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STABILIZATION OF SUBTIDAL SEDIMENTS BY THE TRANSPLANTATION OF THE SEAGRASS *ZOSTERA MARINA* L.

A. Coolidge Churchill
Department of Biology, Adelphi University

Anthony E. Cok
Department of Earth Sciences, Adelphi University

Michael I. Riner
Texas Instruments Company

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A. Coolidge Churchill (Principal investigator)
Department of Biology
Adelphi University

Anthony E. Cok (Co-principal investigator)
Department of Earth Sciences
Adelphi University

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ABSTRACT

The seagrass *Zostera marina* has been successfully transplanted onto dredge spoil, and the method has potential for stabilizing unconsolidated sediments. The recommended transplanting technique uses miniplugs, sediment-free clusters of 4 to 6 shoots, together with entangled roots and rhizomes, which are planted manually without anchoring devices. A total of 5,061 miniplugs were planted in an area of 0.06 hectares (0.14 acres) with 80% survival. A 2- and 3-fold increase in rhizome length and shoot number, respectively, occurred during the first 4 months. The cost of planting 0.41 hectares (1 acre) is estimated at $3,370.

THE PROBLEM AND PROJECT DESCRIPTION

In Great South Bay, New York, planned construction of a sewer outfall line (Environmental Protection Agency 1975) will result in the temporary removal of 1 million cubic yards of dredge spoil and the loss of 41 hectares (100 acres) of the seagrass *Zostera marina* L. In Boca Ciega Bay, Florida, hydraulic dredging has resulted in the loss of 1,400 hectares (3,500 acres) of bay bottom since 1950, much of it covered with the seagrass *Thalassia testudinum K.* (Taylor and Saloman 1968). These projects, large in scale but not unusual, illustrate two major problems: namely, the environmental impact of dredging and filling, and the continued destruction of one of the most productive coastal communities, the seagrass meadow.

During 1975 and 1976, I oversaw a research project which directly relates to these two problems. The objective of this research is stated simply: determine if eelgrass (*Zostera marina*) can be successfully and economically transplanted on subtidal dredge spoil (or on any submerged denuded area) to stabilize the spoil sediments and create or rehabilitate a *Zostera* meadow.

The ability of vegetation to prevent erosion is well known. Planting marshgrass (*Spartina alterniflora*) on both dredge spoil and naturally unstable shore areas produces dramatic effects in the marine environment (Garbisch et al 1975; Woodhouse et al 1972). In fact, salt marsh creation has reached the point where private and governmental agencies may purchase *Spartina* seedlings by the thousands from commercial growers and expect a high level of success when planting in selected areas.

In contrast, the applied use of seagrass transplantation is in its infancy. A variety of transplant methods have been tested under different environmental conditions, and it is clear that failure is as common as success (Addy 1947;

Phillips 1974, 1976; Kelly et al 1971; Weymouth 1973; Eleuterius 1975). Furthermore, nearly all studies to date, except Ranwell et al (1974) and Weymouth (1973), have been done on a small experimental scale and provide little insight into the economic feasibility of large-scale plantings.

A spoil island on the south shore of Long Island (see description below) was the study site for this project. During the first year (1975), the physical characteristics of the shallow waters surrounding the island were described and different techniques of transplanting eelgrass were tested and evaluated. A field-scale planting, completed in 1976, used the technique which manifested the best results from the previous year. A study of the impact of this scale-up planting on the surrounding sediments and a cost estimate were produced. The study of eelgrass seed production was an additional focus of the project. Prompted by the potential use of seeds as a means of establishing eelgrass, this study resulted in the development of a seed "tape" for possible use in planting.

THE STUDY AREA

We conducted all transplant experiments on a spoil island located on the east side of Snake Hill Channel, approximately 1.5 miles from the Captree fishing docks (Figure 1). The island, created by dredge spoil dumpings from Snake Hill Channel in 1965, has no official name and is designated here as Sand Island.

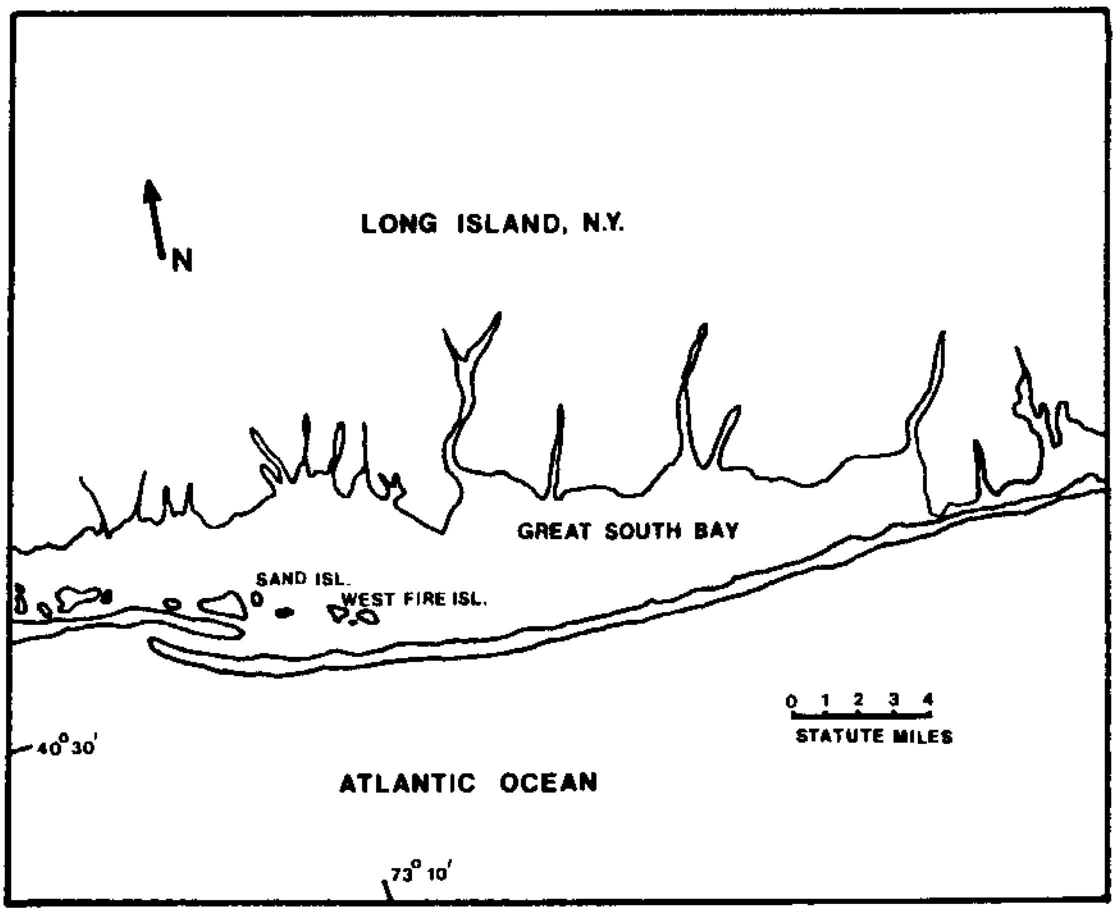

FIGURE 1 *Map of Great South Bay including Sand Island*
This shows the site of the transplant studies and West Fire Island where transplant material was obtained in 1975.

