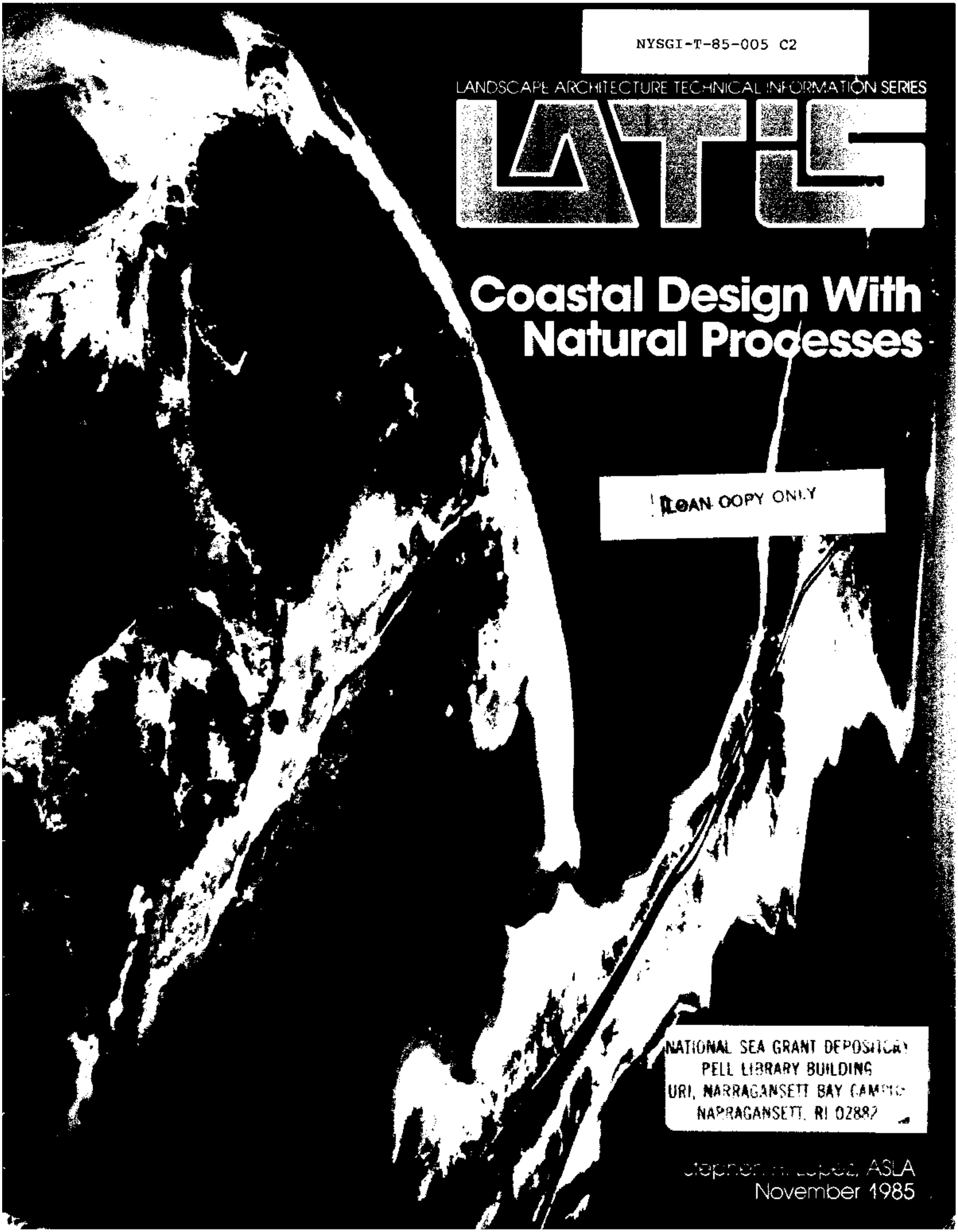
LANDSCAPE ARCHITECTURE TECHNICAL INFORMATION SERIES

# LATIS

# Coastal Design With Natural Processes





Stephen M. Lopez, ASLA

November 1985

LANDSCAPE ARCHITECTURE
TECHNICAL INFORMATION SERIES 9



ISSN: 0195-5764

Volume 6, No. 2 November 1985 P-03-09

Cover Photo: Groinfield at Gateway National Park, Sandy Hook, NJ. Photo by author.

# Coastal Design With Natural Processes

## Along the Ocean and Great Lakes Coastlines of the U.S.— An Introduction

Stephen H. Lopez, ASLA
November 1985

This publication was developed through the American Society of Landscape Architects as an introduction to the subject of coastal design and preservation strategies for those involved with land development and environmental protection.

Prepared as a service to the profession of landscape architecture, it was produced through the joint efforts of the author and the ASLA Technical Services Committee. This committee is responsible for selection and review of topics for all LATIS publications.

TECHNICAL SERVICES COMMITTEE

Helen Hendrickson, ASLA
Alton A. Barnes, Jr., ASLA
Dan L. Johnson, ASLA
Julie A. McQuary, ASLA
Jerome E. Przystup, ASLA

LANDSCAPE ARCHITECTURE
TECHNICAL INFORMATION SERIES 9

Elizabeth A. Dahlstien, Rodney P. Mercer—ASLA Staff Editors

**Acknowledgements**

Many people contributed their ideas and time to the development of this publication. Helen Hendrickson, chair of the ASLA Technical Services Committee, was encouraging and helpful from the inception of the project. The reviewers who graciously contributed their expertise included Chris Campbell, Assistant Professor of Botany at the University of Maine, Orono; Henry Bokuniewicz, Professor of Oceanography at the SUNY Marine Science Research Center in Stony Brook, N.Y.; Norbert Psuty, Director of the Center for Coastal and Environmental Studies at Rutgers, N.J.; Arthur Lieberman, Professor of Landscape Architecture at Cornell University, Ithaca, N.Y.; W. James Barry, Ph.D., Senior State Park Resource Ecologist, California Department of Parks and Recreation; Ronald Tuttle, National Landscape Architect, and Curtis Sharp, National Plant Materials Specialist, both with the U.S. Department of Agriculture, Soil Conservation Service; Jay Tanski, Regional Erosion Specialist, N.Y.S. Sea Grant Extension Program; and Robert Brewster, Horticultural Consultant, Garden City, N.Y.

Many other individuals helped me through their writings as noted in the references cited and the selected bibliography. Acknowledgement is also due to my employer, Cornell University, and to the U.S. Department of Commerce, N.O.A.A., Office of Sea Grant, and the N.Y. Sea Grant Institute and Extension Program for support in preparing this report.

Stephen H. Lopez, ASLA

# Contents

# List of Illustrations

**Introduction**



**Part I: The Natural Environment**

**Coastal Processes Influencing Erosion**



**Barrier Beach Environments**



**Coastal Bluff Environments**



**Part II: Influencing Natural Processes with Vegetation**

**Preserving and Enhancing Barrier Beaches**

**Preserving and Stabilizing Coastal Bluffs**

# INTRODUCTION

Water is one of the most powerful forces shaping the landscape we see, and, where water meets land, that edge is in a constant, dynamic flux. This is the reality confronting coastal property owners. Like any problem, this one presents choices, and the results of those choices speak plainly about our views of ourselves and our relation to the environment. This publication is about how we may design our use of coastal areas in an environmentally sensitive and rational fashion.

Figure 1 **Groinfield**

In this country, water historically has been perceived largely for utilitarian purposes. Early explorers had the backing of monarchies with commercial shipping interests, and so our waterfronts first were evaluated as potential shipping lanes. As trade with the New World developed, great ports sprang up on both coasts. Population centers grew around these ports, and agricultural and residential development of outlying areas ensued.

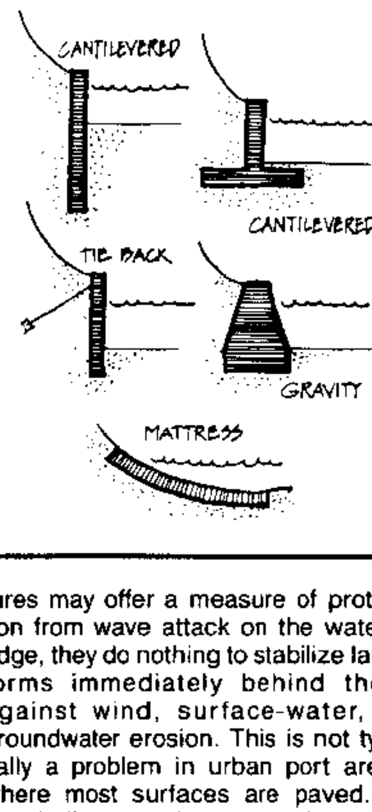
The coastlines, the first area of the country to be exploited by the new settlers, have undergone many changes. The settlers paddocked livestock on convenient barrier islands and grazed them on coastal terraces. In some areas the sensitive dunes were overgrazed, and trampling killed dune grasses. Settlers also cut timber, removing "climax" dune forest—plant communities that had evolved over long periods of time behind the pioneer grass communities on primary dunes. These changes in coastal ecosystems led to live dunes—characterized by constantly blowing and shifting sand—in some coastal areas. Live dunes still are found in locations such as Cape Cod, Massachusetts, and Pismo-Nipomo Dunes, Morro Dune, and Tenmile Dunes in California.

Over time the enduring natural beauty of our coastal areas has drawn more and more residents to year-round and seasonal communities. Though the pressure for coastal development has never ceased, many of the buildable sites that remain have serious erosion problems and many older developments have developed erosion problems.

In recent years, public attention increasingly has been focused on dramatic property losses on the Gulf, the Great Lakes, and the Atlantic and Pacific coasts. With predictions of rising sea levels and cyclical weather patterns exacerbating erosion conditions in many coastal areas in the future, it is imperative that professional designers examine all safeguards possible for coastal development projects.

The use of man-made, "shore hardening" structures—such as bulkheads, sea walls, jetties, and groins—to protect sites is expensive. Benefits of hardening the shoreline outside commercial port areas are controversial. If properly designed, shore hardening structures usually will offer immediate protection to the local shoreline. However, long-range impacts may include accelerated erosion damage (such as loss of beaches) to nearby properties and even damage to the "protected" property itself.

Figure 2 **Erosion Protection**




Though coastal protection structures may offer a measure of protection from wave attack on the water's edge, they do nothing to stabilize landforms immediately behind them against wind, surface-water, or groundwater erosion. This is not typically a problem in urban port areas where most surfaces are paved. In less built up environments, however, vegetation and other erosion control measures will be necessary to complement shore structures.

In areas without structures, a more environmentally sensitive treatment of dunes and bluffs may be possible. While, occasionally, coastal structures still will be necessary to protect development, use restriction to protect the natural environment and policies to enhance natural barriers will often be more appropriate (Nordstrom and Psuty, 1980).

In recommending the use of vegetation to help stabilize coastal areas, it is important to recognize that the basic physical processes at work where water meets land cannot be changed by biotechnical erosion control. As an adjunct to coastal structures, or as a treatment in itself, coastal vegetation can, under certain circumstances, slow the erosive power of water and wind. In addition, plants can actually help reverse wind-induced erosion and cause accretion to occur.

Figure 3 **Definition of Biotechnical Erosion Control**

**The integration of man made structural elements and natural elements, i.e., plant material, to work in tandem to reduce soil erosion caused by wind, water or gravity.**

Adapted from: Grey and Leiser, 1982

This issue of LATIS examines the utility of plantings in coastal erosion control on two forms of coastlines common along our ocean and Great Lakes coasts: the relatively flat beach and dunes characteristic of barrier beaches, and the landforms characterized by relatively narrow beaches backed by bluffs comprised of erodible soil. The natural processes of these coastal landforms are outlined and specialized horticultural requirements are given for conservation of existing plants or introduction of new plants.

Figure 4 **Influence of Vegetation on Soil Erosion**

1. **Foliage and residues intercept rainfall and dissipate energy.**
2. **Root systems physically bind or *restrain* soil particles.**
3. **Residues increase surface roughness and slow velocity of runoff *(retardation).***
4. **Roots and residues increase infiltration by maintaining soil *porosity* and *permeability*.**
5. **Plants deplete soil moisture through *transpiration*.**

From: Grey and Leiser, 1982

# PART I: THE NATURAL ENVIRONMENT

## Coastal Processes Influencing Erosion

The shoreline where water meets land is in a constant dynamic state. Waves that lap so benignly against the beach in summer are, on closer examination, moving many tiny grains of sand. To an observer looking out at the waves approaching shore it is often obvious that the waves are not approaching parallel to the shore but at an angle. When waves hit the beach at an angle they move sand not simply up and down but rather up, over to one side, and down again. The net result is that sand is moved along the beach by waves and longshore currents in what is known as littoral drift.

