Biological Services Program

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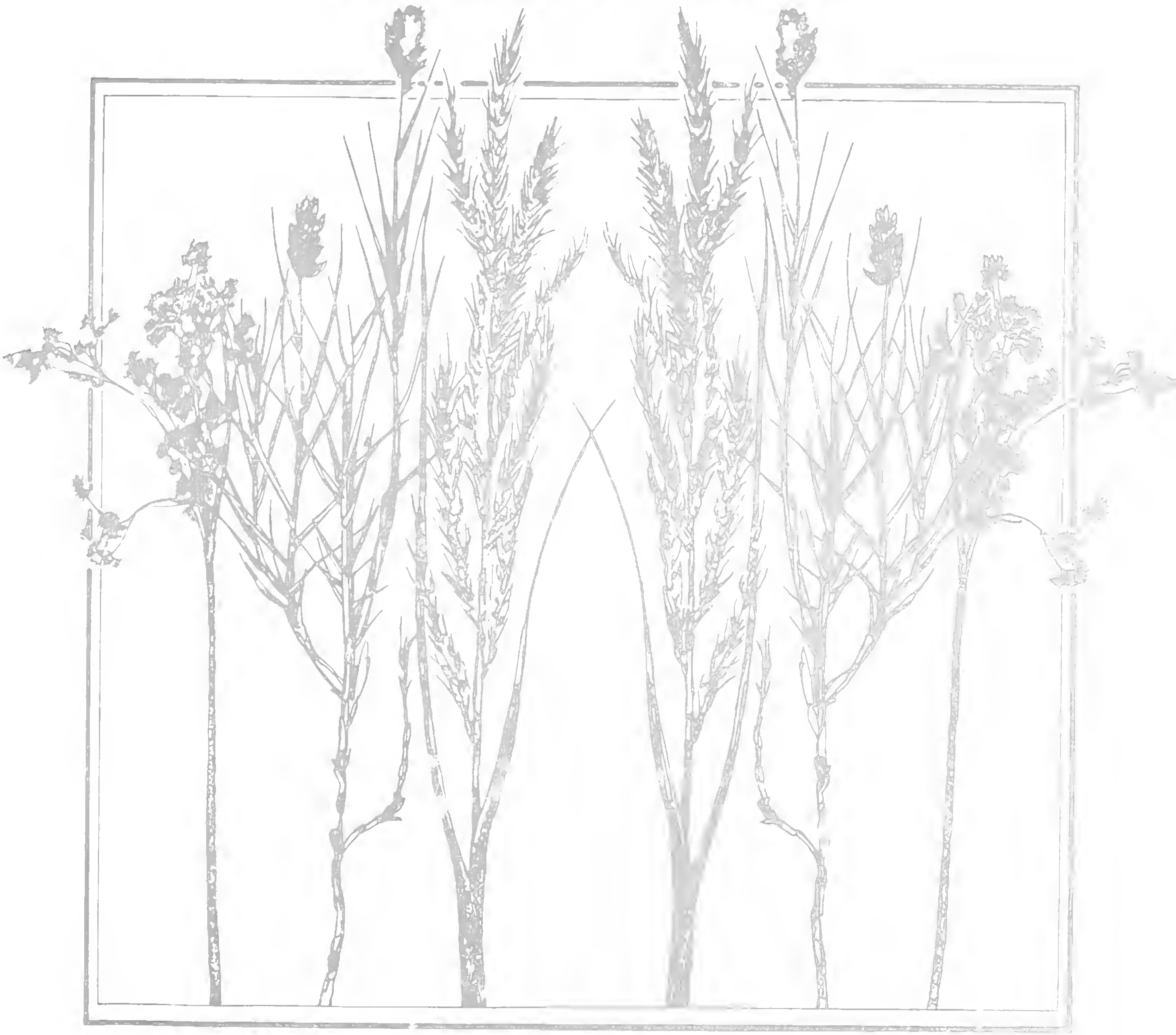
November 1980

REHABILITATION AND CREATION OF SELECTED COASTAL HABITATS: Proceedings of a Workshop



Fish and Wildlife Service

U.S. Department of the Interior

United States Department of the Interior
FISH AND WILDLIFE SERVICE

National Coastal Ecosystems Team
NASA/Slidell Computer Complex
1010 Gause Blvd.
Slidell, Louisiana 70458

27 February 1981

Dear Colleague:

The papers printed in the attached volume were presented at a workshop on Sapalo Island, Georgia in May 1976. Although the workshop often has been referred to as the "Marsh Rehabitation Workshop", the title "Rehabilatation and Creation of Selected Coastal Habitats" is more accurate. The workshop was designed to provide information on replanting methods for dune, marsh, submerged grasses and mangrove species throughout the United States. Experts from each major coastal area were called in to provide the workshop program.

Wide distribution is being made to our basic mailing list. Additional copies are available in limited numbers from the National Coastal Ecosystems Team, 1010 Gause Blvd., Slidell, LA 70458.

If you have any comments, suggestions, or constructive criticism, they will be welcomed here at the Team.

Sincerely,

Robert E. Stewart, Jr.
Team Leader

The Biological Services Program was established within the U.S. Fish and Wildlife Service to supply scientific information and methodologies on key environmental issues that impact fish and wildlife resources and their supporting ecosystems. The mission of the program is as follows:

- To strengthen the Fish and Wildlife Service in its role as a primary source of information on national fish and wildlife resources, particularly in respect to environmental impact assessment.

- To gather, analyze, and present information that will aid decisionmakers in the identification and resolution of problems associated with major changes in land and water use.

- To provide better ecological information and evaluation for Department of the Interior development programs, such as those relating to energy development.

Information developed by the Biological Services Program is intended for use in the planning and decisionmaking process to prevent or minimize the impact of development on fish and wildlife. Research activities and technical assistance services are based on an analysis of the issues, a determination of the decisionmakers involved and their information needs, and an evaluation of the state of the art to identify information gaps and to determine priorities. This is a strategy that will ensure that the products produced and disseminated are timely and useful.

Projects have been initiated in the following areas: coal extraction and conversion; power plants; geothermal, mineral and oil shale development; water resource analysis, including stream alterations and western water allocation; coastal ecosystems and Outer Continental Shelf development; and systems inventory, including National Wetland Inventory, habitat classification and analysis, and information transfer.

The Biological Services Program consists of the Office of Biological Services in Washington, D.C., which is responsible for overall planning and management; National Teams, which provide the Program's central scientific and technical expertise and arrange for contracting biological services studies with states, universities, consulting firms, and others; Regional Staffs, who provide a link to problems at the operating level; and staffs at certain Fish and Wildlife Service research facilities, who conduct in-house research studies.

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REHABILITATION AND CREATION OF SELECTED COASTAL HABITATS: Proceedings of a Workshop

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DISCLAIMER

PREFACE

The papers in these Proceedings were presented at a workshop held at Sapelo Island, Georgia, 16-20 May 1976. Although innumerable delays made earlier publication impossible, the editors believe that the papers still contain useful information which may be applied in the rehabilitation and creation of coastal habitats.

We wish to thank the authors for their patience and cooperation in revising, and in some cases rewriting, their original papers.

Comments or requests for this publication should be addressed to:

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CONTENTS

TECHNIQUES FOR CREATING SALT MARSHES ALONG THE EAST COAST

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The information that I present is the result of research conducted by Dr. W. W. Woodhouse, Jr., Dr. S. W. Broome, and me in North Carolina. Suggested references include Woodhouse (1979) and Woodhouse et al. (1972, 1974, 1976). Our research efforts were supported by the Coastal Engineering Research Center, U.S. Army Corps of Engineers; the University of North Carolina Sea Grant Program; and the North Carolina Coastal Research Program. I cannot speak with any authority about marsh creation results from other areas, except in North Carolina where we worked with a wide range of environmental conditions. Most of the substrates that we worked with in marsh establishment were sandy.

Low regularly flooded salt marshes are flooded twice daily along the Atlantic coast (along the Gulf coast only once daily) and are dominated by smooth cordgrass, *Spartina alterniflora*. From Maine to Florida, these marshes vary along a latitudinal gradient of increasing temperature and decreasing daylight during the summer. Salt marshes may consist of only a narrow fringe seaward from irregularly flooded marsh or shrub communities in the mid-Atlantic region. From Cape Lookout, North Carolina, southward through South Carolina and Georgia, these marshes consist of broad expanses of smooth cordgrass. Along the Gulf coast these marshes may again consist of only a narrow fringe such as at Ocean Springs, Mississippi. Near Brownsville, Texas, is found the westernmost populations of smooth cordgrass and here, too, they come in contact with mangrove which dominates tropical coastlines in protected areas. The same species of smooth cordgrass supposedly occurs all along the coast from Maine to Texas, but we should understand that even though the adjacent populations may interbreed, there is considerable variation in morphological features and physiological responses from north to south. Some of this variation is genetic, and some of it is probably only due to local environmental conditions. We do not have all the answers concerning the variability, but we do know that there are local population variations and that in marsh establishment we should be aware of those variations in any material that we transplant very far from the source of the transplants. Planting material should not be used very far from the area where it was obtained. Certainly plants from Maine should not be planted in Georgia.

We began thinking about marsh creation or marsh initiation in the late summer of 1969, at which time Dr. Woodhouse and I went to the Coastal Engineering Research Center, U.S. Army Corps of Engineers, in Washington, D.C., and talked with some of their personnel about marsh creation. They seemed interested, gave us some seed money, and we started our studies in the fall of 1969. At that time there was considerable open water disposal of dredge material in North Carolina. North Carolina has about 2,400 km (1,500 mi) of navigable channels in its sounds and estuaries, and the Corps' annual expenditures for channel maintenance in 1969 were around 2 to 3 million dollars.

The idea of trying to stabilize the intertidal zone of this dredge material appealed to the Corps because stabilization could reduce the amount of material finding its way back into the same channels from which it was dredged. In theory, it could cut down on channel maintenance costs. Heretofore, nothing has been done to stabilize this material after it was cast out of the pipeline dredge, and through normal wind and wave action, much of it found its way right back into the same channels from which it was dredged. Although the situation has changed and there is no longer open water disposal, there are still areas where marsh can be established. Further, if willful destruction of marshland occurs, we now have the techniques and procedures whereby regulatory agencies or the courts can require restoration.

One of our first attempts to create salt marsh was at a small dredge spoil island in the Pamlico Sound, where the tidal amplitude was only 15 to 30 cm (6 to 12 inches). We had two objectives in mind: to stablize the spoil material in the intertidal zone by transplanting smooth cordgrass and, in so doing, to develop marsh. Our first attempts were not mechanized. We marked off rows and working in teams of two, hand-planted with a dibble bar like foresters use to plant trees. Most plants were set on about a 91-cm (36-inch) center, 91 cm between plants within rows and 91 cm between rows. We used whatever size transplants were available at the time and location but preferably took them from a sandy substrate. Plants from such an area were easy to dig and to separate, and had well-developed root systems. The small young shoots at the base of the stem (culm) were left attached. These young shoots are often responsible for growth and establishment of the transplant. We discovered that we could establish smooth cordgrass marsh with transplants in this manner. A single culm transplant has the potential to grow into a plant with several hundred grams of dry matter accumulation in a 5-mo period. Although a substantial root system had developed under the substrate in this time, stabilization was not fully achieved until the end of the second aboveground growing season, or about 17 mo after planting.

To plant larger areas, we scaled up the operation by using a farm tractor with a modified tobacco planter. Later, we put dual wheels on the back of the tractor and wider tires on the front for extra flotation, so that we could plant more unstable areas. Our planting sites from north to south indicate that we covered the North Carolina coast in our trials. Not all experiments were successful, but we covered a wide range of conditions. From north to south, the coastline varies not only in terms of latitude, but also in tidal amplitude from less than 0.3 m (1 ft) to more than 1.5 m (5 ft). The primary influence on tides along the northern part of the North Carolina coast is wind. However, the southern coast is almost exclusively under the influence of lunar tides. Strong southwest winds blowing across the northern sounds may hold water on planting for several days, or when a northeast wind blows, water may be held off of the plantings for several days. In contrast, on the southern coast there is a regular flooding regime every day.

Let us consider one experimental site and follow it through 3 or 4 yr. Snow's Cut, North Carolina, in the middle of the Cape Fear River, south of Wilmington, had spoil deposited on it about 60 days prior to planting. The substrate was about 96% sand, had a slope of about 2%, and was influenced by a tidal amplitude of about 1.5 m (5 ft). We obtained transplants from an area that was relatively sandy and within 1 km (0.6 mi) of the planting site. Again we used single-stem transplants. We hand-planted on 91-cm (36-inch) centers in April. By June, survival was determined to be over 90%. By September, the rows were still discernable but considerable spread was evident. By spring of the following year, a lateral spread of about 1.5 m (5 ft) was recorded. By the spring of the second year, an observer could no longer clearly identify plant rows, and by the end of the second growing season, for all practical purposes, we had established a marsh. In terms of fauna and flora, the area was not entirely comparable to a natural marsh, but in terms of primary production, it exceeded that of many natural marshes in the vicinity. By the end of the second or third year, it would be difficult for anyone to determine that the area was an artifically created marsh.

We sampled the grass to determine how much was produced at the end of each growing season by measuring biomass and counting the number of culms. We cut the vegetation at ground level and dug out the belowground material to a depth of 30 cm (12 inches). Five months after transplanting there were about 200 g (7 oz) of aboveground biomass per transplant. We found that each transplant had produced somewhat less than 100 g/m^2 below ground. Productivity declined after the first 17 mo, and peak aerial standing crop leveled off from the third through the fifth growing season at between 1,200 and 1,300 g/m^2.

No matter now good a new marsh may look at the end of the first growing season, substrate stabilization has not been achieved. Two full aboveground growing seasons or about 17 mo are required at our latitude to develop a very intricate root and rhizome network that binds the substrate together. We took samples from cores and from complete 0.25-m^2 (2.7-ft^2) plots dug out to a depth of 30 cm (12 inches) to make these determinations. Belowground estimates after the second growing season dropped from about 900 g/m^2 to about 650 g/m^2 by the end of the fourth growing season.

To facilitate making cost estimates of these techniques of marsh establishment, we determined the time required to dig and transplant. Transplants can be dug at the rate of about 150 to 200 transplants per man-hour and planted at the same rate with persons working in a two-man team.

Transplants can be obtained about twice as rapidly with mechanical equipment. We established a smooth cordgrass nursery where we used a tractor-drawn broad-bladed plow which cut beneath the substrate about 10 to 15 cm (4 to 6 inches) to obtain plants. This technique loosened the plants so that teams of men, walking along behind the plow, could lift them out of the ground. By October, the nursery area from which transplants were removed in this manner in spring had completely recovered. In fact, the vigor of the plants in the nursery was improved by thinning the stand and by the action of the plow.

When transplants cannot be used immediately, they can be stored in the trenches much the same as foresters heel in pine trees. Transplants can be covered in a trench in the intertidal zone and stored for 6 to 8 weeks. Comparative tests indicate that there is very little difference in survival and productivity of transplants that have been stored and those that have been dug fresh.

At times there may not be a coastal area available for a nursery. We have experimented with growing smooth cordgrass in a nursery near Raleigh, North Carolina, about 241 km (150 mi) from the coast. We called it a rice paddy because we surrounded it with a dike and irrigated it. Fresh water was pumped into the nursery whenever it began to dry out. We took transplants and seeds from several different areas along the coast and put them in the nursery. After the first season, growth seemed comparable to what we had noted in the coastal nursery.

The following spring we took some of these plants to the coast and compared them with plants freshly dug from the coast. We could detect no significant differences between plants kept in the inland nursery for 1 yr versus those plants dug fresh from the coast and planted in a replicated test on the coast. Plants from seeds sown in the inland nursery that had never been exposed to saline conditions were also transplanted on the coast and compared to natural plants dug along the coast. Again, there were no significant differences in growth and survival between nursery and natural plants. Obviously, smooth cordgrass can be produced in an interim nursery inland from the coast.

What about seeding instead of transplanting? Can seeds be collected in quantity, incorporated into the substrate, germinated and developed into a marsh? We knew that natural seeding, at least in some areas, was quite prevalent. Natural seeding is important in colonizing new areas. Initially we harvested seeds by hand and tried several ways of incorporating them into the substrate. We scarified the substrate, broadcast seed, and scarified it again. We also used clay slurries to affix the seeds to the substrate so that wave action would not remove them, but this method failed.

To harvest larger quantities of seeds we built a two-wheel garden tractor with a cutting blade mounted on the front and a reel that brings the seed heads across the cutting blade where they fall into a canvas catchment bag. Harvesting seeds in this manner can result in collection of enough seeds in about 5 man-hours to seed a hectare. We put the seeds in burlap sacks, stored them for about 1 mo in a coldroom and then ran them through a small grain thresher. Then we stored the threshed seeds, submerged in either instant ocean or estuarine water (25 ppt) in large plastic containers at about 2°C to 4°C (36°F to 39°F).

Seeds must be kept moist and they must be stored cold to retard germination. If estuarine water or instant ocean is not used, some of the seeds will germinate after a few months. The two things that prevent germination are low temperatures and the salinity which acts as an osmotic barrier.

To scale up the seeding operation we used a tractor-drawn, spike-toothed harrow to scarify the substrate. We seeded at the rate of about 100 viable seeds per square meter. Viability was determined on a per milliliter basis and converted to areal extent (100 viable seeds per square meter). After seeds were spread over the area, we again went over the area with the spike-toothed harrow and incorporated them into the substrate. After 5 mo we had a good stand of seedlings. By the end of the second growing season, there was a marsh comparable to one established from transplants.

On certain dredge material deposits, the fine sand may blow around and interfere with vegetation establishment. In seeding operations, it may be necessary to stop the sand from blowing on the young seedlings. Either a sand fence or vegetation can be used to catch the sand and prevent it from covering the young plants while they are very susceptible to burial.

Many areas are relatively inaccessible with a tractor or heavy equipment. One such area was a low profile island which developed in the sound behind the main barrier island after the opening of an inlet. To plant this area, we had to devise equipment that was more mobile. We put dual wheels on a garden tractor and constructed a tool bar with several cultivator sweeps on it. It scarified the area like a spike-toothed harrow. An area about 4 to 4.8 ha (10 to 12 acres) was torn up in this manner and seeded in spring. It required about 7.5 man-hours to scarify and seed the area.

Even though the area was very exposed, by the end of the first growing season about half of the area was occupied by the seedlings. Growth was not especially good, and part of the lack of vigor was probably due to the exposed situation and the high substrate salinities which were up to 40 ppt. Smooth cordgrass does not survive substrate salinities much above about 45 ppt. At the end of the third growing season a marsh had developed from seed.

We fertilized some areas and obtained even better growth. Most sandy substrates require fertilization with nitrogen and phosphorus. Nitrogen should be applied at the rate of 57 kg/ha (50 lb/acre).

Along the North Carolina coastline, we have to harvest seeds in early October before full maturity to avoid losing the seed crop because of shattering. We harvest early enough to get the seeds as they are maturing; otherwise, the crop could be lost because the seeds will shatter in the first storm. Harvesting before full maturity does not affect viability since the seeds continue to develop. They can be taken to the laboratory and put in a coldroom at about 2°C (36°F) and stored temporarily before threshing. Seeds thresh better after being stored for about a month. After being threshed, they are stored in estuarine water as described earlier.

Direct seeding is feasible only in the upper half of the intertidal zone. Wave energies and other factors prevent successful establishment in the lower intertidal zone. Seedlings cannot be established everywhere that transplants can be established. Consequently, it is better to use transplants rather than seeds when time and money permit. On the other hand, if a large area is to be developed into a marsh within a limited time frame, the upper half of the intertidal zone could be seeded and transplants could be used in the lower half. Using both methods under favorable conditions, complete vegetative cover could be obtained just as quickly as with transplanting alone.

Once established, will a smooth cordgrass marsh remain a smooth cordgrass marsh? A full appreciation of the interaction of tidal amplitude, salinity, duration of inundation, and substrate conditions is necessary to make such a determination. For smooth cordgrass to maintain itself, salinities around 20 ppt are necessary. If there are salinities of 5 ppt to 10 ppt, then in all probability smooth cordgrass will not remain dominant more than 3 or 4 yr. The marsh will be invaded by other species. This is not necessarily bad because neither substrate stabilization nor marsh creation is being lost. If the purpose is to establish a marsh and to stabilize the substrate, smooth cordgrass is the best plant to use presently. If, on the other hand, a smooth cordgrass marsh is desired, planting in a low salinity area should not be done, or else planting should be restricted to a particular portion of the tidal regime. Only in the inundation zone that was covered the longest (11.5 hr) did smooth cordgrass dominate through the fourth growing season. All other zones were invaded by other marsh species. The invaders came in during the second growing season but did not become abundant until the third and fourth growing season. In summary, under a low salinity regime, the upper zones are inundated relatively infrequently and are invaded by other species which eventually outcompete and replace smooth cordgrass.

Our marsh establishment methodology has been used to stabilize shorelines such as that near a residential development on the sound side of Bogue Banks, North Carolina. The shoreline had begun to erode because man had interfered with the system. About 10 yr before, a small boat channel was dredged about 100 m (330 ft) offshore and the material was deposited on a narrow fringe of existing marsh. The dredge spoil destroyed the marsh which had served as a buffer and protected the shoreline. There was no erosion problem until the marsh was destroyed. Erosion began shortly, and to combat it, a bulkhead was built, but it started to be undermined. The residents had heard about our work and asked if we could help them. We planted a zone of transplants about 12 m (39 ft) wide and seeded several smaller areas in preliminary tests. By the end of the second growing season, we achieved stabilization with transplants, but the seeding attempts failed.

I have described the use of transplants and seeding to establish a low, regularly flooded, smooth cordgrass salt marsh. I have described how to obtain plants by hand and mechanically and the relative man-hour costs for transplanting versus seeding. I have discussed the application of some of our findings. I do not have all the answers and the techniques that we have developed in North Carolina are not applicable everywhere. Conditions in particular marshes should be studied and techniques that seem appropriate should be applied. In some areas wave energies are too great to achieve any measurable degree of success with vegetation, but where it can be used, vegetation is economically and ecologically feasible. In stabilizing estuarine shorelines, vegetation is in certain situations a logical alternative to man-made structures.

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CREATION OF A SOUTHEASTERN UNITED STATES

SALT MARSH ON DREDGED MATERIAL

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THE SITE

The Buttermilk Sound habitat development site is located in the Atlantic Intracoastal Waterway near the mouth of the South Altamaha River, Glynn County, Georgia (Figure 1). The site is a 2-ha (5-acre) disposal area representing 5 to 7 yr of dredged material disposal. The fringes of the area have already begun to generate creekbank *Spartina alterniflora* marshes.

Most of the area surrounding the site is made up of tidal salt marshes and small high ground hammocks, some of which are remains of dredged material disposal and rice farm diking. The soils of the area have been mapped as wet alluvial land, tidal marsh, and "made land."

Daily tidal inundations cause the surface layers of these marshes to build up very slowly by deposition; there is also a shifting of material caused by a strong tidal current. These strong tidal currents create an average 2.1-m (6.9-ft) tidal regime that floods the marshes twice daily.

The vegetation commonly found on the tidal marshes adjacent to the habitat development site is listed in Table 1. *Spartina alterniflora* is the most common species occurring on the lower elevations of the tidal marsh. Along the creekbanks where the tide inundates the plants twice daily, *S. alterniflora* grows to more than 2 m (7 ft) in height. When these plants die, the dead material is readily swept into the streams and nearby sounds where it is broken down into detritus.

In marshes of slightly higher elevation, the common floral components include *Spartina cynosuroides*, *Juncus roemerianus*, *Borrichia frutescens*, and *Scirpus robustus*. The transition from the marsh to the high ground is often marked by a zone of herbaceous plants such as *Distichlis spicata*, *Spartina patens*, and *Sporobolus virginicus*. Also scattered throughout this area are the shrubs *Iva frutescens* and *Baccharis halimifolia*. In the transitional zone where the soil salinity is much higher, grow specialized plants adapted to this condition (e.g., *Salicornia virginica*, *Salicornia biglovii*, *Batis maritima*, and *Limonium Nashii*).

The dredged material island, slightly less than 2 ha (5 acres) along the southeastern edge of the Atlantic Intracoastal Waterway, was used for the habitat development site. The grossly homogeneous sand substrate with an elevation of 3 m (10 ft) above mean sea level initially had very few resident plant species. Table 2 lists the vegetation actually found on the site prior to its grading and preparation for a habitat development site. The areal coverage of this vegetation was less than 1% of the total area.

The substrate at the site prior to habitat development consisted of 99% quartz sand by weight and had no visible stratification. Some variation in grain size was noted, but the occurrence was random and thus not documentable. The limnic materials are indicative of the high energy system caused by the flow of the Altamaha River and the daily tidal movements. The sand had a very low resistance to deformation and rupture as evidenced by its constant manipulation resulting from current and wave action. Table 3 presents the physical analysis of cores taken from the development site prior to habitat creation.

Table 4 provides a summary of the mineral content of the cores prior to

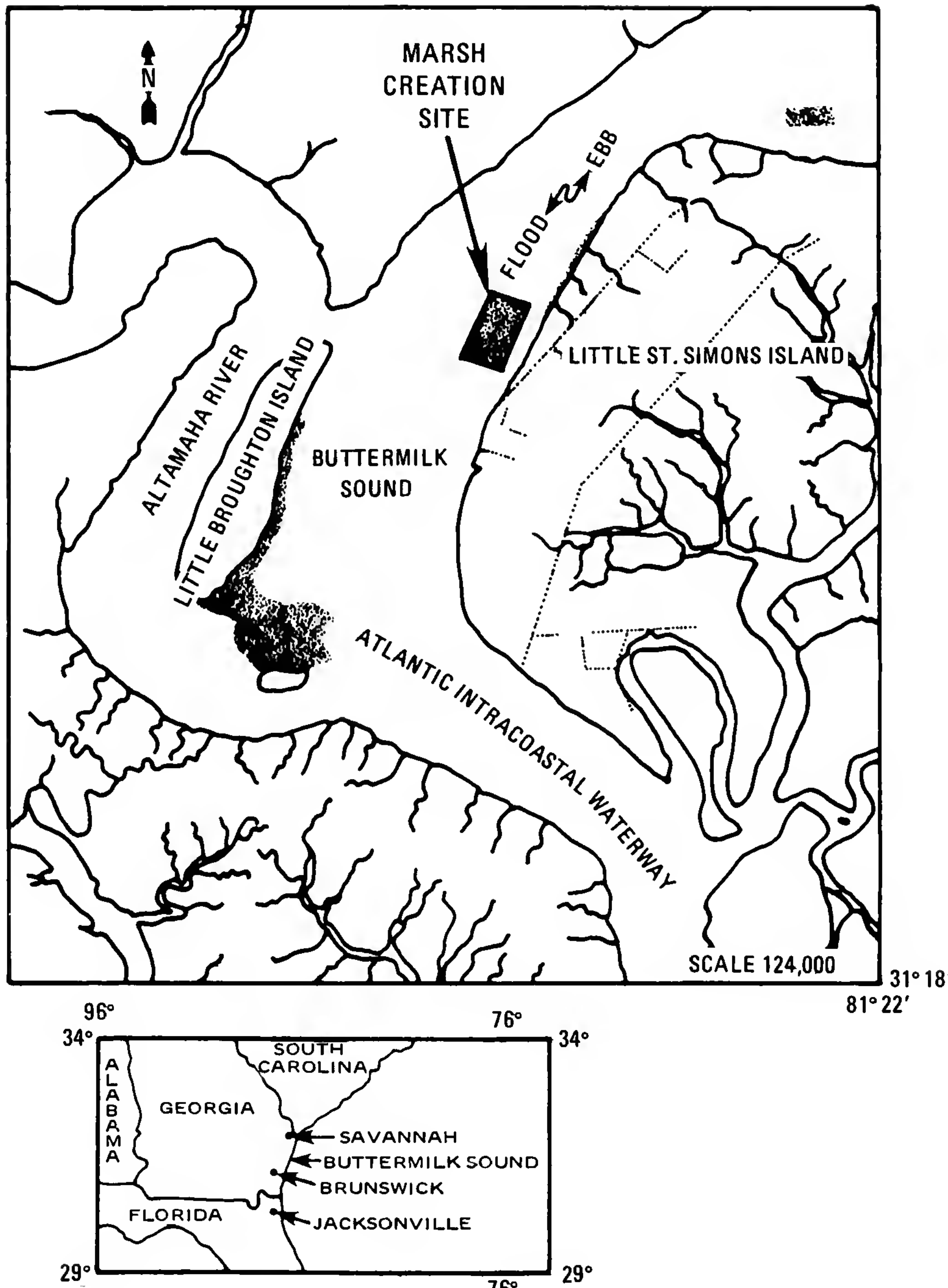

Figure 1. Geographic location of the Buttermilk Sound marsh habitat creation site, Glynn County, Georgia.

Table 1. Vegetation of marshes adjacent to the Buttermilk Sound habitat development site prior to grading.

Scientific name	Common name
Acnida cannabinus	Tidemarsh waterhemp
Boltonia asteroides	Marsh boltonia
Cypress erythrorhizos	Redroot cyperus
Cyperus rotundus	Purple nutsedge
Eleocharis albida	Spikerush
Eleusine indica	Goosegrass
Peltandra virginica	White arm
Pluchea purpuracens	Stinkweed
Polygonum punctatum	Dotted smartweed
Pontederia cordata	Pickerelweed
Sagittaria lancifolia	Bulltongue
Scirpus robustus	Saltmarsh bulrush
Scirpus validus	Softstem bulrush
Sesbania exaltata	Hemp sesbania
Spartina alterniflora	Smooth cordgrass
Typha domingensis	Southern cattail
Zizania aquatica	Wild rice
Zizaniopsis miliacea	Southern wild rice

Table 2. Vegetation identified on the Buttermilk Sound habitat development site prior to grading.

Scientific name	Common name
Acnida cannabinus	Tidemarsh waterhemp
Cyperus rotundus	Purple nutsedge
Eleusine indica	Goosegrass
Pontederia cordata	Pickerelweed
Sesbania exaltata	Hemp sesbania
Spartina alterniflora	Smooth cordgrass
Zizania aquatica	Wild rice

Table 3. Physical analysis of cores taken on Buttermilk Sound habitat development site prior to grading.

Depth of core in cm	pH[wa]	Eh +Mv	% H_2O	%OM	CEC meq
0 - 25	6.9	410	16.4	0.07	0.91
25 - 60	7.0	390	17.7	0.07	0.89
0 - 25	6.9	420	20.0	0.13	0.28
25 - 60	7.1	410	21.8	0.13	0.28
0 - 25	7.0	410	16.4	0.13	0.85
25 - 60	7.0	380	19.1	0.13	0.49
0 - 25	6.9	350	18.2	0.07	0.44
25 - 60	7.1	400	18.5	0.07	0.48
0 - 25	6.9	420	18.6	0.20	1.22
25 - 60	6.8	410	20.0	0.13	0.91
0 - 25	7.0	400	17.3	0.13	0.59
25 - 60	7.0	409	19.0	0.07	0.45

[a]pH[w] = pH of soil and distilled water mixture; Eh = redox potential; $\%H_2O$ = percent water content of the core; % OM = percent organic matter; CEC = cation exchange capacity = milliequivalents per 100 g (3.5 oz).

Table 4. Mineral analysis of cores taken on Buttermilk Sound habitat development site prior to grading.

Depth of core (cm)	Mn[a]	B	S	Fe	P	K	Ca	Mg	Total N[b]	NO_3^- NO_2	NH_3[b]	Total P[b]	PO_4[b]
0-25	4.5	0.25	0.014	52.5	4.0	6.5	63.5	20.5	0.062	1.39	3.46	0.036	0.010
25-60	5.5	0.24	0.008	65.5	4.0	6.5	58.0	21.5	0.052	0.45	3.24	0.026	0.019
0-25	4.0	0.19	0.004	17.0	2.0	4.5	29.0	14.5	0.017	0.40	1.19	0.017	0.006
25-60	< 4.0	0.11	N.D.	18.0	2.0	4.5	30.5	14.5	0.011	0.58	0.81	0.021	0.019
0-25	6.0	0.08	0.006	44.0	3.0	6.0	58.5	17.0	0.045	1.39	2.37	0.033	0.049
25-60	< 4.0	0.08	0.008	45.0	4.0	5.5	63.5	21.0	0.044	0.64	1.57	0.033	0.039
0-25	< 4.0	0.03	0.014	27.0	3.0	10.0	44.0	23.5	0.033	1.08	6.63	0.031	0.149
25-60	4.0	0.09	0.006	42.5	4.0	7.5	58.5	21.0	0.046	0.90	1.38	0.033	0.058
0-25	8.0	0.13	0.004	66.5	8.0	12.5	110.0	28.0	0.083	1.27	1.59	0.042	0.022
25-60	4.0	0.13	0.008	47.5	6.0	8.5	63.5	21.0	0.042	0.70	1.05	0.027	0.009
0-25	5.0	0.06	0.005	43.0	6.0	12.0	80.5	19.0	0.042	1.07	1.79	0.033	0.009
25-60	< 4.0	0.12	N.D.	37.0	2.0	6.0	59.1	16.5	0.037	0.90	5.16	0.023	0.022

[a] Mn = manganese, B = boron, S = sulfur, Fe = iron, P = phosphorus, K = potassium, Ca = calcium, and Mg = magnesium are all expressed in parts per million; Total N = total nitrogen mpg; NO_3-NO_2 = nitrate-nitrite ppm; NH_3 = ammonia ppm; Total P = total phosphorus mpg; PO_4 = ortho-phosphate ppm; N.D. = Not detectable. All readings for copper were 0.4 ppm.

[b] Analysis performed in interstitial water.

site preparation. The elevation was determined by the U.S.Geological Survey prior to site preparation. A level line from a U.S. Coast and Geodetic primary tidal bench mark in Darien, Georgia, was extended to the site. A temporary bench mark, established on high ground of adjacent Little St. Simons Island, was used to determine the elevation of the site. Subsequently, a tidal gage was installed so that simultaneous comparisons could be made between the study area and the primary National Ocean Survey tide stations at Fort Pulaski, Georgia, and Mayport, Florida.

METHODS

Often it may be necessary to supplement the nutrient content of soils with commercial fertilizer applications so that marsh plants can become successfully established. Marsh plant-soil interactions were evaluated in terms of carbon, nitrogen, and phosphorus levels to gain information about nutrient uptake by marsh plants and to determine marsh plant response to fertilizer application.

The site was graded so that an elevation gradient was established from mean high water level to mean low water over a seaward distance of 60 m (200 ft), and 150 m (490 ft) horizontally. Within this intertidal area a series of research plots, each 1.5 by 3 m (5 by 10 ft), were established with a 0.7-m (2.3-ft) border between each plot.

The variables included in the factorial design were (1) elevation: low (lower third of intertidal zone), middle (middle third of intertidal zone), and high (upper third of intertidal zone); (2) vegetation propagules: no propagule introduced except as naturally might occur, or one of the following seven plant species: *Borrichia frutescens*, *Distichlis spicata*, *Iva frutescens*, *Juncus roemerianus*, *Spartina alterniflora*, *Spartina cynosuroides*, and *Spartina patens*. These plants were all common inhabitats of natural marshes near the study area; (3) fertilizer treatment: no fertilizer, low level of inorganic fertilizer (122g/m^2), high level inorganic (244 g/m^2), low level organic (33 g/m^2), high level organic (66 g/m^2).The inorganic fertilizer was manufactured by Kaiser Agricultural Chemicals under the trade name of "Bounty"®. The analysis of the inorganic fertilizer was 10% nitrogen, 10% phosphorus, and 10% potash. The nitrogen components of that fertilizer included 3% nitrate-nitrogen from ammonium nitrate and 7% ammoniacal nitrate. The organic fertilizer manufactured by Kerr-McGee Corporation and sold under the name of "Gro-tone" had an analysis of 16% nitrogen, 4% phosphorus, and 8% potash with organic sources of nitrogen in the formulation; (4) types of propagules: sprigs and seeds. The sprigs were transplanted during June 1975 from marshes adjacent to the research plot. The seeds were collected from seed-producing plants adjacent to the research plot during the summer, fall, and winter of 1975 and were planted in April 1976 after appropriate winter cold treatment. Propagules were planted on 0.5-m (1.6-ft) centers in each of the test plots. Each of the above factors was randomized with three replicates. Consequently, there were a total of 720 test plots in the research area.

Several parameters were measured to follow the success of the developing marsh. Analysis of the soil included mineral nutrients and physical analysis. The test plots were observed for the presence and abundance of macroinvertebrates and vertebrates. Fiddler crabs, snails, and other wildlife use of the area were observed and recorded beginning with the initiation of the project. The chemical analysis of the surrounding waters, as well as the interstitial water in the plots, was conducted throughout the project (Figures 2 and 3). Amounts of nitrogen and phosphorus in the water column appear to follow the typical estuarine pattern of high concentrations in winter and low concentrations in summer. There has been no evidence of eutrophication from the fertilizer added to the test plots.

An analysis of the plants and their success in establishment was made. The remainder of the paper deals specifically with the resultant plant growth of the sprigs transplanted June 1975 as an indicator of the success of the establishment of the salt marsh.

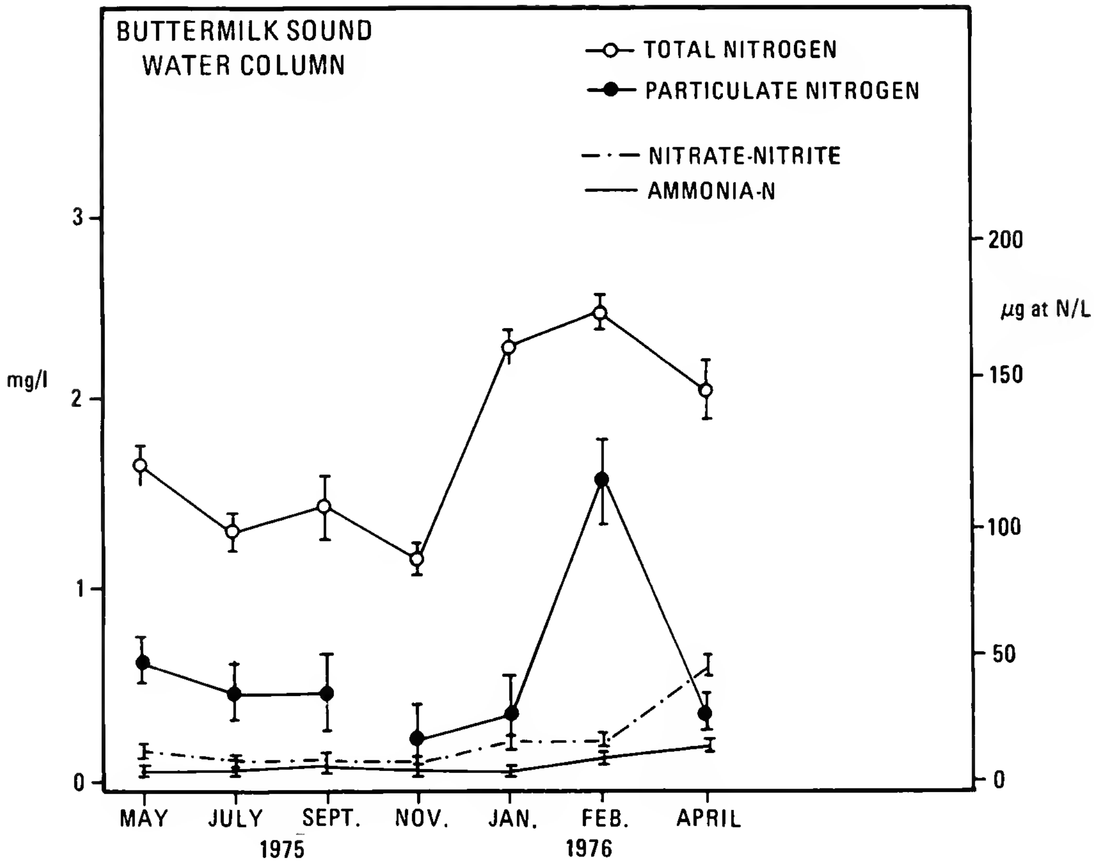

Figure 2. Nitrogen analysis of the water column surrounding the Buttermilk Sound marsh habitat creation site, May 1975 to April 1976.

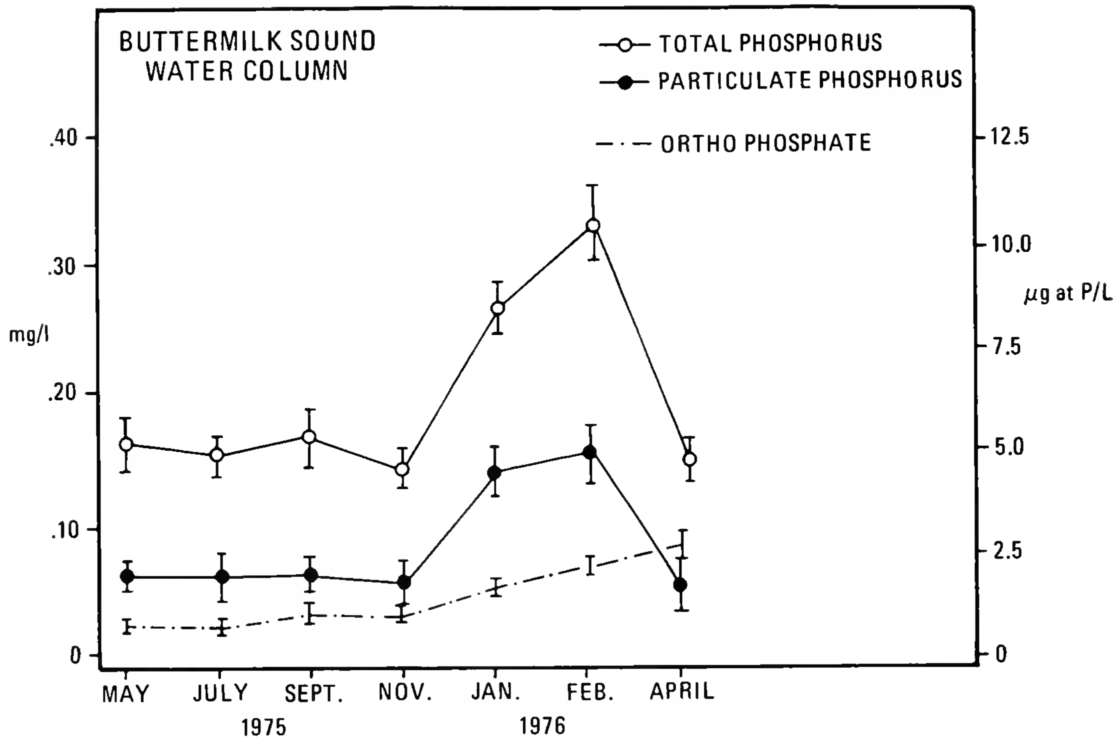

Figure 3. Phosphorus analysis of the water column surrounding the Buttermilk Sound marsh habitat creation site, May 1975 to April 1976.

Plants were identified by use of a small numbered plastic tag so that they could be recognized and quantified using nondestructive testing on a bimonthly basis. Plants were evaluated in terms of their condition, i.e., absent, dying, stable (stressed), stable, or new growth. In addition, the following parameters were assessed: height of the plant in centimeters, basal diameter in hundredths of millimeters, and number of live and dead leaves. The average live stem density and the number of flowering stems were also recorded. In addition to an assessment of the plants using the above created nondestructive technique, destructive sampling was initiated in November 1975 to assess belowground production of plant tissues. The destructive sampling consisted of harvesting a 0.1-m (0.3-ft) subplot in each of the plots. Material from the aerial portion of the plant was dried to a constant weight in a force-draft oven at 100°C (212°F). Macroorganic matter, the biomass of plant tissue below ground, was defined as the quantity of material retained on a 1-mm (0.04-inch) sieve and was assessed by extracting the plant and soil from each 0.1-m^2 (1-ft^2) plot to a depth where no additional root material was recovered. This macroorganic material was also dried and the dry weight expressed on a g/m^2 basis.

RESULTS

The data summarize results through April 1976 relative to the development of sprigs transplanted during June 1975. The results of biomass increases of the various plants are best summarized in Figures 4 through 10. Each of these figures depicts the average sprig height in centimeters (1 cm = 0.39 inch), stems per square meter (1 m^2 = 10.8 ft^2), aerial biomass (g/m^2), and belowground biomass of macroorganic material (g/m^2) at time of transplant (June 1975) contrasted with the same parameters measured via destructive sampling in November 1975.

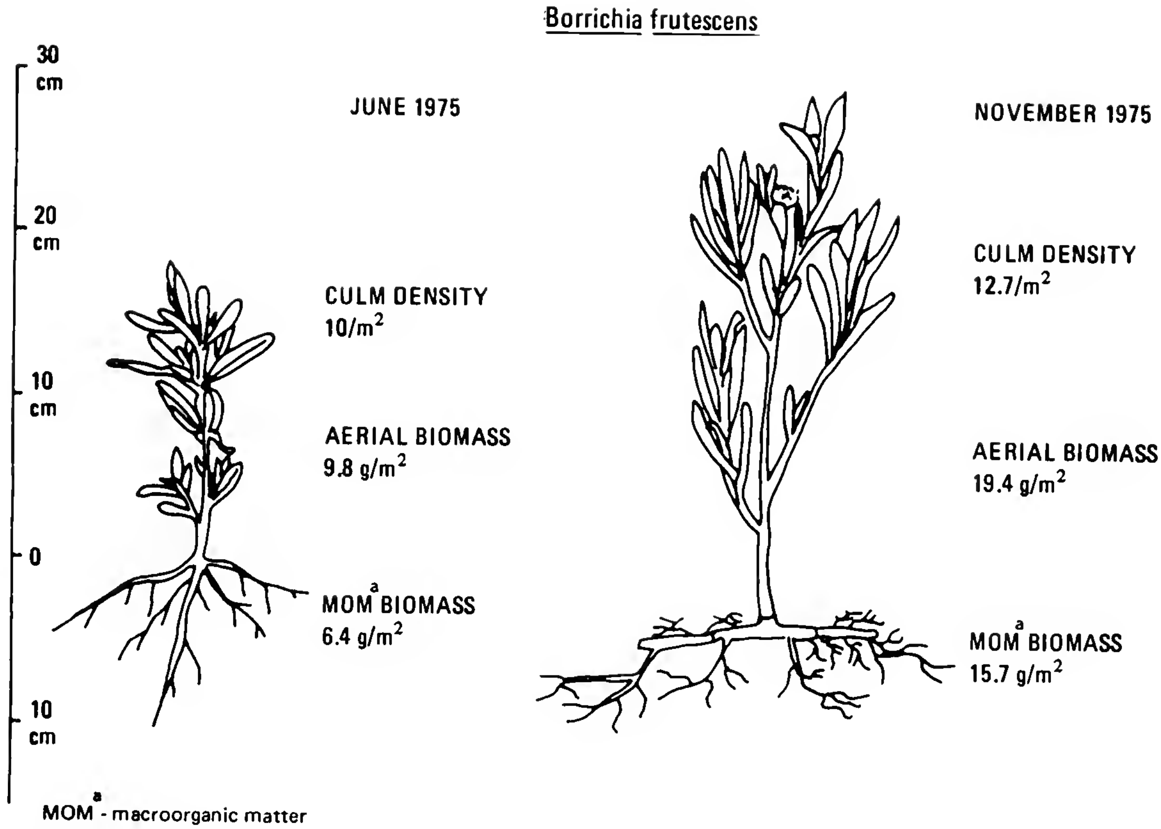

Figure 4. Comparison of Borrichia frutescens plant vigor between transplantation (June 1975) and destructive sampling (November 1975).

