Proceedings of the sixth Annual Conference on Wetlands Restoration and Creation, May 19, 1979, Hillsborough Community College, Tampa, Florida. 1979

Tampa, Florida: Environmental Studies Center, Hillsborough Community College, 1979

https://digital.library.wisc.edu/1711.dl/BYXCVVFQ7HUOO9B

Proceedings of

The Sixth Annual Conference On

THE RESTORATION AND CREATION OF WETLANDS

Sponsored by

Hillsborough Community College
Environmental Studies Center
at Cockroach Bay
in cooperation with the
Tampa Port Authority

May 19, 1979

HILLSBOROUGH COMMUNITY COLLEGE

PROCEEDINGS OF
THE SIXTH ANNUAL CONFERENCE
ON WETLANDS
RESTORATION AND CREATION

May 19, 1979
Hillsborough Community College
Tampa,.Florida

Co-sponsored by
the Tampa Port Authority
and
the Environmental Studies Center
at Cockroach Bay

Dorothea P. Cole, Editor
and
Program Biologist
Environmental Studies Center
Hillsborough Community College
P. O. Box 22127
Tampa, FL 33622

TABLE OF CONTENTS

TABLE OF CONTENTS
(continued)

AN APPROACH TO VALUATION
OF FLORIDA FRESHWATER WETLANDS

by

Brian H. Winchester[1] and Larry D. Harris[2]

[1] CH2M HILL, Inc., P.O. Box 1647, Gainesville, Florida 32602.
[2] School of Forest Resources and Conservation, University of Florida, Gainesville, Florida 32611.

ABSTRACT

A technique is presented for estimating the relative ecological and functional value of Florida freshwater wetlands. Wetland attributes and functions evaluated by this technique include water quality enhancement, water detention, vegetative diversity and productivity, and wildlife habitat value. The field parameters used in the assessment are wetland size, contiguity, structural vegetative diversity, and an edge-to-area ratio. This technique has performed satisfactorily in actual field applications and has been both cost effective and time effective. Allowing flexibility in both the evaluative criteria used and the relative weight assigned to each criterion, it is applicable in any Florida region for which basic ecological data are available.

INTRODUCTION

Interest in the description, classification, inventory, and valuation of wetlands has increased dramatically during the last 10 years. This interest has been stimulated by the accelerated loss of wetlands within Florida and by both state and national legislation in the early 1970's (e.g., 1972 Comprehensive Planning Act, 1972 Coastal Zone Management Act). The interest has ranged from straightforward definition and mapping of wetlands to the development of highly sophisticated energy accounting concepts. Still, to our knowledge there is no easily applied, cost-effective method for estimating the worth of one wetland relative to another.

As much as 2 million acres of the Florida landscape is being developed annually (Harris and Kangas, in press). A significant portion of the land base for this development involves freshwater wetlands. Large acreages are also subject to surface mining in parts of the state, though for many new mines permission to mine wetlands is being granted only on the condition that wetlands be restored or recreated.

These trends lead to some specific needs in the area of wetland valuation. First, an index is needed that will estimate the loss associated with development or mining of one wetland relative to another. Such an index could guide developers, the phosphate industry, and regulatory agencies in the permitting and decision-making process. Secondly, an index is needed which is time effective, cost effective, and relatively objective and straightforward in its application. Thirdly, the index should be applicable without major modification to any region in the state. Finally, as wetland creation and restoration becomes more prevalent, an index is needed to help plan and later gauge the relative merit of different wetland restoration efforts. The valuation technique presented here was developed with these needs in mind.

The technique as presented here is considered to be preliminary and is open to revision and modification. It was intentionally designed to allow flexibility both in the variables used to evaluate wetland value and the relative importance placed on those variables. The technique is clearly not a valuation scheme in the energy accounting sense. Neither would the value generated for a single wetland have much meaning without comparison to other wetlands. For these reasons we consider the greatest strength of the technique to be its ability to estimate the comparative value of different wetlands in a given area.

WETLAND VALUATION: A CONCEPTUAL APPROACH

In their natural state, wetlands possess certain inherent attributes and characteristics which make them of great ecological value. Assuming that parameters can be defined to measure these inherent values, a general approach for determining the relative value of an individual wetland might be expressed as follows:

$$\text{Wetland value} = \sum_{i=1}^{n} C_i \, V_i$$

where V is the numeric magnitude of a given parameter (the parameter value) and C is the coefficient of relative weight given to that parameter (the parameter weight) in determining the wetland's overall value. For example, if four parameters are chosen to assess wetland value, the equation would be:

$$\text{Wetland value} = C_1V_1 + C_2V_2 + C_3V_3 + C_4V_4$$

Since these four parameters will probably be in different units and have different ranges of magnitude, it may be desirable to scale all parameter measurements so that they fall within the same numeric range. This may be accomplished by either assigning the various parameter measurements into numeric classes within the established minimum/maximum range or proportionally scaling the parameter measurements to the established range.

For example, if it were decided that all parameter values (V_i) should fall within a range of 1 to 10, then a parameter having measurements of 1 to 250 might be placed in ten classes (i.e., 1-25, 26-50, 51-75, ...226-250). If in this case, high parameter measurements reflected high wetland value, then the highest class (226-250) would be assigned a numeric magnitude of 10.

Similarly, a parameter measurement varying from 20.0 to 35.0 might be scaled so that measurements of 20.0 and 35.0 correspond to parameter values of 1.0 and 10.0, respectively (assuming the higher measurement represents higher wetland value). All measurements between 20.0 and 35.0 could then be appropriately distributed between 1.0 and 10.0.

Coefficients of parameter weight (C_i) can be assigned to give more or less weight to parameter values according to their importance in reflecting inherent wetland value. Continuing with the present example, if all parameter values were considered to be of equal importance in reflecting overall wetland value, then:

$$C_1 = C_2 = C_3 = C_4$$

and the equation would be reduced to:

$$\text{Wetland value} = V_1 + V_2 + V_3 + V_4$$

On the other hand, if V_2 were considered twice as important and V_3 four times as important as V_1 and if V_4 were equal in importance to V_1, the equation would be:

$$\text{Wetland value} = V_1 + 2V_2 + 4V_3 + V_4$$

WETLAND VALUES AND FUNCTIONS

Before the relative value of a wetland can be assessed, it is necessary to define which wetland attributes and functions are of the greatest importance in determining the inherent value of wetlands. Freshwater wetlands possess many such intrinsic functions and values in their natural, undisturbed state. For wetlands in Florida, we have chosen the following attributes and functions as determinants of overall wetland value: (i) water quality enhancement, (ii) water detention, (iii) ground-water recharge/discharge, (iv) productivity and diversity, and (v) wildlife habitat value.

Water Quality Enhancement. Freshwater wetlands are known to act as chemical and biological scrubbers of water flowing through them. Studies in the southeastern United States have shown this to be true of river swamps (Wharton, 1970; Patrick et al., 1976), cypress swamps (Ewel and Odum, 1978), nonriverine hardwood swamps (Boyt, 1976), and freshwater marshes (Shih and Hallett, 1974).

Water Detention. Wetlands frequently serve as collection basins for surface water, feeding it out gradually through springs, seeps, or open outlets (Gabrielson, 1962). They form an integral part of the regional hydrologic system in that they reduce downstream peak flows during flood periods and help maintain base flows during dry periods (Motts and Heeley, 1973). Riverine wetlands are especially important as natural flood control areas (Massachusetts Water Resources Commission, 1971; U. S. Army Corps of Engineers, 1971).

Groundwater Recharge/Discharge. Some wetlands are significant sites of ground-water recharge or discharge. Other wetlands are perched and have little significant interaction with underlying aquifers. The degree to which ground-water recharge or discharge occurs on a given site depends primarily upon the soil permeability, surficial geology, and hydroperiod of the wetland.

Productivity and Diversity. Wetlands are considered to be among the world's most productive natural ecosystems (Wharton, 1970; Hoffman, 1968). In Florida, the gross primary production of both forested and nonforested freshwater wetlands is believed to be substantially higher than many other Florida plant communities (Brown, 1978; Bayley and Burns, 1974). Wetlands may also be more diverse than surrounding plant communities in terms of vegetative species and structure, though this is not always the case.

Wildlife Habitat Value. Freshwater wetlands provide important habitat for many fish and wildlife species, especially where the wetlands are associated with lakes or streams (Golet, 1973). Many wildlife species occur only in wetland habitats, whereas others are vitally linked to wetlands during a portion of their life cycle. Layne et al. (1977) were of the opinion that wetlands constitute the most important natural habitats for fish and wildlife in the central Florida area.

It should be noted that these five natural wetland functions provide valuable services to man and that the value of these services to man can be enhanced with careful management and utilization of the wetland resource. There are also other aspects of wetlands which are valuable to man when the wetlands are prudently managed. For example, the grazing potential of Florida freshwater marshes and wet prairies is very high (White, 1973). Wetlands are also valuable in that they comprise significant visual/cultural resources with scenic, recreational, and educational values (USDI, 1962; Wharton, 1970; Smardon, 1973).

WETLAND PARAMETERS

Having suggested some inherent wetland attributes and functions which might be assessed in a valuation process, it is necessary to develop easily measurable parameters which reflect the values present in any given wetland. Because the ground-water recharge/discharge activity of an individual wetland can not be adequately assessed without expensive, site-specific geological investigation (Motts and Heeley, 1973) and because such data are generally unavailable for Florida wetlands, we specifically excluded this function from the present valuation process. When either a methodology for rapidly assessing the recharge function of different wetlands is developed or when such site-specific data become available, this function can be easily incorporated into the valuation technique. Consequently, only the four remaining wetland functions were assessed. The field parameters chosen as indicators of these four inherent wetland functions were (i) wetland size, (ii) wetland contiguity, (iii) vegetative structural diversity, and (iv) the type and amount of edge relative to wetland size.

Wetland Size. Each of the four inherent functions previously discussed are related to wetland size. The degree to which a wetland can enhance water quality depends partially upon the retention time of the wetland. This, in turn, is related to wetland size, wetland configuration, and the actual path water takes through the wetland. Therefore, for vegetatively equivalent wetlands of similar shape, we believe that larger wetlands will contribute more to water quality enhancement than will smaller ones. Large wetlands also have a greater capacity to collect and detain water than do smaller wetlands.

Although large wetlands may not have greater gross primary productivities than smaller wetlands, their total production will tend to be greater because of their larger size. They also tend to be more diverse vegetatively and support more diverse wildlife populations (Golet, 1973). It should also be recognized that small wetlands fall below the minimum home range requirements of certain wetland wildlife species.

Wetland Contiguity. The degree to which a wetland is connected to local drainage systems significantly influences its contribution to regional water quality. A perched wetland with no outflow of water except evapotranspiration does not significantly enhance regional water quality. A wetland which is semicontiguous to local creeks and streams or which is connected only during the wet season probably contributes to regional water quality only during periods of peak flow. A highly contiguous wetland directly adjoining or within an established drainageway would be expected to provide the most consistent enhancement of water quality.

The degree of water detention versus retention in wetlands depends on how the wetlands are connected to regional drainage systems. Perched wetlands will serve mainly as retention sites, whereas semicontiguous and contiguous wetlands will function more in detaining water.

Contiguity contributes to many other important ecological functions (Ewel, 1979). Because wetland hydroperiod is related to contiguity and because periodic flooding provides a nutrient/energy subsidy, contiguity indirectly enhances productivity. Many water-borne propagules, both plant and animal, are dependent upon a high degree of contiguity for their dispersal. Wetlands associated with lakes or streams are more valuable to wildlife than are isolated ones and associations of connected wetlands facilitate use by wide-ranging wildlife species and movement of aquatic and semiaquatic species (Golet, 1973).

Vegetative Structural Diversity. Structural diversity of vegetation within wetland plant communities is a general indicator of both floral and faunal diversity. A large number of studies have indicated that wildlife abundance and diversity are directly related to the presence of appropriate vegetation diversity and complexity, with faunal diversity increasing as floral diversity increases (MacArthur, MacArthur, and Preer, 1962; Roth, 1976). Although the relationship between structural vegetation diversity and wildlife species diversity has not been rigorously tested for Florida wetlands, it is expected to pertain. In evaluating structural diversity, both the vertical and the areal distribution of vegetative strata and zones are considered.

Edge/Area Relationships. The linear extent and type of edge associated with wetlands is related to many different ecological functions. Surface runoff entering wetlands from adjoining lands passes through the wetland edge as it enters the wetland. Therefore, the type and amount of edge along the wetland perimeter has bearing on the enhancement of wetland water quality since these edges also perform a scrubbing function.

It is generally accepted that the wildlife abundance and diversity of an area is related to the diversity or interspersion of distinct habitat types (Leopold, 1933). Ecotones and edges often have greater vegetative productivity (Wales, 1972) and commonly have larger wildlife populations than pure stands (Ghiselin, 1977). Wetland edges are extremely important because wetland wildlife species tend to congregate around the edges where they can obtain their requirements from two or more plant communities with a minimum of effort (Golet, 1973). Ghiselin (1977) suggested that an index measuring the amount of edge relative to area could be used as an indicator of relative wildlife productivity between similar habitats. He based this on the premise that of two areas of similar biota, the one having a higher areal proportion of ecotone will also have a higher biological productivity.

However, edge-to-area ratios in themselves are inadequate for determining the wildlife value of a particular tract of land. A number of recent studies have indicated that various edge characteristics significantly influence the wildlife value of edges (Harris and Smith, 1978; King, 1978; McElveen, 1978). Therefore, an edge index that considers these different edge characteristics will better reflect overall edge values.

MEASUREMENT AND RANKING OF PARAMETERS

Before the valuation technique can be applied, it is necessary to define how the four wetland parameters are to be measured and how these measurements are to be translated into parameter values (V_i's). If each parameter is judged a priori to be of equal importance in reflecting the true wetland value and each of the four terms of the equation are limited to a maximum scaled value of 10.0, the general equation would be:

$$\text{Wetland value} = AV_1 + BV_2 + CV_3 + DV_4$$

where each V has maximum and minimum values of 10.0 and 1.0, respectively, and A, B, C, and D are scaling constants. The four wetland parameters can then be measured and scaled as follows.

Wetland Size (V_1). After delineation of wetland boundaries, the acreage of each wetland is determined and ranked into one of 10 classes.

If wetland acreage (WA) is <2.5, $V_1 = 1$
If $2.5 \leq WA < 5.0$, $V_1 = 2$
If $5.0 \leq WA < 10.0$, $V_1 = 3$
If $10.0 \leq WA < 20.0$, $V_1 = 4$
If $20.0 \leq WA < 40.0$, $V_1 = 5$
If $40.0 \leq WA < 80.0$, $V_1 = 6$
If $80.0 \leq WA < 160.0$, $V_1 = 7$
If $160.0 \leq WA < 320.0$, $V_1 = 8$
If $320.0 \leq WA < 640$, $V_1 = 9$
If $WA \geq 640$, $V_1 = 10$

The geometric relationship between the classes and wetland size is shown in Figure 1. Since there are 10 classes of V_1, the scaling constant A is set equal to 1.0.

Wetland Contiguity (V_2). Four contiguity classes are proposed for freshwater wetlands in Florida, depicted in Figure 2. If the wetland is perched and isolated from the regional drainage system, $V_2 = 1$. If the wetland is joined to a local creek or lake system by an indistinct natural connection or a small or partially obscured ditch, $V_2 = 2$. Wetlands which are joined

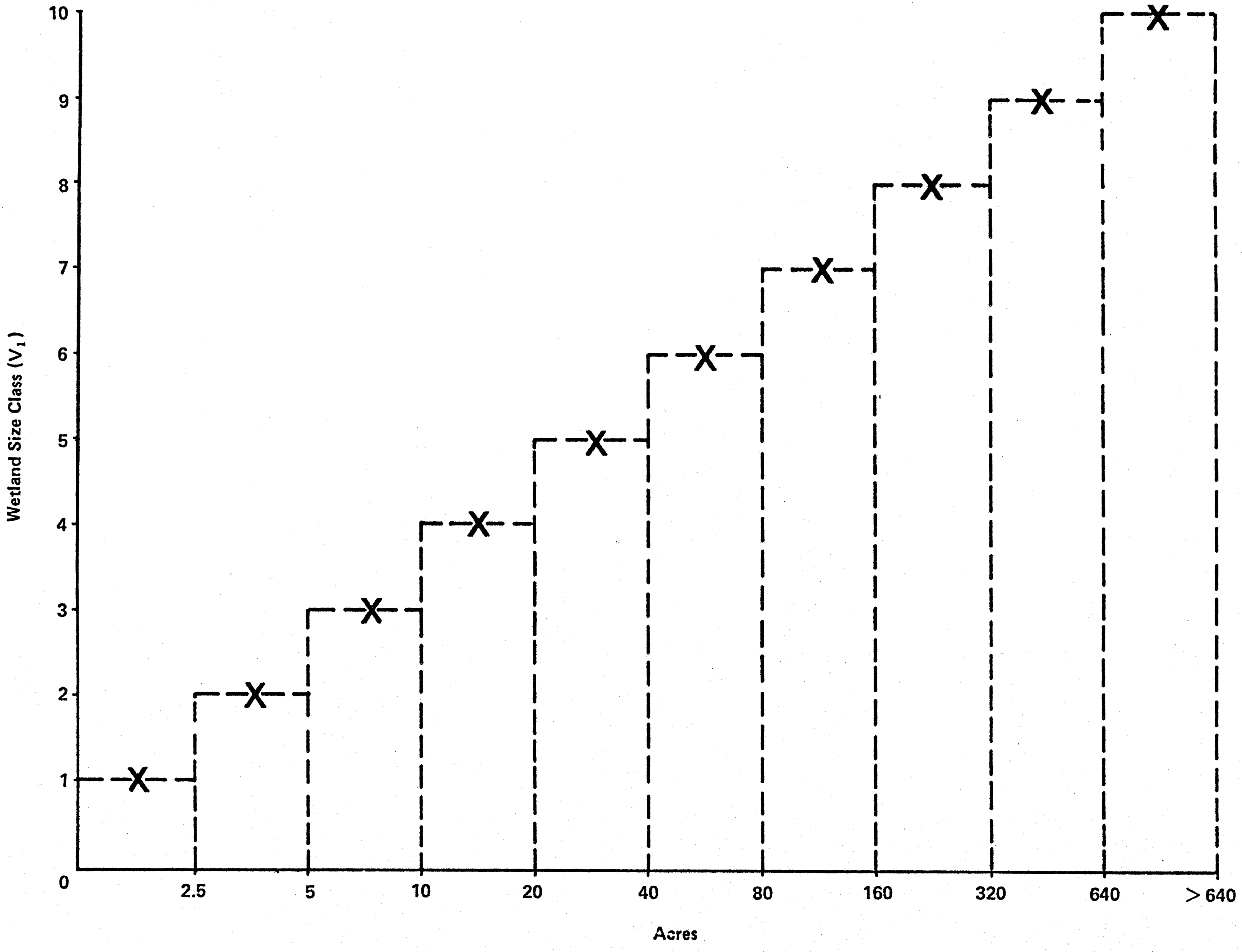


FIGURE 1. Wetland size classes and corresponding acreages for Florida freshwater wetlands.

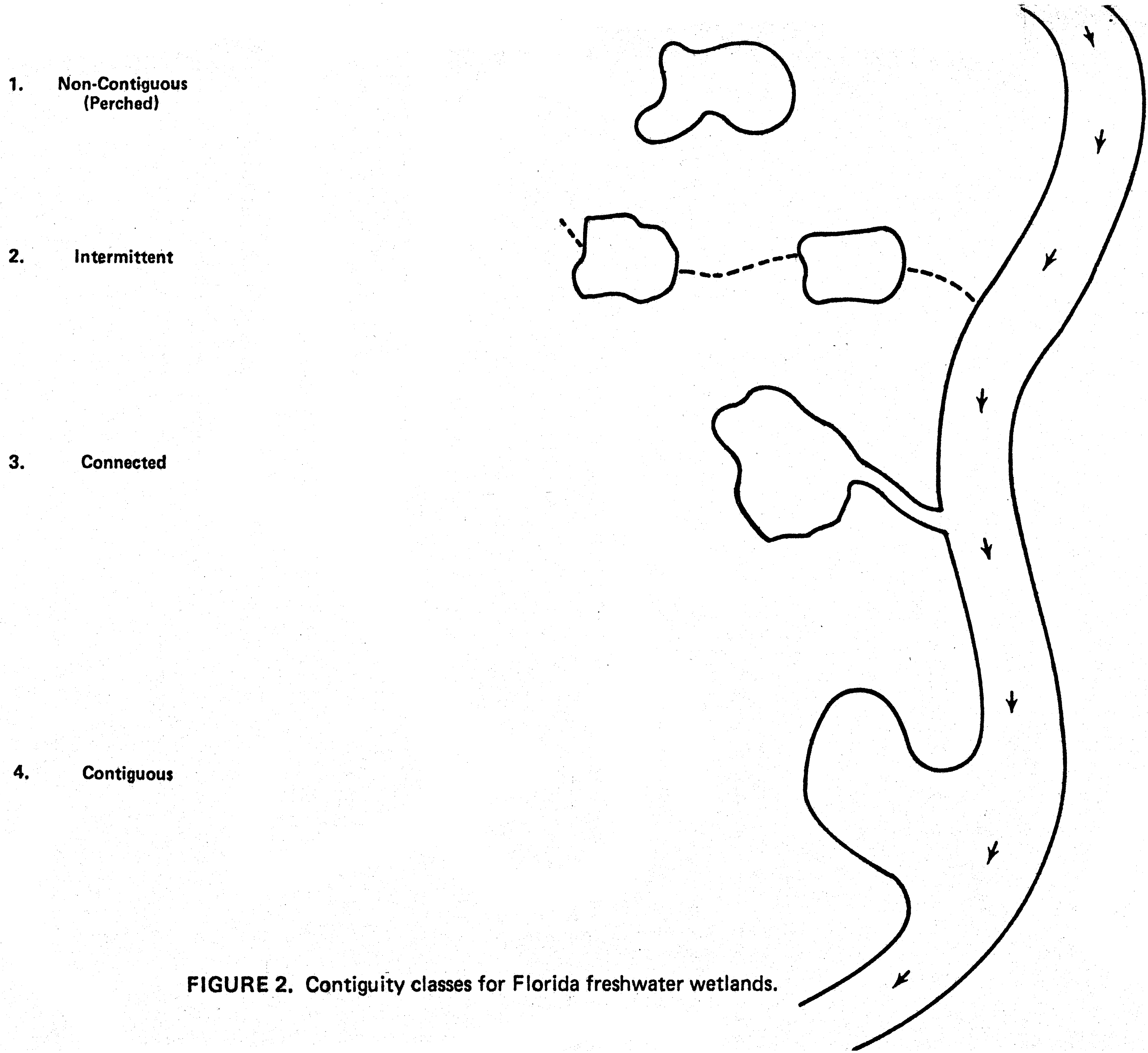


FIGURE 2. Contiguity classes for Florida freshwater wetlands.

to regional drainage systems by distinct natural connections or a well indicated ditch or canal are in the third class, $V_2 = 3$. (These latter two classes probably include most of the wetlands which are only connected to regional systems during wet periods.) Wetlands contiguous to or within established drainageways fall in the fourth class, $V_2 = 4$. Since there are four classes of V_2, the scaling constant B is set equal to 2.5.

Structural Diversity (V_3). Structural diversity varies according to the number and distribution of vegetative strata (vertical diversity) and vegetative zones (horizontal diversity). Five classes are defined. If wetlands have only one vegetative stratum and little zonation, $V_3 = 1$. If an estimated 25% or more of the wetland has two strata or if three or more vegetative zones are present, $V_3 = 2$. If two strata are present throughout the wetland (e.g., shrub swamp), $V_3 = 3$. If three or more strata are present throughout the wetland (e.g., mature swamp), $V_3 = 4$. Finally, if the wetland has three strata but is interspersed with numerous canopy openings or small marshes, $V_3 = 5$. Since there are five classes of V_3, the scaling constant C is set equal to 2.0.

Comprehensive Edge Index (V_4). An edge-to-area index was developed along the same lines as Welch's (1948) shore development index, except that edges were weighted according to the degree of edge drama (the amount of structural difference at the edge between adjoining plant communities) and the estimated gross productivity of the two plant communities. The basic formula is:

$$\mathrm{CEI} = \frac{E_W}{2\sqrt{a\pi}}$$

where CEI is the "comprehensive edge index," E_w is the sum of each wetland's weighted edge lengths, and a is the area of the wetland. One advantage of using this basic formula is that it equalizes the edge-to-area ratio of wetlands having identical configuration, negating the tendency of the edge-area ratio to decrease as the size of a given shape increases. Because the influence of varying wetland size is already considered in V_1, it is desirable to eliminate the influence of size from this parameter.

Each segment of edge surrounding wetlands can be assigned to one of five classes depending on the degree of edge drama. A segment of edge between two plant communities with dramatic structural differences (e.g., swamp and pasture) might have an edge drama value (EDV) of 5.0, whereas a segment between structurally similar communities (e.g., wet prairie and pasture) might have an EDV of 1.0. Secondly, each of the two plant communities can be assigned into one of five productivity classes based on the best available data, with the most productive plant communities having a productivity value (PV) of 5.0. An individual edge segment could then be weighted as follows.

$$E_i = EL\ (EDV = \frac{PV_1 + PV_2}{2})$$

Where EL = edge length in feet, EDV = edge drama value, and PV_1 and PV_2 are the productivity values for the two abutting plant communites. The total weighted edge length (E_w) for that wetland would then be equal to the sum of all its component E_i's and CEI would be:

$$CEI = \frac{\sum_{i=1}^{\eta} E_i}{2\sqrt{a\pi}}$$

Since CEI will occupy a range of values for different wetlands and will not fall into classes like the other parameters, the scaling of V_4 is more complex. However, it can be accomplished by an equation making the lowest CEI's computed equivalent to 1.0 and the highest CEI equivalent to 10.0. Other CEI's would then be scaled between 1.0 and 10.0 according to their location between the two extreme CEI's. This assures that DV_4 (or CEI scaled) is never less than 1.0 or greater than 10.0. The equation would have the following form:

$$CEI_{scaled} = 1.0 + \left[\frac{(CEI - CEI_{min})}{(CEI_{max} - CEI_{min})} * 9.0 \right]$$

where CEI_{max} and CEI_{min} equal the highest and lowest CEI's computed in the analysis, respectively, and CEI is the value desired to be scaled. The scaling term D will obviously vary with each set of wetlands analyzed as CEI_{max} and CEI_{min} vary. If CEI_{max} and CEI_{min} are standardized, then multiple sets of wetlands can be analyzed and the subsequent wetland values computed will be comparable with one another.

The final equation for determining wetland value is:

$$\text{Wetland Value} = 1.0V_1 + 2.5V_2 + 2.0V_3 + DV_4$$

AN EXAMPLE

In the following section, the application of the technique is demonstrated for a 200-acre tract located in central Florida. The nine plant communities present in the vicinity of the tract were assigned edge drama values (EDV) and productivity values (PV) as shown in Table 1. Wetlands occurring on the tract along with their individual wetland values (IWV) are shown on Figure 3.

The derivation of IWV for the hardwood swamp located in the northeastern corner of the tract was accomplished as follows. The swamp's area is approximately 13.1 acres and thus its corresponding acreage class (V_1) is 4. It is directly adjoining a regional drainage system and so has a contiguity class (V_2) of 4. Three strata are consistently present throughout the swamp, making its structural diversity (V_3) equal to 4. Its total edge length of approximately 3,250 feet is comprised of seven component edges where the swamp adjoins pasture, palmetto range, marsh, pine flatwoods, and shrub swamp communities. Weighted edge lengths and CEI were determined as follows:

Adjoining Plant Community	EL	EDV	PV_1	PV_2	E_i
Pasture	1,050	5	5	2	8,925
Palmetto range	450	5	5	2	3,825
Marsh	200	5	5	5	2,000
Pine flatwoods	825	2	5	3	4,950
Marsh	50	5	5	5	500
Shrub swamp	500	2	5	5	3,500
Pine flatwoods	175	2	5	3	1,050

$\Sigma E_i = 24,750$

$a = 13.1$

$CEI = 1929.01$

$CEI_{min} = 368.38$

$CEI_{max} = 5292.24$

$DV_4 = 3.85$

Table 1
Gross Primary Productivity and Edge Drama Values for Typical Plant Communities in West Central Florida

Plant Community	Productivity Class*	Edge Drama Value								
		Pasture	Fresh Marsh	Shrub Swamp	Palmetto Range	Pine Flatwoods	Citrus Grove	Xeric Hammock	Mesic Hammock	Hardwood Swamp
Pasture	2[A]	0	1	2	2	3	3	3	4	5
Fresh marsh	5[B]		0	2	2	3	3	4	4	5
Shrub swamp	5[C]			0	1	2	2	3	4	4
Palmetto range	2[A]				0	2	2	3	4	5
Pine flatwoods	3[A]					0	2	2	3	3
Citrus grove	1[A]						0	2	3	3
Xeric hammock	2[D]							0	2	3
Mesic hammock	3[E]								0	2
Hardwood swamp	5[B]									0

---

*Gross primary production (in $gC/m^2/day$) of productivity classes is as follows: Class 1: $GPP \leq 5.0$, Class 2: $5.0 < GPP \leq 10.0$, Class 3: $10.0 < GPP \leq 15.0$, Class 4: $15.0 < GPP \leq 20.0$, Class 5: $GPP > 20.0$.

A. Brown et al. (1975).
B. Brown (1978).
C. Assumed to be in the same class as fresh marshes and hardwood swamps.
D. Assumed to be between estimate GPP for sandhills (Brown et al., 1975) and mesic hardwood forests (Lugo, Gamble, and Ewel, 1978).
E. Lugo, Gamble, and Ewel (1978).

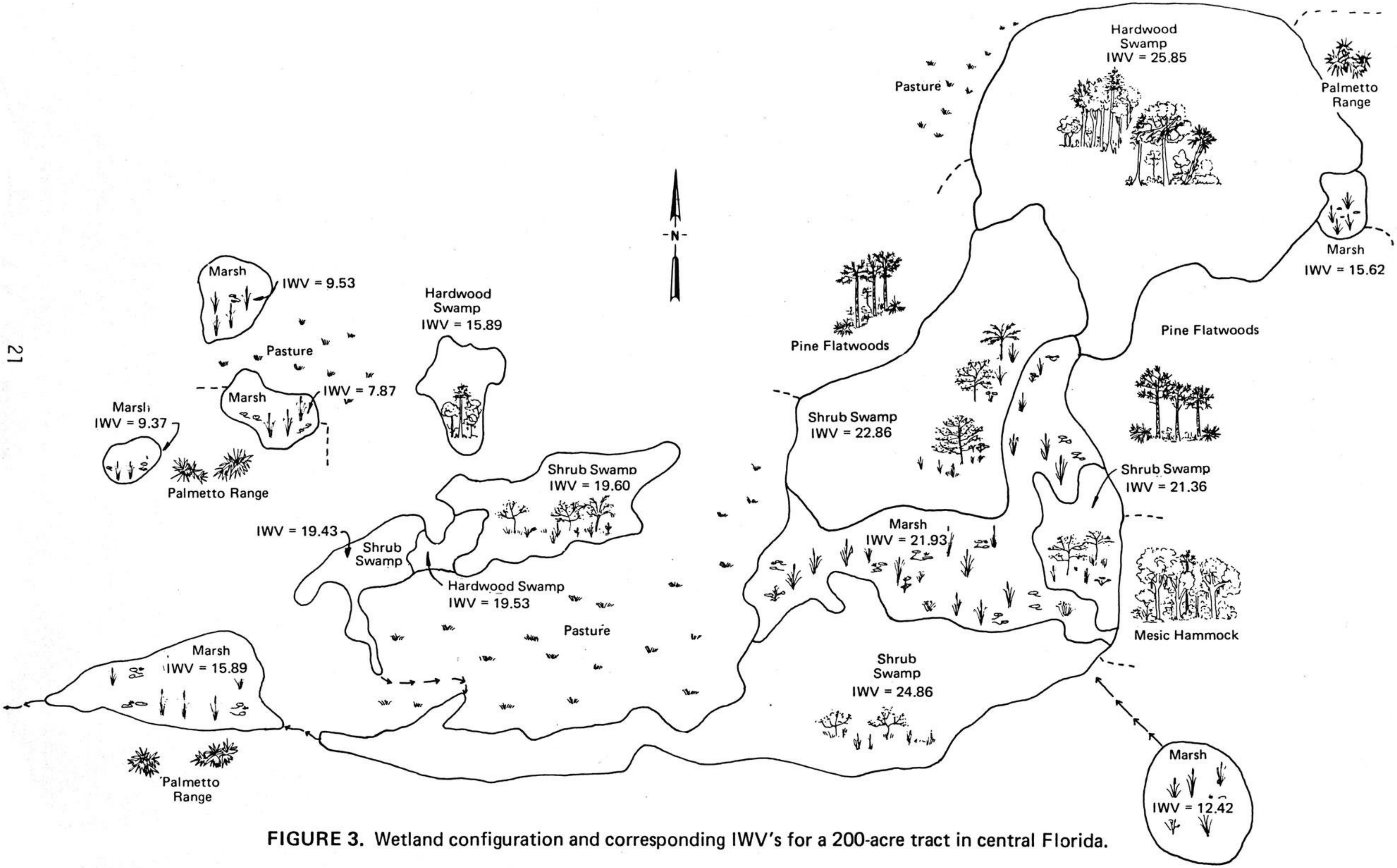


FIGURE 3. Wetland configuration and corresponding IWV's for a 200-acre tract in central Florida.

In this case, CEI_{min} and CEI_{max} were taken from another set of analyses so that these IWV's would be comparable. Individual wetland value for the swamp was computed as follows:

$$IWV = 1.0(4) + 2.5(4) + 2.0(4) + 3.85 = 25.85$$

DISCUSSION AND CONCLUSIONS

A valuation technique such as the one presented here is of little value until it has been tested by actual field application. To date, the techniq has been applied to over 700 individual wetlands within Florida. The individual wetland values produced have been of sufficient resolution to aid industry and agency decisions, and the technique as a whole has been both cost effective and time effective. Based on the application of the technique so far, the valuation of a tract of land containing about 200 wetlands requires approximately 80 man-hours. This assumes that high quality aerial photographs are available, data reduction is computerized, and an experienced person applies the technique.

The overall strengths of the technique may be summarized as follows:

1. The technique effectively ranks freshwater wetlands based on relative ecological value, thereby providing an important tool to aid in decisio concerning wetlands.

2. The technique allows flexibility in both the choice of variables used to assess wetland value and the relative importance placed on those variables.

3. The technique is readily adaptable to computerized processing of data.

4. The technique is sufficiently cost effective and time effective to make its application practical for landowners and state agencies.

5. The technique is expected to be applicable to freshwater wetlands anywhere in Florida.

Limitations of the technique are:

1. Because the technique does not evaluate all potential wetland functions and attributes and the relationships between the parameters examined and actual wetland values are only generally understood, the wetland values generated should be regarded as careful estimates, not absolutes.

2. Wetland values derived for different sets of wetlands during separate analyses are not comparable unless they have been standardized.

3. A certain amount of subjectivity still accompanies the application of the technique. Consequently, to minimize the influence of individual bias, a given set of comparative analyses should always be conducted by the same person or team.

LITERATURE CITED

Bayley, S. and L. Burns. 1974. Condensation of marsh data gathered in the upper St. Johns River basin. Appendix C In: H. T. Odum and M. T. Brown (eds.) Carrying Capacity of Man and Nature in South Florida. Report to U.S. National Park Service and Florida Division of State Planning by Center for Wetlands, University of Florida, Gainesville.

Boyt, F. L. 1976. A Mixed Hardwood Swamp as an Alternative to Tertiary Wastewater Treatment. M.S. thesis, University of Florida, Gainesville, Florida.

Brown, M. T., S. Brown, R. Costanza, E. DeBellevue, K. Ewel, R. Gutierrez, D. Layland, W. Mitsch, and M. Sell. 1975. Natural Systems and Carrying Capacity of the Green Swamp. Report to Florida Division of State Planning. Center for Wetlands, University of Florida, Gainesville.

Brown, S. 1978. A Comparison of Cypress Ecosystems in the Landscape of Florida. Ph.D. dissertation, University of Florida, Gainesville.

Ewel, K. C. 1979. Riparian Ecosystems: Conservation of Their Unique Characteristics. pp. 56-62. In: Strategies for Protection and Management of Floodplain Wetlands and Other Riparian Ecosystems. USDA, Forest Service Publication GTR-WO-12.

Ewel, K. C. and H. T. Odum. 1978. Cypress Swamps for Nutrient Removal and Wastewater Recycling. pp. 181-198. In: (W. P. Wanielista and W. W. Eckenfelder, Jr., Eds.) Nutrient Removal. Ann Arbor Science Publications, Inc., Ann Arbor.

Gabrielson, I. N. 1962. Conservation and Management of Temperate Wetlands. In: Project MAR Proceedings of the MAR Conference. IUCN Publication New Series No. 3:64-69.

Ghiselin, J. 1977. Analyzing Ecotones to Predict Biotic Productivity. Environmental Management 1(3):235-238.

Golet, F. C. 1973. Wetlands and Wildlife. pp. 12-14. In: (J. S. Larson, Ed.) A Guide to Important Characteristics and Values of Freshwater Wetlands in the Northeast. Pub. No. 31, Water Resources Research Center, University of Massachusetts at Amherst.

Harris, L. D. and P. Kangas (in press). Designing Future Landscapes from Principles of Form and Function. Paper presented at National Conference on Applied Technology for Analysis and Managment of the Visual Resource. Incline Village, Nevada. April 1979.

Harris, L. D. and W. H. Smith. 1978. Relations of Forest Practices to Non-Timber Values and Adjacent Ecosystems. Intensive Management Practices Assessment Center 3(5).

Hoffman, L. 1968. Project MAR Proceedings of a Technical Meeting on Wetland Conservation. IUCN Publication New Series No. 12:36-40.

King, T. P. 1978. A Model of Potential Wildlife Response to Spatial Habitat Heterogeneity. M.S. thesis. University of Florida, Gainesville, Florida. 140 pp.

Layne, J. N., J. A. Stallcup, G. E. Woolfenden, M. N. McCawley, and D. J. Worley. 1977. Fish and Wildlife Inventory of the Seven-County Region Included in the Central Florida Phosphate Industry Areawide Environmental Impact Study. Report submitted to U.S. Fish and Wildlife Service under Contract No. 14-16-0009-77-005.

Leopold, A. 1933. Game Management. Charles Scribner's Sons, New York. 481 pp.

Lugo, A. E., J. F. Gamble, and K. C. Ewel. 1978. Organic Matter Dynamics in a Mixed Hardwood Forest in North Central Florida. In: Proceedings of the 2nd Mineral Cycling Symposium.

MacArthur, R. H., J. W. MacArthur, and J. Preer. 1962. On Bird Species Diversity II. Prediction of Bird Census from Measurements. Am. Naturalist 180:319-332.

Massuchusetts Water Resources Commission. 1971. Neponset River Basin Flood Plain and Wetland Encroachment Study. Mass. Water Resources Comm., Boston. 59 pp.

McElveen, J. D. 1978. The Effect of Different Edge Types and Habitat Sizes on the Distribution of Breeding Birds in North Florida. M.S. thesis. University of Florida, Gainesville, Florida. 46 pp.

Motts, W. S. and R. W. Heeley. 1973. Wetlands and Ground Water. pp. 5-8. In: (J. S. Larson, Ed.) A Guide to Important Characteristics and Values of Freshwater Wetlands in the Northeast. Pub. No. 31, Water Resources Research Center, University of Massachusetts at Amherst.

Patrick, W. H., Jr., R. D. Delaune, R. M. Engler, and S. Gotoh. 1976. Nitrate Removal from Water at the Water-Mud Interface in Wetlands. U.S. Environmental Protection Agency, Ecological Research Series. EPA-600/3-76-042.

Roth, R. R. 1976. Spatial Heterogeneity and Bird Species Diversity. Ecology 5(4):773-782.

Shih, S. F. and D. W. Hallett. 1974. Impact of Upland Marsh on Water Quality. Central and Southern Florida Flood Control District, West Palm Beach, Florida.

Smardon, R. C. 1973. Visual-Cultural Values of Wetlands. pp. 9-11. In: (J. S. Larson, Ed.) A Guide to Important Characteristics and Values of Freshwater Wetlands in the Northeast. Pub. No. 31, Water Resources Research Center, University of Massachusetts at Amherst.

U.S. Army Corps of Engineers. 1971. Summary of the Ninth Meeting o the Coordinating Committee for the Charles River Study at Waltham, M Dept. of the Army, New England Division, Corps of Engineers, Waltham Mass. 10 p. + appendixes.

U.S. Department of the Interior. 1962. The Value of Wetlands to Mo Society. In: Project MAR Proceedings of the MAR Conference. IUCN Publication New Series No. 3:57-64.

Wales, B. A. 1972. Vegetation Analysis of North and South Edges in Mature Oak-Hickory Forest. Ecol. Monogr. 42(4):451-471.

Welch, P. S. 1948. Limnological Methods. McGraw-Hill Book Co., In New York. 381 pp.

Wharton, C. H. 1970. The Southern River Swamp--A Multiple Use Envi School of Business Administration, Georgia State University, Atlanta Georgia.

White, L. D. 1973. Native Forage Resources and Their Potential. pp. 1-17. In: Range Resources of the Southeastern United States. American Society of Agronomy and the Crop Science Society of America, Madison, Wisconsin.

HYDROGEOLOGIC VARIABILITY OF FOUR WETLAND SITES IN NORTH CENTRAL FLORIDA

Daniel P. Spangler
Department of Geology
University of Florida
Gainesville, Florida 32611

ABSTRACT

Associated with freshwater wetlands creation and/or restoration is a need to understand natural hydrogeologic models and particularly their variability within and surrounding the wetlands. The work presented here was an outgrowth of several studies sponsored through the Center for Wetlands, University of Florida, by the National Science Foundation and the Rockefeller Foundation, which were a part of a larger plan to test the feasibility of using wetlands as repositories for the recycling of secondarily treated wastes. A network of more than 100 wells and existing nearby deep drainage ditches were used on four different sites to construct hydrogeologic cross sections. Detailed potentiometric maps for two of the four sites revealed time and space dependent variations.

Common to all the wetland sites was the presence of organics underlain by a thin layer(s) of sand, which were underlain by thick layers of clay, and were surrounded by an upland pine forest immediately underlain by generally well-drained, sandy soils. Not so common beneath the wetlands was the presence or absence of shallow, sandy hardpans and dolomite layers of variable thickness, permeability, and horizontal distribution. Although the water table occurred primarily in the sands with subsurface flows generally coincident with the topography, the presence of other near surface aquifers (i.e., dolomite) caused noted anomalies in water table maps.

Water level measurements revealed not only diurnal variations within the wetland caused by transpiration, but seasonal fluctuations were noted in the surrounding uplands with increasing distance from the wetlands, varying in magnitude with topographic slope and the size of the wetland. Wetlands were dischargers or rechargers depending on the subsurface geology and season.

INTRODUCTION

Cypress swamps occur throughout the southeastern United States, from Virginia to Louisiana and to the southern tip of Florida. Cypress trees characteristically grow where water levels fluctuate, that is, dry ground in necessary for seed germination, but saturated soils are necessary for continual and rapid tree growth. In Florida, cypress dominated ecosystems are primarily lake fringes, strands, and domes. This paper addresses some of the hydrogeologic variability noted in four wetland sites of north central Florida. These sites, as located in Figure 1, are the Owens-Illinois Research Site (OIRS), the Hope Construction Site (HCS), the Austin-Cary Control Dome (ACCD), and the Austin-Cary Fertilizer Dome (ACFD).

The cypress trees occur in low, swampy, saucer-shaped depressions with the tallest trees in the center and becoming successively smaller towards the periphery. From a side view the appearance is that of a dome, hence the term cypress dome. Cypress domes may range in size from less than 1 acre to more than 25 acres, with smaller ones tending to be circular and pond-like while larger ones tending to be more asymmetrical.

For more than five years, research sponsored primarily by the National Science Foundation and the Rockefeller Foundation has been conducted by the Center for Wetlands at the University of Florida in evaluating cypress ecosystems, particularly domes. The objective was to test the feasibility of cypress wetlands for water management, water recycling, and particularly their ability to adsorb the nutrients and microbes in secondarily treated sewage and, thus, permitting only water that is equivalent to tertiarily treated waste water to filter into the groundwater. The current summary paper focuses only on the geologic characteristics of several comparative dome studies. For a more thorough treatment of all aspects of the more

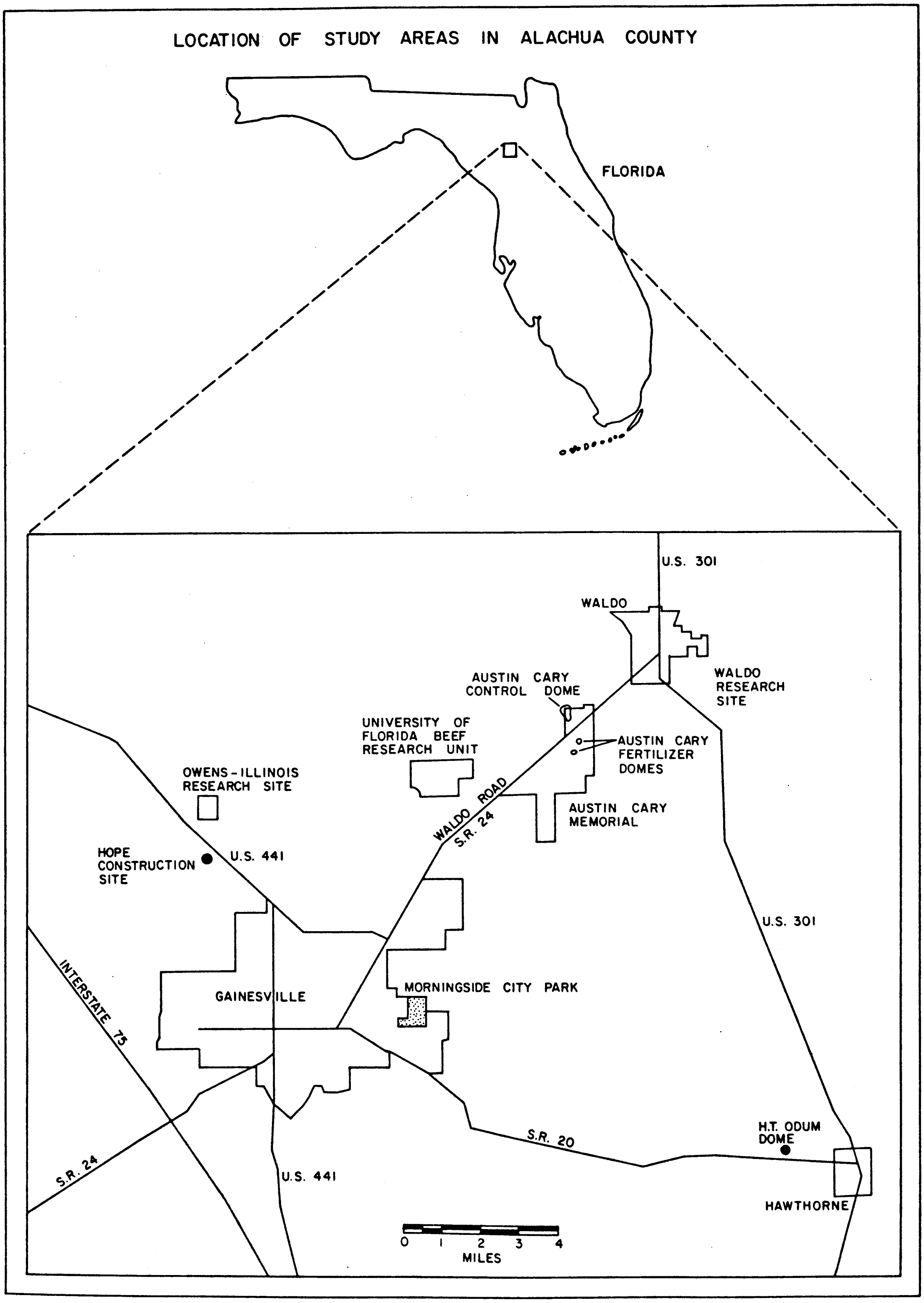


Figure 1. Location of study areas in Alachua County, Florida.

encompassing study, one should refer to the annual reports and their extensive bibliographies, particularly the resulting theses and dissertations (Odum and Ewel, 1974, 1975, 1976, 1978).

More than 125 comparative stratographic borings and monitor wells were installed over a three year period to generalize the applicability of the results. Data in the form of plan view, geologic logs, geographical logs, cross sections, tabulated hydrogeologic parameters, graphs, and potentiometric maps are included in the annual reports. In addition, lengthy analyses and interpretations served a fundamental role in constructing models, provided basic input for other associative and correlative studies, and on-site design criteria.

The Floridan Aquifer, the most productive aquifer in Alachua County, consists of interbedded, soft, porous limestone and hard, dense limestone and dolomite (Clark et al., 1964). A potentiometric map with surface geology is noted in Figure 2. The upper 183 meters (600 feet) of the aquifer is noted in cross section A - A' (Figure 3), and includes the Lake City Limestone, the Avon Park Limestone, the Ocala Group, and possibly a small lens of the Suwannee Formation (Limestone). Secondary artesian aquifers in the overlying Hawthorne Formation consist of sands, sandy clays, and scattered lenses of limestone and dolomite several centimeters to as much as 1.83 meters (6 feet) in thickness. Most of the unit, however, is a clay which serves as an aquiclude. Overlying the Hawthorne Formation are clays and marls of Upper Miocene and Pliocene and sands and clays of Plio-Pleistocene and Recent which contain shallow water table aquifers. The upper 30.5 meters (100 feet) of Figure 3 is discussed in more detail under Results.

METHODS AND MATERIALS

Three methods of drilling were used. The first method involved the

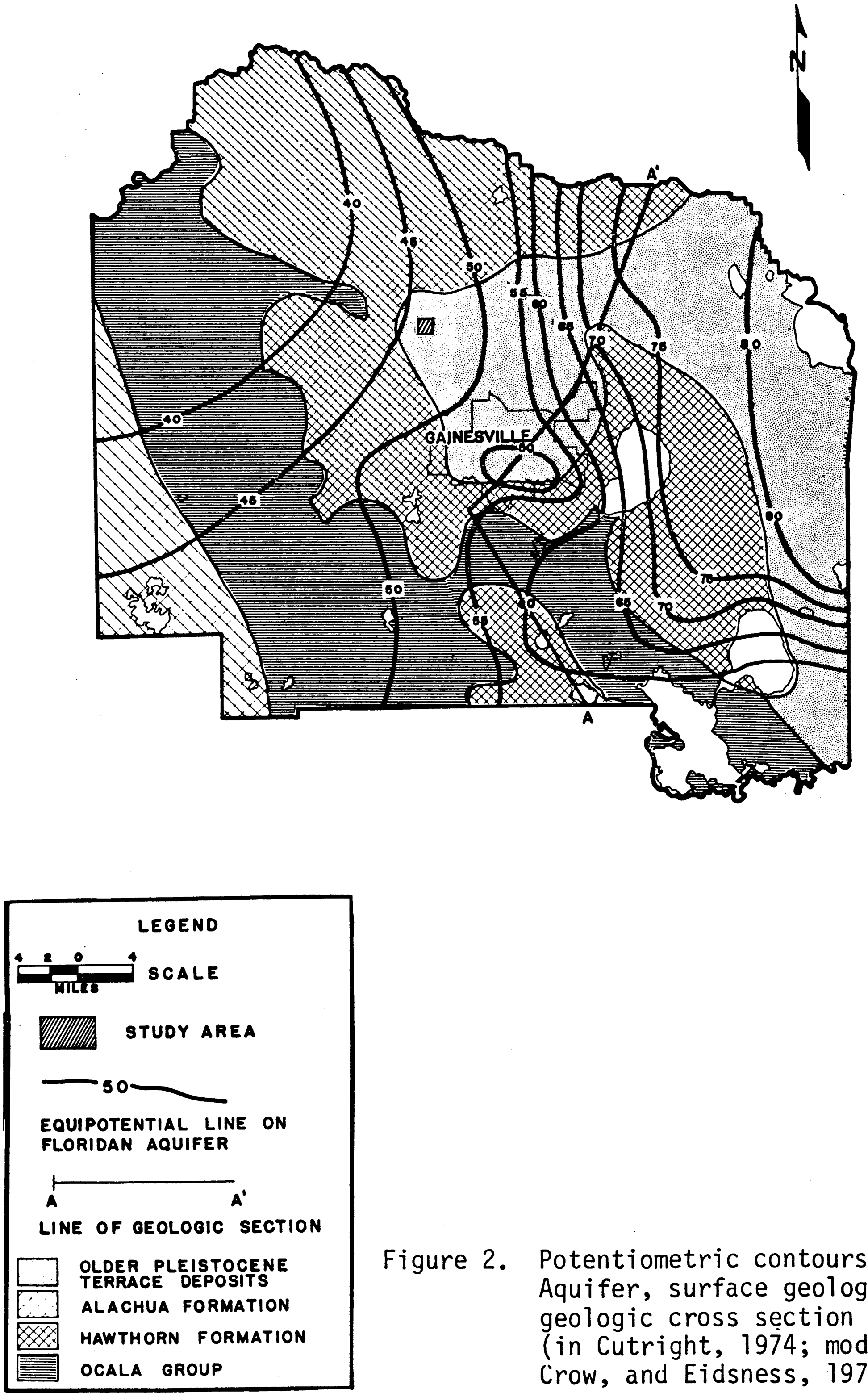


Figure 2. Potentiometric contours on the Floridan Aquifer, surface geology and location of geologic cross section of Alachua County (in Cutright, 1974; modified from Black Crow, and Eidsness, 1973).

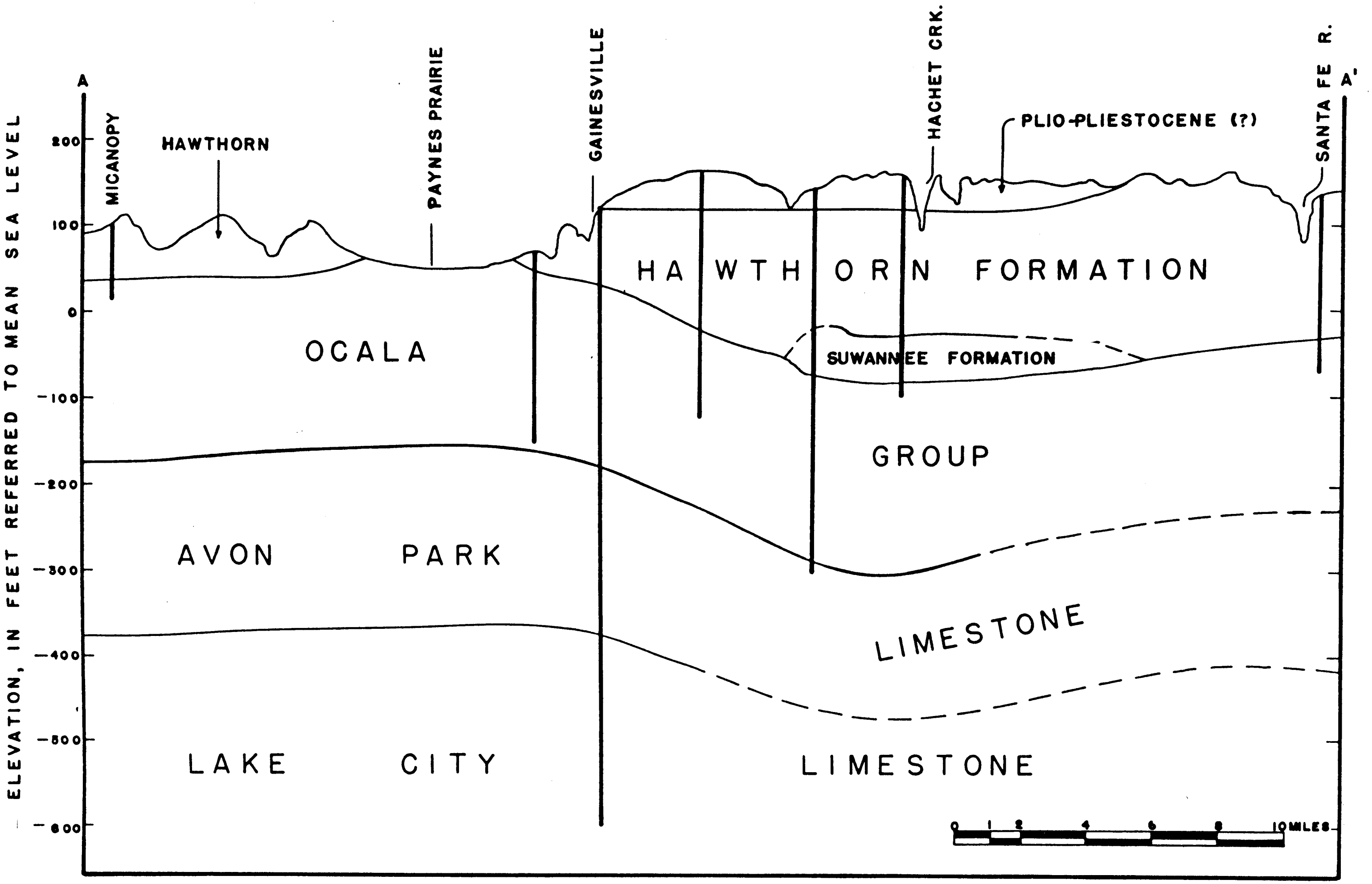


Figure 3. Geologic cross section through Alachua County, Florida showing generalized geology beneath the study site (in Cutright, 1974; modified from Black, Crow, and Eidsness, 1973).

use of a Minuteman portable gasoline power auger which produced a 2 inch diameter hole with depths up to 35 feet. Several of the holes within the domes were jetted or wash-bored using a Homelite two cycle engine pump which produced 60 pounds/inch ^{2} pressure. As the first two methods were limited in depth penetration and produced poor intact samples, the Florida Department of Transportation, using a truck mounted rotary rig, drilled several holes immediately surrounding the domes and in the pine uplands. The latter provided Shelby tube and split-spoon samples which served as the source material in X-ray and permeability analyses. Details of well construction with various types of screens are noted in Figure 4.

The St. Johns River Water Management District provided natural gamma-ray logs for several of the deeper wells. Some of these data are noted later under Results. Semi-weekly and weekly water level measurements were made with a steel tape from surveyed markers on the casing. Many of the wells were monitored continuously with Leupold and Stevens type F water level recorders.

RESULTS

Organics

Cypress domes examined have an organic layer at the level of the lowermost cypress roots and are restricted to the cypress dome. The organics achieve a range in thickness of 0.61 m to 1.22 m (2 to 4 feet) in the center and become progressively thinner towards the margin. Organic particles grade finer downward to the underlying quartz sand and/or sandy clays.

Quartz Sands

The quartz sands are fine to medium surficial grains. Thickness ranges up to 1.53 m (5 feet). Organic particles are commonly mixed with

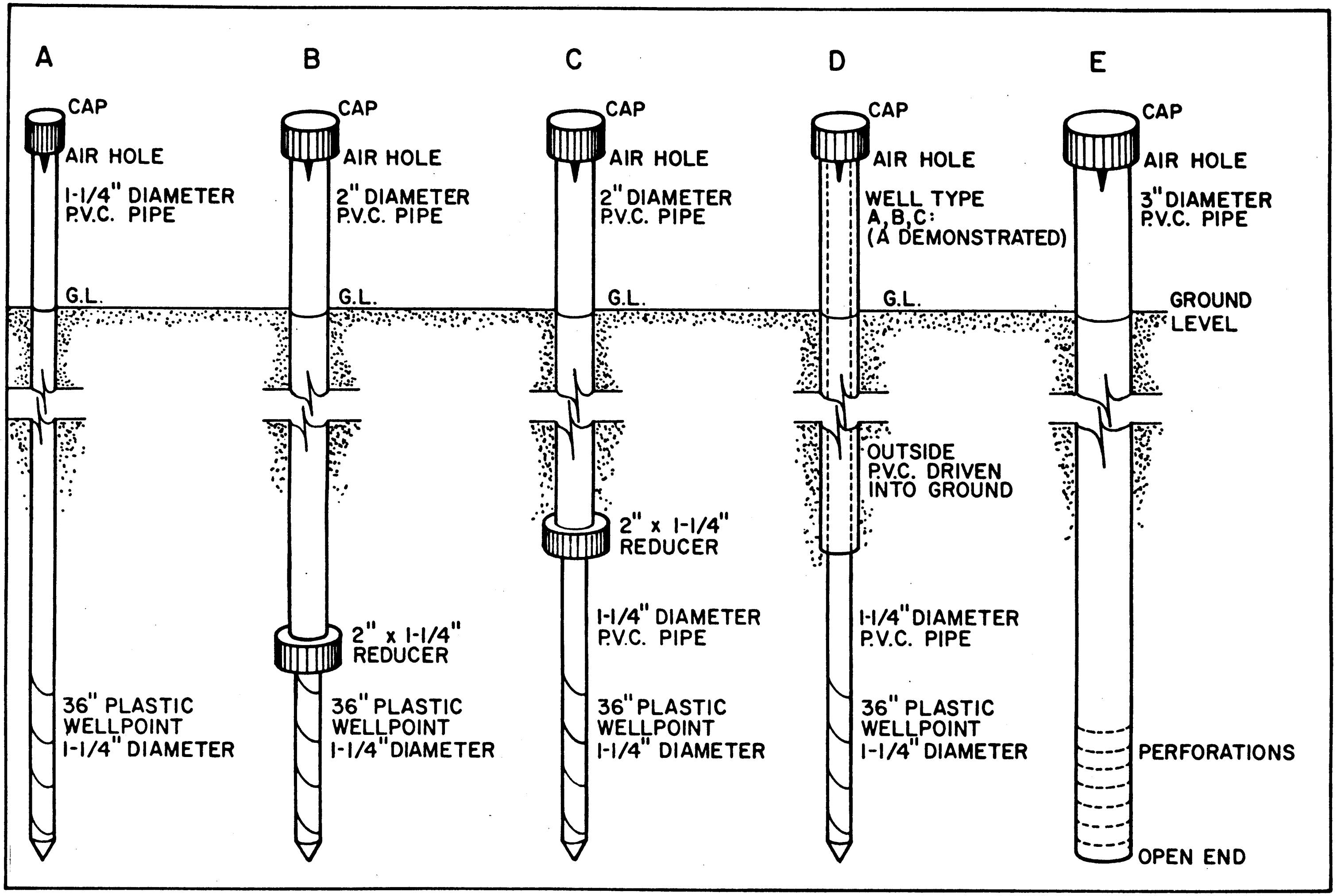


Figure 4. Details of well construction and screens (in Gillespie, 1976).

the quartz sand giving it a dark brown to black appearance. This organic mixture is common both in the cypress domes and in the pine forest and probably confirms the filtering characteristics of sands. The origin of the quartz sands may be channel deposits, aeolian, marine, or residual deposits. All of these probably have made a contribution.

The observation (see Figures 5 and 6) that the thicker quartz sand deposits occur in the pine forest away from the cypress dome (ACCD) was noted by Gillespie (1976). A possible explanation may be that as rain water percolates downward to the water table, 1.53 to 4.58 meters (5 to 15 feet) below the surface in the pine forest, leaching and oxidation of the blue-gray sandy clays and clayey sands results, leaving the sand and removing the clay. Sampling has shown that a possible leach zone does exist immediately below the quartz sands. In this zone, the blue-gray sandy clays and clayey sands have been slightly oxidized to a tan clay and/or bright red sandy clays and clayey sands in heavily oxidized regions. No oxidation has been observed within the ACCD proper, where the water table is near the surface. The downward percolation of oxygenated water would be limited in the dome's stagnant surface waters, and the leaching of the blue-gray sandy clays and clayey sands to quartz sands would be reduced. This is apparently reversed (see Figures 7, 8, 9, and 10) in the HCS and the OIRS, where hardpans suggest an aerobic zone is under the anaerobic pressure filters allowing oxidation of iron and manganese from descending acid waters.

Observation of a number of blue-gray sandy clay and clayey sand samples left exposed to the atmosphere after drilling show that after a heavy rainfall a thin residual quartz sand layer has developed on the surface. After long exposures to several rainfalls, the quartz sand layer becomes progressively thicker. The apparent reason is that the rain leaches the clays and leaves the quartz sand as a residual deposit.

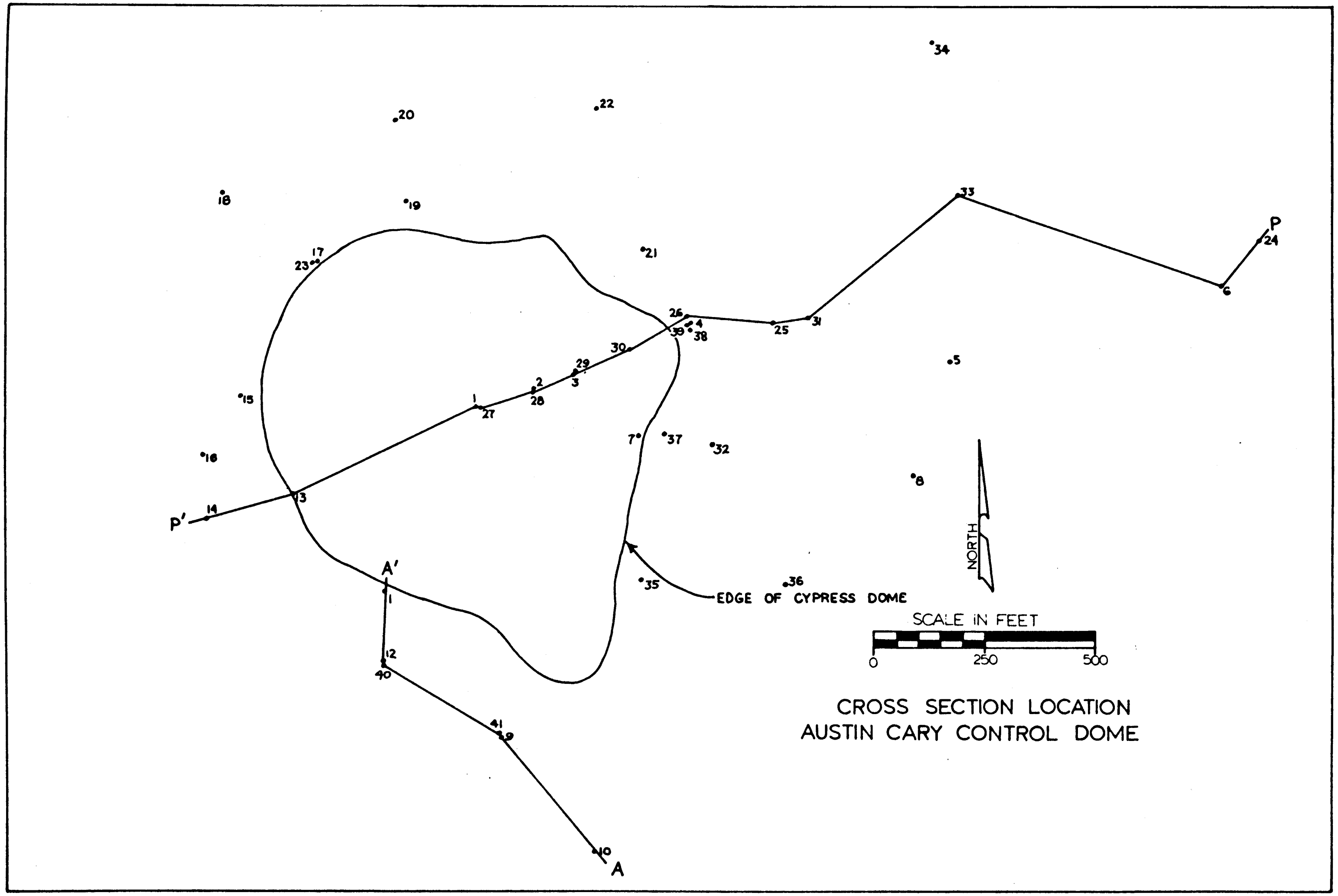


Figure 5. Map of Austin Cary Control Dome (ACCD) showing location of cross section P' - P (Figure 6) and cross section A - A' (Figure 14).

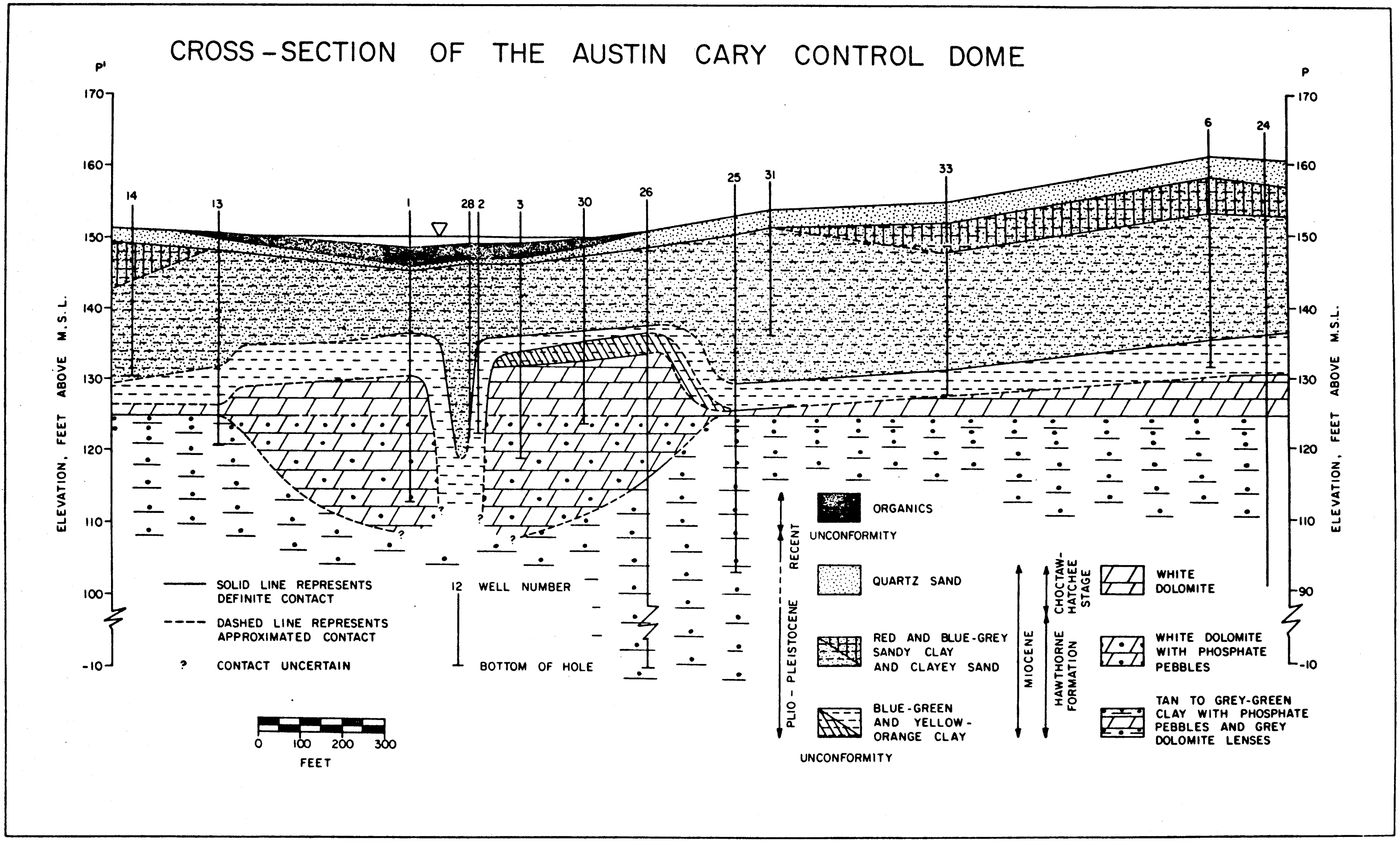


Figure 6. Cross section of the Austin Cary Control Dome (in Gillespie, 1976).

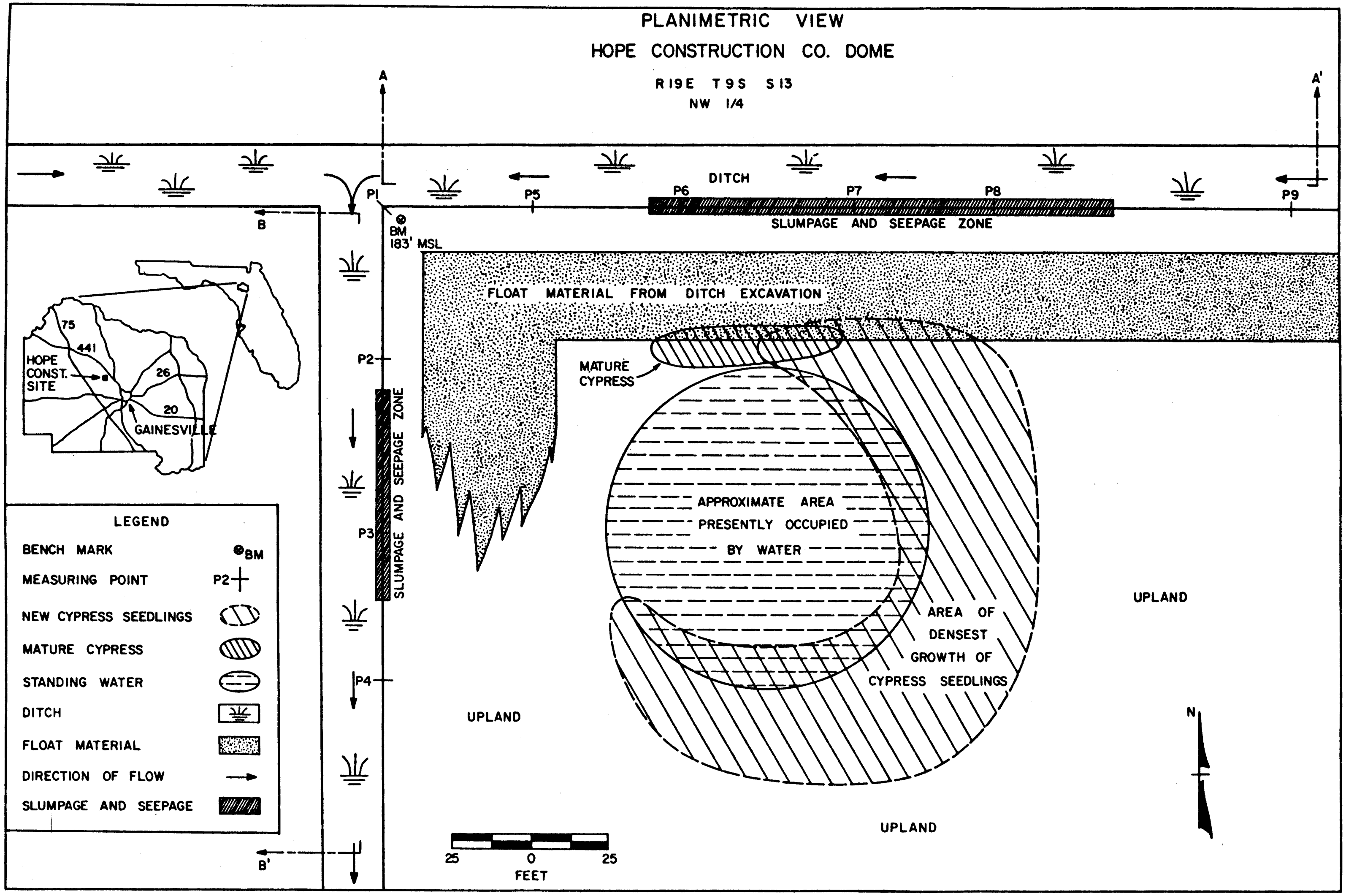
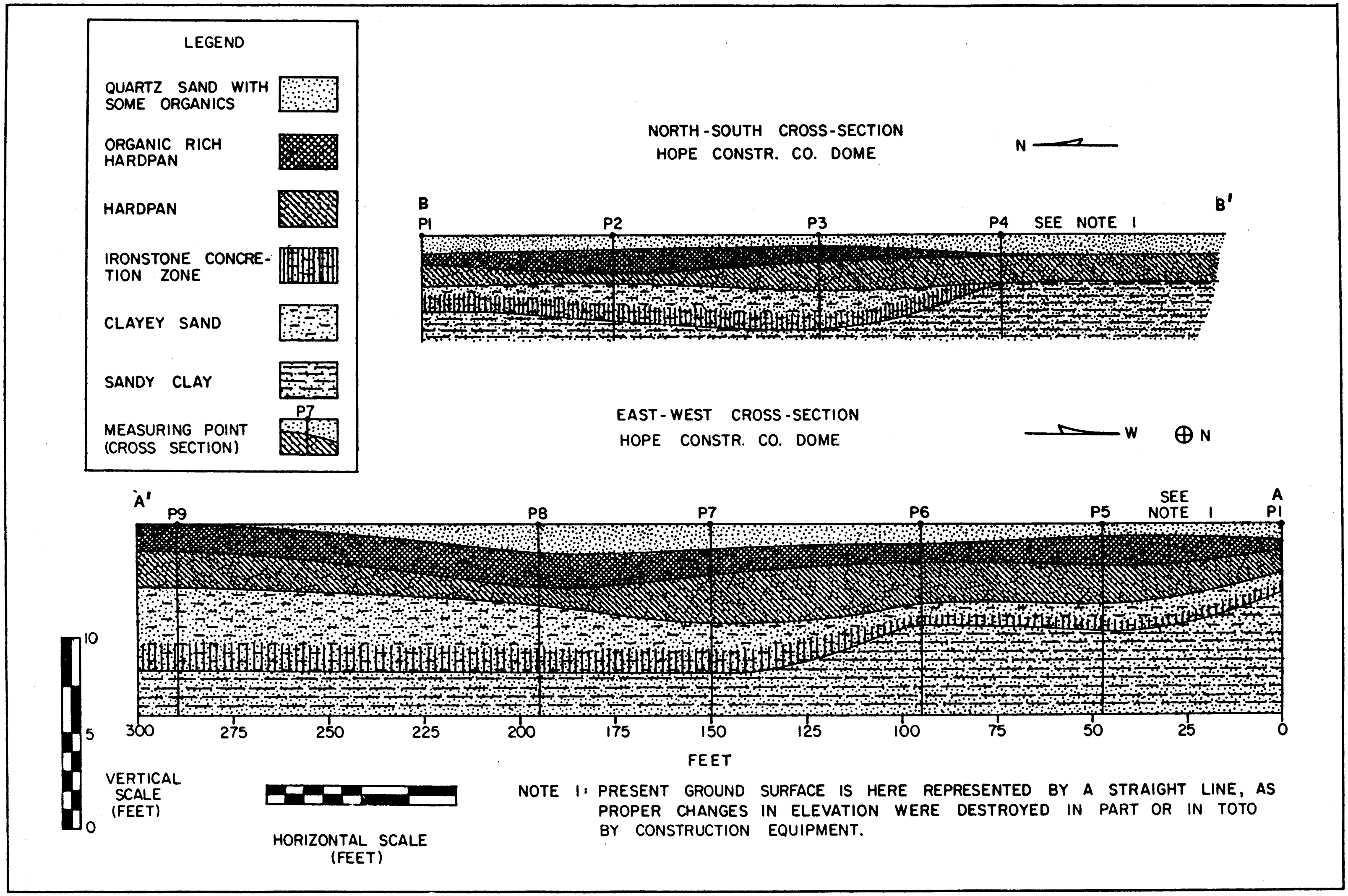


Figure 7. Planimetric view of Hope Construction Site (in Spangler et al., 1976).