In the autumn of 1973, an additional 93,000 cubic yards of spoil from maintenance dredging of the channel were added to the northern edges of the island, increasing its area from approximately 6 hectares (15 acres) to

FIGURE 2 *Aerial photograph of Sand Island after dredging*

The area to the west of the dashed line indicates the size of the island before dredging Snakehill Channel. (Source: Lockwood, Kessler, and Bartlett, Inc. Syosett, New York. Negative 2805-2-240.)

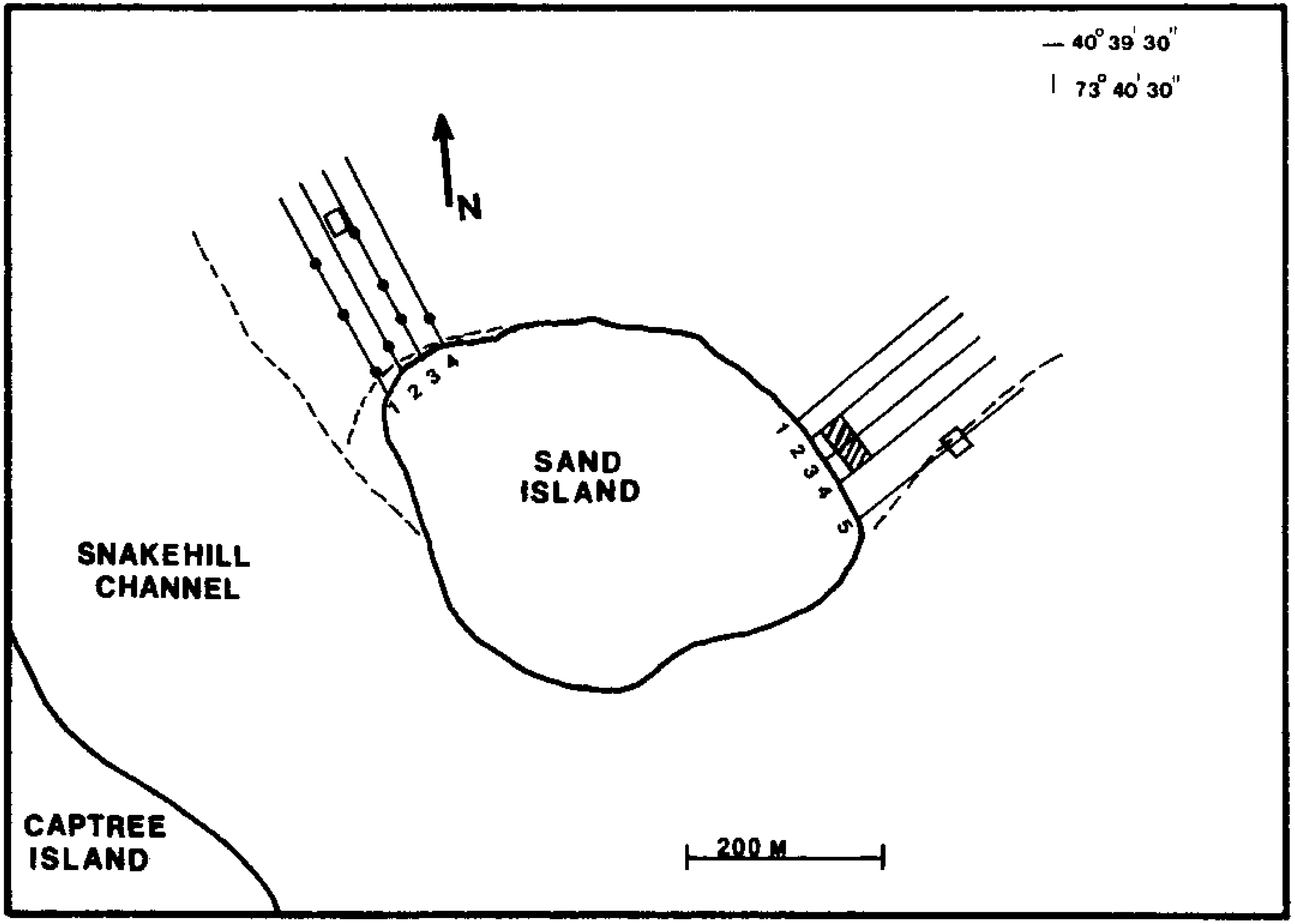

FIGURE 3 *Transect lines and transplant sites at Sand Island*

● 1974 (preliminary plantings)
□ 1975
■ 1976

Dashed lines indicate the position of sand bars.

14 hectares (35 acres) (Figure 2). Since its formation, Sand Island has been used extensively for recreation and served recently as the site of a wetlands creation project sponsored by the Town of Islip.

Permanent transect lines, established on the north and east sides of the island (Figure 3), served as a reference for the location of plantings and such various physical measurements as: current velocity, sediment analysis, and sediment elevations. Preliminary plantings (1974, prior to the start of the project) and the experimental transplants of the first project year were made on the north side of Sand Island in areas where previously established patches of eelgrass were essentially uninfluenced by the spoil deposition. The water depth at the site of the plantings varied between approximately 61 and 121 cm (2-4 ft), depending on the tide. The tidal currents reached maximum velocities of about 0.57 knots (0.29 m/sec).

An additional experimental planting, completed on the east bar (Transect 5), separated a small channel from the shallow flats on the east side. This is visible in Figure 2. The water depth at this area was approximately the same as the north planting site, but the tidal currents were stronger and reached values of 0.82 knots (0.42 m/sec). The sediments were moderately well sorted (Folk 1968) and noticeably loose or unconsolidated.

The field scale plantings in 1976 were located on the east side, close to the island, and on sediments primarily derived from the dredging operation. A more extensive description of this area follows.

EXPERIMENTAL PLANTINGS

Description of Eelgrass

Before considering the specific methods of its transplantation, it is important to describe the general pattern of eelgrass growth and development. A plant consists of a prostrate stem called a rhizome,which typically is found about 2.5 cm (1 inch) beneath the sediment surface (Figure 4). The growing point of the rhizome is at the apex, where the green strap-like leaves also form. The internodes, or sections of rhizome between the attachment point of the leaves, are initially small, so that the rhizome appears to terminate in a tight cluster of leaves called a shoot or turion. The

