat top and reduced growth on the side facing the onshore winds, giving them the appearance of being pruned. This is termed "salt spray pruning" because it results from reduced growth or death of those tree branches, leaves, and buds exposed to the salt spray carried by the onshore winds into these habitats. One of the most common trees in this habitat is American holly. The familiar bright red berries and green, shiny leaves with sharp pointed edges are a familiar sight during the winter holidays. While this species is evergreen, new leaves tend to replace old ones each spring, creating a rich carpet of decomposing leaves on the forest floor that helps contribute to improved soil quality. Holly trees have separate sexes, with male flowers forming on some trees – which will never set berries – and female flowers and fruits forming on others. Its dense branches and abundant leaves provide protection and habitat for a number of birds, many of which, along with mammals, feast on its berries.

Another common tree in the maritime forest is sassafras, with its distinctive aromatic leaves and deeply furrowed, reddish-brown bark. Each tree forms three different-shaped leaves – three-lobed and mitten-

Sassafras *Jeanne Heuser photo*

shaped when young or lower on mature trees, and unlobed at the top of mature trees (Burns and Honkala 1990). Sassafras forms small, yellow flowers in the spring, and like holly, there are separate male and female trees. The blue-black, oval fruits that form on long stems ripen in late summer and are eaten by a variety of birds, including species such as kingbirds and crested flycatchers that usually eat an insect-rich diet. Sassafras bark and roots have been used to make root beer and a variety of teas.

Many of the species seen in the shrub thicket, like eastern red cedar, beach plum, and bayberry, are also found in the maritime forest. Individuals in the forest

often grow stronger and taller than their thicket counterparts in this less stressful habitat. The understory of the maritime forest is dominated by woody vines such as Virginia creeper, poison ivy, and greenbrier (Wetlands Institute 2005). Greenbrier *(Smilax rotundifolia)* gets its name from the sharp, curved thorns that grow along its green stems. The vine produces widely spaced round leaves with pointed tips and can grow tens of feet long as it climbs up trees and other plants in the forest. It produces small white flowers in summer and purple berries in fall on female plants (Chaney C. 2011).

Dune communities support a higher density of small mammals than other nearby habitats (Shure 1970). Cottontail rabbits, white-footed mice *(Peromyscus leucopus),* raccoons, skunks, and red foxes all use the thickets of the maritime forest and the forest itself for cover in the daytime and emerge at night to hunt for food in the forest and on the dunes themselves. Many birds, including mockingbirds and towhees, nest in the thickets and maritime forest while others, such as the scarlet tanager, yellow warbler, and rose breasted grosbeak, make use of the abundant supply of berries produced by the plants in this habitat to fuel their fall migration. The sight of thousands of tree swallows swooping low over the dunes in search of insects is a particularly memorable fall phenomenon. However, the real attraction of the dunes for these normally insect-eating animals is the bayberries. Migrating tree swallows have been found with more than 40 berries in their gut at any one time – quite a feat for such a small bird! Even in winter, dunes and the maritime forest host a number of bird species including the year-round resident yellow-rumped warbler and visitors such as snowbuntings (Wetlands Institute 2005). Attracted by the abundance of small birds and mammals, a wide array of predatory birds visits the dunes, including ospreys, Northern harriers, sharp-shinned hawks, American kestrels, peregrine falcons, and even snowy owls (in winter).

