DREDGED MATERIAL RESEARCH PROGRAM

TECHNICAL REPORT D-77-2

ESTABLISHMENT AND GROWTH OF SELECTED FRESHWATER AND COASTAL MARSH PLANTS IN RELATION TO CHARACTERISTICS OF DREDGED SEDIMENTS

by

John W. Barko, Richard M. Smart, Charles R. Lee
Mary C. Landin, Thomas C. Sturgis, Robert N. Gordon

Environmental Effects Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

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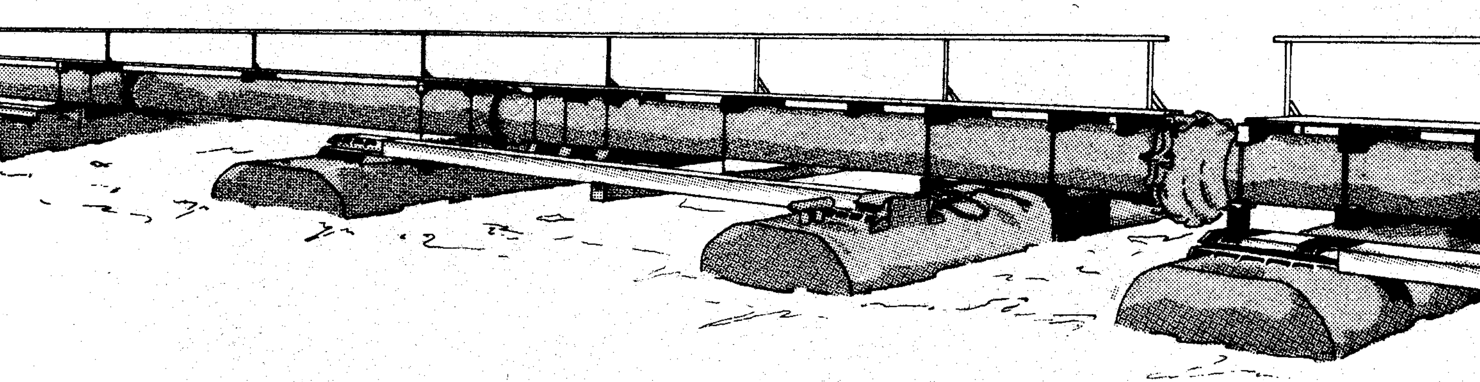

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DEPARTMENT OF THE ARMY
WATERWAYS EXPERIMENT STATION, CORPS OF ENGINEERS
P. O. BOX 631
VICKSBURG, MISSISSIPPI 39180

IN REPLY REFER TO: WESYV

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1. The technical report transmitted herewith represents the results of one of a series of research efforts (work units) undertaken as part of the Habitat Development Project (HDP) of the Corps of Engineers' Dredged Material Research Program (DMRP). The HDP, among other considerations, includes the development of disposal alternatives that are compatible with the Corps' resource development mandate and environmental interests.

2. Recent documentation of the significant loss of marshes in various parts of the United States has prompted the Corps to consider activities that may be useful in replenishing or abating the loss of this valuable resource. As part of the DMRP, attention has been directed toward using dredged material as a potential substrate for marsh development. Existing data indicate that this technique can be compatible with disposal operations and could provide a significant amount of marsh substrate each year.

3. Although field studies have been necessary to investigate several aspects of marsh development on dredged material substrates, many areas of concern can be studied best or, in some cases, only under controlled greenhouse conditions. The work unit reported herein (4B06) was a greenhouse study conducted to determine the establishment, success, and productivity of selected marsh plants on dredged materials of different physical and chemical properties. The study dealt with technical and environmental aspects of the selection and propagation of plants for marsh habitat development. Plant establishment was evaluated under controlled conditions of tidal action and salinity using several dredged material substrates.

4. Results of this study indicate that marsh plants established on sandy dredged material are significantly nutrient-limited in comparison with those propagated on fine-textured dredged material. Salinity is indicated as a possible limiting factor to establishment of brackish marsh plants Triglochin maritima, Distichlis spicata, Scirpus robustus, and Spartina patens. Fresh marsh plants Scirpus validus and Cyperus esculentus became established quickly on all freshwater substrates as

did the salt marsh plants *Spartina foliosa* and *Spartina alterniflora* on saline substrates. With the exception of *Distichlis spicata*, establishment from seed was relatively unsuccessful.

5. Work Unit 4B06 was designed as part of a broader research effort directed toward all phases of marsh development and provides basic answers to problems that could not be tested in field studies. This research will supplement studies being conducted at Miller Sands in the Columbia River, Oregon (4B05); Windmill Point, in the James River, Virginia (4A11); Buttermilk Sound, near Brunswick, Georgia (4A12); Bolivar Peninsula in Galveston Bay, Texas (4A13); Dyke Marsh, in the Potomac River, Virginia (4A17); Salt Pond No. 3, in San Francisco Bay, California (4A18); and Apalachicola, Florida (4A19).

JOHN L. CANNON
Colonel, Corps of Engineers
Commander and Director

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An investigation of the success of establishment and the growth of marsh plants on physically and chemically different dredged sediments was conducted under semicontrolled conditions in a greenhouse. Freshwater, brackish, and salt marsh environments were simulated for concurrent experimentation with various propagules of respective vegetative contingents. Growth of individual marsh plant species was determined on the basis of stem density and total plant biomass.

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20. ABSTRACT (Continued).

Growth of the freshwater plants, affected by the availability of nitrogen, was significantly greater on fine-textured sediments than on sand. Growth of both brackish and salt marsh plants was relatively unrelated to nutrient availability, and was most affected by the salinity of the sediment solution. Within the same period of growth, transplants produced plant populations having greater biomass and numbers of stems than did any of the other plant propagules. Rhizomes, rootstocks, and tubers responded similarly, but to a lesser extent, to sediment differences than transplant propagules of the same species.

Recommendations relevant to marsh-creation projects are made on the basis of results of this investigation as well as a review of pertinent literature.

SUMMARY

Field investigations of marsh plant-sediment interactions have often been affected by climatic, biotic, and hydrologic influences that obscure causal relationships between sediment factors and plant growth. Studies to better define the relationships were conducted by simulating marsh conditions in a greenhouse.

Dredged sediments used in the investigation were obtained from selected freshwater and estuarine locations. These sediments were classified as sand, silty clay, and clay on the basis of particle-size distribution. Nutrient content of the sediments showed the following pattern: nutrient content of sand < clay < silty clay. Among the estuarine sediments, the free-water salinity of clay and silty clay was 17.8 and 31.8 ppt, respectively. The salinity of the estuarine sand, which was free draining, remained in dynamic equilibrium with the salinities of the tidal waters, which were maintained at 12.0 and 24.0 ppt in brackish and salt marsh simulations, respectively.

All sediments were placed in fiberglass tanks and planted with different propagules of eight plant species representative of freshwater, brackish, and salt marshes. Propagules were uniformly distributed across different sediments and subjected to daily tidal inundation. Growth of each species was evaluated on the basis of total biomass and numbers of stems determined at the end of the investigation.

Within the same period of growth, transplants produced plant populations having greater biomass and numbers of stems than did other vegetative propagules or seed. Rhizomes, rootstocks, and tubers responded similarly, but to a lesser extent, than transplants of the same species. In all experiments, seeds were not firmly held by the unconsolidated fine-textured sediments; consequently, losses due to tidal inundation were high. The poor growth of seedlings on coarse sediments was attributed to low nutrient concentrations.

Growth of the freshwater species, *Cyperus esculentus* and *Scirpus validus*, followed the pattern: growth on sand < clay < silty clay. Although substantial, plant growth on clay was limited by nitrogen.

Growth on sand was severely limited by the availability of nitrogen and/or phosphorus.