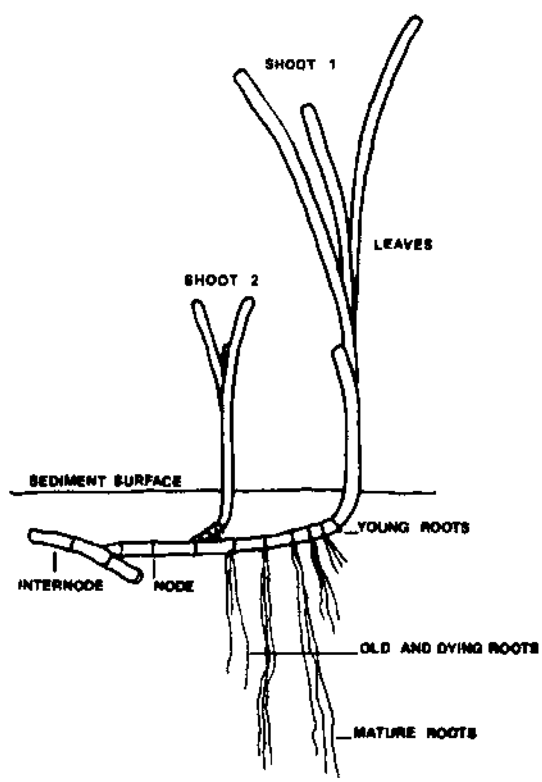

FIGURE 4 *Diagram of eelgrass*

A branch from a fragmented section of rhizome (shoot 1) has produced another branch (shoot 2). The spatial relationship between rhizomes, roots, shoots, and the sediment surface is drawn to approximate scale.

FIGURE 5 *Miniplug prior to planting*
The miniplug is held by the root-rhizome portion.

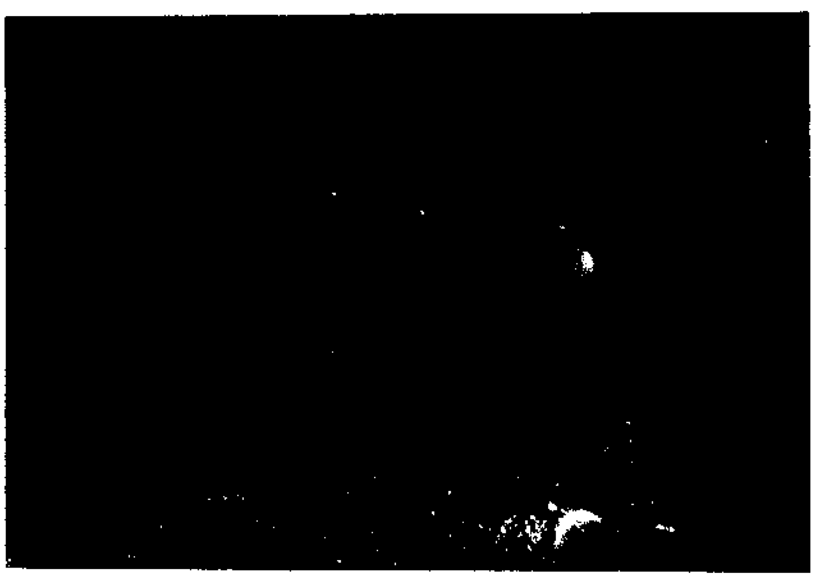

FIGURE 6 *Miniplugs after planting*

rhizome tends to elongate a short distance behind the apex, which results in the lengthening of the internodes and the broadening of space between leaves. One rarely finds plants with more than one leaf behind the terminal cluster, however, even though the rhizome may be 30 cm (1 foot) or longer. It seems that the leaves tend to break off or absciss behind the apex at approximately the same rate that new ones form.

The rhizome produces slender roots near its apex. These roots appear at the same point as the leaves, but on the underside of the rhizome surface. This region of leaf and root attachment is called a node. Typically, 6 to 8 unbranched roots grow at each node and extend 10 to 20 cm (4-8 inches) down into the sediments. The rhizome branches by developing lateral buds, which have a growth pattern similar to the main axis. The branches in turn may branch, giving rise to a network of tangled rhizomes, which, together with the roots, effectively bind and stabilize the sediments. In practice, the concept of an individual plant has little significance, except when considering seedlings or single shoot transplants (see below). This is because natural fragmentation and death of the rhizomes tend to obscure the chronological history of growth and branching beyond one growing season.

Transplant Techniques

Eelgrass used in the experimental plantings all came from a *Zostera* meadow on the north side of West Fire Island (Figure 2). The transplants, prepared at the site of harvest and transported by boat to Sand Island, were transplanted on the same day in the areas shown in Figure 3. We tested three transplant techniques, each representing successively smaller amounts of eelgrass.

The plug technique consisted of a shovel scoop of sediments, approximately 20 cm (8 inches) in diameter and containing an average of 19 shoots, with a sediment ball remaining more or less intact around the rhizomes and roots. We manually planted the plugs into previously made holes and molded the edges to conform to surrounding sediments. Using a 91 cm (3 foot) spacing, we planted the plugs in plots of twenty (4 rows x 5 rows) from 28 May to 3 June 1974. This discussion considers only those plugs in the last plots on transects 1 and 3.

The miniplug technique consisted of a cluster of 4 to 6 shoots with their entangled rhizomes and roots washed clean of all adherent sediments (Figure 5). Grasping the roots and rhizomes in our palms, we planted the miniplugs by pushing the transplant into the sediments until the rhizomes were 2.5 to 7.5 cm (1-3 inches) below the surface (Figures 6,7). We made no attempt to disentangle the roots from the rhizomes.

In the single shoot technique, we prepared transplants by severing small branches from the rhizome material and planting them in the same manner as we planted the miniplugs. In one experiment, the single shoots were soaked for 5 hours in different concentrations (1.0 and 10 mg/l) of the rooting hormone napthaleneacetic acid (NAA) prior to planting. Such a treatment promoted rooting and enhanced transplant survival in the seagrass *Thalassia* (Kelly et al 1971). In another experiment, the single shoots were fertilized at the time of planting by the addition of 3.5 g (0.1 oz) of a slow release fertilizer (Osmocote 14-14-14) to each transplant. There have been no previous attempts to fertilize seagrass transplants, but enrichment, particularly with a nitrogen-rich fertilizer, is routine with salt marsh plantings.

Miniplugs and the treated and untreated single shoots were planted on the north side in May 1975, using a 30 cm (1 foot) spacing in plots containing either 225 or 105 individual transplants (Figure 7).

Transplant Growth and Survival

The apparent pattern of establishment and growth in all techniques reveals itself in a comparison of the second and fourth months after planting.

