BEST MANAGEMENT PRACTICES FOR SHORELINE STABILIZATION TO AVOID AND MINIMIZE ADVERSE ENVIRONMENTAL IMPACTS

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Shoreline stabilization projects can cause significant adverse environmental impacts to the coastal ecosystem. By incorporating conservation measures into a project during the planning, design, construction, and post-construction phases, many of the potential adverse environmental impacts can be avoided and minimized. This paper outlines best management practices (BMPs) that can be utilized as conservation measures to avoid, minimize, and mitigate adverse environmental impacts from shoreline stabilization projects. The first approach that best avoids and minimizes adverse environmental impacts from shoreline management is to "do nothing" and retreat roads and structures away from the shorelines as sea level rises and climate changes, and to prevent new development in naturally hazardous or migrating areas. Where shoreline stabilization *is* proposed, BMPs are presented in sections for dune, beach, nearshore, offshore, inlet and estuarine habitats, and an adaptive management framework is presented for project management (i.e., operations and maintenance) and issues relating to climate change and rising sea level. A glossary is included for key words and an extensive bibliography summarizes the scientific literature that provided scientific background and data in the development of these BMPs as conservation measures.

SECTION I: DUNES

Artificial dunes should not be constructed by heavy equipment (i.e., bulldozers) by scraping the beach for sediment or through the addition of beach fill material mined elsewhere and pumped or hauled to the beach. Artificial dunes are typically constructed in continuous ridges that act like levees or dikes to protect inland areas from flooding and overwash, but they do not function like natural dunes or possess the same ecological services.

Wherever and whenever possible, new dunes should be created through the planting of native vegetation to trap natural windblown sediment. In undeveloped areas especially, vegetation alone should be used so that the resulting dunes are the most natural in size, shape and location, and to mimic natural dune development and growth processes (e.g., upward and lateral growth over time). Vegetation builds better dunes in the long-term (albeit after a short time lag) and maintenance is nearly nonexistent, avoiding environmental impacts after the initial installation.

In highly developed areas and on a small scale, the judicious use of sand fencing could be used as long as appropriate maintenance and removal provisions are undertaken and enforced. For example, fencing should be raised periodically to keep pace with incipient dune growth and should be removed once the new dunes are a few feet tall (e.g., less than 3 feet) or after 18 months have passed so that damage caused by the removal to the surrounding environment is minimized; native plants can then be planted at grade to facilitate further dune growth. Sand fencing materials should never be left on the beach, buried under dunes, as it poses a hazard during storms and will become exposed as dunes migrate or are eroded by storms. Multiple rows of sand fencing should not be used, as they do not mimic natural dune development and growth processes, hinder the movement of wildlife and people, and limit the fetch with which supplemental rows can trap windblown sand.

Sand fencing should not be continuous but should be intermittent to allow passage for people, nesting and hatchling sea turtles, unfledged shorebird and waterbird chicks, and other wildlife that move between the dune line and the rest of the beach. Fencing should be placed perpendicular to prevailing wind directions to best trap naturally blowing sediments. Protective buffers of at least 100 – 180 meters (m) should be maintained around known locations of sensitive or listed wildlife and at least 10 m around sensitive or listed plant species so that fencing and the installation process does not trample or harm nests or vulnerable plant species. Sand fencing should not use materials that create perches for avian predators near known bird nesting areas and should be configured and oriented in accordance with existing guidelines to protect listed species such as sea turtles.

Vegetation plantings on existing or new dunes should consist of native species that reflect the local plant communities for the planting zone (e.g., foredune, dune face, dune crest, back of dune). Botanical surveys should be taken prior to the planting of any vegetation to identify the local plant community assemblages, and where possible historical records should be reviewed to ensure that only plants native to a specific barrier island or beach are used. For example, if historic records indicate that a threatened or endangered species used to occur on a particular beach and is now locally extirpated, it could be reintroduced.

