DREDGED MATERIAL RESEARCH PROGRAM

MISCELLANEOUS PAPER D-77-1

PREGERMINATION REQUIREMENTS AND ESTABLISHMENT TECHNIQUES FOR SALT MARSH PLANTS

by

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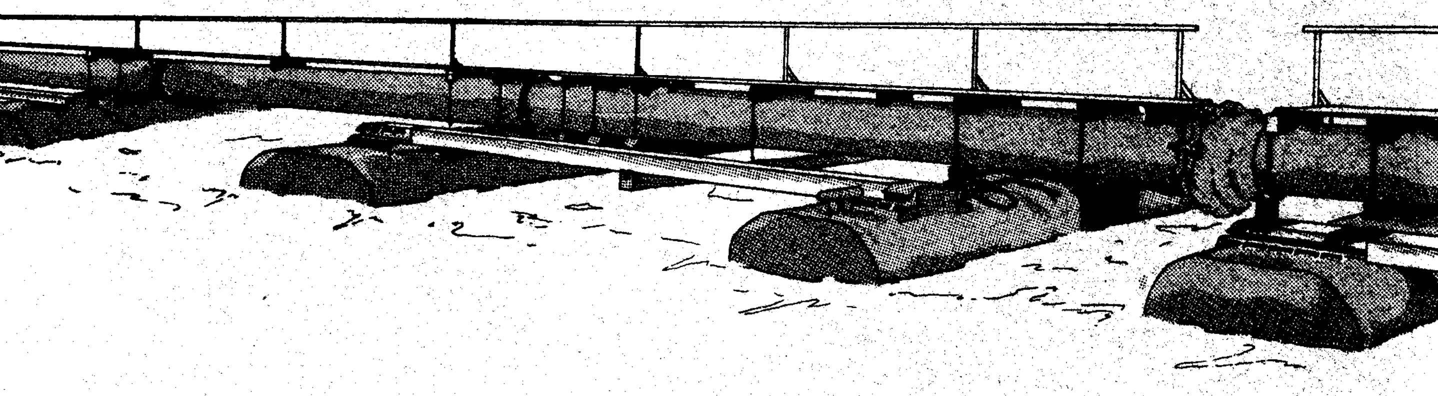

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Under DMRP Work Unit No. 4A09

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SUBJECT: Transmittal of Miscellaneous Paper D-77-1

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1. The miscellaneous paper transmitted herewith represents the results of a series of research efforts (work units) undertaken as part of Task 4A (Marsh Development) of the Corps of Engineers' Dredged Material Research Program (DMRP). Task 4A is part of the Habitat Development Project, which has as one of its objectives the development of environmentally and economically feasible disposal alternatives compatible with the Corps' resources development directive. Marsh development on dredged material is a proven disposal alternative and has been demonstrated on a wide variety of substrates over a broad range of salinities.

2. A working knowledge of pregermination requirements and establishment techniques is essential in those marsh establishment projects that depend upon artificial propagation. Both seeding and transplanting have resulted in successful marsh establishment on dredged material; however, propagation by transplants offers the highest probability of success, particularly on silty or clayey substrates. Beyond initial establishment, the longivity of man-made marshes is dependent upon an ecologically sound balance between substrate elevation, species selection, and local wave and current forces.

3. The information contained in this report represents an ancillary effort accomplished under Work Unit 4A09, "Design and Establish Salt Marsh Ecosystem Simulation." Presented is a state-of-the-art summary of information available through 1974. The contents of the report should be considered preliminary and will be augmented by the findings of field research being conducted at Buttermilk Sound, Georgia (4A12); Apalachicola, Florida (4A19); San Francisco, California (4A18); and Miller Sands, Oregon (4B05) and detailed seed germination studies being conducted under Work Unit 4A21. Related DMRP research reports dealing with marsh plant establishment techniques have been published as Contract Report D-74-9 and Technical Report D-77-2.

JOHN L. CANNON
Colonel, Corps of Engineers
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Pregermination requirements and establishment techniques for several salt marsh plant species are discussed. Both seeding and transplanting have resulted in successful artificial marsh establishment on natural coastal areas and on deposited dredged materials. Since most of the existing studies have been performed on sand substrates, little is known about salt marsh establishment on loam, silt, clay, or highly organic soils. Establishment appears to be independent of substrate, but long-term growth and survival of salt marsh grasses apparently are dependent upon substrate. (Continued)

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20. ABSTRACT (Continued).

Growth regulation appears to be associated with soil physical factors such as percolation, diffusion, drainage, and aeration rather than with the chemical characteristics of the soil. Elevation and hydraulics, which largely determine the periodicity of plant submergence and emergence, appear to control plant distribution and zonation. Since momentum transport also is largely determined by elevation and hydraulics, establishment and growth of salt marsh plants are affected by the bed shear stress of the substrate.

At the present time, site selection for marsh establishment is subjective because quantitative data which would allow realistic calculations of physical stresses on substrates are not available.

Biological, mechanical, and engineering problems associated with artificial marsh establishment are discussed. Consideration of these problems and the rapid process of natural invasion and colonization of salt marsh plants on properly elevated dredged materials has resulted in the conclusion that emphasis should be placed on the development of equipment and techniques to allow fine control of dredged material elevation.

EXECUTIVE SUMMARY

Pregermination requirements, general physiological-edaphic interaction, and establishment techniques for several salt marsh plant species have been discussed. Both seeding and transplanting have resulted in artificial marsh establishment on natural coastal areas and on deposited dredged material. Both the collection and planting of propagules are expensive, time-consuming, and generally limited to areas accessible to and capable of supporting mechanical equipment and men. Seeds have been found to be an undependable source of propagules because of their limited availability and difficulty in storing. Rooting cuttings of several salt marsh grasses appear feasible and rhizomes are discussed as a potentially useful source of plant material irrespective of possible ecotypes and season of the year.

Since most of the existing establishment studies to date (April 1974) have been performed on sand substrates, little is known about salt marsh establishment on loam, silt, clay, or highly organic soils. Establishment appears to be independent of substrate, but long-term growth and survival of salt marsh grasses apparently are dependent upon substrate. Growth regulation appears to be associated with soil physical factors such as percolation, diffusion, drainage, and aeration rather than with the chemical characteristics of the soil.

Elevation and hydraulics, which largely determine the periodicity of plant submergence and emergence, appear to control plant distribution, plant zonation, and successful marsh establishment and maintenance. Since the rate and extent of consolidation in combination with bed shear stress determine the final elevation of dredged material, data allowing realistic calculations of both the rate and extent of changes in elevations determine the amount of dredged material needed to obtain a given final elevation that encourages establishment and maintenance of specific desired plants. Since momentum transport also is largely determined by elevation and hydraulics, establishment and growth of salt marsh plants are affected by the stresses placed on the substrate, i.e., erosion of the substrate and/or physical removal of plants from the

substrate. Site selection for marsh establishment is subjective because quantitative data which allow realistic calculations of substrate stresses are not available. Mixing different types of dredged material, i.e., different substrates such as sand, silt, clay, etc., may be necessary to regulate consolidation, substrate stresses, and physical soil processes to allow successful establishment and maintenance of specific desired plants.

Biological, mechanical, and engineering problems are associated with artificial marsh establishment. Natural invasion and establishment on naturally elevated substrates and on properly elevated dredged material appears to be a rapid process. Consideration of the problems involved and rapid natural marsh establishment has resulted in the conclusion that emphasis should be placed on the development of equipment and techniques to allow fine control of dredged material elevation.

PREFACE

The study reported herein was conducted by the U. S. Army Engineer Waterways Experiment Station (WES) during the period October 1973-April 1974. The study was conducted as part of the U. S. Army Corps of Engineers Dredged Material Research Program (DMRP), which is administered by the Environmental Effects Laboratory (EEL) (formerly Office of Dredged Material Research), WES. The DMRP is sponsored by the Office, Chief of Engineers (DAEN-CWO-M).

The evaluation and suggestions for needed research included herein are based on published data and on discussions with workers at North Carolina State University, the University of Georgia, the State University of New York at Stony Brook, and Environmental Concern, Inc. Copyright permission was granted by Florida State University to reproduce certain tables from the publication by Kurz and Wagner. Certain insights and associations were strengthened by data in published field studies but, in general, these references are not cited in this report.