NOTE I: PRESENT GROUND SURFACE IS HERE REPRESENTED BY A STRAIGHT LINE, AS PROPER CHANGES IN ELEVATION WERE DESTROYED IN PART OR IN TOTO BY CONSTRUCTION EQUIPMENT.

Figure 8. North-south cross section of Hope Construction Site

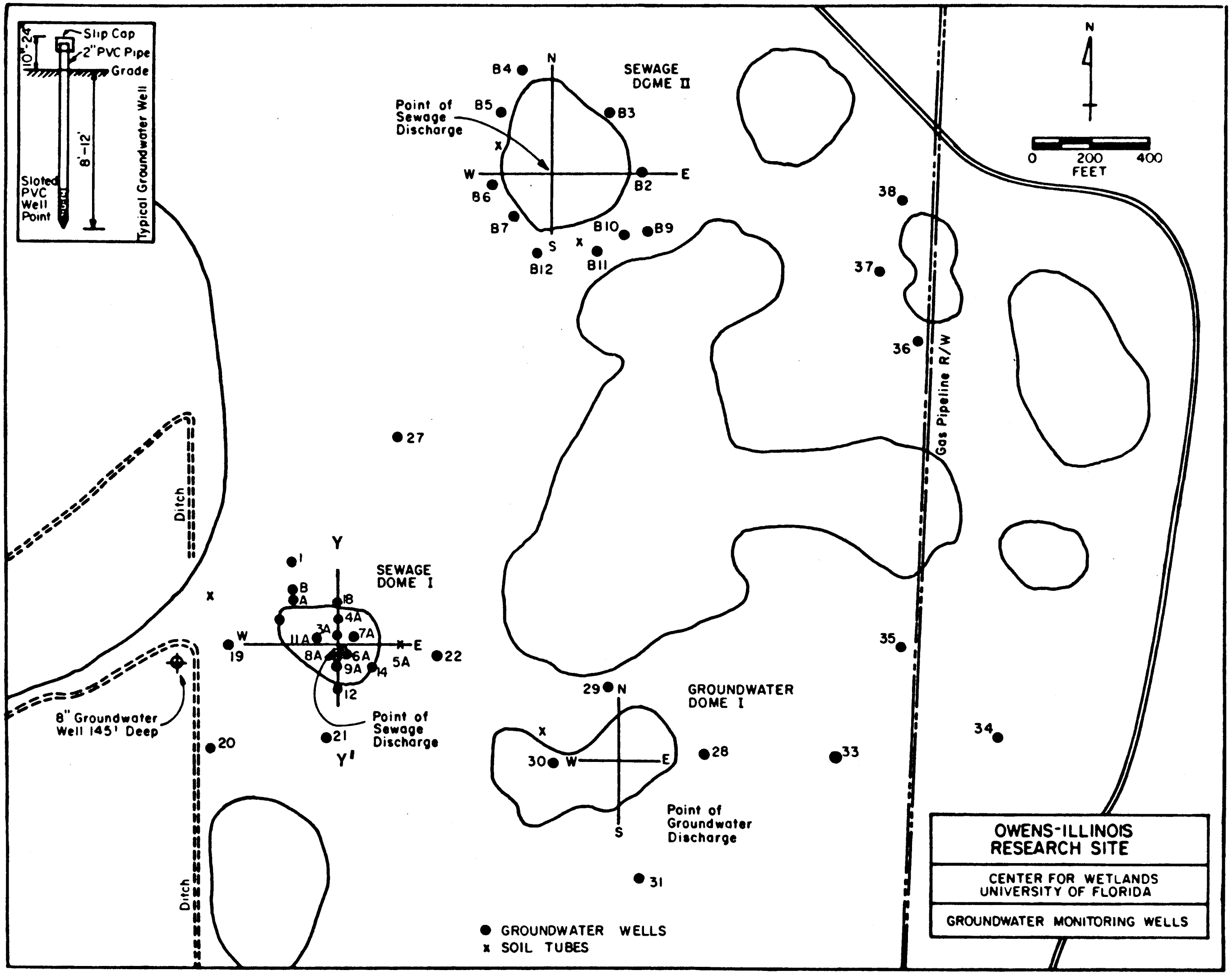


Figure 9. Plan view of Owens-Illinois Research Site showing location of groundwater monitoring wells.

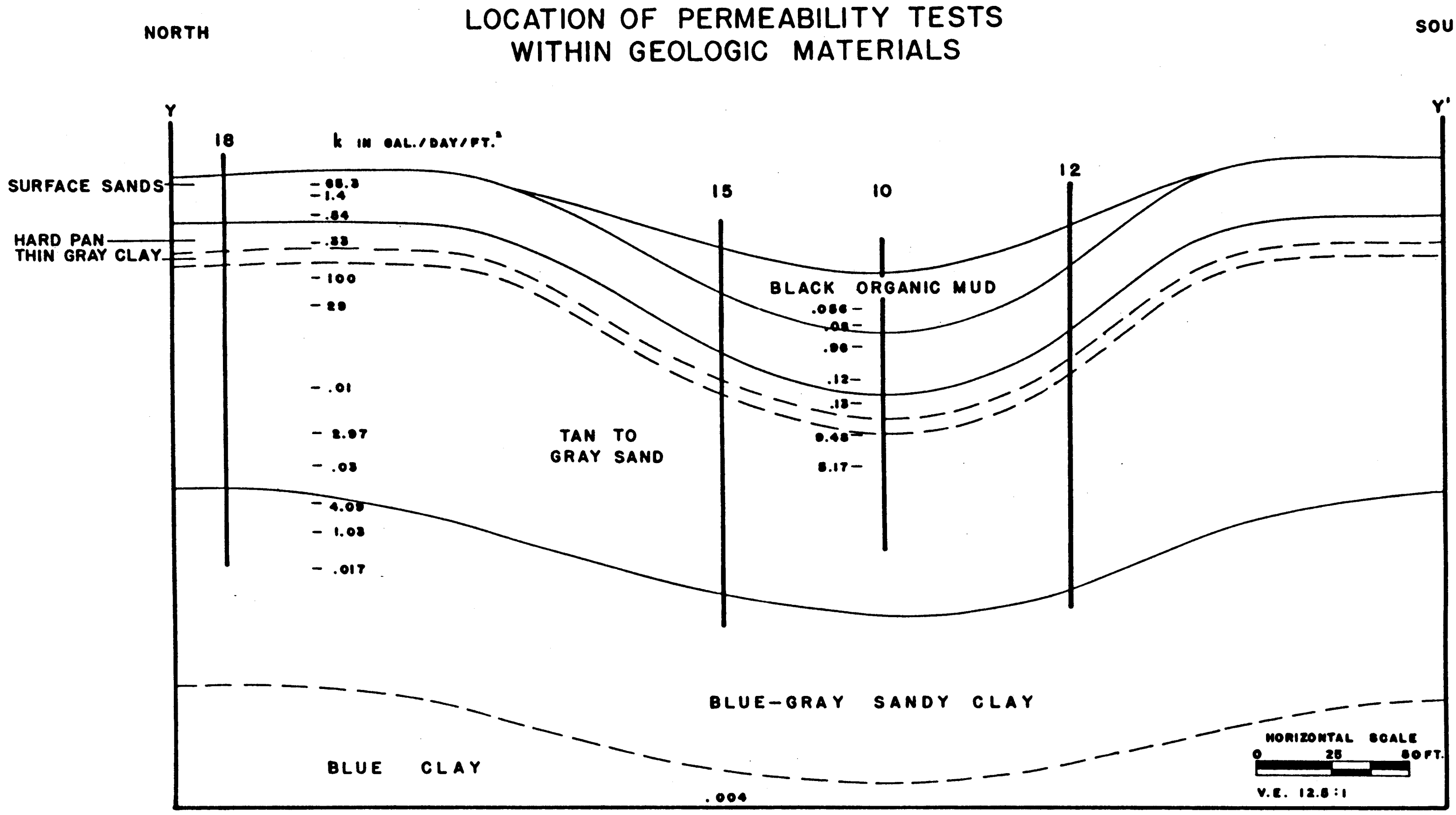


Figure 10. North-south (Y - Y') cross section, location of permeability tests within geologic materials (in Cutright, 1974).

Red Sandy Clays and Clayey Sands

This is a bright red kaolin clay and quartz sand containing some yellow streaks near the top. The horizon has been weathered from the parent material, the blue-gray sandy clays and clayey sands, traces of which become apparent with depth. Thickness ranges from zero in the cypress domes and immediate pine forest to about 2.44 m (8 feet) in distant pine forests (Figures 11, 12, and 13) of ACFD. A well developed hardpan as noted at other research sites to the west (OIRS and HCS, Figures 7, 8, 9, and 10) is non-existent in the ACFD research sites (Figures 5, 6, 11, 12, and 13). Although it is evident the near-surface hydrology dictates the formation of hardpans, more field study is needed here. As may be noted in Figure 7, hardpans thin outward away from dome margins in lower topographic and shallow water table gradients.

Channel-Fill Sands

These are relatively clean quartz sands and silts found in wells #9, #12, #40, and #41 (Figures 5 and 14) in the south section of the ACCD only. They lie above the blue-green clays and adjacent to the blue-gray sandy clays and clayey sands. The channel fill sands are thought to represent deposits of a former stream flowing away from the center of the dome with an ancient spring as a possible source area.

Blue-Gray Sandy Clays and Clayey Sands

These are predominantly kaolin clays and quartz sand found throughout most of the study sites and Alachua County (Figures 6, 10, 12, 13, and 14). In surrounding pine forest and around many of the dome margins their thicknesses average 4.58 to 7.63 m (15 to 25 feet). Within many of the domes (Figures 6, 12, 13, and 14), these clays are thinner.

Wash-boring, coring, and the natural gamma radiation well logs reveal the presence of several alternating layers of sandy clays and

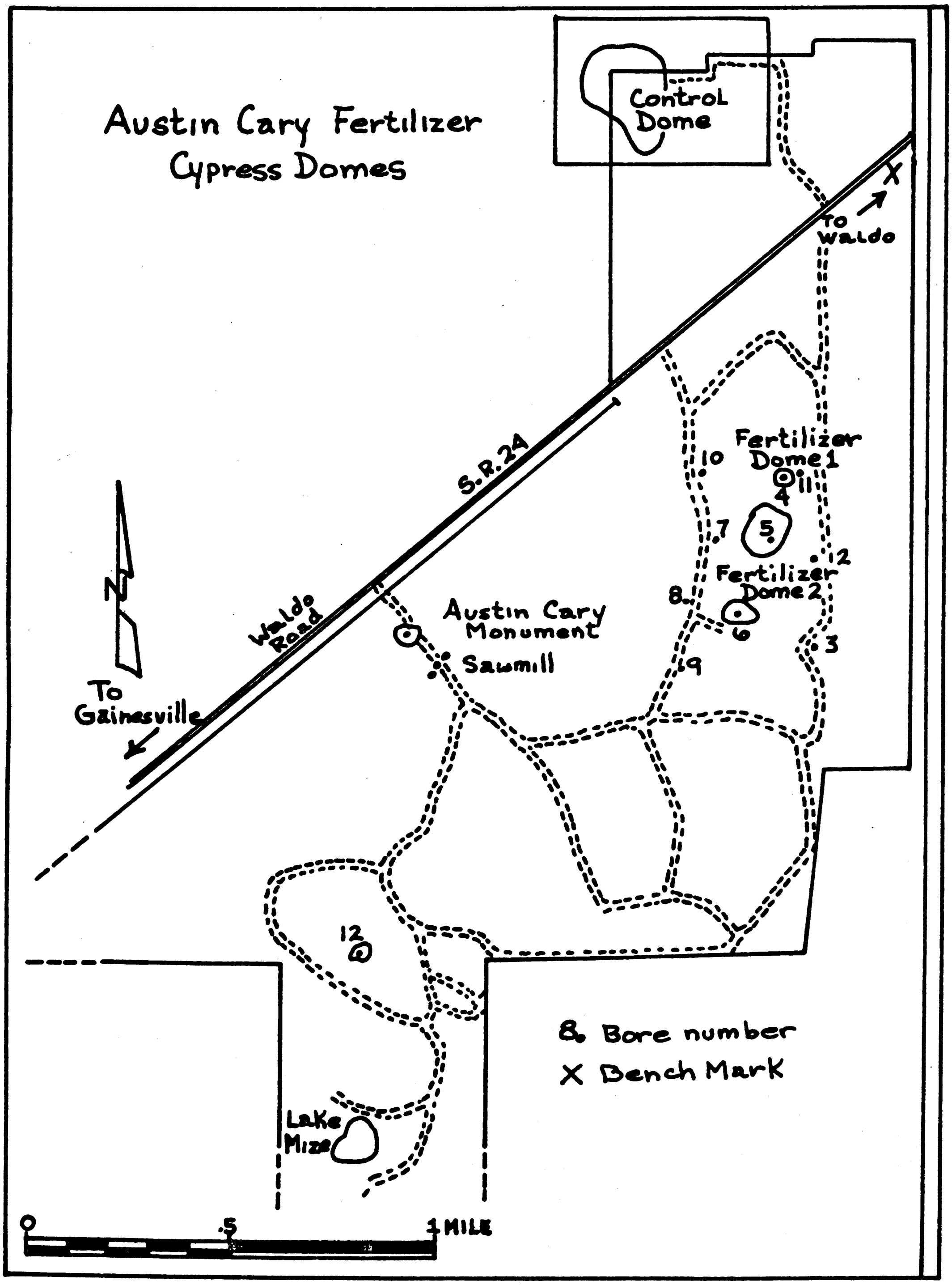


Figure 11. Plan view of Austin Cary Fertilizer Domes and test borings.

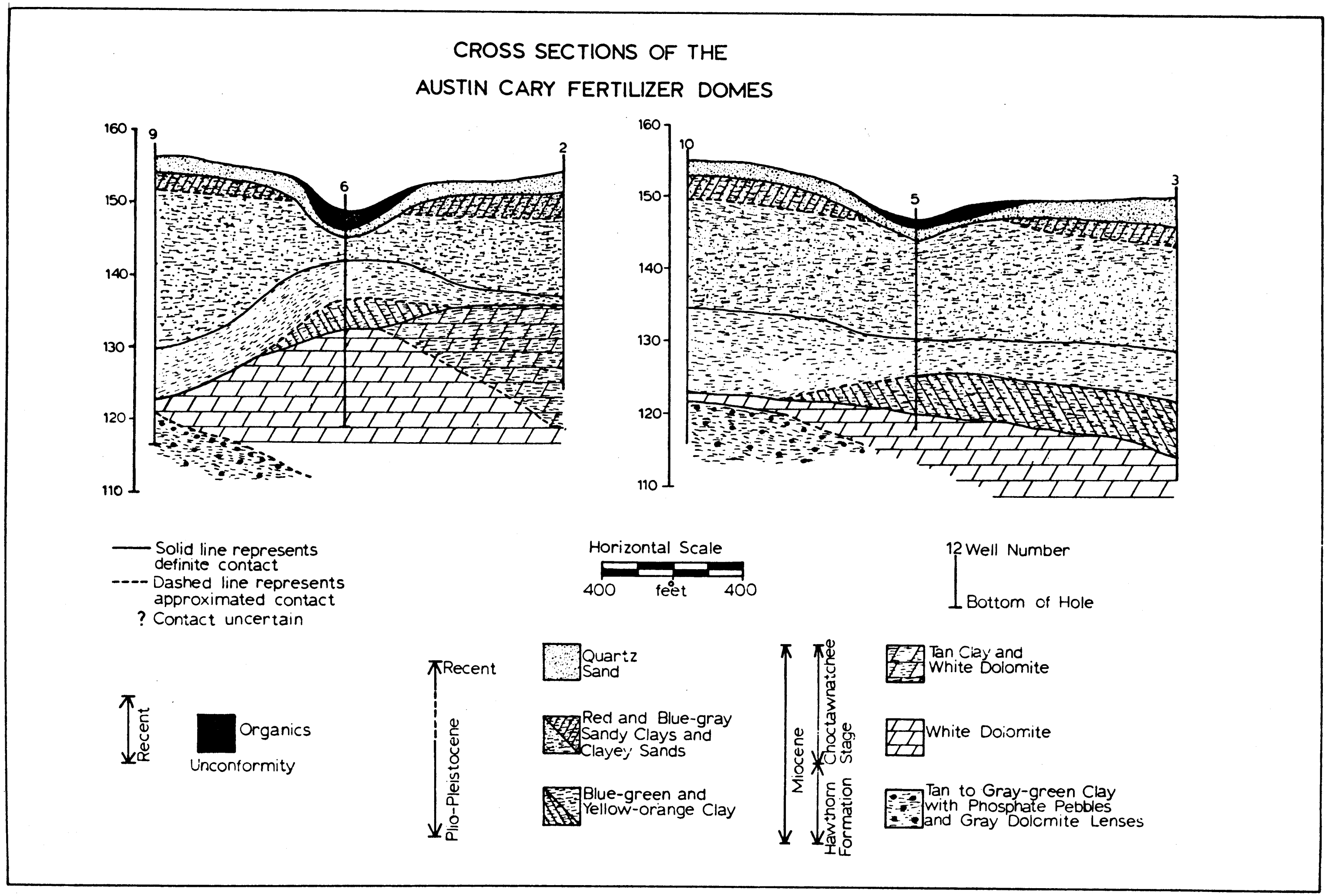


Figure 12. Cross sections of the Austin Cary Fertilizer Domes (in Spangler et al., 1976).

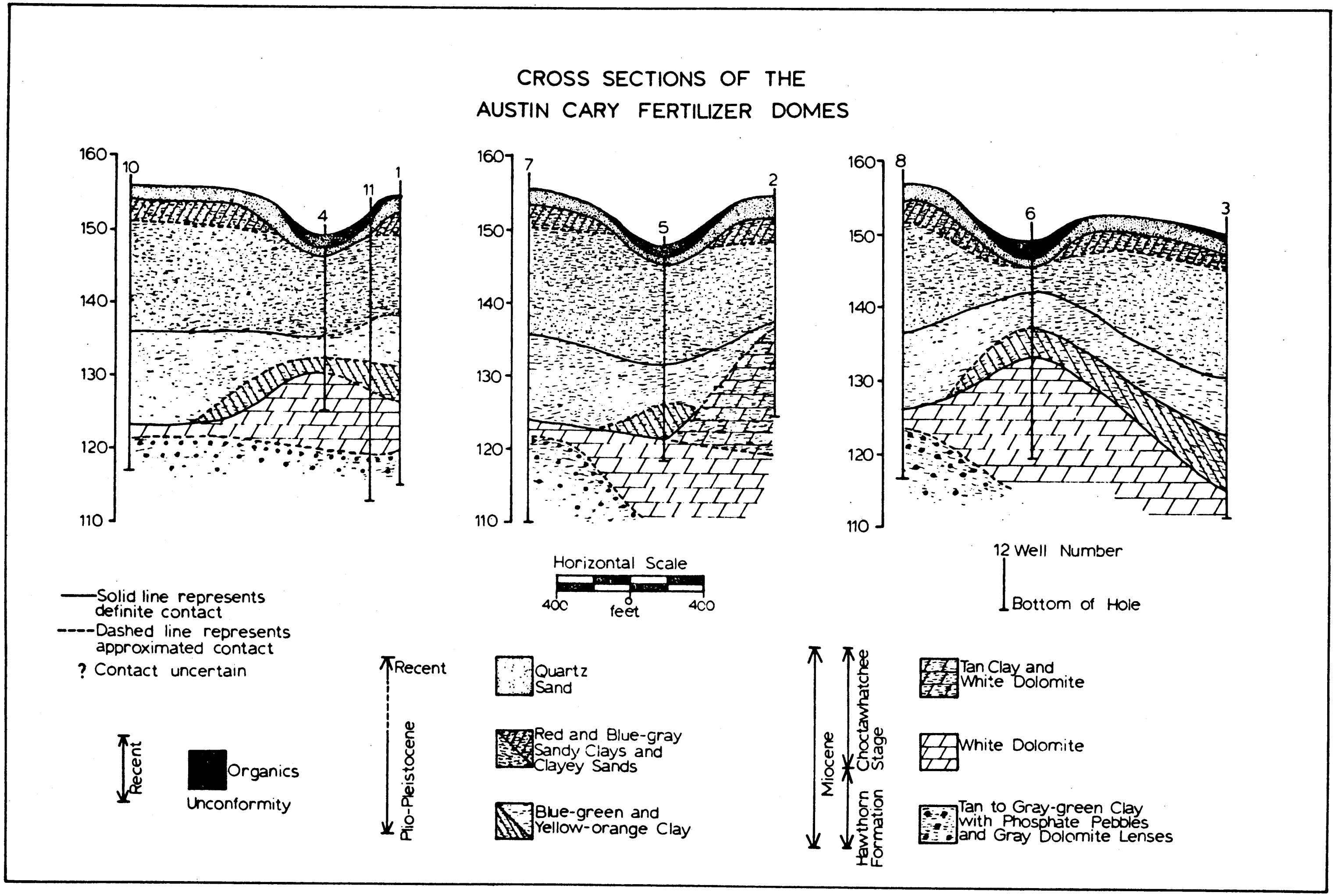


Figure 13. Cross sections of the Austin Cary Fertilizer Domes (in Spangler et al., 1976).

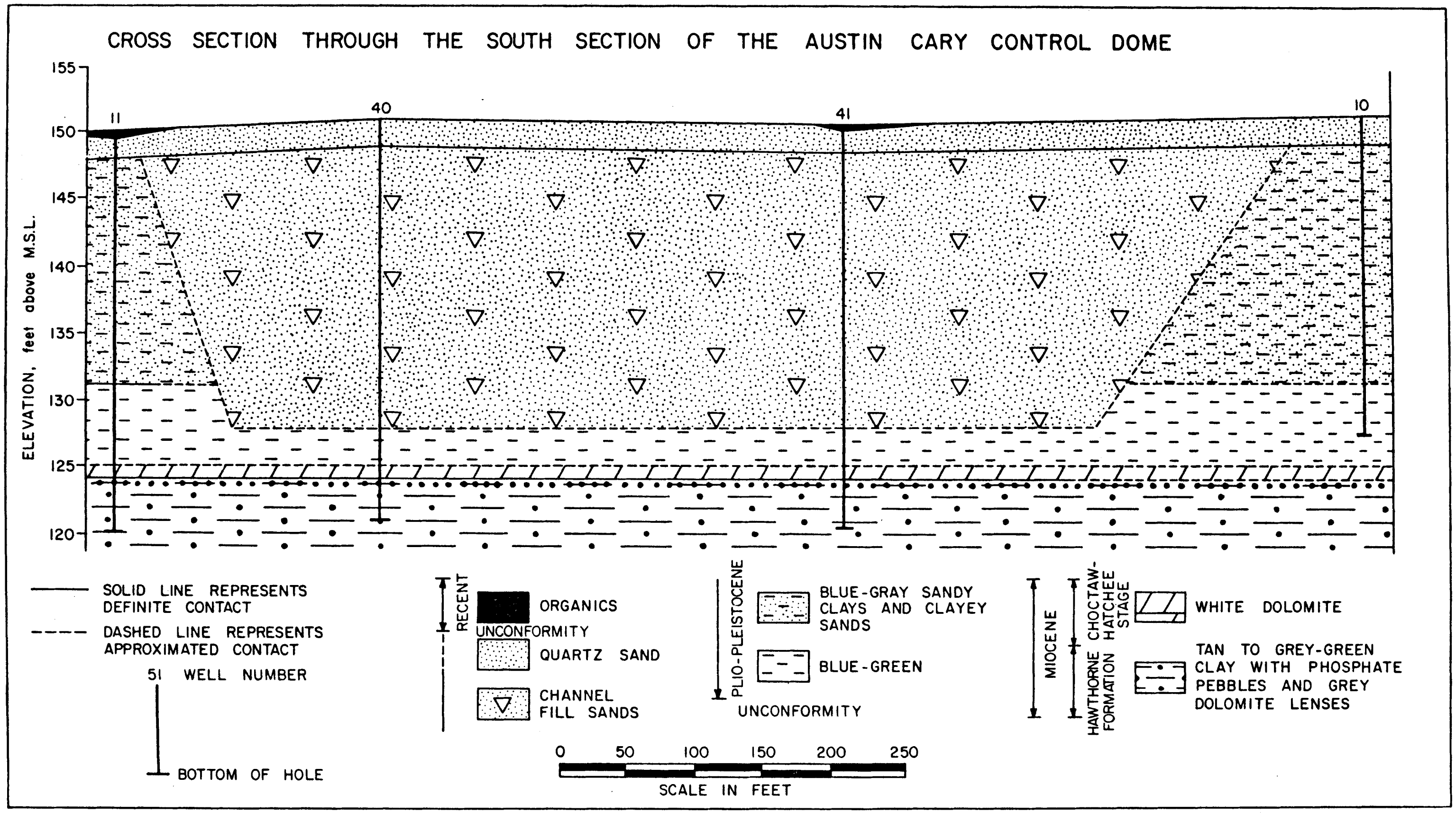


Figure 14. Cross section through the south section of the Austin Cary Control Dome (in Gillespie, 1976).

clayey sands. A lower clayey sand zone, approximately 1.22 m (4 feet) thick lies directly above the blue-green clays.

Hydrogeologically the blue-gray sandy clays and clayey sands compris a complex system of various multi-near-surface aquifers and aquicludes. importance of the alternating sandy clays and clayey sands is their poten filterability with respect to treated wastewaters.

Yellow-Orange and Blue-Green Clays

The yellow-orange clays and blue-green clays (Figures 6, 12, 13, and 14), probably facies, lie unconformably above the white dolomite and below the blue-gray sandy clays and clayey sands (Figures 8 and 10) with a gradational contact. They are of identical montmorillonite composition, and frosted quartz grains are commonly associated with them. In addition, the blue-green clays often have red stringer.

The blue-green clays have been found throughout most study sites and the yellow-orange clays appear to be restricted to domes in the Austin Cary Forest area, where they overlie the thick white dolomite. Thicknesses of the combined units are fairly constant, but range from 1.22 m to 3.05 m (4 to 10 feet).

Hydrogeologically the yellow-orange and blue-green clays are an aquiclude separating the shallow aquifer system from the shallow artesian aquifer and aid in preventing excessive amounts of secondarily treated waste from reaching the very permeable white dolomite.

White Dolomite

The white dolomite is a fine to coarse grain fossiliferous shell marl characterized by alternating thin encrusting zones between softer lay several feet thick. It lies above the Hawthorn formation and the blue-green clays lie unconformably above it. On the basis of ostracod dating by Puri at Brooks Sink, located 4 miles east of the town of Brooker in

Bradford County, the white dolomite has been dated Late Middle Miocene or Late Miocene (Pirkle, 1956).

Thicknesses vary within the study areas from 0.31 to possibly greater than 2.75 meters (1 to 9 feet). Most wells in the pine forest and along the dome margins have white dolomite thicknesses of 0.31 to 1 meter (1 to 3 feet). Within domes and along their margins, the white dolomite becomes 1.83 to 2.75 meters (6 to 9 feet) thick. This is particularly true in ACCD. The relationship of dolomites within and outside of the domes in the OIRS is not well known. Geophysical logs (Smith, 1975) and later work noted in Figure 15 with limited sampling seem to suggest dolomite presence near 7.63 m (25 foot) depths.

Miocene Hawthorn Formation

This is the oldest geologic unit encountered in the study sites, Lower to Middle Miocene, and has been found at depths of 6.10 to 10.07 m (20 to 33 feet) below the surface. The Hawthorn Formation extends to the bottom (48.8 m below the surface) of observation well #26 (Figure 5) at ACCD. Expected depth to the top of the Ocala (part of the Floridan Aquifer) is approximately 64.05 m (210 feet) below the surface at ACCD (Figure 3). At OIRS, the top of the Ocala is approximately 33.6 m (110 feet) below the surface.

The Hawthorn Formation contains abundant pebbles and grains of phosphate (carbonate apatite) in a predominantly clay matrix. The pebbles and grains are brown and black and are concentrated throughout the formation in varying amounts. The most heavily concentrated zone, as evidenced by the natural gamma radiation logs (Figures 16 and 17), is the upper few feet where phosphate pebbles are as much as one half inch in diameter. The natural gamma radiation logs show numerous other phosphate concentrations throughout the formation. Pirkle (1956), in both describing the type

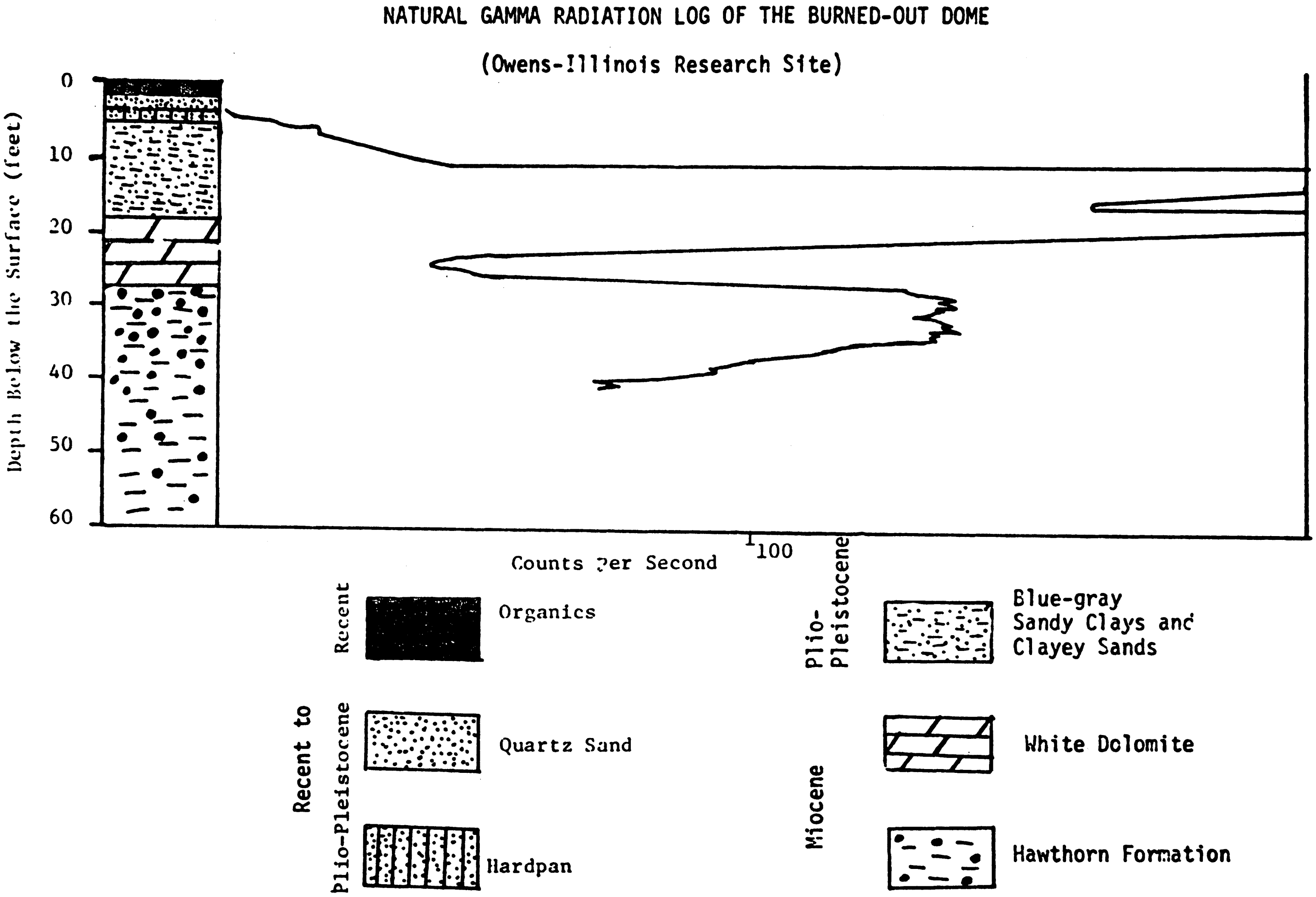


Figure 15. Natural gamma radiation log of a boring in an unnamed dome of Owens-Illinois Research Site south of Sewage Dome I in Figure 9 (in Spangler et al., 1976).

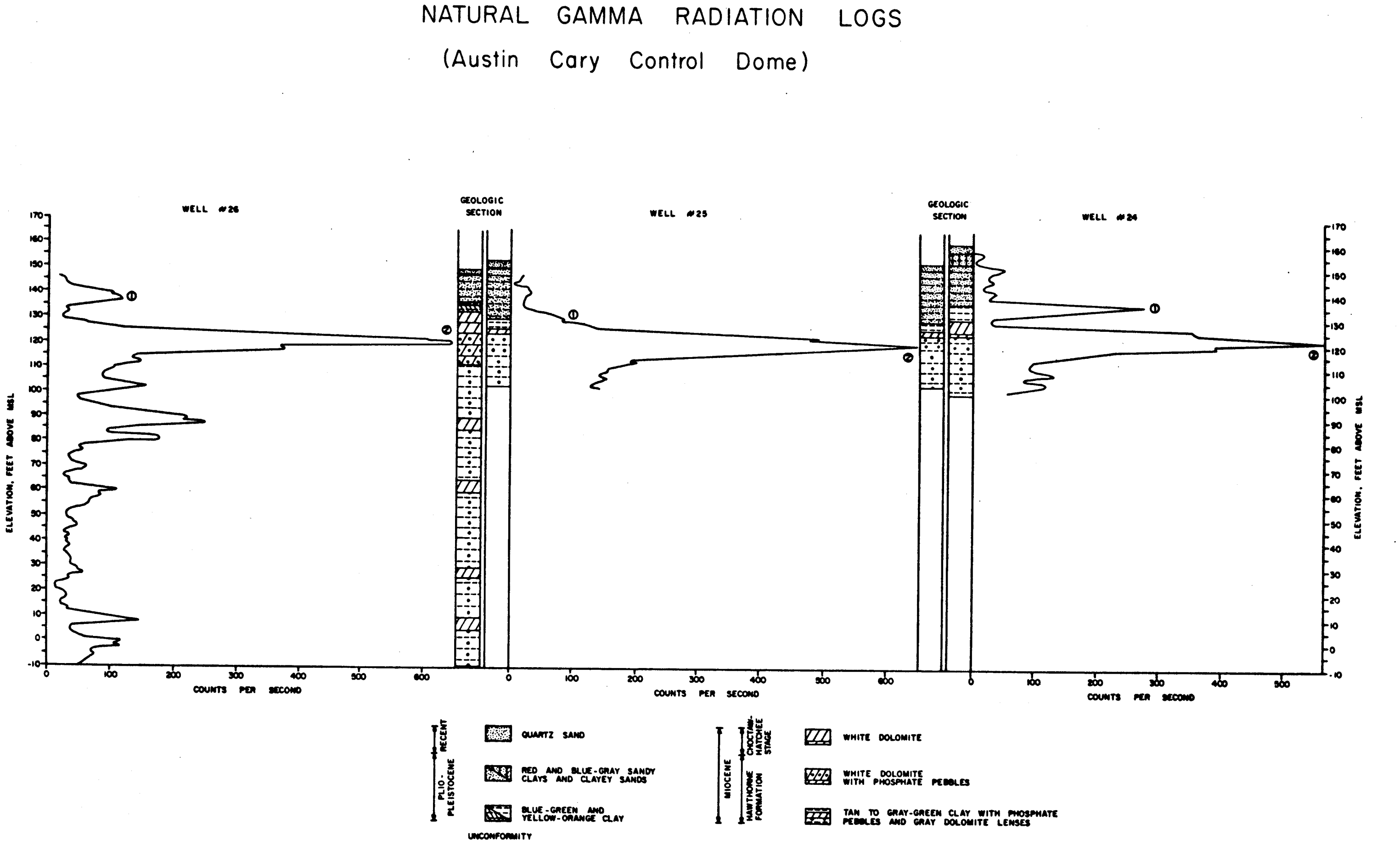


Figure 16. Natural gamma radiation logs for wells #24, #25, and #26 of the Austin Cary Control Dome. See Figure 5 for locations. (in Gillespie, 1976)

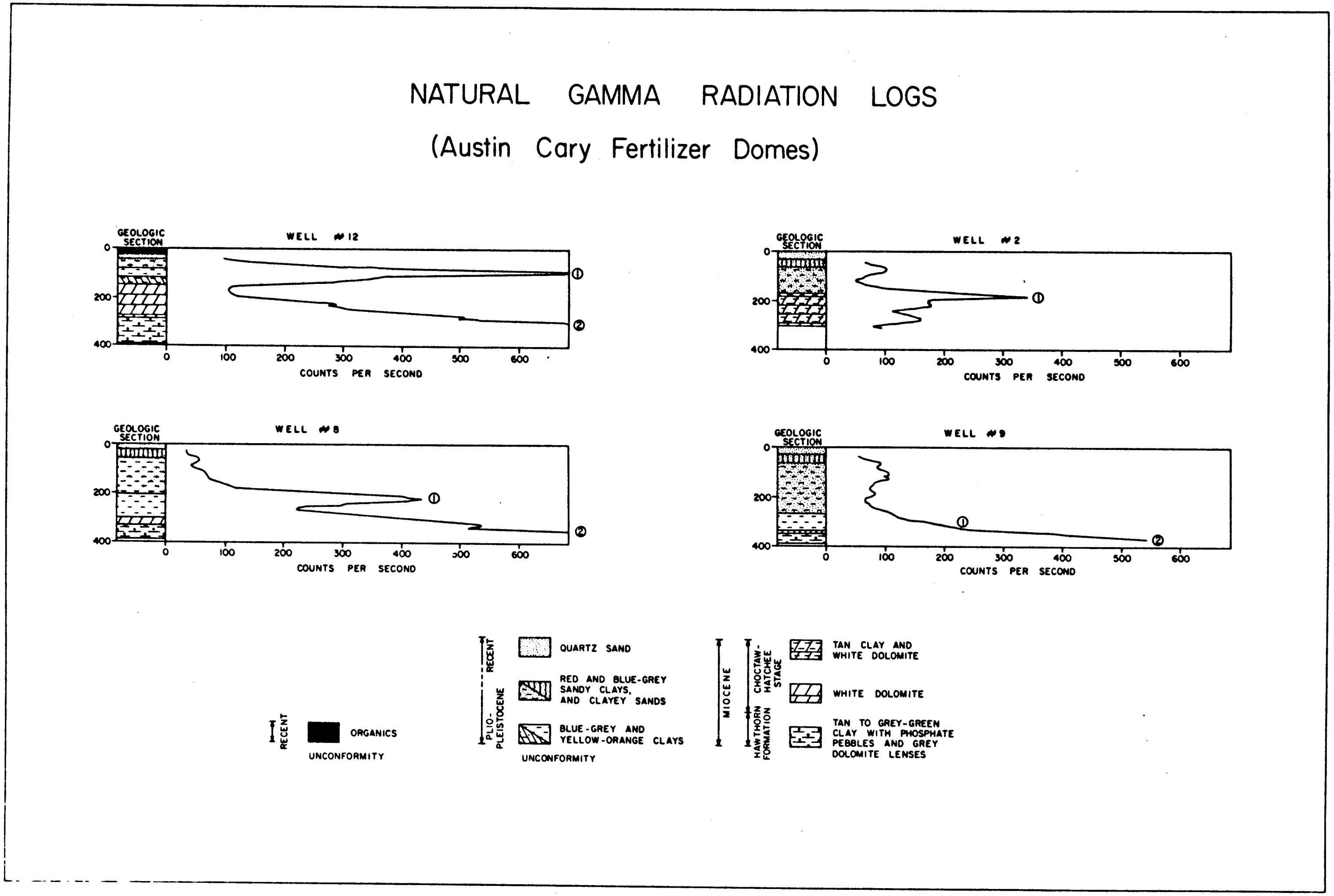


Figure 17. Natural gamma radiation logs for wells #2, #8, #9, and #12 of the Austin Cary Fertilizer Dome. See Figure 11 for locations. (in Spangler et al., 1976)

locality for the Hawthorn Formation in a phosphate quarry near Hawthorne (Figure 1) and other occurrences throughout the plateau, notes a similar concentration in the upper few feet.

The chief component of the Hawthorn Formation is a gray-green attapulgite and montmorillonite clay-carbonate mixture interbedded with numerous thin layers of gray-dolomite, the thickest layer being 1.22 to 1.53 m (4 to 5 feet) approximately 18.3 m (60 feet) below the surface. In many localities the gray-green clay near the upper contact has altered to a tan clay indicating the possible effects of weathering.

In well #26 ACCD (Figure 16), the upper 3.05 m (10 feet) of the Hawthorn Formation consisted of a white dolomite with phosphate pebbles overlying a tan clay. Its extent is uncertain, but based on the logs of wells #1, #3, and #30 ACCD (Figure 6), the white dolomite with phosphate pebbles appears to lie exclusively beneath the dome. At Brooks Sink a similar lithologic sequence occurs (Pirkle, 1956). The exact nature of this section and its importance is unknown although Odum (1953) and Gilliland (1976) suggest phosphate enrichment through reprecipitation where downward percolating acid waters come in contact with carbonate materials.

CONCLUSIONS

In summary, the hydrogeologic study of several cypress domes suggests their viability as depositories for secondarily treated wastes, particularly where the Hawthorn clays (aquiclude) is present. For data on permeabilities of each of the units, one may refer to the cited figures, investigations, and reports mentioned in the Introduction.

A very important but secondary conclusion resulting from this work has been the relationship of hardpans, dolomites, and phosphates to domal areas. These relationships are best noted in several of the presented cross sections, particularly those containing natural gamma radiation logs.

Tentative correlations are possible between these data and the gamma logs. Further study is indicated and needed to describe the origin, movement and deposition of iron, manganese, calcium, magnesium, phosphate, uranium and radon with respect to cypress domes and their underlying groundwater systems.

ACKNOWLEDGEMENTS

This work was supported by grants from the Rockefeller Foundation and the National Science Foundation to the Center for Wetlands, University of Florida (1973-1978). Principal investigators were Drs. Howard T Odum and Katherine C. Ewel. Several graduate students were supported during the hydrogeologic phase of this project, namely Bruce L. Cutright, Russell C. Smith, and Dennis P. Gillespie. John Lundy served as a summer assistant during 1976. This paper has been drawn largely from their work and articles published in a series of more encompassing annual reports. Extensive aid from support personnel is gratefully acknowledged, particular those from the Department of Geology, Florida Department of Transportation, St. John's Water Management District and the Center for Wetlands.

LITERATURE CITED

Black, Crow, and Eidsness, Inc. 1973. Water and Sewer Development Plan, Alachua County, Florida. North Florida Regional Planning Council, Alachua County, Florida.

Clark, W. E., R. H. Musgrove, C. G. Menke, and J. W. Cagle, Jr. 1964. Water resources of Alachua, Bradford, Clay and Union Counties, Florida. Florida Geological Survey Report of Investigations, No. 35. 170 pp.

Cutright, B. L. 1974. Hydrology of a cypress swamp, north central Alachua County, Florida. Master's Thesis. University of Florida, Gainesville, Florida. 83 pp.

Gillespie, D. 1976. Hydrogeology of the Austin Cary Control Dome in Alachua County, Florida. Master's Thesis. University of Florida, Gainesville, Florida. 127 pp.

Gilliland, Martha W. 1976. A geochemical model for evaluating theories on the genesis of Florida's sedimentary phosphate deposits. Mathematical Geology 8(3): 219-242.

Odum, H. T. 1953. Dissolved phosphates in Florida waters. Florida Geological Survey, Report of Investigations, No. 9, Part 1. pp. 1-40.

Odum, H. T. and K. C. Ewel, eds. 1974-1978. Cypress wetlands for water management, recycling, and conservation. First - Fourth Annual Reports to the National Science Foundation (RANN) and the Rockefeller Foundation. Center for Wetlands, University of Florida, Gainesville, Florida.

Pirkle, E. C. 1956. The Hawthorn and Alachua Formations of Alachua County, Florida. Quat. Jour. Florida Acad. Science 19(4): 197-240.

Puri, H. and R. O. Vernon. 1964. Summary of the geology of Florida and a guidebook to the classic exposures. Florida Geological Survey Special Publication No. 5. 312 pp.

Smith, R. C. 1975. Hydrology and stratigraphy of several cypress domes and the surrounding area in Alachua County, Florida. Master's Thesis. University of Florida, Gainesville, Florida. 87 pp.

Spangler, D. P., Gillespie, D., and J. Lundy. 1976. Stratigraphy and hydrologic correlation studies in several cypress domes-north central Florida. pp. 110-128 in H. T. Odum and K. C. Ewel, eds. Cypress wetlands for water management, recycling, and conservation. Third Annual Report to the National Science Foundation (RANN) and the Rockefeller Foundation. Center for Wetlands, University of Florida, Gainesville, Florida.

CREATION OF FRESHWATER MARSHES
IN WEST CENTRAL FLORIDA

Allen G. Shuey and Lawrence J. Swanson, Jr.
Conservation Consultants, Inc.
P.O. Box 35
Palmetto, Florida 33561

ABSTRACT

Three approaches for establishing freshwater marsh vegetation were tested. The approaches were natural recolonization, selective planting, and mulching with organic material from natural marshes. The three methods are evaluated ten months after establishment by comparing species composition and water quality to natural marshes. Preliminary results indicate that freshwater marshes can be established by either the selective planting or mulching techniques. Mulching results in a larger number of species and a higher ground cover in a short period of time.

INTRODUCTION

Increasing public awareness of the value of wetlands has resulted in stricter laws for their protection. This is especially true of the Florida phosphate industry where mining permits often contain requirements for the restoration of wetlands disturbed by mining. Since January 1978, Conservation Consultants, Inc. has conducted a wetlands research program for W.R. Grace & Co. designed to provide information on methods for restoring freshwater marshes. A pilot-scale test of three methods of establishing marshes is in progress. The methods being evaluated include natural recolonization, selective planting and mulching with organic matter from a natural marsh. The organic mulch is believed to contain seeds and vegetative propagules which would grow if placed in a suitable environment.

Because of a scarcity of information on freshwater marshes, two natural marshes were studied to provide baseline information for assessing the success of the restoration techniques. Species composition and water quality parameters are used as the basis for the comparisons. The water quality parameters are being used as measures of restoration success because the protection of water quality is a reason often cited for the need for the preservation or restoration of wetlands.

AREA DESCRIPTION

The studies were carried out on W.R. Grace & Co.'s Four Corners Mine site in southeast Hillsborough and northeast Manatee Couties, Florida. Before construction, the site of the artificial marshes was pine-palmetto flatwoods with soils consisting of sands and clayey sands. No hardpan was present.

The natural marshes are within a few kilometers of the artificial marshes. They are surrounded by severely logged flatwoods. Both natural and artificial marshes are fenced to out keep cattle.

METHODS

The artifical marsh construction began in May 1978 with the removal of all vegetation and topsoil from the 5 ha site. Three circular depressions, each approximately 0.2 ha in area, were excavated to a depth of 2 m and then backfilled to a final depth of approximately 1.25 m. This procedure was employed to thoroughly disturb the substrate in an attempt to simulate soil conditions found on mined land. After the site was contoured, grass seed was spread to establish a ground cover to reduce erosion.

The three depressions were used to test the effectiveness of techniques for establishing marsh vegetation. The first was designated as a control and received no further treatments. The second was selectively planted with marsh plants removed from a nearby site. The third depression received a layer of mulch which consisted of the upper 15 cm of soil from a nearby natural marsh.

Water quality samples were collected monthly. The samples were analyzed for pH, dissolved oxygen, biological oxygen demand, ammonia, organic nitrogen, ortho-phosphate, and turbidity. Each time a water sample was collected, lists were prepared of vegetation present in the marshes. The same sampling procedure was used at the natural marshes.

RESULTS AND DISCUSSION

Vegetation

The control marsh has had very little colonization by marsh plants. Although 27 species have been found in this marsh (Table I), they are widely scattered around the edge of the depression. Cattails (Typha sp.) are the most conspicious colonizers.

The planted marsh contains 34 species of marsh plants. Soft rush (*Juncus effusus*), pickerel weed (*Pontederia lanceolata*), and maidencane (*Panicum hemitomon*) were deliberately planted. The remaining plants were inadvertently introduced with the clumps of the selected species. The original clumps have started to spread but they are still separated by considerable open areas.

The mulched marsh has a dense cover of vegetation over approximately 50% of its surface. The vegetation is primarily distibuted around the shallow margins of the depression. Apparently high water levels shortly after spreading the mulch killed the plant propagules in the center of the marsh. This marsh has the highest diversity of plants with 62 species recorded.

The natural marshes contained more species than the artificial marshes (Table II): 77 in the deep marsh and 66 in the shallow marsh. The shallow marsh was dominated by fennel (*Eupatorium recurvans*), goldenrod (*Solidago microcephala*), coinwort (*Centella asiatica*), *Ludwigia suffruticosa*, slender spikerush (*Eleocharis baldwinii*), and water grass (*Hydrochloa caroliniensis*). The deep marsh was dominated by coinwort, *Axonopus furcatus*, slender spikerush, maidencane, water hyssop (*Bacopa caroliniana*), and pickerel weed.

Water Quality

The pH of the artificial marshes varied between 4.4 and 9.7, compared to the natural marshes where pH varied between 4.1 and 5.9 (Figure 1). Each of the artificial marshes showed a trend of increasing pH. This is in contrast to the natural marshes where the pH remained stable. The high pH values in the control marsh during January and February 1979 coincided with a dense algae bloom.

Dissolved oxygen concentration ranged from 5.3 to 15.1 ppm in the artificial marshes and from 3.3 to 10.5 ppm in the natural marshes (Figure 2). The highest dissoved oxygen concentration occurred during the January - February algae bloom in the control marsh.

Five day biological oxygen demand ranged from 0.2 to 13.6 ppm O_2 in the artificial marshes, compared to a range of 0.2 to 8.0 ppm O_2 in the natural marshes (Figure 3). Except for the high values associated with the January - February algae bloom in the control marsh, the highest BOD values usually occurred in the mulched marsh.

Ammonia levels were low in both natural and artificial marshes (Figure 4). The highest values occurred in the shallow natural marsh (2.26 ppm N) although most of the values were less than 0.2 ppm. The deep natural marsh varied between 0.03 and 0.37 ppm N while the artificial marshes varied between 0.02 and 0.34 ppm N.

Organic nitrogen levels varied between 0.13 and 8.39 ppm in the artificial marshes compared to a range of 0.38 to 8.53 ppm in the natural marshes (Figure 5). The highest values usually occurred in the mulched marsh. The control marsh showed a peak during the Janurary - February algae bloom. The planted and mulched marshes had peaks in August and December. The natural marshes showed fluctuations that were similar in magnitude, but the peaks were at different times.

Ortho-phosphate concentrations ranged between 0.12 and 9.40 ppm PO_4 in the artificial marshes compared to a range of 0.01 to 1.35 ppm in the natural marshes (Figure 6). The control marsh had a pronounced peak during the January algae bloom.

Table I. Listing of Plants found in Artificial Marshes

CONTROL

Axonopus sp.
Azolla caroliniana
Centella asiatica
Conyza canadensis
Cynodon dactylon[1]
Cyperus odoratus
Cyperus polystachyos texensis
Cyperus retrorsus
Cyperus surinamensis
Echinochloa colonum[1]
Eleocharis baldwinii
Erectites hieracifolia
Juncus biflorus
Juncus scirpoides
Juncus sp.
Panicum hemitomon
Paspalum distichum
Paspalum notatum[1]
Phaseolus lathyroides[1]
Polygonum persicaria
Pluchea sp.
Rhynchospora fascicularis
Rumex sp.
Scoparia dulcis
Typha sp.
Xyris spp.

PLANTED

Axonopus sp.
Azolla caroliniana
Cynodon dactylon[1]
Cyperus haspan
Cyperus polystachyos texensis
Cyperus retrorsus
Cyperus surinamensis
Cyperus sp.
Echinochloa colonum[1]
Eleocharis baldwinii
Leersia hexandra
Lindernia grandiflora
Lippia sp.
Ludwigia arcuata
Ludwigia repens
Nymphoides aquatica
Panicum hemitomon
Paspalum notatum[1]
Phaseolus lathyroides
Pluchea sp.

Table I. Continued

Hydrochloa caroliniensis

Hydrocotyle umbellata

Juncus biflorus

Juncus effusus

Juncus repens

Juncus scirpoides

Juncus sp.

Polygonum persicaria

Pontederia lanceolata

Proserpinaca pectinata

Rhynchospora fascicularis

Scoparia dulcis

Typha sp.

Xyris sp.

MULCHED

Andropogon sp.

Axonopus sp.

Bacopa cyclophylla

Bidens mitis

Carex alata

Centella asiatica

Cephalanthus occidentalis

Cynodon dactylon[1]

Cyperus flavescens

Cyperus haspan

Cyperus odoratus

Cyperus polystachyos texensis

Cyperus retrorsus

Cyperus sp.

Digitaria serotina

Diodia virginiana

Echinochloa colonum[1]

Eleocharis baldwinii

Ludwigia pilosa

Ludwigia suffruticosa

Lycopsus sp.

Nymphoides aquatica

Panicum hemitomon

Panicum verrucosum

Paspalum dissectum

Paspalum laeve

Paspalum lentiferum

Paspalum notatum[1]

Phaseolus lathyroides[1]

Polygonum persicaria

Pontederia cordata

Proserpinaca pectinata

Psilocarya nitens

Pluchea sp.

Rhexia mariana mariana

Rhynchospora cephalantha

Table I. Continued

Eragrostis refracta
Eryngium prostratum
Fimbrystylis autumnalis
Hedyotis uniflora
Hydrochloa caroliniensis
Hypericum mutilum
Juncus effusus
Juncus marginatus
Juncus repens
Juncus scirpoides
Leersia hexandra
Lindernia grandiflora
Ludwigia arcuata
Rhynchospora fascicularis
Rhynchospora sp.
Sacciolepis striata
Sagittaria graminea
Scleria reticularis
Scoparia dulcis
Solidago fistulosa
Spartina bakeri
Typha sp.
Utricularia sp.
Woodwardia virginica
Xyris jupicai
Xyris sp.

---

[1] These species were included in the seed mix that was spread on the site to control erosion.

Table II. Listing of Plants Found in Natural Marshes

SHALLOW MARSH

Agalinis linifolia
Amphicarpum muhlenbergianum
Andropogon brachystachys
Andropogon capillipes
Andropogon longiberbis
Aristida sp.
Aristida spiciformis
Axonopus furcatus
Centella asiatica
Cyperus haspan
Cyperus polystachyos texensis
Cyperus retrorsus
Cuscuta campestris
Digitaria serotina
Diodia virginiana
Drosera capillaris
Eleocharis baldwinii
Eragrostis elliottii
Eragrostis refracta
Erectites hieracifolia
Eupatorium recurvans
Fuirena scirpoidea
Gratiola ramosa
Hedyotis uniflora
Hydrochloa caroliniensis
Hydrocotyle umbellata
Hypericum mutilum
Hypericum myrtifolium
Hypoxis juncea
Juncus effusus
Juncus repens
Juncus scirpoides
Lachnocaulon anceps
Lindernia grandiflora
Ludwigia arcuata
Ludwigia suffruticosa
Nymphoides aquatica
Panicum lancearium
Panicum longifolium
Panicum hemitomon
Panicum tenerum
Paspalum distichum
Paspalum laeve
Pluchea rosea
Polygala rugellii
Proserpinaca pectinata
Pterocaulon virgatum
Rhexia mariana mariana
Rhynchospora fascicularis
Rhynchospora schoenoides

Table II. Continued

SHALLOW MARSH

Sabatia grandiflora
Sagittaria graminea
Scleria reticularis
Solanum sp.
Solidago fistulosa
Solidago microcephala
Stillingia sylvatica
Syngonanthus flavidulus
Utricularia inflata inflata
Viola lanceolata
Xyris brevifolia
Xyris elliottii
Xyris fimbriata
Xyris jupicai
Xyris platylepis
Xyris smalliana

DEEP MARSH

Agalinis linifolia
Andropogon brachystachys
Andropogon capillipes
Andropogon longiberbis
Andropogon virginicus
Aristida spiciformis
Aster sp.
Axonopus furcatus
Bacopa caroliniana
Boltonia diffusa
Centella asiatica
Cyperus haspan
Cyperus polystachyos texensis
Cyperus retrorsus
Diodia virginiana
Drosera capillaris
Eleocharis baldwinii
Eragrostis elliottii
Eragrostis refracta
Erigeron vernus
Eupatorium recurvans
Fimbrystylis autumnalis
Fuirena scirpoidea
Gratiola ramosa
Gratiola pilosa
Hedyotis uniflora
Hydrochloa caroliniensis
Hydrocotyle umbellata
Hypericum myrtifolium
Hypoxis juncea

Table II. Continued

DEEP MARSH

Juncus dichotomus
Juncus repens
Juncus scirpoides
Lachnocaulon anceps
Lachnocaulon minus
Lindernia grandiflora
Ludwigia arcuata
Ludwigia pilosa
Ludwigia suffruticosa
Nymphoides aquatica
Nymphaea odorata
Oxypolis filiformis
Panicum lancearium
Panicum longifolium
Panicum hemitomon
Paspalum laeve
Paspalum setaceum
Pluchea rosea
Polygala rugellii
Polygonum persicaria
Pontederia lanceolata
Proserpinaca pectinata
Pterocaulon virgatum
Rhexia mariana mariana
Rhynchospora cephalantha
Rhynchospora fascicularis
Rhynchospora inudata
Rhynchospora schoenoides
Rhynchospora stenophylla
Sabatia grandiflora
Sacciolepis striata
Sagittaria graminea
Scleria reticularis
Setaria geniculata
Solidago fistulosa
Solidago microcephala
Spiranthes praecox
Tithymalus sphaerospermus
Utricularia biflorus
Utricularia inflata inflata
Viola lanceolata
Xyris brevifolia
Xyris elliottii
Xyris fimbriata
Xyris jupicai
Xyris platylepis
Xyris smalliana

FIGURE 1 : pH

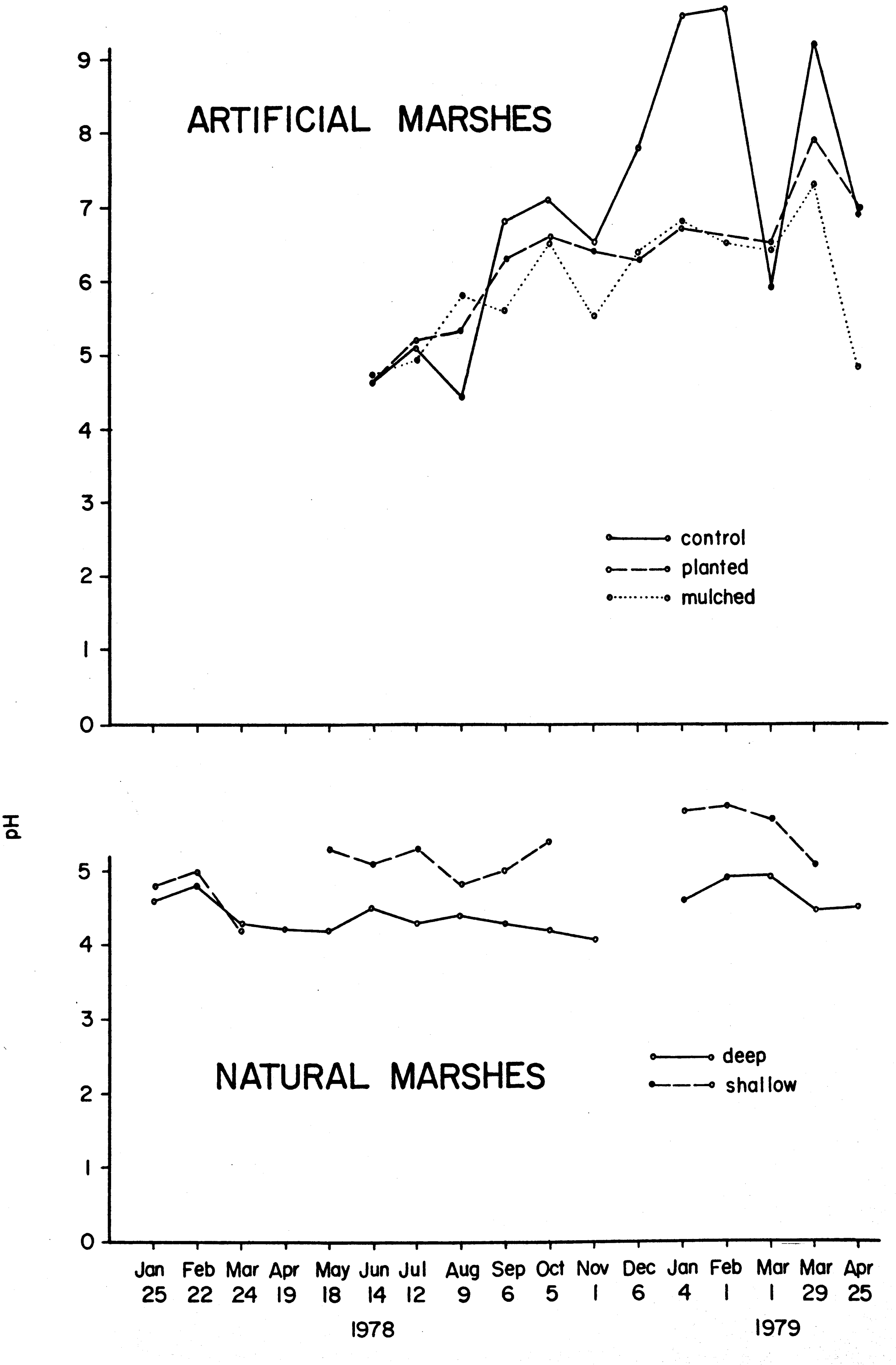

ARTIFICIAL MARSHES
control
planted
mulched
pH
NATURAL MARSHES
deep
shallow
0
1
2
3
4
5
6
7
8
9
Jan 25
Feb 22
Mar 24
Apr 19
May 18
Jun 14
Jul 12
Aug 9
Sep 6
Oct 5
Nov 1
Dec 6
Jan 4
Feb 1
Mar 1
Mar 29
Apr 25
1978
1979

FIGURE 2 : DISSOLVED OXYGEN

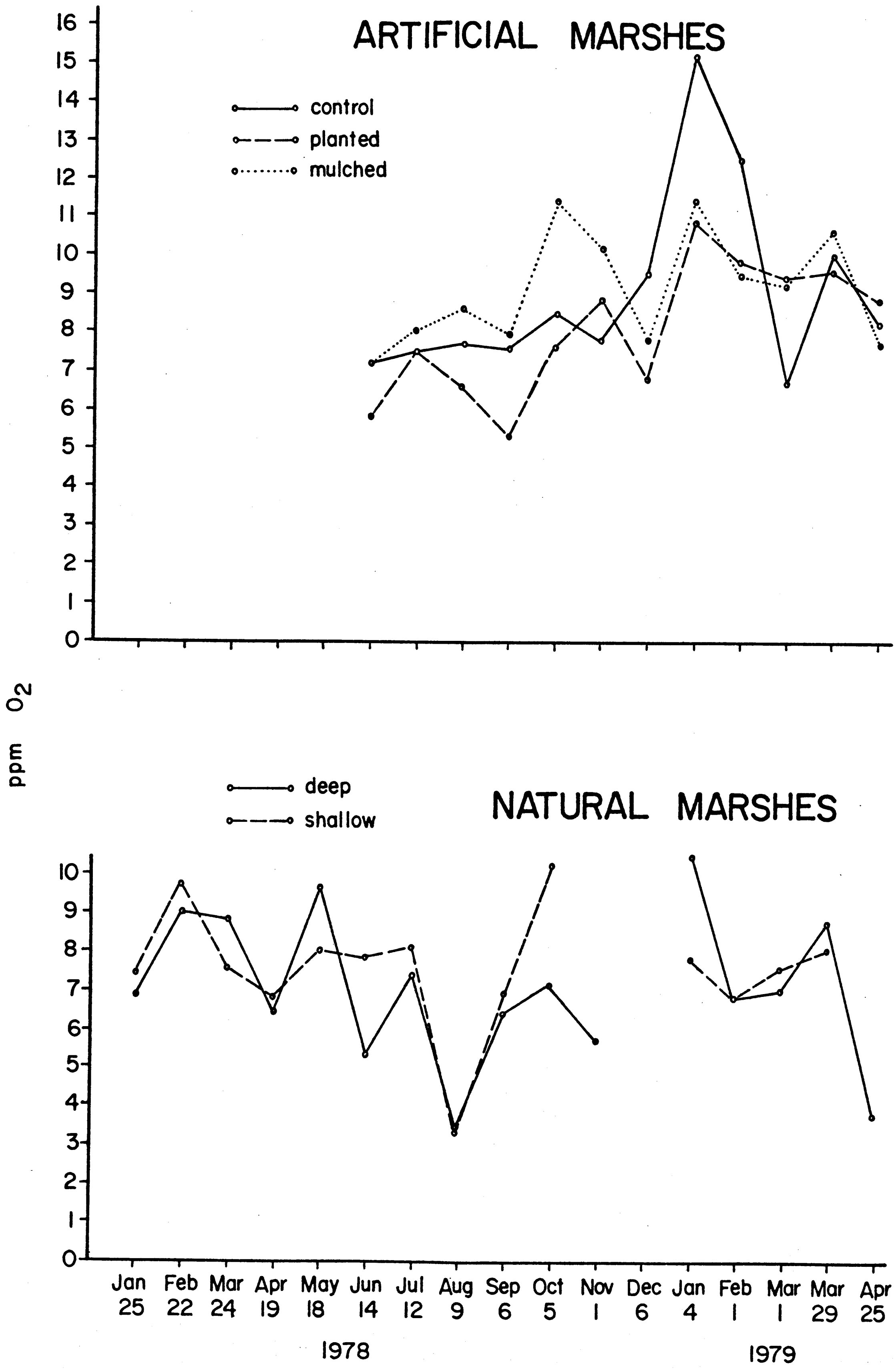


FIGURE 3 : BIOLOGICAL OXYGEN DEMAND

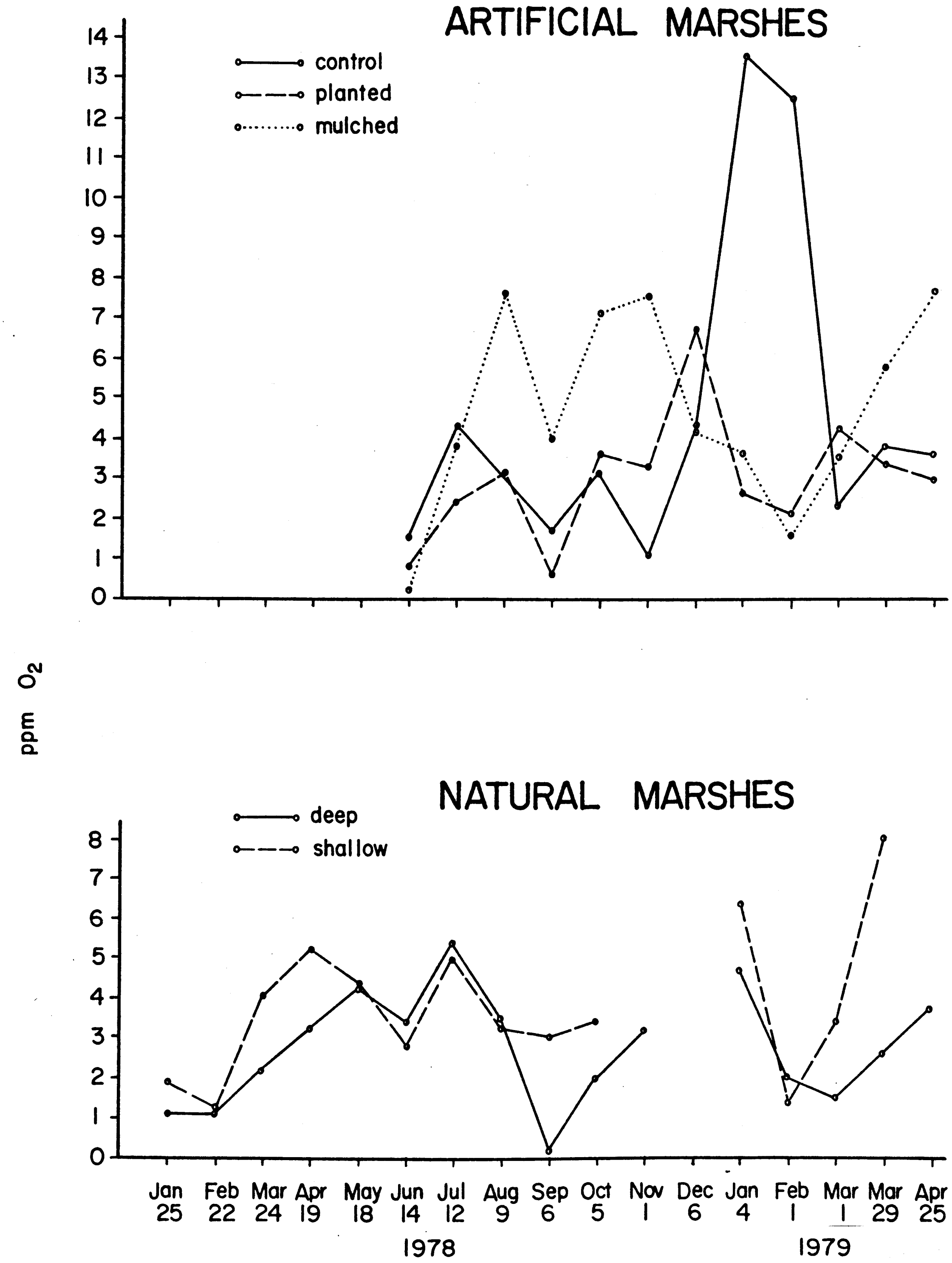


FIGURE 4 : AMMONIA

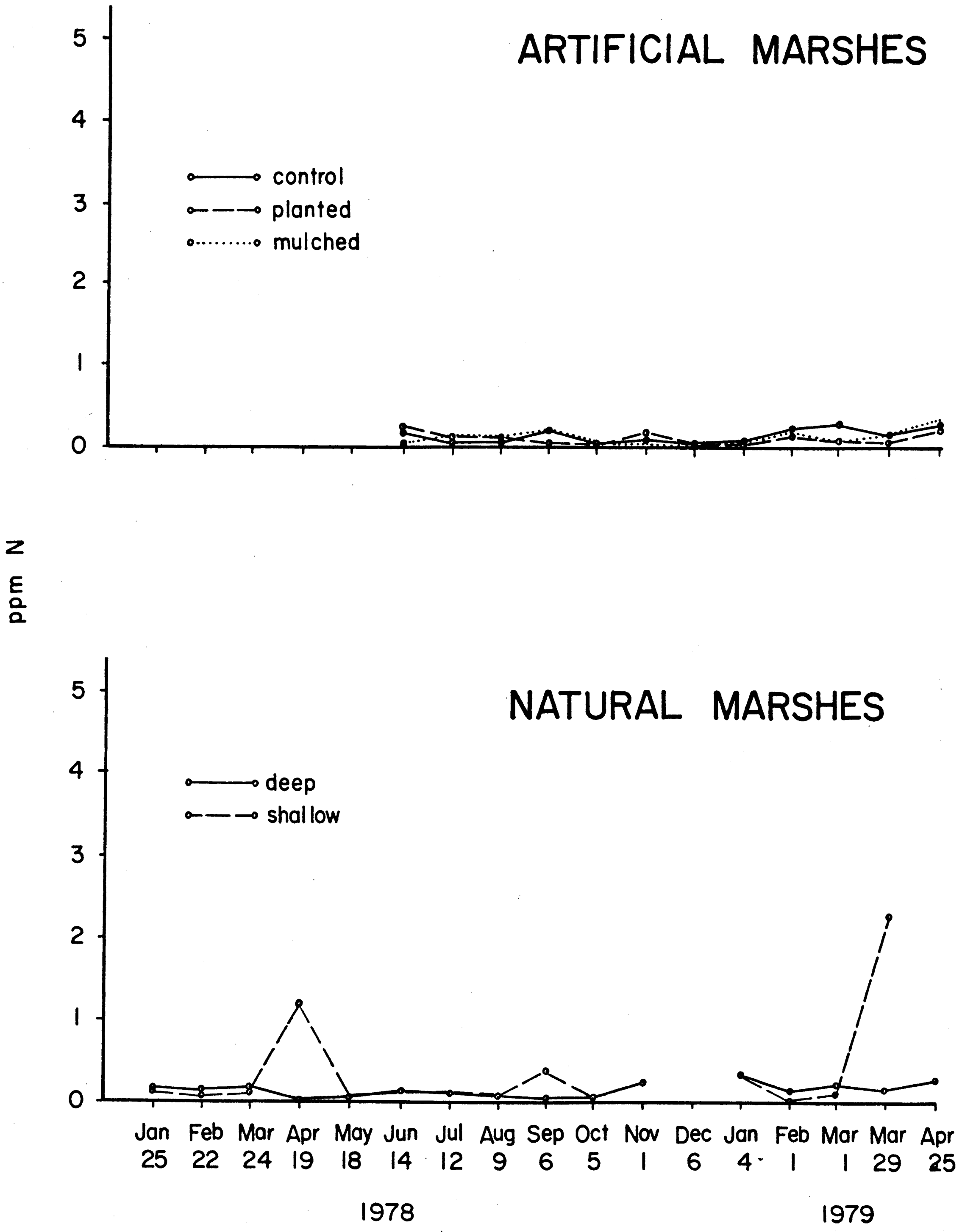


FIGURE 5: ORGANIC NITROGEN

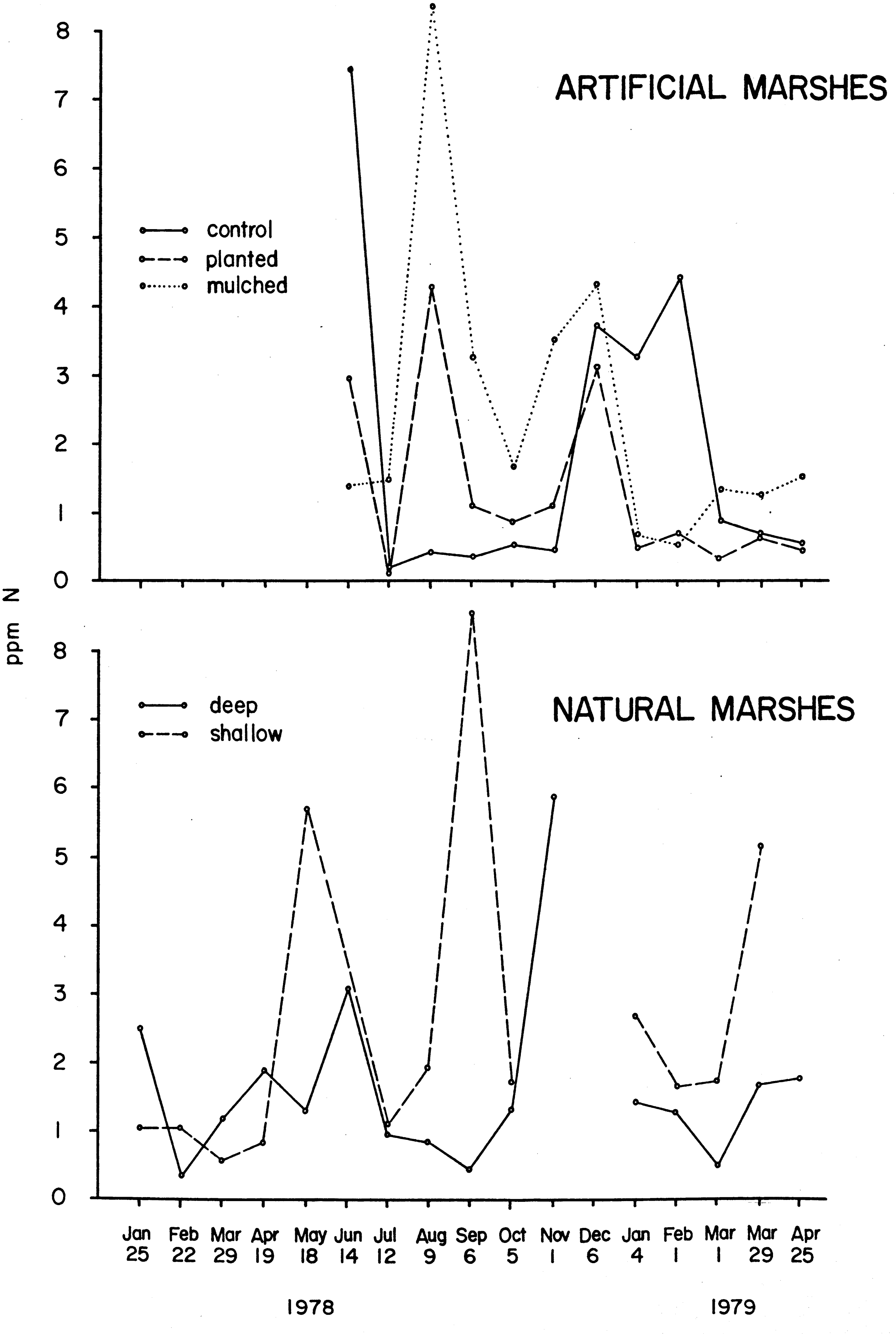


FIGURE 6 : ORTHO-PHOSPHATE

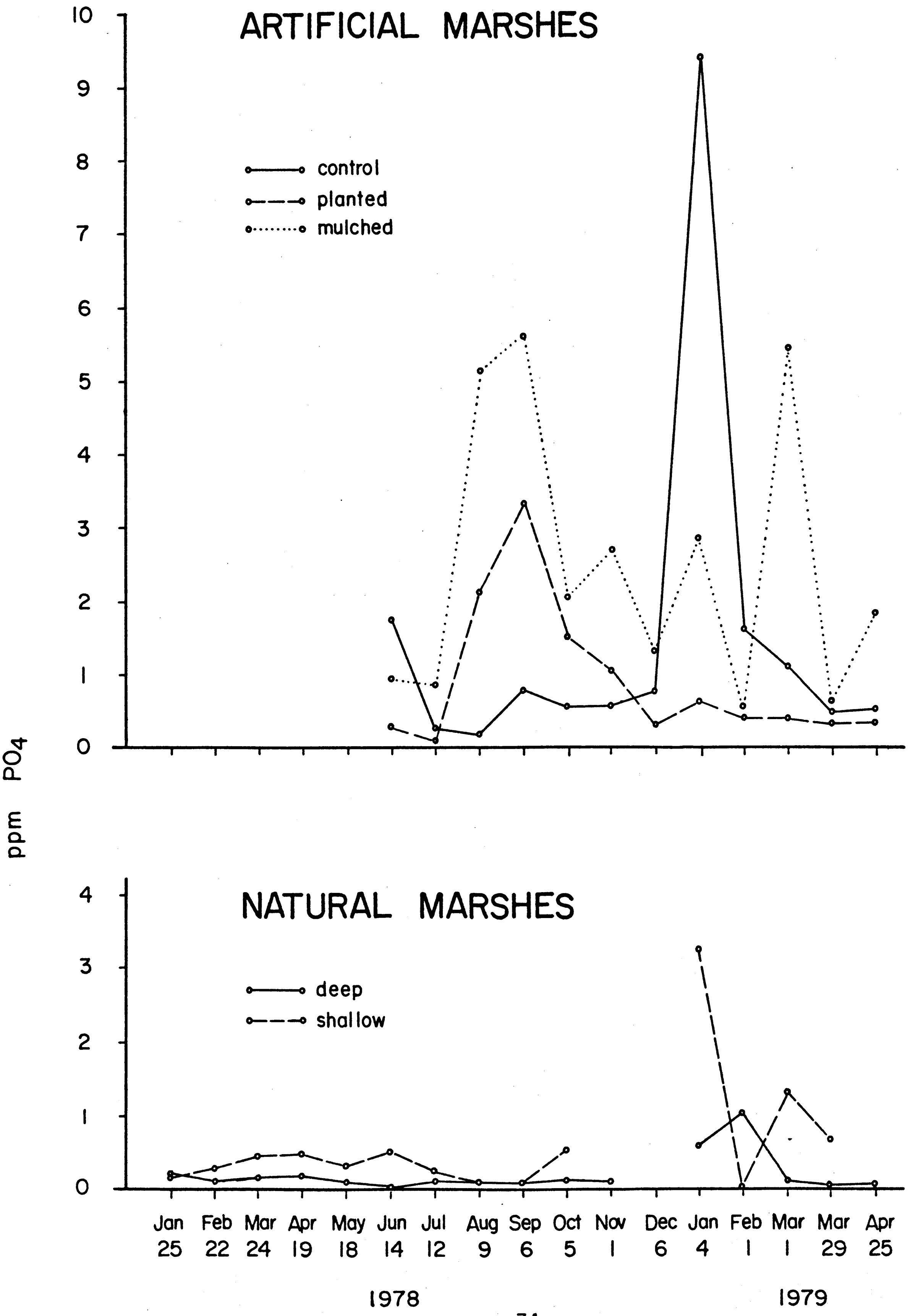
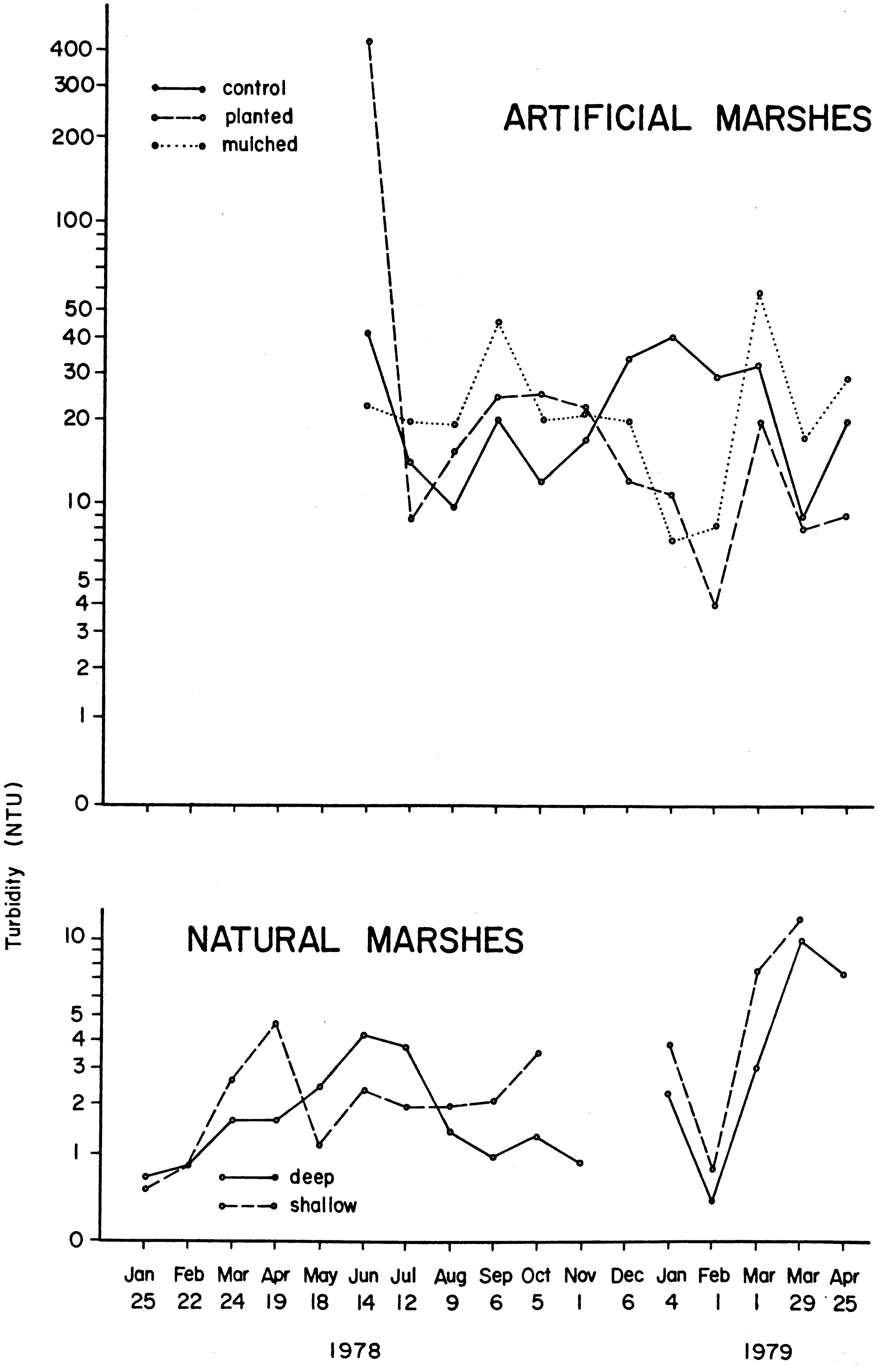


FIGURE 7 : TURBIDITY



Turbidity levels have generally been between 10 and 40 NTU's in the artificial marshes, except for the first month (June 1978) when the planted marsh had a value of 439.9 NTU's (Figure 7). In contrast, the artificial marshes had turbidities which have generally been less than 10 NTU's.

