Shore Erosion Control with Salt Marsh Vegetation

by

Paul L. Knutson and Margaret R. Inskeep

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Salt marsh plants are effective in stabilizing eroding shorelines in many sheltered coastal areas. Exceptional results have been achieved in a variety of intertidal environments at a fraction of the cost required for comparable structural protection. Techniques are available for the efficient propagation of several marsh plants for use in shore stabilization. This report provides a method for determining site suitability, establishes guidelines for planting marshes to control erosion, and compares the costs of vegetation to structural methods of erosion control.

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PREFACE

This report provides criteria for planting salt marsh vegetation to control erosion. It is intended to update information presented in "Planting Guidelines for Marsh Development and Bank Stabilization," CETA 77-3 (Knutson, 1977) and "Wetland Habitat Development with Dredged Material: Engineering and Plant Propagation," TR DS-78-16 (U.S. Army Engineer Waterways Experiment Station, 1978). The work was carried out under the coastal ecology research program of the U.S. Army Coastal Engineering Research Center (CERC).

The report was prepared by Paul L. Knutson and Margaret R. Inskeep, Coastal Ecology Branch, under the general supervision of E.J. Pullen, Chief, Coastal Ecology Branch, Research Division. Illustrations were prepared by L. Martin.

Comments on this publication are invited.

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Ted E. Bishop

TED E. BISHOP
Colonel, Corps of Engineers
Commander and Director

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FIGURES

CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U.S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	by	To obtain
inches	25.4	millimeters
	2.54	centimeters
square inches	6.452	square centimeters
cubic inches	16.39	cubic centimeters
feet	30.48	centimeters
	0.3048	meters
square feet	0.0929	square meters
cubic feet	0.0283	cubic meters
yards	0.9144	meters
square yards	0.836	square meters
cubic yards	0.7646	cubic meters
miles	1.6093	kilometers
square miles	259.0	hectares
knots	1.852	kilometers per hour
acres	0.4047	hectares
foot-pounds	1.3558	newton meters
millibars	1.0197×10^{-3}	kilograms per square centimeter
ounces	28.35	grams
pounds	453.6	grams
	0.4536	kilograms
ton, long	1.0160	metric tons
ton, short	0.9072	metric tons
degrees (angle)	0.01745	radians
Fahrenheit degrees	5/9	Celsius degrees or Kelvins[1]

[1] To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use formula: $C = (5/9)(F - 32)$.
To obtain Kelvin (K) readings, use formula: $K = (5/9)(F - 32) + 273.15$.

SHORE EROSION CONTROL WITH SALT MARSH VEGETATION

by
Paul L. Knutson and Margaret R. Inskeep

I. INTRODUCTION

Erosion in salt and brackish water areas of the contiguous United States can be controlled either structurally or with recently developed nonstructural techniques using native marsh plants. Vegetation, where feasible, is usually more cost-effective than structures built to control erosion. This report provides a method for determining site suitability, establishes guidelines for planting marshes to control erosion, and compares the costs of vegetation to structural methods.

II. BACKGROUND

Coastal marshes are herbaceous plant communities along shorelines periodically flooded by salt or brackish water. Vulnerability to wave attack during early stages of establishment prevents the natural invasion of marshes along many shorelines. Even mature natural marshes may suffer permanent damage from severe storms. A common form of damage is the formation of a scarp or bank on the seaward edge of the marsh. Once a scarp is formed it becomes a focal point of continued erosion.

Both natural and planted marshes (Fig. 1) function in three ways to reduce shore erosion: (1) wave attenuation, (2) sediment capture, and (3) sediment stabilization. Both wave attenuation and sediment capture are directly related to stem density and marsh width (landward to seaward) (Dean, 1978). Stem density is dependent on many variables, including (1) species, (2) geographical area, (3) elevational zone within the marsh, (4) season, (5) maturity of the marsh, and (6) wave climate. Marsh width is influenced by shore slope and tidal range. During the winter when the aerial stems provide only limited resistance to wave energy, the sediment stabilizing function of the plant roots becomes critical. Root mass may increase the shear strength of soils by a factor of 2 or 3 (Gray, 1974).