Ms. Pat K. Falco and Mr. Frank J. Cali conducted the study and prepared the report under the supervision of Dr. Rex L. Eley, Chief, Ecosystem Research and Simulation Division. Dr. C. J. Kirby, Chief, Environmental Resources Division, and Dr. Luther F. Holloway managed the project. Dr. John Harrison, Chief, EEL, provided general supervision for the study. Mr. Nathan Wilds provided assistance in report preparation, and Ms. Mary Landin provided contributions to the text.

Directors of WES during the conduct of the study and preparation of the report were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

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	2.54	centimetres
feet	0.3048	metres

PREGERMINATION REQUIREMENTS AND ESTABLISHMENT TECHNIQUES FOR SALT MARSH PLANTS

PART I: INTRODUCTION

1. The Corps of Engineers (CE) is interested in creating salt marshes from dredged material and establishing marsh plants on diked disposal areas for stabilization and/or habitat creation. The feasibility of such a program was substantiated by the work on artificial marsh establishment performed by Woodhouse, Seneca, and Broome[1,2] at North Carolina State University and by Garbisch et al.[3] at Environmental Concern, Inc.

2. This report contains a state-of-the-art review of data pertinent to pregermination requirements of salt marsh plant seeds and the procedures used for artificial marsh establishment to date (April 1974). Other physiological and edaphic data have been included in an attempt to enhance an objective choice of specific plants to be established under specific environmental conditions.

3. Appendix A presents a list of the scientific names and common vascular plant names of species used in this study.

PART II: STATE-OF-THE-ART REVIEW

Factors Affecting Germination and Growth of Salt Marsh Grasses

4. Workers at North Carolina State University performed the most inclusive and complete set of experiments to date on establishing salt marsh plants.[2,4-8] Their experimental approach, based on the earlier work of Stalter and Baston[9] in South Carolina, was to collect seeds and seedlings from short, intermediate, and tall forms of marsh plants (emphasis on *Spartina alterniflora*) from different geographic regions. These seeds and seedlings were then subjected to various storage, germination, and growth conditions to elucidate the factors regulating germination and growth. These factors included photoperiod, thermoperiod, and salinity regimes during storage, germination, and seedling growth. Effects of substrate, fertilization, elevation, and substrate stresses will be discussed as they relate to germination, growth, and thereby artificial marsh establishment.

Storage

5. Seeds of all salt marsh plants tested apparently must be stored moist if they are to remain viable for even a few months.[1,4,6] Storage over water, in distilled water, and in estuarine water all tend to extend the period of viability. Seeds stored in distilled water exhibited decreased germination at the end of 5 months; seeds stored in estuarine water remained viable for 8 months.[4] Storage at 2° to 3°C is perferred, but a specific cold requirement for germination has been established to date for only one plant, *Uniola paniculata*.[5] Normally, after 8 months of storage at 2° to 3°C in either distilled or estuarine water, all of the seeds had germinated.[4] The storage period was lengthened to at least 12 months by storage in 4 percent sodium chloride (NaCl). Apparently the increased osmotic pressure reduced the rate of germination and inhibited growth of fungi, which might cause problems during prolonged storage.*

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* Personal communication, 1974, E. W. Garbisch, Director, Environmental Concern, Inc., St. Michaels, Md.

6. Data reported by Seneca[6] and Mooring, Cooper, and Seneca[5] indicated that storage at high concentrations of NaCl would be feasible since storage for 8 months at 2° to 3°C in 8 percent NaCl did not kill the seeds. Time of germination was inhibited by increasing the concentration of NaCl from 0 to 8 percent as shown in Table 1, but the effect appeared to be an osmotic inhibition, rather than death of seeds as shown by Ungar[10] for Salicornia europaea, Spergularia marina, Suaeda depressa, and Suaeda linearis. Palmisano[11] demonstrated osmotic inhibition of germination for seeds of several Louisiana salt marsh grasses (Table 2).

7. The three growth forms of S. alterniflora from a given location responded in like manner to various storage and germination procedures.[5] However, storage and germination differences were observed with location and with form and location. These differences were attributed to the fact that the seeds were harvested at different stages of maturity.[4] Seeds of S. alterniflora ripened earlier at the more northern latitudes of the United States. Since it was necessary to pick the seeds before the heads scattered, seeds in various stages of physiological development were harvested.

8. Studies performed in the Phytotron at North Carolina State University under long- and short-day conditions with three diel temperature regimes indicated that height growth rather than flowering of S. alterniflora was more related to length of the light period.[7] In general, faster growth with greater accumulation of biomass occurred under long-day conditions. Seedlings grown under short-day conditions were shorter, contained less biomass, and produced more culms and rhizomes. Although flowering occurred earlier under short-day conditions in the 26° to 22°C and 30° to 26°C thermoperiods, flowering also occurred under long-day conditions in these thermoperiods and appeared related to height growth. Perhaps these data can explain the north-to-south ripening of S. alterniflora seeds in the field. If time of flowering is correlated with the attainment of a specific plant size or mass, this stage could be reached earlier under the long-day conditions in the northern United States. High temperature inhibition of seed set

has been discussed by Louisiana State University investigators as a possible explanation for later seeding in southern marshes.*

9. Photoperiod data also are available for *Spartina anglica* and *S. depressa*. Hubbard[12] observed that *S. anglica* flowered under a 16-hour day (long-day) in a growth chamber; the species remained in a vegetative state under a 10-hour light period (short-day). Williams and Ungar[13] reported that a 10-hour photoperiod stimulated floral induction in *S. depressa*.

Germination

10. All of the marsh plants studied to date had an obligatory after-ripening period.[1,4-6,14,15] This simply means that the seeds cannot germinate immediately after they set. Both mechanical and physiological blocks have been proposed to explain the after-ripening period for *S. alterniflora*, but apparently it is due to physiological processes.[4-6] Germination of all seeds tested was maximal after approximately 90 days.[4-6,14]

11. Woodhouse, Seneca, and Broome[1] and Mason[14] reported data indicating that soaking tended to shorten the after-ripening period. This may be obligatory for seed maturation in the natural habitat. Amen, Carter, and Kelly[15] observed that gibberellic acid and kinetin did not break dormancy nor affect germination of *Distichlis spicata*. Apparently no systematic study of hormone treatment has been done on the seeds of salt marsh plants.

12. Compiled data from all sources indicated that germination of salt marsh plants was highest in fresh water and/or 0.5 percent NaCl (Tables 1 and 2). Decreasing germination percentages were associated with increasing amounts of NaCl. Chapman[16] reported that germination time for many species was correlated with minimum surface soil salinity. Mooring, Cooper, and Seneca[5] observed that in the field, seedlings were found most often near creeks or at the marsh-sound interface. Mason[14] reported that *Spartina foliosa* seeds germinated while attached to the

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* Personal communication, 1974, R. Parrondo, Dept. of Forestry, Louisiana State University, Baton Rouge, La.

parent plant. When water from rainfall and/or dew remained in the inflorescences for several days, the seeds became bright green. The activation of chlorophyll was the first step in the germination process of this plant. Radicle and epicotyl emergence followed. The germinating seeds then fell into the water. Thus, germination of S. foliosa seeds in the field may occur in much fresher water than that in which the plant lives.

13. Compiled data from all sources indicated that there was increased germination under fluctuating temperature conditions, i.e., diel thermoperiods.[5,6] In many instances, constant temperatures inhibited or totally prevented germination.

Growth Requirements

Propagation

14. Marsh plants can be propagated by rhizomes, by seeds, and by transplanting seedlings. Hubbard[17] and others observed that in general bare areas in some natural marshes appear to be invaded by seeds. Lateral growth of rhizomes from seedlings then results in the mat-like growth characteristic of these plants. Data reported by Redfield[18] and Woodhouse, Seneca, and Broome[1] indicated lateral expansion of approximately 0.4 to 0.5 m per year by S. alterniflora. Growth in the intertidal zone and in older stands occurred only by spread of rhizomes.[18]

15. Seed set by these plants generally occurred only in young stands along creek banks.[4,14] As the plants became more crowded, general plant vigor and seed production were reduced. Thus, seed production was low and harvest was difficult.