Vegetation should be locally grown, where possible, and not harvested from wild stock unless the plants are being transplanted from an area where they would otherwise be destroyed by a development or construction project or where harvesting will not adversely affect local populations. Plantings should not be a monoculture but instead a diverse assemblage that reflects the local plant community type(s). Plants should not be planted on a regular spacing with rows but instead should be more random and reflect their natural spacing(s), which should be identified during the botanical survey. Long-term fertilization with nitrogen should not be conducted in order to avoid long-term alterations to species diversity, composition and density (Day et al. 2004).

When using sand fencing or vegetation to restore or create new dunes on a large scale, a geomorphological survey of the barrier island or beach (or a nearby undeveloped, natural area if the project beach is developed) should be conducted prior to action in order to identify the existing, undisturbed dune morphology for replication. The dune length, height, and width; number of dune ridges and their spacing(s); whether wetland swales are present; and the spacing of natural gaps should all be identified. These factors should guide the design of fencing and/or vegetation placement so that any restored or created dunes should blend seamlessly with the existing environment. If the project area is developed and a nearby natural area is utilized as a design model, the surveys should utilize areas in a state as close to the project area as possible; for example, a natural area of heavily vegetated, mature dunes would not be appropriate as a model for a project area devoid of any dunes or vegetation. Rather, incipient dunes and pioneering vegetation would be the more appropriate model.

In all cases, overwash should be allowed to continue unimpeded, including in dune gaps. Off-road vehicle (ORV) traffic should be prohibited on and in between dunes.

Pedestrian traffic should be encouraged to use dune crossovers or designated pedestrian paths to avoid disturbing the dune ecosystem, particularly in areas that host vulnerable species such as nesting birds, beach mice and listed plants.

Beach access points should not be cut into existing dunes but should utilize dune crossovers and boardwalks that avoid disturbing the dune system. Access points should not be located in areas with known wildlife nesting or breeding areas, such as remnant early successional habitats, dune blowouts and overwash areas, in order to avoid impacts to vulnerable or sensitive wildlife and vegetation. Access points should not align with streets or driveways that are perpendicular to the beach, as they can funnel flooding and overwash farther inland than would naturally occur, potentially damaging property and facilitating island breaches.

SECTION II: BEACHES

Hard stabilization should only be used in cases where extreme development has occurred on a shoreline, such as in highly urban areas like Manhattan. Where hard stabilization (e.g., seawalls, bulkheads, revetments, riprap, sandbags, groins) is installed, the eventual loss of the beach and its associated habitats is virtually assured. Therefore, if and when new hard stabilization is justified, a thorough environmental impact statement (EIS) should be prepared and mitigation for the loss of ecosystem services and habitat should be incorporated into the project design. Mitigation measures can include the removal of hard stabilization structures in other nearby locations, the relocation of buildings and structures that are impeding the natural landward migration of the beach system as sea levels rise, or the restoration of beaches where they have been historically lost to shoreline stabilization.

Soft stabilization (i.e., "beach nourishment") causes significant adverse environmental impacts and likewise should only be undertaken after a thorough EIS has been prepared. The design of a beach fill project should incorporate empirical evidence on the performance of other nearby beach fill or dredged material disposal projects; for example, if a nearby beach fill project typically 'disappears' or erodes within 3 years, the engineering design of a new project should not realistically assume that the new project will last 5 to 7 years before requiring "maintenance" with more "renourishment." Emergency "berms" should be considered beach fill projects and be subject to the same BMPs or conservation measures as a planned fill or dredge disposal project; the only difference between an emergency berm project and a planned beach nourishment project is the level of planning and consultation involved.

Where a beach fill or dredged material disposal project is proposed, the new sediment must be compatible with the native sediment on the existing beach. Visitors and wildlife should not be able to distinguish the fill material from the existing native beach material in color, grain size, mineralogy, compaction, or any other characteristic. The native beach sediments should be sampled and analyzed at the dune, across the berm, in the surf zone, and the nearshore before any project is undertaken. The fill material should also be sampled periodically during construction, especially in areas with sensitive plants or wildlife, to catch any incompatible or unexpected material as soon as possible. Comparison of the native sediments to the proposed fill material should be conducted prior to construction, with compatible material defined as:

