Coastal Habitats
5. Dune Restoration

DEFINITION

Coastal dunes are large mounds of sand deposited on the landward side of a beach. Dune formation is reliant on coastal winds blowing in the onshore direction, allowing the sand to accumulate when it encounters an obstacle on the beach (Bralower et al. n.d.). Coastal dunes can be classified into *primary* and *secondary* dunes. Primary dunes are created by direct sand supply from the beach while secondary dunes are formed from alterations to the primary dunes and are located further landward. The highly variable processes of sand deposition, accretion, and erosion result in a diversity of dune morphologies, including blowouts, foredunes, parabolic dunes, and dune fields (Sloss et al. 2012). Dune vegetation, which often forms symbiotic relationships with fungi, helps stabilize the sand and reduce dune erosion (Charbonneau et al. 2016). Coastal dunes face threats from increased urbanization, beach erosion, conversion into developed areas, and shoreline hardening (Carboni et al. 2009). Dune restoration helps stabilize dunes to protect the valuable ecosystem services they provide. The most common dune restoration techniques include dredging sand to build up the dune, planting grasses, and installing fencing around the dune (Olander et al. 2021).

TECHNICAL APPROACH

Despite the constantly changing nature of coastal dunes, dune restoration aims to stabilize dunes by facilitating natural dune creation processes (UNH 2023). Dune restoration differs from beach nourishment in that it builds sand up vertically instead of horizontally. These techniques can be applied to already-existing dunes or can be used to build dunes from scratch. While each of the following techniques can be applied independently, the most successful projects combine multiple techniques (Olander et al. 2021).

1. **Building up dunes with sand:**
    - **Dredging sand:** Dredging sand from offshore sources and transporting it onto the beach via piping is a common dune restoration technique. Similar to beach nourishment, this method of dune restoration is dependent on the source sediment having similar qualities to the sediment on the dune (Nordstrom and Jackson 2021). In many aeolian (wind) regimes, high rates of erosion will require periodic renourishment to maintain the dune (Speybroeck et al. 2006). Dredging sand from offshore is only economically viable for large projects given the high cost of mobilizing a dredger, which can range from $500,000 to $1 million (Dean 2002). To reduce the environmental impacts of dredging and save costs, using sediment already being dredged to deepen channels is recommended. Called *beneficial use of dredged material*, this practice diverts dredged sediment from ending up in a landfill while creating a dune habitat (USACE n.d.).

- **Placing sand using heavy machinery:** For projects where dredging sand from offshore is impractical but sand nourishment is still needed because of a lack of natural sand deposition, placing sand using heavy machinery is an alternative. Sand mined from inland sources and taken to the restoration site can be used (Dobkowski 1998). It is not recommended that sand be extracted from adjacent beach areas, as this would alter sediment deposition patterns and disturb the long-term health of the coast (NCRS 2011). Once the sand has arrived at the beach, heavy machinery is used to sculpt the sand into a dune shape. Then, a small layer of natural dune sand, 3 to 6 in. thick, is placed on top of the imported sand (O'Connell 2008).

2. **Removing invasive species:** Many invasive species can be found on dunes, outcompeting native species, and causing a decline in biodiversity. While some invasive species were introduced to help stabilize dunes, their presence has altered natural sand flow processes. Although manual removal of invasive species is ideal, it is costly and labor intensive. Other control strategies include herbicide application, prescribed burns and burying invasive plants with excavators (Pickart et al. 2021). Common invasive species in dune ecosystems include European beachgrass (*Ammophila arenaria) on the West Coast, Asiatic sand sedge (Carex kobomugi) on the East Coast, and coastal she-oak (Casuarina equisetifolia*) on the Gulf Coast (Charbonneau et al. 2016; Pickart et al. 2021; NatureServe 2022).