CONCLUSIONS

Preliminary results indicate that short-term success in establishing freshwater marsh vegetation is greatest with the mulching technique. The mulching results in a dense ground cover and a high species diversity. Selective planting also appears to be a successful method of establishing freshwater marshes. The completeness of ground cover is a direct result of the amount of labor spent on the project. In most cases economics would dictate a low initial planting density. The species diversity was also lower than with the mulching technique. The control marsh showed very little natural recolonization within the short time span of this study. Water quality parameters in all three artificial marshes generally exceed values found in natural marshes. There is some indication however that water quality is improving as the marshes age.

Monitoring of the natural and artificial marshes is continuing so that long-term results can be evaluated.

ACKNOWLEDGEMENTS

This study was funded by W.R. Grace & Company. Special thanks are due Messrs. Charles Greene and Ralph Gienau for their support of this project.

WETLAND CLASSIFICATION FOR MINING, RESTORATION AND PRESERVATION IN CENTRAL FLORIDA

Jorge Southworth, Gil Backenstoss,

and Ted Forsgren

Bureau of Land and Water Management
Department of Community Affairs

ABSTRACT

There is an estimated 13,800 hectares (51.7 sq. miles) of wetlands in central Florida proposed for phosphate mining during the next 21 years. The impact of functionally destroying these wetlands would be disastrous to the regional drainage system and the receiving water bodies. The Division of Local Resource Management* recognizes the importance of the wetland functions to the region, as well as the need for recovering the phosphate resource. Because mineral extraction and wetlands protection are frequently conflicting objectives that must be balanced, the Division has designed a system for assigning values to wetlands.

A three level classification system has been developed which ranks wetlands in terms of their value to regional hydrology, water quality, and fish and wildlife habitat. The three types are: (1) areas of critical importance considered impossible to replace, which should be preserved; (2) areas of critical importance that may be disturbed if restoration to present or greater quality is guaranteed; and (3) functioning wetland areas that are not critical to the regional system and may be disturbed if their functions are replaced elsewhere in the system. This classification system has been used successfully in reviewing several proposed mining operations in central Florida.

---

*The Division of Local Resource Management in the Department of Community Affairs was formerly the Division of State Planning. This Division has the responsibility for the enforcement of Chapter 380, Florida Statutes, the Environmental Land and Water Management Act. This Act provides for review and approval of Developments of Regional Impact and the designation and regulation of Areas of Critical State Concern.

INTRODUCTION

Much of Florida is underlain with phosphate rock. At the present time only two areas of the state, the Northern Land-Pebble District and the Central Land-Pebble District, are being actively mined for phosphate. In the Central Land-Pebble District, Polk, Hillsborough, Manatee, Hardee and DeSoto Counties have large areas that are being mined or will be mined in the near future.

The Environmental Protection Agency has estimated that 13,800 ha. (51.7 sq. miles) of fresh water wetlands are included in lands that are proposed for mining by the year 2000 (EPA, 1978). These areas are within the drainage basins of the Alafia, Peace, Little Manatee, Manatee and Myakka Rivers. Since the phosphate industry seeks to mine any land for which they hold mineral rights if it will be profitable, many of the wetland areas will be disturbed.

The mining process completely destroys the landscape. Miners, however, can restore the land to many of its previous functions by using good reclamation techniques. Pasture, marshes and lakes are sometimes created during reclamation.

The Division of Local Resource Management is charged with guiding the management of resources on a state and regional basis. The wise management of some of the natural and cultural resources are in conflict with the need to obtain the phosphate resource. In reviewing mining Developments of Regional Impact[**] (DRI's), the Division must try to encourage ore recovery without endangering other resources. The problem areas associated with phosphate mining include such areas as traffic loading on highways, displacement or agriculture use and energy consumption.

The conflicts between the need to recover the phosphate rock and the need to maintain wetlands and natural drainage systems are usually a major concern. Many of these wetlands are critical for the maintenance of water quality and

---

**A Development of Regional Impact is defined in Chapter 380 as a development which because of its character, magnitude or location would have a substantial effect on the health, safety or welfare of citizens of more than one county. Mines, large residential developments, petroleum storage facilities, shopping centers and large industrial developments are some of the types of developments which could be Developments of Regional Impact.

quantity, and as a resource for fish and wildlife within the region. Typically mine sites are large, irregularly shaped tracts containing between 3,000 and 10,000 hectares with varying percentages of wetlands. A mine site may include portions of several major river basins.

Table I illustrates specific examples of proposed phosphate mining operations in Central Florida and shows the amount of wetlands on the tract and the amount of wetlands that would be disturbed by mining. The three mines show the range in size of the different DRI applications that the Division has received. The table also shows that substantial portions of the wetlands are proposed for mining.

Because of the Division's obligation to ensure recovery of mineral resources while protecting the regional wetlands, it was necessary to develop a framework for making wetland and flood plain disturbance decisions. When faced with a proposed mine such as the Phillips/AMAX mine, it became apparent that all wetlands on the tract could not be treated equally. For example, Horse Creek and Brandy Branch are much more important to the regional wetlands system than are the other wetlands on the tract.

METHODS

Based on experience, it was determined that wetland areas and flood plains could be grouped into 3 major categories. The classification of an area is based on the relationship of the wetland or flood plain to the region. The general criteria used in making the decisions are (1) the relationship of the wetland or flood plain to the other wetlands and flood plains in the overall drainage system; (2) the nature of the wetland and its fish and wildlife value; and (3) the probability of successful restoration. The three categories are as follows:

Category I: Preservation

These are the most vital areas because of their importance to the regional drainage system, their value as habitat and the low probability of successful

TABLE I

Areas of Impact on Representative Mining Tracts

(in Hectares)

Mining Company	Total Area	Area to be Mined or Disturbed	Total Area of Marsh	Area of Marsh To be Disturbed	Total Area of Swamp	Area of Swamp To be Disturbed
1	5,420	3,959	973	831	356	285
2	5,547	3,905	833	656	516	461
3	1,976	553	257	39	178	19

replacement. They are typically:

1) strategically located in the regional drainage system, such as headwaters;
2) important in maintaining water quality and the hydrologic regime of the area;
3) large enough in size to be significant as wildlife habitat;
4) relatively rare within the region;
5) important as a seed source for other areas to be reclaimed;
6) difficult, if not impossible, to recreate;
7) slow to develop into a mature condition.

It is not necessary for a wetland or flood plain to have all of these characteristics to be placed in this category.

The greatest restoration problem is probably hardwood swamp creation. In fact, it is estimated to take 2 to 3 times the lifetime of the average mine to create a mature hardwood swamp system. For this reason, a regionally significant hardwood swamp would fall within Category I and would be preserved. A 20 hectare isolated cypress pond would also fall within this category if it was an uncommon habitat type in the area.

Category II: Restoration

While functions of areas in this category may be as important as in a Category I area, the Category II areas can be mined and restored after mining without significant adverse impacts to the regional system. This category can be divided into 2 sub-groups: (1) natural areas which provide the full range of functions and (2) altered areas which have lost some of their former functions. If, for example, an area of flood plain has been graded, drained, and planted in pasture grass, then the minimum reclamation requirement would be for the restoration of the flood plain to these functions. A restored flood plain would have the same water treatment and retention characteristics after mining that it had prior to being mined. The miner would, however, be allowed to recreate an improved natural system if so desired. Category II - natural areas are:

1) an important part of the regional drainage system;
2) sometimes critically associated with Class I areas;
3) important in maintaining water quality;
4) critical to maintaining the hydrologic regime of the region;
5) important as fish and wildlife habitat;
6) typically a type that can be easily restored.

Marshes which extend back from a creek channel are in this category and must be completely restored.

Category II - altered areas are:

1) important as part of the regional drainage system;
2) important in maintaining the hydrologic regime;
3) not particularly important as habitat;
4) artificially altered.

A channelized portion of a creek which has little or no vegetation would be in this category. It could be improved by returning the creek to a meandering, vegetated water course.

Category III: Replacement

These are of less value to the region because they are not contiguous to the regional drainage system. They do have important functions in water quality and quantity control, as well as providing habitat. These functions, however, can be replaced by providing equal areas of these habitats in each basin after mining. Category III areas are:

1) isolated from the regional system;
2) important as detention areas;
3) good habitat for fish and wildlife;

4) common within the region;

5) easily replaced.

A small swamp strand adjacent to a small marsh, isolated from the drainage system, would fall in this category. Mining of this area would be acceptable with replacement at some location in the basin.

DISCUSSION

This three tiered system is used in making the final determination of the fate of a wetland or flood plain in mining areas. If it is possible for a miner to show that a particular situation merits special consideration, then the Division will allow variances from this system. For example, Phillips/AMAX needed to have temporary dragline crossings of Horse Creek and Buzzards Roost Tributary, areas that fell within the preservation category. When Phillips/AMAX proposed to confine the crossings to a reasonably small area, and take extensive precautions to protect the water courses, and assured restoration, then the Division selected sites that would have minimal impacts and approved the proposal after no practical alternative could be found. Similarly, if there was a 20 hectare "mother lode" phosphate deposit on one side of a 200 hectare cypress pond, disturbance could be allowed if the area would be restored to a functional wetland and the remainder of the cypress pond was protected and preserved during the mining process.

Further, the restoration of previously altered systems to a natural wetland system with agreement for preservation can be used to mitigate the regional impact of destroying wetlands within the boundary of a proposed slime pond or mining area that would otherwise be lost.

In summary, every mining request is unique and must be handled appropriately. The Division has developed criteria for making decisions on proposals to mine wetlands and flood plains for phosphate. These criteria, as they are refined, are being applied consistently to phosphate mine DRI's. The system has worked successfully in reviewing several mine proposals. When fully developed, the criteria should serve to help develop mine plans which will meet state and regional requirements. Hopefully, data from restoration efforts and other research will help to refine this system.

LITERATURE CITED

U.S. Environmental Protection Agency, 1979. Central Florida Phosphate Industry, Final Area-wide Environmental Impact Study. Region IV, Atlanta, Georgia.

LITERATURE REVIEWED

Wharton, C.H., 1970. The Southern River Swamp, A Multiple Use Environment, School of Business Administration, Georgia State University.

Wharton, C.H., et al, 1977. Forested Wetlands of Florida - Their Management and Use, Center for Wetlands, University of Florida, Gainesville, Florida.

WETLANDS RECLAMATION TECHNOLOGY DEVELOPMENT
AND
DEMONSTRATION FOR FLORIDA PHOSPHATE MINING

By

Terry Gilbert

Tim King

Brian Barnett

Florida Game and Fresh Water Fish Commission
Office of Environmental Services
P. O. Box 1840
Vero Beach, Florida 32960

and

J. N. Allen, Jr.

Robert S. Hearon

International Minerals and Chemical Corporation
P. O. Box 867
Bartow, Florida 33830

ABSTRACT

The Florida Game and Fresh Water Fish Commission and International Minerals and Chemicals Corporation in cooperation with the U. S. Fish and Wildlife Service have initiated a three year study to determine techniques for establishing wooded and herbaceous freshwater wetland habitat on phosphate mined land in Central Florida. Primary funding for the project is from the U. S. Fish and Wildlife Service. IMCC donated a previously mined 22.3 hectare (55 acre) tract as a project site and provides all engineering and physical reclamation services. FGFWFC is providing overall coordination and supervision for the project and accomplishes daily activities at the test site. Study site selection, design and final contouring, plant selection and the planting effort itself was directed toward evaluating the growth and survival of wetland and transitional plant species in response to geophysical and hydrological conditions found after phosphate mining. Our study results may be utilized to design future wetland reclamation demonstration projects with interested phosphate mining companies in the Central Florida area.

INTRODUCTION

Central Florida phosphate mining is primarily concentrated in Polk and Hillsborough Counties, while many new mines are proposed in Manatee, Hardee, and DeSoto Counties. During the past ninety years, phosphate mining in Florida has disturbed hundreds of square kilometers of land, and in the next forty years is expected to affect an additional 2,590 square kilometers (640,000 acres).

Strip mining is the most feasible means of recovering the phosphate resource and these intensive operations have had a significant impact on the ecology of Central Florida.

Until 1975, some mined-out areas were abandoned and allowed to revegetate naturally without concern for future use. However, continuing loss of usable or productive land prompted the industry and various governmental agencies to establish mandatory reclamation guidelines.

Due to economic considerations, past reclamation programs resulted in extensive lake systems and well drained land conducive to agriculture. Currently, most reclaimed uplands are planted to improved pasture where mowing and grazing preclude normal vegetative succession to more complex habitat.

Reclamation is an essential consideration in minimizing long-term mining impacts on fish and wildlife populations, but definitive procedures for restoring habitat values and beneficial ecological functions of mined lands are virtually non-existent. Although most mining companies have conducted planting programs to beautify or enhance the recreational potential of some sites, there has been no large scale research effort directed toward creation of wildlife habitat on phosphate mined land in Florida.

In order to address this problem, the FGFWFC in cooperation with IMCC planted approximately 4,750 hydrophytic, mesophytic, and xerophytic tree seedlings and freshwater marsh plants on reclaimed mined land study plots in Polk County during the winter of 1977-78. These plots contained over 25 plant species which were monitored to determine their suitability for future use in an in-depth mine reclamation study. Data is presently being collected on the first year's growth and survival and results will be published this summer (1979).

Last September, the FGFWFC also sponsored a one year study by the Florida State Museum on plant succession and wildlife utilization of reclaimed and unreclaimed mined land in Central Florida.

Because of their recognized value to society and prevalence in new mining areas, it seems apparent that future phosphate reclamation programs must include plans for wetlands restoration. Some companies are now conducting pilot programs aimed at developing basic strategies for cost-effective wetlands restoration.

In September 1978, the Office of Environmental Services of the Florida Game and Fresh Water Fish Commission entered into a cooperative agreement with the U. S. Fish and Wildlife Service to develop and demonstrate the technology for establishing equivalent wetland wildlife habitat on phosphate mined land. The objectives were to define, using existing literature sources, the natural wetland habitats of Central Florida with respect to fish and wildlife utilization and vegetative profiles as related to inundation regimes; define the successional stages and relative wildlife habitat value of each wetland type; and determine key vegetative species of each habitat which might be planted to accelerate plant succession. This information was used to design and construct a wetland test site and initiate a monitoring program to evaluate the growth and survival of selected target wetland plant species on mined land.

The overall goal of our study is to determine the feasibility of establishing functional, self-perpetuating wetland habitats and transitional areas on phosphate mined land. It is not an attempt to duplicate specific native wetland communities, such as hardwood swamps or bay forests, but rather an investigation to determine methods of establishing equivalent habitat for wetland wildlife. We are attempting to predictably influence and accelerate the natural invasion of wetland and wetland transition vegetation on a reclaimed mine site by introducing woody and herbaceous vegetation and by engineering design to create appropriate shoreline contours, subaqueous slopes, water depth and substrate quality. If the appropriate initial establishment procedures can be determined, as this system matures through natural plant succession it should serve as habitat for a wide variety of fish and wildlife species and provide some of the beneficial functions normally associated with natural wetland communities.

AREA DESCRIPTION

The wetland test site was constructed on a 22.3 hectare (55 acre) tract adjoining the Peace River south of Bartow, Florida, near the Clear Springs Beneficiation Plant on IMCC property. The site was mined between October 1967 and March 1968, and the spoil piles were leveled in mid 1978. The tract was selected on the basis of its:

1. Proximity to a source of native plant materials.
2. Gently sloping topography exhibiting broad upland and lowland zones.
3. Apparent broad range of surface soils and potential inundation patterns.

The Peace River floodplain and upland transition areas bound the site on the north, west, and south. The forest composition varies as the floodplain elevation increases from west to east. Low-lying hydric areas are dominated by bald cypress (*Taxodium distichum*), and pop ash (*Fraxinus caroliniana*) which grade into transition areas characterized by red maple (*Acer rubrum*), Florida elm (*Ulmus americana* var. *floridana*), cabbage palm (*Sabal palmetto*), water oak (*Quercus nigra*), sweetgum (*Liquidambar styraciflua*), and sugarberry (*Celtis laevigata*). Elevated xeric sites are dominated by live oak (*Q. virginiana*), laurel oak (*Q. hemisphaerica*), southern magnolia (*Magnolia grandiflora*) and mockernut hickory (*Carya tomentosa*)

The site is bounded on the east by a graded mine road and a 80.9 hectare (200 acre) reclaimed pasture which serves as a drainage area. Rainfall is routed onto the test site via two sets of inflow pipes located beneath the road.

Additional earthmoving was performed by IMCC during November and December 1978 to complete test site construction. An earthen berm/access road was constructed along the western and southern test area perimeter to increase the surface water holding capacity of the site's lowland area. The berm height was set at 28.3 meters (93.0 feet) MSL. Outfall pipes were also installed in the berm at the south end. Four pipes were set at 27.1 meters (88.9 feet) MSL to fix the normal high water line for the test area and ten additional pipes were set at 27.4 meters (90.0 feet) MSL. The structure is designed to handle the anticipated runoff volume from a maximum 10-year, 24-hour rainfall event.

The test site's lowland area contains distinct northern and southern basins. A shallow meandering channel was excavated to connect these areas during normal water levels. A one-half acre pond about 2.4 meters (8 feet) deep which spreads to approximately 2.4 hectares (6 acres) at normal high water was created in the northern basin to provide permanent open water habitat for aquatic life. Excavated spoil was graded over the basin to provide gently sloping contours up to the pond shoreline. The contours of the shallow southern basin were preserved to test wetland plant establishment over a broad area. Meandering channels were also excavated to route water from the inflow pipes to the lowland area.

METHODS AND MATERIALS

IMCC provided a topographic map of the completed site with contour lines at two foot and one foot intervals above and below the 27.4 meter (90.0 foot) elevation, respectively. An abbreviated version of the topographic map showing existing and planned on-site monitoring locations is provided in Figure 1.

The entire test area was apportioned into a permanent grid of 176 - 30.5 meter (100 foot) square plots. Except for a narrow band of Chobee sandy clay loam along the southwest edge of the test area, all on-site soils are derived from mined overburden. Five overburden variants were mapped by the SCS during a February 1979 field survey. This range of overburden types should make our study results more widely applicable. Composite samples were collected from the upper foot of soil in each plot and analyzed for nutrients, pH, organic matter, sand-silt-clay fractions and cation exchange capacities.

Monitoring equipment installed by IMCC included six rainfall gauges, four water quality monitoring stations, and three staff gauges for visually monitoring water levels in the north and south basins and the connecting stream. Groundwater monitoring devices consist of nine regularly spaced piezometers (shallow wells), which were drilled to a depth of 9.1 meters (30 feet) and cased with 0.1 meters (4.0 inch) PVC pipe.

IMCC is constructing a fixed crest weir at two sets of inflow pipes. Continuous water level recorders will be installed to measure the volume of incoming runoff by documenting changes in water level behind the spillways. Water level recorders will also be installed in the pond and marsh test areas.

After construction, the test area was disced and upland portions above the 27.4 meter (90.0 foot) contour fertilized and seeded with a mixture of

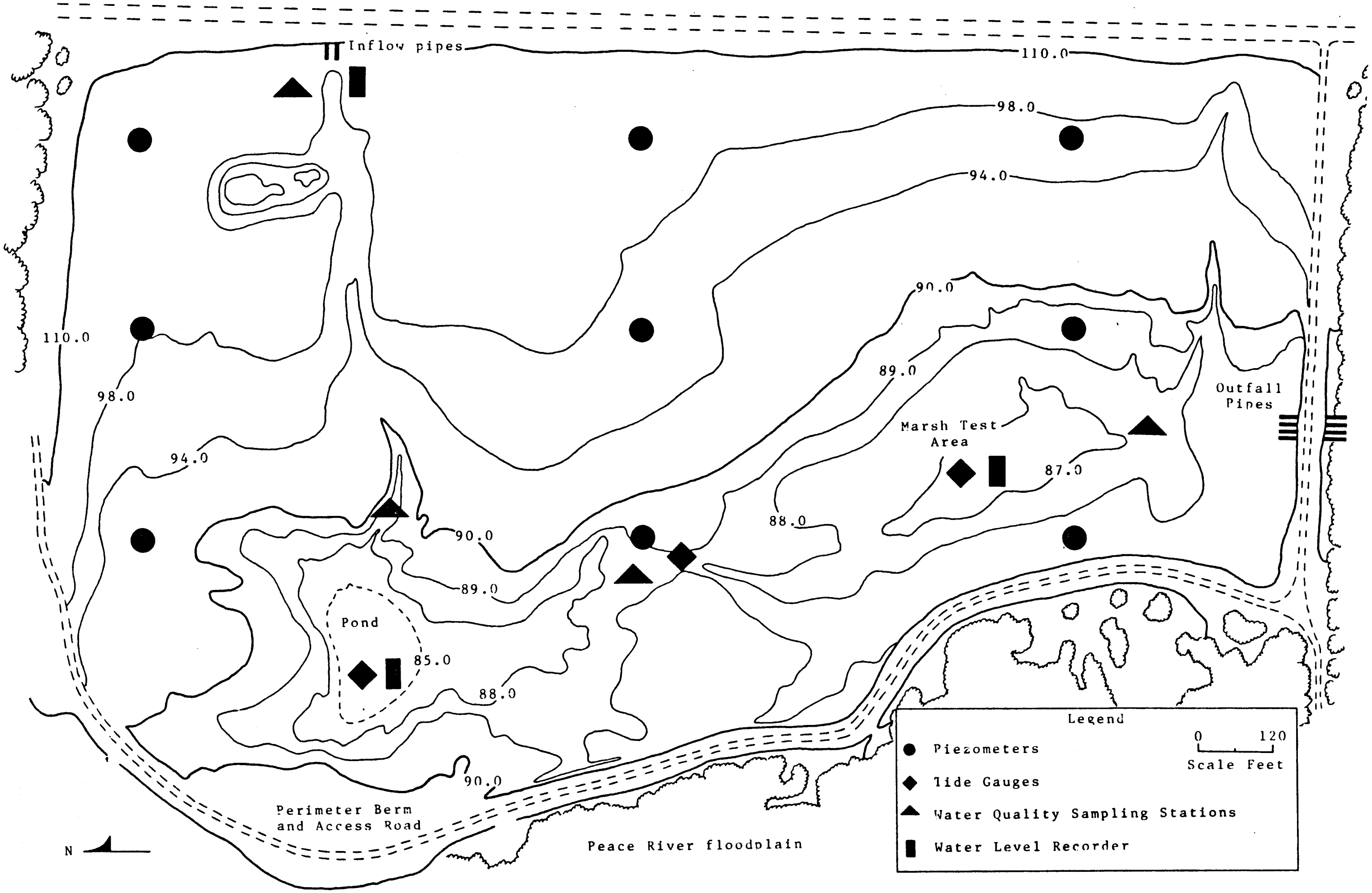


Figure 1. Wetland Test Site showing abbreviated topographic features and monitoring locations

Bermuda grass, ryegrass, and subterranean clover. This seed mixture was used to provide slope stabilization and ground cover while minimizing potential competition with our upland plantings. The lower portions of the site were not fertilized or seeded.

Study plot design and planting arrangements were chosen to allow us to relate plant survival and growth to the physical environment in which each species was established. The test plots selected for planting represent the range of site conditions including soil differences and potential soil moisture regimes or inundation zones. The biology of individual plant species was considered in making plot assignments. Since background data on the site's surface and groundwater hydrology was nonexistent, potential soil moisture zones were estimated based on site topography and the known high water elevation dictated by the height of the berm outfall pipes.

We are evaluating the suitability of various woody and herbaceous wetland and transitional plant materials which were established by:

1. Transplanting local trees,
2. Planting bare-root nursery seedlings,
3. Transplanting freshwater marsh plants,
4. Direct seeding,
5. Documentation of natural plant succession.

A total of 106 wetland and transitional trees of 0.1 meters (4.0 inches) DBH or less were transplanted from the Peace River floodplain to appropriate on-site areas from December 11 to 22, 1978,using a truck-mounted hydraulic tree spade. The trees included bald cypress, pop ash, red maple, Florida elm, water oak, laurel oak, sweetgum, cabbage palm, and ironwood (*Carpinus caroliniana*). Each tree was ringed with soil and watered intermittently for two weeks.

Nursery-grown bare-root seedlings were utilized in our intensive tree planting effort because we required large numbers of each species, all of a single age class. These trees were purchased from the Florida Division of Forestry's (FDF) Chiefland Nursery for $11.00 to $60.00 per 1,000. They were hand-planted during January and February, 1979. The Project Forester from the Lakeland District of the FDF furnished information on our seedling stock and provided on-site tree planting instructions.

A total of 10,400 seedlings representing 16 species were planted in 26 multi-species plots. Each plot contains four to five species which were planted at five-foot centers according to a pre-determined planting guide which randomly assigned each species to its grid locations and indicated which were to receive a slow release fertilizer tablet. This planting arrangement was selected to test the effects of the fertilizer tablets and to randomize the response to plot soil moisture variation. The wetland and transitional species were planted in as many plots as possible to evaluate their success over the full range of site conditions.

In addition, approximately 2,100 seedlings were randomly planted at appropriate elevations throughout the site. These planting locations were also recorded.

Table 1 lists the species and total numbers of seedlings planted on the test site. Each species selected for planting is native to Florida; however,

Table 1. Tree Seedlings Planted on Peace River Wetland Test Site During January and February, 1979.

Species	Total Number Planted
North Florida Slash Pine (*Pinus elliottii* var. *elliottii*)	600
South Florida Slash Pine (*Pinus elliottii* var. *densa*)	602
Sand Pine (*Pinus clausa*)	450
Loblolly Pine (*Pinus taeda*)	500
Longleaf Pine (*Pinus palustris*)	650
Spruce Pine (*Pinus glabra*)	650
Red Cedar (*Juniperus silicicola*)	620
Bald Cypress (*Taxodium distichum*)	1295
Catalpa (*Catalpa bignonioides*)	675
Cottonwood (*Populus deltoides*)	700
Sycamore (*Platanus occidentalis*)	525
Sweetgum (*Liquidambar styraciflua*)	525
Tupelo gum (*Nyssa aquatica*)	950
Red Maple (*Acer rubrum*)	1500
Green ash (*Fraxinus pennsylvanica*)	1150
Live oak (*Quercus virginiana*)	480

approximately half do not occur naturally in Polk County. We recognize that the soil types we are trying to revegetate are not "native" to the Central Florida area, and some of these species may prove useful for fast stabilization and early alteration of mined sites.

Herbaceous freshwater marsh plants were transplanted to the site from nearby wetland habitats (Figures 2 and 3). A total of 12 6.1 meter (12 foot) square marsh test plots were planted in May 1979. Three pick-up truck loads of marsh plant material were removed from roadside ditches in Osceola and Polk County, Florida. The following species and numbers of clumps (1-4 individual plants) were transplanted onto the test site: arrowhead (Sagittaria lancifolia) 52, pickerelweeed (Pontederia lanceolata) 57, maidencane (Panicum hemitomon) 42, and soft rush (Juncus effusus) 23. Approximately 5,000 maidencane rhizomes obtained from the SCS were planted in January 1979, in selected areas of the marsh test area and the northern inflow channel to stabilize the streambed.

A monitoring program was developed for the test site to characterize: (1) the survival and growth of the various plantings, (2) the natural plant successional trends on the area, (3) the surface and subsurface hydrology, (4) the development of the area's aquatic community, (5) the effect of the emerging aquatic and wetland communities on surface water quality, and (6) the associated trends in wildlife utilization. This program was fully operational in early June 1979, and will continue through the life of the project.

Figure 2. Wetland test site showing south perimeter berm outfall pipes and Peace River floodplain during marsh planting.

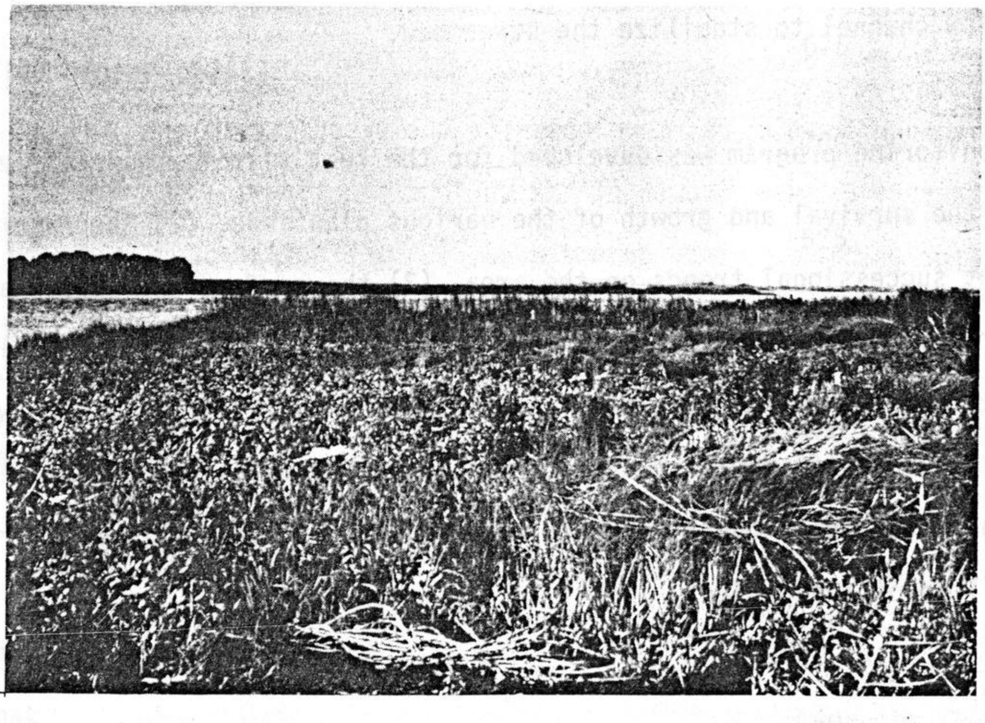


Figure 3. Planting marsh test plots on the wetland test site.

DISCUSSION

During the last year of the study, a survey of the phosphate industry will be made to determine those companies willing to participate in a future wetland demonstration project as part of their reclamation program. Overall study results and recommendations will be incorporated in a phosphate reclamation handbook.

PROBLEMS ASSOCIATED WITH THE SUCCESSFUL RE-CREATION OF WETLANDS IN MINED AREAS OF DESOTO AND MANATEE COUNTIES, FLORIDA

Gary Uebelhoer

AMAX Environmental Services, Inc.
402 South Kentucky Avenue
Suite 600
Lakeland, Florida 33801

ABSTRACT

The AMAX Chemical Corporation and the Phillips Petroleum Company have entered into an agreement with the Florida Division of State Planning and Sarasota County which protects some 1,100 acres of forested wetlands from encroachment by surface phosphate mining and requires the companies to restore an additional 2,300 acres to wetland conditions following mining. Given this reclamation requirement, this paper describes the ongoing studies being performed by AMAX to develop wetlands reclamation techniques to fulfill these commitments.

AMAX studies currently underway or being planned for the near future include: a) transect analysis of wetland areas, b) groundwater hydrologic investigations, c) laboratory and field revegetation experiments, d) small scale test reclamation plots, and e) cooperation with other wetland restoration efforts by members of Florida's phosphate industry.

INTRODUCTION

The AMAX Chemical Corporation and the Phillips Petroleum Company have agreed with the Florida Division of State Planning to reclaim approximately 2,300 acres to wetland conditions after phosphate surface mining is completed. Figure 1 illustrates the regional location of the site. Because AMAX/Phillips have no active phosphate operations in Florida at this time, the reclamation research effort is currently focused upon a systematic investigation of the wetlands existing on the property. Transect analyses of vegetative, topographic, and soil conditions in areas to be restored as wetlands were prepared to document existing conditions and investigate the interdependence of vegetative support factors. A network of streamflow gauging stations and pairs of shallow and deep piezometers have been installed to provide information about water-table levels beneath the site. Geomorphological investigations have provided preliminary information about the characteristics of cast mine spoils which may be redistributed as topsoil and/or substrate following mining. Finally, litter/propagule studies have begun to assess the viability of field litter as a seed source for native re-vegetation.

The purpose for these studies is to learn more about the inter-relationships between functioning wetland systems and the supporting soils, topographic, and hydrologic conditions by examining existing wetlands on the property. Using information about the existing wetlands, test reclamation/revegetation experiments will be developed to

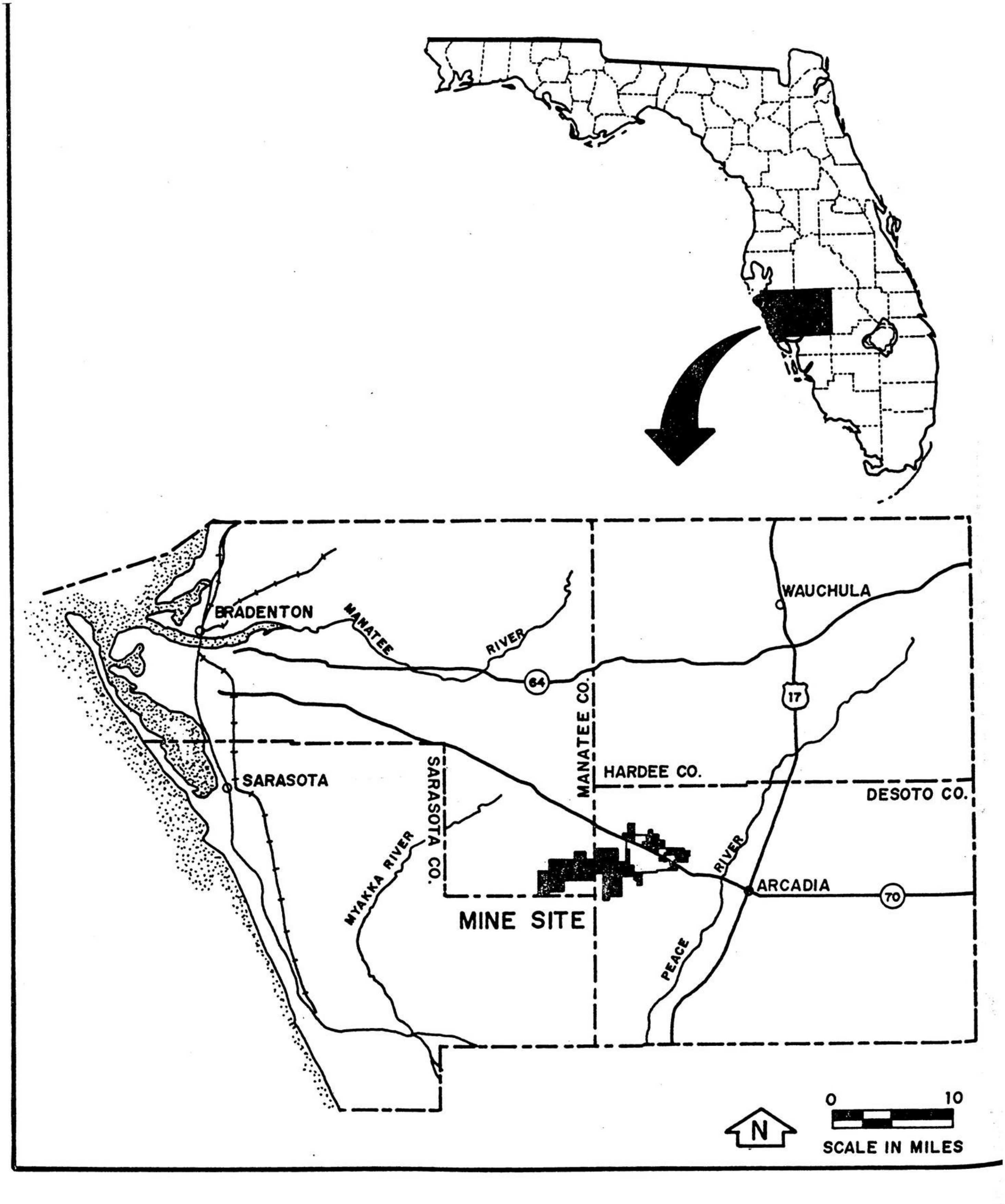


Figure 1

REGIONAL LOCATION OF PROPOSED MINE SITE

investigate techniques to re-establish the supporting factors critical for wetlands survival.

Please note that the efforts described in this paper represent the first phase of an extended development program designed for completion in 1984. Accordingly, few conclusions can be drawn at the present time.

SITE DESCRIPTIONS

Figure 2 is a site-specific property map which identifies the boundaries of the property, wetlands designated for preservation from encroachment, lands to be reclaimed to wetland conditions, and locations of detailed transect study areas. Most of the acreage to be reclaimed to wetland conditions lies in the Big Slough drainage system in Manatee County. Agricultural practices and public works projects have created an artificial drainage canal system which has brought about a transition in ecological succession from wetland conditions to a stressed state including upland species.

In Manatee County, the property ranges from 39 to 61 feet above mean sea level with little elevation gradient across the land. Although some areas have been maintained as permanent improved pasture, much of the land is covered by pine/oak/palm flatwoods with isolated marshes and depressions. At the lower elevations in unimproved areas, selected areas include mesic hammocks and floodplains. Cattle grazing throughout all areas of the property has reduced the vegetative cover and density in the unimproved

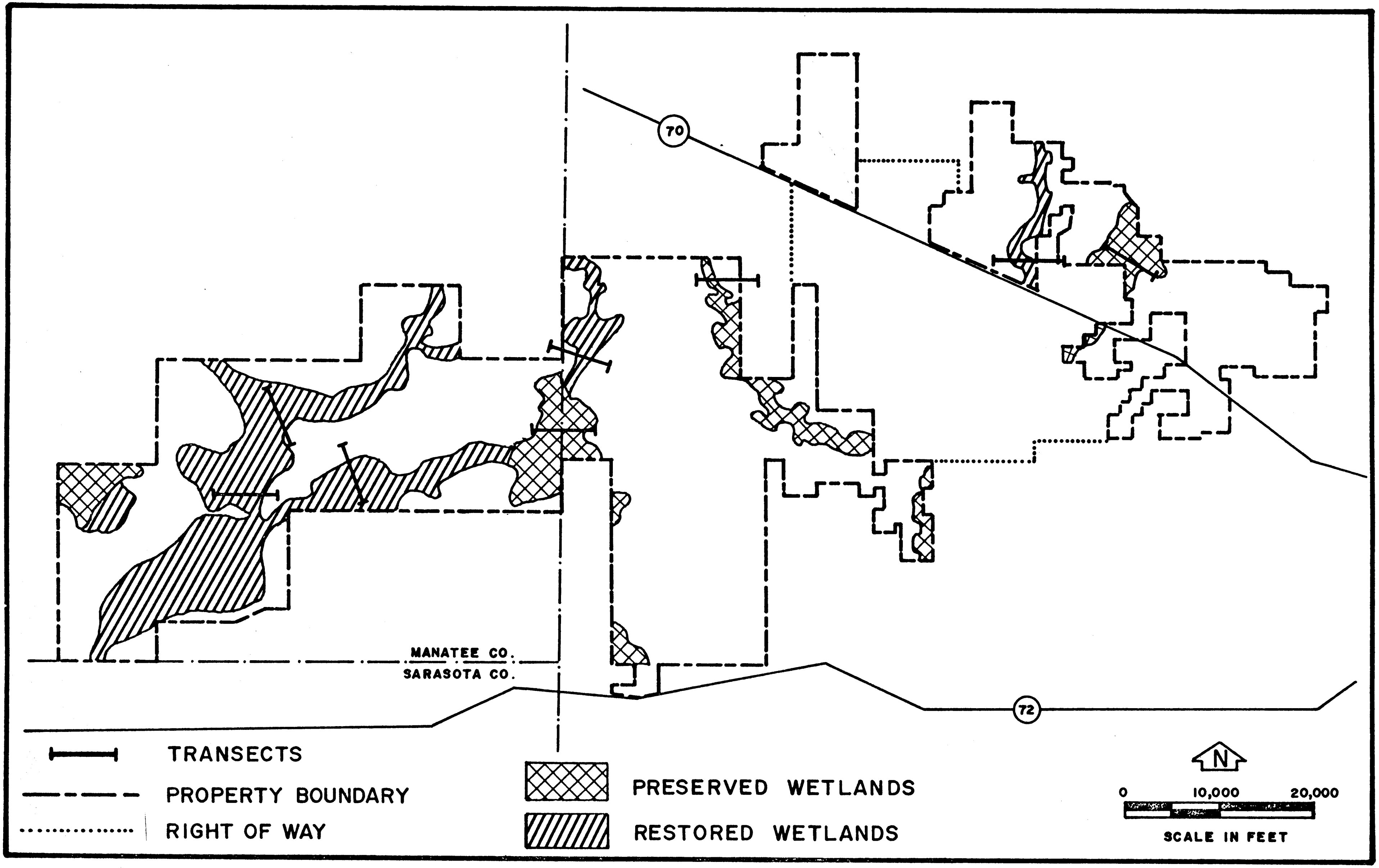


Figure 2
WETLAND BOUNDARIES AND TRANSECT LOCATIONS

native areas. Periodic, selective burning also has affected the vegetation existent on the property.

METHODS

As noted previously, this program combines a series of studies designed to analyze the interdependence of factors supporting wetland vegetation. Each of those efforts is described below.

A. Vegetation Transect Program

The first step taken was to carefully examine the vegetation, soils, and topography along the eight transect lines shown in Figure 2. Of the eight transects, five are located in areas to be reclaimed as wetlands following mining,and three are in areas to be preserved from encroachment. A total of 17,000 linear feet has been transected.

Registered survey crews provided mean sea level elevations to 0.01 feet from stadia readings taken every 25 feet along the transect lines and staked the lines for guidance of the vegetation and soils teams. Upon completing surveying, vegetation adjacent to the transect line was mapped continuously in a 25 foot wide belt.

Each belt transect was divided into 25 foot lengths, using the surveyor stakes established along the transect lines as markers. As a result, each transect represents a series of contiguous square quadrats, each 25 feet on a side. Within each quadrat, a sub-quadrat was nested, 10 by 25 feet in size. The 25 foot side of the sub-quadrat away from the survey line was used for sampling by line interception. Vegetation was divided into tree, sapling, seedling and non-arboreal classifications for the quantitative inventory.

Field data was tallied to include density, basal area, frequency, height, and cover information. From the tabulated data, community characterization and cutaway diagrams were prepared.

Following the vegetation analyses, soils along the transect belts were mapped by U.S. Soil Conservation Service and AMAX personnel using standard field sampling techniques. The soil horizons were measured to a total depth of six feet at the center of each quadrat, using a soil bucket auger. Soil horizons were classified according to texture and color. Soil conditions and characteristics were visually described and documented. Cross sections illustrating topography with corresponding soil types and vegetative cover were then generated.

B. Surface and Groundwater Studies

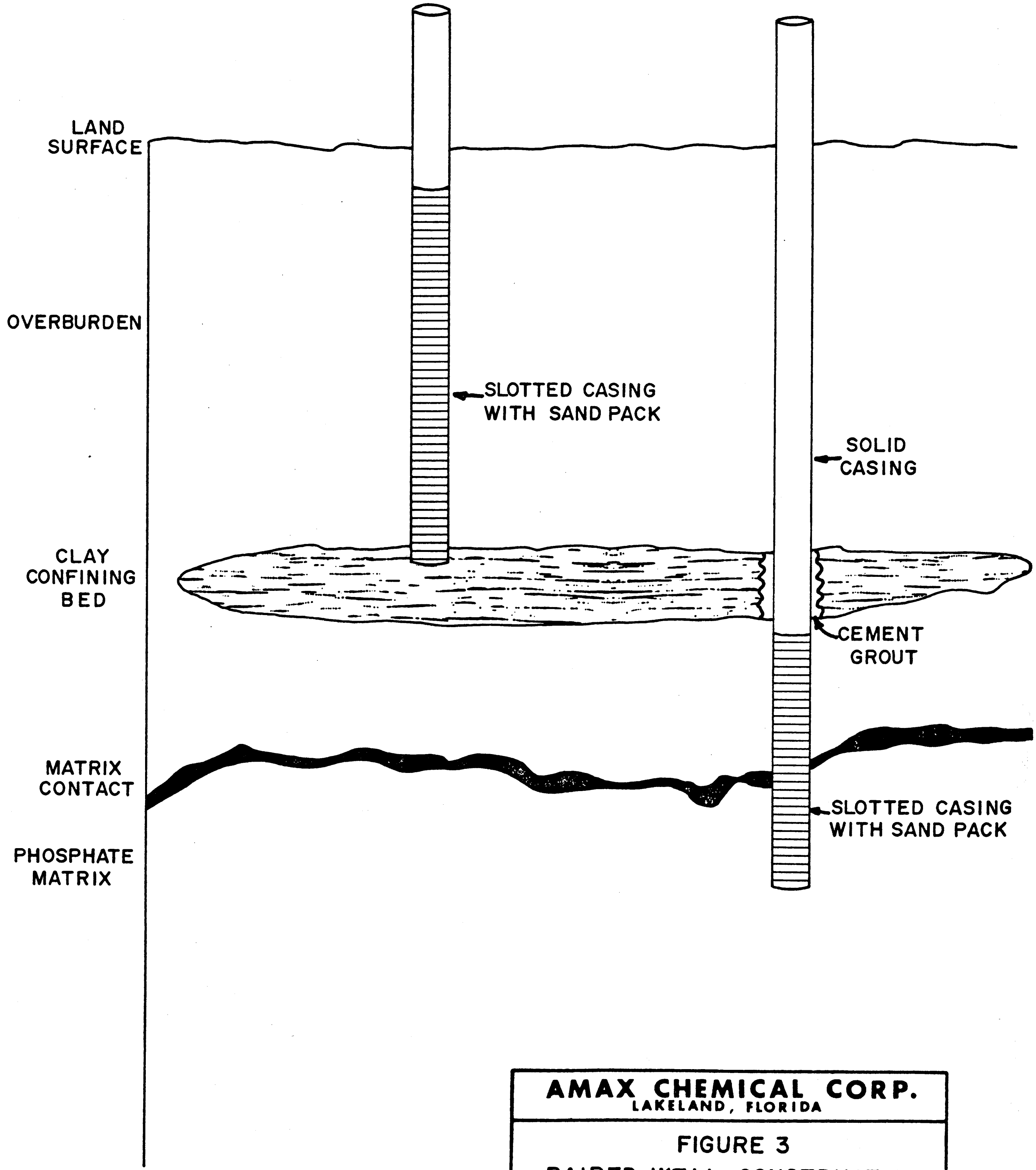
Ongoing water resources observations are taken from continuous rainfall gauges, pan evaporation stations, streamflow gauging stations, and observation wells drilled into the water table, the secondary surficial aquifer, and the Floridan Aquifer.

Nine streamflow gauging stations have been installed on the Big Slough drainage system and its tributaries. Four of the nine stations are equipped with continuous water level recorders. The other five stations are staff gauges, which are read on a weekly basis. Flow data is being collected to develop a property-wide water budget and to provide data to measure the dewatering effects of man-made watercourses on adjacent lands. Bank storage information will be used in designing new stream beds following mining.

Water table and secondary surficial aquifer water levels are measured weekly in sixty-six piezometers located across the property. Twenty-two of the piezometers monitor water levels in the overburden immediately above initial clay confining lenses lying between land surface and the phosphate matrix contact. The remainder of these piezometers monitor water levels in the secondary surficial aquifer zone, including the phosphate matrix and the overburden located below the uppermost clay lenses.

Exploratory geological drilling revealed that the initial clay confining lenses are discontiguous across the property. Because these upper confining lenses occur in certain wetland areas, pairs of shallow and deep piezometers were installed along the vegetation transect lines where the clay layers exist. Parallel water level measurements should indicate whether the water table in these areas is perched by these clay layers above the water level of secondary surficial aquifer.

Construction of the paired piezometers consisted of installing slotted PVC pipe below the upper confining clay lens in the deep wells, penetrating the phosphate matrix. Solid PVC was installed from below this clay bed upward to land surface, using cement grouting to maintain isolation of the two systems. The shallow wells do not penetrate the clay layer and are constructed using slotted PVC pipe from land



AMAX CHEMICAL CORP.
LAKELAND, FLORIDA

FIGURE 3
PAIRED WELL CONSTRUCTION
DIAGRAM

Scale NOT TO SCALE

Data by GU | Drft. MK | Drwng. No.

AMAX personnel mapped soils through these same areas. Lithologic analysis of overburden from nearby exploratory drill holes was performed to locate intermittent confining beds in the profile and to describe the horizons beneath the surface soil layers and sandy substance. Interpretation of this information was used to determine whether unique substrate conditions exist supporting varying vegetative covers.

Subsequent to these programs, additional drilling on selected areas of the property has continued on a sporadic basis for exploratory, geotechnical, and environmental reasons. Dependent upon the exact drilling sites, selected overburden samples are analyzed for grain size, soil texture and permeability. Additional parameters include cation exchange capacity and nutrient analyses on selected samples. Visual lithologic logs are kept for each drill hole which include descriptions of the surface soil and overburden as well as the phosphate ore.

During the course of an archaelogical survey of the property, 916 one-half meter deep test excavations were completed primarily to locate artifacts. Because this program thoroughly covered the property, soil profiles were prepared for each test excavation. While the level of detail and interpretation of the soil profiles did not parallel previous mapping efforts, sufficient information was gathered to confirm visual classifications of soils maps available from the Soil Conservation Service.

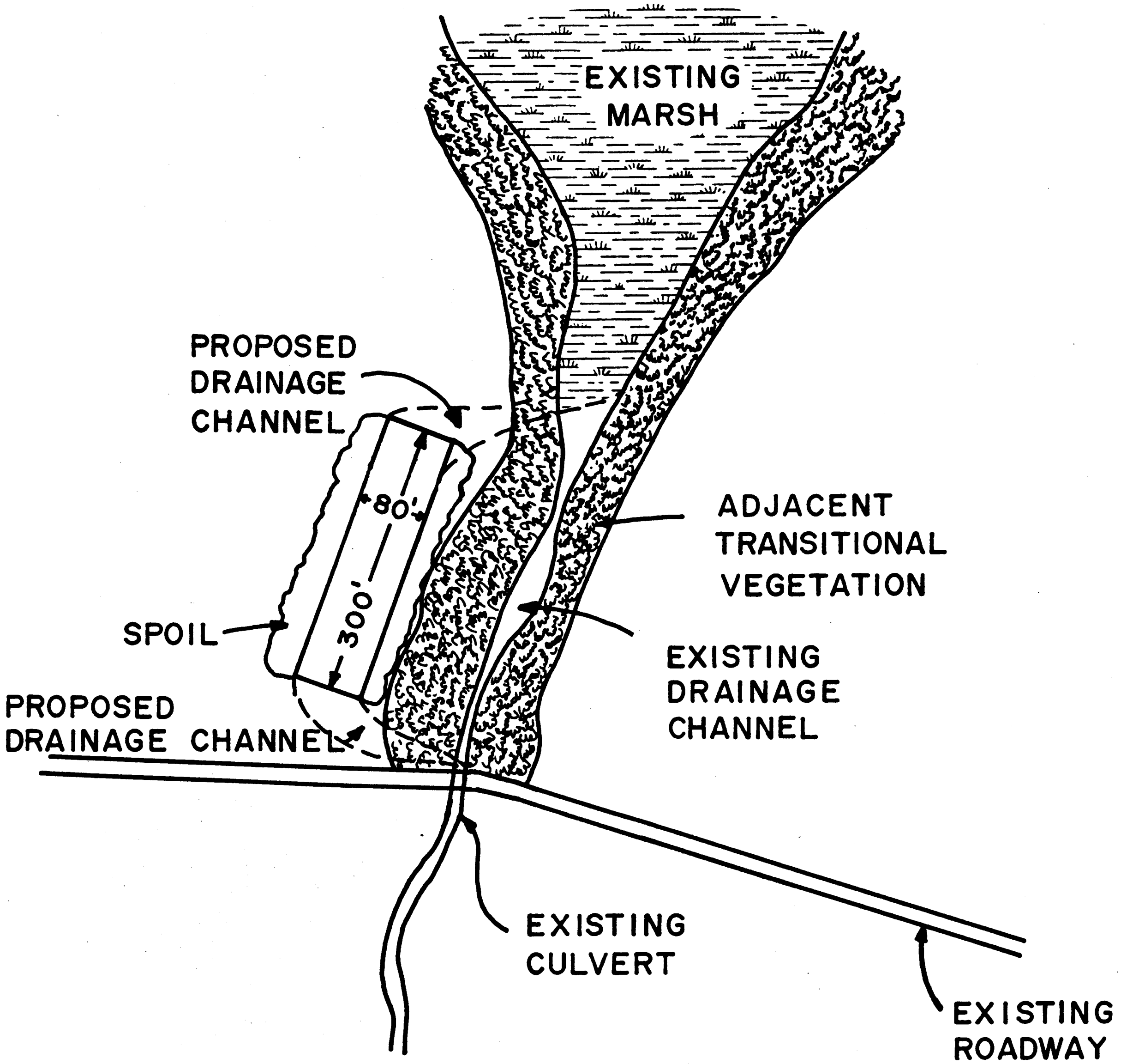
A small bulk sample of phosphate is being excavated from an 80 foot by 300 foot area for metallurgical testing by a small construction dragline. As the dragline uncovered overburden and matrix, topsoil and overburden from the site were visually described and sampled for grain size and permeability information.

D. Metallurgical Laboratory Activities

Metallurgical testing at the onsite research and development laboratory is producing small quantities of waste sands and clays similar to those that will be generated by the full-scale plant. Because these wastes will be used as a landfill substrate to fill mine cuts for reclamation, samples of the sand, clays, and re-combined sand-clay mixtures are being analyzed to determine physical, chemical, hydrologic, and agronomic properties. Analytical procedures include grain size distribution, permeability testing, and nutrient analyses. These analyses are being performed to determine the similarity of waste products to the characteristics of *in situ* overburden and matrix.

E. Re-vegetation Experiments

During the vegetation transect program, three field litter sites were selected in the general vicinity of the transects. One site consisted of a marsh, the second a hydric swamp near a stream channel, and the third, a mesic floodplain forest. At each site, the fresh litter was raked and the topsoil rototilled. The loose materials were transferred to standard greenhouse flats where they were kept moist for twelve weeks. Seedlings and sprouts were identified and counted on a weekly basis over the twelve week germination period.



AMAX CHEMICAL CORP.
LAKELAND, FLORIDA

FIGURE 4
BULK SAMPLE SITE MAP

Scale 1" = 200'

Data by GU | Drft. MK | Drwng. No.

Following successful germination in the greenhouse, the next level of investigation is to perform similar experiments under actual field conditions on barren soils to test the applicability of litter as a seed source. Pilot scale mechanical collection and deposition of the litter/propagules and varying application rates will be important if litter is to be used in full scale reclamation.

Field work will not begin before the litter deposition site has sufficiently weathered and been disturbed to create less than ideal germination conditions. Scheduling of the field effort is dependent upon seasonal factors which, if not considered, can artificially bias results.

Reclamation of the bulk sample site will serve as the first test plot. As shown in Figure 4, current plans are to re-grade the mined area to form a new stream bed at nearly the same elevations as the existing watercourse. Upon stabilization, flow will be diverted into the mined area. Various seed source strategies will be evaluated for use in further tests. Detailed plans for this plot will not be prepared until results from hydrologic monitoring in the area and additional germination tests are completed. The plans will be reviewed with other wetland reclamation project investigations to ensure that these efforts are not duplicating other previous or ongoing tests.

RESULTS

As mentioned in the earlier discussion, the investigations described above represent a long-term program designed to yield specific wetland reclamation techniques for use in the mid to late 1980's. As a result of this approach, the results discussed below represent knowledge gained to date.

A. Hydrology

Figures 5 and 6 contain hydrographs of water levels in two pairs of piezometers drilled as part of the groundwater observation program. Table 1 contains the tabular results and the total depths of these wells.

The four wells featured in Figures 5 and 6, (wells BS-1, BS-2, E28, and E29) are located along a line perpendicular to the flow of Big Slough in the southwestern corner of the property. Wells BS-1 and E28 are wells immediately adjacent to the watercourse and are approximately 65 feet from the center of the channel. Wells BS-2 and E29 are located approximately 200 feet from the channel. A clay lens exists from about five to seven feet below land surface with a lateral reach to approximately 300 feet from the Slough. As a result, wells E28 and E29 monitor the water levels in the surficial sands above this clay lens.

Comparison of the hydrographs in Figures 5 and 6 illustrates the dewatering effects of the Slough on the surficial sands and the lateral extent of the immediate dewatering "reach". Analysis of this data over longer periods of time provides insight into the bank storage and transmissivity characterisitics of the surficial sands and can be compared with similar hydrologic information about other parts of the property and waste poducts to assist the post-mining reclamation design.

TABLE ONE

DEPTH TO WATER MEASUREMENT

IN PAIRED PIEZOMETERS ADJACENT TO BIG SLOUGH

DATE	BS-1	E28	BS-2	E29
6/12/79	4.44'	5.50'	5.78'	5.50'
6/19/79	4.38'	4.02'	4.95'	4.83'
6/28/79	3.48'	5.50'	3.87'	3.69'
7/06/79	3.68'	5.50'	4.23'	4.45'
7/12/79	2.58'	3.54'	3.18'	3.19'
7/20/79	2.47'	3.44'	3.25'	3.38'
7/26/79	2.74'	3.57'	3.35'	3.32'

WELL DEPTHS:

BS-1: 31 Feet
BS-2: 28 Feet
E28: 5 1/2 Feet
E29: 5 1/2 Feet

FIGURE 5

HYDROGRAPHS OF WATER LEVELS IN PAIRED PIEZOMETERS ADJACENT TO BIG SLOUGH (DEPTH-TO-WATER)

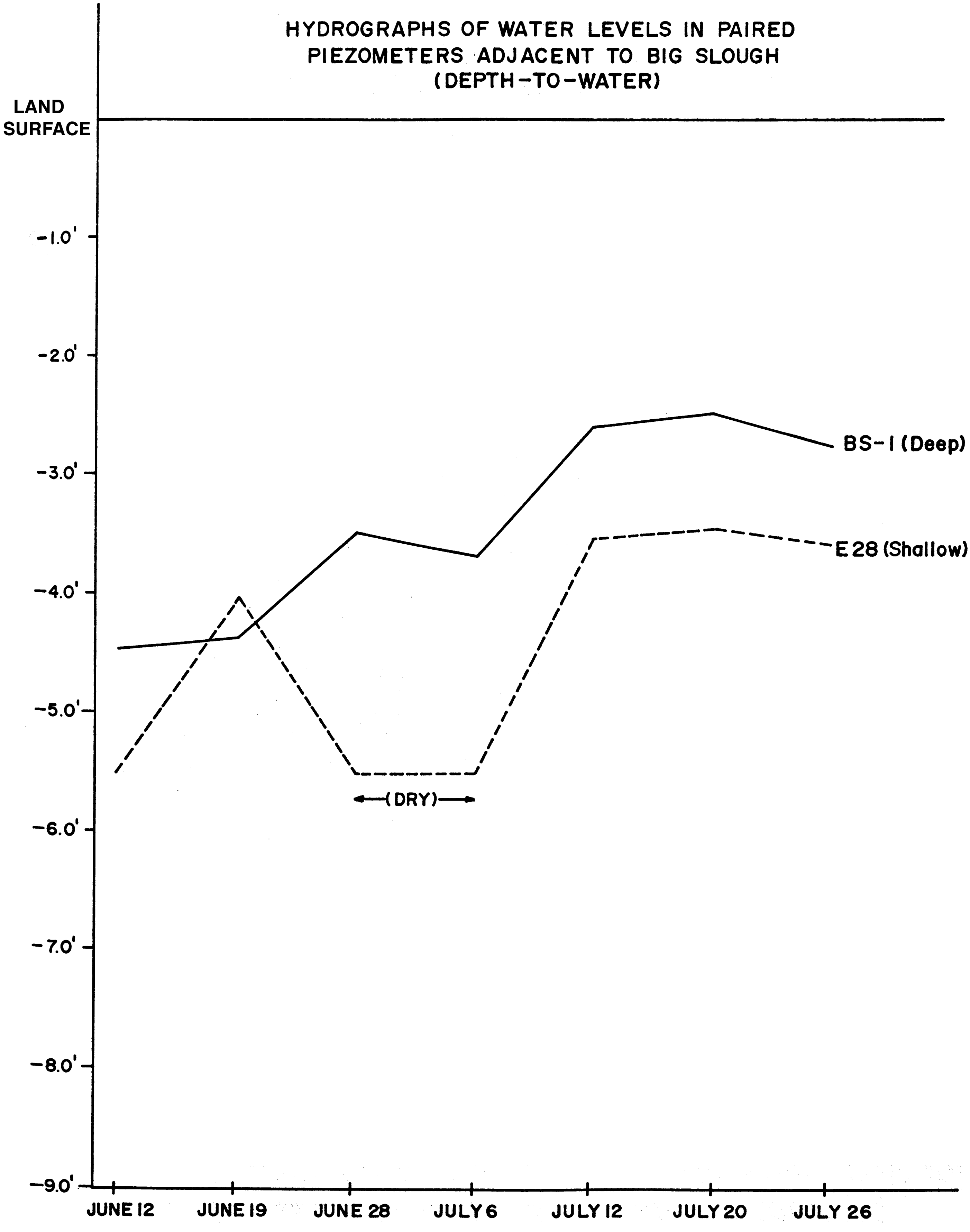


FIGURE 6

HYDROGRAPHS OF WATER LEVELS IN PAIRED PIEZOMETERS ADJACENT TO BIG SLOUGH (DEPTH-TO-WATER)

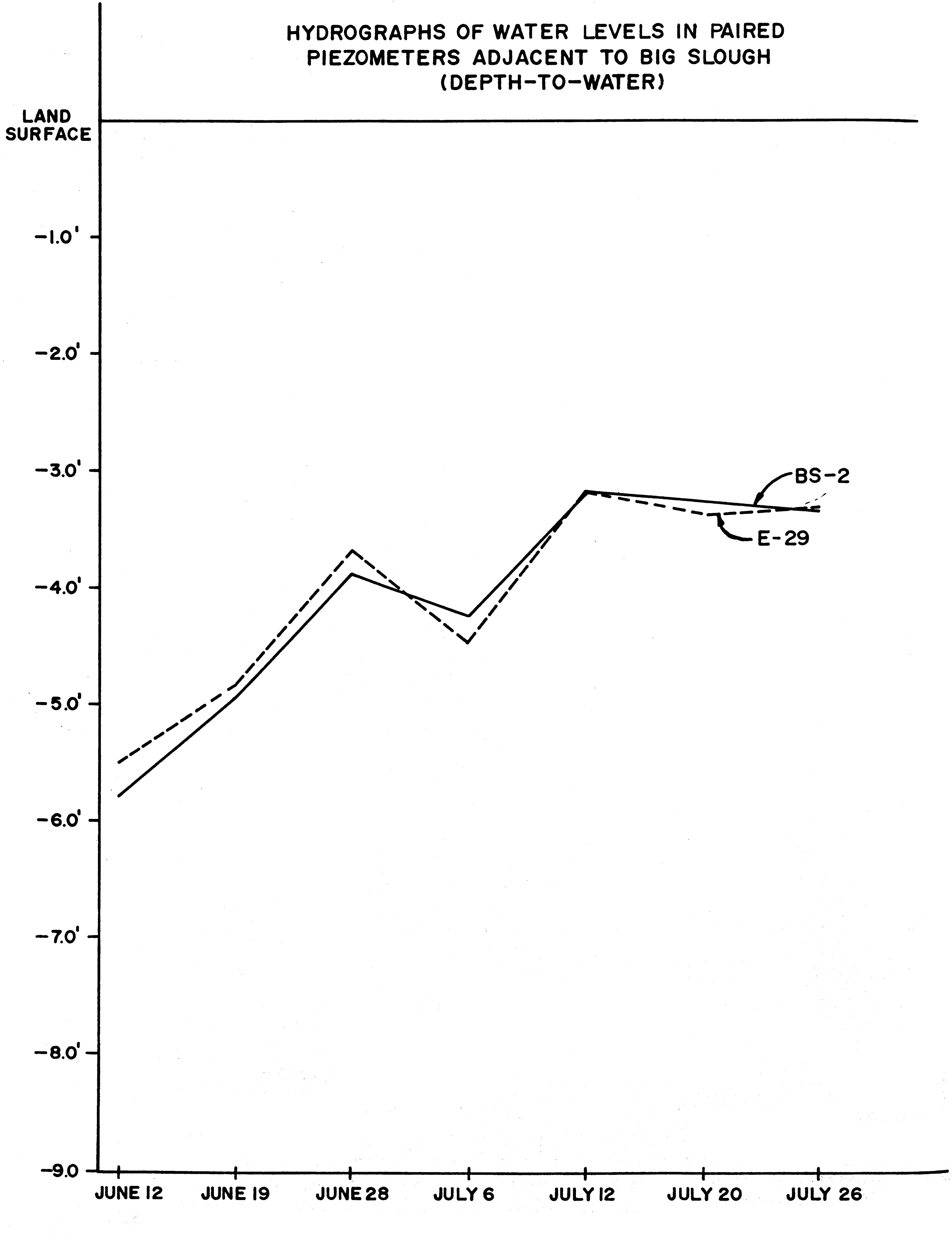


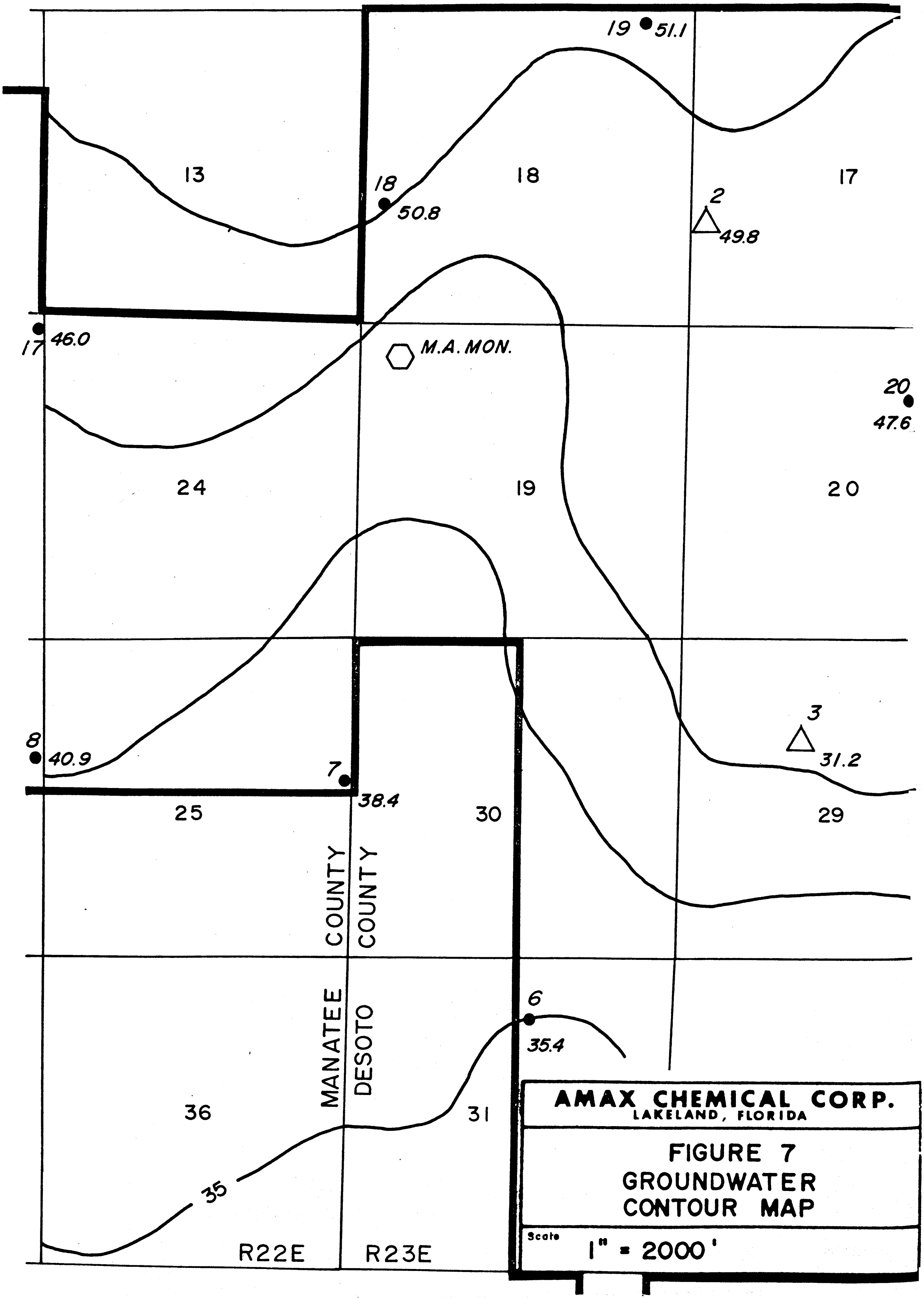
Figure 7 contains a computer-generated contour map of groundwater levels during the dry season from a section of the property near the bulk sample site. These contour maps can identify the drainage sinks across the property and visually describe the dewatering effects of the man-made canal system in Manatee County. When prepared in a depth-to-water format by subtracting groundwater contour levels relative to mean sea level from the topographic land surface contours, these maps illustrate hydroperiods in wetland areas of concern. Use of a computer contouring program allows for simpler manipulation of the data.

B. Geomorphology

Figure 8 illustrates the lithologic description or picture of the substrate beneath one of the study areas. This illustration shows the initial clay confining bed in the overburden and the discontiguous nature of this zone. In this location, a second clay zone was observed immediately above the matrix contact which appeared to be thicker and more contiguous. Beneath the mineable zone, a much thicker clay bed also was observed.

C. Vegetation

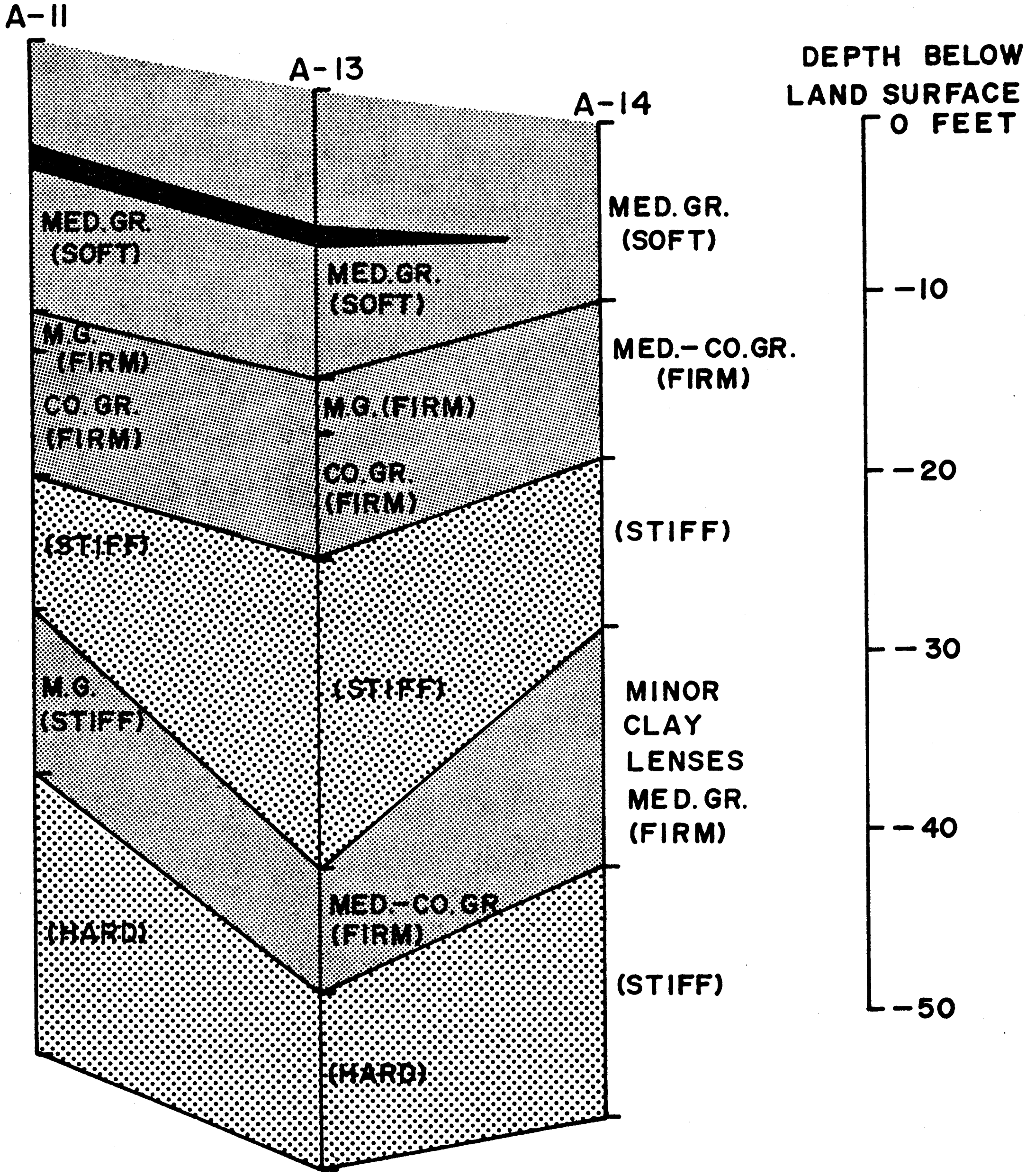
Data from the vegetation transect program was first transformed to cutaway diagrams which visually describe the subsurface geology, soils, topography, and vegetative factors including density, percent cover, and canopy height. Ongoing statistical analyses are being performed to identify the correlation between soils, topography and groundwater levels and the species presence and dominance. Data analysis steps are designed to be flexible with subsequent steps planned



AMAX CHEMICAL CORP.
LAKELAND, FLORIDA

FIGURE 7
GROUNDWATER
CONTOUR MAP

Scale 1" = 2000'



LEGEND

▒ SAND

■ HARDPAN

░ CLAY

AMAX CHEMICAL CORP.
LAKELAND, FLORIDA

FIGURE 8
SAMPLE STRATIGRAPHIC DESCRIPTION

Scale
1" = 10'

Data by DK	Drft. MK	Drwng. No.

only after completing preliminary statistical work.