1. Material consisting solely of natural sediment and shell material, containing no construction debris, toxic material or other foreign matter;
2. Material consisting predominantly of quartz, carbonate (i.e., shell, coral) or similar material with a particle size distribution ranging between 0.0625 millimeters (mm) and 4.76 mm, classified as sand by either the Unified Soils or Wentworth classification systems;
3. Material similar in color and grain size distribution (sand grain frequency, mean and median grain size and sorting coefficient) to the native material in the project area;
4. Material containing less than or equal to 2 % fine-grained sediment (< 0.0625 mm, considered silt, clay and colloids) by weight, unless sufficient sampling of the project area indicates that the native sediment grain size distribution contains > 2 % fine-grained material, in which case compatible material should be considered the percentage of fine-grained native material plus no more than an additional 2 % by weight;
5. Material containing coarse gravel, cobbles or material retained on a ¾ inch sieve in a percentage or size not greater than found on the native beach;
6. Material that does not result in cementation of the beach; and
7. Material that does not contain carbonate (i.e., shell) material that exceeds the average percentage of carbonate material on the native beach by more than 15 % by weight.

The overall volume of fill material to be added to the beach in any fill episode should not exceed 50% of the estimated annual net sediment transport for the beach in order to minimize the magnitude of the disturbance to the ecosystem and to prevent large-scale alterations of the local coastal processes.

The beach fill design that avoids the most adverse environmental impacts to the beach is probably the one began in 2004 at Assateague Island National Seashore in Maryland, where sand bypassing at the adjacent inlet is conducted by using a shallow hopper dredge to place fill only in the nearshore environment, as close to the beach as possible. As the hopper slowly dumps its fill, the dredge moves closer to shore as its load lightens. No fill is placed on the subaerial portions of the beach, avoiding impacts to those habitats and their resident and migratory wildlife and plants. Impacts will still occur on nearshore habitats, however.

Where beach fill is proposed for the subaerial portions of the beach, the design template should replicate the natural, existing beach profile, including any bar and trough morphology. Several small scale fill projects minimize adverse impacts when compared to a single, large-scale project. Fill should not be placed in a continuous section of beach, but should be divided into several short sections where every other section is filled. This design leaves undisturbed refugia for fish and wildlife resources, which then can enhance the recovery of invertebrates within the fill sections by having source populations scattered throughout the project length instead of only at the ends. Sediment will naturally move from the fill sections into the unfilled sections on the littoral drift, increasing the beach width in unfilled sections over time but without direct burial of the benthic ecosystem. Subsequent 'renourishment' episodes can alternate which sections receive fill. Individual sections should not exceed 2000 feet in length unless scientifically rigorous monitoring indicates that this length is too long to facilitate benthic recovery or that benthic recovery occurs relatively fast and the length may be increased. The timing of the deposition (e.g., the season – fall, winter, spring or summer) should avoid the most biologically productive seasons, including spawning and recruitment periods for benthic invertebrates; this should enhance recovery rates following deposition of the fill material. For the eastern and southeastern United States, the best construction window is generally from November to February.

Beach fill should be of the thinnest depth possible (Defeo et al. 2009 recommend repeated application of layers of sediment, none thicker than 30 centimeters (cm)) to facilitate the repopulation of fill areas with benthic invertebrates. Some invertebrate species may survive shallow burial, minimizing mortality of these resources. The berm height should not be uniform but should vary along the beach fill, allowing waves, tides and overwash to penetrate the beach to varying degrees and creating a diversity of topographical microhabitats while maintaining necessary beach profiles for successful sea turtle nesting. If necessary, contract specifications should explicitly prohibit overfill so that these conservation measures are implemented as intended.

Heavy equipment use should not leave ruts on the beach. Storage of heavy equipment and pipe on the beach should be avoided to the extent possible, using staging areas off of the beach wherever available.

Construction schedules should avoid the most productive biological seasons, typically the nesting season for sea turtles, shorebirds and waterbirds but in some areas also may include migration or overwintering periods where fauna are present in high concentrations.