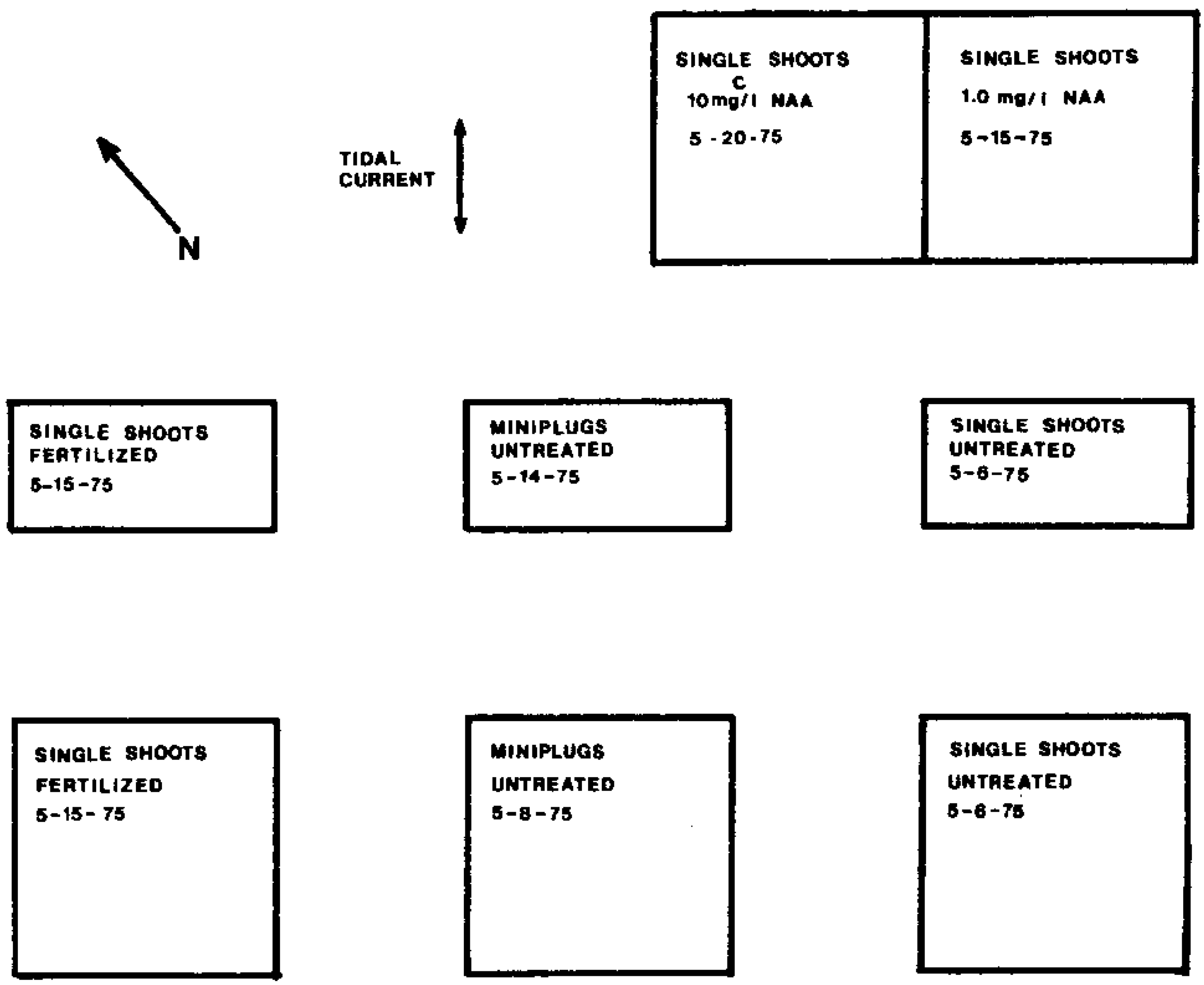

FIGURE 7 *Relative positions of the experimental plots (1975)*

The nature and date of the plantings appear within each plot. The large plots measured 4.3 m x 4.3 m (14 feet x 14 feet) and contained 225 transplants. The small plots measured 4.3 m x 2.1 m (14 feet x 7 feet) and contained 105 transplants.

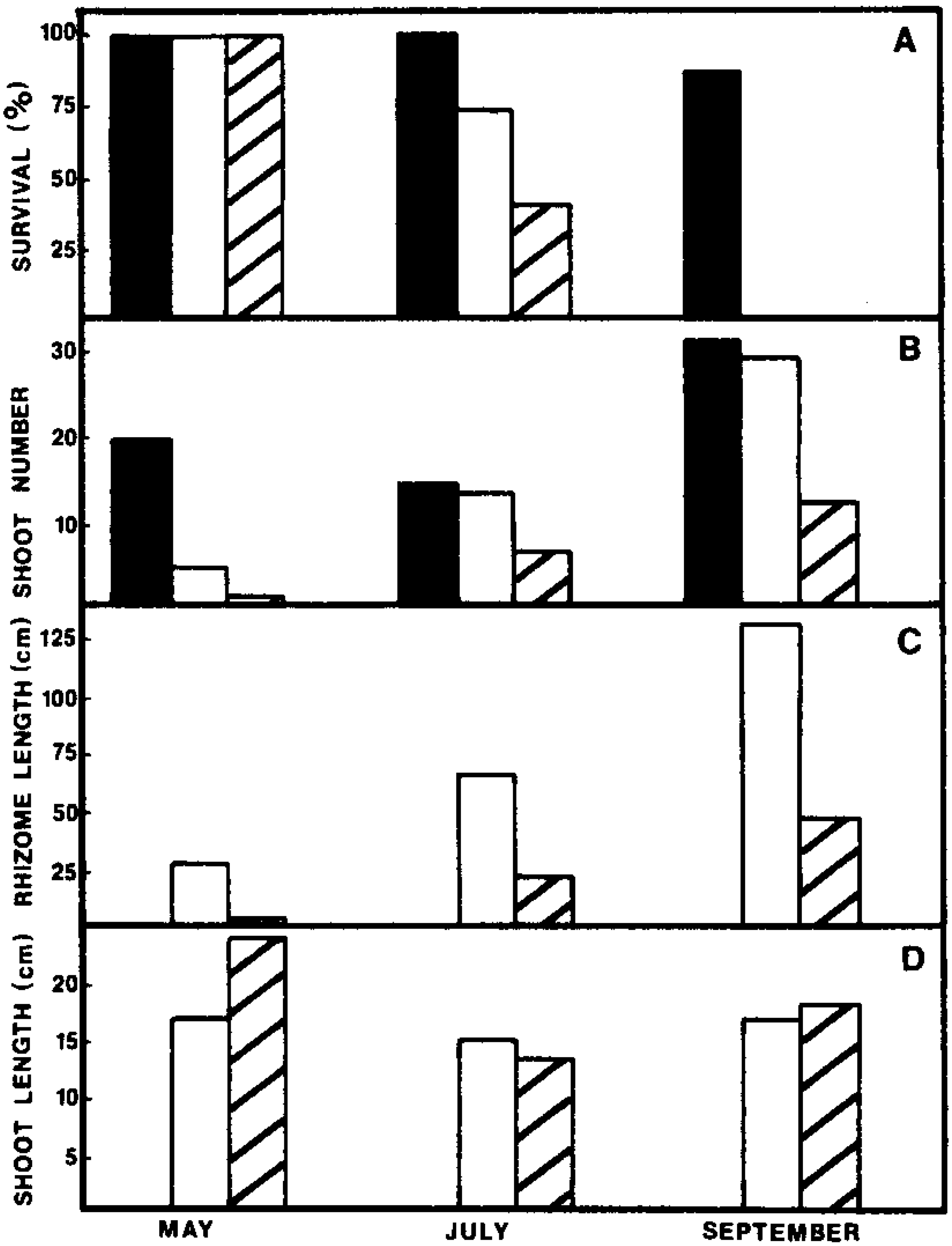

FIGURE 8 *Bar graph of transplant survival, shoot number, rhizome length, and shoot length*

(A) transplant survival, (B) shoot number, (C) rhizome length, (D) shoot length, ■ plugs, □ miniplugs, ▨ single shoots.
The transplants were planted in May and observed in July and May. Survival of miniplugs and single shoots was not determined in September, due to decimation by clammers. Shoot and rhizome length were not determined for the plugs.

