Procedures for Applying Marsh Grass Methodology

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TABLE OF CONTENTS

FIGURES

TABLES

PROCEDURES FOR APPLYING MARSH GRASS METHODOLOGY

I. INTRODUCTION

The effects of marsh vegetation on wave heights were not addressed in the National Academy of Sciences (NAS) report (NAS 1977) that is the foundation of the Federal Emergency Management Agency (FEMA) wave height methodology. A search of the literature revealed that little is known about the effect of marsh vegetation on hurricane induced waves. New procedures were developed (FEMA 1984) to account for the effects of marsh vegetation on these waves, and the results show that marsh plants can significantly reduce wave heights in some cases. In other cases, wave heights can increase or remain nearly constant because of the effect of wind energy input.

Computer program WHAFIS (Wave Height Analysis for Flood Insurance Studies) is used by many FEMA Study Contractors. Provisions were added to the program to enable users to simulate hurricane induced wave growth and decay in salt marshes. The following sections describe the data gathering process and the use of the computer program.

II. GATHERING DATA

A. Sources of Data for Identifying Plant Types

The data required to model marsh grass can be expensive to gather by direct observation in the field. While some field work may be necessary, the user can usually rely on average values of marsh grass plant parameters. These parameters depend on the plant types and the region of the country where the marsh is located. The plant types can usually be determined by remote sensing or through the use of maps, reports, or consulting with local wetland scientists. The identity of marsh grasses in the study area should be verified by scientific name to the species level; common plant names should not be used as they can vary from place to place.

Remote surveys of vegetated segments should be conducted using National Wetlands Inventory (NWI) maps (Figure 1) and color infrared (CIR) or black and white aerial photographs (Figure 2) to identify and delineate plant communities. State agencies, Federal agencies, and universities can be of assistance in identifying plant types in each community (see Appendix I for data sources). NWI maps and aerial photographs scaled to 1:24000 will aid in transferring data to U.S. Geological Survey (USGS) 7.5 minute series quadrangle maps and limit the resolution of a plant community or segment to about 10,000 square feet.

The coding available on the NWI maps provides information on the type of wetlands habitat in a region, not on the species present. Identifying vegetation species based solely on the data from the NWI map is difficult and requires considerable knowledge of the local flora. Help in identifying vegetation can be obtained by using aerial photographs. However, recognition of individual species from photographs requires special remote sensing and wetlands expertise (Avery, 1968).

With practice, the user will be able to correlate marsh grass plant types with variations in color or grey tone, and texture on air photos. However, due to subtle variations in film processing and in plant dimensions from one study area to another, experience gained in one area may not be completely transferrable to another. So, a coarse field survey may be needed for a given study area to verify the photo interpretation. See Figures 4-10 for drawings of the 7 most prevalent marsh plant species along the U.S. Atlantic and Gulf coasts and their "habitats" (Eleuterius 1981; Nixon 1982; Silberhorne, et. al., 1974). These figures are not, in general, drawn to scale. A good source of marsh plant drawings to scale (but lacking plant habitats) is Correll and Correll (1972).

Identifying and mapping vegetation from aerial photographs requires the ability to evaluate information from many different sources (Miller, 1961). For example, although coastal vegetation may appear in aerial photographs as a patchy distribution (Figure 2), it is frequently found in distinct zones depending, in part, upon ground elevation above Mean Sea Level (MSL) (Figure 3a) and salinity tolerance (Figure 3b). In black and white photographs, texture can be used to distinguish plant types in areas having the same tonal characteristics (Miller, 1961). For example, while a marsh grass area and shrub area may have the same tone on a photograph, the marsh grass area is smooth textured in relation to the shrub area. Marsh vegetation species are best delineated using summer or fall CIR aerial photographs. Variations in color and shade can be used to differentiate the plant types.

Making an identification also requires integrating information about which plant types, i.e., species, occur and are most dominant in a coastal region. Seven salt marsh grasses (Figures 4-10) are found along the U.S. Atlantic and Gulf of Mexico coasts in areas large enough to resolve on aerial photographs. One species, Spartina alterniflora, is present as two sub-species: tall and medium. To help identify the probable plant types of marsh grass present, the location of the study area should be determined in reference to the coastal regions shown in Figure 11. Tables 1 and 2 list the "dominant" and "significant" plant types, respectively, in each region. Table 4 lists the abbreviations for the marsh plant types used in Table 2. "Dominant" plant types refer to the plant types that cover the largest amount of ground area in the salt and brackish marshes. "Significant" plant types refer to the several plant types in each region that occur in large enough patches (at least 10,000 square feet) to significantly affect wave heights. Data that are missing from Table 2 do not necessarily indicate that a particular plant type is absent from a region; in some instances, a plant type may be present, but the typical area of coverage may not be large enough to significantly affect wave height determinations. The South Texas region is included in Table 2 for purposes of spatial interpolation by the WHAFIS program (see section III.A) even though this region appears to have insignificant amounts of marsh grass. In summary, the following sources of information should be integrated to obtain an initial identification of the marsh grass types that are present:

- o Dominant plant types (Table 1).
- o Significant plant types (Table 2).
- o NWI maps.
- o Aerial photographs (black and white and CIR).
- o Preferred elevation range (zonation) for each plant type (Figure 3a).
- o Salinity tolerance of plants (Figure 3b).

B. Multiple Plant Types

Often, several different plant types may be found in the same marsh. The relative abundance of each plant type, as well as the areal extent of non-vegetated areas must be determined. Each marsh plant type prefers different ranges of salinity (see Figure 3b) and climatic conditions. Salinity levels are related to elevations above mean tide level. Therefore, each plant type has a preferred elevation range (see Figure 3a). Climate affects the geographic range of each plant type. As a result, some plant types, such as Juncus gerardi and Cladium jamaicense, are not found in all regions (see Table 2). These preferences make it unlikely that certain marsh grass varieties will grow in the same marsh within a given region; e.g., C. jamaicense does not grow with S. alterniflora in Region 1.

Care should be taken in interpreting Figure 3a. When the local tide range is less than one foot, the boundaries between species can deviate somewhat from that shown on the figure. Furthermore, in regions (such as Region 5, the Northeastern Gulf) where S. alterniflora does not occur in significant amounts, both Juncus species and Distichlis spicata can grow down to the mean tide level.

Some plant types are usually found together, e.g., tall and medium varieties of S. alterniflora. Typically, 20 percent to 25 percent of S. alterniflora can be characterized as tall. The tall variety is usually found adjacent to tidal creeks.

In some cases, the marsh grass is intermixed with trees, shrubs, small water courses, and bare ground areas. Sometimes plant communities are layered, e.g., marsh grass in the lower layer and trees or shrubs in the upper layer or layers. Layering occurs only in a minority of cases because trees and shrubs tend to grow either inland or at somewhat higher elevations than marsh grass.

After the user has determined which plant types are present in the marsh grass transect segment, he must estimate the "relative areal extent" of each plant type. Each segment models a rectangular "swath" of ground centered on the transect. Within each swath, vegetation usually occurs in individual "patches" or zones (see Figure 12).

Vegetation patches usually contain only one plant type but may contain more if layering or intermixing has occurred. To represent the relative areal extent of each plant type in a marsh grass transect swath, the parameter F_{cov} is used. F_{cov} is defined for each species as the ratio of total patch area for that species to the total swath area for the transect segment.

Another parameter, N, is used for each plant type (in a given transect segment) to represent the average number of plants per square foot in a typical patch. F_{cov} and N for each plant type are related as shown below:

Number of plants in segment = (F_{cov}) (N) (area of segment swath)

III. USE OF DEFAULT DATA

A. Determination of Default Data Values by WHAFIS

Several input marsh grass parameters are required to perform a wave height analysis. Many of them vary according to plant type and region; others (wave period, effective drag coefficient, F_{cov}) are not dependent on region or plant type. Region and plant type-dependent parameters tend to vary in a relatively narrow range about their mean values. Therefore, use of the WHAFIS program has been facilitated by supplying it with default values for these parameters, as well as those not dependent on region and plant type.

Default regional plant parameter data used in the program and presented in Table 2 are discrete values and only approximate the regional averages of a continuum of data.

The WHAFIS program has a procedure for calculating the spatially interpolated value of each region-dependent parameter. For purposes of this interpolation, the default value of a plant parameter for a particular region is assumed to be the parameter value at the midpoint (in the longshore direction) of the region. The spatial interpolation formula used by the program is:

$$Reg_i = Reg_p\, Wt_p + Reg_s\, Wt_s \qquad (1)$$

$$Wt_s = 1.0 - Wt_p, \qquad (2)$$

where Reg_i is the spatially interpolated value of a given region-dependent parameter, Reg_p is the parameter value for the primary region, Reg_s is the parameter value for the secondary region, and Wt_p is the spatial weighting factor for the primary region value (the range of Wt_p is $0 < Wt_p \leq 1$). The primary region is usually the region where the marsh is located. The secondary region is usually the adjacent region closest to the study area. However, non-adjacent primary and secondary regions may be selected. If the marsh is located near the center of the primary region, or the user feels that interpolation is not necessary, then Wt_p can be set equal to 1.0 and equations 1 and 2 reduce to $Reg_i = Reg_p$. Plant parameters north of Region 1 do not appear to be significantly different from those in the northern half of Region 1. Therefore, interpolation is not necessary for marshes in the northern half of Region 1.

For a given plant type, if default plant parameter data for both the primary and secondary regions are not available to the program, then special interpolation procedures are used. If default data are not available for either region (e.g., for the plant type J. gerardi with South Florida as the primary region and the South Atlantic as the secondary region), no interpolation is possible and an error message is printed by the program. If default data are available for one region but not the other (e.g., for the plant type S. alterniflora with the Chenier Plain as the primary region and South Texas as the secondary region), the number density, N, is set equal to zero for the region where no data are available (South Texas in the example) and the interpolated value of N is determined by equations 1 and 2 as usual. The stem diameter and height cannot be zero, so no interpolation is performed; rather, the values are taken from the other region where data are available.

Regression relationships were developed between stem height and two of the other plant parameters, namely, base stem diameter "D_1" and number density N. These regression equations are built into the program. If site-specific data on average stem height are available, then the actual average stem height should be entered as input data, instead of relying on the default regional average. The other two plant parameters will then be automatically calculated by the program based on the regression equations. Mid stem diameter, D_2, and top stem diameter, D_3, by default are related (see Figure 13) to the base stem diameter by ratios that depend on plant type (see Table 3). The frontal area of the leaves by default is related (see Figure 13) to the frontal area of the stem by a ratio that also depends on plant type (see Table 3). The frontal area of the inflorescence (i.e., flowering head) has been neglected since the percentage of plants with an inflorescence is usually small enough (FEMA 1984) for the effects of the inflorescence on the waves to be negligible.

The user may choose to override any default values supplied by the program if more accurate data are available than regional averages or regression relations. A brief explanation of each parameter that has a default value is give below:

Parameter	Explanation
T_i	Initial Wave Period. The default value is determined from data entered on the IE card (see Section III).
C_D	Effective drag coefficient. Includes the effect of plant flexure and modification of the velocity distribution caused by marsh grass. Default value is 0.1. The default value is appropriate for all marsh grasses unless strong evidence to the contrary can be found. For rigid vegetation, a value of 1.0 is recommended.