Results from the greenhouse litter germination experiments are summarized in Table 2. Seventy-seven species were identified during the twelve week germination period. Included in this total are five tree species, three shrubs, three woody vines, and sixty-six herbs. Species data from the greenhouse plants is being compared to vegetation present at the litter collection sites to see if any discernable trends are present. Species viability data also is being analyzed to prepare density and dominance projections.

DISCUSSION

Preliminary data produced by these programs have been helpful in understanding how the property "functions" ecologically and in identifying factors which affect the reclamation planning efforts.

First, geomorphological investigations have found that an organic hardpan layer which exists above Polk County phosphate deposits does not occur on a widespread basis at the site in Manatee and DeSoto Counties. Areas of the property are underlain, however, by upper clay confining lenses in a discontiguous fashion. Piezometer measurement and other hydrologic investigations are now focusing upon confirming whether these upper confining lenses in the overburden elevate or perch the groundwater table. Data collected to date suggests that, on a property-wide basis, the groundwater levels are not significantly influenced by these clay layers.

Vegetation analyses and germination studies have

TABLE TWO

SUMMARY RESULTS

GREENHOUSE LITTER GERMINATION STUDY

Community Type	No. Plants per Sq. Meter	No. Species	No. Trees per Sq. Meter
Flatwoods	670	20	0.0
Hydric Hardwoods	765	33	9.0
Mesic Hardwood	374	42	74.4
Pasture (Improved)	1,429	24	0.0
Marsh	1,925	16	0.0

identified the level of inter-relationship between existing vegetation and topographic, soils, and water-level support factors. Using this information as the foundation, future efforts are being planned to evaluate the similarity of re-distributed overburden and waste materials to the *in situ* surficial sands. While laboratory and field germination tests do not represent test reclamation, these efforts do examine the viability of litter/propagules as a seed source given specific support conditions. Combining the knowledge gained from these tests with knowledge of the expected post-reclamation lithology should indicate whether post-mining conditions will be sufficient to support wetland systems.

Finally, future efforts will focus upon the rates of litter application on a mechanical scale to determine whether support seeding will be required. Data from this and other studies suggests that marsh re-vegetation can be accomplished using litter as the seed source. Similar information related to mesic and hydric hardwood species appear incomplete at present.

CONCLUSIONS

The above discussion of results essentially provides the conclusions which can be drawn from the project at this interim stage. Site-specific problems and opportunities have been identified and ongoing programs are being designed to reflect this knowledge. While the objective to develop balanced and efficient wetland reclamation techniques has not been met, none of the information gained so far suggests that wetland reclamation cannot be accomplished. Studies by other organizations have investigated methods for re-establishing marshes and hardwood wetlands on mined lands. Development of these techniques should enable AMAX and other mining companies to meet the objective of improved reclamation by including natural wetland areas as one of many final land uses following mining.

PRINCIPLES OF MARSH ESTABLISHMENT

L. Jean Hunt

Environmental Laboratory
Waterways Experiment Station
Vicksburg, MS 39180

ABSTRACT

Marshes have been successfully established on substrates of dredged material in a variety of locations and situations. Study of the development of these areas has led to recognition of principles of marsh establishment in general.

Of six field sites built during the U. S. Army Corps of Engineers Dredged Material Research Program, three were in salt water and three in fresh, three on substrates of sand and three on silt or clay, and three in a river and three in a coastal situation. All sites were tidally influenced. The sites were located in Oregon, California, Texas, Florida, Georgia, and Virginia.

The research has produced information and recommendations on appropriate elevations, plant invasion, need for site protection, need for fertilization, plant species and propagule selection, spacing, and time of planting. This information is recorded in a series of field site reports and summarized in this paper.

INTRODUCTION

A five year Corps of Engineers research program was conducted between 1973 and 1978 at the Waterways Experiment Station in Vicksburg, Mississippi: the Dredged Material Research Program (DMRP). Overall objectives of the research were to provide information on the environmental impact of dredging and dredged material disposal operations and to develop disposal alternatives, including consideration of dredged material as a manageable resource.

In that light, the feasibility of several types of habitat development were tested. Through the use of literature, laboratory, and field studies, it was demonstrated that desirable vegetation can be established on a substrate of dredged material.

The principles derived from this research are valid marsh vegetation establishment for reasons of erosion control, marsh restoration, land enhancement, or general ecological benefit.

AREA DESCRIPTION

The DMRP was nationwide in scope and relied on a variety of test conditions to provide data that can be extrapolated. Six habitat development field sites were established in 1975 and 1976:

Miller Sands, an island in the Columbia River, Oregon
Salt Pond No. 3 in South San Francisco Bay, California
Bolivar Peninsula in Galveston Bay, Texas
Drake Wilson Island in Apalachicola Bay, Florida
Buttermilk Sound in the Atlantic Intracoastal Waterway, Georgia
Windmill Point in the James River, Virginia.

Selection criteria for the sites were chosen to take advantage of ongoing maintenance dredging projects within Corps Districts, to obtain broad geographical representation, and to allow work in systems of varying energy, salinity, and substrate conditions. Of the six sites, three were in fresh or brackish water and three in saline water. Substrates of three were sand and three silt or clay. Three were in coastal and three in riverine situations. The sites range in size from 2 ha (Georgia) to 9 ha (Virginia). Table 1 characterizes site variation.

Table 1

Site Name, Location, Characteristics, and Variables Tested

Site Name, State	Substrate	Salinity	Number of Elevation Zones	Primary Species Planted	Propagule Types	Spacing	Timing	Fertilizer Treatment
Miller Sands, OR (riverine)	Sand	Fresh	3	*Carex obnupta* *Deschampsia caespitosa*	Sprigs and seeds	0.5 m	--	0, low, high, split low, split high
Salt Pond 3, CA (coastal)	Clay	Saline	Gradient	*Spartina foliosa*	Sprigs and seeds	0.5, 1.0, 2.0, 3.0 m	Apr through Jan on sprigs	--
Bolivar Peninsula, TX (coastal)	Sand	Saline	3	*Spartina alterniflora* *Spartina patens*	Sprigs and seeds	0.5 m	Jul, Feb & May on sprigs of *S. alt.*	0, low, high, split low, split high
Drake Wilson Island, FL (coastal)	Silt fill, sand dike	Saline to brackish	1 for *S. alt*, gradient for *S. pat.*	*Spartina alterniflora* *Spartina patens*	Sprigs	0.3, 0.6, 0.9, 1.8, 2.7 m	--	--
Buttermilk Sound, GA (riverine)	Sand	Fresh to brackish	3	*Borrichia frutescens* *Distichlis spicata* *Iva frutescens*	Sprigs and seeds	0.5 m	May through May on sprigs of *S. alt.*	0, low and high inorganic, low and high organic

Table 1 (concluded)

Site Name, State	Substrate	Salinity	Number of Elevation Zones	Primary Species Planted	Propagule Types	Spacing	Timing	Fertilizer Treatment
				Juncus roemerianus *Spartina alterniflora* *Spartina cynosuroides* *Spartina patens*				
Windmill Point, VA (riverine)	Silt fill, sand dike	Fresh	1	*Peltandra virginica* *Scirpus americanus* *Spartina alterniflora* *Spartina cynosuroides*	Sprigs and seeds	0.38 m	--	0, 1 level

METHODS AND MATERIALS

Site construction activities included dike construction and dredged material disposal in Virginia and Florida, grading of existing disposal sites to intertidal elevations in Georgia, Texas, and Oregon, and disposal with dike breeching for tidal access in California. Construction was followed by experimental propagation of marsh species. Factors tested included elevation, plant species, propagule type, spacing, timing, and fertilizer application (Table 1). The experimental design varied somewhat with differential opportunities and constraints at each site. In Oregon, Texas, and Georgia the three elevation zones were divided into three blocks (replicates), each of which was subdivided into plots which were randomized for experimental treatment, including controls. The other three sites used replicated plots and subplots according to the variables tested (Table 1). Additional species were tested in Oregon, methods of substrate preparation were tested in California, and the effectiveness of protection from wave and wind energies was examined in Texas. Upland plantings were included at the Oregon and Texas sites, but are not discussed in this paper.

Monitoring of the sites was initiated immediately after planting. Measurements were made of propagule survival, plant growth and productivity, invading plant species, wildlife use of the sites, soil and sediment characteristics, and selected aquatic parameters such as benthic colonization and water quality. Observations on engineering structures, sediment accumulation, and need for protection of the plantings were included.

Summary reports have been prepared on habitat development activites at the field sites (Allen et al. 1978, Clairain et al. 1978, Cole 1978, Kruczynski et al. 1978, Lunz et al. 1978, and Morris et al. 1978), including planning, construction, and monitoring as well as results of planting. Botanical details are found in Heilman et al. (1978), Reimold et al. (1978), Virginia Institute of Marine Science (1978), and Webb et al. (1978). All aspects of the DMRP that pertain to marsh development, including laboratory and field studies, engineering methods, and research conducted by other agencies and individuals, were compiled into a synthesis report (Environmental Laboratory, 1978).

RESULTS

The reader is referred to the summary reports cited above for data and detailed results of plantings at each field site and for information on the other measurements taken. Key points are given below.

Elevation

Elevation and attendant inundation were the major determinants of vegetation success, with the magnitude, frequency, and duration over time of inundation critical. Irregularities in flooding such as occurred at the Texas site, where tide levels are strongly influenced by wind direction and velocity, affected growth of planted species, but the relative elevations at which the species grew were as expected.

Species were planted over a range of elevations that received both suitable and unsuitable amounts of inundation and showed differential survival along the elevation gradient. In Oregon, *Deschampsia caespitosa** and *Carex obnupta* both established in the upper two elevation zones; inundation over 60 percent of the time was unfavorable. In California, *Spartina foliosa* established well only in the lower two thirds of the site and was unable to withstand competition in the upper third. *Spartina alterniflora* and *S. patens* in Texas grew best at inundation times of

---

* Tables 2 and 3 list scientific and common names of plants.

Table 2

Scientific and Common Names of Species Planted and Location of the Site

Scientific Name	Common Name	State(s)
Borrichia frutescens	Saltmarsh oxeye	GA
Carex obnupta	Slough sedge	OR
Deschampsia caespitosa	Tufted hairgrass	OR
Distichlis spicata	Salt grass	GA
Iva frutescens	Marsh elder	GA
Juncus roemerianus	Black needlerush	GA
Peltandra virginica	Arrow arum	VA
Scirpus robustus	Saltmarsh bulrush	VA
Spartina alterniflora	Smooth cordgrass	TX, FL, GA, VA
Spartina cynosuroides	Rough cordgrass	GA, VA
Spartina foliosa	California cordgrass	CA
Spartina patens	Saltmeadow cordgrass	TX, FL, GA

Table 3

Scientific and Common Names of Other Plant Species Mentioned

Scientific Name	Common Name	State(s)
Acnida cannibina	Water hemp	GA
Digittaria sanguinalis	Crabgrass	GA
Panicum sp.	Panic grass	GA
Pluchea odorata	Marsh fleabane	GA
Polygonum punctatum	Water smartweed	OR
Pontederia cordata	Pickerelweed	VA
Sagittaria latifolia	Arrowhead	VA
Salicornia spp.	Pickleweed	CA

approximately 70-85 percent and 25-30 percent, respectively. *S. patens* was planted at elevations from -0.3 to 1.5 m above msl in Florida, but did best at 1.0-1.4 m above msl. An equally distinct zonation of survival and growth occurred at the site in Georgia, with *S. alterniflora* being the only species to withstand inundation more than 18 hr/day (75 percent of the time) and *S. patens* growing best in the upper zone which was inundated less than 6 hr/day (25 percent of the time). *Borrichia frutescens*, *Iva frutescens*, *S. alterniflora*, and *S. cynosuroides* were most successful in the middle elevation zone.

Elevation and time of inundation affected invading plants as well as those planted. As flooding time decreased at the site in Virginia, the number of species surviving and invading increased. The number of species invading at higher elevations in Oregon, Texas, and Georgia was also greater than that at lower elevations.

Invasion

Rates of invasion were variable among the sites. At Windmill Point in Virginia, dredged material was deposited in February 1975, invading propagules were visible in mid-April, and the site was covered sparsely by plants in June and thickly in July. Over 75 species were recorded then in three general communities, and the planned propagation experiments had to be scaled down. The dominant species in the intertidal community were *Sagittaria latifolia* and *Pontederia cordata*. A high number of species (42) invaded the Buttermilk Sound site in Georgia over the study duration with four being encountered most frequently (*Acnida cannabina*, *Panicum* sp., *Digittaria sanguinalis*, and *Pluchea odorata*). The same number of species of invaders was recorded over time in Florida, but only *Distichlis spicata* became well established, occupying the elevations between *S. alterniflora* and *S. patens*.

Fewer invading species were recorded at the other three sites. There was insignificant invasion at Bolivar Peninsula in Texas and then only in the upper zone. *Salicornia* spp. dominated the upper elevations in California as the only intertidal invaders. On Miller Sands in Oregon, *Polygonum punctatum* was an important invader of the upper zone.

Protection

Hazards to plant establishment existed at several of the field sites. Excessive wave and wind energies from Galveston Bay were decreased in Texas by placement of a sandbag dike which acted as a wave break. Each site in Virginia, Florida, and California was entirely protected and confined by a dike. In Georgia, a natural protection from excessive energies came about due to placement of the experimental plantings. A berm of dredged material was placed and stabilized with a sand fence and plantings to shield the developing marsh from wind in Oregon.

Canada geese destroyed the plantings in Virginia by feeding on them. It was necessary to build a fence around the Texas site to exclude rabbits and feral goats and to trap nutria from the Oregon site.

Plant species selection

Several species were knowingly planted at unsuitable elevations for survival and growth but were selected for their potential and all did establish at appropriate elevations. Additional species should be considered in some locations, based on ancillary growth tests at the sites and successful invasion. Ancillary plantings of six west coast marsh plants were done in Oregon; all were successful on this small scale. In Georgia, four invading species were well established and three could be desirable plantings (*Panicum* sp., *Acnida cannibina*, and *Pluchea odorata*). *Distichlis spicata* in Florida and *Salicornia* spp. in California should be considered in species selection because of their successful invasion.

Propagule selection

Sprigs and seeds were tested at the field sites; additional propagule types, such as cuttings, have been planted by others. Only at Buttermilk Sound in Georgia were seeds as successful as sprigs. In Texas growth from seeding occurred only in the upper zone. Seeds did not grow in California or Oregon or in two species in Virginia (*Scirpus robustus* and *Spartina alterniflora*).

Fertilization

Addition of nutrients apparently had no long-term effect at any site. *Deschampsia caespitosa* responded to fertilizer, but this was not a factor in survival since one year later no effect was detected. *Carex obnupta* showed no response. Any effect of fertilizer at the Texas site was overshadowed by sedimentation and attendant nutrient influx, attributed largely to stilling action of the sandbags. Response to fertilizer application in Georgia was variable and short-term. No response was detected in Virginia.

Spacing

Optimum distance between propagules was tested in California and Florida. Spacing of 0.5 m between sprigs resulted in best growth of *Spartina foliosa* in California; 1.0 m was satisfactory in the lower two thirds of the site, but greater spacing than that was inadequate. In Florida, *S. alterniflora* grew equally well at spacings of 0.3, 0.6, and 0.9 m, but poor survival resulted at spacings of 1.8 and 2.7 m. *S. patens* showed opposite results, with 1.8 and 2.7 m spacings judged best for plant growth. Cover, however, was less initially.

Timing

Spring planting produced the greatest number of shoots at the California site because of a longer growing season, but time of planting did not affect overall survival. There were few statistically significant differences in survival or performance of plantings over time in Georgia, but the months of May, April, March, January, and February, in decreasing order, appeared most suitable overall. These months coincide with greatest precipitation and cooler temperatures. Although July planting dates were successful in Texas, February through May is recommended to allow recovery from transplant shock and maximum growth during the first year.

Vegetation growth

Differential rates of plant survival, growth, spread, and colonization were noted among species and sites. The most rapid plant cover occurred in Virginia, primarily due to invasion. Sites in Georgia and Florida vegetated rapidly because of invasion and spread of planted species, with the experimental plots coalescing rapidly. Coalescence was not as rapid in California or Texas, but was obvious by the end of the study. Plants in Oregon showed the slowest growth and colonization.

DISCUSSION AND CONCLUSIONS

Elevation, attendant inundation, and tolerance to flooding of planted and invading species were the primary determinants of marsh composition. Of secondary importance at one or more sites were site protection, soil fertility, propagule type, and spacing of plantings.

To plan a marsh or to predict the ultimate vegetative composition of a site, one should determine the species composition of marshes in the area and of the same elevation. With this information it is possible to select species to be successfully planted and to determine species likely to invade and establish.

Lower intertidal elevations are more difficult to vegetate than higher elevations receiving less tidal inundation. Few species are tolerant of lower levels, reducing chances of survival of planted and invading vegetation.

Patterns of invasion observed allowed some generalizations. If a site has a fine-grained intertidal substrate and is protected, less effort will be required to plant it because invasion and colonization will be an active process. The sites in Virginia and Florida are illustrative. Freshwater sites may exhibit faster growth of cover than saline sites, e.g. Virginia and Georgia. An exception to this was found in Oregon.

With these relative statements one can determine the adequacy of cover that may result in a certain period of time. Establishment of cover took six months in Virginia because of invasion and colonization, but occurred much slower in Oregon. For purposes of stabilizing a site and obtaining adequate cover in a short time, planting was necessary in Oregon.

The amount of protection necessary from wave and wind energies or animal damage should be determined at each site. If marsh vegetation is already present under similar conditions, either no protection or protection during the initial stages of marsh establishment will be needed. Protection may be derived from either placing the site in a low-energy location or constructing a protective structure. Animal damage potential depends on the type and population density of grazers with access to the site.

Protection by structures and by the developing plants themselves resulted in a beneficial sediment accumulation in Oregon, Texas, and Georgia. The sand at lower elevations especially was covered by and infiltrated with fine-grained material that was higher than sand in organic matter and available nutrients. This occurred to the extent in Georgia that, by the end of the study, soils at the site were similar to those of nearby natural marshes.

Fertilization was unnecessary at most sites, both because the tides apparently caused it to leach and because the sediments accumulating were nutrient-rich. Quick-release fertilizer, had it been applied, might have had some effect. Based on these results, fertilization is recommended only if rapid cover (first season) is required or if fine-grained material will not be accumulating.

Seed is not recommended as a propagule type unless water levels are going to be relatively low during germination and early establishment, or the site is in the upper portion of the elevation zone. Tidal action can dislodge seeds and wash them from the site before or just after germination. Seeding is less expensive than sprigging,but less reliable and less generally applicable. Seeding might be considered to augment sprigging.

A spacing of 0.5-1.0 m between propagules is recommended for most situations. Greater spacing may be adequate if a lesser degree of stabilization and cover is needed or if insufficient funds are available.

Marsh development techniques are considerably advanced over their status a few years ago and can be reliably applied in many situations. Use of the literature, observations of the character of existing marshes, and awareness of the major principles of marsh establishment will allow replacement and enhancement of this resource.

LITERATURE CITED

Allen, H. H.; Clairain, E. J., Jr.; Diaz, R. J.; Ford, A. W.; Hunt, L. J.; and Wells, B. R. Habitat development field investigations, Bolivar Peninsula marsh and upland habitat development site, Galveston Bay, Texas; Summary report. U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. 1978. Technical Report D-78-15.

Clairain, E. J., Jr.; Cole, R. A.; Diaz, R. J.; Ford, A. W.; Huffman, R. T.; Hunt, L. J.; and Wells, B. R. Habitat development field investigations, Miller Sands marsh and upland habitat development site, Columbia River, Oregon; Summary report. U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. 1978. Technical Report D-77-38.

Cole, R. A. Habitat development field investigations, Buttermilk Sound marsh development site, Georgia Intracoastal Waterway, Georgia; Summary report. U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. 1978. Technical Report D-78-26.

Environmental Laboratory. Wetland habitat development with dredged material: Engineering and plant propagation. U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. 1978. Technical Report DS-78-16.

Heilman, P. E.; Greer, D. M.; Brauen, S. E.; and Baker, A. S. Habitat development field investigations, Miller Sands marsh and upland habitat development site, Columbia River, Oregon; Appendix E: Postpropagation assessment of botanical and soil resources on dredged material. U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. 1978. Technical Report D-77-38.

Kruczynski, W. L.; Huffman, R. T.; and Vincent, M. K. Habitat development field investigations, Apalachicola Bay marsh development site, Apalachicola Bay, Florida; Summary report. U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. 1978. Technical Report D-78-32.

Lunz, J. D.; Zeigler, T. W.; Huffman, R. T.; Wells, B. R.; Diaz, R. J.; Clairain, E. J., Jr.; and Hunt, L. J. Habitat development field investigations, Windmill Point marsh development site, James River, Virginia; Summary report. U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. 1978. Technical Report D-77-23.

Morris, J. H.; Newcombe, C. L.; Huffman, R. T.; and Wilson, J. S. Habitat development field investigations, Salt Pond No. 3 marsh development site, South San Francisco Bay, California; Summary report. U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. 1978. Technical Report D-78-57.

Reimold, R. J.; Hardisky, M. A.; and Adams, P. C. Habitat development field investigations, Buttermilk Sound marsh development site, Atlantic Intracoastal Waterway, Georgia; Appendix A: Propagation of marsh plants and postpropagation monitoring. U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. 1978. Technical Report D-78-26.

Virginia Institute of Marine Science. Habitat development field investigations, Windmill Point marsh development site, James River, Virginia; Appendix D: Environmental impacts of marsh development with dredged material: Botany, soils, aquatic biology, and wildlife. U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. 1978. Technical Report D-77-23.

Webb, J. W.; Dodd, J. D.; Cain, B. W.; Leavens, W. R.; Hossner, L. R.; Lindau, C.; Stickney, R. R.; and Williamson, H. Habitat development field investigations, Bolivar Peninsula marsh and upland habitat development site, Galveston Bay, Texas; Appendix D: Propagation of vascular plants and postpropagation monitoring of botanical, soil, aquatic biota, and wildlife resources. U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. 1978. Technical Report D-78-15.

MARSH RESTORATION ON DREDGED MATERIAL
BUTTERMILK SOUND, GEORGIA

1978

Michael A. Hardisky
Georgia Department of Natural Resources
Coastal Resources Division
1200 Glynn Avenue
Brunswick, Georgia 31520

ABSTRACT

The Dredged Material Research Program (DMRP), U.S. Army Corps of Engineers, Waterways Experiment Station, has conducted a research program to determine alternatives for the disposition of dredged material. The objectives of this program include the determination of the environmental effects of dredging and disposal operations and development of environmentally and economically feasible disposal alternatives. The study began in 1975 in an estuary at the mouth of the Altamaha River near Brunswick, Georgia. A large, open water, dredged material disposal area was graded to a gently sloping plane extending from mean high to mean low water. Seven marsh plant species were selected and transplanted onto the experimental area. Initial results confirm the feasibility of marsh development. Continued monitoring has described a number of successional changes related to interspecific plant competition and edaphic changes. Biomass determinations during 1978 indicate that characteristic underground root biomass profiles for most species have developed. Aerial portions developed by the transplanted areas also approximate mature marsh values. The effects of natural invasion by brackish and freshwater plant species have in most cases been detrimental to the experimental plants. The potential wildlife habitat value of this created marsh is discussed.

INTRODUCTION

The Dredged Material Research Program (DMRP), U.S. Army Corps of Engineers, Waterways Experiment Station, has conducted a research program for the Office, Chief of Engineers, on the alternatives for the disposition of dredged material. Included in the objectives of this program were the determination of environmental effects of dredging and disposal operations and development of environmentally and economically feasible alternatives.

The Buttermilk Sound Habitat Development Site was located in the Atlantic Intracoastal Waterway in the mouth of the South Altamaha River, Glynn County, Georgia, (Figure 1). The site was a 15 hectare area representing 5 to 7 years of dredged material disposal. The initial substrate of the site consisted of 99% quartz sand (by weight), with no visible stratification. Mineral and nutrient availability in this substrate was very low.

During the spring of 1975, the site was subdivided into 720 plots (each plot was 1.5 by 3.0 metres with an 0.7 metre border). The plots were divided into zones representing 8 hours of tidal inundation per day (upper third of intertidal zone); the area inundated 8-16 hours per day (middle third of the intertidal zone); and the area inundated more than 16 hours per day (lower third of intertidal zone). Wetland plants chosen for the site included: *Borrichia frutescens, Distichlis spicata, Iva frutescens, Juncus roemerianus, Spartina alterniflora, Spartina cynosuroides,* and *Spartina patens.* In addition to these seven species of plants, plots were included where no species were planted (control). Sprigs of each species were planted during June of 1975, and seeds of each species were planted during April 1976 (Figure 2).

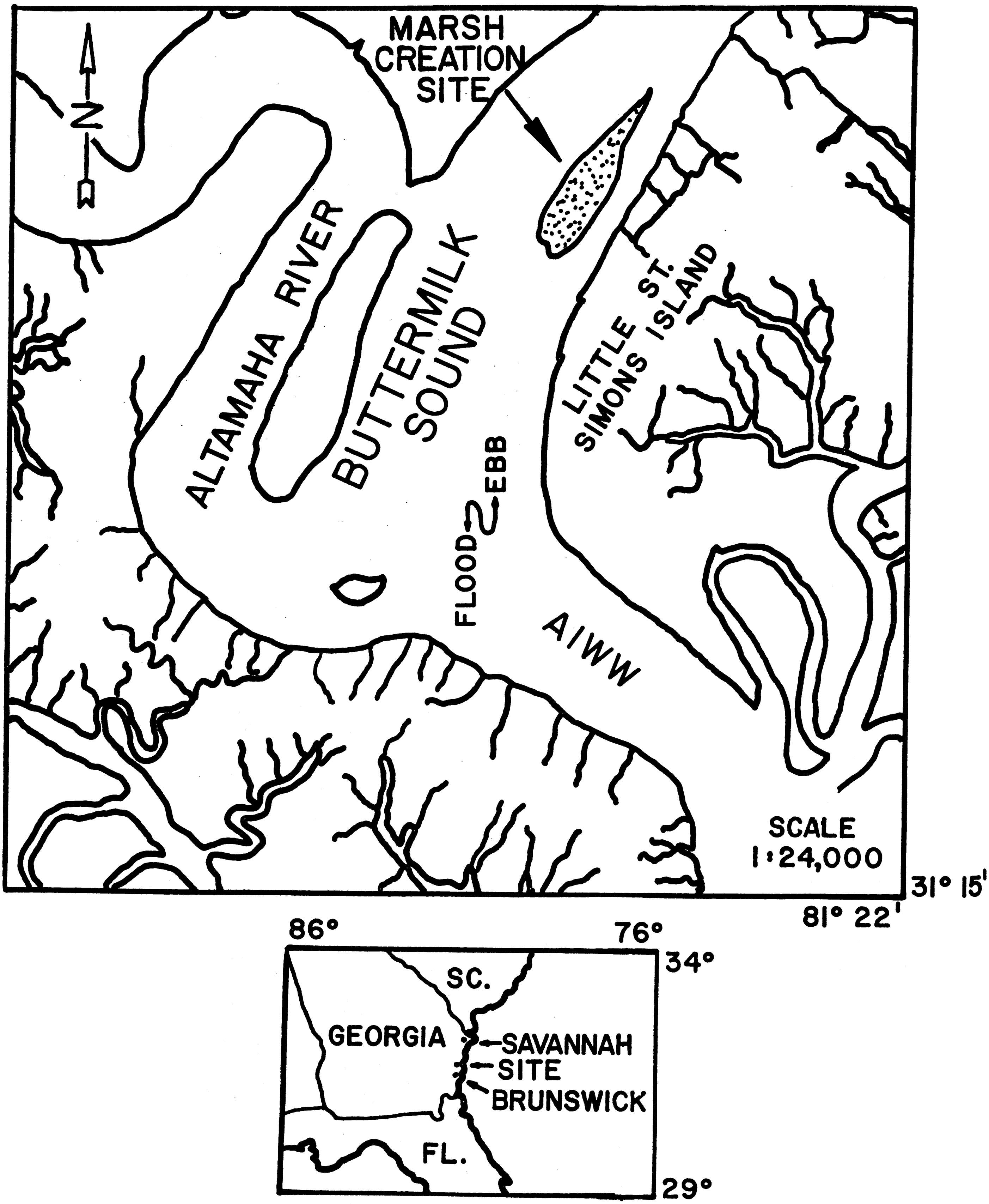


Figure 1.--Location of Buttermilk Sound Marsh Habitat Development site.

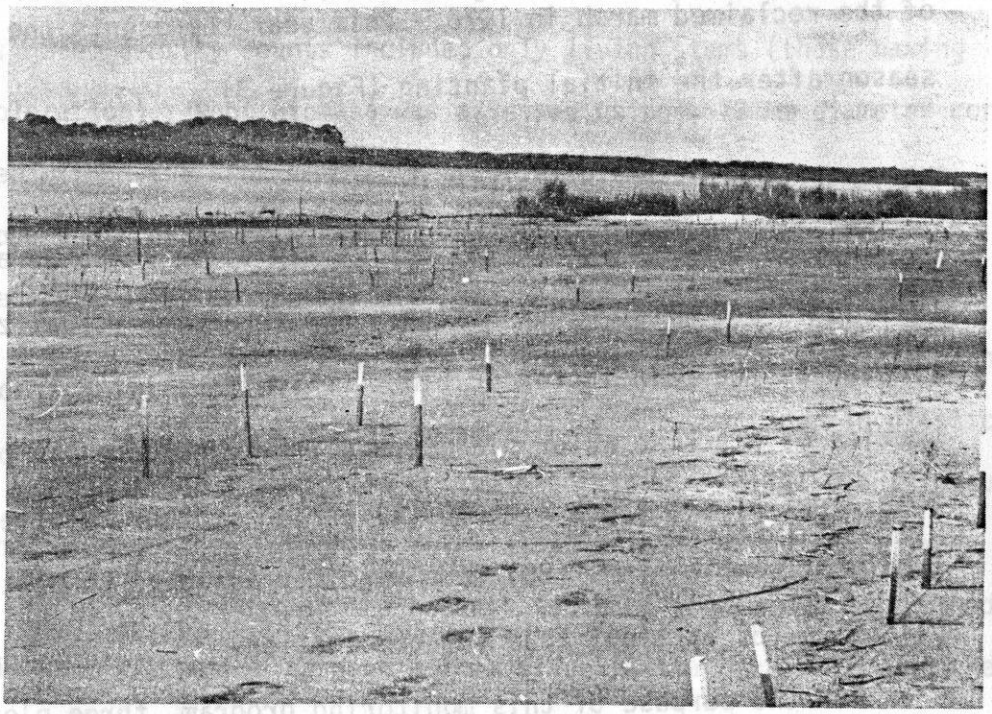


Figure 2.--Buttermilk Sound site two weeks after planting, July 1975. View is south.

Figure 3.--Buttermilk Sound site three years after planting, June 1978. View is south.

This paper deals with the monitoring of the macrobiotic component of the reclaimed marsh in 1978. This year represents the fourth growing season after the initial planting (Figure 3).

METHODS

The original experimental design was established as a split-split-plot in a randomized block design. The three intertidal zones were treated as the main factor or block. Five fertilizer treatments, eight species of brackish water plants, and two types of plant propagules were considered as a 5 x 8 x 2 factorial arrangement of treatments. Factorial treatment combinations (80) were randomly assigned to plots in each replication (3) by tidal zone (3) combination.

For the purpose of this monitoring program, three plots representing each species were randomly selected from each replicated block (zone) using a table of random numbers. If species had not survived anywhere within one replicated block (zone), it was not sampled. In order to assess the invading plant population, control plots were sampled in a similar fashion to the experimentally planted plots. Plots were selected without regard to fertilizer treatment or propagule type.

Destructive biomass sampling was conducted similar to the previous work of Reimold, *et al.*, 1978a. Quadrat sizes ranged from $0.01m^2$ to $0.25m^2$ depending on the spatial pattern of the plant population in question. The shrub *Iva frutescens* represented a unique growth form with respect to the other grasses and forbs sampled. The scarcity of surviving *Iva frutescens* shrubs eliminated the option of harvesting entire bushes. Therefore, *Iva frutescens* was sampled by visually assessing the portion of the canopy which occupied a $0.25m^2$ area and harvesting that part of the shrub. The variables assessed in every plot were stem density, crab burrow density, root biomass, aerial biomass, flowering stem density and invading species density. Stem density counts included only living stems (those having green coloration). Root biomass was assessed using a 73 mm diameter core extracted within the area sampled for aerial biomass. The cores were taken to a depth of 25 cm. Aerial samples from control areas were separated by species in the field. The root biomass sample from the control plots represented a composite of the root material from all plant species present. Aerial and root plant samples were packaged in plastic bags in the field and transported to the laboratory. Aerial plant tissue was washed if necessary, weighed, dried at 95°C in a forced draft oven and the dry weight biomass to the nearest tenth of a gram was determined. Each soil core was washed through a 1 mm sieve (Gallagher,1974), and the retained organic material was then dried to a constant weight. Aerial and root samples were multiplied by the appropriate factor and expressed as grams dry weight per square meter.

The analysis of variance for the dependent variables was performed using the General Linear Model procedure outlined by Barr, *et al.*, 1976 using an IBM 370 computer. Significant differences were determined using Duncan's Multiple Range test.

RESULTS

Figures 4 and 5 illustrate the development of aerial and root biomass during June 1978 for each third of the intertidal zone. The planted species are perennial plants,as is indicated by the larger aerial biomass during the spring as opposed to the lower aerial development by the annual invading plants. A variety of growth forms are also represented. Shrub versus grassland forms are present, as well as intraspecific plant

FIGURE 4.

AERIAL AND BELOW GROUND BIOMASS

UPPER THIRD OF INTERTIDAL ZONE

7 June 1978

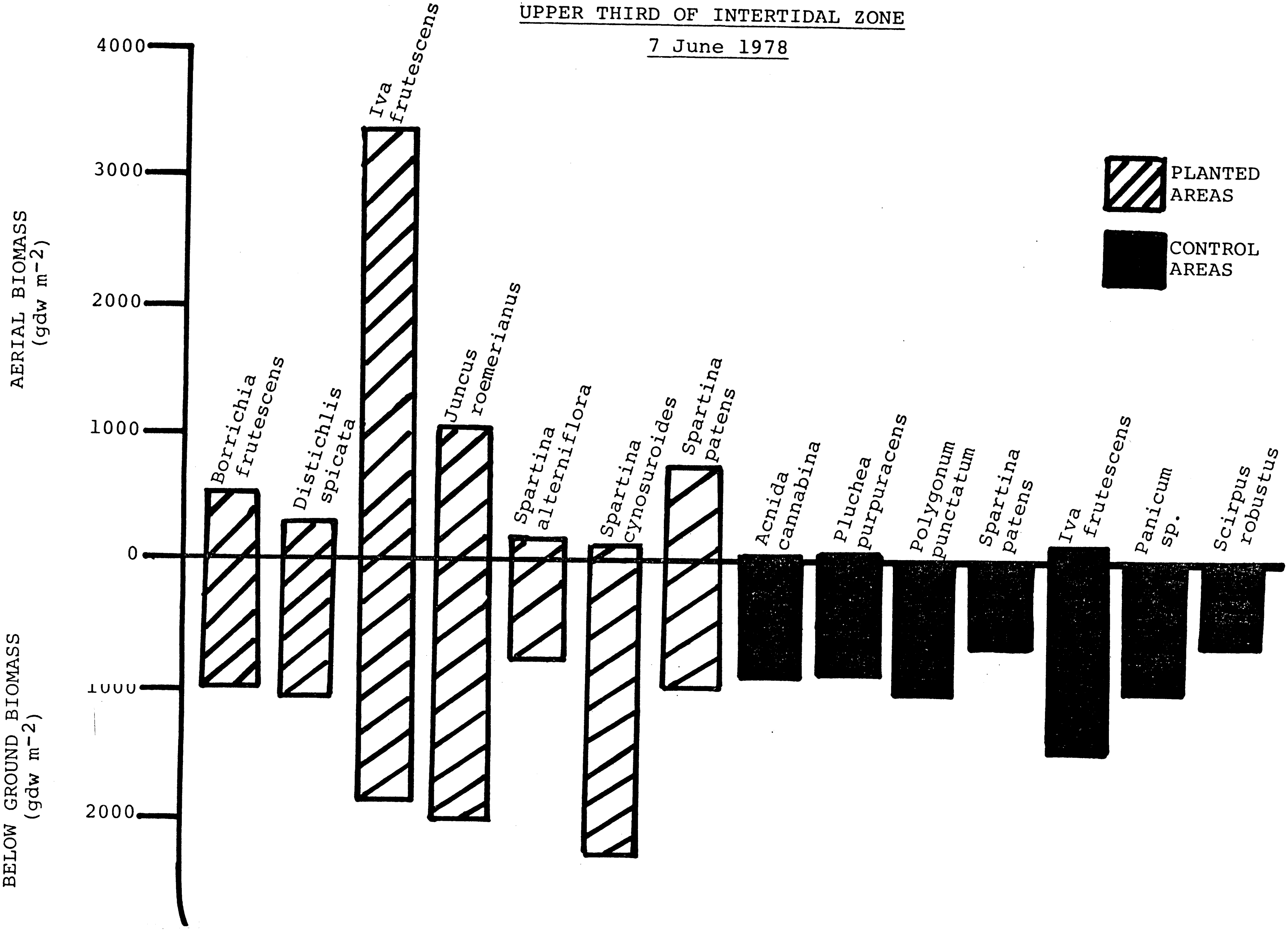
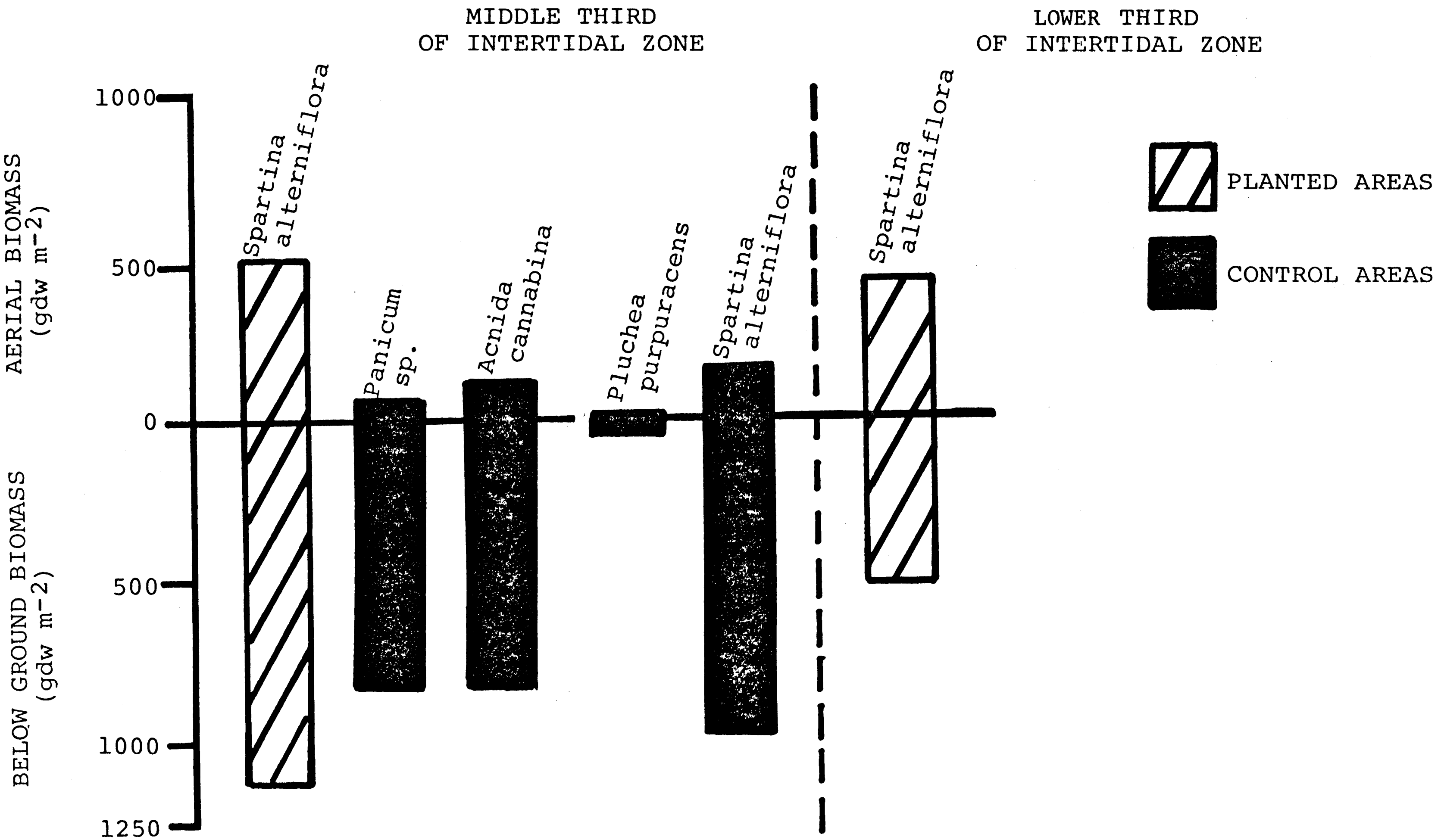


FIGURE 5.

AERIAL AND BELOW GROUND BIOMASS
MIDDLE AND LOWER THIRD OF INTERTIDAL ZONE
7 JUNE 1978



morphology variation within the intertidal zone. *Spartina alterniflora, Acnida cannabina* and *Panicum sp.* produced much larger aerial biomass values in the middle third of the intertidal zone than was produced in the upper third of the intertidal zone. Stabilization of a dredged material is directly related to below ground biomass development. Much less interspecific and elevational variation is evident for below ground biomass. The below ground standing crop biomass appears to be more constant over the annual cycle than the aerial portion. The erosion control represented by the below ground root mat of *Spartina alterniflora* was evident. A deep gulley scoured by ground water runoff at the site was healed by the encroachment of *Spartina alterniflora* in the middle third of the intertidal zone. The dense root mat of *Spartina patens* also provides substantial resistance to erosion. The landward progress of a runoff gulley in the upper third of the intertidal zone was stopped by a *Spartina patens* sward. These two instances suggest the ability of *Spartina alterniflora* and *Spartina patens* to resist erosion.

The pattern of aerial and below ground biomass distribution over the site was changed somewhat in the October 1978 sampling period (Figures 6 and 7). In general, aerial biomass increased for the planted and invading plant species. The bulk of the invading plant species in all intertidal zones was not adequately represented by the sampling. These seasonal changes in the above ground habitat are important to a variety of wildlife species utilizing the area. The invading plants on the site would not provide adequate cover for wildlife during the fall and winter months. However, the assemblage of a variety of plants at the site does provide year round habitat. The below ground root mat changed little from the June sampling. The most pronounced changes were associated with *Spartina alterniflora* in the middle and lower intertidal zones. The persistance of

FIGURE 6.

AERIAL AND BELOW GROUND BIOMASS

UPPER THIRD OF INTERTIDAL ZONE

24 OCTOBER 1978

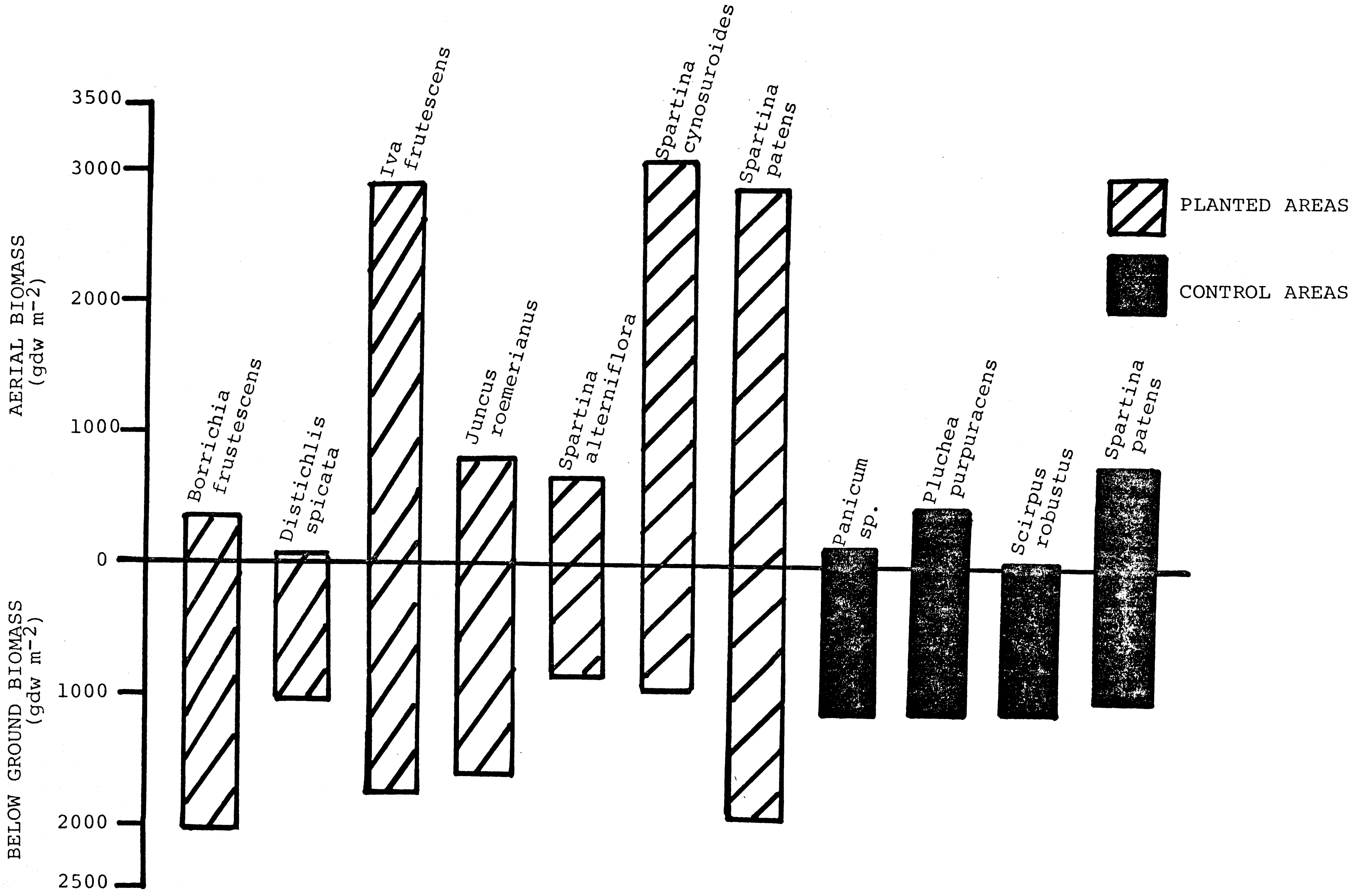
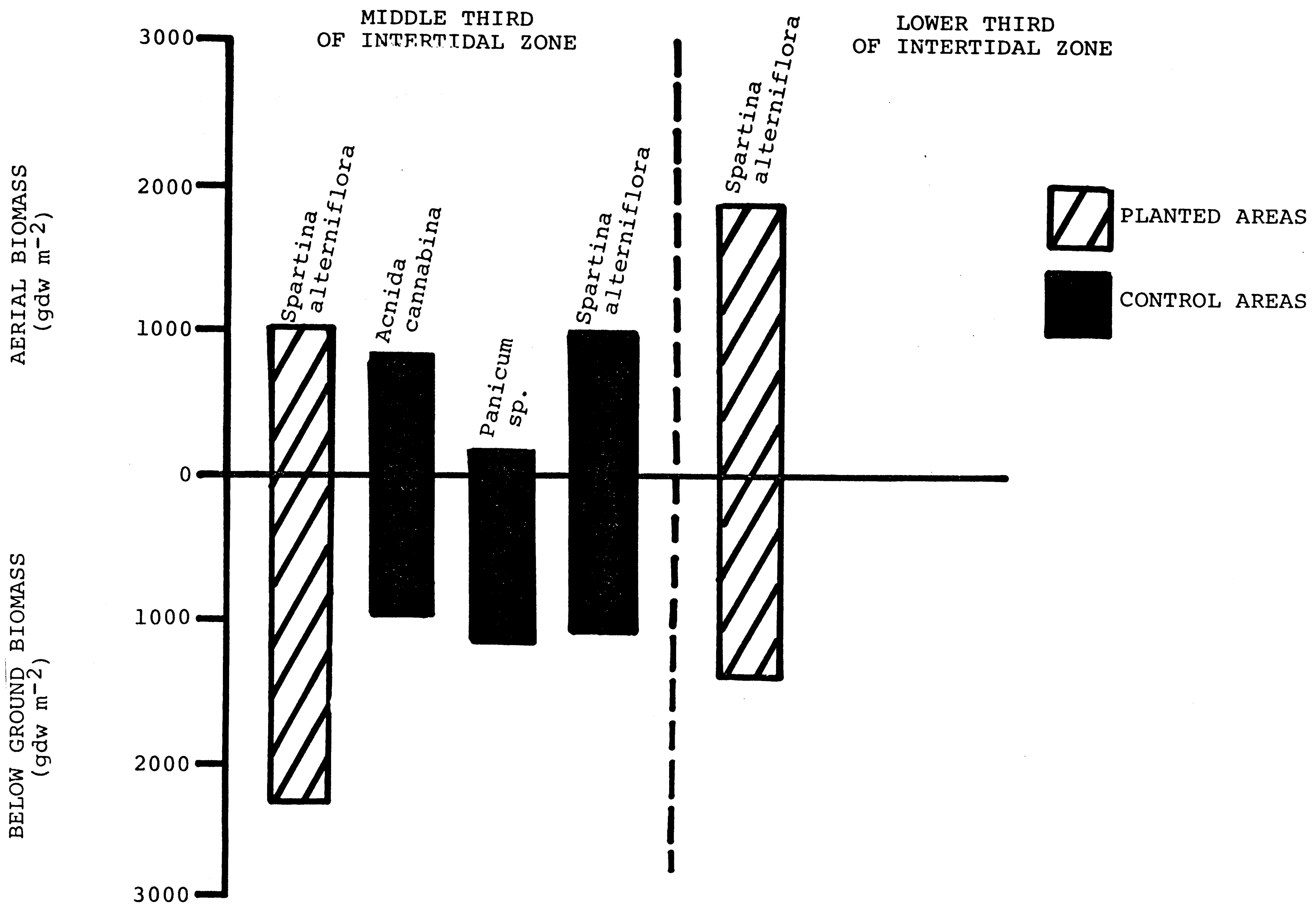


FIGURE 7.

AERIAL AND BELOW GROUND BIOMASS

MIDDLE AND LOWER THIRD OF INTERTIDAL ZONE

24 OCTOBER 1978



the root mat throughout the growing season assures the stabilization of the dredged material.

Table 1 depicts the analysis of variance for each of the plant parameters measured when considered by species, intertidal zone or the combination of the two. The only interaction which yielded a significant difference was species. Table 2 describes the variable means associated with the plant species differences. The significant differences noted for aerial biomass reflect a shrub growth form in *Iva frutescens* and dense sward growth for *Juncus roemerianus* and *Spartina patens*. The only significant difference in culm density and fiddler crab burrow density (*Uca pugnax, Uca pugilator*) was associated with *Spartina patens*. It is interesting to note that no significant differences were evident between species for below ground biomass. The coalescence of invading and planted species have provided a rather uniform root mat over the entire upper third of the intertidal zone.

Another comparison of interest when considering the success of a marsh establishment attempt is the relationship between planted and control areas. The means for measured parameters for planted and control areas are found in Table 3. In all cases of significant differences, the planted areas were more successful than control areas. This is an important factor when considering the worth of marsh establishment with transplants as opposed to simply constructing a gently sloping grade and relying upon natural revegetation. The analysis of variance describes the disparity between aerial and root biomass for planted and control areas to continue to exist. Therefore, after four growing seasons, it is evident that transplanting or seeding still affords the best success in terms of aerial biomass production and root mat development.

TABLE 1

Significance of Treatments from the Analysis of Variance for all Plant Species Sampled, Buttermilk Sound, Ga. 1978

Treatment	Aerial Biomass	Below Ground Biomass	Stem Density	Flowering Stem Density	Crab Burrow Density
Species	****	NS	****	NS	**
Zone	NS	NS	NS	NS	NS
Species x Zone	NS	NS	NS	NS	NS

Probability level: NS = not significant, * = 0.05, ** = 0.01, *** = 0.001, **** = 0.001

TABLE 2

Variable Means for Planted Species in the Upper Third of Intertidal Zone, Buttermilk Sound, Ga. 1978

Species	Aerial Biomass gdw/m^{-2}	Below Ground Biomass gdw/m^{-2}	Stem Density m^{-2}	Flowering Stem Density m^{-2}	Crab Burrow Density m^{-2}
Borrichia frutescens	454 c	1541 a	86 b	3 a	51 b
Distichlis spicata	224 c	1012 a	860 b	0 a	83 b
Iva frutescens	3132 a	1736 a	100 b	3 a	53 b
Juncus roemerianus	919 b	1848 a	638 b	20 a	97 b
Spartina alterniflora	245 c	785 a	63 b	2 a	52 b
Spartina cynosuroides	447 c	1585 a	74 b	5 a	41 b
Spartina patens	1963 b	1215 a	2065 a	0 a	418 a

Means followed by similar letters were not significantly different at p - 0.05 according Duncan's Multiple Range test.

TABLE 3

Variable Means for Planted Versus Control Areas, Buttermilk Sound, Ga. 1978

Type	Aerial Biomass gdw/m^{-2}	Below Ground Biomass gdw/m^{-2}	Stem Density m^{-2}	Flowering Stem Density m^{-2}	Crab Burrow Density m^{-2}
Planted	1377 a	1042 a	507 a	8 a	94 a
Control	958 b	198 b	167 a	2 a	22 b

Means followed by similar letters were not significantly different at $p = 0.05$ according to Duncan's Multiple Range test.

Spartina alterniflora constituted the most widely distributed plant species on the site, extending from the mean high water level to the top of the lower third of the intertidal zone. The adaptability of this plant to varying environmental conditions permitted its survival in all three of the intertidal zones at the experimental site. As a result of this plant's adaptability and luxuriant aerial and root biomass production, it is most desirable for revegetation attempts. As with all species at the site, *Spartina alterniflora* was planted onto all three intertidal zones. The resultant population described the optimum elevation regime for *S. alterniflora*.

Table 4 summarizes an analysis of variance for *Spartina alterniflora* response as affected by elevation (zone) and sampling date (season). Both zone and season described a number of significant interactions. Variable means for each interaction are depicted in Table 5. Aerial biomass and culm density were significantly lower in the upper third of the intertidal zone. These parameters suggest *Spartina alterniflora* to be less successful in the upper zone. The middle and lower thirds of the intertidal zone were similar with the exception of culm density. The higher densities in the lower intertidal zone suggest a less stable community associated with newly forming plant swards. The higher concentration of crab burrows in the upper and middle thirds of the intertidal zones is consistent with *Uca pugnax* population estimates for a Georgia salt marsh by Wolf, *et al.*, 1975. Wolf, *et al.* found significantly larger crab populations in the short and medium *Spartina* zones and a minimal population associated with the creekbank areas. Although large differences in below ground biomass existed between the intertidal zones,

TABLE 4

Significance of Treatments from the Analysis of Variance for *Spartina alterniflora*, Buttermilk Sound, Ga. 1978

Treatment	Aerial Biomass	Below Ground Biomass	Stem Density	Flowering Stem Density	Crab Burrow Density
Zone	**	NS	***	NS	*
Season	**	NS	**	**	NS
Zone x Season	*	NS	NS	NS	NS

Probability level: NS = not significant, * = 0.05, ** = 0.01, *** = 0.001.

TABLE 5

Variable Means for *Spartina alterniflora*, Buttermilk Sound, Ga. 1978

Intertidal Zone	Aerial Biomass gdw/m-2	Below Ground Biomass gdw/m-2	Culm Density m-2	Flowering Culm Density m-2	Crab Burrow Density m-2
Upper Third	245 b	785 a	63 c	2 a	52 a
Middle Third	821 a	1734 a	213 b	12 a	45 a
Lower Third	1173 a	940 a	483 a	23 a	7 b
SEASON					
June	422 b	786 a	160 b	0 b	24 a
October	1070 a	1520 a	347 a	24 a	44 a

Means followed by similar letters were not significantly different at $p = 0.05$ according to Duncan's Multiple Range test.

no means were significantly different. This was due in part to large sample variations in the six replicates comprising the means. Flowering culm densities failed to be significantly different in each zone but did not indicate the highest density was associated with the lower third of the intertidal zone where the greatest incidence of colonization by *Spartina alterniflora* was occurring.

Seasonal differences were evident for aerial biomass, culm density and flowering culm density. The increased aerial biomass for October is consistent with the occurrence of maximum standing crop biomass described for Georgia marshes by others (Smalley, 1958; Gallagher, *et al.*, *in press*; Odum, 1961). The maximum culm density in October reflects the recruitment of young culms for the next year's aerial crop. *Spartina alterniflora* flowers in the fall as is indicated in Table 5. Below ground biomass and crab burrow density were not significantly different with season. Mean below ground biomass doubled by October indicating production and accumulation had occurred during the year. This is consistent with previous findings (Valiela, *et al.*, 1976, and Gallagher and Plumley, 1979).

DISCUSSION

When replanting a dredged material disposal area for the purpose of habitat development, there are a number of important considerations to ponder. The foremost purpose of habitat development is the stabilization of the dredged material, for without stabilization there can be no habitat. Secondly, the habitat itself must be diverse in terms of the vertical layering of the vegetation canopy and be somewhat unique as compared to immediately adjacent habitats. This, of course, is the optimum which would yield a maximum "habitat value." A third consideration is the contribution of the new habitat to the estuarine system. The size of the developed habitat in proportion to the adjacent estuary will determine its impact in terms of primary production, nutrient cycling and habitat creation. The replanted marsh now resembles other natural marshes in the area. There is evidence that this habitat may be unique within the estuarine system.

In May 1978 a large area of *Spartina alterniflora* on the site was grazed by West Indian manatees, *Trichechus manatus* Linnaeus, (Figure 8). *Spartina alterniflora* is abundant in the estuary surrounding the site; however, no instances of manatees grazing on *S. alterniflora* in Georgia have been reported. The major difference between existing creekbank *Spartina* marshes and the newly developed marsh is the slope of the marsh. Most creekbank marshes have a steep bank along the water's edge exposing only a narrow band of vegetation to deep tidal waters. The site has a flat, gently sloping topography, which exposes a much larger band of *Spartina alterniflora* in deep tidal waters. The *Spartina alterniflora* on the site was,therefore,more accessable to the manatees. Campbell and Irvine (1977) suggest manatees feed primarily on submerged vegetation; therefore,the large area of young *Spartina alterniflora* shoots at high water would provide an acceptable foraging area. Evidence such as this indicates the site may have unique habitat properties.

A comparison of aerial biomass values per unit area achieved by each of the plant species at the site to aerial biomass values of mature marshes in the area is found in Table 6. Creekbank *Spartina alterniflora* for Buttermilk Sound is the mean aerial biomass of the middle and lower thirds of the intertidal zone. Highmarsh *Spartina alterniflora* for Buttermilk Sound is the aerial biomass for *S. alterniflora* in the upper third of the

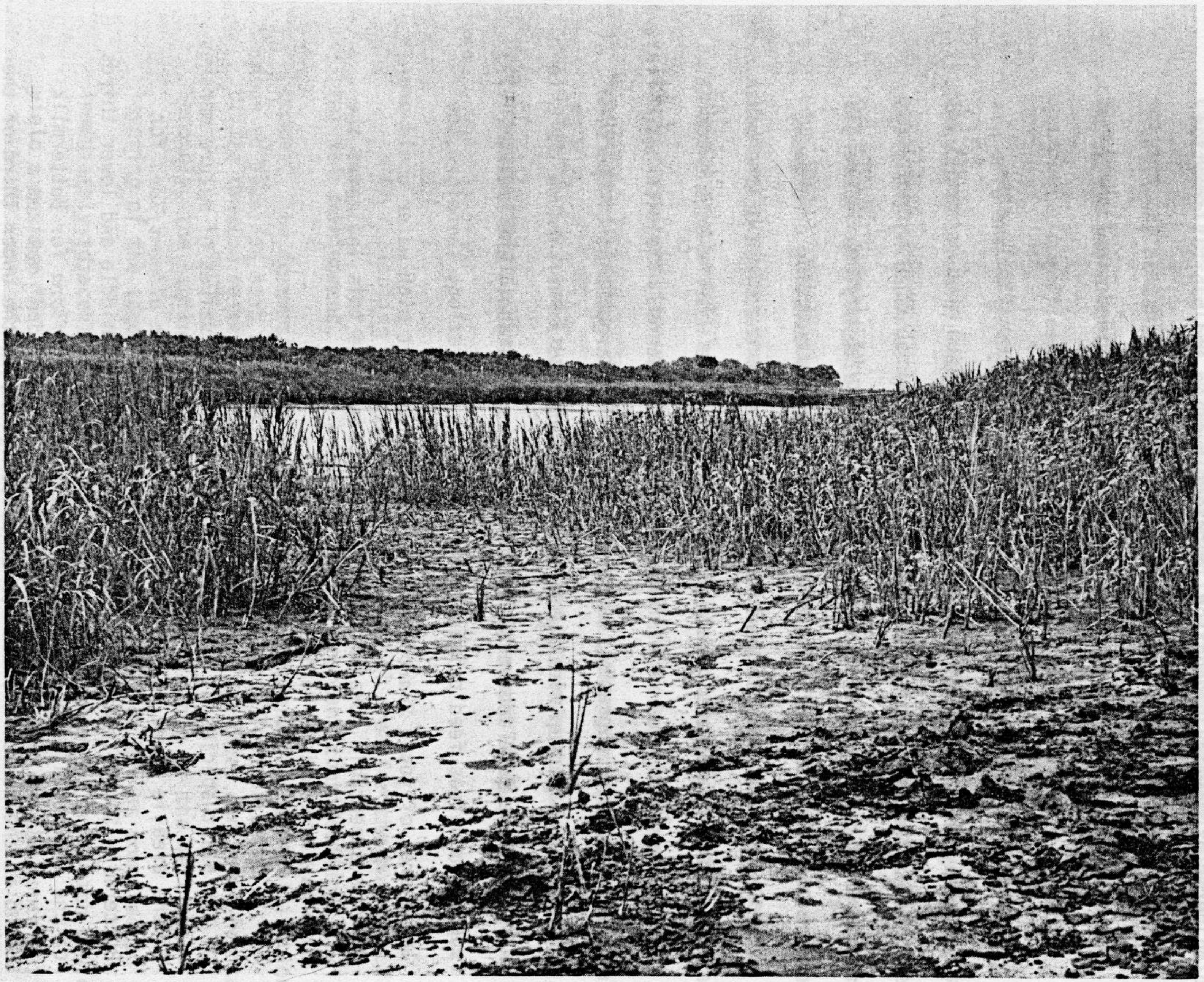


Figure 8.--*Spartina alterniflora* at the Buttermilk Sound site which was grazed by manatees. View is southeast.

TABLE 6.

A Comparison of Aerial Biomass at Buttermilk Sound and other Georgia Salt Marshes

Plant Species	Buttermilk Sound		Other Georgia Marshes		Source
	June Aerial Biomass gdw/m^{-2}	October Aerial Biomass gdw/m^{-2}	June Aerial Biomass gdw/m^{-2}	October Aerial Biomass gdw/m^{-2}	
Borrichia frutescens	523	384	1800	1060	Reimold and Linthurst 1977
Distichlis spicata	360	87	1089	1243	Reimold and Linthurst 1977
Iva frutescens	3384	2916	1917	1306	Reimold and Linthurst 1977
Juncus roemerianus	1023	813	2150	2100	Gallagher et al. in press
Spartina alterniflora Cb	484	1460	1550	1900	Gallagher et al. in press
Spartina alterniflora Hm	199	291	1105	800	Reimold et al. 1978b
Spartina cynosuroides	207	687	3066	2228	Reimold and Linthurst 1977
Spartina patens	755	3170	1740	1098	Reimold and Linthurst 1977

Cb = Creekbank   Hm = Highmarsh

intertidal zone. *Iva frutescens* and *Spartina patens* were the only species on the site to attain aerial biomass levels comparable to other Georgia marshes. The October aerial biomass for creekbank *Spartina alterniflora* at the site approached the value for mature creekbank marshes. The other plant species demonstrated much lower aerial biomass values on the site than for mature marshes. The low aerial biomass at Buttermilk Sound may reflect the competitive interaction of the planted versus invading plant species. *Borrichia frutescens* and *Distichlis spicata* have been adversely affected by taller invading plant species. Another example is the dense overstory created by *Sesbania exaltata* and *Baccharis halmifolia* which has shaded the shorter planted species. The competitive interactions occurring on the site explain the less than optimal aerial biomass development by most of the planted species.

Table 7 provides below ground biomass values for a number of marsh plant species sampled in established stands. *Borrichia frutescens* and *Spartina patens* were the only species to have comparable root biomass values to those of other Georgia marshes. For the remaining plant species the magnitude of root biomass development was minimal as compared to other marshes. Differences for aerial biomass between mature and the replanted area were not as pronounced. The disparity between root development at Buttermilk Sound and other Georgia marshes suggests the underground components of the established marsh are still in developmental phases and the mature state may be years away.

TABLE 7.

A Comparison of Below Ground Biomass at Buttermilk Sound and other Georgia Marshes

Plant	Buttermilk Sound		Other Georgia Marshes		Source
	June Root Biomass gdw/m^2	October Root Biomass gdw/m^2	June Root Biomass gdw/m^2	October Root Biomass gdw/m^2	
Borrichia frutescens	972	2111	964	640	Gallagher et al. 1977
Distichlis spicata	1011	1011	3056	3638	Gallagher et al. 1977
Iva frutescens	1880	1593			
Juncus roemerianus	1975	1708		25,373*	Gallagher 1974
Spartina alterniflora Cb	809	1864		3987	Gallagher 1974
Spartina alterniflora Hm	741	828	5481	10,254	Hardisky, unpublished data
Spartina cynosuroides	2254	916	7480	17,441	Gallagher et al. 1977
Spartina patens	932	1872	1507		Gallagher et al. 1977

Cb = Creekbank Hm = Highmarsh

*Sampling date unknown

CONCLUSIONS

The continued development of the plant populations at Buttermilk Sound indicates a viable marsh habitat has been established. Vegetation and macroinvertebrate population changes identify an active and young successional stage to be in existance. The experimental transplantation of the seven marsh plants randomly into the same area, at elevational levels other than each plant's optimum range, and within a salinity regime lower than what each plant can tolerate has created this actively changing community. Interspecific plant competition and edaphic changes are the major processes dictating the spacial and temporal development of the plant community on the site.

The June 1978 sampling indicated that *Spartina patens* had a significantly greater aerial biomass than any other species in the upper third of the intertidal zone. No other significant differences among species were noted. No significant differences in mean root biomass concentration among different plant species were noted for this zone.

The middle and lower thirds of the intertidal zone were occupied by *Spartina alterniflora* and a limited number of invading plant species. *Spartina alterniflora* in the middle intertidal zone produced higher aerial and below ground biomass levels than in the lower third of the intertidal zone. Crab burrow densities decreased with lower elevation.

The October 1978 sampling revealed that *Spartina patens* maintained a significantly greater culm density in the upper third of the intertidal zone than any other plant species. *Spartina patens* and *Iva frutescens* produced significantly greater aerial biomass values than any other species in the upper third of the intertidal zone. No significant differences for root biomass were noted among species in the upper third of the intertidal zone. No significant differences for root biomass were noted among species in the upper third of the intertidal zone. The October 1978 crab burrow densities associated with each plant species were greater than in 1977. Crab burrow densities exhibited greater variation among plant species than was noted in 1977 (Reimold, *et al.*, 1978a).

Although the volunteering plant species proliferated over most of the site, they maintained significantly less aerial and root biomass than the planted areas. This documents the advantage of transplanting a dredged material disposal area rather than relying upon natural revegetation.

Spartina alterniflora survived in all three intertidal zones. The optimum elevational range of this plant was identified by significantly greater aerial biomass and culm densities in the middle and lower thirds of the intertidal zone. The *Spartina alterniflora* in the upper intertidal zone had commensurate population parameters to the 1977 sampling; however, this steady state may soon decline in lieu of increased competition from other plant species. Seasonal differences in plant measurements were evident for *Spartina alterniflora*. In all cases the October sampling period provided higher mean values.

The stands produced by each plant species were, in most cases, lower in aerial and below ground biomass than other mature marsh communities in Georgia. *Iva frutescens* and *Spartina patens* were the only species to equal or exceed aerial biomass concentrations of neighboring marsh areas. *Borrichia frutescens* and *Spartina patens* yielded below ground biomass values similar to other Georgia salt marshes. The lag in biomass production for most species indicates a longer time is required for development of a mature marsh ecosystem.

The data from 1978 have identified a number of trends for future change at the Buttermilk Sound site. *Distichlis spicata* initially emerged as one of the best candidates for habitat development. The rapid spreading ability and dense aerial and root biomass production of this plant were desirable attributes for stabilization of dredged material. The influx of numerous fresh and brackish water plants had provided an extensive overstory too tall for *Distichlis spicata* to compete with successfully. It appears that *Distichlis spicata* provided an important role in initial stabilization but will deteriorate as the marsh habitat continues to mature. *Spartina alterniflora* continues to exert its dominance over the lower and middle thirds of the intertidal zone. The accumulation of nearly 20 cm of silt, clay and detrital particles suggests the edaphic environment will remain favorable to *Spartina alterniflora.* Below ground root mat development has been extensive over the entire site. The lack of significant differences in mean root biomass values confirms the proliferation of below ground components of all plant species. Development of a substantial root mat is essential for stabilization and continued aerial habitat development.

The Buttermilk Sound Marsh Habitat development site has provided adequate stabilization of the deposited dredged material. The habitat continues to change as evidenced by the alteration of the species composition and dominance. Young habitats are characteristically diverse. Future changes will yield more pronounced dominance by key plants and will continue to be influenced by cyclic changes in the salinity regime as dictated by the flow of the Altamaha River.

ACKNOWLEDGMENTS

The work described in this report was conducted under contract for the U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi. Logistical support was provided by the Georgia Department of Natural Resources, Coastal Resources Division, Brunswick, Georgia.

Mrs. Kathy Smith, Brenda Sailors and Ervin Davis assisted with data compilation and analysis. Barbara Harrington and Chris Nichols provided photographic support and assistance in preparation of figures. Milledge Smith, Gail Phillips, Schelley Stamps, Steve Olsson, Joanna Butler and Jean Hunt assisted with the field work. Eleanor Waters, Lucy Peeples and Nancy Bevan assisted with the preparation of the manuscript.

Ms. Jean Hunt from the U.S. Army Corps of Engineers, Vicksburg, Mississippi served as the contract manager.

LITERATURE CITED

Barr, A. J., J. H. Goodnight, J. P. Sall and J. T. Helwig. 1976. A user's guide to SAS 76. Sparks Press, Raleigh, N.C. 329 pp.

Campbell, H. W., and A. B. Irvine. 1977. Feeding ecology of the West Indian manatee *Trichechus manatus* Linnaeus. Aquaculture 12:249-251.

Gallagher, J. L. 1974. Sampling macro-organic matter profiles in salt marsh root zones. Soil Sci. Soc. Amer., Proc. 38(1):154-155.

_________, and F. G. Plumely. 1979. Underground biomass profile and productivity in Atlantic coastal marshes. Amer. J. Bot. 66:156-161.

_________, F. G. Plumely, and P. L. Wolf. 1977. Underground biomass dynamics and substrate selective properties of Atlantic coastal salt marsh plants. U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, Tech. Rep. D-78-28, 167 pp.

_________, R. J. Reimold, R. A. Linthurst and W. J. Pfeiffer. (In press). Aerial production, mortality, and mineral accumulation dynamics in *Spartina alterniflora* and *Juncus roemerianus* in a Georgia salt marsh. (Ecology).

Odum, E. P. 1961. The role of tidal marshes in estuarine production. Conservationist 15(6):12-15.

Reimold, R. J., and R. A. Linthurst. 1977. Primary productivity of minor marsh plants in Delaware, Georgia and Maine. U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, Tech. Rep. D-77-36, 104 pp.

_______, M. A. Hardisky and P. C. Adams. 1978a. Habitat development field investigations Buttermilk Sound Marsh Development Site, Atlantic Intracoastal Waterway, Georgia. Appendix A: Propagation of marsh plants and postpropagation monitoring. U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi. Tech. Rep. D-78-26, 1498 pp.

______, M. A. Hardisky and P. C. Adams. 1978b. The effects of smothering a *Spartina alterniflora* salt marsh with dredged material. U.S. Army Waterways Experiment Station, Vicksburg, Mississippi. Tech. Rep. D-78-38, 483 pp.

Smalley, A. E. 1958. The role of two invertebrate populations, *Littorina irrorata* and *Orchelimum fidicinium* in the energy flow of a salt marsh ecosystem. Ph.D. Thesis. Univ. Ga., Athens. 126 pp.

Valiela, I., J. M. Teal and N. Y. Persson. 1976. Production and dynamics of experimentally enriched salt marsh vegetation: Belowground biomass. Limnol. and Oceanogr. 21(2):245-252.

Wolf, P. L., S. F. Shanholtzer and R. J. Reimold. 1975. Population estimates of *Uca pugnax* (Smith, 1870) on the Duplin estuary marsh, Georgia, U.S.A. Crustaceana 29(1):79-91.

AN ENVIRONMENTAL ASSESSMENT OF RESTORED SALT MARSHES IN NEW JERSEY

Stephen E. Fauer
Wetlands Ecologist
Environmental Assessment Council, Inc.
789 Jersey Avenue
New Brunswick, New Jersey 08902

and

Michael Gritzuk
Executive Director
Ocean County Utilities Authority
P. O. Box "P"
Bayville, New Jersey 08721

ABSTRACT

The Ocean County Utilities Authority (OCUA), located in Ocean County, New Jersey, was mandated by the Army Corps of Engineers to restore seven salt marshes that were to be disturbed by the installation of OCUA's regional sewer interceptors. OCUA asked its environmental consultants, the Environmental Assessment Council, Inc. (EAC) for the following: (1) an independent analysis of the relative success of the *Spartina alterniflora* and *S. patens* transplants in each salt marsh, (2) an appraisal of the success of the entire project, and (3) an evaluation of whether the project had been a "worthwhile expenditure ." These seven salt marshes were restored during the summer of 1977 and examined by EAC in January, June and July of 1978. Although the project was generally successful, certain problems resulted in the death of many transplants. The most common problem appeared to be drought induced salt accumulation followed by smothering of young transplants by *Zostera marina*.

The ecological value of some of these marshes could, however, have been improved. EAC believes that by conducting ecological surveys prior to restoration, a salt marsh can be restored which will satisfy Army Corps requirements, provide aesthetic benefits, but most importantly, satisfy the ecological needs of each individual location. This would allow for optimizing potential salt marsh productivity and its associated wildlife benefits while providing "the most salt marsh for the dollar." These goals are believed important for justifying such projects to the tax paying public.

INTRODUCTION

The Ocean County Utilities Authority, a public utility of Ocean County, New Jersey, was given the federal and state mandate of constructing and managing a regional sewerage system for Ocean Couty's populace. This regional sewerage system includes three 20+ MGD sewage treatment plants, 36 pump stations and 160 miles of interceptor lines. The overall system is a composite of three subsystems designated as the Northern, Central and Southern Service Areas. While installing interceptors for the Southern Service Area, two areas were encountered where it was deemed cost effective to place interceptors through existing salt marshes. Pursuant to Section 404 of the Federal Water Pollution Control Act, the Army Corps of Engineers mandated that all the marshes disturbed by this action be restored.

Subsequent to interceptor installation, seven salt marshes comprising a total area of 2.6 ha (6.5 acres) were restored. It is believed certain problems which occured after restoration and in part detracted from the success of this operation could have been prevented by pre-restoration ecological surveys.

AREA DESCRIPTION

Ocean County is located in southeastern New Jersey, lying approximately 80 km east of Philadelphia and 90 km south of New York City. Long Beach Island, a barrier island stretching along the seaward side of the county, separates Barnegat Bay and Little Egg Harbor from the Atlantic Ocean. Within these bays many hectares of salt marsh are found. The approximate locations of the restored marshes are denoted with asterisks in Figure 1.

In the absence of baseline descriptions, the species composition of the pre-existing marshes was inferred by reconnaissance of adjacent undisturbed marshes. Six marshes are believed to have been dominated by *Spartina patens* (Salt hay) with the following subordinate species: *Distichlis spicata* (Salt grass), *Salicornia europaea* (glasswort), *Pluchea odorata*

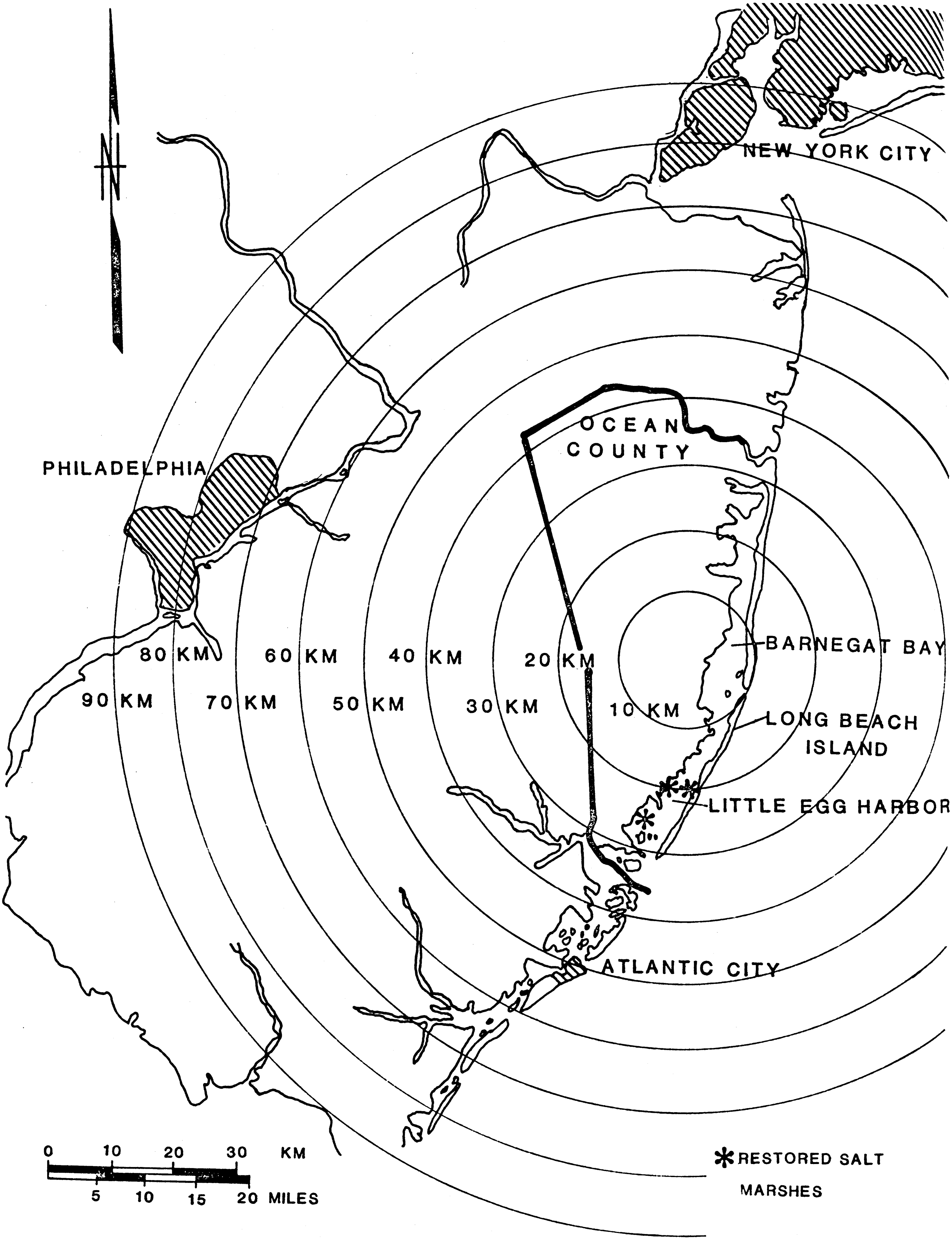


FIGURE 1 LOCATION OF OCEAN COUNTY, NEW JERSEY AND THE RESTORED SALT MARSHES

(marsh fleabane) and *Limonium carolinianum* (sea lavender). The seventh marsh had been completely dominated by *Phragmites australis* (reed grass). Some of the marshes probably supported *Baccharis halimifolia* (groundsel tree) and *Iva frutescens* (marsh elder) upon the levees adjacent to mosquito ditches.