3. **Planting dune grasses:** Dune grasses are critical for stabilizing the sand in the dune and supporting biodiversity (Johnston et al. 2023). Planting dune grasses is challenging because of the harsh and windy conditions. To establish a stable environment, placing mechanically crimped straw or biodegradable netting over straw provides a substrate for the plants to establish on (Pickart 1988). Planting design should mimic the natural dispersal of plants on nearby dunes, with clumped and dispersed planting designs displaying highly variable success rates based on their location (Woods et al. 2023). Plants can either be purchased as plugs (young plants grown in individual containers) or transplanted from nearby healthy dunes. Hand planting is recommended for areas with steep slopes, but tractor-drawn planters can be used in flatter areas (Figure 1; NRCS 2011). The species planted will differ by region, with the most common plantings being American beachgrass (*Ammophila breviligulata*) and sea oats (*Uniola paniculate*) on the East Coast, bitter panicum (*Panicum amarum*) and gulf cordgrass (*Spartina spartinae*) on the Gulf Coast and American dune grass (*Leymus mollis*) and beach bur (*Ambrosia chamissonis*) on the West Coast (Woods et al. 2023; Pickart 1988; Johnston et al. 2023; NRCS 2011). Planting later successional species may be a more effective way to stabilize the dune (Charbonneau et al. 2016).

4. **Installing fences around the dune:** Sand fencing helps trap sand deposited by the wind, building up the dune (Figure 2; NCCOS 2020). Sand fences lead to a shorter and wider dune complex compared to naturally occurring dunes, meaning that it may not be the appropriate intervention based on the desired dune morphology (Itzkin et al. 2020). Many projects only install fencing on three sides of the dune, leaving the seaward side unfenced to allow sand to blow into the dunes (Johnston et al. 2023). The type of fence used varies, but generally wood or plastic fencing ranging from 2 to 4 ft will suffice (OCRM n.d.). The fences must be secured in the dune to withstand

Figure 5.1 Planting dune grasses in Florida

Photo courtesy US Department of the Interior

Figure 5.2 Sand fencing on dunes in Alabama

Photo courtesy Alabama Extension

wind and erosion, with a minimum depth of 4 ft underground (O'Connell 2008). Fence placement is important, as the fences should be positioned beyond the range of storm tides but seaward of the toe of the dune scrap (OCRM n.d.). Multiple rows of fences can be used to increase stability (O'Connell 2008). Periodic breaks in the fencing should be considered to allow for the movement of sea turtles and other wildlife. In addition to aiding in sand accretion, fencing also limits pedestrian access to the dune (OCRM n.d.).

5. **Reducing beach grooming:** Beach grooming is when tractors grade the sand on beaches to smooth out any holes or debris. This practice is common on many urban beaches and improves the conditions for beach recreation. However, beach grooming is detrimental to beach biodiversity, with grooming eliminating wrack (clumps of seaweed) and the coastal strand zone from the beach (Dugan and Hubbard 2010). A form of passive restoration is to cease beach grooming and install sand fencing, allowing the dune to regenerate naturally. A buffer zone of around 4 to 5 m is recommended between grooming activities and the dune restoration site (Johnston et al. 2023).
6. **Avoid adverse impacts from beach access:** Pedestrian access boardwalks through the dune restoration site are critical to protecting the dune while maintaining public beach access. Boardwalks should be sited in a way that does not damage the dunes or require the movement of sand (OCRM n.d.).

OPERATIONS AND MAINTENANCE

Operations and maintenance of a dune restoration project is estimated to cost $100 to $500 per linear foot per year (NOAA 2020). This includes regular invasive species removal, restricting beach grooming, and inspecting and repairing sand fences and boardwalks after severe storms. In dry climates, dune plants may need to be watered. In areas with high erosion rates, sand may need to be added to the dunes periodically.