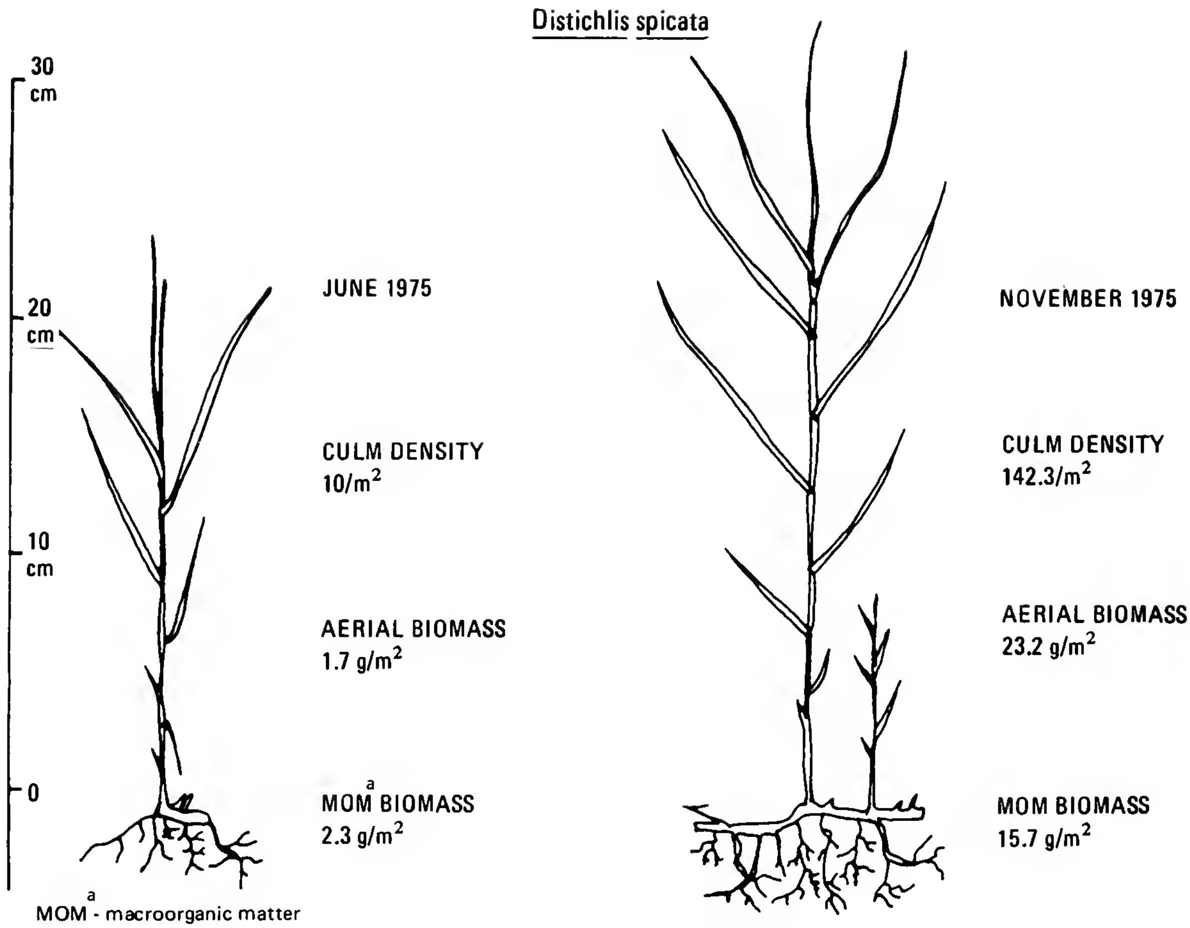

Figure 5. Comparison of Distichlis spicata plant vigor between transplantation (June 1975) and destructive sampling (November 1975).

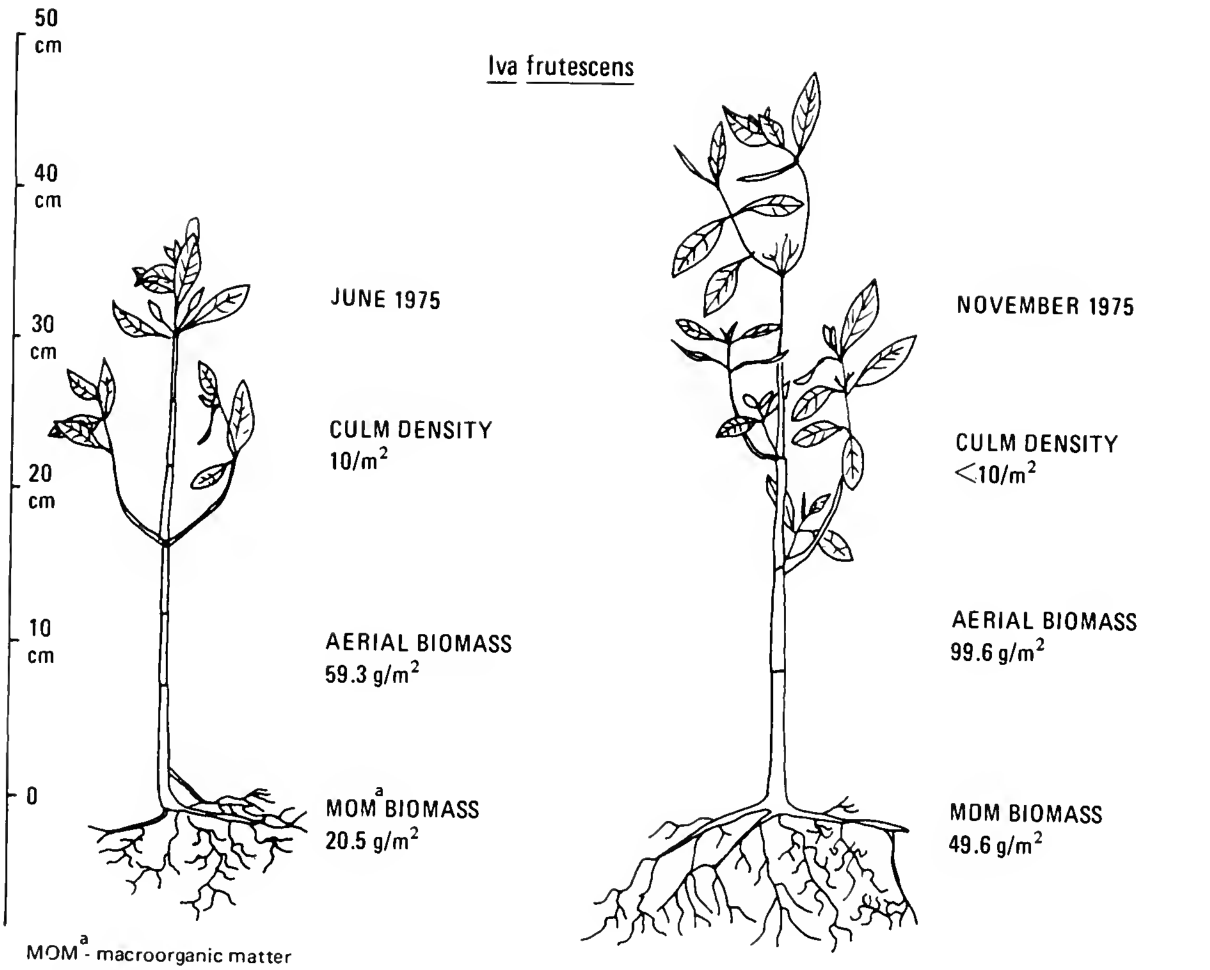

Figure 6. Comparison of Iva frutescens plant vigor between transplantation (June 1975) and destructive sampling (November 1975).

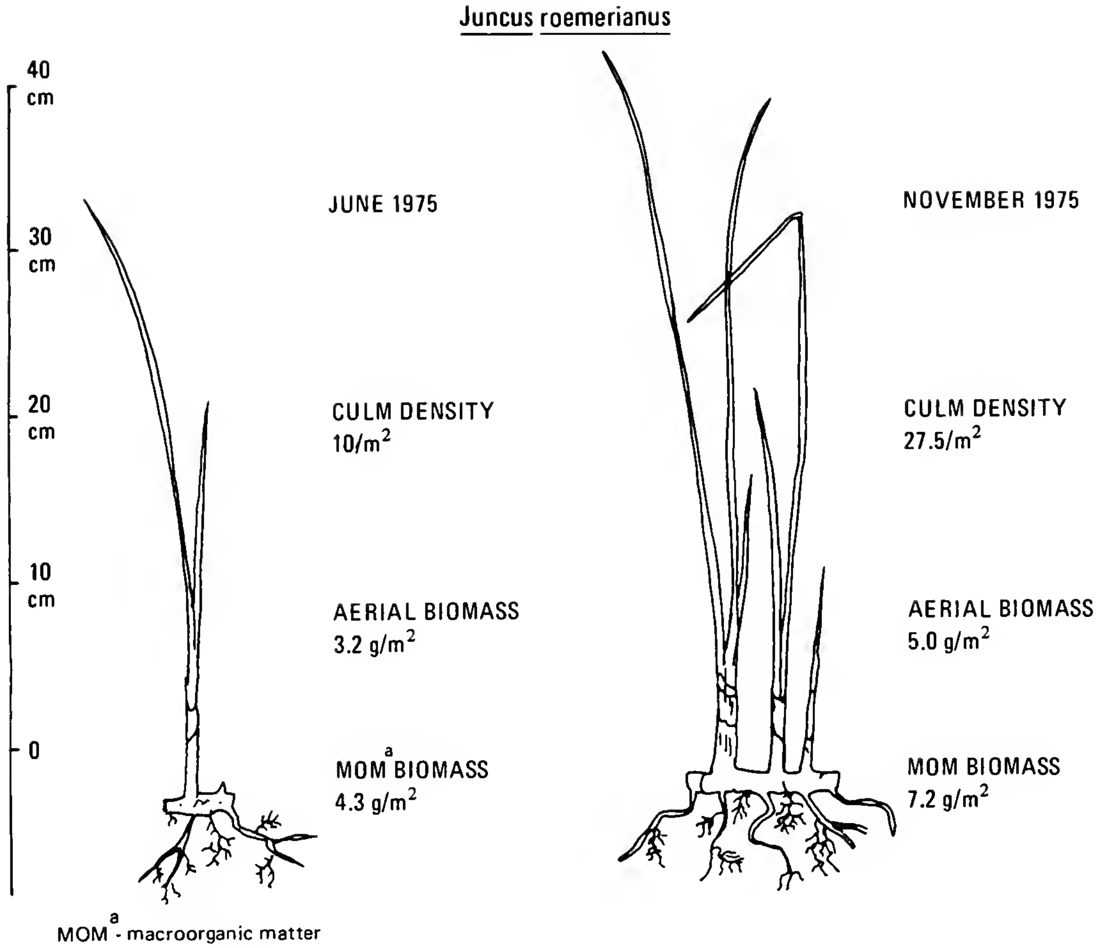

Figure 7. Comparison of Juncus roemerianus plant vigor between transplantation (June 1975) and destructive sampling (November 1975).

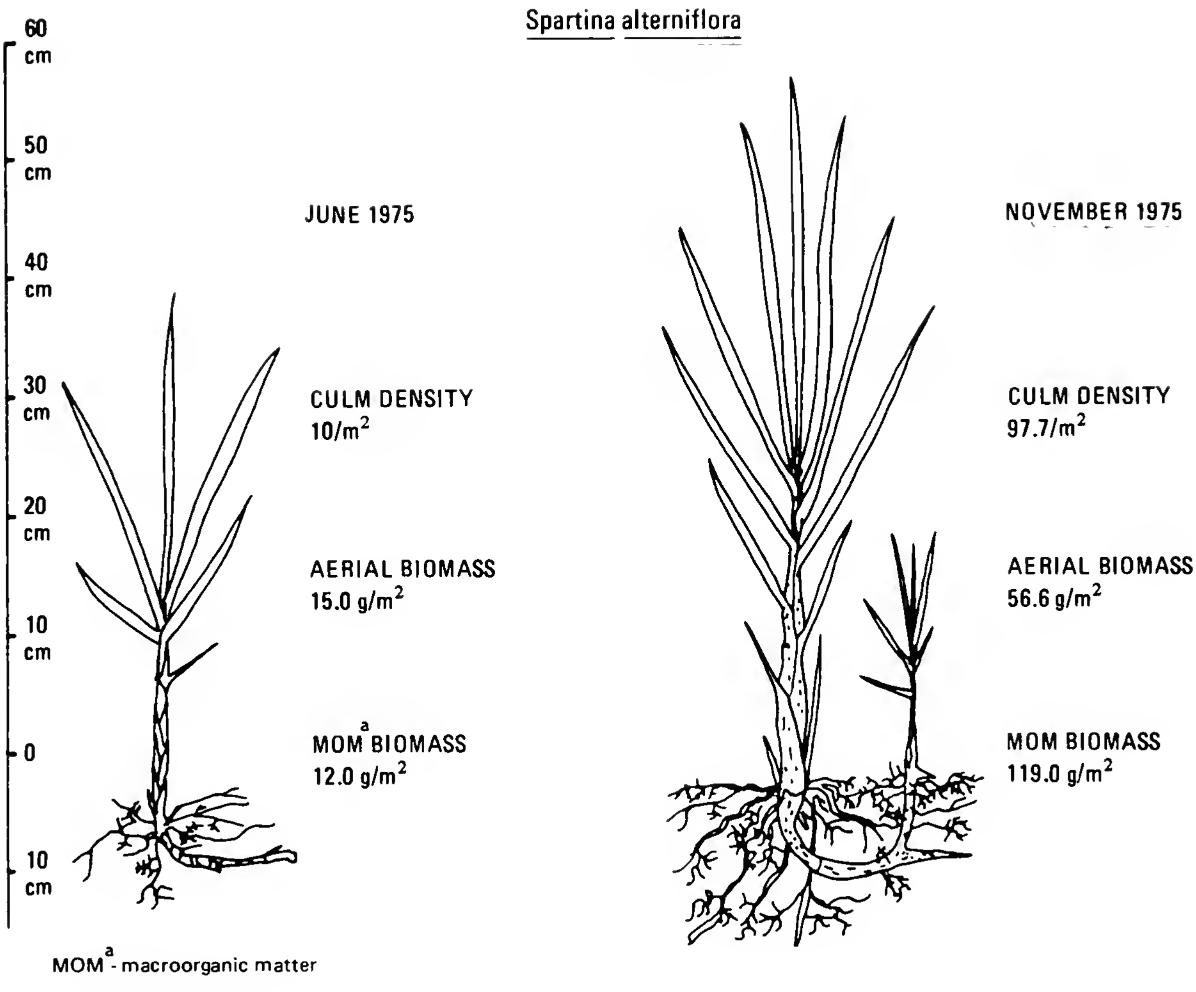

Figure 8. Comparison of Spartina alterniflora plant vigor between transplantation (June 1975) and destructive sampling (November 1975).

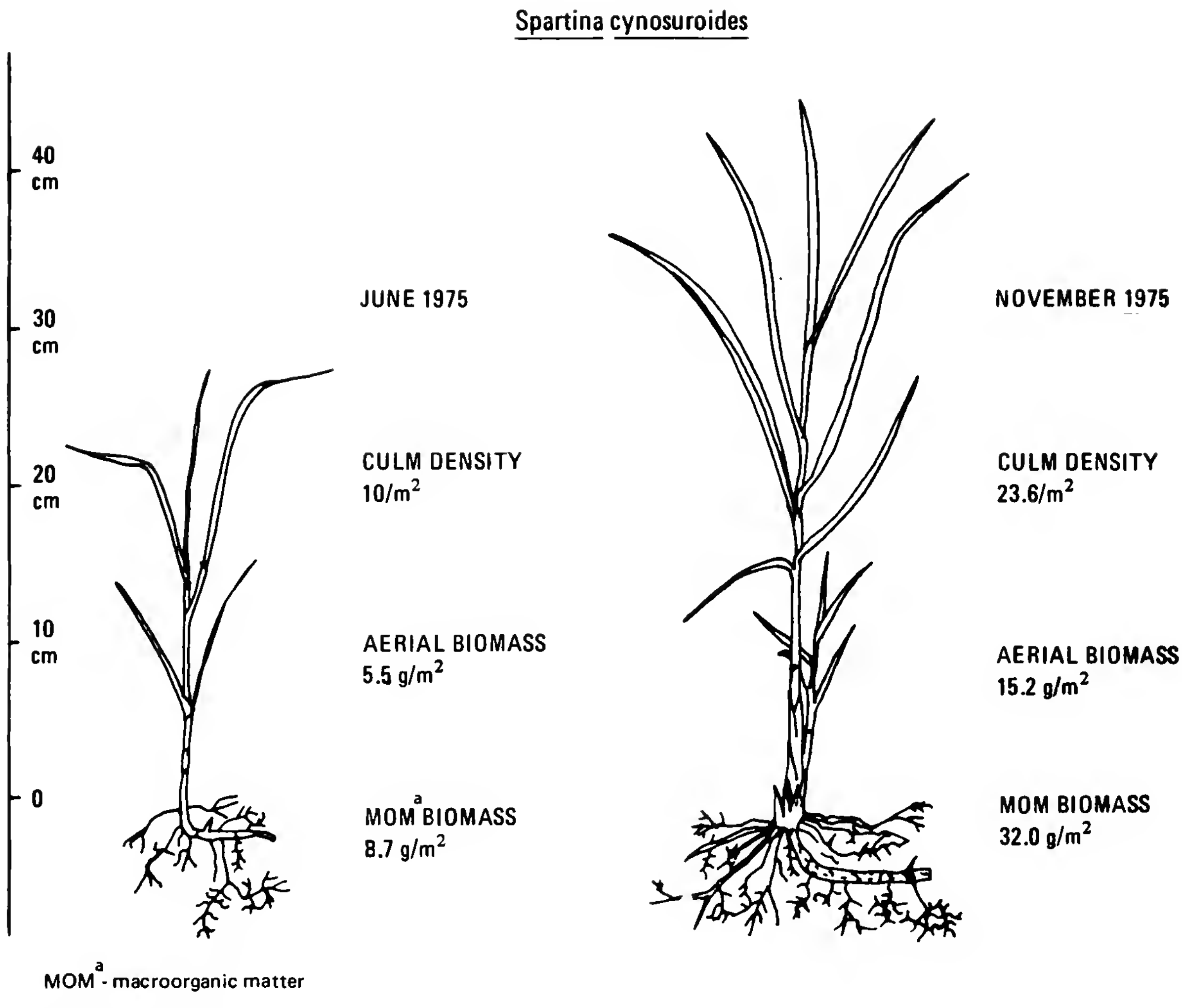

Figure 9. Comparison of Spartina cynosuroides plant vigor between transplantation (June 1975) and destructive sampling (November 1975).

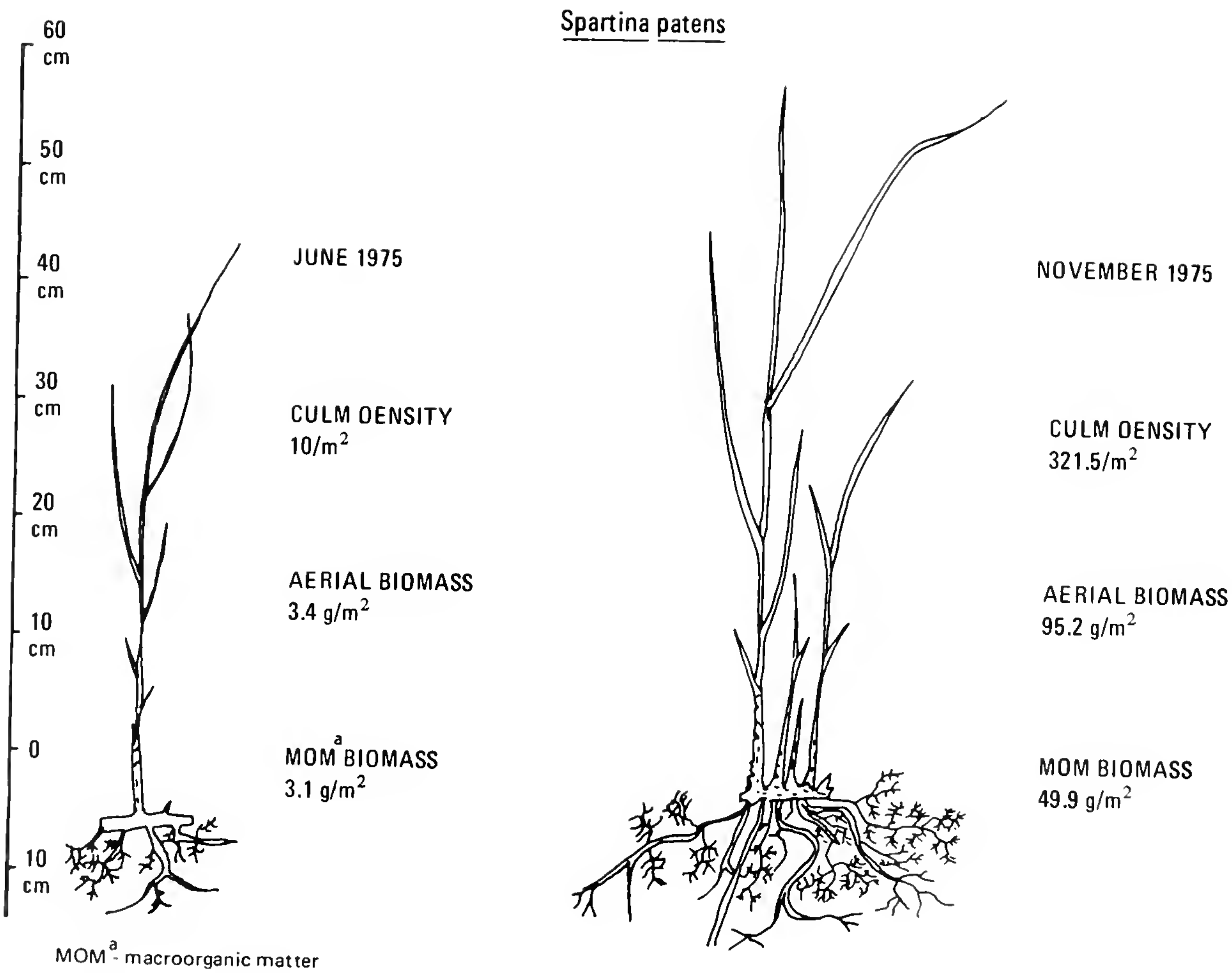

Figure 10. Comparison of Spartina patens plant vigor between transplantation (June 1975) and destructive sampling (November 1975).

TECHNIQUES FOR CREATING SALT MARSHES ALONG THE CALIFORNIA COAST

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Five or six researchers attempted to germinate Spartina on the West coast but could not find seed, and one of the investigators concluded that Spartina only reproduced vegetatively. Consequently, the U.S. Army Corps of Engineers requested that I plant a dredge spoil area and financed my efforts to learn how to propagate Spartina. I discovered a good key to locating Spartina seed. I looked for a patch that was infested with ergot because there had to be an embryo present before the ergot would become established. Our salt marshes are on mucky soils that are not consolidated uniformly over the whole area, so machinery could not be used. I believe machinery could be adapted to the mucky soils, but engineering facilities and continuity to the research resources were lacking.

A harvest technique that proved very satisfactory required a team of two men in a boat, one with a pole, and the other with a pair of hedge pruning shears. The man with the pole pushed the plant over the boat, and the other man snipped off the seed heads. In 2 days, we harvested enough seed to fill three 55-gal (208-liter) drums.

By accident I discovered how to store these seeds. I just looked at the situation and said, "Well, these drop into the water so they must require water"--and so we transferred them to gallon jars and put them in the refrigerator. After about a month, I decided to flush the seeds because they smelled bad. We took the seeds out every 2 or 3 weeks, flushed the old water out, and put in fresh water. Then I noticed that the seeds were germinating in the refrigerator about March. I examined the Salicornia seed that we had saved the same way and it was also germinating.

We tried many fertilizers and different methods of achieving germination. We discovered that there was some germination right in the spikes. Some of the seeds were bright green with the radical already showing on the seeds and these germinated immediately. There is a differential of germination that is characteristic of the seed. Some of the Spartina germinated immediately. A few weeks later a few more germinated and this continued until March when the rest came up. If all plants in arid regions germinated at once with the first rain, the history of vegetation would be one of extinction. I suspect that is also true with aquatic plants.

We also tried cuttings and based our efforts on the experience of people on the East coast. Some people say that our cordgrass is also S. alterniflora but we learned from experience that it makes no difference; the least important thing about a plant is its name. There is enough variation within a given species so that similar techniques do not quarantee success. We made cuttings from the rhizomes and fall buds and had good success with both. In the long run, it did not make much difference whether we used rhizomes or fall buds.

But our problems with salt marsh construction are of three types: (1) areas that were reclaimed in San Francisco Bay that had approximately 97% of the original salt marsh destroyed by diking; (2) some beautiful marshes outside of these dikes that have come in since the diking. We can learn a lot about the recovery of marshes by studying these areas; and (3) land that not much has happened to; it has only been used for grazing. In the latter case we can remove the dike and let nature take its course. But the first example is a very serious problem. I doubt if the marsh can be flooded immediately and be expected to revert to salt marsh. It will not do it! The salinity is too high; it will take a long time for the salt to be leached out. Some experimental work manipulating the soil will be needed. The Army Engineers would like to fill such marshes with dredge spoil. However, there is more than one dredge spoil problem in the San Francisco Bay area. I can show dredge spoil that was laid down in 1952; by 1973 it still was bare soil. It takes a long time before the salts in those soils will leach out and vegetation will grow.

There is another phase-actually planting dredge spoil. We learned that with time the spoil will consolidate and machinery can be taken in. First, we did everything by hand because we could not use machinery. We prepared a seed bed, fertilized some, and did not fertilize others. We used different kinds of fertilizers; and most interesting are the areas showing the best growth 3 yr after fertilization. We have not fertilized since then because we did not think it is necessary; the plants are doing fairly well. The first year they did not look very well, but the second year they were growing fairly well, and the third year I was amazed to see the results. Some of the single bud cuttings had 14 or 15 shoots coming up. However, it was very discouraging the first year. The plants stayed alive, but they did not grow much.

Our best luck was in the lower tidal areas. We got very good establishment beyond the area of the low-low tide and the high-low tide. We got a little established above that but not very conclusive results. These results alone suggest that we are dealing with a genetically different situation with the plants.

SALT MARSH CREATION IN THE PACIFIC NORTHWEST:

CRITERIA, PLANTING TECHNIQUES, AND COSTS

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INTRODUCTION

Wave Beach Grass Nursery contracted with the Corps of Engineers Waterways Experiment Station at Vicksburg, Mississippi, to provide a report of basic data collected through one growing season on pilot test planting of six species of vascular plants endemic to the area at Miller Sands. This island complex under tidal influence is located near River Kilometer 39 (River Mile 24) on the lower Columbia River, Oregon. This report outlines the progress of the pilot test from plant selection, collection, planting, and growing season from 21 June 1975 through 18 November 1975. Although my experience with marsh plantings is limited, I have worked with plant materials and in the erosion control field on the Pacific coast for 34 yr.

METHODS

The geographic location of Miller Sands is 9.7 km (6 mi) from Tongue Point on the eastern edge of the city of Astoria, Oregon. The test site was created in June 1974 by the Corps of Engineers' placement of 612,000 m^3 (800,000 yd^3) of dredged material. Particular size analysis shows basically sandy materials ranging from 2.8 to 3 mm (Oregon State University, 75 samples). The lower 9 m (30 ft) of the site is not of dredged materials, but contains long-term accumulated sediments of very fine silt and wood particles.

Plants were selected because of availability of uniform stock sufficient to plant both plots of the species. Plants were selected as near to the early growth stage as possible to avoid possible shock of excessive topping. Species selected for planting were Eleocharis palustris, Juncus balticus, Juncus effusus, Scirpus validus, Carex lyngbyei, and Deschampsia caespitosa.

Sites for plant collection were selected with the following factors in mind:

1. Quality and vigor of plants present on site;
2. State of growth, both top growth and root system;
3. Location in relation to distance from site;
4. Age of plant that would minimize the need for extensive cleaning;
5. Quantity of plant stock growing on site in order to avoid depletion problems;
6. Stands growing in sandy areas similar to the planting test plot.

The collection procedure was the same for all species. All plants were hand dug by shovel, and sand was cleaned from the roots by dipping them in water. The sprigging method was used because of the time factor resulting from the late-season start. All plants were topped to a uniform height before digging to provide surface integrity to the entire plot. Failure to observe this procedure may have resulted in tidal currents washing out areas extending above the general plant surface height and resulted in a progressive failure of the entire planting. The rhizome or root length was a personal judgment of what would constitute a transplant of sufficient size to allow for expected top growth recovery and new feeder root establishment. Lengths of the root cuttings were generally made with a section of rhizome containing from one to three culms or stems. Pruning of feeder root systems was not necessary.

Two methods of plant material storage were attempted, but one method was quickly discarded. The initial method was to heel-in prepared plants in sandy intertidal areas. However, the heeled-in plants, after one tide, were so firmly settled that it became a major job to redig them; and major damage occurred in the second removal operation. The second method was storage in plastic containers placed in the intertidal marsh areas that provided shade. Even more important was the twice-a-day covering of the plants by the tide, which prevented excessive drying.

All plants were planted either the same day or within 24 hr after digging, weather permitting. During storage trials, some plants were stored up to 5 days without any problems. The Corps of Engineers predetermined that plants were to be placed at an elevation ranging from +0.50 MLLW to +6.0 MLLW. Length of plots varied as did the number of plantings per plot. Because of even, flat terrain at the site and uniform sand material, no site preparation, such as plowing, disking, harrowing, or raking, was necessary. On an intertidal sandy site of this type, I believe any advanced agitation of the material would cause negative results when trying to firm the plant at time of planting. Also, tidal erosion could be increased and the sediment transport rate accelerated.

Fertilized and unfertilized plots followed the same layout design, planting depth, and plant height. Table 1 gives the spacing, planting depth, and culms per planting stock for species planted in this test.

The initial fertilizer selection for the pilot test was made with maximum root growth and minimum culm and leaf growth in mind. The fertilized plots all received a single hand broadcast application of Elephant brand 11-55-0 pelleted fertilizer at the rate of 100 kg/ha (90 lb/acre). Second year application should promote culm and leaf growth and reproduction. Ammonia-based fertilizers may cause severe problems with the lagoon fisheries. According to Ted Blahm, National Marine Fisheries Service, the entire lagoon, now highly productive, could suffer if this problem is not solved.

The possibilities of creating new or better marsh habitats are only a short time away. We are about 2 yr away from developing accurate cost figures for large scale plantings. This will depend on further results from research now underway on plant selection, fertilizer rates, density, and spacing. Equipment is now available that, with some modification, can be used for planting on upper elevations of the intertidal areas with conditions similar to Miller Sands. This equipment is capable of planting 180,000 plants per day during good weather. Cost per hectare will drop sharply with machine planting.

The future will see marsh establishment not only on existing spoils, but also on carefully selected maintenance dredging disposal sites. Island sites could be created as new feeding and nesting areas for wildlife to help replace those lost to shoreline development. Marsh creation could also be used as an environmental trade-off to help enhance waterfowl and fishery habitat of any wetland area.

Table 1. Spacing, planting depth, and mean number of culms per planting stock for species used in the study.

Species	Spacing (cm)	Planting depth (cm)	Culms per planting stock
Eleocharis palustris	50	8	3
Juncus balticus	50	8-10	8
Juncus effusus	50	10	7
Scirpus validus	50	10	3
Carex lyngbyei	50	10-13	3
Deschampsia caespitosa	50	10-13	7

SALT MARSH SOIL DEVELOPMENT

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Salt marsh creation may be considered to be basically a problem of developing salt marsh soils from marine sediments. First, it must be decided what a marsh soil is and how it develops. Second, must be determined what characteristics of the original sediment (i.e., dredged material) are especially important in enabling us to predict whether it might be easily transformed into a salt marsh soil. Third, the natural system to select plants which may facilitate the desired changes in the substrate must be examined.

The concept of soil depends on the viewpoint of the investigator. Since our concern is in creating coastal ecosystems and a major step is getting vegetation to grow on the substrates, our viewpoint is edaphical. Sediments from which natural marshes develop are tidally deposited resulting in rather uniform grain size fractionation. Dredging is the usual method of deposition of sediments for marshes created artifically on the coast. This technique leads to complex and variable parent material, making the establishment of proper conditions for plant growth difficult. Regardless of the method of deposition, the objective is to duplicate the natural anatomy of soil which takes the form of a profile changing with depth. Numerous soil formation processes (Table 1) interact to develop the anatomy which reflects both the parent material and the environment.

The original variable mixture of minerals will have organic matter added by plant, animal, and microbial activity (humification). In some cases, dredged material will already be rich in organic material. The amount of air and water in the soil will depend on sediment grain size, elevation relative to the tides, and soil structure. Depending on the salinity of the tidal water and frequency of inundation, salinization may be a major process in determining the final nature of the soil. Structure is often minimal in marsh soils because of sodium saturation of the cation exchange capacity. These puddled conditions reduce drainage, resulting in even more poorly drained soils than occur at similar nonsaline sites. Anaerobiosis in the waterlogged soils results in gleization.

Soils are classified by a method similar to the classification of plants and animals, (i.e., orders, suborders, great groups, subgroups, families, and series). From profile descriptions, the taxonomic position of the soil may be determined. Most marsh soils fall into one of two orders. Those which are primarily organic are Histosols. In the coastal areas where sulfates from seawater are reduced to sulfides, the soils are called Sulfihemists. The other order of soils represented in the marsh are the Entisols (recently formed mineral soils). Within that group, the Sulfaquents are common salt marsh soils. The description in Table 2 of the Capers Series is typical of many marsh soils along the southeast Atlantic coast of the U.S. Table 3 contains a description of a typical marsh soil from a sandy Georgia marsh. There is no "O" horizon of partially decayed organic matter in many southern marshes. The combination of tidal flushing and rapid litter turnover interacts to reduce organic matter accumulation in the most hydrologically active marshes.

An "O" horizon at the top is much more common in the northern latitudes, e.g., in Maine, and along the Pacific Northwest coast. These organic layers develop where decay is not as rapid as it is in the south. There is a series of other horizons, A, B, and C, which are basically mineral horizons. "B" horizons are not frequently seen in salt marsh soils. Usually in southern salt

Table 1. Some processes of soil formation.

Name	Process
Eluviation	- Movement of material out of a portion of a soil profile. Important in forming the "B" horizon.
Illuviation	- Movement of material into a portion of a profile.
Salinization	- The accumulation of soluble salts such as sulfates and chlorides of calcium, magnesium, sodium and potassium in salty (salic) horizons.
Alkalization	- The accumulation of sodium ions on the exchange sites in a soil.
Humification	- The transformation of raw organic material into humus.
Gleization	- The reduction of iron under anaerobic soil conditions, with the production of bluish to greenish gray matrix colors, with or without concretions of yellowish, brown or black concretions.
Podzolization	- The migration of aluminum, iron and organic matter from a horizon.
Laterization	- Movement of silica out of the horizon with accumulation of iron oxides.

Table 2. Description of Capers Series marsh soil from Chatham County, Georgia (described by R. W. Wilkes).

CAPERS SERIES

The Capers series is a member of fine, mixed, nonacid, thermic family of Typic Sulfaquents. These soils have very dark clay loam "A" horizons over dark gray and greenish gray clay "C" horizons. They are saturated continuously with saltwater.

Typifying Pedons:		Capers clay loam - idle. (Colors are for moist soil unless otherwise stated.)
A11 --	0- 8"	Very dark gray (10YR 3/1) clay loam; weak fine subangular blocky structure to massive; very sticky; many large pithy fibrous roots; common small clam shells on surface; neutral; gradual wavy boundary. (4 to 10 inches thick)
A12g --	8-19"	Very dark gray (10YR 3/1) and black (10YR 2/1) clay loam; massive; sticky; many large fibrous roots; neutral; clear waxy boundary. (10 to 20 inches thick)
C1g --	19-33"	Dark gray (10YR 4/1) clay; massive; sticky, when squeezed in the hand soil flows between the fingers with some difficulty; many fine roots; neutral; gradual wavy boundary. (8 to 16 inches thick)
C2g --	33-50"	Greenish gray (5GY 5/1) clay; massive; sticky, when squeezed in the hand soil flows between the fingers with some difficulty; few fine roots; mildly alkaline; gradual wavy boundary. (6 to 18 inches thick)
C3g --	50-60"	Greenish gray (5GY 5/1) silty clay; massive; sticky, when squeezed in the hand soil flows between the fingers with some difficulty; few fine roots; mildly alkaline.

Table 3. Description of the soil in a *Salicornia virginica* marsh.

Horizon depth (cm)	Color	Texture	Mottles	Structure & consistency	pH	Boundary	Remarks
A1 (0-7)	light brownish gray 2.5Y 6/2	fine sand	few fine prominent yellowish brown	single grained loose	7.3	gradual wavy	few small mostly line fibrous roots, N-value < 0.7
C1g (7-32)	light brownish gray 10YR 6/2	fine sand	common medium prominent brown 10YR 5/3 and medium faint light gray 10YR 7/1	single grained loose	7.4	gradual wavy	N-value < 0.7
C2g (32-80)	light gray 10YR 6/1	fine sand	few large prominent yellowish brown 10YR 5/6	single grained loose	7.6	clear wavy	N-value < 0.7
C3g	greenish gray 5GY 5/1	sandy clay loam	few small pockets pockets of gray (5Y 5/1) and dark gray (5Y 4/1) sandy loam and loamy sand	massive friable	8.7	-	few small dead fibrous roots, N-value < 0.7

marsh soil, the transition is from an "A" horizon, where the organic matter degraded into small particles and to humus, right into a "C" horizon, where the material has not been affected very much by processes of soil formation. In some sections of the country, the Soil Conservation Service is mapping salt marshes by soil types which will help characterize soils in local situations. If descriptions of the various soils that occur in your area are available, this can serve as a reference source to indicate how far along the process of soil formation is in a marsh. More complete discussions of soils in general may be found in Buol et al. (1973) and Brady (1974). Salt marsh soils are less thoroughly understood than upland soils, but a literature is developing (Cotnoir 1974; Coultas and Calhoun 1976; Gallagher et al., 1977; Coultas 1978).

The problems associated with the development of salt marsh soils from marine sediments are in one of five categories: stability, acidity, moisture, salinity, and nutrients. These can be considered separately, although it is clear they interact and depend to some degree on one another. Without stability the other factors do not matter. Salinity may reduce soil structure and decrease stability. Similarly, high moisture conditions may decrease stability by increasing the flow characteristics of the soil. Of concern is the ability of the material to be confined until such time that roots of the marsh plants can add to substrate stability. Through the Dredged Material Research Program, the U.S. Army Engineer Waterways Experiment Station in Vicksburg, Mississippi, has produced a large amount of literature about techniques for protecting dredged material from erosion and methods for stabilizing it.

A second problem is acidity. The Dutch recognized this problem in their acid meadow soils called Katterklei, referred to as "cat clays" in this country. The extreme acidity, which may be as low as pH 2, arises as the consequence of a series of reactions beginning with the accumulation of sulfides which are produced by the reduction of sulfates from seawater. The resulting iron polysulfides in the sediments cause no acidity problems until the sediments are exposed to oxygenated conditions where iron sulfate and sulfuric acid are formed. The acid yield depends on the ratio of iron to sulfur, as well as the total amount present. This cat clay situation arises in marsh creation sites where the sediment is placed high in the intertidal zone with the objective of producing a transitional zone marsh (the high marsh area which grades into upland). Effects of low pH on the plants may be direct or indirect through its influence on soil ion balance. Tied closely to the cat clay problem is that of soil moisture since the degree of waterlogging determines the oxygenation of the soils.

The soil moisture situation involves both the degree of saturation and the periodicity of various moisture regimes. The lower elevation salt marsh soils are usually near saturation much of the time. The anaerobic conditions, coupled with salinity, play a major role in the zonation seen in marshes. Much effort has been directed toward understanding the environmental factors involved in controlling the distribution of salt marsh plants over the last 75 yr. A brief discussion of zonation in wetlands can be found in Gallagher (1977).

Soil salinity is influenced by five factors. The first is the salinity of the estuarine water flooding the marsh. The second factor is elevation relative to the intertidal zone. Evapotranspiration from the marsh results in water loss and accumulation of salt. Low in the intertidal zone where flooding is frequent and soil water circulation relatively great, soil salinity is similar to that of the estuarine water. At higher elevations in the marsh where water circulation is reduced, salinities are increased. Near the marsh fringe, salinities again drop as the relative influence of rainfall to salt water increases. The third factor in determining the soil salinities is the environmental complex; temperature, pan evaporation, and rainfall all interact to influence water balance in the marsh. A fourth factor is soil texture. Coarser textured soils are generally more responsive to flushing by rainfall and tidal waters.

Finally, the species of plants may influence evapotranspiration through their productivity and water-use efficiency.

The last category associated with developing soils from marine sediments is the ability of the substrate to supply nutrients. Coarse sands will generally be lower in nutrients than finer textured substrates. Sandy marshes in North Carolina have been shown to respond to additions of N and P (see E.D. Seneca - "Techniques for Creating Salt Marshes along the East Coast" in another section of this proceedings). Similarly, marshes in Georgia (Gallagher 1975), Delaware (Sullivan and Daiber 1974), Massachusetts (Valiela and Teal 1974), and Oregon (Gallagher unpublished) have responded to nitrogen applications.

Given these soil problems, there are certain plants (occurring in the natural marsh) that have characteristics which may make them useful in facilitating certain desired changes in the substrate. These plants are generally not tested experimentally in artifically created marshes; nor has the plasticity of the characteristics to environmental conditions been evaluated. In the absence of such experimentally tested information, consideration of plant characteristics may help the manager to plan his research needs.

Sporobolus virginicus, *Distichlis spicata*, and *Salicornia virginica* are tolerant of a wide range of salinities. *Spartina patens* is adaptable to growth in the upper marsh and also in drier areas which might be found in the upper levels of dredged material deposits.

There are several recommendations for managers who are looking for plants of different rooting depths. The depth of roots may be important for stabilizing soils or for preventing roots from penetrating a soil zone which is inhospitable or may contain a contaminant that could be translocated to aerial food webs. The following recommendations are applicable to the southeast and to some extent to the mid-Atlantic States. *Salicornia* and *Sporobolus* are typically shallow rooted. High marsh *Spartina alterniflora*, *Distichlis spicata*, and *Spartina patens* grow to intermediate depths. Low marsh *Spartina alterniflora*, *Juncus roemerianus*, *J. gerardi*, and *Phragmites communis* grow fairly deep. If the goal is to increase soil leaching, *Distichlis spicata*, *Spartina patens*, and *Sporobolus virginicus* are good choices. These same species have high root: shoot ratios that favor quick stabilization.

If the plant characteristics are not known, an aluminum irrigation pipe corer can be used to sample root systems (Gallagher 1974). This information may help in selection of the proper plant to bring about the desired change in the substrate.

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SALT MARSH SUBSTRATE INTERACTION: MICROORGANISMS

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INTRODUCTION

Odum (1971) described several ideas of ecological succession, and a summary of those characteristics describing community development are presented in Table 1. The creation of a coastal ecosystem from dredged materials will begin with an orderly process in community development. The succession in the community will proceed from an unstable low biomass environment and eventually culminate in a stable high biomass ecosystem. In the early stages of community succession,the rate of primary production will generally exceed the rate of community respiration. However, as development proceeds, the ratio of primary production to community respiration will approach one. But, when production exceeds respiration, organic matter and biomass will accumulate in the ecosystem and the resulting production to biomass ratio will decrease.

As the ecosystem develops further, organisms will be linked together in a relatively simple linear food web. Primary production will initially support the microheterotrophs (bacteria, yeast, and protozoans) by supplying the necessary organic carbon, and the meiofauna and macrofauna will graze on the microheterotrophs. As the system matures, the food web will become more complex and the system will switch from a grazing food web to a detrital food web, typified by the marshes in Georgia. This brief review of ecosystem development emphasizes the flow of energy from the primary producers to the secondary producers. The goal of community development is to increase stability within the ecosystem and to achieve a large and diverse population of organisms. Understanding the succession of benthic community development and production rates of various populations in dredged materials will greatly increase our knowledge of coastal ecosystems.

In these proceedings several investigations have reported on the establishment of rooted aquatic plants within wetland areas and dredged materials. There have been only two reports about invasion and colonization of dredged materials (Garbisch et al. 1975; Cammen 1976b) by macrobenthos, and there has been no report that dealt with microbial development in dredged materials. The gap in the flow of energy between primary producers and macroinvertebrates requires investigation. In addition, there has been no report on the importance of microbial populations in higher plant establishment in dredged materials. Therefore, information on microbial development in dredged materials is desperately needed so that comprehensive guidelines can be formulated for coastal ecosystem habitat development.

METHODS

SAMPLING SITE

Microbial colonization in dredged materials planted with marsh plants was investigated at Buttermilk Sound, Georgia, and was supported by the U.S. Corps of Engineers, contract to Dr. Robert Reimold. Data were collected between January and September 1976.

AERIAL VIEW OF SITE

Buttermilk Sound Habitat Development Site (BSHDS) is shown in Figure 1. The dredged material (elevation 2.4 m or 8 ft)was graded on the eastern side of the island from mean low water (MLW) to mean high water (MHW). The site 5 mo later showed considerable deposition of sediment (clay and silt) and organic debris above MLW (Figure 2). Below MLW, sand waves were quite evident, indicating high energy water movement. The MLW zone was very unstable, and the movement of sand in the northern section of the

Table 1. Characteristics of community development.

Community variable	Ecological succession	
	Early stages	Late stages
Community energetics		
Primary production to community respiration	> 1	≃ 1
Production to standing crop biomass	Low	High
Food chain	Grazing	Detritus
Community structure		
Total organic matter	Small	Large
Species diversity	Low	High
Nutrient cycling		
Mineral cycle	Open	Closed
Homeostasis		
Stability	Poor	Good

Figure 1. Aerial photograph of the Buttermilk Sound Habitat Development Site (BSHDS) a few months after grading from mean low water to mean high water. BSHDS is center left of photograph and is located at eastern side of the Intercoastal Waterway (not shown).

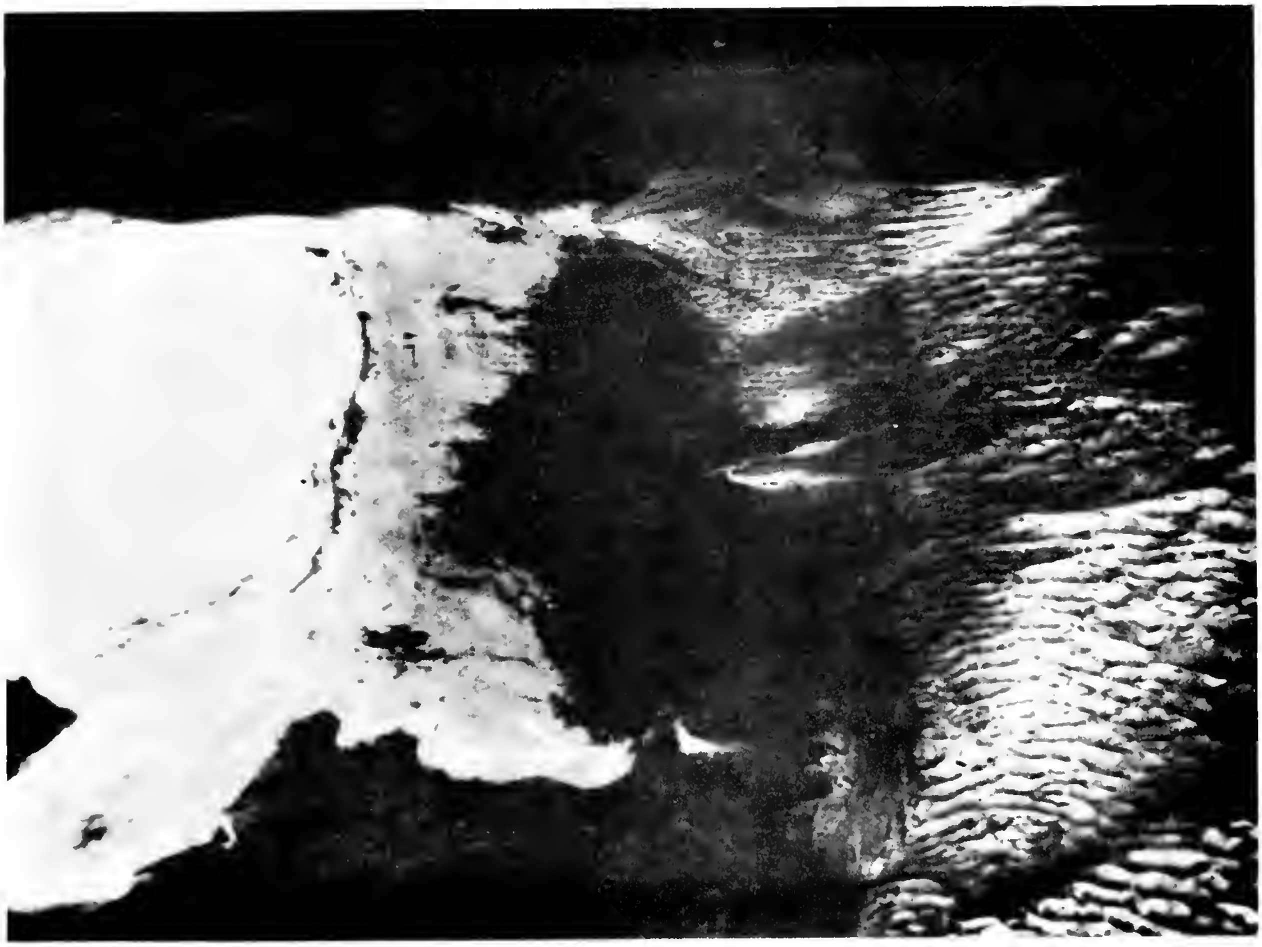

Figure 2. Aerial photograph of BSHDS approximately 5 months after the photograph shown in Figure 1. The very dark area, center right, is due to detritus build-up on the site. Sand waves are seen at the far right hand side of photograph.

site formed a sandy shoal in the Intercoastal Waterway. The site was divided into three replicate blocks covering the three tidal zones (upper, middle, and lower thirds). Within each block and tidal zone the blocks were further subdivided into 90 plots which were either planted with marsh plants, sprigs, or seeds, or fertilized with various amounts of organic or inorganic fertilizers. Each plot was bordered by a 0.5-m (1.6-ft) wide pathway for access to the plots (Figure 3).

For practical reasons, the microbiology was done on two planted areas, sprigged with either Spartina alterniflora (SA) or Spartina patens (SP), and a nonplanted (NP) area within each replicate-tidal block. The random location of SA, SP, and NP plots within each block is shown in Figure 4.