Among brackish and salt marsh species, only *Spartina alterniflora*, *S. foliosa*, *S. patens*, and *Distichlis spicata* were successfully established on all estuarine sediments. *Triglochin maritima* and *Scirpus robustus* could not be established on silty clay and failed to attain appreciable biomass on sand or clay sediments. Plant growth on the estuarine sediments generally followed the pattern: growth on sand $\leq$ silty clay < clay. While growth of all species on sand was apparently limited by the availability of nitrogen and/or phosphorus, the large differences in growth between silty clay and clay could not be attributed to nutrients. The high free-water salinity of silty clay was considered responsible for the reduced growth of plants on this sediment.

During the investigation, an increase in the free-water salinity of the fine-textured estuarine sediments was observed. This salinity increase could not be related to an evaporative concentration of salts, since changes in moisture content during the experiment were negligible. Rather, the increased salinity of these sediments was attributed to salt accumulation in the root zones of salt-excluding marsh plant species used in the investigation. Fine-textured dredged sediments are typically impermeable and leaching of accumulated salts did not occur.

Based upon the results of this investigation and a review of pertinent literature, several conclusions and associated recommendations were made:

- Transplants should be used in marsh-establishment efforts whenever possible. These propagules seem to be more adaptable to a variety of conditions and their use should increase the likelihood of successful establishment.
- Although fertilization may be of some benefit in promoting rapid establishment and growth of marsh plants on coarse-textured sediments, fertilization of fine-textured sediments seems unwarranted in most cases.
- High salinity was identified as an important factor affecting

both the establishment and growth of coastal marsh plants in this investigation. Therefore, only the most salt-tolerant species should be planted in marsh establishment efforts where the salinity of the sediment solution is or is likely to become high. Through research, definitive information is needed on the relative salt tolerances of the more common coastal marsh plants.

PREFACE

The work described in this report was performed as part of the Dredged Material Research Program (DMRP), which is sponsored by the Office, Chief of Engineers (DAEN-CWO-M), and is administered by the Environmental Effects Laboratory (EEL), U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi.

This report is based on a greenhouse study conducted during the summer and fall of 1975 by Drs. J. W. Barko and C. R. Lee, Ms. M. C. Landin, and Messrs. R. M. Smart, T. C. Sturgis, and R. N. Gordon, under the general supervision of Dr. P. G. Hunt, Chief, Ecosystem Processes Research Branch, Dr. R. L. Eley, Chief, Ecosystem Research and Simulation Division, and Dr. J. Harrison, Chief, EEL. The study was undertaken as part of the DMRP Habitat Development Project, which is managed by Dr. H. K. Smith. Contract manager was Dr. L. F. Holloway who contributed significantly to the experimental design of the study.

Dr. C. B. Loadholt, Professor of Biometrics, Medical College of South Carolina, assisted the authors on statistical matters. Dr. P. G. Murphy, Associate Professor of Botany, Michigan State University; Dr. J. L. Gallagher, Director, University of Georgia Marine Institute; and Dr. D. Gunnison and Mr. J. D. Lunz, EEL, are acknowledged for their critical review of this report.

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

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ESTABLISHMENT AND GROWTH OF SELECTED FRESHWATER AND COASTAL MARSH PLANTS IN RELATION TO CHARACTERISTICS OF DREDGED SEDIMENTS

PART I: INTRODUCTION

1. The importance of navigable waterways and harbors to the economic growth of the United States necessitates the dredging and disposal of large quantities of sediment each year. Historically, methods of disposal have been few, and the suitability of these methods has been evaluated largely on the basis of economics alone. In recent years, concern over the environmental impact of dredging activities culminated in the development (Boyd et al. 1972) of the Dredged Material Research Program (DMRP). One of the goals of the DMRP is the assessment of present methods and the development of new methods of dredging and disposal with regard to existing and potential environmental impacts.

2. The possibility of using dredged sediments to create marshes, originally elucidated by Larimer (1969), has been subsequently investigated under the auspices of the Habitat Development Project of the DMRP. In consideration of the stabilizing influence of vegetation on newly deposited dredged sediments and also because of the importance of vegetation as a trophic substrate, emphasis has been placed on methods of establishing plants on dredged sediments. Although techniques for the establishment of marsh plants have been well documented (Kadlec and Wentz 1974, Wentz et al. 1974), the relatively meager information available on plant-sediment interactions has often hindered successful application of the techniques. Accordingly, the use of controlled experiments to assess plant-sediment interactions was considered an essential direction of investigation.

3. The objective in this study was to elucidate the primary edaphic factors that affect the establishment and growth of selected marsh plants from different propagules on dredged sediments. Genetic differences in growth potential of different species were not of experimental concern. Rather, growth of each propagule of each species was

independently evaluated with respect to characteristics of the different dredged sediments upon which it was established. In order to negate the potentially confounding effects of uncontrollable environmental conditions on results, this investigation was conducted under simulated marsh conditions in a greenhouse.

4. Representative plant species from freshwater and coastal marsh habitats were selected on the basis of their widespread occurrence or suitability to a particular locale. Coastal marsh species were subdivided on the basis of their occurrence within different zones in natural marshes. For the purpose of this study, those species more commonly occurring on the seaward edge of a marsh are distinguished as salt marsh plants. Similarly, those species more commonly occurring at higher elevations within a marsh or in areas of lesser salinity are distinguished as brackish marsh plants. These distinctions are made with full knowledge of common overlap in zones of occurrence.

PART II: METHODS AND MATERIALS

Greenhouse Environment

5. The investigation was conducted from 1 July to 12 December 1975 in a fiberglass greenhouse equipped with thermostatically controlled heating and cooling systems. Cooling, facilitated by shade cloth that reduced light intensity by 30 percent, was provided by evaporative cooling pads, which also increased humidity. Heat was supplied by gas heaters with four forced-air distribution tubes spanning the width of the greenhouse. Temperature and humidity were maintained within limits representative of growing seasons in natural marshes of the southern United States.

Experimental Approach

6. The investigation was conducted in 24 fiberglass tanks measuring 1.5 by 0.9 by 0.9 m deep. Each tank was equipped with an automated tidal simulation system and was partitioned into four plots, each plot having a surface area of approximately 0.35 m^2. Each tidal simulation system (Figure 1) was controlled by a series of timers. At the

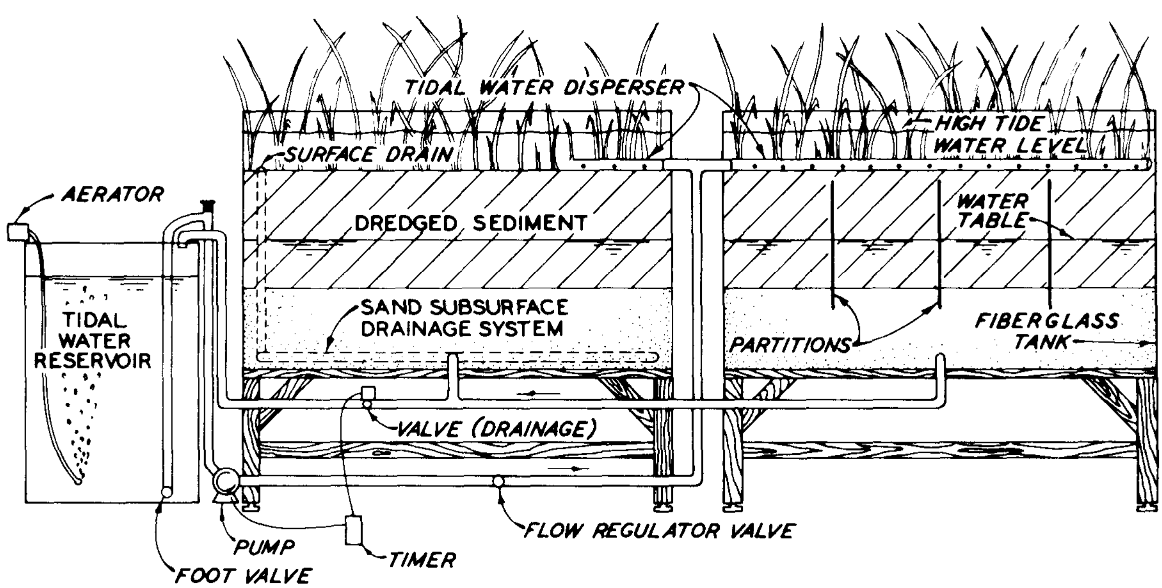

Figure 1. Design of tidal simulation system

beginning of a tidal cycle, the drainage valve was closed, and the tanks were filled to a preset level. After filling, the tidal water was held for a preset interval before draining back into the tidal reservoir. Surface drainage was provided by a polyvinyl chloride (PVC) pipe extending from the soil surface to the drainage system. Subsurface drainage was provided by a perforated PVC piping system overlain with 25 cm of sand saturated with water of the same composition as the tidal water. The position of the drainage outlet controlled the depth of subsurface drainage. All tidal reservoirs were fitted with opaque fiberglass covers to prevent the development of algal blooms and subsequent removal of nutrients. Reservoirs were constantly aerated to provide mixing and to prevent anaerobiosis.