FACTORS INFLUENCING SITE SUITABILITY

- ✓ **Near existing dunes:** Existing natural dunes will give the new dunes greater protection from the elements as the plants get established on the new dune. Redundant dunes help increase the protection of inland development. This also works with landward beach migration resulting from sea level rise (O'Connell 2008).
- ✓ **As far as possible away from mean high water:** Building the dune further inland gives it greater protection from tidal erosion. It also prevents the vegetation from becoming inundated (O'Connell 2008).
- ✓ **Parallel to the beach berm:** The *beach berm*, or flat part of the beach, provides a buffer that absorbs wave energy and tidal fluctuations. Placing dunes parallel to the beach ensures that all of the beachfront receives similar levels of protection (Kidd 2001).
- ✓ **Straight morphology:** While natural dunes can have a variety of morphologies, restored dunes tend to have a straight, linear morphology (Nordstrom et al. 2000). Additionally, too many bends in the dune adds to fencing costs (Kidd 2001).

- ✓ **Windy conditions:** Dunes need wind to transport sand from the beach. A lack of wind will result in dunes being replaced by scrubland, as dune grasses need open and mobile conditions to compete (Pye et al. 2014).
- ✗ **Adjacent to seawalls, bulkheads, and groins:** Seawalls, bulkheads and groins cause erosion in adjacent areas. Additionally, hard shoreline armoring reduces sediment transport, making it difficult to build up a dune (McKann et al. 2021).
- ✗ **Heavy pedestrian or vehicle traffic:** Unofficial pedestrian or vehicle trails create gaps in the dunes. During a severe storm, these gaps may be exploited by a storm surge and cause a blowout, washout, or washover (McKann et al. 2021).
- ✗ **High grazing pressure:** Vegetation helps hold down the sand in the dune; a loss of vegetation from grazing can cause erosion. It is difficult to get vegetation to grow back under harsh conditions (McKann et al. 2021).
- ✗ **Major inflections in the seaward face of the dune:** Inflections in the seaward face of the dune will cause the wind to eddy and remove sand, facilitating erosion (Kidd 2001). If a natural dune shows this characteristic, it can be addressed in the restoration project design.
- ✗ **Narrow beaches:** Narrow beaches will not have enough space for both the beach berm and the dune. This will either cause the landward migration of the dune into upland (usually developed) areas or erosion of the dune from tidal exposure.
- ✗ **Arid regions:** Dune plants need a baseline level of precipitation to survive. This barrier can be outcome with intensive irrigation and fertilization.

TOOLS, TRAINING, AND RESOURCES FOR PLANNING AND IMPLEMENTATION

Name and Link	Resource Type	Year	Authors/ Authoring Organization	Geography	Description	Resource Includes: Design/Construction Guidance?	Site Selection?	Monitoring Guidance?	Example Projects?
Beach and Dune Restoration	Guidebook	2022	Karl Nordstrom and Nancy Jackson	Global	This guide is a compilation of dune restoration knowledge, covering specific techniques as well as project planning and stakeholder engagement. Chapters three through eight are especially relevant to dune restoration practitioners.	✓	✓	✓	✓
Foredune Restoration in Urban Settings	Book chapter	2013	Karl Nordstrom and Nancy Jackson	National	Incorporating the natural dynamism in dune ecosystems into restoration projects is covered in the chapter, in addition to specific techniques. The authors also discuss the benefits involved with dune restoration and balancing restoration with recreation.	✓	—	✓	—
Coastal Dune Protection and Restoration	Guidebook	2008	Woods Hole Oceanographic Institution	East Coast	This guide covers the main dune restoration techniques as well as helpful graphics to visualize the restoration process. Additional topics covered include maintenance, conserving shorebird habitat, and managing pedestrian use.	✓	—	—	✓
Coastal Dunes: Dune Protection and Improvement Manual for the Texas Gulf Coast – 6th edition	Guidebook	2021	Texas General Land Office	Gulf Coast	Focusing on the role that dunes play in the larger coastal system, this guide details the techniques of dune construction, improvement, and repair. A special emphasis is placed on maintaining beach access, including the construction of dune walkovers.	✓	✓	—	✓