Parameter	Explanation (Continued)
F_{cov}	Coverage parameters (see section II B). The default value is calculated by the program so that each plant type in the marsh grass transect segment is represented equally. This is often inappropriate. For example, tall and medium varieties of <u>S. alterniflora</u> are usually not found in equal proportions. The default value of F_{cov} determined by the program is calculated as if the sum of the coverage parameters for the plant types in the segment is equal to 1.0. Non-vegetated areas and water courses often represent a significant portion of the total marsh grass area; therefore, in many cases, the sum of the coverage parameters for all plant types is not equal to 1.0.
h	Unflexed stem height (feet). For marsh grass, the stem height does not include the flowering head of the plant (i.e., inflorescence). The default value is determined according to the plant type and region. If the user has an accurate estimate of the average stem height, it should be entered so that the program can move accurately to determine the base stem diameter and number density using regression equations instead of regional averages.
N	Number density. Expressed as plants per square foot. The average spacing between plants, b, and the number density, N, are related by $N=1/b^2$. The default value of N for marsh grass is determined from the plant type and region if the stem height is not entered on the MG card (see Section III), or the stem height and regression equations built into the program, if the stem height is entered.
D_l	Base stem diameter (inches). The default value for marsh grasses is determined from the plant type and region if the stem height is not entered on the MG card (see Section III), or the stem height and

Parameter	Explanation (Continued)
	regression equations built into the program if the stem height is entered (see Figure 13).
D_2	Mid stem diameter (inches). The default value for marsh grasses is determined from the plant type and the base stem diameter (see Figure 13).
D_3	Top stem diameter (inches). The top stem diameter is measured at the base of the inflorescence. The default value for marsh grass is determined from the plant type and the base stem diameter (see Figure 13).
CA_b	Ratio of the total frontal area of the cylindrical portion of the leaves to the frontal area of the stem below the inflorescence (see Figure 13). The default value for marsh grass is determined from the plant type.

The default values of marsh grass plant parameters h, D_1, D_2, D_3, and CA_b are usually sufficiently accurate for the wave height determinations used in Flood Insurance Studies. The user may wish to include the effects of other vegetation types, such as trees and shrubs, by a suitable re-interpetation of the marsh grass plant parameters (e.g., stem diameter represents trunk diameter and so forth).

B. Activation of Default Data Values in WHAFIS

In general, the default value of an input parameter is supplied by WHAFIS whenever the user leaves the data field blank or enters a zero into the field. To enter an input parameter value that is "effectively zero" without triggering the default value for that parameter, a value of 0.001 or smaller must be used. The difference in results caused by using 0.001 instead of 0.0 is negligible.

IV. INPUT FORMAT

A. General Description

In order to model marsh grass, some necessary changes were made to the WHAFIS input format: 1) An extra field was added to the IE card and 2) two new cards (VH and MG) were added.

The computer will supply default values for some input parameters. As with the original WHAFIS input format, a zero or blank in a data field causes a default value to be used.

There are two options to input vegetation data to the WHAFIS program -- via the VE and VH cards. The VE card option is described in the original WHAFIS procedure. This option may be used if:

1. Only one plant type is present.
2. The vegetation can be represented as a stand of equivalent rigid vertical cylinders.
3. The effect of wind on wave growth is negligible compared to plant-induced dissipation.

Otherwise, the VH card option should be used.

IE CARD (INITIAL ELEVATIONS)

If the VH card option is used, the initial wave period must be entered in Field 7 of the IE card, or the default value will be used by the program. The IE card is the first one in the input deck. The format for the card is as follows:

Data Field	Columns	Variable	Description
0	1-2		IE.
1	3-8		Stationing of end point of initial overwater fetch in feet (zero at beginning of transect).
2	9-16		Elevation at end point in feet (usually zero at beginning of transect).
3	17-24		Overwater fetch length (miles). For unlimited fetch, use 24 miles or greater.
4	25-32		10-year surge elevation (feet).
5	33-40		100-year surge elevation (feet).
6	41-48		Initial wave height (feet).
7	57-64		Initial wave period (seconds). A blank/zero defaults to a calculated wave period. See below for further details.

A new data field (Field 7) for entering initial wave period is required because wave height dissipation due to marsh grass depends on wave period. Since no other wave height calculations are dependent on wave period, the initial wave period is not required when marsh grass is not present.

The program will calculate the initial wave height for conditions appropriate to a bay or behind a barrier island from the initial fetch length (Field 3). The program uses a total depth of 26 feet and a wind speed of 80 mph for these calculations. If the transect begins on the open coast or if the average depth of the initial fetch is significantly different from 26 feet, then the user should calculate the wave period and enter the result in Field 7 of the IE card. For open coast conditions, an initial wave period of 12 seconds or greater is recommended.

If an initial wave height is specified (Field 6), then an initial wave period is also required.

VH CARD (VEGETATION HEADER FOR MARSH GRASS)

Marsh grass is often part of a plant community that may consist of several plant types. The VH card is used to enter data that apply to all plant types modeled in the transect segment. To enter data for each plant type, a separate MG card for each plant type must follow the VH card. The program will supply default input data values for the most frequently occurring kinds of marsh grass based on the plant type and the region where the marsh is located. Default marsh grass parameters are stored in the program for 8 regions (see Figure 11).

Since plant parameters vary continuously from region to region, a provision is made for interpolating marsh grass data between the midpoints of nearby regions. See section II C for details.

Stationing of the beginning point of the marsh grass segment is not required on the VH card since WHAFIS takes this station from the end point of the previous transect segment. Stationing at the end of the segment is required, however.

A marsh grass segment need not be manually subdivided into several smaller subsegments to resolve significant non-linear wave height variations within the segment. Unlike the usual vegetation (VE) segment or a building (BU) segment, WHAFIS automatically subdivides a marsh plant (VH) segment into sufficiently small subsegments to adequately resolve the wave height variation within the segment. With a VE or BU segment, the user must manually divide the transect segment into a sufficient number of smaller subsegments (and use a separate VE or BU card for each subsegement) to be assured of adequately resolving the wave height variation within the whole segment. With a VH segment, only one VH card is needed. The format for this card is given below.

Data Field	Columns	Variable	Description
0	1-2		VH.
1	3-8		Stationing at end point of marsh vegetation segment.
2	9-16		Elevation at end point of marsh vegetation segment.
3	17-24	Reg_p	Number of the primary region to be used for looking up and interpolating default plant parameters. Range is 1 to 8, inclusive.
4	25-32	Wt_p	Weighting factor for the primary region to be used in spatially interpolating plant parameters. Default value is 1.0. Range is 0 to 1, inclusive.
5	33-40	Reg_s	Number of secondary region to be used for looking up and interpolating default plant parameters. Range is 1 to 8, inclusive. Not required when Wt_p is equal to 1.0.
6	41-48	N_{pl}	Number of plant types. Range is 1 to 10, inclusive. One MG card is required for each plant type.
7	49-56		A blank or zero indicates no charge to the 10-year surge elevation; otherwise, new 10-year surge elevation.
8	57-64		A blank or zero indicates no change to the 100-year surge elevation; otherwise, new 100-year surge elevation.
9	65-72		Not used.

Data Field	Columns	Variable	Description
10	73-80		This field is for overriding the default method of averaging flood hazard factors for A zones. If 1 in column 80, averaging process begins or ends at end of vegetation segment; otherwise, default averaging method is used. For further details, see below.

To decrease the number of "gutters" shown on Flood Insurance Rate Maps, the Flood Hazard Factors for contiguous A zones are averaged together. Normally, the length weighted averaging process can begin or end only at 1) the beginning of the transect, 2) the end of the transect, 3) a V zone gutter. However, a provision is included so that the user can begin or end the averaging process at the end station of any transect segment (fetch, obstruction, or marsh grass segment). To activate this option, enter a 1 in column 80 of any input card.

MG CARD (MARSH GRASS)

The MG card is used to enter data for a particular plant type. The first MG card must be preceded by a VH card. The program will supply default data for most common marsh grasses (see Tables 2 and 3). If all default values are to be used, Fields 2 through 9 may be left blank; otherwise, the user may override any default by entering data into the appropriate field. If a plant type not listed in the table is used, then Fields 2-9 must contain non-zero data. The format for an MG card is as follows:

Data Field	Columns	Variable	Description
0	1-2		MG.
1	5-8		Plant type abbreviation (see Table 4).
2	9-16	C_D	Effective drag coefficient. Default value is 0.1.
3	17-24	F_{cov}	Decimal fraction of vegetated area to be covered by this plant type. A blank or a zero causes a default to be calculated so that each plant type is represented equally (see Figure 12).
4	25-32	h	Mean unflexed height of stem (feet). For marsh grass, the inflorescence is not included (see Figure 13 and Table 2).

Data Field	Columns	Variable	Description
5	33-40	N	Number of plants per square foot (see Table 2).
6	41-48	D_1	Base stem diameter (inches) (see Figure 13 and Table 2).
7	49-56	D_2	Mid stem diameter (inches) (see Figure13 and Table 3).
8	57-64	D_3	Top stem diameter (inches) (se Figure 13 and Table 3).
9	65-72	CA_b	Ratio of the total frontal area of cylindrical part of leaves to frontal area of main stem (see Figure 13 and Table 3).
10	73-80		Not used.

B. Example:

Statement of Problem

A marsh grass transect segment in the South Atlantic Region is to be modeled. An aerial photograph of the area shows that approximately 15 percent of the marsh is taken up by small watercourses or other non-vegetated areas. The elevation of the marsh ranges from 1 to 3 feet National Geodetic Vertical Datum of 1929. The transect segment begins at station 500 feet and extends to station 3,000 feet. How should the segment be modeled for the WHAFIS program?

Solution

Step 1: Identify those plant types that are present.

A preliminary identification based on CIR and NWI maps indicates that *S. alterniflora* is present. The marsh is only slightly above mean tide level. Therefore, according to Figure 3, only *S. alterniflora* grows there.

Step 2: Determine F_{cov} for each plant type.

Fifteen percent of the total marsh grass segment area is taken up by water courses, so 85 percent is taken up by *S. alterniflora*. Tall (SALT) and medium (SALM) varieties of this grass are always found together. The usual proportion is approximately 25 percent tall, so F_{cov} for SALT is .25 x .85 = 18. F_{cov} for SALM must, therefore, be .85 - .18 = .67. A windshield survey of a similar area showed that the plant type identification and estimates of F_{cov} are resonable.

Step 3: Code WHAFIS input data according to section III B.

VH	3000	3	3	0	0	2
MG	SALT	0	.18			
MG	SALM	0	.67			

V. EQUATIONS USED TO CALCULATE WAVE HEIGHT VARIATION IN MARSHES

The approximate wave energy conservation equation governing wave height variation in marshes is:

$$\frac{d}{dx}(C_g E) = \dot{W}_{net} - \dot{E}_p \quad (3),$$

where

E = time averaged total wave energy per unit area

C_g = wave group velocity

$\dot{W}_{net}$ = time averaged rate of net wind energy input per unit area

$\dot{E}_p$ = time averaged rate of energy dissipation per unit area due to plants

x = distance along the transect

The factors E, $\dot{W}_{net}$, and $\dot{E}_p$ are averaged over a wave period. The factor $\dot{W}_{net}$ includes the effect of wave "whitecapping."

Expanding the derivative on the left side of equation 3, it is found that this equation can be expressed as

$$(C_g)\frac{dE}{dx} + (E)\frac{dC_g}{dx} = \dot{W}_{net} - \dot{E}_p \quad (4)$$

Due to the relatively small changes in the stillwater depth in most marshes, the second term on the left hand side of equation 4 can be neglected. Therefore, the wave energy equation used in the WHAFIS program to calculate wave heights in marshes is given by

$$(Cg)\frac{dE}{dx} = \dot{W}_{net} - \dot{E}_p \quad (5)$$

If hurricane waves were monochromatic, the "wave energy density" E would be related to the wave height by

$$E = (1/8)(\rho)(g)(H^2) \qquad (6)$$

where

ρ = water mass density,

g = gravitational acceleration,

H = the wave height.

However, monochromatic waves exist only in the laboratory. Real waves have a range of heights and periods, referred to as a "wave spectrum."