Figure 5 **Surf and Swash Zone**

To appreciate the magnitude of this natural process, consider the estimate that approximately 740,000 cubic yards of sand annually pass by the barrier beach at East Hampton, New York, on Long Island's South Shore. The littoral drift concept is complicated by the fact that the drift does not occur unidirectionally. At East Hampton the westward sand movement of 440,000 cubic yards per year exceeds the eastward sand movement of 300,000 cubic yards per year for a net westward rate of about 140,000 cubic yards per year (Bokuniewicz, 1981).

Figure 6 **Dune Scarp**

Seasonal erosion and accretion is another natural process of importance to coastal development. Each year 200 to 300 feet of beach may be lost to the erosive action of winter storms. A similar amount of beach typically is replaced in the summer months largely through nourishment from sand in offshore sandbars. In years of very severe winter storms, there may be a net loss in the depth of beach. In years of mild weather, there may be a net gain in depth of the beach. It is, therefore, important in evaluating a coastal site for development to vist the site in late winter or secure photographs (preferably air photos) of the site in winter to become aware of the seasonal beach variation. If possible, obtain air photos of the area after the last major storm of the past fifty years or more to evaluate exposure risk. Check tide tables for the date and time the photos were shot to estimate mean tide levels. The most severe and dramatic erosion usually occurs episodically, that is, during infrequent major storms. Consulting local experts, such as long-term residents, may also be helpful.

Storm waves are very erosive because of their large dimensional characteristics. Storm wave period and height are different from waves associated with calm weather. When storm wave height is added on to storm-tide height, the result can be wave action

Figure 7 **Major Factors Affecting Erosive Power of Waves**

1. **Fetch**
2. **Frequency**
3. **Period**
4. **Wave Height**
5. **Storm (flood) tide height**

on natural features or structures at a height significantly above mean water height. It is not uncommon on the northeastern seaboard, for instance, to have storm wave combined with flood tide action resulting in heights 10 to 15 feet above mean water.

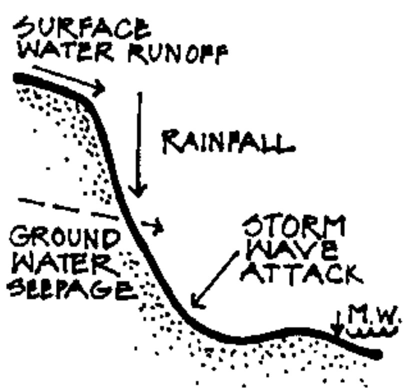
Behind the shoreline itself, several additional processes affect coastal erosion. Wind, for instance, affects sandy areas by blowing sand off the beach or bluff and into the ocean or by blowing sand some distance upland. Wind is a basic force shaping coastal dunes.

Flooding from high tide waters on barrier beaches will affect backdune areas where gaps occur in otherwise continuous dune systems, or where dunes are found in discontinuous segments called fields. Floodwaters often carry suspended sediments that settle out as the flow loses speed. The resultant washover fans may leave sand deposits in backdune areas and may be carried into bay waters flanking barrier islands. Some scientists speculate that this natural process preserves barrier islands by allowing them to build elevation and migrate up the continental shelf in the face of rising sea level (Leatherman, 1979).

In severe storms, weak points in barrier islands may be breached and new inlets formed. Similarly, accretion in another location may cause closure of an inlet. These natural events may be catastrophic for developed areas if roadways are washed out or navigation impaired for port areas.

Surface water from runoff can dramatically affect coastal bluffs comprised of erodible soil, often leaving behind deep gullies where concentrated flow occurs over the lip and down the face. Less obvious is the impact of individual raindrops, each dislodging a few grains of soil and causing them to fall down the face of the bluff. Water that percolates into the

Figure 8 **Impacts of Water On Bluffs**




ground on bluffs will often reappear if it meets a relatively impermeable layer of soil, such as clay lens or compacted till, and travel along it to the face where it seeps out. The soil instability caused in this situation can lead to mass movement, or slumping (Kuhn and Shepard, 1984). The deleterious effect of water in winter and early spring occurs when large chunks of frozen soil on the bluff face break loose due to expansion differentials and slide down to the beach or into the sea.

Figure 9 **Influence of Vegetation on Mass Movement**

1. **Roots mechanically reinforce soil by transfer of shear stresses in soil to tensile stresses in roots.**
2. **Evapotranspiration and foliage interception limit buildup of *soil moisture stress*.**
3. ***Buttressing* and *arching* forces counteract shear stress.**
4. ***Weight surcharge* tends to destabilize in downslope direction and stabilize in perpendicular to slope.**
5. ***Root wedging* tends to destabilize rock masses.**
6. ***Windthrow* results from strong winds blowing downslope.**

From: Grey and Leiser, *Biotechnical Slope Protection and Erosion Control* Van Nostrand-Reinhold. 1982

## Barrier Beach Environments

Barrier beaches are coastal landforms, typically comprised of sand, found at the water's edge. Where these landforms are separated from the mainland by bays, they are known as barrier islands or spits, depending on whether or not they are attached to the mainland at some point.

The foreshore of the beach is exposed to the daily impact of ocean waves and is subject to constant change. Because of its inherent instability, it does not support any plant life of significance to erosion control.

On the beaches of the northeast and Great Lakes coasts, Seaside Spurge *Euphorbia polygonifolia* may be found in addition to Sea Rocket *Cakile endulata* and Beach Pea *Lathyrus japonicus*. On the Gulf coast, Sea Rocket, Pennyworts *Hydrocotyle spp.*, Railroad Vine *Ipomoea Pes-caprae*, and Saltmeadow Cordgrass *Spartina patens* are common on the beach. On the west coast the Sedge *Carex macrocephala* and the Lupine *Lupinus littoralis* are pioneer plants that may be found on the beach. South of Santa Cruz, Sand Verbena *Abronia maritima*, Ragweed *Ambrosia chamissonis*, and Sea Rocket are common.

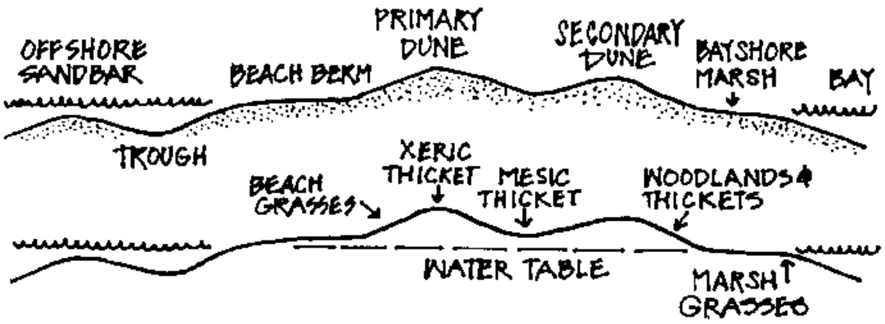
Figure 10 **Major Factors Affecting Barrier Beach Erosion**

1. **Winter storm wave action erodes sand and transports it litorally and to offshore sandbar.**
2. **Summer wave action returns sand to the beach.**
3. **Wind blows sand out to sea.**
4. **Interference of man in natural system exacerbates natural erosion.**
5. **Rising sea level.**

Figure 11 **Saltmeadow Cordgrass**

The dunes immediately flanking beaches are known as the primary dunes and those farther behind as the secondary dunes. Where beaches and dunes meld into the mainland, there is a gradual gradation of plants from the primary foredune (ocean facing) pioneers, mostly grasses, to the secondary dune thickets to forested uplands. On barrier islands, the secondary dunes usually lead to salt meadow or marsh on a protected bay. The bayshore ecology is much different from the barrier beach and will not be discussed here.

Figure 12 **Dune Morphology**




Plants growing in close proximity to salt water will be affected by salt spray. Some plants are tolerant of salt but in varying amounts; therefore, plants will be found growing in "belts" according to degree of salt tolerance. The least salt-tolerant plants will be found in sheltered backdune areas. Many plants are intolerant of salt spray and will not be found growing near salt water.

The dry dune areas behind the beach are similar in many respects to a desert environment for the plants growing there. It is very hot with sand surface temperatures of 120 degrees Fahrenheit not uncommon. It is also very dry. Rainwater percolates rapidly through sand, so plants must have deep root systems to reach the water table below. Plants found in very dry environments typically will have waxy coatings on their stems and leaves or other protective features to minimize loss of moisture through transpiration.

The most common primary foredune plants are herbaceous perennials. By far the most common along the mid-Atlantic, Great Lakes, and northeast coasts is American Beachgrass *Ammophila breviligulata,* often interspersed with varying amounts of Seaside Goldenrod *Solidago sempervirens,* Sea Rocket, Seaside Spurge, Beach Pea, and Beach Wormwood *Artemisia Stellerana.*

On the west coast, European Beachgrass *Ammophila arenaria* is found extensively as an introduced species, and it has supplanted American Dunegrass *Elymus mollis* as the primary species in many areas. Common Yarrow *Achillea Millefolium*—also an introduced species—and Beach Strawberry *Fragaria chiloensis* are frequently found in conjunction with American Dunegrass or European Beachgrass. Use of European Beachgrass has caused some concern, as it crowds out native dune plant species.

On the southeast and Gulf coasts, Sea Oats *(Uniola paniculata),* mixed with Bitter Panicum *(Panicum amarum),* is the common herbaceous cover of coastal dunes. On Great Lakes coasts, Prairie Sandreed *(Calamovilla longifolia)* is often interspersed with American Beachgrass (Lewis, 1982) and in some areas is clearly the most common species.

These pioneer plants of sandy dunes vary in adaptability to stabilized conditions. Sea Oats and European Beachgrass seem to adapt as important components of climax communities, whereas American Beachgrass loses vigor with stabilized sand for reasons that are not well understood. Though American Beachgrass will not completely die out in stabilized conditions, other plants such as Sea Oats (in the southeast where their ranges overlap), Bitter Panicum, and Saltmeadow Cordgrass will assume competing positions (Graetz, 1973).

Figure 13 **American Beachgrass Culms**

Figure 14 **Seaside Goldenrod**

Figure 15 **American Dunegrass**

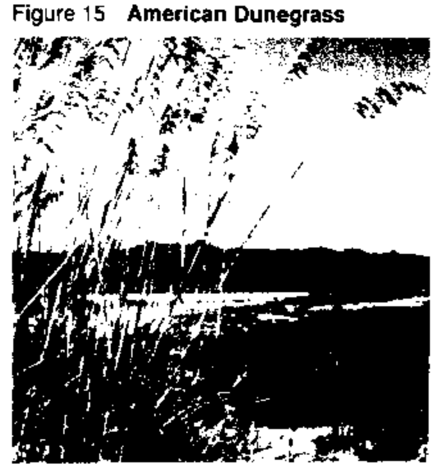


Figure 16 **Sea Oats**

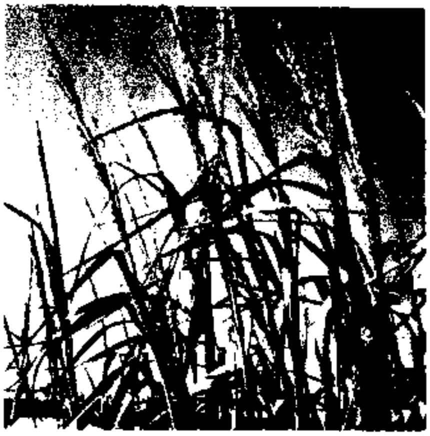


Figure 17 **Bitter Panicum**

Figure 19 **Holly, Red Cedar, Hudsonia, etc.**

Figure 20 **Beach Plum**

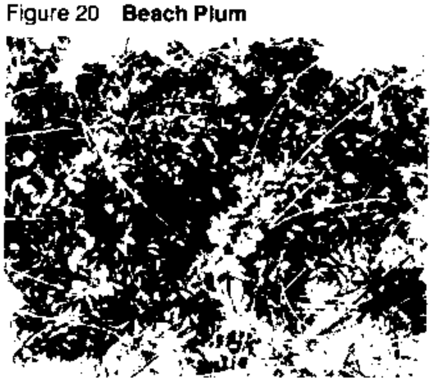


Figure 21 **Rugosa Rose**

These primary foredune plants act as dune stabilizers. They slow the wind at the dune surface and cause deposition of wind-borne sand. During storms, their root systems help hold sand in place, thereby slowing the rate of dune erosion. Where protective vegetation has been removed or killed by trampling or other causes, the dune is more susceptible to wind and water erosion. Worn pathways through primary dunes may be the site of an eventual blowout and subsequent breach.