Name and Link	Resource Type	Year	Authors/ Authoring Organization	Geography	Description	Resource Includes: Design/Construction Guidance?	Site Selection?	Monitoring Guidance?	Example Projects?
Coastal Shoreline and Dune Restoration: Plant Materials Technical Note	Document	2011	Natural Resources Conservation Service (US Department of Agriculture)	Gulf Coast	This technical note gives information about planting designs, the qualities of dune species and planting techniques. Additional topics covered include fencing installation and site management.	✓	—	—	—
Sand Dune Conservation, Restoration, and Management	Guidebook	2013	J. Patrick Doody	Global	Covering the ways in which human activity has altered sand dunes, this book gives a comprehensive overview of the geomorphic, policy, and ecological considerations that impact dune restoration. The authors also cover best management practices, invasive species, and interactions between dunes and the urban environment.	✓	✓	✓	✓
Reestablishing Naturally Functioning Dunes on Developed Coasts	Journal article	2000	Karl Nordstrom, Reinhard Lampe, and Lisa Vandemark	East Coast	The authors discuss how the built environment of the coast interacts with dunes. Additional topics covered include increasing dune longevity, site selection, spatial arrangement of dunes, and protecting target species.	✓	—	—	✓
Hawai'i Dune Restoration Manual	Guidebook	2022	University of Hawai'i Sea Grant College Program	Designed for Hawai'i but most of the information is more broadly applicable.	This guide covers all the main facets of dune restoration, including invasive species removal, constructing boardwalks, and rebuilding dunes. The authors also include a troubleshooting section, monitoring advice, and information about the relationship between dune restoration and beach nourishment.	✓	✓	✓	✓

Name and Link	Resource Type	Year	Authors/ Authoring Organization	Geography	Description	Resource Includes: Design/Construction Guidance?	Site Selection?	Monitoring Guidance?	Example Projects?
Dune Manual	Guidebook	2016	New Jersey Sea Grant Consortium	East Coast	Covering dune ecology and engineering, this guide gives specific instructions for restoring both front and back dune ecosystems. Additional topics covered include season variability, dune breaches, Federal Emergency Management Agency (FEMA) dune standards, and invasive species.	✓	✓	—	—

GRAY INFRASTRUCTURE ALTERNATIVES

Dune restoration can be an alternative to several gray infrastructure approaches designed to reduce coastal properties' risk of flooding and erosion: bulkheads, riprap/revetments, seawalls, groins, and artificial breakwaters. The ability of a dune restoration project to replace or supplement one of these gray infrastructure types depends strongly on the project's location and whether it is designed to create the necessary outcomes. Certain environmental conditions may require gray infrastructure rather than dune restoration. See the gray infrastructure alternative tables in Section 1 for a comparison of dune restoration to these alternatives.

LIKELY BENEFITS AND OUTCOMES

Primary objectives for each strategy are highlighted.

Climate Threat Reduction

- **Storm protection:** During severe storms, dune vegetation can reduce wind speeds, attenuate waves, and lessen the wind-driven erosion of sediment. Dune vegetation develops extensive root systems; this underground biomass is critical to maintaining the dune under pressure. Eroded dunes are more likely to experience overwash, whereas waves generally collide with and do not overtop intact dunes (Bryant et al. 2019).

- **Reduced flooding:** Dunes are highly effective at repelling coastal floodwaters. While the magnitude of this benefit may depend on the height and width of the dune field and its proximity to the ocean, strong vegetation can preserve a dune during storm surges. Dunes can dissipate floodwater energy and thus protect landward properties (Fernández-Montblanc et al. 2020).
- **Sea level rise adaptation and resilience:** While dunes cannot stop sea level rise, they are able to better prepare coasts to withstand it. Dunes can catch sand from the wind, building up dune height and width and fostering accretion. The increased elevation adds further protection (Aerts et al. 2018). Dunes are also highly mobile, allowing them to migrate landward as sea level rise intensifies.
- **Carbon storage and sequestration:** While dune ecosystems do not store as much carbon as other ecosystems, they still have a role to play in combatting climate change (Jones et al. 2008). Dune ecosystems can rapidly sequester carbon because of their nature as an early succession ecosystem. Dune soils have a high concentration of carbonate, storing carbon in the sand. Heavily vegetated dunes store more carbon than barren ones, an important consideration for management.