Survival for long periods of time did occur, however. Well established patches of eelgrass appeared the following summer (August 1975) in the mini-plug plot, and after 26 months the density of shoots in the two plug plot was similar in appearance to the surrounding natural population.

The number of shoots and the amount of rhizome material associated with each transplant increased significantly over the four month period (Figure 8b and c). The increase is most clearly seen, however, by a diagramatic illustration of growth in a single shoot (Figure 9). After two months the initial rhizome axis had increased eight times in length and produced five lateral branches. A third order of branches developed by September and the

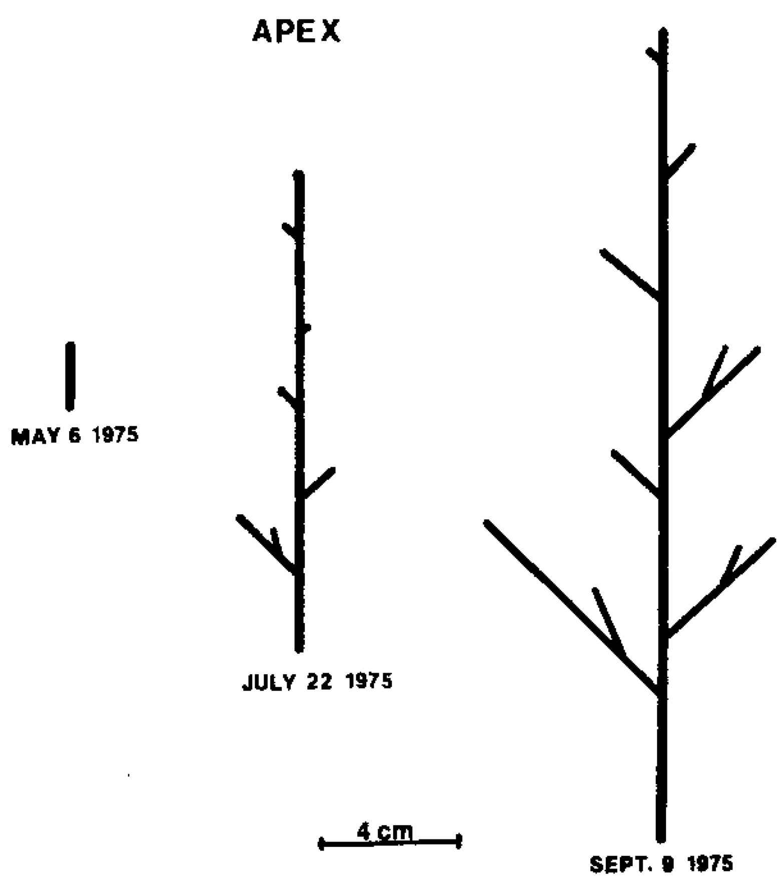

FIGURE 9 *Rhizome elongation and branching of single shoot transplant*

Scale diagrams of the rhizome main axis and branches from the single shoot transplants reflect growth after two and four months.

rhizome length increased to 46 cm (18 inches). The rhizomes are apparently capable of vigorous and rapid growth and show little evidence of a setback or recovery period after transplantation. This proved true of the miniplugs as well; after four months they had produced an average of 1.3 m (51 inches) of branching rhizomes buried within the sediments (Figure 8c). The number of shoots in a miniplug increased fivefold between May and September, reaching a total value comparable to that of the plugs. This indicates a point of diminishing return, where increasing the size of the initial transplant has little effect on the amount of new growth produced.

The average length of the shoots (Figure 8d) decreased during the first two months and then increased slightly between July and September. The initial decrease is primarily a result of including the new, smaller shoots in determining the average values. It is possible, however, that abscission of the older and therefore longer leaves, which invariably occurs soon after transplanting, may contribute to the observed decrease. The increase in shoot length between July and September, while small, is of interest. It occurs at a time when the shoots in natural populations are decreasing in length (Riner 1976; Burkholder and Doheny 1968), thus suggesting a basic difference in the growth pattern of transplanted and undisturbed eelgrass.

Survival and growth of the plants soaked in the two hormone concentrations were essentially similar to the untreated transplants (Table 1). Even the number of roots produced at each node on the rhizome (usually 6-8 roots/node) remained unchanged. Enrichment with the slow release fertilizer stimulated some increase in weight of the shoot and rhizome portions, but not in shoot length or number. Possibly the fertilized shoots had stouter rhizomes and wider leaves. Unfortunately, neither of these two parameters was measured.

TABLE 1 *Comparison of fertilized, hormone treated and untreated single shoots after two months* (Standard deviations appear in parentheses.)

Transplant treatment	Survival (%)	Shoot number	Length (cm) Shoot	Length (cm) Rhizome	Weight (g) Shoot	Weight (g) Rhizome
Untreated	36	6.7 (±2.4)	14.1(±2.3)	20.4(±8.6)	0.58(±.29)	0.57(±.30)
NAA(1mg/l)	40	4.9 (±1.4)	15.9(±3.2)	18.0(±7.0)	0.45(±.24)	0.56(±.27)
NAA(10mg/l)	40	5.3 (±1.9)	16.6(±3.9)	19.2(±8.1)	0.52(±.22)	0.58(±.24)
Fertilized	11	6.8 (±3.9)	14.2(±3.2)	22.9(±15.4)	0.99(±.83)	1.28(±.94)

The most striking characteristic of the fertilized transplants was their poor survival. The fertilizer was added to the plants by adhering the small pellets to pieces of masking tape which were then buried with the rhizomes. I suspect that some organism, perhaps the calico crab *(Ovalipes ocellatus)*, was attracted to the buried tape while foraging and uprooted the plants.

The plantings on the east side at transect 5 were not successful and indicated the limits of transplant survival in an unstable bar area. Although some of the initial 900 miniplugs were present after two months and even showed some evidence of rhizome increase, they completely disappeared by the end of August, three months after transplanting. Sand grains, visibly transported in the strong tidal currents (0.82 knots), tended to abrade the leaves, and the umcompacted nature of the sediments (mean $\emptyset = 1.75$) allowed loosening and ultimate loss of the miniplugs. It is doubtful that even plugs with their own balls of sediments could be established successfully in such an area. In a preliminary planting (June 1974), 80 plugs were planted along the bar separating Snake Hill Channel from the flats on the north side of Sand Island.

The conditions resembled those on the east bar except for the stronger currents, which reached values of 1.3 knots (0.66 cm/sec). All traces of the plugs disappeared within two weeks.