Planted marshes can often succeed on shorelines where natural processes have failed to provide plant cover. These marshes, like natural marshes proceed through a cycle which includes a period of establishment, a period of stability, and a period of erosion, where wave-induced erosion is a factor (Knutson, et al., 1981). The functional life of planted marshes will be shorter in areas where waves are more severe.

III. DETERMINING SITE SUITABILITY

1. Evaluating Wave Climate.

a. Indicators of Wave Severity. In brackish and salt water tidal areas, wave climate severity has a major influence on marsh establishment. Three shoreline characteristics--fetch, shore configuration, and sediment grain size--are useful indicators of wave climate severity and planting success (Knutson, et al., 1981). *Fetch*, the distance the wind blows over water to generate waves, is inversely related to successful erosion control. *Shore*

Figure 1. Oldest recorded salt marsh planting (planted in 1928), Cherry Stone Inlet, Virginia.

configuration, the shape of the shoreline, is a subjective measure of the shoreline's vulnerability to wave attack. For example, a cove is relatively sheltered while a headland is vulnerable to wave attack from many directions. The *grain size* of beach sands is also related to wave energy. Fine-grained sands frequently indicate low energy beaches while coarser materials indicate higher energy beaches. Two additional factors should be considered when evaluating wave climate--boat traffic and offshore depth. Shore areas in close proximity to boat traffic will be subject to ship-generated waves. Shallow offshore depths impede the development and growth of larger waves. However, no method is available for numerically evaluating boat traffic and offshore depth.

b. Method for Evaluating Wave Climate. Knutson, et al. (1981) developed a method for evaluating wave climate based on observed relationships between fetch, shore configuration, grain size, and success in controlling erosion in 86 salt marsh plantings in 12 coastal states. The method evaluates planting potential on a case-by-case basis, using a vegetative stabilization site evaluation form (Fig. 2). Each of the four *Shore Characteristics* on the form is measured for the area in question, the *Descriptive Categories* best describing the area are identified, and the *Weighted Score* associated with each descriptive category is noted. A *Cumulative Score* is calculated, and the success rate associated with the appropriate range of cumulative scores is noted under *Score Interpretation*. Sites with a cumulative score of 300 or greater (observed success rate of 80 to 100 percent) are very promising planting environments. However, even sites with a cumulative score of 201 to 300 (observed success rate of 30 to 80 percent) will often constitute an acceptable risk considering the higher costs associated with structural shore protection alternatives (see Sec. VII).

1. SHORE CHARACTERISTICS	2. DESCRIPTIVE CATEGORIES (SCORE WEIGHTED BY PERCENT SUCCESSFUL)				3. WEIGHTED SCORE
a. FETCH-AVERAGE AVERAGE DISTANCE IN KILOMETERS (MILES) OF OPEN WATER MEASURED PERPENDICULAR TO THE SHORE AND 45° EITHER SIDE OF PERPENDICULAR 	LESS THAN 1.0 (0.6)	1.1 (0.7) to 3.0 (1.9)	3.1 (1.9) to 9.0 (5.6)	GREATER THAN 9.0 (5.6)	
	(87)	(66)	(44)	(37)	
b. FETCH-LONGEST LONGEST DISTANCE IN KILOMETERS (MILES) OF OPEN WATER MEASURED PERPENDICULAR TO THE SHORE OR 45° EITHER SIDE OF PERPENDICULAR 	LESS THAN 2.0 (1.2)	2.1 (1.3) to 6.0 (3.7)	6.1 (3.8) to 18.0 (11.2)	GREATER THAN 18.0 (11.2)	
	(89)	(67)	(41)	(17)	
c. SHORELINE GEOMETRY GENERAL SHAPE OF THE SHORELINE AT THE POINT OF INTEREST PLUS 200 METERS (660 FT) ON EITHER SIDE	COVE 	MEANDER OR STRAIGHT 	HEADLAND 		
	(85)	(62)	(50)		
d. SEDIMENT GRAIN SIZE OF SEDIMENTS IN SWASH ZONE (mm)	less than 0.4	0.4 – 0.8	greater than 0.8		
	(84)	(41)	(18)		
4. CUMULATIVE SCORE					

5. SCORE INTERPRETATION			
a. CUMULATIVE SCORE	122 – 200	201 – 300	300 – 345
b. POTENTIAL SUCCESS RATE	0 to 30%	30 to 80%	80 to 100%

Figure 2. Vegetative stabilization site evaluation form.