Salinity

16. The exact physiological mechanisms regulating salt transport by plants growing in saline environments are still debated. The reader is referred to a recent review article by Rains[19] for discussion and references relative to this topic. Two of the more generally accepted hypotheses of ion regulation involve the dual mechanisms of ion transport. In the hypothesis, two distinct kinetic responses were associated

with ion absorption. One mechanism operated below approximately 1 mmol external concentration and was extremely ion specific, so that uptake of an ion could occur selectively in the presence of large amounts of chemically similar ions; e.g., potassium uptake in the presence of sodium. A second mechanism operated within a concentration range of 1 to 50 mmol and was not as ion specific as the other. Uptake was affected by the presence of other ions in this higher concentration range. This dual mechanism allows for luxury uptake of specific ions. The original salt respiration idea was expanded to the concept of a "proton pump" with effected charge separation and supplied energy for either adenosine triphosphate (ATP) synthesis or absorption of ions. Both of these systems were under enzymatic regulation and were directly or indirectly regulated by changes in ATP to adenosine diphosphate (ADP) ratio.

17. External environmental regulation of ion transport in saline environments could be mediated through bicarbonate or chloride ion. According to Jacoby and Laties,[20] cytoplasmic bicarbonate regulated the activity of phosphoenolpyruvate carboxylase which in turn regulated organic acid synthesis. Although the exact mechanism is not known, increased ion absorption was associated with increased organic acids in the plants. Reduced levels of organic acids generally were found in plants adversely affected by saline environments. Chloride ion inhibited oxalic acid oxidase. The inhibition could result in accumulation of oxalic acid, resulting in increased availability of anions for cationic balance.

18. Compiled data from all sources indicated that growth of certain marsh plants was maximal from 0.5 to 1 percent salinity (Tables 3 and 4). Between 1 and 2 percent salinity, the plants survived but did not grow. Between 2 and 4 percent salinity, survival was time-dependent; i.e., all plants died but some lived longer than others.

19. Seneca[6] observed a close correlation between laboratory values for germination and growth regulation by salinity and the observed salinity in natural seeding habitats of <u>Ammophila breviligulata</u>, <u>Panicum amarulum</u>, <u>S. patens</u>, and <u>Uniola paniculata</u>. Data collected in this

study also indicated that field seedlings of S. patens and U. paniculata were more tolerant to increasing salinity than laboratory grown seedlings raised from seeds collected at the same location.

20. Kurz and Wagner[23] and Palmisano[11] reported data from extensive field studies on water, salinity, and soil characteristics of Florida and Louisiana salt marshes. Data from Kurz and Wagner,[23] including a summarized study of tidal marsh zonation; chlorinity ranges, medians, and means; and tidal range of S. alterniflora, are presented in Tables 5 and 6 and Figure 1, respectively.

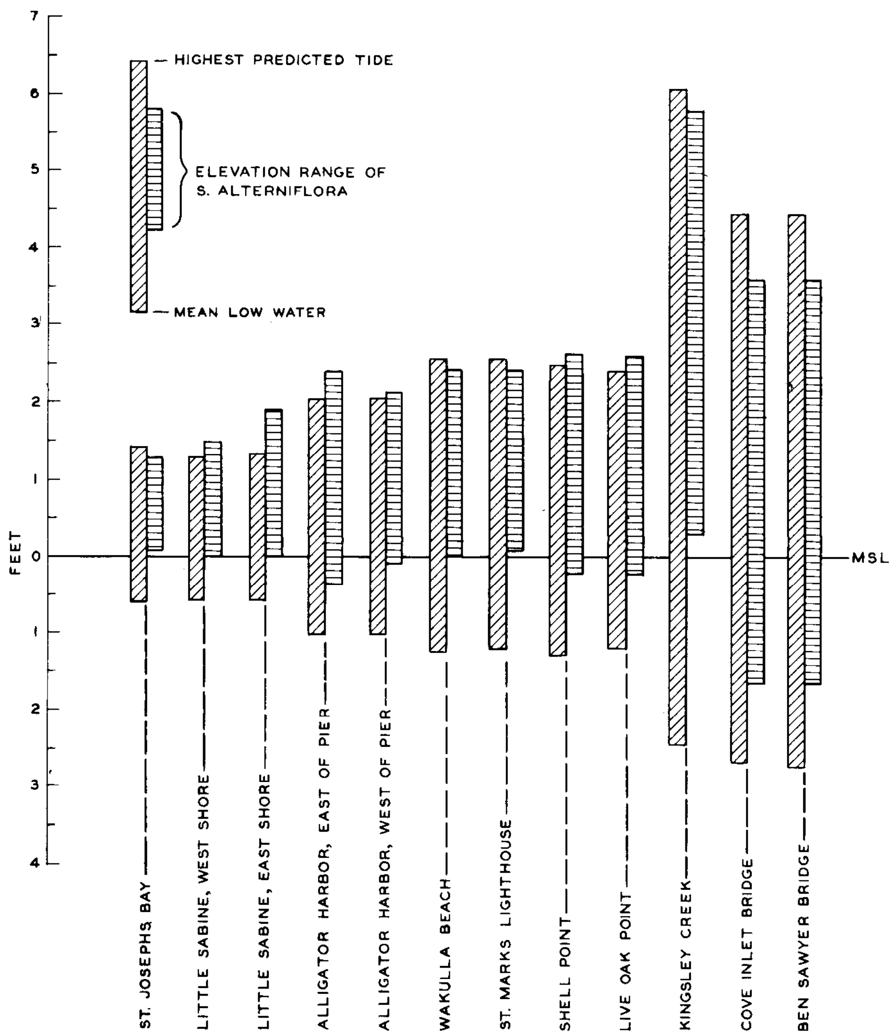

Figure 1. Elevation range of Spartina alterniflora in relation to tides (from Kurz and Wagner[23])

21. Kurz and Wagner[23] discussed the interaction of salinity and total water content of the soil on growth and zonation. In general, growth of all marsh plants decreased with increasing salinity, but the amount of water present in the soil can mitigate the effects of increased salinity. These authors rated some common marsh plants according to their absolute water requirement in the following order: S. alterniflora (highest water requirement), Salicornia perennis, Batis maritima, Juncus roemerianus, and Iva frutescens. J. roemerianus had the greatest coverage of any tidal marsh species and a greater latitude in soil water requirements and tolerances, but was not as tolerant as S. alterniflora to salinity. I. frutescens had a very restrictive range of water requirements. S. patens rarely occurred where chlorinity was greater than 1.5 percent but did occur at higher chlorinities in the Distichlis spicata-Juncus roemerianus ecotone marsh flats, where the soil water content was relatively high.[23]

22. The factors controlling water content of marsh soils on the Gulf and Atlantic coasts of Florida are complex.[23] Organic materials on the soil surface decreased with increasing elevation. This organic material retarded percolation of water into the soil so that the salinity and actual water content of the lower marsh were frequently lower than they were at higher elevations.

23. Palmisano[22] discussed the inherent difficulties in making reliable, meaningful soil moisture and salinity measurements in Louisiana gulf coast marsh soils. In general, the problem is one that results from the widely varying and high water contents of the soils. Many of the techniques used to estimate soil salinity are based on air-dried soil samples. Since many marsh soils contain over 90 percent water, drying concentrates the soluble salts so that total salts measured by Palmisano[22] on an air-dry basis were frequently over five times the water salinity of the Gulf of Mexico. Water salinity, collected from the same station, was only two thirds of Gulf salinity. Palmisano[22] devised a simple conversion factor to transform air-dry soil salinity to the salinity of the sample as it was collected in the field.

$$\text{Soil salinity (wet weight)} = \text{soil salinity (dry weight)} \times \frac{\text{dry wt sample}}{\text{wet wt sample}}$$

Total soil salts, on a wet weight basis, were generally lower than water salinity. When calculated on the basis of free soil water present in the soil, they were practically identical. Palmisano's data also indicated the importance of soil organic content on soil salinity and soil water since both parameters exhibited a significant negative relationship with organic content.

Substrate

24. Data are incomplete on the effects of substrate on the germination and growth of salt marsh palnts. Garbisch et al.[3] concluded that substrate characteristics did not appear to limit vegetation establishment. Woodhouse, Seneca, and Broome[1] reported that establishment of *S. alterniflora* appeared to be independent of substrate, but definite differences in growth and survival associated with substrate occurred as the stands matured. These differences at one site appeared to be correlated with increased salinities due to structure of the substrate. Woodhouse, Seneca, and Broome[1] reported that *S. alterniflora* did not grow when soil salinity exceeded 45 ppt NaCl. Smith[24] reported that dieback of *S. alterniflora* in Louisiana marshes was associated with poor drainage and increased soil salinity. Woodhouse, Seneca, and Broome[1] reported "other substrate effects that are large enough to be significant," but did not discuss the nature of these effects.