Construction should avoid sensitive habitats and areas with high ecological value such as migratory bird staging sites, aquatic spawning areas, and colonial waterbird nesting sites. Buffers of 100 m should be maintained around wading bird colonies, 200 m around mixed tern / skimmer colonies, and 100 - 200 m around solitary bird nests and larger for species with precocial chicks. Buffers of at least 10 m should be maintained around sensitive plants. In project areas where construction will be conducted 24 hours a day, 7 days a week, with multiple pieces of heavy equipment, buffers may need to be enlarged since the disturbance would be continuous (versus periodic disturbances with pedestrians). During non-breeding periods, buffers may be needed around roosting sites or migratory staging areas for sensitive bird species.

Renourishment episodes should only be conducted after all of the ecological monitoring (e.g., invertebrate, avian, fisheries, listed species) shows that the beach ecosystem has fully recovered (100% as compared to control areas) for a duration of at least one year, preferably two or three, in order to avoid permanent perturbations to the system. Disturbances should be episodic and their ecological impacts should not overlap between fill episodes (i.e., a renourishment episode should not take place before the impacts from the previous fill event have completely abated).

Scientifically rigorous pre-project, during construction, and post-project monitoring should be conducted according to the design protocols recommended by Peterson and Bishop (2006).

Beaches should not be raked or mechanically cleaned; wrack material should be left in place with the exception of marine litter or human trash, which should be collected by hand. Wrack materials are an essential component of the foodweb of sandy beach ecosystems, as well as a source of organic material and traps for windblown sediment to create foredunes.

In areas where beach nourishment creates a beach seaward of existing hard stabilization or heavy development, where the beach has been lost due to erosion and/or sea level rise, associated ecosystem functions such as nesting habitat for shorebirds, waterbirds or sea turtles, may be restored. Future renourishment episodes should then follow the aforementioned BMPs (e.g., protective buffers) for protection of ecological resources that have returned to or colonized the re-created beach.

SECTION III: NEARSHORE

The nearshore environment, which for ecological purposes can be defined as the active littoral or surf zone, contains a variety of ecological resources, including foraging fish and benthic invertebrates. In some areas, reefs and hardbottoms or other geologic outcrops may be present. These resources and habitats may be directly or indirectly impacted by shoreline stabilization projects.

Significant buffers should be maintained around all reefs (natural or artificial), hardbottoms, submerged aquatic vegetation (SAV) and other high value habitats, including areas designated as Essential Fish Habitat (EFH) or Habitat Areas of Particular Concern (HAPC). Buffers should be delineated prior to construction so that the design and construction planning can incorporate avoidance measures in advance. Buffers should be at least 500 m surrounding these sensitive and valuable habitats.

If beach fill sediment for a dredge disposal or nourishment project is compatible with the native material, nearshore communities should not be adversely affected by raised turbidity levels as the fill material dewaters and the sediment is reworked by wave and tidal action. Some turbidity is likely, however, and should be monitored with appropriate instrumentation and monitoring protocols. Where water quality standards are exceeded, work should cease and appropriate mitigative measures incorporated into the construction methods and design. Similarly, if introduced fill material contains too much coarse material, the benthic fauna may be adversely affected in their ability to burrow into the sediment and predators such as fish and birds may be less able to locate benthic prey; if such a situation occurs, post-construction mitigation should occur, including the removal of excess coarse material where warranted and the avoidance of that sediment source for future fill projects.

Long-term monitoring should also be conducted where geologically limited habitats such as reefs and hardbottoms are present near the work area to ensure that fill material does not move off of the artificially constructed beach / berm and bury or smother these fragile habitats. If such burial is documented, post-construction mitigation should be pursued and any renourishment episodes should increase protective measures such as buffer size.

Nearshore areas including sandbars and tidal shoals should not be used as a sediment source for beach fill projects. Removal of nearshore material for beach placement can increase wave energy reaching the beach by altering the nearshore bathymetry, defeating the purpose of an “erosion control project” and exacerbating the need for shoreline stabilization project(s).

Hard stabilization structures such as breakwaters and rubble mounds should not be constructed in nearshore areas due to their significant adverse environmental impacts. Artificial reefs may have ecological value if designed, installed and monitored properly and if they are located in appropriate areas.