The lee side of the primary dune and the protected areas of secondary dunes are characteristically vegetated in a zoned mosaic pattern. This means that micro-environmental conditions favor the dominance of various plants in relatively close proximity; thus, making generalizations is difficult. Two limiting factors seem to play a key role, however: height above sea level and exposure to salt-laden sea breezes (Martin, 1959).

Elevation controls distance from the surface to the water table. Plant communities below 5 feet above mean sea level in secondary dune areas have more water available and often are dominated in the mid-Atlantic and northeast by Highbush Blueberry *Vaccinium corymbosum* interspersed with Poison Ivy *Rhus radicans* and Common Greenbrier *Smilax rotundifolia*. Less frequent species include Black Tupelo *Nyssa sylvatica*, Sassafras *Sassafras albidum*, and Red Maple *Acer rubrum*. Very wet, marshy areas may support Phragmites *Phragmites communis* stands or freshwater marsh plant communities.

Above the 5 foot elevation, conditions are much dryer and harsher. Plants characteristic of this zone in the mid-Atlantic and northeast include Bayberry *Myrica pensylvanica*, Beach Plum *Prunus maritima*, Black Cherry *Prunus serotina*, Shadbush *Amelanchier canadensis*, Red Cedar *Juniperus virginiana*, American Holly *Ilex opaca*, Pitch Pine *Pinus rigida*, Poison Ivy *Rhus radicans*, Beach Heather *Hudsonia tomentosa*, Virginia Creeper *Parthenocissus quinquefolia*, and Beach Rose *Rosa virginiana*. Common introduced species include Japanese

Figure 18 **Blowout**

Black Pine *Pinus thunbergiana* and Rugosa Rose *Rosa rugosa*. Though the secondary dune area is host to a diverse woody plant community, the grasses common on the primary foredune also will be found here.

The plants listed above are found in many locations along the Great Lakes coasts as well. However, Wormwood *Artemisia campestris*, Willows *Salix spp.*, Bush Honeysuckle *Diervilla Lonicera*, Common Juniper *Juniperus communis*, Creeping Juniper *Juniperus horizontalis*, White Pine *Pinus Strobus*, and White Cedar *Thuja occidentalis* have been found to form the typical cover of open sandy ridges and dunes in Wisconsin )Salamun and Stearns, 1978).

On the west coast, some experts feel that dune plant communities appear in general to correlate more strongly with "successional" plant groupings than other factors (Kumler, 1969). Others view dune succession as zonation over space rather than change with time (Barbour and Major, 1977). Herbaceous cover is gradually invaded by shrubs such as California Huckleberry *Vaccinium ovatum*, Common Bearberry *Arctostaphylos Uva-ursi*, and Shallon *Gaultheria Shallon*, as well as the Brake Fern *Pteridium aquilinum*. Trees that gradually invade stabilized areas include Beach Pine *Pinus contorta*, Sitka Spruce *Picea sitchensis*, and the climax forest tree Western Hemlock *Tsuga heterophylla*. Species composition may vary for southern California locations.

In the southeast and Gulf areas, Sea Grape *Coccoloba Uvifera*, Yaupon Holly *Ilex vomitoria*, Wax Myrtle *Myrica* *cerifera*, Wild Olive *Osmanthus americanus*, and Spanish Bayonet *Yucca spp.* are common scrub zone plants in the dunes. Also, the Sand Pine *Pinus clausa*, Slash Pine *Pinus Elliottii*, Live Oak *Quercus virginiana*, Chapman's Oak *Quercus Chapmanii*, Myrtle Leaved Oak *Quercus myrtifolia*, Cabbage Palm *Sabal Palmetto*, and Saw Palmetto *Serenoa repens* are found in varying abundance. In protected bays and lagoons, White, Black, and Red Mangrove are found.

All of these plants serve to stabilize the dunes by holding the sand with their roots and by slowing the wind at the surface, causing wind-borne particles to drop out.

Figure 22 **Sitca Spruce Invading American Dunegrass**

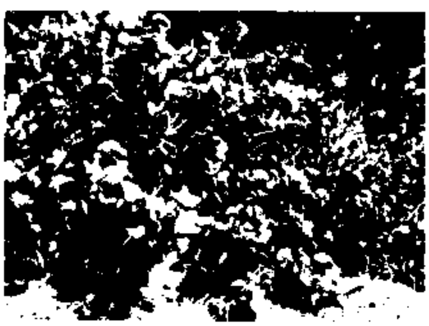


Figure 23 **Sea Grape**

Figure 24 **Southern Waxmyrtle**

Figure 25 **Cabbage Palm**

Figure 26 **Saw Palmetto**

Figure 27 **Sand Oak**

## Coastal Bluff Environments

Coastal bluffs are comprised of soil characteristic of many formerly glaciated areas. They usually consist of fairly narrow beaches backed by high, eroding banks of soil. Waves erode the toe of the bluffs, undercutting their faces. Eventually, the undercut faces slough off, opening up large, bare patches of soil to accelerated surface erosion. Where erosion is frequent on the face of a bluff, trees rarely reach fully mature size. However, on the top of the bluff mature forests of quite large specimens often will be found, but when erosion of the face causes the lip to move back, these larger trees are undermined and fall down the face of the bluff.

Figure 28 **Major Factors Affecting Bluff Erosion**

1. **Winter storm wave action eroding toe.**
2. **Surface water impact and runoff.**
3. **Ground water seepage.**
4. **Interference of man in natural systems and processes.**

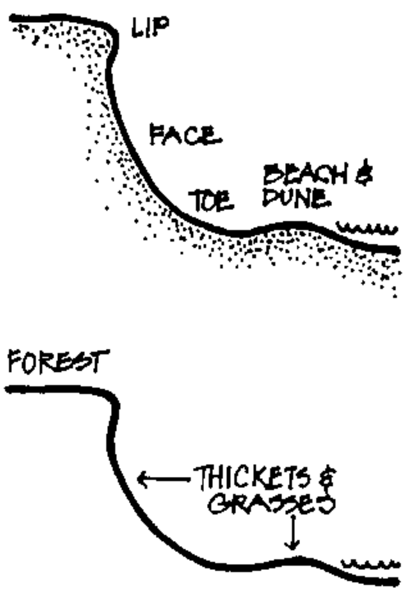
Unlike barrier beaches, bluffs do not build back to their former configuration with seasonal accretion. Sections that are eroded are gone forever. The material that is eroded from the face of the bluff supplies the beach with sand. In areas where bluffs are very stable it is often obvious that beaches are narrower and comprised of much coarser material that resists movement by wave action.

Many of the same plants that grow in primary and secondary dune areas will grow here provided they receive adequate light. Where the beach is deep enough at the toe of the bluff to have developed a dune system, a mosaic of plants similar to that on barrier beaches develops.

Figure 29 **American Beachgrass at Bluff Toe**

On the face of the bluff, soil conditions often are variable. Drought-resistant plants will be found in dry sandy soils. Heavier clay soils or areas immediately above compacted soil layers will support plants requiring more moisture, as these areas tend to be wetter.

Figure 30 **Bluff Morphology**




Exposure also plays an important role in determining plant distribution on the bluff. For instance, though Flowering Dogwood *Cornus florida* is a common subcanopy species in upland forests in the northeast, it will be found less frequently on the bluff face. On the other hand, Shadbush *Amelanchier sp.* is more common on the bluff face than in upland locations. Other woody plants common on mature Long Island, New York, bluffs in well-drained soils include Beech *Fagus grandifolia,* Red Maple *Acer rubrum,* Hickory *Carya spp.,* Black Oak *Quercus velutina,* Maple-leaved Viburnum *Viburnum acerifolium,* Virginia Creeper *Parthenocissus quinquefolia,* Witch Hazel *Hamamelis virginiana,* and Huckleberry *Gaylussacia baccata.* In younger stands Black Cherry *Prunus serotina,* Sassafras *Sassafras albidum,* Pitch Pine *Pinus rigida,* Red Cedar *Juniperus virginiana,* Bayberry *Myrica pensylvanica,* and Highbush Blueberry *Vaccinium corymbosum* will be found (Good and Good, 1970). In wet areas various Willows *Salix sp.* and Phragmites may be found.

In Wisconsin, clay bluffs, ravines, and lake terraces are vegetated with a variety of trees including Sugar Maple *Acer saccharum,* Paper Birch *Betula papyrifera,* White Ash *Fraxinus americana,* Green Ash *Fraxinus pennsylvanica,* Hop Hornbeam *Ostrya virginiana,* White Pine *Pinus Strobus,* Cottonwood *Populus deltoides,* Red Oak *Quercus borealis,* Smooth Sumac *Rhus glabra,* White Cedar *Thuja occidentalis,* and Basswood *Tilia americana.* Common shrubs include Red Osier Dogwood *Cornus stolonifera,* Honeysuckle *Lonicera spp.,* Chokecherry *Prunus virginiana,* Currant *Ribes americanum,* High Bush Cranberry *Viburnum Opulus,* and Wild Grape *Vitis riparia.* The many herbaceous species include Asters *Aster spp.,* Field Horsetail *Equisetum arvense,* Wild Strawberry *Fragaria virginiana,* Wild Geranium *Geranium maculatum,* Early Meadow-rue *Thalictrum dioicum,* and Violets *Viola spp.* (Salamun and Stearns, 1978).

On fairly stable bluffs, mature forests will be found on the face as well as on top. On very unstable bluffs, large unvegetated areas will alternate with areas characterized by immature trees, shrubs, and herbaceous plants. On some areas of coastal bluffs, approximately 25 percent of the bluff face is exposed over time (Bokuniewicz and Tanski, 1980). Ironically, mature forests can destabilize the "stable" bluffs they grow on by adding weight to the scope.

Figure 31 **Poison Ivy, Virginia Creeper, etc.**

# PART II: INFLUENCING NATURAL PROCESSES WITH VEGETATION

## Preserving and Enhancing Barrier Beaches

Where protection of property or lives is of paramount importance, the first line of defense against the sea to be considered is environmentally sensitive development controls limiting exposure to erosion hazards. With suitable controls hazard will not be courted, or at least not so flagrantly, in the first place. A sensible set of environmental controls would include appropriate use regulations, protection of existing beach and dune profiles and vegetation, and restriction of vehicular and pedestrian circulation in sensitive dune areas.

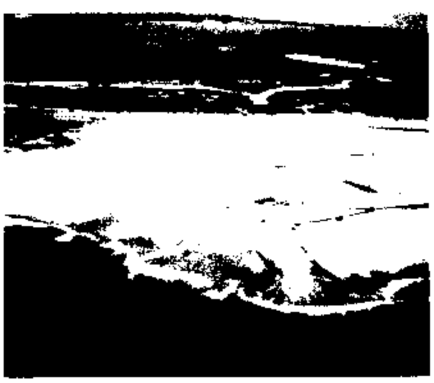


Figure 32 **Artificial Beach Nourishment**

Man-made shore protection structures include both rigid and nonrigid construction. If an enhanced dune structure—similar in function to a dike—is used, very careful location, construction, and plant selection will be necessary for success in dune establishment and maintenance. In some protected locations, fringe marshes or Mangroves may be helpful in stabilizing shorelines.

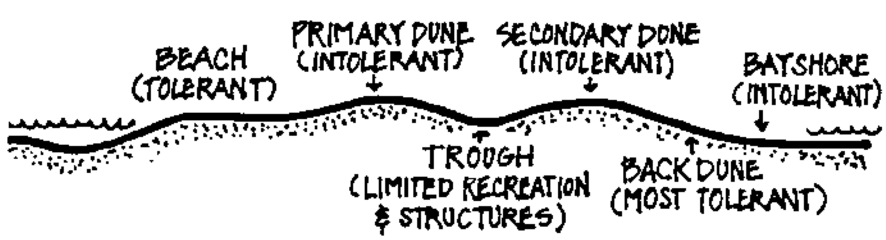
*Use Regulations*

Use regulations appropriate in barrier beach areas should consider type as well as intensity of development (McHarg, 1969). The beach is tolerant of controlled recreational use but not of building. The primary dune is intolerant of even the lightest of circulation, and so access to the beach across this area needs to be carefully regulated and channeled. The trough behind the primary dune is tolerant of limited development and circulation. The secondary dune is intolerant of development and use. The subsequent backdune area is generally most tolerant of use and development. It must be kept in mind, though, that these areas are not static, and so development must also take into consideration inevitable change in location and dimension of barrier island features and barrier islands themselves (Nordstrom and Psuty, 1980).