The spectrum can be modeled as if it were monochromatic if a properly defined "effective wave height" for the spectrum is used. If there were no interaction between waves of different periods and heights, then the higher waves in the spectrum would be attenuated by marsh vegetation more than the lower ones effectively reshaping the spectrum. It has been observed (Hasselmann, et. al, 1973) that real wave spectra tend to preserve their shapes when undergoing change. To account for this "shape preserving" characteristic of real spectra, the "effective wave height" for the spectra must be chosen as the "zero moment wave height" H_{m0}. By definition, H_{m0} is proportional to the "zeroth frequency movement" of the wave energy spectral density, hence its name. Physically, H_{m0} at a given location is approximately four times the variance of a wave record at that location. Based on the "effective wave height" and "shape preserving" considerations just described, the expression used in the present model to calculate the wave energy density is given as

$$E = (1/8)(\rho)(g)(H_{m0})^2 \qquad (7)$$

The net wind input "$\dot{W}_{net}$ and plant induced energy dissipation $\dot{E}_p$ can also be expressed in terms of H_{m0}. Functionally, they are given (FEMA 1984) by

$$\dot{W}_{net} = (F_1)\ \{(U^2/g)(1/m)-1\}\ (H_{m0})^{2-(1/m)}$$
$$- (F_2)\ \{(U^2/g)^{-1}\}\ (H_{m0})^2 \qquad (8)$$

$$\dot{E}_p = (f_p)(H_{r\,[illegible]})^3 \qquad (9a)$$

where

$$f_p = (\rho\, g/12\pi)\Gamma \qquad (9b)$$

$$\Gamma = \sum_{i=1}^{N_{pl}} (F_{cov,i})(C_{D,i})\{(AW)_i\}(N_i)(F_{3,i}) \qquad (9c)$$

$m = 0.42$

$\pi = 3.14159...$

$U =$ windspeed $=$ 88 ft./sec. (60 m.p.h.)

$N_{pl} =$ number of plant types in a marsh grass segment

$F_{cov,i} =$ coverage parameter for the i^{th} plant type in the marsh grass segment

$C_{D,i} =$ effective drag coefficient for the i^{th} plant type in the segment

$N_i =$ "number density" for the i^{th} plant type in the segment

$(AW)_i =$ average "wetted" frontal area per unflexed plant for the i^{th} plant type in the segment

and F_1, F_2, $F_{3,i}$, $i=1,...,N_{pl}$ are functions of stillwater depth, wave period, and windspeed. The factors $F_{3,i}$, $i=1,...,N_{pl}$ are also functions of the plant characteristics. The algebraic expressions for F_1, F_2, $F_{3,i}$, and $(AW)_i$ are given in Appendix II.

In equation 8, the first term accounts for wind energy input to the waves, and the second term for wave energy dissipation due to "whitecapping" and bottom friction. For a stillwater depth of 10 feet and negligible plant dissipation, the wave height variation predicted by the energy equation must be the same as that for an "inland fetch" as defined by the NAS (1977). Therefore, the windspeed "U" in equation 8 was chosen to be the same as that suggested by the NAS (1977) for inland fetches, namely, 88 ft./sec. (60 m.p.h.). When plant induced dissipation is absent, equation 8 approximates the <u>net</u> input of wind energy (i.e., wind input minus dissipation due to whitecapping and bottom friction) to the waves predicted by the Shore Protection Manual of the U.S. Army Corps of Engineers, Coastal Engineering Research Center (1977). In both equations 8 and 9, the change in wave period with depth and fetch is accounted for.

In equations 9a and 9b, the factors $C_{D,i}$, $(AW)_i$, $F_{3,i}$ account for plant flexing, vertical variation of the current, and the dissipation due to the main plant stem and the cylindrical part of the marsh grass leaves. Equations 9a and 9b have an algebraic form similar to that used for rigid vegetation. For rigid vegetation, the effective drag coefficient $C_{D,i}$ is usually chosen to be 1.0. In addition, the vertical variation of the current induced by the rigid vegetation is usually assumed negligible. For marsh grass, however, the vertical variation of the current induced by the grass is significant. This variation along with the considerable flexure that the grass undergoes over a wave cycle requires that $C_{D,i}$ be reduced significantly for marsh grass. The recommended value for $C_{D,i}$ is 0.1 (FEMA 1984).

Equations 5, 7, 8, 9, combined and rewritten in a form that is easier to solve, is:

$$\frac{dR}{dx} = a - \{ b + (c)R^m \} R \qquad (10)$$

where

$$R = (H_{m0})^{\frac{1}{m}} \qquad (11)$$

In equation 10, "a" depends on windspeed, "b" on the windspeed and depth, and "c" on the depth, wave period, and plant characteristics. The expressions used for a, b, and c are given in Appendix II.

Equations 10 and 11 are solved using a combined analytic-finite difference numerical method. A marsh grass transect segment is divided into variable length one-dimensional grid cells. A grid point is associated with the boundary between each cell and the beginning and end of the segment. The WHAFIS program solves equations 10 and 11 and computes the zero moment wave height H_{m0} at the j^{th} grid point based on the value of H_{m0} at the $(j-1)^{th}$ grid point. This computation is done for all grid points in the segment. Grid point j=1 corresponds to the beginning of the segment. The grid cell lengths are automatically set by WHAFIS to efficiently resolve the non-linear wave height variations within the marsh grass segment.

The zero moment wave height H_{m0} is not of direct interest ·· Flood Insurance Studies. For these studies, the "controlling wave height" H_c is used. H_c is approximately equal to the "1% waveheight," i.e., the average height of the highest 1 percent waves. As suggested by the NAS, H_c is related to the significant wave height H_s by

$$H_c = 1.6\, H_s \qquad (12)$$

In relatively deep water, H_s is approximately equal to H_{m0}. In general, H_s is greater than H_{m0}. The two wave heights can be related (Thompson and Vincent, 1983; FEMA 1984) to each other. The functional form of the relationship is

$$H_s = (S')\, H_{m0} \qquad (13)$$

where S' is a multiplicative factor that is a function of stillwater depth and H_{m0} itself. The approximate expression for S' is given in Appendix II. Equation 13 is convenient to use if H_{m0} is known and the value of H_s is needed. When H_s is known and the value of H_{m0} is needed, equation 13 must be solved for H_m as a function of H_s and stillwater depth. The resulting expression for H_{m0} is

$$H_{m0} = H_s / S \qquad (14)$$

where S is a function of H_s and the stillwater depth (as contrasted to S', which is a function of H_{m0} and stillwater depth). The expression for S is given in Appendix II.

The numerical scheme to solve equations 10 and 11 needs an initial value of H_{m0} at the beginning of the marsh grass segment. However, such a value is not immediately available from the computations done before the segment. Rather, an initial value of H_c is available at the beginning of the segment. To generate an initial value of H_{m0}, equations 12 and 14 are used. First, equation 12 is solved for H_s in terms of the available value of H_c at the beginning of the segment. Then this value of H_s is inserted into the right side of equation 14 and the initial value of H_{m0} determined by evaluation.

As waves propagate across the marsh, they may encounter stillwater depths that meet the breaking wave criterion. This criterion is expressed in terms of the controlling wave height as

$$H_{c,b} = 0.78\,(d) \qquad (15)$$

where

d = stillwater depth

$H_{c,b}$ = breaking wave height of the controlling wave.

To test for breaking, H_{m0} is first converted to the equivalent controlling wave height H_c using equations 12 and 13. H_c is then compared with $H_{c,b}$ and reset to $H_{c,b}$ if H_c is greater than $H_{c,b}$. Equations 12 and 13 are also used to convert the calculated value of H_{m0} to the corresponding value of H_c at the last grid point in the marsh grass segment. This H_c value is then used as the initial value of the next WHAFIS segment.

VI. COMPUTER OUTPUT

A. Enhancements to the Computer Output Format

A new section has been added to PART 1 (input data) so that the input read by the program is "echoed" in the output listing with headings describing the contents of each data field. Any default marsh grass data used by the program as input data is also displayed. PART 2 (wave heights and elevations) has been modified so that the type of transect segment is shown next to the stationing of the segment.

B. Sample Output

Appendix III shows a sample WHAFIS output generated using the input data coded in section III B.

C. Trends in Computed Wave Heights Based on Sensitivity Tests

The trends described below may be useful to the user in determining whether the computer output is reasonable, and in interpolating wave elevations between transects:

- The wave period affects the stillwater depth (d) to wavelength (L) ratio, (d/L). For $(d/L) > 0.04$, wave dissipation decreases as the wave period decreases. For $(d/L) < 0.04$, wave dissipation is barely affected by changes in wave period.
- Wave height growth can occur if the wave height is sufficiently small at the beginning of the marsh grass segment.

- If stillwater depths are relatively constant over a long transect segment, then a near balance between wind energy input and energy dissipation can occur. As a result, wave heights may remain nearly constant over large areas.
- Most of the increase or decrease in wave height occurs at the beginning of a marsh grass segment.
- For a given stillwater depth, wave energy dissipation due to a given vegetation type "i" depends on the product of the factors $C_{D,i}$, N_i , $F_{cov,i}$, and A_i. Therefore, if one factor increases and another decreases such that the product remains the same, no change occurs in the dissipation induced by the vegetation type.
- Wind energy input makes the calculated wave heights relatively insensitive to the precise values of input parameters used.
- *S. alterniflora* medium is the least dissipative and *C. jamaicense* is the most dissipative of the "marsh grass" varieties.

VII. REFERENCES

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Silberhorn, G.M., G.M. Dawes, and T.A. Barnard, Coastal Wetlands of Virginia. Interim Report No. 3. Guidelines for Activities Affecting Virginia Wetlands, Virginia Institute of Marine Sciences, Gloucester Point, Virginia, 1974, 52 pages.

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Turner, R.E., and J.G. Gosselink, "A Note on Standing Crops of Spartina alterniflora in Texas and Florida," Contributions in Marine Science, 19, University of Texas, 1975, pages 113-118.

TABLE I - DOMINANT MARSH PLANT TYPES BY REGION AND HABITAT

Region Number	Region Name	Habitat	Dominant Species
1	North Atlantic	salt[1]	* *S. alterniflora* (medium, tall)
		brackish[2]	*Spartina patens*
2	Mid-Atlantic	salt	*S. alterniflora* (medium, tall)
		brackish	* *Juncus roemerianus*/*S. patens*
3	South Atlantic	salt	* *S. alterniflora* (medium, tall)
		brackish	*J. roemerianus*
4	South Florida	salt	*S. alterniflora* (medium, tall)
		brackish	* *C. jamaicense*
5	Northeastern Gulf	salt	---
		brackish	*J. roemerianus*
6	Delta Plain	salt	* *S. alterniflora* (medium, tall)
		brackish	*S. patens*
7	Chenier Plain	salt	*S. alterniflora* (medium, tall)
		brackish	* *S. patens*
8	South Texas	salt	---
		brackish	---

[1] Salt concentration is greater than 20 parts per thousand (ppt)
[2] Salt concentration is between 5 and 20 ppt

*When more than one dominant plant type occurs within the region, the indicated type covers the largest geographic area (acreage).

---Indicates that there are insignificant amounts of marsh plants with the given habitat in the region.

TABLE 2 - "SIGNIFICANT" MARSH PLANT TYPES IN EACH REGION AND DEFAULT REGIONAL PLANT PARAMETER DATA USED BY WHAFIS

Region No.:	1	2	3	4	5	6	7	8
Region Name:	North Atlantic	Mid-Atlantic	South Atlantic	South Florida	Northeastern Gulf	Delta Plain	Chenier Plain	South Texas
CLAD	---	---	---	7.50 {+} 0.0656 6	6.00 {*2} 0.0260 6	---	---	---
DIST	---	0.78 {*1} 0.0039 211	1.00 {*1} 0.038 243	1.00 {+} 0.0038 248	--- ---	1.08 {*4} 0.0035 102	1.08 {+} 0.0035 102	---
JUNM	1.23 {*1} 0.0042 300	1.23 {+} 0.0042 300	---	---	---	---	---	---
JUNR	---	2.95 {+} 0.0095 147	2.95 {+} 0.0095 147	---	2.95 {*3} 0.0095 147	3.00 {*4} 0.0106 83	2.95 {+} 0.0095 147	---
SALM	1.39 {*1} 0.0184 45	1.06 {*1} 0.0103 36	1.63 {*1} 0.0141 12	1.63 {+} 0.0141 12	---	1.67 {*4} 0.0141 21	2.62 {*5} 0.0211 16	---
SALT	1.86 {*1} 0.0175 37	2.21 {*1} 0.0169 18	3.20 {*1} 0.0183 10	3.20 {+} 0.0183 10	---	3.20 {*4} 0.0183 10	3.20 {+} 0.0183 10	---
SCYN	---	---	8.20 {+} 0.0492 6	---	---	4.00 {*4} 0.0267 7	---	---
SPAT	1.03 {*1} 0.0025 409	0.85 {*1} 0.0019 327	1.65 {*1} 0.0019 236	---	2.58 {*2} 0.0026 236	1.88 {*4} 0.0016 333	1.88 {+} 0.0019 333	---

Data arranged in vertical triplets:
h, stem height below inflorescence, in feet
D, base diameter, in feet
N, number density, in inverse square feet.