SECTION IV: OFFSHORE

Similar to the BMPs for nearshore areas, offshore areas may also contain rare and valuable habitats like hardbottoms and reefs that should be protected with large buffers (at least 500 m). Offshore areas are typically used as the source for sediment for beach fill projects, which mine suitable materials from the seafloor and transport the material to the beach via dredges, barges and/or pipelines. Mine sites also should be located away from significant spawning areas or other habitats valuable to local fishery or benthic resources, including areas designated as EFH, HAPC or Marine Protected Areas (MPA).

Mine sites for beach fill material should not be excavated such that large depressions or holes are left on the seafloor, significantly altering the local bathymetry (and thus coastal processes and ecological habitats). Excavation should use a series of shallow, staggered cuts (furrows) that limit the area of disturbance and allow undisturbed areas in between cuts to serve as refugia and a source for repopulation of benthic resources; this method also limits alterations to the seafloor bathymetry, which may have regional and long-term adverse effects. Dredging should leave a sufficient layer of sediment that matches as closely as possible the original surface layer to avoid exposing a dissimilar sediment on the surface.

SECTION V: INLETS

Inlets are particularly valuable ecosystems, as they provide foraging, spawning, nesting, staging, roosting and migratory habitat for countless shorebirds and waterbirds, anadromous and catadromous fish, crabs, shrimp, invertebrates, waterfowl and other fish and wildlife resources. The highly dynamic nature of inlets creates a complex assemblage of habitats, including bare and sparsely vegetated spits; subaerial, intertidal and submerged shoals; sandbars; overwash and tidal flats; and passageways for aquatic resources. The constantly shifting nature of inlets creates a cycle of emergence, growth and renewal of these habitat types that is self-sustaining when left undisturbed.

Due to their incredible ecological significance and the significant adverse environmental impacts that hard stabilization generates, inlets should not be stabilized with jetties, terminal groins, revetments, riprap, geotubes, sandbags or any other hard structure. The cumulative impacts of inlet management and manipulation along the Atlantic and Gulf coasts of the U.S. already are significant and adverse and should preclude any undisturbed or relatively undisturbed inlet from being stablilized, mined or otherwise managed.

The flood and ebb tidal deltas of an inlet should not be mined for sediment for use in beach fill projects or to re-align channels away from threatened structures. Shoals are spawning areas for crab and shrimp, roosting and foraging habitat for birds, shelter for SAV, and an essential element of the inlet ecosystem. Mining shoals for sediment unbalances the natural equilibrium of coastal processes, disturbing and displacing fish and wildlife resources and leading to habitat loss and fragmentation. Removal of material from inlet shoals typically leads to increased erosion on adjacent shorelines as the system attempts to fill the sediment deficit, which can increase hazards to private property and infrastructure in developed inlet hazard zones. In some areas, protection of subaerial shoals (e.g., restricting boater access and activities such as parties, fires and dogs) may be a form of mitigation for increased recreational or development activity facilitated by shoreline stabilization projects on nearby beaches.

Dredging of new navigational channels through previously undisturbed inlets should be discouraged as this process removes sediment from the system much like shoal mining does. Undisturbed inlets naturally bypass sediment from one side of the inlet to the other, and navigational channels can become sediment sinks, depriving downdrift beaches and habitats of their sediment supply. Deep channels may have regional impacts as sediment is continuously removed via maintenance dredging from the channels and moved elsewhere, generally outside of the inlet and nearby coastal system. Excessively deep channels may also alter the salinity regime in adjacent estuaries by increasing the tidal prism and altering the hydrodynamics of the inlet, resulting in adverse ecological impacts well beyond the actual inlet area.

For existing navigational channels, dredged material should be disposed of within the inlet system, placed where it can bypass to downdrift beaches on wave and tidal processes. Nearshore placement of dredged material would avoid impacts to the beach and dune ecosystem and most closely replicate natural sand bypassing processes, which are subaqueous at inlets. Channel maintenance activities should occur on more frequent small scales instead of infrequent large scales in order to minimize the magnitude of the disturbance to the coastal ecosystem.

Restoration of inlet complexes provides an opportunity for mitigation required by other disturbance projects. Hard structures can be removed, dredged channels abandoned, and buildings and infrastructure relocated away from inlet shoulders. Preservation (e.g., conservation easements, fee title) of undisturbed inlet complexes with large buffers along each shoreline to allow natural movement of the inlet over time should be encouraged and pursued wherever possible.