Patterns of Species Diversity on Dunes

The series of somewhat predictable changes that happen over time in an entirely new habitat is called *primary succession.* Dunes are unusual in that the different steps in the process are often visible in one place at the same time. In areas where dunes are actively growing by accreting sand, the dunes nearest the ocean represent the youngest stages in the process with fresh sand delivered from the ocean, creating a brand new habitat. When the sand is first blown in from the beach, it is essentially sterile, though it may carry with it a small amount of nutrients held to each grain's surface by ionic bonds. The sand of the foredune is more or less pure mineral. Organic materials, which hold water like a sponge and provide a source of nutrients as they decompose, are more or less absent. The soil thus dries rapidly after storms and tends to heat and cool easily. The salt stress created by the constant rain of sea spray into this community, combined with the abrasive effects of the sand blowing onto the dune from the beach, makes this a very hard place to live. However, for the very small number of specialized species that live there, it provides some advantages, particularly in terms of lack of competition and relatively low levels of herbivory. Over time the dunes build out in front of the present-day community. What is today's foredune will eventually become a secondary dune and so on. Thus, as one walks inland on the dunes, one is generally moving into communities that were reclaimed from the sea longer and longer ago. Moving landward into these communities, the stresses created by salt spray and blasting from the windblown sand lessen. In addition, as the plants of the primary dune grow and die, their decomposing tissues are added to the soil, helping to build its organic content. As conditions improve, the species present help facilitate the establishment of others, and the diversity of species present increases. In addition, as soil richness and access to nutrients improve, the kind of plants present changes from grasses and short-lived plants to shrubs and eventually to long-living trees.

Ecosystem Services of Dunes

Coastal dunes form the first line of protection for the communities behind them (e.g., uplands and wetlands such as interdunal swales and bayside tidal marshes) by reducing the energy of storm waves. Dunes play a vital role in protecting coastal areas from erosion, coastal flooding, and storm damage, as well as sheltering the properties and ecosystems behind them from wind and sea spray. Dunes also protect the tidal wetlands on the bayside of barrier islands and provide an important sand reservoir for the beaches themselves. Dune vegetation traps windblown sand, preventing it from being blown inland where it can a problem for homeowners and coastal infrastructure (roads, drainage, etc.) while helping build the dunes themselves.

In recent years the importance of coastal dunes in protecting the mosaic of natural and human communities behind them from the effects of projected climate change has been increasingly recognized (Nordstrom 2000). Expected relative sea level rise for the New Jersey coast between 1990 and 2100 is between 0.31 and 1.10 meters, with a median expected value for sea level rise in this region of about 0.71 meters (Cooper et al. 2008). If sea level rise occurs within the median range of this estimate, the result would be that 100-year storms (storms that statistically have a 1% chance of occurring in any given year) will happen 3 or 4 times more often in the future, and the resulting storm surges would inundate vast areas along the New Jersey coastline (Cooper et al. 2008, Lathrop and Love 2007). Other studies suggest that this would actually be at the low end of what we should expect. For example, Cooper et al. (2008) suggest "approximately 1% to 3% of the land area of New Jersey would be permanently inundated over the next century and coastal storms would temporarily flood low-lying areas up to 20 times more frequently." Similarly, Miller et al. (2014) suggest an expected rise in relative sea level of 1 meter along the New Jersey coastline, resulting in almost annual coastal floods. The presence of dunes significantly reduces coastal flooding, even during extreme storm events (Houser et al. 2008). Thus, careful management of healthy dunes can reduce the need for expensive and time-consuming rehabilitation in the future.

With careful management, dunes can be compatible with the habitat requirements of a variety of specially adapted plants and animals, including several beach species that are federally or state listed as threatened or endangered (e.g. seabeach amaranth and piping plover) and can act as a filter for rain and groundwater. In addition, dunes form habitat for a variety of animals, including migratory butterflies and song birds and a number of birds of prey. Dunes have a high aesthetic value for humans and have a rich cultural heritage both in terms of their use by native peoples and in modern times, as European colonization has its roots almost exclusively in coastal areas. Due to this, and their key role in protection of human infrastructure, in a recent economic analysis of different ecosystems (Costanza et al. 2006), dunes and coastal beaches were found to be, by far, the most valuable ecosystem in New Jersey on a per-acre basis.

Vulnerabilities

Reduced Genetic Diversity

New Jersey's coastal areas are typified by expensive multiuse infrastructure and high population densities. Consequently, dunes are managed to provide ecosystem services such as wildlife habitat and supporting services like flood and storm surge protection to the community. In most cases after significant coastal erosion, reconstruction of dunes

occurs. The current practice is to pump sand from offshore to build beaches, which can further be bulldozed to form artificial dunes. Dune stabilization occurs through the placement of sand fences, other artificial barriers, or most commonly, planting with vegetation (Miller and Petersen 2006). Increasingly the goals of dune reconstruction for infrastructure protection and recreation have been linked with ecological restoration to provide a more functional, healthy, and sustainable dune.