2. Other Environmental Factors.

Salinity is a major stress on all plants growing within the intertidal zone. However, the species specified for use in this report are all salt tolerant. The salinity tolerance range for each species is presented in the following section on planting guidelines.

Soil type will mainly affect the planting technique and need for fertilizer since most salt marsh plants tolerate a wide range of substrates. The actual planting will be easier in loose sandy soils than in heavy plastic or very compact soils.

Strong tidal action can undermine plantings; therefore, location and migration of tidal channels in the vicinity of prospective plantings should be considered.

The presence of healthy marsh patches on or near the site is an excellent indicator that there are no environmental factors which are likely to limit plant establishment at the site.

IV. PLANTING GUIDELINES

1. Selecting Plant Species.

For erosion control projects, the intertidal zone is the most critical area to be planted and stabilized. If a healthy band of intertidal marsh can be established along a shore, revegetation of the slope behind it will occur through natural processes. Four species of pioneer plants have demonstrated potential in stabilizing the part of the intertidal zone which is in direct contact with waves: smooth cordgrass *(Spartina alterniflora)* along the gulf and Atlantic coasts, Pacific cordgrass *(Spartina foliosa)* on the Pacific coast from Humboldt Bay south to Mexico, and Lyngbye's sedge *(Carex Lyngbyei)* and tufted hairgrass *(Deschampsia caespitosa)* in the Pacific Northwest.

2. Site Preparation.

The width of the substrate at an elevation suitable for plant establishment will determine in part the relative effectiveness of the erosion control planting. A practical minimum planting width for successful erosion control is 20 feet (6.0 meters) (Knutson, et al., 1981). On the Atlantic and gulf coasts, marsh plants will typically grow in the entire intertidal zone. Marsh plants seldom extend below the elevation of mean tide on the southern Pacific coast or below lower high water in the Pacific Northwest. Because of these elevational constraints, the more gradual the shore slope, the broader the potential planting width. On steeply sloping shores, there may be little area suitable for planting. If the potential planting area is not 20 feet in width, the shore must be sloped or backfilled to extend it. Backfilling must be done enough in advance of planting to allow for settling and firming.

Salt marsh plants rely heavily on exposure to direct sunlight and will not grow in shaded areas. Therefore, any overstory of woody vegetation present at a site should be cleared above the planting area and landward to a distance of 10 to 15 feet (3 to 5 meters).

3. Planting.

Vegetative transplants are used for erosion control plantings as direct seeding is very unlikely to be effective on sites subject to erosion. Vegetative transplant types include (a) sprigs, stems with attached root material (Fig. 3); (b) pot-grown seedlings; or (c) plugs, root-soil masses containing several intact plants dug from the wild. Sprigs are the least expensive to obtain and easiest to handle, transport, and plant. They may be obtained from field nurseries, planted at least a year in advance, or collected from young marshes or the edges of expanding established marshes. Pot-grown seedlings are more expensive to grow and plant, more awkward to handle and transport, but relatively easy to produce and are superior to sprigs for late season plantings. Plugs are the most expensive to obtain, difficult to transport, and should probably be used only when no other sources are available. Plugs are usually necessary only when a dense root mat or cohesive sediments in the harvest area complicate the separation of plants into sprigs. The Soil Conservation Service may be helpful in locating and obtaining plant materials. A Soil Conservation Service State conservationist is located in all the State capitals.

Figure 3. Smooth cordgrass sprig.

Requirements for the successful transplanting of salt marsh plants include (a) opening a hole or burrow deep enough to accommodate the plant, (b) keeping the hole open until the plant can be properly inserted, (c) inserting the plant to the full depth, (d) closing the opening, and (e) firming the soil around the plant. Three to five sprigs are inserted in each planting hole. Plugs and pots are planted individually. Planting must be done during low water when the site is exposed. Hand planting (Fig. 4), using dibbles, spades, and shovels, is the most practical method for small-scale plantings (less than 1 acre).

Figure 4. Hand planting by workers from North Carolina State at Raleigh (photo courtesy of W.W. Woodhouse, Jr., E.D. Seneca, and S.W. Broome, North Carolina State at Raleigh).