Evaluation of Transplant Techniques

The experimental plantings clearly demonstrate the feasibility of successfully transplanting eelgrass in shallow waters. There are limits to transplanting, as shown by the failure of the bar plantings, but each of the different techniques tested is capable of establishment and extensive growth during the first four months after planting. Miniplugs are considered the best method for use in scale-up plantings. Although miniplug survival rated lower than plug survival, the ease of harvesting and handling sediment-free material far outweighs this disadvantage. This can be appreciated readily by a comparison of the transplant weights; 100 miniplugs are equivalent to about 1 kg (2.2 lb) of fresh plant material, whereas 100 plugs weigh 350 kg (770 lb).

Loss of miniplugs proved greater than loss of plugs, but losses were not so great as to require use of special anchoring or protective devices around transplants. Such methods have been used in other studies (Phillips 1974, 1976; Kelly et al 1971; Eleuterius 1975) and may improve survival, but only at the price of additional labor and time. Growth of the miniplugs exceeded that of the single shoots and after four months nearly equalled that of the plugs. The advantage, therefore, of planting plugs with a larger initial shoot number was lessened by the more rapid growth of the miniplugs over time. The treatment of transplants with the two hormone concentrations proved unproductive, and of little benefit to transplant growth and survival. The value of fertilization requires further study.

LARGE-SCALE PLANTINGS

Description of the Plantings

During late May and early June 1976, 5,061 miniplugs were harvested on the north side of Sand Island and planted approximately 20 m off shore along the east side (Figure 10). This is the part of the island built by spoil dumping in 1973, and there appears evidence of subsequent erosion and sediment loss (Figure 11). Dividing the transplants into six 100^2 plots (Figure 12, Plots A-F), we planted them at 33 cm intervals (with the exception of Plot E), so that the total area planted was 0.06 hectares (0.14 acres).

FIGURE 10 *Collecting miniplugs for planting*

Washed free of sediments, the clusters of shoots with entangled roots and rhizomes (miniplugs) are separated and stored in buckets supported by inner tubes until planting. Planting consists of manually pushing the root and rhizome portion of the miniplug into the sediments.

FIGURE 11 *Evidence of erosion and sediment loss at the planting site*

The stake supporting the survey pole was initially placed on the east side of Sand Island. After 18 months, erosion exposed approximately 45 cm (18 inches) of the stake.

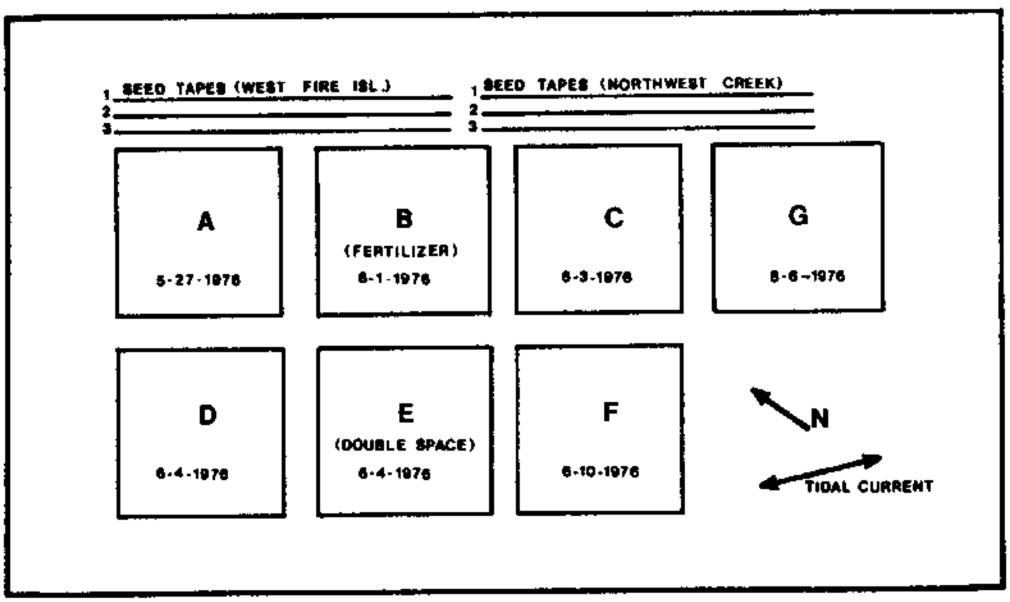

FIGURE 12 *Relative positions and planting dates of plots in the large-scale plantings (1976)*

Each plot contained 961 miniplugs, except for Plot E which had 256. The positions and relative lengths of seed tapes planted in October 1976 are also indicated.

While this is the largest number of individual transplants completed, it is not the largest area planted. Ranwell et al (1974) planted *Zostera* at 3 m (9.8 feet) intervals on 0.86 hectares (2.13 acres).

The effect of fertilization was again tested by enriching each of the transplants in Plot B with a 3g tablet of Agriform (14-4-6) at planting time. An additional plot (Figure 12--Plot G) was planted in August to examine the survival and growth of transplants completed late in the growing season.

Transplant Survival and Growth

The pattern of survival and growth in 1976 was similar to the experimental plantings of 1975. Both the number of shoots and the length of the rhizome portion of the untreated miniplugs increased, although not as markedly as in

TABLE 2 *The mean shoot number, shoot length, and rhizome length of the 1976 transplants*
The fertilized transplants and those planted in August are listed separately for comparison. The number of transplants examined in each category = n. (Standard deviations are in parentheses.)

Time of harvest	Description of transplants	Shoot number	Length (cm) Shoot	Length (cm) Rhizome
10 June 1976	Initial (n=41)	5.5(±1.9)	39.3(±14.4)	32.2(±10.4)
7 August 1976	Untreated (n=62)	6.5(±3.1)	21.9(±7.5)	47.8(±21.1)
	Fertilized(n=21)	7.0(±4.3)	19.2(±6.8)	40.7(±15.2)
	Initial August (n=11)	6.8(±3.1)	34.3(±5.4)*	48.2(±14.2)
6 October 1976	Untreated (n=44)	18.1(±6.7)	20.8(±7.8)	73.7(±29.8)
	Fertilized (n=15)	15.4(±5.9)	22.9(±3.7)	66.8(±23.7)
	August (n=15)	5.6(±3.2)	25.0(±8.2)	47.9(±23.3)

*After cropping the terminal 15 to 20 cm prior to planting.

1975 (Table 2). The average shoot length decreased as expected during the first two months, and then remained essentially unchanged into October. Transplant survival, including those fertilized, was excellent and exceeded 80% four months after planting.

Transplants completed in August, late in the growing season, did not do well. The survival rate was lower for these, and there was little indication of rhizome growth or new shoot production after two months. Furthermore, harvesting and transplanting miniplugs in August was awkward and more difficult because of the increased size of the shoots and rhizome material. These observations support the conclusions of Riner (1976) and Phillips (1976) that transplanting should be completed early in the growing season, at least when natural beds serve as a source material.

As in the preceding year, fertilization did not significantly enhance the number or length of the shoots and rhizomes. The fertilized miniplugs did not appear any more robust than the untreated plants. This failure of fertilization to promote growth is disappointing, particularly because of the dramatic results sometimes observed after enriching dune and salt marsh plants (Woodhouse and Hanes 1966; Garbisch et al 1975).