Superscripts indicate source of data in vertical triplet:

*1 = Hardisky & Reimold, 1977
*2 = Monte, Aug. 1983, Field Data
*3 = Kruczynski et al., 1978
*4 = Hopkinson et al., 1980; Diameters extrapolated
*5 = Turner & Gosselink, 1975; Diameters extrapolated
\+ = Extrapolated Data

---Indicates that there are insignificant amounts of this plant type in the region

TABLE 3 - DEFAULT PLANT PARAMETERS THAT ARE SPECIES-DEPENDENT

	Stem		Leaf
Plant Species	CD_{mid}	CD_{top}	CA_b
Spartina alterniflora	0.40	0.20	1.59
Spartina patens	0.50	0.50	1.38
Spartina cynosuroides	0.57	0.22	1.41
Juncus roemerianus	0.50	0.50	0.0
Juncus gerardi	0.83	0.42	0.80
Distichlis spicata	0.50	0.25	1.75
Cladium jamaicense	0.60	0.35	5.84

CD_{mid} = Ratio of mid stem diameter to basal stem diameter of plant

CD_{top} = Ratio of top stem diameter (at base of inflorescence) to basal stem diameter of plant

CA_b = Ratio of maximum frontal area of cylindrical parts of the leaves to the maximum stem frontal area (below the inflorescence)

TABLE 4 - ABBREVIATIONS OF MARSH GRASS TYPES

Species or Sub-species	Abbreviation
Cladium jamaicense	CLAD
Distichlis spicata	DIST
Juncus gerardi	JUNM
Juncus roemerianus	JUNR
Spartina alterniflora (medium)	SALM
Spartina alterniflora (tall)	SALT
Spartina cynosuroides	SCYN
Spartina patens	SPAT

APPENDIX I - SOURCES OF MARSH DATA

Wetland Inventory Maps

NWI maps (1:24000, 1:100000, 1:250000) exist for most of the U.S. Atlantic and Gulf of Mexico coastlines. For information on areas mapped and how the maps are made contact:

Dr. John Montanari or Dr. Frederick Lavery
National Wetlands Inventory
U.S. Fish and Wildlife Service
St. Petersburg, Florida 33703
(813) 893-3624.

To order NWI maps contact:

Greg Desmond
National Cartographic Information Center (NCIC)
507 National Center
Reston, Virginia 22092
(703) 860-6019.

A publication that explains the coding for the NWI mapping system is:

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe, Classification of Wetlands and Deepwater Habitats of the United States. Office of Biological Services, U.S. Fish and Wildlife Service, Department of the Interior, Washington, D.C., 1979, FWS/OBS-79/31.

Aerial Photographs

To map marshes, color IR aerial photographs (1:12000 - 1:30000 scale) are recommended during the late summer to early fall. For additional information, see:

McCormick, J. and H.A. Somes, Jr., Coastal Wetlands of Maryland. WAPORA, Inc.: Chevy Chase, MD, 1982, 243 pages.

Reimold, R.J., J.L. Gallagher, and D.E. Thompson, Coastal Mapping with Remote Sensors. Pages 99-112 in Proceedings of the Coastal Mapping Symposium, Am. Soc. Photogrammetry, Washington, D.C., 1979.

Thompson, D.E., J.E. Ragsdale, R.J. Reimold, and J.L. Gallagher, Seasonal Aspects of Remote Sensing Coastal Resources. Pages 1201-1249 in (F. Shahrokhi, ed.): Remote Sensing of Earth Resources, Vol. 2, University of Tennessee Space Institute, Knoxville, Tennessee, 1973.

Aerial photographs are available from NASA, the U.S. Army Corps of Engineers, private companies, and various state agencies. NCIC will provide free computer searches on all available photographic coverage.

For additional information on aerial photointerpretation, see:

Avery, T.E., Interpretation of Aerial Photographs. Burgess Publishing Co.: Minneapolis, Minnesota, 1968, 324 pages.

Miller, V.C. Photogeology. McGraw-Hill Book Co., Inc.: New York, New York, 1961, 248 pages.

Siegal, B.S., and A.R. Gillespie, eds., Remote Sensing in Geology. John Wiley and Sons: New York, New York, 1980. 702 pages.

Marsh Species and Plant Parameter Data

Each coastal state has a coastal zone management (CZM) office (Table I). One of the duties of each CZM office is to define the coastal boundary of the state and the critical areas (marshes) in the coastal zone. Many states have mapped the marshes or can provide information on the local wetlands. Other state agencies that may have marsh information include Natural Resources, Permitting Divisions, and Park and Refuge Management agencies.

In addition, the U.S. Fish and Wildlife Services National Coastal Ecosystems Team (NCET) will be able to provide some information and free publications on marshes. For further information, contact:

Wiley M. Kitchens
Community Profiles Project Officer
National Coastal Ecosystems Officer
U.S. Fish and Wildlife Service
1010 Gause Boulevard
Slidell, Louisiana 70458
(504) 255-6511

or the Information Training Specialist at the same address and telephone number.

Local universities with Sea Grant programs and coastal research laboratories can provide information on marsh grass identification and plant parameter data, if necessary.

The Federal Office of Sea Grant maintains a free publication that lists all universities with marine science and related curricula, and a list of the faculty and their specialties. For a copy, contact:

Office of Sea Grant and Extramural Programs
NOAA
Room 625
6010 Executive Boulevard
Rockville, Maryland 20852
(301) 443-8923

APPENDIX II - EXPRESSIONS FOR THE FACTORS F_1, F_2, $F_{3,i}$, $(AW)_i$, a, b, c, S, AND S'

The factors F_1, F_2, and $F_{3,i}$ are expressed as

$$F_1 = \kappa_1 (\alpha)^{1/m} C_g$$

$$F_2 = \kappa_1 C_g / \beta_h$$

$$F_{3,i} = g^2 (T/L)^3 (r\cosh_i)^3$$

where

$\kappa_1 = (1/4) \rho g m (\sigma)^{1/m}$

ρ = mass density of sea water (20° C) = 1.99 slugs/cu.ft.

g = gravitational acceleration = 32.2 ft./sec^2

m = 0.42

σ = .0125

α = .283

π = 3.14159...

C_g = group velocity of waves at spectral peak

$= (\{1/2\} + \{ (2 \pi d / L)/\sinh(4 \pi d / L) \}) (L/T)$

d = 100-year stillwater depth

L = local wavelength of waves at spectral peak

$= (2 \pi d L_0)^{1/2} \{ 1.0 + (1.25) (d/L_0) \}^{-1}$

L_0 = equivalent deep water wavelength of waves at spectral peak

$= 5.12 T^2$

T = period of waves at spectral peak

= T_{in}, if H_{m0} increases with increasing propagation distance "x" and $\{H_{m0}/(\alpha\beta_h)\} < 1.0$

= remains unchanged if H_{m0} decreases or remains the same with increasing "x"

= remains unchanged if $(H_{m0}/\alpha \beta_h)$ is = 1.0 or is > 1.0

$T_{in} = \alpha_t \beta_t \tanh\{(0.77/\beta_t) (g F/U^2)^{.25} \}$

H_{m0} = zero moment wave height

β_h = tanh{ γ_h (g d /U^2)$^{.75}$ }

γ_h = 0.53

U = windspeed = 88 ft./sec. (60 m.p.h.)

α_t = (2 π /g) 1.20 U

β_t = tanh{ γ_t (d g/U^2)$^{.375}$ }

γ_t = .833

F = "equivalent fetch" for calculating "T", the period of waves at the spectral peak

$= (U^2/g) \{ (\beta_h/\sigma) \tanh^{-1}(H_{m0}/\alpha\ \beta_h) \}^{1/m}$

$rcosh_i = \{\cosh(\pi h_i / L)\} / \{\cosh(2 \pi d/L)\}$, if $d > (h_i/2)$

$= 1.0$, if $d \leq (h_i/2)$

h_i = unflexed stem height (excluding the inflorescence, flowering head, if the plant is marsh grass) for plant type "i"

The expression for wetted frontal area $(AW)_i$ is given by

$$(AW)_i = (AW_s)_i + (2/\pi)(AW_l)_i$$

where

$(AW_s)_i$ = wetted stem frontal area, per plant, for plant type "i" when the plant is unflexed

$= \{ (D_1)_i + \{(D_2)_i - (D_1)_i\}\{d/h_i\} \} \{d\}$; $d \leq (h_i/2)$

$= (1/4) \{(D_1)_i + (D_2)_i\} (h_i)$

$+ \{(D_2)_i + \{(D_3)_i - (D_2)_i\}\{(d/h_i) - (1/2)\}\} \{d - (h_i/2)\}$; $(h_i/2) < d \leq h_i$

$= (A_s)_i$; $H_i < d$

$(D_1)_i$ = base stem diameter for plant type "i"

$(D_2)_i$ = mid stem diameter for plant type "i". It is measured halfway between the stem base and inflorescence base for marsh grass.

$(D_3)_i$ = top stem diameter for plant type "i". Is is measured right below the inflorescence for marsh grass.

$(A_s)_i$ = stem frontal area, per plant for plant type "i" when the plant is submerged and unflexed

$= (1/4) \{(D_1)_i + (2)(D_2)_i + (D_3)_i\} (h_i)$

$(AW_l)_i$ = wetted maximum frontal area of cylindrical parts of the leaves, per plant, for plant type "i" when the plant is unflexed. This maximum frontal area occurs, for a fixed stillwater depth, when the cylindrical part of the plant's leaves are all perpendicular to the direction of the wave induced current.

$= (A_l)_i \ (d/h_i) \quad ; \ d \leq h_i$

$= (A_l)_i \quad ; \ d > h_i$

$(A_l)_i$ = maximum frontal area of cylindrical parts of the leaves, per plant, for plant type "i" when the plant is unflexed and completely submerged

$= (CA_b)_i \ (A_s)_i$

$(CA_b)_i$ = ratio of $(A_l)_i$ to $(A_s)_i$. In other words, the equation right above this line defines $(CA_b)_i$.