Normally, planting crews work in pairs with one worker opening holes and the other inserting the plant and closing the hole. The fertilizing may be done by a third worker during planting or may be handled as a separate operation. Machine planting (Fig. 5) of sprigs, where the terrain allows, can do a

Figure 5. Machine planting by workers from North Carolina State at Raleigh (photo courtesy of W.W. Woodhouse, Jr., E.D. Seneca, and S.W. Broome, North Carolina State at Raleigh).

more uniform job and is far more economical than hand planting in large-scale plantings. The tractor-drawn planters used for planting cabbage, tomatoes, tobacco, etc., require either no alteration or a simple adjustment of the row opener for certain soils. Barriers to machine planting are inadequate traction on compact substrates, insufficient flotation on soft sites, or the presence of tree roots or stones (Woodhouse, 1979).

Planting depth is basically independent of the method or material used. Most species do best when planted 1 or 2 inches (3 or 5 centimeters) deeper than they were growing. Where erosion is expected, deeper planting is recommended. If, on the other hand, deposition is likely, plants should be set very close to the depth they were growing when dug or when removed from pots (Woodhouse, 1979).

4. Planting Specifications for Principal Species.

a. Smooth Cordgrass (Fig.6).

(1) Planting techniques--sprigs, pot-grown seedlings or plugs.

(2) Plant spacing--3 feet (1 meter) on sheltered sites (4,000 transplants per acre), 1.5 feet (0.5 meter) on exposed sites (16,000 propagules per acre).

(3) Planting zone--mean low water to mean high water where the tidal range is less than 6 feet (2 meters); mean tide to mean high water where tidal range is greater than 6 feet.

(4) Planting width--the entire planting zone should be planted when practicable. However, there is typically no advantage in planting to a width of more than 60 feet (20 meters). A practical minimum width is 20 feet or 60 percent of the intertidal zone, whichever is larger. When only a part of the planting zone is to be planted, the planting should be from mean high water seaward.

(5) Salinity range--5 to 35 parts per thousand.

(6) Optimal planting dates--northern range, April and May; Mid-Atlantic, March, April, and May; southern range, February, March, April, and May.

b. Pacific Cordgrass (Fig. 7):

(1) Planting techniques--sprigs, pot-grown seedlings or plugs. Since the natural spread of Pacific cordgrass is relatively slow, no more than 10 percent of harvest area should be disturbed when collected in the wild.

(2) Plant spacing--1.5 feet (16,000 propagules per acre).

(3) Planting zone--mean tide to mean low high water.

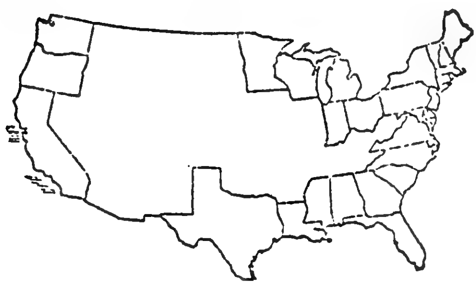
(4) Planting width--the entire planting zone should be planted when practicable. However, there is usually no advantage in planting to a width of more than 60 feet. A practical minimum width is 20 feet or 60 percent of the upper one-half of the intertidal zone, whichever is larger. When only part of the planting zone is to be planted, the planting should be from mean low high water seaward.

a. Seed head (inflorescence)

b. Distribution (shaded area)

Figure 6. Smooth cordgrass.

a. Seed head (inflorescence)



b. Distribution (shaded area)

Figure 7. Pacific cordgrass.

(5) Salinity range--less than 35 parts per thousand.

(6) Optimal planting date--March and April.

c. Lyngbye's Sedge (Fig. 8):

(1) Planting technique---sprigs. Plants can be readily moved from high to low salinity sites but not the reverse.

(2) Plant spacing--1.5-foot centers or about 16,000 plants per acre.

(3) Planting zone--mean lower high water to mean higher high water.

(4) Planting width--the entire planting zone should be planted when practicable; however, there is typically no advantage in planting to a width of more than 60 feet. A practical minimum width is 20 feet or 60 percent of the planting zone, whichever is greater. When only part of the planting zone is to be planted, the planting should be from mean higher high water seaward.

(5) Salinity range--0 to 20 parts per thousand.

(6) Optimal planting period--April, May, and June.

d. Tufted Hairgrass (Fig. 9):

(1) Planting technique--sprigs.