*Protecting Profiles and Vegetation*

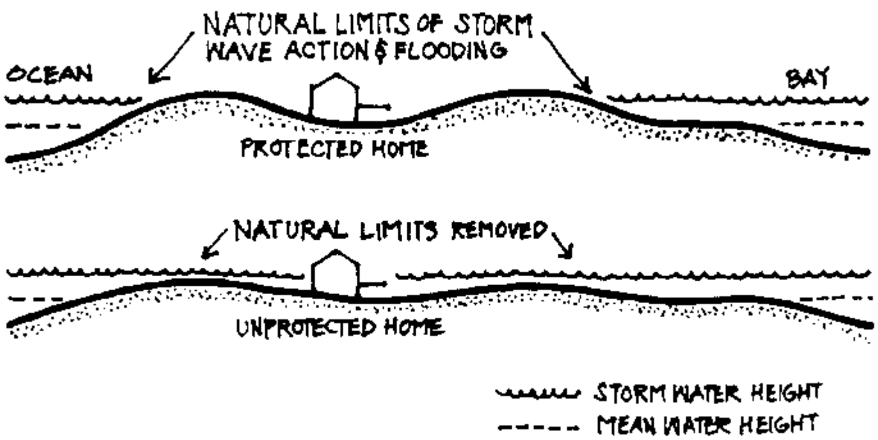
Protecting the existing profiles and vegetation of coastal areas often proves a difficult concept to sell. Property owners view beach dunes as inconvenient view obstructors, and some developers and public agencies have bulldozed dunes in the past to improve the view. This approach to opening up broad, expansive views has no place by the sea where it may be necessary to remove dunes or dune vegetation to achieve the effect. Removal of dunes and dune vegetation is removal of a measure of protection against storm tides and storm wave action high above mean water. In areas where natural causes have led to the beginnings of a blowout (wind-induced erosion of a dune that, if left unchecked, could cause part of the dune to blow away), the affected area should be snow-fenced and planted as soon as possible.

Figure 33 **Barrier Beach Suitability to Development and Use**




From McHarg, 1969

Figure 34 **Dune Protection Benefits**




Note: Natural Storm Damage Barriers Do Not Guarantee Protection/The Coastal Zone Will Always be Dynamic

*Controlling Pedestrian and Vehicular Traffic*

Control of pedestrian and vehicular traffic circulation is a critical issue in barrier beach areas. While most uses of the beach itself will not be harmful, the cumulative effects of seemingly benign but uncontrolled pedestrian use of dune areas can significantly harm the existing vegetation. Off-road vehicles (ORVs) are a source of great concern in sensitive dune areas. They can cause much damage very quickly. Traffic in backdune areas should be restricted to marked paths and roadways preferably raised above the dunes to further minimize adverse impacts. Signs, as appropriate, should be utilized and fencing will sometimes be neessary.

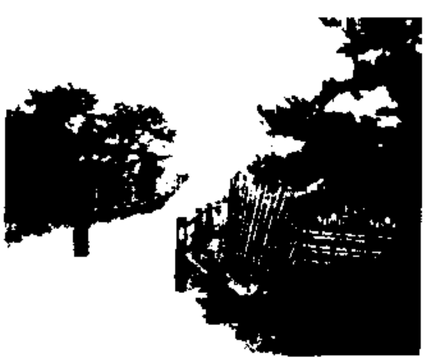


Figure 35 **Dune Protection Sign and Beach Access**

Signs should receive special attention. They offer a unique opportunity to reach out to the public with an educational message and encourage voluntary compliance with restrictions. Signs near parking or other access areas can be of two types. A warning sign will simply state that access across dunes is restricted to marked paths. If a fine is imposed on violators, that should be posted also. Warning signs would be appropriate on the beach side of dunes as well.

A more detailed sign, appropriate at the entrance of access paths, will explain the ecological importance of dunes and the role controlled circulation plays in shoreline conservation. Drawing attention to especially sensitive plants and potentially harmful plants will be educational.

Of course, care should be taken to avoid visual clutter with signs. A well-designed signage system should incorporate coordinated graphics, grouping of signs in one location where appropriate, and other design features described in the texts on this subject.

Snow fencing is useful in controlling pedestrian traffic, since such fencing is difficult to climb over. It will also double as a sand collector, so care should be taken in placement. Occasionally, breaks will appear due to vandalism or natural deterioration. These should be repaired as soon as possible.


Figure 36 **Dune Protection Signs and Snow Fencing**

Design of access paths across dunes can be simple or very elaborate. The simplest marked path is bare sand, though compacted soil (a clay-loam mix) will be more durable. Occasionally, mats constructed of planks fastened together with flexible connectors or braided cable are used as a walking surface. These are especially useful on dune banks where footing is difficult in the dry sand. Even on the simplest path, snow fencing or a post and rail fence for guidance should be provided.

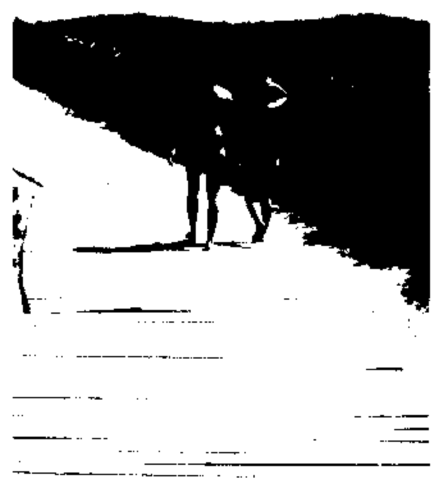


Figure 37 **Beach Access—Plank Mat**

More elaborate access paths consist of raised wooden walkways with railings. These require more maintenance and are more expensive, but they do a better job of protecting sensitive dune surfaces. Walkovers should be built high enough off the dune surface to allow for sand accumulation and healthy plant growth underneath. They are typically built of treated or rot resistant wood.

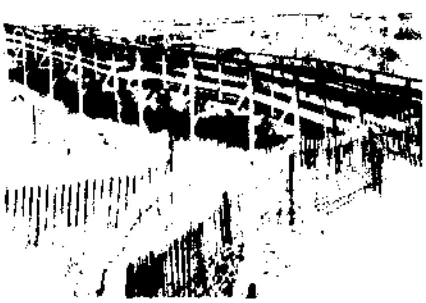


Figure 38 **Elevated Beach Access**

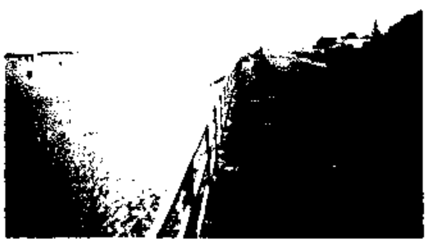


Figure 39 **Coney Island Boardwalk**

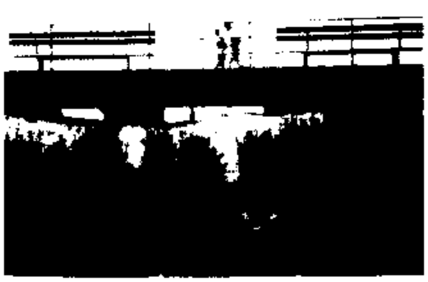


Figure 40 **Dune Attempting Re-establishment Beneath Boardwalk**

ORVs can have severe impact on dunes. Studies have shown that even one pass across seedlings of annuals and perennials will kill them. Unrestricted ORV usage can denude and cause artificial truncation of dunes. Potential blowouts are created where washovers or breaches may occur. Recovery from ORV tracks can take four years or longer (Leatherman, 1979).

Management implications are that unrestricted ORV use should be prohibited in dune areas. Where allowed, use should be restricted to the intertidal area, as vegetation in that area is the most tolerant of traffic, and to only a few designated trails. Since tolerance of dune plants is low, the latter restriction limits damage though it does not eliminate it. Ramps should be provided for crossing over sensitive areas.

Figure 41 **Management Considerations for Barrier Beaches**

1. **Restrict development by type and area.**
2. **Maintain and protect existing vegetation.**
3. **Maintain and protect existing profile.**
4. **Repair damaged areas.**
5. **Restrict circulation in sensitive areas.**

*Structural Improvements*

No matter how carefully development controls are drawn, protection from the sea can never be guaranteed. The need for structural improvements to the shoreline to achieve a greater degree of protection in any location will depend on many factors (U.S. Army Corps of Engineers, 1981). Some will be site specific due to coastal process considerations. A professional engineer with knowledge of shore protection structures should always be consulted in coastal development projects to evaluate the need for structural improvements. Keep in mind that an important and very expensive structure such as a bridge or lighthouse will generally demand more protection than a less critical improvement. Due to the astronomical cost of shore protection structures and their dubious merit in many applications, they often will be foregone in favor of what nature has to offer: a sandy beach and a fairly frail dune. In either case, with or without shore protection structures, plants will be essential for controlling erosion behind the beach—in the dune areas.

Figure 42 **Filled Groin**

Figure 43 **Seawall Replaces Beach and Dunes**

Figure 44 **Gabions and American Beachgrass**

Where shore structures are used, the role of plants is largely complementary. The dune may be spared as the first line of defense, but it will still offer a secondary defense and so the loose sand must be knit together as tightly as possible. This is achieved most economically, and in a most environmentally sensitive manner, through the use of plants.

Where shore structures are not used, a deep beach and ample dune is the only defense against strong seas. It has already been stated that the barrier beach is in a state of constant, dynamic flux. Therefore, a natural defense system cannot be guaranteed as an adequate line of defense against ocean storms.

Some scientists feel dunes provide scant protection—that the sand on the beach itself provides the greatest buffer. They point out that dunes, even with dense vegetation, succumb rapidly to direct wave attack. This apparently is due partly to the grain size of wind-sorted dune sand, which is substantially smaller than beach sand. Its lighter mass makes it more readily susceptible to wave erosion. Below elevation 20, however, much of the dune sand is water laid.

Where dunes have been used successfully in stabilizing barrier beaches, such as at North Carolina's Cape Hatteras National Seashore, they have caused some of the same problems associated with rigid, man-made shore structures. Beaches have significantly narrowed and the beach profile has steepened. Also, the high dunes have prevented oceanic overwash—a process that naturally raises the elevation of barrier islands, moves them shoreward in the face of rising sea levels (Coates, 1973), and revitalizes marshes on the bay side of the island.

It is apparent, therefore, that enhanced dune systems, though typically less costly and more "natural" than man-made structures, also have potential drawbacks as a long-term solution to shoreline stabilization on barrier islands. Where enhanced dune systems are used for protection, it may be more constructive to think of the primary dune not as a continuous dike but rather as a field or zone of broken dunes allowing controlled overwash and dissipation of wave energy in the backdune area (Coates, 1973). Since flooding and sand burial in certain areas obviously would result from this management strategy, it would be necessary to limit uses and structures in these areas to those tolerant of flooding and burial.

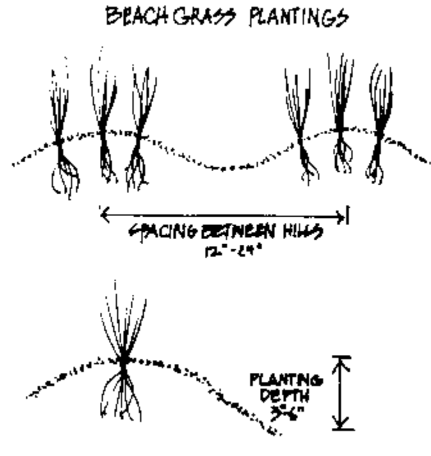
In undeveloped areas where the management objective is simply to maintain barrier islands in their natural condition, it usually will not be necessary to intervene at all in natural processes. As the islands are overwashed, existing grasses well adapted to growing through sand deposits will soon colonize and stabilize new overwash terraces—often within one growing season. The barrier island will be a dynamic area that will respond to natural forces shaping it, but likely will survive and evolve naturally over time.