The factors a, b, and c are expressed as

$$a = \{(\alpha)(\sigma)\}^{1/m} \ (U^2/g)^{1/m - 1}$$

$$b = \{(\sigma)/\beta_h\}^{1/m} \ (U^2/g)^{-1}$$

$$c = \Gamma/\{3 (\pi) (m) (C_g)\}$$

where Γ is defined in the main body of the report and all other factors are defined earlier in this appendix

The factors S' and S are expressed as

$$S' = (S')_{ac} \quad ; \quad 1 \le (S')_{ac} \le (R')_{av}$$
$$= 1.0 \quad ; \quad (S')_{ac} < 1.0$$
$$= (R')_{av} \quad ; \quad (S')_{ac} > (R')_{av}$$

$$S = 1.0 \quad ; \quad S_a \le 1.0 \text{ and } S_c \le 1.0$$
$$= 1.7 \quad ; \quad S_a \ge 1.7 \text{ and } S_c \ge 1.7$$
$$= S_{ac} \quad ; \text{ otherwise,}$$

where

$$(S')_{ac} = (S')_a \quad ; \quad \epsilon' \le 2.0$$
$$= (S')_c \quad ; \quad \epsilon' > 1.0$$
$$(S')_a = (S')_{com} - (1.411) \log_{10}(\epsilon')$$
$$(S')_c = (S')_{com} - .1188 - (1.017) \log_{10}(\epsilon')$$
$$\epsilon' = \epsilon/.002$$
$$\epsilon = \text{"significant wave steepness" based on } H_{m0}$$
$$= H_{m0}/(4\ L)$$
$$(S')_{com} = .9 + (.4271) \log_{10}(dbar/dbar_{ref})$$
$$dbar = \text{"relative depth"}$$
$$= d/(g\ T^2)$$
$$dbar_{ref} = \text{"reference value of dbar"}$$
$$= 5.5722\ 10^{-6}$$
$$(R')_{av} = \text{smaller of } R_{av} \text{ and } 1.7$$
$$R_{av} = 1.477 + (.477) \{ (dbar_0/dbar)^{1.044} - 1.0 \}$$
$$dbar_0 = 1.357\ 10^{-3}$$

and

$$S_{ac} = S_a \quad ; \ (\varepsilon')_c \leq 2.0$$

$$= S_c \quad ; \ (\varepsilon')_c > 2.0$$

$$S_a = 1.0 \qquad ; \ f_a \leq 1.0$$

$$= f_a + (1.411) \log_{10}(f_a) \qquad ; \ 1 < f_a < 1.375$$

$$= 1.7 \qquad ; \ f_a \geq 1.375$$

$$f_a = -(1.411) \ \log_{10}\{ \ \kappa_a \, (\varepsilon')_a \ \}$$

$$\kappa_a = (.2303) \ (dbar/dbar_{ref})^{-.3027}$$

$$(\varepsilon')_s = \varepsilon_s$$

ε_s = "significant wave slope" based on significant wave height

$$= H_s/(4 \ L)$$

H_s = "significant wave height"; i.e., average height of the highest (1/3) waves

$$S_c = 1.0 \qquad ; \ f_c \leq 1.0$$

$$= f_c + (1.017) \log_{10}(f_c) \qquad ; \ 1 < f_c < 1.466$$

$$= 1.7 \qquad ; \ f_c \geq 1.466$$

$$f_c = -(1.017) \ \log_{10}\{ \ \kappa_c \, (\varepsilon')_s \ \}$$

$$\kappa_c = (.1705) \ (dbar/dbar_{ref})^{-.42}$$

$$(\varepsilon')_c = (\varepsilon')_s \ / \ S_c$$

APPENDIX III

WAVE HEIGHT COMPUTATIONS FOR FLOOD INSURANCE STUDIES (VERSION 2.1)
SAMPLE TRANSECT

PART1 INPUT

IE	0.000	0.000	24.000	6.000	9.000	0.000	12.000	0.000	0.000	0.000
IF	500.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
VH	3000.000	3.000	3.000	0.000	0.000	2.000	0.000	0.000	0.000	0.000
MG	SALT	0.000	0.180	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MG	SALM	0.000	0.670	0.000	0.000	0.000	0.000	0.000	0.000	0.000
IF	3500.000	9.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ET	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

	END STATION	END ELEVATION	FETCH LENGTH	SURGE ELEV 10-YEAR	SURGE ELEV 100-YEAR	INITIAL WAVE HEIGHT	INITIAL W. PERIOD			AVERAGE A-ZONES
IE	0.000	0.000	24.000	6.000	9.000	0.000	12.000	0.000	0.000	0.000

	END STATION	END ELEVATION	NEW SURGE 10-YEAR	NEW SURGE 100-YEAR						AVERAGE A-ZONES
IF	500.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

	END STATION	END ELEVATION	REGION 1	REGION 1 WEIGHT	REGION 2	NO. OF PLANT TYPES	NEW SURGE 10-YEAR	NEW SURGE 100-YEAR		AVERAGE A-ZONES
VH	3000.000	3.000	3.000	0.000	0.000	2.000	0.000	0.000	0.000	0.000

	PLANT TYPE	DRAG COEFF.	COVERAGE RATIO	AVG. STEM HEIGHT	NUMBER DENSITY	BASE STEM DIAMETER	MID STEM DIAMETER	TOP STEM DIAMETER	LEAF-STEM AREA RATIO	
MG	SALT	0.000	0.180	0.000	0.000	0.000	0.000	0.000	0.000	0.000

	PLANT TYPE	DRAG COEFF.	COVERAGE RATIO	AVG. STEM HEIGHT	NUMBER DENSITY	BASE STEM DIAMETER	MID STEM DIAMETER	TOP STEM DIAMETER	LEAF-STEM AREA RATIO	
MG	SALM	0.000	0.670	0.000	0.000	0.000	0.000	0.000	0.000	0.000

PLANT CHARACTERISTICS INCLUDING VALUES SUPPLIED BY THE PROGRAM

PLANT TYPE	DRAG COEFF.	COVERAGE RATIO	AVG. STEM HEIGHT	NUMBER DENSITY	BASE STEM DIAMETER	MID STEM DIAMETER	TOP STEM DIAMETER	LEAF-STEM AREA RATIO
SALT	0.100	0.180	3.200	10.000	0.220	0.088	0.044	1.590

PLANT TYPE	DRAG COEFF.	COVERAGE RATIO	AVG. STEM HEIGHT	NUMBER DENSITY	BASE STEM DIAMETER	MID STEM DIAMETER	TOP STEM DIAMETER	LEAF-STEM AREA RATIO
SALM	0.100	0.670	1.630	11.800	0.169	0.068	0.034	1.590

	END STATION	END ELEVATION	NEW SURGE 10-YEAR	NEW SURGE 100-YEAR						AVERAGE A-ZONES
IF	3500.000	9.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

----------END OF TRANSECT----------

NOTE:

SURGE ELEVATION INCLUDES CONTRIBUTIONS FROM ASTRONOMICAL AND STORM TIDES.

PART2 WAVE HEIGHTS AND ELEVATIONS

LOCATION		WAVE HEIGHT	WAVE ELEVATION
IE	0.00	7.02	13.91
IF	500.00	6.24	13.37
VH	3000.00	3.08	11.15
IF	3500.00	0.00	9.00

PART3 LOCATION OF AREAS ABOVE 100-YEAR SURGE

NO AREAS ABOVE 100-YEAR SURGE IN THIS TRANSECT

PART4 LOCATION OF SURGE CHANGES

STATION	10-YEAR SURGE	100-YEAR SURGE

NO SURGE CHANGES IN THIS TRANSECT

PART5 LOCATION OF V ZONES

STATION OF GUTTER	LOCATION OF ZONE
3012.69	WINDWARD

PART6 NUMBERED A ZONES AND V ZONES

STATION OF GUTTER	ELEVATION	ZONE DESIGNATION	FHF
0.00	13.91		
		V 9 EL=14	45
379.12	13.50		
		V 9 EL=13	45
1510.73	12.50		
		V 9 EL=12	45
2251.68	11.50		
		V 9 EL=11	45
3012.69	11.10		

		A 8 EL=11	40
3151.92	10.50		
		A 8 EL=10	40
3383.97	9.50		
		A 8 EL= 9	40
3500.00	9.00		

ZONE TERMINATED AT END OF TRANSECT

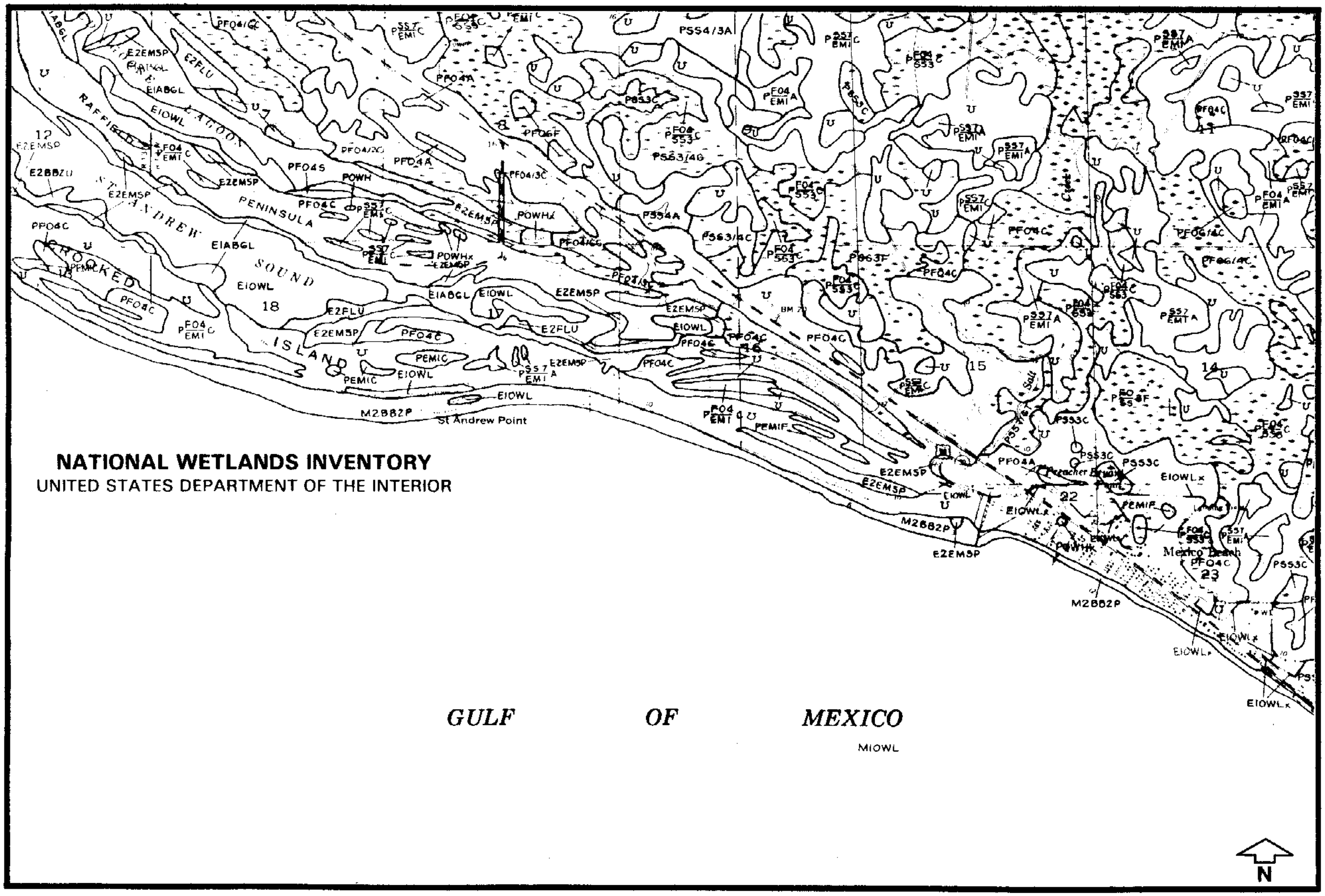


FIGURE 1

Example of National Wetlands Inventory Map.
Map Scale is 1:24000.