ORV should not be allowed in inlet areas during periods of nesting or migration, or if significant overwintering populations of wildlife are present.

SECTION VI: ESTUARINE

Estuaries should not provide a sediment source for oceanfront beach fill projects due to sediment compatibility issues and the adverse impacts sediment removal would have on the estuarine ecosystem. Where dredging is necessary, dredge disposal materials should stay within the local system as close to the project area as possible. Dredged materials disposal should not occur in areas with significant benthic resources where burial is likely to occur. Disposal should not bury marshes, tidal flats, SAV, oyster reefs, clam beds, or other valuable benthic or fishery resources occur; buffers of at least 500 m should be maintained around such areas.

In some cases, dredged material can be beneficially used to restore or enhance habitat. Dredge disposal islands in certain areas have become valuable bird nesting areas and their creation and/or maintenance with compatible material may offset the adverse impacts of dredging (albeit with out-of-kind services). The beneficial use of dredged material may also aid in the restoration of SAV, or where the material is rocky, in the restoration of oyster reefs. In areas where hard stabilization along the estuarine shoreline has led to the loss of intertidal habitat, dredged material may potentially restore such habitat through localized, small-scale fill projects in front of the hard structures or where such structures can be removed. Restoration of intertidal estuarine shoreline habitats may benefit nesting horseshoe crab and diamondback terrapin as well as foraging waterbirds and shorebirds. New canals or channels should not be dredged to reach habitat restoration project areas, nor should adjacent marsh, SAV, oyster reefs, etc., be disturbed during the construction phase. Any beneficial use of dredged material project should include appropriate post-construction monitoring to determine if the intended benefits are realized, and the project should be adaptively managed to incorporate the results of such monitoring in future operations and maintenance activities.

Overwash material should not be removed from estuarine areas or habitats; overwash fans and flats are a natural component of the coastal ecosystem and a necessary process to aid in the migration of estuarine habitats during rising sea levels. As these habitats (both on barrier island and mainland shorelines) are naturally maintained with raised elevations from overwash, adjacent mainland development should benefit from enhanced storm protection in the long-term as the risk of inundation is lessened with higher elevations.

Finger canals should not be dredged in estuarine areas or on the bayside of barrier islands or spits; these canals increase the naturally shallow bathymetry, lead to the loss of intertidal and shallow bottom habitats such as marsh and SAV, and serve as a conduit for storm surge during severe storms.

Hard stabilization structures should not be constructed along estuarine shorelines, including bulkheads for new marinas and personal boat slips. Riprap and rubble debris should not be placed along the estuarine shoreline. All hard stabilization structures lead to the loss of intertidal habitat over time, and prevent the migration (and thus maintenance) of estuarine shoreline habitats (i.e., tidal marshes and flats, beaches) during rising sea levels.

The cumulative impacts of personal docks and piers (which are often associated with bulkheads) should be carefully considered prior to the permitting or rebuilding of new docks and piers. Docks, piers and similar structures built over estuarine waters are generally demolished during severe storms, leading to significant amounts of debris following the storm. This debris should be carefully and quickly removed so that estuarine resources and habitats are not permanently harmed or buried by these materials.

SECTION VII: CLIMATE CHANGE AND RISING SEA LEVEL

Given the current trends and predictions for climate change and continuously rising sea levels, shoreline stabilization projects should utilize an adaptive management approach that allows for designs to be modified with changing conditions over time. Beach nourishment of the seaward shoreline, for instance, will not allow a barrier island or mainland beach to migrate to higher ground as sea level rises higher and higher. Instead, beachfront structures should be relocated away from the beach and the beach system (including dunes) should be allowed to migrate landward in space over time. After severe storm events where beachfront structures are heavily damaged, they should not be rebuilt in place but rebuilt significantly farther landward where feasible or not rebuilt at all where not feasible. Hard stabilization structures such as jetties should be removed to facilitate the long-term natural maintenance of tidal inlets as sea level rises and inlets shift in space along with the adjacent barrier islands. Similarly, navigational channels should shift in location over time to accommodate migrating islands and inlets.