7. To incorporate differences in salinity and tidal regime, the investigation was separated into three experiments: fresh water, brackish, and salt marsh. The tidal conditions shown in the following tabulation were used in the brackish and salt marsh experiments and were chosen to simulate those occurring in natural marshes. Freshwater sediments were not inundated by a tide but were kept wet by frequent flooding of the sediment surface and by maintaining a high water table.

		Tidal Conditions			
Experiment	Salinity ppt	Tidal Frequency*	Duration of Inundation hr/day	Depth of Tidal Inundation cm	Water Table Depth cm
Salt marsh	24	Twice daily	6	15	10-15
Brackish marsh	12	Daily	2	5	15-20
Freshwater marsh	Fresh water	NA	NA	NA	0-5

* Onset of each tidal cycle was automatically delayed 15 min each day to vary times of inundation with respect to photoperiod.

8. Tidal water used in the brackish and salt marsh experiments was prepared from Instant Ocean (Aquarium Systems Inc., Eastlake, Ohio), a synthetic seawater medium, and deionized water. The chemical

composition of water used in the freshwater experiments was based on concentrations found in river waters (Riley and Chester 1971). Ammonium nitrate and potassium phosphate were added weekly in amounts to achieve concentrations of 1 mg N/ℓ and 0.3 mg P/ℓ in all solutions. In addition, the solutions were changed every 4 weeks to prevent possible depletion of other elements. Salinity of the tidal water was monitored on a weekly basis by measuring refractive index on an American Optical refractometer with a direct-reading salinity scale. Evaporative losses of water from the tidal solutions were replaced with deionized water to maintain salinity at the desired level.

Selection and Characterization of Dredged Sediments

9. Collection sites described in the following tabulation were selected to obtain sediments of varied texture and nutrient composition.

	Sediment Type--Source		
Environment	Sand	Silty Clay	Clay
Fresh water	Intracoastal Waterway between Destin and Panama City, FL	Maumee River, Toledo, OH	Drainage canal, Tallulah, LA
Estuarine	Intracoastal Waterway between Destin and Panama City, FL	St. John's River, Jacksonville, FL	Savannah River, Savannah, GA

At the time of collection, these sites were being used for disposal operations. Thus, none of the sediments used in this investigation had been previously invaded by vegetation. Where necessary, the dredged material was sieved through 12.7- and 6.4-mm screens to remove debris prior to introduction into the experimental tanks.

10. Following the placement of sediments into the experimental tanks, a sample was taken from each tank for physical and chemical characterization. Particle-size composition (texture) was determined by the hydrometer method of Day (1956) and by sieve analysis of sandy sediments. Duplicate subsamples for determinations of nitrogen (N) and phosphorus (P) were dried at 70°C to constant weight, pulverized, and chemically

digested. Samples to be analyzed for total P were digested with red fuming nitric acid at 180-200°C for 4 hr, diluted with 1:10 hydrochloric acid, and filtered. Samples to be analyzed for total Kjeldahl nitrogen (TKN) were digested according to the method of Bremner (1960). Analyses of N and P were conducted with a Technicon Autoanalyzer. Oxidation-reduction potential (Eh) of the sediments was routinely determined during the investigation with an Orion Model 801 digital pH meter equipped with duplicate platinum electrodes that were positioned at 1 and 10 cm below the sediment surfaces. An identical instrument, equipped with a pH electrode, was used to measure the pH of each sediment.

11. Free-water salinity (i.e., salinity of the sediment solution) of fine-textured sediments was determined at the beginning and end of the investigation by measuring the refractive index of the supernatant from centrifuged sediment samples on an American Optical refractometer. The high moisture content of these sediments (>65 percent of the wet weight) enabled salinity measurements to be obtained without adjusting moisture content, as recommended by Bower and Wilcox (1965). Free-water salinity of sand sediments was equivalent to the salinity of the tidal water.

Selection, Preparation, and Planting of Marsh Plant Propagules

12. Selection of plant propagules (Table 1) was based on previous experience. Transplants were included because they appear to be adaptable to a wide variety of conditions (Woodhouse et al. 1972). Where feasible, seed was used as an additional propagule due to the relative economy of seeding over planting (Garbisch et al. 1975). Where problems of availability or germination were encountered or expected, other propagules were substituted for seed. Seed germination of *Scirpus* spp. appears to be highly variable (Harris and Marshall 1960). The U. S. Fish and Wildlife Service recommends the establishment of *Cyperus* as well as *Scirpus* from vegetative propagules (Salyer 1949). Therefore, tubers and rhizomes of *Cyperus* and *Scirpus*, respectively, were chosen for study. Since seed of *Triglochin maritima* was not available,

rootstocks of this species were chosen as an additional propagule.

13. Vegetative material of each species was collected from Louisiana marshes with the exceptions of *Spartina foliosa* and *Triglochin maritima*, which were collected from marshes in California and Oregon, respectively. These materials were used in the production of nursery stock that was maintained prior to initiation of experimentation. All transplants, rhizomes, and rootstock propagules used in the investigation were obtained from this stock of plants. Seed was obtained from Environmental Concern, Inc., St. Michaels, Maryland. Brackish and salt marsh species were initially maintained in fresh water and gradually acclimated to those salt concentrations to which they would be exposed during experimentation. Planting was accomplished during the first two weeks in July 1975.

Measurement of Plant Response

14. Experiments were individually terminated when it appeared that the population of one or more plant species within an experiment had achieved maximum biomass. Termination dates for the freshwater, salt, and brackish marsh experiments were early September, mid-November, and mid-December of 1975, respectively. At termination, stem counts were obtained, and the plants were harvested in their entirety. Aboveground biomass was clipped at the sediment surface, rinsed with tap water to remove adherent contaminants, and ovendried to a constant weight at 105°C. Similarly, belowground biomass was removed from the sediment, washed over a 1-mm sieve, and ovendried. Dried plant material was weighed. Only the aboveground biomass was ground in a Wyley mill, subsampled, and chemically digested (as previously described for sediments) for analyses of nitrogen (TKN) and phosphorus content. Analyses were performed with a Technicon Autoanalyzer.

15. In the context of this investigation, establishment of a species from vegetative propagules was considered successful where mean final biomass (at harvest) was statistically greater than or equal to mean initial biomass (at planting). Establishment from seed

propagules was considered successful where the mean final biomass of plants grown from seed exceeded 10 g dry weight m^{-2}.

16. Since the initial number and biomass of propagules of each species (Table 1) were equally distributed across sediments (at time of planting), final biomass (at time of harvest) was used as a measure of success of establishment and growth. Analysis of variance techniques and multiple comparison tests (Sokal and Rohlf 1969) were used to assess statistical differences in species biomass. Where appropriate, chemical data were similarly treated.