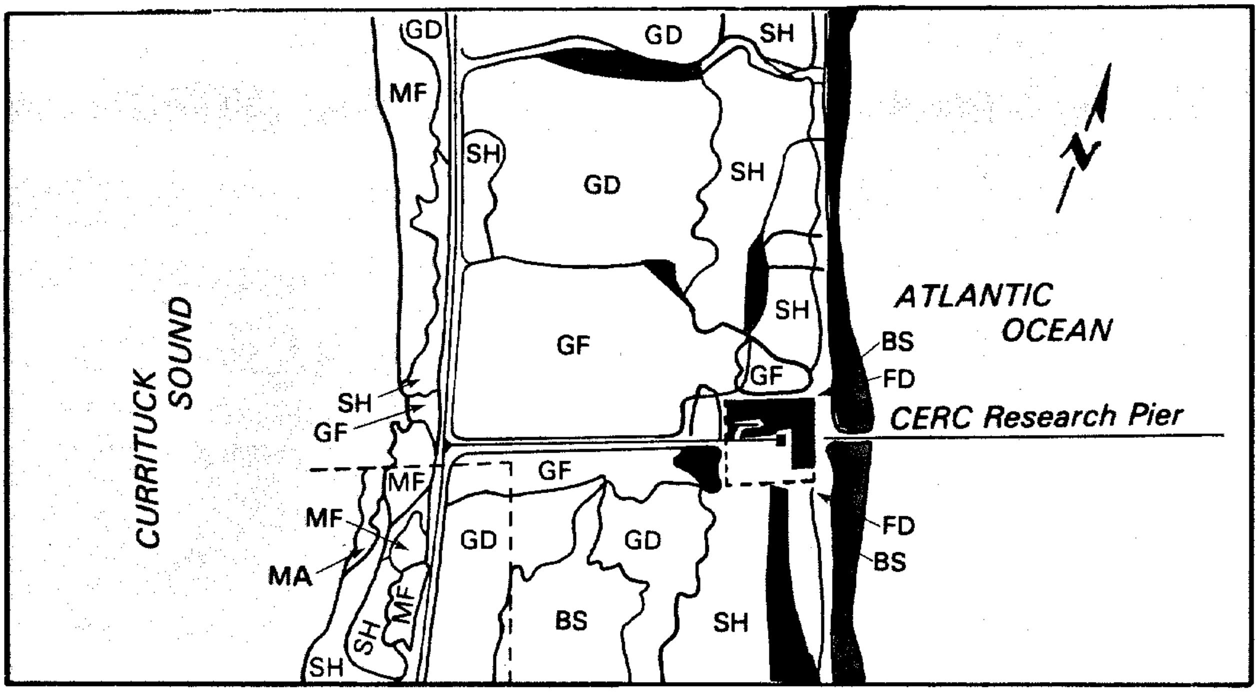


FIGURE 2

Example of patchy distribution of coastal vegetation seen in some aerial photographs (based on plate from U.S. Army Coastal Engineering Research Center)

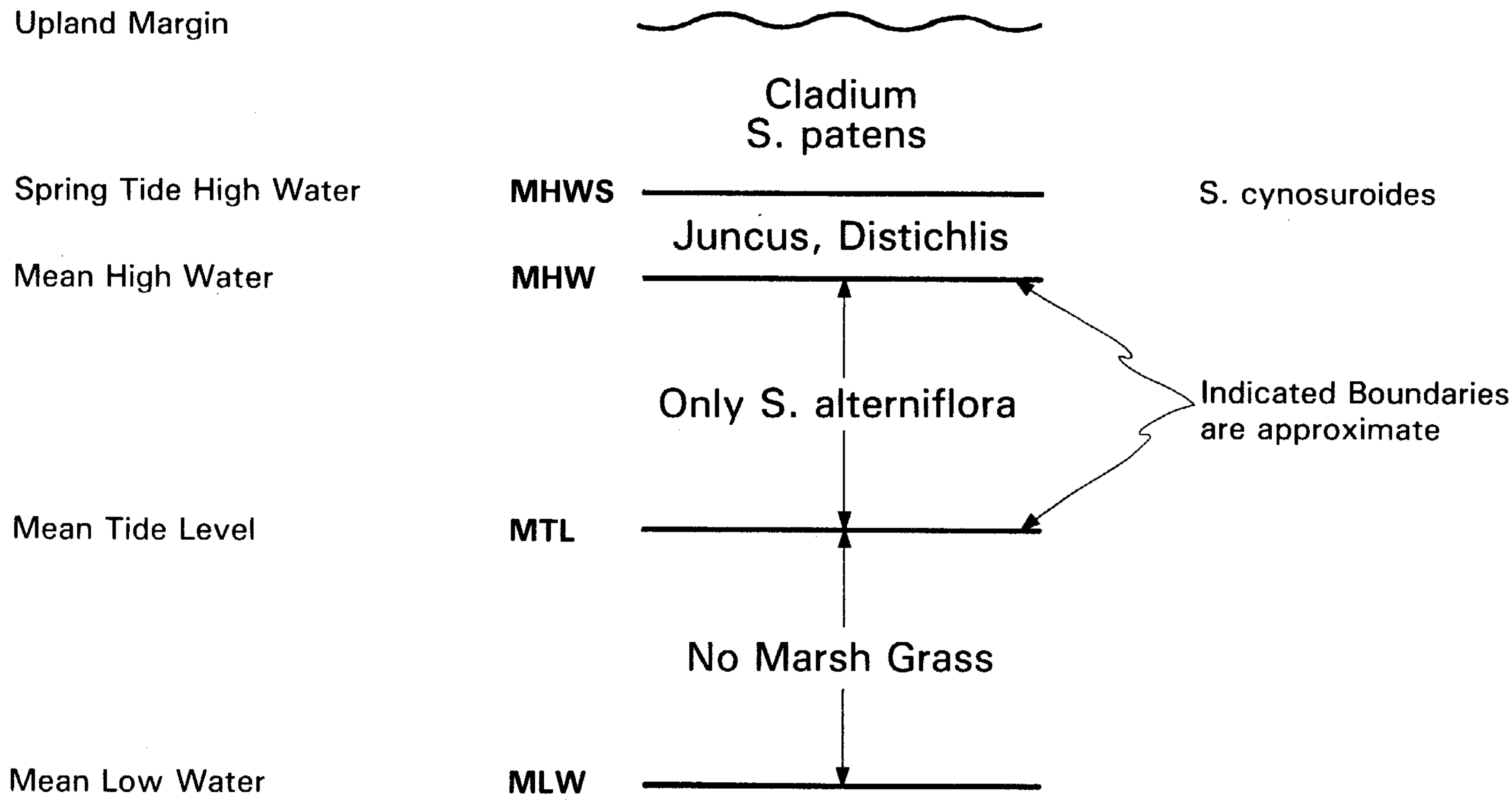
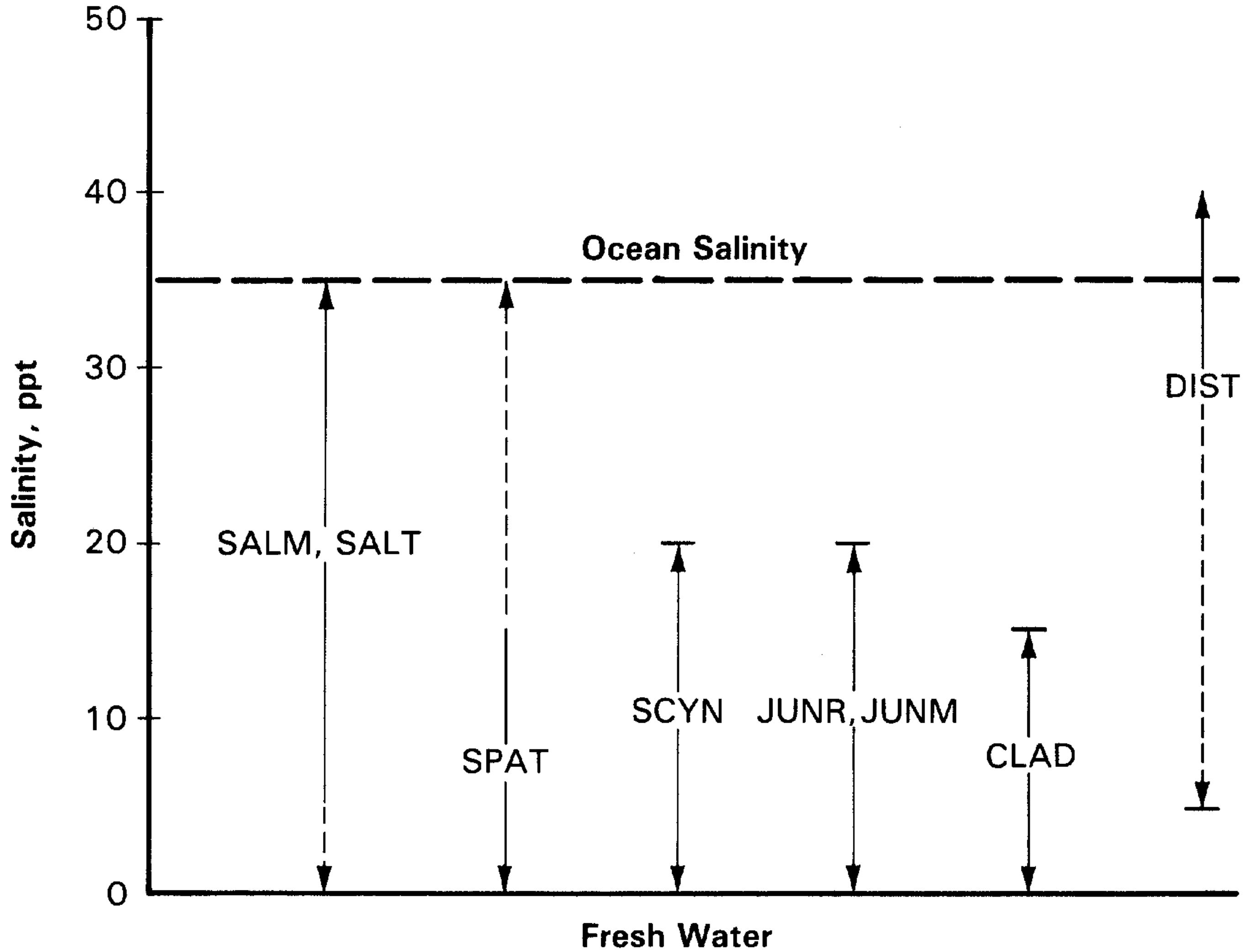


FIGURE 3A
Tidal control on salt marsh plant zonation.
See section II for further information.

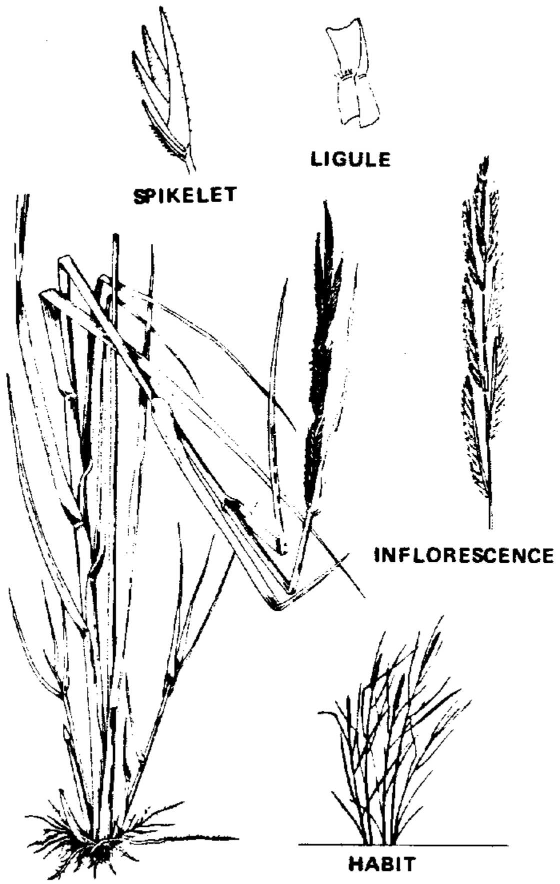
Salinity Ranges from Knutson and Woodhouse (1983)



Indicates the usual salinity range tolerated by a particular species

Indicates that a particular species can tolerate the indicated salinity range but is usually not found in significant quantities.

FIGURE 3B
Salinity tolerance of marsh plants.



Spartina alterniflora

Note: On this and subsequent plant illustrations, the dried plant specimens were sometimes bent by the botanist to fit standard-size herbarium paper. In natural growth position, the plants are reasonably straight and erect.