(2) Plant spacing--3 feet or about 4,000 transplants per acre.

(3) Planting zone--mean higher high water and above.

(4) Minimum planting width--none.

(5) Salinity range--fresh and brackish.

(6) Optimal planting period--April, May, and June.

5. Other Useful Species.

The above four species, generally the effective pioneers in the intertidal zone, provide an environment into which other species may invade. In some cases, however, planting of the entire slope is advisable to control erosion caused by storm tides, surface runoff, or wind. The species potentially useful in such cases are as follows:

(a) Black needle rush *(Juncus roemerianus)*

(b) Common reed *(Phragmites australis)*

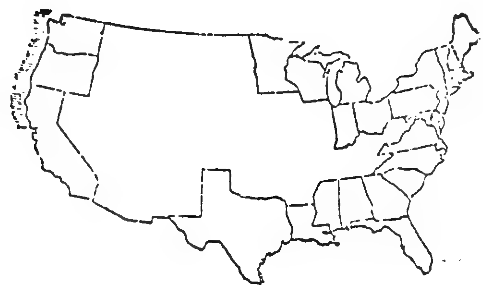
(c) Cordgrasses:

(1) Big cordgrass *(Spartina cynosuroides)*

(2) Gulf cordgrass *(Spartina spartinae)*

(3) Saltmeadow cordgrass *(Spartina patens)*

a. Seed head (inflorescence)



b. Distribution (shaded area)

Figure 8. Lyngbye's sedge.

a. Seed head (inflorescence)

b. Distribution (shaded area)

Figure 9. Tufted hairgrass.

(d) Mangroves:

(1) Red (*Rhizophora mangle*)

(2) Black (*Avicennia germinans*)

(3) White (*Laguncularia racemosa*)

(e) Saltgrass (*Distichlis spicata*)

(f) Seaside arrowgrass (*Triglochin maritima*)

(g) Siltgrass (*Paspalum vaginatum*)

V. FERTILIZATION

Fertilization is recommended for all plantings subject to wave stress except where previous experience has indicated it is not needed. Two general types of fertilizer can be used--soluble or slow release. Soluble materials should be broadcast and disked in before planting, spread in the planting furrow, placed in a second hole beside the planting hole, or placed in the bottom of the planting hole and covered with soil before the plant is inserted. Slow-release materials, such as Osmocote or Mag Amp, should be effective when applied in the planting hole or furrow.

If soluble materials are used, they should be applied at a rate of 100 pounds per acre (1 kilonewton per hectare) of nitrogen (N) and 100 pounds per acre of phosphate (P_2O_5) at time of planting. In conventional mixed fertilizers, the number designations such as 10-10-10 represent the percentages (by weight) of nitrogen (N), phosphate (P_2O_5), and potash (K_2O), respectively, in the mixture. Therefore, the amount of 10-10-10 fertilizer per acre needed to provide 100 pounds of nitrogen and 100 pounds of phosphate would be 1,000 pounds. A topdressing of an additional 100 pounds per acre of soluble nitrogen (N), 6 to 8 weeks after planting, will be helpful on deficient sites and a third 100-pound application 6 weeks later will be advisable on acutely deficient sites.

Slow-release materials, if used in lieu of soluble fertilizer, should be applied at a rate of 100 pounds per acre of nitrogen at time of planting. Slow-release materials should always be placed in the planting hole or furrow. For conventional slow-release mixtures (14-14-14 or 16-8-12), about 0.5 ounce (15 grams) of fertilizer should be placed in each hole. When slow-release materials are used, no additional applications are necessary during the first growing season.

If plant cover and development are not adequate by the second growing season, fertilize again with 100 pounds of nitrogen using a soluble source broadcast at low tide in early spring. After establishment, the color of the grass itself can be used as a general indicator of available nitrogen. Dark green leaves indicate an adequate supply while lighter shades of green and yellowing lower leaves during active growth result from too little nitrogen.