Table 1

Initial Biomass and Areal Density of Propagules

Experiment	Plant Species	Propagule	Biomass* Mean g m^{-2} (dry wt)	Biomass* CV	Areal Density**
Freshwater marsh	*Scirpus validus*	Transplant	133.3	5.5	18
		Rhizome	53.0	3.0	18
	Cyperus esculentus	Transplant	11.5	6.9	36
		Tuber	18.5	5.5	72
Brackish marsh	*Distichlis spicata*	Transplant	134.3	5.0	18
		Seed	-	-	250
	Spartina patens	Transplant	182.9	2.5	18
		Seed	-	-	250
	Triglochin maritima	Transplant	119.1	7.0	18
		Rootstock	52.3	4.8	18
	Scirpus robustus	Transplant	168.9	8.0	18
		Rhizome	123.6	4.7	18
Salt marsh	*Spartina alterniflora*	Transplant	332.1	2.6	18
		Seed	-	-	250
	Spartina foliosa	Transplant	139.8	2.2	18
		Seed	-	-	250

* Means are based on six replications. The coefficient of variability (CV) equals the standard deviation ÷ the mean × 100. Dash indicates that no determination of seed mass was made.

** Areal density equals the number of propagules per plot.

PART III: RESULTS

Physical and Chemical Characterization of Dredged Sediments Used in Study

17. Soil texture refers to the relative proportions of the textural fractions: sand, silt, and clay (Hillel 1971). Overall designations of sediments used in this study (Table 2) were determined on the basis of the textural fractions. Although silt fractions of clay and silty clay sediments were comparable, the proportion of sand was greater and clay lesser in silty clay than in clay. Sand sediments contained negligible quantities of silt and clay particles.

18. Concentrations of N and P (Table 3) differed significantly (Duncan's analyses at $P < 0.05$) among sediments of both freshwater and estuarine origins. Fine-textured sediments (clay and silty clay) contained higher concentrations of N and P than did sand. Irrespective of sediment origin, the N-content of silty clay was greater than that of clay. Among the fine-textured freshwater sediments, the P-content of silty clay was greater than that of clay. In contrast, the P-content of the estuarine clay was greater than that of silty clay of the same origin.

19. The salinity of the two fine-textured estuarine sediments differed markedly. Estimated on the basis of six replicate analyses, the initial mean free-water salinity of silty clay was 31.8 ppt, which significantly exceeded (Student's T analysis at $P < 0.05$) the initial mean free-water salinity of clay estimated at 17.8 ppt. The free-water salinity of sand, equivalent to the salinity of the tidal groundwater, was 12.0 and 24.0 ppt in brackish and salt marsh experiments, respectively.

20. Weekly determinations of sediment pH and Eh of both freshwater and estuarine sediments revealed negligible changes in these parameters during the study. Few determinations of pH on sand fell outside the range of 7.0 to 8.0, and median pH of this sediment was approximately 7.4. Irrespective of sediment origin, the pH of the fine-textured sediments generally fell within the range of 6.5 to 7.5.

Table 2

Textural Characterization of Dredged Sediments

		Textural Fraction*					
		Sand		Silt		Clay	
Origin	Sediment Type	$\bar{y}$, percent	CV	$\bar{y}$, percent	CV	$\bar{y}$, percent	CV
Fresh water	Sand	99.9	0.0	<0.1	0.0	<0.1	0.0
	Silty clay	16.3	32.6	36.7	6.7	47.0	6.0
	Clay	10.6	8.0	31.9	2.7	57.5	0.0
Estuarine	Sand	99.7	0.1	<0.3	0.0	<0.3	0.0
	Silty clay	22.2	24.8	28.6	19.2	49.2	4.6
	Clay	3.5	78.8	27.0	4.5	69.5	4.1

* Based on U. S. Department of Agriculture classification. Means ($\bar{y}$) and coefficients of variation (CV) for freshwater and estuarine sediments were based on 2 and 6 replications, respectively.

Table 3

Sediment Concentrations of Nitrogen and Phosphorus

		Sediment Concentrations, g kg^{-1} (dry wt)*			
		Nitrogen		Phosphorus	
Origin	Sediment Type	$\bar{y}$	CV	$\bar{y}$	CV
Fresh water	Sand	<0.1	0.0	<0.05	0.0
	Clay	1.1	27.1	0.63	8.6
	Silty clay	3.3	42.4	1.25	16.2
Estuarine	Sand	0.3	44.9	<0.05	0.0
	Clay	3.2	19.2	1.94	8.0
	Silty clay	5.2	17.5	1.65	6.3

* Means ($\bar{y}$) and coefficients of variation (CV) for freshwater and estuarine sediments were based on 4 and 12 replications, respectively.

Median pH of both fine-textured sediments was approximately 7.0. Median values of Eh of the same sediments determined at sediment depths of 1 and 10 cm were approximately -175 and -225 mv with respect to depth. No differences in Eh were related to sediment origin. At the 1-cm sediment depth, the median Eh of sand was approximately +375 mv. Median Eh of the same sand, determined at the 10-cm sediment depth, which was below the water table, was approximately -125 mv.

21. Determinations of sediment moisture content, made at the beginning and end of each experiment, indicated negligible changes in this characteristic of the fine-textured sediments of either origin during the investigation. Moisture contents of silty clay and clay were similar, and these ranged from 65 to 75 percent of the total sediment weight. The moisture content of sand, which was free draining, varied with the tidal cycle.

Establishment and Growth of Selected Freshwater Marsh Plants on Dredged Sediments of Freshwater Origin

22. The freshwater marsh plants, *Cyperus esculentus* and *Scirpus validus*, were successfully established from vegetative propagules on all sediments. In both species transplants produced the highest rate of growth and largest accumulation of biomass.

23. Growth of *Cyperus* and *Scirpus* from transplant propagules (Table 4) was significantly greater on silty clay and clay than on sand, and was significantly greater on silty clay than on clay. The superior overall growth of these species on fine-textured sediments relative to that on coarser sediments is reflected in both above and belowground parts. In contrast, species differences in growth on the fine-textured sediments include significant differences in aboveground material only. Growth of the same species from nontransplant propagules (Table 4) was insufficient for the detection of strong statistical differences in biomass. Belowground plant parts were relatively unresponsive to sediment differences. Greater aboveground biomass was attained on the fine-textured sediments than on sand. In this regard, growth of these

Table 4

Mean Biomass of Plants Established on Freshwater Sediments

Species	Propagule	Biomass	Sediment Type-Biomass, g m^{-2} (dry wt)*		
			Sand	Clay	Silty Clay
Cyperus esculentus	Transplant	Total	65 a	1587 b	2875 c
		Aboveground	34 a	995 b	2263 c
		Belowground	31 a	592 b	612 b
Scirpus validus	Transplant	Total	234 a	1368 b	2324 c
		Aboveground	108 a	881 b	1856 c
		Belowground	126 a	487 b	468 b
Cyperus escultentus	Tuber	Total	87 a	108 a	410 a
		Aboveground	43 a	85 a	329 a
		Belowground	44 a	23 a	81 a
Scirpus validus	Rhizome	Total	77 a	481 b	619 b
		Aboveground	32 a	362 b	529 b
		Belowground	45 a	119 a	90 a

* Means are based on two replications. When followed by different letters, values within a biomass category are significantly different at $P < 0.05$. Significance was determined using Duncan's multiple comparison test.

species from nontransplant propagules mimicked that from transplants.

24. In general, areal density of stems of both *Cyperus* and *Scirpus* (Table 5) varied with sediment type and was positively correlated with total biomass. Plant populations established from transplant propagules were significantly more dense on silty clay than on either clay or sand and were significantly more dense on clay than on sand. Statistical confirmation of the same trend for populations established from nontransplant propagules was not possible.

25. Differences in ratios of belowground (BG) to aboveground (AG) biomass (Table 6) denote relative differences in growth of respective plant parts on different sediments. Ratios of BG:AG biomass of *Cyperus*, established from transplants, and of *Scirpus*, established from rhizomes as well as transplants, are significantly greater on sand than on clay or silty clay. Recalling the significantly greater growth of these species on clay and silty clay relative to that on sand, an inverse relationship between BG:AG ratio and growth emerges. This ratio is also presumed to be inversely related to fertility.