Failed dune planting. *Chris Miller photo*

Restoration, maintenance, and sustainability of barrier islands begins with a healthy dune system. The primary colonizer in this successional system is American beachgrass (*Ammophila breviligulata)*. Dunes, therefore, depend on the successful colonization and establishment of *A. breviligulata*. In situations where dunes are disturbed in anthropogenically developed areas, restoration efforts to reestablish stable dunes involve planting a single genotype of beachgrass identified as 'Cape' American beachgrass (Skaradek et al. 2003).

'Cape' American beachgrass was selected in the early 1970s by the USDA from a common garden and reciprocal transplant experiment with three other genotypes from the Eastern United States. 'Cape' was selected for its ease of propagation and aboveground performance compared to collections from Delaware ('Lewes' strain) and North Carolina ('Hatteras' and 'Bogue' strains). Overall, 'Cape' grew wider leaves and more culms than strains collected from Lewes, Delaware and Hatteras, North Carolina (Gaffney 1977). In virtually all maintenance and restoration activities along the natural range of *A. breviligulata,* from North Carolina to Canada and in the Great Lakes, 'Cape' is used to restore and maintain dune function (Skaradek et al. 2003; Miller and Petersen 2006). Often this variety performs very well, but not in all cases. For example, in the early 1990s dune restoration at Avalon, New Jersey resulted in the establishment of foredunes and the successful succession to maritime forest. However, in 1992, a dune restoration effort in Atlantic City, New Jersey, planted with 'Cape' experienced 100% mortality within two years of planting. Additionally, approximately one hundred other restoration sites along the Mid-Atlantic have experienced partial or complete mortality of 'Cape' plantings.

Mortality of 'Cape' plantings in a restoration setting can be attributed to several factors. First, timing of the planting is crucial, as noted in this manual and by the USDA planting guidelines (Miller and Peterson 2006). The timing of plantings corresponds to adequate soil moisture and favorable environmental conditions for bareroot plants to establish an adequate root system and mycorrhizal colonization. Secondly, sand-particle size can influence establishment. Dredged sand is often larger and not susceptible to movement, thereby limiting burial of the grass and reducing vigor (Maun and Lapierre 1984). Furthermore, sand-particle size is inversely related to water-holding capacity, so larger sand particles mean less water availability for bareroot plantings. The practice of artificially mounding sand into a dune to a height several meters above the water table further exacerbates the grass' ability to find water and establish a robust root system. Finally, other factors such as fungal endophyte and mycorrhizal infection, nematode root herbivory, and lack of genotypic diversity play roles in establishment (Emery and Thompson 2010; Emery and Rudgers 2011). Finally, the genotypic diversity of American beachgrass has the potential to affect all biotic and abiotic factors mentioned above, given the performance variation of different genotypes (Emery and Rudgers 2011).

Genetic diversity of American beachgrass in non-restored areas can be extensive. For example, plant populations in

three locations spanning the entire coastline of New Jersey showed non-restored populations had high levels of genotypic diversity, whereas restored populations on constructed dunes had low diversity or only a single genotype. Furthermore, 'Cape' was not found in native populations. Most foredune populations consisted of many small- to medium- sized clones. From a restoration perspective, genetically diverse plantings might increase restoration success. The current practice of genetic monoculture restoration does not mimic naturally occurring diversity and can result in reduced population performance, loss of community interactions, and altered ecosystem function. Using locally sourced plants may influence the long- and short-term success of dune restoration.