MICROBIAL BIOMASS

Adenosine triphosphate (ATP) standing stocks in planted and nonplanted plots were measured over time and at various depths (Bancroft et al. 1976). In addition, bacterial biomass was estimated by plate counts on Difco 2216 Marine Agar, and the plates were incubated aerobically and anerobically. Yeast biomass was estimated by planting on Sabouraud Dextrose Agar (2% NaCl). Benthic algae, diatoms, and protozoans were followed qualitatively (microscopically) by noting which genera were present.

RESULTS AND DISCUSSION

ATP BIOMASS

Seasonal variation of ATP biomass with depth in 27 plots (NP, SA, and SP) is shown in Figures 5, 6, and 7. From January to about July, the concentration of ATP increased in the surface stratum but ATP concentrations remained unchanged in the 5- to 7-cm and 10- to 12-cm (2- to 2.8-inch and 4- to 4.7-inch) strata. The decrease in ATP biomass with depth suggests that the carbon input is from the surface and the source of carbon may be from the detrital and algal carbon deposited on the surface.

Unfortunately, data are not available on microbial development at other dredged material sites. However, for comparison with other coastal systems, the ATP biomass found at Buttermilk Sound was 20 times lower than microbial biomass reported by R.L. Ferguson and M.B. Murdock working in subtidal estuarine sands in the Newport River estuary, North Carolina. Christian et al. (1975) working in the Spartina marshes contiguous to Sapelo Island, Georgia, reported microbial ATP biomass 50 times higher than the concentration measured at Buttermilk Sound. These differences are not surprising because the habitat at Buttermilk Sound is in its early stages of development.

The biomass may have had an effect on the initial establishment of marsh plants in dredged materials, but that hypothesis is unlikely when one considers the ATP biomass similarity in the NP, SP, and SA plots. The opposite is also possible, i.e., plant growth is not influencing microbial ATP biomass in the sediment, at least in the early stages of development.

Since there was no plant-microbial biomass correlation, and biomass was similar in planted and nonplanted plots, detritus deposition may be one of the most important factors in the carbon enrichment of coastal systems. Detritus is defined as silt and clay (abiogenic origin) and organic matter (biogenic origin). Thus, given suitable time, the course sands at Buttermilk Sound will be filled in with smaller particles which will hold a larger microbial flora. In addition, the detritus deposited on the site probably contained attached microorganisms. In the estuary, 80%-90% of the bacteria are attached to detrital particles larger than 14 micron and few are free in the water (Hanson and Wiebe 1977). Cammen (1976a), working with dredged materials near Drum Inlet, North Carolina, reported an accumulation of organic matter at an annual rate of 80 to 100 gC/m^2 for the top 13 cm (5 inches). Therefore, microbial biomass will be increasing with detrital build up at BSHDS.

BACTERIAL BIOMASS

The bacterial populations (aerobic and anaerobic) in dredged materials were

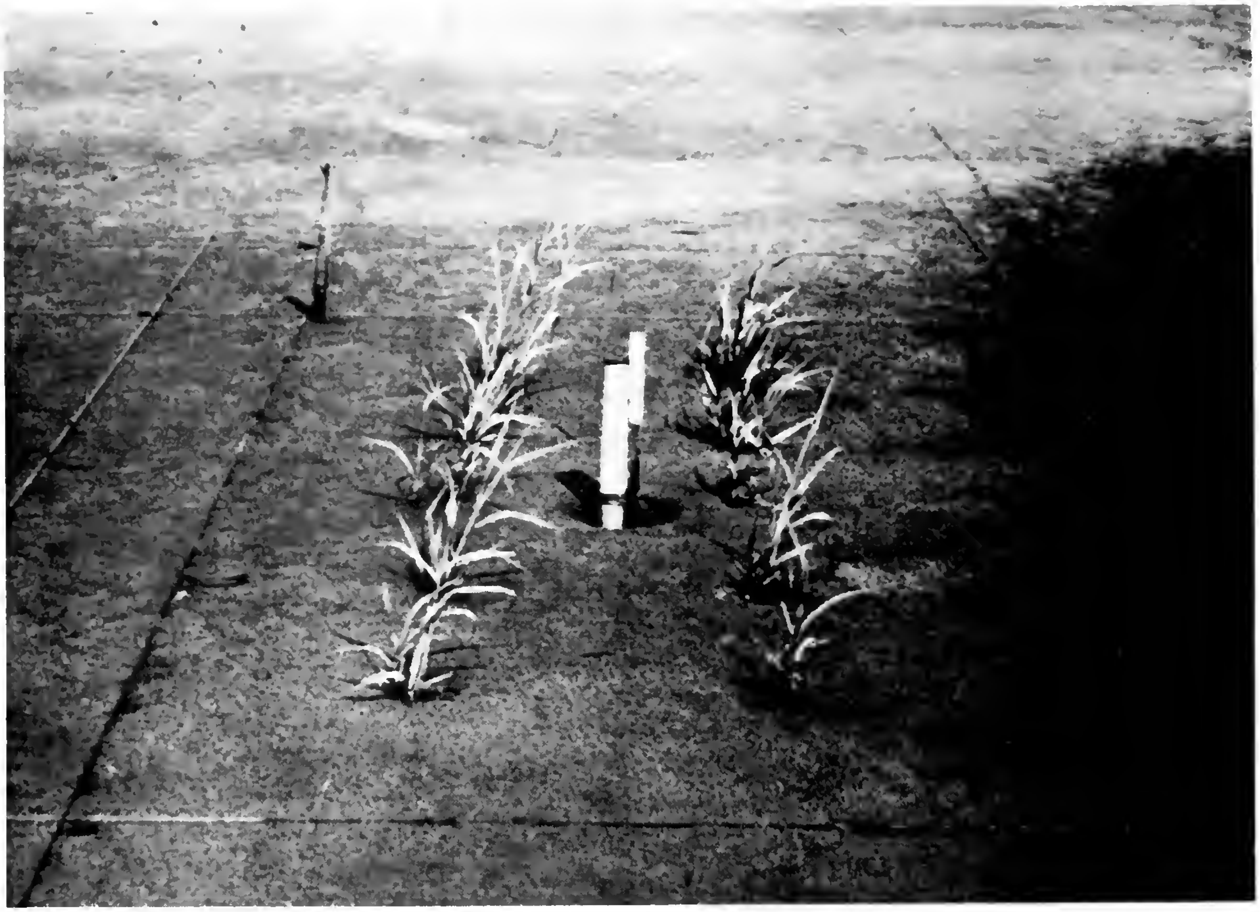

Figure 3. Close-up view of one plot sprigged with Spartina alterniflora. The dark foreground is due to detritus deposition. Interstitial water well is seen in the center of the plot. Each plot is spaced apart by a 0.5-m border.

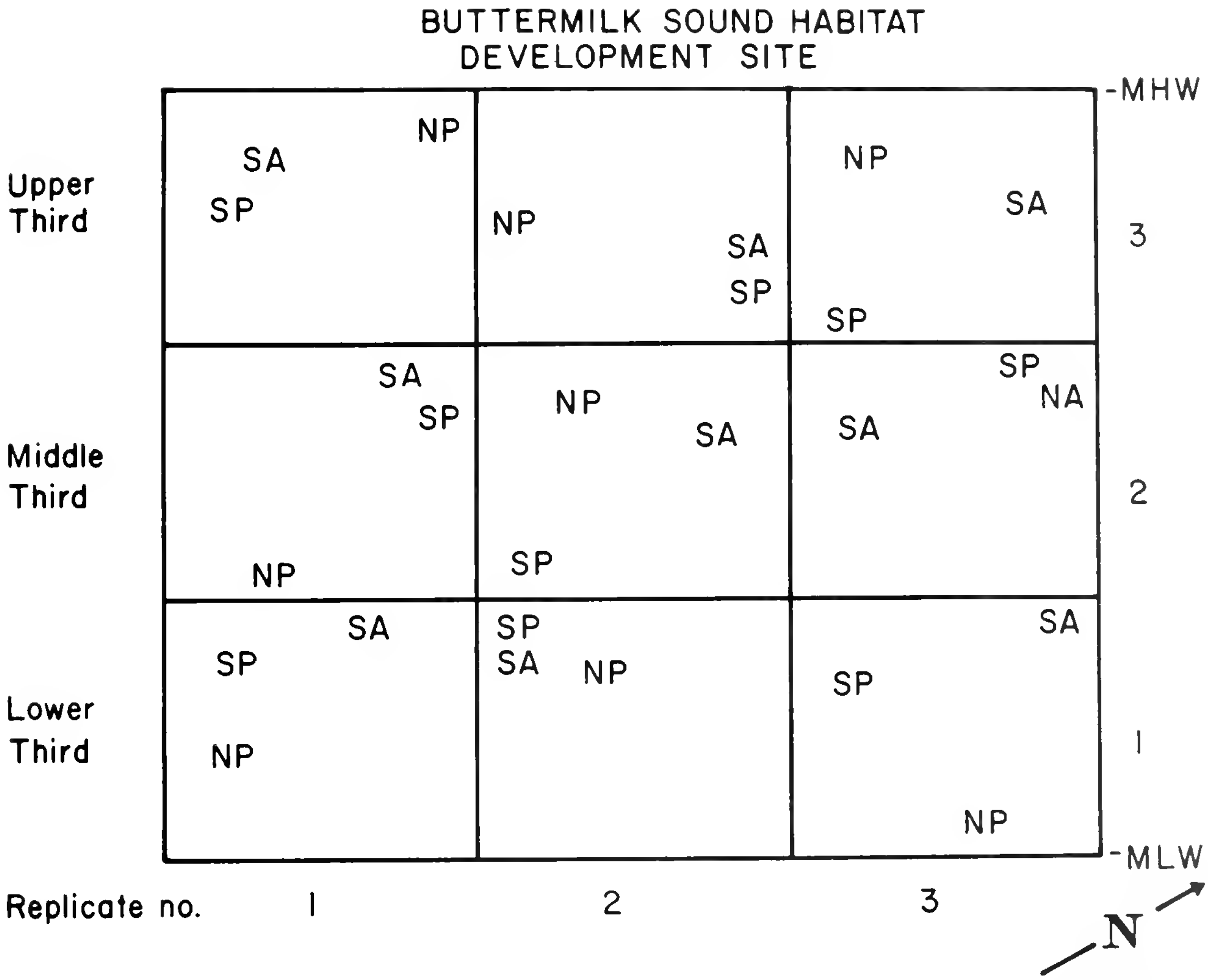

Figure 4. Diagrammatic location of the Spartina alterniflora (SA) and Spartina patens (SP) and nonplanted (NP) plots at BSHDS within each block and tidal zone.

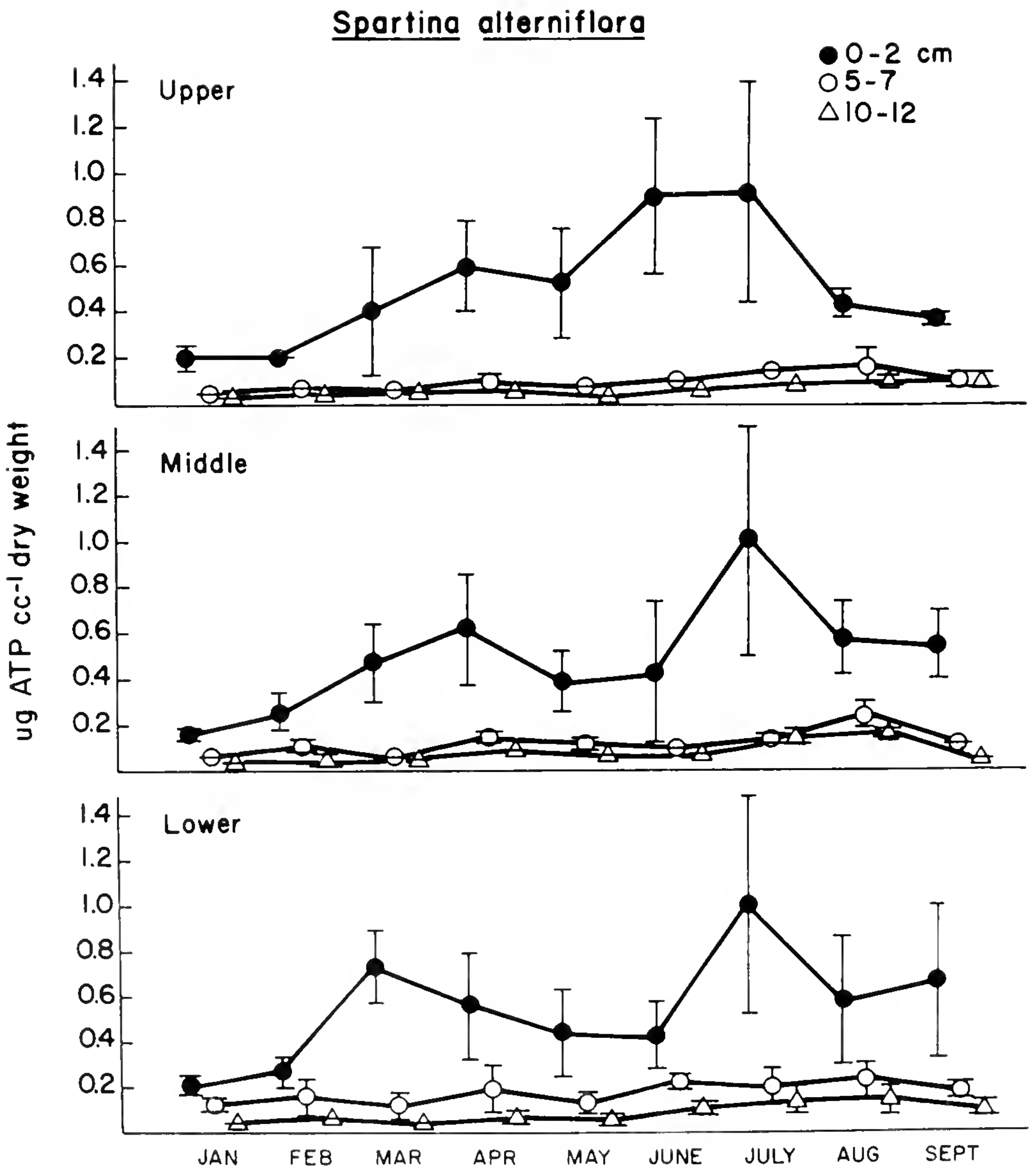

Figure 5. Microbial biomass (ATP) in the sprigged Spartina alterniflora plots in the uppe middle, and lower tidal zones. Seasonal ATP concentrations were measured at three depths: ●, 0-2 cm; ○, 5-7 cm; and △, 10-12 cm. The ATP values for each block within each tidal zone were pooled together and the mean ±SE plotted.

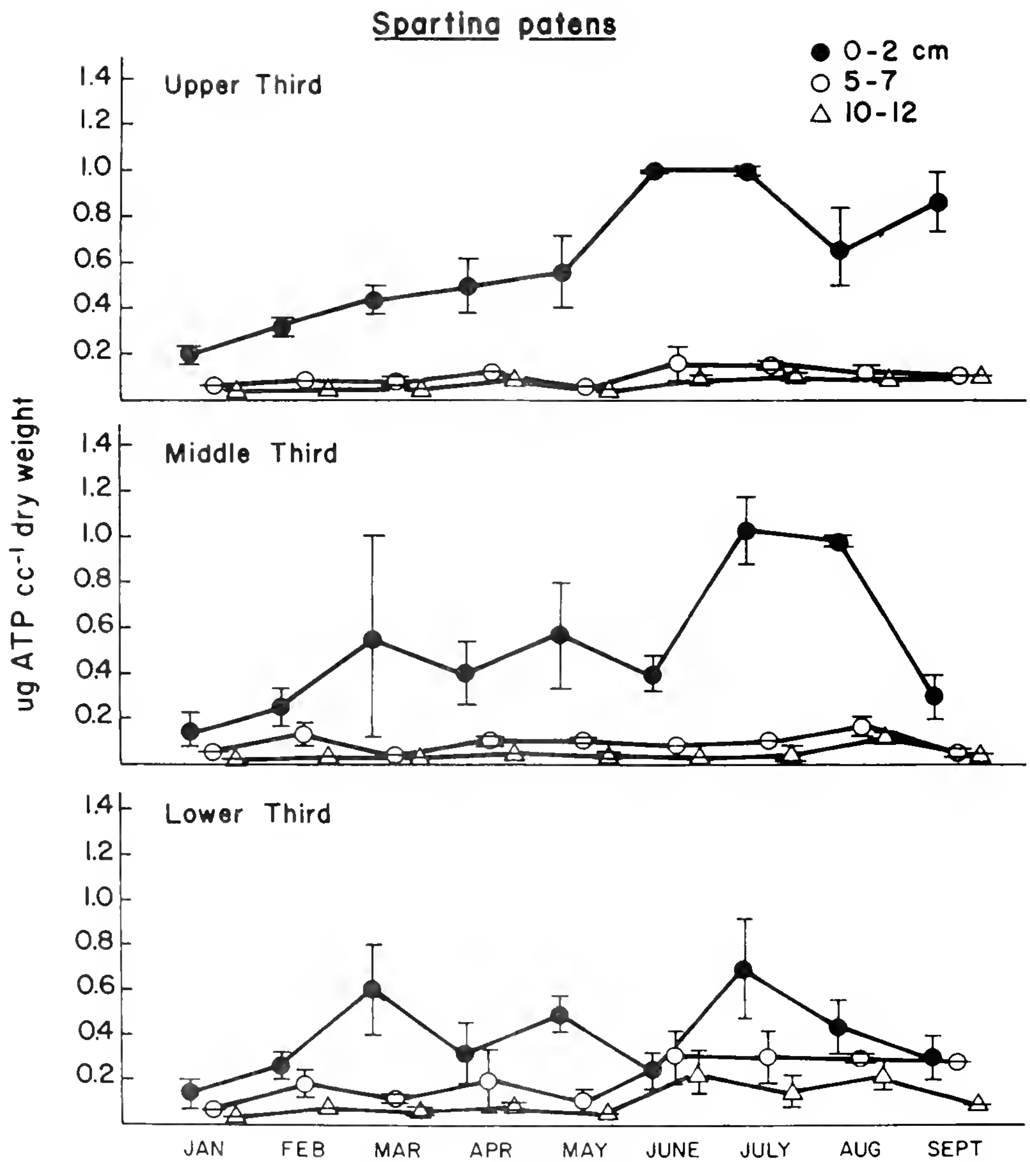

Figure 6. Microbial biomass (ATP) in the sprigged Spartina patens plots. See Figure 5 for details.

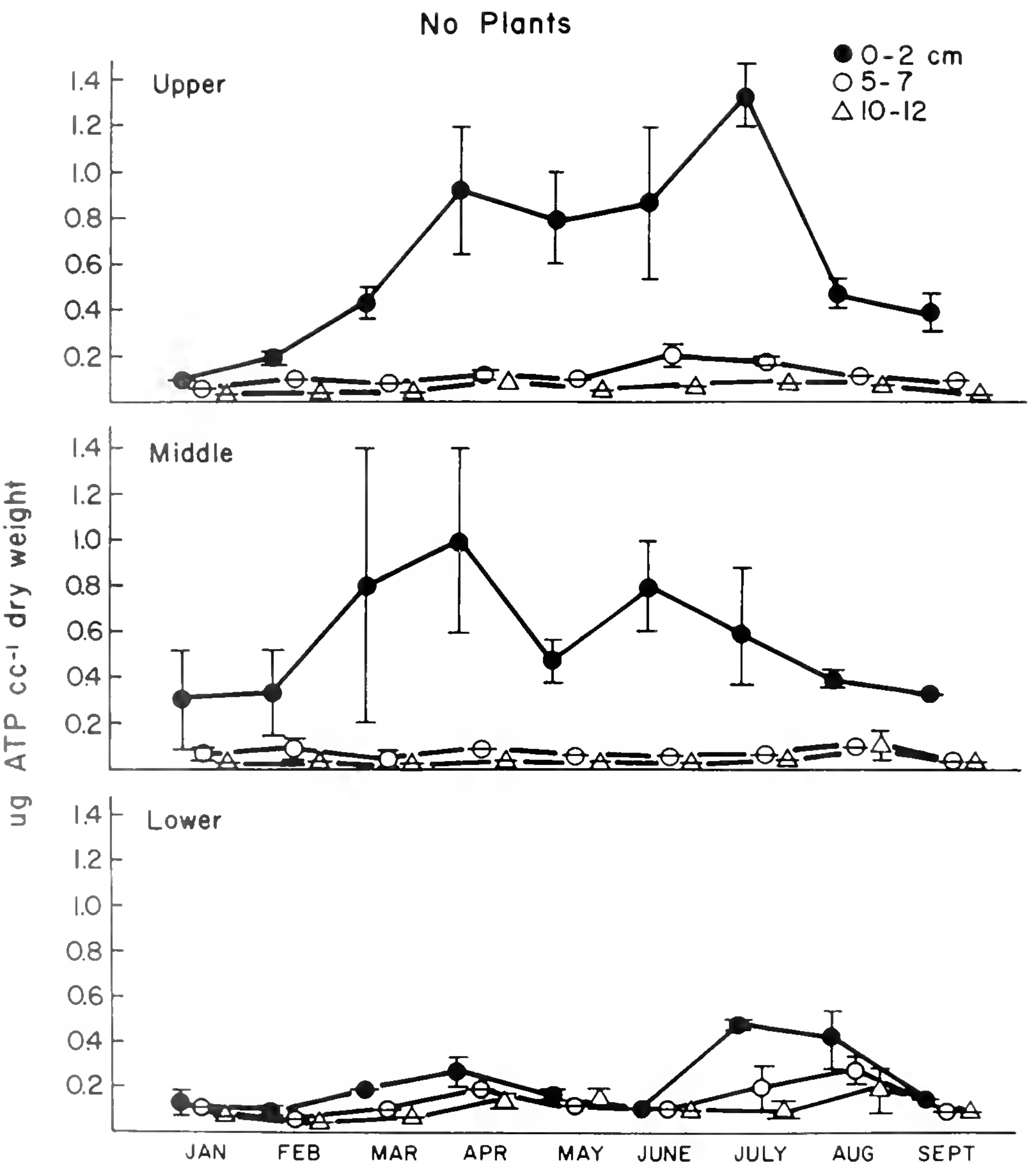

Figure 7. Microbial biomass (ATP) in nonplanted plots. See Figure 5 for details.

investigated over time in relation to the planted and nonplanted plots in the mid-tide zone. Figures 8, 9, and 10 show the bacterial populations between January and September for NP, SA, and SP plots at three depths. In the surface stratum, the bacterial populations were generally greater than 5 X 10^5 colony forming units (CFU) per gram dry weight. The populations were generally an order of magnitude lower in the substrata than in the surface stratum.

The dredged materials at Buttermilk Sound were essentially aerobic in January 1976. During the later part of the year, black iron sulphide zones were noticed in the substrata, and it was expected that the facultative anaerobic population would increase relative to the aerobic population. However, the data (Figures 8, 9, 10) indicate that there were no significant differences between the numbers of anaerobes and aerobes. Several reasons may account for the low anaerobic bacterial population. Methodology is the primary reason: (1) 2216 Marine Agar is a selective medium, preventing the expression of certain anaerobes; (2) sensitivity of strict anaerobes to O_2; and (3) essential vitamins and minerals required by fastidious anerobic bacteria were not provided in the medium. The procedure allowed only the expression of facultative heterotrophic anaerobes.

The relative numbers of aerobes and anaerobes in the dredged materials were an order of magnitude lower than the bacterial numbers in estuarine sediments from the North Inlet Estuary, South Carolina (Stevenson et al. 1972). Grain size has a tremendous influence on bacterial numbers in sediments and the medium to coarse sands at BSHDS may account for the low population density.

YEAST BIOMASS

The relative abundance of the yeast populations in the middle tidal zone was also investigated with respect to depth and time (Figure 11). The yeast population decreased with depth similar to bacterial populations and ATP concentrations. The yeast population was approximately an order of magnitude lower than the bacteria population.

ALGAL POPULATIONS

The diversity of the benthic algal community increased between January and September 1976 (Table 2). In January, approximately 7 genera of diatoms were observed whereas by September an additional 10 genera were observed at the BSHDS. The increase in ATP concentrations over time in the surface strata may in part be due to the colonization of these diatoms. Blue-green algae were occasionally found but were not dominant. Oscillatoria was the primary alga found on the sediment surface.

PROTOZOANS AND MEIOFAUNA POPULATIONS

Protozoans and meiofauna have been observed in most of the sediment studied. Qualitatively, the fauna were more abundant towards the end of the summer. Garbisch et al. (1975) and Cammen (1976b), working with dredged materials in Chesapeake Bay, reported an invasion of microinvertebrates. Such an invasion may be occurring at BSHDS, but the impact on the microbial flora is unknown.

SIMPLE BOX MODEL FOR BSHDS

A conceptualized view on the flow of carbon (energy) in the system is shown in Figure 12. Bacteria, yeast, algae, and meiofauna are the major biological components in the heterotrophic compartment. Most of the heterotrophic energy is obtained via the autotrophs (marsh plants and algae) either as particulate organic carbon or dissolved organic carbon. Tides support some of the energy requirement of the heterotrophs and enhance the overall productivity of the coastal ecosystem with the deposition of detritus.

In addition to tidal deposition of detritus, tides seed the habitat with living organisms. In return they enhance the flow of energy through the system. Microbes and macrobes are well known as decomposers and nutrient regenerators in aquatic systems and probably are more important in supplying nutrients to the macrophytes than are rivers and oceanic water of Georgia. Some preliminary studies in Georgia marshes indicate that most of the annual Spartina production

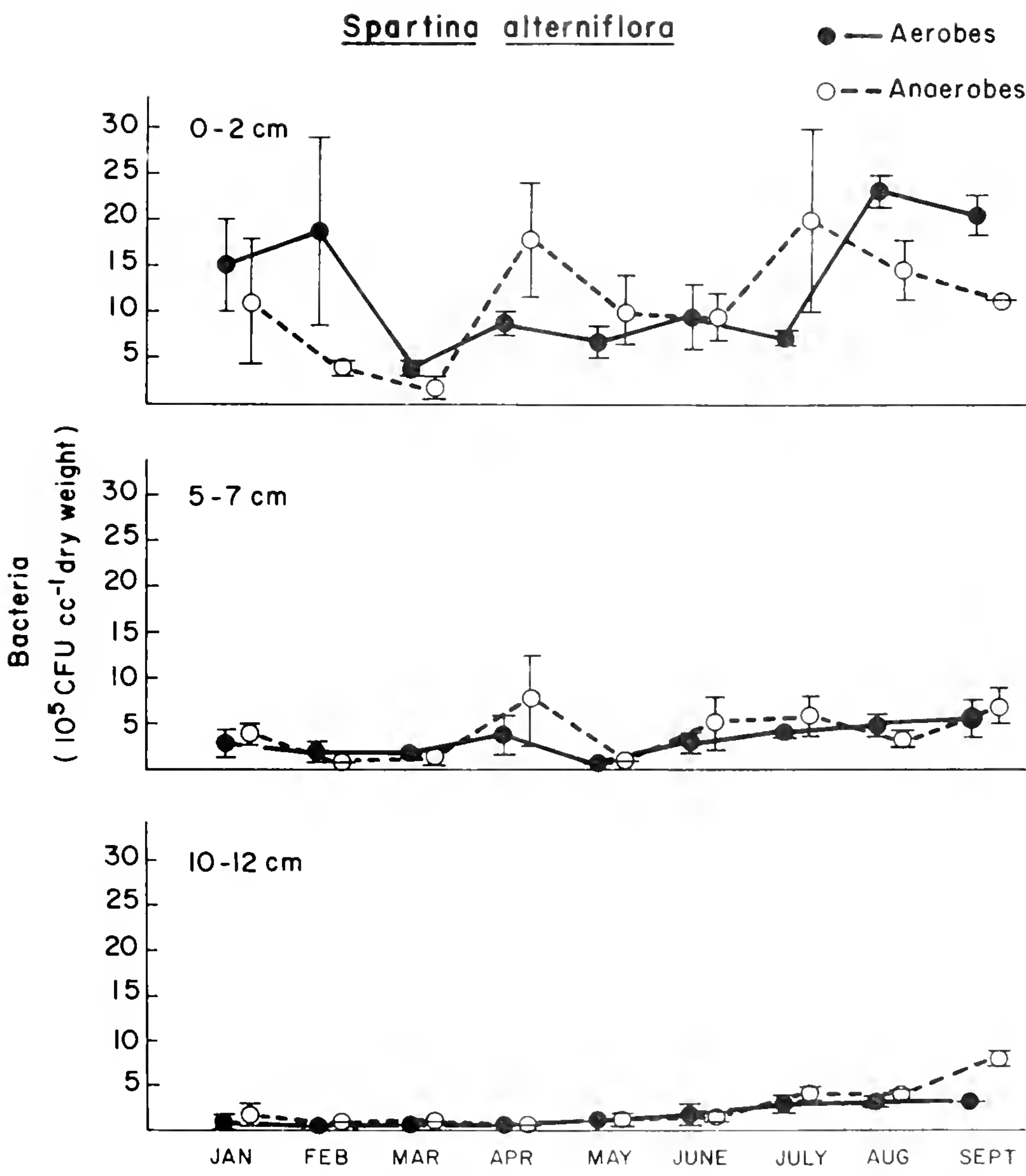

Figure 8. Bacterial biomass (colony forming units, CFU) in Spartina alterniflora plots in the middle tidal zone at depths (0-2, 5-7, and 10-12 cm). Aerobic and anaerobic CFU for each block were pooled and the mean ±SE plotted. Aerobes, ●—● and anaerobes, ○-○.

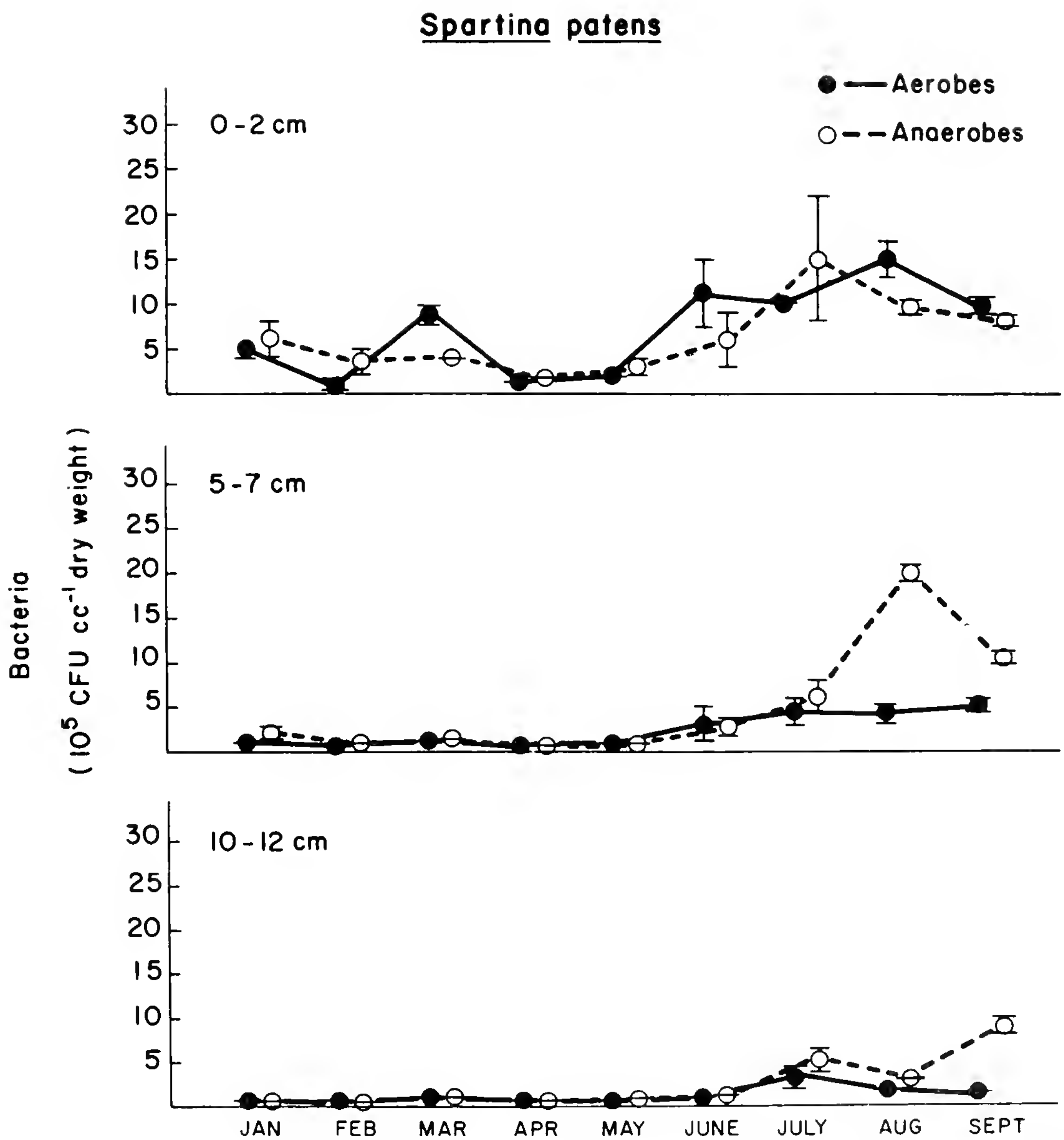

Figure 9. Bacterial biomass (CFU) in Spartina patens plots in the middle tidal zone. See Figure 8 for details.

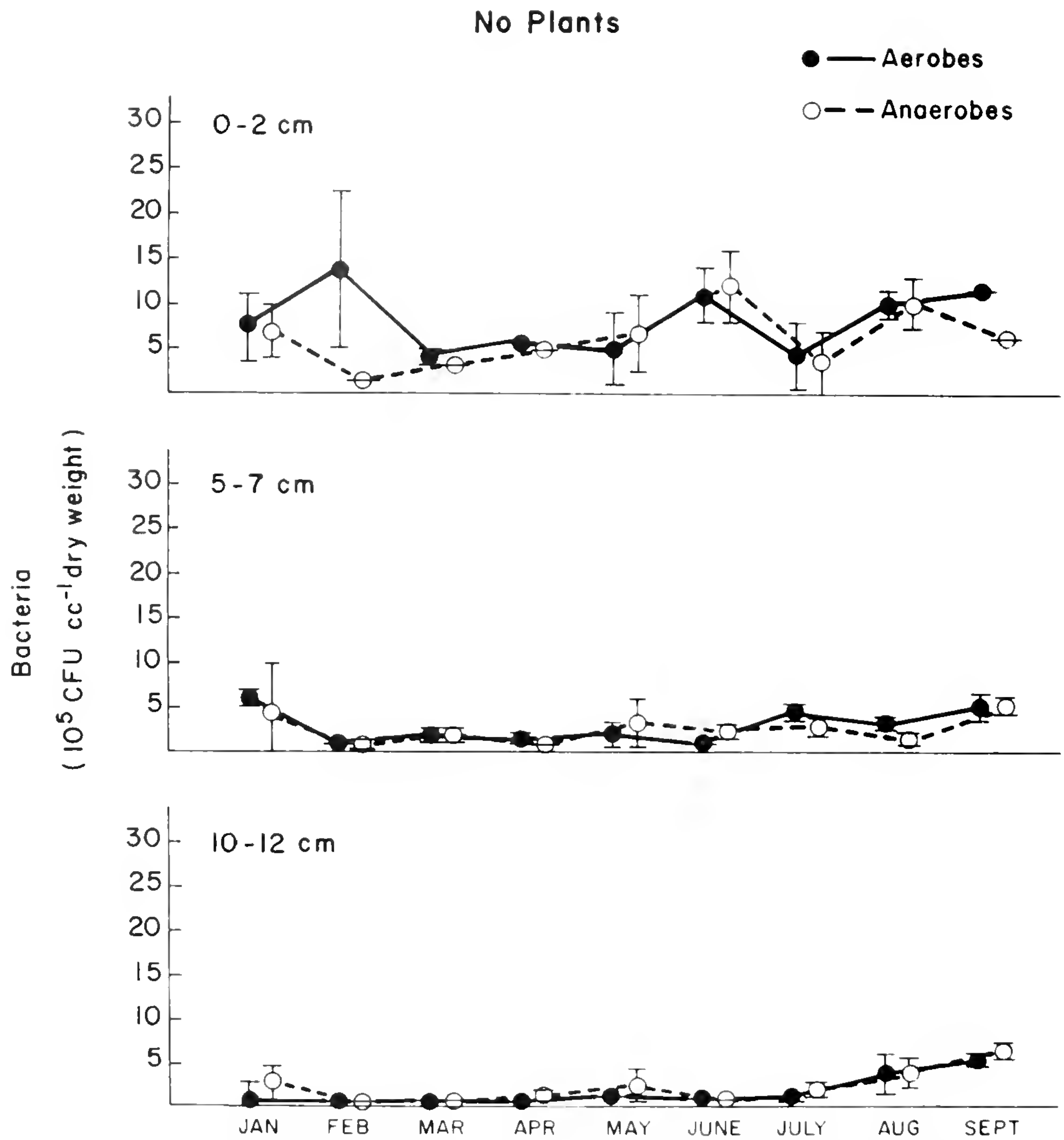

Figure 10. Bacterial biomass (CFU) in nonplanted plots in the middle tidal zone. See Figure 8 for details.

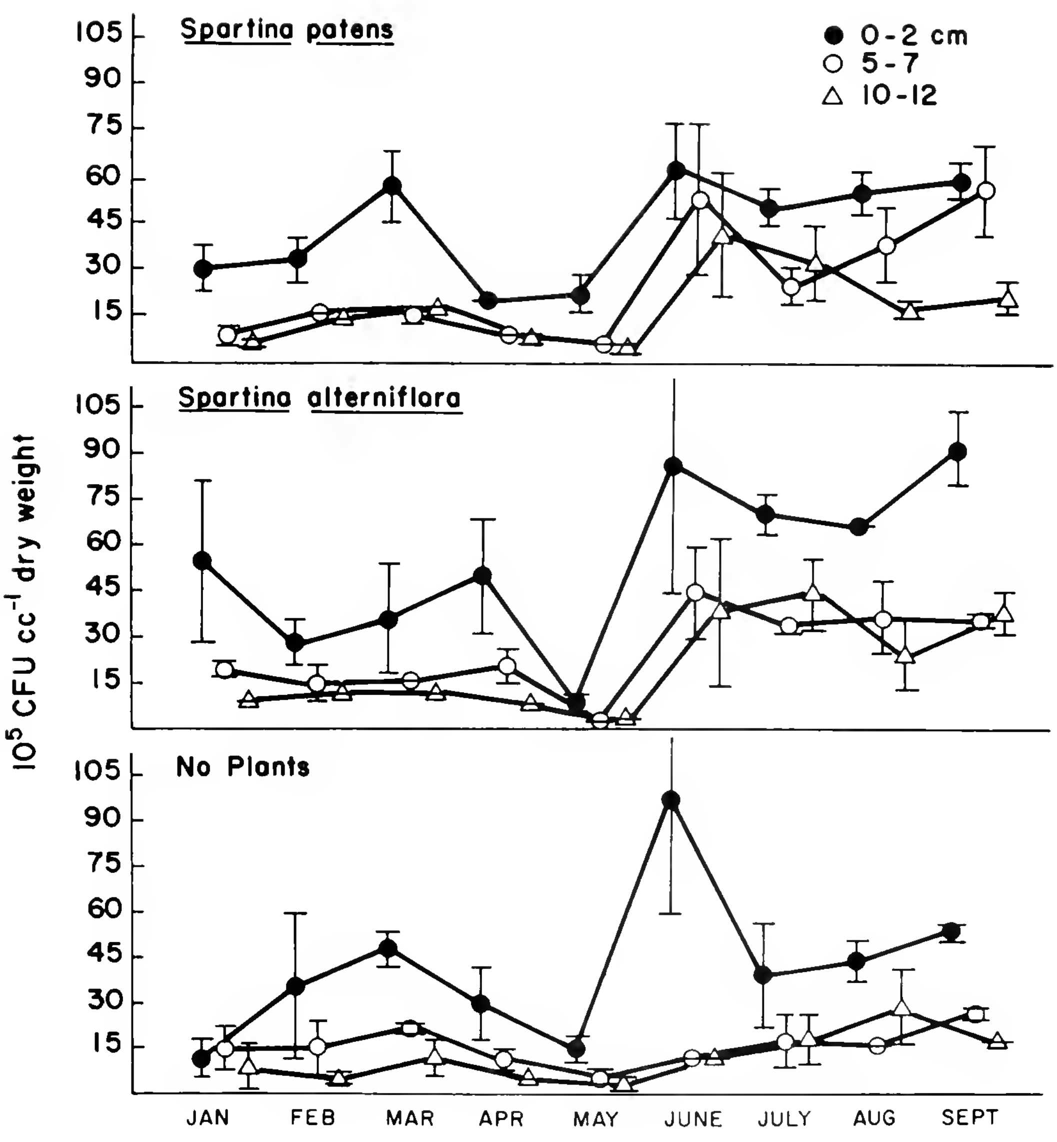

Figure 11. Yeast biomass (CFU) in Spartina alterniflora, Spartina patens, and nonplanted plots in the middle tidal zone at three depths: ●, 0-2 cm; ○, 5-7 cm; and △, 10-12 cm. CFU's for each block were pooled and the mean ±SE plotted.

Table 2. List of diatoms observed at Buttermilk Sound habitat development site.

Genera present	Month	
	January[a]	September
Navicula	+	+
Pleurosigma	+	+
Amphipleura	+	+
Epithemia	+	+
Meloseia	+	+
Fragilaria	+	+
Cyclotella	+	+
Mastogolia	-	+
Nitzchia	-	+
Denticula	-	+
Eunotia	-	+
Frustulia	-	+
Chaetocerous	-	+
Cocconeis	-	+
Amorpha	-	+
Achanthes	-	+
Coscinodiscus	-	+

a + = present; - = absent

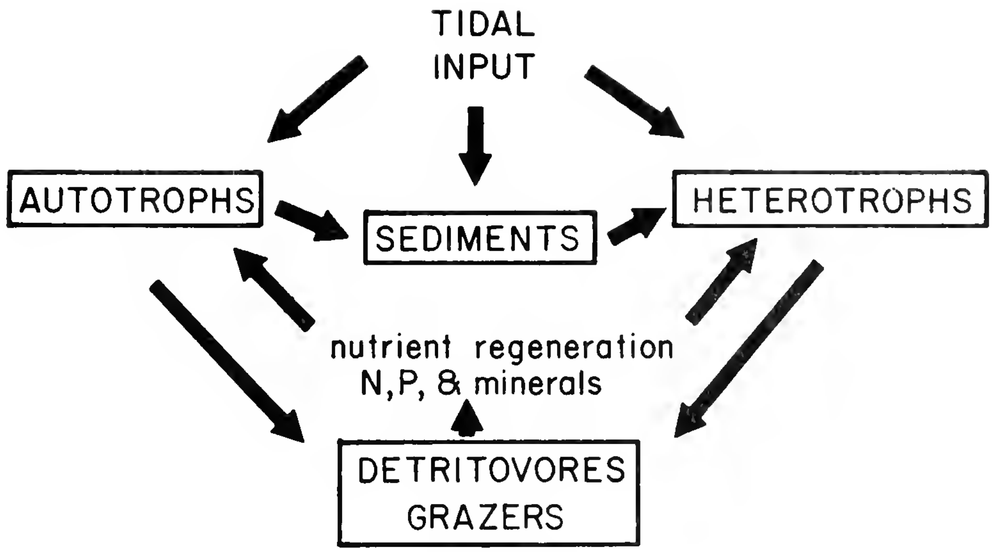

Figure 12. Schematic representation of carbon and nutrient cycling in connection with coastal ecosystem development of dredged materials.

is supported by nutrient recycling in the marsh (Haines et al. 1975; Chalmers et al. 1976). Therefore, based on the information available, nutrient regeneration by microbenthos and macrobenthos and tidal input of particulate organic carbon (detritus) play an essential role in coastal ecosystem development.

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DETERIORATION OF MARSH IN SAN FRANCISCO BAY

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I was asked to discuss deterioration of ecosystems. This puzzles me because I have been rather critical of the notion of the ecosystem all my life. System belongs to mathematics and logic, not to biology. You never will find a pure example of the ecosystem because nature is so variable. You will find a pattern around which your data will vary. However, the data is correlated with the system; it is not the system.

I have just been dealing with a problem of the deterioration of an ecosystem, the delta system of the San Joaquin and Sacramento rivers as they flow into San Francisco Bay and join a group of marshes. I discovered the dominant effect of plundering one resource and what happens to it. The primary natural resource in the marsh is its capacity to act as a living filter that maintains the water quality of the system. There were 777 to 1,036 km^2 (300 to 400 mi^2) of delta marshes at the mouths of the San Joaquin and Sacramento Rivers. Someone discovered there was land under those marshes that was worth cultivating, so he drained the area and got it out into the open.

The first loss was the natural filter that maintained the water quality of the San Francisco Bay. The second loss was the fisheries of San Francisco Bay. The loss of marshes included the salt marshes of San Francisco Bay, and the total destruction was between 95% and 97% of the marsh area. The area was diked, the remaining water pumped off, and the land left to dry out. So we lost the filter system. I do not know how you could evaluate that in terms of dollars but it was an enormous thing. Now there are no commercial fisheries in San Francisco Bay. This change did not occur instantly; the last fishery to go was a tiny shrimp with a very nice flavor. Oyster and shrimp fisheries, crabs, and practically everything else disappeared because the impurities that came into San Francisco Bay were no longer going through a natural filter.

The next loss was when the marsh lands were exposed to the hot, dry California air: the peat began to shrink and it began to settle because of farm equipment on it and the annual plowing that broke up the soil. Plowing pulverized the surface and it began to blow away. A related problem was the tectonic settling of land: the lowering of the entire west coast 10.7 m (35 ft) in 10,000 yr. Land which was at tidal level is now 6.4 m (21 ft) below sea level. So the farmers lost the investment they had put in the land. When the dikes broke, the farmer said, "I can not afford to repair the dike because the land is not worth it." He lost his land and the State lost the land's agricultural potential. The total loss involves an enormous amount of money.

Thus, man destroyed a whole series of natural resource values that were very important to us and resulted in the deterioration of a gigantic ecosystem which includes human beings. Not only did drainage of the delta marshes affect the San Francisco Bay, but the fisheries along the coast of central California also never recovered from that loss. I suspect that if someone knew all the facts, the losses would be traceable to the decline in quality of water that came into San Francisco Bay as a consequence of losing the extensive marsh system.

Last week the Bureau of Water Quality control voted to allow the lowering of the quality of water that is permitted to enter Susson marsh because there is not enough fresh water to supply the needs of Los Angeles. Therefore, Susson marsh will suffer. Susson marsh is important to the ecosystem because it has about 140 plant species whereas the bay salt marshes have only 9 or 10 species. No two plants of a given kind have exactly the same range of tolerance for everything in the environment. The range of tolerance for the species is greater than the range of tolerance for any one individual. Man is destroying over one-half of the system by changing Susson to a salt marsh because he is doing away with the enormous diversity in the filtering capacity of the system. People did not know what they were doing when they decided to take more freshwater from Susson marsh. Soon it will mainly be a saltwater marsh.

It has been said that no culture that is dependent upon irrigation has ever survived. The Inca culture disappeared. You can still find the abandoned agricultural terraces. The Inca culture died out as a consequence of salination of the soils. The same thing happened to the cradle of agriculture in the Middle East. The soils became salty when water evaporated and left dissolved salts on the soil surface. The same happened in Greece--irrigated soils became too saline to grow crops.

The Bureau of Reclamation (BR) has done some brilliant research on this problem and they may have resolved the problem with a system of natural filters that are combined with artificial filters. BR drains the agricultural water through the soil and they claim that picks up most of the pesticides. They say they have never found more than a trace of pesticides after the water goes through the soil. Pipes under the soil pick up the wastewater and it is drained through an anaerobic filter. The process is going to be costly because they need to continually feed the anaerobic filter with a carbon salt source. They are going to have to add dried plant material for the anaerobic organisms to feed on as they take up the salts that they require. BR expects to build a long system of marshes where they hope to keep this water zigzagging back and forth to get the greatest mileage out of the marsh system and to get rid of enough dissolved solids so that the water can be returned to the bay. But the big problem is eliminating the salination of soils in arid regions. We know actually very little about natural filters.

SAND DUNE HABITAT CREATION ON THE PACIFIC COAST

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Initial stabilization of sand dune areas should be done by planting European beach grass (Ammophila arenaria).

Clean plants by shaking sand and silt from the roots. Remove stalks and trash from the culms. Break off the underground stems so that one or two nodes remain. Sort grass culms and tie them into bundles weighing approximately 4.5 kg (10 lb). Cut the tops so that the overall length of the planting stock is about 50 cm (20 inches).

Plant in hills with at least three live culms per hill and a spacing between hills of about 46 cm (18 inches). Plant the grass to a depth of 30 cm (12 inches), cover with sand or silt, and compact the soil to exclude air from the roots (nodes). The top of the plant should extend approximately 20 cm (8 inches) above the ground. Do not plant on any area until the moisture is within 8 cm (3 inches) of the ground surface. Do not plant when the temperature exceeds 16° C (61° F) or when freezing conditions prevail.

Fertilize plantings with ammonium sulfate commercial fertilizer (Elephant brand or equal) at the rate of 45 kg/ha 40 lb/acre) of available nitrogen. Apply the fertilizer on a calm day and during a season when rain can be expected periodically (irrigation may be substituted for rain).