Establishment and Growth of Selected Salt Marsh and Brackish Marsh Plants on Dredged Sediments of Estuarine Origin

26. The salt marsh plants, *Spartina alterniflora* and *Spartina foliosa*, were successfully established from transplant propagules on all sediments. Seed of both of these species provided total biomass yields of less than 10 g dry weight m^{-2}, which has been interpreted as unsuccessful establishment on all sediments. In contrast, the success of establishment of brackish marsh plants (*Distichlis spicata*, *Spartina patens*, *Scirpus robustus*, and *Triglochin maritima*) was variable. Although all of these species were established from transplant propagules on sand and clay, only *Distichlis spicata* and *Spartina patens* could be established on silty clay. With the exception of seed of *D. spicata*, which yielded a total biomass of 486 g dry weight m^{-2} at a density of 4326 stems m^{-2} on clay, establishment from nontransplant propagules was unsuccessful. Seed of *D. spicata* on other sediments and of *S. patens*

Table 5

Mean Areal Density of Stems of Plants Established on Freshwater Sediments

Species	Propagule	Sediment Type-Mean Areal Density*		
		Sand	Clay	Silty Clay
Cyperus esculentus	Transplant	191 a	1238 b	2983 c
	Tuber	218 a	129 a	656 b
Scirpus validus	Transplant	231 a	604 b	947 c
	Rhizome	144 a	305 a	312 a

* Means of two replications. Units are numbers of stems m^{-2}. When followed by different letters, values within a propagule category were significantly different at $P < 0.05$. Significance was determined using Duncan's multiple comparison test.

Table 6

Mean Ratios of Belowground to Aboveground Biomass of Plants Established on Freshwater Sediments

Species	Propagule	Sediment Type-Mean Ratios*		
		Sand	Clay	Silty Clay
Cyperus esculentus	Transplant	0.90 a	0.64 ab	0.27 b
	Tuber	1.22 a	0.40 a	0.23 a
Scirpus validus	Transplant	1.18 a	0.55 b	0.25 b
	Rhizome	1.39 a	0.33 b	0.18 b

* Means of two replications. When followed by different letters, values within a propagule category were significantly different at $P < 0.05$. Significance was determined using Duncan's multiple comparison test.

on all sediments produced less than a 10 g dry weight m^{-2} yield. Poor results with seed in this investigation were caused by low germination and high losses due to tidal inundation. Mortality of rhizomal and rootstock propagules of *S. robustus* and *T. maritima*, respectively, was initially very high and those propagules which did survive did not grow.

27. Growth of the salt marsh plants, *S. alterniflora* and *S. foliosa*, from transplant propagules (Table 7) was significantly greater on clay than on either silty clay or sand. While growth of *S. alterniflora* was significantly greater on silty clay than on sand, growth of *S. foliosa* on these two sediments was comparable. With the exception of *T. maritima*, growth of all brackish marsh plants (Table 7) was significantly greater on clay than on other sediments. Of the two species that were established on silty clay, *D. spicata* demonstrated significantly greater growth on silty clay than on sand. Growth of *S. patens*, however, was slightly greater on sand than on silty clay, although the difference was not significant at the 5-percent level. Sediment-related differences in growth, based on total biomass of salt and brackish marsh species, include significant differences in growth of both above and belowground plant parts.

28. Differences in the areal density of stems of salt and brackish marsh species (Table 8) generally reflect parallel differences in total biomass of the plants. Plant populations were significantly more dense on clay than on either silty clay or sand. The mean areal density of stems was higher on silty clay than on sand, but only in *S. alterniflora* and *D. spicata* was the difference significant at the 5-percent level.

29. Differences in BG:AG biomass ratios (Table 9) denote relative differences in growth of respective plant parts on different sediments. In general, an inverse relationship exists between BG:AG biomass ratios and growth of both brackish and salt marsh plants. Significant differences in BG:AG biomass ratio (high on sand and low on clay) reflect significant differences in plant growth (high on clay and low on sand). Again, the BG:AG ratio is presumed to be inversely related to sediment fertility.

Table 7

Mean Biomass of Salt Marsh and Brackish Marsh

Plants Established on Estuarine Sediments

Species	Biomass	Sediment Type-Mean Biomass*		
		Sand	Silty Clay	Clay
Spartina alterniflora	Total	255 a	1904 b	4670 c
	Aboveground	112 a	1131 b	3056 c
	Belowground	143 a	773 b	1614 c
Spartina foliosa	Total	145 a	195 a	743 b
	Aboveground	36 a	83 a	390 b
	Belowground	109 a	112 a	353 b
Distichlis spicata	Total	234 a	1047 b	1978 c
	Aboveground	124 a	749 b	1466 c
	Belowground	110 a	298 ab	512 b
Spartina patens	Total	373 a	283 a	1704 b
	Aboveground	227 a	171 a	1227 b
	Belowground	146 a	112 a	477 b
Triglochin maritima	Total	151 a	-	194 a
	Aboveground	17 a	-	46 b
	Belowground	134 a	-	148 a
Scirpus robustus	Total	235 a	-	518 b
	Aboveground	53 a	-	185 b
	Belowground	182 a	-	333 b

Note: Dash indicates that efforts to establish plants were unsuccessful.

* Means of two replications. Units are grams dry weight m^{-2}. When followed by different letters, values within a biomass category are significantly different at $P < 0.05$. Significance was determined using Duncan's multiple comparison test.

Table 8

Mean Areal Density of Stems of Salt Marsh and Brackish Marsh Plants Established on Estuarine Sediments

Species	Sediment Type-Mean Areal Density*		
	Sand	Silty Clay	Clay
Spartina alterniflora	166 a	638 b	1610 c
Spartina foliosa	108 a	263 a	837 b
Distichlis spicata	615 a	2913 b	4268 c
Spartina patens	772 a	894 a	3430 b
Triglochin maritima	199 a	-	407 b
Scirpus robustus	49 a	-	194 b

Note: Dash indicates that efforts to establish plants were unsuccessful.

* Entries are means of two replications. Units are numbers of stems m^{-2}. When followed by different letters, values within a propagule category are significantly different at $P < 0.05$. Significance was determined using Duncan's multiple comparison test.

Table 9

Mean Ratios of Belowground to Aboveground Biomass of Salt Marsh and Brackish Marsh Plants Established on Estuarine Sediments

Species	Sediment Type-Mean Ratios*		
	Sand	Silty Clay	Clay
Spartina alterniflora	1.40 a	0.72 a	0.53 a
Spartina foliosa	2.99 a	1.40 b	0.95 b
Distichlis spicata	0.89 a	0.40 ab	0.35 b
Spartina patens	0.64 a	0.67 a	0.39 b
Triglochin maritima	7.72 a	-	3.25 b
Scirpus robustus	3.47 a	-	1.80 a

Note: Dash indicates that efforts to establish plants were unsuccessful.

* Ratios based on means of two replications. When followed by different letters, values within a propagule category were significantly different at $P < 0.05$. Significance was determined using Duncan's multiple comparison test.

Mineral Nutrient Concentrations in Shoots of Marsh Plants Grown on Dredged Sediments

30. With the exception of N in the freshwater flora, concentrations of N and P in plant shoots (Table 10) were directly related to concentrations of these nutrients in the sediments.

31. The concentration of P was significantly greater in the two freshwater plant species grown on fine-textured sediments than on sand. The concentration of N was significantly greater in species grown on silty clay than on either clay or sand, but was comparable in both species grown on sand and clay.

32. Among species grown on estuarine sediments, concentrations of N and P were greater in shoots of plants grown on silty clay and clay than in shoots of plants grown on sand. These differences were significant in all species except *Triglochin maritima* and *Scirpus robustus*, in which variability in N and P, as well as growth, was relatively high.