Possibly the amount of fertilizer added was simply too small to produce a marked effect on growth, although it was applied directly to the roots. Garbisch (1976), for example, recommends top dressing *Spartina* transplants with 1 oz. of Osmocote 19-6-12, which is equivalent to 5.3 g of nitrogen, a value more than 10 times that added in this study (0.49 g N/transplant). Further studies with increased doses of fertilizer are needed before I can make a recommendation on the value of nutrient enrichment.

TABLE 3 *Sediment elevation in relation to mean low water (MLW) level.* The number of stations surveyed = n.

Area	26 May 1976 (cm)	7 October 1976 (cm)	Net change
With grass (n=15)	-59.7	-52.7	+7.0
Without grass (n=30)	-50.2	-44.1	+6.1

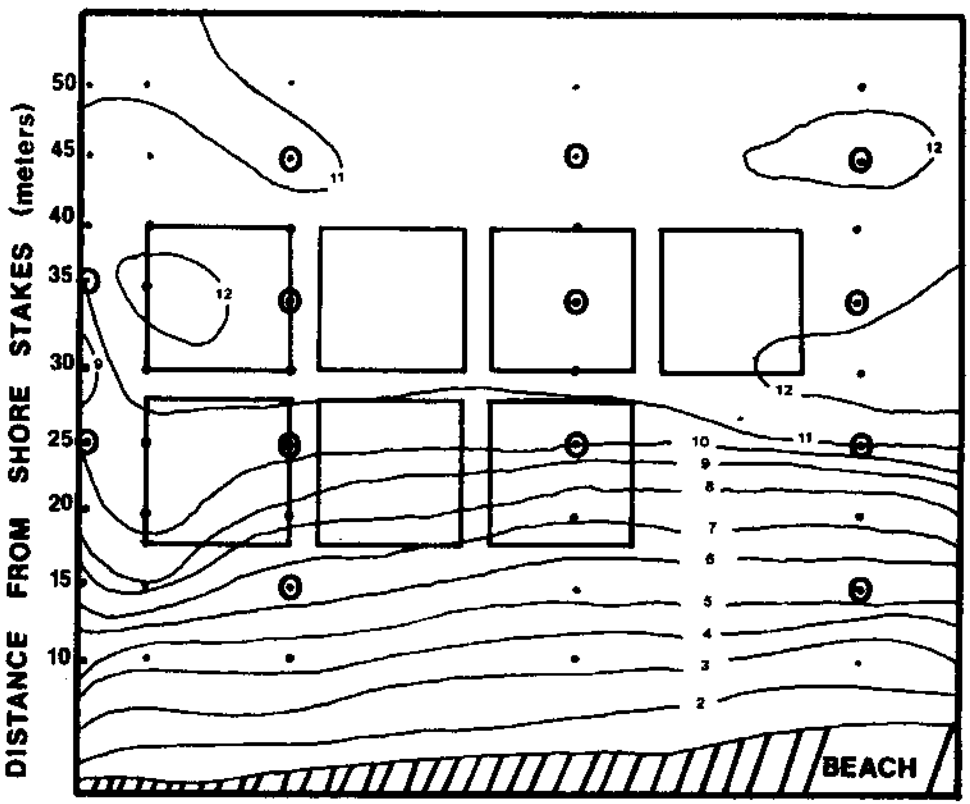

FIGURE 13 *Contour map of the large-scale plantings*

Each contour line represents an interval of 6.1 cm (0.2 feet). Small dots indicate the survey stations, and circles represent the locations of sediment core samples.

Impact of Transplants on the Sediments

Two methods were used to evaluate the impact of transplants on the sediments. First, elevations of the sediments in and around the plant area were recorded at the time of planting and again at the end of four months. Sediments within a seagrass bed typically are elevated with respect to surrounding barren areas because of increased deposition and substrate stabilization by the roots and rhizomes (Burrell and Schubel 1977). Secondly, we determined the granulometric properties of the sediments before and after planting. Sediments in eelgrass are generally finer than surrounding sediments without grass. This is because the grass slows the water movement and thus reduces its sediment carrying capacity.

At the time of planting the area was relatively uniform in depth. There were no marked changes in elevation except for a gently increasing shallowness in those plots closest to the beach (Figure 13). The average depth within the grass plots was 59.7 cm (23.5 inches) below mean low water (MLW), with the mean elevation of the surrounding sediments at 50.2 cm (19.7 inches) below MLW (Table 3).

Between May and October, the incoming tidal currents, which varied from 0.5 to 0.7 knots over the planting area, transported material in a northeastern flow across the shallow flats. This resulted in a mean sediment accumulation of 6.3 cm (2.5 inches) at all survey stations. The stations with grass showed a larger accretion than those without grass (Table 3), but the difference was small and close to the limits of the survey equipment. Transplants can tolerate a deposition of 7 cm (2.7 inches), but it was disappointing that we did not observe a greater difference between the planted and unplanted areas. I suspect that the stabilizing effects of the transplants will be more evident during the winter when erosion and net sediment loss are heavier.

A change in the granulometric properties of the sediments (Table 4) accompanied the accumulation of sediment material. There was a tendency for the mean and median grain sizes to decrease (increased Ø values) with a concomitant reduction in the uniformity (increased sorting values) of the sediments. As mentioned earlier, such changes are expected generally in areas where seagrass vegetation is establishing itself. In this study, however, they occurred at stations both with and without grass, and therefore do not reflect an exclusive effect of the plants.

TABLE 4. *Properties of the sediments before and after planting*

The values of mean and median grain size are in phi (Ø) units, which are convertible to millimeters using the following relation: [illegible] size (mm) = [illegible]. The symbols in parentheses identify the specific [illegible] according to Folk (1968). The number of cores used = n.

	Depth within the core (cm)	26 May 1976 with grass (n=4)	26 May 1976 without grass (n=9)	2 October 1976 with grass (n=4)	2 October 1976 without grass (n=9)	Net change with grass	Net change without grass
MEAN (M_z)	0-2	1.57	1.59	1.92	1.91	+0.35	+0.32
	2-4	1.44	1.65	1.64	1.75	+0.20	+0.10
	4-8	1.84	1.71	1.77	1.73	+0.06	+0.02
	8-20	1.92	1.82	1.80	1.82	+0.12	+0.07
Median (M_d)	0-2	1.58	1.59	1.84	1.96	+0.26	+0.37
	2-4	1.66	1.64	1.79	1.74	+0.13	+0.10
	4-8	1.83	1.71	1.78	1.71	+0.05	+0.00
	8-20	1.95	1.75	1.77	1.85	+0.18	+0.10
Sorting (σ_I)	0-2	0.76	0.65	0.89	0.73	+0.13	+0.08
	2-4	0.66	0.64	0.78	0.67	+0.12	+0.03
	4-8	0.70	0.69	0.76	0.66	+0.06	-0.03
	8-20	0.71	0.75	0.76	0.74	+0.05	-0.01
Skewness (SK_I)	0-2	-0.08	-0.05	+0.14	-0.02	+0.23	+0.02
	2-4	-0.10	-0.08	+0.08	0.00	+0.18	+0.08
	4-8	-0.10	-0.07	+0.09	+0.05	+0.19	+0.12
	8-20	-0.09	-0.07	0.00	-0.02	+0.09	+0.05

Again, as in the results of elevation changes, I believe that the natural sedimentation processes which typically accompany the relatively calm summer weather have overshadowed the impact of the transplants. The contrast between the planted and unplanted areas will become more marked during the winter or after the second growing season, when plant density has increased.