The planting stock should be planted within 8 hr after removal from the nursery areas or heeling-in beds. The heeling-in beds should be well-drained damp trenches with the roots (nodes) covered with at least 23 cm (9 inches) of soil. Stock should not be kept in heeling-in beds longer than 2 weeks. Before they are planted at the planting site, the plants must be kept in a cool, shady place or otherwise protected against damage from excessive drying.

The planting stock may be handled and transported by any method that does not damage the planting stock or the area to be planted. Continual maintenance is required on beachgrass for about the first 2 yr; after that, only periodic maintenance is required. When large blowout or blowover areas develop, the most effective maintenance procedure is to replant with beachgrass and then spread brush on the steep edges. Refertilizing all weak areas seems to bring back a sufficient cover,if the plant root systems have not been uncovered.

Secondary or permanent stabilization in uplands or border plantings associated with a deflation plain usually is accomplished by one of two methods. In most areas, the beach grass plantings are 2 yr old, when follow-up plantings of 1-0 Cytisus scoparius (Scotchbroom) and 2-0 Pinus contorta (lodgepole pine) are planted on 2.4-m (7.8-ft) centers. The planting season is normally 15 December to 1 February. Sctochbroom is used as a temporary plant with several benefits. First, growth is more rapid than the pine so it provides wind protection for about 8 yr. Second, Scotchbroom is a legume and provides some nitrogen. Scotchbroom is also very fire resistant and provides good upland bird cover and feed.

Scotchbroom is normally shaded out between the 10th and 12th yr; the result is a dense lodgepole pine forest habitat that includes other woody species which have invaded from nearby plant communities. Be certain to plan for vegetative firebreaks in large plantings of this kind. Failure to plan for firebreaks can result in large losses to permanent cover and creation of very adverse conditions for rehabilitation. Two species are most commonly used. The best is Lathyrus japonious seeded in a permanent grass mixture. Seeds are treated with H_2SO_4 or scarified. Fires with intense heat rarely burn over 4 m (13 ft) into a stand of this plant. The other plant is

Scotchbroom; 1-0 nursery-grown plants are planted on 1-m (3-ft) centers in solid bands 15 m (49 ft) wide. Scotchbroom is very expensive due to nursery costs; the seed treatment for nursery plantings includes scarification or hot water treatment.

The second method used to stabilize border or upland areas, mainly in the Clatsop Plains project, has been disking of beachgrass, followed by seeding to a permanent grass mixture. A fall planting should be considered because rain is infrequent in spring. The seed mixture for drier upland sites is the following:

Lupinus littoralis	7.8 kg/ha (7 lb/acre);
Poa macrantha	16.8 kg/ha (15 lb/acre);
Lathyrus japonicus	16.8 kg/ha (15 lb/acre); and
Festuca rubra	9.0 kg/ha (8 lb/acre).

If the first three species are not available, then an alternative mixture of seed normally that is available on the commercial market is the following:

Festuca rubra	9 kg/ha (8 lb/acre);
Lolium multiflorum	5.6 kg/ha (5 lb/acre);
Vicia villosa	28 kg/ha (25 lb/acre); and
Festuca elatior	11.2 kg/ha (10 lb/acre).

All seedings should receive 16-20 or 12-12-12 fertilizer application at a rate of 336 kg/ha (300 lb/acre).

When selecting sites for upland habitat improvement, the land manager should consider the complete habitat for all expected users. A mixture of forest, grasslands, and open sand is most desirable. The dry upland dune sites lend themselves to multiple use management for wildlife habitat and human recreation. Long-range effects of creating new vegetative habitats should be carefully analyzed before planting. I do not favor stabilization efforts unless coastal dunes are threatening existing resources, or lack some varied habitats.

The deflation plain offers the best opportunity in the Pacific coastal dunes for intensive habitat creation and management. Selected areas, usually formed by prevailing winds scouring areas behind foredunes, are excellent. After being scoured by the wind, down to the water table, the seed bed is perfect for machine-drilled seed mixtures.

Some areas can be used year after year with some site preparation such as disking and leveling. In the Pacific Flyway we concentrate on a mixture that supplements the dwindling food supply for wildlife.

Seeding should occur in late May or early June, the date depending on when the wind scouring reaches the summertime water table. Planting too early results in germination, some growth, and then total failure. In addition, the irregular edge caused by failure results in real problems in following seasons due to uneven terrain. After the judgment had been made to plant, the following mixture is seeded and fertilized.

(Forest Service Mixture):

Barley	112 kg/ha (100 lb/acre);
Perrenial rye grass	7.8 kg/ha (7 lb/acre);
Alta fescus	25 kg/ha (22 lb/acre);
Lotus major	4.5 kg/ha (4 lb/acre); and
fertilizer 13-13-13	224 kg/ha (200 lb/acre).

Seed should not be drilled until the water table is at the surface of sand. Apply mixture at approximately 100 kg/ha (90 lb/acre). Areas to be seeded with barley or barley-grass seed mixture should be fertilized with commercial fertilizer at the rate of 45 kg of nitrogen, 90 kg of phosphate, and 90 kg of potash per acre (448 kg/ha [400 lb/acre]) of 10-20-20 fertilizer. Fertilizer should be applied immediately prior to or concurrent with drilling of seed. Fertilizer may be applied either by hand or mechanically, after planting is completed, during or immediately prior to rain, and only on days when wind velocities are low enough so as not to cause significant drift of the fertilizer.

Seed should be drilled with either a single- or double-disk grain drill. Barley used in this mixture has several roles. First, it germinates in not more than 2 days. This rapid growth allows it to serve as a "nurse crop," preventing wind erosion to the slower germinating permanent grasses and legumes. We have occasionally produced 100 bushels/ ha; thus, the fall feed for migratory waterfowl is plentiful. All deflation plains are flooded by heavy rainfall in winter.

In one 100-ha (247-acre) planted area, we have counted as many as 2,000 geese, hundreds of ducks, and 1,500 swans. This use by waterfowl was in contrast to only occasional overnight rest stops in the same area before planting. One flock of geese, which contained marked identifiable members, remained in the area for 6 weeks in midwinter. The permanent grasses and legumes were grazed especially heavily by the swans and northbound black brant (Branta nigricans) in the spring. However, repeated plantings tend to build up organic material to the point where disking becomes increasingly difficult. Seeding only barley would lessen this problem.

The legume, Lotus carniculatus, can survive several months underwater without adverse effect. This plant is heavily grazed by blacktail deer (Odocoileus hemionus).

Areas bordering the deflation plain may have to be stabilized to avoid damage to seeded areas by blown sand. Planting of American beachgrass (Ammophila arenaria) and woody species will afford protection and provide excellent nesting areas with dense protective cover.

In the Oregon dunes, we also annually release ring-necked pheasants (Phasianus colchicus). However, the ever-increasing vegetation makes hunting difficult. The transplanting of beaver (Castor canadensis) also increased water tables throughout much of the deflation plains. Be cautious, however, because vegetative plantings may result in total natural revegetation of the entire deflation plain. Even though a planting makes excellent habitat,it also cuts off the ocean supply of sand. Our plantings have been cooperative efforts between the Oregon Fish and Wildlife Commission and Federal landowners (U.S. Forest Service or BLM).

In my 34 yr of experience, no other areas produced results as quickly. The Oregon Coastal Conservation and Development Commission in our Coastal Zone Management program requests clear identification of all potential deflation plains sites and encourages their preservation. With the ever-increasing encroachment of man's activities on existing coastal habitats, these areas should be preserved whenever practical.

DUNE COMMUNITY CREATION ALONG THE ATLANTIC COAST

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The information that I report is the result of research conducted along the Atlantic Coast by Dr. W. W. Woodhouse, Jr., Dr. S. W. Broome, and me. Suggested references include Woodhouse (1978) and Woodhouse et al. (1968, 1976). We have received support from the Coastal Engineering Research Center, U.S. Army Corps of Engineers; the University of North Carolina Sea Grant Program; and the North Carolina Coastal Research Program.

I am going to describe the function of sand dunes along the Atlantic Coast; how to build and stabilize them, what is good and bad about them, some applications, and some of the knowledge that we have accumulated during the past 15 yr of research.

Coastal dunes are natural features of most sandy shorelines, especially in temperate regions. They result largely from sand being trapped by vegetation. Onshore winds move sand onto the beach. Along the North Carolina coast, northeast winds are primarily responsible for moving this sand from deposits above the high tide line, on a berm, onto the dunes. Almost any obstruction in the path of blowing sand will cause it to settle out, accumulate, and build a dune. Perennial grasses are especially efficient at facilitating this task.

The native dune community along the Atlantic Coast is dominated by perennial grasses. Northward of Virginia, American beachgrass (Ammophila breviligulata) is dominant; from North Carolina southward to Florida and along the Gulf coast to Texas, sea oats (Uniola paniculata) dominates. Because of their dominance and their superior sand-trapping capacity, perennial grasses are used to initiate dune development.

Although these perennial grasses reproduce both sexually and asexually (vegetatively), vegetative reproduction by extensive rhizome systems is most important in stabilizing the sand and building a dune. The principal grasses used in dune creation along the Atlantic Coast are American beachgrass, sea oats, and bitter panicum (Panicum amarum). New shoots and roots arise intermittently along the rhizomes of these grasses. In the case of American beachgrass, rhizome growth can enable a dune to migrate toward the sand supply at a rate of about 1.4 m (4.4 ft)/yr.

Coastal dunes are flexible barriers. They are part of the nearshore dynamic zone that changes with the wave climate both seasonally and in response to sporadic storm activity. Dunes serve as sand reservoirs to nourish the beach during storm attack. A portion of the dunes may be eroded, the material carried out in the surf zone and deposited on offshore bars, and then returned at some later time. As much as 3 m (10 ft) of sand at the base of the dune may be taken out during a severe storm. A significant portion (over half) of this sand may return within the next two or three tidal cycles; in time most of it may return. Unfortunately, man does not often appreciate the fact that foredunes are a part of this dynamic zone, which is continually undergoing change.

Further, sea level is rising; it may be only 2 to 3 mm (0.08 to 0.12 inch) a year, but coastal lands are being claimed by the sea and the forces of erosion. Coastal dunes are not effective barriers against this type of situation. Nature is taking what it needs to establish new beach and shoreline profiles. There is little that man can do without tremendous expenditures to change this trend.

Coastal dunes can be built in many ways and the method used may influence the vegetation that exists on them. Substrate moisture conditions in dunes are related to the texture of the sand which in turn may be a result of the method used to construct the dune. Dunes can be built mechanically with a bulldozer, hydraulically with a pipeline dredge, with sand fences, or by a combination of methods. First, consider pushing up sand with bulldozers. This is actually dike-building and is at best a temporary means of halting the ocean's advance. It is usually resorted to only in emergency situations. During the Ash Wednesday storm of 1962 along the North Carolina coast, personnel of the Cape Hatteras National Seashore worked all night with a bulldozer to keep a barrier dune intact and prevent overwash from flooding a developed area.

Another option is to use a pipeline dredge to pump sand from a barrow area (e.g., sand spit or lagoon) onto the beach and build a new berm and dune system hydraulically. Placement of sand onto the beach in this manner is called beach nourishment. In 1965, the U.S. Army Corps of Engineers nourished Wrightsville Beach, North Carolina, at a cost of about $468,750/km ($750,000/mi) of beach. This procedure has been repeated since 1965 at a cost of $1,250,000 to $1,875,000/km ($2 to 3 million/mi) of beach. This process may have to be repeated again and again. The economics of the situation in this case might dictate or indicate that beach nourishment, time and again, is the answer in this relatively heavily developed area. A part of the specifications followed by the Corps in a nourishment project is that the upper portion of the nourished area be planted and stabilized. Under favorable conditions this will result in dune formation.

In some situations a dune can be built with sand fence (snow fence) or with sand fence and vegetation together. Under certain conditions, it is possible to plant grass and, as the grass grows, it accumulates sand, and a dune forms. With this technique, the dune is being stabilized as it is being built.

Whether the dune is pushed up mechanically, pumped up hydraulically, or formed by fences or grasses, the sand must be stablized to be a protective device. You can accumulate all the sand you want, but sand can be moved by the prevailing winds unless it is stabilized. In underdeveloped areas along some coastlines, it is feasible to build a dune just by planting dune grasses. When you consider something like beach nourishment, you are dealing with millions of dollars. A dune can be built in a few years after planting with American beachgrass for about $6,250/km ($10,000/mi).

Coastal dunes are abused by man, his animals, and his machines. Grazing has been a major problem in the past; traffic, both foot and vehicles, is a major problem now. Almost any dune system along the Atlantic coast or Gulf of Mexico at one time or another has undergone grazing pressure by various domestic animals, including sheep, cattle, horses, pigs, and goats. These animals had a tremendous impact and in many cases completely denuded the coastal dunes.

Some present-day ecologists say dune systems are in a dynamic equilibrium even though man has interfered with these systems for several hundred years. Presently, the problem is not grazing but man's impact with foot and vehicular traffic. Dune vegetation is very susceptible to damage by traffic. Land managers should control access to beach areas by directing it along wooden, elevated walkways. One of the very desirable features of dune grasses is their capacity to reestablish following storm activity. Traffic interferes with this capability of the vegetation. There is no way that plants can reproduce well in areas used heavily by vehicles. Dune buggies may have their place, but it is not on a frontal dune system along the Atlantic coast. Get them further inland, possibly on certain live dunes.

The absence of dunes along most of the Atlantic coastline is usually due to a lack of sand or sufficient winds to move the sand onto the vegetation, or due to man's interference through his activities, or his animals' activities. Dunes are natural features. They will develop if there are vegetation and a sand supply. Placement of vegetation about 100 m (330 ft) from the high tide line will result in dune formation provided there is an adequate sand supply.

Dunes are fragile structures requiring protection and stabilization; vegetation is usually the only practical solution. What particular features must coastal plants possess to stabilize dunes? They must have physiological and morphological features that enable them to live in the relatively severe habitat at the land-sea interface.

What have we accomplished along the North Carolina coast in the last 15 yr in terms of stabilizing the unstabilized dune areas and in building dunes in some areas where we thought they should be placed? American beachgrass occurs naturally around the Great Lakes and along the Atlantic coast from Nova Scotia to northern North Carolina. It is the principal grass used to build and stabilize dunes along the Atlantic coast, including areas southward of its natural distribution. Why? Because it is relatively easy to propagate in the nursery, is relatively easy to handle and prepare for transplanting, grows rapidly after planting, has a relatively long growing season compared to other grasses, and is a very efficient sand-trapper and dune builder. Nursery-grown strains of American beachgrass have been field-tested for superior vigor under localized conditions in both New Jersey and North Carolina. Selections have been made based on these tests and locally adapted varieties are now available through commercial growers.

What about fertilization response? Dune grasses respond favorably to fertilization. The primary response is to nitrogen with a minor response to phosphorus and little or no response to potassium. A 30-10-0 fertilizer is recommended, applied at the rate of about 23 kg/ha (50 lb/acre). Do not apply more than this amount of nitrogen at a time. Any amount in excess of this will, in all probability, be leached from the soil. Granulated fertilizers are readily available and easy to apply with a cyclone seeder. Do not put the fertilizer on when you plant. Wait until the root systems develop; then apply it on several occasions so that your total may be 68 kg (150 lb) the first growing season. If planting takes place in February or March, apply 23 kg (50 lb) of nitrogen in late May, the same amount in July, and again in August or September. With these split applications, plants are able to make maximum use of the fertilizer materials. If you have a large area of dune system to fertilize, a helicopter can be used. Pelletized fertilizer can be very evenly distributed by helicopter. After the pellets absorb water, they adhere to the sand.

American beachgrass should not be used alone in dune plantings along the south Atlantic coast. It is less drought tolerant and less tolerant of high temperatures than either sea oats or bitter panicum. Further, it is susceptible to a scale insect (Eriococcus carolinae) and also a fungal pathogen (Marasmius). The fungus, which causes Marasmius blight of American beachgrass, is not known to occur north of North Carolina. Any planting of American beachgrass made south of about Oregon Inlet, North Carolina, will be invaded by sea oats in time, provided that there is a seed supply of sea oats nearby. Usually, in 8 to 10 yr after a dune is planted to pure American beachgrass, the beachgrass is replaced by other species, primarily sea oats. Still we use American beachgrass to initiate dunes and provide the initial cover. Why? Because beachgrass establishes quicker and traps sand at a faster rate than any of the other plants available.

Our major emphasis at present is to determine the best adapted strains of native plants and to determine the best mixture of these plants to use for stabilization. We have experienced almost complete failure with saltmarsh cordgrass (Spartina patens) except in a few places. It is found on dunes, but does not do well when planted alone. In mixed plantings with sea oats, and sometimes with bitter panicum, it does very well.

Some of you may wonder why we do not experiment with some other types of plants besides grasses. We are looking at some other species, such as seashore elder (Iva imbricata), a succulent-leaved semi-woody plant of the aster family. We are studying its physiology, germination capability, and response to transplanting. In places, seashore elder dominates the dune community, but we do not think that it is a particularly good stabilizer and recommend its use only in mixed species plantings.

Results of mixed species plantings have led us to realize their advantages over conventional monocultures. A mixed species experimental planting on Ocracoke Island, North Carolina, included 50% American beachgrass and 50% sea oats. After 10 yr sea oats still dominate much of the zone where the sand is no longer active or accumulating. In the active sand zone where it is accumulating on the ocean side of the dune, American beachgrass dominates. This is a characteristic response of American beachgrass; it does best where fresh sand is accumulating and it will grow toward the sand supply on the beach (berm) at a rate of up to 3 m (10 ft) per year. The rhizome network of American beachgrass has much greater potential for spread than does that of sea oats. Even though American beachgrass has some problems (e.g., disease, insect pests) along our coastline, it also has some definite advantages. In mixed species plantings, beachgrass acts as a nurse crop, builds the dune, and has the capacity to alter the dune's configuration by growing toward the sand supply. Eventually beachgrass will surrender dominance to other plants which results in a natural vegetative composition which is what we wanted in the first place.

In many cases in the past, man-initiated dunes have been placed too close to the ocean. Sandy shorelines advance and retreat; initial placement of a dune planting must allow for this movement. Because the overall trend along much of the Atlantic coast is that of a receding shoreline, dunes should be built at least 100 m (33 ft) from the high tide line.

In another mixed-species experiment near Drum Inlet, North Carolina, we put in a 0.6-m (2-ft) sand fence to accumulate a small ridge of sand prior to planting. We did this to gain a little elevation on a very exposed beach. The planting included sections of American beachgrass, sea oats, and bitter panicum, alone and in combination. By the third growing season, the American beachgrass section had accumulated more sand and moved further toward the ocean than either the bitter panicum or the sea oat sections. A section of the bitter panicum and sea oats together did almost as well as the section of American beachgrass alone; however, the mixture did not migrate as far toward the ocean. The mixture of American beachgrass and bitter panicum was no more effective than that of American beachgrass alone. American beachgrass is still superior to anything else that we have tried. When we planted a three-way mixture (American beachgrass, sea oats, and bitter panicum), a dune was created that was a little steeper on both the front and back slopes than dunes created by American beachgrass alone. For all practical purposes, however, sand accumulation was the same. Experiments indicate that it is best to use mixtures of grasses to stabilize and build dunes along our coastline, even though American beachgrass alone might accumulate sand at a faster rate. The mixture is best because American beachgrass is subject to disease and insect problems which become evident the second growing season following planting.

Coastal foredunes are the first line of defense. They are dominated primarily by perennial grasses with a scattering of other plants. Woody plants do not appear to be the answer to problems involved with dune building and dune stabilization with a situation of rising sea level and a retreating shoreline. Shrubs grow on the back side of the foredune and in other protected areas. They cannot survive on the top and ocean slope of the foredune because they cannot withstand the high concentrations of wind-borne salt spray. Behind the foredunes there may be inner dune areas, swales, or sand flats, where grasses and other herbaceous vegetation still dominate, but where shrubs become more prominent. Still further inland, a zone of woody vegetation develops. This woody vegetation may be a low-growing maritime shrub thicket or it may be a maritime forest. It is composed of wax myrtle (Myrica cerifera), yaupon (Ilex vomitoria), red cedar (Juniperus virginiana), live oak (Quercus virginiana), and laurel oak (Quercus laurifolia) together with greenbriar (Smilax spp.), wild grapes (Vitis spp.) and poison ivy (Rhus radicans). Where you find trees or shrubs next to the ocean, it is probable that the ocean has cut to them, not that the trees and shrubs have grown toward the ocean.

In summary, coastal foredunes are

dynamic natural features along our coastline which are usually dominated by perennial grasses. They are fragile structures which may be damaged or destroyed by man's activities, as well as by natural forces. They afford protection and are important in preserving the integrity of the coastal fringe, but they should not be considered permanent structures which provide lasting protection for man's structures such as roads and buildings. They require protection and appreciation of their functional role in coastal systems.

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MANGROVE SWAMP CREATION

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INTRODUCTION

Mangroves are trees and shrubs that grow at the edge of warm seas of the world. They dominate 75% of the shoreline between 25° North and 25° South latitude (McGill 1959). Mangroves reach their maximum development and diversity in Southeast Asia (Macnae 1968) where Chapman (1970) listed 44 species and 14 genera. By contrast, Chapman tabulated only eight species and four genera in the Western Hemisphere.

The Florida species are the red (Rhizophora mangle), black (Avicennia germinans), and white (Laguncularia racemosa) mangroves (Figures 1 through 3). All three species occur in the southern part of Florida. White mangrove is the most cold-sensitive of the three species, red mangrove is intermediate, and black mangrove (which grows from just south of Jacksonville on the east coast, around the peninsula of Florida, and westward along most of the U.S. Gulf coast to Mexico) is the most cold-resistant.

Red mangrove fruits germinate on the parent tree to form pencil-shaped propagules (unrooted seedlings). Black and white mangroves form fruits which, like red mangrove propagules, drop from the tree when they are mature.

A mangrove swamp is a complex ecosystem. Although the species of plants are relatively few, the animals are numerous and diverse (Macnae 1968). The goal of a mangrove planting or replanting program should be the development of a functional, diverse ecosystem.

In this report I will cover factors that are known to be involved in mangrove establishment, review mangrove planting experiments, and evaluate the state of the art of mangrove swamp creation.

ECOLOGICAL FACTORS IN MANGROVE ESTABLISHMENT

LIGHT

Mangroves require open sunlight for optimal growth. The light intensity at ground level under a full canopy of mangrove forest may be only 5% to 10% of the open sun values. Mangrove seedlings ordinarily require more light than this to grow and become trees. Seedlings that fall to the ground under parent trees or are carried by the tides to areas of heavy canopy shade may begin development, but most die. An interesting feature of the growth-limiting effects of low light levels can be seen in the portion of a mangrove forest where the canopy has been removed by a lightning strike (Teas 1974). Dense growth of seedlings is found in such lighted openings; however, in nearby shaded areas the low light level suppression of seedlings continues (Figure 4).

TIDAL DEPTH AND FLUSHING

Another factor in mangrove establishment is tidal depth. Many red mangrove seedlings become planted and begin to grow along the shore of Biscayne Bay below mean sea level and even below mean low tide (Figure 5). However, aerial photographs over a decade showed that none of the seedlings at the site shown in Figure 5 developed into trees at substrate elevations lower than -9 cm (-0.34 ft) below mean sea level (Teas 1976). Roots of mature red mangroves often extend 30 cm (12 inches) or more below mean low tide in channels between mangrove islands in south Florida. The difference may be that the roots of the mature trees have well-developed aerenchyma (air conducting) tissues, whereas

Figure 1. Red mangrove, showing prop roots.

Figure 2. Black mangrove, showing pneumatophores, the characteristic slender vertical aerial roots.

Figure 3. White mangrove on dry (filled) land.

Figure 4. Growth of mangroves under canopy opening caused by a lightning strike.

Figure 5. Biscayne Bay shore at a low tide, showing red mangrove seedlings in foreground at substrate elevations too low for trees to become established.

the nonspecialized roots of young seedlings probably suffer from anaerobiosis. The failure of young seedlings to develop in deep water is probably the reason why moderately shallow bays do not become overgrown by red mangroves.

Large areas of mangroves have been killed in the past by reducing or blocking tidal flow to mangroves with highway construction and diking. Indeed, the limitation of tidal circulation by diking, usually combined with pumping water to maintain continuously high water level, has been a standard means by which mangroves were killed prior to filling the land for real estate development. An area in Dade County that was temporily cut off from tidal flow was studied by Teas et al. (1976). Mangroves occasionally adapt to reduced tidal flow; however, live mangrove forests are rarely found where completely excluded from tidal flushing. Stoddart et al. (1973) reported one such situation on the island of Barbuda in the Lesser Antilles.

Mangrove species differ in their response to altered tidal flushing patterns. Both black and white mangroves in Florida are typically more resistant to the effects of diking and flooding than are red mangroves. Noakes (1955) reported that in the Malayan mangrove forests channelization, which increases tidal flushing, favors the development of Rhizophora (the genus of Florida mangrove) over several other genera. Evidence from occasional survivors among diked Florida mangroves suggests that decreasing tidal flushing of a mixed stand would favor black and white mangroves over the reds, and conversely, that increasing tidal flushing should favor red mangroves over blacks and whites (Teas et al. 1976).

SALINITY

Salinity is a factor in mangrove growth. No mangroves are considered to be obligate halophytes, that is, to require salt, although they may be facultative halophytes, that is, tolerate salt and even grow better with some salt than without salt (Waisel 1972).

It has been noted repeatedly in the literature that mangroves grow larger in the zone of lower, fluctuating salinities some distance into an estuary from the shore than they do in saline waters near the shore (e.g., Davis 1940). Giant red mangrove trees on Molokai, Hawaii, are not found at the shore, but rather in the brackish zone some distance from the sea (Teas et al. 1975). It has been suggested that the lesser growth of mangroves in the more saline waters may be a metabolic "price" paid for salt tolerance (Carter et al. 1973; Teas 1974).

Mangroves may grow fairly well in freshwater. In 1933, Davis carried red mangrove propagules to the National Botanic Garden in Washington, D.C., where they were grown in greenhouses and reached a height of more than 3 m (10 ft) (Figure 6). I was assured by a long-time employee of the Garden that these mangroves had always been watered with tapwater. There are records of mangroves having been grown in freshwater for a century at Hamburg, Germany (Ding Hou 1958). Mature mangroves of several species can be seen growing in freshwater several hundred meters above sea level in the Botanical Garden at Bogor, Indonesia (H.J. Teas, unpublished). According to Ding Hou, mangroves at Bogor have grown and reproduced in freshwater for more than a century.

Thus, mangroves tolerate, but do not require saltwater. This tolerance of saltwater is probably very important to mangroves because it reduces competition from nonsaline tolerant species (Teas 1977). As noted earlier, mangroves do not prosper at low light levels. Mangroves are slow growing compared to many nonsaline tolerant herbaceous and woody plants that would overshadow and outcompete them if saline soils did not provide the mangroves a competitive advantage.

WAVE AND CURRENT ACTION

Another factor in mangrove establishment and survival is shoreline energy from natural waves, currents, and boat wakes. Wave action can wash out well-established mangroves. Figure 7 shows a site along the Intracoastal Waterway in Broward County, south of Fort Lauderdale, Florida, where mangroves (and other species)are toppling into the water because of erosion caused by boat wakes. A rock breakwater or barrier of floating tires, of the type

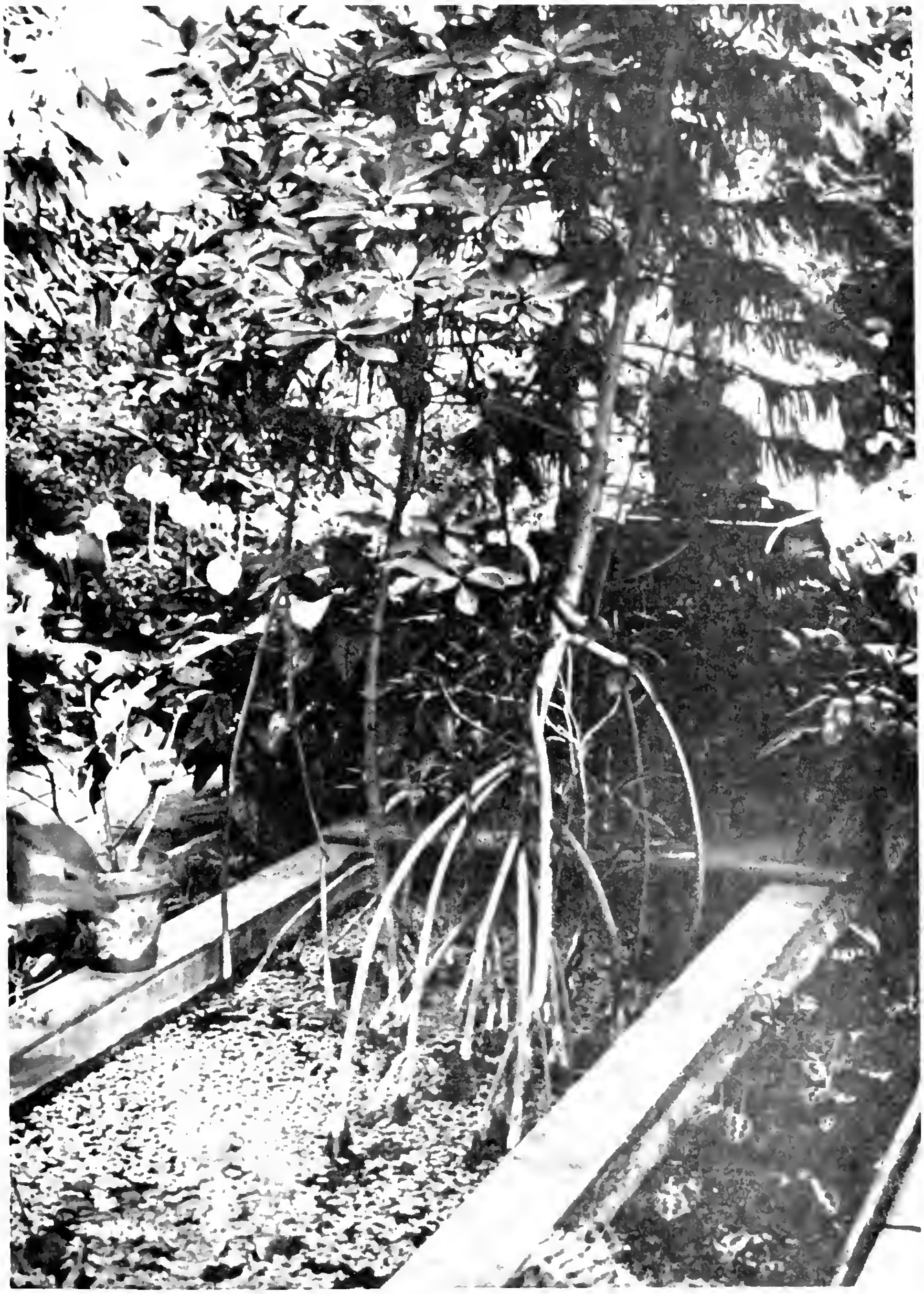

Figure 6. Red mangroves growing in fresh water at National Botanic Garden, Washington, D.C. Photo by Dr. P. Schroeder, 1974.

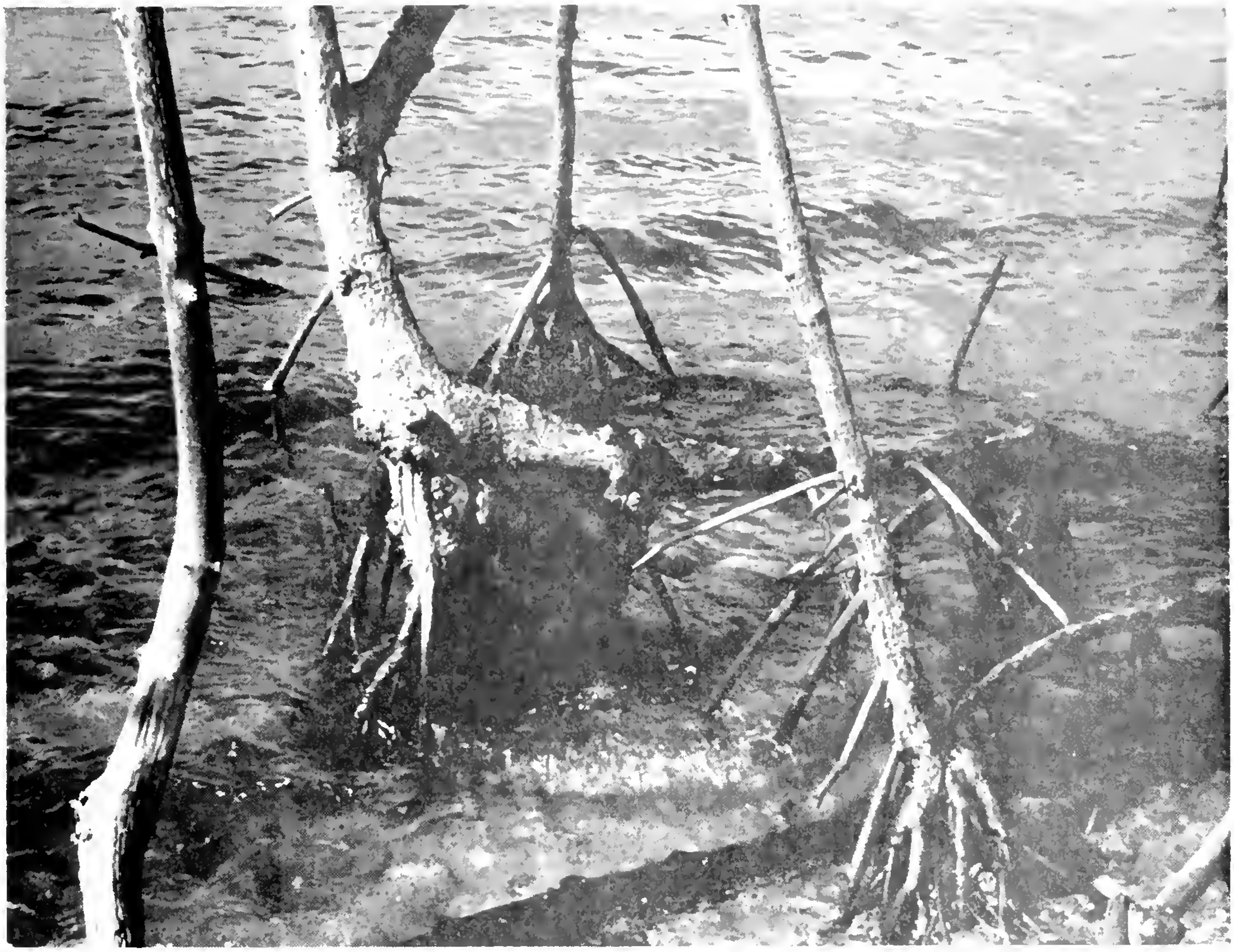

Figure 7. Red mangroves subjected to boat wake erosion, Broward County, Florida.

reported by Dr. Seneca in these proceedings, might protect such a shoreline.

Figure 8 shows red mangroves near the Card Sound Bridge in Florida being subjected to wave erosion. No new seedlings were becoming established in this area.

ROOT MAT AND SOIL HOLDING

The relatively greater resistance to wave erosion of the root systems of the black and white mangroves in comparison with red mangroves is an important factor in shoreline stabilization and mangrove swamp creation. The root system of red mangroves (Figure 9) does not form nearly as dense a mat as do roots of white or black mangroves. Figure 10 shows the storm-washed (probably hurricane) roots of a white mangrove. Black mangroves have a dense root mat similar to the whites.

Black and white mangroves are found in areas of higher wave energy than red mangroves, especially on rocky shores. Figure 11 shows black and white mangroves, but no red, that have successfully colonized an exposed soil bank along south Biscayne Bay, Florida. Also, black or white mangroves are probably better than reds for planting on rocky sites.

If rapid shoreline stabilization is desired for protection against erosion, black or white mangroves may be more suitable than reds. Lewis and Dunstan (1975) have suggested that rapid soil stabilization might be achieved by planting Spartina alterniflora, and then planting mangroves in the Spartina. Mangroves appear to compete successfully in such a situation. Rapid shoreline stabilization can be achieved by planting mangroves at greater density,then allowing natural thinning to occur, or thinning artificially, as suggested by Pulver (1975).

FLOTSAM AND JETSAM

Another enemy of mangrove seedling establishment is floating trash (flotsam) that can cover, break off, or uproot seedlings. Even mats of the floating seagrass or algae can sometimes uproot an unprotected mangrove planting. It may be possible in some cases to construct small breakwaters to divert the floating trash from a planting site.

SUBSTRATE AND MINERAL NUTRIENTS

In a mangrove swamp, which is a "climax" or "subclimax" forest, there is probably a tight coupling of mineral nutrients. The mineral elements from mangrove leaves, wood bark, and other debris that reach the forest floor are efficiently recycled by the trees.

Atmospheric nitrogen is fixed by microorganisms in the mangrove soils (Kimball and Teas 1975). The amount of fixation found, on the order of 5.6 to 16.8 kg/ha (5-15 lb/acres) per year, is not spectacular by comparison with an equal area in a field of soybeans. An unknown factor in mangrove swamp nitrogen utilization is whether or not denitrification (nitrogen loss) occurs in mangrove soils. As noted by Pomeroy ("Nutrient Cycling in Coastal Ecosystems" in this volume) rates of nitrogen loss can offset nitrogen fixation in some soils.

In a mangrove forest, some of the mineral nutrients in leaves, fruits and propagules, wood and other debris are lost from the system when carried out with the tide. Along many mangrove shores, mineral nutrients are gained when seagrass, algae, and other plant materials are washed into the forest, decay, and release mineral nutrients.

Some soils, such as broken coral and nutrient-deficient leached soils, provide poor substrates for mangrove development (Macnae 1968). There is some evidence that south Florida marl soils, with their high pH and deficiencies of certain mineral elements, may be a poor soil for mangroves (Teas 1974).

SPHAEROMA ROOT PARASITE

The isopod parasite Sphaeroma terebrans, a pill bug-sized root borer, is a serious problem for red mangroves in some areas (Rehm and Humm 1973). Sphaeroma is also known to attack black and white mangroves (Rehm 1976). In an area of heavy Sphaeroma infestation, parasites were found even in the timbers of wooden derelict boats (H. J. Teas,

Figure 8. Red mangroves in high wave energy area, near Card Sound Bridge in south Florida.

Figure 9. Roots of a red mangrove. Photo by Dr. T. Lodge.

Figure 10. Roots of a storm-eroded white mangrove in Florida Bay.

Figure 11. Black and white mangroves established on a rocky shore on Biscayne Bay.

unpublished). The parasite bores into roots and stems of mangroves, weakening them so that they may break off or fall over from the stress of boat wakes or wind.

Figure 12 shows a young black mangrove seedling at Port Charlotte, Florida, that has been attacked by Sphaeroma, and Figure 13 shows Sphaeroma-damaged mature red mangroves, 9 to 10m (30 to 33 ft) tall, that are falling into the water along the Intracoastal Waterway in the northern part of Biscayne Bay, probably from a combination of boat wakes and Sphaeroma damage (Teas et al. 1976). Hannan (1975) reported that all his plantings of red mangroves located 10 cm (4 inches) too low in the tidal zone at an Indian River site were killed by Sphaeroma, but that trees planted above this level were not attacked.

DISEASES

Olexa and Freeman (1975) reported three fungus diseases of mangroves in Florida. Two of them were pathogenic on black mangroves and one on red mangroves. The latter was identified as Cylindrocarpon didymum and is thought to cause the prominent galls found on red mangroves in south Florida (Figure 14). These authors suggest that the red mangrove disease may cause mortality and that the prevalence of the disease may indicate that the affected mangroves are stressed. The red mangrove gall disease does not often affect young seedlings and has not appeared in our experimental plantings. The two diseases of black mangroves were not reported as widespread. It is uncertain at present whether these or other diseases are likely to be a problem in mangrove planting.

PUBLIC ACCESS

At some experimental sites accessible to the public, there has been damage to planted mangroves (Teas et al. 1975). The technique of providing a sign on the site that explains the purpose of the experiment might reduce such losses. Reimold, at this conference, demonstrated such a sign that was apparently successful at a Spartina planting site.

REVIEW OF MANGROVE PLANTING

OLDER LITERATURE

Mangroves have been planted for many years. They were planted in Sri Lanka (Ceylon) to induce silt deposition and in Java to stabilize the banks of fish ponds and canals (Macnae 1968).

Mangroves were introduced into Hawaii in 1905 on the island of Molokai to check soil erosion (MacCaughey 1917). Recently, this author (Teas et al. 1975) checked several of the Hawaiian Islands for mangroves and found a well-developed forest of Rhizophora on the southwest coast of Molokai and smaller stands on several other islands. Some of the Rhizophora trees on Molokai were greater than 0.3 m (1 ft) in diameter and estimated to be more than 21 m (70 ft) tall.

Red mangroves were planted in Florida before 1917 among ballast stones of the Florida Overseas Railway as a protection against storm erosion (Bowman 1917). Davis (1940) reported having planted 4,100 red mangrove propagules at Long Key in the Dry Tortugas Islands. One year later approximately 80% survived, but 32 yr later all had died and/or been washed away by storms (Teas 1977).

FLORIDA PLANTINGS SINCE 1970

Savage (1972) reported on plantings of red mangrove seedlings in a variety of situations in the Tampa-St.Petersburg area. He had a low survival rate in most cases.

Teas et al. (1975) planted young red mangrove seedlings on the east coast of Florida along waterways leading into the North Fork of the St. Lucie River. At the Coral Reef Waterway site, which is subjected to waves from boat traffic, there were no survivors after 7 mo from 178 seedlings planted. A low energy site, Canal B-19, had good survival, and a dense growth of mangroves was established within 5 yr. Figure 15 shows a part of this planting at 4 yr. At the Elkcam Waterway, a moderate energy site, seedlings were planted through a jute mesh mat (Figure 16). The majority of the seedlings were lost or broken, and survival was low after 3 yr. However, at the Elkcam Waterway site, plants on

Figure 12. Black mangrove seedling attacked by Sphaeroma at Port Charlotte, Florida. The holes in the stem were caused by Sphaeroma which were still living in the stem.

Figure 13. Large red (and a few white) mangroves falling over from boat wakes in heavy *Sphaeroma* damage area, Intracoastal Waterway, Dade County, Florida.

Figure 14. Gall on trunk of red mangrove.

Figure 15. Red mangroves planted at low energy site (Canal B-19) at age of 4 yr.

Figure 16. Red mangrove seedlings planted in jute mesh at Elkcam Waterway, St. Lucie County, Florida.

the side of the Waterway away from frequent human access fared better than those near more frequented areas. Some of the losses at more urbanized sites resulted from seedlings being trampled by fishermen, knocked over by small boats, and in some cases apparently pulled up.

Teas et al. (1975) reported on a low energy mangrove planting site on the west coast of Florida at Grassy Point in the Port Charlotte area. At this location, approximately 60,000 red mangrove propagules were planted in 1974. A portion of this experiment is shown in Figure 17. An estimated 85% to 90% survived for 1 yr; however, checks at 2.5 yr (Teas and Jurgens, unpublished) showed that many of the seedlings planted low in the tidal range were being lost because of Sphaeroma damage.

Red, black, and white mangroves were transplanted to a high energy site in Biscayne Bay, on the north side of the Julia Tuttle Causeway, and after 10 mo only 7 of the original 320 plants survived; after 24 mo, none was alive. Forty-seven small red, black, and white mangrove trees were transplanted from nature into a freshwater pool at the University of Miami campus (Figure 18), and 47% were surviving after 2 yr (Teas 1977). Most of the losses were in the first few weeks.

At a low energy canalside site near Miami, 88 pot-grown red, black, and white mangroves up to 3.6 m (12 ft) tall were planted.The survival rate after 6 mo was 100% (Teas 1977).

Kinch (1975) summarized several years of experiments on mangrove transplanting to a spoil island in Roberts Bay at Marco, Florida (Figure 19). After 3 yr, only 15.7% of the plants survived. This low survival rate may have been caused at least partly by subsidence of the soft fill used in forming the island.

Hannan (1975) transplanted 4-yr or older red mangroves in the Jensen Beach area on the east coast of Florida. He obtained good survival, i.e., 85% to 100% at 13 mo, of root-balled plants transplanted at or above the mid-tide range.

Teas (1977) used a tree crane to transplant 14 black and white mangroves up to 6m (20 ft) tall (Figure 20) that had been root-pruned several months earlier and top-pruned at the time of transplanting. After 6 mo none survived. The losses probably resulted from improper handling in transplanting, since root-pruning and top-pruning alone do not kill trees of this size.

THE MANGROVE SWAMP ECOSYSTEM

Mangroves, growing where temperature, water, salinity regime, substrate, mineral nutrient supply, and other factors are fairly optimal, form well-developed forests that are botanically complex. As Macnae (1968) has detailed for Indo-Pacific mangrove forests, many animal species are found living in or dependent on the mangroves. The diversity of mangroves inhabitants in the Caribbean is indicated, for example, by lists of animals found in mangroves of Puerto Rico (Cerame-Vivas 1974), Trinidad (Bacon 1970), and south Florida (Tabb et al. 1962; Odum and Heald 1972; Carter et al. 1973). Birds, fish, invertebrates, and mammals inhabiting mangroves in south Florida were listed by Simberloff and Wilson (1969), Breitwisch (1976), de Sylva (1976), Odell (1976), Owre (1976), and Voss (1976). Mangrove detritus-food web relationships have been described by several writers (Macnae 1968; Odum and Heald 1972). Odum and de la Cruz (1967) reported on the role of Spartina detritus in a Georgia salt marsh estuarine ecosystem.

There appear to be special problems associated with the establishment of mangroves in unvegetated shoreline areas or in former mangrove areas that have become dominated by other plants. For example, Macnae (1968) points out that clear-cut mangrove forests along the Gulf of Thailand near Bangkok did not revegetate with mangroves. Also, the herbicide-killed mangrove forests on the Saigon River delta were very slow to become revegetated long after significant concentrations of herbicide had disappeared from the soil (Lang 1974) (Figure 21). In Vietnam, erosion of the exposed soil and loss of mineral elements may have been involved (Lang 1974). Areas near Flamingo in Everglades National Park, where the mangroves were killed by a hurricane in 1965, became vegetated

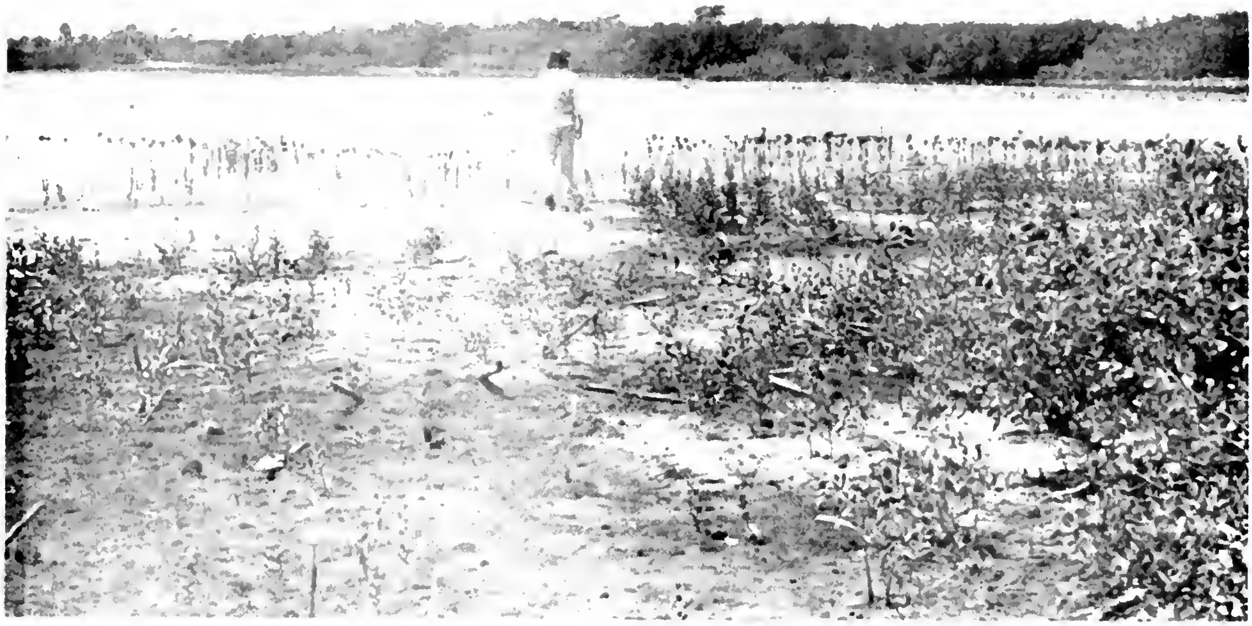

Figure 17. Hand-planted red mangroves at Grassy Point, age 1 yr.

Figure 18. Transplanted mangroves in the freshwater pool at University of Miami.

Figure 19. Spoil island in Roberts Bay, with transplanted mangroves.

Figure 20. Black mangrove being moved for transplantation by use of a tree crane.