For developed areas, it often will be desirable to maintain a healthy enhanced dune system, relying most importantly on implementation of use and development regulations discussed earlier to protect against environmental degradation. Where human or natural factors then inescapably cause damage to dunes, these areas should be repaired immediately with snow fencing and/or planting.

*Dune Construction*

Where radical events have caused removal of a large section of the dune system and rebuilding is desired, the most common method is a combination of snow fence and planting. The planting will typically be of drought-tolerant grasses—American Beachgrass in the mid-Atlantic, northeast, and Great Lakes areas, Sea Oats on the southeast and Gulf coasts, and European Beachgrass or native species on the west coast.

Figure 45 **Dune Planting Techniques—Materials**




From: Sharp, 1982.

Figure 46 **Hand Planting of Beachgrass**

Figure 47 **Mechanical Planting of Beachgrass**

Snow fence should be placed in such a way that two objectives are met: the fencing parallels the shoreline as closely as possible, and the fencing is at right angles to prevailing winds. Where seasonal wind shifts occur, wind direction in the driest season—when sand is most mobile—should be used to orient fencing. Obviously this method of laying out snow fencing will often require staggering individual sections to achieve the desired effect, and it will not control seasonal wind shifts well. According to some authorities, use of side spurs in snow-fence configurations do not appreciably add to accumulation success but can account for a 20 percent increase in project cost (Savage, 1963). However, others feel that side spurs are cost-effective and have employed them successfully in local erosion control projects.

Figure 48 **Dune Building Technique—Setback**

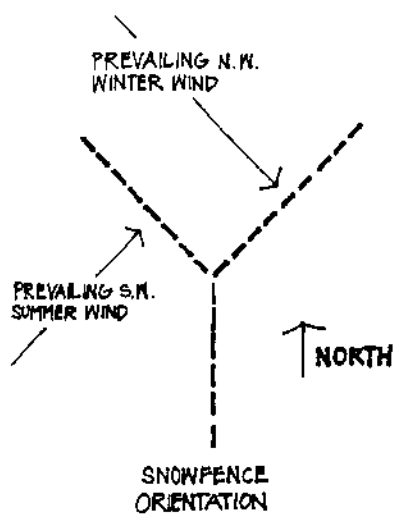



Figure 49 **Snow Fencing**

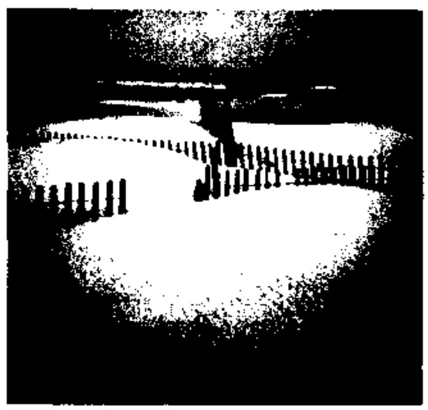
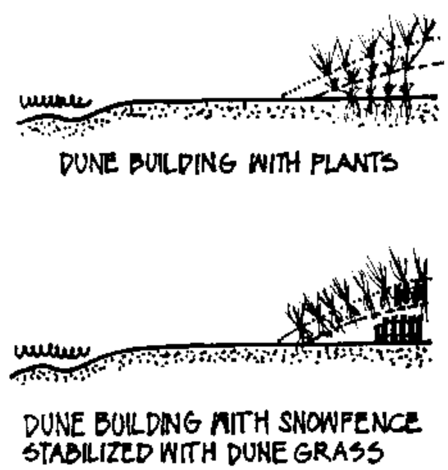


Figure 50 **Snow Fencing and American Beachgrass**

Figure 51 **Mature Dune Restoration Area—Bayberry, American Beachgrass, etc.**

Specifying dune plantings is a critical element of a dune-restoration program. It is important that the plants, such as American Beachgrass, which is available as culms, are fresh and not left to dry out in the open air. American Beachgrass culms are planted three to five per hill at 18 to 24 inches o.c. on sites of moderate energy intensity. On sites of low energy intensity, one culm per hill will cover well in the first year. The culms are planted at a depth of 3 to 6 inches either by hand with a spade or mechanically. A slow-release fertilizer added to the planting hole at the time of planting may aid in first year growth but also may cause overstimulation and subsequent stand reduction in following years unless fertilization is repeated. Specify improved strains of Beachgrass (contact local U.S.D.A. Soil Conservation Service offices for recommendations on available species).

Figure 52 **Dune Planting Techniques**



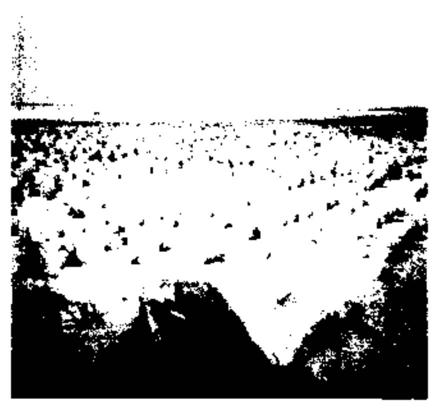



Figure 53 **Large-scale American Beachgrass Planting**

Figure 54 **Residential Beachgrass Planting**

Fertilization has proven effective in stimulating American Beachgrass communities that are in decline due to sand starvation. Beachgrass responds most strongly to applications of nitrogen but will also benefit from phosphate. A mixture of three parts nitrogen to one part phosphate has proven most effective but commercially available 8-8-8 or 10-10-10 formulas may be substituted with alternate applications of straight nitrogen. Two or three applications of water-soluble fertilizer per year for one to three years, or until stands revive, will be required. Slow-release fertilizers are generally ineffective in broadcast applications as they require longer exposure to moisture to release nutrients, but conventional, water-soluble fertilizers have proven effective even with rapid leaching of sand. Fertilizers should be pelletized to avoid drift (Lewis, 1982). Large areas may be fertilized effectively by helicopter.

American Beachgrass is susceptible to diseases including soft scale *Eriococcus carolinae* and Marasmius blight. Some areas have experienced serious die out problems as a result. This is a good reason why a monoculture in dune plantings should be avoided where possible.

Planting of Sea Oats or Bitter Panicum in the south may require irrigation prior to planting, especially if planting is by hand. Irrigation will greatly ease both mechanical and hand planting by giving the dry sand typical in warmer climates greater cohesiveness. Otherwise, furrows or holes fill back in before plants can be inserted.

Establishment of Bitter Panicum as the pioneer plant on barrier beaches requires similar treatment to that of American Beachgrass. It differs in that it may be planted year-round on the Gulf of Mexico, though autumn is the least desirable planting season. Also, primary stems should be specified in autumn or early spring plantings and fillers should be specified in late spring and summer plantings. One culm per hill is typical. Spacing and depth are similar to that for American Beachgrass.

Sea Oats are not good initially as stabilizing plants. Though they will dominate in time, they should first be interspersed with Bitter Panicum or American Beachgrass, depending on the area. On the south Atlantic coast, February through April is the best planting season. In the Gulf, January through February is best for planting. One culm per hill is typical with just one or two rows mixed in with other dune plantings adequate.

Saltmeadow Cordgrass can be used along much of the east coast on lower, more moist sites. It is sometimes planted on low energy backshores for initial dune establishment. Plant in late winter and spring with five to ten stems per transplant, one transplant per hill. This plant is also known as Salt Hay. It was extensively harvested in the past and provided forage for grazing livestock.

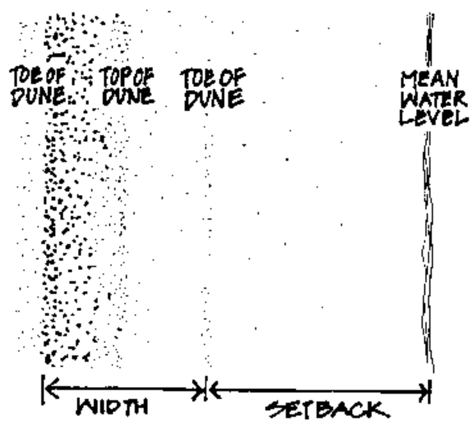
Japanese Sedge *Carex kobomugi* is an excellent plant to use in areas with potential for heavy foot traffic. It produces a low-growing cover that tolerates sand accumulation.

On the Pacific coast, European Beachgrass, easy to propagate, has been the major pioneer species planted. Planting season is late autumn, winter, and early spring. It is recommended that three to five stems per hill be planted. High initial survival rate is necessary as European Beachgrass does not infill readily.

American Dunegrass, the native pioneer species on Pacific coast dunes, has proven difficult to propagate and so has not been extensively planted. However, it has recently been receiving greater attention and use as a preferred native species. It must be planted when dormant in late November through February and when temperatures are below 13 degrees centigrade. Several stems per hill will help compensate for poor initial survival rate.

The placement and height of dunes are also of critical importance. A dune should not be established seaward of the extent of seasonal beach erosion. If seasonal beach erosion is 200 feet, the toe of the primary dune should not come closer than 200 feet from mean water when the beach is at its widest.

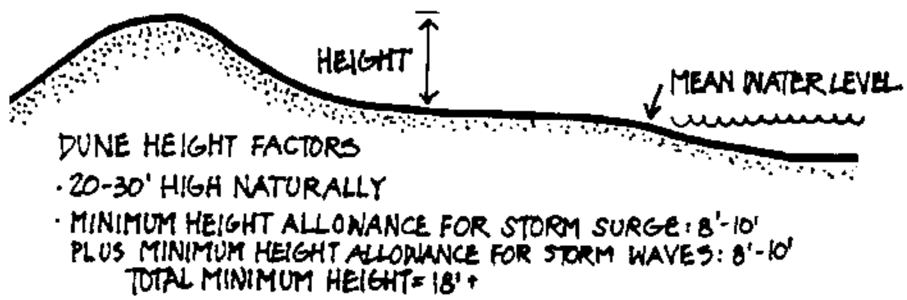
Figure 55 **Dune Building Technique—Setback**




**Factors controlling dune width:**
**100′-250′ width common—width controlled by minimum height and maximum slope design.**

**Factors controlling dune setback:**
**200′ minimum recommended by Dutch to allow for seasonal beach erosion. Setback should consider local seasonal beach erosion rates.**

Figure 56 **Dune Building Technique—Height**




The width of the dune will be a factor of height and slope of the dune face. Widths of 100 to 250 feet are common, and a height of 15 feet or more should be planned to protect against overtopping. (Dunes often achieve heights of 20 to 30 feet naturally.) With a 1-on-3 slope, a 15-foot-high dune would be 90 feet in width.

The protective height of a 15-foot-high dune on a beach 10 feet above mean water would be a total of 25 feet above mean water. This would offer about the best natural protection for inland development that could be expected if the dune line were continuous.

The actual minimum distance for development from the shoreline will depend on the distance that must be allowed from mean water for seasonal beach erosion and preservation of the primary dune. Assuming an annual 200 feet of seasonal beach erosion and 90 feet minimum width for the primary dune, then development should be held at a minimum of 290 feet from mean water when the beach is at its widest. While this setback formula may be useful in establishing a minimum, a realistic assessment of constantly shifting dune sands and shoreline would suggest greater allowance in setbacks for prudence. Increasing the minimum setback distance would allow for natural variance in beach erosion.

*Fringe Marshes and Mangroves*

For protected coastal areas in mid-Atlantic states, a procedure has been developed for creating a fringe marsh to enhance beach accretion (Sharp, Belcher, Oyler, no date; Garbish, 1977; Woodhouse, 1979). Analysis of the vegetative treatment potential is based on a scoring system of several environmental factors. The shoreline treatment consists of Smooth Cordgrass *Spartina alterniflora* plantings in the intertidal zone and Salt Meadow Cordgrass *Spartina patens* on the beach between high tide and the toe of the primary dune. The marsh grasses slow water in the intertidal zone causing deposition of sediment. As the beach builds seaward, the Smooth and Saltmeadow Cordgrass communities adjust to their new environments. The Smooth Cordgrass community moves seaward with the new intertidal zone, and the Saltmeadow Cordgrass colony expands in width as the distance between high tide and the toe of the primary dune grows wider. It is advisable to repair existing dune areas or plant new ones concurrent with fringe marsh development.

On the southeast and Gulf coasts, Mangroves are an important shore-stabilizing plant in protected areas. Mangroves are trees or small shrubs, some of which are characterized by a maze of dense roots that encourage deposition of sediments. Common species are Red Mangrove *Rhizophora Mangle*, Black Mangrove *Avicennia germinans*, and White Mangrove *Laguncularia racemosa*. Red Mangrove is the most tolerant of flooding and the White Mangrove is the least tolerant.