Table 10

Mineral Nutrient Concentrations of Nitrogen and Phosphorus in Shoots of Marsh Plants Established on Freshwater and Estuarine Sediments

Origin of Sediment	Species	Nutrient	Sediment Type-Nutrient Concentration, g kg^{-1} dry shoot*		
			Sand	Clay	Silty Clay
Fresh water	*Cyperus esculentus*	N	13.1 a	12.3 a	22.9 b
		P	0.43 a	3.27 b	6.31 c
	Scirpus validus	N	13.3 a	15.8 a	31.3 b
		P	0.46 a	3.57 b	5.17 b
Estuarine	*Spartina alterniflora*	N	11.3 a	17.6 b	23.4 c
		P	0.98 a	2.75 b	3.55 c
	Spartina foliosa	N	15.8 a	23.9 b	27.2 b
		P	1.20 a	2.99 b	3.38 c
	Distichlis spicata	N	7.2 a	27.3 b	30.3 b
		P	0.41 a	1.29 b	1.39 b
	Spartina patens	N	5.8 a	21.8 b	25.8 c
		P	0.29 a	1.45 b	1.64 b
	Triglochin maritima	N	23.3 a	45.0 a	-
		P	0.76 a	1.50 a	-
	Scirpus robustus	N	4.8 a	17.0 a	-
		P	0.28 a	0.95 a	-

Note: Dashes indicate that no nutrient data were obtained.

* Means are based on two replications. When followed by different letters, concentrations of a nutrient within a species are significantly different at $P < 0.05$. Significance was determined using Duncan's multiple comparison test.

PART IV: DISCUSSION

Interrelations Between Sediment Nutrient Concentrations, Tissue Nutrient Concentrations, and the Growth of Marsh Plants

33. Although the distribution of rooted vegetation may be influenced to a greater extent by sediment texture than by chemical composition (Sculthorpe 1967), plant growth is intimately related to the chemical composition of the sediment. Although finer textured sediments have a greater adsorptive area and typically contain higher concentrations of nutrients than coarse sediments, texture probably has little direct effect on plant growth (Haslem 1973). In this investigation, the fine-textured sediments of freshwater origin contained significantly greater concentrations of N and P and supported proportionately more plant growth (Figure 2) than did sand.

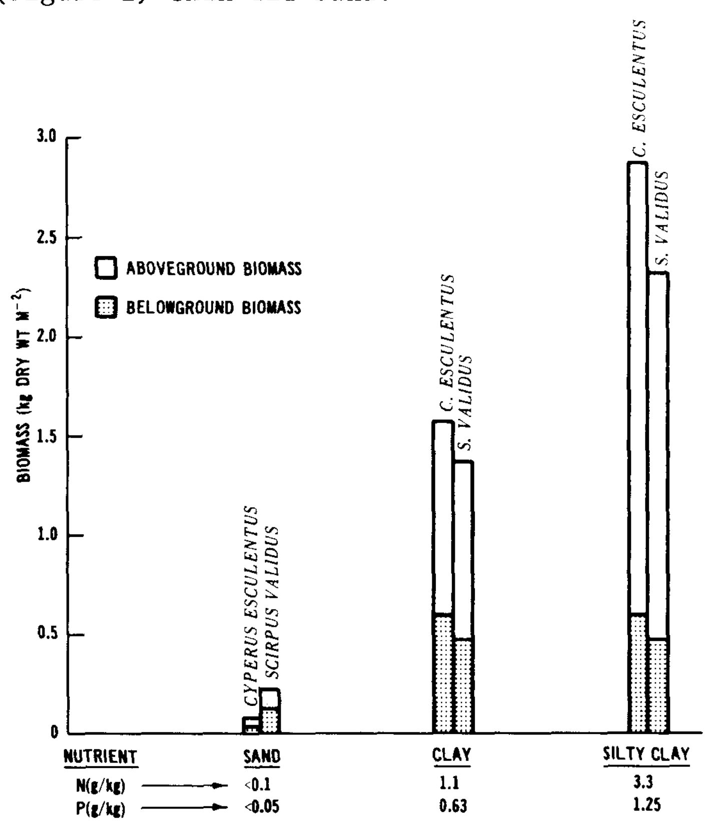

Figure 2. Biomass of marsh plants grown on freshwater sediments in relation to sediment concentrations of nitrogen and phosphorus

34. Elemental analysis of plant tissue is useful in evaluating the adequacy of environmental nutrients for plant growth (Gerloff 1969). The essential relations on which tissue analysis is based are shown in Figure 3, in which the terminology has been modified for appropriateness to this investigation. Below the critical tissue concentration of an essential element, its availability in the sediment limits growth. Increased availability stimulates growth, and the subsequent increase in biomass proportionately dilutes the concentration of the nutrient in the plant tissue. Consequently, the tissue concentration of a nutrient remains relatively constant until the nutrient is no longer limiting. Above the critical concentration of a nutrient, availability does not limit growth, and the nutrient is taken up luxuriously. When the tissue concentration of a nutrient exceeds the critical concentration, the requirement of the plant for that particular nutrient has been exceeded, and correlation with growth cannot be considered as functional. Similarly, correlation between sediment nutrient concentration and growth can be interpreted as functional only when tissue concentration remains unresponsive over a range of sediment content of the nutrient in question.

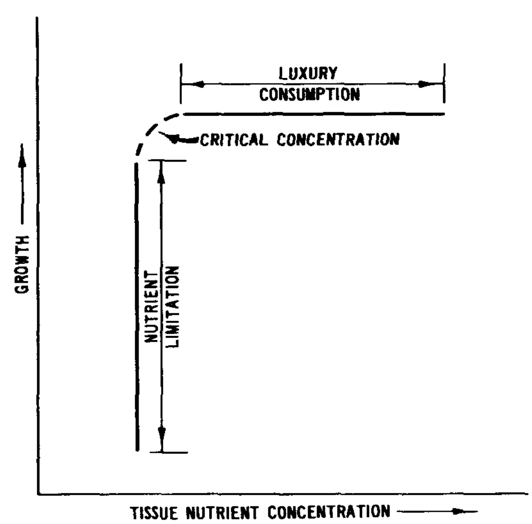

Figure 3. Idealized relationship between growth and tissue concentration of an essential element. (Modified from Gerloff 1969)

35. Compared to the P-concentration in shoots of the freshwater plants grown on sand, the significantly greater concentrations in shoots of plants grown on the fine-textured sediments suggest luxurious consumption of this element (Figure 4). Therefore, the greater growth (i.e., biomass) on clay and silty clay sediments does not appear to be functionally related to the concentration of P.

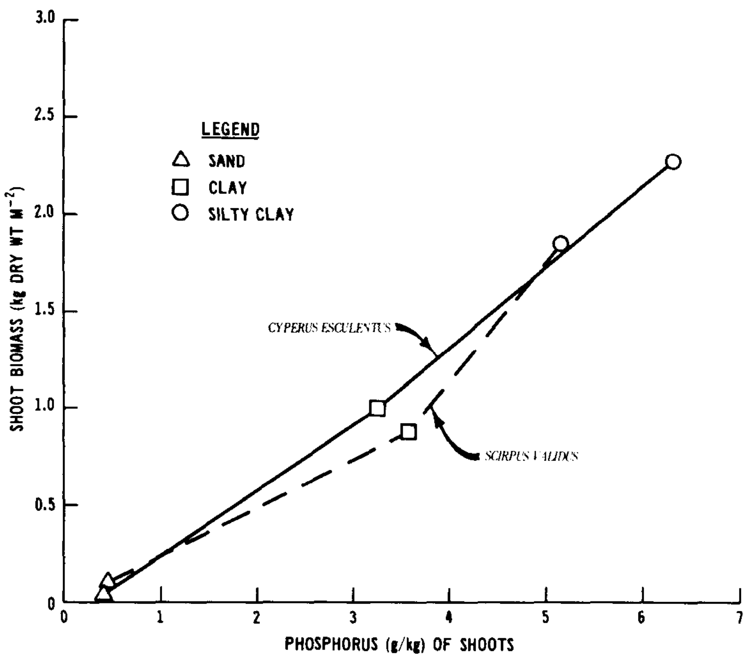

Figure 4. Relationship between phosphorus concentration and biomass of shoots of marsh plants grown on freshwater sediments