FIGURE 4

Spartina alterniflora (Saltmarsh Cordgrass).
Botanical drawing, from Eleuterius (1981), p. 45.

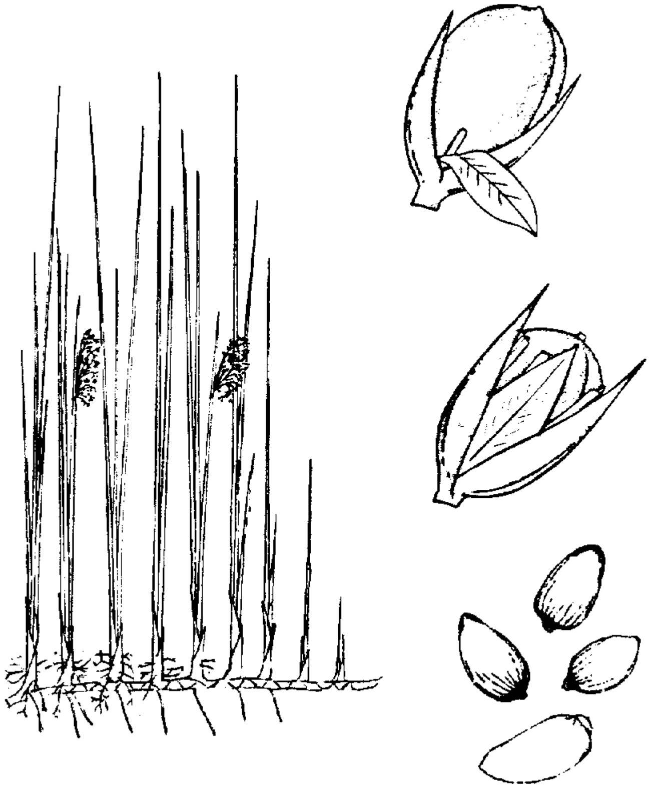
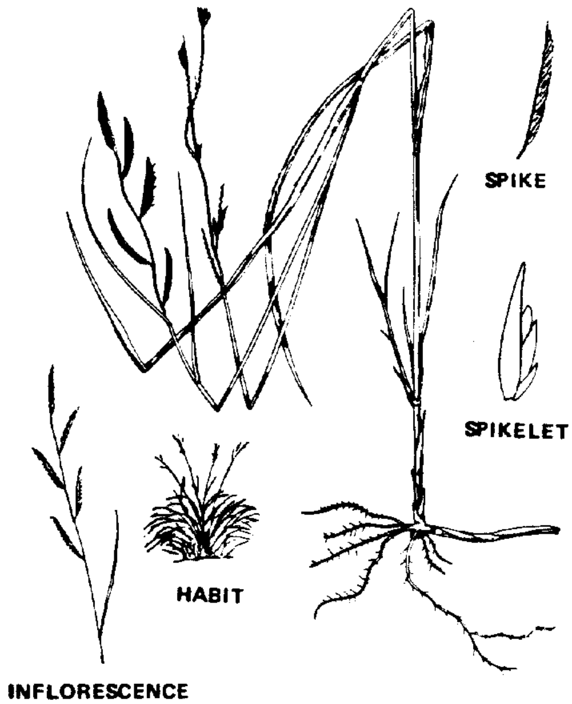


FIGURE 5
Juncus roemerianus (Black Needlerush).
Botanical drawing, from Eleuterius (1981), p. 71.

FIGURE 6
Juncus gerardi (Black Grass).
Botanical drawing, from Nixon (1982), p. 22.



Spartina patens

FIGURE 7
Spartina patens (Saltmeadow Grass).
Botanical drawing, from Eleuterius (1981), p. 37.

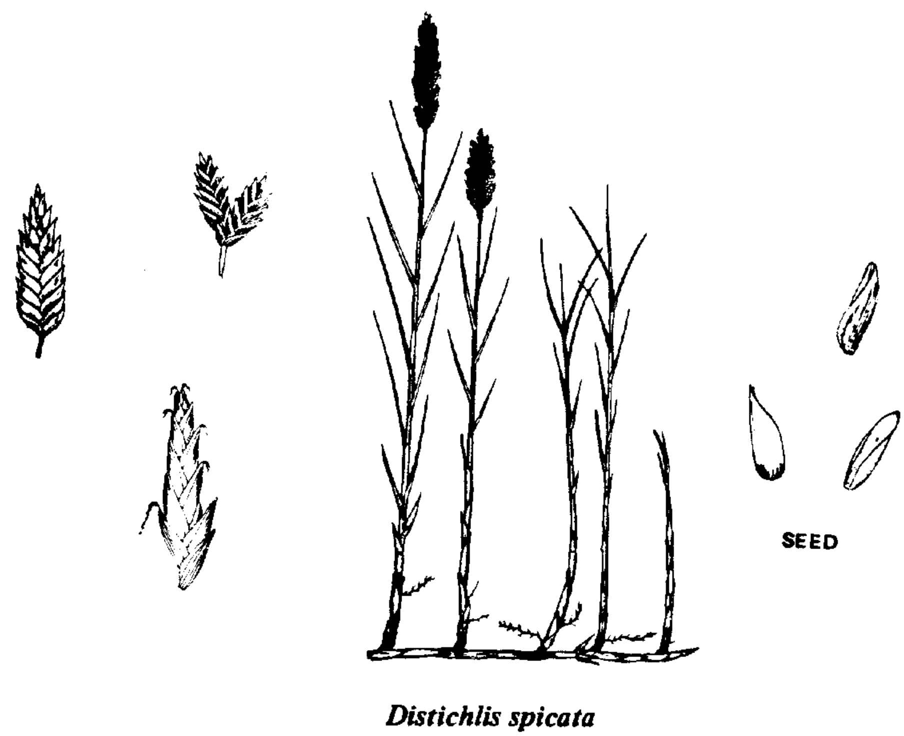


FIGURE 8
Distichlis spicata (Salt Grass).
Botanical drawing, from Eleuterius (1981), p. 37.

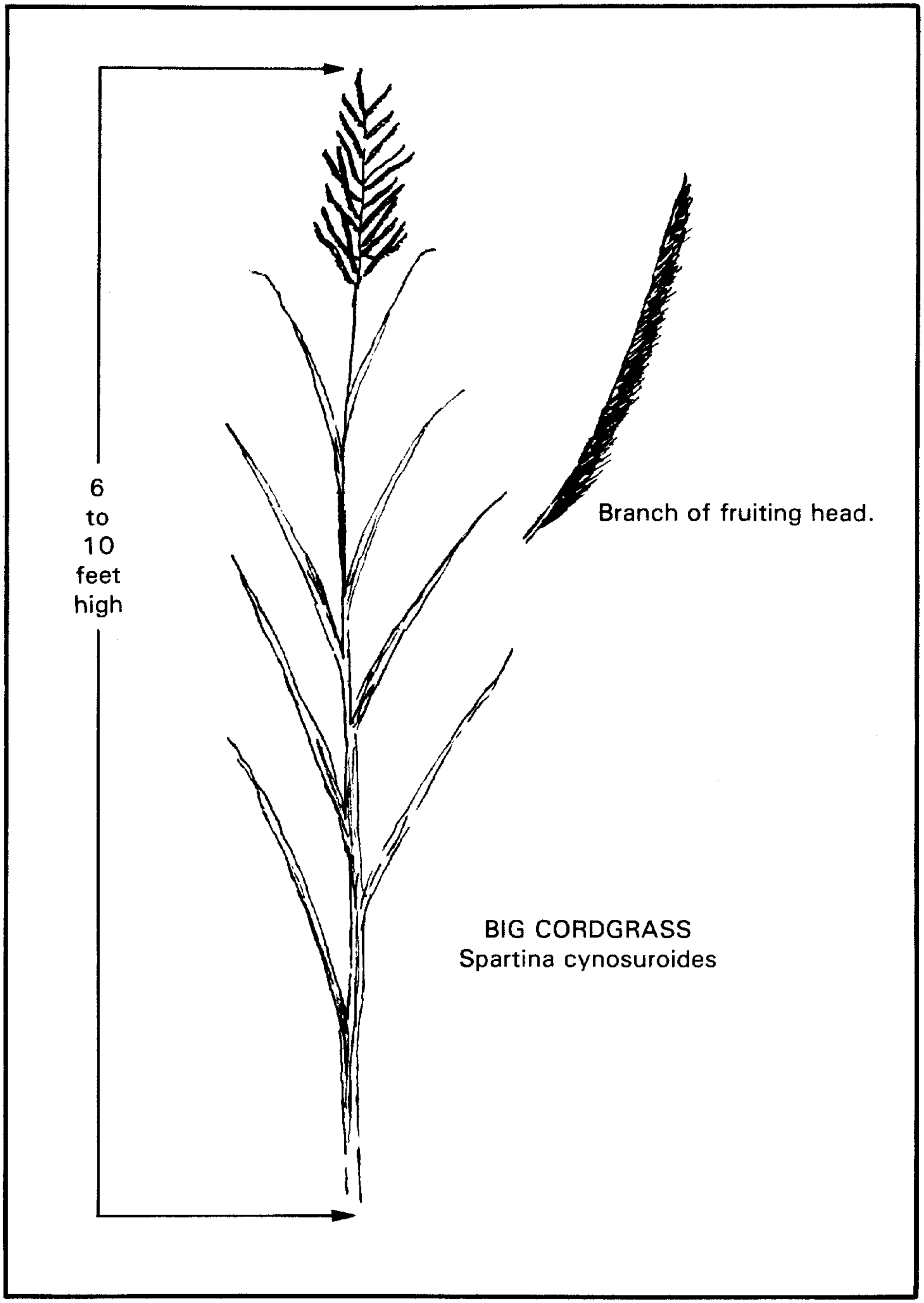


FIGURE 9

Spartina cynosuroides (Big Cordgrass).
Botanical drawing, from Silberhorn, Dawes, and Barnard (1974), p. 13.

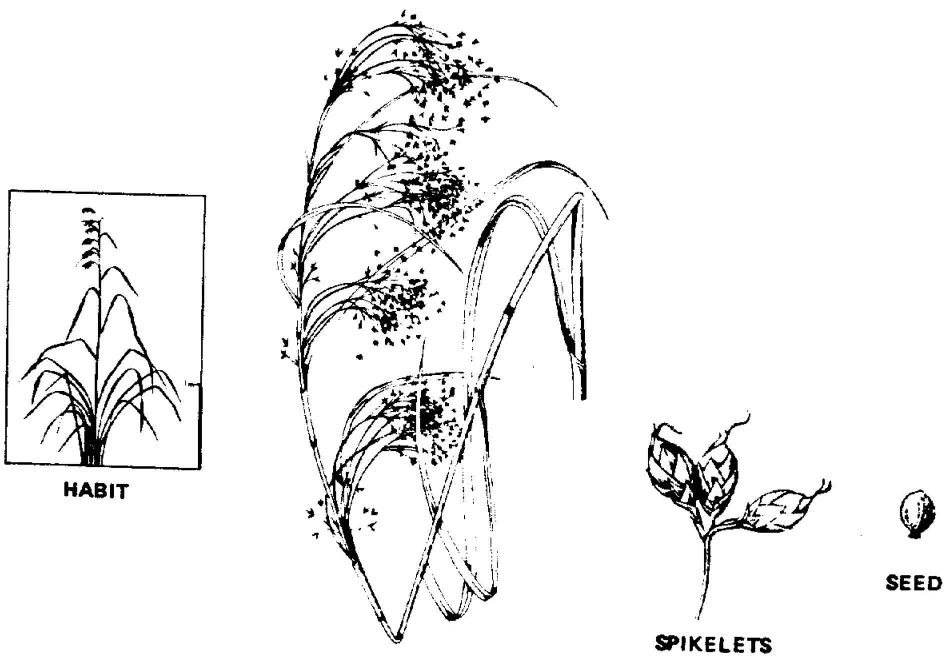


FIGURE 10
Cladium jamaicense (Saw Grass).
Botanical drawing, from Eleuterius (1981), p. 49.