Seedlings of Red and Black Mangrove can be collected in the fall, and some nurseries do offer planting stock. Red Mangrove seedlings have the highest survival rate. Plants should not be set out until they are at least two years old, so seedlings will require potting until mature enough. Planting above the high-tide line will help ensure that wave action does not disturb the plants as they are becoming established. Once established, they will spread seaward (Stevely and Rabinowitz, 1982).

Figure 57 **SCS Fringe Marsh Test Plot**

Figure 58 **Mature Fringe Marsh**

## Preserving and Stablizing Coastal Bluffs

As with barrier-beach development, the single most important deterrent to property damage and health-and-safety risk in coastal bluff development is sensible development and use controls. Coastal bluffs, unlike barrier beaches, do not rebuild themselves following seasonal erosion. Eroded sections are gone forever. Environmentally sensitive controls would include appropriate use restrictions, protection—and in some cases modification—of existing bluff vegetation and profile, and restriction or control of pedestrian and vehicular traffic on the bluff face.

Figure 59 **Homes Threatened by Bluff Recession**

If toe erosion is the most serious problem affecting bluff stability, it will be necessary to utilize rigid man-made structures to control erosion, or to use appropriate setbacks and allow the bluffs to erode naturally. In either instance, bluff plantings will slow additional erosion from surface runoff.

*Use Regulations*

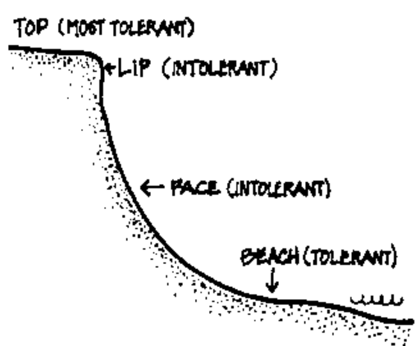
Use regulations for coastal bluff areas are pretty straightforward. The beach is tolerant of intensive recreational use but not of building. Where dunes exist behind the beaches and in front of the toe of the bluff, they are sensitive to development, and the same restrictions that apply to primary dunes on barrier beaches will in general apply here. The toe, face, and lip of the bluff are intolerant of any use, and access, where necessary, should be strictly limited to specially constructed stairs. The top of the bluff allowing setback for lip erosion, is tolerant of development provided no additional stresses are added to the bluff, such as excess surface runoff or a destabilizing amount of weight.

*Protecting Profiles and Vegetation*

Existing bluff profiles and vegetation often need protection. Where erosion has opened gullies or caused slides or slumping, these areas should be repaired immediately. Gullies may be filled before planting if the fill can be stabilized temporarily until vegetation binds it. However, filling may be impractical in some instances and, if so, should be avoided.

The toe of the bluff, the face, and the lip are all very sensitive to erosion, and all development—except for erosion-control structures—should be strictly forbidden here. If erosion-control structures such as bulkheads or revetments are allowed, it must be kept in mind that these will have a tendency to cause the beach to narrow and adjacent properties downdrift of littoral action to experience more severe erosion. Since it is much more difficult to control the proliferation of bulkheads once they have been allowed in a few sites, a regional planning approach to the issue is desirable.

Figure 60 **Bluff Suitability to Development and Use**




Frequently, views from the top of the bluff will be enhanced by selective removal or pruning of existing vegetation on the lip or upper face. Thinning forest cover can be actually beneficial if it will encourage growth of ground covers and shrubs that more effectively bind the soil surface and help prevent erosion from runoff. It may be necessary to infill with additional plantings, though, if the existing understory is not tolerant of increased light.

Figure 61 **Access Stair**

Figure 62 **Management Considerations for Coastal Bluffs**

1. **Restrict development by area.**
2. **Maintain and protect existing vegetation.**
3. **Maintain and protect existing profile.**
4. **Repair damaged areas.**
5. **Restrict circulation in sensitive areas.**
6. **Remove undercut trees, leaving roots.**
7. **Relieve heavy shade by selective tree removal and/or pruning to encourage low growing cover.**
8. **Intercept surface water runoff and pipe down to beach discharge or otherwise dispose.**
9. **Avoid excessive lawn watering or other surcharge to ground water possibly resulting in aggravated seepage and slope instability.**

*Controlling Pedestrian and Vehicular Traffic*

The bluff toe, face, and lip should be restricted to access of any type except on designated stairs or roads built especially for this purpose. Stairs typically are built of treated wood and should be set up off the soil surface at least 12 inches. Minimum spacings of 1/4 inch between planks will allow for through drainage and some light penetration underneath for plant growth there. Adequate signage will help in directing users to appropriate access areas and, in difficult spots, it may be necessary to resort to fencing or vegetative barriers.

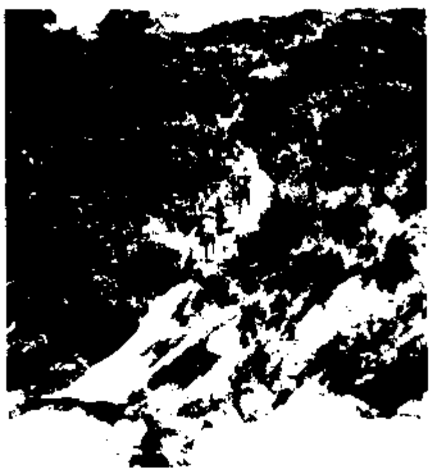


Figure 63 **Pedestrians on Bluff Face**

Signs for bluff areas should direct people to access points. Warning signs should prohibit walking or climbing on the face of bluffs and identify penalties, if any, for violators. Signs would be appropriate at both the top and bottom of the bluff.

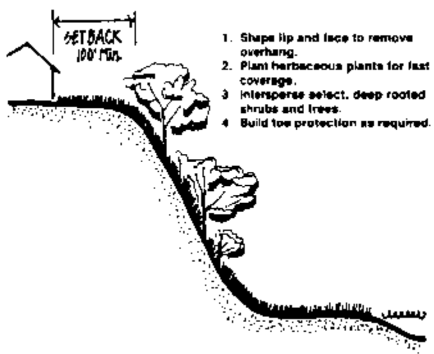
More detailed signs or interpretive displays explaining the importance of bluff vegetation in erosion control may be appropriate. These signs are useful tools for teaching about sensitive plants and erosion control.

Snowfencing sometimes is used to physically define restrictions on access. Holes should be repaired as soon as possible since paths can be quickly worn.

*Structural Improvements*

Any coastal bluff development must factor two important considerations: historical bluff recession rate and anticipated structural life of the development. For example, if bluff recession is one foot annually and a structure has a life expectancy of 100 years, it should be setback a minimum of 100 feet from the bluff lip. Another important consideration in setback is episodic erosion—the erosion resulting from major storms or other catastrophic events. Research on bluff erosion has demonstrated that most serious erosion is episodic (Bokuniewicz and Tanski, 1980; Kuhn and Shepard, 1984). Though annual recession rates may average only one foot, a serious storm can claim 20 feet or more at once. Though there are no set guidelines, additional setback distance for structures will always be prudent.

Figure 64 **Bluff Stabilization and Development Techniques**




Where bluff recession is primarily due to toe erosion resulting in undercutting and subsequent slumping of the face, structural improvements are usually the only means to gain stability. Concurrent with shoreline stabilization, the bluff face and lip should be shaped to attain as flat a slope as possible with a smooth transition from bluff face to the top of the bluff. All fallen trees and debris should be removed and the bluff immediately planted to prevent additional runoff erosion. Structural improvements in addition to shoreline stabilization may include terracing and surface and underground drainage systems.

In instances where surface and sub-

Figure 65 **Bluff Undercutting and Slumping**

Figure 66 **Undercut Lip and Trees**

Figure 67 **Groin—Accretion and Erosion**

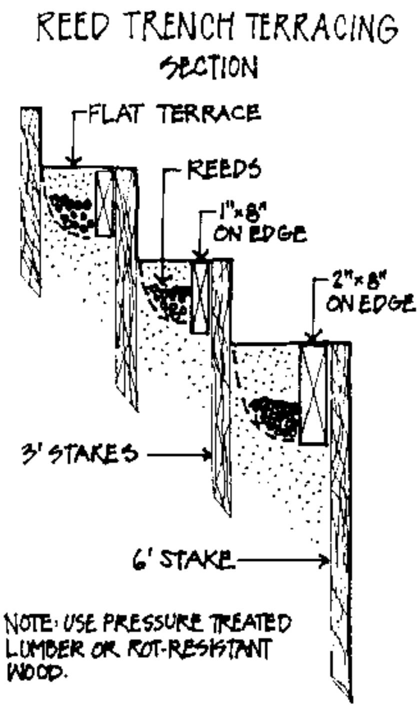
surface erosion are serious problems, they will need to be addressed with grading or structural modifications. For surface-water problems, all user-induced exacerbations, such as pool discharges, will require control and suitable alternatives. Similarly, for groundwater problems, such contributing factors as lawn sprinkler systems will require careful evaluation and control.

The next step in controlling surface or subsurface water will be to analyze interception and diversion. It is sometimes possible to divert runoff to storm drainage in the street. Otherwise, runoff will have to be collected at a low point and piped down the bluff.

Groundwater problems are more difficult to resolve. Digging into the bluff to install drainage tile has inherent flaws. Since the bluff face is often at an oversteepened angle of incline, disturbance could cause mass movement, exactly the event the designer is trying to prevent. Furthermore, alleviation of groundwater problems at the face of the bluff will not eliminate soil moisture stress behind the area where subsurface drains are placed. A soils engineer should be retained before costly and complex subsurface drainage work is recommended, and cost/benefit ratios should be carefully examined.

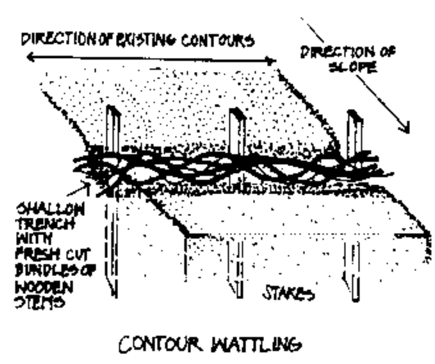
As an additional bluff erosion control, terracing is often employed. Terracing should be kept as simple and lightweight as possible. The reed trench (Grey and Leiser, 1982) alternative causes the least disturbance of subsurface soil and has been quite effective in some locations. The contour wattling (Grey and Leiser, 1982) method holds some promise also.

Figure 68 **Biotechnical Slope Protection Techniques—Reed Trench Terracing**




From Grey and Leiser, 1982

Figure 69 **Biotechnical Slope Protection Techniques—Contour Wattling**




From Grey and Leiser, 1982

### *Managing Natural Processes of Bluffs*

The utility of bluff plantings in controlling erosion stems chiefly from their control of erosion resulting from surface or groundwater movement. Surface erosion results from impact energy of individual raindrops and sheet or channelized flow over the lip and down the face. Plants that bind together the bluff soil will aid greatly in resisting surface erosion.

Groundwater erosion occurs when water percolating through bluff soil layers hits a relatively impermeable layer and travels along it to the surface at the face of the bluff. Plants can serve useful functions by holding soil together at the surface and, via root arching and buttressing forces (Grey and Leiser, 1982), holding soil masses together to help prevent mass movement. Transpiration also will aid in reducing soil moisture stress.

In preparing exposed bluff areas for revegetation, it will often be desirable to shape the surface. Deep gullies should be filled to remove channelized erosion features. The lip, if overhanging, should be cut back where space permits to smooth the transition from the face of the bluff to the top.

An oversteepened bluff face should be graded back to a stable angle of incline. The angle of repose of a bluff face will often be much greater than that encountered in other areas. It is not uncommon to find angles of incline in excess of 3:1, and stable angles of 1:1 have been reported with assistance of terracing (Grey and Leiser, 1982).

In areas where existing plants have developed a dense canopy, light is prevented from reaching the understory. This results in a sparse groundcover, and so the canopy should be thinned to encourage growth here. This can be accomplished by selective pruning of branches and removal of some of the larger plants.

It may be desirable to construct a diversion or waterway at the top with swales or other features to divert runoff. If so, runoff should be directed where it will not run down the face in another location, where it can be picked up in existing stormwater drains, or where it can be piped down the face to discharge safely in the water.