25. Mason[14] emphasized the role that the microflora and fauna may play in "conditioning" the substrate so that the marsh grasses could grow. Oxygen and nutrient availability as well as soil pH could be regulated by the presence of soil microflora and fauna. Mason[14] reported field observations indicating that growth of algae *Enteromorpha* and *Ulva* may be necessary before *Salicornia spp.* can invade an area.

26. The microbiology of saltwater marshes is just beginning to be studied. Hansen* is presently conducting studies on the microbiota of a marsh near Sapelo Island, Ga. Hood and Colmer[25] reported data on

* Personal communication, 1973, R. Hansen, University of Georgia Institute of Marine Sciences, Sapelo Island, Ga.

bacteria from the Barataria Bay area of Louisiana.

27. Total numbers of aerobic heterotrophic bacteria were enumerated in selected water sediment sites in Barataria Bay during a 7- and a 12-month period, respectively.[25] Peak populations in the sediments occurred during late spring and early summer; bacterial concentration in the water column varied greatly from month to month. On a wet weight basis, sites in Airplane Lake had the highest total counts; Lake Palourde had the least number of bacteria. However, in all areas, total bacterial populations correlated with organic matter on a dry weight basis. Sulfate reducers, agarolytic, cellulolytic, proteolytic, and lipolytic types of bacteria, were enumerated. A large microbial population occurred on the marsh grass, particularly in the soil-root interface. Data indicate that these plant microenvironments possibly are the most biologically active biotypes within the marsh.

28. Meyers, Ahearn, and Miles[26] reported a large standing crop of yeast in the sediments of Barataria Bay, particularly in association with the Spartina-soil interface. Significantly greater concentrations of yeast were present in the Spartina spp. soil which is exposed to daily tidal flooding than in sediments taken from adjacent bayous. During 1969, yeast concentration in Spartina spp. soil ranged from 720 to 90,000 cells/cm^3 of sediment; yeast concentration in substrate from the bayous ranged from 50 to 5,000 cells/cm^3.

29. The predominant indigenous yeast population comprised sporogenous species, Pichia spartinae and Kluyveromyces drosophilarum. While species of Pichia have been isolated occasionally from marine environments, Kluyveromyces is seldom reported and little is known about its ecology. Since these organisms can utilize amines, authors speculated about their possible role in estuarine nitrogen regeneration processes.

30. Apparently no data are available relative to an obligatory microflora or fauna that might precede or accompany germination and establishment of salt marsh plants. Table 7 of this report (from Kurz and Wagner[23]) is included to indicate the type and extent of algae associated with some marsh plants in Florida.

31. Mason[14] discussed the role of diffusion of oxygen and nutrients

in a loamy dredged material and indicated that slow diffusion through the substrate could be responsible for the delayed growth of microorganisms in the dredged material. He also discussed the implication of slow diffusion on the growth of marsh plants in such a substrate.

32. Hall* has attempted to estimate the rate and extent of the exchange (diffusion) of organic materials dissolved in estuarine water and marsh soil at Sapelo Island. He reported that little or no microbial oxidation of ^{14}C-labeled substrates (amino acids and sugars) was detected in mud and/or marsh soils. The results also indicated that the rate of material exchange (diffusion) into and out of marsh soils is a slow process.

33. The surface of marsh soils and areas immediately adjacent to roots of *Spartina alterniflora* frequently were aerobic even when inundated. Two distinct processes apparently were responsible for this phenomenon:

a. As incoming tide flooded the marsh surface, a layer of air was trapped at the soil interface. (Chapman[27])

b. Gasses diffused through air space which extended from the leaves to the tips of the roots of some marsh plants. (Teal and Kanwisher[28])

34. Chapman[27] reported the following analyses on layers of compressed gas under tide water in New England marshes:

Site	Percent CO_2	Percent O_2	Percent Residual Gas
Spartina alterniflora, zone 1	1.8	3.4	94.8
zone 2	3.2	8.3	88.5
Spartina patens zone	0.5	17.3	82.1
Distichlis spicata zone	1.8	17.3	81.5

35. The enrichment of CO_2 over atmospheric concentration of 0.03 percent is probably indicative of microbial activity in and on the soil and plants. Mason[14] also discussed the fact that soil immediately

* Personal communication, 1973, J. Hall, University of Georgia Institute of Marine Sciences, Sapelo Island, Ga.

adjacent to S. foliosa roots was aerobic due to oxygen diffusion through the plant. Thus, through a complex series of purely physical and biologically mediated processes including slow percolation, frequent leaching of soil surface, and oxygen diffusion, the roots of marsh plants, especially S. alterniflora, may not be in as harsh an environment as they may initially seem. Kurz and Wagner[23] also discussed the role of a freshwater table and rainfall in reducing the periods of exposure to severe conditions of salinity and desiccation.

36. Palmisano's[22] data indicated that growth of S. alterniflora was retarded in higher organic soils. Kurz and Wagner[23] reported that pioneer growth of marsh grasses more commonly occurred in sandy soil regions. Field observations by other investigators seem to substantiate these observations.* Net accumulation of organic materials from growth and death of marsh plants resulted in increased elevation, particularly in S. alterniflora marshes. Thus, the plants generally make their habitat increasingly unsuitable for future growth.

Fertilization

37. Woodhouse, Seneca, and Broome,[1] Garbisch et al.,[3] and Broome, Woodhouse, and Seneca[8] studied the effects of fertilization with nitrogen (N), phosphorus (P), or a combination of the two on the development of artificially planted marshes. The effects of fertilization varied with location, time of application, age of plants, and other factors. At a given time and place, N, P, and combined N and P applications have all stimulated growth of S. alterniflora. Mason[14] discussed the possibility of N and P regulation of a loamy dredged material. Garbisch et al.[3] and Broome, Woodhouse, and Seneca[8] indicated that fertilizer applied to sandy substrates remained localized in the area where it was applied.

Elevation

38. Establishment. Compiled data indicated that land elevation and hydraulics of an area were primary factors controlling establishment

* Personal communication, 1973, E. Seneca, North Carolina State University, Raleigh-Durham, N. C., and 1974, E. W. Garbisch, Director, Environmental Concern, Inc., St. Michaels, Md.

and vertical distribution of salt marsh plants.[1,14,17,23,29,30]

39. Workers at North Carolina State University, Environmental Concern, Inc., and the State University of New York at Stony Brook agreed that substrate stresses were very important in marsh establishment and preservation. In areas of high wave action, establishment may be difficult, if not impossible. Garbisch et al.[3] reported that large plants with well-developed root systems had to be planted several centimetres deep for successful establishment in such areas. It was also necessary to construct breakwaters to reduce wave action on certain planted areas.[3]

40. Woodhouse, Seneca, and Broome[1] discussed the choice of sites along the North Carolina coast and indicated that "some sites can be seeded and many can be transplanted, but that there are others where, due to rapid erosion or accretion, the establishment of vegetation is not immediately possible."

41. Terry* at the State University of New York indicated that one of the most pressing problems in artificial marsh establishment is making an intelligent site selection. Since the selection is purely subjective, only the extreme conditions, i.e., quiescent and highly turbulent, are obviously low and high risks, respectively, for successful marsh establishment. Many conditions between these extremes are questionable when justifying the expenditure of the sums necessary for seeding or transplanting salt marsh plants.

42. Workers at the Institute of Marine Sciences, University of Georgia, Sapelo Island, Ga., indicated in 1973 that elevation, inundation, and drainage are extremely important in marsh plant establishment on dredged materials. Consolidation of the materials results in changes in elevation, erosion, root penetration, diffusion, and other factors. The processes involved here are largely unknown. Actual water content, soil moisture tension, and increased salinity could singly or in combination prevent successful marsh establishment.

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* Personal communication, 1973, O. Terry, New York State University, Stony Brook, N. Y.

43. Plant distribution. Johnson and York[29] indicated that the relative time of submergence limited the vertical range of *S. alterniflora*. Hinde[31] reported that the vertical distribution of marsh seed plants on San Francisco Bay was controlled by the degree of tidal flooding to which they were subjected. The *Spartina* species zone ratio was 4.05, the *Salicornia* species zone (*Salicornia ambigua* dominant) had an emergence-submergence ratio of 1.25, and *Distichlis spicata* had an emergence-submergence ratio of 0.67. *Spartina* species at their lowest occurrence endured a maximum submergence of 21 hours. The upper 0.7 m of the *Spartina* species range coincided with the lower 0.7 m of the *Salicornia* species range. *Salicornia* species eventually replaced *Spartina* species as the elevation increased. *D. spicata* was distributed intermittently with *Salicornia* species; it rarely occurred with *Spartina* species and was unable to compete in the submerged habitat. It was found in pure stands only on the tops of dikes. Mason[14] also discussed the zonation of west coast marshes into low and high marshes with intermediate zones of characteristic plant distributions. He described ideal salt marsh as occurring "on a gently sloping plane whose bayward extent is a function of the grade of its place and the depth and duration of tidal water over it. The steeper the grade the shorter the distance from shore to marsh edge."