Invasive Species

The loss of dune habitats to human development means species specialized to these habitats are often already relatively rare. Consequently, the additional threat posed by exotic and invasive species in these habitats is a matter of particular concern. One such species in this regard is Asiatic sand sedge *(Carex kobomugi).* This species first arrived in New Jersey in the early 20th century and has spread rapidly, both through natural propagation and – for a period from the 1960s to the 1980s – deliberate propagation. In recent decades, the expansion of this species has been approximately exponential. For example, in 2008 there were 39.9 acres of dune infested by the sedge at Island Beach State Park – almost exactly double the amount that was present in 2002. Similarly, there were 54 acres of the sedge at Sandy Hook – more than triple the area that was infested in that park in 2002. This sedge grows in extremely dense mats, with stem densities of over 600 stems per square meter and typical densities of 100-200 stems per square meter being observed. These densities are much higher compared to typical stem densities of American beachgrass with 40-50 stems per square meter observed. This dense growth rapidly crowds out other species. This results in the densities of native plants like American beachgrass and goldenrod being significantly reduced wherever the sedge grows. Many native plant species are completely absent from the dune once the

Asiatic sand sedge monoculture. *Louise Wootton photo*

sedge invades. As the invasion matures, the plant forms more or less a monoculture on the dunes (Wootton 2003, Wootton et al. 2005, Burkitt and Wootton 2011). Since native animals did not evolve with the sedge, few will eat it or use it for habitat. Thus, animals that depend on the native dune vegetation are likely to be negatively impacted by the decline in numbers and loss of the native plants from these areas.

Ecosystem resilience is defined as the ability of that system to maintain its function when faced with novel disturbance (Webb 2007). Biological diversity appears to be an important factor in determining the resilience of ecosystems and thus their ability to sustain themselves in the face of environmental challenges. The relationship between diversity and resiliency appears to derive from the apparent redundancy of species within healthy ecosystems (Peterson et al. 1998, Elmqvist et al. 2003). The presence of species with different but overlapping functions within an ecosystem, as well as of species operating at different scales, results in a variety of tolerances and responses to new conditions. The result is that, when diversity levels are high, at least some of the species are likely to be able to thrive and thus to maintain ecosystem services under whatever set of conditions prevail in that area at any point in time. A more biologically diverse ecosystem generally displays more resilience, or a greater ability to overcome a natural disaster or human-caused destruction (Naeem 1998). As previously discussed, invasion by Asiatic sedge decreases both the abundance and the number of native

species (species richness and diversity) that characterize healthy dune ecosystems. Thus, invaded dunes are likely to be less resilient to future environmental changes or other challenges.

Because the sedge is able to grow farther into the beach than American beachgrass, the species also causes problems for beach-nesting birds such as piping plover (federally threatened) and least tern and black skimmer (state endangered). These species will only nest in open sandy areas between the high-tide mark and the vegetated portions of the dunes because the dense vegetation can provide places for their predators to hide. When the sedge pushes into the high beach, the birds will nest farther down the beach, putting their nests at higher risk of being lost to inundation during high spring tides and storms, and creating greater conflict with recreational beach users. In addition, plover chicks are known to use open, sandy corridors between vegetated dunes as pathways to more interior habitat suitable for foraging (Loegering and Fraser 1995). The dense growth pattern of the Asiatic sand sedge leaves few bare areas of dune, which cuts off these pathways for birds to move between habitats, which will further reduce survival of these already endangered species. The sedge can also compete with high-beach plant species such as seabeach amaranth (federally listed) and seaside knotweed (state listed).

As mentioned earlier, dune vegetation plays an important role in maintaining healthy dunes by trapping blowing sand and building the dune. Because the sedge is shorter in stature than native dune plants, it has been suggested that it might scavenge less sand at the front of the dune. Dunes invaded by this species may be wider and lower than dunes where native species thrive (Shisler et al. 1987, Pronio 1989). However, this is not well documented, and at least one recent study (Reo et al. in revision) suggests that dune heights may be similar in invaded dunes versus natively vegetated dunes.