Social and Economic

- **Property and infrastructure protection**: Higher dunes protect inland properties and infrastructure from erosion, flooding, sea level rise, and extreme storms. Unlike many gray infrastructure approaches that accelerate erosion in adjacent areas, dune restoration provides the same protection without the erosion risk (Komar and Allan 2010). Many dune restoration projects are designed to buffer infrastructure, such as coastal highways. Dunes were successful at limiting damage to infrastructure even in extreme weather conditions, such as Hurricane Sandy in 2013 (USACE 2013).
- **Reduced erosion:** Restored dunes are effective at reducing beach erosion. Dune vegetation forms a symbiotic relationship with mycorrhizal fungi, which helps the plant develop strong roots that reduce erosion. Dunes also prevent water from reaching areas further upland, limiting erosion there (Sigren et al. 2014).
- **Increased property values:** Dune restoration reduces erosion, protecting coastal properties and thus increasing their value. However, complaints that higher dunes block beach views lead some to argue that dune restoration does not increase property values (Olander et al. 2021). As awareness increases about the benefits of nature-based solutions (NBS), it is likely that dune restoration will result in an increase in property value (Mutlu et al. 2023).
- **Reduced or avoided costs:** Dune restoration projects can help adjacent property owners save money on their flood insurance through FEMA's Community Rating System (CRS) program. The CRS rating system rewards communities that complete projects to reduce flood risk, including dune restoration. This incentive often helps generate public support for dune restoration projects (Young and Clark 2015). Dunes can also trap and store sand, allowing them to supply sand to eroded beaches in the future. This is especially important as hardened coasts disrupt natural sediment transport processes. Dunes can serve as a sand bank and reduce the need for nearby beach nourishment projects (Hoonhout and de Vries 2019).

- **Jobs:** Contractors will need to be hired to perform the restoration activities, boosting the local economy.
- **Mental health and well-being:** Dune restoration preserves access to intact beaches, improving residents' mental health and psychological well-being.
- **Cultural values:** Dunes are valuable cultural resources, inspiring art and spiritual values (Richardson and Nicholls 2021).

Ecological

- **Enhanced biodiversity:** Beach berms and groomed beaches generally have low levels of biodiversity because of the lack of shelter and high levels of human disturbance on the open beach. Replacing an open beach with a vegetated dune can significantly restore biodiversity by reintroducing habitat (Johnston et al. 2023). Furthermore, invasive species removal as a part of restoration can also enhance biodiversity. Planting a diverse set of species allows for more interspecific interactions to occur, luring additional species to the site (Pickart 2021).
- **Increased primary productivity:** Planting vegetation on a dune spurs rapid growth, which boosts primary productivity. Once the original plants become established, more plants will naturally colonize the dunes and increase the overall biomass of the ecosystem (Sigren et al.2014).
- **Reduced runoff:** Dunes receive a large amount of surface water, both from tidal exchanges and overland runoff. Dunes facilitate the infiltration of surface water back into the ground, reducing runoff (Bridges et al. 2015).

BARRIERS AND SOLUTIONS FOR PRACTITIONERS

Common Barriers

Several barriers are common across many of the NBS strategies; these are described in more detail in Section 1 of the Roadmap. Additional notes about the barriers specific to dune restoration are included here.