44. The low, low marsh was composed of almost a pure stand of *S. foliosa*; the high, high marsh was composed largely of *Salicornia pacifica* with some overlap of marsh border halophytes and some extension of the high marsh races of *Salicornia* beyond the tide control. Between these two intertidal marshes was an extensive area of overlay made up of a rather uniform race of *S. pacifica*, a race of *S. foliosa* with more slender culms than that in the low, low marsh and much less densely spaced, and rather extensive patches of *Jaumea carnosa*.

45. Adams[30] supported this view with data collected in areas of different tidal regimes from Massachusetts to Florida. He reported that the mean elevation of occurrence above mean sea level divided by one half the mean tidal range of the area concerned was a constant for each salt marsh grass species. This constant could be useful in site

selection for artificial marsh creation since given any two variables as known the third could be calculated. For example, since the constant for a desired plant is known and the mean tidal range could be measured, the mean elevation necessary for successful establishment of the desired plant could be estimated, or given the mean elevation and the constant for a desired plant, necessary adjustments for maintaining the desired mean tidal range could be estimated for feasibility.

46. Adams[30] classified the marshes of southeastern North Carolina into two major types, high and low marsh. The high marsh was characterized by Aster tenuifolius, Borrichia frutescens, Distichlis spicata, Fimbristylis castanea, and Spartina patens. The low marsh was further divided into those areas dominated by Juncus roemerianus, by Spartina alterniflora-Salicornia perennis-Limonium carolinianum, and by S. alterniflora alone.

47. Redfield[18] supported the emergence-submergence ratio postulate with data from Cape Cod, where the tidal range differs greatly on opposite sides of the Cape. He reported that the vertical range of plants was on the average about two thirds of the mean tidal range, but was subject to local variation. The critical level below which S. alterniflora did not grow was approximately 2 m below mean high water.

48. Redfield[18] described plant distribution at Barnstable Marsh, Mass., as follows:

a. Intertidal zone occupied almost exclusively by tall (1- to 2-m) S. alterniflora.

b. At or near mean high water level, short (0.15- to 0.3-m) S. alterniflora occurred.

c. High marsh was occupied by a S. patens association consisting of S. patens and D. spicata with scattered L. carolinianum, Plantago maritima, Aster subulatus, and Solidago semperivirens.

d. At higher levels along the margins or in isolated areas where the surface was raised, pure stands of Juncus gerardi existed.

49. Perhaps observations by Kurz and Wagner[23] best illustrated the important role of elevation in determining distribution of marsh plants. They found extreme cases of vertical compression in some Florida marshes

where four zones, including Juncus roemerianus marsh, Distichlis spicata meadow, and Salicornia spp. flats and barrens, occupied a vertical range of only 3 cm. In another area, they observed a gradation from J. roemerianus marsh to slope side D. spicata occupying a vertical range of less than 8 cm. Another fraction of a centimetre lower would have included the S. alterniflora stand. Palmisano[22] and Chabreck[32] studied plant associations and extent of vegetative cover in Louisiana gulf coast marshes. These authors correlated plant associations with soil type and salinity rather than with elevation alone. These data are included in this report to describe plant associations and distributions in Louisiana since comparable elevation data from Louisiana marshes were not found. Palmisano[22] reported the following species associations in Louisiana gulf coast marshes based on the soil salinity as the measured regulating factor:

a. Saline marsh communities of S. alterniflora, D. spicata, and J. roemerianus.

b. Brackish marsh communities of S. patens, Scirpus olneyi, and Scirpus robustus.

Artificial Marsh Establishment

50. Field tests performed at North Carolina State University[1,4] and Environmental Concern, Inc.,[3] were very similar and their results were in close agreement. For these reasons, the reader is referred to a short, concise publication by Woodhouse, Seneca, and Broome[1] for the available practical information on artificial marsh establishment. The following is a brief summary of this information.

Spartina alterniflora

51. Seeding. Seed source, harvesting, and storage were all problems. The number of viable seeds per litre varied from 500 in the poorest lot to 27,000 in the best lot (average value was 10,000 viable seeds per litre). Seeds should be harvested as near maturity as possible and must be harvested before the heads scatter. Seeds usually were produced only in areas recently colonized by S. alterniflora. Little flowering and seed production occurred in the short-height zones of older marshes.

Most seeds in the older marshes were produced by the tall forms along creek banks.

52. Locally, seed production may be reduced by infestation by flower beetles (family Mordellidae), which destroy the flowers, and by fungal growth (ergot) on the flowers. The latter was frequently noted in the field studies at North Carolina State University and Environmental Concern, Inc. Seeds must undergo after-ripening for about 90 days before at least 80 percent germination within 12 days can be obtained.

53. The major problem appeared to be keeping seeds in place until germination and establishment occurred. Seeds had to be covered to a depth of 1 to 4 cm. Discing, raking, and harrowing all seemed to aid in establishment. Broadcast seeding resulted in more rapid spread of plants than confining the seeds in drill rows. Seeding rates were adjusted according to germination studies on each lot of seeds used, such that about 1000 viable seeds per square metre were planted.[4] On the middle Atlantic coast, April planting was more successful than March planting because of more favorable weather.

54. Although germination occurred over a wide elevation range, appreciable numbers of seedlings survived in a rather narrow zone near the mean high water line. Broome, Woodhouse, and Seneca[8] reported that the elevation range over which seedlings could be expected to survive was limited to above the upper 20 to 50 percent of the elevational range of naturally occurring stands in a given area.

55. Although the initial growth rate of seedlings was slower than that of transplants, by the end of the first growing season, both types of plants were approximately the same size and the seedlings far exceeded the transplants in cover. Transplanting of a few plants into a given area could serve as a seed source for natural seeding.

56. Transplanting. In obtaining plants, digging and separation of stems was much easier from young stands on sandy substrate. The plants were separated into single large stems. Plants had to be kept moist until transplanted. It was preferable to collect planting stocks from areas with tidal and salinity ranges similar to the selected planting site.

57. A planting depth of 10 to 15 cm was desirable. Plant spacing has not been varied a great deal, but spacing on a 1-m center resulted in complete cover by the end of the second year in the worst conditions studied.

58. Successful plantings have been performed from December through July, but, in general, spring plantings (April to May) were preferred. Successful establishment was possible throughout most of the intertidal range, but there appeared to be a fairly definite elevation below which plants could not survive. This elevation appeared to be determined by the period of exposure and inundation. Substrate apparently did not affect establishment, but did appear to have definite effects on ultimate growth and survival.

59. Choice of planting sites. The choice of planting sites was a difficult decision to make due to the inability to predict accurately the degree and timing of erosion or deposition during the establishment period. It was clear that seeding should be confined to the most protected sites, to a fairly narrow band of elevation, and to a limited time span during the year (April to May). Transplanting, on the other hand, allowed much more flexibility as to site selection and could be done from December to July, with April and May optimum.

Other plants

60. In North Carolina, *Spartina patens* was successfully planted to overlap *Spartina alterniflora* at several sites.[1] Lower-end cutoff was 0.6 m (mean sea level (msl), 1929 datum) at Oregon Inlet and 0.7 m (msl, 1929 datum) at Snow's Cut. *Panicum amarulum*, which may be directly seeded, appeared promising for initial stabilization of dredged materials above the elevation of good growth for *Spartina patens*.[1]

61. The following marsh grass species have been established successfully in well-sorted, uncompacted substrates dominated by sand-sized particles:[3] *Ammophila breviligulata*, *Distichlis spicata*, *Juncus roemerianus*, *Panicum virgatum*, *Phragmites communis*, *Scirpus olneyi*, *Scirpus robustus*, *Spartina cynosuroides*, *Spartina alterniflora*, *Spartina patens*, *Typha angustifolia*, and *Typha latifolia*.