In new bluff plantings it is important to select plants that will establish themselves quickly and cover and bind the soil surface. Grasses, trailing vines, and spreading shrubs are the best choices. A mat to hold surface soil while the plants establish themselves will often be helpful, as will a slow-release fertilizer added to each plant

Figure 70 **Mature Terracing Project**

Figure 71 **Fully Denuded Bluffs— Severe Surface Erosion**

pit. It is important to disturb the soil as little as possible; therefore, work will most likely be done by hand—an expensive procedure.

Of special concern in bluff plantings are unusually moist conditions, resulting from groundwater seepage, and unusually shady conditions where high bluffs face north. In the first situation, a sandy bluff, otherwise requiring plants characteristic of a dry environment and well-drained soils, might require instead plants characteristic of wet, poorly drained soils where seepage occurs.

On north-facing bluffs, shady conditions will be an additional concern. American Beachgrass will not tolerate much shade, for instance, and will not be suitable for shady conditions in the northeast. Virginia Creeper, Traililng Honeysuckle varieties, or Crown Vetch will be much more successful here. Switch Grass *Panicum virgatum* also may work.

For rapid establishment of protective cover, hydroseeding offers potential. Hydroseeding requires heavy equipment, though, and an appropriate angle from which to spray. An unstable bluff lip and poor operator visibility would limit application from above. Beach access would be necessary for optimal application from below.

In the final analysis, bluff erosion can be controlled to a certain extent, buying time for property owners at the top of the bluff. Plants can play an important role, but the basic processes of bluff erosion will continue. Wave attack on an unprotected toe will continue to undermine the bluff causing the face to steepen and slough off. Protection of the toe will not guarantee permanent erosion control, either. Eventually the beach may recede, the toe protection structure may be undermined, and the bluff once again may be susceptible to erosion.

There are no easy solutions for land preservationists at the water's edge, especially in bluff areas. Erosion can be slowed but never completely controlled. Moreover, material eroded from a bluff supplies sand for beaches at the foot of the bluff. Complete control of bluff erosion will cause beaches to disappear over time. A community or regional management plan must therefore consider controlled erosion—allowing erosion to occur in some areas, to supply beach material, and restricting erosion in other areas (Bokuniewicz and Tanski, 1980).

Figure 72 **Bluff Slump Attributable to Bulkhead Failure**

Figure 73 **Stone Revetment**

# PART III: CONCLUSION

An understanding of natural processes and the role of vegetation is critical in coastal design. Coastal plantings are useful as natural erosion inhibitors. An appreciation of their functional and aesthetic qualities will lead, it is hoped, to greater conservation measures by individuals, private groups, and public agencies working with geologists, soil scientists, horticulturalists, ecologists, and design professionals.

Preservation of natural vegetation and landforms without introduction of erosion control structures is most feasible in areas of low-intensity development. Where major developments require protection, erosion-control structures may be appropriate. In either instance vegetation will be an important component of the overall design solution and will be helpful in controlling erosion in coastal areas.

Availability of vegetative stock and local conditions will determine which plants are best suited to individual sites and when or how they should be planted. For advice on local considerations and planting stock availability, contact your local Soil and Water Conservation District personnel or District Conservationist with the U.S.D.A. Soil Conservation Service. They maintain current lists of suppliers and literature on plants especially suited to local growing conditions. Other organizations that may prove helpful include Cooperative Extension (especially the Sea Grant Extension Programs), state natural-resource agencies, and the U.S. Army Corps of Engineers. The latter two may require permits for work in the coastal zone.

As with other design problems, each site requires a specific solution. The parameters presented in this publication are general. A site-specific solution will require more specificity in resolving local erosion problems.

The sciences that explore our understanding of coastal processes are continually evolving. New theories arise that challenge dogmatic thinking. Our greater appreciation of natural forces shaping shorelines is leading to new approaches to conservation. The consideration of natural processes and the wise use of plant materials are unique tools of the landscape architect and clearly mark an important role for the professional in coastal-development or conservation projects.

However, it is important that landscape architects recognize the highly specialized nature of coastal erosion control and that they consult with erosion specialists, geologists, soil scientists, ecologists, and horticulturalists with coastal expertise. Local site conditions vary dramatically and each site requires a highly individualized design solution.

# GLOSSARY

(Adapted from U.S. Army, Corps of Engineers, 1981, and Leatherman, 1979)

*Backshore*—The zone of the shore or beach lying between the foreshore and the coastline and acted upon by waves only during severe storms, especially when combined with exceptionally high water.

*Barrier beach*—Land mass composed of sand and other loose sediments transported by waves, currents, storm surges, and winds, that protects other features, such as lagoons and salt marshes, from direct wave attack of the open ocean.

*Barrier island*—Subcategory of*barrier beach.*

*Beach*—The zone of sedimentary material that extends landward from the low-water line to the place where there is marked change in material or form, or to the line of permanent vegetation (usually the effective limit of storm waves). The seaward limit of a beach—unless otherwise specified—is the mean low-water line. A beach includes foreshore and backshore.

*Berm*—A nearly horizontal part of the beach or backshore formed at the high-water line by waves depositing material. Some beaches have no berms, others have one or more.

*Biotechnical*—Use of living organisms, e.g., plants, to resolve a technical problem.

*Blowout*—Dune erosion by wind.

*Bluff*—A high, steep bank composed of erodible materials.

*Bulkhead*—A structure or partition placed on a bank or bluff to retain or prevent sliding of the land and protect the inland area against damage from wave action.

*Coast*—The strip of land, of indefinite width (up to several miles), that extends from the shoreline inland to the first major change in terrain features.

*Downdrift*—The direction of predominant movement of littoral materials.

*Dune*—A ridge or mound of loose, wind-blown material, usually sand.

*Erosion*—The wearing away of land by the action of natural forces.

*Foreshore*—The part of the shore lying between the crest of the seaward berm (or upper limit of wave wash) and the water's edge at low water. The foreshore is ordinarily traversed by the runup and return of the waves.

*Groin*—A fingerlike structure built perpendicular to the shoreline, usually with other groins, to trap littoral drift or retard erosion of the shore.

*Groundwater*—Water within the earth that supplies wells and comes to the surface by seepage or in springs.

*Jetties*—One or two groins built at the sides of an inlet to protect and maintain navigable inlets.

*Littoral*—Of or pertaining to a shore.

*Littoral drift*—The sedimentary material moved along the shoreline under the influence of waves and currents.

*Littoral transport*—The movement of littoral drift along the shoreline by waves and currents. Includes movement parallel (longshore transport) and perpendicular (on-offshore transport) to the shore.

*Longshore*—Parallel to and near the shoreline.

*Marsh*—An area of soft, wet, or periodically submerged land, generally treeless and usually characterized by grasses and other low vegetation.

*Nourishment*—The process of replenishing a beach. It may be brought about naturally, by accretion due to the longshore transport, or artificially, by the deposition of dredged materials.

*Overtopping*—The passing of water over the top of a natural or man-made structure as a result of wave runup or surge.

*Permit*—A document issued that expresses the assent of a government agency, so far as concerns the public rights and the general public interest, for the accomplishment of certain works (e.g., construction).

*Revetment*—A facing placed on a bank or bluff of stone to protect a slope, embankment, or shore structure against erosion by wave action or currents.

*Riparian rights*—The rights of a person owning land containing or bordering on a water course or other body of water in or to its banks, bed, or waters.

*Riprap*—A layer, facing, or protective mound of rubble or stones randomly placed to prevent erosion, scour, or sloughing of a structure or embankment; also, the stone used for this purpose.

*Runup*—The rush of water up a beach or structure, associated with the breaking of a wave. The amount of runup is measured according to the vertical height above still-water level that the rush of water reaches.

*Scour*—Removal of underwater material by waves and currents, especially at the base or toe of a shoreline structure.

*Seawall*—A structure separating land and water areas, primarily designed to prevent erosion and other damage due to wave action. See also *bulkhead.*

*Shore*—The narrow strip of land in immediate contact with the water, including the zone between high- and low-water lines. See also *backshore* and *foreshore.*

*Spit*—Subcategory of *barrier beach*—attached to the mainland.

*Tide*—The periodic rising and falling of water that results from gravitational attraction of the moon and sun acting on the rotating earth.

*Updrift*—The direction opposite that of the predominant movement of littoral materials.

*Wave height*—The vertical distance between a wave crest and the preceding trough.

*Wave length*—The horizontal distance between similar points on two successive waves (e.g., crest to crest or trough to trough), measured in the direction of wave travel.

*Wave period*—The time in which a wave crest travels a distance equal to one wave length. Can be measured as the time for two successive wave crests to pass a fixed point.

# REFERENCES CITED AND SELECTED BIBLIOGRAPHY

## Part I: General References


Bennett, D., 1970. *202 Questions for the Endangered Coastal Zone. American Littoral Society, Sandy Hook, NJ.*

*Coates, D.R., 1973, ed. Coastal Geomorphology.* State University of New York, Binghamton, NY.

Foley, D.J., 1965. *Gardening by the Sea.* Parnassus, New York, NY.

Fulton, K., 1981. *A Manual for Researching Historical Coastal Erosion*, Report No. TCSGCP-003. California Sea Grant College Program, University of California, Santa Cruz, CA.

Goodno, R.H., 1978. *Landscaping the Seashore Cottage*, Marine and Coastal Facts No. 4. Massachusetts Sea Grant Program, Massachusetts Institute of Technology, Cambridge, MA.

Gray, D., and A. Leiser, 1982. *Biotechnical Slope Protection and Erosion Control.* Van Nostrand Reinhold, New York, NY.

Gray, D.H., 1975. *The Role and Use of Vegetation for the Protection of Backshore Slopes in the Coastal Zone. University of Michigan, Ann Arbor, MI.*

*Great Lakes Basin Commission, 1976. The Influence of Vegetation on Slope Processes in the Great Lakes Region. Ann Arbor, MI.*

*Greene, C., and M. Potts, 1967. The Salty Thumb.* Montauk Village Association, Inc., Montauk, NY.

Heikoff, J., 1975. *Shorelines and Beaches in Coastal Management: A Bibliography.* Council of Planning Librarians: Exchange Bibliography, Monticello, IL.

Koppleman, L.E., P.K. Weyl, M.G. Gross, and D.S. Davies, 1976. *The Urban Sea: Long Island Sound.* Praeger, New York, NY.

Lewis, R.R., 1982, ed. *Creation and Restoration of Coastal Plant Communities.* CRC Press Inc., Boca Raton, FL.

McHarg, I., 1969. *Design with Nature.* Doubleday and Company, Inc., New York, NY.

Menniger, E.A., 1964. *Seaside Plants of the World: A Guide to Planning, Planting and Maintaining Salt Resistant Gardens.* Hearthside Press, New York, NY.

Olson, G., 1976. *Fertility Soil Map Units in Suffolk County, NY*, Cornell Agronomy Mimeo, 76-13. Cornell University, Department of Agronomy, Ithaca, NY.

Petry, L.C., and M.G. Norman, 1963. *A Beachcomber's Botany.* The Chatham Conservation Foundation, Inc., Chatham, MA.

Sharp, W.C., 1977. *Conservation Plants for the Northeast.* U.S. Department of Agriculture, Soil Conservation Service, Program Aid No. 1154, Washington, DC.

Sharp, W.C., 1982. *"Best of beach vegetation." Parks and Recreation Resources*, 1[1]-Jan.-Part I., 1[2] Feb.-Part II, 1[4,5]-May/June Part III, 1[7,8]-July/August-Part IV.

U.S. Army, Corps of Engineers, 1981. *Low Cost Shore Protection.* Washington, DC.

U.S. Army, Corps of Engineers, 1977. *Shore Protection Manual.* Coastal Engineering Research Center, Ft. Belvoir, VA.


## Part II: Coastal Bluffs


Bokuniewicz, H., and J. Tanski, 1980. "Managing localized erosion of coastal bluffs." *Proceedings of the Conference Coastal Zone '80*, pp. 1883-1898. ASCE, Hollywood, FL.

Canada Center for Inland Waters, 1976. *The Vegetation of the Great Lakes Canadian Shoreline: Its Role in Controlling Rates of Erosion.* Environment Canada, Burlington, Ontario, Canada.

Clemens, R.H., *The Role of Vegetation in Shoreline Management: A Guide for Great Lakes Shoreline Property Owners.* Great Lakes Basin Commission, Ann Arbor, MI.

DeYoung, B., and L. Brown, 1979. *Controlling Bluff Groundwater along the Great Lakes.* NYS Sea Grant Extension Program, Ithaca, NY.