- **Expense:** As sea levels continue to rise, the beach and dune ecosystems must either move inland to survive or be submerged. Often, high-priced coastal real estate is located directly inland of dunes, generating significant opposition to moving or restoring dunes. Past managed retreat initiatives have achieved only limited success in acquiring coastal properties because of high costs (Vandemark 2000).
- **Capacity**
- **Public opinion**
- **Conflict with other land uses:** Beach grooming prevents dunes from forming by eliminating topographic changes in the beach, reducing wrack and inhibiting vegetation growth (Dugan and Hubbard 2010). However, beach grooming is essential to attracting tourists to a beach, with many visitors desiring a certain beach aesthetic

not compatible with dune restoration (Nordstrom et al. 2000). Finding compromises to restrict beach grooming around restoration sites is critical to a successful project (Johnston et al. 2023).

- Regulation
- Lack of effectiveness data

Economic

- **Cost of sediment:** Sediment used to restore a dune needs to be compatible with the natural beach sand in terms of grain size and color. However, sediments that meet these criteria may not be located nearby, adding high transportation costs to the project. Sediment is a nonrenewable and highly valuable resource, making it difficult to procure (Palaparthi et al. 2022). Furthermore, dune restoration projects often compete with beach nourishment projects for the same sediment sources. Collaborating with already-planned dredging projects for a beneficial use of dredged material is a way to overcome this barrier (USACE n.d.).

Community

- **View obstruction:** There are numerous lawsuits claiming that dune restoration projects have obstructed the view from an oceanfront property. While higher dunes protect these properties, they also block scenic ocean views, which angers some property owners (Olander et al. 2021).
- **Construction disruption:** Construction on dunes may impact access to nearby beaches for recreation. This will impact the local economy which is often highly dependent on tourism revenue. To mitigate this disruption, construction could be scheduled for the offseason when fewer visitors are present (Olander et al. 2021).
- **Off-road vehicle (ORV) use:** ORVs have deleterious impacts on dune health, with ORV tracks causing dune degradation. Studies have shown that ORV use causes a decline in native species and species richness, opening the door to invasive species to recolonize the dune (Hogan and Brown 2021). ORVs should be prohibited from the restoration site to increase the likelihood of a successful project.
- **Limited beach access:** Beach access paths create gaps in the dunes, increasing the risk for overwash and dune erosion during severe storms. Sand paths have a greater impact on dunes than wooden boardwalks (Purvis et al. 2015). However, financial constraints mean that wooden boardwalks can only be built in a limited number of locations, reducing beach access.
- **Temporary increase in flood risk:** While invasive species are detrimental to the ecology of dunes, they are effective at anchoring sediment. Invasive species allow dunes to grow in height and stability, reducing erosion and increasing coastal flood protection. When invasive species are removed as part of a dune restoration project, their ability to repel floods ceases as well. Once established, native plants will have the same coastal defense properties, but it may take a few years before the vegetation cover reaches its previous extent (Biel et al. 2017).

Ecological

- **Different morphology than natural dunes:** Restored dunes are generally smaller and more linear than natural dunes. Restored dunes also exhibit lower species diversity than natural dunes. This means that the benefits of dune restoration may be less impactful than conserving natural dunes (Nordstrom et al. 2000).
- **Degradation of sediment source habitat:** Sediment for dune restoration is generally extracted via dredging from the bottom of a channel. This process has many negative environmental impacts, including increasing suspended sediments, turbidity, and siltation rates. Excess sediment in the water disrupts the ecology of coral reefs, seagrasses, and estuaries, contributing to their decline (van Maren et al. 2015).
- **Drought:** In arid regions, dune plants often struggle to establish due to a lack of rainfall. Therefore, most dune restoration projects are limited to areas that receive more rainfall or require irrigation to help the plants survive. Another solution to increase plant survival is to use jellyfish biomass as fertilizer, partnering with local invasive jellyfish removal projects (Emadodin et al. 2020).