METHODS

Restoration Procedures

After interceptor installation, clean, sandy fill was graded into the right of way (ROW). The contours of the marsh were designed to approximate pre-existing elevations. Hay bales were placed along most of the ROW's to prevent erosion of sandy material into the adjacent, undisturbed marshes.

Young peat-potted plants of cord grass and salt hay were chosen as transplant species. The placement of either species was based on the position of mean high water with relation to the elevations in the marshes. Cord grass was planted in the lower, more frequently inundated elevations while salt hay was transplanted in the higher and drier locales.

All seven marshes were restored in summer 1977. Some of these transplants died immediately and were replaced by October 1977. EAC's inspections took place in January 1978, June 1978 and May 1979.

Inspection Procedures

EAC examined the marshes both to determine the viability of the transplants and assess the ecological status of the restored marshes relative to the undisturbed marshes lying adjacent to the ROW. Viability of the transplants was determined visually during the January inspection. Although the culms of *Spartina* grasses are dead in winter, live plants were still distinguishable from dead ones. The culms of transplants which had died the previous fall were spindlier and far less robust than the culms of those plants which were still living. These observations were corroborated by inspecting the roots of selected plants to assess viability.

During the June inspection, the winter viability observations were reconfirmed and other specific parameters were examined to assist with the ecological assessment.

1. Foliar Export. Which marshes, if any, displayed the greatest foliar export? This is significant in terms of detritus contributions.
2. Erosion. If erosional forces exist which would inhibit the success of a restored salt marsh, then perhaps an alternate habitat type should be created.
3. Debris. Debris which washes into marshes can either diminish a marsh's ecological value by smothering young plants or be beneficial by acting as a mulch around the bases of older plants.
4. Succession. Are any early signs of plant succession evident? This could indicate what the marsh will ultimately look like and perhaps when.
5. Wildlife. Does the restored marsh have any wildlife associated with it? How does the marsh's wildlife value compare to that of the undisturbed marsh?

RESULTS

Foliar Export - While no quantification was attempted, it seems that these marshes are not contributing as much detritus on a per plant basis as is usual in such marshes. Cord grass culms, which are known to decompose rapidly, remained in many locales throughout the winter and into spring. Dead salt hay culms are also present among new seasons growth.

Erosion - There are no severe erosional problems. One marsh displayed localized accretion which probably resulted from shifting sands during a storm tide.

Debris - Storms tend to dislodge large amounts of benthic eel grass and, in conjunction with the concurrent storm tides, help deposit it on land. When the eel grass washes over the young *Spartina* spp. transplants, they are buried and often smothered. When the transplants have matured, however, they can withstand detrital disturbance and, in fact, are aided by it. Nylon mesh fences were erected to prevent this, but the weight of the eel grass in combination with the tidal forces eventually brought them down.

Succession - Volunteer species were found in the restored marshes in June 1978. These included *Suaeda maritima* (sea blite), *Cyperus* sp. (chuffa), glasswort, sea-lavender and reed grass. Additionally, most of the successful transplants are spreading via rhizomes and seed. Cord grass, especially, has begun to invade certain areas originally planted with salt hay. It is expected that within 5-6 years these marshes will be fully vegetated and as diverse as the pre-existing marshes.

Wildlife - Various forms of wildlife were observed in the marshes. Willets were observed in the restored marshes as well as red-wing blackbirds and mallards. Although no nests were observed, willets and redwings are known to nest in adjacent marshes. Horseshoe crabs were seen mating in the sloughs of one marsh. In these same sloughs small fish and possibly elvers were observed.

Two other items of interest were noted during the inspections. Although salt marsh restoration efforts were generally successful, two problems prevented this project from being a complete success.

1. Water stress, aggravated by the presence of excess salts, killed many of the young *Spartina* spp. transplants.

The marsh areas planted with salt hay were graded at higher elevations. These areas seemed to experience varied amounts of salt toxicity problems. Apparently, this problem resulted from high tides followed by drought. Some marshes experienced extensive salt hay mortality.

Cord grass transplants generally were unaffected by salt toxicity for two reasons. They were planted at lower elevations where the substrate was almost always moist. Therefore, in most cases, excess salts did not build up. Certain areas of cord grass were partially chlorotic, however, possibly indicating slight salt stress. Secondly, cord grass is generally more salt tolerant than salt hay. One small stand of cord grass was not inundated as frequently as the other cord grass stands. Although it did not grow as well as these other stands, it is still living as of May 1979.

2. In one restored marsh where *Spartina patens* was planted, an alternate species selection would have been appropriate.

One salt marsh was previously vegetated with a pure stand of reed grass. When it was restored, salt hay was planted. The salt hay is growing extremely well and, in fact, when compared to the other six marshes, is very successful. There are several factors, however, which detract from the success of this marsh. Normally, there is no tidal inundation on site. Therefore, there is no detrital export. Secondly, the reed grass began to reinvade the site even as the salt hay was being planted. Thus, in five years, one can expect to see reed grass dominating the site.

DISCUSSION AND CONCLUSIONS

Generally, those portions of the restored marshes which received ample moisture supported the healthiest vegetation. The moist conditions prevented the accumulation of excess salts. These areas were in swales, adjacent to hay bales or where eel grass acted as a mulch.

In those marshes where both salt hay and cord grass were planted, generally the cord grass (which was planted in swales) grew better than the salt hay. These plants have spread out and completely filled in their habitat. Other cord grass plants,which were either higher in elevation or subject to minor accretion, did not grow as well.

Salt hay growing next to hay bales and salt hay implants that survived the intrusion of eel grass debris both grew well. In the former situation, the hay bales act as sponges, slowly releasing rain water to the soil. In the latter situation, when eel grass wraps around a mature plant,it acts like a mulch reducing evaporation from the soil around the plant.

The salt hay growing without the influence of inundation also grew extremely well. In this instance, the absence of salts allows these plants to grow in an almost fresh water environment.

Generally, foliar export appeared to be poor. Removal of dead cord grass, known to contribute significantly to the estuarine detritus pool when growing along the water's edge (Nadeau, 1972), was very poor. Although the transplanted cord grass was growing very well in swales and along newly created sloughs, the tidal action is apparently insufficient to effect foliar export. Thus, while the cord grass is growing well, to date it does not seem to be contributing much detritus.

When this project was conceptualized, environmental consultants were not fully cognizant of ecological problem solving methodologies, especially the value of baseline data. It is the authors' contention that many of the above highlighted problems could have been avoided had ecological surveys been performed prior to interceptor installation. One should decide how the marsh is to be restored based on existing conditions and the ecological needs of the area. A marsh can be planted for (a) optimum detritus production, (b) cosmetic re-creation of the original marsh (c) wildlife benefits, or (d) simply for substrate stabilization. By performing ecological assessments of the original, undisturbed marshes, one can make a judgement (based on the previously mentioned parameters) that will result in a marsh that is compatible with the existing environment. Through the federal and state construction grants program, the OCUA paid $76,334. for restoring 2.6 hectares. As a result, there should be some assurance that these marshes are fulfilling a role other than placating the Army Corps of Engineers.

When planning to restore a salt marsh, the following decisions need to be made in terms of the final product and costs.

1. How many species should be planted in a restored marsh? The authors believe if one herbaceous species were planted per marsh, time and money could be saved if the marsh could be graded to essentially one uniform elevation. Either salt hay or cord grass could be grown successfully in monotypic stands. Since salt hay is generally more conducive to wildlife (especially birds) than cord grass, but cord grass is a better detritus producer than salt hay, one preference is a matter of providing what the study area calls for, either wildlife habitat or detritus production. It should be noted that planting monotypic stands presents no problem to the biological equilibrium of the study area. As indicated earlier, the diversity of these marshes increase naturally.

If one wishes to restore a salt marsh to further increase wildlife utilization, a combination of salt hay, marsh elder or groundsel tree and sloughs is recommended. Shisler, et al. (1978) have shown that in Ocean County, New Jersey a combination of salt hay and marsh elder (growing upon the levees of the mosquito ditches) provides "...nesting and foraging sites for various species of birds, and islands of refuge for small mammals and birds." Nesting birds specifically mentioned were red-wing blackbirds, sharptail sparrows, marsh wrens, and northern clapper rails. Additionally, Post (1974) as reported by Shisler, et al. (1978) showed that seaside sparrows consistently use marsh elder as a foraging site.

2. What species should be selected for restoration? To help decide between planting for detritus production, cosmetic restoration or substrate stabilization, one should evaluate the pre-existing marshes. Although detritus production from vascular plants is important, current research indicates (Correll,1978; Sirois and Frederick, 1978) "...that the upland and tidal marsh communities are not as important sources of estuarine organic matter as scientists previously believed them to be." (Correll, 1978). Phytoplankton are the chief contributors of organic matter in estuarine ecosystems. Submerged vascular plants, periphyton and benthic algae are secondary contributors which vary in their significance with respect to water depth, bottom contours,

turbidity, etc. Therefore, unless it is desired or favorable to plant cord grass, more value in terms of wildlife and substrate stabilization can be derived from planting salt hay.

The final consideration in species selection is compatibility with its surroundings. In one situation, salt hay was planted in what had been a *Phragmites* marsh. This was an unnecessary expense. Because there is no inundation here, an alternative species could have been planted which stabilized the soil as well as salt hay. Table 1 provides some alternative species suggestions for restoration purposes when substrate stabilization is the chief concern. In this example, any of a number of species could have been planted as seed and then mulched with hay. This would have stabilized the substrate efficiently until reed grass reinvaded the site. In this situation, the reinvasion of reed grass is inevitable unless the habitat becomes more hydric. While water or moist soil enhances reed grass' ability to invade a site and stimulates bud development (Kadlec and Wentz, 1974), this plant "...will not grow in permanent water or tolerate even temporary water depths over 15 cm." (Ward 1942, as reported in Kadlec and Wetnz, 1974).

In summary, the success of the *Spartina* transplants was generally good. A walk-through performed May 1979 revealed that all the marshes are adequately stabilized. Areas that had suffered salt toxicity problems have begun to recover. Additionally, cord grass is beginning to spread into new areas formerly transplanted

Table 1

RELATIVE SALT TOLERANCE OF GRASSES AND FORAGE LEGUMES

TOLERANT (12-6 MMHOS)[1]	MODERATELY TOLERANT (6-3 MMHOS)	SENSITIVE (3-2 MMHOS)
Alkali sacaton - *Sporobolus airoides*	White sweetclover - *Melilotus alba*	White Dutch clover - *Trifolium repens*
Saltgrass - *Distichlis stricta*	Yellow sweetclover - *Melilotus officinalis*	Meadow foxtail - *Alopecurus pratensis*
Nuttall alkali-grass - *Puccinellia nuttalliana*	Perrennial ryegrass - *Lolium perenne*	Alsike clover - *Trifolium hybridum*
Bermuda grass - *Cynodon dactylon*	Mountain brome - *Bromus marginatus*	Red clover - *Trifolium pratense*
Tall wheatgrass - *Agropryron elongatum*	Harding grass - *Phalaris tuberosa var. stenoptera*	Ladino clover - *Trifolium repens forma giganteum*
Rhodes grass - *Chloris gayana*	Beardless wildrye - *Elymus triticoides*	Burnet - *Sanguisorba minor*
Rescue grass - *Bromus catharticus*	Strawberry clover - *Trifolium fragiferum*	
Canada wildrye - *Elymus canadensis*	Dallis grass - *Paspalum dilatatum*	
Western wheatgrass - *Agropyron smithii*	Sudan grass - *Sorghum sudanense*	
Tall fescue - *Festuca arundinacea*	Hubam clover - *Melilotus alba var. annua*	
Barley (hay) - *Hordeum vulgare*	Alfalfa - *Medicago sativa*	
Birdsfoot trefoil - *Lotus corniculatus*	Rye (hay) - *Triticum aestivum*	
	Oats (hay) - *Avena sativa*	
	Orchard grass - *Dactylis glomerata*	
	Blue grama - *Bouteloua gracilis*	
	Meadow fescue - *Festuca elatior*	
	Reed canary - *Phalaris arundinacea*	
	Big trefoil - *Lotus uliginosus*	
	Smooth brome - *Bromus inermis*	
	Tall meadow oatgrass - *Arrhenatherum elatius*	
	Milkvetch - *Astragalus species*	
	Sourclover - *Melilotus indica*	

---

[1] Millimhos (MMHOS) is a measure of conductivity; an indication of the amount of salts in solution. Mathematically it is the reciprocal of resistance (i.e., ohms).

Source: Hanes, et al., 1970

with salt hay and salt hay is also beginning to spread. New growth has originated from both rhizomes and seed.

The restoration efforts have successfully re-established the salt marshes. The prime assets of these marshes are believed to be (in decreasing order) (1) they are aesthetically pleasing, (2) the chance of erosion has significantly decreased and (3) wildlife habitat has been re-established. Wildlife value could have been increased by transplanting either marsh elder or groundsel tree. As these marshes mature, they will eventually blend into their surroundings and, barring unforeseen disturbances, will remain in a natural biotic state forever. Therefore, the authors deem these restoration efforts a worthwhile expenditure.

Six of the seven restored marshes are considered worthwhile epxenditures because of the attributes outlined above. The former reed grass marsh, while supporting successful transplants, was restored with an inappropriate species (salt hay). Since the reed grass is rapidly out-competing the salt hay, this expenditure is believed wasteful. By planting an alternate species, a good deal of money could have been saved.

In summary, some recommendations have been presented which may reduce the cost of salt marsh restoration and could insure that the restored marshes will blend into the surrounding ecosystem and/or contribute necessary amenities to the environment. The decisions should be based upon ecological analyses and observations performed prior to disturbance. Additionally, if possible, one herbaceous species should be planted per restored marsh to save time and money in grading and planting.

ACKNOWLEDGEMENTS

The authors wish to thank Mr. Tom Glenn and Dr. John Koppen of the Environmental Assessment Council, Inc. for their critical review of the manuscript. Mr. David Siddons of the Ocean County Utilities Authority is to be thanked for his engineering support and general assistance in the preparation of this manuscript.

LITERATURE CITED

Correll, David L. 1978. Estuarine Productivity. BioScience 28(10): 646-650.

Hanes, R.E., L.W. Zelazny, and R.E. Blaser. 1970. Effects of Deicing Salts on Water Quality and Biota. National Cooperative Highway Research Program. Report 91. Highway Research Board, National Academy of Sciences, 2101 Constitution Avenue, Washington, D.C. 20418.

Kadlec, J.A. and W.A. Wetnz. 1974. State-of-the-Art Survey and Evaluation of Marsh Plant Establishment Techniques: Induced and Natural. Prepared for U.S. Army Waterways Experiment Station. Corps of Engineers. Vicksburg, Mississippi 39180.

Nadeau, Royal J. 1972. Primary production and export of plant materials in the salt marsh ecosystem. Ph.D. Thesis. Rutgers University, New Brunswick, New Jersey. 175 pp. (Diss. Abstr. 33:1504-B).

Post, W. 1974. Functional analysis of space-related behavoir in the seaside sparrow. Ecology. (55): 564-575.

Shisler, J.K., T.L. Schulze and B.L. Howes. 1978. The effect of the marsh elder (*Iva frutescens*) on the standing crop biomass of *Spartina patens* and associated wildlife. Biol. Conserv. (14): 159-166.

Sirois, D.L. AND S.W. Frederick. 1978. Phytoplankton and primary production in the lower Hudson River estuary. Estuarine and Coastal Marine Science (7): 413-423.

Ward, E. 1942. Phragmites Management. Trans. N. Am. Wildlife Conf. (7): 294-298.

AN ANALYSIS OF THREE MARSH-CREATION PROJECTS IN TAMPA BAY RESULTING FROM REGULATORY REQUIREMENTS FOR MITIGATION

William K. Fehring and Carl Giovenco
Department of Environmental Affairs

Tampa Port Authority
Tampa, Florida

and

William Hoffman
Tampa Marine Institute, Inc.
Tampa, Florida

ABSTRACT

Increasing environmental concern and governmental regulations over projects which impact wetlands have resulted in a sharp increase in situations where such impact is supposed to be mitigated through the creation of new wetlands. Three such projects in the Tampa area are examined:

1. The planting of red mangrove seedlings in front of residential seawalls in Apollo Beach.
2. The transplanting of Spartina plugs to create a small marsh in Neptune Lagoon.
3. The transplanting of black mangroves and Spartina to create some two hectares of marsh on spoil islands in Hillsborough Bay.

The probable success of each of these projects is discussed in terms of the nature of the responsible organization, ownership of the project site, social acceptance of the project, technique used in planting, and physical factors such as wave energy, elevation, and temperature.

INTRODUCTION

Over the past few years, increasing pressure for "balance" between environmental protection and economic development has forced regulatory agencies to turn increasingly to the use of mitigation to achieve acceptable compromises in permit negotiations. In the area of dredge and fill, such mitigation has often taken the form of marsh-creation projects. The concept and designs for these projects have come from a limited number of experimental or prototype projects reported at conferences such as this one.

Because there are often considerable sums of money involved in the mitigation projects themselves, in the modifications to project designs, and in the delays resulting from extended negotiations between applicants and regulatory agencies, there is a need to assess the effectiveness of marsh-creation as a regulatory tool. The purpose of this paper is to examine three such projects, comparing the expectations of the regulatory agencies with the actual results to date.

APOLLO BEACH SITE

Area Description

In 1973 Frandorson Properties applied to the Tampa Port Authority and other agencies for a permit to construct some 854 m of vertical concrete seawall. Due to erosion which had occurred over several years, placement of the seawall on the property lines required the backfilling of a strip of submerged lands up to 8 m wide and approximately 580 m long. The existing shoreline was lined by black and white mangroves up to 1 m in height and supported oyster beds in the adjacent shallows.

Regulatory personnel and local environmentalists opposed the proposed filling and recommended that any structure be placed above the mangroves. The developers contended that such a change would make the lots too small for

for waterfront homes. In order to break a long-standing deadlock on the issue, the Authority staff proposed that the developers relocate the proposed wall shoreward five feet and construct a rip-rap protected berm, planted with mangroves, along the southerly 260 m of the wall. An additional 213 m of shoreline was to be planted with mangroves without the berm. This was the first mitigation project required by the Authority and its purpose was to re-create a vegetated shoreline and the associated biological communities outside the new seawall. The relocation of the proposed wall also left an additional 107 m of the existing shoreline below the the proposed wall alignment. It was thought that this shoreline would not be disturbed by the construction of the wall.

Project approval was granted in the fall of 1974 and the seawall was installed during the summer of 1975. During construction all the vegetation along the entire 854 m shoreline was destroyed, including the 107 m area which was to be undisturbed. Following the completion of the wall, the lots were sold and homes constructed. No work on the vegetated berm was undertaken for several years. While the motives of the developers were not clear, the impression was created that they were hoping that the requirement would be forgotten. In 1976 the permit for the seawall work expired.

In the meantime, residents began to move into the area unaware of the mitigation requirement. A set of boat davits and two docks appeared along the seawall. In order to prevent undue disruption of residents and to force the developers to complete the mitigation, the Authority was forced in 1977 to establish a ban on residential docks in the area until the work was completed. The developers agreed to accept a one-year extension of the permit, beginning January 1, 1978, during which time they were to complete the required work. By this time, there were numerous residences along this area.

Methods and Materials

At the urging of the Authority, the developers obtained recommendations from an environmental consultant regarding how to accomplish the work. These recommendations included:

1) Establishing a low protective wall with cement-sand bags
2) Raising the level of the berm behind the sandbags to the level of mean high water
3) Transplanting 1 to 3-year old black mangroves from nearby areas within the development and placing them at 1 meter intervals along the berm.

In the late spring of 1978, the developers undertook the work using the services and manpower of their seawall contractor who had no experience in this type of work. First, bags of dry sand and cement mix were filled on site and placed in a row one meter out from the wall. These bags were piled three-to-four courses high in a somewhat random manner. The sand-cement mix was supposed to cure and harden, once thoroughly soaked. The bags were not pinned together nor was filter cloth placed under the bags.

Next, visquine was placed along the inside of the bags to prevent sand from escaping through the structure. Visquine was also placed over a considerable portion of the area to be filled. The Authority had recommended that filter cloth be used for this purpose. Fill dirt from the uplands was then placed behind the breakwater and leveled.

In late May, the Authority was told that the mangroves for the berm had "arrived" at Apollo Beach. An inspection on site disclosed that the developers had acquired red mangroves seedlings, Rhizophora mangle L., from the Division of Forestry. Ignoring the recommendations of their consultant, they proceeded to plant these red mangrove seedlings at 1 m intervals along the berm on June 6, 1978. The seedlings were planted in the plastic containers in which they were received. Forestry officials had supposedly stated that the seedlings would grow out of the containers without problems. The elevation of the berm varied considerably, with many of the seedlings planted at elevations as much as 0.15 m below mean high water. A total of 275 seedlings were planted along the berm, but only 100 were planted in the area north of the berm.

Results

Reinspection of the site two days later uncovered the first of many problems to be encountered. Residents were angry about the project, stating that "those damned plants" would breed mosquitos and would block their view of the bay. Already numerous seedlings had been knocked over or stepped on by children and dogs playing on the berm. One woman complained that she could no longer keep her dogs contained in her back yard. Another resident complained that the berm prevented him from using his boat davits.

The project was next inspected two months later at a time when the tide was quite high. Only 182 seedlings were counted, but those which remained appeared healthy even though they had been consistently flooded by high summer tides.

By early September, deterioration of the sandbags had begun to appear. Some bags were found to have fallen from the breakwater, and the sand behind these areas had washed out. A count taken at low tide found 210 seedlings remaining, but only three of these were found in the area without the berm. Some of the plants remaining appeared to be washing out, but many were apparently undisturbed, as illustrated in Figure 1. The primary loss, up to this point, appeared to be disturbance by children and dogs and the clearly evident removal of seedlings by adjacent property owners.

The developers did perform some replacement of the deteriorated bags during this period, but deterioration of the revetment continued. In mid-October, 205 seedlings were still surviving, all but one of them up on the berm. Many of the seedlings now had new sets of leaves and the stalks of some of those that had been broken off showed new growth.

By the end of November an entire new course of bags had been added to the breakwater, for it was now obvious that without filter cloth under them the bags were slowly sinking into the sand. A great number of plants had been washed away by the increasingly heavy winter wave action. Those plants which had not washed away appeared to be quite healthy.

A severe storm in early December knocked many of the bags over and washed away many of the remaining plants. An even more severe storm occurred in early January and applied the final touches to the failure of the project. Bags were ripped apart and the few seedlings still present were uprooted and scattered, as shown in Figure 2. The plants still on the project site showed little lateral root growth due to the restriction caused by the plastic pots. The bags installed in November were found to be so soft they could be broken apart by hand.

Since January the Authority has been trying to convince the developer to reconstruct the project using *Spartina alterniflora* rather than mangroves and a solid concrete cap on the breakwater. The developer has balked at this suggestion citing the opposition of local residents and the fact that they have already spent over $30,000 on this project with no appreciable results. The latest discussions have concerned placing the sandbags as rip-rap against the seawall and creating a small marsh in an undeveloped section of the subdivision to replace the habitat lost in 1975.

NEPTUNE LAGOON SITE

Area Description

In 1975, the City of Tampa applied for a permit to maintenance dredge some 9,175 cubic meters of silt from two small lagoons which lie between the city storm sewers and a residential canal system in the Westshore area of the city. As part of the project, the city proposed to widen the roadside berm which bordered the lagoon by filling in from 3 to 6 m of submerged land along an area 80 m in

Figure 1. The berm at Apollo Beach 3 months after planting. Note deterioration of the sandbags and the plastic collars on the seedlings.

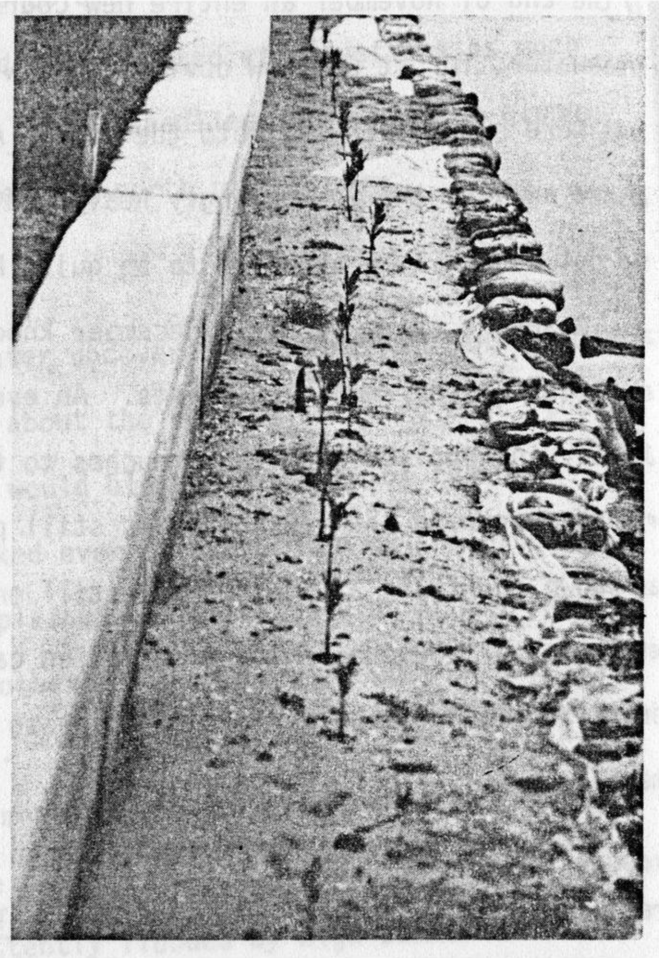
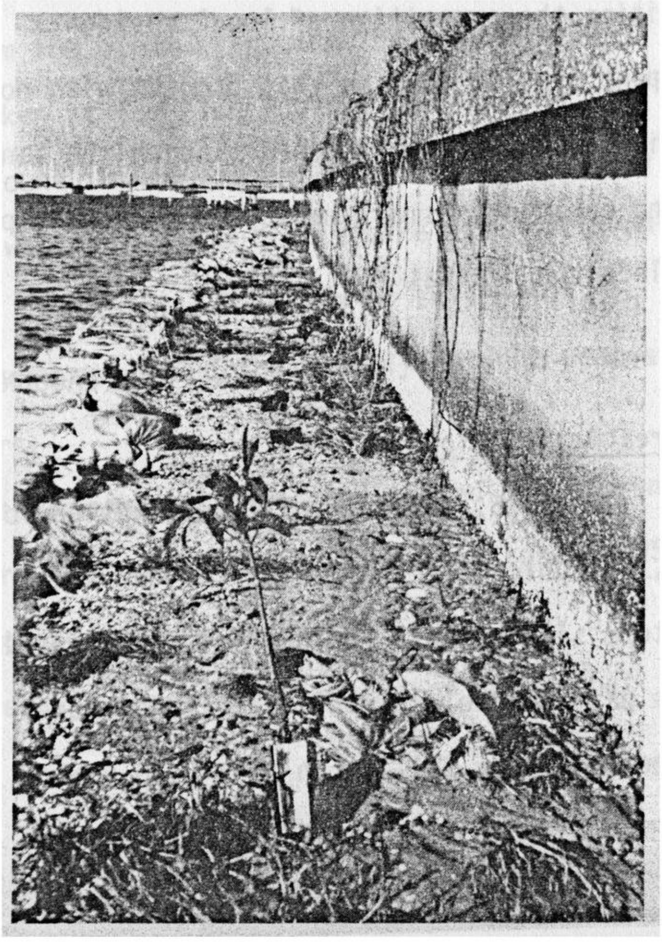


Figure 2. The berm following a storm in early January. No mangroves remained planted. Note the lack of roots extending from the plastic collars after 7 months of growth.



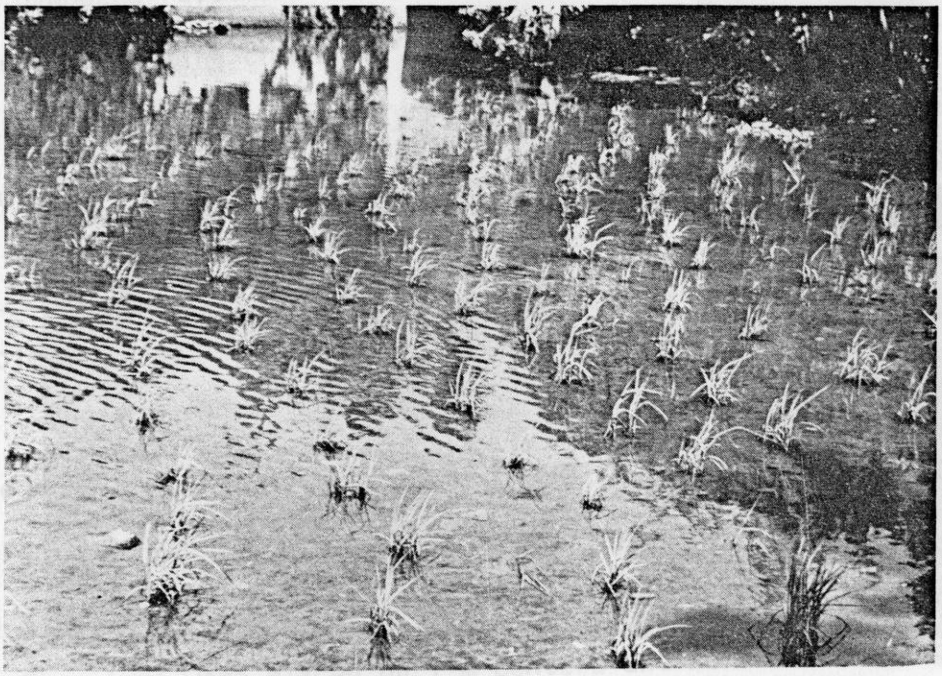


Figure 3. The transplanted Spartina plugs in the lower lagoon at Neptune Beach.

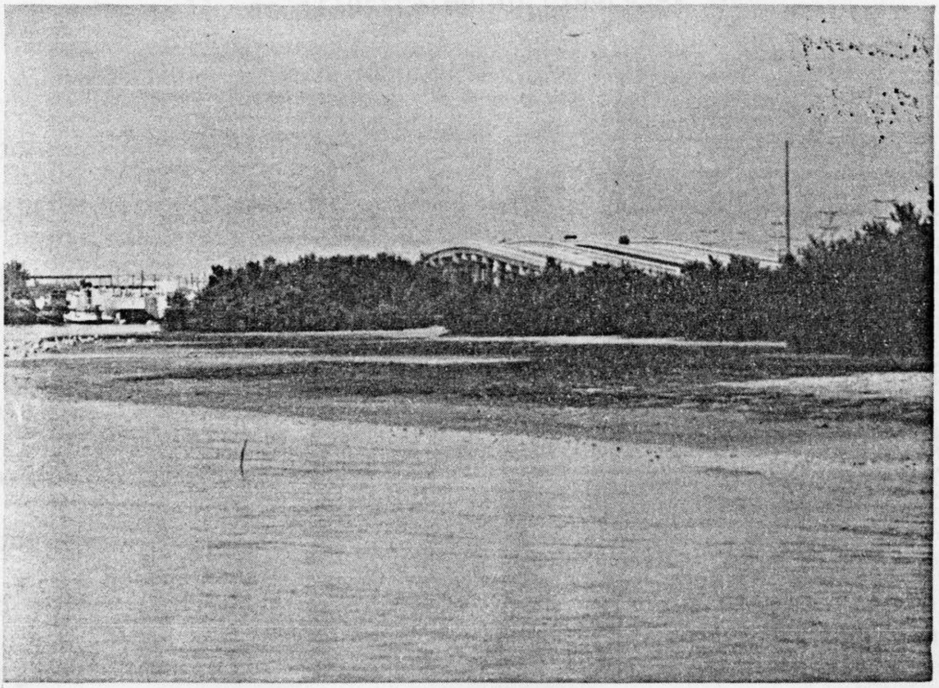


Figure 4. The site of the proposed shrimp facility along the 22nd Street Causeway.

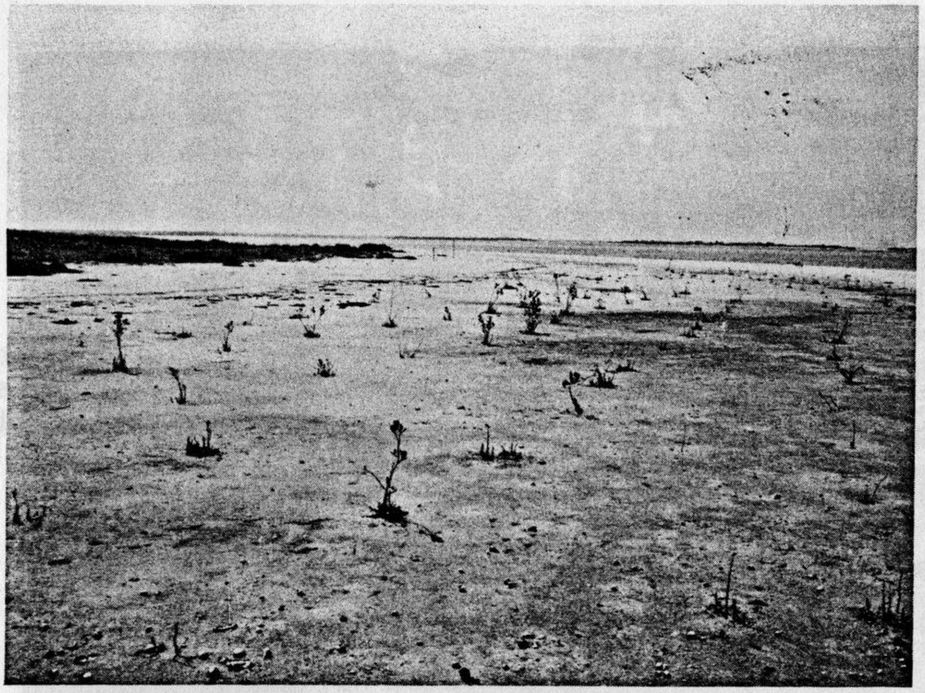


Figure 5. Recently transplanted black mangroves along the shore of the Hillsborough Bay spoil island.

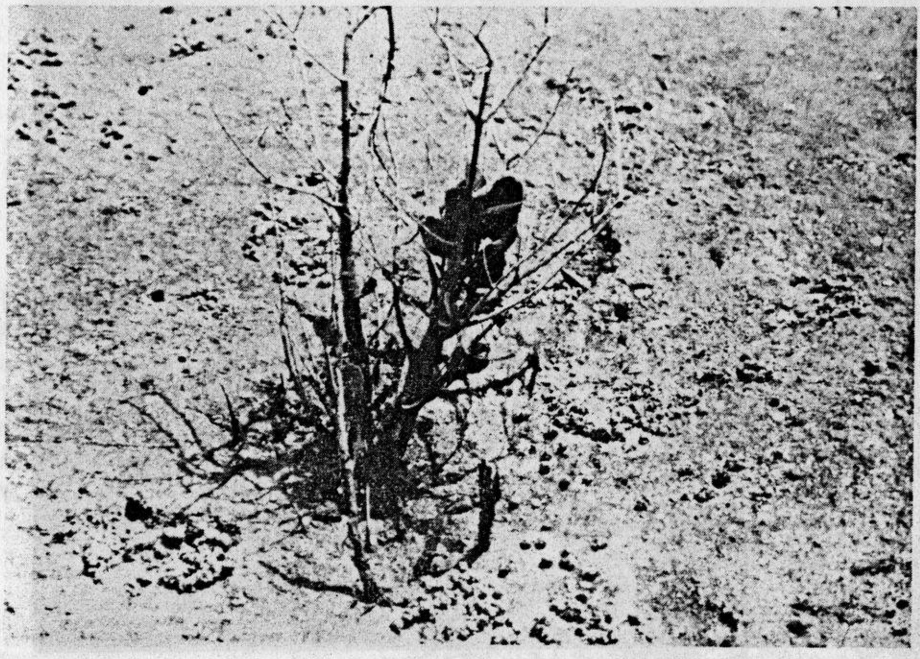


Figure 6. New growth of leaves emerging from the base of a transplanted white mangrove on the spoil island.

length. The proposed revetment along this berm precluded the possibility of replacing the pre-existing community of small mangroves along the new shoreline. To replace the lost habitat, the city agreed to create two small Spartina marshes within the lagoons. The project was started in the fall of 1978.

Methods and Materials

The project contractor created a berm in each lagoon using a portion of the dredged material. The elevation of the berms was supposed to be 0.25 m (msl), while mean high water in the area is approximately +.47 m (msl). In December 1978, the Tampa Marine Institute transplanted approximately 700 plugs of *Spartina alterniflora* to these berms from a marsh at the north end of Old Tampa Bay. The plugs were placed on 1 m centers and were moved using posthole diggers. While the overall project cost was $135,000, the marsh creation cost was less than $5,000.

Results

Inspections during February, March, and April found the plugs in the lower lagoon doing quite well, as illustrated in Figure 3. While no lateral shoots had appeared, good vertical growth was observed. However, most of the plugs in the upper lagoon had died or were doing very poorly. A check of water quality found no difference between the lagoons, but it was found that the plugs in the upper lagoon were planted an average of 7 cm lower than those in the lower lagoon. Apparently, the resulting difference in inundation was enough to cause almost total failure in one area and success in the other. It should be noted that even in the lower lagoon the tallest plugs were found at the higher elevations along the edge of the road.

Informal discussions have been held with the city regarding raising and replanting the berm in the upper lagoon. Before this might happen, however, it will be necessary to determine the actual elevations of both berms and compare this to the tidal regime in the area.

SHRIMP FACILITY SITE

Area Description

The final project we wish to present involves a facility proposed by the Port Authority for the docking of shrimp boats and packing of shrimp. To accomodate expansion of a local shipyard, the existing shrimp docks along abandoned World War II Drydocks had to be replaced. The only feasible location was determined to be the shore of an old fill site created for a road causeway and expanded by disposal from a local flood-control project. While the last spoil disposal on this site occurred only 10 years ago, the area supports a healthy fringe of black mangroves, Avicennia germinans L., and a productive intertidal area. The area is shown in Figure 4.

The Authority started with a plan which would have involved some 5.25 hectares of intertidal or sub-tidal land. The regulatory agencies involved required hectare for hectare replacement of the habitat to be destroyed. While there are great expanses of new spoil islands nearby, there was not sufficient area on which the Authority could claim sole responsibility for marsh-creation to replace all 5.25 hectares. Therefore, half the project was deleted until some future date, and the Authority agreed to create 2 hectares of new marsh.

This work is to be accomplished on three spoil islands in Hillsborough Bay. The primary site is a small new spoil island created by the Tampa Harbor Deepening Project. This island, approximately 4.5 hectares in area, was created for wildlife usage and is protected from severe wave action by a 365 hectare disposal island nearby. The shore of the large island was not available to the Authority because the Corps of Engineers is committed to planting that area. The second site to be used is the interior lagoon of an old spoil island in the Big Bend area. If necessary, a third site will be a spit on Bird Island, an Audubon sanctuary near the Alafia River.

Methods and Materials

These marsh areas are to be created first by transplanting all available young mangroves from the project site and later by transplanting *Spartina* plugs from nearby marshes. This work is being done by the Young Adult Conservation Corps program of the Tampa Marine Institute and the environmental staff of the Authority. The mangrove transplanting has to be completed before the project site can be cleared and was started on January 16, 1979. The construction project will not begin until late 1979. Transplanting was started during the winter, with the expectation that the plants would be essentially dormant during the cold weather and, therefore, less likely to suffer shock from transplanting.

Initially, trees of approximately .5 m were pruned to 2/3 of their height, dug up with shovels, rootballed using burlap bags, and transported to the new spoil island by boat. Most of the trees were black mangroves, but some white mangroves, *Laguncularia racemosa* L., were moved. These trees were mostly found at elevations above mean high water and had limited pneumatophore development. With few exceptions, the trees were transplanted within three hours.

The initial set of trees were planted in rows on 2 meter centers from 0.15 m above mean high water (+0.73 m mlw) down to 0.15 m below mean high water across a small lagoon. This elevation was chosen because it represents the most common range for black mangroves in this area. Due to the numbers of trees involved, no attempt was made to match initial and transplanted elevations for individual trees. Since the island was nearly a year old, the soil was well compacted and appeared similar to other mangrove areas. By mid-February the crew had been able to work 7 days and plant 446 trees. The plantings had crossed the lagoon and were now being placed along a large tidal flat on the southwest part of the island. This area is shown in Figure 5. This area is well protected from wind-waves and ship wakes by the adjacent disposal island. Those trees planted earlier were already showing great individual differences in leaf loss and apparent viability.

Results

Progress on the project was severely limited by weather and by the limited availability of the planting crew. By mid-May, 946 trees had been moved in a total of 15 working days. This represented less than 20% of the required area of new marsh. With the warming of the weather, progress on the mangrove transplanting portion of the project improved and this work will be completed some time this summer. The transplanting of Spartina to create the balance of the required 2 hectares of marsh will begin at that time.

The viability of the transplanted trees is of considerable concern. By mid-April, a casual glance at the earliest plantings appeared to show a complete failure of the project. Almost all of these trees had lost their leaves. However, on closer inspection, a number of trees, particularly those planted at higher elevations, showed new growth and many were still green under the bark.

By mid-May, this regeneration had become much more obvious. Numerous trees showed new leaves growing from the base of the trunk as shown in Figure 6. Of the first 100 trees planted mostly above mean high water, 34 showed this new growth. However, only 5 of the second 100, planted below mean high water in the lagoon, exhibited any regeneration. It appears that transplanting to a more inundated area will not be successful, due most likely to the lack of pneumatophores on these particular trees. This area will be replanted with Spartina during the summer months to create a mixed marsh.

Other factors which appear to be influencing the viability of the transplants are transpiration during transit to the spoil site, temperature, and the size of the trees moved. It is suspected that the strong winds created by the boat's speed may be increasing the transpiration of the trees, thereby increasing the mortality resulting from root damage. Efforts are now being made to reduce this wind exposure.

With the onset of warmer spring and summer weather, it was also observed that the transplanted trees showed less leaf-loss and generally greater survival at all elevations. Apparently, any tendency toward winter dormancy did not compensate for the increased exposure to cold shock suffered by those trees moved in January and February. Future transplanting of this nature will be scheduled for the summer months.

It has also been noted that the larger trees which have been moved, 0.5 to 2 m in height, are clearly doing better as a group than smaller trees. Some, in fact, are flowering at present and may produce seeds this fall. This difference was not expected, since the smaller trees can be moved with a larger proportion of their root system. However, in light of this observation an additional sweep through the project for larger trees will be made before this portion of the project is ended.

DISCUSSION AND CONCLUSIONS

All three of these projects have experienced technical problems such as the breakwater construction at Apollo Beach, the elevation of the berm in Neptune Lagoon, and the elevation of transplants on the spoil island. Problems such as these, however, can be overcome by increased experience with this type of work on the part of regulatory personnel, consultants, and contractors. We now know that filter cloth should have been placed under the sandbags and the berm at Apollo Beach to keep the bags from settling and to provide support for root systems. We know that a solid concrete cap, interlocking pins, and bags filled with wet concrete made with fresh water were needed to prevent the breakwater from being knocked apart. We also suspect that Spartina would have been a better choice than mangroves because it spreads more quickly and reaches a lower height at maturity.

However, the Apollo Beach project had several problems not shared by the others. Among these were the reluctance of the developer to undertake the project expeditiously and to obtain and use the expert assistance needed to complete the project successfully. By the time the project was undertaken, the area of the berm was owned by the adjacent upland owners and the only real tools the Port Authority had at its disposal to get the work done were bluffs and threats regarding future permits the developer would need in other parts of the subdivision. This delay also created social problems of community acceptance and assistance during the formative part of the project. Because the developer would have no future interest in the area, the cheapest approach to get the Port Authority "off their backs" was used.

In comparison, the marsh in Neptune Lagoon was designed to trap some sediment from road run-off before it entered the water. The berms were designed in part to increase the velocity of water flow and decrease siltation in the lagoons. The marsh was made an integral part of the project.

The Port Authority owns the submerged lands and spoil islands in Hillsborough County and will do so for the foreseeable future. The mangrove transplanting project is and will be part of a much larger resource management program involving many other spoil islands. It is anticipated that this will eventually include many times the 2-hectare area of marsh involved in the shrimp facility project described here.

In conclusion, our experience tends to support, perhaps unfortunately, the present policy of state and federal agencies regarding the use of mitigation as a regulatory tool. Such techniques as marsh-replacement are generally restricted to "public" projects where long-term responsibility for, and management of, the newly created resource is available. Until such time as private land developers can assure the same type of long-term committment to the success of the project, the use of this type of mitigation in their permits may not be advisable.

PLANTINGS OF RED MANGROVES (*RHIZOPHORA MANGLE L.*) FOR STABILIZATION OF MARL SHORELINES IN THE FLORIDA KEYS

by

Harold W. Goforth, Jr.
Chemistry and Biochemistry Branch
Marine Sciences Division
Naval Ocean Systems Center
San Diego, California 92152

and

Jack R. Thomas
Environmental Marine Sciences Program
Florida Keys Community College
Key West, Florida 33040

ABSTRACT

Shoreline stabilization using mangrove plantings offers an environmentally and economically superior alternative to the construction of seawalls, riprap, etc. Three developmental stages of red mangroves (i.e., propagules, seedlings and small trees) were planted to provide erosion protection along three separate sections of marl shoreline at Key West, Florida.

Mangrove propagules ("beans") which were carefully removed from mature fruits or collected from shoreline debris exhibited the greatest vertical growth. However, survival of this stage ranged from 86-14% ($\overline{x}$ = 45%) and was inversely related to the degree of shoreline exposure. Seedlings (approximately 1 year old) did not exhibit a significantly greater survival rate ($\overline{x}$ = 48%) or vertical growth than propagules. Transplants of small mangrove trees (i.e., approximately 2-3 years old) were highly successful on all three shorelines exhibiting an average survival of 98% after 23 months. Degree of exposure to erosion and/or burial proved more important in determining seedling survival than either of the organic amendments or tidal heights tested. Using a power auger to bore holes and seagrass wrack as mulch proved to be an effective and economical method of planting all three developmental stages of red mangroves along organically deficient marl shorelines. However, marl shorelines exposed to moderate wave, tidal, or wind action are best planted with small mangrove trees to insure transplant survival and erosion protection.

INTRODUCTION

Three species of mangroves (*Avicennia germinans, Laguncularia racemosa,* and *Rhizophora mangle*) grow throughout the Florida Keys and provide a natural barrier to erosion forces along undisturbed shorelines. Mangroves are acknowledged as significant contributors to nature's land building process (Davis, 1940; Savage, 1972; Carlton, 1974) even though their role in this process may have been previously over emphasized (Thom, 1967). Nature's land building pace however, has often been too slow for modern man who has often resorted to land fill operations to "reclaim and develop" wetlands in southern Florida (Passavant and Jefferson, 1976; Teas et al, 1976). Seawalls and riprap are typically used as substitutes for mangroves to stabilize the shorelines of these newly created plots of land. Unfortunately, seawalls and riprap cannot substitute for mangroves in their diverse biological role as a source of detritus and habitat for a variety of animals (Heald and Odum, 1969; Teas,1976). In recognition of this fact, a number of studies have been conducted in recent years to develop transplanting techniques for all three species of Florida mangroves (Savage, 1972 & 1978; Hannan, 1975; Pulver, 1975 & 1976; Teas et al, 1975 & 1978; Lewis and Dunstan, 1976; Evans, 1977; Teas, 1977). These studies reveal the primary determinants of transplant survival and optimal growth to be: (a) tidal elevation, (b) wave energy, (c) salinity and organic content of the substrate, and (d) human interference*. Savage (1972) concluded that the black mangrove (*Avicennia germinans*) offered greater potential for statewide shoreline rehabilitation projects due to its extensive pneumataphore development and wider geographical distribution. In southern Florida however, the

---

*and to this add unidentified mangrove-eating animals as reported for St. Croix, Virgin Islands (Lewis, elsewhere in this publication).

red mangrove (*Rhizophora mangle*) is frequently used for shoreline transplant projects because of its local dominance and the ready availability of transplant stock.

This transplant project was conducted to satisfy a mitigation requirement for the loss of 70 meters of red mangrove shoreline resulting from a construction project at the Florida Keys Community College (FKCC), Stock Island, Key West, Florida. Since the primary goal of this project was to re-establish a red mangrove shoreline, the study was designed to employ techniques which would increase the probability of transplant success. Additionally, a secondary goal was to test these techniques under several experimental conditions. Within this context the study was designed to determine the relative success of: (a) three developmental stages of red mangrove transplant stock, (b) two tidal heights, (c) two organic amendments and (d) three degrees of exposure to erosion forces.

AREA DESCRIPTION

The transplant sites for this study were located on the campus of Florida Keys Community College at Stock Island, Key West, Florida. Figure 1 shows the three marl shorelines (Sites A, B and C) which were utilized as transplant sites in this study. The three shorelines had experienced varying degrees of erosion and only limited natural recruitment of mangroves during the ten years since placement of the marl fill. Figure 1 also shows the average annual wind velocity and frequency for Key West over a 25-year period (Boylan, 1974). Site A faced south and was "protected" on three sides by adjacent land masses and received only limited wind wave action. Site B faced east and was "exposed" to the greatest wind wave action and as a result was eroding more rapidly than either of the other two shorelines. Site C faced north and was

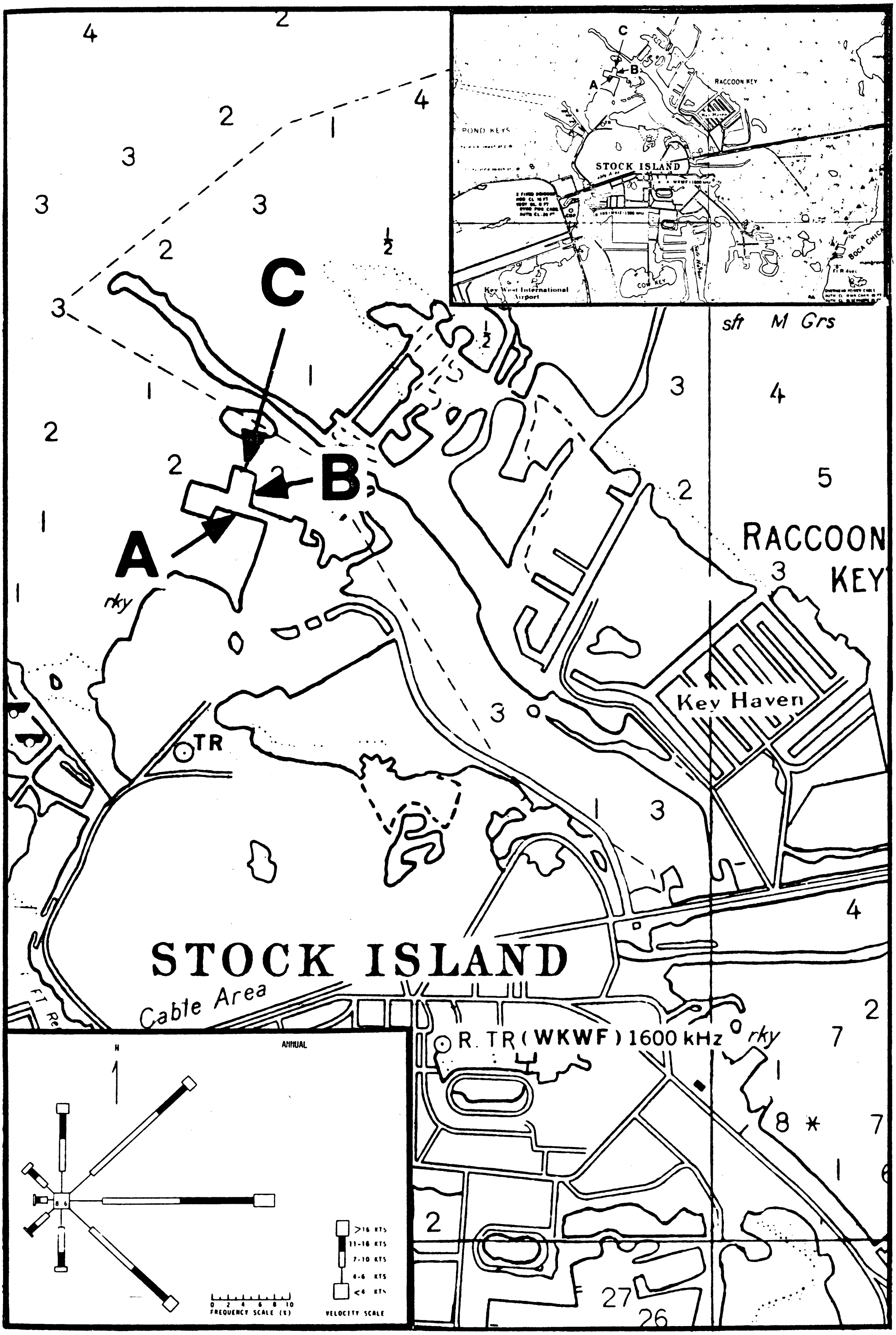


Figure 1. Location of mangrove transplant sites at Key West, Florida.

"partially protected" from wind wave action by a small mangrove island located approximately 25 meters to the north. The physical characteristics of the three transplant sites were quite similar except for their distinctly different exposures to wind wave action.

MATERIALS AND METHODS

Collection and Selection of Mangrove Plants

TYPE A. Mangrove propagules were picked from mature fruits on trees in an established mangrove stand or collected from shoreline debris windrows. Only propagules that could be extracted from a mature fruit with a gentle steady force were collected from trees. Propagules collected from the shoreline debris were required to satisfy the following criteria: (1) presence of an undamaged green terminal growth bud; (2) absence of evidence of dehydration (e.g., brown wrinkled appearance); (3) absence of developing roots and leaves; (4) absence of insect (*Poecilips rhizophorae*) or isopod (*Sphaeroma terebrans*) damage; and (5) possess the general characteristics of a propagule recently released from a mature fruit. Approximately half of the forty-two propagules were collected by each method. Propagules were then pooled, wrapped in moist newspaper for 12-48 hours, and later selected by chance for planting at one of the three sites. No attempt was made to determine the relative success of propagules collected by these two methods.

TYPE B. Small mangrove seedlings (approximately 12-18 months old) were collected from a nearby natural mangrove nursery on Raccoon Key (Figure 1). Military folding shovels were used to dig up the seedlings along with a 0.2 m deep x 0.2 m diameter root ball. Seedlings were 0.2-0.5 m tall ($\overline{\chi}$ = 0.33 m), had 4-10 leaves ($\overline{\chi}$ = 6.6), and were collected within the 0.0 m to +0.3 m (MLW) tidal elevation range. Seedlings were placed in 0.2 m diameter nursery pots to facilitate handling and to protect the root ball complex. Potted seedlings were then transported to the transplant site in the bed of an open truck.

TYPE C. Small mangrove trees possessing aerial prop roots (approximately 2-3 years old) were collected at the same location and in the same manner as Type B plants but with minor differences. Type C plants were removed with a root ball diameter corresponding to the leaf drip line and were transported to the transplant site without the use of nursery pots. The Type C mangrove trees were 0.4-0.8 m tall ($\overline{\chi}$ = 0.56), had 1-7 aerial prop roots ($\overline{\chi}$ = 3.3) and root ball diameters that ranged from 25-50 percent of the tree height (Figure 2).

Planting Procedure

Two organic amendments were utilized in this study to enhance growth and survival of mangroves planted on organically deficient marl shorelines (Figure 3). Commercially available peat (Genuine Canadian Sphagnum-Beaver Brand - Berwick, Nova Scotia) was obtained from a local nursery and staged along the transplant sites. Seagrass wrack in various stages of decay was collected from local beaches using standard gardening tools and transported to the transplant sites.

Prior to initiation of the planting operation, a two day tidal monitoring survey was conducted to establish the time and height of the tidal stages at the transplant sites. Based upon the tidal reference points established during this survey, construction rods were installed 2 meters apart in rows corresponding to the 0.0 m and +0.3 m (0.0 ft. and +1.0 ft.) MLW tidal heights. Rows were positioned in a staggered arrangement so that mangroves were planted at 1 meter intervals along 42 meters of shoreline at each site.

A hydraulic power auger and operator were rented (@ $25/hr) to bore transplant holes into the packed marl substrate at the three sites (Figure 4). Beyond the obvious economic and time saving advantages of a power auger, it

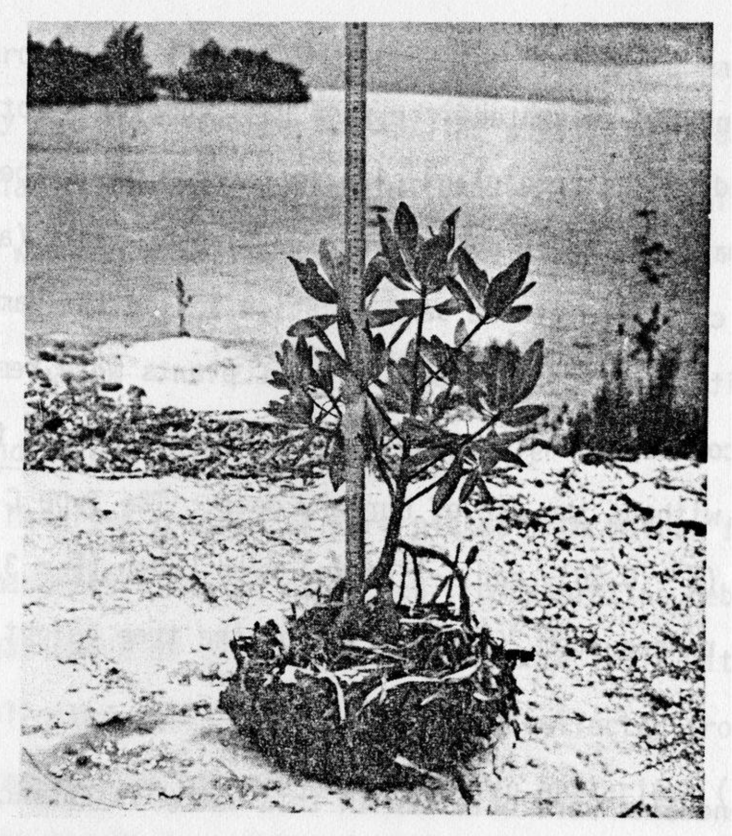


Figure 2. Typical small mangrove tree (type C) used as transplant stock.

Figure 3. Peat and decaying seagrass wrack used as organic amendments to the marl substrates.

was thought that the loosening of the packed marl in the area adjacent to the hole may improve the free exchange of seawater and prevent the formation of a subsurface hypersaline condition. Forty-two holes at each site (i.e., a total of 126) 0.41 m (16 inch) in diameter and 0.45-0.61 m (18-24 inches) deep, were bored at a cost of $1.00/hole. Boring and planting operations were accomplished during daytime low tides of -0.1 m (-0.3 ft.) MLW which provided optimal working conditions (Figure 5). The loose marl removed from the augered holes was shoveled into a wheelbarrow and mixed 50:50 with one of two organic amendments (i.e., peat or seagrass wrack). Mangrove plants were then placed in the holes along with the marl:organic mixture and secured with bailing wire to a 1 m section of construction rod that was driven into the substrate immediately adjacent to the plant (Figure 6). A metal identification tag with coded treatment information was also attached to each plant. Transplants were made according to an experimental design which distributed the transplant treatments (i.e., developmental stages, tidal heights, and organic amendments) in a regular repeating triplet arrangement at each site. This arrangement was designed to minimize the effect of any within site variation.

Monitoring Procedures

Transplant monitoring began in July 1977, and has continued until the present (May 1979) with the assistance of students enrolled in the Environmental Marine Science Program at FKCC. The parameters of mangrove growth initially monitored included: (a) the height of each plant above substrate, (b) leaf counts of propagules and seedlings only (not small trees) and (c) prop root counts of small trees only. As a result of subsidence of plants into the loosened substrate (also noted by Pulver, 1976) the growth parameters were modified. Beginning in October 1977, heights of plants were measured from a nylon band fastened around the trunk near the substrate. Leaf counts at this

Figure 4. Power auger used to bore transplant holes (Site C).

Figure 5. Transplant crew working during low tide conditions (Site C).

time were extended to include small trees to account for any lateral growth which may occur. Heights were measured from the nylon band to the tip of the central growth bud to the nearest millimeter using a meter stick. The presence or absence and comments on the general appearance of each plant were also recorded. The use of construction rods and identification tags greatly facilitated the location and monitoring of mangrove transplants during the two years of this study.

Figure 6. Mangrove propagule (Type A) with identification tag secured to construction rod.

RESULTS

Propagules (Type A)

Survival of propagules after 23 months of monitoring was 71% at the protected site and 57% at the partially protected site (Figure 7). At the exposed site (Site B) propagule survival decreased rapidly during the first three months to 30% and then more slowly to 7% at 19 months. Only one propagule survived at the exposed site after 23 months (Figure 7). The mean survival for propagules for all three sites was 45%.

Survival of propagules planted in the organic amendments at site A was 75% in peat and 83% in seagrass wrack. At site B the only surviving propagule was planted in peat while at site C, 62% survived in peat and 50% in seagrass wrack. The mean survival for propagules at all sites was 48% in peat and 44% in seagrass wrack.

Survival of propagules planted at the two tidal heights was as follows: Site A: 57% at 0.0m and 100% at +0.1m; Site B: 0% at 0.0m and 7% at +0.1m; Site C: 43% at 0.0m and 71% at +0.1m. The mean survival rate of propagules at the two tidal heights was 33% at 0.0m and 59% at 0.1m.

Vertical growth of the propagules was similar at all three sites when average height measurements (i.e., Site A = 31.35 cm, Site B = 26.43 cm; Site C = 26.41 cm) were compared (Figure 8). The appearance of more rapid growth after March 1978, at the exposed site (Site B), is probably due to the lower number of plants surviving, thus skewing the statistical mean. The average number of leaves produced per plant generally parallels the trend in vertical growth (Figure 8). The slightly more erratic graph generated for leaf production at the exposed site is again probably due to the loss of plants at that site (only one survived).

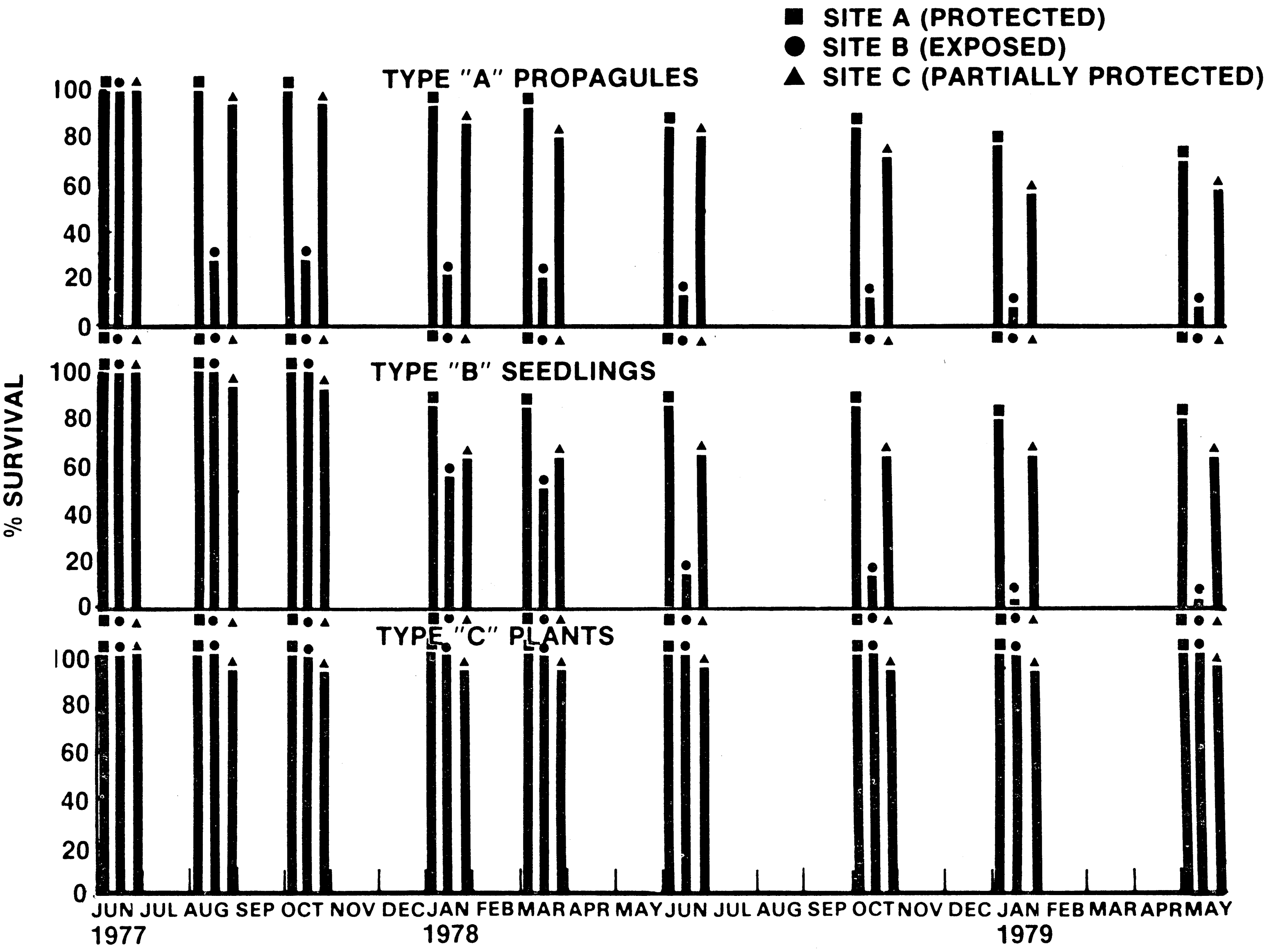


Figure 7. Survival of transplanted red mangroves.

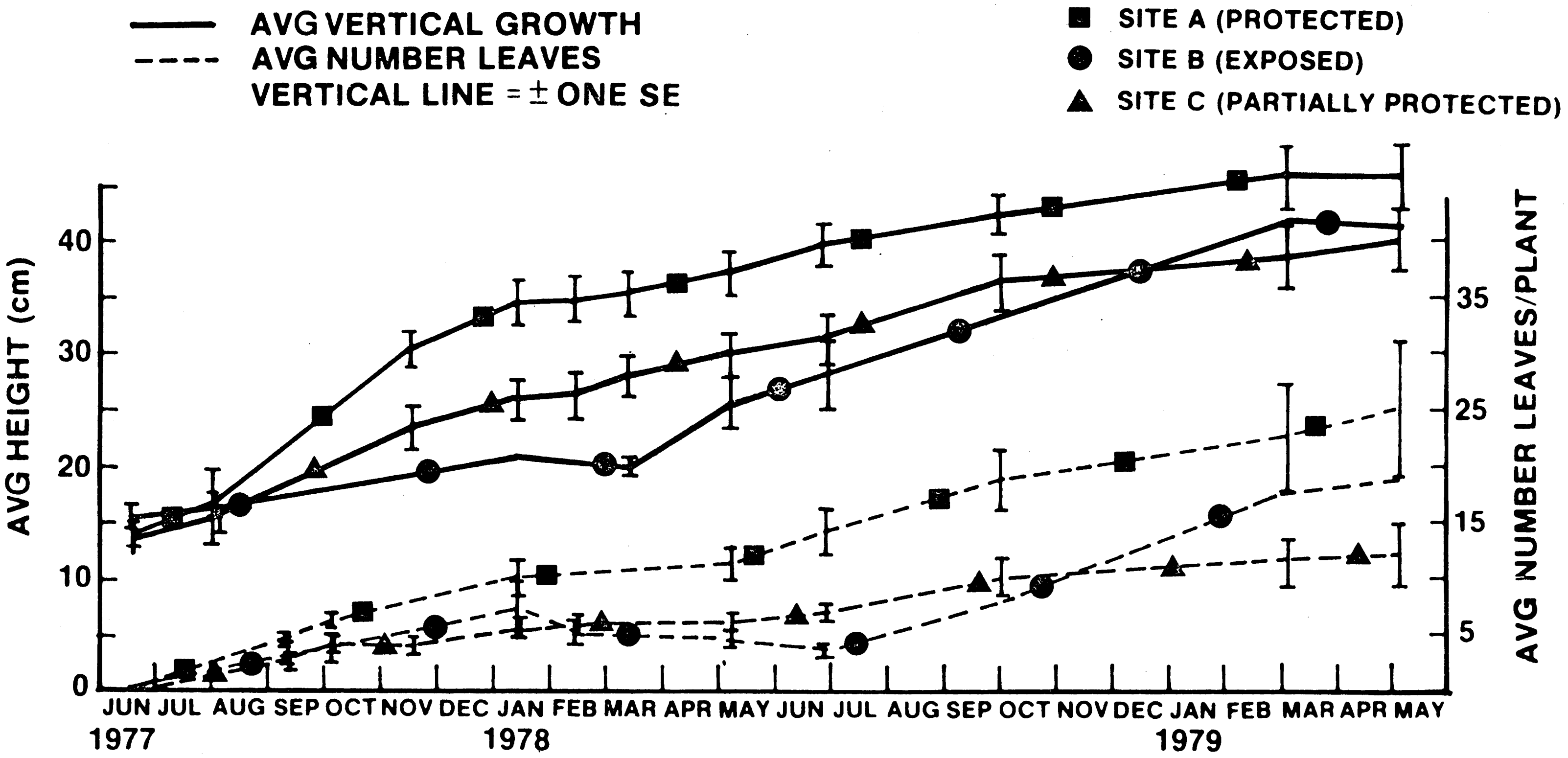


Figure 8. Growth of red mangrove propagules (Type A).

Seedlings (Type B)

Survival of the transplanted seedlings was no more successful than that of propagules with a total of 48% remaining after 23 months. At the protected site 79% survived while 64% survived at the partially protected site and none remained at the exposed site (Figure 7).

Survival of seedlings planted in the two organic amendments was as follows: Site A: 50% in peat and 29% in seagrass wrack; Site B: no survivors; Site C: 36% in peat and 29% in seagrass wrack. The mean survival for seedlings for all sites was 29% in peat and 19% in seagrass wrack.

Survival of seedlings planted at the two tidal heights was as follows: Site A: 29% at 0.0m and 50% at +0.1m; Site B: 0% at 0.0m and 7% at +0.1m; Site C: 14% at 0.0m and 50% at +0.1m. The mean survival for seedlings at all sites was 14% at 0.0m and 36% at +0.1m.

The average vertical growth of seedlings (i.e., Site A = 8.47 cm; Site B = no survivors; Site C = 12.93 cm) was significantly ($P<.001$) less than propagules (Figure 9). Although this may be due to branching and lateral growth, the leaf count data (i.e., the average number of leaves per plant), does not support this explanation. The trend of slow growth is observed both in terms of increased vertical height and leaf production.

Small Trees (Type C)

Transplanted small trees provided the best survival with a total of 98% remaining after 23 months (Figure 7). Only one transplanted young tree was lost during that period. That loss occurred at the partially protected site during the first month following the transplant and may have resulted from mechanical injury incurred during the transplanting operation.

Vertical height measurements of the small trees failed to reveal any substantial growth. In fact, the data indicated negative growth in some cases

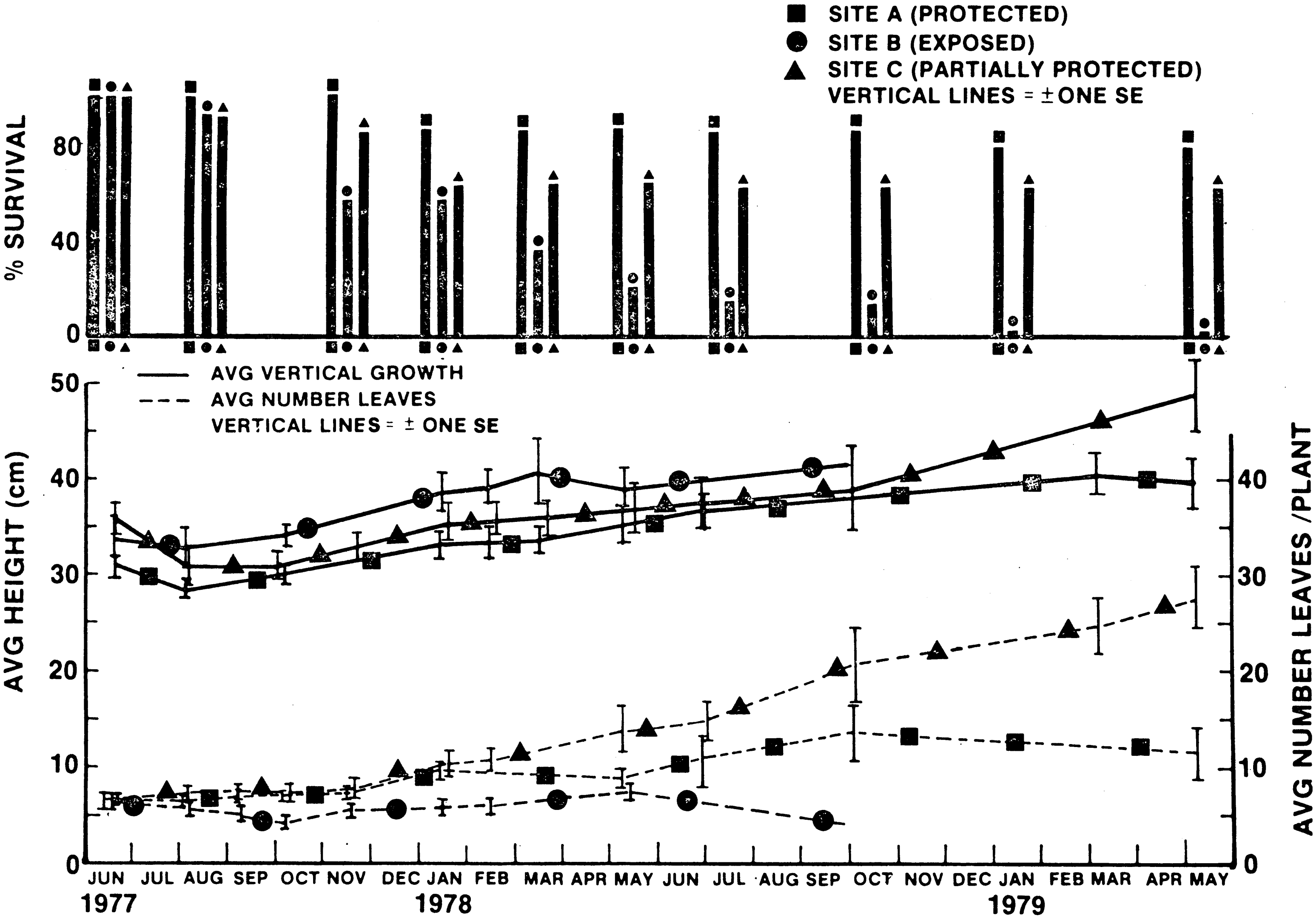


Figure 9. Survival and growth of red mangrove seedlings (Type B).

due to subsidence. However, on-site observations revealed good growth of the plants although much of this was in the form of lateral branching. This growth is apparent upon examination of the leaf and prop root production data (Figure 10). Interestingly, the average number of leaves and prop roots did not increase significantly during the first year following transplanting. However, during the second year increases were observed in both leaves and/or prop roots at all sites. Using leaf and prop root counts as estimates of growth of small trees indicates the greatest growth occurred at the exposed site (Site B) with a mean increase of 64 leaves and 5 prop roots. Growth of small trees at the protected site (Site A) was observed principally in prop root development with a mean increase of 20 leaves and 6 prop roots. Yet, growth at the partially protected site (Site C) was slightly less with a mean increase of 18 leaves and only 2 prop roots.