VI. MAINTENANCE

Once a site is planted, it will be necessary to keep it free from debris that might smother the plants, especially during the first two growing seasons. Litter such as wood, styrofoam, algae, and dislodged submerged plants forming a strandline should be removed in both the fall and the spring. Another source of possible plant damage in some regions is predation from Canada and snow geese which are fond of the roots and rhizomes of marsh plants. Rope fences on the seaward edge of the marsh will exclude waterfowl during the first few growing seasons. Fences should consist of wood, metal, or plastic pickets strung with nylon rope spaced at 6-inch (15 centimeter) intervals from the sediment surface to mean high water (E.W. Garbisch, Environmental Concern, Inc., personal communication, 1977).

VII. COSTS

The principal cost of a project (unless site preparation or temporary protection is required) is the labor required to obtain or produce propagules and plant them. Harvesting and planting must usually be confined to about a 5-hour period per tide which substantially affects the cost of labor. Smooth cordgrass, Pacific cordgrass, Lyngbye's sedge, and tufted hair grass sprigs can be harvested, processed, and planted by hand at a rate of about 10 man-hours per 1,000 sprigs. Using plugs of any species is at least three times more time-consuming than using sprigs (30 man-hours per 1,000 plugs). Preparing and planting nursery seedlings of any species takes about 23 man-hours per 1,000 seedlings. To estimate labor requirements for a particular project, first determine the number of planting units required as follows:

$$\text{No. of planting units} = \text{area of planting} \times \frac{1}{(\text{plant spacing})^2}$$

(Plant spacing for erosion control projects is typically 1.5 feet.)

Second, determine the labor required to prepare and plant these units as follows:

$$\text{Labor required} = \text{No. of planting units} \times \frac{\text{man-hours}}{1{,}000 \text{ planting units}}$$

(As noted above, sprigs require about 10 man-hours per 1,000 planting units, plugs about 30 man-hours per 1,000 planting units, and nursery seedlings about 23 man-hours per 1,000 planting units.)

The cost of fertilizer varies but will probably cost no more than $50 to $100 per acre (1980) including labor or about 5 to 10 cents per linear foot for a 30-foot-wide (10 meter) planting. Slow-release fertilizer is more expensive, about $500 to $1,000 per acre or $0.50 to $1.00 per linear foot for a 30-foot-wide planting. However, the use of slow-release materials will eliminate the need for postplanting fertilizer applications.

Figure 10 compares planting costs per foot with the costs per foot of several alternative structural devices. (Labor costs assumed to be $15 per hour plus 100 percent overhead.) Vegetative stabilization is lower in cost than any structural erosion control measure.

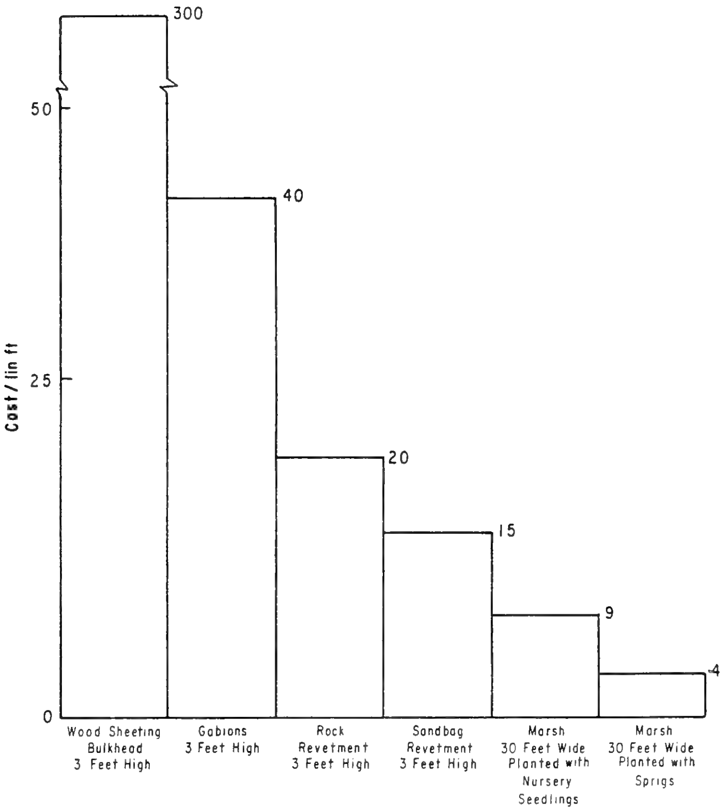


Figure 10. Cost comparison (dollars per linear foot) of various shore stabilization methods (structural costs after Eckert, Giles, and Smith, 1978).