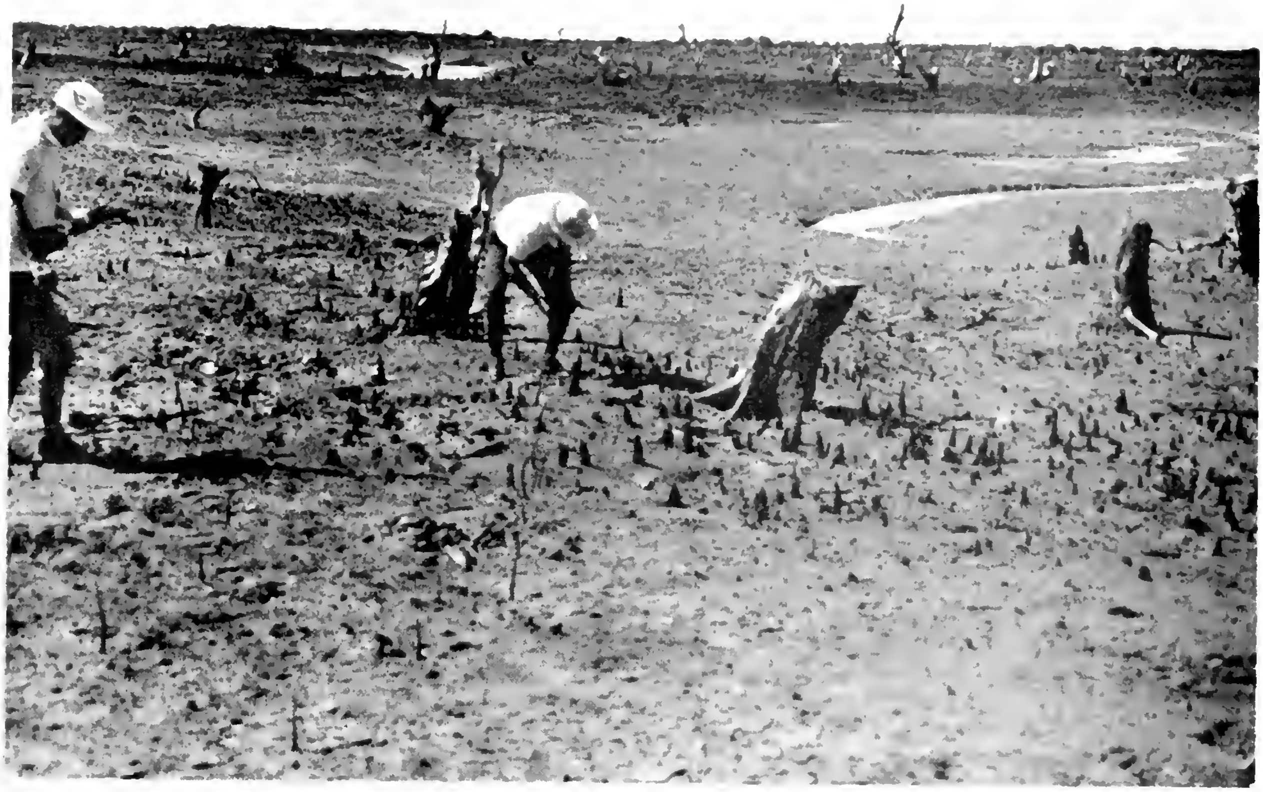

Figure 21. Investigators counting experimentally planted seedlings in Saigon River delta, 7 yr after herbicide defoliation of the mangrove forest. Note absence of mangrove vegetation in an area that had been forested before aerial spraying.

with halophytic herbs (Craighead 1971), and only in 1976 were (black) mangroves present.

Biological changes take place that appear to be necessary for fresh alluvial soils to be utilized by mangroves. These include the activities of bacteria, blue-green algae, diatoms, and green algae (Schuster 1952), as well as working of the soil by invertebrates (Macnae 1968). In the course of mangrove forest development, soils can apparently change from 5% to 15% organic matter in an alluvial or marl soil to 38% to 90% organic matter in a mangrove peat soil (Macnae 1968; Teas 1974). The creation of a mangrove swamp may well be accelerated by adding organic matter and fertilizer that would provide the soil equivalent to a fairly mature forest.

If the site is distant from other mangrove swamps, faunal and floral development might be accelerated by introducing invertebrates, algae, and other life from an established swamp.

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CREATION OF SEAGRASS BEDS[1]

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INTRODUCTION

Seagrasses are marine vascular plants which, except for one genus, occur in shallow protected coastal waters on muddy sand substrates. *Phyllospadix* grows on very high energy coasts on rock in the North Pacific. In the Indo-Pacific region, *Thalassodendron* and *Amphibolis* may occur on rock, but *Phyllospadix* is the only genus limited to growth on rocky substrates. The seagrasses function principally in detritus-based food chains. Dr. Pomeroy (at this meeting) stated that about 90% of the biomass enters the particulate and dissolved phase, while 10% is used by grazers.

U.S. Fish and Wildlife Service biologists from the west coast are probably most concerned with eelgrass (*Zostera marina*) because of black brandt (*Branta bernicla nigricans*) whose summer and winter ranges and migratory routes are governed almost primarily by the major concentrations of eelgrass. The brants' diet is about 80% eelgrass and they are wholly dependent on it. On the west coast, brandt are the principal animal using eelgrass.

Seagrasses function in a submerged environment with roots' binding sediment and leaves' forming baffles which trap sediments. This function was very well illustrated in the early 1930's during the so-called "wasting disease" in the North Atlantic, when up to 99% of all the eelgrass (*Zostera marina*) disappeared. Soon after, up to 0.3 m (1 ft) of sediments eroded in many areas.

Seagrass leaves die and decompose, forming detritus which feeds a number of long complex food chains. Many of our commercial animals, such as clams and oysters, use this detritus. Shrimp and certain fish are still the result of detritus food chains, whether these detritus chains are marsh or seagrass derived.

TRANSPORTATION

GENERAL ECOLOGY OF SPECIES USED

The two species that I am most involved with for transplanting in the Caribbean region are turtlegrass (*Thalassia testudinum*) and shoalgrass (*Halodule wrightii*) and in the temperate zone on both coasts, eelgrass. *Thalassia* seems to grow best in water temperatures from 20°C to 32°C (68°F to 90°F), a range of water salinity of 20 ‰ to 35 ‰, rather gentle water currents of 2 to 3 knots but of low energy, and relatively clear water. I have observed the best *Thalassia* growth down to 9 to 10 m (30 to 33 ft), although reports state that it does grow deeper. Substrates are mixed silty mud and sand. Seagrasses will tolerate some sedimentation, but I do not know how much. I have observed up to 20 cm (7.9 inches) of sediment dumped on *Thalassia* and *Halodule* at Port Aransas, Texas, over 6 mo. While *Thalassia* reacted very poorly, *Halodule* appeared to thrive.

Halodule has a broader tolerance level for all environmental parameters listed above. Temperature extremes for *Halodule* may extend from 15°C to 35°C (59°F to 95°F), while salt tolerances are much wider, from perhaps 20 ‰ to 45 ‰, even to 60 ‰ in some areas in the Laguna Madre, Texas. There is evidence that temperature or salinity variations exist within subspecies in the distributional range of seagrass species. After transplanting from the Laguna Madre into the normal salinity of Redfish Bay, Texas, I cannot tell the difference between the transplants of *Halodule* from the two locations and indigenous growth in Redfish Bay. It is

[1] This report is based upon research supported in part by the National Science Foundation under Grant ID074-24358.

more difficult to take Redfish Bay plants and place them in the highly saline Laguna Madre than to place Laguna Madre plants in Redfish Bay, but the conclusion is that Halodule is an adaptable plant.

Little is known about light requirements of Halodule. The species seems to be principally an intertidal plant, extending perhaps to 1.5 to 2.0 m (5.0 to 6.5 ft) deep, although I have seen some plants growing in deeper water. In the northeast Gulf of Mexico off Apalachicola in Florida, I have observed Halodule from 5 to 6 m (16 to 20 ft) deep. Halodule appears to tolerate a more sandy substrate than will Thalassia.

The optimum temperatures for eelgrass seem to lie between 10°C to 20°C (50°F to 68°F). In Puget Sound, eelgrass grows in a range of water temperatures from 6°C (43°F) in winter to 18°C (64°F) in summer in some shallow bays. In Rhode Island, strains of eelgrass tolerate 25°C (77°F to 82°F) in summer. Eelgrass dies at 18°C to 20°C (64°F to 68°F) in Puget Sound and at 25°C to 28°C (47°F to 82°F) in Rhode Island. Eelgrass probably forms different temperature races in different areas; if that is correct, it could influence survival when plants are transplanted over too great a distance. Salinity optima for eelgrass seem to range from 20 ‰ to 35 ‰, even though in the Baltic Sea the salinity can be as low as 6 ‰. Again, it is possible that Baltic Sea eelgrass is a different strain from eelgrass elsewhere. The best eelgrass growths in Puget Sound are found from 7 to 10 m (23 to 33 ft) deep; reports of eelgrass extending to 30 m (98 ft) deep exist for the Mediterranean Sea and off San Diego in the San Diego Trench. Eelgrass prefers a substrate of silty sand, but I have not seen eelgrass, nor any other seagrass, growing in pure sand. Eelgrass will tolerate some sedimentation, but I am not aware of studies defining sediment tolerances for the species.

The range of Thalassia and Halodule begins in Venezuela or perhaps as far south as Brazil, and extends northward around the Gulf of Mexico to Cape Canaveral, Florida. There is a disjunct population of Halodule at Beaufort, North Carolina.

Eelgrass grows from Cape Hatteras, North Carolina, northward to the southern tip of Greenland, with the best growths extending from New Jersey to Nova Scotia. On the west coast there are eelgrass populations in the Gulf of California, but better growths begin near the middle of Baja, California, and extend northward to the Bering Sea in the Arctic Circle.

TRANSPLANTATION WORK

Background

Seagrass transplantation programs to date have been concerned with three seagrass species, Halodule wrightii and Thalassia testudinum in the Gulf of Mexico and southern Florida, and eelgrass in the north temperate zone on both coasts. Van Breedveld (1975) reported several transplant experiments using manateegrass (Syringodium filiforme) near St. Petersburg, Florida. Previous field observations and experimental work indicate that in the tropical system Halodule is a pioneer plant and Thalassia is a climax plant. In the temperate zone eelgrass is both a colonizing and a climax species.

My studies on transplanting seagrass had two overall objectives. The first was to investigate basic biological problems in seagrasses, such as intraspecific variation, phenotypic plasticity, adaptations to the environment, and physiology. The second objective was to develop transplanting techniques which will allow an accelerated recovery of damaged meadows such as occurred on a massive scale from 1931 to 1933, when 90% to 99% of all the eelgrass in the North Atlantic disappeared. The malady was called the wasting disease and was attributed to a small mycetozoan organism. Scientists now believe that this die-off was caused by a slightly upward shift in water temperatures during that period, during which the plants were secondarily weakened. Plants unable to adjust to the temperature change died. In both Europe and the United States research showed that it took 30 yr for full natural recovery of the meadows. Managers are trying to speed up the normal recovery time by using transplants.

A second case of natural disappearance occurred in the Chesapeake Bay. Dr. Robert Orth (1975) of the Virginia Institute of Marine Science recently reported that a great influx of cow-nosed rays was attracted by an increased number of clams in the eelgrass meadows and the rays uprooted many hectares of the plant. Orth and associates (personal communication) were interested in transplanting to restore the eelgrass beds.

Camp et al. (1973) documented an increase of Lytechinus, a sea urchin, which invaded Thalassia beds in the northeast Gulf of Mexico and damaged many hectares of the plant.

Mr. Mike Brim (personal communication) from Panama City related that a hurricane went through the area September 1975 and caused the disappearance of several seagrass beds.

In all the above-mentioned cases, a natural disturbance upset the growth of indigenous seagrass beds, and managers would like to restore them. The same transplanting techniques would also be appropriate for areas where human activity has impaired and reduced seagrass growths.

Previous Transplantation Work

Seagrass transplantation techniques have gradually developed over the last 30 yr. Addy (1947a) reported that eelgrass was transplanted many times under the auspices of the U.S. Biological Survey (now the U.S. Fish and Wildlife Service). Addy used both seeds and vegetative stocks of the Pacific coast eelgrass, which were then transplanted in Massachusetts. He transferred eelgrass from Massachusetts to North Carolina, presumably as a follow-up after the wasting disease, and reported that no notable achievements were made in these plantings and many failed completely.

Addy (1947b) transplanted eelgrass seeds and vegetative material near Woods Hole using the sod method (a shovelful of substrate with plants intact) and reported successful transplants.

In 1960, as a follow-up from several years of massive bay dredging around St. Petersburg, I was asked to transplant Thalassia and Halodule in Tampa Bay. I used sods of Halodule and Thalassia but had no success with Thalassia, probably because of the erosion of fine silts in the bay sediments. The transplants of Halodule had moderate success; about half became established and showed some increase of ground cover.

In 1964 I began transplanting studies using eelgrass in Puget Sound. The technique involved attaching a series of plants, washed free of sediment, to an iron bar; placing this bar in a trench 5 to 6 cm (2.0 to 2.4 inches) deep; and covering it with surrounding sediment. In 1966, Fuss and Kelly (1969) initiated transplants of Thalassia and Halodule in Florida and noted good rhizome growth on a few transplants, but their methods did not seem to promise extensive field applications (see also Kelly et al. 1971). In more recent years, a number of people have begun transplanting using a variety of techniques (Table 1): Eleuterius (1974), Phillips (1974), Ranwell et al. (1974) in southern England, Thorhaug (1974), and Van Breedveld (1975).

The plug method involves cores of seagrass taken with a plastic sewer pipe. I have used a 20-cm (7.9-inch) diameter pipe, 90 cm (35.4 inches) long with opposing holes through which iron bars are placed for handles (Figure 1). The holes are sealed with aquarium cement. A wooden cap is placed on the top with a hole in it and is sealed to the pipe by aquarium cement. The pipe is pushed down into the sediment, a cork is placed in the cap, and the entire device is pulled up with the plug intact. The plug is transported to the transplant site, the sediment plug removed using another pipe, and the plug placed in the hole.

The anchoring methods I have used include individual shoots with the rhizome section affixed serially along pipes and construction rods (Figure 2). The wire mesh anchor method involves bunches of shoots affixed to mesh by rubber bands.

A number of years ago Mr. Robert Jones (personal communication), U.S. Fish and Wildlife Service refuge manager at Izembek Lagoon, Alaska, reported that he had affixed individual leafy shoots of eelgrass to nails (Figure 3) and dumped them over the side of a boat at

Table 1. Seagrass transplantation techniques and locations reported in the literature.

Technique	Author	Species used	Location
I. Vegetative material			
A. Non-anchoring methods			
1. Plants washed free of sediment and rhizome mat covered with sediment	Addy (1947a)	*Zostera marina* from Pacific coast	Woods Hole, MA
	Addy (1947a)	*Z. marina* from Massachusetts	Beaufort, NC
	Backman (personal communication 1973)	*Z. marina*	San Diego, CA
	Phillips in 1975	*Z. marina*	Puget Sound, WA
2. Sods (plants with sediment intact; shovelful of plants)	Addy (1947a, b)	*Z. marina*	Woods Hole, MA
	Phillips (1974; work done in 1960)	*Thalassia testudinum*; *Halodule wrightii*	Tampa Bay, FL
	Phillips in 1974-75	*Z. marina*	Puget Sound, WA; Cold Bay, AK
	Phillips in 1974-75	*T. testudinum*; *H. wrightii*	Port Aransas, TX
	Ranwell et al. (1974)	*Z. noltii*	Norfolk and Suffolk, Great Britain
3. Plugs (plants with sediment intact; placed in hole)	Burkholder and Doheny (1968)	*Z. marina*	Long Island, NY
	Van Breedveld (1975)	*T. testudinum*; *Syringodium filiforme*	Tampa Bay, FL

continued

Table 1. (continued).

Technique	Author	Species used	Location
	Phillips in 1974-75	*Z. marina*	Puget Sound, WA
	Phillips in 1974-75	*T. testudinum*;	Port Aransas, TX
4. Individual shoots in cans placed in ground	Fuss and Kelly (1969), Kelly et al. (1971)	*T. testudinum*; *H. wrightii*	Tampa Bay, FL
B.. Anchoring methods			
1. Pipes and construction rods	Fuss and Kelly (1969), Kelly et al. (1971)	*T. testudinum*; *H. wrightii* (treated and untreated with 10% NAPH)	Tampa Bay, FL
	Eleuterius (1974)	*T. testudinum* *H. wrightii*	Mississippi Sound, MS
	Phillips (1972, 1974; work done in 1964-65)	*Z. marina*	Puget Sound, WA; plants from Cold Bay, AK placed in Puget Sound
	Phillips in 1974-75	*Z. marina*	Puget Sound, WA; Cold Bay, AK
	Phillips in 1974-75	*T. testudinum*; *H. wrightii*	Port Aransas, TX
2. Bricks (individual shoots with rhizome section)	Fuss and Kelly (1969), Kelly et al. (1971)	*T. testudinum*; *H. wrightii* (treated and untreated with 10% NAPH)	Tampa Bay, FL

continued

Table 1. (concluded).

Technique	Author	Species used	Location
3. Wire mesh (small "bunch" of shoots fixed to mesh)	Backman (personal communication 1973)	*Z. marina*	San Diego, CA
	Eleuterius (1974)	*T. testudinum*; *H. wrightii*	Mississippi Sound, MS
	Phillips in 1975	*Z. marina*	Puget Sound, WA; Cold Bay, AK
4. Nails (individual shoots with rhizome fixed to nails)	Jones (personal communication 1965)	*Z. marina*	Cold Bay, AK
	Phillips in 1974-75	*Z. marina*	Puget Sound, WA; Cold Bay, AK
	Phillips in 1974-75	*T. testudinum*; *H. wrightii*	Port Aransas, TX
II. Seeds	Addy (1947a)	*Z. marina* from Pacific coast	Woods Hole, MA
	Thorhaug (1974)	*T. testudinum* from Bahamas	Biscayne Bay, FL

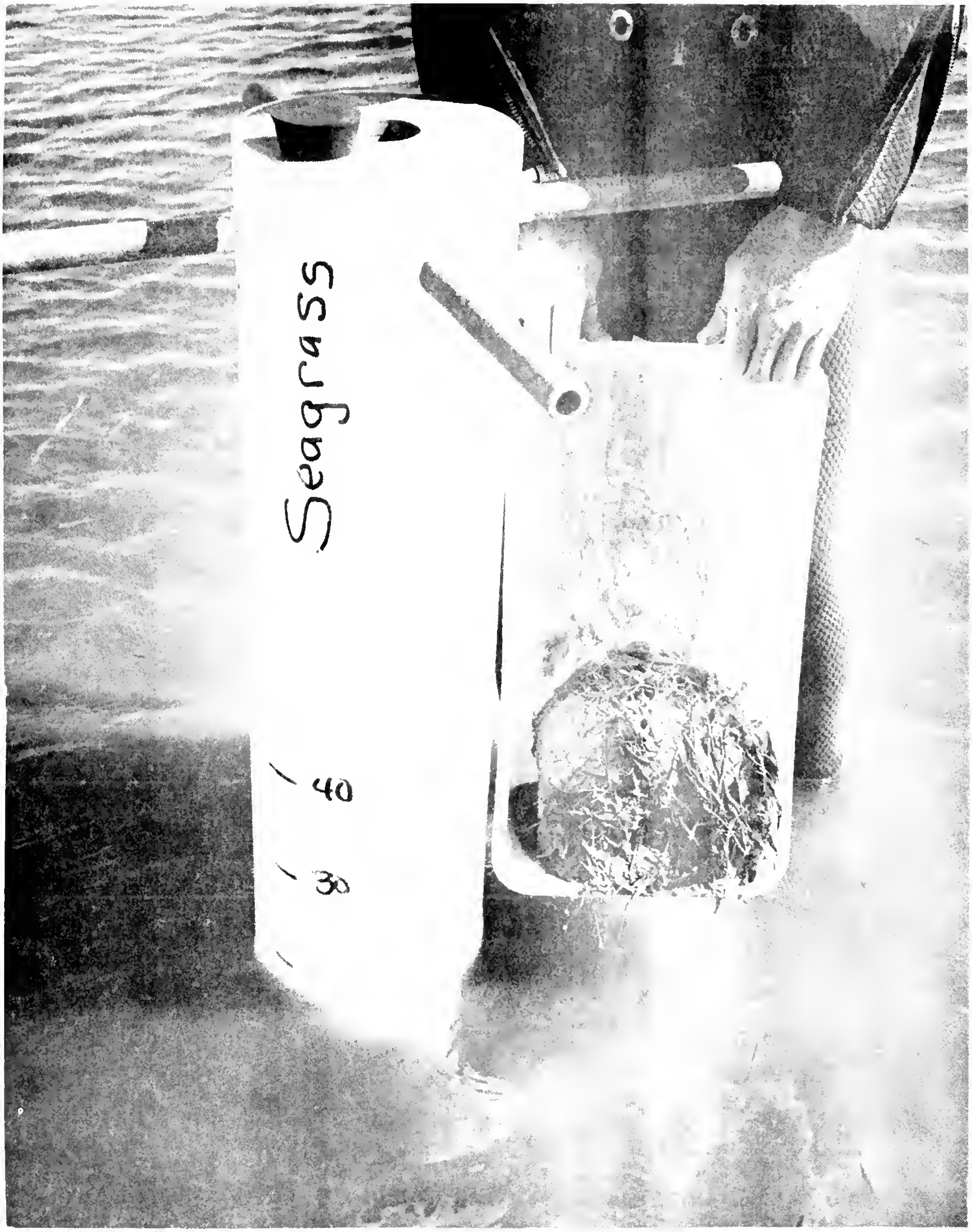

Figure 1. Coring device used for taking 20-cm (7.9-in) diameter plugs.

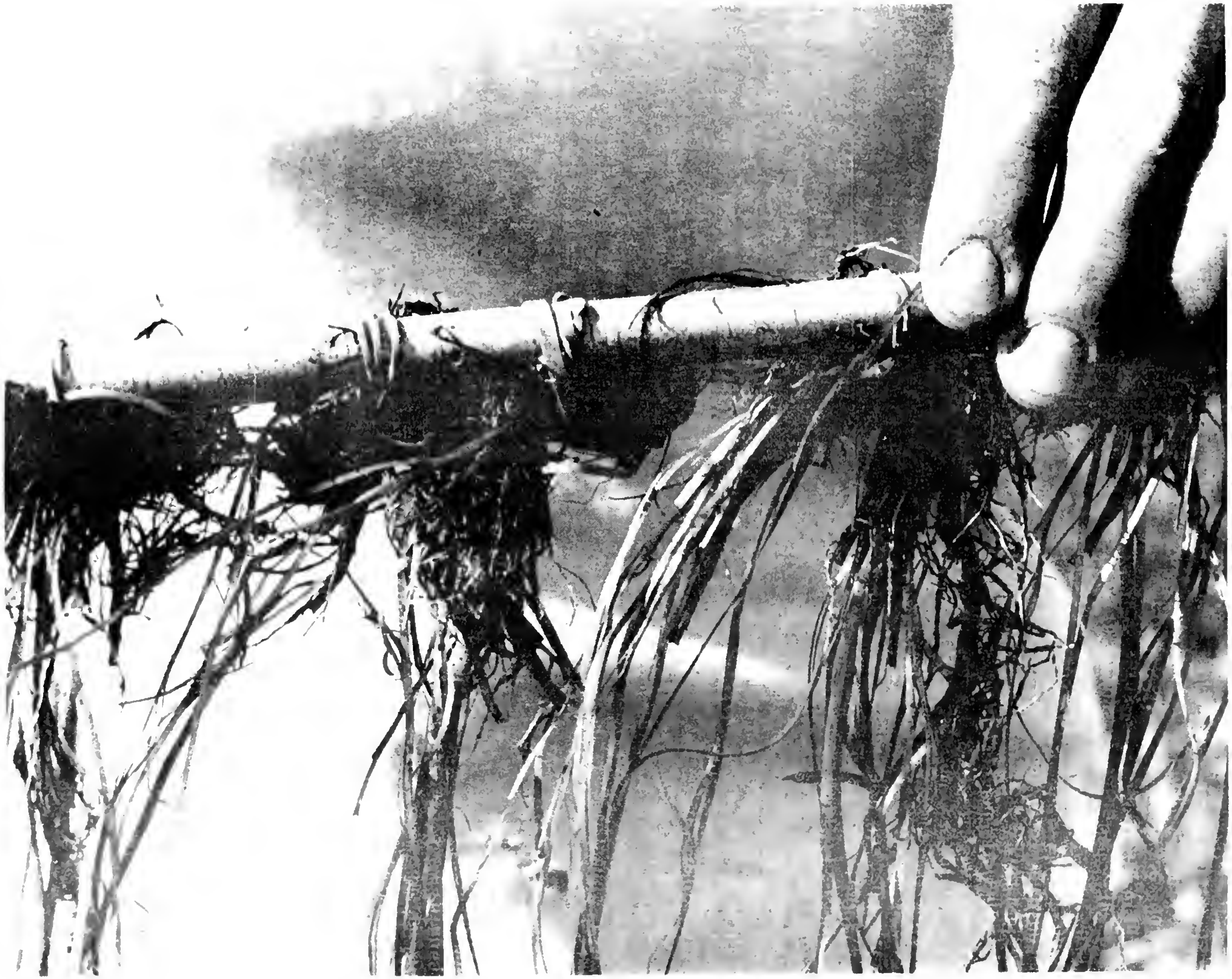

Figure 2. Seagrass shoots fixed by rubber bands to iron pipe.

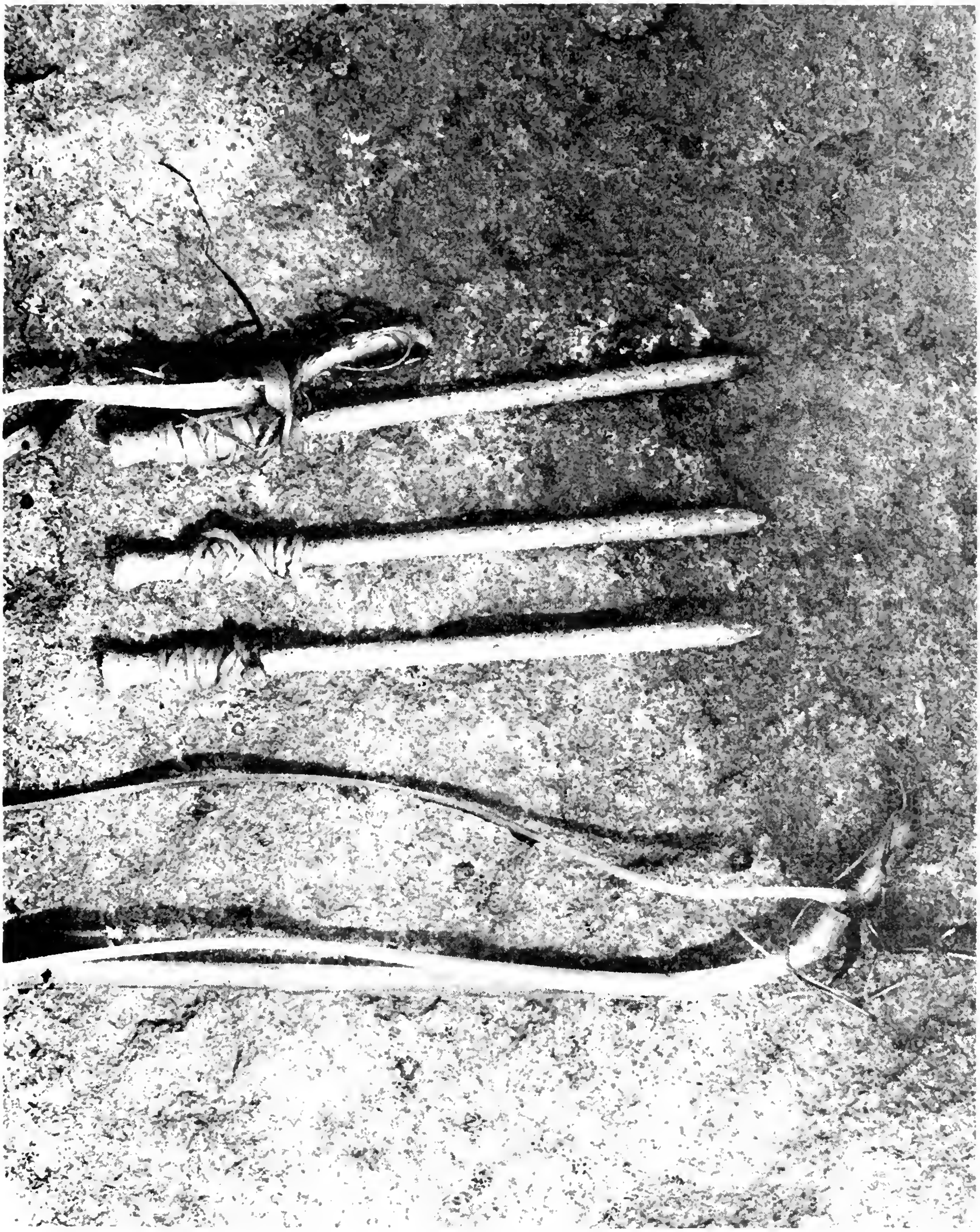

Figure 3. Seagrass shoots fixed individually by rubber bands to nails.

Adak Island. He later reported that the plants grew very well.

Evaluation of Methods

I have had no success in transplanting Thalassia and Halodule attached to steel rods. All plants anchored in this manner died within 3 mo. The method does work, however, with eelgrass, and in areas where the sediment is unusually fine, I would suggest that this method be used. The technique using nails as anchors is the easiest of the methods to use when planting by SCUBA diving. The underwater plots in Puget Sound were 4 m (13 ft) deep; installing plugs and sods at that depth was difficult and time consuming. Nails were easily installed, and eelgrass plantings, made using nail anchors, withstand an erosive current flow. The major problem was that the ubiquitous flatfish (mostly English sole, Parophrys vetulus), which are found in all of the indigenous eelgrass stands in Puget Sound, settle down on top of the plugs and cause them to erode.

In Izembek Lagoon, clusters of eelgrass were attached to wire mesh in April 1975, and by August 1975, only plants in 2 of 10 plots survived, but these had produced good growth. The use of sods and plugs is better suited for transplanting eelgrass in Alaska. I have had good success with establishment and continued growth of eelgrass using plugs and recommend this method for planting on a massive scale.

From July 1974 to 1976, I installed 78 experimental plots in both the Laguna Madre and Redfish Bay near Port Aransas, Texas (Table 2). Laguna Madre is a high salinity area; Redfish Bay is a normal salinity area. These experimental plots were reduced to approximately 30 plots because of the death of plants on rods and erosion of plants. Of the four methods used in transplanting Thalassia, the fixation to anchors using nails and rods was discontinued, and the two nonanchoring methods using sods and plugs were continued.

I transplanted every 3 mo during a period of 1 yr to determine seasonal differences in the success of transplantation. I also found that plant establishment was most successful when plantings were made in spring. Spring is the normal active vegetative growth period of indigenous plants. Transplantation during the summer, autumn, and winter was successful,but good solid establishment with vegetative shoot production and rhizome-root growth seems to be delayed until the following spring period (late February, perhaps lasting until May).

From 26 August 1975 until 16 February 1976, a large dredging project in the channel off Port Aransas released a quantity of unconsolidated silt into the water. Up to 20 cm (7.9 inches) of silt was deposited over a number of experimental plots and provided an opportunity to evaluate siltation on plantings. Reactions of both Halodule and Thalassia to siltation were noted when I dug the plots out. Thalassia had produced new rhizome tips from the upright branches; Halodule had reacted to siltation by angling its rhizome growth upward to stay on top of the sediments. In certain cases, both Thalassia and Halodule were completely covered by the silt,and on 16 April 1976, some of these plots were uncovered. Thalassia that had been buried for several months was either dead or showed diminished growth; however, Halodule that had been buried showed very vigorous, active vegetative growth with an abundance of new rhizomes, short shoots, and leaves.

On two different occasions,I transferred Alaskan plants from Izembek Lagoon to Puget Sound and used rods as an anchoring device. In 1964 when this was first attempted, the plants lived for 6 weeks, putting out new leaves, shoots, rhizomes, and roots, but then suddenly died. This was tried agin in summer, 1974, and the plants lived for 9 mo, putting out new shoots, leaves, rhizomes, and roots, and then the plants suddenly died. This suggests that we were working with latitudinal ecotypes in eelgrass. McMillan (1979) showed populational differentiation to chilling temperatures along a latitudinal gradient from the southern Gulf of Mexico - Caribbean to the northern Gulf for Thalassia, Syringodium, and Halodule.

On 12-13 December 1974, I established a seagrass garden at Manchester in Puget Sound and installed 14 plots using anchoring methods (rods and

Table 2. Growth of seagrass transplants (selected examples).

Species	Location	Date of transplantation	Date of observation	Extent of growth
Halodule wrightii	Redfish Bay, TX	13 Nov 1974	26 Aug 1975	6 plugs[a] originally totaling 1900 cm^2 filled up a m^2 plot in 9 months.
		27 Jan 1975	26 Aug 1975	6 plugs from high salinity Laguan Madre half filled a m^2 plot in 6 months.
		28 Jan 1975	15 Feb 1976	6 plugs filled and extended out of a m^2 plot by 30 cm in 12 months
		7 April 1975	26 Aug 1975	6 plugs from Laguna Madre completely filled a m^2 plot in 4 months.
Thalassia testudinum	Redfish Bay, TX	22 July 1974	26 Aug 1975	Plot m^2 filled with sods. Plants established; show new rhizome, short shoot, and leaf growth; some tendency to escape limits of plot.
		13 Nov 1974	26 Aug 1975	6 plugs placed in m^2 plot. Two plugs grown together with expanding growth after 9 months.
		28 Jan 1975	26 Aug 1975	6 plugs placed in m^2 plot. Some tendency to expand cover by new rhizome and short shoot production after 7 months.
		8 April 1975	26 Aug 1975	Plot m^2 filled with sods. Plants escaping out of plot by new rhizome and short shoot production after 4.5 months.

Table 2. (concluded).

Species	Location	Date of transplantation	Date of observation	Extent of growth
Zostera marina	Puget Sound, WA	18 Dec 1974	12 Nov 1975	50 short shoots anchored to rods, occupying 1,000 cm^2. Plot 25% full of plants after 11 months. Plot 1.5 m^2. Active new growth. Intertidal plants placed in subtidal.
		13 Jan 1975	12 Nov 1975	50 short shoots anchored to rods, occupying 1,000 cm^2. Plot 40% full after 10 months. Plot 1.5 m^2. Active new growth. Subtidal plants placed in subtidal.
		19 Jan 1975	12 Nov 1975	50 short shoots anchored to rods, occupying 1,000 cm^2. Plot 50% full after 10 months. Plot 1.5 cm^2. Active new growth. Intertidal plants placed in in subtidal.
		19 Dec 1974	12 Nov 1975	4 plugs placed in m^2 plot. Plot 30% full after 11 months. Active new growth. Subtidal plants placed in subtidal.
		27 May 1975	12 Nov 1975	10-15 patches of plants originally totalling 750 cm^2 filled a 1.5 m^2 plot in 5.5 months. Detached plants merely placed on bottom and rhizome system covered over with sediment. Extremely active growth. Subtidal plants placed in subtidal.

[a]The surface area of each plug was 314 cm^2.

nails), nonanchoring methods (sods and cores), and also detached plants that had been washed free of sediment, put down on the bottom, and covered over with sediment. Successful establishment of plants was noted among the five methods. The best success was observed in the detached plants washed free of the sediment and merely covered over (Table 2). This method may be usable in Puget Sound, because the sand fraction of the sediments in the eelgrass is fairly heavy, and even with a current of 2 or 3 knots, such as flows over that garden, the sediment remains intact. Sediments of eelgrass meadows further south at San Diego may have a larger silt content, and the method probably could not be used there. Zostera seems to be moderately tolerant, and both anchoring and nonanchoring devices can be used for planting. If the silts are too fine, anchoring devices can be used for establishment.

In Puget Sound where the sediments are heavy, I can merely cover over the plants, have them establish and fill up a plot very quickly. Where the silts are fine in eelgrass meadows, anchoring methods should be used. There is some indication from these experiments and others done in 1970 in another part of Puget Sound, that transplantation done in spring (March through May) gives the best chance of successful establishment. In Izembek Lagoon, Alaska, I have installed a number of eelgrass plots using nails and rods as anchors and using sods; I have also used the wire mesh method. Almost universally in Alaska, all anchoring devices result in low survival, while the use of sods and plugs results in complete establishment.

CONCLUSIONS

In areas of environmental stress which might occur in a local area or at extreme limits of the distributional-ecological range, such as in Izembek Lagoon for eelgrass or in Texas for Thalassia and Halodule, seagrasses apparently will not tolerate fixation to iron anchoring devices for planting. In Puget Sound, eelgrass establishes and grows after being affixed to iron anchors and planted as sods or plugs. I recommend using the sod or plug methods because they allow seagrasses to be moved and transplanted while keeping the root-soil interface intact and were more successful in the extreme geographical limits of the area as well as the optimum areas. In the optimum ecological area, however, the plug method may be more costly than simply planting detached fragments.

The manager should adopt whatever method seems appropriate considering the location, species concerned and sediment type. I prefer the plug method for the following reasons: (1) equipment which removes the plugs from indigenous growth is easily designed; (2) whole meadows of indigenous growth would not have to be greatly perturbed to get planting stock; (3) a great number of plugs could be easily transported; and (4) plugs can be more easily installed than sods.

Halodule invaded plots within 1 mo in Boca Ciega Bay, Florida, after denuding two large bottom areas within a Thalassia meadow (Phillips 1960). After 5 mo the plots were half full of Halodule, but there was no ingrowth of Thalassia. Halodule in the Caribbean seagrass system appears to be a pioneer plant. Thalassia is a climax plant and responds slowly and poorly to severe perturbations such as siltation and change in substrate type. Halodule appears to be stimulated by perturbations. Based on field observations and transplants I have made, I suggest using Halodule in restoring an area. Halodule is easily manipulated and will tolerate wide salinity and siltation variation.

Very little transplanting, except that by Eleuterius (1974), has been done on dredged materials. Eleuterius had very little success with plantings of Thalassia and Halodule on dredged materials in Mississippi Sound. Since dredged material seems to have characteristics different from the soil supporting indigenous growth, a plug which keeps the soil-root-rhizome interface intact should have the best chance of success. Also, I recommend the use of Halodule if transplanting were to be done in the South. The specific technique to be employed depends somewhat on the nature of the soil. In Thalassia-Halodule habitats I have seen silts too fine to anchor the plants. Since anchoring devices impede survival,I recommend the plug method using the soil as an anchor.

With Zostera marina, a variety of transplant methods appear satisfactory. Eelgrass is both a pioneer and a climax species; the species should fulfill more general functions than the two-species seagrass system (Thalassia-Halodule) in the Caribbean. The cheapest method would be to first look at the sediments, and, if they contain a quantity of sand, use detached fragments; however, if they are finer material, use anchoring devices. No large-scaled experiments have been done on transporting and holding of plugs. I suggest taking the plugs with biodegradable plastic tubes in which the cores could be stored until used. If so, the cores with the plugs in them might even be held in the same bay system where the material was taken or where transplant is to be made; however, soil within the plug should be protected from washing.

Finally, do not go too far away to find the source of the transplant stock. There is increasing evidence of latitudinal ecotypes based on temperature. I suggest using local stocks as much as possible.

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TECHNIQUES FOR CREATING SEAGRASS MEADOWS IN DAMAGED AREAS ALONG THE EAST COAST OF THE U.S.A.

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DECISIONS BY GOVERNMENT AGENCIES CONCERNED WITH RESTORATION OF SEAGRASSES

The process of restoration is one of the most hopeful avenues of biology for dealing with man. However, until recently, restoration of submerged vegetation was not even considered a possibility and waterfront construction was expected to do a certain amount of irreversible damage to the adjacent sublittoral communities. We can no longer afford to have our remaining nearshore submerged resources damaged by development interests. Therefore, there are two alternatives: (1) save the area immediately adjacent to the coast as a natural strip with no development and build behind this or (2) carefully write permits limiting what developers can do to the submerged land and then enforce these measures.

In establishing guidelines for rational restoration of seagrasses (or other plant species) the agency with authority immediately encounters questions which it is often not prepared to answer in the early stages,but which are essential for a successful final product. What size area should be restored? What species should be planted? What stand density should be achieved? What time period can be permitted to achieve this density?

Site specific information is necessary to answer the above questions. The developers' report may not contain this information or may not be credible. The questions of the size area to restore will be a site specific one. Filling valuable waterfront acreage may be judged to warrant from 3:1 to 10:1 (restored acres: filled acre ratios). Marina building or navigational channels may possibly be assessed at 1:1 to 3:1. The next question is where the restoration will occur. At many sites the exact area to be impacted will be restored after the impact has occurred. Other sites will require adjacent areas restored because the original site will not be on land or will be too deep for growth of seagrasses (as in the case of channels). Often a previously damaged site, at some distance from the impacted site, is chosen. In choosing a second site, one should keep in mind suitability of this site for successful restoration (physical, chemical, and geological characteristics), as well as the biological suitability of this site as a substitute for the original (in terms of nursery area and other considerations).

The species to be planted is usually the dominant species found in the preimpact survey. However, there are several exceptions. If the area had previously been impacted by man's activities (such as by drainage canals or other effluents), the original vegetation may have been supplanted by other species. To reestablish the original vegetation, rather than that presently dominant, would usually be preferable unless the water quality had changed so much that the original vegetation could not survive. If there are two or more abundant seagrass species present, one of the following plans can be chosen. (1) Restore several species simultaneously; (2) restore the fastest growing species first to stabilize sediment and prepare the area for revegetation; then restore the slower growing species into this matrix; (3) restore only the species which will return very slowly by natural means and allow the naturally faster growing species to invade; (4) restore only the species needed for a purpose such as a food source or as nursery-stock.

Information is often incomplete for such a decision. The decision of which species to plant may have a large effect on the cost of the effort. Nevertheless, the first decision should be based strictly on the biological rationale and only after this decision is made should economic considerations and compromises be considered. To plant the wrong species because of economic considerations might do more harm than good.

Often the cost considerations will cause a compromise between size of restored area and what is planted. In my opinion, if cost is the determining factor, it is better to restore a smaller area correctly than a large area incorrectly. An exception would be when sediment stabilization is the only goal.

The density to be achieved and the time period are highly dependent on density of seagrasses currently present in the area. The usual case would be to reestablish the same density within a reasonable time scale of about 3 to 6 yr. If the ultimate density is to be established in a very short time scale (such as months), the cost may become economically unfeasible (Thorhaug and Austin 1977). Note that the question of what density is present is a seasonal consideration in most areas, with late spring peaks and winter lows (Thorhaug and Roessler 1977). Use the highest seasonal density in the estimations.

Spatially the density of the seagrass may not be even throughout the area. One might choose an average density of the entire area as the restoration goal, but it is more advisable to restore the area in several different densities. If, for instance, a near-shore peat wedge sustains a higher standing crop than offshore sediment, it should be restored in that ratio. The time period for recovery to a given density is a function of the rate of growth of the plants. (Seagrasses spread laterally by rhizomal growth.) This rate is highly dependent on species and environmental conditions and must be environmentally determined. Best estimates are achieved when a pre-impact growth study has been done in that area.

The remainder of this article discusses rationale, historical detail, methods, results,and economic cost analysis of planting seagrasses. More information can be found in Thorhaug and Austin (1977) and Thorhaug (1977).

INTRODUCTION TO THE IMPORTANCE OF SEAGRASSES

Although the marine environment is thought to be a place of high productivity, a great portion of the ocean has very low or no productivity. There are a few "hot spots," such as upwellings which provide a good deal of the total productivity of the oceans. Among these "hot spots" are the seagrass beds which colonize coastal areas of the marine environment. There are 12 genera of angio sperms which have adapted to the marine environment. Eel grass (Zostera marina) and turtle grass (Thalassia testudinum) are dominant, respectively, in the U.S. temperate and tropical to subtropical zones. On the east coast of the U.S. Zostera dominates southward to South Carolina. In Florida and the Gulf of Mexico Thalassia dominates, interspersed with Syringodium and Halodule.

Seagrasses function in the marine environment in several ways. First, they produce a great deal of organic carbon, much of which enters the food chain both by direct feeding and by detritus. Production estimates are 300 to 600 g dry weight per meter per year for turtle grass (Thorhaug and Roessler 1977). Secondly, the seagrass provides a shelter and place of attachment for many small animals which form the seagrass community. Third, the roots of the seagrass systems bind the sediment and also provide a baffle for particles so that they enhance the stability of the sediment beneath them, as well as the clarity of the water. And lastly, they act as a nutrient and trace metal cycling system for various elements in the marine environment.

Recently, there has been a series of studies on the ecology of both the temperate species Zostera and subtropical species Thalassia (Phillips 1960, 1972; den Hartog 1972; Thorhaug 1974; Thayer et al. 1975; McRoy and Helfferich 1979; Thorhaug and Roessler 1977). Several points of the ecology are important to restoration efforts. The seagrasses are found in the coastal regions of the world; high densities are usually found close to shore, particularly in bays, estuaries, and lagoons. The densest stands of seagrass occur very close to shore and density often decreases seaward. This pattern is unfortunate because man's impacts generally occur immediately adjacent to the shoreline; if the seagrasses were richer in the offshore waters the severity of man's impact on seagrasses might be lessened. Seagrasses support a rich community of invertebrates and fishes, indeed the Thalassia community is one of the richest known in the tropics, rivaling that of the coral reef in diversity and numbers of animals (de Sylva 1976; Voss 1976; Thorhaug and Roessler 1977). When the seagrasses are removed, the animal community becomes depauperate in those areas (Bader et al. 1972; Roesser et al. 1974; and Thorhaug et al. 1974).

Another major point is that after being removed, regrowth of seagrass occurs very slowly, especially for Thalassia, the dominant species in the subtropical and tropical climates. Revegetation rates vary among species of seagrasses. Thalassia testudinum has not recolonized in many areas in South Florida and the Caribbean even 50 years after it was removed.

NEEDS FOR RESTORATION OF SEAGRASSES

Why do we need to restore seagrasses? First, many marine and estuarine areas throughout the continental United States and Caribbean are increasingly being damaged by man's activities. Very often this damage occurs just adjacent to the shoreline where seagrass communities are present, and years or decades are required for them to return naturally to their former condition. The impact is often a combination of effects such as urban runoff, sewage, bulkheading, and others. It is in the public interest to restore thse biologically rich areas for recreation, sport and commercial fisheries, esthetic considerations, and sediment retention (worth $83,000/acre).

Second, it is important to restore seagrass into areas directly damaged in the past by building programs (such as filled areas for bridges and causeways or artificial land formations) accomplished before restoration techniques were available. Thirdly, the seagrasses are one of the few groups of marine plants known to have diseases. In the 1930's, most of the eel grass in the North Atlantic disappeared due to the "wasting disease"; changes in the populations of the associated animals occurred. The U.S. Fish and Wildlife Service pioneered the restoration efforts in the United States for seagrasses after the wasting disease. However, a solution was never found. It seems highly desirable to have techniques to replant seagrasses if this phenomenon occurs again.

HISTORY OF RESTORATION OF SEAGRASSES

The history of restoring seagrasses is in its infancy, compared to restoration of other plant systems, for the same reasons that major work in sublittoral marine botany is very recent compared to that of land botany. Seagrass restoration began almost simultaneous with the development of SCUBA equipment. In 1947 Addy attempted seagrass transplanting for the U.S. Biological Survey on the Northeast coast of the U.S. as well as between Pacific and Atlantic coasts to recolonize stocks denuded by wasting disease; there were no notable achievements and many transplants failed. In 1960 the Florida State Board of Conservation became concerned about the effect of real estate development in shallow bays. From 1960 to the present the latter organization has attempted transplants mostly with plugs (Fuss and Kelley 1969; Kelly et al. 1971; Phillips 1974, Phillips in this volume; and Van Breedveld 1976). Van Breedvelds' attempts with a posthole digger were the most successful.

Phillips in 1964 and 1965 conducted reciprocal transplant experiments across tidal zones in Puget Sound and transplants between Alaska and Puget Sound (Phillips 1974). An attempt at turfing seagrasses by Ranwell et al. (1974), who transplanted Zostera noltii and Zostera marina on a pilot trial scale in Norfolk and Suffolk, Great Britain on intertidal mud flats, was successful. The most promising method of large-scale restoration of seagrass communities has been by seed. The first large-scale restoration by seed was done by Thorhaug (1974) in Biscayne Bay, Florida. Thorhaug and Phillips are both presently working on transplantation techniques.

The objectives of this section of the paper are to review the techniques by which seagrasses have been transplanted and the success of some of these techniques, and to describe the problems encountered in restoring seagrasses so that the present state of restoration can be assessed for application of the Department of the Interior.

METHODS AND RESULTS

The major methods used for transplanting various species of seagrasses have been (1) plugs, (2) turfs, (3) individual mature plants (turions), and (4) seeds (see Table 1 for data of discussion below). A series of techniques, such as planting seagrasses with various anchors, chemical additivies, and shelter, have been attempted in various locations.

PLUGS

This method involves shoveling or otherwise removing (by a posthole digger) a piece of sediment with seagrass blades, roots, and rhizomes. This piece is transported intact to the recipient site where a second hole is dug and the piece inserted with an anchor or covered with sediment. Problems of this method are that the donor site is damaged, the process requires considerable manual labor, and the transplants have only been done intertidally or in very shallow water.