In highly developed areas where beach fill is maintained (at ever increasing costs) in the long-term, the frequency of beach fill “renourishment” or “maintenance” episodes should be determined by the actual performance of the initial fill material (as documented by long-term monitoring) instead of the predicted performance based on engineering and mathematical modeling. Hard stabilization structures are not consistent with an adaptive management approach, nor are they practical in the long-term as sea levels rise an estimate one meter or more by 2100.

Shoreline stabilization projects should include pre-project (identifying baseline conditions), construction, and post-project monitoring that is scientifically rigorous and incorporates control areas and other features as recommended by Peterson and Bishop (2006). The results of ecological monitoring should guide the “maintenance” of shoreline stabilization projects, with design features or construction methods modified to avoid or minimize any adverse effects documented by the monitoring.

Some level of monitoring should persist for the entire lifespan of a shoreline stabilization project (often 50 years for a beach fill project), but the monitoring protocols may be modified over time as warranted by previous monitoring results. Shoreline stabilization projects such as beach fill should not disturb the ecosystem more than a severe storm would disturb the system, so that the faunal recovery period is similar to that of a natural disturbance. For example, the individual pulse perturbation to a sandy beach ecosystem from a single beach fill episode should not decrease or depress essential ecosystem functions by more than 50% so that the perturbation does not permanently alter the ecosystem; monitoring may indicate that the 50% perturbation threshold may not sufficiently minimize adverse impacts to critical resources such as threatened or endangered species, Important Bird Areas, critical habitat for listed species, or migration or overwintering staging sites. In such a case, the adaptive management approach would incorporate these monitoring findings and lower the perturbation threshold for future fill events. Likewise, if monitoring determines that a fill episode had no significant, lengthy adverse impacts on critical ecosystem functions, the perturbation threshold could be raised for future fill events.

The distribution of microhabitats within the coastal ecosystem, including beaches, dunes, inlets and estuaries, are shifting in location as sea level rises at an accelerating rate and climate change alters sea surface temperatures and other oceanographic processes. A hands-off approach to shoreline management would best avoid the permanent loss of coastal ecosystem habitats. As a result, overwash materials should not be removed from the interior or bayside of islands or spits (including roads and driveways), dune ridges should not be built to function as levees, and inlets and shorelines should not be locked in place by hard structures. Where buildings are damaged and left exposed in intertidal areas following severe storm events, they should be removed and not rebuilt instead of rebuilt and protected in place with shoreline stabilization projects. If these BMPs can be incorporated into shoreline stabilization projects, habitat loss, fragmentation and degradation may be minimized in a period of changing climate and rising seas.

GLOSSARY

Adaptive management An iterative process where monitoring or learning by doing better informs future management decisions when precise information is lacking or uncertainty remains as to the extent, intensity and duration of effects resulting from a set of actions (e.g., shoreline stabilization or management); subsequent management decisions are improved through

	the incorporation of new information obtained by monitoring the effects of previous actions
Aeolian	Of or pertaining to the wind, in this case windblown (aeolian) sediment transport or movement of sand
Beach	The area of unconsolidated sediments, stretching from the dunes to the intertidal zone; the underwater portion of the beach profile is sometimes referred to as the shoreface
Beach nourishment	The placement of sediments mined or transported from another location on a beach in order to temporarily reverse or slow down long-term erosion and protect structures located behind the beach
Benthic	Living on the bottom, in this case animals that live on the sea, bay or estuary floor and generally remaining submerged at all times
Best management practice (BMP)	Methods or techniques that can be used to avoid or minimize environmental harm or impacts in land management or construction activities
Breakwater	An engineering structure built in the water off of a shoreline with the intention of slowing down waves before they strike the beach, sheltering the adjacent shoreline
Bulkhead	A wall, typically built on the estuarine shoreline, to protect adjacent structures from erosion or storm flooding, or to allow for deep water immediately next to the shoreline for the mooring of boats
Downdrift	The direction in which the littoral drift or longshore sediment transport is moving sediment
Dune	A mound or ridge of unconsolidated sediment, usually sand-sized particles, that is built through the accumulation of windblown sand
Ebb tidal delta or shoals	Bodies (shoals) of sediment formed by the interaction of ebb, or falling, tides with incoming waves at a tidal inlet; ebb tidal shoals are generally smaller than flood tidal shoals and remain submerged during all tidal periods
Estuary	A semi-enclosed body of water which has open connections to the ocean and within which marine waters are diluted or mixed with freshwater, forming a body of water with lower salinity than the ocean and higher salinity than rivers
Fetch	The distance over which wind or waves can move unobstructed
Flood tidal delta or shoals	Bodies (shoals) of sediment formed by the interaction of flood, or rising, tides with the relatively calmer waters of a bay or estuary at a tidal inlet; flood tidal shoals are generally larger than ebb tidal shoals and can be exposed at periods of low tide
Geomorphology	The topography, or landforms, of a given area
Geotube	A very large sandbag, generally about one meter in diameter and tens of meters in length; geotubes can be stacked on top of each other to form a wall or mound to protect structures from the encroaching ocean and are sometimes buried under sediment to reinforce artificial dunes
Groin	An engineering structure built perpendicular to the beach, typically constructed of wood pilings, sheet metal, large rocks, or concrete, with the intention of trapping sediment in the littoral drift and slowing local erosion rates