PART III: DISCUSSION OF ARTIFICIAL MARSH ESTABLISHMENT AND RECOMMENDATION FOR RESEARCH EMPHASIS

62. Before definite conclusions can be drawn about when it is desirable and what techniques can be used most successfully in a given situation, additional research is needed on several aspects of artificial marsh establishment. Successful marsh establishment has been possible with both seeding and transplanting techniques[1,3] but both methods are time-consuming, expensive, and limited to areas accessible to and capable of supporting mechanical equipment and men.

Source of Plant Material

63. Seeds are not a reliable source for salt marsh plants because their natural production is spotty and sparse.[4,14] Seeds normally are produced in large numbers only in immature stands and along stream banks (especially S. alterniflora). Their harvesting is time-consuming and expensive. Small-scale nursery operations for production of salt marsh grass seeds and plants have been established at Environmental Concern, Inc., St. Michaels, Maryland.

64. The seeds are dormant when shed and have an obligatory after-ripening period of approximately 90 days.[1,4-6,14,15] Seeds cannot be stored for periods exceeding 12 months. The seeds must be stored moist and preferably at 2 to 3°C.[1,4,7]

65. Woodhouse, Seneca, and Broome[1] reported that seeds can be used successfully for marsh establishment only in areas of small tidal amplitude and only for a few months (April-May) of the year. Best growth resulted from broadcast seeding at a planting depth of 3 to 4 cm. Seeds must be covered to prevent washing away and thus can be used only in areas accessible to man. Development of methods for aerial application such as spraying the seeds in an oil carrier could prove successful. Since dispersing seeds in the dredged material itself could be a viable method, equipment that would allow dispersion of seeds in the last few centimetres of deposited dredged material should be developed.

66. Collecting plants for transplanting is time-consuming and expensive.[1] Borrichia frutescens, Distichlis spicata, Salicornia species, and Spartina foliosa cuttings all appear to root fairly rapidly. Gallagher* indicated that phloem scraping appeared to stimulate root production on cuttings of Borrichia frutescens.

67. Rhizomes appear to be likely candidates as propagules due to their general physiological characteristics. They are hardy, do not have to be kept moist, are always available in large number, and have been used in laboratory studies as planting stock. Mason[14] indicated that rhizomes had not rooted as rapidly as cuttings of Spartina foliosa and Salicornia species, but under field conditions, rhizomes are recognized as a natural invader. Both rhizomes and rooted cuttings might be useful for aerial applications, but rhizomes, on a physiological basis alone, appear to have the longest potential lifetime, to be the easiest material to handle, and to be the most readily available plant material irrespective of season. Rhizomes perhaps could be planted while diked areas are still underwater, but almost nothing is known about the use of rhizomes as planting stock.

Substrate

68. Little is known about artificial marsh establishment and growth on organic, silt, and clay substrates. Data from field studies[11,23] and general field observations indicated that both rate and extent of growth and seed production of Spartina alterniflora decreased as the organic content of the soil increased. Compiled data from all sources[1,3,30] indicated that establishment appeared to be independent of substrate, but Woodhouse, Seneca, and Broome[1] reported that there were definite substrate effects on growth and survival of S. alterniflora. Poor drainage and increased salinity due to substrate structure were apparent causes of growth retardation. Mason[14] discussed the role

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* Personal communication, 1973, Jack Gallagher, University of Georgia Institute of Marine Sciences, Sapelo Island, Ga.

of diffusion of oxygen and nutrients in regulating the growth rate of microorganisms and marsh plants in a loamy dredged material.

69. Kurz and Wagner[23] and Palmisano[11] reported data on salinity and soil water content in Florida and Louisiana marshes. They discussed in detail the interactions of soil salinity and total soil water content on the growth of some marsh plants. They ranked certain marsh plants in order of decreasing water requirement. Kurz and Wagner[23] presented an excellent discussion of the role of organic material in regulating percolation through marsh soil. Percolation had a major influence on salinity, water content, and replenishment of nutrients.

70. The substrate effects on growth could be due to differences in physical processes mediated by differences in consolidation, exchange capacity, and other factors rather than chemical content of the soil types. Laboratory experiments should be designed to estimate the range of soil moisture tension and salinity regimes that allow reasonable growth rates in different substrates. It may be necessary to mix dredged materials before planting to ensure successful long-term marsh survival. Data from fertilization studies[1,3,4] indicated that N, P, or combined applications of N and P sometimes resulted in increased growth of planted marsh. The response varied with time, place, and age of plants.

71. In summary, marsh establishment appears to be independent of substrate; long-term growth and survival of S. alterniflora appears to be dependent upon substrate. Incomplete data indicate that this growth retardation could be related to physical processes such as percolation, diffusion, drainage, and aeration, rather than the chemical content of the substrates.

Elevation, Hydraulics, and Natural Colonization

72. Establishment and zonation of salt marsh plants appear to be dependent upon elevation and hydraulics which in turn regulate the periodicity and duration of plant submergence and emergence.[18,23,29-31] Woodhouse, Seneca, and Broome[1] and Garbisch et al.[3] stressed the fact

that tidal action could physically wash plants from established areas. Terry* at the State University of New York indicated that it was exceedingly difficult to make an intelligent site selection for marsh establishment. Substrate stress data are needed to allow such selections. Experiments designed to estimate the amount of energy (momentum) required to erode sand, clay, and silt substrates and to wash plants of various sizes from such substrates should be done. These data in combination with mathematical models on energy stresses on substrates, calculated from in situ hydraulic and elevational measurements, would allow a quantitative approach to site selection. Storms cannot be predicted, but Woodhouse, Seneca, and Broome[1] minimized the effects of these events by late spring plantings. Natural invasion and colonization by seeds, plants, and rhizomes in tidal water are common occurrences in marshes and could serve as propagule sources for artificial marsh establishment. Redfield[18] and the University of Georgia Institute of Marine Sciences personnel have indicated that invasion and establishment of salt marsh plants on naturally elevated dredged material disposal areas are fairly rapid processes. The investigators indicated that these areas usually are covered within 2 years if the elevation is proper.

73. Several constraints and considerations regarding artificial marsh creation seem to be important. These include the facts that seeds and seedlings are difficult to obtain in large numbers;[1,3] that marsh establishment and survival are highly dependent upon the physical factors of elevation and hydraulics;[1,3,4,18,23,29-31] and finally, that natural invasion and establishment are rapid processes.[18,**] For these reasons, highest priority should be given to the engineering aspects of marsh establishment by developing equipment and techniques for fine control of elevation of dredged material at the disposal site. The elevation should be compatible with the hydraulics and substrate of the area in order to maximize the likelihood of successful establishment.

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* Personal communication, 1973, O. Terry, New York State University, Stony Brook, N. Y.

** Personal communication, 1974, E. W. Garbisch, Director, Environmental Concern, Inc., St. Michaels, Md.

74. Possibly, natural invasion could be encouraged by discing adjacent marsh areas to facilitate rhizome propagation. Techniques such as these would minimize the ecotype problem. Because of the great abundance of rhizome material in most natural marshes, only small areas would require discing, resulting in a minimal amount of damage to the existing marsh. Marsh damage also should be considered when mechanical equipment is used for seed and seedling harvest and planting. The extent of mechanical damage is dependent upon substrate type.

75. Geese, muskrats, and other animals constitute a threat to early-stage marsh establishment. Garbisch reported that geese denuded an area of artificially established marsh. The roots and rhizomes were not destroyed and the plants sprouted the following spring. Gound cover the second year was apparently as extensive as it was before the geese denuded the area the preceding fall.

76. Rapid drainage of diked disposal areas helps to prevent crust formation and promote rapid plant establishment and stabilization. Mixing of dredged material types and the physical design of diked areas with drainage structures should be encouraged to promote rapid drainage. Consolidation of various types of dredged materials must be determined to allow a realistic estimation of final elevation.

77. If marsh establishment in a certain area is considered a poor risk, the capability should exist to adjust the elevation and hydraulic regime to encourage colonization and establishment of seegrasses, freshwater plant communities, or upland plant communities.

78. In summary, biological, mechanical, and engineering processes are important for successful colonization, establishment, and growth of salt marsh grasses on dredged materials. All aspects of this area of research should be encouraged, but at the present time the effects of substrate on growth and survival of marsh grasses and quantitative data pertinent to site selection are pressing needs.