The large-headed sedge *(Carex macrocephala)* has also started to move in to New Jersey's coastal dunes (Wootton 2007). Native to Asia and the Pacific coast of North America, this sedge seems to grow much less aggressively than the closely related Asiatic sand sedge, and thus is less of a threat to this habitat. Other non-native species in the primary dunes include dusty miller *(Artemisia stelleriana),* rugosa rose *(Rosa rugosa),* Russian thistle (*Salsola kali),* and crab grass *(Digitaria sangoinalis).* Dusty miller is a garden escapee species. Its leaves are covered with velvety white hairs that give them a grey green color. Even its yellow flower spikes are coated with a dense mat of white fur. The hairs help to protect the plant from wind, and thus help minimize loss of water to evaporation. Their light color also reflects light, helping to keep the plant cool in the intense heat of the summer. While exotic to New Jersey, this plant doesn't seem to be an aggressive invader of the dunes. Native to Asia, rugosa rose has attractive pink or white, fragrant flowers that are a source of pollen and nectar for a number of insect species, and the red rose hip fruits are a rich source of vitamins and sugars for birds and mammals. While this plant does have desirable properties, it is not as good at stabilizing dunes as the native shrubs that it often outcompetes, and thus is not a particularly desirable species in this community

Large-headed sedge
Louise Wootton photo

Rugosa rose *Louise Wootton photo*

(IPANE n.d.). Little is known about the ecological impacts of Russian thistle or crab grass in New Jersey dunes. However, these species have the potential to be a problem in the future, and their presence on dunes should be noted and monitored as a precautionary measure, especially in areas with known populations of threatened and endangered species.

Although not common on dunes, multiflora rose *(Rosa multiflora)* is of concern in the high dunes and maritime forest, since it is a truly invasive species. Multiflora rose forms dense thickets that exclude native plants through both above- and below-ground competition and can prevent the movement of larger animals. Like most roses, this plant has thorny stems and compound leaves. However, instead of creating individual larger blooms, this species forms clusters of sweet smelling white or pink flowers in summer. These flowers set to form small red fruits that are eaten by birds, spreading the plant to yet more habitats.

Within the maritime forest a few tree species, such as European privet *(Ligustrum vulgare)*, Japanese black pine, and autumn olive *(Elaeagnus umbellata)* can become invasive, outcompeting native tree species. However, it is the invasive vines that tend to be more problematic. Some common invasive vines include Japanese honeysuckle (*Lonicera japonica),* English ivy *(Hendera helix),* oriental bittersweet *(Celastrus orbiculatus),* and virgin's bower clematis *(Clematis flammula).* These vines smother the trees they climb, pulling down branches, and can lead to the entire tree being vulnerable to falling during wind events. They also create shade on the forest floor below, which can inhibit growth of native understory plants and germination and growth of seedlings of native trees. Other species such as garlic mustard *(Alliaria petiolata)* and porcelain berry *(Ampelopsis brevipedunculata)* invade the forest floor, competing directly with the native plants and tree seedlings.

Human Impacts on Dunes

In 2000, New Jersey had the highest population density among the 50 states – 1,195 persons per sq mi in 2010 (NJ State Library 2012). The desirability of scenic ocean views combined with the high human population densities on the Atlantic Coast mean that coastal dunes and their associated maritime forests have been particularly impacted by development. Only 31.2 of the 130 miles of shoreline between Sandy Hook and Cape May Point have not been developed by humans (Farrell et al. 2013). Since many of the plant and animal species found in these habitats are found nowhere else, and often cannot survive in areas impacted by human development, contraction of these habitats means that those species are becoming increasingly rare.

Another way humans can impact dunes is through foot and vehicular traffic. Many coastal recreational activities require travel across or near dunes. Bathers, beach fishermen, bird watchers, and many others are drawn to these areas for recreation. As noted earlier, many of the dune species are highly intolerant to compaction from vehicular or foot traffic. Thus, even in protected habitats, humans are at risk of irreparably damaging the specialized organisms that live in these areas through their activities. Driving, raking, or walking near the toe of the dune must be strongly restricted since this can prevent the normal and healthy expansion of dunes into the high beach, as well as potentially damaging or killing rare and endangered species such as seabeach amaranth growing there. Movements across the dunes should be limited to designated pathways, and despite the human desire to shorten the route toward any destination, these paths should not run perpendicular to the ocean, since such pathways form funnels for the ocean's energy, promoting erosion of dunes and flooding of the communities behind them. Education and outreach programs as well as policing of dunes are needed to limit people's movements to designated pathways and to keep traffic away from the active dune front. As mentioned earlier, use of off road vehicles and mechanical beach rakes should also be avoided.