Transplant Costs (1977 Values)

The costs of expendable items used for this transplant include the following:

4 bales of peat	$36.00
Power auger/operator (rental)	125.00
Nursery pots	24.00
Construction rods	11.50
Bailing wire	3.50
	$200.00

The manpower requirements for the transplant project were divided as follows:

Supervisor (on site) $8.00/hr. x 20 hours=				$160.00
Technician:	Site preparation	6 hours		
	Seagrass collection	2 hours		
	Mangrove collection	6 hours		
	Planting	30 hours		
	@ $2.50/hr.	44	=	$110.00
				$270.00

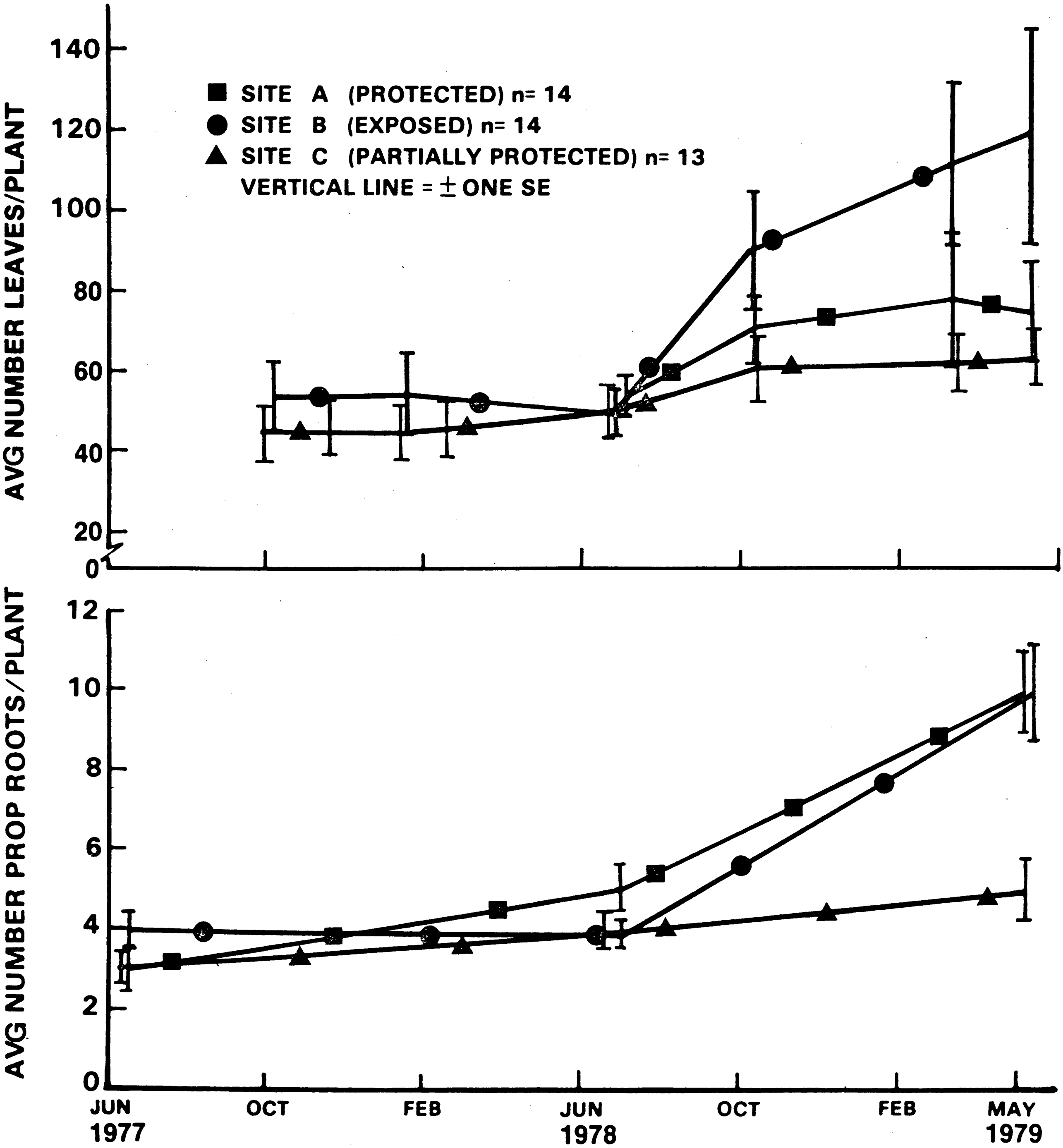


Figure 10. Growth of small red mangrove trees (Type C).

The total cost of transplanting 142 mangroves at 1 meter intervals along 126 meters of marl shoreline was $470.00 or approximately $3.75/plant. This cost is quite attractive when one considers the expensive and nonbiological alternatives (i.e., seawalls, riprap, etc.) available for shoreline stabilization and erosion protection.

DISCUSSIONS AND CONCLUSIONS

The use of vertical height as an estimate of growth became a troublesome parameter to monitor and evaluate during this project. The subsidence mentioned previously, coupled with the effects of lateral branching obscured indications of real growth, particularly among the older plants. The nylon band used as a reference point for measuring heights provided only a temporary solution as many of these snapped off and were lost after one year. This occurred mostly with the small trees apparently due to expansion of the trunk. Leaf counts and lateral branching would appear to provide a better overall indicator of growth than height alone, although the collection of these data can become tedious with the more mature plants.

The most rapid growth in terms of increased vertical height was observed among the propagules (i.e., mean increases of 31-26 cm). This is not surprising considering the need for the propagule to become established as rapidly as possible. The older plants, such as the seedlings and young trees, may divert some energy into adaptation to the new environment. Even without the effects of transplant shock the seedlings may direct energy towards the rapid production of secondary root systems for increased stability. This however, appears to be contraindicated in other studies (Savage, 1972a).

Substantial growth of small trees was not indicated until the second year. At the end of 23 months the average leaf count on young trees was noticeably higher at the exposed site than at the other two sites. This is probably due to the high quantity of seagrass debris that washed up on this sho The accumulated beach wrack apparently contributed additional nutrients producing more luxuriant growth than often observed on marl shores (Teas et al, 1976). Accumulation of organic debris on the other more protected shorelines was negligible in comparison. Paradoxically, the debris which was responsible for the burial and failure of propagules and seedlings at this exposed site appears to have been responsible for the more luxuriant growth of the surviving small trees.

In this study seedlings showed no advantage over propagules in terms of growth or transplant survival. At the end of 23 months it is difficult to distinguish one age class from another. Several of the seedlings have begun to develop prop roots but propagules have not. Therefore one advantage of transplanting established seedlings as an erosion prevention measure is apparently an earlier onset of prop root development for stabilization.

The loss of propagules and seedlings appeared to be directly related to the wind and wave energy regime to which the shoreline is subjected. These younger plants were rapidly buried by seagrass debris carried in by strong prevailing wind driven waves. This burial process was augmented by high water levels during spring tides, but this factor alone does not account for the loss of the propagules and seedlings. Tidal influences were observed to be similar at all sites. Survival of both propagules and seedlings was approximately twice as great at the +0.1m tidal level at all sites. This finding again demonstrates the sensitivity of developing mangroves to tidal elevation and the importance of carefully determining tidal heights to optimize transplant success as suggested by Lewis (1979).

The growth and survival of both propagules and seedlings planted in peat and seagrass wrack was quite similar. It appears that the use of commercial peat as an organic amendment offers no advantage over the more economical and readily available seagrass wrack.

The overwhelming success, in terms of survival, of the small trees used in this transplant indicates a preference for their use on exposed shorelines. This preference is suggested in summary by other studies (Savage, 1972b; Pulver, 1976) but with qualification. Caution is emphasized in that indiscriminate removal of young trees may adversely affect the donor site. However, further losses due to competition at the donor site, a conservative percentage of trees may be removed, theoretically without impact (see Pulver, 1976; Teas, 1974). In light of the susceptibility of propagules and seedlings to loss by erosion and burying, the use of small trees appears to be singularly necessary for transplant projects intended to rapidly stabilize a shoreline against erosion.

Observations of these three transplant sites have suggested the need for continued monitoring through a third year. The focus of this further monitoring centers on:

1. The effectiveness of the transplanted mangroves in stabilizing these marl shorelines.
2. The effectiveness of the transplants in promoting natural recruitment on the shore.

Lost seedlings and propagules at the exposed site will be replaced by additional small trees. Wind and wave data will be collected and changes in the beach slope will be monitored. Recruitment from neighboring mangrove stocks will be monitored within the transplant plots and compared to similar shorelines without transplants. Growth rate and survival data will continue to be collected and compared with natural controls.

ACKNOWLEDGEMENTS

We wish to extend our sincere appreciation to the following Environmental Marine Science students at Florida Keys Community College (FKCC) for their assistance during the collection and planting phases of this study: R.I.B. Bolton, Teri Cline, Tim McDonough, Richard Roberts, Karie Rosa and Gary Sackett. Gratitude is also expressed to other students too numerous to list who assisted during the two years of transplant monitoring.

A special note of gratitude is extended to Bruce Cummins of FKCC for his dedication and assistance in maintaining the continuity of the study during critical periods when both authors were absent.

Gratitude is also expressed to Bill Ceely, Ray Kinsey and Dr. John S. Smith of the FKCC Administration for their financial and moral support required for this study.

LITERATURE CITED

Boylan, R. L. 1974. Local area forecaster's handbook for Naval Air Station, Key West, Florida. Naval Weather Service Environmental Detachment, U. S. Naval Air Station, Key West, Florida. 52p.

Carlton, J. M. 1974. Land-building and stabilization by mangroves. Environ. Conserv. 1(4):285-294.

Davis, J. H. 1940. The ecology and geologic roles of mangroves in Florida. Carnegie Institution of Wash. Publ. 517. Papers from Tortugas Laboratory. 32:303-412.

Evans, R. K. 1977. Techniques and seasonal growth rate of transplanted mangroves. Proc. Fourth Annual Conf. on the Restoration of Coastal Vegetation in Florida. Hillsborough Commun. College, Tampa Bay, Florida pp. 77-108.

Hannan, J. 1975. Aspects of red mangrove reforestation in Florida. Proc. Second Annual Conf. on Restoration of Coastal Vegetation in Florida. Hillsborough Commun. College, Tampa, Florida. 203p.

Heald, E. J., and W. E. Odum. 1969. The contribution of mangroves to Florida Fisheries. Proc. Gulf and Caribb. Fish. Inst., 22nd Ann. Session. pp. 130-135.

Lewis, R. R. 1979. Large scale mangrove restoration on St. Croix, Virgin Islands in Proc. Sixth Annual Conf. on Wetlands Restoration and Creation Hillsborough Community College, Tampa, Florida. pp. 231-242.

Lewis, R. R., and F. M. Dunstan. 1976. Results of mangrove planting experiments on a spoil island in Tampa Bay. Report to the Tampa Port Authority, Tampa, Florida. 8p.

Passauant, N., and C. A. Jefferson. 1976. Natural reclamation of filled land, Boca Ciega Bay. Proc. Third Annual Conf. on Restoration of Coastal Vegetation in Florida. Hillsborough Commun. College, Tampa, Florida pp. 75-104.

Pulver, T. R. 1975. Suggested mangrove transplanting techniques. Proc. Second Annual Conf. on Restoration of Coastal Vegetation in Florida. Hillsborough Commun. College, Tampa, Florida. 203p.

Pulver, T. R. 1976. Transplant techniques for sapling mangrove trees, *Rhizophora mangle, Laguncularia racemosa,* and *Avicennia germinans,* in Florida. Florida Dept. of Natural Resources, Florida Marine Research Publications No. 22. 14p.

Savage, T. 1972a. Florida mangroves as shoreline stabilizers. Florida Department of Natural Resources. Professional Papers Series No. 19. 46p.

Savage, T. 1972b. Florida Mangroves: A Review. Fl. Dept. Natural Resources, Leaflet Series, Vol VII: Part 2, No. 1.

Savage, T. 1978. The 1972 experimental mangrove planting -- an update with comments on continued research needs. Proc. Fifth Annual Conf. on the Restoration of Coastal Vegetation in Florida. pp. 43-71.

Teas, Howard J. 1974. Mangroves of Biscayne Bay. Report to Metropolitan Dade County Commission, Dade County, Fl.

Teas, H. J. 1976. Productivity of Biscayne Bay Mangroves. In:Biscayne Bay: Past, Present and Future. A. Thorhaug (Ed.). Univ. of Miami Sea Grant Special Report No. 5. pp. 103-112.

Teas, H. J. 1977. Ecology and restoration of mangrove shorelines in Florida. Environ. Conser. 4(1):51-58.

Teas, H. J., W. Jurgens, and M. C. Kimball. 1975. Plantings of red mangrove (*Rhizophora mangle L.*) in Charlotte and St. Lucie counties, Florida. Proc. Second Annual Conf. on Restoration of Coastal Vegetation in Florida. Hillsborough Comm. College, Tampa, Florida. pp. 132-161.

Teas, H. J., H. R. Wanless, and R. Chardon. 1976. Effects of man on the shore vegetation of Biscayne Bay. In:Biscayne Bay: Past, Present and Future. A. Thorhaug (Ed.). Univ. of Miami Sea Grant Special Report No. 5. pp. 133-156.

Teas, H. J., and W. Jurgens. 1978. Aerial plantings of *Rhizophora mangle* propagules in Florida. Proc. Fifth Annual Conf. on the Restoration of Coastal Vegetation in Florida. Hillsborough Comm. College, Tampa Bay, Florida. pp. 1-25.

Thom, B. G. 1967. Mangrove ecology and deltaic geomorphology: Tabasco, Mexico. J. of Ecology. 55:301-343.

LARGE SCALE MANGROVE RESTORATION ON
ST. CROIX, U.S. VIRGIN ISLANDS

Roy R. Lewis, III
Mangrove Systems, Inc.
504 S. Brevard Ave.
Tampa, Florida 33606

ABSTRACT

During the summer of 1979, 65,000 red mangrove (Rhizophora mangle L.) seeds were planted at a mitigation site on St. Croix, U.S. Virgin Islands.

Survival after six weeks was approximately 75% based on actual counts in planted areas. Seeds were lost primarily due to physical removal and natural mortality.

Total cost was $12,500/ha with seeds planted on 0.7-0.8 m centers. This cost could be reduced by 50% with the use of more experienced personnel.

INTRODUCTION

The island of St. Croix (Figure 1) is located 145 km southeast of the island of Puerto Rico and is one of three U.S. Virgin Islands, the others being St.Thomas and St. John's.

Mangrove habitats are limited in the Virgin Islands and the largest areas which did exist have been destroyed by land development (Island Resources Foundation,1977).

Those mangrove forests that remain are composed of the same three species of mangroves found throughout the Caribbean: *Rhizophora mangle* (red mangrove), *Avicennia germinans* (black mangrove), and *Laguncularia racemosa* (white mangrove).

During October-November 1972, Martin Marietta Alumina impounded a portion of an existing forest on the south shore of St. Croix through construction of a U.S. Environmental Protection Agency required cooling pond. The impounding and subsequent submergence of the root systems by flooding killed the impounded mangroves.

At the request of the U.S. Corps of Engineers, Jacksonville District, Martin Marietta Alumina agreed to undertake a mangrove replanting program to compensate for the loss of the impounded forest. It was agreed that attempts would be made to locate suitable planting sites up to a total of 12.1 hectares (the area of the impounded forest).

MATERIALS AND METHODS

A detailed survey of the site was performed during February 1978 and 5.54 ha identified as suitable for planting efforts. All parties agreed that 4.05 ha of this would be planted during the summer of 1978 (Figure 2).

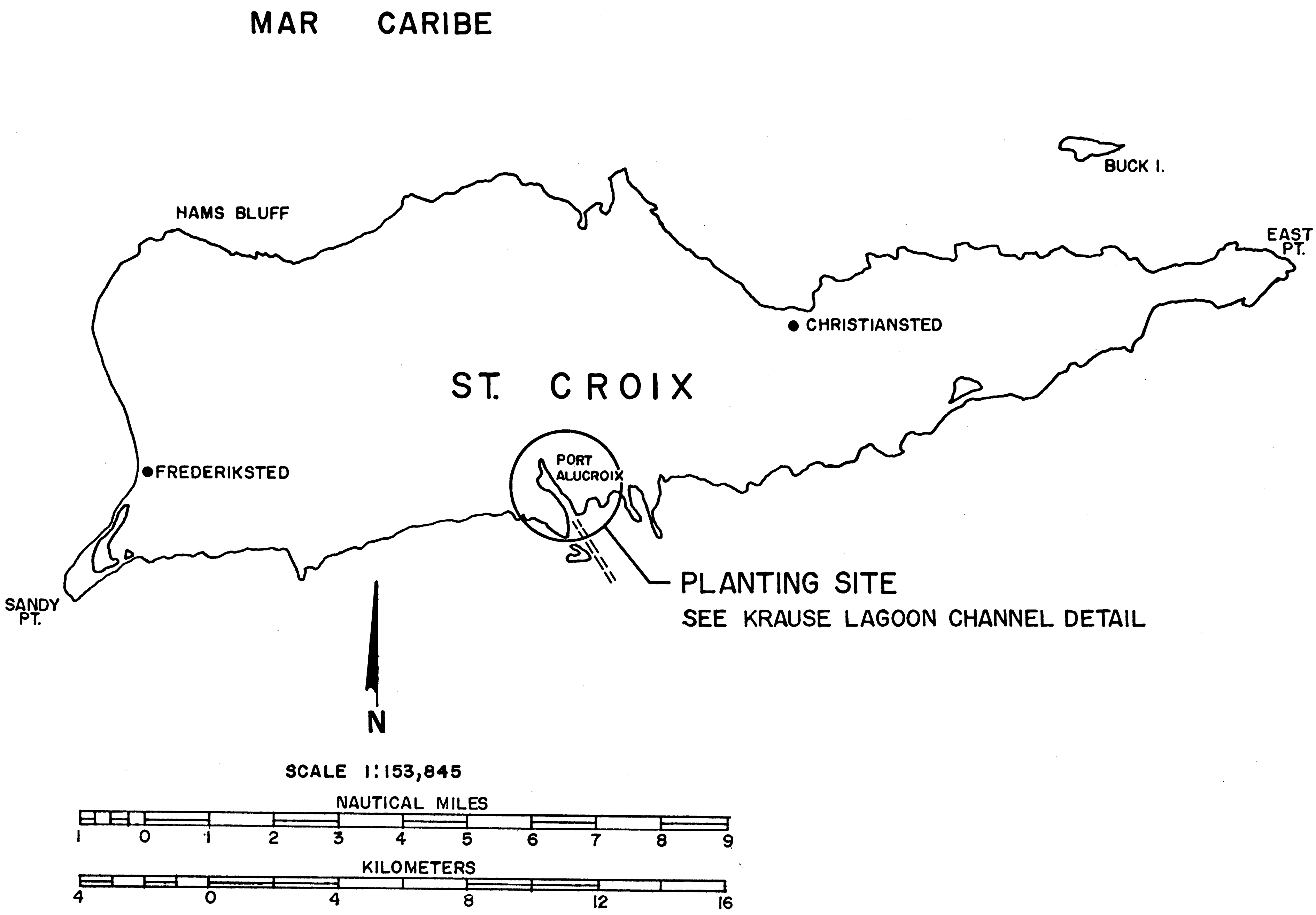


Figure 1. The island of St. Croix, U. S. Virgin Islands, showing planting site.

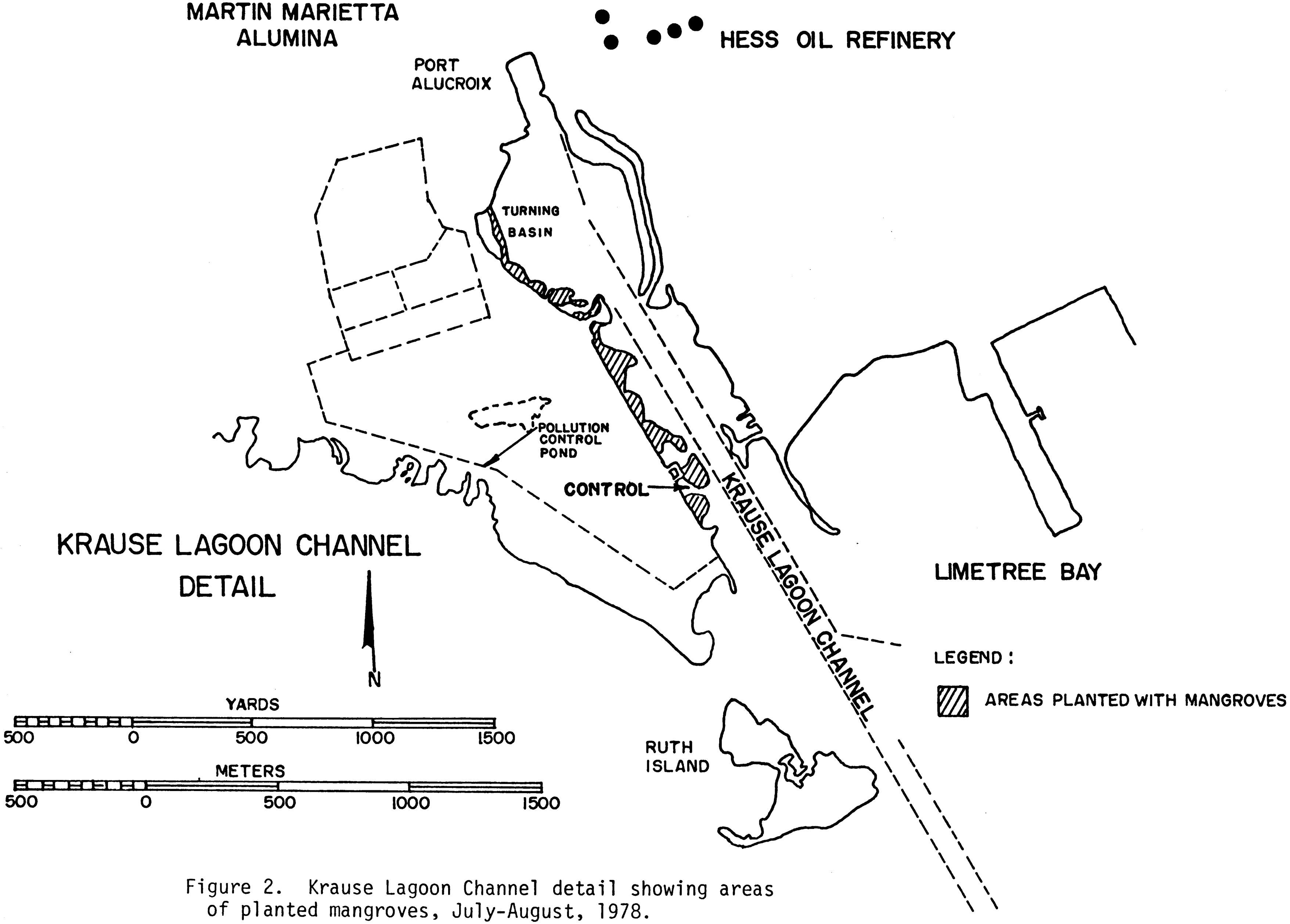


Figure 2. Krause Lagoon Channel detail showing areas of planted mangroves, July-August, 1978.

All of this designated planting area consisted of a red mangrove forest that had been severely damaged by an oil spill in the early 1970's from a grounded ship in the adjacent Hess Oil Refinery ship channel (Figure 3). The sediment in this area consisted largely of very soft organic mud and still contained oil residues. Analysis of this oil showed values as high as 50,000 ppm of oil and grease dry weight. A test plot of red mangrove propagules was established in this area in the spring of 1978 to determine the feasibility of planting this site. Good survival and growth after two months indicated the area could be used.

During the period 1 July-11 August 1978 an eight man crew supervised by Mangrove Systems, Inc. personnel collected red mangrove seeds from trees on the Martin Marietta property and the Salt River area. Seeds were collected by picking ripe seeds from trees or collecting recently fallen seeds from the shoreline. Seeds were transported in buckets of seawater and usually planted within 24 hours.

The seeds were hand planted in the areas indicated in Figure 2. Due to the periodic shortage of seeds and the difficulties in working in very soft sediments, the rate of installation of seeds varied from 5,000 to 200 per day. A typical planting area is shown in Figure 4. The soft sediments required the use of plywood "duck boards" to support the planter's weight. Several of these are seen in Figure 4.

During the six weeks of the project, a total of 65,000 seeds were installed. The initial plan was to place the seeds on 1 meter centers, but in practice the distance more closely approached 0.7 - 0.8 m.

An unwooded (5m x 5m) and a wooded (15m x 25m) control area were established that were not planted. These were to determine the amount of volunteer seeds that might invade the area.

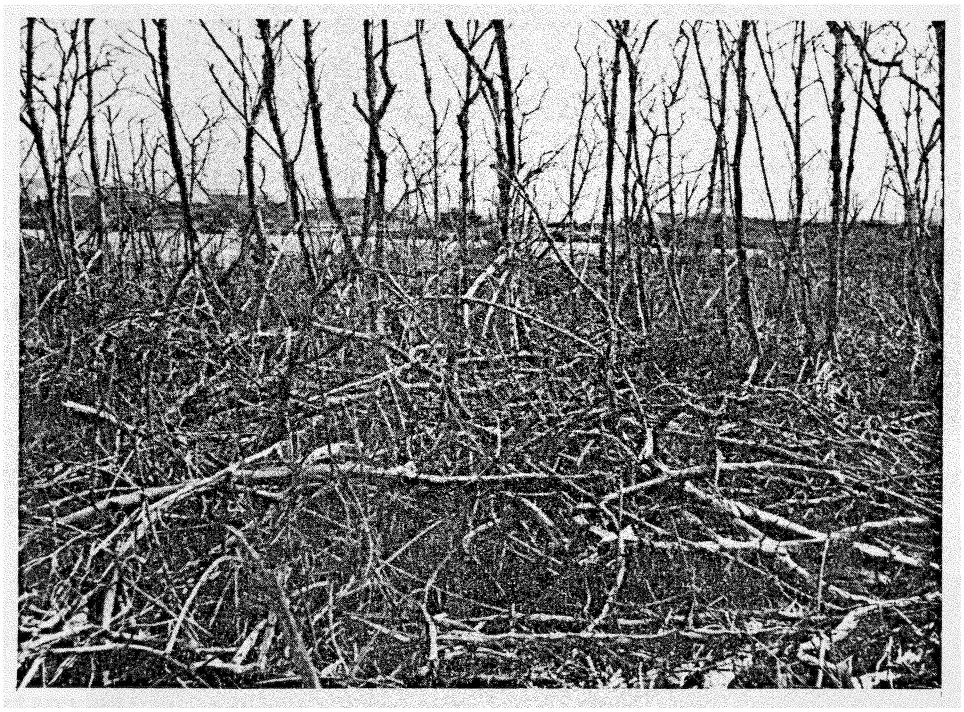


Figure 3. Oil damaged mangrove forest along the Port Alucroix ship channel, August 1978.

RESULTS

Figures 4 and 5 show a typical planting area in August 1978 and April 1979. Figures 6 and 7 show another similar area at the end of planting and six months later. Survival and growth of the planted seeds varied from 0% to 100% in sampled plots. The overall average was 75%. The main reason for failure of seeds were the following:

1. Physical removal due to erosion, accumulations of seagrass wrack, or floating debris (Figure 8).
2. Eating of the planted seeds by unknown biological agents, possibly crabs.
3. Death of seedlings by natural causes.
4. Apparent planting at too high an elevation.

This latter cause was kept to a minimum by the careful placement of the seeds at intertidal elevations. The tidal range on St. Croix is only 24 cm and the survey information was critical in locating the seeds in the upper half of the tide range for optimum survival.

Volunteers in the control plots were very limited, with one in each plot during the six months of plantings.

Total cost to date has been $50,000 including a detailed site survey ($8,000), boat and trailer ($4,000), and administrative costs involved with the planning of the project. As indicated before, a total of 240 man-days were required for the mobilization and planting. The total cost works out to $12,500/ha ($5,000/acre). For any repeated efforts at this size project a more valid figure would be about ½ of these values. This reduction in cost can be accomplished through a bid process requiring a fixed estimate on the cost of the project and the use of more experienced personnel. Also the distance of the project from primary project supervision increases the cost. These estimates are still five times that of Teas (1977), but do include a realistic estimate of overhead, profit, and material wear and tear. Teas' (1977) estimates were primarily for research plantings and not commercial ventures, as he noted.

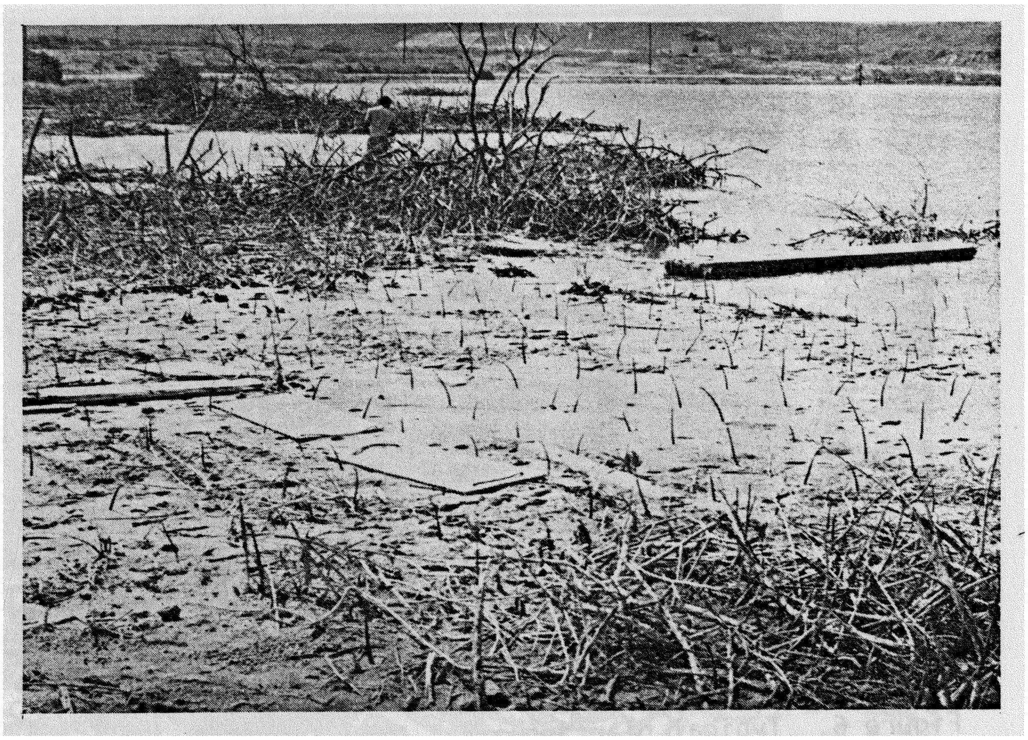


Figure 4. Typical planting area, August 1978. Note plywood duck boards in foreground.

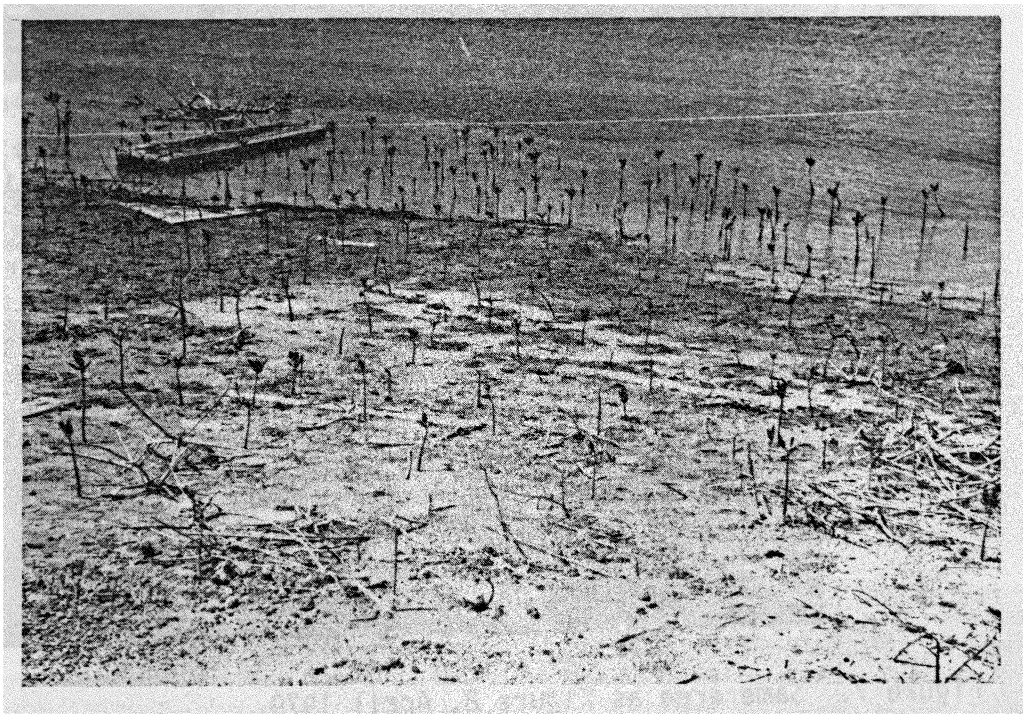


Figure 5. Same area as Figure 4, April 1979.

Figure 6. Typical planting area, August 1978.

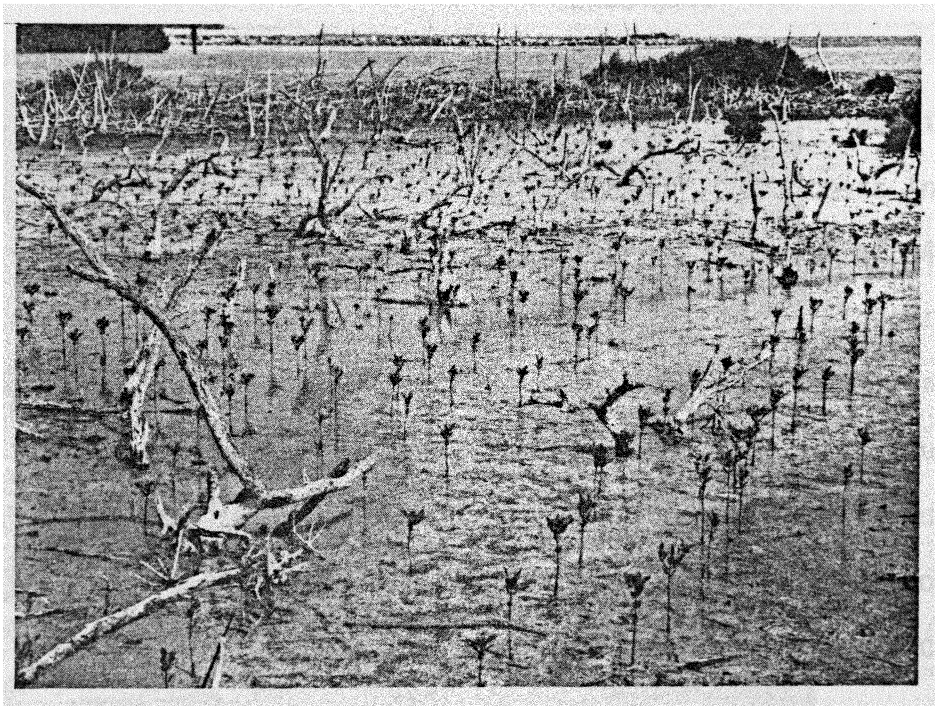


Figure 7. Same area as Figure 8, April 1979.

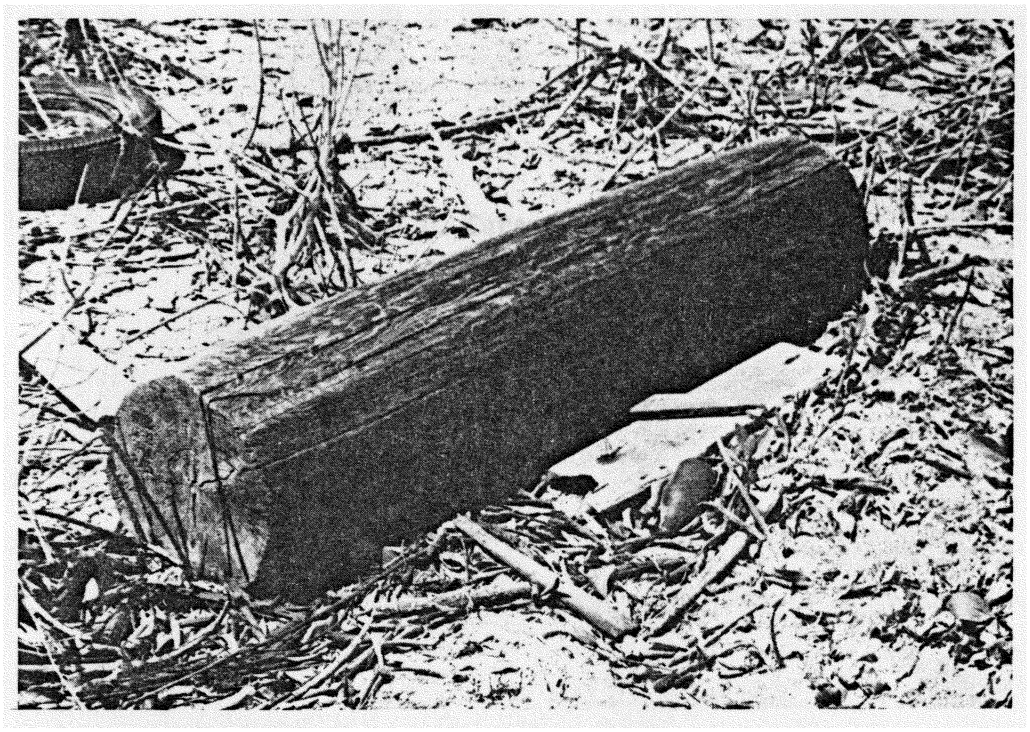


Figure 8. Floating debris that has removed some of the planted seeds.

LITERATURE CITED

Island Resources Foundation. 1977. Marine Environments of the Virgin Islands: Technical Supplement No. 1. Report prepared by IRF for the Virgin Islands Coastal Zone Management Program.

Teas, H. T. 1977. Ecology and restoration of mangrove shorelines in Florida. Environmental Conservation 4(1): 51-58.

BIOLOGICAL APPLICATION FOR THE STABILIZATION OF DREDGED MATERIALS, CORPUS CHRISTI, TEXAS: SUBMERGENT PLANTINGS

Paul D. Carangelo

Carl H. Oppenheimer

Phyllis E. Picarazzi

Port Aransas Marine Laboratory

The University of Texas Marine Science Institute

Port Aransas, Texas 78373

The University of Texas Marine Science Institute
Contribution Number 363

ABSTRACT

Small test plots of upland, emergent, and submergent environments on recent and old dredged material and other barren sites in Corpus Christi Bay were transplanted with selected local natural plants. Data from the first year's growing season 1977-78 is presented. Selection of nursery sites, determination and location of sprig transplant and seed varieties, substrate type, soil amendment, modification, and post-plant monitoring were considered. Laboratory work included soil chemistry and textural analysis, not included herein

Submergent plantings were made with *Halodule wrightii*, *Thalassia testudinum*, and *Ruppia maritima*. *Ruppia* transplants did not survive at the site tested. Growth of *Halodule* transplants ranged from .048 to 1.296 m^2/year, $\bar{x}$ = .627 m^2/year for each "sod" transplant unit (TPU), for original TPU of .010 m^2, and from .527 to 1.512 m^2/year, $\bar{x}$ = 1.004 m^2/year for each "grid" TPU, of original TPU .026 m^2. *Thalassia* growth ranged from .009 to .036 m^2/year, $\bar{x}$ = .020 m^2/year for each "sod" TPU, original TPU ca .022 m^2. Unplanted controls at some sites developed volunteers of *Ruppia maritima* or *Halophila engelmanni*.

Emergent plantings of *Spartina alterniflora* indicate a high degree of variability relating to differences in elevation, wave energy flux, sediment type, and time of year of planting. Rate of growth for ideal conditions range from 1.01 to 1.790 m^2/year, $\bar{x}$ = 1.428 m^2/year, for each culm TPU ca .003 m^2.

Upland plantings tested and evaluated the following materials as transplant stock. Vegetative sprigs: *Spartina patens*, *Paspalum vaginatum* *Paspalum monostachyum*, *Panicum amarum*, *Sporobolus virginicus*, *Cynodon dactylon*, *Distichlis spicata*, *Schizacharium scoparius*, *Andropogon glomeratus*, *Fimbristylis castanea*, *Eleocharis montivedensis*, *Monanthochloe littoralis*, and seed material:

Kliensgrass 75, Blue Panicgrass (*Panicum antidotale*), Buffelgrass, Common Bermuda, Hubam clover, *Atriplex semibaccata*, *Gaillardia pulchella*, indigenous *Andropogon saccaroides* and *Centrus ciliari*, Bell Rhodesgrass, weeping Lovegrass (*Eragrostis curvula*), *Kochia scoparia* and Gulf Ryegrass (*Lolium* sp.).

No soil amendments were used for the submergent and emergent test sites. Upland sites were modified with organic soil conditioners including sewage sludge, hay and waste grain from the Port grain elevator.

INTRODUCTION

The Corpus Christi Bay area has been developed for water transportation and recreation since the middle 1800's. During this time numerous areas have been impacted by the disposal of dredged materials as water accesses were developed. Because of the arid environment and nature of the dredged material, plant colonization on dredged spoils has been slow and during the interim erosion by wind and rain continually washes the material back into the water. The channels fill with this material and maintenance dredging is needed at frequent intervals.

This report provides information on the types of plants that can be used to accelerate the rate of revegetation on dredged materials and other non-vegetated estuarine areas with a minimum of cost and effort. Only the submergent portion of the research is reported at this time.

Selected small plots on typical upland, emergent, and submergent environments on dredged material, natural barren sites, and disturbed estuarine habitat were transplanted with native local plants, and selected seed varieties.

The methods and plants selected were developed to provide an economic solution to erosion and to enhance the aesthetic and habitat quality of these areas. Estimation of planting effort, success toward stabilization to reduce back erosion, accessability of plant source and best survival characteristics under arid conditions have been considered. Soil amendments were tested in the drier upland soils to provide organic material, moisture retention and nutrients.

Roughly estimated there are 18 square miles of emergent disposed dredged material in the Corpus Christi area. No dredged material stabilization studies have been reported for Corpus Christi.

Maintenance and new dredging will likely continue in the south Texas area as a part of social, economic and recreational activities expansion. The

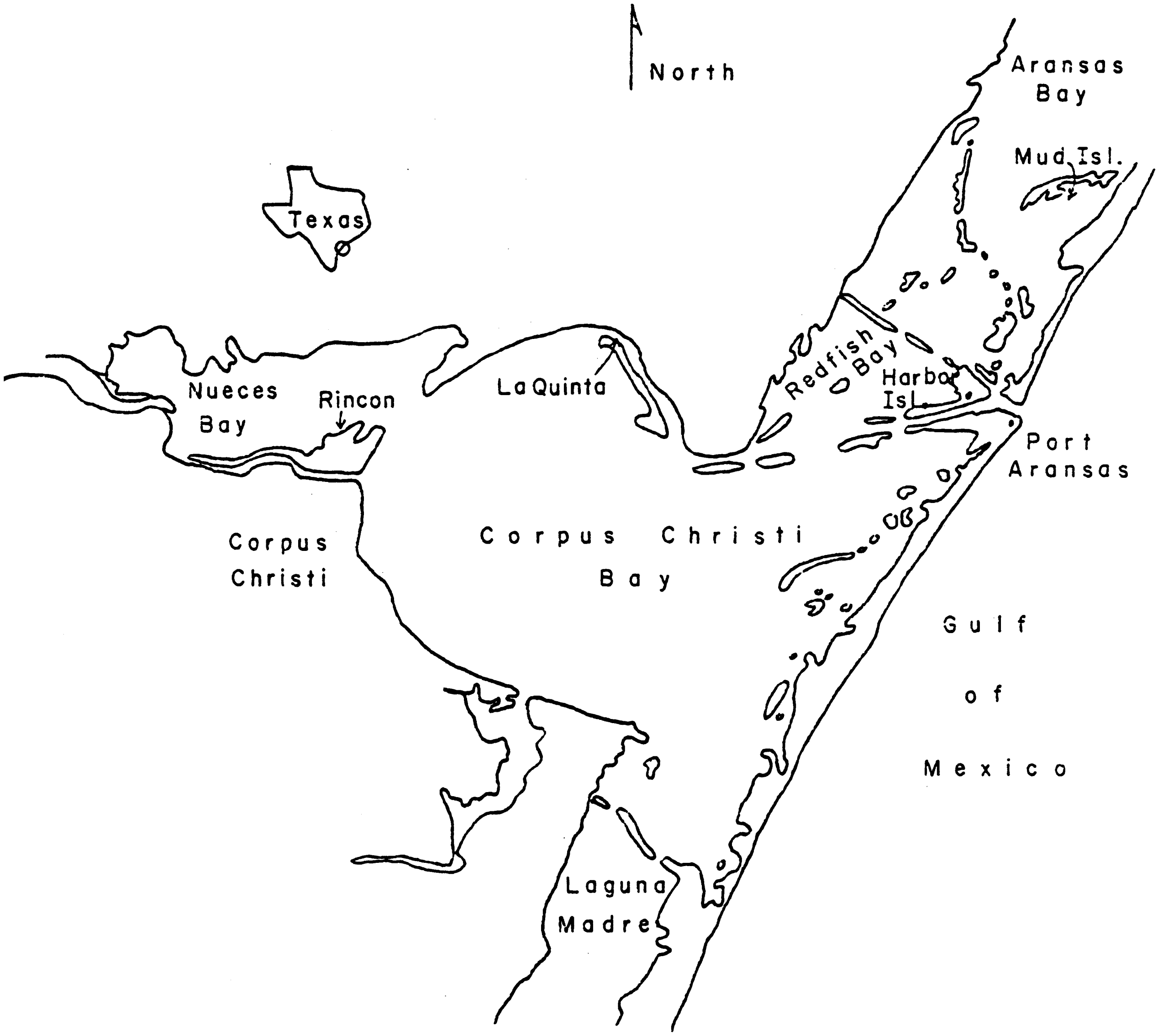


Figure 1. Location map of study sites in the Corpus Christi Bay area.

results of this project properly applied, in addition to erosion control and habitat development, may permit the dredging of sensitive environmental areas through the application of restorative techniques, promoting the culture of existing vegetated areas, and vegetating sparsely vegetated estuarine habitat. Indirectly the data may be used to assess the value of extant natural vegetation in and around the Corpus Christi five bay system.

AREA DESCRIPTION

Climate in the area according to the Thornthwaite classification (1948) is semi-arid, dry sub-humid, with an average rainfall of 29 inches and 60 inches of evaporation. Winters are generally mild influenced by occasional freezing weather of short duration and high winds associated with the passage of northers. Summers are characteristically hot and dry with continual on-shore wind and resultant salt distribution as an aerosol. Occasionally catastrophic hurricanes and more frequent tropical storms occur. The area is noted for its low topographic relief.

Area tides are discussed by Smith (1974), and Watson and Behrens (1976). Sediments are discussed by Shepard and Moore (1955) and Holland (1975). Hydrography is discussed by Collier and Hedgepath (1950) and recent salinities by Behrens (1966).

METHODS AND MATERIALS

The project has been conducted in small test plots in representative upland, emergent, and submergent environments. The areas are located on Figure 1. Upland sites are at Rincon and Harbor Island; emergent sites at Rincon, Harbor Island, LaQuinta Channel, the Corpus Christi Ship Channel located to the immediate south of Harbor Island, and the Upper Laguna Madre. Submergent sites were Rincon in Nueces Bay, Mud Island in Aransas Bay, and the Laguna Madre.

Planting dates were June 1977, November 1977, and March 1978 with supplemental plantings of Spartina alterniflora in August 1977 and June 1978. Most observations were made at one month, six months and one year after planting.

Field research was conducted to select the study sites and nursery stock source locations, to determine transplant varieties and types, sediment or soil modification and preparation, and to monitor growth and survival.

Statistical methods (Levy and Madden, 1933) and photography were used for upland and emergent,and scale mapping for the emergent and submergent portions. Sediment properties were determined following Richards (1954) and Folk (1968).

The variables designated for the project were: location (i.e. upland, emergent, and submergent at different types of environments); type of soil modification (mechanical, amendments of sewage sludge, waste grain, hay from barrier island vegetation, no amendment and control); soil/sediment salinity, nutrient composition, and texture. Other significant environmental factors were also addressed (e.g., site wave energy influence where applicable). Climate records obtained from the National Oceanic and Atmospheric Administration, Corpus Christi, were inventoried.

The emergent and submergent areas were not mechanically modified with the exception of the June 1978 emergent plantings at Harbor Island. The upland areas were divided into controls and amended areas. Upland amendments were either disced or rototilled into the substrate. The use of typical farm equipment such as plows, discs and seeders was considered only in certain areas.

Planting methods and techniques with the exception of those developed during this project, were adapted after those found in Kadlec and Wentz (1974) and Eleuterius (1974), whose methods were directly applicable to the Corpus Christi area.

Seagrass work utilized sods (Phillips, 1960) and grids (Eleuterius, 1974) as the primary transplant units (TPU). Sods (Figure 2) are partial shovelfulls of viable seagrass and associated sediment. Grids (Figure 3) are vinyl coated fencing with sediment free roots and short shoots attached. These TPU's were installed with SCUBA.

Seagrass mapping underwater involved the use of plexiglass sheets 283.029 cm x 129.54 cm x 0.3175 cm and adaptation of the concept from Connell (1961) and others. These sheets were oriented to accomodate the particular sample being monitored, and the field maps were subsequently transferred to large sheets of paper for detailed planimetry in the laboratory (Figures 4 and 5).

RESULTS

The results are presented as general observations taken throughout the study period to the present. Specific documentation is from fall 1978 data when an extensive evaluation of the success of the transplants, extent of growth, and quality of development compared to natural areas or controls was conducted. Reported values in metric units are conversions from data collected in English units.

In this paper the submergent portion alone is discussed in detail. Data summary and results for the emergent and upland portions of this project are presented in Carangelo et al., 1979 (in preparation).

Submergent Plantings

Transplant units of Halodule wrightii, Thalassia testudinum, and Ruppia maritima were used. Ruppia normally grows in conjunction with Halodule and Thalassia, therefore Ruppia often occurred as a volunteer when the latter two were transplanted. Table I summarizes the results for seasonal transplant

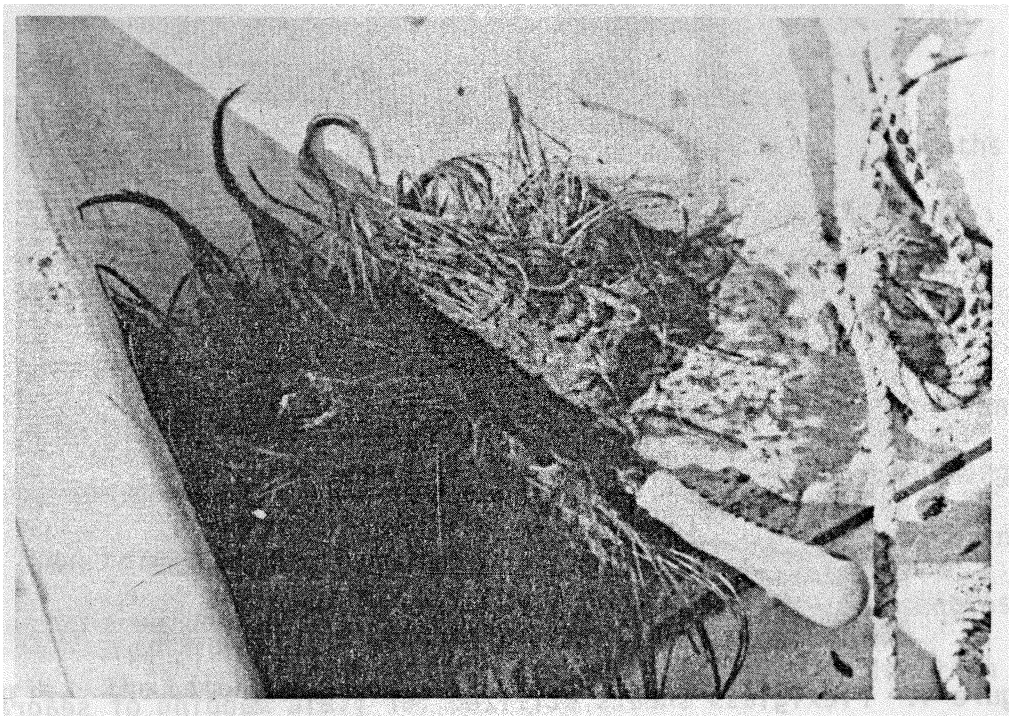


Figure 2. Sod transplant units used in this study. Generally four TPU's ca. 0.01 m^2 can be obtained from a "shovelfull of Halodule and Ruppia, and two TPU's ca. 0.022 m^2 for Thalassia. Thalassia sods are not cut apart with the trowel but are separated carefully by hand to keep rhizome shoots intact. There are zero to seven, average three, intact rhizome shoots per Thalassia TPU.

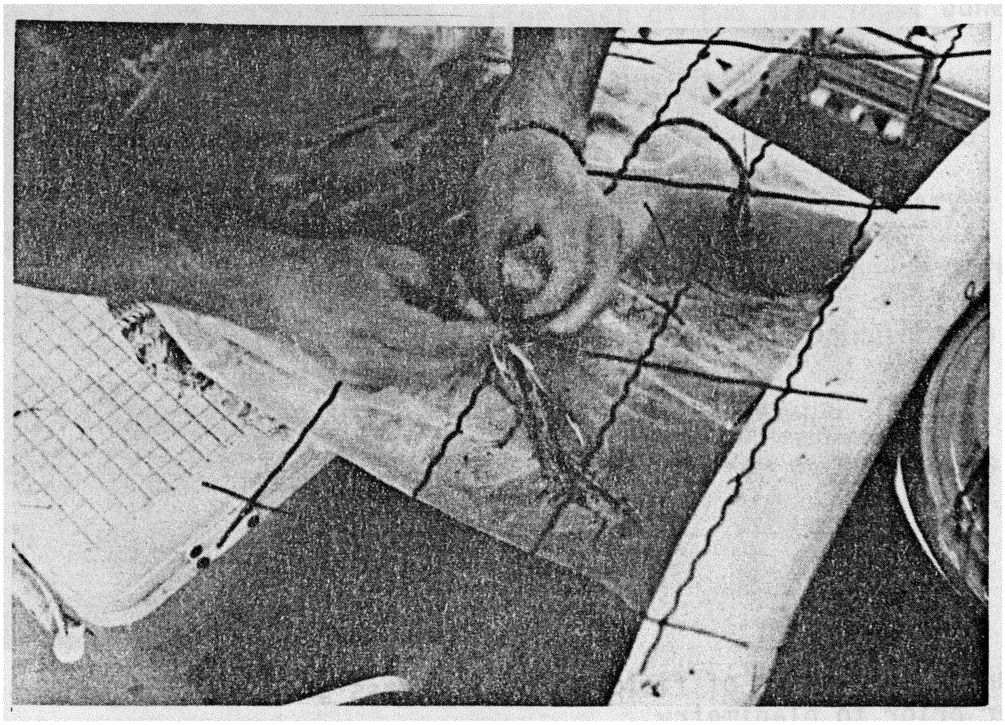


Figure 3. Preparation of a grid transplant unit. Grid TPU's contain total ca. 0.026 m^2 Halodule or Ruppia sediment free material. A shovelfull yields ca. twelve seagrass parcels of which seven or eight are attached with twist ties to the grid frame to complete the grid TPU.

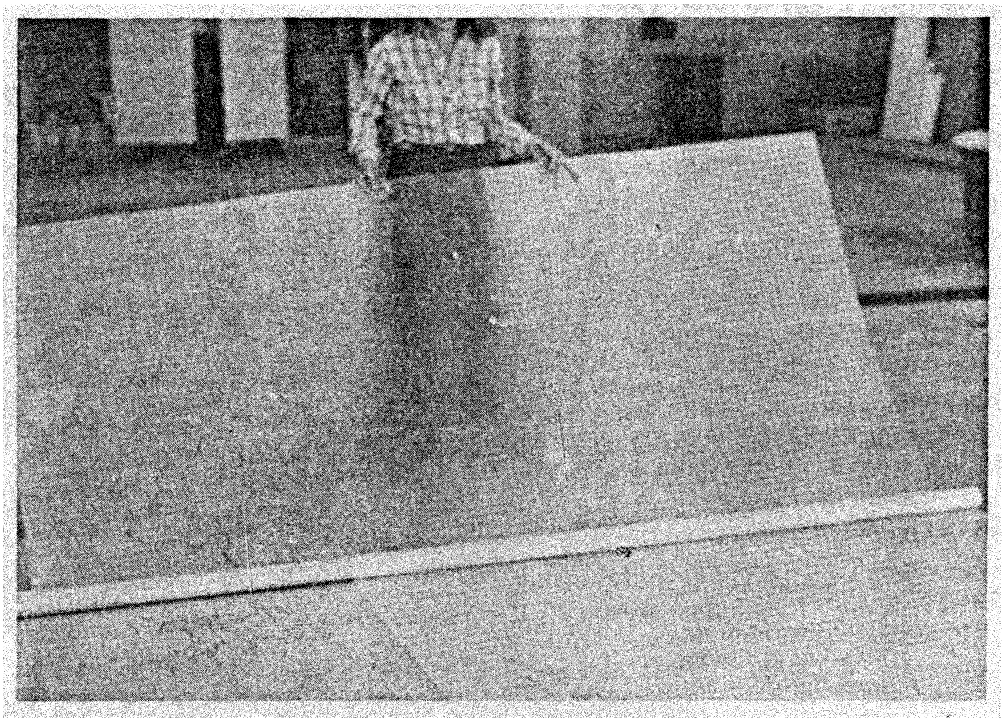


Figure 4. Plexiglass sheets utilized for field mapping of seagrass transplant areal growth extent.

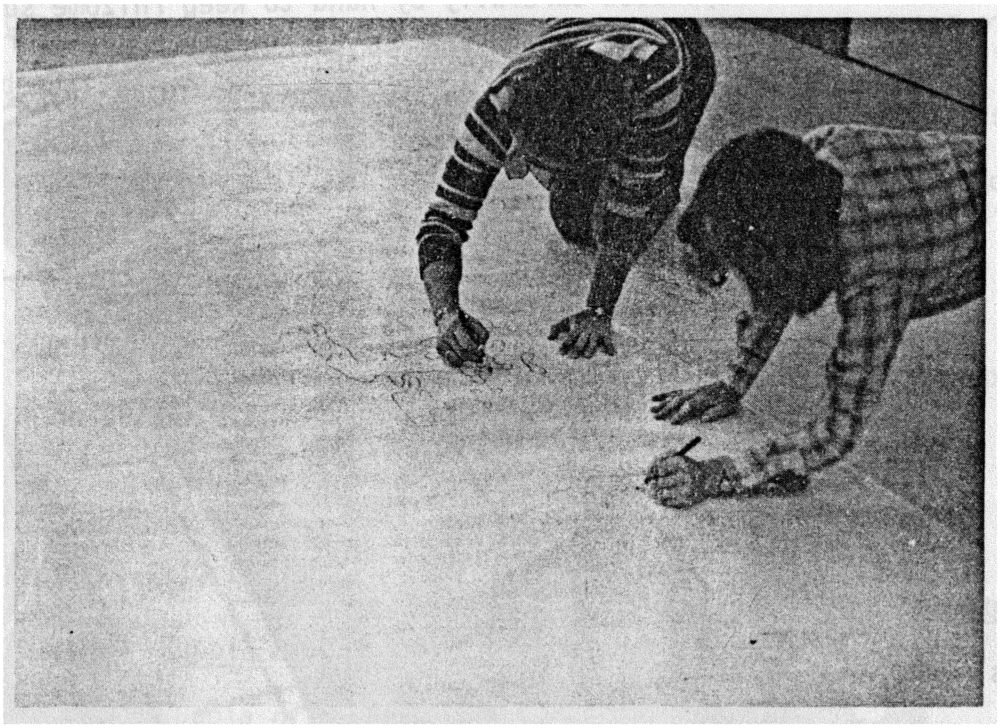


Figure 5. Transfer of field mapped seagrass growth to large sheets of paper prior to planimetry.

growth at Laguna Madre, Rincon and Mud Island study sites.

Laguna Madre

The quality of the transplanted Halodule in the upper Laguna Madre ranged from poor to good with June transplants being better. Vitality and morphology compared favorably to natural control stands after 14 months of growth. However, an inspection in May 1979, 23 months after planting, revealed the grasses to have declined somewhat from that observed during mapping in November 1978, reported in Table I. Invasion of Halophila was generally complete in the study area. Bare areas adjacent to the transplant sites which were monitored as unplanted controls indicated that no submergent grasses other than Halophila had developed. The Laguna Madre site represents a naturally barren area consisting of firm silty sand overlain with seagrass and algal debris. The Laguna Madre itself represents one optimum location for growth of Halodule wrightii in the Corpus Christi area.

Rincon

No survival of Halodule or Ruppia transplants occurred at this site. The plants disappeared within six months after each of two plantings, June 1977 and November 1978. Excessive tidal exposure on the gradual beach, periodic low salinity, high turbidity and organism damage are considered to cause the resultant decline of transplants in the Nueces Bay estuary. Sediment chemistry and texture is being examined in existing although marginal Ruppia beds in the lower Nueces Bay system. The Rincon site represents a barren area influenced by a history of clay dredged material deposition. This material had been substantially reworked by wave action for several years prior to transplanting.

Table 1.

Growth of Seagrass at *Laguna Madre* Measured November 1978
All values in meters squared area (1) footnote

Planting Date	JUNE 1977		NOVEMBER 1977			MARCH 1977	
Number Months Post Planting	17 months		12 months			8 months	
Water Depth (meters)	.6096		.6096			.6096	
Transplant Unit (TPU) Method (2) footnote	sods	grids	sods	grids		sods	grids
Number of TPUs Installed	18	19	18	10	10	18	20
Percent Survival	100.00	100.00	55.6	100.0	100.0	100.0	95
				leaf	root		
1. *Halodule* Transplants	8.7976	28.7339	9.3736	3.2236	2.0438	.8546	10.8414
volunteer Halophila	13.7120	14.6968	6.8374	3.4559	10.6371	17.6789	14.6968
Average Growth per *Halodule* TPU	*0.487*	*1.5124*	*0.5212*	*0.3224*	*0.2044*	*0.04738*	*.5425*
% Cover *Halodule*	*39.5*	*55.0*	*58.0*	*22.5*	*19.1*	*5.6*	*42.0*
Area Sample m^2	22.7141	52.7486	16.4061	16.4489	13.1639	18.7286	26.0027

Growth of Seagrass at *Rincon* Observation June 77 - October 78

Planting Date	JUNE 1977			NOVEMBER 1977	
Number Months Post Planting	17 months			12 months	
Water Depth (meters)	.1524		.3658	.1524	.3658
Transplant Unit (TPU) Method (2)	sods	grids	sods		
Number of TPUs Installed	20	20	20		
Percent Survival	0	0	0		
1. *Halodule* Transplants	0.0	0.0	0.0		
volunteer	0.0	0.0	0.0		
Average Growth per *Halodule* TPU	*0.0*	*0.0*	*0.0*		
% Cover *Halodule*	-	-	-		
Area Sample m^2	-	-	-		
Transplant Unit (TPU) Method (2)				sods	grids
Number of TPUs Installed				18	18
Percent Survival				0.0	0.0
2. *Ruppia* Transplants				0.0	0.0
volunteer				0.0	0.0
Average Growth per *Ruppia* TPU				*0.0*	*0.0*
% Cover *Ruppia*				-	-
Area Sample m^2				-	-

Growth of Seagrass at *Mud Island* Measured October 1978

Planting Date	NOVEMBER 1977				MARCH 1978			
Number Months Post Planting	12 months				8 months			
Water Depth (meters)	.4572		1.0668		.4572		1.0668	
Transplant Unit (TPU) Method (2)	sods		sods		sods		sods	
Number TPUs Installed	18		18		18		18	
Percent Survival	100.0		100.0		100.0		100.0	
1. *Thalassia* Transplants	0.1672		0.3159		0.6410		0.3344	
volunteer *Ruppia*	16.5176		-		-		-	
volunteer *Halodule*	-		-		-		-	
Average Growth per *Thalassia* TPU	0.0093		0.0177		0.0353		0.0186	
% Cover *Thalassia*	*0.7*		*1.2*		*2.5*		*1.3*	
Area Sample m^2	26.0585		26.0585		26.0585		26.0585	
Transplant Unit (TPU) Method (2)	sods	grids	sods	grids	sods	grids	sods	grids
Number TPUs Installed	18	18	18	18	18	18	18	18
Percent Survival	100.0	100.0	11.1	0.0	100.0	100.0	16.6	0.0
2. *Halodule* Transplants	23.3272	23.6245	0.0	0.0	14.1115	10.5813	0.0	0.0
volunteer *Ruppia*	-	-	-	-	-	-	-	-
volunteer *Thalassia*	-	-	-	-	0.1858	-	-	-
Average Growth per *Halodule* TPU	*1.2913*	*1.3099*	*neg*[3]	*0.0*	*0.7804*	*0.5853*	*neg*[3]	*0.0*
% Cover *Halodule*	*89.5*	*90.6*	*0.0*	*0.0*	*54.2*	*40.6*	*0.0*	*0.0*
Area Sample m^2	26.0585	26.0585	26.0585	26.0585	26.0585	26.0585	26.0585	26.0585
Transplant Unit (TPU) Method (2)	none		none		none		none	
Number TPUs Installed	none		none		none		none	
Percent Survival	-		-		-		-	
3. *Control*								
volunteer *Ruppia*	*7.6178*		*0.0*		*0.0*		*0.0*	
% Cover Volunteer	*29.2*		*0.0*		*0.0*		*0.0*	
Area Sample m^2	26.0584		26.0584		26.0584		26.0584	

---

(1) Values reported in metric units are conversions from data collected in English Units. They represent corrected values of total growth extent measured minus sum total area for original TPU's.

(2) Sods are viable seagrass and associated sediment; *Thalassia* sods tpu ca 0.022 m^2 and *Halodule* and *Ruppia* sods ca. 0.010 m^2
Grids are vinyl coated fencing (45.7 cm x 22.9 cm) with sediment free roots and short shoots attached. Grids contain ca 0.026 m^2 seagrass (*Halodule* or *Ruppia*).

(3) Negligible - surviving units dimension less than original TPU.

Mud Island

The growth development of Thalassia was relatively slow in this area. However, the transplants compared to undisturbed natural control areas with regard to vitality and vegetative morphology. Each transplant unit (TPU) had between 0 to 7 new rhizomes (average 3) each with several emerging short shoots. Thalassia survived in both the shallow 0.46 meter depth of water as well as the deeper 1.07 meter depth plantings. Better growth occurred in the deeper water as wave action scouring took place around the plants in the shallower areas. As of May 1978 Thalassia transplants at the 1.07 meter depths did not compare to natural stands at similar depths having low shoot densities and short leaf lengths. Thalassia plantings in the 0.46 meter depths were similar to natural stands at the same depth and wave energy climate.

Halodule developed at a more rapid rate than Thalassia in the 0.46 m depth. It did not survive at the 1.07 meter water depths. The plants in the deeper water decreased, starting in May 1978 and were completely absent by October 1978. As of May 1979, 18 months after installment, transplants in the 0.46 meter water depths did not exhibit a decline but the vitality and vegetative morphology did not compare favorably to undisturbed natural stands, having low shoot densities and short leaf lengths.

At this site, Ruppia from adjacent undisturbed beds invaded the 0.46 meter water depth control plots. Control plots were unintentionally sited adjacent to a temporarily disturbed Ruppia stand nearshore which subsequently revitalized and encroached upon the controls. No invasion of submerged grasses has occurred in the 1.07 meter depth controls.

The Mud Island site represents a site disturbed in 1977 which was originally a well-developed Halodule/Thalassia/Ruppia/Syringodium seagrass system. A boat and barge covered the area with shell, silt, and sand from propeller wash. The silty sand substrate was influenced by abundant seagrass root and shoot material destroyed and buried by the disturbance activity.

DISCUSSION

Studies utilizing submergent, emergent, and upland vegetation to stabilize dredged materials and disturbed estuarine habitats have not been reported for the Coastal Bend region of Texas. A dune stabilization study on Padre Island by Dahl (1974) was reported but represents a different set of environmental and edaphic conditions. Dodd and Webb (1975), and Webb *et al*. (1978) describe shoreline stabilization and marsh development in the Galveston Bay area of Texas. Webb (1978) also conducted upland plantings. Chapman (1967) attempted the transplant of *Spartina alterniflora* on hydraulically deposited spoil in Galveston Bay. Chaney *et al*. (1978) described plant species composition of some spoil islands in the Corpus Christi area. Dr. Ron Phillips (pers. comm.) attempted submergent grass transplants locally circa 1974, some of these initial efforts are reported in McRoy (1975).

Submergent

The marine angiosperms *Thalassia testudimum* Koing, *Halodule wrightii* Ascherson, Phillips *et al*. (1974), *Syringodium filiforme* Kutz, *Halophila engelmannii* Acherson, and *Ruppia maritima* L. occur locally. Area wide seagrass plant communities can be characterized as heterogenous although nearly monotypic stands of *Halodule wrightii* associated with *Halophila* and *Ruppia* occur in the Upper Laguna Madre of Texas. The shallowest waters, including those frequently exposed during low winter tides, generally support *Halodule* and *Ruppia*, while the deeper waters, i.e. water depths no greater than minus ca. 1.8288 meters (six feet) mean sea level, support *Thalassia*, *Syringodium*, and marginal *Halophila*. In some instances marginal *Ruppia* will inhabit water depths immediately below the lower limit of Thalassia, i.e. approximately minus approximately 2 meters (six feet) mean sea level.

Wiginton and McMillan (1979) found seagrasses in Texas bays are largely confined to depths above minus two meters.

Areawide, zonation, at least related to water depth, is an exception rather than a rule.

The data presented document the transplantation of Thalassia, Halodule, and Ruppia in this area and provides observations concerning the growth and survival of the transplants up to seventeen months post planting. None of the transplants were installed on dredged material, strictu sensu.

Transplantation was successful in June, November and March. Each species responded uniquely to the test sites with regard to both the quantitative evaluation of growth extent and percent survival at different planting dates, and yielded different responses in transplant vigor and other vitality criteria such as leaf length, color, degree and type of epiphytism and relative shoot densities in comparison to natural stands.

Overall the best time to transplant submergent vegetation is after spring revitalization or before winter dieback. In the Corpus Christi area this period falls roughly from mid-March or late April to early November or early December. During these periods vegetative material is in a condition which eases transport, TPU selection, and allows maintenance of the material in an intact three dimensional form which aids in TPU installation.

Seagrass could be restored locally if certain precautions are taken. Observations indicate, in a Halodule-Ruppia grassflat site previously damaged or destroyed by mechanical activities such as oil well or pipeline installation, if the predisturbance elevation is restored and the original surface sediment replaced, depending on the size area affected, most low to moderate wave energy Halodule and Ruppia grassflats will restore themselves within a one to five year period following the disturbance. In some areas transplanting efforts provide little extra benefit (Rick Kalke and Scott Holt, 1979 pers. comm.). However, when the original substrate is removed, the existent grasses destroyed, the area of destruction great, and/or the elevation decreased well below that found in the original condition, regrowth could occur rapidly outward from undisturbed peripheral Halodule and Ruppia stands but colonization in deeper water is extremely slow in which case transplantation would be required.

Both case observations forwarded for Halodule or Ruppia restoration will probably not apply to impacts in Thalassia type grassbeds of this region. Data presented indicate growth of transplanted Thalassia is slow. Phillips (pers. comm.) notes Thalassia is at the limit of its environmental tolerances in the Coastal Bend region of Texas. Oppenheimer and Brogden (1976) report 18,894 acres (7839. 834 hectares) of grassflats, characterized by Thalassia, were present in the Corpus Christi five bay system as of 1974. Field observations indicate the greater proportion of these grassflats are the Halodule-Ruppia type rather than the Thalassia type.

Locations of Thalassia type grassbeds are seemingly associated with areas which are older with regard to recent sediment depositions and are afforded the protection of deeper waters or low to moderate energy shoreline orientations. The deeper waters off the southern shoreline of Mud Island and shallower waters on the western shorelines of the Harbor Island complex approaching Corpus Christi Bayou and California Hole are two examples. Mud Island has built and stabilized since 1833 (Collier and Hedgpeth, 1950), and noted portions of Harbor Island have been stable since 1884 (U.S. Coast and Geodetic Charts, 1884 to present).

It is emphasized that within a given segment of this region restoration options are technique and site specific. Even a moderately damaged area may require some transplantation and cultural manipulation in the restoration attempt.

ACKNOWLEDGEMENTS

This work was supported as a part of the Texas A & M University Sea Grant Program in Environmental Quality with matching funds from the Corpus Christi Navigation District No. 1 (Port of Corpus Christi) and the University of Texas. Partial funding for the Mud Island project was also received from Edwin Cox, Inc. The work was coordinated with Dr. Philip Oetking of the Port of Corpus Christi. Special thanks to Cora Nessmith who contributed variously in this effort.

LITERATURE CITED

Behrens, E.W. 1966. Surface salinities for Baffin Bay and Laguna Madre, Texas April 1964-1966. Publ. Inst. Mar. Sci., Univ. Tex. Vol 11, November.

Chaney, A.H., B.R. Chapman, J.P. Karges, D.A. Nelson, R.R. Schmidt, and L.C. Thebeau. 1978. Use of Dredged Material Islands by Colonial Seabirds and Wading Birds in Texas. Dredged Material Research Program, T.R. D-78-8, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, April.

Chapman, C.R. 1967. Estuarine Program, Report of the Bureau of Commercial Fisheries Biological Laboratory, Galveston, Texas. U.S. Bureau Commercial Fisheries, Circular #295, p. 19, Washington, D.C.

Collier, A., and J.W. Hedgpeth. 1950. An Introduction to the Hydrography of Tidal Waters of Texas. Publs. Inst. Mar. Sci., Univ. Tex. Vol 1, No. 2, November.

Connell, J.H. 1961. The Influence of Interspecific Competition and Other Factors on the Distribution of the Barnacle *Chthamalus stellatus*. Ecology 42:710-723.

Dahl, C.E., G.A. Fall, S.G. Appan. 1975. Construction and Stabilization of Coastal Foredunes with Vegetation: Padre Island, Texas, MP 9-75, U.S. Army Coastal Engineering Research Center, Fort Belvoir, Va., 22060, September.

Dodd, J.D. and J.W. Webb. 1975. Establishment of Vegetation for Shoreline Stabilization in Galveston Bay. Miscellaneous Paper No. 6-75, U.S. Army Coastal Engineering Research Center, Fort Belvoir, Va. 22060, April.

Eleuterius, L.N. 1974. A Study of Plant Establishment on Dredge Spoil in Mississippi Sound and Adjacent Waters. U.S. Army Corps of Engineers, Mobile District, Mobile, Alabama 36601, November.

Folk, R.L. 1968. Petrology of Sedimentary Rocks. Hemphill's, Austin, Texas, 170pp.

Holland, J.S., N.J. Maciolek, R.D. Kalke, L. Mullins and C.H. Oppenheimer. 1975. A Benthos and Plankton Study of the Corpus Christi, Copano and Aransas Bay Systems III. Summary of the Three-year Project. Final Report to the Texas Water Development Board, August.

Kadlec, J.A. and W.A. Wentz. 1974. State-of-the Art Survey and Evaluation of Marsh Plant Establishment Techniques: Induced and Natural. Volumes I and II. Dredged Material Research Program, D-74-9. U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi 39180, December.

Levy, E.B. and E.A. Madden. 1933. The Point Method of Pasture Analysis. New Zealand Journal of Agronomy, Vol. 46, pp. 267-279.

McRoy, C.P. ed. 1975. Biology of Seagrass Ecosystems: Report of a Summer Field Course. Seagrass Bulletin 1. Seagrass Ecosystem Study Project Office, Institute of Marine Science, University of Alaska, Fairbanks, Alaska 99701, February.

Oppenheimer, C.H. and W.B. Brogden. 1976. The Ecology of a Texas Bay. In: Harvesting Polluted Waters. O. Devik, ed. pp. 237-279.

Phillips, R.C. 1960. Observations on the Ecology and Distribution of the Florida Seagrasses. Professional Papers Series Number Two, Florida State Board of Conservation, Marine Laboratory, St. Petersburg, Florida. 72 pp.

Phillips, R.C., C. McMillan, H. F. Bittaker and R. Heiser. 1974. Halodule wrightii Asherson in the Gulf of Mexico. Contr. mar. Sci. Vol. 18.

Richards, L.A., ed. 1954. Diagnosis and Improvement of Saline and Alkali Soils. United States Department of Agriculture Handbook No. 60, Washington, D.C. 20402. February.

Shepard, F.P. and D.G. Moore. 1955. Central Texas Coast Sedimentation: Characteristics of Sedimentary Environment, Recent History and Diagenesis. Bulletin of the American Association of Petroleum Geologists. Vol. 39, No. 8, August.

Smith, N.P. 1974. Intracoastal Tides of Corpus Christi Bay. Contr. mar. Sci. Vol. 18.

Thornthwaite, C.W. 1948. An Approach Toward a Rational Classification of Climate. Geogr. Rev. 38(1):55-94.

U.S. Coast and Geodetic Survey, Coast Chart No. 210 Aransas Pass and Corpus Christi Bay with the Coast to Latitude 27°12' Texas, (Series 1884 to present), Published through Department of Commerce and Labor, Washington, D.C.

Watson, R.L. and E.W. Behrens. 1976. Hydraulics and Dynamics of New Corpus Christi Pass, Texas: A Case History, 1973-75. U.S. Army Coastal Engineering Research Center, Fort Belvoir, Va. 22060, September.

Webb, J.W., J.D. Dodd, B.W. Cain, W.R. Leavens, L.R. Hossner, C. Lindau, R.R. Stickney, and H. Williamson. 1978. Habitat development field investigations, Bolivar Peninsula marsh and upland habitat development site, Galveston Bay, Texas, Appendix D: Propagation of vascular plants and postpropagation monitoring of botanical, soil, aquatic biota, and wildlife resources. TR D-78-15. U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Wiginton, J.R. and C. McMillan. 1979. Chlorophyll Composition Under Controlled Light Conditions as Related to the Distribution of Seagrasses in Texas and the U.S. Virgin Islands. Aquatic Botany 6:171-184.

GROWTH OF THALASSIA RESTORED BY SEEDLINGS IN A MULTIPLY-IMPACTED ESTUARY

Anitra Thorhaug
Department of Biological Sciences
Florida International University
Tamiami Campus
Miami, Florida 33199

ABSTRACT

This study of large-scale restoration and growth of seedlings of _Thalassia testudinum_ is a continuation of a program described in previous conferences on restoration and creation of wetlands and coastal systems in Florida. The first _Thalassia_ restoration project at Turkey Point, Biscayne Bay, had more than 6,000 seeds successfully planted of which 80% grew. The second project included testing the water quality in the various basins of north Biscayne Bay for _Thalassia_ seedling growth. The third project included disease aspects of growth of _Thalassia_. The animal communities which recolonized a four-year-old _Thalassia_ community were the last to be reported on.

The present project involved planting at two sites in a multiply impacted part of north Biscayne Bay. Each site was approximately five acres. Site 1, the 36th Street Causeway, was on the sides of a 20-year-old dredge and fill DOT causeway constituting a major artery across the bay. This site was planted with 41,000 _Thalassia_ seedlings. Site 2, Margaret Pace Park, was a more recently filled area adjacent to one of the most intensively developed and multiply impacted portions of north Biscayne Bay. An oil terminal had formerly been situated at this site; and sewage outfall, urban storm runoff and continual major port activity have also occurred. High tidal currents were found there due to man's artificial construction of water flow into north Biscayne Bay, as well as fairly high water turbidity in certain wind and tidal conditions.

The results shows that after two months' growth, there was no statistical difference between the blade length of _Thalassia_ seedlings at the more impacted sites (Sites 1 and 2) in north Biscayne Bay and the two months' seedling growth at the south Biscayne Bay Turkey Point site planted

four years previously. There was no statistical difference between the root length and number or rhizome appearance between the two impacted sites, Sites 1 and 2, in north Biscayne Bay.

After six months, growth was vigorous at Sites 1 and 2. There was no statistical difference in blade length between these sites. There were statistically significant differences between blade length at each of the sites versus Turkey Point. Root length was not statistically different between Sites 1 and 2. However, root number and rhizome development and length was statistically difference between the Turkey Point planting and the two impacted sites, the 36th Street Causeway and Margaret Pace Park. This would indicate that some differential growth is associated with water and/or sediment quality.