36. In spite of the order of magnitude greater concentration of N in clay than in sand, concentrations of N in the shoots of the freshwater plants grown on these sediments were not significantly different. Although the greater growth (i.e., biomass) on clay can be associated with the greater availability of sediment N, the proportionate dilution of shoot concentrations of this element by increased growth (Figure 5) indicates an apparent N-limitation of growth on clay as well as sand. Inability to correlate biomass and tissue N of *Spartina alterniflora* was noted and similarly interpreted by Broome et al. (1975 a and b) in their investigation of natural salt marshes of North Carolina. In

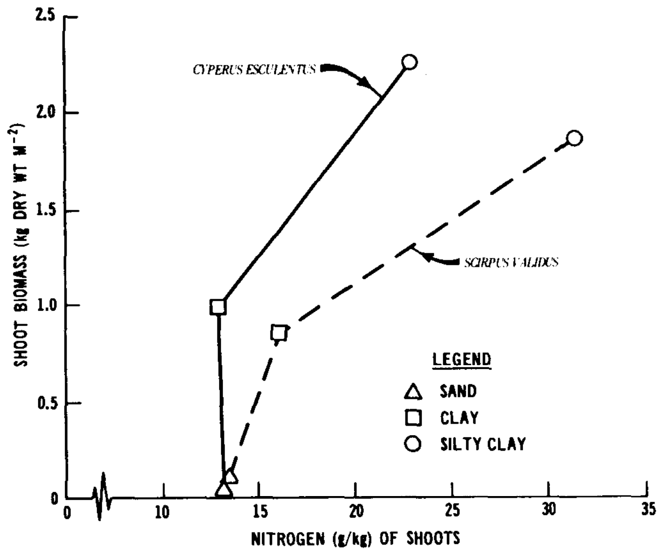

Figure 5. Relationship between nitrogen concentration and biomass of shoots of marsh plants grown on freshwater sediments

contrast, the greater growth on silty clay is accompanied by an increase in tissue N-concentration (Figure 5), which precludes the possibility of an N-limitation of growth on silty clay.

37. The fine-textured estuarine sediments also contained significantly greater concentrations of N and P than did sand. While plant growth on clay (Figure 6) reflected these higher concentrations, growth on silty clay did not.

38. Relationships between shoot biomass and concentrations of both P (Figure 7) and N (Figure 8) of plants grown on the estuarine sediments are very similar in pattern. Both elements were consumed luxuriously on clay and silty clay, and neither, therefore, could have limited plant growth. Growth on sand was potentially limited by nitrogen and phosphorus among other possible elements.

Plant-Salinity Interrelations

39. Recalling the nearly twofold greater initial salinity of silty clay (31.8 ppt) relative to that of clay (17.8 ppt), it was concluded that the higher salinity of the former sediment inhibited

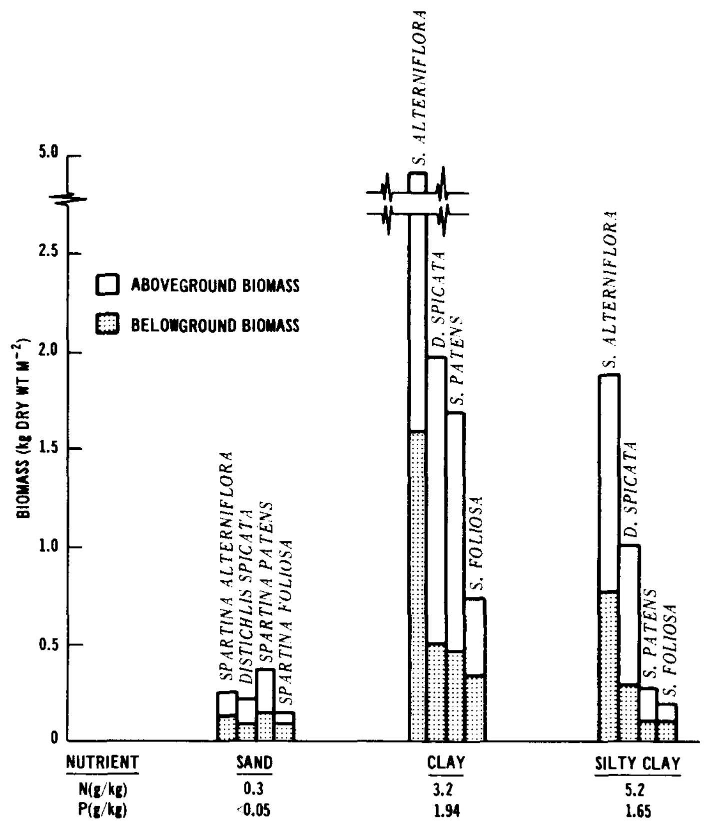

Figure 6. Biomass of marsh plants grown on estuarine sediments in relation to sediment concentrations of nitrogen and phosphorus

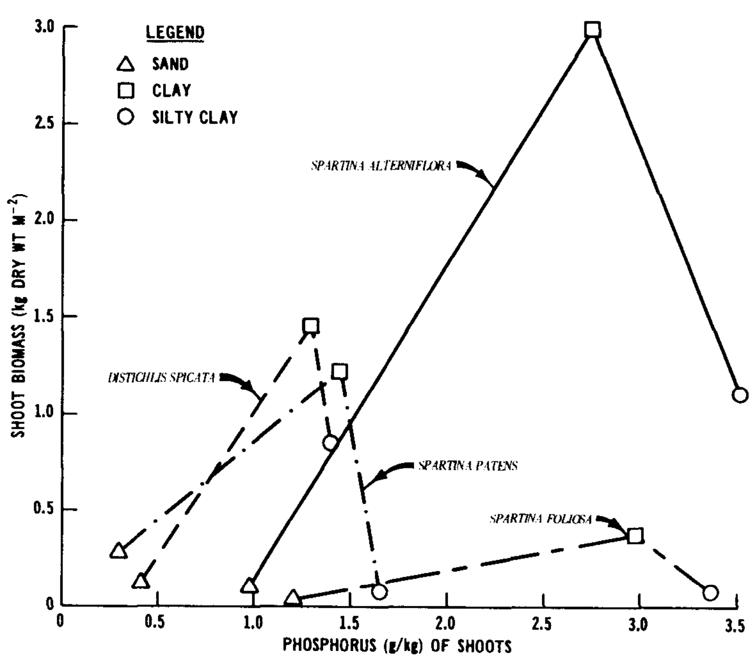

Figure 7. Relationship between phosphorus concentration and biomass of shoots of marsh plants grown on estuarine sediments

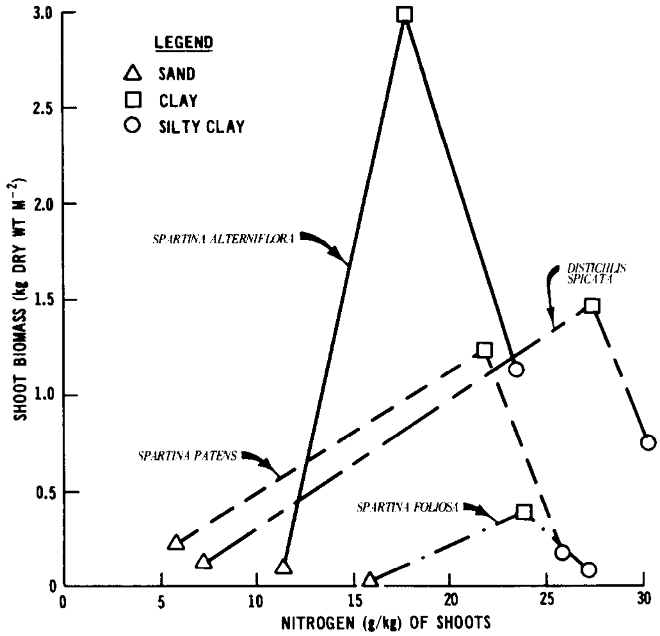

Figure 8. Relationship between nitrogen concentration and biomass of shoots of marsh plants grown on estuarine sediments

the establishment and growth of the marsh plants used in this investigation. It is commonly accepted that soil solutions of high salt concentrations cause growth retardation in most plants (Adams 1963, Waisel 1972); however, little definitive information exists on the tolerance of different coastal marsh species to high salinity. Moreover, comparison of results obtained in different investigations is complicated by differences in methodology (Barbour and Davis 1970). Palmisano (1972) reported a greater than 50-percent reduction in the growth of four marsh species of the gulf coast at salinities above 15 ppt. Barbour and Davis (1970) noted the inability of five marsh species of the California coast to survive at salinities greater than 22 ppt. In an investigation of plant establishment on dredged sediments, Woodhouse et al. (1972) reported die back of *S. alterniflora* at sediment solution salinities exceeding 45 ppt. Adams (1963) suggested that salt concentrations equivalent to approximately 70 ppt (twice sea strength) prohibited establishment and survival of all marsh plant species.