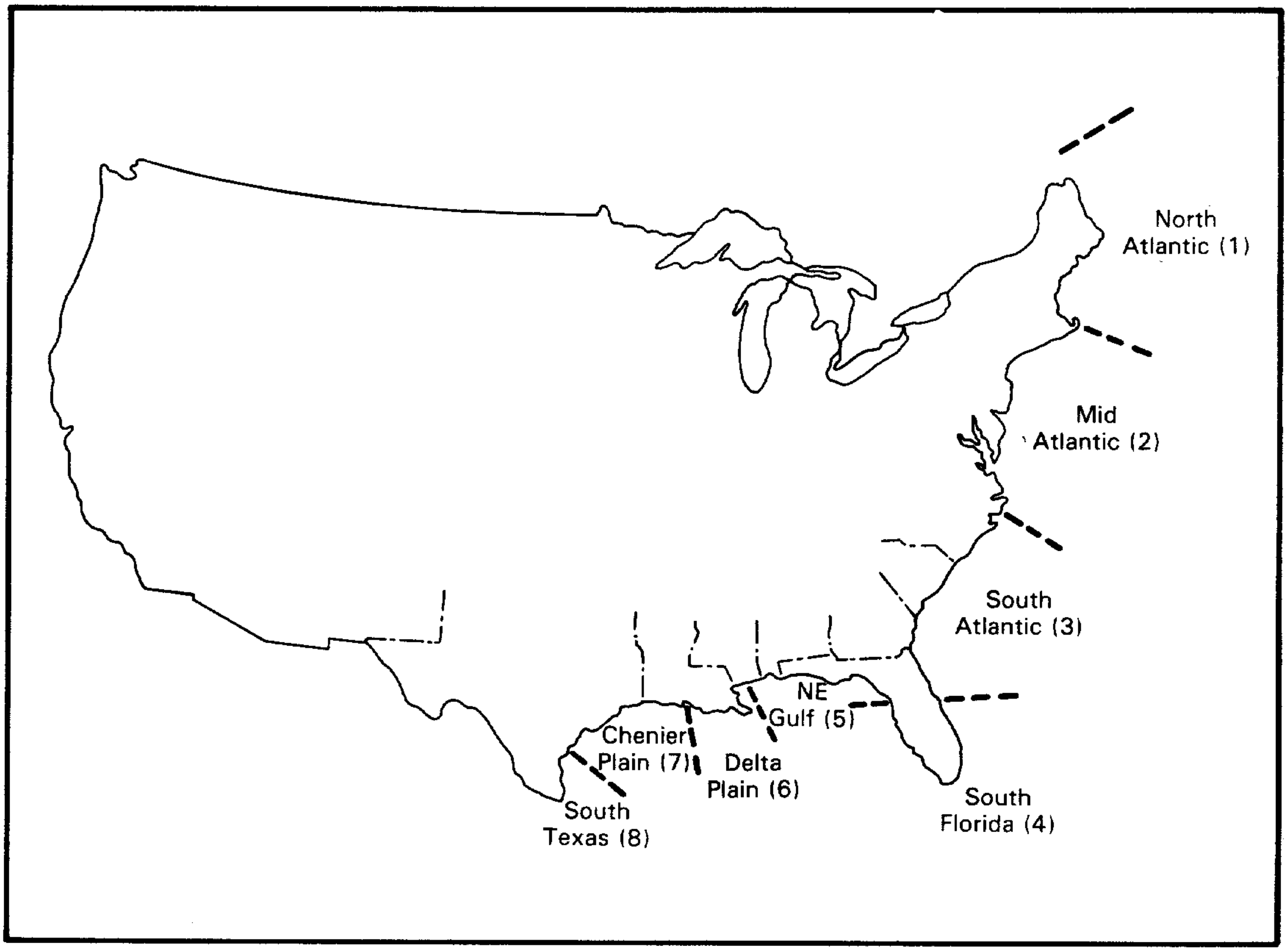


FIGURE 11

Coastal wetland regions of Atlantic and Gulf coasts having enough marsh grass to significantly affect wave heights. Region numbers are indicated in parentheses

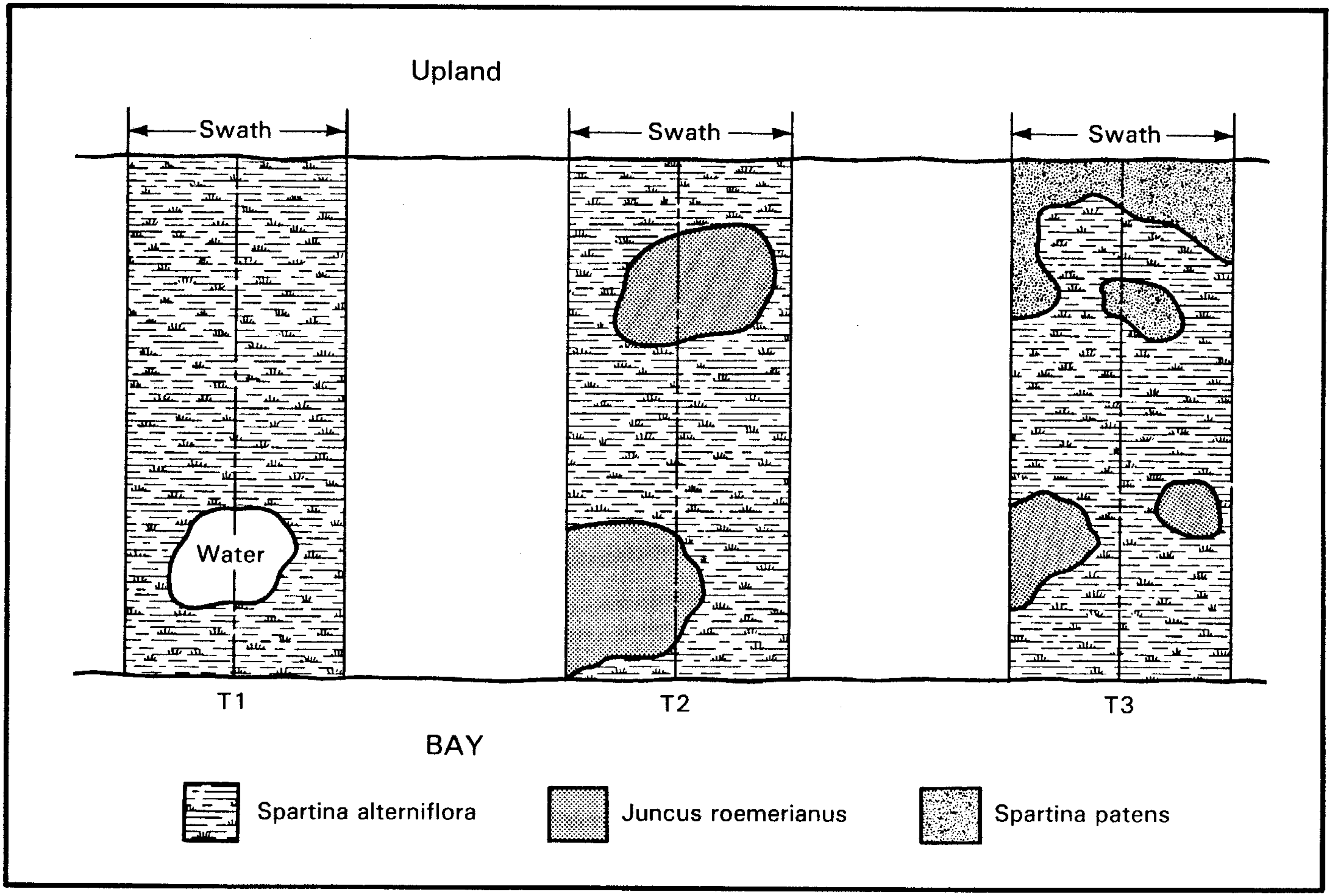


FIGURE 12
Three examples of ground cover variation within transect swaths.

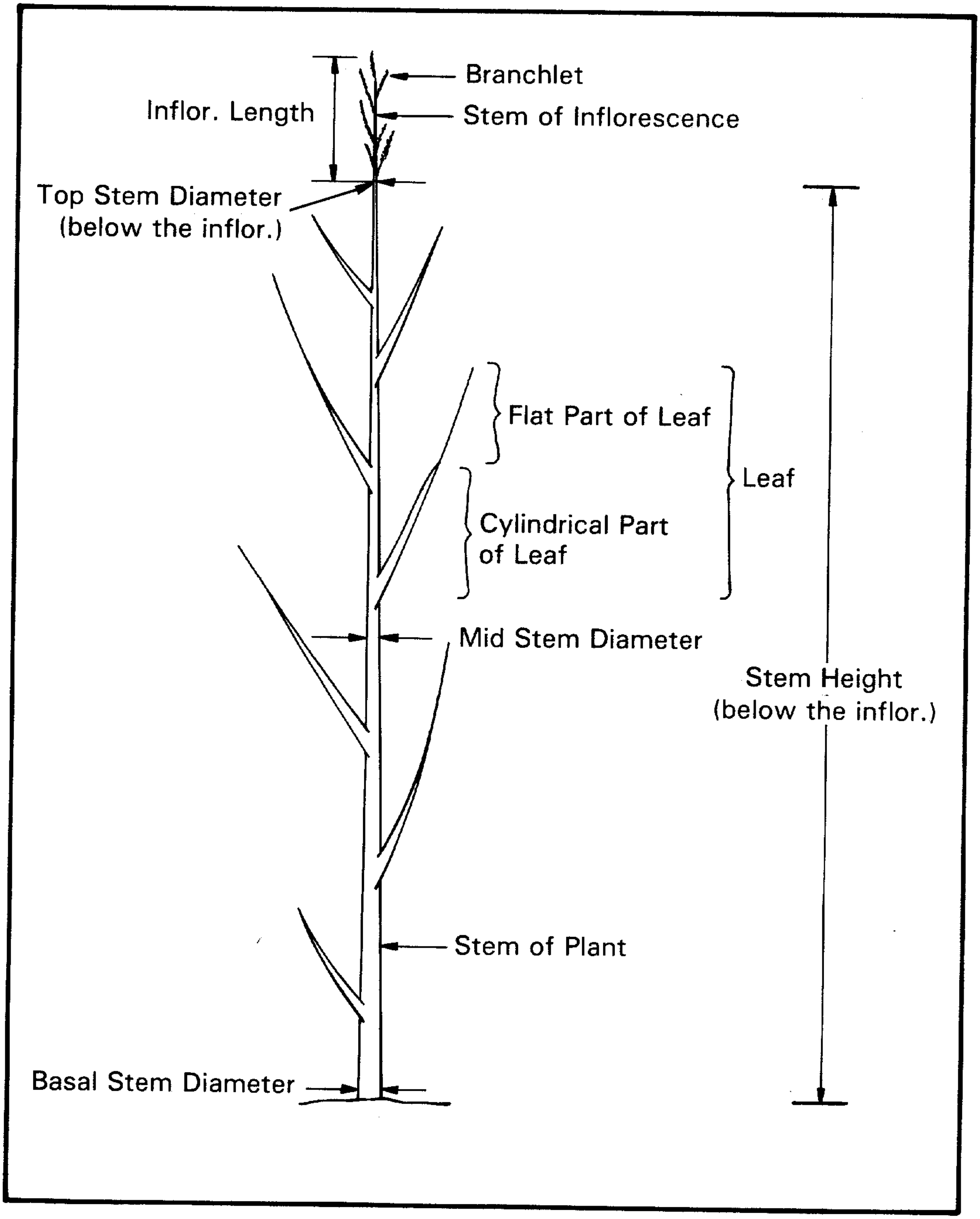


FIGURE 13
Schematic diagram of marsh grass plant geometry.