INTRODUCTION

Thalassia testudinum was successfully transplanted by seedling in August 1973 (Thorhaug, 1974). These first reports of Thalassia seedling growth were made and are summarized in Table 1. Reports of that effort at Turkey Point, Biscayne Bay, have shown that within the restoration areas blade densities achieved the same magnitude as control areas (Thorhaug, 1979). Thorhaug and McLaughlin (1978) and McLaughlin et al. (in press) showed that animal communities which recolonized the transplantation area are similar in number and diversity to those in control areas and are highly dissimilar to areas which are still barren within the same locality in south Biscayne Bay. McLaughlin et al. (in press) show that the fisheries organisms such as juvenile pink shrimp and juvenile forms of fishes, in particular, have highly significant differences between barren areas and restored areas.

The multiply impacted area of north Biscayne Bay has been the focus of several conferences and decision-making assemblies (Thorhaug, 1976 and McKenry, 1976), resulting in the decision that restoration of seagrasses was of high priority in the process of rehabilitating this bay.

Several levels of government, from county to federal, have decided that there are advantages to be accrued from restoration of seagrasses and have proceeded in various levels of effort.

This study concerns mitigation by Dade County Port of Miami and Miami-Dade Water and Sewer Authority of two sites in north Biscayne Bay. Focus is on the growth characteristics of the seedlings of Thalassia testudinum as they respond to various substrates within short time periods after planting.

Table 1. The growth of *Thalassia* test seedlings after various growing times planted in August, 1973 at Turkey Point, Biscayne Bay, Florida. Data is from Thorhaug (1974 and in press).

	6 months	3 months
BLADES		
Length	15.5	7.6
Number new	2.9	5.0
Number old	n.d.*	n.d.
ROOTS		
Length	6.6	5.9
Number	8.4	n.d.
RHIZOMES		
Length	5.2	0
Percentage	n.d.	0

n.d.=no data

METHODS

Siting

The decision for siting the mitigation plots was, in good part, based on the experience of Thorhaug and Hixon (1975) as to areas of optimal success as well as a series of aerial photographs and aerial observations which had been studied. The original concept was to pick one site which would allow optimal growth conditions and a second site which would be representative of the average highly impacted condition of water quality, bottom type and other physico-chemical factors in the north bay. Thus two discrete sites were chosen and large-scale planting undertaken.

Site 1 (Figure 1) was a causeway constructed in 1958 by piling up bay sediments immediately adjacent to the site. Thus, deeper areas are found on either side of the causeway. The fairly coarse sand had been recolonized by Halodule wrightii and Syringodium filiforme in patches in the intervening 20 years. The northwest half to about 40 yards offshore was the planting site. The slope was about 20-30°.

Site 2 was a public park which had been filled during the last 20 years. Riprap covered most of the intertidal area. The sublittoral shallow was coarse sand and rock with patches of Halodule wrightii to about 1.3 to 1.6 m. The bottom contained fine silt covered with Halophila baillonis to about 3 m. This second site had high turbidity, high tidal currents, and a storm drain in its midsection.

The criterion of usefulness to the citizens was also considered. Therefore, areas near to shore were chosen rather than central basin areas, so that eventually the areas could be opened for fishing or contact sports. The seagrass restoration was hoped to clarify some of the turbidity problem, at least in the immediate and adjacent area where the seagrass restoration was undertaken.

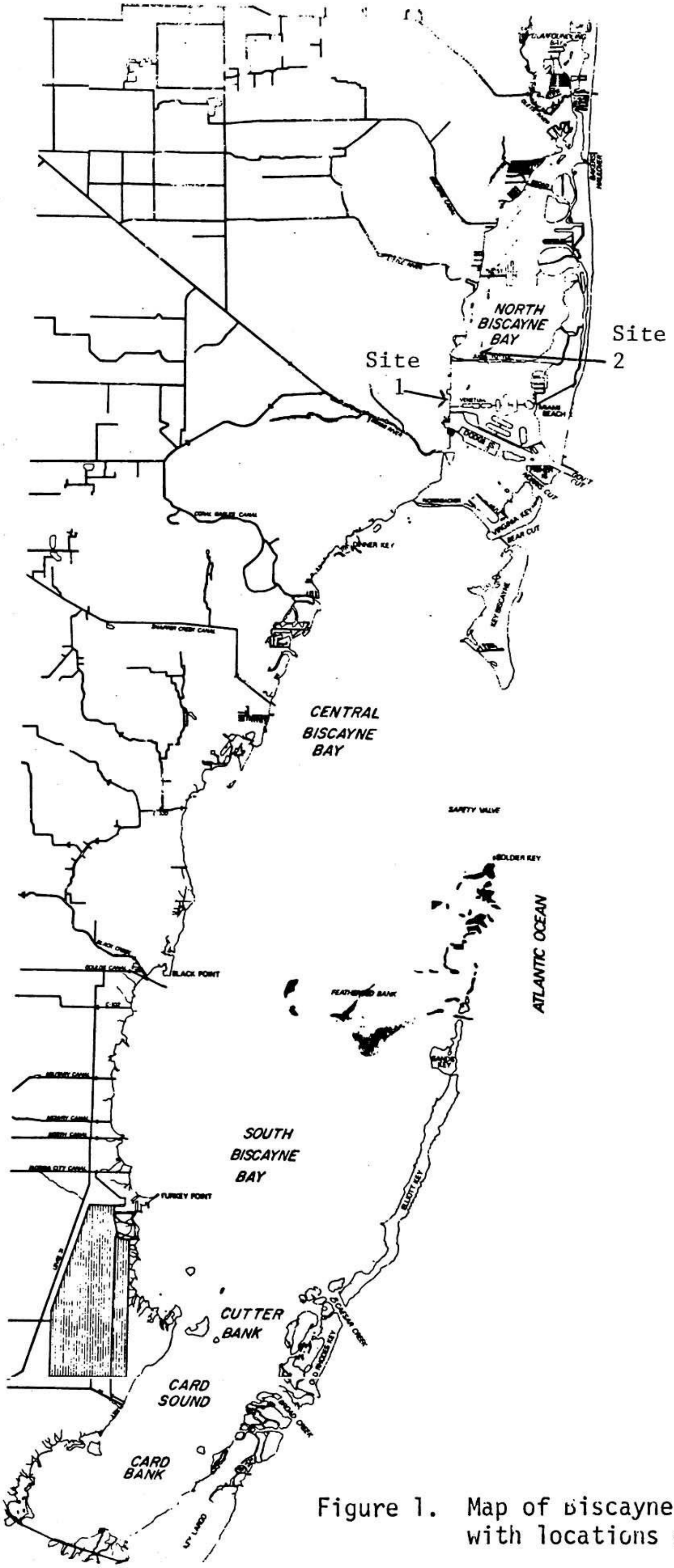


Figure 1. Map of Biscayne Bay, Miami, Florida, with locations of Sites 1 and 2.

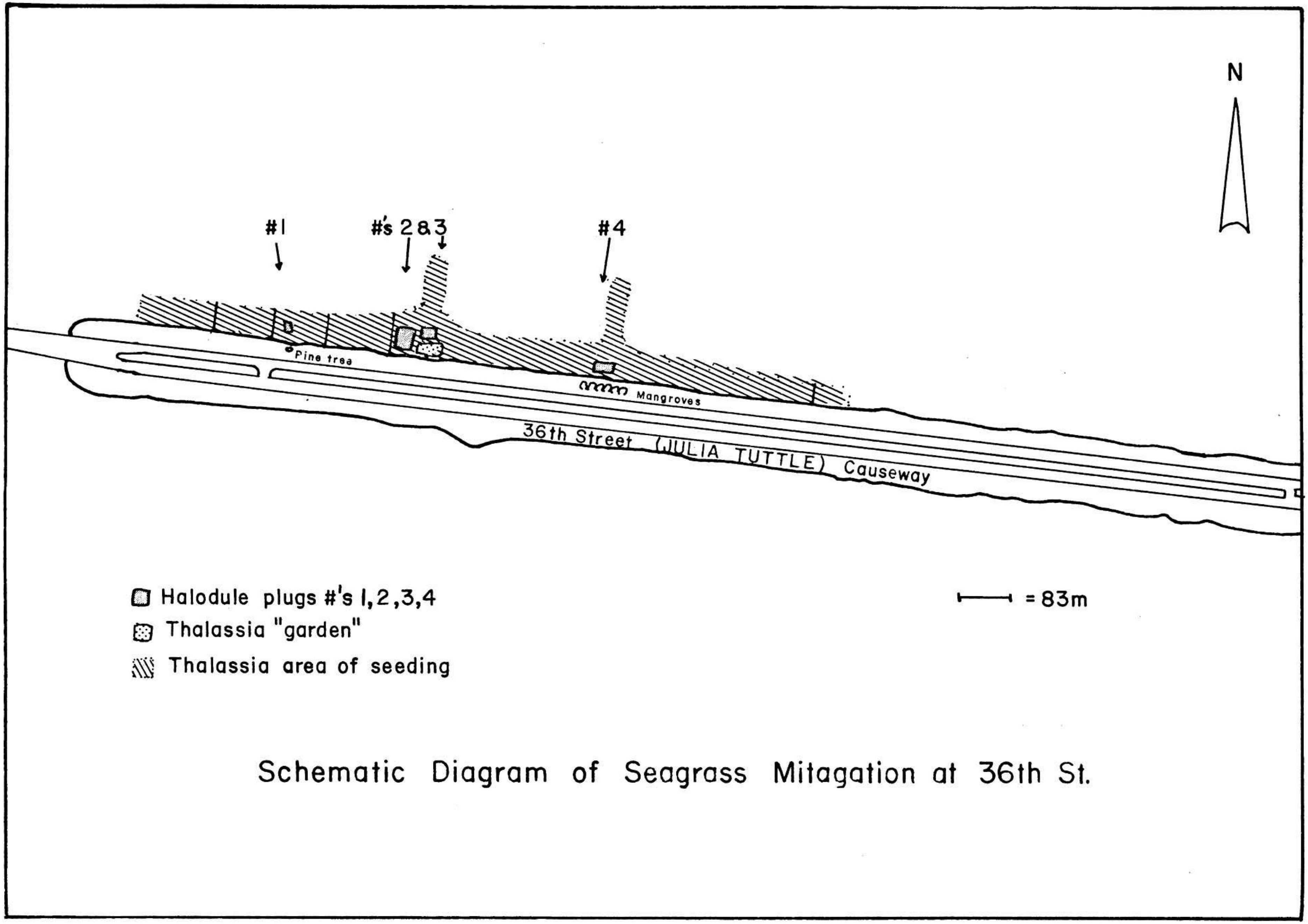


Figure 1a. Site 1 in north Biscayne Bay. Schematic map.

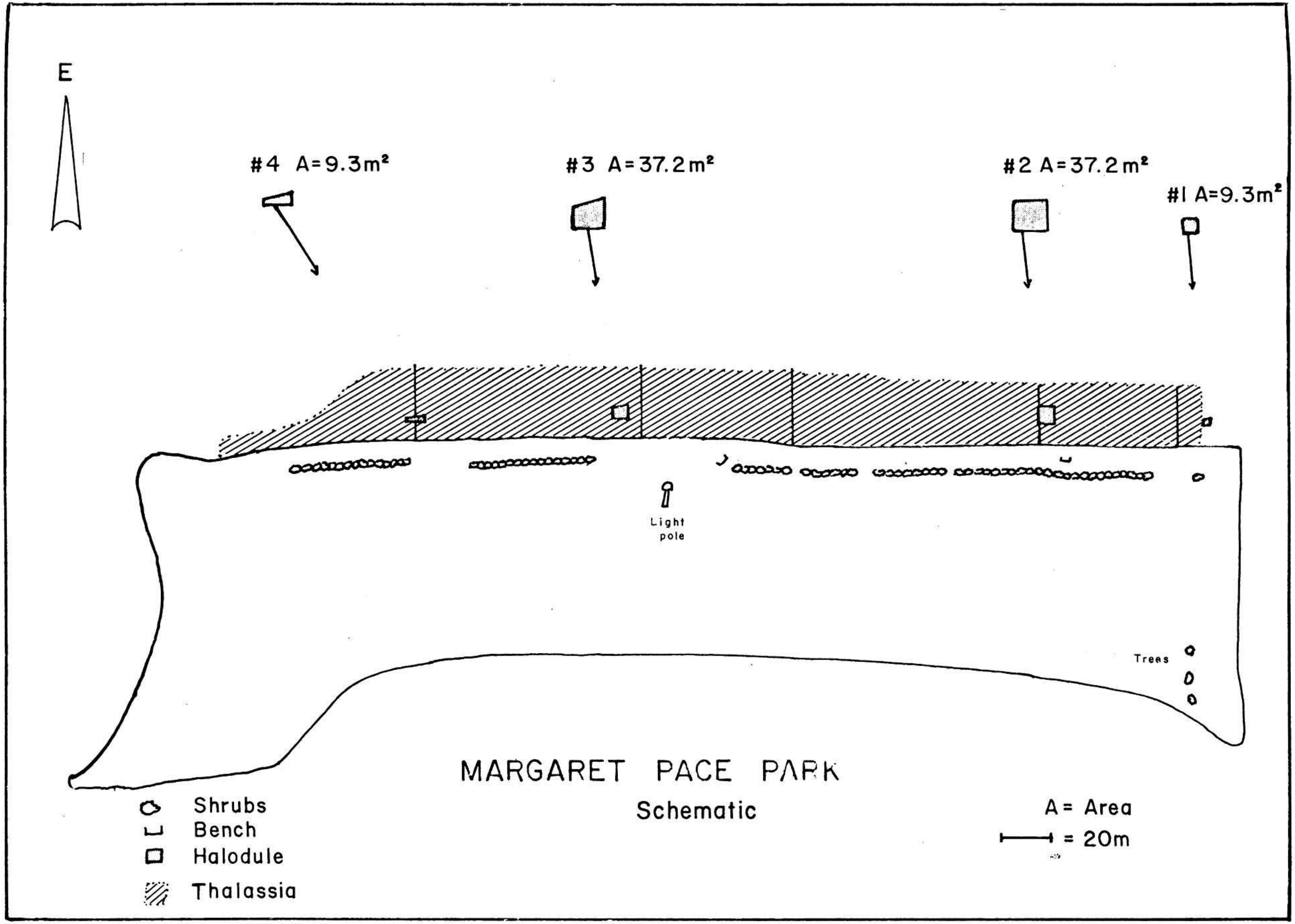


Figure 1b. Site 2 in north Biscayne Bay. Schematic map.

Within each of these sites, there were barren areas, areas of sparser seagrass, and areas being recolonized by two successional (Thorhaug and Bach, 1975) seagrasses, Halodule wrightii and Syringodium filiforme. These were subjected to an inventory and the number of blades was counted at various intervals, so that the patterns of the successional grasses would also be known.

Thalassia Seedling Installation

At Site 1 approximately 41,000 seedlings were installed from one foot below the low tide to -4 m mean low tide. Seedling collection and preparation followed the methods of Thorhaug (1974). Seedlings were planted in late August 1978 by hand, using only disease-free seedlings. The vegetation presently there was a successional stage of Halodule wrightii, occasionally interspersed with round patches of Syringodium filiforme. As the water went below -2 m mean low tide, Halophila baillonis became the dominant species. The Thalassia was planted outward into the deeper water in two strips. Most of the planting was done in parallel rows at 0.3 m centers along the northwestern coastline of the causeway. The existing seagrass was sparsely distributed from the mean low tide to about 1 m from the mean low tide.

At Site 2, approximately 37,000 Thalassia seedlings were planted by a series of divers using SCUBA on lines on 0.3 m centers going outward from the shore to a depth of approximately -4 m mean low tide.

It should be noted that in both of these places, a somewhat denser "garden area" was planted immediately adjacent to the shore and marked so that the effect of density greater than 0.3 m intervals (e.g., 0.2 and 0.1 m intervals) could be seen in terms of final blade density. The method of planting was manual and followed that of Thorhaug (1974) at Turkey Point and Thorhaug and Hixon (1975). Seedlings were also installed in intertidal or very sparse *Halodule wrightii*, in *Syringodium filiforme*, in plugs of *Halodule* which were put in large barren areas and in barren sand.

Measurements of blades were taken from green at base upward to tip. Number of old blades included old blade sheaths still attached to the shoot. Roots per blade bundle were counted, including roots broken off. Rhizome length was measured from seed outward to meristem tip.

RESULTS

The results of the Thalassia seedling growth for Site 1 can be seen in Table 2.

Results showed that vigorous growth of roots, blades and rhizomes was occurring at both the more optimum site in the multiply impacted estuary of north Biscayne Bay (Site 1) and at the more highly impacted site (Site 2). Growth rates, in many cases, were not statistically significantly different at the 99% level (t-test difference between means) from those at Turkey Point, which was a singly impacted site in an otherwise relatively untouched part of Biscayne Bay.

The growth of the *Thalassia* blades was statistically significantly higher (at the 99% level of significance) within the denser growth of the successional seagrasses *Halodule wrightii* and *Syringodium filiforme* than it was in the restored *Halodule* plugs or into bare sand. There was no difference in growth of the blades within the various densities (garden versus other) or types of successional seagrass (Table 3). The number of blades was statistically significantly higher (at the 99% level) in the sand from those within the other seagrasses. There was no statistically significant

Table 2. The growth of <u>Thalassia testudinum</u> seedlings after various time periods at the 36th Street Causeway and Margaret Pace Park in north Biscayne Bay. Length is given in centimeters.

	6 Months Data		3 Months Data	
	36th Street	Margaret Pace	36th Street	Margaret Pace
BLADES*				
Length	10.1 (±3.61)**	6.7 (±1.79)	10.8 (±3.09)	8.0 (±1.65)
Number new	3.2 (±0.80)	3.7 (±0.84)	3.7 (±1.00)	3.6 (±1.18)
Number old	-	2.6 (±0.87)	2.4 (±1.19)	2.6 (±1.17)
ROOTS*				
Length	7.8 (±2.90)	6.8 (±1.42)	7.8 (±3.19)	6.9 (±0.79)
Number	5.1 (±1.48)	4.2 (±1.70)	3.3 (±1.25)	3.6 (±1.13)
RHIZOMES*				
Length	0.2 (±0.41)	0.2 (±0.38)	-	-
Percentage	25%	17%	0%	0%

*Subsampling as follows: 6 months: 36th Street Causeway - 53 stations
Margaret Pace Park - 25 stations

2 months: 36th Street Causeway - 61 stations
Margaret Pace Park - 36 stations

**Standard deviation

Table 3. The growth of _Thalassia testudinum_ seedlings after six months' growth at an impacted site in north Biscayne Bay as a function of sediment type and other vegetation present. Length is given in centimeters.

	Garden	Intertidal _Halodule_	_Syringodium_	_Halodule_ Plugs	Sand
BLADES*					
Length	11.9	10.8	12.7	6.1	6.3
Number new	3.2	3.4	3.0	3.0	3.8
Number old	n.d.	n.d.	n.d.	n.d.	n.d.
ROOTS*					
Length	9.0	6.8	7.3	6.5	8.9
Number	4.6	5.6	4.0	6.0	5.0
RHIZOMES*					
Length	0.2	0.5	0	0	0
Percentage	20%	60%	0%	0%	0%

*53 stations

difference after six months in the root number, the root length or the rhizome length within any of these planting subsites.

The differences between multiply impacted estuary optimum site and average site were seen only in the blade length which, after both two months (Table 2) and six months, was longer at the optimum site, Site 1, than at Site 2. There was no statistically significant difference between number of blades, number of old blades, root length and root number, rhizome length or percentage of plants having rhizomes between these two sites.

Results from a previous planting at Turkey Point are seen in Table 1.

DISCUSSION AND CONCLUSIONS

Thus, the results have shown that the recovery rate of Thalassia seedlings planted in an average highly impacted site (Site 2) and in an optimum site (Site 1) within a multiply impacted estuary is vigorous after short time periods. There appears to be a difference in blade length related to the sediment and/or vegetation type in such a manner that those planted with little vegetation around them tend to spread the leaves out and produce more leaves as though to optimize the surface for photosynthesis. Those planted in dense or sparse grass tend to grow rapidly upward with fewer, but taller, leaves, as though to optimize their surface for light. The plants in the area where water has daily high turbidity (Dade County DERM, 1978) did not have as long blades as those where clearer water was observed more frequently.

The rhizome and root development was greater, although not statistically significantly so, in the area of more optimal conditions. Continued monitoring of this site for several years will occur, so that the rate of success of spreading of the seedlings can be looked at as a parameter of water quality.

The length of blade, length of rhizome and numbers of these parameters were similar to those at Turkey Point and have been compared in another paper (Thorhaug, 1979). This showed that although there were statistically significant differences in length of blade and in number of roots and rhizomes at both the singly impacted site and at the multiply impacted site growth did occur vigorously within the first three months.

Survival is best judged after two years' growth in such a large area with extremely scattered small seedlings among longer-bladed successional plants. It was extremely difficult at our Turkey Point site to judge until the second to third year. Thus, it was not measured at Site 1 and 2 after three or six months.

The Turkey Point site was almost an optimal situation for testing seagrass restoration since a single effluent (thermal) had been released and then taken offstream. The macrovegetation had been denuded, but the sediment and the surrounding water quality remained fairly intact. In north Biscayne Bay estuary, multiple changes to circulation (van de Kreeke, 1976; Michel, 1976), water quality (McNulty, 1970; Waite, 1976) and sediment (Wanless, 1976) had occurred, so that little was in the original condition. In addition, the changes occurred decades ago (Thorhaug, Roessler and Tabb, 1976) rather than a single year or two before and, thus, the situation was thought to be entirely different.

The vigorous growth of Thalassia seedlings back into two multiply impacted sites gives hope for future restorations in Biscayne Bay and other multiply impacted urbanized estuaries and coastal areas throughout the Gulf of Mexico, south Florida and the Caribbean.

ACKNOWLEDGEMENTS

The north Biscayne Bay work was sponsored by Dade County Port and Miami-Dade Water and Sewer Authority. The Turkey Point work was sponsored by DOE grant #EY 76 S 05 4493 and Florida Power and Light Company.

LITERATURE CITED

Dade County Department of Environmental Management. 1978. A short-term water chemistry assessment of north Biscayne Bay. Dade County DERM, Miami, FL. 64 pp.

McKenry, C.E.B. 1976. Consensus. Sea Grant Special Report No. 6. University of Miami, Coral Gables, FL. 23 pp.

McLaughlin, P.A. and A. Thorhaug. 1978. Restoration of *Thalassia testudinum*: animal community in a maturing four-year-old site - preliminary results. pp. 149-161 *IN*: D.P. Cole (ed.). Proc. 5th Annual Conf. on Restoration of Coastal Vegetation in Florida. Hillsborough Community College Press, Tampa, FL.

McLaughlin, P.A., S.F. Treat, A. Thorhaug and R. Lemaitre. (in press) The animal community of a restored seagrass (*Thalassia*) bed. Aq. Bot. (in press).

McNulty, J.K. 1970. Effects of Abatement of Domestic Sewage Pollution on the Benthos, Volumes of Zooplankton, and the Fouling Organisms of Biscayne Bay, Florida. University of Miami Press, Coral Gables, FL. 107 pp.

Michel, J.F. 1976. The impact of works of man on the physical regime of Biscayne Bay. pp. 265-270 *IN*: A. Thorhaug (ed.). Biscayne Bay: Past/Present/Future. Sea Grant Special Report No. 5. University of Miami, Coral Gables, FL.

Thorhaug, A. (ed.). 1976. Biscayne Bay: Past/Present/Future. Sea Grant Special Report No. 5. University of Miami, Coral Gables, FL. 315 pp.

Thorhaug, A. 1979. Restoration of impacted Florida estuaries. Fla. Scientist 42(S):27.

Thorhaug, A. (in press) Environmental management of a highly impacted, urbanized tropical estuary: rehabilitation and restoration. 14th European Marine Biology Symposium, Helgoland, Germany, 1979. (in press)

Thorhaug, A. and S. Bach. 1975. Natural and altered successional patterns of subtropical estuarine marine plants. Am. J. Bot. 62(S): 33. (Abstract)

Thorhaug, A. and R. Hixon. 1975. Revegetation of *Thalassia testudinum* in a multiple-stressed estuary, North Biscayne Bay, Florida. pp. 12-27 *IN*: R. Lewis (ed.). Proc. Second Annual Conf. on Restoration of Coastal Vegetation in Florida. Hillsborough Community College Press, Tampa, FL.

Thorhaug, A., M.A. Roessler and D. Tabb. 1976. Man's impact on the biology of Biscayne Bay. pp. 301-312 *IN*: A. Thorhaug (ed.). Biscayne Bay: Past/Present/Future. Sea Grant Special Report No. 5. University of Miami, Coral Gables, FL.

Van de Kreeke, J. 1976. Tides in Biscayne Bay. pp. 39-49 *IN*: A. Thorhaug (ed.). Biscayne Bay: Past/Present/Future. Sea Grant Special Report No. 5. University of Miami, Coral Gables, FL.

Waite, T.D. 1976. Man's impact on the chemistry of Biscayne Bay. pp. 279-285 IN: A. Thorhaug (ed.). Biscayne Bay: Past/Present/Future. Sea Grant Special Report No. 5. University of Miami, Coral Gables, FL.

Wanless, H.R. 1976. Man's imapct on sedimentary environments and processes. pp. 287-299 IN: A. Thorhaug (ed.). Biscayne Bay: Past/Present/Future. Sea Grant Special Report No. 5. University of Miami, Coral Gables, FL.

TRANSPLANTING OF EELGRASS AND SHOALGRASS AS A POTENTIAL MEANS OF ECONOMICALLY MITIGATING A RECENT LOSS OF HABITAT

M. S. Fonseca and W. J. Kenworthy*

Department of Environmental Sciences
University of Virginia
Charlottesville, VA

J. Homziak

University of North Carolina
Institute of Marine Sciences
Morehead City, NC 28557

and

G. W. Thayer

National Marine Fisheries Service
Beaufort Laboratory
Beaufort, NC 28516

---

*Present address: National Marine Fisheries Service
Beaufort Laboratory, Beaufort, NC 28516 .

ABSTRACT

Seagrass communities are recognized as important and productive components of the coastal ecosystem. Man's increasing utilization of the coastal zone through dredging and commercial fishing practices often damages these important communities. In this study, damage to seagrass (*Zostera marina* and *Halodule wrightii*) meadows by scallop dredging in Carteret County, North Carolina, is being mitigated through replantation of seagrass stocks in the perturbed sites.

Making a replantation project an effective management tool necessitates reduction of capital expenditure. In our study, seagrass shoots were woven into biodegradable paper meshes (20 X 20 cm) and planted at the perturbed site on 1 m^2 intersections. This technique bypassed logistical problems encountered when handling many bulky turfs or plugs of seagrass with attached sediment.

Experiments performed on site are designed to: 1) determine if origin of transplant stock (substrate/energy environment) is influential in survival of the shoots, 2) assess aspects of mixed species (*Z. marina* and *H. wrightii*) planting, 3) ascertain optimal seasons for transplanting in this locale, 4) characterize physical, chemical and biological succession associated with revegetation, and 5) perform cost analyses of the operation and contrast this with economic benefits realized in the restoration of this habitat.

At this time there is evidence of an initial origin-specific survival of plant stock. Mixed species plantings have a negative impact on overall shoot production. *H. wrightii* does not grow well in certain

seasons even when fresh terminal shoots are utilized. Fall plantings have been a general success. A substantial increase of *Z. marina* shoots has occurred through vegetative reproduction. Numbers of juvenile scallops have increased around the transplanted shoots as the scallops require an off-the-bottom substrate for attachment. Successional patterns of physical, chemical and biological components of the site are still being evaluated. Costs for our procedure, which yields a significant revegetation rate, are projected to run less than $6000/ha.

INTRODUCTION

Seagrasses are now universally considered important, productive components of the coastal ecosystem (den Hartog, 1971; Wood et al., 1969; Thayer et al., 1975). Many studies have verified their contribution to groundfisheries (Adams, 1976a, b; Kikuchi, 1974), shellfisheries, especially scallops (Thayer and Stuart, 1974), as well as the estuarine and nearshore food webs in general (Odum et al., 1972; McRoy and Helfferich, 1977; Thayer et al., 1975).

The seagrasses generate a thick rhizome complex that supports an extensive leafy cover much like a terrestrial meadow. This seagrass cover creates a semi-protected and stable habitat for many commercially valuable species. The vast amounts of organic material produced by the seasonal turnover of seagrasses create a substrate for large numbers of decomposers which, in turn, form the base for higher trophic levels (Peterson, 1912; Odum et al., 1972; Fenchel, 1977). The stability of the habitat is documented by reports of some seagrass meadows surviving the destructive scouring of hurricanes in the Gulf States (Oppenheimer, 1963; Thomas et al., 1961).

However stable, productive and relatively self sustaining the seagrass meadow may be, it is easily and often subject to tremendous perturbations by even the most innocent human activity. Walking through the seagrass meadow places the shoots underfoot, driving them deep into the muddy bottom, which often kills them. Motorboat cuts (especially at low tide) leave scars which persist for years (Zieman, 1976). Clam "kicking" digs deep pits in the bottom and commercial scalloping with epibenthic drags (the common dredge) tears out huge numbers of shoots with attached rhizomes and roots which can totally disrupt the productivity of the system. In

North Carolina scalloping activities are initiated in December, when Zostera marina (eelgrass) seedlings are just beginning their germination cycle, and extends through late winter when adult plants are in their seed-bearing growth state. Destruction of these seedlings and flowering shoots greatly increases the time required for natural regeneration of the meadow.

During the winter of 1977-1978, we observed an area in Back Sound, Carteret County, North Carolina being dragged for scallops by several commercial vessels of the 15 to 20 foot class. An on-site count found seven dredges operating simultaneously in a very small area having a high density scallop population area. Catches were as high as 8 bushels per dredge per hour. At that time we noted the large quantities of Z. marina being uprooted, some of which was floating at the surface. Although having seen only one day of what was maximum fishing pressure, we were intrigued and returned to the site several days later to examine the seagrass meadow. Ground observation revealed large swaths cut by the dredges and deep ruts made in the bottom by boat props as heavily laden vessels attempted to leave the area after fishing. We found little or no regrowth during a ground inspection in June 1978 and made an aerial survey of the location. The photographs revealed that a large portion of the embayment had indeed been denuded of Z. marina cover (approximately 3.2 ha). This suggested that the area was a prime site for experimental and practical application of seagrass revegetation.

Background

Because of man's increasing utilization of subtidal, intertidal, and supratidal wetlands for housing development and for onshore facilities related to offshore energy related interests, these wetlands are subject to both small scale and large scale destruction. Mitigative measures are now being considered as one means of establishing a program of zero habitat loss through preservation, restoration, and habitat creation (Lindal et al., in press). Transplanting submerged vegetation as a means of restoration has been under consideration for a number of years. As early as 1947, Addy prepared a preliminary guide for planting the temperate seagrass *Zostera marina*. Although this is one of the earliest works published, he considered several of the factors which are a focal point of contemporary research. Since Addy's initial work, a number of investigators have attempted transplants with the marine grass *Thalassia testudinum* (Phillips, 1960; Strawn, 1961; Jones, 1968; Kelly et al., 1971; Eluterius, 1975), however, on a very small scale and with limited success. Kelly et al.(1971) experimented with various anchoring devices such as concrete blocks, cans, short pipes, burlap bags and construction rods. In addition, they evaluated the use of hormone treatments (10% NAPH). All of these transplants utilized vegetative sprigs which had been removed from their original substrate.

Continued interest in the methodology of transplanting and correlative factors have been the emphasis of Phillips' (1974) research. He has evaluated the potential for planting *Z. marina* on a small experimental scale addressing questions concerning anchoring devices (constuction rods) and the adaptive capabilities of plant stocks in reciprocal transplants across geographical and tidal ranges. On a much larger scale, Ranwell et al. (1974) have attempted transplants of *Z. marina* and *Z. noltii* in Great Britain. They considered both the origin and destination of transplants; however, they employed turfs (plugs) which included both the vegetation and its associated substrate. They reported favorable results and commented on the need for more research on the economic feasibility of this method. Robilliard and Porter (1976) also attempted revegetation of Z. marina with the plug method. Although they made a number of recommendations for improving the method, they did not report the success of the planted vegetation (for results, see Goforth and Peeling, these proceedings). In their discussion they pointed out the numerous problems associated with the handling of the weighted plugs and the logistics of a large scale, subtidal transplant.

In a very recent study, Churchill et al. (1978) successfully transplanted Z. marina onto an old dredge spoil site. They recommended a technique using "miniplugs" which consist of sediment-free clusters of 4 to 6 shoots, together with entangled roots and rhizomes without anchoring devices. They also evaluated the use of hormones (NAA), fertilization (0.49 g N/ transplant), time of planting, spacing of transplants, and the feasibility of using seeds. They recommended transplanting early in the growing season, but found no significant improvement with the hormone or the dose of fertilizer. They encountered several problems associated with using the seeds of Z. marina, especially difficulties of collection and often poor germination rates.

They physical and chemical properties of the substrate and the use of seedlings have been the emphasis of recent attempts at planting tropical species. VanBreedveld (1975), in an experimental transplant, reevaluated a variety of anchoring devices and some qualitative characteristics of the substratum. He suggested that the best method for planting H. wrightii, Syringodium filiforme, and T. testudinum was by plugs. Phillips (1978) attempted propagation of H. wrightii on subtidal unconsolidated dredge spoil. Based on this work, he suggested that 0.375 m^2

plugs, planted on 0.9 m^2 centers, was the most appropriate method.

An alternative to the approach of transplanting mature, vegetative shoots has been evaluated by Thorhaug (1974, 1977), who used *Thalassia testudinum* seeds. Unfortunately, the preliminary results that have been published do not provide an adequate basis for evaluating the feasibility of this method. Howeber, there are certain advantages to using seeds of the tropical species *T. testudinum*. These include their ease of handling, apparent development of actively growing meristems, and lack of destruction of source areas for vegetative transplants (Thorhaug, 1977).

Objectives

The primary objective of this project is to revegetate an area in which the existing seagrass meadows were seriously damaged by commercial shellfishing activities. In association with this goal, these are several secondary objectives:

1) To determine if the origin (substrate/energy environment) of the transplanted *Z. marina* stock significantly affects transplant success.
2) To determine if transplant success is a function of either of two seasons of growth: Does a seasonal bias against transplant success exist?
3) To characterize the physical, chemical and biological processes associated with the seagrass meadow's successional development after transporting.
4) To monitor the changes in population density of commercially-important species of shellfish, primarily *Argopecten irradians*.
5) To determine the economic benefit of the technique by cost/benefit analysis: this will compare capital expenditure against actual measured shellfish repopulation and theorized trophic contributions of areal measurements of seagrasses. We may then make a comparison between the cost/benefit of this technique and other published techniques.

Thus, we hope not only to provide empirical information relevant to the questions of transplant success and cost/benefits, but also theoretical information on the interaction of submerged seagrasses with their environment and on factors controlling the succession and development of this important world-wide coastal habitat type. It is imperative to obtain such information in order to implement effective revegetation programs.

The Experiment

The primary aim of this experiment was to reduce the amount of time within which a viable seagrass meadow may develop. Under natural conditions, damaged seagrass beds often take many years to recover (Orth, 1976; Zieman, 1976; den Hartog, 1971). On the other hand, the most rapid method by which the meadow may be reestablished, by artificially revegetating the entire area, is extremely costly. We have attempted to strike the most advantageous compromise between recovery time and cost by revegetating only a small portion of the damaged area to what is equivalent to an advanced stage of succession for this habitat type.

Both physical and biological factors influence the growth of seagrasses, and, thus, may significantly affect the development rate and the ultimate success of the transplants. Three factors, in particular, substrate/energy regime within which the plants grow (Kenworthy and Fonseca, 1977), season of the year (Churchill et al., 1978), and interaction with other marine angiosperms are believed to affect the success and growth of transplant stock.

Substrate Energy Considerations

Wind and tides exert considerable force in shallow water, creating a spectrum of energy regimes and sedimentary environments. Seagrasses respond to this substrate/energy gradient by changes in net productivity and mode of propagation. Under high energy/coarse sediment conditions, grass beds develop primarily by vegetative extension: isolated hummocks of grass gradually expand and coalesce, creating extensive areas of cover by means of vegetative propagation. In these habitats the net productivity of roots and standing crop of roots and rhizomes is consistently high (Kenworthy, M.Sc. Thesis, in prep.).

The low energy environments, where fine sediments predominate and meadows are continuous with low relief (Fonseca, M.Sc. Thesis, in prep.), seedlings are of increased importance in the expansion of seagrasses to unvegetated areas. Net productivity and standing crop of roots are significantly lower than in high energy environments (Kenworthy, M.Sc. Thesis, in prep.).

Stock origin is believed to be an important consideration in a seagrass transplant. In a previous laboratory study (Kenworthy and Fonseca, 1977), substrate parameters and the energy environment from which stock was taken were both shown to significantly affect the growth of transplanted _Z. marina_. We have applied these laboratory findings to field experiments to determine if these results hold under _in situ_ conditions. _Z. marina_ from high-energy regimes (HEZ) and low energy regimes (LEZ) are utilized in separate plantings. The growth strategy of _Z. marina_ in the high energy environment closely resembles that of a pioneer type species. Meristem production is accelerated in high energy regimes (greater than the low energy area), resulting in a more rapid addition of new shoots, which, in turn, enhances the development of the meadow (Kenworthy, M.Sc., Thesis, in prep.). Allocation of net biomass production into roots provides physical security and increased surface area for the absorption of nutrients from sediments. By selecting stocks with the greatest root biomass (not rhizome), we may optimize the potential for nutrient utilization in the initial stage of the transplant.

Seasonal Aspects

Growth of Z. marina in the middle Atlantic region shows definite seasonal trends which appear to follow annual patterns of light and water temperature. A vigorous growth period occurs between March and early June associated with increases in available light and temperatures rising into the optimum range for the plants' growth. During June, July and August, growth activity is reduced and both sexual and asexual reproduction cease. In late September and continuing through the winter months, as temperature decreases, Z. marina experiences a second period of growth and vegetative reproduction. In this study seasonal effects were tested by conducting half of the transplant in the fall of 1978 and the remainder in the spring of 1979.

Mixed Species Planting

Sometimes a second species of seagrass, Halodule wrightii, grows in association with Z. marina. Commonly referred to as "shoal grass", this species occurs both in isolated stands and in mixtures with Z. marina. Little is known of the biological interactions between these two species, especially in relation to the development and maintenance of the seagrass meadows.

We do know that their association presents a unique situation with respect to their centers of distribution. North Carolina is at the southern limit of the range of Z. marina, a temperate, cold water species. H. wrightii, on the other hand, is a tropical species and North Carolina represents the extreme northern limit of its distribution. The transplant site experiences a wide range of seasonal temperatures, encompassing the optimal growth temperatures for both species. By combining the two species in the transplant, we attempted to extend the time period in which the vegetation may establish itself. We tested the possibility of both positive and negative interactions by transplanting Z. marina (HEZ and LEZ) both alone and in mixtures with H. wrightii (termed HEZX and LEZX).

AREA DESCRIPTION

The site is a shallow embayment within a Spartina marsh called Middle Marsh (Fig. 1). The marsh is located in Back Sound, just behind the Outer Banks, south and east of Cape Lookout, North Carolina, U.S.A. The precise location of the site is: 76° 37' 17.5" West Longitude and 34° 41' 37.2" North Latitude. The embayment communicates with a larger sound system through four broad breaches in the encircling Spartina marsh. On the ebb tide, water flows east to west, entering through breaches A and B, exiting at breaches C and D (Fig. 1). During the flood tide, the circulation reverses itself and utilizes the same channels, only in the opposite directions. The specific site is somewhat deeper than adjacent portions of the embayment with a mean depth at MLW of 35 cm. Consequently, the site experiences rare periods of total drainage and exposure. The habitat is subject to lower physical energy than the surrounding Back Sound area because of the encircling Spartina marsh. The Spartina belt reduces current velocity and wind-wave development. This inhibits erosional processes at the site. The protected nature of the area enhances the feasibility of a successful replantation.

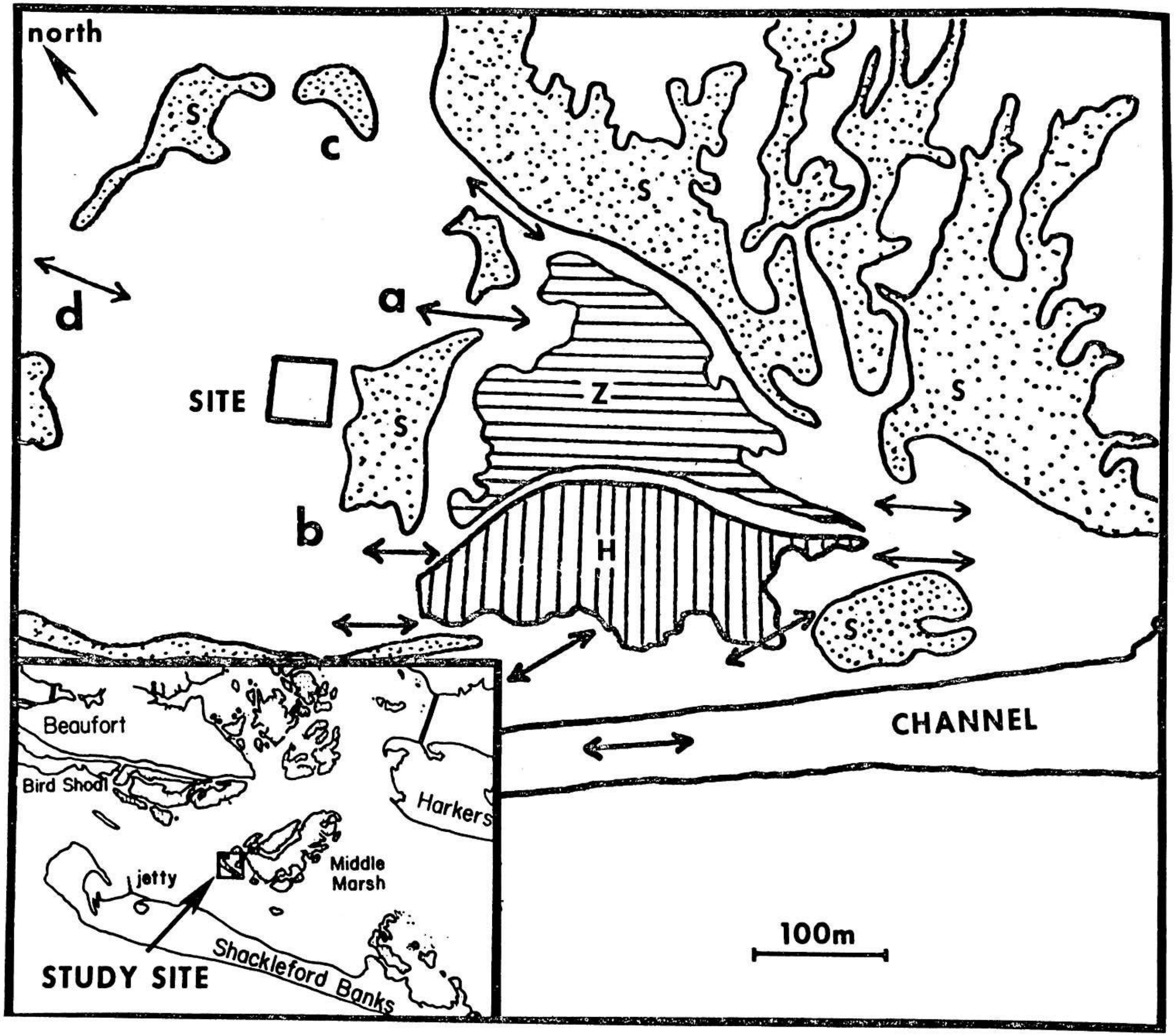


Figure 1. An aerial view of the Middle Marsh, Back Sound, Carteret County, North Carolina. Currents flow according to arrows on ebb (left) and flood (right) tides. Z = *Z. marina*, H = *H. wrightii*, S = *S. alterniflora*. Site is labelled.

MATERIALS AND METHODS

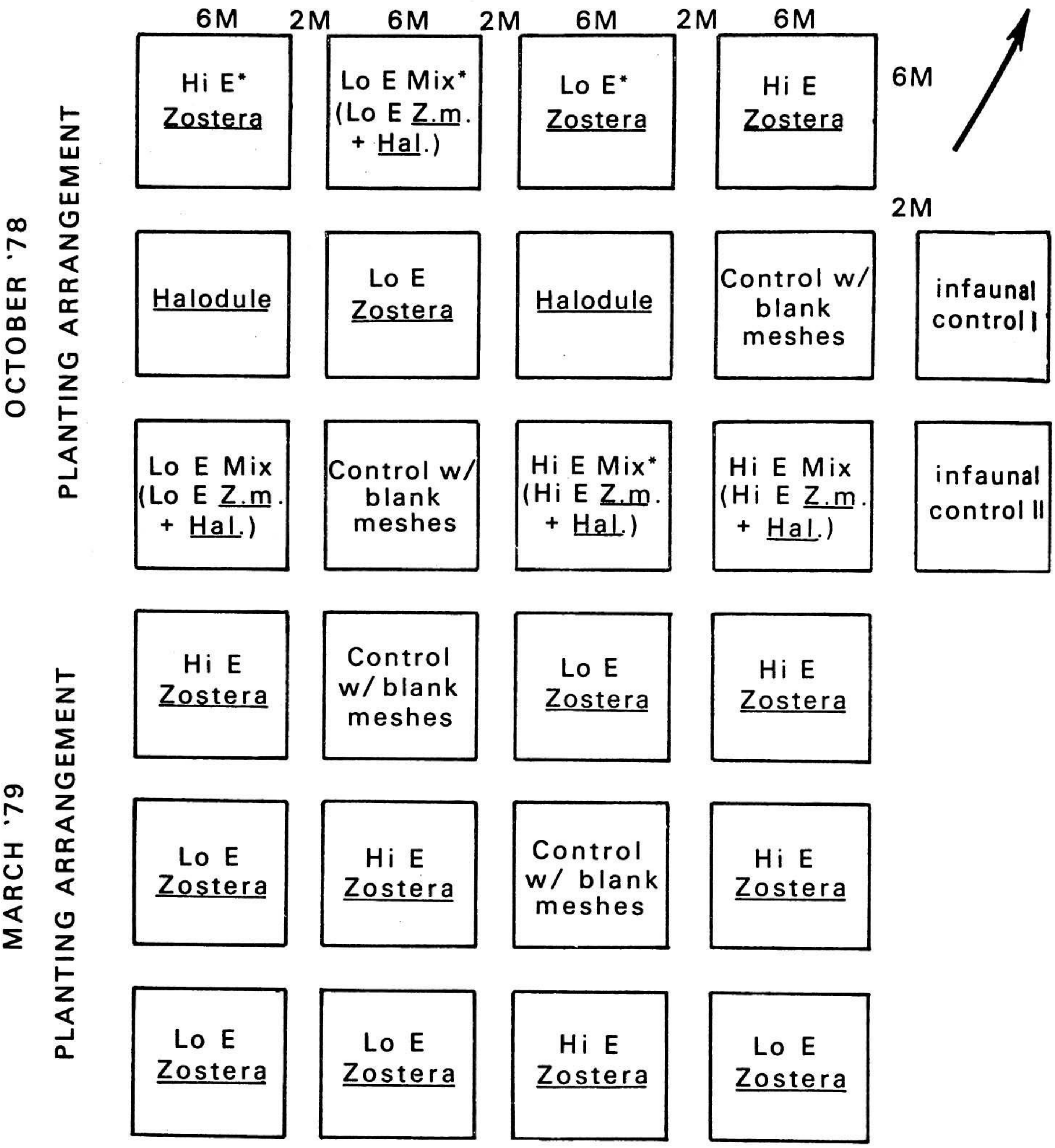
In this project, a new approach to transplanting marine angiosperms has been developed. Mature shoots of the appropriate seagrass species were dug from preselected meadows (in this case, Z. marina source beds were selected for particular energy regimes and sediment parameters). The seagrasses were then rapidly transported to a processing area where usable material was separated underwater. For Z. marina, sections of rhizomes with shoots were retained, while for H. wrightii only terminal shoots were utilized. The prepared plants then were woven into pre-cut 20 cm X 20 cm squares of biodegradable mesh paper (Gulf States Paper Co., Tuscaloosa, Ala.)[1]. Z. marina and H. wrightii alone were woven at a density of 15 shoots per 0.04 m^2 mesh. Combinations were composed of seven or eight Z. marina shoots, along with seven or eight H. wrightii shoots. After weaving, the meshes were stored in aerated flowing seawater until they were moved to the transplant site.

The transplant site consists of two blocks, one block designated for fall transplanting, the other for spring. Each block consists of fourteen 6 m X 6 m squares (Fig. 2), two replicates of five treatments, plus two mat controls (meshes without shoots) and two external controls (untreated). Each 36 m^2 treatment or control was laid out several days prior to the actual transplant with surveying equipment and marked with bright ribbon or tape.

The 0.04 m^2 meshes were placed on 1 m^2 centers within each 6 m X 6 m plot (Fig. 3) by a SCUBA-equipped diver and pinned to the substrate with sharp pins about 25 cm in length. Meter square centers were determined by

---

[1] Mention of trade names is not an endorsement of the product by the National Marine Fisheries Service, or any other sponsor institution.



Hi E* *Zostera*	Lo E Mix* (Lo E *Z.m*. + *Hal*.)	Lo E* *Zostera*	Hi E *Zostera*	
Halodule	Lo E *Zostera*	*Halodule*	Control w/ blank meshes	infaunal control I
Lo E Mix (Lo E *Z.m*. + *Hal*.)	Control w/ blank meshes	Hi E Mix* (Hi E *Z.m*. + *Hal*.)	Hi E Mix (Hi E *Z.m*. + *Hal*.)	infaunal control II
Hi E *Zostera*	Control w/ blank meshes	Lo E *Zostera*	Hi E *Zostera*	
Lo E *Zostera*	Hi E *Zostera*	Control w/ blank meshes	Hi E *Zostera*	
Lo E *Zostera*	Lo E *Zostera*	Hi E *Zostera*	Lo E *Zostera*	

Figure 2. Vertical view of replicated treatments and layout of transplant in Middle Marsh. Each treatment is 6 m on a side with 2 m corridors. Each square is 36 m^2 with 49 meshes.

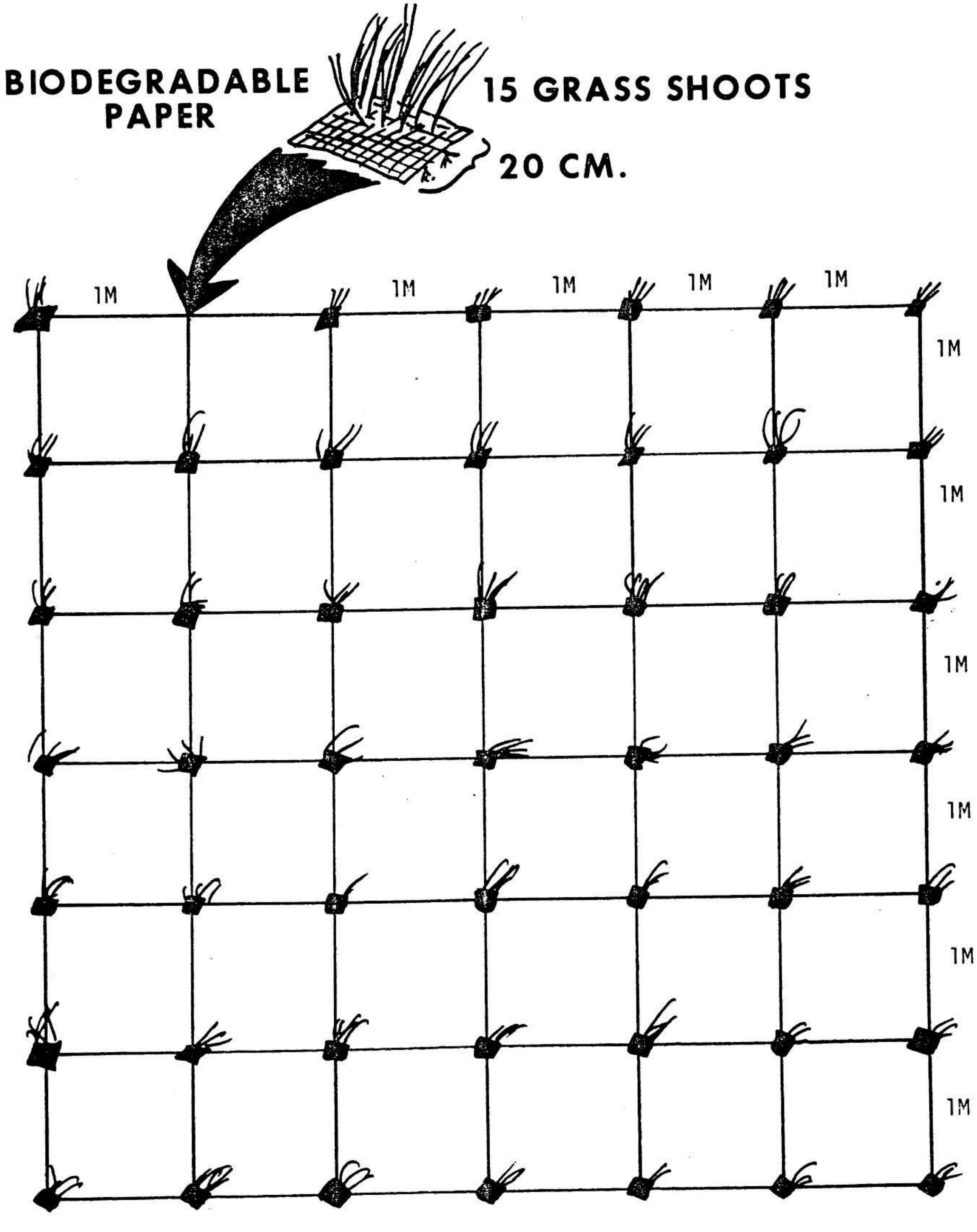


Figure 3. Layout of an individual treatment. Fifteen shoots are woven into a 20 x 20 cm partially biodegradable mesh (1 mesh unit). These are planted on 1 m^2 centers on a 6 x 6 m grid for a total of 49 meshes/replicate treatment.

using a 1 m^2 frame as a reference, starting at a corner and moving it progressively across the 36 m^2 plot. Each 6 m X 6 m plot receives 49, 0.04 m^2 meshes of the appropriate treatment. Fifteen shoots, 0.04 m^2 of mesh approximates densities of 375 shoots/m^2 of natural cover, producing an average areal density of 20 shoots/m^2.

Meshes were kept on site aboard a tender vessel equipped with flowing seawater and aeration facilities. Support personnel for divers consisted of a "buddy" diver (either snorkel or SCUBA, depending on water depth) who supplied the planter with meshes and stakes and acted as a "safety man", a "transport" diver who ferried supplies to the various planting teams, and a shipboard supervisor who provided supplies and directions to the divers. Total personnel for the transplant consisted of six divers (3 teams), one "transport" diver and one supervisor, with five relief personnel.

Monitoring Physical Processes

Throughout the duration of the experiment portion of the transplant, physical processes associated with the Middle Marsh site and the habitat in general are being monitored.

The site was surveyed with a line transit for topographical description and a datum established. Cores made of lexan, 3 cm in diameter and 122 cm long, were taken for analysis of sediment particle size by mechanical wet sieving and organic matter by combustion at 550°C (Zieman et al., 1977). Measurements were made to evaluate the general pattern of water movement within the site. These include discharge per tidal cycle, mean velocity, maximum shearing velocity, and recording of tidal stage. All measurements were made along a transect down the direction of ebb and flood flow from outside the site and extending across the various plots (Fonseca, M.Sc. Thesis, in prep.).

Besides a general site flow characterization, each treatment plot is measured with a current velocity meter for velocity profile alterations (Fonseca, M.Sc. Thesis, in prep.). These data will be collected only when it becomes apparent that the transplant is successful and vegetative cover is spreading. In the arrangement and densities planted, no significant flow variation can be measured. Temperature and salinity were measured at planting, November, February and May.

Monitoring Chemical Processes

Physico-chemical parameters of the interstitial water, e.g., dissolved NH_3 (Koroleff 1969), Eh and pH, of the sediments were monitored in March with diffusion chambers (Hesslein, 1976). The chambers were placed into the substrate to the desired depth and allowed to equilibrate for ten days. Sampling was accomplished by removing the chamber and puncturing the Nuclepore membrane. Water samples for nutrient determination were removed and stored temporarily in evacuated glass containers. The Eh and pH measurements were made on site by potentiometric methods.

Monitoring Plant Growth and Development

To assess the relative success of the transplant, plant growth data are compared to data obtained from natural seagrass populations. Since morphological and biomass measurements involve destructive sampling of the seagrasses, sample size will be determined by the amount of available plant material immediately prior to the 1979 sampling period. Biomass was sampled at randomly selected stations with a PVC coring device (325 cm^2). The corer is inserted into the sediment to a depth of 20 cm in order to sample both above-ground and below-ground leaves, root, and rhizome biomass. The samples are returned to the laboratory, sorted into the various components and dried at 100°C to a constant weight. For the fall transplant, shoot densities were recorded in November, February, and May by counting the shoots within each of the treatment plots. In each plot, five meshes were randomly selected, located by a diver who then recorded the shoot densities within each square. A similar time sequence will be conducted for the spring transplant.

The success of the transplant will depend upon the capability of the shoots to produce new vegetative meristems. This is accomplished by both sexual reproduction (seed propagation) and asexual reproduction (vegetative extension of lateral shoots and meristems). Asexual reproduction was monitored in the same sequence as the shoot densities. The squares chosen for density observations also serve for sampling of vegetative reproduction. Estimates of vegetative reproduction were made from calculations based on the plant density changes between sampling period. Sexual reproduction was monitored in the May sampling period for the fall transplant. Flowering shoots of Z. marina were counted in cores taken for the plant biomass samples. With this information, an estimate of the reproduction potential, as a percent of flowering shoots and number of seeds, were made for the high and low energy treatments.

Scallop populations were sampled in February (the local population maximum) by counting the number of individuals associated with meshes during the shoot counts. This afforded 10 replicate samples per planting treatment. Counts were performed in control sites by randomly locating 10 bare meshes and counting the scallops found in a 1 m^2 area north and east of the assigned mesh. These counts were then extrapolated to total number scallops/treatment, number scallops/shoot, and average number scallops/m^2.

RESULTS

Total population counts per sample time and treatment are presented in Table 1 and Figures 4-6. At 203 days HEZ had produced the highest shoot density, LEZ and LEZX the next highest, followed by the control and HEZX. Recovery of the control area was delayed until 1.4 years after impact. This natural revegetation occurs as seeds from a previous year germinate and reproduce asexually. However, this did not commence until a second season of potential vegetative growth following the perturbation.

Table 2 describes the number of meshes which survived, average shoot number per mesh, per sample time, and per treatment. In all cases, there was an initial decline of shoots/mesh and after 130 days (over the mid-winter) there had ebeen a reduction in number of meshes existing, especially for _H. wrightii_ treatments and HEZX. The decline in number of shoots/mesh for _Z. marina_ was arrested by 130 days, but _H. wrightii_ had continued to diminish and no longer was evident in any of the treatments by May. Treatment HEZX lost 67% of its meshes, while LEZX lost only 25% of its meshes. Treatments HEZ and LEZ maintained high numbers of meshes (10 and 11% lost, respectively), but HEZ had nearly twice as many shoots per mesh after 203 days.

Table 3 describes the cover rate of surviving shoots after 203 days. HEZ provides nearly 40% more cover per day as compared to LEZ and LEZX which have similar source stocks remaining. HEZX lost many meshes over the course of the winter and consequently provided less cover. Once natural vegetation had established (January 1, 1979), cover rate was comparably high.

Table 4 outlines the results for an analysis of scallop, *Argopecten irradians*, populations within the transplant. Scallop density showed a fairly constant relation to grass cover (scallop/shoot ratio). Clearly, there is a strong relationship between transplant success and number of scallops observed. In the HEZ treatment, where the shoot population is larger (Table 4), the number of scallops are somewhat higher than other treatments. A closer look at all treatments suggests a near linear relationship between shoot density (Table 1), total numbers of scallops, and scallop density (Table 4).

Table 5 shows the results of our preliminary cost comparison for larger scale published transplants of *Z. marina*. Costs are presented on an areal basis (density dependent cost/ha) and also on a per shoot basis (not density dependent). These comparisons provide an opportunity to relate the various methods and initial planting effort to the project cost. On a per shoot basis the cost varies from a minimum of $0.009 to a high of $0.27. We have included in the analysis a projected cost per shoot ($0.028), based on expected improvements in the weaving technique.

Table 1. Total shoot count and average density/m^2/treatment are listed by sample time (days).

Treatment	(0 days) Oct.15,'78	Average dens./m^2	(27 days) Nov.11,'78	Average dens./m^2	(127 days) Feb.22,'79	Average dens./m^2	(203 days) May 6,'79	Average dens./m^2
HEZ	1470	20.4	951	13.2	5749	79.9	23,930	332.4
LEZ	1470	20.4	755	10.5	2622	36.4	12,698	176.4
HEZX	1470(H+Z)	20.4(H+Z)	824(H+Z)	11.4(H+Z)	1331 (Z)	18.5 (Z)	1,506 (Z)	20.9 (Z)
LEZX	1570(H+Z)	20.4(H+Z)	1068(H+Z)	14.8(H+Z)	3167 (Z)	43.9 (Z)	12,914 (Z)	179.4 (Z)
<u>Halodule</u>	1470	20.4	921	12.8	0	0	0	0
Control	0	0	0	0	245 (= 1.4 yrs after impact)	3.4	3,096	43

Table 2. Number of meshes remaining and average number/mesh at each sample time by treatment. HEZ = transplant source from high-energy environment, *Zostera* alone; LEZ = transplant source from low-energy environment, *Zostera* alone; HEZX = transplant source from high-energy environment in mixture with *Halodule*; LEZX = transplant source from low-energy environment in mixture with *Halodule*; *Halodule wrightii* = transplant source from low-energy environment, *Halodule* alone; Control = meshes without seagrass.

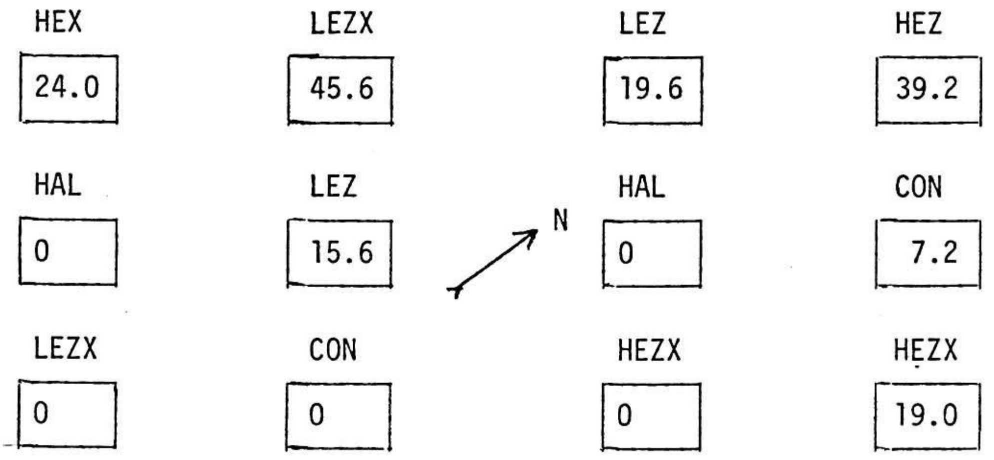
Treatment	SHOOT EVALUATION							
	0 Days		27 Days		127 Days		203 Days	
	Oct. 15, 1978		Nov.11, 1978		Feb. 22, 1979		May 6, 1979	
	#mesh	Avg.#/mesh	#mesh	Avg.#/mesh	#mesh	Avg.#/mesh	#mesh	Avg.#/mesh
HEZ	98	15	98	9.7	89	64.6	89	257
LEZ	98	15	98	8.7	88	11.4	88	142
HEZX	98 (Z)	7.5	98 (Z)	8.4	32	41.6	32	45
	(H)	7.5	(H)	0	-	-	-	-
LEZX	98 (Z)	7.5	98 (Z)	10.8	74	42.8	74	165
	(H)	7.5	(H)	0	-	-	-	-
Halodule wrightii	98	15	98	9.4	10	0	-	-
Control	98	0	98	0	98	0	98	0

Table 3. The average areal rate of cover is given for the initial 203 days. Each treatment is analyzed for average area/mesh and number of meshes remaining. Percent of plot covered and covering rate (m^2/day) are also listed. HEZ = transplant source from high energy environment, *Zostera* alone; LEZ = transplant source from low energy environment, *Zostera* alone; HEZX = transplant source from high energy planted in mixture with *Halodule*; LEZX = transplant source from low energy planted in mixture with *Halodule*; Control = meshes without seagrass.

Treatment	Average area $mesh^{-1}$ (m^2)	# of meshes $treatment^{-1}$	% of plot covered	Cover m^2 day^{-1}
HEZ	.233	89	28.8	.102
LEZ	.148	88	18.1	.064
HEZX	.085	32	3.7	.013
LEZX	.187	74	19.2	.068
Control (Since 1/1/79; known date of seed germination`	0	98	7.5	.042

Table 4. Scallop counts/treatment are compared with cover (scallops/shoot) and average density is presented. Below, distribution of scalops in the transplant site is presented as numbers/treatment.

Treatment	February 22, 1979 Scallops		
	Total # scallops /72 m^2	Scallops/shoot	Average scallops/m^2
High E *Zm* (HEZ)	63.2	.011	.878
Low E *Zm* (LEZ)	35.2	.012	.488
High E mix (HEZX)	19	.014	.264
Low E mix (LEZX)	45.6	.014	.633
Halodule wrightii (Hal)	--	--	--
Control (Con)	7.2	.029	.10



HEX	LEZX	LEZ	HEZ
24.0	45.6	19.6	39.2
HAL	LEZ	HAL	CON
0	15.6	0	7.2
LEZX	CON	HEZX	HEZX
0	0	0	19.0

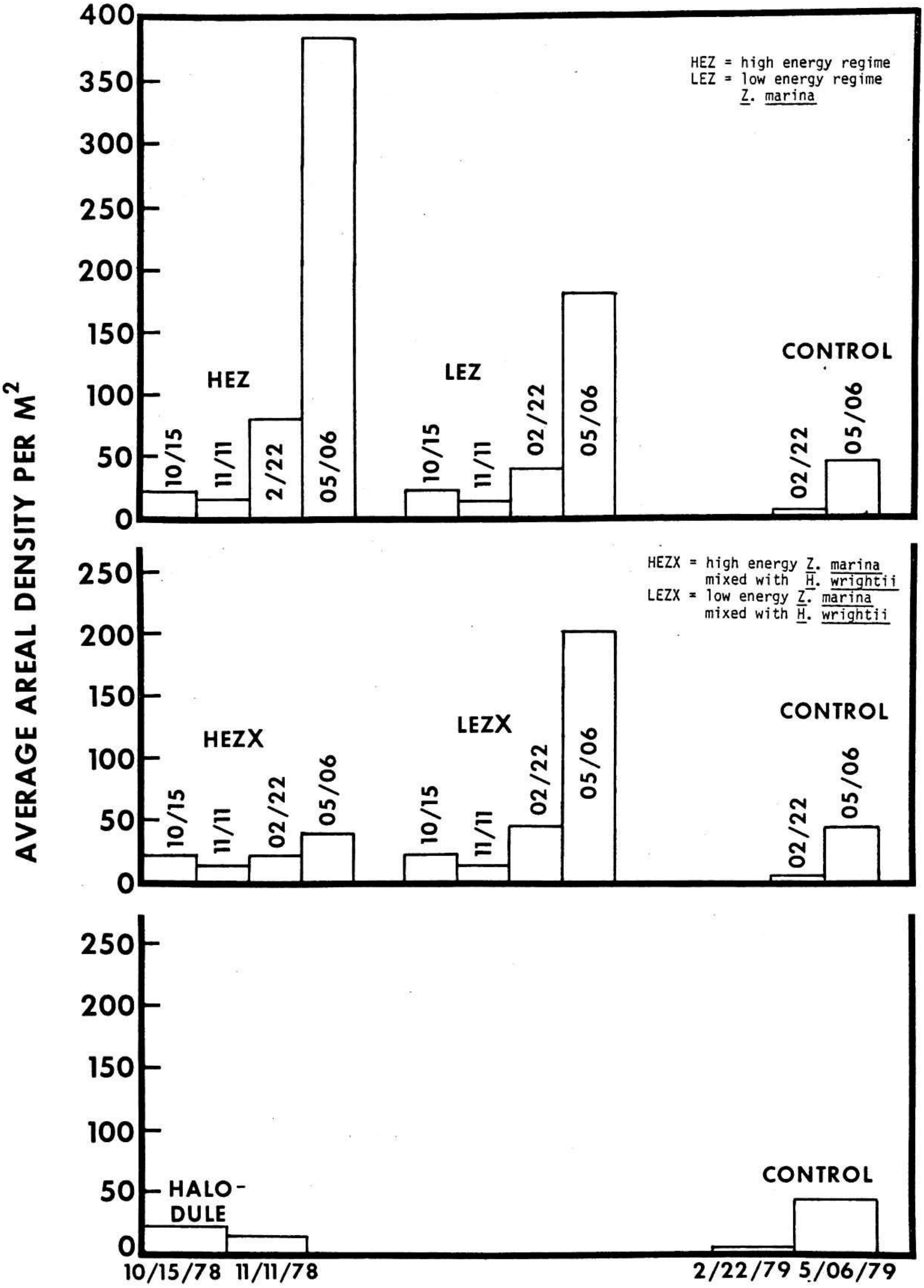
Table 5. An estimated cost comparison of Z. marina transplants is given based on available literature. Under our woven mesh method two costs are listed: (1) present, and (2) projected by technique modification. Technique is listed by years published to consider cost addition by inflation.

Investigator	Estimated Cost Comparison Based on Available Literature			
	Average dens./m^2	Per ha. density	Min. cost/ha ($10,000 m^2$ or 2.47 acres)	Cost/shoot
Robilliard and Porter (1970) Plugs	4.5	45,350	$12,596	$0.27
Ranwell et al. (1973) Plugs	11.2	112,000	3,000	0.03
Churchill (1978) Plugs without sediment	65.4	654,000	5,976	0.009
North Carolina (1979, this study) Woven mesh	20.4 20.4 (proj)	204,166 204,166	17,582 5,769	0.086 0.028

DISCUSSION AND CONCLUSIONS

Sample collection and data analyses are still being compiled on root-rhizome production, flowering, infaunal populations, sediment texture and chemistry, currents and benefit analysis. Several more months of observations are necessary on both the winter and spring transplants before definitive conclusions can be drawn regarding these parameters. Changes in the number of shoots over time are shown in Figures 4-6. While natural revegetation of control plots has been slow, selected treatments have successfully colonized their transplant sites. This is highly encouraging, since Z. marina is near its southern geographic (and probably physiological) limit in the Beaufort area.

To elucidate the actual success of the various treatments, the number of meshes surviving the transplant should be considered (Table 2). While transplants HEZ and LEZ are comparable in number of meshes retained over the winter, the resultant cover rate is obviously different (Fig. 7, Tables 2-3). This is an impressive rate of colonization which far exceeds that of control plots where natural vegetation was allowed to occur. HEZX and LEZX treatments did not have similar numbers of meshes surviving. We do not presume this difference to be a function of treatment, but rather, they appear to have been lost by influence of extrinsic factors (i.e., animal perturbation, wind waves, different divers with different degrees of planting proficiency). The differences in surviving meshes accounted for the obvious difference in the cover rate we observed for the mixed Z. marina - H. wrightii treatments. But scaling the cover (Table 3) by the initial stock available showed that the LEZX treatment had a somewhat better cover rate than did the high energy mixed transplants (HEZX). For example, 74 meshes



Figures 4, 5, and 6 (top to bottom). Average density/m^2 (areal) is plotted by sample time. Dates range from 1978 to 1979.

survived in the LEZX treatments, while 32 survived in the HEZX treatments (a scale factor of 2.3:1); aerial coverage was 0.064 and 0.013, respectively, but when scaled for the difference in available source plants, the HEZX still only covered 0.03 m^2/day or 47% of that of LEZX. Nevertheless, we are satisfied that the meshes can be put in place and retained. There was acceptable mesh success in all but one treatment.

It appears that planting of high energy plants by this technique in silty environments enhances their growth. Our results confirm an earlier study (Kenworthy and Fonseca, 1977) where reciprocal transplants of Z. marina originating in sand grew better when placed in a silt substrate than did replanted shoots originating from that silt substrate. In this study, we have demonstrated a higher rate of new shoot generation and cover (m^2) with plants originating from a sandy substrate when placed in a predominantly silty sediment. The mechanism controlling this response is unknown, but we suspect that some degree of biotype development in Z. marina is related to the prevailing sediment chemistry (silty sediment with higher organic content, lower oxidation reduction potential and poorly-oxygenated vs. a sandy sediment with lower organic content, a higher oxidation reduction potential and better oxygenation) and its associated environment. Plantings into high energy environments have yet to be explored.

In answer to the question of planting season, we feel that fall is the best time for several reasons. First, a fall planting for Z. marina allows the maximum period of uninterrupted growth. Spring plantings will experience thermal stress by the following summer season in North Carolina. Second, selection of plant stock is tedious in the spring since Z. marina is seeding. Seed-forming shoots are unacceptable for whole-shoot transplantation since they die shortly after fruiting. The loss of vegetative reproduction potential by this die-back (if such shoots are selected) is not acceptable. Also, greater amounts of source stocks must be dug up to procure vegetative shoots.

H. wrightii did not survive the fall planting. We have yet to see any sign of regrowth, but that will not be ruled out until the summer growth season of undisturbed H. wrightii meadows is past. Although the winter season was probably detrimental to their survival (as it is naturally) and terminal shoots were selected, we did not replant H. wrightii during the spring transplant. The greatest problem was the time required for collecting, sorting and weaving the apical shoots. Since cost-effectiveness is one goal of this study, we elected to postpone further H. wrightii work until a semi-automated weaving apparatus, now under development, is completed.

Scallop populations were assessed in both transplant and control plots, and the data presented in Table 4. Scallop density showed a fairly constant relation to grass cover, and individuals were either non-existent or in low abundance in control and H. wrightii plots. Further observations are expected to show similar relations and will lend credence to the hypothesis that transplants, if successful, are a potential method of mitigation at the community level.

Ultimately we wish to have the capability to predict the time required to establish a seagrass meadow whose density is comparable to that of a natural meadow. This will, of course, depend on both the environmental conditions as they relate to the optimum for growth and also the initial density and spacing of plants. The final solution will require a consideration of the cost involved at the time of planting.

Using our data for the HEZ, LEZ and control plots, we have selected a model which describes well the growth for the planted and control seagrass populations (Fig. 7). As expected, growth is exponential over the study period and is described by the equation:

$Y_t = Y_o e^{rt}$, where

Y_t = population at time t

Y_o = initial population

e = base of natural logarithm

r = instantaneous coefficient of population growth

HEZ added shoots at a much higher rate than all other treatments and consequently covered a larger area during the same time period (Table 3). From actual areal measures of mesh cover and concurrent shoot counts, we developed a linear regression of shoot number vs. area (m^2) covered (Fig. 8).

$y = mx + b$, where

y = area covered (m^2)

x = # of shoots

We note that the ratio of area covered to number of shoots decreases as the number of shoots increases. We can describe this relationship better by rearranging the equation:

$y = mx + b$;

$x = \frac{y-b}{m}$ = # shoots, and

$\text{area/shoots} = \frac{y}{x} = \frac{mx + b}{x} = \frac{b}{x} + m$

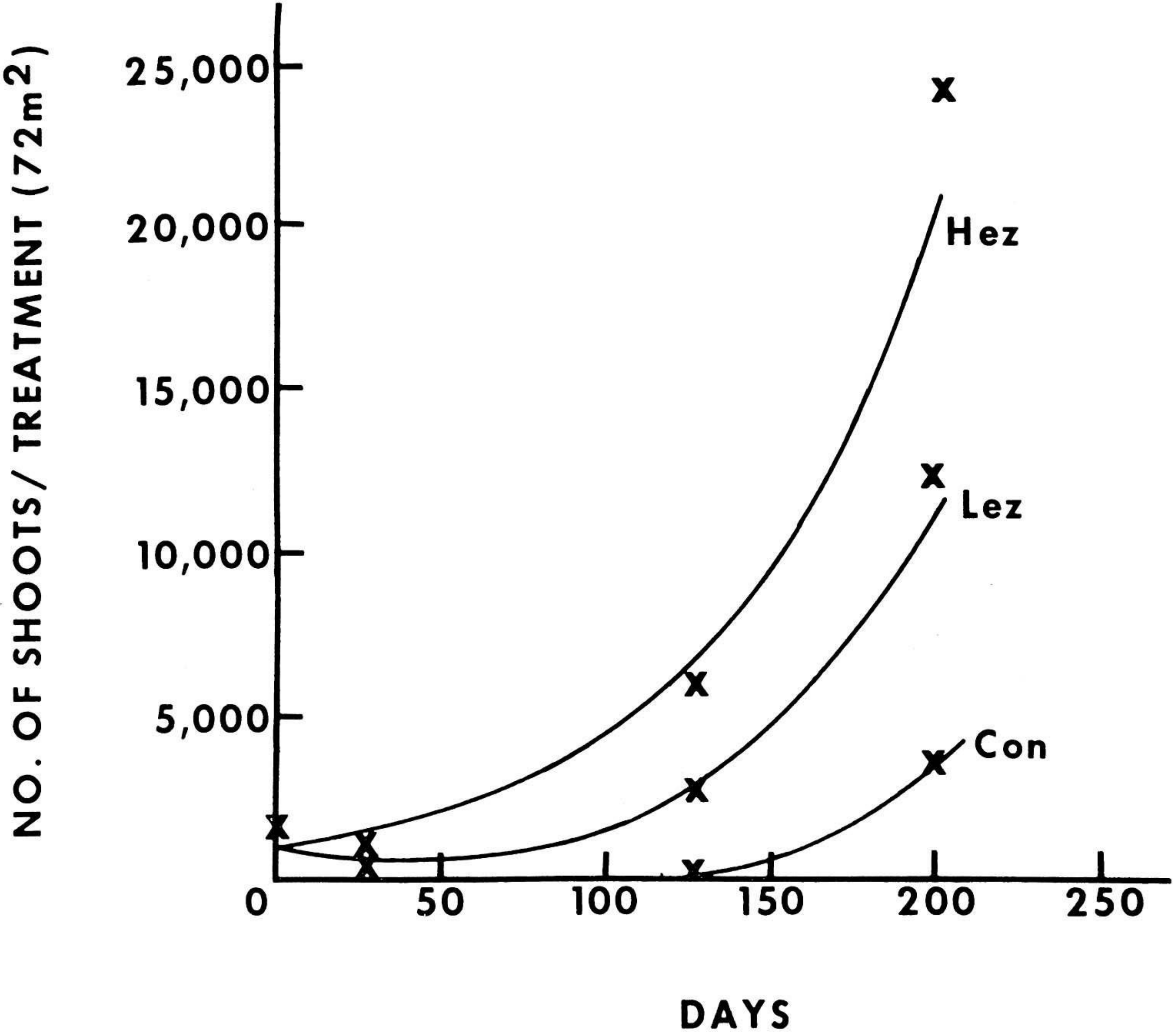


Figure 7. Plots of most successful treatments, HEZ and LEZ, as shoots present/ treatment (72 m^2) as a function of days. Control is also presented.