40. It is hypothesized that the ratios of biomass obtained on

clay to that on silty clay presented in the tabulation below reflect salinity tolerances for those plant species that were successfully

Species	Relative Tolerance*
Distichlis spicata	1.89
Spartina alterniflora	2.45
Spartina foliosa	3.81
Spartina patens	6.01

* Units are ratios of biomass on clay (salinity = 17.8 ppt) to biomass on silty clay (salinity = 31.8 ppt). Species are presented in order of decreasing tolerance.

established on these sediments. *Distichlis spicata*, *Spartina alterniflora*, and *Spartina foliosa* were least inhibited and consequently more tolerant of the higher salinity of silty clay. *Spartina patens* was severely inhibited on silty clay, and thus less tolerant of the higher salinity than the former species. *Triglochin maritima* and *Scirpus robustus* (not presented in the preceding tabulation) did not tolerate the higher salinity of silty clay and could not be established on this sediment. Distributional analyses of the coastal vegetation of North America (Duncan 1974, MacDonald and Barbour 1974) indicate that those species which were most tolerant of high salinity in this investigation are typically more widely distributed within natural marshes than others. Less tolerant species are restricted in their distribution with respect to tide and are less frequently encountered in potentially highly saline areas.

41. One of the more interesting findings of this investigation was the apparent effect of plant growth on the free-water salinity of fine-textured estuarine sediments (Table 11). In general, increases in free-water salinity were directly related to plant growth; thus the salinization effect was of much lesser magnitude in silty clay where growth was inhibited relative to growth on clay. Since changes in sediment moisture content were negligible during the period of investigation, increases in salinity represent the accumulation of salts

Table 11

Free-water Salinity of Fine-textured Estuarine Sediments

Sediment Type	Species-Salinity, ppt*					
	Initial	Unvegetated	*Spartina patens*	*Spartina foliosa*	*Distichlis spicata*	*Spartina alterniflora*
Silty clay	31.8 a	28.5 a	31.3 a	31.0 a	34.5 b	40.0 c
Clay	17.8 a	25.0 b	28.0 b	31.8 b	27.5 b	43.0 c

* Means are based on two replications. When followed by different letters, values within a sediment type are significantly different at $P < 0.05$. Significance was determined using Duncan's multiple comparison test.

rather than the concentration of static quantities.

42. Evaporative loss of water from a sediment surface with subsequent capillary recharge from a saline water table promotes the accumulation of salts in sediment surfaces regardless of changes in moisture content. Moreover, more rapid losses of water due to plant transpiration (Gessner 1959) can increase the rate of influx of water and salts. Salt-secreting marsh plants (i.e., those listed in Table 11) possess mechanisms in their roots for the screening of toxic ions and for decreasing their penetration into the plant (Waisel 1972). This increased flux of water and salts, coupled with salt exclusion by plant roots, can potentially result in large increases in the salinity of the sediment in the root zone of the plants. The capacity of marsh plants to promote the accumulation of salts in sediments is roughly proportional to the efficiency of their salt-exclusion mechanisms and to their rate of transpiration. Implications regarding the impact of sediment salinity and vegetationally induced changes therein on marsh establishment efforts are obvious. This discussion of salinization is only applicable to impermeable sediments, however, since permeable sediments (i.e., sandy sediments) are readily leached and would be expected to contain salts in dynamic equilibrium with tidal groundwater.

PART V: CONCLUSIONS AND RECOMMENDATIONS

43. *Distichlis spicata* was the only species successfully established from seed. Marsh plant establishment from seed presents several problems. The germination of most seeds is highly variable, and, in order to ensure moderate success, seeds must be correctly pretreated. Seeds are also vulnerable to being dislodged and swept out of the sediment by tidal action or heavy rainfall. Under most natural conditions only a very small percentage of seeds can be expected to produce seedlings. Since seedlings are delicate and therefore extremely vulnerable to physically and biologically mediated damage, losses at this stage of development may be as prohibitive to establishment as poor germination. It is notable that among natural populations of marsh plants, establishment in uncolonized areas usually does not occur by seed (Sculthorpe 1967).

44. Although plant populations were comparably established from all vegetative propagules on freshwater sediments, populations were established with much less success from rhizomes than from transplants in the estuarine sediments. It has been suggested (Bernstein and Hayward 1958) that the effects of salinity on a plant may vary depending on the stage of development. Accordingly, differences in the sensitivity of different propagules to salinity may have affected establishment of the brackish marsh species in this investigation. Compared with the growth of transplants, growth of plants established from other vegetative propagules was much less. This lesser growth was probably induced by the imposition of a limitation on the duration of the investigation. Irrespective of propagative mode, successfully established plant populations can be expected to achieve maximum density, dictated by characteristics of the planting site within a few years following planting (Woodhouse et al. 1972).

45. Coarse-textured sediments are characteristically poor in nutrients. In this investigation it was concluded that the growth of all species on sand was nutrient limited. Where rapid development of vegetative cover on coarse-grained sediments is desirable, limited

application of fertilizer is recommended. However, it must be cautioned that brittle growth induced by high N-levels (Ranwell 1972), coupled with proportionately reduced root growth (Valiela and Teal 1974, Valiela et al. 1976), would increase the likelihood of severe plant damage from wave action.

46. Plant growth on fine-textured dredged sediments, where not inhibited by high salinity in this investigation, was comparable to or exceeded most published estimates of plant production in natural marshes (Westlake 1963). Fertilization of the sediments used in this investigation would have served no practical purpose, since existing nutrients would have become limiting only at a much higher rate of production. The characteristically high productivity of marsh vegetation is maintained in part by the continual replenishment of nutrients in the form of nutrient-rich sediments deposited on the marsh (Gorham and Pearsall 1956, Ranwell 1964). These sediments are not unlike fine-textured dredged sediments, which should, in most cases, contain adequate concentrations of nutrients to support plant growth. Because of this, it is recommended that fine-textured dredged sediments not be fertilized in marsh-creation projects.

47. The influence of high salinity on the establishment and growth of marsh plants on dredged sediments has not been investigated. However, based on the results of this investigation, it is possible that the salinity of many estuarine dredged sediments may impede or at least inhibit the establishment of vegetation. Due to salt intrusion in estuarine systems (Odum 1971), the salinity of water overlying the sediments may approach that of seawater (35 ppt). As this water is intermixed with sediments during dredging, it may impart higher concentrations of salts to the sediment solution. Since most dredged sediments initially contain between 80- and 90-percent water by weight (Murphy and Zeigler 1974), even moderate drying can be expected to significantly increase the free-water salinity.

48. By artificially maintaining a water table and simulating tidal inundation of the sediments in this investigation, it was possible to prevent the increased concentration of salts associated with

reduction in water content. However, vegetatively induced accumulations of salts in the fine-textured sediments were noted and discussed herein. Since the development of organic structure in a fine-textured sediment would eventually promote leaching, plants might be selected on the basis of their ability to rapidly accrue belowground mass in sites where salinization processes would be expected to adversely affect marsh-creation efforts. Additionally, the burrowing activities of invertebrate animals can be expected to promote improvements in drainage (Green and Askew 1965).

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