Design life of vegetative stabilization projects is about 5 to 10 years (Knutson, et al., 1981), which is comparable to other low-cost shore protection measures.

EXAMPLE PROBLEM

The following examples demonstrate the use of guidelines for a property owner who wishes to stabilize 300 feet (90 meters) of shoreline:

1. Determining site suitability:

GIVEN: The shoreline is located along a tidal river. The distance across the river (fetch perpendicular to shore) is about 0.6 mile (1 kilometer). The distance across the river 45° to either side of perpendicular is about 0.9 mile (1.5 kilometers). The shoreline is relatively straight and the sand on the eroding beach is fine (0.25 millimeter).

FIND: Determine the likelihood of successful stabilization with salt marsh vegetation at this site using the vegetative stabilization site evaluation form (Fig. 2).

SOLUTION: The cumulative score for this site is 87 + 89 + 62 + 84 = 322, which indicates that successful stabilization at this site is nearly certain.

2. Selecting plant species:

GIVEN: Property is on the Atlantic coast.

FIND: Determine the appropriate species to plant in this region.

SOLUTION: Smooth cordgrass would be the proper plant to use in this area (see Sec. IV,1).

3. Preparing the site:

GIVEN: The property owner estimates that the wetted part of the intertidal zone (mean high water to mean low water) is about 30 feet (9 meters) wide. Tidal range on the river is about 1.5 feet. About one-half of the shoreline is shaded by trees.

FIND: What site preparation is needed at this site?

SOLUTION: Smooth cordgrass grows throughout the intertidal zone in areas where tidal range is less than 6 feet (Sec. IV,2). Therefore, the entire wetted part of the intertidal zone (30 feet) can be planted. Because this exceeds the minimum width for erosion control plantings (20 feet), no shoreline sloping or backfilling will be necessary. However, the trees shading the shoreline will have to be cleared for a distance of 10 to 15 feet landward of mean high water (Sec. IV,2).

4. Planting specifications:

GIVEN: There are several natural stands of cordgrass near the site, and there is a 30-foot-wide shoreline available for planting.

FIND: Determine the width and overall area of the planting, the type of transplant that will be used, plant spacing, and the method of planting.

SOLUTION: It is recommended for smooth cordgrass (Sec. IV,4) that the entire available planting zone be planted when practicable. Therefore, the planting width should be 30 feet, and the area of the planting is 30 feet by 300 feet or 9,000 square feet. Sprigs are the lowest cost type of transplant and are available from natural stands near the site. Hand planting would be favored on this site because the area of the site is less than 1 acre (43,560 square feet) and there is a possibility of encountering tree roots during planting.

5. Fertilization:

GIVEN: The property owner has elected to use a soluble fertilizer which has a composition of 10-10-10 because of its lower cost.

FIND: Determine the amount of fertilizer that will be required for the initial application.

SOLUTION: Initial fertilization with soluble fertilizer is 100 pounds of nitrogen (N) and 100 pounds of phosphate per acre (43,560 square feet). This planting is 9,000 square feet or 0.2 acre (0.1 hectare) and will require 20 pounds of nitrogen--20 pounds of phosphate. 10-10-10 fertilizer is 10 percent nitrogen and 10 percent phosphate by weight. Therefore, 200 pounds of fertilizer will be needed to provide the 20 pounds of nitrogen and 20 pounds of phosphate needed for this planting (see Sec. V).

6. Estimating planting costs:

GIVEN: The planting is 9,000 square feet in size, and sprigs will be used at a spacing of 1.5 feet.

FIND: Determine the number of planting units and man-hours required to plant this project.

SOLUTION (see Sec. VII):

$$\text{(1) No. of planting units} = \text{area of planting} \times \frac{1}{(\text{plant spacing})^2}$$

or

$$4{,}000 \text{ planting units} = 9{,}000 \text{ square feet} \times \frac{1}{(1.5)^2} \text{ feet}$$

$$\text{(2) Man-hours required} = \text{No. of planting units} \times \frac{\text{man-hours}}{1{,}000 \text{ planting units}}$$

or

$$40 \text{ man-hours} = 4{,}000 \text{ planting units} \times \frac{10 \text{ man-hours}}{1{,}000 \text{ planting units}}$$

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