In a series of studies, the Florida Department of Natural Resources attempted to plant Thalassia and Halodule in Tampa Bay by plugging (Table 1). Kelly et al. (1971) attempted to correct the efforts of Phillips'turf work by anchoring and sheltering methods (Table 1). Among 120 plants transplanted in a previously dredged canal, only 6 out of 40 of their experimental plugs, and 16 out of 40 in the control area survived. Then Van Breedveld (1976) devised a more successful technique of plugs using a posthole digger. Success rates on the Van Breedveld experiments varied from 0-100% depending on the method that he used; however, using the posthole digger with a clump of sediment and planting in rows of three in early spring was the most successful method which had 100% survival. (He also concluded that the uses of hormones had not benefited the transplants.)

Larkum (personal communication) in Mortons Bay, Queensland, Australia, transplanted plugs of Zostera capricorna by digging plugs and placing them in holes, achieving a fairly high establishment rate.

TURFS

This method is like sodding a lawn. A piece of sediment and soil is cut out and stacked for transport. Then a shallow trench,into which the sod is placed, is cut at the recipient site. Phillips in 1960 (Phillips 1974) planted turfs (he called them sods) of Thalassia and Halodule. He had no success with Thalassia due to erosion by currents; some success was achieved with Halodule.

Ranwell et al. (1974) transplanted Zostera noltii and Z. marina v. angustifolia on mud flats near Norfolk, England, with a high rate of success. Initial trial examinations were followed by a second larger scale experiment, with the planting of 1,950 turfs in 0.9 ha (2.3 acres) in March. Zostera began growing in the transplanted areas within the next few months and some plants increased by 50% within 6 to 7 mo. The survival rate appeared to be about 100% in the first year and about 35% after 2 yr. The Zostera flowered and fruited and spread about two times the original size in the area.

Bachman in San Diego (unpublished report) transplanted a small group of Zostera; however, success rates were not reported. Larkum (1976) in Botany Bay, Australia, transplanted Posidonia australis and Zostera capricorna turfs both in the field and in the laboratory. These did survive although the success rate was not reported.

TURIONS

Turions are single blade groups with stem and rhizome attached. No attempt is made to include the apical meristem in a turion. Kelly et al. (1971) reported planting individual turions with the rhizomes removed. Eleven of 60 plants survived. In Washington, Phillips made reciprocal turion transplants which appeared to thrive and produced flowers and seeds as well as initiating new vegetative growth in the upper zones.

Table 1. Summary of seagrass restoration.

Method	Author	Place	Shelter	Number	Anchoring method	Chemical additive	Dimension of transplant	Success	Genus
Plugs	Kelly et al. 1971	Tampa Bay, Florida	Blocks	120	1. Tin can 2. Burlap bag 3. Wrap in polyethylene for transport	NAA	20 cm^2	Control 40% Exper. 15%	*Thalassia*
Plugs	Van Breedveld 1976	Tampa Bay, Florida	Rows of plants	266	30 cm substrate into hole	5% NAA 5% Root dip	30 cm deep posthole digger	0-100%	*Thalassia*
Plugs	Van Breedveld 1976	Tampa Bay, Florida	Rows of plants	15	30 cm substrate into hole	5% NAA 5% Root	30 cm deep posthole digger	100%	*Syringodium*
Plugs	Larkum 1976	Mortons Bay, Australia			Oug holes				*Zostera*
Plugs	Phillips 1960 Reported 1975	Tampa Bay, Florida	Concrete blocks, wood barricades	Not reported	Buried with soil	None	10 cm^2	Some	*Halodule*
Plugs	Phillips 1960 Reported 1975	Tampa Bay, Florida	Concrete blocks, wood barricades	Not reported	Buried with soil	None	10 cm^2	None	*Thalassia*
Turfs	Ranwell et al. 1974	Norfolk, England	-	20	Spaded into hole	-	22X15X 10 cm		*Zostera*
Turfs	Ranwell et al. 1974	Norfolk, England	-	1,950 into 2.3 acres	Spaded into hole	-	22X10X 15 cm	100% yr 1 35% yr 2	*Zostera* *Zostera*

continued

Table 1. (concluded)

Method	Author	Place	Shelter	Number	Anchoring method	Chemical additive	Dimension of transplant	Success	Genus
Turfs	Backman (unpubl)	San Diego, California	Wire screening	Not reported	Turf buried at site Screening Plastic trays	-	Not reported	Rhizomal growth	_Zostera_
Turfs	Larkum 1976	Botany Bay, Australia	-	Not reported	Dug holes	-	Not reported	-	_Zostera_
Turions	Kelly et al. 1971	Tampa Bay, Florida	Concrete block enclosures	60	Construction rods bricks, pipes	10% NAA	Single blade Group	18% in some	_Thalassia_
Turions	Phillips 1974	Whidbey Isle, Washington	None	243	Iron pipes & trenches	-	Single blade Group	Dependent on depth - 100% to none	_Zostera_
Turions	Eleuterius 1975	Biloxi, Mississippi		335 343 210	Mesh wire & and construction rods	-	45 cm X 45 cm	3% 3%	_Thalassia_ _Halodule_ _Cymodocea_
Seeds	Addy 1974a,b	Woods Hole, Massachusetts	None	-	None	-	Single seeds	No results reported	_Zostera_
Seeds	Phillips 1972	Friday Harbor, Washington	None	25	Iron rods & trenches	-	Single seeds	None	_Zostera_
Seeds	Thorhaug 1974	S. Biscayne Bay, Florida	None	6,000	Plastic	10% NAA	Single seeds	80%	_Thalassia_
Seeds	Thorhaug 1974	N. Biscayne Bay, Florida	None Peat pots	600	Plastic	10% NAA	Single seeds	15-55%	_Thalassia_

Plants at lower depths decreased and then died.

SEEDS

Addy in 1947 planted Zostera seeds but the plants did not grow. Phillips planted 45 Zostera seeds in Puget Sound anchored to iron pipes with rubber bands and had no success, probably because the seeds were transplanted from shallow water to depths deeper than Zostera generally grows in the area, indicating that seedlings may have high light requirements.

One of the most successful seeding methods to date was that of Thorhaug (1974). Roots were gathered by hand from densely fruiting beds in the Caribbean. They were immediately dehisced and the seeds separated from the fruit pods. Seeds were transported back to Miami under running seawater conditions. Some of the seeds were kept in a nursery while others were immediately planted. Various growth-promoting chemicals were used. NAA soaks at 10% for 1 hr appeared to have significantly increased root propagation of the seedlings. Long soak times and higher concentration of this auxin did not appear to affect the root growth significantly.

Planting techniques include plastic 12-cm (5-inch) anchors (with monofilament attached to locate the seedlings) secured about each seedling. Two parallel corridors (150 by 6 m or 492 by 20 ft) were planted at the Turkey Point Power Plant discharge canal, Biscayne Bay, Florida, in a 9.3-ha (23-acre) area previously denuded of Thalassia and other microphytes by heated effluents. (Offstream cooling was employed at the time of planting, so that thermal effluents were no longer being released.) Previous to thermal discharges, this area had supported a lush meadow of seagrasses. Seedlings began growing immediately upon dehiscing. Up to 10 roots per plant appeared in the first 3 weeks, which enabled the plants to begin to anchor themselves. After 4 mo, one apical meristem per plant appeared on 50% of the seedlings. After 5 mo, 89% of the seedlings had apical meristems.

Thousands of seeds were planted in mid-September 1973 at various intervals: 0.25, 0.1, and 0.5 m (0.82, 0.33, and 1.64 ft). Leaf growth was vigorous in the months immediately following the planting. New short shoots were sent up from the rhizomal apical meristem after 9 mo, and apical meristems were between 0.3 to 0.5 m (1 to 1.6 ft) (Table 2). Leaf and rhizome growth was vigorous after 8 mo; roots per blade group were 8.6 cm (3.4 in) with a maximum length of roots 14.0 cm (5.5 inches). After 2.5 yr dense areas of Thalassia with 500-1,000 blades/m^2 (46-93 blades/ft^2) had developed in the transplanted areas whereas control areas had 0 to 10 blades/m^2 (0 to 1 blade/ft^2). The percentage of success was approximately 80%, which was higher than most of the other methods. Twenty-one percent of the plants were missing, and it is estimated that 10% of these missing plants remained in an area of several hundred feet surrounding the planted matrix.

Observations showed that the animal community began reestablishing itself almost immediately after the transplants were set. Foraminifera covered the young seedling blades. Fish, certain crustaceans, and mollusks moved back into the area. (There has been no quantitative study of animal community reassemblage on any seagrass transplant effort.) The Thalassia planted in a Halodule zone appeared to grow more vigorously in the first few months than that planted in a zone of green algae (chiefly Penicillus capitatus), or that planted in a bare peat zone.

The major result from this large-scale planting was that plants expanded laterally in a vigorous manner within the first year (rhizome length growing to 0.5 m [1.6 ft] while sending up many short shoots with further blade groups). After 2.5 yr the transplant area was covered with moderately dense Thalassia. We are continuing to study this succession and hope to begin studying the animal community in the restored versus natural and nonrestored areas.

A second seedling feasibility study was made in North Biscayne Bay, Florida. Areas included dredge spoil islands; bottoms damaged by sewage pollution, by dredging or general urban runoff; areas of high tidal currents; and areas of shifting sand. Feasibility plots of 0.25 m^2 (2.6 ft^2) were planted in fall

Table 2. Planted *Thalassia testudinum* seedling growth (N=130) from late August 1973 to early March 1974 at Turkey Point, Biscayne Bay, Florida (from Thorhaug 1974).

	Mean length (cm)	Maximum length (cm)	Minimum length (cm)	% of samples with plants attaining such mean
Longest leaf on primary shoot	16.5±4.0	29.6	8.2	100
Longest leaf on second shoot	7.4±4.8	18.0	2.3	54
Longest leaf on third shoot	6.0±5.5	15.1	1.5	18
Longest leaf on third shoot	6.9±8.3	12.7	0.3	4
Rhizome length	4.7±2.5	8.2	0.0	89
Longest root length	6.8±2.8	17.0	3.2	100
Total number of roots	8.6±2.6	14.0	2.0	100

1974 and spring 1975. Survival rates after 6 mo ranged from 0% to 52.5%. Areas of low survival included (1) those with strong tidal currents, (2) those with wave action from boats on the intercoastal waterway causing high turbidity as well as physical impact to the seedlings, and (3) a submerged dredge island which was eroding with shifting and unconsolidated sediments. Areas most amenable to seedling growth included low energy peaty bottoms or sandy consolidated bottoms, especially in areas where a pioneer seagrass species such as *Halodule* or *Syringodium* had already begun to recolonize after the impact (Thorhaug and Hixon 1975).

ECONOMIC ANALYSIS

The following discussion is from Thorhaug and Austin (1977). The defined objective of planting seagrass is to achieve a given "cover" that will reduce erosion, siltation, and turbidity, and to improve the habitat for marine organisms. Therefore, the cost analysis is in terms of dollar costs to achieve a given cover for a given size area (bottom)in a given time period. The costs of the three propagation phases (collection, nursery, and planting) are related to the number of seeds to be handled. The first objective is to determine the number of seeds required for the project. Five pieces of information are required to estimate the required number of seeds:

1. natural mortality rate of the seeds planted
2. natural growth rate (lateral expansion rate) of an individual plant
3. the desired "cover" to be achieved
4. time period permitted to achieve the desired cover
5. size of the area (bottom) to be planted

The first two variables are determined by environmental conditions at the planting site (e.g., depth, turbidity, temperature, wave energy level, and type of bottom). The third, fourth, and fifth variables are policy decisions. Presumably the desired cover would be similar to cover indigenous to the area as determined by what existed in another area with similar conditions or from knowledge about what previously existed at the planting site. The time permitted to achieve the cover is an arbitrary policy decision, but it has a significant influence on the number of seeds that must be planted.

The monetary costs of restoration depend on three types of variables. The first set of variables are environmental parameters determining the natural mortality and growth rates of the seeds. The second type variables are policy decisions relating to the size of the area to be planted and the time period permitted to achieve a desired cover of grass. The third type variables relate to the dollar cost of collecting, nursery work, and planting the number of seeds dictated by the first two types of variables.

DISCUSSION

Tropical and subtropical estuaries are different from that of northern estuaries where one can dump a slug of heavy metals or heated effluent on a phytoplankton-based food chain for a few days. In northern latitudes, if one stops dumping the heavy metals or the heated effluent, the photoplankton will renew itself and within a short time the food chain can be reestablished. In contrast, there are situations in Biscayne Bay, Florida, where the entire food chain has been completely disrupted by man's activities for decades after the disruption ceased.

I would also like to point out that the plants involved are the tropical and semitropical grasses. I have previously said that the semitropical-tropical regions are more fragile ecosystems than the temperate (Thorhaugh 1976). This fragility is unfortunate because most of the activity in terms of managing estuaries and nearshore waters has occurred in the temperature zone. The principles gained from northern studies do not always relate to the tropics because the tropics probably are the place where life began. If these tropical organisms, which are geologically very old, were able to migrate out of the tropics, they probably would have; but they are there now because they are less flexible than more northern ones.

The best example of intolerance of tropical seagrasses is their response to heated effluents. The best known standards of how much heat could be released (based on experience in temperate zone rivers and offshore waters) were applied to southern Florida. The test was a dismal failure. South Florida has a much more fragile ecosystem and organisms could not withstand the same heat increases that ecosystems in temperate waters could withstand. Government agencies must be particularly careful attempting to apply criteria of plant tolerance to trace metals or dredging in temperate waters to situations in the tropics, reasoning backwards from the more complex temperate to the simple ecosystem of the tropics.

I would like very briefly to discuss the alternatives. I disagree with Dr. Phillips' statement ("Creation of Seagrass Beds" in this volume) that we should plant _Halodule_ rather than _Thalassia_ because _Halodule_ grows faster. I feel there are extremely important unknowns yet to be determined about restored _Thalassia_ versus restored _Halodule_ before we can responsibly make that statement. For example, does _Halodule_ support the same animal communities that the _Thalassia_ does? Most of the arguments about restoration of seagrasses are based on the fact that one is disrupting the animal community, the fisheries potential, or the food web. We have no evidence for this at all in the case of _Halodule_ because there has been no intensive study on the animal community associated with _Halodule_. There have been many studies in various areas on the animal community associated with _Thalassia_. We do know that pink shrimp, the stone crab, and many other desirable animals leave (see Thorhaug and Roessler 1977 for a review or Thorhaug et al. 1973).

A second question centers around restoration of _Halodule_. Is one restoring the same animals with a restored _Halodule_ community that one would be if one restored _Thalassia_? This is a different question from what is originally in an untouched community of _Thalassia_. A third question is, under various conditions what is the _Halodule_ root system really going to do to stabilize the sediment. Stabilization is one of the effects most desired in restoration, and _Halodule_ does not seem to function as effectively as _Thalassia_ as a sediment stabilizer in regrowing areas. Fourth, there are many areas where _Thalassia_ is just naturally not going to regrow so there must be some effort to reestablish _Thalassia_. In other places it may reseed over a long period, but can we wait for it to naturally reseed or revegetate? My suggestion might be to plant a mixed community in these semitropical and tropical areas. In such a situation one would not plant as much _Thalassia_ because it is more expensive to plant than _Halodule_. _Halodule_ would start to form a cover and then one would come back in to restore _Thalassia_.

The cost analyses that have been done on the only scale experiments to date are for _Zostera_ and _Thalassia_. _Zostera_ was restored in England with the free labor of prisoners and students. Thus, the most expensive item, labor, was avoided. This effort really represented a bare minimum. When added up, it was about $2,500/ acre to actually plant 2,000 turfs, so it was a large-scale experiment. However, it should be noted that it was done intertidally, which is always less expensive than in submerged areas. There was no formal economic analysis of this, simply a totaling of expenses.

The Florida Board of Natural Resources has attempted to restore _Halodule_ and _Thalassia_, for which they have estimated that it is necessary to plant 186,000 plugs of _Thalassia_ per acre in order to get the kind of cover that the Board of Natural Resources desires. According to their unpublished estimates (Van Breedveld, personal communication) which use minimum labor costs (which I believe are unrealistic based on other restoration efforts [see Terynk in these proceedings] because you are not going to find people who will stand for 12 hr, chest deep in freezing water, to plant these seagrasses for $2.30), the cost will be about $50,000 an acre by the plugging method.

Our estimates for _Thalassia_ (given in detail by Austin in Thorhaug and Austin 1977), based on about 7,000 _Thalassia_ having been planted in about 15,000 m^2 using the seeding method, range at the moment (depending on many factors, and without mechanization) between $2,000 and $8,000 an acre after 3 to 4 yr.

Planting seagrasses is not cheap. We are working now on mechanization, growth-promoting hormones, and fertilizers, things that should speed growth, lessen mortality, and lessen the cost.

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COASTAL HABITAT DEVELOPMENT IN THE DREDGED MATERIAL RESEARCH PROGRAM

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INTRODUCTION

The Dredged Material Research Program (DMRP) is being conducted at the Corps of Engineers Waterways Experiment Station at Vicksburg, Mississippi. As manager of the Habitat Development Project, I plan, manage, and carry out the habitat development aspects of DMRP. Realizing your differing levels of acquaintance with the program, I will present an overview of the DMRP and then concentrate on the habitat development aspects. See Table 1.

Dredging the navigable waterways of the United States is important to the Nation's economy and vital to creating and maintaining the channels, harbors, and associated facilities that accommodate the large volume of domestic and foreign waterborne commerce. The primary purpose of most of this dredging is to maintain a designated channel or area at a predetermined water depth by removing bottom accumulations. These accumulations are the result of discharges and erosion, transport, and deposition often influenced by storms and flooding and augmented by man's actions.

Principal responsibility for navigation facility maintenance and improvement is vested in the Corps of Engineers. With its own equipment or by contract, the Corps periodically dredges thousands of kilometers of waterways and hundreds of commercial port facilities and small boat harbors assigned to it by Congress for maintenance. The annual costs of waterways maintenance are approaching $250 million and annual maintenance dredging volumes exceed 214,100,000 m^3 (280,000,000 yd^3). The new work portion approximates $50 million and 61,200,000 m^3 (80,000,000 yd^3) annually.

The large volumes of dredged material often present extraordinary disposal problems. In the past, economics was the almost exclusive criterion used in determining disposal location and method. However, during the past decade, environmental impact has become a significant criterion and, from a practical standpoint, the one controlling many dredging projects. Although limited, some procedures and technology do exist and are being used to avoid or reduce adverse environmental impacts; however, the real problem lies elsewhere. With few exceptions, the state of knowledge and site-specific studies have failed to provide definitive information on what constitutes an adverse impact caused either by nature of the material or the mode of disposal. Hence, opinions and actions regarding dredging and disposal often are based almost entirely on fears of unknown consequences rather than facts; decisionmakers have had no way to quantify effects or determine alternatives for rational solutions to problems.

To better depict the scope of the dredging effort and its potential environmental impact throughout the continental United States, it is necessary to understand that annual dredging requirements by Corps Districts vary considerably. The largest volume, which is nearly 151,470,000 m^3 (198,100,000 yd^3), is dredged in the Lower Mississippi Valley Division, while one of the smallest requirements is the New England Division's 1,836,000 m^3 (2,401,000 yd^3). Dredging costs, however, present an entirely different picture. Although the national average cost per cubic yard is still well under $1, geographically the

[1] This same report was presented at the 42nd North American Wildlife Conference.

Table 1. Dredged Material Research Program, Technical Structure.

Project/Task		Objective
Environmental Impacts and Criteria Development Project		
1A	Aquatic Disposal Field Investigations	Determine the magnitude and extent of effects of disposal sites on organisms and the quality of surrounding water, and the rate, diversity, and extent such sites are recolonized by benthic flora and fauna.
1B	Movements of Dredged Material	Develop techniques for determining the spatial and temporal distribution of dredged material discharged into various hydrologic regimes.
1C	Effects of Dredging and Disposal on Water Quality	Determine on a regional basis the short- and long-term effects on water quality due to dredging and discharging bottom sediment containing pollutants.
1D	Effects of Dredging and Disposal on Aquatic Organisms	Determine on a regional basis the direct and indirect effects on aquatic organisms due to dredging and disposal operations.
1E	Pollution Status of Dredged Material	Develop techniques for determining the pollutional properties of various dredged material types on a regional basis.
2D	Confined Disposal Area Effluent and Leachate Control	To characterize the effluent and leachate from confined disposal facilities, determine the magnitude and extent of contamination of surrounding areas, and evaluate methods of control.
Habitat Development Project		
2A	Effects of Marsh and Terrestrial Disposal	Identification, evaluation, and monitoring of specific short-term and more general long-term effects of confined and unconfined disposal of dredged material on uplands, marsh, and wetland habitats.
4A	Marsh Development	Development, testing, and evaluation of the environmental, economic, and engineering feasibility of using dredged material as a substrate for marsh development.
4B	Terrestrial Habitat Development	Development and application of habitat management methodologies to upland disposal areas for purposes of planned habitat creation, reclamation, and mitigation.
4E	Aquatic Habitat Development	Evaluation and testing of the environmental, economic, and engineering feasibility of using dredged material as a substrate for aquatic habitat development.
4F	Island Habitat Development	Investigation, evaluation, and testing of methodologies for habitat creation and management on dredged material islands.
Disposal Operations Project		
2C	Containment Area Operations	Development of new or improved methods for the operation and management of confined disposal areas and associated facilities.
5A	Dredged Material Densification	Development and testing of promising techniques for dewatering or densifying dredged material using mechanical, biological, and/or chemical techniques prior to, during, and after placement in containment areas.
5C	Disposal Area Reuse	Investigation of dredged material improvement and rehandling procedures aimed at permitting the removal of material from containment areas for landfill or other uses elsewhere.
6B	Treatment of Contaminated Dredged Material	Evaluation of physical, chemical, and/or biological methods for the removal and recycling of dredged material constituents.
6C	Turbidity Prediction and Control	Investigation of the problem of turbidity and development of a predictive capability as well as physical and chemical control methods for employment in both dredging and disposal operations.
Productive Uses Project		
3B	Upland Disposal Concepts Development	Evaluation of new disposal possibilities such as using abandoned pits and mines and investigation of systems involving long-distance transport to large inland disposal facilities.
4C	Land Improvement Concepts	Evaluation of the use of dredged material for the development, enhancement, or restoration of land for agriculture and other uses.
4D	Products Development	Investigation of technical and economic aspects of the manufacture of marketable products.
5D	Disposal Area Land-Use Concepts	Assessment of the technical and economic aspects of the development of disposal areas as landfill sites and the development of recreation-oriented and other public or private land-use concepts.

NOTE: This technical structure reflects the second major program reevaluation made after the second full year of research accomplishment and is effective as of August 1975.

cost varies over a wide range and is rising steadily. The dredging and disposal cost is highest in New England, nearly $5/yd^3$. The cost in the Lower Mississippi Valley is lowest, just under $0.40/yd^3$. Note that this is an inverse situation from the total amounts of dredged material listed above. Thus, the scope of the problem, in an economic context, does not correlate proportionately to the quantities. In some locations, the cost has risen to over $10/yd^3$.

The tremendous range of dredging and disposal costs is due to several factors. A large percentage of dredged material is fine-grained sediment and, as a consequence, it is a natural sink for contaminants resulting from urban and agricultural runoff, domestic and industrial sewage, and other polluting sources. Sediments dredged from waterways once were most commonly disposed of in open water or on marshes. But now, because of some known consequences of dredging and disposal, and a concern over the unknown consequences of such actions, the general practice has been to confine contaminated materials on land behind dikes. In many areas, this has increased the cost of the operation by a factor of at least 10.

In 1970, Congress passed legislation that called for an interim 10-yr program of building confined disposal facilities to retain all contaminated material from the harbors in the Great Lakes. With the anticipated cost of this program for this one region of the U.S., estimated at approximately a quarter of a billion dollars, Congress recognized a need to understand far better what are truly the environmental effects of dredged material disposal. Consequently, the same legislation that mandated the Great Lakes diking program included authorization for a comprehensive, nationwide research program to provide much needed answers. Hence, the DMRP was established as a multi-objective research plant that would require 5 yr and $30 million to complete. The program began in 1973 and was completed in March 1978.

Insofar as environmental effects are concerned, the DMRP is as concerned with disposal in upland and wetland areas as it is with open-water disposal. It is concerned with the productive use of both the dredged material and the disposal sites. Principal emphasis is on marsh and habitat development as the most promising productive or beneficial disposal alternatives. Realizing that confined land disposal is a viable alternative, the DMRP is concerned with improving the effectiveness, acceptance, and environmental compatibility of confined disposal and making it more economical. The program has been divided into four project areas: the Environmental Impacts and Criteria Development Project, the Disposal Operations Project, the Productive Uses Project,and the Habitat Development Project. I will briefly touch on the first three projects and then proceed to a more detailed discussion of the Habitat Development Project.

ENVIRONMENTAL IMPACTS AND CRITERIA DEVELOPMENT PROJECT

The Environmental Impacts and Criteria Development Project is the focal point for research about the effects on water quality and aquatic organisms of both land and open-water disposal as well as land containment of dredged material.

Aquatic Disposal Field Investigations are a principal concern of this project. Four major field investigations of the physical, biological, and chemical impacts of open-water disposal are being conducted in the Pacific Ocean off the mouth of the Columbia River, Oregon; the Gulf of Mexico off Galveston, Texas; Lake Erie off Ashtabula, Ohio; and an estuarine site near the Duwamish Waterway in Elliott Bay, Seattle, Washington. To date, the baseline research and controlled disposal investigations are completed and the post-disposal monitoring is currently underway at all four sites.

Another concern of this project is the short- and long-term movements of dredged material in open water. A mathematical estuarine dispersion model has been developed and is presently being field verified. The objectives of the field study are to quantitatively define the physical processes by which dredged material released from a barge, hopper-dredge, or pipeline is conveyed to, and emplaced upon the bottom at selected sites and how the data compare with mathematical simulation outputs from the model.

Short-term, high-intensity laboratory elevations have been completed to determine the effects of contaminated dredged materials on the water column. Results of these laboratory studies show that acute chemical effects on the water column range from insignificant to completely nonexistent. Much of the controversy associated with mobilization of a wide range of contaminants is unfounded and was not shown to occur in a broad range of sediment and water conditions. Only ammonium, iron, and manganese were shown to be released to the water column in quantities significantly greater than background. These findings are being tested in the field investigations which I previously mentioned.

Laboratory tests on the chemical stability of sediment water systems cannot be directly related to the response of organisms. In studying the response of selected organisms to the physiochemical conditions, we have found that many of the projected impacts associated with open water disposal were unfounded fears. However, this task has delineated certain areas of significant ecological concern.

Vertical migration investigations have shown that representative bottom-dwelling organisms have a significant ability to migrate upward through coverings of various depths of dredged material. Those organisms most severely impacted are sand-dwelling organisms that have a clay-like sediment deposited on them, and mud-dwelling organisms covered with sandy dredged material. This indicates the desirability of choosing a disposal site.

Heavy metals availability to benthic organisms from the solid phase portion of dredged material is currently under study. Preliminary results using grossly contaminated Houston Ship Channel sediments indicate a general toxicity of the sediments, but uptake of a wide selection of heavy metals was not occurring.

The final task area that I am going to mention in this project is concerned with the environmental impact created by placing dredged material in containment areas, as well as sanitary landfills and quarries that could be disposal areas under some of the various beneficial use concepts being explored. The main goal is to determine if contaminations introduced into these confined areas through dredging and disposal will be immobilized, with negligible long-term release, or be discharged in environmentally unacceptable quantities with the effluent or leachate. Effluent is released almost continuously for several weeks during the filling of most disposal areas. This effluent could result in chronic discharge problems in confined bodies of water. Following filling of a land disposal area, short- or long-term leaching could potentially mobilize chemical constituents from the dredged material and threaten surface and groundwater quality.

DISPOSAL OPERATIONS PROJECT

Most of our engineering or operations research effort is being conducted by the second project, the Disposal Operations Project. This project is primarily concerned with improving the efficiency of dredged material disposal. Several aspects of this project include dike design and improvement of dewatering techniques, landscaping of disposal sites, silt curtain performance, and treatment of contaminated, dredged material. Because participants interests at this workshop are primarily biological, I have elected to devote little time to this project.

PRODUCTIVE USES PROJECT

The basic philosophy for the third project of the DMRP, the Productive Uses Project, is to develop new or innovative disposal methods, primarily on land, to provide disposal alternatives which derive maximum value from the resource potential of dredged material. To provide the information necessary, the Productive Uses Project is responsible for investigating viable productive uses of dredged material, or where environmental considerations preclude its use, the evaluating of new concepts for disposal in upland areas. Specifically, the project is divided into the four tasks. The tasks are upland disposal of dredged material at long distances from the dredging project; the use of dredged material for land enhancement whether as a landfill material or as a soil; the development of products such as shrimp, lawn sod, or horticultural crops grown in dredged material; and, finally, with the development of disposal areas into recreational or commercial sites.

A major effort in this project is to identify, in a categorical sense, potential disposal areas at remote inland locations some distance from the dredging operations; to examine components of an inland transport system; and to assess environmental, technical, economic, and institutional factors associated with upland disposal. An example would be the use of abandoned pits or quarries, both as a disposal option and a significant land use benefit.

The concept of the beneficial use of dredged material for land improvement, especially in agriculture, appears promising. Under this task the physical and chemical qualities of dredged material as a soil base or amendment will be evaluated. Another potential use of dredged material is for sanitary landfill cover. Presently sanitary landfill cover can be purchased for up to \$6.54/m^3 (\$5/yd^3). In some cases, the use of dredged material would be economically competitive.

The Productive Uses Project is also exploring possibilities of manufacturing marketable products of commodities from dredged material or using disposal sites for similar activities. Products manufacture (e.g., ceramics or bricks) has not proven feasible on a scale which could significantly affect large quantities of dredged material. In some isolated cases the manufacture of a synthetic aggregate may be worthwhile.

A recently completed study dealt with the feasibility of using disposal areas for growing land sod or horticultural products. The study found that there is a considerable demand for such products, particularly near large urban centers, and in some cases this may be a feasible alternative.

The potential for mariculture of shrimp and other commercially valuable species is being investigated by Dow Chemical Company. Dredged material was transferred to two 0.10-ha (0.25-acre) ponds located within Dow's facilities at Freeport,Texas, and about 0.3 m (1 acre) of material was placed in each pond. Two similar ponds received no material and were designated control ponds. After an initial fertilization to stimulate algal growth, about 10,000 juvenile shrimp were placed in each of the four ponds. No other food was added throughout the experiment. Previous shrimp mariculture work indicated that the survival rate should be 50% or greater. All four ponds were harvested after 3 mo. Over 75% of the shrimp survived, and those raised on dredged material were significantly larger than those in the control ponds.

The disposal area land-use concepts task is assessing the technical and economic aspects of developing disposal areas as landfill sites. We have also included the development of recreational areas and other public or private land-use concepts.

HABITAT DEVELOPMENT PROJECT

The final project, the Habitat Development Project, is divided into five tasks: (1) the effects of dredged material disposal on marsh and terrestrial habitat, (2) marsh development, (3) terrestrial habitat development, (4) aquatic habitat development, and (5) island habitat development. These tasks are closely related and often grade naturally into one another.

The basic emphasis of these tasks can be summarized in two main objectives: to determine the environmental impact of habitat development and to evaluate habitat development as a disposal alternative.

Major emphasis is being placed on the first task, determining the effects of disposal in marsh and terrestrial areas. To a larger extent, all of the work in the Habitat Development Project relates to this task. The environmental impacts of dredged material disposal and habitat creation at all of our field sites are being carefully evaluated, and this information will form the basis of most of our findings and conclusions relative to impact assessment. In addition to the field studies, much of the ongoing work in impact assessment is directly related to heavy metal and nutrient cycling research which will be discussed under the marsh development task. See Figure 1.

A typical example of research being conducted in this task area is a study at St. Simons Island in Georgia, to determine the effects of smothering on marsh grasses. In this study, Spartina alterniflora, the dominant salt marsh grass, is being subjected to disposal of sand, silt, and clay dredged material at controlled depths from 7.6 cm (3 inches) to 1 m (3.3 ft). The experiment will be repeated during the dormant, growing, and reproductive seasons to interpret seasonal impacts. The impact of these disposal applications will be determined by changes in marsh productivity and succession.

The development task is the principal thrust of the Habitat Development Project. We have, or have attempted, field studies at Branford, Connecticut; in the James River, Virginia; in the Potomac River near Washington, D.C.; on the coast on the Bolivar Peninsula, Texas; in San Francisco Bay; at Miller Sands in the Columbia River; and at Grays Harbor, Washington.

The field site at Branford, Connecticut, was terminated last October. We had intended to develop a 3.2-ha (8-acre) marsh as an extension of the existing marsh, thereby disposing of 30,600 m^3 (40,000 yd^3) of fine-grained, contaminated dredged material. From its conception, this project met with substantial local opposition, and, despite numerous safeguards and assurances, we were never able to gain community approval. The most common concern voiced by opponents was that the newly created marsh might, because of its experimental nature, threaten real estate values in the area. Other concerns were odor, danger to neighborhood children, and mosquitoes. Repeated delays finally placed the project in an untenable time frame which resulted in its cancellation.

A 5.6-ha (14-acre) marsh development site in the James River, Virginia, was built last year by taking 53,550 cm^3 (3,207 $inches^3$) of contaminated fine-grained dredged material from the navigation channel and confining it behind a hydraulically placed sand dike. We had intended experimental planting on this site, but Mother Nature was more efficient, and by July of the first growing season, the area had naturally vegetated. Fortunately, a desirable mix of wetland species developed including arrow arum (Peltandra virginica), pickerel weed (Pontederia cordata), and arrowhead (Sagittaria spp.). The main thrusts of research at the James River site now involve the potential uptake of contaminants by plants growing on the dredged material and documentation of the biological productivity of the site. These studies should result in important findings regarding the environmental impact and feasibility of marsh development as a disposal alternative.

We have a potential marsh development site quite close to Washington, D.C. at Dyke Marsh on the Potamac just south of Alexandria. This area was extensively mined for gravel in the 1930's, and during these mining operations a considerable portion of Dyke Marsh was destroyed. Ownership of the area has since passed to the Government, and the National Park Service has a Congressional mandate to restore Dyke Marsh to its original configuration. We have entered into a cooperative study with the Park Service, the Corps' Baltimore District and the Fish and Wildlife Service to evaluate the feasibility of using dredged material from the Potomac River as a substrate for marsh establishment at this site.

The marsh will be restored by placing approximately 229,500 m^3 (300,000 yd^3) of dredged material, covering 11.3 ha (28 acres) at an intertidal elevation behind a sand dike. The feasibility phase of this study will be completed May 1976. If the project proves feasible, and agency and public support is obtained, we will proceed to the detailed design phase. If this project is completed, approximately 10% of Dyke Marsh will be restored to near-original conditions.

A former dredged material island at Buttermilk Sound on the Georgia coast was selected for study. We have established a 1.2-ha (3-acre) salt marsh at this site by shaping a mound of dredged material so that approximately half was intertidal. More than 800 plots have been established at this site to test the survival and productivity of eight plant species at three tidal elevations, under four fertilizer regimes. This project is also designed to obtain data

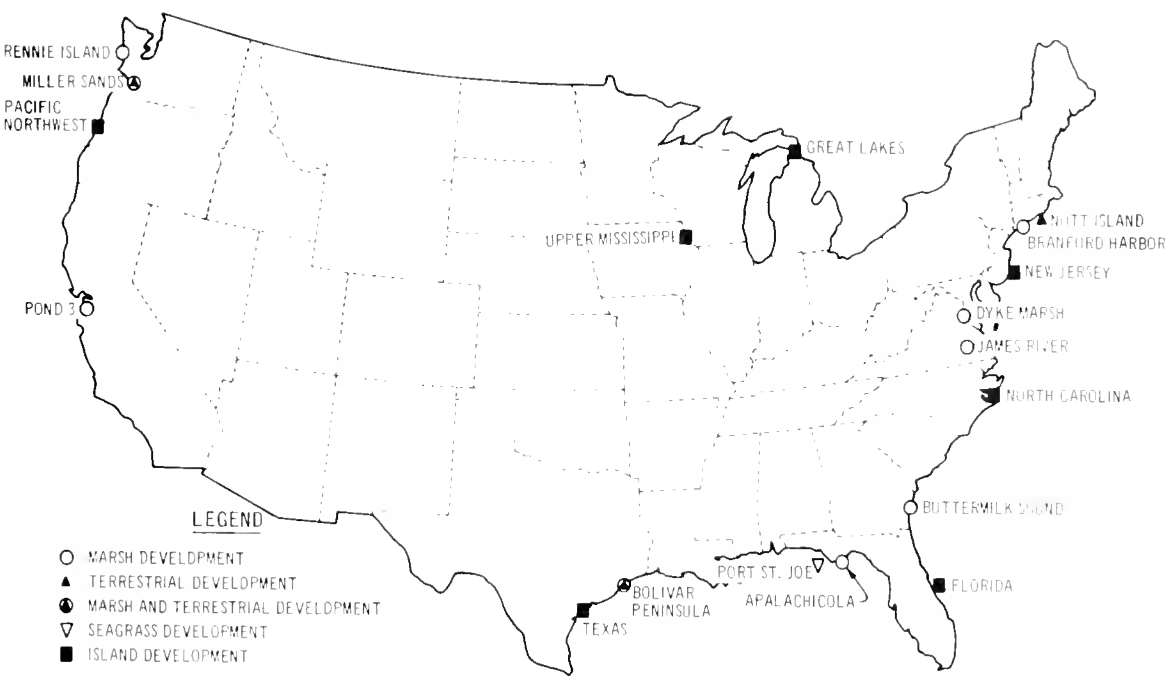

Figure 1. Location of dredged material research program habitat development field studies.

on nutrient cycling in the marsh systems. Another aspect of the research there involves substrate stabilization and productivity in the algal mat that is often characteristic of marsh communities. I should mention that the University of Georgia is conducting this research.

We have a salt marsh site near Galveston, Texas. Dredged material is routinely removed from the Intracoastal Waterway and pumped into Galveston Bay. We plan to establish a marsh on this dredged material by enclosing 4.8 ha (12 acres) with a sand bag dike to provide protection from high wave energies. The sandbags are each 3 x 1.2 x 0.6 m (10 x 4 x 2 ft)and weigh about 3 kg (7 lb) when full.

A problem on Bolivar Peninsula is a very large population of feral goats. Consequently, we will be enclosing the area with (hopefully) goat-proof fence. Texas A&M University has been awarded the contract to establish marsh on this area, and they will be planting this month. The major emphasis at this research area will be to determine fertilizer requirements for two salt marsh species, *Spartina patens* and *S. alterniflora*, and to carefully evaluate benthic colonization of an artifically propagated area.

Those who are familiar with the San Francisco Bay area are certainly aware that a great deal of the Bay has been converted to residential or commercial purposes. Thousands of hectares in South Bay have been diked for salt production. About 2 yr ago the Corps' San Francisco District filled one of these salt ponds with dredged material,intending to make a marsh. The District has since entered a cooperative program with the DMRP, and the site has been planted in common West Coast marsh species. Approximately 2 ha (5 acres) were planted from a tractor-mounted seeder and a total of 4 ha (10 acres) was seeded. One technique tested there was the use of erosion control paper to hold the seeds in place. The research at this site is directed toward determining salt marsh productivity on fine-grained materials, determining optimum spacing for propagation, and testing various seeding techniques.

Earlier I mentioned a marsh site at Grays Harbor, Washington. That project was terminated after the baseline studies indicated that extremely high energy conditions at the site would make marsh development unfeasible from engineering and economic standpoints.

We have a freshwater site at Miller Sands in the Columbia River in Oregon. We are now planning to test three species of marsh grass covering 2.4 ha (6 acres) at the site. If this proves successful, approximately 121 ha (300 acres) of marsh could be placed at the site.

An integral part of our marsh research has been a series of detailed studies into the productivity and site selectivity of various marsh species throughout the United States. The major part of this research has been conducted by the Louisiana State University, the University of Georgia, and the University of Virginia. A major emphasis of the studies has been the determination of the productivity of so-called minor marsh plants. Together with our field studies, we have conducted greenhouse experiments on marsh productivity on various dredged material substrates.

The potential of contaminant uptake by marsh plants growing on contaminated dredged material is a major concern and is being addressed by a 3-yr study. We are mid-way in this research, with the main thrust being the development of an extraction procedure that will enable us to predict plant uptake of contaminants from dredged material.

Another major task is the development of biologically desirable habitat on dredged material placed above the high tide line. The product of these studies will be guidelines for the selection or reclaiming of disposal sites for wildlife use. An important part of this effort will be the establishment of a methodology for selecting target species and desired habitats. Necessary information will be provided on edaphic factors, plant requirements, and target species management.

Upland habitat development field studies are now underway at Nott Island, Connecticut; on the Bolivar Peninsula, Texas; and on Miller Sands in the Columbia River. All of these studies address the problems of establishing productive habitats on high sandy, and therefore, droughty, disposal sites.

Nott Island is located in the Connecticut River, about 11 km (7 mi) from its confluence with Long Island Sound. Upland disposal of sandy dredged material from the navigation channel is a historic problem in this area. A 3.2-ha (8-acre) site was established on Nott Island last year. The area is confined by a 2.1-m (7-acre)sand dike and we have filled the site with 22,950 m^3 (30,000 yd^3) of coarse-grained material from the navigation channel. To improve the agronomic characteristics of this substrate, we have top dressed the area with 3,825 m^3 (5,000 yd^3) of fine-grained material from a nearby recreation channel. The area will be planted in the spring and fall with plant species that will provide highly desirable pasture for Canada geese (Branta canadensis).

Another study at the Nott Island site is the stabilization of this sandy dredged material and its eventual conversion to desirable wildlife habitat. A third effort at Nott Island involves the development of techniques for control of reed grass (Phragmites communis). This species has little wildlife value in that area and is a vigorous invader on upland disposal sites.

In addition to the marsh development site near Galveston, Texas, a part of the research there also involves the reclamation of this upland disposal site. Our studies there are evaluating the success of several desirable wildlife plant species under a series of fertilizer regimes. Upland plants will include pine, honey locust (Gleditsia triacanthos),smooth sumac (Rhus glabra), and bluestem and panic grasses.

We have a 20-ha (50-acre) upland habitat site in conjunction with our marsh development at Miller Sands in Oregon. This site will be developed as nesting habitat for Canada geese.

The objective of the aquatic habitat development project is to establish tidal flats and seagrass beds on dredged material and to evaluate the bottom so that it is in the photic, but subtidal zone. In many cases, elevating the bottom with dredged material would significantly increase the biological productivity of a site. The planning phase of aquatic habitat development has been completed and it appears that research will take the form of a state-of-the-art survey of the potential for dredged material stabilization by seagrasses. It is too late in the DMRP to undertake a major field research effort in this area. However, if our initial studies indicate that dredged material stabilization is a promising disposal alternative, it will receive increased attention before the completion of this project.

Our island habitat development task is designed to assess the importance of dredged material island habitat to wildlife, particularly shore birds. There is evidence indicating that dredged material islands provide exceptionally important nesting habitat for some species of gulls, terns and herons along the Atlantic and Gulf coasts. The island development task,like the aquatic habitat task, is a new research area and the planning phase has just been completed. The approach will be to quantify on a regional basis the importance of existing dredged material islands to wildlife. These will include data on breeding bird concentrations, habitat preferences, and nesting periods that will permit decisions on the optimum size and shape of dredged material islands, and recommendations about the management and continued disposal on these areas. The first of our regional studies of bird use of dredged material is being conducted in the Great Lakes. Additional research in Texas, Florida, New Jersey, and Oregon should be underway this summer.

SUMMARY

We have found that habitat development using dredged material offers an alternative disposal method that is often feasible from a biological, engineering, and economic standpoint. Careful implementation of this alternative could significantly increase the extent of our wetland resources in parts of the United States.

SALT MARSH CREATION: IMPACT OF HEAVY METALS

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INTRODUCTION

The impact of heavy metals on marshes depends on the composition, distribution, availability, and biological effects of the metals in the sediments and water at the site. This report discusses factors affecting the fluxes and biological activities of heavy metals in salt marsh environments.

Heavy metals differ from synthetic organic contaminants because they occur naturally and are therefore almost always present at low concentrations in estuarine environments. Concentrations in polluted systems include those occurring naturally in addition to those added directly or indirectly as a result of human activity. In contrast to organic materials which can generally be degraded, at least to some extent, heavy metals are chemically stable and are not removed from contaminated ecosystems by degradation. However, the mobility and toxicity of certain metals may be affected by their chemical form and biochemical associations.

When considering the toxicity of heavy metals, a distinction should be made between those essential to living organisms and toxic metals which have no known beneficial biochemical function. Examples of the former are V, Cr, Mn, Fe, Co, Cu, Zn, Mb, and Sn. These metals are often incorporated into proteins and can exist as metalloenzymes which serve as biochemical catalysts. Organisms usually have some control over the intake of essential metals, and unless they are exposed to overwhelming concentrations, toxicity is not a problem. In some cases increased levels of these metals may actually stimulate growth of marsh plants. Organisms are not as well equipped to control their exposure to the toxic metals (Hg, Cd, Pb, and As) which have not been shown to be essential. Natural exposure to these metals is very low and homeostatic control of concentrations has not been developed by most organisms (Buhler 1973).

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SOURCES OF HEAVY METALS IN ESTUARINE-SALT MARSH SYSTEMS

Heavy metals occurring in estuarine ecosystems can be derived from the continental interior or may come from local sources. Weathering processes are responsible for the natural breakdown of minerals. However, these processes can be greatly accelerated by activities such as mining, industrial production, and burning of fossil fuels.

Estuaries can often be considered as funnels for the transport of pollutants to the sea, but some parts of the estuarine system (e.g., salt marshes) may also act as filters for pollutants. Windom (1975) calculated annual net input of several metals into estuaries of the southeastern United States based on metal concentrations and river flow. Annual losses to marsh sediments were estimated by measuring metal concentrations in the sediments and assuming a sedimentation rate of 1 mm/yr (0.04 inch/yr). It was estimated that 80% to 90% of Cu, Cd, and Hg were transferred through the estuaries whereas the other 10% to 20% were lost to the sediments. The quantity lost to the sediments was roughly equivalent to the amount found in the particulate matter of the rivers. In contrast, all of the Fe and 60% of the Mn were transferred to the sediments.

In addition to continental input through rivers, metals can be introduced into coastal regions by local sources of pollution. One source may be direct output from industrial (or municipal) effluents. An example of this type of pollution is discharge of Hg from chlor-alkali plants. Local metal input into the water also results from dredging. Metals already present in the sediments may be released into the water during dredging by changing conditions of Eh (redox potential) and pH.

PROCESSES CONTROLLING CONCENTRATION AND AVAILABILITY OF HEAVY METALS IN ESTUARIES

The total concentration of a heavy metal in an estuary or marsh may not determine its availability or toxicity to organisms. For example, occluded metals (enclosed within crystalline mineral particles) may not be biologically available. On the other hand, metals dissolved in the water or loosely sorbed to particles are directly available to plants and other organisms. Intermediate in availability are metals bound in organic material which can be made available as the result of decomposition or ingestion of the organic material (Gibbs 1973).

The biological role of a metal in a salt marsh estuarine system is influenced by its distribution in the system. Several processes interact to determine metal distributions. If a system is in equilibrium, thermodynamic processes determine the distribution of the metal between the solid, liquid, or gaseous phases. The form of a metal which is most thermodynamically stable can be predicted from relative solubilities of various forms of the metals under varying conditions of Eh and pH (Garrels and Christ 1965).

Equally important in most natural systems are kinetic processes which control the physical, chemical, and biological distribution of the metals in the marsh estuarine system. Physical processes are responsible for the transport of metals in the water column and for the removal of particulate material (e.g., trapping of particulate material in the salt marshes). Chemical and biological mechanisms may control the distribution of the metals between soluble and particulate material (Figure 1). Types of chemical reactions influencing metal distribution include precipitation, oxidation-reduction, sorption, and complexation. These kinetic reactions can occur when a system in equilibrium is disturbed.

For example, during dredging operations, normally reduced sediments are exposed to oxygen and a series of reactions affecting heavy metal concentrations can occur. Windom (1973) studied the heavy metal concentrations in the water of collected dredged spoils in closed containers and the change in concentrations with time after discharge (Figure 2). After dredging, the concentration of Fe in the overlying water fell below that typically found in the water column over the sediment. It remained low for 10 days and then showed a rapid increase in the water. Total Cu and Pb followed similar patterns, but Cu^{++} ion remained consistently low. An explanation is that Fe^{++} was oxidized upon contact with O_2 and precipitated as $Fe(OH)_3$ which sorbed the Pb and complexed Cu compounds.

After 10 days in the closed container, the system became anoxic and under reducing conditions the Fe returned to solution as Fe^{++} or metastable iron sulfide, thus freeing other metals associated with the $Fe(OH)_3$ precipitate. Cu^{++} ion apparently was not associated with the precipitate and did not markedly change in concentration. Zn and Hg showed the opposite trend. Relatively high concentrations were observed over the first few days when oxygen was apparently present, but the levels in solution decreased when the Fe concentration increased. It appears, therefore, that disturbing sediments in a dredging area causes short-term effects on metal distribution and activity but has little long-range effect.