EXAMPLE PROJECTS

Name and Link	Location	Leading Organizations	Techniques Used	Size	Cost, $	Duration	Project Description	Climate Threats Targeted	Lessons Learned or Adaptive Management
Santa Monica Beach Restoration Pilot Project	Santa Monica, CA	The Bay Foundation, City of Santa Monica, California Department of Parks and Recreation, University of California Santa Barbara	Installed sand fencing, planted native plants, and ceased beach grooming	3 acre	300,000	Not provided	On a heavily groomed urban beach, workers used sand fences and native plants to create a small dune complex. The site was used as a breeding ground for the endangered western snowy plover (*Charadrius nivosus nivosus*).	Sea level rise, increased storm severity	The project was well-received by the community and an additional 5 ac of dune will be restored nearby.
Cape Lookout Dune Restoration Project	Cape Lookout State Park, OR	**US Geological Survey,** Oregon State Parks, Oregon State University, Oregon Department of Geology and Mineral Industries	Cobbled berm construction, increasing dune elevation with geotextile bags, sand nourishment, installing native plants	1 acres	125,000	4 months	Workers constructed a cobbled berm and artificial dunes to help protect a nearby campground and road. The dunes were made of geotextile bags and sand and stabilized with native plants.	Sea level rise, severe storms, coastal flooding	Extreme waves overtopped the entire length of the dune, inflicting minor damage on the structure. To prevent this from happening again, the dunes will be elevated and potentially moved further inland.

Name and Link	Location	Leading Organizations	Techniques Used	Size, acres	Cost, $	Duration	Project Description	Climate Threats Targeted	Lessons Learned or Adaptive Management
Flagler Beach Dune Restoration Project	Flagler County, FL	US Army Corps of Engineers, Flagler County	Sand nourishment, installing native plants	2.6 linear mi	35 million	6 years (ongoing)	After Hurricane Matthew destroyed the natural dunes and a major coastal highway, leaders decided a dune restoration project was needed. Additional sand is being placed on the dunes, which will then be covered by native plants.	Sea level rise, severe storms, coastal flooding	The project has encountered numerous setbacks, including operations being disrupted by successive storms and ballooning costs. The elongated project timeline is a result of work stoppages during sea turtle nesting season.
Abbots Lagoon Coastal Dune Restoration Project	Point Reyes National Seashore, CA	**National Park Service**	Mechanical removal of invasive European beachgrass (*Ammophila arenaria*) and ice plant (*Carpobrotus* spp.)	120 acres	3.24 million	7 months	Contractors mechanically removed the invasive species by burying them 6 to 9 ft under the sand. After the invasive species were removed, native plants recolonized the dune.	Sea level rise	After restoration was completed, invasive species still recolonized some areas. These plants were then treated with herbicide and mowed.
Duxbury Beach Crossover 1&2 Dune Restoration Project	Duxbury, MA	Duxbury Beach Reservation, Inc., Woods Hole Oceanographic Institute	Sand fencing, sand nourishment, planting native species	38 acres	1.4 million	4 months	Contractors built up the dune by transporting sand quarried inland via truck to the site. Next, sand fences were installed, and native vegetation was planted, including American beachgrass (*Ammophila breviligulata*).	Coastal flooding, severe storms	The project was scheduled to avoid disturbing nesting seasons for shorebirds.

Name and Link	Location	Leading Organizations	Techniques Used	Size, acres	Cost, $	Duration	Project Description	Climate Threats Targeted	Lessons Learned or Adaptive Management
McFaddin Beach and Dune Restoration Project	McFaddin National Wildlife Reserve, TX	**US Fish and Wildlife Service,** National Oceanic and Atmospheric Administration, Texas Commission of Environmental Quality, Texas General Land Office, Texas Parks & Wildlife Department	Sand nourishment, planting native vegetation	17 linear mi	87 million	16 months (ongoing)	Sand is being dredged offshore and piped to the restoration site. After the sand is graded, then contractors will plant native vegetation. The project will protect the valuable salt marsh ecosystem that lies behind the dune.	Coastal flooding, sea level rise, increasingly severe storms	A smaller 2017 pilot project helped planners hone the best restoration strategies for this immense project.

Bolding indicates DOI affiliates.

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