Infauna	Invertebrate animals that live within the sediment near the surface, such as mole crabs, polychaete worms and clams
Inlet	A water passageway between barrier islands or spits which connects the ocean with estuaries, bays or freshwater rivers
intertidal	The area of a shoreline that is alternately exposed to air and submerged under water with changing positions of the daily tide
Jetty	An engineering structure, typically constructed out of large stone, concrete or sheet metal that is built perpendicular to the shoreline along an inlet shoulder in order to hold or stabilize the inlet and its channels in place
Littoral drift, or longshore sediment transport	The current formed by waves striking a shoreline at an angle which moves sediment along a shoreline, predominantly in one direction (from updrift to downdrift)
Marsh	An area of partially submerged vegetation, typically saltmarsh reed grasses such as *Spartina* spp. or *Juncus* spp. along a shoreline or in an estuary, which may be exposed at low tide and mostly submerged at high tide
Nearshore	The active littoral, or surf, zone where wave action moves significant amounts of sediment on a daily basis
Offshore	The area of the seafloor or ocean that is farther away from the beach or shoreline, seaward of the surf zone
Revetment	An engineering structure, typically a sloping wall constructed of large rocks, installed along a shoreline to protect adjacent structures from erosion and encroaching waters
Riprap	Material or debris such as rock, brick, concrete block or similar hard materials that is placed along a shoreline to slow down local erosion rates
Rubble mound	A mound or ridge of rubble debris (rock, concrete, etc.) placed in the water off of a shoreline that acts like a breakwater to slow down waves and shelter adjacent shorelines
Sandbar	An underwater mound or ridge of sediment in the outer surf zone portion of a beach profile, typically noticed by the area where waves are breaking before striking the beach
Seawall	A wall, typically built of sheet metal or concrete, that is installed parallel to and on the landward side of the beach in order to protect structures from tidal flooding and wave action
Sediment supply	The volume of sediment moved annually along a beach by the littoral drift, or longshore sediment transport
Shoal	A body of sediment that rises in elevation from the surrounding sea or bay floor and that may be exposed during periods of low tide; shoals are generally found near or within tidal inlets
Subaerial	The portion of the beach that remains dry and not submerged during periods of high tide
Subaqueous	The portion of the beach, estuary or ocean that remains submerged under water during all tidal periods
Submerged	Under water
Surf zone	The area adjacent to a shoreline in which waves are breaking and running up on to the

beach

Terminal groin A groin that is placed at the end of an island adjacent to an inlet

Tidal flat A marshy, muddy or sandy nearly flat landform that is alternately exposed and submerged during periods of low and high tides

Trough A shallow, straight depression on the landward side of a sandbar

Updrift The direction from which the predominant littoral drift or longshore sediment transport is moving; jetties and groins can trap this sediment on their updrift sides, blocking its movement to downdrift beaches

Wrack Organic materials such as seaweed, marsh grass and other vegetation that is deposited on a beach by waves and tides

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