Biotic influence on the fluxes and fates of heavy metals in a salt marsh can be expected due to the high biological activity of the system. Plants may affect movement of metals by (1) removing them from solution or (2) transferring the metals from one compartment to another (e.g.,from the sediments to the water column). Metals may be taken up from the sediments or water and stored

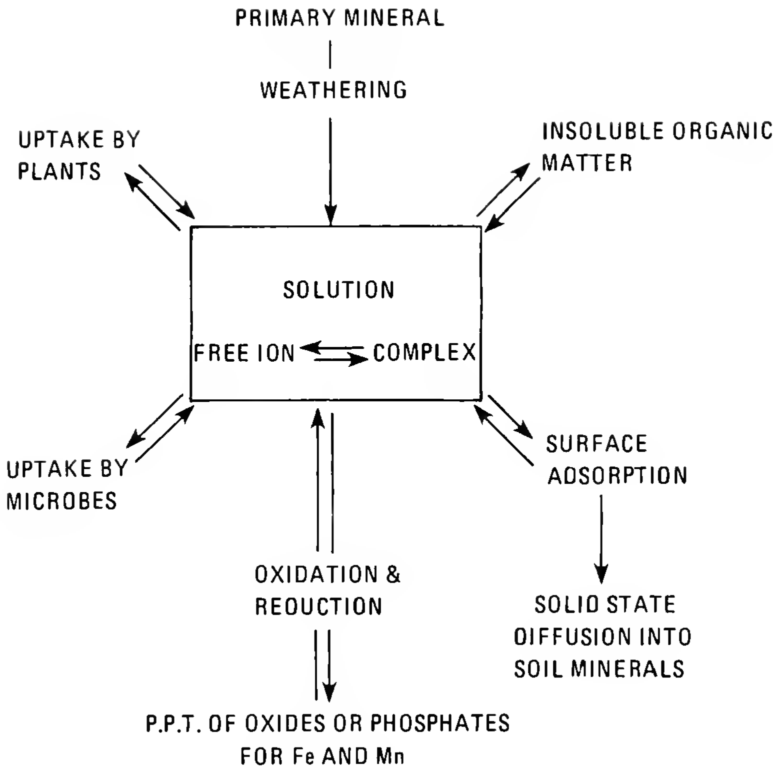

Figure 1. Potential sites for competitive uptake of metals in the marsh (from Dunstan and Windom 1975).

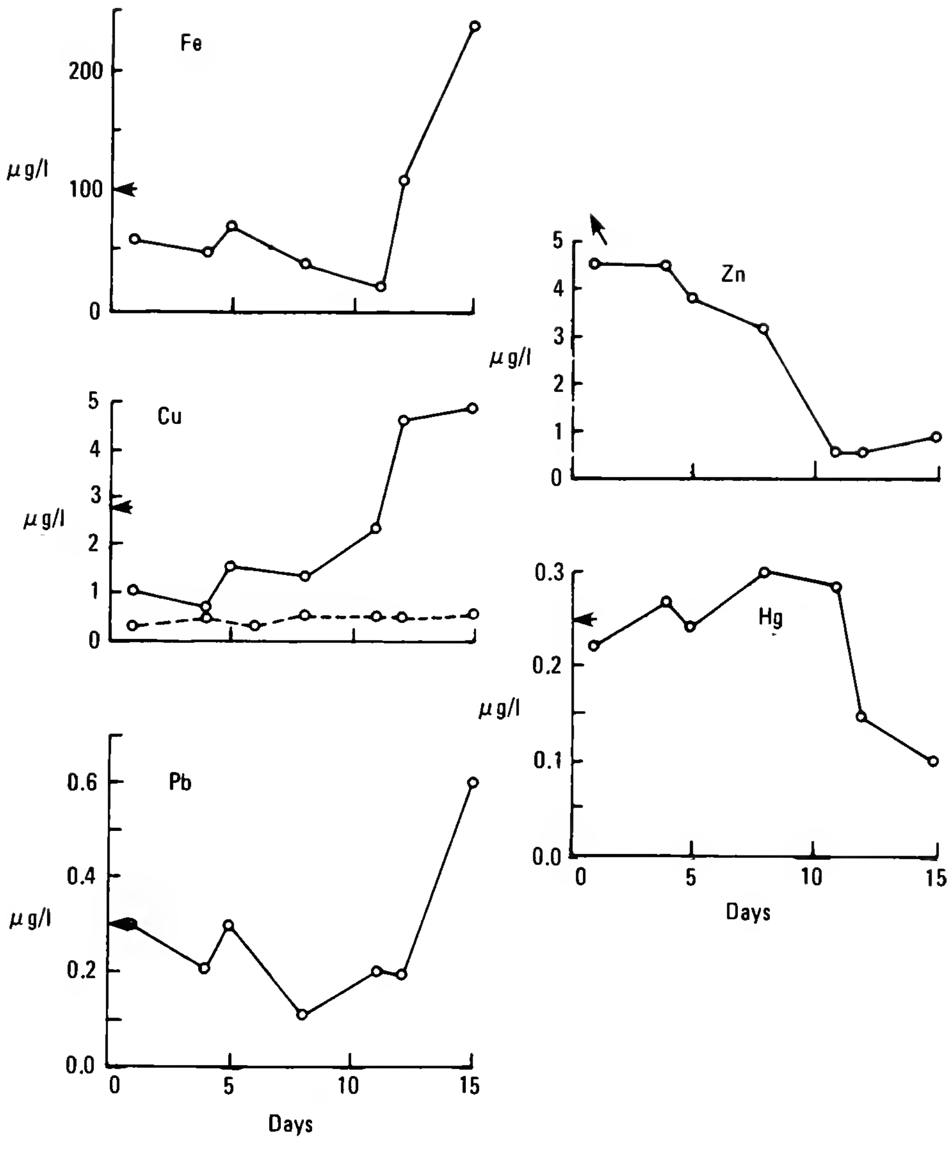

Figure 2. Changes in total dissolved metal concentrations in the water of the water-sediment system of discharged spoil with time after discharge. Levels in the water column prior to dredging are indicated by arrows. Dashed line for copper represents Cu^{++} changes, Brunswick Harbor (from Windom 1973).

in the plant tissues. Those retained in plant tissues may be physically transferred with dead plant material. Transfer to other organisms, sediments, or the water occurs when the plant residue is eaten or decomposed.

Studies by Dunstan and Windom (1975) suggest that metals are not taken up and retained by plants in the marsh to the extent that they occur in the sediments. Concentrations of most heavy metals (Fe, Mn, Zn, Pb, Cu, and Cd) were lower in tissues of saltmarsh cordgrass (Spartina alterniflora) than in the sediments supporting the plant's growth. An exception was Hg which occurred at higher levels in the plants than in the sediments.

Unlike most other heavy metals, Hg can exist chemically in different states (solid, liquid, or gas)and can be microbiologically converted into several forms of varying toxicity in sediment-water systems (Wood 1974). Methyl Hg is of particular interest because (1) it is highly toxic to higher organisms, (2) it can be formed from other forms of Hg in the sediments, and (3) it is retained by muscle tissue and tends to be concentrated by food chain amplification. Although methyl is the prominent form of Hg in most fish and higher animals in coastal areas (Gardner et al. 1975a, Gardner et al. 1978), it is not so in marsh sediments and plants (Windom et al. 1976). If formed in the sediments, its residence time must be short.

Laboratory and field studies of Hg in Spartina alterniflora (Gardner et al. 1975a) showed that plants exposed to high levels of Hg can take up and distribute the metal in their tissues. Methyl Hg tends to concentrate in the upper portions of the plant (leaves and seeds), whereas inorganic Hg generally accumulates in the roots. The very low (below detection) levels of methyl Hg found in natural growths of Spartina suggest that this compound is not retained by the plant. The plant, however, could be a potential mechanism for transporting the compound across the sediment water interface (Gardner et al. 1975b).

Studies of a salt marsh ecosystem which had been industrially contaminated with inorganic Hg (chlor-alkali plant) indicated that methyl Hg can be formed in the salt marsh and can accumulate to high levels (1-60 ppm) in tissues of fish, mammals, and birds living in the region (Windom et al. 1976; Gardner et al. 1978). Sediments and plant roots from the immediate area contained high (0.2-1.7 ppm) levels of total Hg, but negligible quantities of methyl Hg. The primary consumers, Littorina irrorata and Uca sp., contained elevated levels of total Hg and methyl Hg as did their predators. In contrast, lower concentrations of Hg and methyl Hg were found in herbivorous fish and mammals.

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MARSH CREATION: IMPACT OF PESTICIDES ON THE FAUNA, USE OF INFRARED PHOTOGRAPHY, DITCHING AND DIKING

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This paper is about pesticides and fauna. I do not intend to talk about the chemistry of pesticides but simply about how a particular pesticide has affected an estuarine system and what we have done to follow the fate of that pesticide.

We have studied toxaphene which is used to control boll weevil in cotton in estuaries near Brunswick, Georgia, (near a toxaphene manufacturing plant) and in the Duplin Estuary, a pristine estuary, part of a National Estuarine Sanctuary indicative of the Carolinean Biogeographic Province of estuaries from Cape Hatteras to Cape Canaveral. There are two sources of toxaphene pollution in the estuary: one from a manufacturer in Brunswick and the other from agricultural runoff. As part of the U.S. Environmental Protection Agency (EPA) estuarine monitoring program for pesticides we have looked at fish, finfish, shellfish, sediment, and marsh plants from South Carolina to the Florida border from 1968 to 1976. Except for the early years of that study (1968 to 1971), we never found any measurable quantities (according to EPA detection limits) of toxaphene anywhere except very close to the Brunswick, Georgia, manufacturing plant. We have studied the toxaphene manufacturing operation and how it impacts swimming organisms in the estuarine water column.

Since our study began, the levels of toxaphene in the manufacturing plant effluent decreased from parts per hundred to parts per billion (less than 2 ppb). Levels in the past year have decreased to 2 ppb.

How did this affect the receiving waters of the estuary? We could take organisms that live in the estuary, catfish or goldfish as scientists often do, put them in tanks with different concentrations of toxaphene, and determine some water quality standards or lethal concentrations within which the fish could survive. But what does that actually mean in the estuary where the organisms live?

We decided that one approach would be to look at species diversity. We compared several different diversity indices to see how the numbers fluctuate over the years, looking first at diversity measured as an index of species richness or variety. This latter diversity is useful for comparing one community to another. We considered the Shannon-Weaver index which combines the variety and evenness components of diversity. The Shannon-Weaver, $\bar{H}$, as we refer to it, is also quite useful because it is independent of sample size. If one does not have as many samples in one area as another, one can still make useful comparisons. Shannon-Weaver, $\bar{H}$, is also a reasonable index to use because it has a normal distribution and consequently it can be used for standard significance tests such as a t-test.

Another index, the index of evenness (J index), assumes that the evenness or apportionment of individuals among species is comparable. This evenness varies inversely with indices that are based solely on dominance. In other words, we are not looking at one great or abundant species, or one small and minor species (in terms of numbers of individuals), but rather in terms of how evenly distributed they are, whether there would only be three of everything or thousands of everything.

Another index we considered is the number of moves index, (NM) that enables us to rank the diversity index and scale it so that the maximum is one and the minimum is zero.

We based our analysis of the Duplin Estuary and the Brunswick Estuary on nekton sampled with an otter trawl over an 8-yr period. There was a dramatic change both in the number of species and in the number of individuals over the years. We evaluated biomass, the wet weight of nekton, to get some idea of their size. We have changes in biomass and numbers over the periods sampled.

The diversity indices for Terry Creek, the stream into which the toxaphene effluent was discharged, reveal that in 1968 there were only three different kinds of organisms that lived there as opposed to nearly 25 species by 1976. We considered the biomass of the same area and noted increases in biomass with time also.

After the first 3 yr, the number of species remained more constant in the Brunswick Estuary than it did in the natural Duplin estuary. At all the Brunswick sampling stations, there were variations in the biomass although the number of species stayed rather constant.

The index of diversity "D" is based on species richness or variety. "D" in Terry Creek increased, and so did biomass between 1968 and 1976. $\bar{H}$, the Shannon-Weaver index, independent of sample size has some merits that other indices do not have. In terms of number of individuals, there are not any differences between diversity indices from 1973 to 1976 although between 1968 and 1973 there were great differences.

The Shannon-Weaver index when computed on the basis of biomass reveals no significant differences during the last 3 yr of the study. The apparent toxaphene concentration of the effluent from the manufacturing plant was in parts per hundred in 1970 and less than 10 ppb by 1976.

The evenness index "J" documents the apportionment of individuals among species. We noted this index approaching unity, but the change was not as striking as that seen with some of the other indices considered.

Perhaps some have used otter trawls to sample fish. It is really quite simple to measure and weigh each fish. There are a number of simple computer programs that can be used to compute all previously mentioned diversity indices. After one has taken the trouble to sample the fish, one might want to use that data to compute a species diversity index. I caution not to compute only one index because therein are some weaknesses. I recommend a review of "Fundamentals of Ecology," (Odum 1971) which contains a chapter summarizing species diversity, the different indices, the requisite, the mathematical equations, and their meaning.

Several things have come to my attention during this meeting that are important but were not part of the program. One is the proper uses and interpretation of color infrared (IR) photography. Those who do not use color IR photography in their work probably should consider it. Much information can be gleaned from color infrared photography that is not on the old black and white photography. When I say color IR, I am not talking about the satellite imagery that is made into a color product on which one can view all of Maryland or all of Arizona. I am talking about photography on which one can actually see some of the 1-, 4-, or 18-hectare sites with which one has to work with every day. What kind of details can one expect to see?

One might be able to pick out each individual plant and enumerate the total number of plants. The photography is useful for ecological delineation and for economic delineation including legal purposes. Photography can be used to determine where the location of something is on the face of the earth. As an example, color IR photography has been used in wetlands to delineate the boundary of the biological mean high water line. Such delineation, however, did not stand up in court.

At Sapelo we coupled ground truth measurements (tide gauges) with aerial photography in order to remotely determine the mean high water mark. We then surveyed the marsh to locate the elevation of mean high water and found it fairly closely paralleled the dividing line between the tall and short forms of salt marsh cordgrass (Spartina alterniflora) near the mouth of the estuary. We went 1 km further upstream on the same estuary and found mean high water to parallel the break between Spartina alterniflora and Juncus roemerianus. For ecological purposes, that division is approximately where the tide flows and ebbs every day. If one is going to say that a line on the face of the earth is the mean high water line, which carries an implication of knowledge of ownership, one is going to get oneself in trouble with photography because it will not work in every case.

Scale of photography is important; one must be experienced in considering the scale on photography. Satellite imagery is often at a scale of 1:250,000. The U.S. Geological Survey is planning to develop quad sheets that are 1:10,000 when the United States fully adopts metric. This 1:10,000 is low level photography and there are a number of things one can resolve in wetlands using such a scale.

Analysis of aerial photos of water at the mouth of a stream will reveal patterns about the currents on an ebb or flood tide. The photos also document the conditions of the banks, bare spots, little hammocks, etc. With photography of the scale 1:10,000, we are able to get close to the face of the earth.

Suppose that instead of looking at 1:10,000 scale photography one wants to get a little closer because one is interested in more detailed information. One would then need to consider three principal scales: 1:10,000, 1:5,000, and 1:2,500. With the latter scale one can actually see dead plant materials on the color IR photos. The bright red patches along the streams may be saltmarsh cordgrass that grows up to 3 m (10 ft) high in summer. One can see some differences in patterning, color and texture of the water, indicating some differences in current, detritus concentration and turbidity.

There is a variety of applications for which one can use quality, color IR aerial photography.

Another item I was requested to discuss was ditching and diking as they relate to habitat creation. All have been involved with ditching and diking since many have made wildlife impoundments. Such activities create a landing area for geese and ducks and have some effects on mosquito control. Mosquito control has had a significant impact on the wetlands. Bourn and Cottam (1950) studied mosquito control diking and ditches of marshes around the Delaware Bay.

What does ditching do in wetlands? It obviously reduces the water level. That is one of the objectives of creating a ditch, i.e, to drain the wetlands. One may want to reduce the water level because of the mosquito, or maybe because in WPA times ditching provided occupational therapy. But what does this reduction in water level cause, at least in the marshes in the more northern latitudes? It drains the peat; it lowers the standing water level in the wetlands; and it can cause an oxidation of the peat.

Some of the wetland plants we have discussed over the last few days have different tolerances to salt; thus, reductions in water level can cause invasion of upland plant species further out into what used to be a salt marsh. The fact that the water level is lower, or drains off quicker, or does not stand there as long, will favor the invasion of a number of the upland species of plants. A ditch reduces the number of hectares of vegetated wetland. Even though each ditch may only be 46 to 61 cm (18 to 24 inches) wide, a vast area soon is occupied with bare mud surfaces and open ditches. A ditch can reduce the area of marsh by about 30%.

Another problem with ditching is the creation of cat clays. How does ditching result in cat clay problems? Each little scoopful of soil that is excavated from the wetland during ditch construction is placed on the surface of the marsh. Anaerobic material that used to be under the surface goes through numerous oxidation steps and ends up as a cat clay. Each one of those little clusters of highly acidic material will not serve as a substrate for any vegetation for a number of years.

It is bad enough that each of the deposits of cat clay does not support plants, but there is also a little halo around it because, as rain falls, the acidic material is leached out and the plants are killed around dredged material. In some of the Delaware marshes, 15 yr passed before plants started growing on such spoil. Because the resultant elevation of each pile of excavated marsh material was 0.3 to 0.5 m (1 to 1.6 ft) above the original elevation of the marsh, the cat clay was not recolonized by traditional plants, but by some marsh fringe or upland plants, including cedars, high tide bush, and similar species.

Thus, there are some rather subtle affects of ditching that one may not have considered. For example, ditching effects the seasonal cycle of nutrients. Pomeroy described the quick turnover of nutrients, such as phosphorous, and their importance in wetlands, but there was a seasonal periodicity to it and ditching greatly alters that.

A case history of altering a watershed will give some further documentation of what I mean. Glacial Lake Hackensack was formed long ago in New Jersey, just west of Manhatten. After sea level went down, the glacial lake became a big white cedar swamp. The swamp was approximately 11 to 16 km (7 to 10 mi) wide in places and 32 km (20 mi) from north to south. During the 18th and 19th centuries, American pioneers established transportation corridors across the swamp consisting of cedar trees that they had cut and laid on their side (called plank roads). Some of the cedar swamp was a little bit lower, occasionally inundated by the tides, and it supported vegetation (salt meadow hay _Spartina patens_). Nearby land owners became concerned about where their property line was in this cedar swamp. They started making ditches to show where their property lines were.

With a change in economic consideration, cedar became important for pencils, poles, and other purposes. Soon the residents started to cut the cedar trees. Over the years they cut all of them. They mainly cut in winter time when the swamp would freeze over. They put "meadow shoes," which were like snow shoes, on the horses. In went the horse and wagon and the poles were cut and hauled out. The residents sold the cedar poles and cut the salt meadow hay. Some hay was sold for food for horses, but most of it was used for insulation for ice houses and for packing material. Thus, the high marsh was continually bisected by new ditches. Where other plants, _Typha_ for example, started to grow, residents would take a scythe and cut them so they would not keep encroaching on their land each year and would have a valuable salt hay meadow to work.

About that time, residents and government agencies started ditching for mosquitoes. But they did not put the dredged material out on the marsh surface beside the ditch because it was rich peat, and there was a lot of interest in agriculture, hot houses, greenhouses, and truck farms. So they loaded the peat on a barge and sold it to nearby residents for their potting sheds.

When people started populating the area so heavily that they needed a source of freshwater, they dammed up the headwater of the Hackensack River estuary and essentially cut the flow of fresh water into the estuary; 100% of the flow was diverted at least 100 days out of the year.

All these changes have occurred within the last 200 yr in what was once a meadow land-cedar swamp. Within the last 40 to 45 yr _Phragmites communis_ has invaded and covered most of the former swamp.

How does one make decisions about an area like this? Does one make the decision based on what plants are there today? Does one add all that information that I have discussed and integrate that into his thinking? I believe we also have to think about the future of this area. If these events have taken place in 50 yr or 200 yr, perhaps the meadowlands are in some sort of ephemeral state that is slowly, maybe rather quickly, transgressing to a low level of upland. I do not know the absolute future of the meadowlands, but I think it is a good scenario to evaluate whenever one considers ditching or diking. I believe that this case history may serve to illustrate a very dynamic, interactive process.

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MARSH CREATION: EFFECTS OF PESTICIDES ON THE FLORA

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Marsh managers must contend with two kinds of situations at the ecosystem level with respect to pesticides. In the first situation, the marsh is the target for pesticide application. In the second situation, the wetland ecosystem, whether it be a marsh or a mangrove swamp, is not the target, but the recipient of an accidental spill. These situations can be separated into direct effects, e.g., when a herbicide defoliates mangrove trees; or indirect effects, e.g., when pesticide washes out of a wetland to the estuary where it has an effect which feeds back to alter the wetland. We thus have at the ecosystem level a two by two matrix of situations to consider: target or nontarget exposure, direct or indirect effects (Table 1).

Table 1. Types of interactions between wetland and pesticides.

Effects	Ecosystems, species or processes: Target (T)	Nontarget (NT)
Direct (D)	TD	NTD
Indirect (I)	TI	NTI

In the past, the acreage of natural marshes along our coast has decreased as the result of development. Although slowed by recent laws and public awareness, this decline will probably continue. To maintain coastal productivity, new marshes are being planted on dredged material, and suggestions to enhance the productivity of those already in existence are being made. Since numerous workers have shown that marshes will respond to added nitrogen (Sullivan and Daiber 1974; Valiela and Teal 1974; Gallagher 1975), various fertilization schemes have been proposed.

It appears that there is a trend toward an agricultural type of management of marshes and other coastal ecosystems. Such intensive management may be a prelude to the kinds of insect and disease situations experienced in agriculture. Vast areas of single-species stands which are selected for specific purposes, e.g., vigorous forage growth, big roots, or little roots, are often subject to damaging outbreaks of disease and insect attacks. Unless we are extremely careful, we could be creating problem conditions in coastal ecosystems similar to those already existing in agriculture.

Consider the scenario where there might be a problem with tar spot disease on Spartina alterniflora. Under these circumstances, the marsh flora community might be the target for an application of fungicide. This application would control fungus "X" and protect the plants, a target direct effect (TD) at the species and process level. At the same time, it might "protect" the detritus from fungus "Y" which may be important in mineralizing dead marsh plants, a nontarget indirect effect (NTI) at the species and process level. In addition to influencing plant growth rate in two ways, the management plan might influence the decomposition rate and the remainder of the food web. Management programs need to be carefully assessed to avoid doing more harm than good. Once we have determined that a particular pesticide would control the problem with a target organism, extensive testing must be done to evaluate the effects on nontarget organisms or processes.

I do not know of any cases where wetland ecosystems have been the target of fungicide applications to date, but they have been the focus for herbicide and insecticide applications. In a New Jersey study, the mosquito larvicide (No. 2 fuel oil plus Tritan X as a wetting agent) decreased the standing crop of Spartina patens by about 37% (Slavin, Good, and Squiers 1975). At the ecosystem level, it was a target direct interaction (TD). At the floral species and process level, it was nontarget direct (NTD).

Before considering situations where wetland ecosystems are not the target pesticides, let us consider another hypothetical case for the types of problems that must be considered during management planning. Consider a mosquito control ditch that is filled with grass in a marsh in Delaware. One of two things needs to be done if the ditch is going to be maintained (another decision): 1) the ditch will have to be redug soon, or 2) a herbicide could be used to kill the plants, maintain the water flow, and minimize siltation. If the herbicide is used in the ditch, the chances are great that it is going to have a dramtic effect on the phytoplankton which are present. The diatom community is very sensitive to various herbicides. It is much easier to show the effect of the herbicide on the phytoplankton than on the emergent plants. The film on the surface of the water in the marsh is rich in phytoplankton. In Georgia marshes, as much as 40% of the phytoplankton in the marsh water may be concentrated on this surface film (Gallagher and Pfeiffer 1977). Some pesticides may concentrate in the surface film, thus reducing a large percentage of this productivity. The algal production on the soil surface in the marsh may amount to as much as 50% or 30% of the total production (Pomeroy 1959; Gallagher and Daiber 1974). The standing crops are very small, but the turnover rates are high. The possible impacts on the marsh from chemical treatment may be great even if only the primary producers are considered. However, the alternative of redigging the ditches more frequently may be as, or more, damaging and less cost effective.

There are other situations where the marsh is not the target ecosystem, but someone makes a mistake. Maybe workers are filling their sprayers at a bridge over a stream when something distracts their attention, and some of the spray runs back into the river. Perhaps a plane spraying cotton fields in Alabama passes over a river without turning off the sprayer. Even worse, a crop duster's plane may crash in the marsh. There have been some studies on these kinds of problems with herbicides.

Edwards and Davis (1974) chose the most common herbicide used in cotton fields for experiments conducted in the Georgia marsh. In the first year of their study, they sprayed an arsenate type of herbicide on marsh plots in a series of concentrations and measured the impact on the plants, animals and soils. Edwards and Davis (1974) thought that the heavy, waxy cuticle on Spartina leaves caused the spray to run off and not be absorbed. In the second year of the study, they designed an experiment which could soak the plants more like the exposure they would get under real world conditions. In the new design, they placed galvanized rings in the marsh and during normal high tides they pumped in water with various concentrations of an arsenate herbicide, monosodium-methane-arsenate. The low concentrations were 10 and 100 ppm, twice the highest recommended rate for any agricultural situation. Their high concentration was 90,000 ppm which was 20 times that recommended to sterilize soil.

The arsenate herbicide works as a contact killer and only turned parts of the leaves brown. The next spring there was no observable difference between plots where either the high or low concentration of the arsenate herbicide was applied. Edwards and Davis (1974) also considered the animals that live on and in the marsh. Although the arsenate accumulated in the soil, the impact was small since arsenic is abundant in the crust of the earth.

In later studies, the Auburn University group applied fluorometuron, a systemic herbicide, to Spartina alterniflora (personal communication from D.E. Davis, Auburn University, Auburn, Alabama). Preliminary results indicate this herbicide had a somewhat greater impact on the marsh than did the arsenate herbicide. The dynamics of the breakdown of the pesticide may be more important than its immediate short-term effect. Accumulation with long-term, low-level application associated with slow degradation could result in damaging levels accumulating.

Pesticides are lost from soils in five ways. One loss is due to volatilization in areas of the coastal zone where the surfaces are hot. The beach or the black surface of the marsh is an example of areas where volatilization is a potentially significant loss. Chemical decomposition is a second way of losing pesticide. There are difficulties predicting these losses because we do not know what happens to most types of pesticides under the anaerobic conditions of marshes. The bulk of the research has been about agricultural soils where the balance of water and oxygen favor oxidation, not the reverse as in marshes. Photodecomposition is a third loss factor of significance. Photodecomposition is significant in the case of toxaphene. Durant and Reimold (1972) postulated that ultraviolet light was responsible for the degradation of toxaphene-contaminated dredge material placed in a marsh. A fourth factor influencing loss of pesticides in soils is microbial metabolism, and it, too, is not well understood in many of the coastal soils and ecosystems. Research has usually been concerned about biological metabolism in agricultural ecosystems. Removal of pesticides by plants is another form of loss which has not been widely studied. We do not know that Spartina will pick up toxaphene and translocate it (Gallagher et al. 1979). The residence time of these chemicals in soil varies greatly and is influenced by many factors. DDT has a half life between 3 and 30 yr, chlorodane about 8 yr, and heptachlor 2 to 4 yr. Toxaphene has been measured to have an 11-yr half life in some agricultural soils. Gallagher and Wolf (in press) used uptake by Spartina as an indicator of the presence of toxaphene in the soil and found tissue levels to be near zero after only 7 mo without additions.

We collected soil samples from Terry Creek area where we know that they had been exposed to toxaphene for many years. We sectioned the samples and measured the toxaphene levels in the mud. After separating the mud from the macro-organic material (that not passing a 1-mm sieve), we measured the toxaphene in fractions. We found approximately 400 mg/m^2 in the macro-organic matter in the creekbank soils and 150 mg/m^2 in the mud. In the high marsh far away from the creek, there was very little toxaphene (less than 20 mg/m^2)in either the macro-organic matter or mud (Gallagher et al. 1979).

Organisms do not spend their lives in the whole organic or mud zone; they are often localized in specific areas. To evaluate specific micro-habitats, we collected cores of the marsh and dissected them. The shoots were cut and we separated the live roots and rhizomes from the bulk of the mud. All the soil that stuck to the live roots we called rhizosphere soil. The soil that stuck to the roots was influenced by the roots, as were the microbes present in that soil. The dead roots had the highest toxaphene levels, the dead material next, and the live materials were much lower. All material associated with organic matter had higher concentrations than the mud (Gallagher et al. 1979). The dead roots probably had more toxaphene in them for one of two reasons: 1) either they had a lot of cracks in the surface and the material is absorbed or adsorbed, or 2) the organic material in the roots is more easily degraded by microbes than the toxaphene; therefore, it becomes enriched as the vegetation rots away.

The examination of a few actual cases of pesticide-marsh flora interactions and several hypothetical cases has pointed out the complexities of the problem of pesticides in the wetlands. Basic knowledge of wetland processes will aid in theorizing the fate and trophic transfer in the various food chain modules. Once these are identified, they must be tested with various pesticides. If it is determined that potentially serious problems exist in situations where wetlands are the target ecosystems, they can be avoided by changing the management practice. The uncontrolled situation is that where the wetland is a nontarget ecosystem. Methods of ameliorating such interaction should receive research priority.

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NUTRIENT CYCLING IN COASTAL ECOSYSTEMS

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The coastal zone is an active place: biologically, geologically, and in terms of human activity. The coastal zone really extends out to the edge of the continental shelf, and it extends inland on the coastal plain, but in the estuaries and nearshore ocean we see the real meeting ground of the oceanic and continental regimes. The meeting of the continent with the ocean produces a number of conditions that are important in making the coastal zone one that is biologically active and productive.

One important feature is the shallowness of the water so that the bottom influences the system. In the open ocean, the bottom is so far away from the surface that material falls out, and although materials do come back, they do not come back very swiftly. The time necessary for water to return from the bottom of the ocean to the surface is on the order of thousands of years. In shallow water, however, it takes only weeks or months to bring materials back from the bottom into the water column. Materials need not be lost permanently, in biological terms, in the sediments of the coastal zone.

The coastal zone is an area of vigorous water movement and so is the middle of the ocean. But in the middle of the ocean, most of the vigorous water movement is near the surface. In much of the coastal zone, vigorous water movement extends much of the way or all of the way to the bottom. This enhances further interaction with the bottom and results in the exchange of materials between the water and the bottom of the system. These factors work together with the penetration of light, because of the shallowness of the water in the coastal zone, to produce a system that is highly productive.

Coastal ecosystems are highly productive and contain a variety of plant communities. Figure 1 is modified from Mann (1972) showing the relative rates of productivity of a number of the plant types in the coastal zone and comparing them with some terrestrial systems and the open sea. Highly productive systems include <u>Zostera</u>, the eelgrass, <u>Thalassia</u>, the turtlegrass, and the giant kelps, particularly in Canada, according to Mann. Johannes et al. (1972) and others show that coral reefs do in fact have productive macroalgae. I have added the coral reef values we have for Pacific atolls. I do not know if the Caribbean reefs are in this same range or not. This indicates that most estuarine situations or other coastal areas, especially those with macroscopic plants, are regions of very high primary productivity.

That leads into the question of nutrient supply because, to maintain high productivity, plant nutrients must be sufficient. These systems will not function without a continuing supply of nutrients. Coastal ecosystems may have clear water or turbid water. That appears to be of fundamental importance in determining the way such plant nutrients as phosphorus and nitrogen are supplied (Pomeroy et al. 1972). Both clear and turbid systems must have a nutrient supply. The clear water system must obtain its nutrient supply from the water. Turbid systems appear to have the advantage of a stable nutrient reserve in the sediments, particularly if there are clays or fine organic sediments.

In clear water systems around coral reefs, most of the nutrient elements are tied up in living material. Turnover of the living material, plus the flow of water, maintains a continuing supply of nutrients. Obviously, there are systems which are not at either extreme (clear or turbid). In fact, a relatively small supply of fine sediments conveys stability of nutrient availability (Pomeroy et al. 1972).

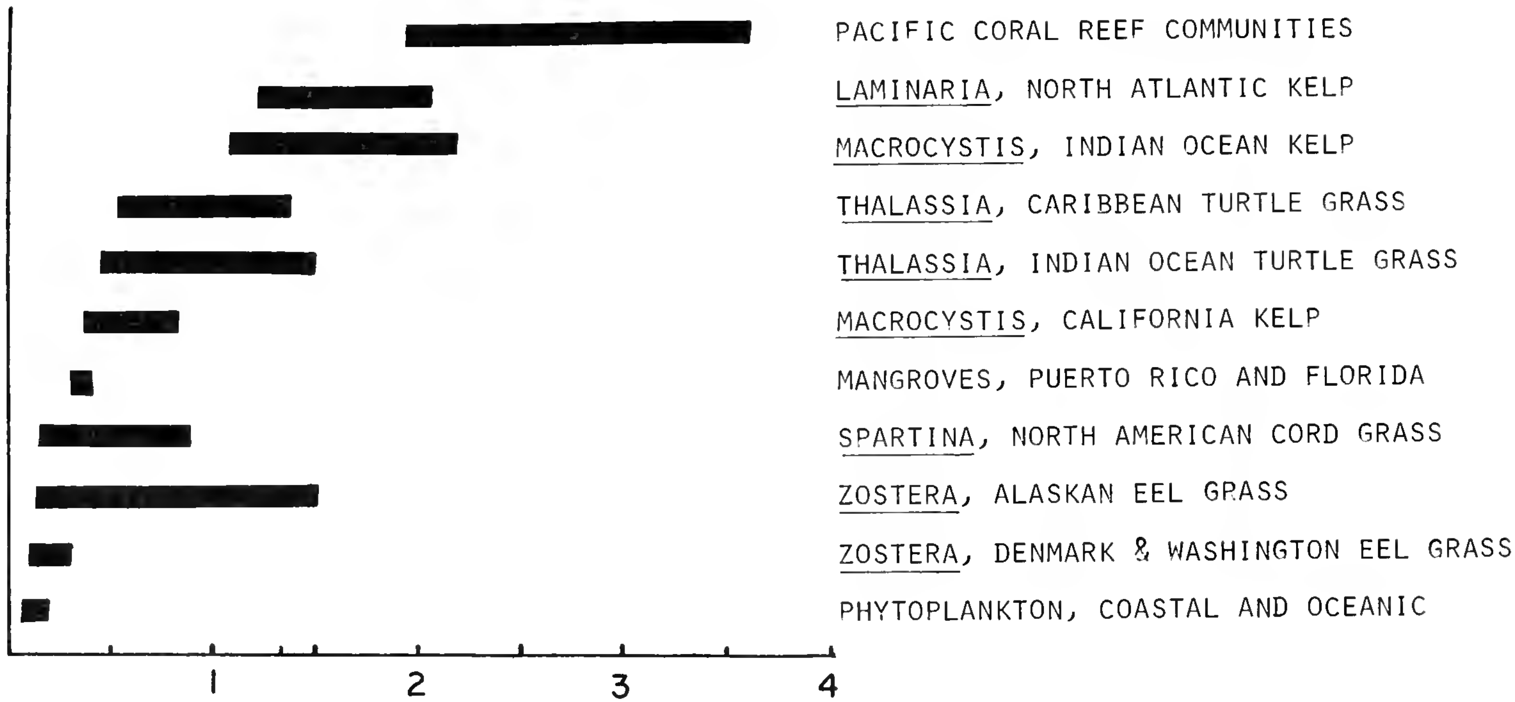

Figure 1. Net primary production, (10^3 gC fixed/m^2/year) in shallow-water marine ecosystems (from Mann 1972, with added data on coral reefs from Sargent and Austin 1949, Odum and Odum 1955, and Johannes et al. 1972).

Recycling of nutrients is dependent on the structure of the food web. Figure 2 illustrates a food web which would be appropriate for almost any coastal zone with some type of macroscopic plants. Grazers consume perhaps 10% of the macroscopic plants, and 90% of them are degraded by bacteria and fungi. The elements in the tissues of the plants, such as phosphorus and nitrogen, are recycled primarily through death and degeneration. It may not be generally appreciated that the obvious grazer does not consume most of the grass. The grazers in forest and grassland rarely get 10% of the crop. Most of it really follows the detritus route, which is much less obvious. We all see large animals and small ones; we do not see the bacteria. Nevertheless, they are the degraders of much of the total material, and move it through particulate and dissolved pathways. The end result is the recycling of such elements as nitrogen and phosphorus into inorganic forms which are available to plants.

Although it may not be wholly deserved, phosphorus has received much attention in recent years. The classical view of the phosphorus cycle still has good circulation in textbooks and in the scientific community. This view is one of seasonal changes in the abundance of phosphorus in the water. The concentration of phosphorus in the water increases during the winter in the temperate zone. It is utilized by aquatic plants in the spring when the weather gets warm and days longer. Then, there is a summer crash when the supply of nutrients becomes depleted. Production presumably slows down for that reason, staying at a relatively lower level through fall and winter.

This classical view of the annual cycle of abundance of phosphorus was developed 50 yr ago when it was first possible to measure phosphorus chemically by colorimetric methods. In the 1950's, people began to use 32P in aquatic research. They quickly found that phosphorus was more mobile than they had realized. While observers had been thinking in terms of seasonal changes in abundance, in fact, the standing stock of phosphorus in any water body was usually replaced every few days. In some lakes it was replaced every few minutes (Rigler 1956). The seasonal cycle that people had been seeing and measuring chemically was really a shifting equilibrium point, superimposed on a rapid recycling seen only by labeling the pool with a radioactive tracer. Now that we are aware of this and use tracer methods, we know that there is a great deal of recycling of phosphorus.

The high productivity of coastal systems, in many cases, depends heavily on recycling, rather than on a continued supply of new phosphorus into the system. This has been examined in many ecosystems including the coastal upwellings off Peru. Dugdale and Goering (1967) have estimated that 50% of the nitrogen used is recycled and 50% is newly upwelled. For the coastal waters off Georgia, Haines (1975) estimated that 95% of the nitrogen was recycled. I am sure the same is true of phosphorus. Recycling is a major factor in continuing productivity of many coastal ecosystems.

Figure 3 is a simplified version of how I view the phosphorus cycle in a shallow coastal system where sediments are present. In the classical view, bacteria are generators or remineralizers of phosphorus, but nobody has yet succeeded in finding these bacteria in natural waters. We now think that the major role of bacteria really is scavenging phosphorus. Bacteria take phosphorus wherever they can get it. They may take it from food material or they may take it from the pool of phosphorus in the water. In fact, the bacteria are competing with the phytoplankton for a common source of dissolved phosphate, and the bacteria compete very well and will get some of the phosphate away from the phytoplankton.

But the life cycles of bacteria are very short. They die or they are consumed by other organisms. The turnover time of bacteria is probably a matter of one day in most systems. So the result is that phosphate moves through both phytoplankton and the bacteria to filter-feeding consumers and benthic-deposit feeding consumers. These consumers excrete the phosphate since most of what they consume must be utilized to supply energy. Most of the phosphorus in the organic matter that they consume

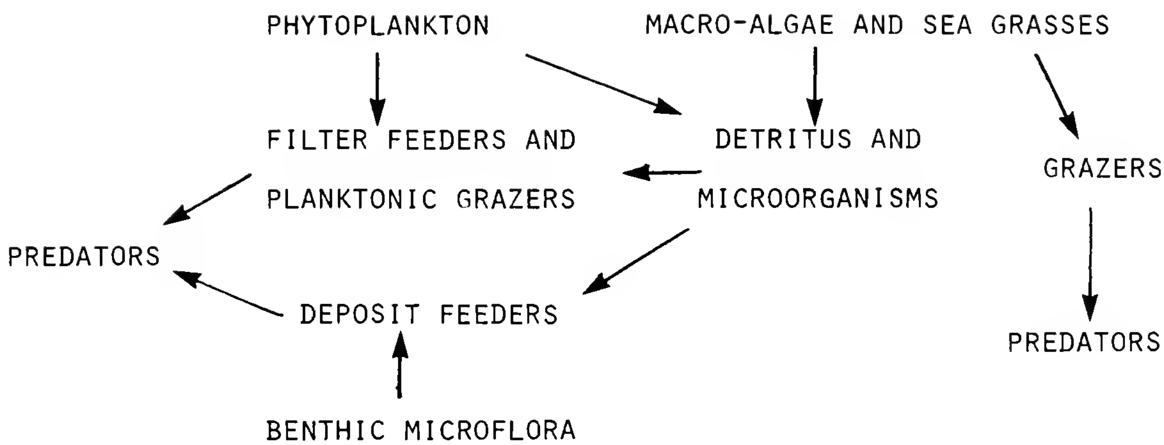

Figure 2. Generalized food web for the coastal zone, showing the relationships of the detritus food chain and the grazing food chains.

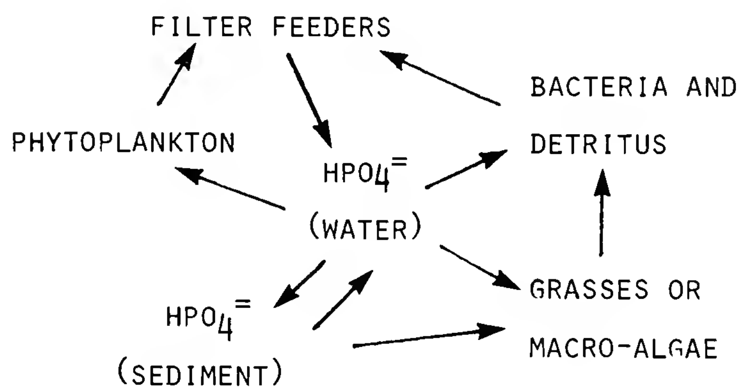

Figure 3. Generalized compartmental model of the flux of phosphorus through coastal zone ecosystems.

is excreted as phosphate. By the time food has gone through the first level of carnivores, 90% or more of the phosphate has been excreted. The rapid recycling that we find with tracers is not the production of phosphate by bacteria, but rather the rapid consumption and excretion of most of it back as phosphate.

There is a substantial experimental basis for this view of the recycling of phosphate (Pomeroy 1970). Microscopic organisms with short life spans tend to be the important organisms in terms of recycling nutrients as well as in expenditure of energy. The larger organisms, although they have other valuable attributes, are not major recycling organisms in terms of moving phosphorus or other elements around in the ecosystem. Fallout of organic matter carrying phosphorus to the bottom is a potential sink taking phosphorus out of circulation. If the fallout is not very far, phosphorus does not get out of the system. What reaches bottom will go into the mouths of hungry organisms or into the bodies of bacteria and get back into the system again. The recycling of elements in shallow water tends to be more complete than in the deep ocean.

Also, there is a physicochemical equilibrium between phosphate in the water and the sediments, especially clay sediments which adsorb phosphate on the surfaces of the platelets of clay. There will be many times more phosphate on the clay than in the water when there is an equilibrium. The equilibrium establishes itself in a matter of minutes and is a continuing process, going on all the time. To some extent, this tends to be a stabilizing influence on the amount of phosphate in the water (Pomeroy et al. 1965). In the real world, the clay is not fully suspended, so the equilibrium is only realized to the extent that there is interaction between water and clay.

The clay is probably more important in another way. Plants are growing in it, and they are getting phosphate out of the interstitial water. There is a continual pumping of phosphate out of the sediments by the grass; then, when the grass dies, it is degraded and phosphate goes into the water. So, recycling between water and sediments is driven by the growth of marine grass. As it grows, the grass also leaks, and Reimold (1972) studied the rate at which it loses phosphate. The washing of the grass by the tide removes about as much phosphate as is actually incorporated in the annual growth of grass, so the amount of phosphate pumped from the sediment may be twice as much as that incorporated by growth.

There is also inflow of phosphorus from rivers to coastal waters, which supplies a portion of the annual requirement of plant populations in the coastal zone. This is a very indirect contribution and its importance is not clear. Phosphorus coming down a river is not going directly to plants. For phytoplankton or even kelps the effect of phosphorus carried by rivers may be more immediate than in a system with intertidal plants. In a salt marsh, for example, phosphorus recycling is much more important in the short term than input from rivers. In terms of geological time, rivers are important.

We often overlook the fact that phosphorus comes from the ocean as well as the rivers. In fact, probably more of the phosphorus that cycles through the coastal zone comes from the ocean. There are a number of mechanisms that bring phosphorus in from the ocean, such as the upwellings off Peru and South Africa, that are well known and very dramatic. There is a less known type of upwelling along the edge of the continental shelf of the U.S. Atlantic coast. Periodically, the Gulf Stream washes up on the shelf. The idea that nutrients move toward shore across the continental shelf was originally proposed in a mathematical model by Riley (1967). His model showed that nutrients had to go inward across the shelf with the inner part of the shelf being supplied with nutrients by the ocean. What the physical oceanographers are beginning to tell us now would verify this, that indeed the ocean is of major importance in supplying nutrients to the coastal zone.

In any case, phosphorus is not an element that is limiting in coastal zone water. There is plenty of it around, except in the cleanest tropical situations, such as the Florida Keys or Hawaii; those are the only situations in which phosphorus might be a limiting factor.

Nitrogen has many similarities to phosphorus and some differences in its cycles. One of the biggest differences is that the main reservoir of nitrogen is the atmosphere rather than planetary rocks. As nitrogen gas, it is available only through nitrogen-fixing organisms. The nitrogen fixers are bacteria and blue-green algae. So a very limited range of organisms is involved in nitrogen fixation. Other organisms depend upon the continuing fixation of nitrogen by a taxonomically limited group.

Nitrogen fixers are widespread; many are in the coastal zone. We have always thought of them as being present in soil; however, they are present in much of the ocean as well. There are blue-green algae in the tropical and sub-tropical oceans. We now know that there are abundant blue-green algae on coral reefs, and there is active nitrogen fixation there. There are blue-green algae in salt marshes, and there is nitrogen fixation there as well. In most coastal systems which we have examined with modern methods, we have found nitrogen fixation. This does not necessarily mean that nitrogen is abundantly available in the coastal zone because there is denitrification going on as well. The important point about denitrification is it is done by an even more limited group of specialists. These are obligate anaerobic bacteria. Denitrification occurs only where there is an anaerobic environment, notably in sediments such as those found in marshes. A stagnant estuary, with the bottom water depleted in oxygen, might have some denitrification. Much of the denitrification is probably associated with the bottom of the continental shelf or with the estuaries.

Nitrogen also goes through the same kind of food web cycle as phosphorus. With a few exceptions,nitrogen is accumulated by bacteria and plants. It is consumed and regenerated, and most of the regeneration is in the form of ammonia, so there is a very rapid cycle of ammonia much like the rapid cycle of phosphate. At any one time, there is very little ammonia in the system because ammonia is, for most plants, the preferred form. It is the most reduced form and, therefore, the energetically optimal form. Aquatic plants will take the ammonia first and leave the nitrate until last. Ammonia rapidly recycles, being taken up by the plants, passed on to the animals and bacteria, and excreted as ammonia again into the water.

Nitrogen coming in from the ocean is mainly nitrate. There is a big reservoir of nitrate in the ocean, and when deep water washes up onto the continental shelf in one way or another, it brings some nitrate into the coastal zone. So there is an input of nitrate from the ocean, and this, of course, will be utilized by plants, will go into the cycle, and will be recycled as ammonia.

There is a tendency to view micro organisms in two categories: the good guys who are nitrogen fixers and the bad guys who are the denitrifiers. We should remember that in reality what is important is that the cycle keeps turning over. If we did not have the denitrifiers, the nitrogen would become locked up somewhere, and not be in the atmosphere. The atmosphere could be depleted, not overnight, but in a rather short extent of geological time.

Carbon is rarely a limiting element, as far as I am aware, in the coastal zone. There is approximately a thousand times as much of it in the water as the plants could utilize. There is a good supply of it in the atmosphere for the intertidal grasses and mangroves. We look upon the cycle of carbon as something important to study, but not as something that is limiting the system in any way.

The cycle of sulfur in the coastal zone may be more significant than we have realized. Sulfate is abundant in the ocean and is not going to be a limiting element. We are now interested in the sulfur cycle because there are volatile sulfur compounds being produced by organisms in the coastal zone. H_2S and volatile organic compounds are going into the atmosphere. Such things as dimethyl sulfide and a number of other low molecular weight sulfur compounds are apparently produced by algae in substantial quantities (Lovelock et al. 1972). These are being produced, not just in anerobic sediments, but also by kelp beds or even phytoplankton, and contribute to the sulfur supply in the atmosphere. There is an input to the atmosphere that is probably proportional to productivity, which means that the highly productive coastal zones are probably regions of relatively high input of sulfur to the atmosphere. Another high input of sulfur to the atmosphere is from the burning of fossil fuels which contain sulfur. We associate acid rain with the burning of fossil fuel, which is probably correct, but at the present time there is a certain amount of controversy as to the relative magnitude of sulfur production by the volatilization of sulfur from natural and anthropogenic sources. This is of practical importance because of the role of sulfur in acid rain.