79. Since the consensus of investigators consulted was that natural colonization and establishment are rapid processes, the Corps should emphasize the engineering aspects of dredged material disposal to obtain fine control of elevation at the disposal site. This fine

control of elevation would be based on consolidation data for the type of dredged material, the hydrology of the area, and realistic estimates of energy effects.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

80. Both seeding and mechanical transplanting of *Spartina alterniflora* on certain intertidal areas and on deposited dredged material have resulted in successful marsh establishment within a 2-year period. Both transplanting and seeding are time-consuming, expensive, and limited to areas accessible to and capable of supporting men and equipment. Little information on artificial marsh establishment is available for any type of substrate other than sand. Effects of drainage, consolidation, and crust formation on establishment and maintenance of artificially created marshes are largely unknown. No data are available relative to the essentiality of specific microfloral or faunal development prior to successful marsh establishment. Substrate drainage, consolidation, and crust formation could be important in this respect.

81. Natural marshes are not a dependable seed source because seed set is poor and varies from year to year and with geographical location. Collecting viable seed is also expensive and time-consuming because of the limited accessibility to mechanical harvesters. Ecotypes of *S. alterniflora*, and possibly other species, appear to restrict the use of both seeds and seedlings to limited geographical areas.

82. Specific germination requirements are well known only for a few marsh plants. Seeds of marsh grasses are dormant when harvested. In general, moist storage for 90 days at 2° to $3^{\circ}C$ is required for after-ripening. Seeds cannot be successfully stored for periods exceeding 12 months.

83. No data are available on the use of rhizomes for marsh establishment. Work in progress at the University of Georgia Institute of Marine Sciences, Sapelo Island, Ga., and at the San Francisco Bay Marine Research Center, Inc., San Francisco, Calif., indicates that marsh grass cuttings root easily.

84. Elevation and hydraulics, which result in differing salinity flux regimes, are important determinants of successful marsh

establishment and maintenance. Few data are available on the soil characteristics of the substrate or their importance in germination and establishment.

85. Available data indicate that seed set, seed germination, and seedling growth of salt marsh plants in general are optimal in fresh water. These plants are apparently able to live in salt marshes because their tolerance to salt and/or anaerobic conditions exceeds that of freshwater marsh plants.

86. Nutrient studies, productivity studies, and general field observations indicate that the intermediate and high marshes of the east and gulf coasts are less productive on a plant basis than the low and stream-side marshes. This decreased productivity could be due to decreased nutrient availability caused by reduced tidal flux and/or poorer drainage in the intermediate and high marshes.

87. Field observations along the east and gulf coasts indicated that areas which are elevated by natural processes and by dredging are rapidly (within 4 to 5 weeks) colonized by marsh plants that become established marshes within a 2-year period.

88. Field observations along the Georgia coast indicate that continuous high water content is a prime deterrent to the establishment of marsh plants on dredged materials.

Recommendations

89. To implement disposal practices to allow successful natural colonization, establishment, and maintenance of salt marshes, the following recommendations are made:

- *a*. The effects of substrate on marsh plants should be determined, i.e., the biological role (e.g., aeration, ability of roots to penetrate soil, etc.) and the physical role (e.g., differences in physical stresses on various soil types) should be delineated.
- *b*. Determine optimum elevation and hydraulic regime for the specific population desired on a particular dredged material disposal site.
- *c*. Investigate the range of turbulence which specific marsh plants can withstand, e.g., the amount of energy required

to remove *Spartina alterniflora* from sand, clay, and silt substrates.

d. Develop hydraulic mathematical models which would allow realistic estimates of momentum transport given the elevation of dredged material, currents, tides, and other pertinent data for any given area.

e. Develop methods for allowing tidal flux into diked disposal areas to permit colonization and establishment of marsh plants.

f. Collect habitat data on the elevation and hydraulic regime to encourage colonization and establishment of submerged seagrasses and upland communities in those areas where marsh grass establishment is not feasible.

g. Develop disposal technology that will allow fine control of dredged material placement within reasonable economic confines.

90. Recommendations to insure successful implementation of a widespread, intensive artificial marsh development on dredged material are as follows:

a. Establish a large dependable seed source.

b. Develop a method for successful seed storage for periods of at least 2 to 3 years.

c. Determine the true ecological range of various assumed ecotypes so that an intelligent choice of seed source for any given area can be made.

d. Determine substrate, salinity, and turbulence tolerances of each seed, seedling, and mature plant desired for specific marsh establishment.

e. Develop methods of rapid drainage of diked areas to allow successful colonization and establishment.

f. Design lightweight, efficient harvesters and combines to mechanically harvest natural or planted seed sources.

g. Develop methods for seeding or planting inaccessible areas, including dispersion of seeds in the last 3 to 4 cm of deposited dredged material, spraying seeds from boats or aircraft, and manual planting of seedlings from boats.

91. Because of the difficulty in developing all the techniques necessary for successful establishment of marshes by using seeds or seedlings, it is recommended that rhizomes or plant sprigs be considered as an alternative material for use in establishing marshes.

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Table 1

Effects of Salinity on the Germination of Salt Marsh Plants

Plant	NaCl Effects Percent Maximum Germination	NaCl Effects Percent Maximum Tolerance Limits for Germination	Reference
Spartina alterniflora	0.0	6.0-8.0 (Some germination at 6 percent; no germination at 8 percent)	5
Spartina patens	0.0	4.0	6
Ammophila breviligulata	0.0	1.0-1.5	6
Panicum amarulum	0.0	1.5-2.0	6
Uniola paniculata	0.0	1.0-1.5	6
Suaeda depressa	0.0-0.5	4.0	10
Salicornia europaea	0.0	5.0	10
Spergularia marina	0.0-0.5	2.0	10
Suaeda linearis	0.0-1.0	5.0	10

Table 2

Salinity Content That Effects a 50 Percent Germination Reduction for Salt Marsh Plants

Plant	Salinity* ppt
Distichlis spicata	7.7
Scirpus olneyi	5.9
Scirpus americanus	4.7
Setaria magna	6.5
Echinochloa walteri	3.9
Oryza sativa	15.8
Scirpus robustus	14.7
Polygonum pennsylvanicum	10.0
Sacciolepis striata	10.0
Sesuvium portulacastrum	No inhibition at 12.0

* From Palmisano.[11]

Table 3

Effects of Salinity on the Growth of Salt Marsh Plants

Plant	NaCl Effects		References
	Percent Maximum Growth	Percent Maximum Tolerance Limits for Growth	
Spartina alterniflora	0.5 to 1.0	Growth less than 0.0% at 4.0	5
Spartina patens	0.0 to 0.5	4.0	6
Ammophila breviligulata	0.0	Good growth at 0.5 to 1.0; survival but no growth at 2.0; no survival at 4.0	6
Panicum amarulum	0.5 to 1.0	Some growth at 2.0; survival time-dependent at 4.0	6
Uniola paniculata	0.0	Moderate growth rate at 0.5 to 1.0; survival but no growth at 2.0; survival time-dependent at 4.0	6
Spartina foliosa	0.0 to 1.0	3.0 to 4.5	21
Suaeda depressa	1.0	Survival at 4.0 but with definitely decreased rate of floral induction and dry weight of flowers and fruit	13

Table 4

Effects of Salinity on the Growth of Salt Marsh Plants

50 Percent Reduction in Live Weight

Plant	Salinity,* ppt
Scirpus olneyi	10.0
Scirpus robustus	10.0
Spartina patens	8.0
Distichlis spicata	15.0

* From Palmisano.[22]