Garbish, E.W., Jr., 1977. "Marsh developments for shore erosion." *Great Lakes Basin Workshop Proceedings.* Great Lakes Basin Commission, Ann Arbor, MI.

Good, R.E., and N.F. Good, 1970. "Vegetation of the sea cliffs and adjacent uplands on the north shore of Long Island, New York." *Bulletin* of Torrey Botanical Club, 97[4]: 204-208.

Hall, V.L., and J.D. Ludwig, 1976. *Evaluation of Potential Use of Vegetation for Erosion Abatement along the Great Lakes Shoreline.* U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Ft. Belvoir, VA.

Illinois Coastal Zone Management Program. *Harmony with the Lake: Guide to Bluff Stabilization.* Illinois Dept. of Transportation, Chicago, IL.

Kuhn, G.G., and Shepard, F.P., 1984. *Sea Cliffs, Beaches, and Coastal Valleys of San Diego County.* University of California Press, Berkeley, CA.

Tainter, S.P., 1982. *Bluff Slumping and Stability: A Consumer's Guide.* Michigan Sea Grant Program, Ann Arbor, MI.

U.S. Army, Corps of Engineers, 1978. *Help Yourself: A Discussion of Erosion Problems on the Great Lakes and Alternative Methods of Shore Protection.* North Central Division, Chicago, IL.

U.S. Department of Agriculture, Soil Conservation Service, 1970. *Shoreline Bluff Erosion Control*, Information Sheet NY-65. Riverhead, NY.


## Part III: Barrier Beaches


Barbour, M.G., and J. Major, 1977, ed. *Terrestrial Vegetation of California.* John Wiley & Sons, Inc., New York, NY.

Barrier Island Workshop, 1976. *Barrier Islands and Beaches: Technical Proceedings* *of the 1976 Barrier Islands Workshop*. Conservation Foundation, Washington, DC.

Bokuniewicz, H.J., M. Zimmerman, M. Keyes, and B. McCabe, 1980. *Seasonal Beach Response at East Hampton, NY*. Marine Sciences Research Center, SUNY at Stony Brook, NY.

Bokuniewicz, H.J., 1981. "The seasonal beach at East Hampton, New York." *Shore and Beach*. July, pp. 28-33.

Costaris, C.H., and H.H. Hendrickson, 1983. *Landscaping at the Seashore*, Extension Bulletin 433. Cooperative Extension Service, Cook College, New Brunswick, NJ.

Davis, J.H., Jr., 1975. *Stabilization of Beaches and Dunes by Vegetation in Florida*, Report No. 7., Florida Sea Grant Program, Gainsville, FL.

Gares, P., K. Nordstrom, and N. Psuty, 1983. *Coastal Dunes, Their Function, Delineation, and Management*. Center for Coastal and Environmental Studies, Rutgers University, New Brunswick, NJ.

Gares, P., K. Nordstrom, and N. Psuty, 1980. "Delineation and implementation of a dune management district." *Proceedings of the Conference Coastal Zone 80*, pp. 1269-1288. ASCE, Hollywood, FL.

Graetz, K.E., 1973. *Seacoast Plants of the Carolinas for Conservation and Beautification*. UNC-SG-73-06. University of North Carolina Sea Grant Program, Raleigh, NC.

Jagschitz, J.A., and R.C. Wakefield, 1966. *Restoration and Retention of Coastal Dunes with Fences and Vegetation*, Bulletin No. 382. Agricultural Experiment Station, University of Rhode Island, Kingston, RI.

Jagschitz, J.A., and R.C. Wakefield, 1971. *How to Build and Save Beaches and Dunes*, Marine Leaflet Series No. 4, Agricultural Experiment Station, University of Rhode Island, Kingston, RI.

Jagschitz, J.A., and R.S. Bell, 1966. *American Beachgrass: Establishment, Fertilization and Seeding*. Bulletin #383, Agricultural Experiment Station, University of Rhode Island, Agricultural Experiment Station, Kingston, RI.

Knutson, P.L., 1978. *Planting Guidelines for Dune Creation and Stabilization: Coastal Zone '78*, pp. 762-779. ASCE, San Francisco, CA.

Lane, A.C., 1977. *Stabilization of Barrier Dunes by Vegetation*, Marine and Coastal Facts No. 2. Massachusetts Sea Grant Program, Massachusetts Institute of Technology, Cambridge, MA.

Leatherman, S.P., 1979. *Barrier Island Handbook*. National Park Service, Washington, DC.

Martin, William E., 1959. "The Vegetation of Island Beach State Park, New Jersey." *Ecological Monographs*, 29[1].

Mayo, B.S., and L.B. Smith, Jr., 1982, ed. *Proceedings of Barrier Island Forum and Workshop*, Provincetown, MA, May 1980. National Park Service, North Atlantic Region, Boston, MA.

Nordstrom, K., and N. Psuty, 1980. "Dune district management: a framework for shorefront protection and land use control." *Coastal Zone Management Journal*, 7[1]:1-23.

Peterson, J.M., and E. Dersch, 1980. *A Guide to Sand Dune and Coastal Ecosystem Functional Relationships*, Extension Bulletin E-1529. Michigan Sea Grant Marine Advisory Service, East Lansing, MI.

Salamun, P.J., and F.W. Stearns, 1978. *The Vegetation of the Lake Michigan Shoreline in Wisconsin*, Advisory Report No. 420. University of Wisconsin Sea Grant College Program, Milwaukee, WI.

Salmon, J., D. Henningsen, and T. McAlpin, 1982. *Dune Restoration and Revegetation Manual*, Report No. 48. Florida Sea Grant College, University of Florida, Gainesville, FL.

Savage, Terry W., 1963. "Experimental study of dune building." *Proceedings of the Eighth Conference of Coastal Engineering*, ASCE, Mexico City, Mexico.

Seltz, J., 1976. *The Dune Book: How to Plant Grasses for Dune Stabilization*, UNC Sea Grant Publication 76-16. University of North Carolina Sea Grant College Program, Raleigh, NC.

Seneca, E.D., and W.W. Woodhouse, Jr., 1977. *Dune Stabilization with "Panicum Amarum" along the North Carolina Coast*, UNC Sea Grant Publication 77-03. University of North Carolina Sea Grant College Program, Raleigh, NC.

Stout, J., 1980. *First Aid for Damaged Beaches and Dunes*, DMASGP-80-003-2. Mississippi-Alabama Sea Grant Consortium, Auburn, AL.

Tri-State Conference Report, 1974. *Methods for Beach and Sand Dune Protection*, UNC Sea Grant Publication RP #70. University of North Carolina Sea Grant College Program, Raleigh, NC.

U.S. Army, Corps of Engineers, 1975. *Construction and Stabilization of Coastal Foredunes with Vegetation: Padre Island, Texas*, Miscellaneous Paper No. 9-75. Coastal Engineering Research Center, Fort Belvoir, VA.

U.S. Army, Corps of Engineers, 1980. *Experimental Dune Restoration ankd Stabilization, Nauset Beach, Cape Cod, Massachusetts*, Technical Paper No. 80-5.

Coastal Engineering Research Center, Fort Belvoir, VA.

U.S. Department of Agriculture, Soil Conservation Service, 1984. *Plants for Coastal Dunes of the Gulf and South Atlantic Coasts and Puerto Rico*, Agriculture Information Bulletin 460. Washington, DC.

U.S. Department of Interior, Heritage, Conservation and Recreation Service, 1980. *Report of the Barrier Island Work Group*. Washington, DC.

Walton, T.L., Jr., and T.C. Skinner, 1983. *Beach Dune Walkover Structures*, Map-18. Florida Sea Grant Program, Gainesville, FL.

Woodhouse, W.W., Jr., E.D. Seneca, and S.W. Broome, 1976. *Ten Years of Development of Man-Initiated Coastal Barrier Dunes in North Carolina*. Agricultural Experiment Station, University of North Carolina. Raleigh, NC.

Zak, J.M. *Controlling Drifting Sand Dunes on Cape Cod*, Bulletin No. 563. Massachusetts Agricultural Experiment Station, University of Massachusetts, Amherst, MA.

## Part IV: Marshes

Broome, S.W., E.D. Seneca, and W.W. Woodhouse, Jr., 1981. *Planting Marsh Grasses for Erosion Control*, UNC Sea Grant Publication 81-09. University of North Carolina Sea Grant College Program, Raleigh, NC.

Lane, A.C., 1979. *Establishing New Salt Marshes*, Marine and Coastal Facts No. 7. Massachusetts Sea Grant Program, Massachusetts Institute of Technology, Cambridge, MA.

Sharp, W.C., C.R. Belcher, and J. Oyler. *Vegetation for Tidal Stabilization in the Mid-Atlantic States*. U.S. Department of Agriculture, Soil Conservation Service, Broomall, PA.

Stevely, J., and L. Rabinowitz, 1982. *Mangroves, A Guide for Planting and Maintenance, MAP-25*. Sea Grant Marine Advisory Program, University of Florida, Gainesville, FL.

*U.S. Army, Corps of Engineers, 1978. Wetland Habitat Development with Dredged Material: Engineering and Plant Propagation*, Tech. Report DS-78-16. Waterways Experiment Station, Washington, DC.

Woodhouse, W.W., Jr., 1979. *Building Salt Marshes along the Coast of the Continental United States*, sp. Rep. No. 1, U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, VA.

## Part V: Legal, Planning, and Management References

Carter, L.J., 1975. *The Florida Experience: Land and Water Policy in a Growth State*. Johns Hopkins University Press, Baltimore, MD.

••*Clark, J., 1974. Coastal Ecosystems: Ecological Considerations for Management of the Coastal Zone*. Conservation Foundation, Washington, DC.

Clark, J., 1977. *Coastal Ecosystem Management: A Technical Manual for the Conservation of Coastal Zone Resources*. John Wiley, New York, NY.

Coastal Zone Management Act of 1972. U.S. Government Printing Office, Washington, DC.

Goodell, H., 1972. *Environmental Application of Remote Sensing Methods to Coastal Zone Land Use and Marine Resource Management*. Washington, DC.

Heikoff, J., 1976. *The Politics of Shore Erosion: Westhampton Beach*. Ann Arbor, MI.

Hite, J., and J. Stepp, 1971. *Coastal Zone Resource Management*. Praeger, New York, NY.

Kavenaugh, W.K., 1980. *Vanishing Tidelands: Land Use and the Law, Suffolk County, NY, 1650-1979*. NYS Sea Grant Institute, Albany, NY.

Marr, P.D., 1976. *Governmental Jurisdictions of the New York Coastal Zone*. NY Sea Grant Institute, Albany, NY.

Morisawa, M., and A.M. King Cuchlaine, 1974. *Monitoring the Seashore: A Guide for Measuring Beach Erosion*. NYS Sea Grant Extension Program, Ithaca, NY.

NYS Legislature, 1945. "Report. . . (on) the problem of checking erosion along the Atlantic shoreline." Steidinger Press, Albany, NY.

Nassau-Suffolk Regional Planning Board, 1976. *Integration of Regional Land Use Planning and Coastal Zone Science: A Guidebook for Planners*. U.S. Department of Housing and Urban Development, Washington, DC.

Roy Mann and Associates, Inc., 1975. *Shoreline Appearance and Design, A Planning Handbook*. (From *People and the Sound* series) National Park Service/New England River Basins Commission, Springfield, VA.

Sorensen, J.C., 1971. *A Framework for Identification and Control of Resource Degradation and Conflict in the Multiple Use of the Coastal Zone*. Berkeley Department of Landscape Architecture, Berkeley, CA.

# INDEX OF PLANTS

**Note:** Plant nomenclature follows *Hortus Third*, by the Staff of the Liberty Hyde Bailey Hortorium at Cornell University, published by Macmillan Publishing Company, Inc., New York, NY, 1976.

**About the Author**

Stephen Lopez is a landscape architect and city planner. He received his B.L.A. from the State University of New York, College of Environmental Science and Forestry at Syracuse, and his M.S. in Planning from Pratt Institute in New York City. Experienced in both the private and public sectors, he directs the Lower Hudson River Office with Cornell University's Sea Grant Extension Program. His expertise includes design, construction, physical and fiscal planning, and education.

LATIS

LATIS, Landscape Architecture Technical Information Series, is produced by the American Society of Landscape Architects, the national organization that represents the profession of landscape architecture in the United States.

ASLA

American Society of Landscape Architects