There are two ways in which we look upon elements like nitrogen and phosphorus as key elements in aquatic coastal systems. One is as limiting factors, and the other is as causes of eutrophication. Let us look first at the limiting factor aspect. In 1925, W. R. G. Atkins (1925) noted that the ratio of nitrogen to phosphorus in the English Channel was 16 atoms of nitrogen to 1 atom of phosphorus. This was true of both the material in solution in the water and the material bound in plankton. He noticed that in summer the nitrogen and phosphorus were depleted from the water and were tied up in the plankton at exactly the same time. Redfield (1934) extended the observation to the North Atlantic, and showed that the ratio of 16 to 1, nitrogen to phosphorus, was true for surface ocean water in general in the North Atlantic.

This has become known as Redfield's ratio because he extended it and proposed its cause. By recycling these elements so rapidly, the phytoplankton come to control the ratio in the whole system. Redfield's ratio has come to be a kind of magic thing for ecologists, and we look for it wherever we go. We seldom find it except in the open ocean. In the coastal waters, one may find ratios as low as 3 to 1, or 1 to 1, much less nitrogen in proportion to phosphorus. This has led many people to say that nitrogen is the limiting element in the coastal zone, which may be true.

However, the absolute amount of nitrogen in the coastal zone is far greater than in ocean surface water, so the limitation of production, if any, is a relative one. In the ocean there is relatively little nitrogen fixation or denitrification. In the coastal zone both processes are active, and the N:P ratio is controlled by the relative rates of those two processes.

Our other concern is eutrophication. The salt marsh in Georgia is a eutrophic system. It is a natural eutrophic system, about as eutrophic as it could be without going out of balance. So eutrophication is not necessarily something that man does to systems. We can find systems which are naturally very productive and which an ecologist would call eutrophic systems. On the other hand, there are systems which are not naturally eutrophic which man can influence by organic pollution from human sewage waste or from industrial organic waste. When we make them eutrophic, this usually leads to a condition which is not aesthetically pleasing to us. Eutrophication may have other problems associated with it. It certainly will change the system.

We can point to certain examples of this; New York Harbor and Houston Ship Channel are in competition for the worst system in the country, if not in the world (Smith 1972). Both are complicated cases because there are various types of pollutants present, not just organic matter and nutrients, but toxins and organic compounds of all kinds. Eutrophication is certainly part of the problem in both systems, and probably both are less eutrophic than they would be if they were not toxic.

The old saying of the engineer is that the solution to pollution is dilution. We have been applying this to the rivers and lakes of our continent and we have nearly reached the end of that. We have been applying it to the estuaries and we have nearly reached the end of that, too. Now we are looking at the ocean as the ultimate sink for our excess waste. Right now, this is the cheapest thing to do. I suppose in the long run we could find ways to use wastes more effectively, to economically recycle them effectively rather than throw them away. In the long run the best thing to do is not throw away nitrogen and phosphorus, and then find new sources for agriculture. In the short run, we have to throw them away for economic expediency and look to the ocean as a sink. When we look to the ocean, we look first to the coastal zone.

When an ecologist or an oceanographer thinks of the ocean, he thinks of very deep water, usually far from land. However, most ocean dumping is virtually done on the beach. The real cost of dumping in the deep ocean is high, perhaps prohibitive in some instances, so we still have the problem of eutrophicating the coastal zone. When this kind of question comes up, one needs to ask where in the ocean is one going to dump waste. The coastal zone is much more resilient than the estuary, if one considers the coastal zone all the way out to the edge of the shelf. It is a large area, and it can take a lot of abuse. Therefore, we have to look at both sides of these questions. There are going to be many impacts on the coastal zone, taken in a broad sense, that are going to be quite reasonable and which the zone can assimilate successfully. There are others that it can not. Nutrients are simply one of many aspects we need to consider in evaluating the increasing impacts on the coastal zone.

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SALT MARSH CREATION: IMPACT OF SEWAGE

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Under the auspices of a project funded by the Office of Water Research and Technology entitled The Capacity of the Spartina Salt Marsh to Assimilate Nitrogen from Sewage Sludge, two graduate students, Barry Sherr and Alice Chalmers, and I have been studying the nitrogen cycle in coastal marine ecosystems. Our focus has been on the basic nitrogen cycle in the marsh as well as the impact of applying sewage sludge onto the marsh; specifically, what happens to the nitrogen in the sludge? I will compare our study to a similar, although longer and more comprehensive, study which has been carried out by Valiela et al. (1974) in a Massachusetts salt marsh.

Increasing amounts of sewage are being deposited in coastal wetlands because this is an inexpensive and convenient way for urban areas on the coast to dispose of sewage. Unfortunately, a lot of the sewage has not even had primary treatment, and the increasing biological oxygen demand (BOD) in coastal wetlands has already resulted in marked deterioration of water quality in some northern estuaries. We cannot treat estuaries like giant flush toilets because they do not flush. Estuaries are naturally productive because physical processes in the estuaries, e.g., sedimentation in the marshes and estuarine water circulation, tend to keep materials that come into estuaries within the estuary. Thus, when sewage is introduced into an estuary, the materials tend to remain there.

One of the major components of sewage that we should be concerned about are the plant nutrients, e.g., in secondarily treated sewage there will be phosphate, ammonia, and nitrate in large quantities which will stimulate phytoplankton growth in the estuary, and vascular plant and benthic algal production in the marshes. Impacts from other sewage materials may be a bit more subtle. Heavy metals and chemicals, such as pesticides and petroleum hydrocarbons, are abundant in sewage. Also, very little is known about the fate of the pathogenic microorganisms in sewage in estuaries.

Sewage impact on salt marshes can be experimentally evaluated by analyzing: (1) accumulation of substances such as inorganic nitrates, heavy metals, and pesticides in plants, fauna, and soils; (2) the stimulation of certain biological processes in the marsh, e.g., plant production and microbial activity; and (3) the inhibition of microbial processes. There are also subtle, indirect effects that cannot be predicted. By observing a whole range of processes in the marsh, one may detect indirect chain reaction effects resulting from the impact of sewage on salt marshes.

Gosselink et al. (1974) assigned a high monetary value to the ability of salt marshes to act as tertiary sewage treatment systems. Salt marshes are not very effective for secondary sewage treatment because salt marshes and estuaries are such highly productive systems to begin with, and already contain plenty of organic material. If more organic matter in primary or untreated sewage is added, the estuaries will be overloaded, and the water will show decreased oxygen tensions and other signs of deterioration. However, estuaries may be efficient at tertiary treatment for removal of inorganic nutrients in secondarily treated sewage. Pomeroy et al. (1972) reported the ability of marsh clay sediments to extract phosphorus from water via chemical reaction. Apparently nitrogen is the nutrient which is more interesting to study because addition of nitrogen can increase plant productivity in salt marshes. Gosselink et al. (1974) assigned a per year value of \$34,580 per ha (\$14,000 per acre) to northern estuaries presently "treating" secondarily treated sewage discharged into estuarine waters.

Major differences between our study and that of Valiela et al. in Massachusetts were (1) their study of the response of a salt marsh to sewage enrichment was carried out over several years, had controls of inorganic nutrient fertilization as well as nonfertilization and measured more marsh processes and (2) they used commercially prepared sewage fertilizer which had been amended with inorganic fertilizer. We used sewage sludge from an Athens, Georgia, treatment plant, air dried the sludge, and then ran it through a grinder to make it into a crumbly powder. Our sewage sludge was from an anaerobic digestion process, but at times a significant fraction may have been only primarily treated.

We applied the dry sludge at the rate of 25 g/m^2 per week at biweekly intervals, which was equivalent to Teal and Valiela's high rate of fertilization. They also tested a lower rate of about 8 g/m^2 per week. During our 1-yr study, a total of 1.2 kg/m^2 was applied. We compared our fertilized short *Spartina* marsh with a tall *Spartina* creekbank marsh and with a separate unfertilized short *Spartina* marsh as a control.

In the first year the Massachusetts group did not report any increase in plant biomass (Valiela et al. 1975). After comparing their high frequency of sewage sludge fertilization with fertilization with urea only, they concluded that it was the nitrogen in sewage sludge that resulted in increased plant growth. Phosphorus fertilizer did not increase the standing plant biomass in either the low or high marsh. The sewage sludge and urea-enriched plots, which had the same nitrogen content applied, showed two- to three-fold increases in plant biomass (Valiela et al. 1975). Plants in a Massachusetts high marsh tended also to become morphologically more like plants in the low marsh during the sewage enrichment study.

In the first year of sludge fertilization of our experimental plots, the aboveground live *Spartina* biomass increased about a third over our control *Spartina* biomass (Figure 1). In some months of the year our experimental plots had almost as much live *Spartina* biomass as the tall plants by the creek, which was the more productive area of the marsh. On the other hand, the dead *Spartina* biomass in our fertilized plots did not increase significantly above the control during the course of the experiment. One might expect that as the experimental live plant biomass died off in the winter, there would be a corresponding increase in the dead material, but so far this effect has not become apparent.

We also attempted to monitor the response of belowground plant biomass to enrichment. Measuring live belowground plant biomass was difficult in these marshes because: (1) there was so much dead matter and (2) the clay sediments clung to the roots so tightly that it was very difficult to accurately separate the live plant roots and rhizomes from dead roots and rhizomes. As a crude indication of belowground plant growth, we measured the total macroorganic matter (MOM), i.e., the organic material larger than 2 mm (0.08 inch) in our three plot areas.

A seasonal comparison of the total belowground MOM to a depth of 30 cm in our three plots showed much variation (Figure 2). The trend during the course of the experiment was a slight increase in the belowground MOM in our experimentally enriched plots compared to the control plots. A rather drastic drop in the amount of MOM in the tall *Spartina* (creekbank) marsh sites was also noted. The data also indicate that organic matter is mineralized more rapidly in the low marsh sediments, which could explain in part the rapid disappearance of the creekbank soil MOM.

Valiela et al. (1976) separated the live roots and rhizomes from the total dead belowground MOM by visual observation and staining procedures. They found very little live root and rhizome material in comparison to the total amount of dead matter. The dry weight of live roots in their *Spartina* marsh was much less than the dry weight of the rhizomes. Sewage fertilization appeared to decrease the standing crop of roots in the marsh. Valiela et al. (1976) speculated that the enriched plants required fewer roots because they had a relatively higher standing stock of

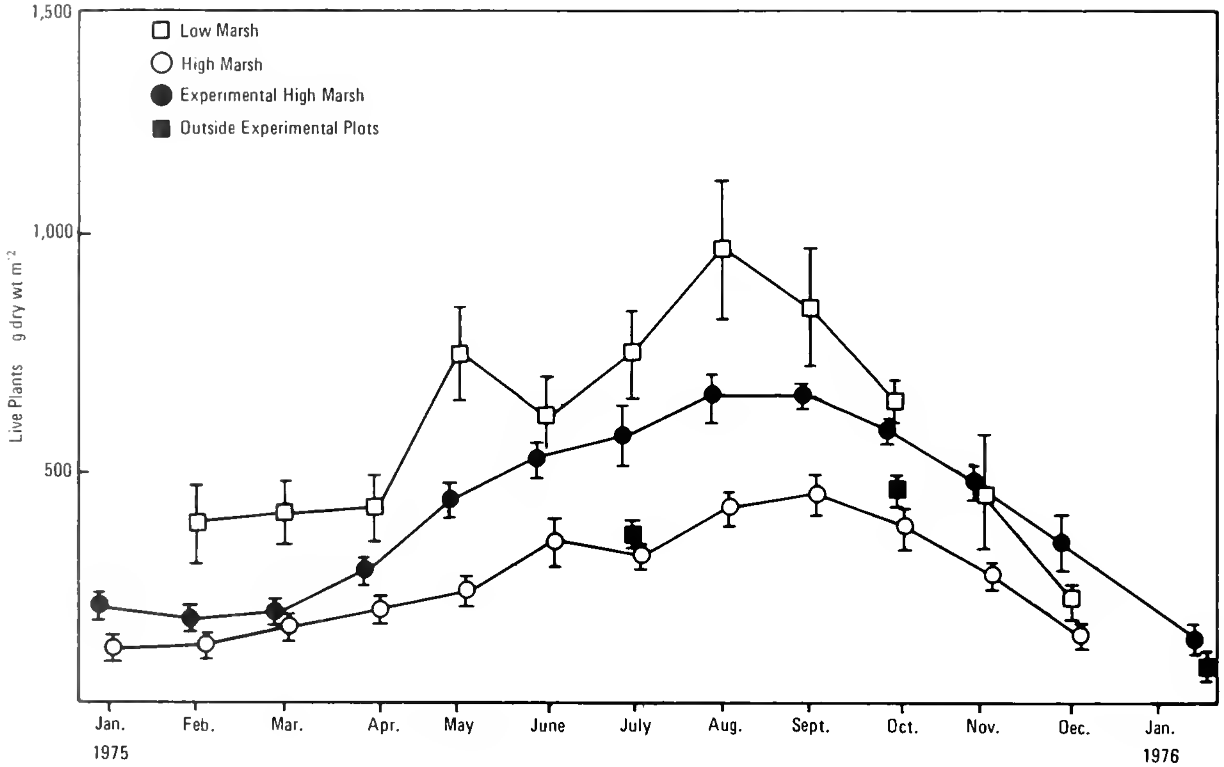

Figure 1. Seasonal variation of live above ground biomass in the study plots, mean ± 1 SE (Chalmers et al. 1976).

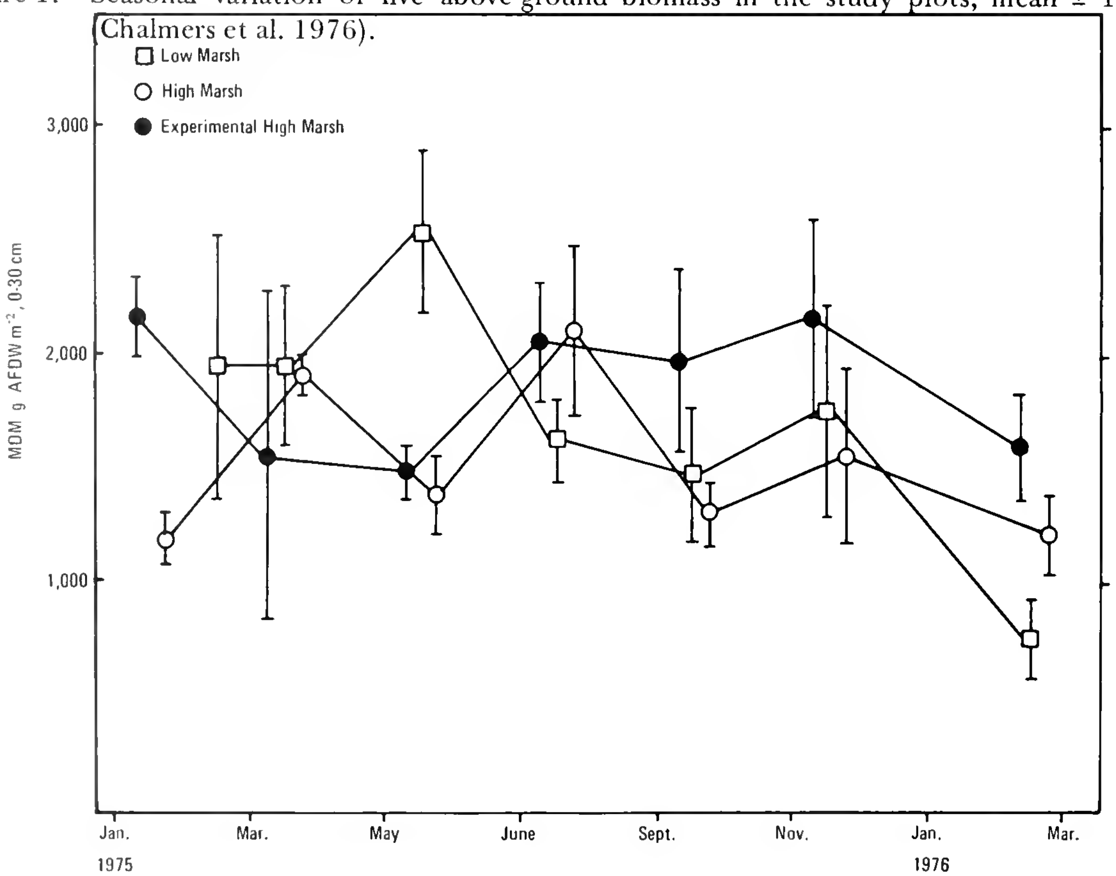

Figure 2. Seasonal variation of below ground macro-organic matter as grams ash-free dry weight (AFDW) per m^2 for the study plots (Chalmers et al. 1976).

nutrients than did control plants. In plots given the high level of sewage fertilization, the amount of roots was less than in the lower fertilization level plots or in the control plots.

In plots fertilized with urea, the root mass was about the same as that of control roots. In the high marsh, there were also fewer live roots in the high enrichment level than in the control. However, the amount of rhizomes and the amount of dead matter differed very little between the fertilized and unfertilized plots. Sewage fertilization apparently does not stimulate belowground growth, and may, in fact, decrease root growth in salt marshes. Valiela et al. (1976) found a seasonal root production pattern with an increase of root growth in the spring, followed by a decline in live root biomass.

Sewage enrichment can effect processes in the marsh other than plant growth. Addition of sewage fertilizer to a Massachusetts salt marsh decreased rates of nitrogen fixation in the marsh after the amount of ammonia in the sediment interstitial water increased (Van Raalte et al. 1974). An increase in denitrification was observed in the enriched plots that was significantly higher than that of the unfertilized plots (Valiela et al, in press). The authors did not quantify this to determine exactly how much of the added nitrogen was lost through reduction to gas. Consequently, they surmised that the marsh could effectively remove the nitrogen in sewage. Sewage nitrogen depressed the natural rate of nitrogen fixation, and the marshes used nitrogen in the sewage rather than nitrogen that would have been available through nitrogen fixation. At the same time, increased rates of denitrification in the marsh could remove more of the nitrogen in the sewage.

The rate of benthic algal production,which might be expected to be stimulated, actually decreased in Massachusetts (Estrada et al. 1974; Van Raalte et al. 1976). This decrease is a good example of an indirect effect of sewage enrichment. The rate of benthic algal production decreased in the fertilized plots because the increased standing plant biomass shaded the algae to the extent that the algae were light-limited. In our marsh, Bob Christian and Keith Bancroft studied the effect of sludge fertilization on microbial populations and activity. They measured adenosine tri-phosphate (ATP) in the sediment and found no differences in ATP (as a measure of microbial biomass) in the experimental plots compared to the control plots. Bancroft also analyzed the "energy charge" of the macrobial population as a measure of microbial activity, i.e., whether they are simply resting spores with a low energy charge or cells growing exponentially with a high energy charge. No difference in the energy charges was found between the sludge fertilized plots and the control. Apparently, the microbial populations in a mature marsh soil are very resistant to change in their immediate enrichment.

Valiela et al. (in press) presented a summary of the natural budgets of three different heavy metals (lead, zinc, and cadmium) in a marsh and compared the same budgets with a forcing function of the added metals in a sludge fertilizer applied to a marsh. About 90% of the added lead was retained in the marsh sediments, a small amount was lost, and some was accumulated in the marsh plants. More of the zinc (16.7%) was lost from the marsh, and Valiela et al. (in press) theorized that the zinc was exported from the marsh on sediment particles or as dissolved inorganic compounds. The remainder of the added zinc was accumulated in marsh sediments and plants. About half of the cadmium was lost by unknown mechanisms, and half was accumulated in sediments and marsh plants.

Is salt marsh disposal a good way to get rid of sewage? I agree with Pomeroy et al. (1969) that we should probably regard sewage as a resource rather than as a waste product. If we need to get rid of sewage, in some respects the salt marsh is a good tertiary treatment facility. Marsh plants and benthic algae have high rates of production and can assimilate some nutrients. The clay soils in Georgia estuaries can accumulate a lot of phosphate. The marsh is a fairly stable community and appears to be quite resilient, at least to enrichment stresses. The accreting sediments in salt marshes can allow for long-term storage of materials in the soils. Of course, the extent to which one can get rid of sewage in this fashion will depend on how much sedimentation is taking place.

In the Massachusetts marsh, the accretion rate was a matter of centimeters per year, and in the Georgia marsh, the sedimentation rate is considerably less, about a millimeter per year. In Massachusetts, about 80% to 96% of the nitrogen added in the sewage sludge fertilizer was retained in the marsh sediment, whereas in our study we can only account for 60% of the nitrogen that we added in sewage sludge; the rest was probably washed out by the tides. Some of the nitrogen could have been denitrified or volatilized as ammonia off the sediment surface. The Massachusetts group found that the waterlogged sediments in the marsh soils apparently can get rid of significant amounts of nitrogen through denitrification. On the other hand, the accumulation of toxic materials in marsh sediments will have long-term effects which we do not know much about. The marsh plants can pump certain ions, which might include toxic compounds, from the soil to the estuarine water. We also do not have any idea about the maximum loading rate beyond which the marsh system will begin to deteriorate.

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THE PRICING AND EVALUATION OF NATURAL RESOURCES

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As an economist, I believe we have been working with complex interrelationships very successfully as a profession for 200 yr. Civilized nations created monetary systems very early as a common denominator for value either as a stock or a transaction. I do not propose to bring you the answers, but I will discuss how economists think and some of the strange things they do or say.

We define economics as a study of any action or process which has to do with the creation of goods and services to satisfy human wants. As I look over this program, I see it is concerned with creating salt marshes, sand dunes, mangrove swamps, and habitats associated with these areas. In effect, there is concern with creating goods and services. This program does suggest an economic interest; therefore, the plan of action this evening will be to discuss some of the economic interests in natural resources and how we as economists try to work with natural scientists in understanding the biological and social interface. I will also try to explain some of the basic premises of economics and spend just a few minutes with the economic thought processes. Then I would like to open the meeting to any questions you have. I was impressed by some of the problems ecologists do face and the fact that perhaps we economists have not adequately addressed those problems yet.

There has been interest these past few days in the technical creation of communities in salt marshes and other coastal habitats. I am certain the concern has had to do with the state of the art for increasing the quantity or the quality, or both, of these coastal habitats. For example, I am sure some of the questions asked include how do we create more salt marshes, or more sand dunes, or how do we manage such areas to create a viable and a productive habitat? I am sure questions have arisen as to how much do these habitats cost and how much do they produce? But has it been asked to what extent do they satisfy human wants? Keeping these thoughts in mind may help explain some of the thought processes of economists and some of the problems we have. Remember, economics is often defined as not just the creation of goods and services, but also the creation of those goods and services that satisfy human wants.

Proceeding further with the definition, one could say that economists are a bunch of narrow-minded, selfish fellows who are only interested in humans and the personal satisfaction of the species. Perhaps that is correct. Perhaps most economists are introverts, but we are really interested in economics as a body of knowledge wherein the central interest is, and should be, the satisfaction of human wants. I ask you also, would not Darwinian survival theory support this economic premise of satisfying human wants by the production of goods and services?

Since this is the Bicentennial, I will mention that Adam Smith's book "Inquiry into the Theory and Wealth of Nations" was first published in 1776, 200 yr ago. I will not go into much detail, except to say that Adam Smith's concept of the economic man has a direct ecological counterpart. The concept is that economic man is one who goes about producing goods and services for himself and in so doing contributes to the welfare of society as a whole. The economic man is led by an invisible hand to promote an end which is no part of his intention.

A layman could easily conclude from the literature of ecology that each element of the food chain goes about pursuing its own interests in making a living while quite unintentionally providing a meal for the next link or a service to some link far removed. If one thinks a little about Adam Smith's concept of economic man or an ecologist's concept of an ecosystem, one can easily conclude that both concepts are quite self-centered and perhaps immoral with respect to religious or philosophic concepts of life. However, we do recognize those religious or philosophic concepts which arise in humans, by their will, to produce goods and services to serve their fellow man, not just for themselves. Some economists avoid this moral issue by assuming that economists do not make moral judgments, that it is not the domain of economists to make moral judgments. The economist concludes that he is only interested in the efficiency with which man goes about producing his goods and services.

I suppose there is no single concept in economics that gets us into more trouble that this concept of efficiency and what it means. However, this assumption, that the central objective of economics is efficiency, has led to the development of two factions or two approaches in both the economic literature and in professional practice. These are the positive and normative approaches to economic thinking.

The basis of the positive approach is to avoid moral, ethical, or normative judgments and to take the economic system as it is. We take the economic system as it is to be studied, modeled, forecasted, and reacted to; we accept the economic system for what it is. This is the modern version of the Adam Smith's classical school, in which self-interest is the prime motivation for all economic behavior. Positive economists generally conclude that both individuals and the whole society benefit most without governmental intervention in economic life. The basic premises are individual economic freedom and private property.

The basis of the normative approach is to make value judgments respecting the performance of the economic system. The normative economist is not satisfied with what is, but espouses a belief that economists should be concerned with what should be. This line of thought, which developed from the mid-19th century historical school, largely in Germany, says that economic policy should be derived from lessons in history and should evolve to meet judgments about human needs. The normative economist considers the government to be the most responsible motivator for economic behavior. The basic premise is government direction of economic activity and expansion of what we call the public interest doctrine, that is, the doctrine of an expanded public role of government, particularly with respect to natural resources which would become a public trust for the use of all people.

Now that we have established the rationale for all things coming in pairs, such as normative and positive economics, male and female, and Democrats and Republicans, perhaps we can better understand why economists never seem to agree and why so many economic statements seem pardoxical or certainly contradictory with respect to their purpose. I would like to explore some of the more substantive economic concepts which relate to pricing natural resources generally and to coastal ecosystems particularly.

First, the major subject matters with which we are concerned include production, consumption, distribution, and allocation. These terms refer to technical aspects of economics. They are technical in the sense that production includes the physical and economic combinations of goods and services;consumption refers to the limits and choices in consuming certain resources or goods and services; distribution is the process of equalizing supplies and demands among producers and consumers; and allocation is the scheme by which we permit resources or goods and services to be owned or controlled by the various sectors of the economy.

The economic theory counterparts of these technical aspects include, for production--the familiar supply functions; for consumption--the demand functions; for distribution--the exchange system; and for allocation--the pricing system. Of course, pricing and exchange get mixed up quite a bit. Pricing is a part of any exchange, but in a modern economic system pricing is much more;

it is directed toward achieving an equilibrium. The economic concept of supply and demand requires a price. Without a price one has no supply and demand functions--merely physical production and consumption. The economic concept of supply and demand must include a price.

The simplest exchange system in the world is a barter system where there is no cost of exchange. However, in a complex society where the producers are far removed from the consumers, one has large costs of exchange. I think this is one of the larger problems we face in the economy today. People are disgruntled with the high cost of exchange, the high cost of moving a tomato from south Florida to New York City. People cannot readily understand costs of exchange. Many people would very much like to see if we could not do things a little differently in the exchange system. That is, could we go back to a simpler economy in which the costs of exchange could be reduced? I do not see much hope for reduced exchange costs. Most of us would not accept a primitive economy. We like luxuries too much to revert to spending so much time producing directly what we consume. The exchange system governs the allocation of resources.

The positive economist accepts the premise that the existing allocation of resources and goods and services is acceptable. We allocate goods and resources in the relatively competitive economy through the ownership or control of those resources. The economist looks at four basic groups or categories of resources which are familiar to all: land, labor, capital, and management. In land, we include all of the natural resources, the renewable resources, such as wildlife, and nonrenewable resources such as extractive minerals. These natural resources are embodied in the economist's concept of land. The ownership of land and the resulting allocations are accepted by the positive economist as a fait accompli including the rents that are paid for land. The rent is the price for the use of that land. The rents that accrue to land are the method of allocating a part of the total goods and services of the economy to the owners of land.

The same is true of labor. Most of us sell our labor, which includes the technical skills we have. In fact, most of us in today's society have little to sell except labor. As we sell our labor, goods and services in the economy are allocated to us on the basis of our ability to command a price for our labor, a wage if one will.

Of course the owners of capital, essentially investors, receive the interest, and management receives the residual or profits, or various other forms of compensation which might result from the ownership of the particular technical skills required to combine the land, labor, and capital into a productive operation.

The heart of all this production, consumption, distribution, and allocation is a price system. What I would like to point out is that there are other ways of allocating besides a price system. We can allocate by law; we can legislate. We do a lot of that. We develop a policy or a standard or we pass a law. For example, the national effluent discharge permit system is a policy which affects allocation of resources. In this case, resources are reallocated from the private users of products to the public sector. Costs of effluent disposal are subsequently passed on to the consumers rather than being absorbed by the reduction in fishery habitat.

The ultimate legislated allocation of goods and services would be in a centralized economy, wherein one just passes down a budget or sets an arbitrary price or allocates goods and services on whatever premises may be arbitrarily judged appropriate. The two polar positions are the laissez-faire of a free market allocation system vs. the centralized government allocation system. These are the two extremes of allocation systems, both of which must have a pricing system for balancing needs and surpluses, demands and supplies. The pricing system is often referred to erroneously as being inaccurate or inappropriate. The pricing system is not perfect. I will try to explain some of the limitations of pricing systems so that we can understand how to better use prices as a guide to resource allocations.

The problems in the pricing system are most noticeable in areas of natural resources and environmental concerns where markets are not well-defined. We can do lot of tinkering with the pricing system to improve resource allocations. But we must not conclude, as do some economists and many noneconomists, that we should throw out the pricing system because it does not work perfectly. My conclusions are that the pricing system is the best thing we have going for us in terms of allocating goods and services. What we need to do is to identify long-range concerns with respect to overall goals and select those areas where market prices seem incompatible with social needs to do some tinkering with the pricing system.

For economic efficiency we must maintain a reasonably effective system of market pricing. There are several theories with respect to what a market price is. In a competitive economy a market price is one which no individual, no firm, no government agency can affect by itself through its buying or selling. In other words, it is all of the decisions made in the economic system as a whole which determine the market price.

We do have a few situations of operating competitive market price systems that work fairly well. The wheat market is about the best example of a competitive market system one can find since there is no buyer nor any individual farmer, by himself, that can affect the price of that commodity. However, as we move into more restrictive market structures, we start tinkering with this competitive market price. Some of the tinkering we do deliberately to effect public policies, or to effect preferences, or to accomplish goals other than the allocation of goods and resources. In the economics profession, the model we use is the perfectly competitive economy. That is the model on which our theoretical base rests.

The opposite of the competitive model is the monopoly or the single firm situation in which the firm, the individual, or the government by its own decision controls the price for a commodity by controlling the amount that is offered for sale. In this monopolistic situation, the prices are generally above both the average cost and the marginal cost of production. Therefore, we have a disequilibrium when measured against the competitive model. A disequilibrium exists since the monopolist, in controlling the amount of output and affecting the price, can obtain excess profits from the enterprise.

There are certain industries with such unique characteristics that they are natural monopolies. That is, it would be uneconomic or inefficient to allow, for example, public utilities to compete with each other in the open market. We would have power lines all over the place. These industries are designated as natural monopolies which we control by government intervention by regulating their economic activities. This is one of the first areas where we have government intervention or tinkering with the price system. The government issues an exclusive franchise to serve a certain segment of the population or State or municipality. In exchange for that franchise without competition, the government regulates the prices charged.

This creates an inflexibility or a rigidity in which adjustments are not easily made for changing conditions. Any needed changes are costly, inefficient, and vigorously opposed by incumbents. If one does not believe this, one can read some of the newspapers about problems of the Administration's efforts to deregulate the airline and trucking industries which have been protected from competition. A power utility with a franchised area is certainly not interested in deregulation. The industry enjoys regulation because it has a guaranteed return on investment, and that is something the wheat farmer in a competitive market does not have.

Those are the two extremes. There are other ways in which we tinker with the price system, especially through what I refer to as administered prices. We live in a system of administered prices. The environment for administered pricing is one in which we have a few firms or a group of firms or an industry in which people can either get together or, perhaps, because of the structure of the industry, intuitively determine a pricing scheme which is higher than a competitive price. Let me illustrate how we tinker with prices to change the value of goods in a market to better understand the value system for marshlands and the pricing system from the perspective of the economist (Figure 1).

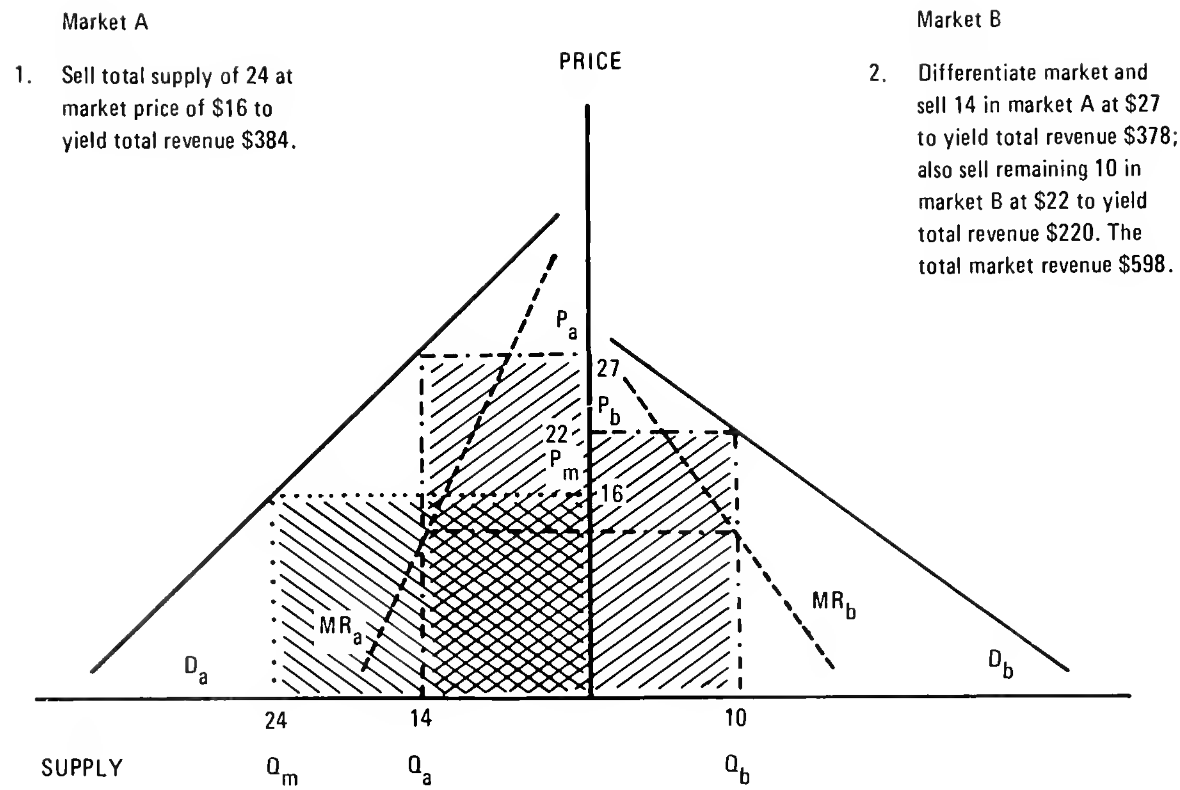

Figure 1. Price discrimination between two markets by product differentiation and market exchange control at no additional marketing cost.

If we have or can develop two markets, A and B, which by definition have different demand functions and thus different average revenue schedules in each market, we can easily see how a single firm or group that produces a single product can manipulate or administer these prices by allocating the product in different markets.

The classic example is in dairying. The dairy industry has two sets of prices: one for fresh milk and one for manufactured milk. We also practice discrimination in the international market, where we have one set of export prices and another set of domestic prices. The criteria for administering prices is that we must separate the two markets to prevent arbitrage or prevent any unauthorized exchange between the two markets. If we have a single demand and a single quantity of product, say 24 blue tutus, we would sell all 24 in market A for P_m or \$16 for a total revenue of \$384 , a simple one-price market system for a supply of 24 tutus.

If we discover that red tutus can be sold in another market at no additional cost, we can allocate the total tutu supply, Q_m, between markets A and B on the economic principle of equating the marginal revenues in the two markets at Q_a and Q_b respectively, where the marginal revenues for blue tutus, MR and red tutus MR_b are equal. Now the prevailing market prices are P_a (\$27) for blue tutus and P_b (\$22) for red tutus. This differentiation of the tutu market into blues and reds now yields total revenue for 24 tutus of \$598 (\$378 for blue tutus and \$220 for red tutus) - a significantly larger revenue by defining the two markets than could be obtained in the single market. This is one way to manipulate prices. We do this every day and this is why, in administered pricing systems, we get pricing and allocation of resources which are less efficient in terms of the competitive model.

We frequently manipulate prices for public utilities where the units of product consumed must be used sequentially. In this case, we start out with a series of declining block pricing schedules for electrical energy, a product in which the consumer must buy the first unit before he can have a second unit. Therefore, the firm or industry can control the price charged for successive units. In this situation, the controller of the resource or product gains most of the value under the demand curve by block rate pricing. This is the pricing system that exists in most public utilities, such as communications, water systems, power systems, and others.

These administered prices have little in common with a competitive pricing system, which is the standard against which we measure the economic performance of an industry or a firm. I hope this gives you some idea of how some economists earn their living and how prices, regardless of how they are determined, serve to allocate resources rather efficiently within whatever constraints are imposed by private or government manipulation.

Let me briefly touch on another matter which affects prices and values, with respect to the three basic types of goods that we deal with and how the character of the goods affects price. There are economic goods, free goods, and public goods.

An economic good is anything that has value in use or that is scarce, i.e., anything for which we are willing to pay. Anything with a price is an economic good. Free goods are those that are abundant, there is more than enough to go around, and therefore there is no price. You can always tell a free good because it has a zero price. We have this third category which really gives us problems. That is the public goods which society values, but has no effective way of pricing to its individual members.

Public goods fall into the area of things that we intuitively hold to be good or valuable, but which we are unwilling, as individuals, to pay for. It is the normative concept. Because of the nature of these goods or services which cannot be individually owned or controlled, we as individuals are not willing to pay for them. The result is a situation in which you have the free rider problem, where people can enjoy certain goods or services without having to pay. There is a terrific enforcement problem, such that beneficiaries of these economic activities cannot be excluded for nonpayment. Such public goods include defense, schools, and various governmental services in which we feel strongly that, even though there may be a limited private market, the common good would be better served by vigorous governmental participation. Of course, defense is the largest public good that we provide ourselves, and you can immediately see the exclusion problem in these things. If one provides national defense, one can not exclude a citizen beneficiary.

On a smaller scale, we have the same situation with respect to a floodplain. That is why we have so much governmental activity in flood control and flood damage reduction. The assumption is that flood control is a public good because, within the floodplain itself, one cannot easily exclude anyone who is unwilling to pay for that protection. Of course, there are various police or legislative methods through which one could require payment, but one cannot get a voluntary payment.

Much of the nation's natural resources fall into this category of public goods, or at lease in the transition from a free good to a public good. In the water resources area, we have been able to see the transition of water as a commodity from a free good (where there was little or no price attached to it), to a public good, and thence to an economic good in which the price is quite high. It is the public goods sector where we have our real problem with pricing. How do we price the public goods? How do we charge the beneficiaries of public goods?

Related also to the public goods sector is a concept which I often find advantageous to explain, that is, the concept of externalities. An externality exists when one cannot exclude a beneficiary from receiving a benefit, nor can one very easily force him to pay for a benefit received. Normally, we have thought of externalities in terms of negatives or negative goods. For example, pollution is an externality because we have traditionally discharged our effluents and our pollutants for zero private cost. Any cost incurred was either borne by third parties, such as downstream people or downwind people or by the public sector in terms of wildlife damage or habitat damage. An externality exists when the market system cannot voluntarily and effectively register or sum the total merits of the good. We sometimes make people pay by passing a law or by enforcing a standard such that we internalize these costs. The only other recourse is through the courts. Recently, we have had a lot of settlements of externalities through the courts in both the private and public sectors, especially, since the National Environment Policy Act (NEPA) of 1969.

The last thing I would like to mention is with respect to the goals and objectives of economics. The first is that of achieving efficiency. Efficiency is the objective with which we are most frequently concerned. The companion concept to efficiency, and one we do not hear too much about, is equity. The concept of equity does not necessarily mean equality. Equity in economics more accurately means fair treatment rather than equal treatment. Equity refers to the distribution or changes in the distribution, which exist or may be brought about by economic or political activities. In any public policy decision or in any economic decision, we always have the two impacts: the efficiency impact and the equity impact. The central question of efficiency is how much does it cost or how much does one pay for it? The central quesion of equity is who pays?

Some policy decisions increase efficiency; some certainly decrease efficiency. Most policy decisions change the distribution of benefits and costs so that some groups of people are enriched, or at least made better off,while others are damaged or made worse off. For example, if the Environmental Protection Agency should impose an effluent discharge standard on kraft mills but not on newsprint mills, then this would damage users of kraft relative to users of newsprint. It would increase kraft costs and affect both producers and consumers of their products. This is a situation in which a policy decision has an adverse equity impact. However, the total efficiency for the economy may be either good or bad, depending on the tradeoffs between the predecision social costs and postdecision private costs. Efficiency is the size of the pie, and equity is how we slice the pie for the various sectors.

In the free market system we solve our equity problem by saying that the existing allocation of resources and talents and goods and services is acceptable. This is the positive approach. In the normative approach we say that the equity situation is unacceptable; therefore, we will implement certain policies to change the distribution of goods and services, either as flows or as stocks. This approach results in progressive income taxes, progressive excise taxes, and transfers from one sector of the economy to another, generally by governmental activity. The objective is to change the equity status by changing the payees and beneficiaries for the given economic activity.

Going further into the goals of economics, we have several that I should mention. One goal that is often attributed to economics is that of growth. Growth is defined as an increase in the gross national product. Now this is a perennial national policy. We wish to grow at a certain rate, to increase the gross national product at a certain rate, to keep the growth from declining too much. It is the rate of growth that we are interested in.

Another national goal is to have full employment. This is essentially the thought that everybody who wants a job should have the opportunity to have one. However, as you see in a complex industrialized society, we have great difficulty balancing full employment and economic growth. Another national goal is a stable price level, or control over inflation. These are the three basic national economic goals: growth, full employment,and stable prices. Of course, we have not determined how to achieve these three goals simultaneously.

It seems we cannot have all of these things. We have to reach some kind of a compromise. When we get different answers about what the national policy should be with respect to interest rates, with respect to the taxing system, or with respect to the welfare system, we are trying to reach some kind of agreement about what the national goals are with respect to balancing growth rates, employment, and price levels. All the other things to do with investments in our natural resources would be subject to these overall larger goals.

For any goal or mix of national economic goals, how much are our natural or environmental resources worth? There are several ways we try to value natural resources where there is no established market. If we have a market in which prices are established, then we have a dollar measure of the value of those resources at any given time. There are five different methods of evaluation and each method will give one a different value for a nonmarket good.

The first one is the market value to the consumer or the participant. This is a measure of the direct market value of the activity in terms of alternative costs of purchasing on the market a different type of activity or a different good. That is, we are always trying to get the best deal for the dollar in the market. The market value is determined on the basis of our willingness to pay directly for a good, a service, or an activity. This is a direct method of measuring value in the commercial sector.

The second method is the sectoral economic impacts, which are the direct impacts of an investment or an expenditure in a community. The multiplier effect that comes from an initial expenditure is alleged to measure the larger efficiency impact of a consumption or investment activity. If the expenditure is for a good or service, where it is retained largely in the designated area, one has a high multiplier of three, four, or five dollars of activity in a given geographic area. However, when the initial expenditure is for an import or where the material and labor are brought in from the outside, then the local multiplier effect is very low and there is little or no economic impact. This method of measuring value by the sectoral impact is often used as an estimate for a hunting day or a fishing day spent in a particular area. The direct expenditure, plus the multiplier impacts, is perceived as a measure of the real value of a resource in the public sector.

The third measurement is the personal cost of participation. This is a surrogate for total willingness to spend for all direct and associated costs of participation. In recreational activities this would include the associated cost of travel, lodging, special equipment, and similar items. It is the cost of getting there or the total cost of participating which is perceived as the real value of a natural resource used in this manner.

The fourth method of measurement is the social value to the participant. This is essentially a measure of how much each participant or each consumer values the activity or the goods or services he is purchasing, such as a fishing experience or a hunting experience. Perhaps more accurately, the way the economist measures this social value is the willingness to forgo the experience. In other words, instead of asking how much is one willing to pay, one would ask how much is one willing to give up to participate in this activity? Would one give up a whole day's wage or would one give up two days' wages for half a day of fishing? That would be the social value as we measure it. According to most of the research we have done, this method gives the highest value. The direct market value generally gives the lowest value.

Another evaluation technique I wish to mention is what we call the reservation value to potential participants. One will also see this referred to as "option demand." The reservation value is a measure of the willingness to reserve or maintain an opportunity to participate or enjoy a good in the future. In other words, I am buying an option for future participation. I do this by paying dues to the Sierra Club to preserve an area or by making a contribution to a museum for an art piece. The option demand is simply a normative judgment that I would like to have the opportunity for future participation in an activity. It is irrelevant whether or not I ever participate. This is the driving force behind the valuation of much of our natural resources, particularly all the parks, game refuges, and things we would like to preserve for the future.

This reservation value is a relatively new approach that economists have taken. There is not much in the literature on it yet, and we are just getting around to formalizing this concept of an option demand. If there is any approach that might be worthwhile researching in terms of natural resources, fisheries, wetlands and wildlife valuation, it is the concept of an option demand. At least, it is a positive approach which recognizes that these resources have values for the future. What we need is a way of formalizing the concept just as we have formalized market pricing and the various discriminatory pricing systems mentioned earlier.

In summary, I hope we have developed a better understanding of the role of prices and the pricing system in allocating and managing our natural resources or natural environments. At least we have looked at some of the applications of pricing theory in both the private market sectors and the public goods sectors of the economy. We have also looked at the limitations of a pricing system as a basis for the evaluation of either current values or investment decisions that involve the management and development of natural resources, such as estuaries, fisheries, and wildlife. Many people are proposing the existence of enormous prices (what they really mean is value) for natural environments in the hope of attracting attention to their management, development, or preservation. However, these proposals will not be taken seriously by society unless they can be adequately documented and verified either empirically or intuitively. We face the prospect of living with a range of prices and values for our natural resources within which reasonable political decisions can be made for this segment of the public goods market.

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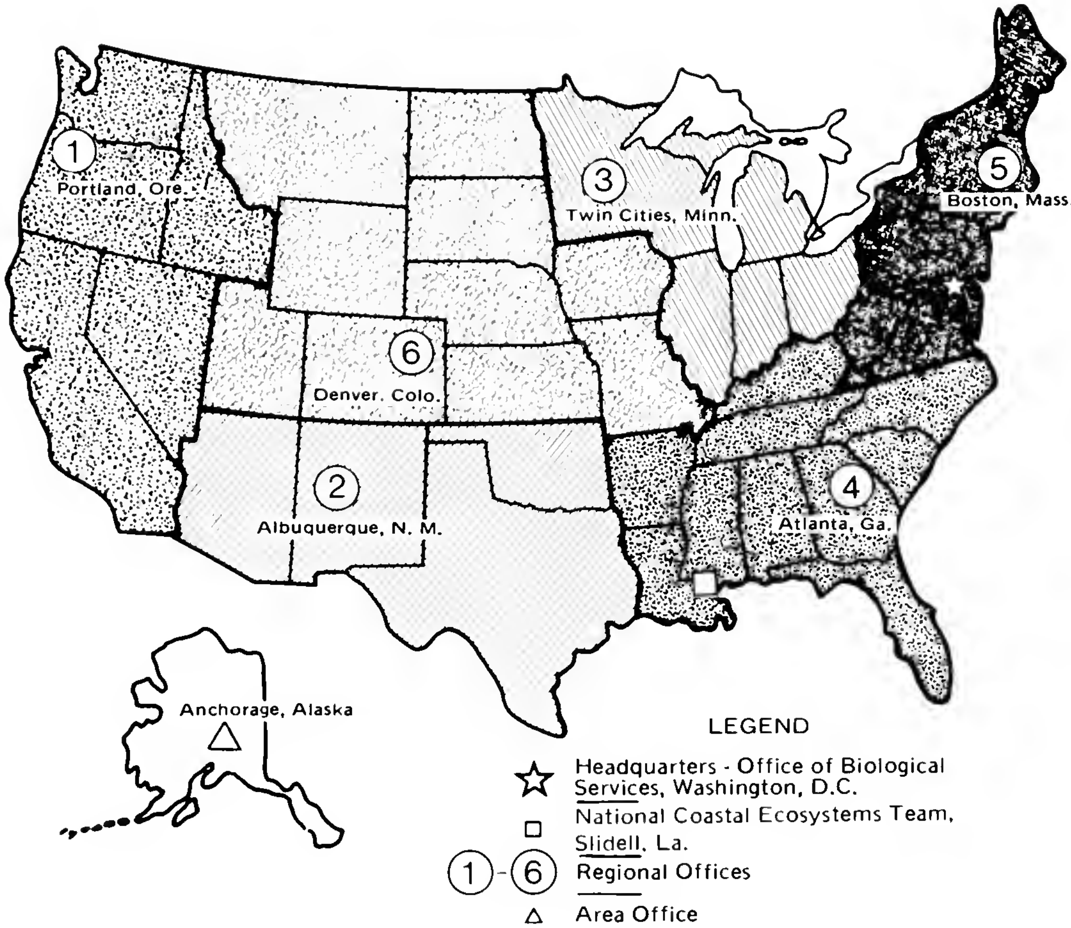

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