Table 5

Summarized Study of the Tidal Marsh Zonation

1. Flatwoods	2. Barrens	3. Salt Flats	4. Junus roemerianus Marsh	5. Spartina alterniflora
Fresh soil water xeromorphs	Blue-green algae and/or a dense diatom flora at times, no seed plants	Stunted xeromorphs halophytes	Luxuriant halophytes	Channel, pool, and beach halophytes
Slash-pine, saw-palmetto, and wiregrass	No uniform pattern of stratification. Reworked and redeposited raw sand; sometimes partially differentiated B-horizon about 2.5 ft* or more	As in barrens, but with more humus. B-horizon often evident	Juncus roemerianus dominant, occasional Limonium carolinianum, Distichlis spicata, or Batis maritima	Spartina alterniflora, often no competitors; sometimes dominant with intermingling of Juncus roemerianus, Aster spp., Batis maritima, or Salicornia spp.
Water table about 4 ft deep, as shown by hardpan	A water table indicated by hardpan or stained layer. Surface soil dry except at tidal flooding or rain	A water table indicated by an indefinite hardpan. Surface soil moist but not waterlogged	Soils usually waterlogged at surface. Variable depth B-horizon suggested	Upper stratum mucky with high organic content, soaked and waterfilled cavities at flood tide. Below this, stratum up to 42 in. thick of moist but not actually waterlogged soil that overlies the water table
Salinity low or negligible	Highest salinity of the tidal marshes	Usually higher than salinity of tidal waters	Salinity mostly near that of tidal water, but in some places runs lower or higher than tidal water	Salinity varies from near that of tidal water at beaches and channels to higher than tidal water in trapped pools of water
pH 3.5-5.5	Alkaline; pH 7.5-8.5	pH about 5.5-7.5	Acid, with lowest pH of salt marshes. pH about 4.5-6.5	Acid to alkaline, pH 4.7-8.5, but usually a pH of 5.5-7.5
Sand permits percolation of water down to hardpan	Porous sand with less colloidal material and organic matter at surface than in salt flats permits more rapid percolation and evaporation. Therefore, high concentration of salts	Soil intermediate between Juncus roemerianus and barrens in humus and porosity; intermediate percolation rate	Mature sandy mulch with high Juncus roemerianus peat content overlying sandy substrate. B-horizon evident near salt flats and near mainland	Ranging from beach sand to soil with the greatest peat, colloidal, and silt content and the least sand of the salt marsh soils; no B-horizon observed
Chlorinity negligible except near marsh soil	High salt content of soil excludes seed plants. Absence of these and resulting high evaporation rate favors maintenance of high salinity	Open, low vegetation and partially porous soil permits salt concentration by evaporation and percolation, but not to extent reached in barrens	Dense vegetation. High humus content of soil hinders evaporation and percolation. Frequent tidal flooding tends to reduce chlorinity to sea-water concentration, consequently chlorinity lower than in Distichlis spicata flats or barrens	As in Juncus roemerianus marsh, plus more continuous inundation maintains tidal concentration of salts. In trapped pools vegetation more open, hence more evaporation and greater chlorinity
Seldom flooded by the water	Flooded only by high tides and then only for short time	Floods more frequently than barrens	Frequent flooding and for long periods	Greatest tidal flooding of all marsh. On beaches extends down to mean sea level (msl)

Note: Data from Kurz and Wagner.[23]

* A table of factors for converting U. S. customary units of measurement to metric (SI) can be found on page 5.

Table 6

Chlorinity Ranges, Medians, and Means

1. Tidal Marsh Species

Species	Range	No. Samples	Median	Mean
Iva frutescens	0.00-2.45	52	0.56	0.77
Spartina patens	0.06-5.38	42	0.63	0.00
Salicornia perennis	0.78-5.07	91	2.05	2.30
Batis maritima	0.06-4.89	64	1.56	1.77
Distichlis spicata	0.10-3.90	92	0.87	1.56
Juncus roemerianus	0.06-2.99	105	0.88	1.00
Spartina alterniflora	0.10-4.64	74	1.51	1.69

2. Peripheral Flatwoods Species

Species	Range	No. Samples	Median	Mean
Pinus elliottii	0.06-0.99	21	0.40	0.40
Sabal palmetto	0.03-2.22	22	0.42	0.60
Quercus virginiana	0.03-4.32	24	0.37	0.67
Ilex vomitoria	0.08-2.22	21	0.31	0.44
Juniperus silicicola	0.14-2.22	13	0.33	0.53
Myrica cerifera	0.06-0.94	18	0.31	0.35
Baccaharis halimifolia	0.06-1.78	27	0.37	0.56

3. Pure Stand Communities

Species	Range	No. Samples	Median	Mean
Pinus elliottii	0.06-0.99	21	0.40	0.40
Baccharis halimifolia	0.19-0.44	5	0.34	0.33
Iva frutescens	0.10-1.98	22	0.47	0.55
Salicornia perennis	0.87-5.07	12	2.50	2.69
Distichlis spicata	0.78-3.11	23	1.57	1.66
Juncus roemerianus	0.23-2.44	26	1.43	1.30
Spartina alterniflora	0.76-4.22	14	1.43	1.79

Note: Data from Kurz and Wagner.[23]

Table 7

The Zonal Relationships of the Algae with the Phanerogamic Communities

Phanerogamic Community	Locality	Dominant Algae
Spartina spp.	Beaches-Shell Point	*Bostrychia*, *Enteromorpha*, and *Melosira*
Spartina spp.	Beaches-Live Oak Point	Soil diatoms; washed up: *Chondria*, *Digenia*, *Enteromorpha*, *Sargassum*, *Polysophonia*, *Champia*, and *Fosliella*
Barrier beach ridge	Live Oak Point	Rich soil diatom flora, *Schizothrix*, *Calothrix*, *Microcoleus*, and *Lyngbya*
Flatwoods border barrens	Shell Point	Diatoms
Spartina spp. island	Tidal Channel at Shell Point	*Microcoleus chthonoplastes* Gom. on channel bottom; Oyster shells: *Phormidium fragile* Gom. and *Lyngbya confervoides* Gom.; Island and soil only diatoms; *Spartina* culms with *Bostrychia*, *Enteromorpha flexosa*, and *Melosira*
Juncus roemerianus marsh	Shell Point	Culms of rushes with *Bostrychia*, young plants of *Caldophora*, soil diatoms, *Chaetomorpha*, *Enteromorpha*, and *Lyngbya aestuarii*
Distichlis spicata meadow	Live Oak Point	Same as above with increase in *Enteromorpha*
Flatwoods	Live Oak Point	*Gloeocystis Grevillei* (Beck.) Dr. and Daily; one moss and one lichen

Note: Data from Kurz and Wagner.[23]

APPENDIX A: SCIENTIFIC AND COMMON VASCULAR PLANT NAMES MENTIONED IN THIS REPORT

Ammophila breviligulata	American beach grass
Aster subulatus	Annual salt-marsh aster
Aster tenuifolius	Perennial salt-marsh aster
Baccharis halimifolia	Groundset tree
Batis maritima	Saltwort
Borrichia frutescens	Sea oxeye
Distichlis spicata	Salt grass
Echinochloa walteri	Salt-marsh cockspur grass
Fimbristylis castanea	Marsh fimbristylis
Ilex vomitoria	Yaupon
Iva frutescens	Marsh elder
Jaumea carnosa	Jaumea
Juncus gerardi	Black grass
Juncus roemerianus	Needlerush
Juniperus silicicola	Southern red cedar
Limonium carolinianum	Sea lavender
Myrica cerifera	Wax myrtle
Oryza sativa	Rice
Panicum amarulum	Beach panic grass
Phragmites communis	Giant reed
Pinus elliottii	Slash pine
Plantago maritima	Seaside plantain
Polygonum pennslyvanicum	Pennsylvania smartweed
Quercus virginiana	Live oak
Sabal palmetto	Cabbage palmetto
Sacciolepis striata	Sacciolepis
Salicornia ambigua	Woody glasswort
Salicornia europaea	Slender glasswort
Salicornia pacifica	Pacific glasswort
Salicornia perennis	Perennial glasswort
Scirpus americanus	Common three-square

Scirpus olneyi	Olney three-square
Scirpus robustus	Salt-marsh bulrush
Sesuvium portulacastrum	Sea purslane
Setaria magna	Giant setaria
Solidago semperivirens	Seaside goldenrod
Spartina alterniflora	Smooth cordgrass
Spartina anglica	English cordgrass
Spartina cynosuroides	Big cordgrass
Spartina foliosa	Pacific cordgrass
Spartina patens	Salt-meadow cordgrass
Spergularia marina	Sea sandwort
Suaeda depressa	Western sea blite
Suaeda linearis	Tall sea blite
Typha angustifolia	Salt-marsh cattail
Typha latifolia	Broadleaf cattail
Uniola paniculata	Sea oats

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Falco, Pat K

Pregermination requirements and establishment techniques for salt marsh plants / by Pat K. Falco and Frank J. Cali. Vicksburg, Miss. : U. S. Waterways Experiment Station, 1977.

35, [6], 2 p. ; 27 cm. (Miscellaneous paper - U. S. Army Engineer Waterways Experiment Station ; D-77-1)

Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under DMRP Work Unit No. 4A09.

References: p. 33-35.

1. Coastal engineering. 2. Dredged material. 3. Dredge spoil salt marshes. 4. Salt marsh establishment. 5. Spartina alterniflora. 6. Marsh plant species. I. Cali, Frank J., joint author. II. United States. Army. Corps of Engineers. III. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper ; D-77-1.

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