Taking the derivative of the ratio of area covered to number of shoots per number of shoots, we have

$$\frac{d(y/x)}{dx} = -bx^{-2}$$

which demonstrates a law of diminishing returns. This relationship is plotted in Figure 9 and illustrates that as the number of shoots increase per mesh unit, the rate of increases in coverage decreases. It appears that after approximately 15 shoots/mesh unit, the change in coverage rate is very small. This relationship agrees well with the observed growth habit of *Z. marina*. Since colonizing *Z. marina* grows in a general radial pattern (as do most seagrasses), as the surface area of the circle-like patch increases, the rate of perimeter extension decreases, as does the ratio of perimeter to area covered, so that inter-plant competition increases.

A procedure for utilizing our data for results of HEZ planting is presented in Table 6. One must make an initial choice of desired coverage as a function of days before entering into the method of pricing and spacing. Once the initial choice is made, the associated cost versus time to cover is rejected or accepted. If rejected, the user may opt for higher cost with a shorter coverage time or vice versa. If accepted, the procedure then goes on to dictate spacing for a grid pattern of planting. A maximum time of 250 days is chosen, as this covers the growth season for *Z. marina* here in Beaufort, North Carolina. Thirty-five shoots/mesh was chosen as a maximum because it is logistically unacceptable to fit more shoots in a 20 X 20 cm mesh. A user must realize that this table is based on the growth of high energy, sand origin, *Z. marina* placed in a low energy silty substrate environment in North Carolina, and during the maximum active growing season;

Table 6. To calculate cost, number of meshes needed, spacing, and approximate time to complete cover, chose a value from the matrix based on time and cost. Area to be planted = _____m^2, divided by matrix value (_____m^2), equals number of meshes needed to gain a continuous meadow in the number of days given (left hand column of table). Multiply the number of meshes needed by the given cost per mesh (rate on number of shoots/mesh), this equals total cost of the transplant ($______). Either ACCEPT or REJECT. If cost is rejected, go to the table and select a longer time and/or a smaller mesh for a lower cost. If accepted, calculate spacing: $\sqrt{AREA}/\sqrt{\# MESHES}$ = approximate on center spacing in a grid pattern (M^2) of the transplant necessary to attain the selected coverage in the time given (_____M).

	Shoots/mesh and cost/mesh						
Time to complete cover (density ≈1000/m^2) (Days)	5	10	15	20	25	30	35
	$.14	$.28	$.42	$.56	$.70	$.84	$.98
	Cover Per Mesh at Given Time in M^2						
50	.051	.061	.069	.077	.085	.094	.103
100	.062	.082	.10	.119	.138	.158	.177
150	.086	.129	.171	.214	.257	.30	.343
200	.14	.235	.332	.429	.524	.621	.717
250	.26	.476	.693	.909	1.125	1.341	1.558

i.e., which may represent optimum results. The values in the matrix for cover (m^2) per mesh at time t were generated in two steps: 1) the initial number of plants per mesh was applied to the exponential equation for growth of HEZ along with the desired time to achieve complete cover, yielding expected number of shoots/mesh at time t; then, 2) the number of shoots/mesh was converted into area covered by the regression equation (Fig. 8) for area covered vs. number of shoots, which is the value presented in the matrix. Assumption of more conservative growth and cover rates may be necessary in other environments.

From our analysis of the data for growth we are able to predict areal coverage for extended time periods within the growing season. Furthermore, we have identified the information necessary to make these predictions: the instantaneous coefficient of population growth (r), and the relationship between area covered vs. the number of shoots (see Fig. 8). Future revegetation projects utilizing Zostera would be improved if these data were available on a regional basis throughout the geographical range of the species.

Cost, including pre, during, and post transplant activities, were calculated. These costs include all labor, planning, site preparation, plant stock handling (including planting), materials (here, mostly expendables, since non-expendables such as SCUBA gear, boats and motors were provided at no cost), monitoring and administrative costs. Cost per shoot seems to be the best parameter for comparison, since it includes an a priori judgment of necessary stock needed/technique/site to achieve a desired cover. Also, if investment return is considered by the rate at which shoots proliferate, cost per shoot may be plotted against time (Fig. 10). There are two costs and two curves presented. The higher cost is the actual cost of our experi-

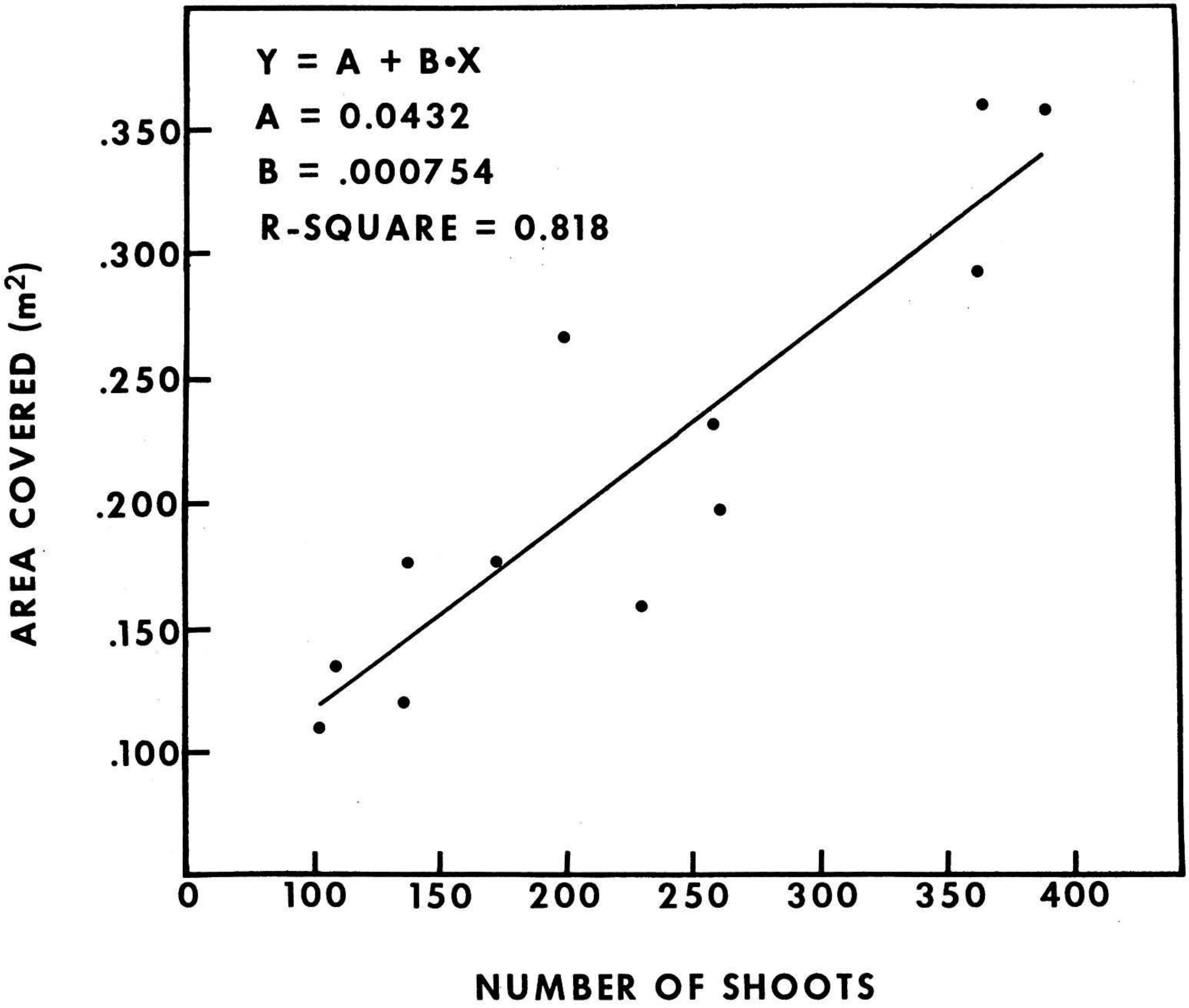


Figure 8. Plot coverage (m^2) as a function of number of shoots present. Included were both HEZ and LEZ treatments in the determination of the regression equation.

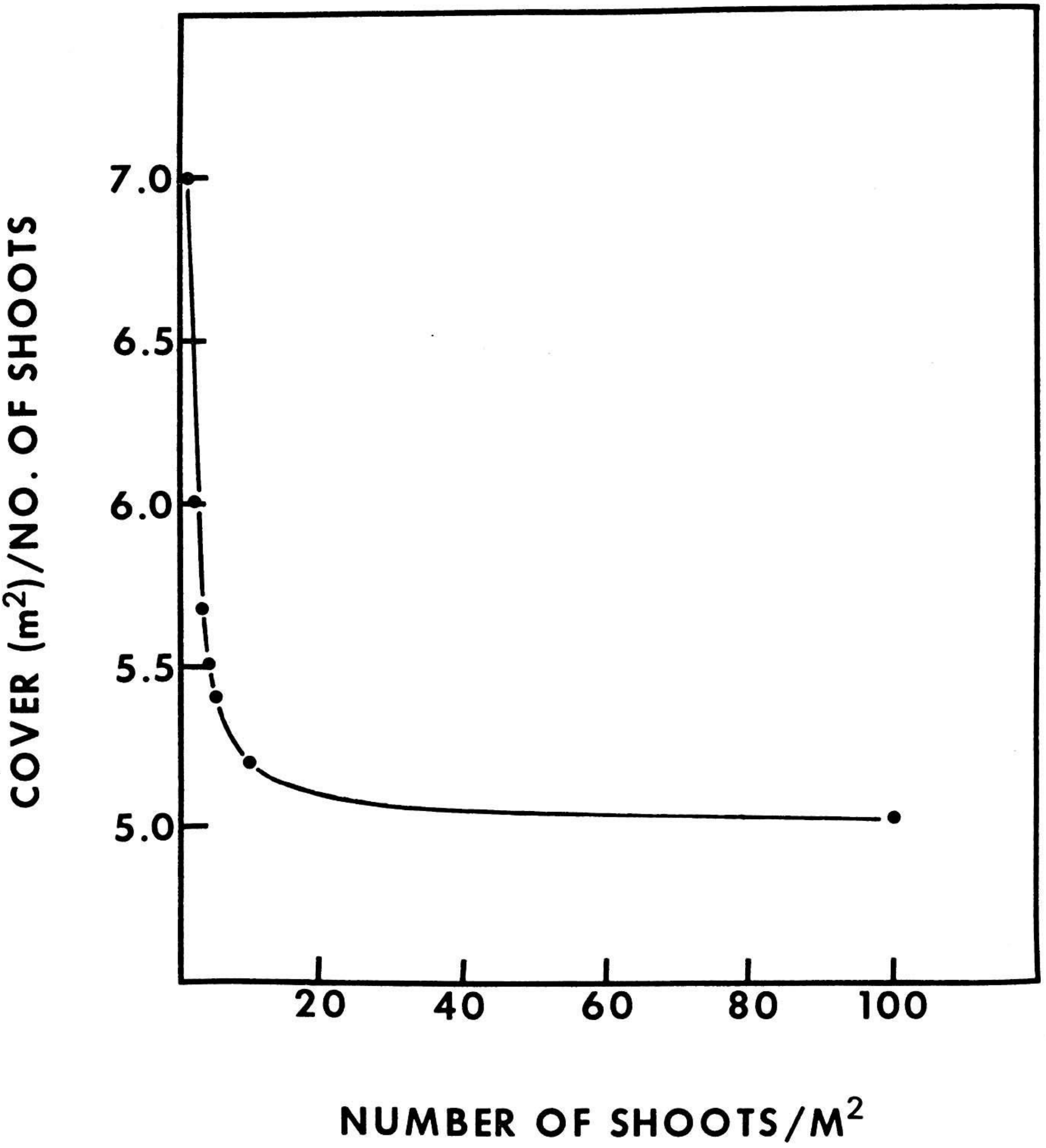


Figure 9. Plot of the ratio of cover (m^2)/ # shoots (y/x = y axis) in respect to the number of shoots present (x = x axis).

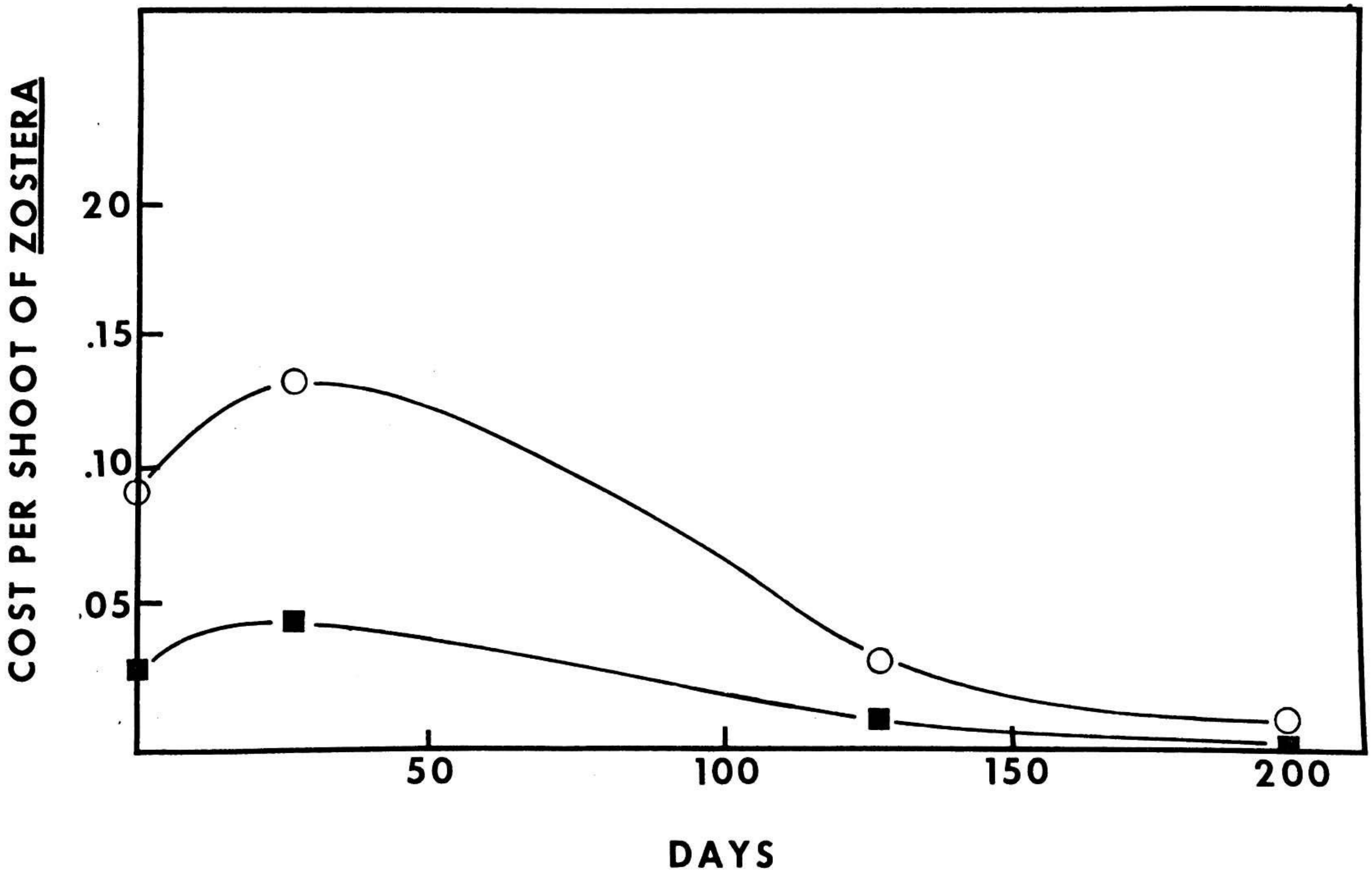


Figure 10. Total transplant cost divided by number of shoots is plotted here against number of days since planting. Top curve is by present technique. Bottom curve is projected cost by technique mechanization.

ment. Automated weaving techniques now under development are projected to reduce costs to the value presented. Plotting the cost/shoot vs. time enables one to assess the cost as it is affected by the success of the planting. The actual cost is governed by the initial planting; however, as the population experiences growth by the addition of shoots, the actual cost/shoot may be adjusted.

While comparing our method and the often utilized plug technique, we noted an important difference. Methods utilizing the non-sediment approach adopted here and by Churchill et al. (1978) circumvent certain logistic problems. Most important of all, this technique eliminates the problems associated with transport of attached sediment which is especially cumbersome in subtidal operations. Approximately 40 metric tons of sediment will be moved in plug operations on a hectare basis (based on extrapolation of plug planting, 4.5" in diameter, on one meter centers by Orth [1979 pers. comm.]), compared to approximately 1.2 metric tons for carrying the meshes for a hectare. A qualitative evaluation of our technique appears in Table 7.

The popularity of the plug technique seems to originate from the concern that the vegetation has some requirement for the sedimentary environment from which it originates. Our study and those of Churchill et al. (1978) and Kenworthy and Fonseca (1977) have indicated that Z. marina is not necessarily substrate specific in terms of growth requirements. We conclude that plugs will not necessarily improve the success of planting, considering the large mass of sediment that must be moved. We do not propose abandoning the plug method. As transplanting is still in a developmental phase, it would be unwise to forego a method which has been reasonably successful (see Goforth and Peeling, these proceedings, Ranwell et al. 1974). However, our

Table 7. An evaluation of this technique is presented, based on qualitative observations after the planting.

TECHNICAL EVALUATION

Advantages:	Disadvantages:
1. Logistic burden reduced by low weight of mesh and vegetation.	1. More time consuming on small scale (less than 150 m^2) than cores at present time.
2. Good on soft sediments where core integrity is a problem.	2. Cost of material.
3. Good in water depths that necessitate SCUBA diving.	3. Presently, labor intensive in mesh preparation (higher cost).
4. Rapid planting.	
5. Storability	
6. Stock selection for apical meristems is possible (especially important in tropical species)	
7. No special equipment beyond construction of weaving machine.	
8. Higher growth rates (function of stock selection).	

goal in the long run is to reduce cost, and we believe that elimination of the handling of large amounts of sediment will contribute to cost reduction.

Further applications of this technique include the planting in high energy environments and in previously uncolonized areas, especially dredged material. Obviously, seagrass cannot be planted just anywhere. There are reasons based on the plant's physiological requirements as to why it does not occupy all habitats. But, conscious planning of dredge material placement could facilitate at least subtidal replantation of seagrasses. The major problem facing such a replantation scheme can be considered within the context of theories regarding ecological succession. In this study we have revegetated an area that previously supported a seagrass habitat. Following the perturbation, the area no doubt retained some characteristics conducive to seagrass growth. Our replantation more nearly resembled an example of a secondary succession, while planting onto a dredge material may be likened to a primary successional process. In the case of dredge material, there has been no previous conditioning of the environment, especially the sediment. This is not to say that seagrass, _Z_. _marina_ at least, cannot be successfully transplanted onto dredge material. Churchill et al. (1978) have had success planting on a dredge material island which was allowed to condition for 3 years prior to planting. Again, if care and planning are taken in island construction, we believe that creation of a seagrass habitat in association with the island is feasible. This method, employing a mesh, provides added stabilization for the initial colonization of the shoots. This is consistent with the expected requirements for vegetation in coarse unconsolidated sediment, as dredge material often is. We recommend that prior to planting, a thorough examination of the energy regime and projected stability of the island be undertaken in order to be assured it is most favorable for planting.

We stress that such techniques are not an excuse to eliminate present meadows based on the virtue of an existing technology to replace them. The importance of seagrasses is measured by the communities associated with them. Loss of a meadow means loss of a vital link in the estuarine food web. The seagrass-based food web is large and extends far beyond the boundary of the seagrass meadow. Based on trophic disturbance associated with the loss of Zostera by a blight in the 1930's, we can only assume the disruption can be severe. Restoration by replantation may rapidly restore the plant population, but no technology exists to replace the associated communities whose continued loss we cannot afford.

ACKNOWLEDGMENTS

We gratefully acknowledge the support of both North Carolina Sea Grant (#1-0-152-5220-RE153+4), Dr. Hans Paerl of the University of North Carolina, Institute of Marine Science, for sponsoring the grant, and the Southeast Fisheries Center, National Marine Fisheries Service, Beaufort Laboratory for supporting transplanting operations. We would also like to thank Mr. Dennis Spitsbergen of the North Carolina Division of Marine Fisheries who was instrumental in securing the transplant site as a research protectorate. In the initial phase of the project, the generosity of the following people, who donated hard work, made the project possible: Dr. Steven Bach, Patty Boyd, Deborah Coble, Dr. David Colby, Gay Goodwin, Martha Kenworthy, Linda Phillips, Mark Robertson, Susan Schmidt, and Garriet Smith. Others who later travelled great distances to labour or consult in this project are: Paul Gapsynski, Ken Moore, Dr. Robert Orth, Dr. Polly Penhale, Dr. Ronald Phillips, Rita Zieman, and Dr. Joseph Zieman and their help is greatly appreciated.

LITERATURE CITED

Adams, S. M. 1976. The ecology of eelgrass, Zostera marina fish communities. Part I. Structural analysis. J. Exp. Mar. Biol. Ecol. 22(3): 269-291.

Adams, S. M. 1976. The ecology of eelgrass, Zostera marina fish communities. Part II. Functional analysis. J. Exp. Mar. Biol. Ecol. 22(3): 293-311.

Addy, C. E. 1947. Eel grass planting guide. Maryland Conservationist 24: 16-17.

Churchill, C. A., A. E. Cok, and M. I. Riner. 1978. Stabilization of subtidal sediments by the transplantation of the seagrass Zostera marina L. New York Sea Grant, NYSSGP-RS-78-15.

den Hartog, C. 1971. The dynamic aspect in the ecology of sea grass communities. Thalassia Jugoslavica 7: 101-112.

Eluterius, L. N. 1975. Submergent vegetation for bottom stabilization, p. 439-456. In L. Eugene Cronin, ed. Estuarine Research, Volume II. Academic Press, New York, N.Y.

Fenchel, T. 1977. Aspects of the decomposition of seagrasses, p. 123-145. In C. P. McRoy and C. Helfferich, eds. Seagrass ecosystems: a scientific perspective. Marcel Dekker, Inc., New York.

Hesslein, R. H. 1976. An in situ sampler for closer interval pore water studies. Limnol. Oceanogr. 21: 912-914.

Jones, J. 1968. Primary productivity of the tropical marine turtle grass, Thalassia testudinum Konig, and its epiphytes. Ph.D. Dissertation. Univ. Miami, Coral Gables, Fla. 196 p.

Kelly, J. A., C. M. Fuss, and J. R. Hall. 1971. The transplanting and survival of turtle grass, *Thalassia testudinum*, in Boca Ciega Bay, Florida. Fish. Bull. 69(2): 273-280.

Kenworthy, W. J., and M. S. Fonseca. 1977. Reciprocal transplant of the seagrass, *Zostera marina* L., effect of substrate on growth. Aquaculture 12: 197-213.

Kikuchi, T. 1974. Japanese contribution on consumer ecology in eelgrass (*Zostera marina* L.) beds with special reference to trophic relationships and resources in inshore fisheries. Aquaculture 4: 145-160.

Koroleff, F. 1969. Determination of NH_3 in a small volume. Conseil. Intern. Explor. Mer Interlab. Report no. 3, p. 19-22. Helsinki.

Lindall, W. N., Jr., A. Mager, Jr., G. W. Thayer, and D. R. Ekberg. In press. Estuarine habitat mitigation and planning in the Southeast. Proceedings of the National Mitigation Symposium, Colorado State Univ., Fort Collins, Colo.

McRoy, C. P., and C. Helfferich. 1977. Seagrass ecosystems: a scientific perspective. Marcel Dekker, Inc., New York. 314 p.

Odum, W. E., J. C. Zieman, and E. J. Heald. 1972. The importance of vascular plant detritus to estuaries, p. 91-114. Proceedings Coastal Marsh and Estuarine Management Symposium, Louisiana State University, Baton Rouge, La.

Oppenheimer, C. H. 1963. Effects of Hurricane Carla on the ecology of Redfish Bay, Texas. Bull. Mar. Sci. 15: 59-72.

Orth, R. J. 1976. The demise and recovery of eelgrass, *Zostera marina*, in the Chesapeake Bay, Virginia. Aq. Bot. 2: 141-159.

Petersen, C. G. J. 1912. Uber menge und jaresprodktion der benthospflanzen an den westeuropaischen kusten. Gnt. Rev. D. Ges. Hydrobiol., In Hydrographie, pp. 47-52.

Phillips, R. C. 1960. Observations on the ecology and distribution of the Florida seagrasses. Fla. St. Bd. Cons. Mar. Lab., St. Petersburg, Spec. Sci. Rep. no. 4.

Phillips, R. 1974. Transplantation of seagrasses with special emphasis on eelgrass Zostera marina L. Aquaculture 4: 161-176.

Phillips, R. C. 1978. Habitat development field investigations, Port St. Joe seagrass demonstration site, Port St. Joe, Fla. Dredged Mat. Res. Prog. Tech. Rep. D-78-33.

Ranwell, D. S., D. W. Wyer, L. A. Boorman, J. M. Pizzey and R. J. Waters. 1974. Zostera transplants in Norfolk and Suffolk, Great Britain. Aquaculture 4: 185-198.

Robilliard, G. A., and P. E. Porter. 1976. Transplantation of eelgrass (Zostera marina) in San Diego Bay. Consultation for U. S. Defense Naval Undersea Center, NUC TN 1701. 36 p.

Strawn, K. 1961. Factors influencing the zonation of submerged monocotyledons at Cedar Key, Florida. J. Wildl. Manage. 25(2): 178-189

Thayer, G. W. and H. Stuart. 1974. The bay scallop makes its bed of seagrass. Mar. Fish. Rev. 37(7): 27-30.

Thomas, L. P., D. R. Moore, and R. C. Work. 1961. Effects of Hurricane Donna on the turtle grass beds of Biscayne Bay, Florida. Bull. Mar. Sci. Gulf and Caribb. 11(2): 191-197.

Thorhaug, A. 1974. Transplantation of the seagrass, Thalassia testudinum Konig. Aquaculture 4: 177-183.

Thorhaug, A. 1977. Cost analysis on transplanting Thalassia testudinum. 4th Ann. Conf. on Rest. of Coast. Veg. in Fla. Tampa, Fla. 14 May 1977. Hillsborough County Comm. College.

van Breedveld, J. 1979. Transplanting of seagrass with emphasis on the importance of substrate. Fla. Mar. Res. Publ. #17. 26 p.

Wood, E. J. F., W. E. Odum and J. C. Zieman. 1969. Influence of seagrasses on the productivity of coastal lagoons, p. 495-502. In A. A. Castanares and F. B. Phleger, eds. Coastal Lagoons, a symposium. Ciudad Universitaria, Universidad Nacional Autonoma de Mexico.

Zieman, J. C. 1976. The ecological effects of physical damage from motor boats on turtle grass beds in southern Florida. Aq. Bot. 2(2): 127-139.

Zieman, J. C., C. P. McRoy, K. A. Bridges, and R. Iverson. 1977. Techniques and methods for studies of seagrass beds. D.M.R.P., U. S. Army Waterways Experiment Station, Vicksburg, Mississippi. 204 p.

INTERTIDAL AND SUBTIDAL EELGRASS (*Zostera marina* L.) TRANSPLANT STUDIES IN SAN DIEGO BAY, CALIFORNIA

by

Harold W. Goforth, Jr.
Chemistry and Biochemistry Branch
Marine Sciences Division
Naval Ocean Systems Center
San Diego, California 92152

and

Thomas J. Peeling
Environmental Coordinator
Facilities Planning Department
Naval Facilities Engineering Command
Alexandria, Virginia 22332

ABSTRACT

Seagrass beds are frequently impacted by shallow water marine construction projects. A variety of seagrass transplant methods have been developed with varying degrees of success. Few studies, however, have developed methods that are economical or applicable to large scale subtidal and intertidal transplants (i.e., greater than 0.5 hectare). This paper describes the development of a rapid and successful method of revegetating large areas using plugs of vegetative stock transplanted in biodegradable fiber pots. The use of fiber pots improves success by keeping the root-rhizome-substrate complex intact, reducing damage during handling, providing a substrate for anaerobic sediment bacteria, and reducing the initial loss of transplants resulting from erosion. A 2.5 year pilot study involving a transplant of 46.5m^2 of subtidal vegetative stock demonstrated success of: 46% for 1,331cm^2 plugs; 35% for 410cm^2 plugs and less than 7% for 182cm^2 plugs. After 1.5 years, the number of emergent rhizomes from the two largest plugs sizes (i.e., 5.5 for 1,331cm^2 plugs and 6.3 for 410cm^2 plugs) were not significantly different ($p<0.001$).

Based upon these findings a larger transplant project was conducted in March 1978 to vegetate approximately 1.62 hectares (i.e., 0.93 subtidal and 0.69 intertidal hectare) of recently deposited dredge material in San Diego Bay. The transplant utilized 12,000 plugs (324cm^2) planted on 0.6m centers in rows 1m apart and required 4,500 man hours. Transplant success after 7 months (one growing season) varied from 10%-70% depending upon transplant site. The most successful transplant site was an intertidal area (0.14 hectare) that exhibited 70% survival and an average increase in area of three times the original plug size. Vegetative growth rates in donor beds were sufficient to obscure any evidence of plug removal after one growing season.

INTRODUCTION

The important ecological role of seagrasses has been reviewed by several authors (Phillips, 1960 and 1978; den Hartog, 1970; Humm, 1973; Thayer et al., 1975; McRoy and Helfferich, 1977). As primary producers, seagrasses utilize photosynthesis to capture energy which is then channeled into the marine ecosystem via several paths: 1) Some organisms (e.g., sea urchins, turtles, some ducks and fish) feed directly upon fresh seagrass leaves; 2) detritus-feeding amphipods consume decomposed seagrass leaves and are, in turn, preyed upon by small fish; 3) still other organisms (e.g., bacteria and fungi) decompose seagrass detritus into its basic components which are released into the water column to support phytoplankton populations.

Secondary to their role as primary producers is the protection seagrass beds afford organisms such as shrimp, lobsters, crabs, scallops and juvenile fishes. Seagrass leaves also provide a substrate for the attachment of numerous epiphytes and epifaunal invertebrates. These epibiota, in turn, serve as food items for commercial and non-commercial fish species that inhabit the seagrass beds.

In addition to their contribution to the biology of the marine ecosystem, seagrasses play an important role in modifying the geologic and hydrographic characteristics of an area. Acting as baffles, seagrass leaves reduce the velocity of water over the bed causing suspended particles to settle out and become trapped at the base of the plant. In this way seagrasses reduce turbidity, increase sedimentation rates, stabilize sediments, and attenuate wave action upon adjacent shorelines.

Unfortunately, seagrass beds are often temporarily or permanently impacted by shallow water marine construction projects involving dredging. Dredging activities may affect seagrass beds directly through the physical removal and destruction of plants, or indirectly as a result of increased turbidity and reduction in available light. The amount of light reaching the bottom (i.e., relative irradiance) is reported to be a critical natural environmental factor limiting the local subtidal distribution of seagrasses. However, data from two studies (Robilliard and Porter, 1975; and Backman and Barilotti, 1976) suggest that the effects of turbidity upon *Zostera* is temporary and reversible if the period of high turbidity (i.e., 18-37% relative irradiance) is limited to less than 8 months. Additional research is needed to determine the recouperative response of seagrasses following various degrees of shading for periods less than 8 months.

Long-term or permanent loss of *Zostera* typically occurs as a result of dredging projects which physically remove or smother established beds. Impacts of this nature currently require mitigating or compensating actions to receive permit approval from state and federal regulatory agencies. It is in cases such as these that seagrass transplanation has been increasingly employed as an effective method of recolonizing impact areas or establishing new beds.

Seagrass Transplantation Attempts

The loss of seagrasses resulting from natural and man-made causes has served as the stimulus for the development of seagrass revegetation techniques. Following the devastation of *Zostera* beds along the North Atlantic Coast as a result of the wasting disease (1931-1933), the U. S. Fish and Wildlife Service attempted revegetation using seeds and vegetative stock with little success (Addy,1947a). Later Addy (1947b) reported improved success using a shovelful of intact plants and associated substrate (referred to as a turf, sod, or plug*).

---

*Note: These authors prefer the term "plug" (Phillips, 1977) as more descriptive of the vegetative stock typically obtained using cylindrical coring devices.

This method was later used by Phillips (1960) in an effort to transplant *Thalassia* and *Halodule* into areas of Tampa Bay, Florida, that had been denuded by dredging activities. Using plugs of approximately 254cm^2, Phillips reported moderate success with *Halodule* but failure with *Thalassia* as a result of substrate erosion.

Further attempts to transplant *Halodule* and *Thalassia* were made using growth hormones, erosion barriers, and a variety of anchoring devices including tin cans, burlap, and plastic bags (Kelly et al., 1971). Their most successful method (i.e., 6 of 6 survived a year) utlized single turions that were stripped of rhizomes and associated substrate, dipped into 10% Napthalene acetic acid, attached to construction rods with plastic-coated wire, and then planted. Phillips (1974) experimented with this method in a *Zostera* transplant in Puget Sound, Washington, and reported 100% mortality in six months. Van Breedveld (1975) attempted to duplicate the method recommended by Kelly et al. with *Thalassia* but reported 100% mortality in two months.

In an effort to develop an alternative method of seagrass revegetation, Thorhaug (1974) conducted field and laboratory tests with *Thalassia* seeds and seedlings. Results of laboratory seed culture revealed high mortality from fungal infections. Field tests with seeds indicated successful germination and rapid initial growth with 80% of the seedlings surviving after eight months. However, other studies and field observations of *Thalassia* and *Zostera* seed development are less encouraging (Setchel 1929; Phillips, 1960 and 1971; Zieman, 1975; De Cock, 1977).

Van Breedveld (1975) tested several methods of transplanting seagrasses and found the plug method (111cm^2 - 182cm^2 plugs) to be the most successful (27-50%). Van Breedveld and others have stressed the need for using adequate amounts of meristematic tissue (Thorhaug, 1974) and the maintenance of the integrity of the root-rhizome-substrate complex to minimize the effects of transplant shock (Phillips, 1974).

Several reviews of seagrass transplant methods (Phillips, 1974; Boone and Hoeppel, 1975; Goforth and Peeling, 1975; Robilliard and Porter, 1976) have suggested that the use of single turions and seeds lack the success, cost-effectiveness, or versatility necessary for large scale (i.e., greater than 0.5 hectare) seagrass revegetation projects. The first large scale *Zostera* transplant (0.86 hectare) using the plug method was conducted in Great Britain by Ranwell et al (1974). After one year, 100% of the 1152 plugs ($355cm^2$) had survived and increased in area by a factor of four. However, survival dropped to 35% the second year because of rapid erosion of transplant material, thus emphasizing the critical importance of site selection and long-term monitoring. More recently, Phillips (1977) conducted a large scale transplant utilizing 1488 plugs ($195cm^2$ and $390cm^2$) of *Halodule wrightii* to vegetate two dredge spoil sites. After one year, approximately 30% of the plugs had become fully established and had increased in area by a factor of 0.7.

This paper reports the results of two seagrass transplant projects using the plug method in San Diego Bay, California. The first was a subtidal transplant operation conducted in March 1976 by Woodward-Clyde Consultants under contract to the Naval Ocean Systems Center. This project satisfied a mitigation requirement placed upon the Navy by regulatory agencies to transplant $46m^2$ of *Zostera* out of an area of planned dredging and pier construction. This project was designed as a pilot study to test the relative success of three plug sizes and the use of biodegradable fiber pots to prevent transplant erosion.

The second transplant was conducted in March 1978 and used the knowledge and experience gained from the pilot study to establish 1.62 hectares (4 acres) of *Zostera* upon dredged material in San Diego Bay. This project compensated for the destruction of 1.1 hectares (2.7 acres) of *Zostera* associated with a Navy beach restoration project (i.e., Delta Beach) and was designed to vegetate 0.93 subtidal hectare (2.3 acres) and 0.69 intertidal hectare (1.7 acres).

AREA DESCRIPTION

Subtidal Transplant Sites (1976 Transplant)

Three sites in San Diego Bay were initially selected as suitable locations to receive the transplant material removed from the proposed pier construction site (Figure 1). One site (Site A) was located at the north end of Shelter Island on a barren shoal that had been dredged and backfilled the previous year to install a large sewer main (Robilliard and Porter, 1975 and 1976). A second site (Site B) was located at the south end of Shelter Island within a barren area adjacent to an established *Zostera* bed. A third site was composed of a series of barren areas within the existing *Zostera* beds along the western shore of North Island. The water depth ranged from -1.2 to -2.4 m (-4 to -8 ft.) mean lower low water (MLLW) at the three transplant sites. The sediments within the donor bed and the North Island transplant site were 75% sand and 25% silt with a mean grain size of 0.073mm (3.77 ϕ) and described as silty sand. The sediments at the north end of Shelter Island were 66% sand and 34% silt with a mean grain size of 0.073mm (3.77 ϕ) and also described as silty sand. The sediments at the south end of Shelter Island were 82% sand, 16% silt and 2% gravel with a mean grain size of 0.254mm (1.98 ϕ) and described as coarse to very coarse sand.

Subtidal and Intertidal Transplant Sites (1978 Transplant)

One subtidal and two intertidal areas were selected as transplant sites for the Delta Beach transplant project (Figure 2). The subtidal site (Site A) was a large barren area approximately 75m off-shore at a depth of -1.5m to -1.8m

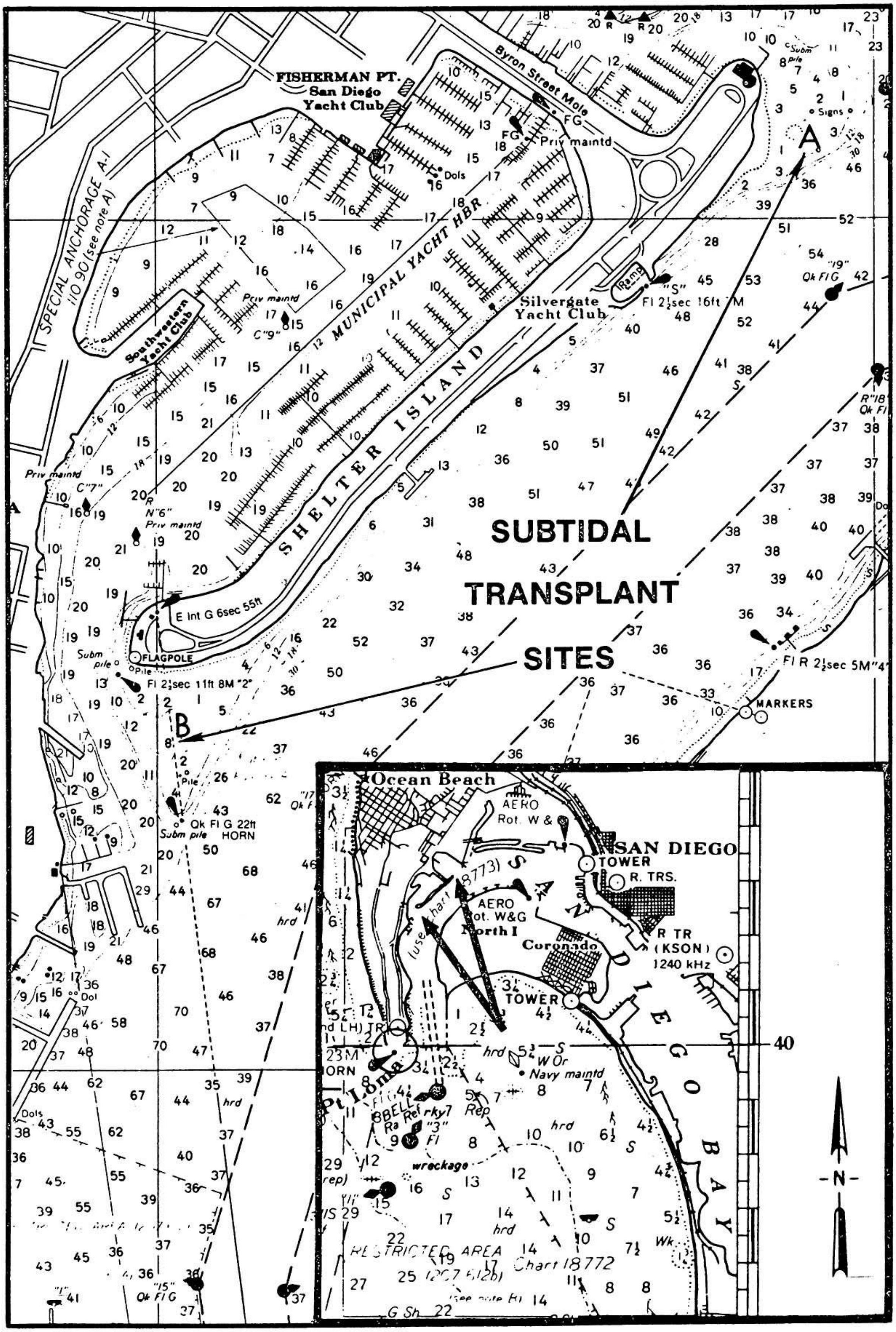


Figure 1. Location of Pilot Study subtidal transplant sites in San Diego Bay, California (1976).

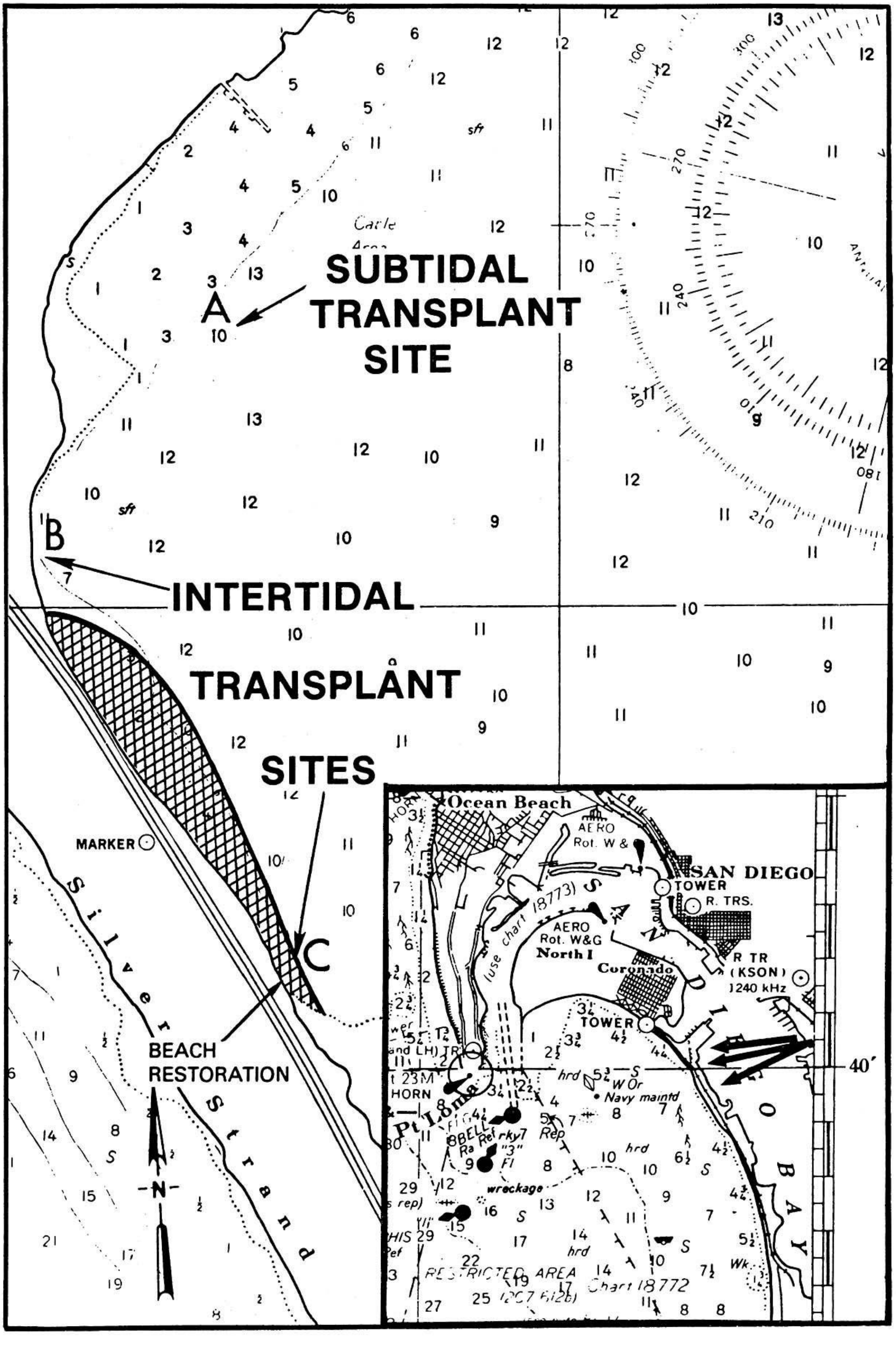


Figure 2. Location of subtidal and intertidal transplant sites for the Delta Beach Project in San Diego Bay, California (1978).

(-5 ft. to -6 ft.) MLLW, recently created by the placement of dredge material. The sediments at this site were 63% sand and 37% silt, with a mean grain size of 0.044mm (4.51 ϕ), and described as silty sand. One intertidal site (Site B) was located in an unvegetated area north of the beach restoration project adjacent to an undisturbed *Zostera* bed. The water depths at Site B ranged from 0.0m to -0.6m (0.0 ft. to -2.0 ft.). The second intertidal site (Site C) was located along the southern end of the beach restoration project at a depth of 0.0m to -0.6m (0.0 ft. to -2.0 ft.) MLLW.

MATERIALS AND METHODS

Subtidal Transplant (1976)

This transplant was conducted during March 1976 by Woodward-Clyde Consultants (Environmental Systems Division, San Diego, CA) under contract to the Naval Ocean Systems Center. The transplant project was entirely subtidal and required SCUBA during both the plug removal and planting stages. A total of $46m^2$ of vegetative stock was transplanted into the three sites described earlier. Each transplant site was delineated with 8.4mm (0.25 inch) polypropylene line held in place with 16.7mm (0.5 inch) construction rods. Three plug sizes were tested: 15 cm diameter x 11 cm deep (6" x 4.5"), 23 cm diameter x 11 cm deep (9" x 4.5"), and 32 x 42 x 5 cm. These three plug sizes represented areas of $182cm^2$, $410cm^2$, and $1,331cm^2$, respectively. Also tested was the ability of biodegradable containers made of molded wood fiber (Western Pulp Products Co., Corvallis, Oregon) to maintain the integrity of the root-rhizome-substrate complex and reduce losses due to erosion. The container sizes corresponded to the plug sizes described above.

Planting Procedures (1976)

A detailed account of the transplant methods and techniques used for this project has been reported previously (Robilliard and Porter 1976). The following is a summary of this earlier report.

Vegetative material was removed from the *Zostera* bed at the proposed pier construction site by divers using short-handled folding shovels (i.e., military entrenching tools). The *Zostera* beds in this area had been surveyed in November 1975 and found to have a turion density of 140-370/m^2 ($\overline{x}$ = 220) and a biomass of 44-119gm dry wt./m^2 ($\overline{x}$ = 82.8). Vegetative material was placed into fiber pots, brought to the surface, and temporarily stored in a dinghy. Once the dinghy was filled it was off-loaded onto a larger work boat. The work boat was driven to a planting site and positioned over a transplant plot and the plugs shuttled to divers on the bottom. Plugs were then planted in rows using short-handled shovels according to a predetermined design. Unpotted plugs were planted using the same technique as potted plugs except that the sides of the pots were torn away just prior to placement in the transplant hole. The sediment that was removed while digging the hole was used to fill-in around the edges of a plug as in terrestrial gardening.

Monitoring Procedures (1976)

A total of twelve monitoring surveys were conducted during the 2.5 years of this pilot study to determine the survival of each treatment. The transplant plots in the barren areas of the *Zostera* bed along the western shore of North Island were surveyed for only 7 months (one growing season). After this period sedimentation (i.e., approximately 2-4 cm) from nearby dredging made it difficult to locate the plot lines. Also dense growth of both transplanted and natural material made the location of individual transplant treatments impossible. The transplant site at the north end of Shelter Island (Site A) was monitored for 1.5 years until the plot lines were disrupted by anchors from fishing boats. Fortunately, the plot lines at the south end of Shelter Island (Site B) remained intact and monitoring was possible for the full 2.5 years. In addition to survival data the number of emergent rhizomes growing out of the fiber containers was determined after 18 months (i.e., two growing seasons). To obtain these counts it was necessary to clean the sediment from around the edge of the potted plug and expose the rhizomes. Because of the rather disruptive nature of this procedure rhizome counts were obtained only once.

Sediment Analyses

Sediment cores were collected for grain size analysis by divers using a 4.75 cm diameter plastic tube with an "orange-peel" core retainer. The tube was pushed 15 cm into the bottom and carefully capped to avoid the loss of fines. Samples were returned to the laboratory within 3 hours and analyzed using the Emery tube technique for sands (Emery,1938) and the wet pippetting technique for silts and clays (Krumbein and Pettijohn,1938).

Zostera Bed Mapping Procedure

To determine the extent and degree of impact of proposed construction projects upon seagrasses, an accurate map of the area in question must be developed. The accuracy of this map depends, in part, upon the time, manpower and funds available for such a survey. In determining how much money and effort should be spent on developing such a map, one must first consider the economic trade-off. An over estimation of the amount of seagrass impacted may result in an expensive mitigation requirement or possible permit denial by the regulatory agencies. Detailed survey maps often reveal significant algal coverage or barren areas within seagrass beds previously assumed to be solid. Therefore, the time and money spent on seagrass mapping surveys is often a wise investment, since it frequently results in a smaller mitigation or compensation requirement. Following this rationale, detailed surveys were conducted to map the *Zostera* beds along the shorelines at both construction sites. The basic mapping procedure is a modification of the beach survey method used by Navy frogmen and involves the following: (1) installation of a row of markers (e.g., stakes or small flags) at regular intervals (e.g., 3-15m apart) along the shore to be surveyed to serve as a baseline; (2) positioning of swimmers (with writing slates) at regular intervals (e.g., 3-15m apart) along a line perpendicular to shore held tight between a person at one of the baseline markers and a swimmer seaward of the bed; (3) swimmers record presence or absence of seagrass and depth of water (measured with a capillary depth gauge or calibration marks on their legs); (4) swimmers move parallel to the shoreline to the next marker and repeat the sequence. This technique has been used by frogmen for decades and is a simple, rapid method of obtaining accurate beach profiles with limited manpower and equipment (Figure 3).

Figure 3. Navy frogmen recording observations while mapping Zostera beds at Delta Beach.

Subtidal and Intertidal Transplant Procedures (1978)

The procedures for this subtidal transplant were similar to those used during the pilot study in 1976 but included several modifications to improve the efficiency and success. To avoid the loss in work efficiency associated with turbid water, transplant procedures were designed for use in zero visibility water. This was accomplished by installing several large grids (50m x 50m with 25 rows spaced 2m apart) made of 8.4mm polypropylene line prior to initiating the transplant. Small plastic tags secured to these lines at 0.6m (2 ft.) intervals marked the location of each transplant. Grid lines were anchored in place every 8m with 1m lengths of 16.7mm construction rod bent into the shape of a cane. Buoys were anchored independently at the four corners of each grid to provide surface reference points (note: buoys secured directly to the grid lines may cause the lines to become unanchored during strong winds). Based upon the survival data from the pilot study and logistical considerations, a plug size of 20 cm diameter ($324cm^2$) was chosen for this transplant. The vegetative material for this transplant was obtained from nearby *Zostera* beds which were found to have a turion density of $300\text{-}650/m^2$ ($\overline{x} = 458$) and a biomass of 39-88 gm dry wt/m^2 ($\overline{x} = 77.8$) in March 1976. This project involved 12,000 plugs of vegetative material which were planted in an area of 1.62 hectares (4 acres). Because of the magnitude of this project it was necessary to divide the transplant into the following tasks.

Preparatory Work: Coring devices were made of 20 cm diameter (8 inch) PVC sewer pipe 85 cm (30 inches) long with a "T" handle made from 2.5 cm (1 inch) schedule 40 PVC pipe. The bottom edge of the coring devices were modified using a saber saw and file to produce a beveled, saw-toothed cutting surface.

Grid lines were cut to the proper length and marked at 0.6m intervals by twisting apart the braid and inserting a plastic tag. The planting grids were then assembled on land using the marked lines and rolled onto a spool until required for installation at the sites.

Biodegradable fiber pots were modified to insure unconfined rhizomal growth by boring four pairs of 2.5 cm diameter (1 inch) holes spaced 90 degrees apart around the pot circumference. This procedure was followed because the fiber pots used in the pilot study degraded slowly and thus restricted rhizomal penetration into the surrounding substrate.

Site Preparation: Prior to commencing the transplant operation, subtidal and intertidal grids were installed (as described earlier) to delineate the transplant areas and identify the location of individual plugs. Figure 4 shows the material and equipment required being staged at the transplant site.

Figure 4. Transplant equipment (e.g., coring devices, cases of pots, grid lines, construction rods, and rubber boats) staged at the Delta Beach transplant site.

Plug Removal Procedure: Plugs were obtained during extreme low tides to avoid the use of divers and facilitate the rapid collection of vegetative material (Figure 5). Potted plugs were then loaded into rubber boats and towed to a transplant site where planting crews were working. To insure optimal utilization of manpower, 50-100 plugs were collected near the end of each work day and staged on shore overnight for the immediate use by planting crews the following morning.

Figure 5. Removal of plugs during low tide from the Zostera donor bed near Delta Beach.

Planting Procedures (Intertidal): Intertidal planting involved the removal of a plug of substrate using the coring device and the placement of a potted plug into the resulting hole. Since the pots and coring devices had the same diameter, no additional digging was required. Pots were planted so that the substrate inside was level with the surrounding substrate (Figure 6). Any projection of the pot above the substrate was torn off and discarded to reduce the possibility of erosion. Intertidal planting was conducted by two-man teams, one man coring out the holes while a second man planted the pot and secured it in position. Planting team members rotated jobs as required to prevent unnecessary physical fatigue. During the intertidal planting operation, a pot placement crew shuttled pots from arriving rubber boats to the transplant grid. Pots were placed beside the plastic tags to allow planting teams to work continuously without interruption or delay.

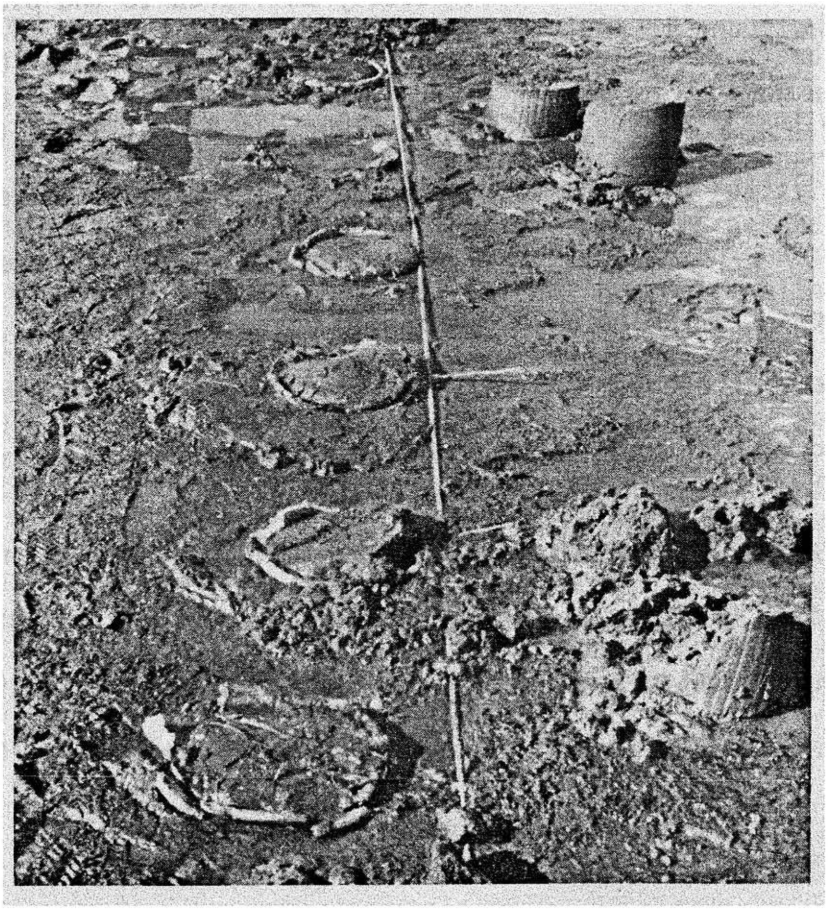


Figure 6. Potted plugs of Zostera planted at 0.6 m centers on intertidal dredge material at Site C (1978).

Planting Procedures (Subtidal): Subtidal planting was accomplished by three-man teams working from a small rubber boat. One man remained in the boat and handed pots of transplant material to a second man (SCUBA diver) who shuttled them to the bottom where a third man (SCUBA diver) planted the pot. Planting involved digging a small hole with a short-handled folding shovel, placing the pot in the hole, and filling in around the edges with the sediment that was removed from the hole. The diver on the bottom wore approximately 18 kg (40 lbs) of weight and had a safety line attached to his weight belt that went to the rubber boat. The diver on the bottom moved along the grid line from one plastic tag to the next and signaled the surface with the safety line each time he needed another pot. This procedure worked efficiently even in zero visibility water. The three members of the planting team rotated jobs every 60-90 minutes to avoid unnecessary fatigue or boredom. Rubber boats loaded with pots were continuously delivered to the planting teams and the empty boats returned to the donor site to be refilled. Once the planting grids were installed the division of labor was as follows: (a) coring crews ("pluggers"); (b) planting teams ("planters"); (c) boat drivers (including one foreman for coordination) towing rubber boats between "pluggers" and "planters"; (d) a support crew onshore that provided charged SCUBA tanks, shovels, weights, coffee, etc., as needed; and (e) a technical supervisor who monitored quality control and managed the overall operation to prevent delays and wasted manhours.

RESULTS

Pilot Study (1976 Transplant)

The transplant survival data for this study is presented in Figure 7. Fluctuations in percent survival data are due to errors in counting which occurred during surveys conducted in turbid water. Nevertheless, general trends in survival are evident and the final survival counts (i.e., September 1977 and 1978) were accurate as they were made under good diving conditions. Survival after 7 months (i.e., one growing season) for 182cm^2 potted plugs, 410cm^2 potted plugs, 1,331cm^2 potted plugs, and unpotted plugs was 58%, 80%, 77% and 34%, respectively. The use of fiber pots appears to have greatly improved the survival of transplanted plugs during the first growing season. Unpotted plugs showed a rapid initial failure with approximately 50% surviving after the first month. In comparison, survival of potted plugs after one month ranged from 76-100% depending upon plug size. Survival of unpotted plugs beyond the first growing season became increasingly difficult to monitor accurately thus making that data of questionable value. This was due to experimental design and the inability to distinguish between transplanted and naturally recruited clumps of *Zostera*. This, however, was not a problem with potted plugs since their containers persisted throughout the study making their identification relatively easy. Survival after 18 months (i.e., two growing seasons) for potted plugs of 182cm^2, 410cm^2, and 1,331cm^2 was 7%, 35%, and 50%, respectively. The mean number of emergent rhizomes after 18 months for the 410cm^2 and 1,331cm^2 potted plugs was 6.3 and 5.5, respectively (not significantly different P<.001). Increased area coverage by the transplanted plugs as a result of rhizomal growth was also quite evident after eighteen months

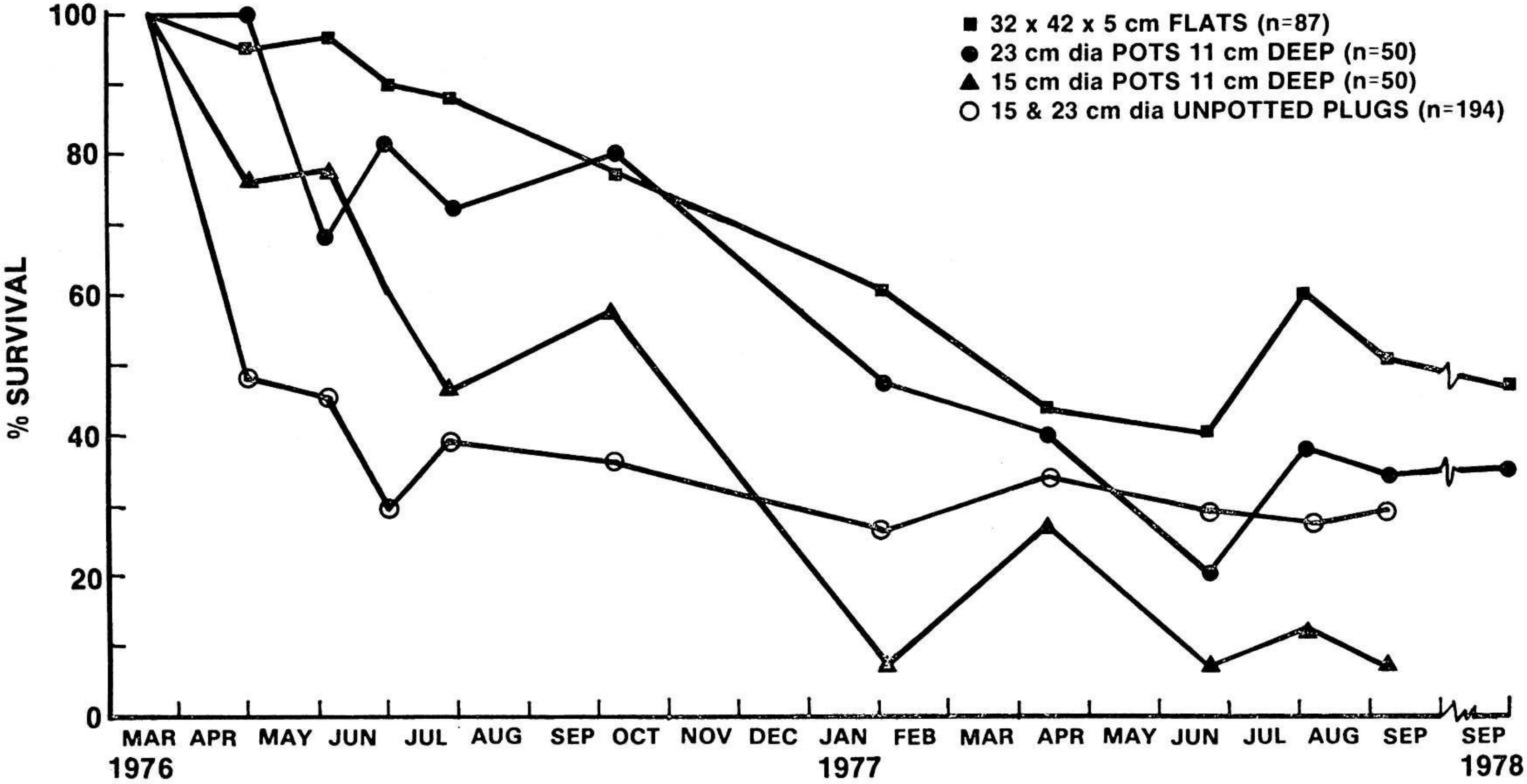


Figure 7. Percent survival of <u>Zostera</u> transplant treatments during the 2.5 year Pilot Study.

(Figure 8). Survival after 30 months (i.e., three growing seasons) for the $410cm^2$ and $1,331cm^2$ potted plugs was 35% and 46%, respectively.

The effects of sediment characteristics upon transplant survival was not fully examined in this pilot study. However, the greater relative success of transplants into the coarser sediments ($\overline{x}$ grain size = 0.254 mm) at Site B, compared to that into finer sediments ($\overline{x}$ grain size = 0.073mm) at Site A is notable. Even though the mean grain size and percent silt were quite similar at Site A and the donor bed, this did not appear to have enhanced the survival of transplants at Site A.

Figure 8. Growth of subtidal transplant plug after 18 months (two growing seasons).

Subtidal Transplant (1978)

A single monitoring survey (after one growing season) was conducted by divers at the subtidal transplant site (Site A) of the Delta Beach Project. The qualitative results of this survey revealed that the transplants into this area had experienced significant losses. Only an estimated 10% of the transplants had survived and these were restricted to the tops of small hummocks of dredge material. A solid carpet of *Gracilaria* sp. covered the bottom below these hummocks and appeared to have effectively out competed the *Zostera* transplants for the available light. Additional surveys are scheduled for this site to monitor transplant survival and measure the relative light intensities at the bottom.

Intertidal Transplant (1978)

An aerial photo survey using infrared film revealed good transplant success after one growing season at both intertidal transplant sites (Sites B and C). Transplant survival at Site B (based solely upon area coverage) was estimated between 50-75%. A quantitative monitoring survey conducted during low tide at Site C revealed an average survival of 68.5%. Transplanted plugs at Site C were found to have increased in area coverage by an average of 2.98 times their original size. Some plugs had increased in area by as much as 10-20 times and as a result the transplanted rows had grown together in many places to form a solid bed (Figure 9). The biodegradable fiber pots were rapidly deteriorating allowing emergent rhizomes to grow unrestricted into the adjacent substrate. Even with the use of plastic tags as markers, the rapid growth and pot deterioration made location of individual transplant plugs very difficult. Future monitoring surveys will be forced to rely upon area coverage within the rows of polypropylene line to determine success of these intertidal transplants.

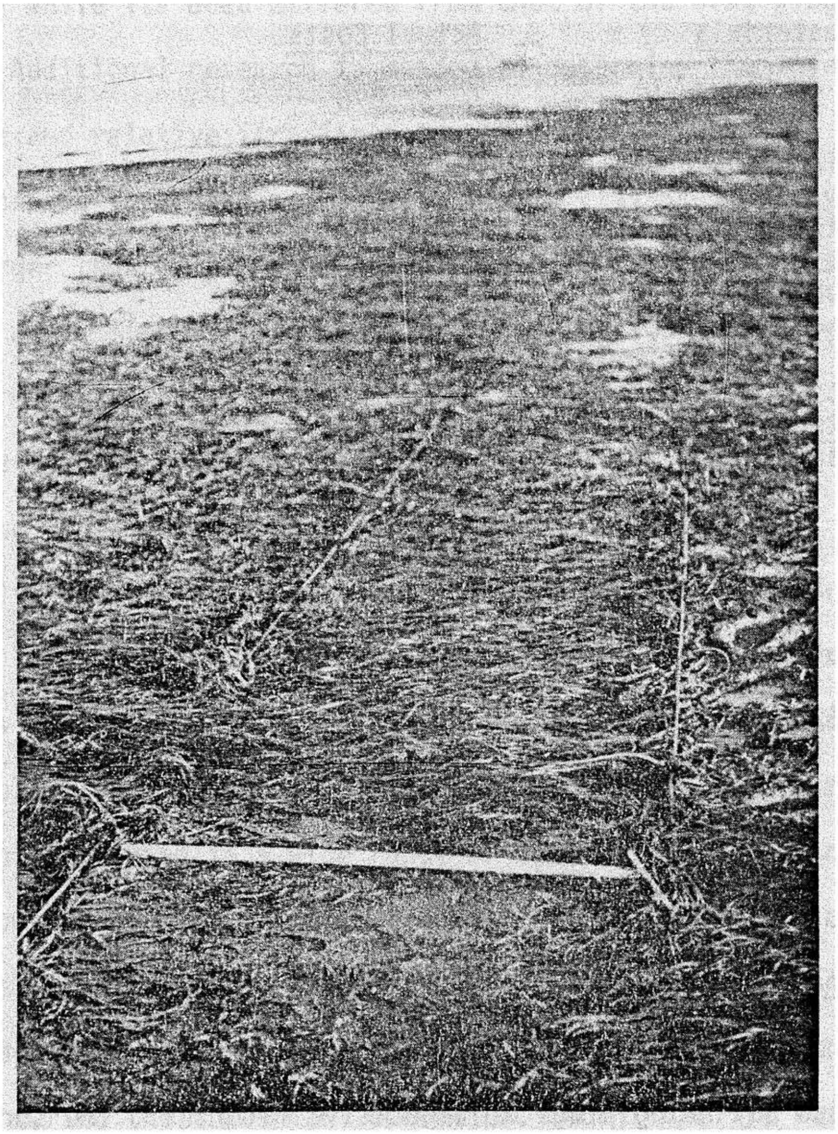


Figure 9. Growth of intertidal transplant plugs after 7 months (one growing season).

Transplant Costs (1978)

Area planted

1.62 hectares (0.93 subtidal and 0.69 intertidal hectares)

or 4 Acres (2.3 subtidal and 1.7 intertidal acres)

Cost of expendable materials	Actual Costs
12,000 fiber pots @ $0.173 each	$2,076
36,000 ft. of 0.25 inch polypropylene line	202
PVC pipe for 15 coring devices	162
0.5 inch construction rod	151
	$2,591

Manpower requirements (Estimated hourly wages)	Hours	Estimated Costs
Divers @ $10.00/hr.	2,435	$24,350
Other technicians @ $4.00/hr.	1,941	7,764
Subtotal	4,376	32,114
Supervisor hours @ $20/hr.	160	3,200
TOTAL	4,536	$35,314

CONCLUSION AND DISCUSSION

Subtidal Transplant (1976)

The results of this pilot study have shown that *Zostera* can be successfully transplanted in San Diego Bay using plugs of vegetative material. The survival of transplants using this method is affected by plug size, site selection (e.g., sediment characteristics and water depth), and the use of biodegradable containers. The finding that larger plug sizes experienced greater survival was anticipated; however, the fact that this relationship was not linear may be significant. It appears that the survival of plugs transplanted into subtidal areas with low relative irradiance may depend upon the presence of a minimum amount of vegetative material. This suggestion is based upon the finding that the two larger plugs had similar survival rates (i.e., 35 and 46%) even though they differed in area by a factor of 3.2. The smallest of the three plug sizes experienced significantly greater failure (less than 7% survival) while its area differed from that of the next plug size by a factor of 2.3. Additional research is needed to determine the interactive effect of plug size and relative irradiance upon transplant survival. The relatively small increase in transplant success (i.e., 11%) achieved by using plugs 3.2 times larger than 410cm^2 does not compensate for the increased logistical problems associated with the use of the larger 1,331cm^2 plugs.

The greater survival of transplants at the site having coarse sediments contrasts with the failure of transplants at the site which had fine sediments similar to those at the donor site. Failure of transplants into fine sediments may result from a greater susceptibility to erosion, more frequent reduction in light levels due to resuspension of sediment, or other environmental factors.

It has been suggested by Phillips (personal communication, 1978) that *Zostera* plays the role of both a pioneer and climax seagrass and thus is capable of surviving in a wide range of sediments. It is this plasticity that allows *Zostera* to colonize areas with relatively coarse sediments and to successfully adapt as the sediments become increasingly fine (Orth, 1977).

The use of biodegradable pots greatly facilitated the handling of vegetative material during the transplant operation. Additionally, survival of transplants in pots was approximately double that of unpotted transplants after one growing season. The failure of "biodegradable" pots to deteriorate rapidly may have unnecessarily limited the growth of emergent rhizomes into the surrounding area. This problem, however, was later alleviated by using fiber pots made with less bonding matrix.

In summary it was concluded from the pilot study that:

1. *Zostera* can be successfully transplanted into barren subtidal areas using the vegetative plug method.

2. The use of fiber pots and the selection of sites with coarse sediments should be considered to improve transplant success.

3. The selection of plug size may determine the success of transplants into subtidal areas with reduced light penetration.

4. Plugs larger than 410cm^2 were difficult to handle and exhibited only slightly greater survival.

Subtidal Transplant (1978)

The significant failure of transplants at the subtidal site appears to be due to the lack of sufficient light reaching the transplanted plugs. This may have resulted from the heavy growth of *Gracilaria* at this site, and its shading of transplant plugs. Additionally, the depth at this site may have been too great for *Zostera* to successfully compete with algae for the available light. The survival of transplants on the shallow portion of the fill further suggest that transplant success was light limited. Survival of transplants on these hummocks also suggests that failure was not a result of plug size or transplant methods.

In summary, it was concluded that:

1. Future transplants onto newly created areas of subtidal dredge fill should be conducted only after measurement of the relative irradiance at the site.

2. It may be necessary to conduct a short term pilot transplant in areas where light levels appear to be marginal (i.e., 20%).

Intertidal Transplant (1978)

The greater transplant success and growth observed at the intertidal sites

(Sites B & C) may be due in part to the higher light intensities at these sites. Patches of *Gracilaria* and other algae covered approximately 15-20% of the area within the transplant boundaries at Site C. However, at this site the *Zostera* transplants appeared to be only moderately affected by the shading and smothering of the algal cover. The exceptional increase in area coverage (i.e., 10-20 times) by many of the intertidal transplant plugs suggests that either smaller plugs or wider spacing of transplants may be possible. The incorporation of either of these modifications would substantially reduce the transplant costs per hectare. Further reductions in transplant costs can be realized by conducting transplant operations in the lower intertidal zone (i.e., 0.0m to -1.0m) during minus tidal conditions thus increasing the efficiency of workers and eliminating the need for SCUBA divers. Selecting a donor bed that is at the same general tidal height,healthy, and near the transplant site is also recommended to optimize survival and reduce logistical problems.

In summary, it was concluded that:

1. Intertidal transplants of *Zostera* using potted plugs of vegetative material (324cm^2) can become successfully established upon dredge material after a single growing season and increase in area coverage by a factor of 3.

2. Intertidal transplants (i.e., 0.0m to -1.0m) are less expensive and more successful than subtidal transplants (i.e., -1.0m to -2.0m) where lower light levels may limit growth rates.

3. Additional studies are needed to determine the optimal plug size and spacing for intertidal transplants of *Zostera*.

4. The use of fiber pots made with a very weak bonding matrix will deteriorate rapidly allowing for unrestricted rhizomal growth during the first growth season.

5. A need exists to establish a set of commonly accepted parameters for

evaluating seagrass transplant success (e.g., density, biomass, area coverage and time) to allow for comparisons between the various transplant methods under development.

LITERATURE CITED

Addy, C. E. 1947a. Germination of eelgrass seed. J. Wildlife Mgt. 11:279.

Addy, C. E. 1947b. Eelgrass planting guide. Md. Conserv. 24:16-17.

Backman, T. W., and D. C. Barilotti. 1976. Irradiance reduction: Effects on standing crops of eelgrass (*Zosteria marina L.*) in a coastal lagoon. Mar. Bio. 34:33-40.

Boone, C. G., and R. E. Hoeppel. 1976. Eelgrass (*Zostera marina L.*) transplantation and restoration in San Diego Bay, California (draft). Environ. Effects Lab., U. S. Army Engineer Waterways Exp. Station, Vicksburg, Mississippi Tech. Rept. 50 p.

DeCock, A. W. A. M. 1977. Culture of *Zostera marina L.* in the laboratory. Aquaculture 12:279-281.

den Hartog, C. 1970. Seagrasses of the world. North-Holland Publishing Co., Amsterdam. 280 p.

Emery, K. O. 1938. A rapid method of mechanical analysis of sands. J. Sed. Petrol. Vol 8:105-111.

Goforth, H. W., and T. J. Peeling. 1975. Eelgrass (*Zostera marina L.*) beds along the western shore of North Island Naval Air Station, California. Mar. Environ. Mgmt. Office, Naval Undersea Center, San Diego. 23p.

Humm, H. J. 1973. Seagrasses. In:A summary of knowledge of the eastern Gulf of Mexico. J. I. Jones et al. (Eds.). Amer. Petrol. Inst. Wash., D. C. pp. IIIC-1 to IIIC-10.

Kelly, J. A. Jr., C. M. Fuss, Jr., and J. R. Hall. 1971. The transplanting and survival of turtle grass, *Thalassia testudinum*, in Boca Ciega Bay, Florida. Fish. Bull. 69(2):273-280.

Krumbein, W. C. and F. J. Pettijohn. 1938. Manual of Sedimentary Petrology. Appleton-Croft Publishing Co., New York, N. Y. 549 p.

McRoy, C. P., and C. Helfferich. 1977. Seagrass ecosystems: A scientific perspective. Marcel Dekker, Inc. New York, N. Y. 314 p.

Orth, R. J. 1977. The importance of sediment stability in seagrass communities. Pages 281-300 in B. C. Coull, ed. Ecology of Marine Benthos. University of South Carolina Press, Columbia, S. C.

Phillips, R. C. 1960. Observations on the ecology and distribution of the Florida seagrasses. Fla. State Bd. of Conserv., Prof. Papers Series. No. 2. 72 pp.

Phillips, R. C. 1971. Seed germination in *Zostera marina L.* Amer. J. Bot. 58(2):459.

Phillips, R. C. 1974. Transplantation of seagrasses, with special emphasis on eelgrass, *Zostera marina L.* Aquaculture. 4:161-176.

Phillips, R. C. 1977. Seagrass bed development on dredged spoil at Port St. Joe, Florida. Proc. Fourth Annual Confer. on the Restoration of Coastal Vegetation in Florida. Hillsborough Commun. College, Tampa Bay, Florida. pp. 1-14.

Phillips, R. C. 1978. Seagrass and the coastal marine environment. Oceanus 21(3): 30-40.

Robilliard, G. A. and P. E. Porter. 1975. Short-term effects of a dredging-pipelaying-backfilling project on an eelgrass bed in San Diego Bay. Woodward-Clyde Consultants, Envicon Div., San Diego, California. 53 p.

Robilliard, G. A., and P. E. Porter. 1976. Transplantation of eelgrass (*Zostera marina*) in San Diego Bay. Woodward-Clyde Consultants, Environmental Systems Div., San Diego, California. 36 p.

Setchell, W. A. 1929. Morphological and phenological notes on *Zostera marina L.* Univ. Calif. Publ. in Botany. 14(19): 389-452.

Thayer, G. W., D. A. Wolfe, and R. B. Williams. 1975. The impact of man on seagrass systems. Amer. Sci. 63:288-296.

Thorhaug, A. 1974. Transplantation of the seagrass *Thalassia testudinum* Konig. Aquaculture. 4:177-183.

van Breedveld, J. F. 1975. Transplanting of seagrasses with emphasis on the importance of substrate. Fla. Dept. Nat. Resour. Mar. Res. Lab., Fla. Mar. Res. Publ. No. 17. 26 p.

Zieman, J. C. 1975. Seasonal variation of turtle grass, *Thalassia testudinum* Konig, with reference to temperature and salinity effects. Aquatic Botany. 1:107-123.

ACKNOWLEDGEMENTS

The Sixth Annual Conference on Wetlands Restoration and Creation and these Proceedings are the result of efforts of many people. Thanks are extended to Roy R. "Robin" Lewis for his assistance in organizing and moderating the Conference and for his assistance in editing these Proceedings. Thanks are due also to Fred Webb, Paul Stanley, Lynn Elliott and Steve Lumbardt for their assistance in preparation for the Conference. Carla Wright of the Hillsborough County Aquatic Weed and Mosquito Control Department is gratefully thanked for the use of the department's Salt Marsh display.

Special thanks are extended to the Tampa Port Authority for its continuing financial assistance for the publication of these Proceedings. Plano B. Valdes of Hillsborough Community College is thanked for his support of the Environmental Studies Center and its efforts, including this annual Conference.

Finally, the contributors to the Conference and these Proceedings are thanked for their research of restoration and re-creation of our important wetlands.