Skewness is a relatively sensitive measure of changes in the finest and coarsest sediment particles of a sample. There was a significant difference in skewness values between areas with and without grass for the uppermost 2 cm of sediment. Such changes are often obscured and unnoticed in the determination of mean and median particle sizes. The net change in skewness of +0.23 for grass areas as opposed to +0.02 for areas without vegetation indicates that the plants have been effective in extracting and trapping small quantities of fine suspended particles.

Cost Analysis

Cost estimates have been projected for planting an area of 0.41 hectares (1 acre) based on the time and labor used in the 1976 plantings (Table 5). There are two important assumptions in the projected values: first, that the plantings are restricted to shallow waters (less than 1.2m, or 4 feet); second, that the source of the transplants is within approximately 1 mile of the transplant site, thereby minimizing transportation costs.

TABLE 5 *Transplant statistics and projected costs*

Projected statistics are for planting 0.41 hectares (1 acre) with different spacing between transplants.

	Transplant statistics				Cost ($)			
	Time (man-hr)	Transplant spacing (m)	Number of transplants	Area (hectares)	Labor[1]	Boat[2]	Other[3]	Total
1976 plantings	190	0.3 & 0.6	5,061	0.06	-	-	-	-
Projected plantings	1655	0.3	44,100	0.41	8,275	4,300	200	12,775
	414	0.6	11,025	0.41	2,070	1,100	200	3,370
	189	1.0	5,041	0.41	945	500	200	1,645

1. Based on wages of $5/hour
2. Based on boat cost of $100/day
3. Includes shovels, buckets, ropes, etc.

The projected costs vary from $1,645 to $12,775 and depend primarily on the number of transplants and the spacing adopted. The excessive cost of using a 0.3m (1 foot) spacing makes it impractical although it was primarily used in this project. Growth and survival of double-spaced transplants (66 cm, or 2 feet) were equivalent to the more crowded planting. I believe the resulting cost reduction outweighs the advantage of an initially larger plant density.

The cost of the double-spaced plantings is similar to that of transplanting the marsh grass *Spartina alterniflora,* a method used increasingly by private and governmental agencies to stabilize intertidal sediments. The minimum price for potted *Spartina* seedlings, for example, is $.025 per pot when purchased from Environmental Concern Inc. (Garbisch 1976), and would cost $2,756 exclusive of labor if used to plant 0.41 hectares (1 acre) with double-spacing. The cost of planting with a 1.0 m spacing is the lowest, but also represents the smallest initial plant density. We therefore recommend double-spacing as the most satisfactory compromise between cost and the expected time required to develop a stabilizing plant cover.

SEEDING

General Considerations

This study investigates the potential of using *Zostera* seeds as a means of planting eelgrass. At first glance, the use of seeds would seem an obvious answer to some of the problems, particularly those of time and energy required in transplanting eelgrass.

Seeding, however, is not without its own problems. Populations of eelgrass with abundant flowering plants must be located; methods of harvesting and threshing the seeds are required; and techniques for implanting the seeds within the sediments with minimal loss must be available.

The greatest handicap, at least at the start of this project, was the lack of available information about the biology of eelgrass seeds. This included the time of seed formation, the period of seed release, and seed abundance. These considerations were so fundamental to using seeds for planting that we spent considerable time investigating them.

Flower and Seed Production

Eelgrass flowers abundantly in the shallow waters of Long Island. The flowering plants are observable from April until mid-July, by which time seed release is completed. Only the lower portions of the flowering shoots remain. The flowers are small, unisexual, and surrounded by leaflike spathes. Varying numbers of male and female flowers occur within the same spathe, but always in a ratio of approximately two females to one male (Figure 14).

A plant may produce 200 female flowers, each consisting of a single pistil within which one seed develops. At maturity, the seeds are small, elliptical (3mm X 1mm, or 1/12 inch X 1/25 inch), and vary in color from dark brown to grey. The average number of pistils per plant depends on the

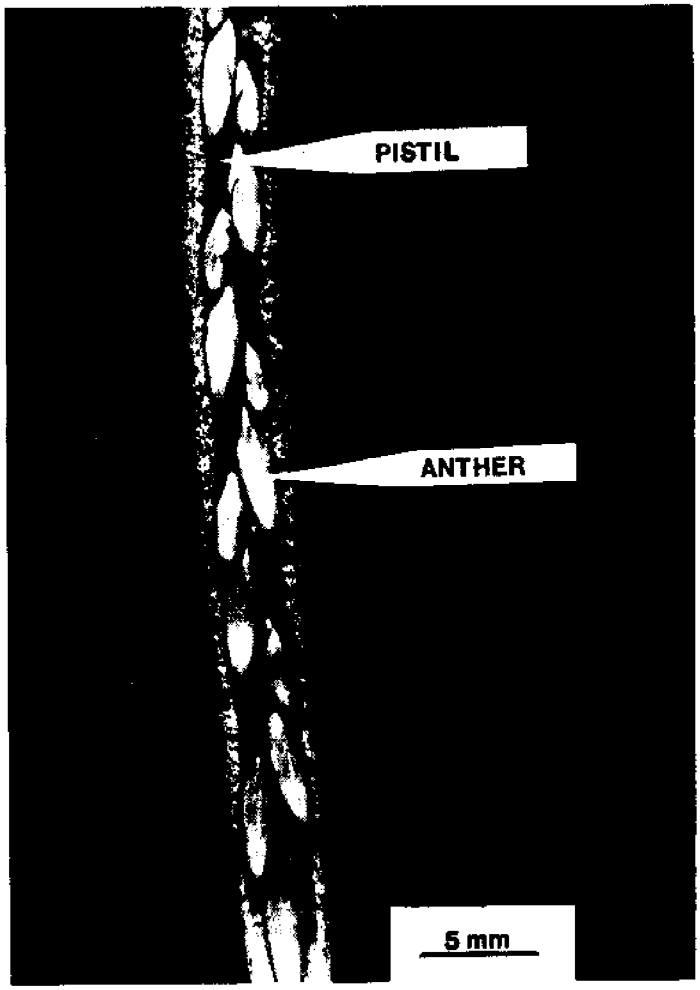

FIGURE 14 *Male and female flowers of eelgrass*

This spathe from a flowering plant reveals the male (anthers) and female (pistils) flowers. While both are ready for pollination, pollen release is delayed to assure cross-pollination.

TABLE 6 *The number of female flowers (pistils) produced by flowering shoots at different locations on Long Island*

Each pistil has the potential to produce one seed. Pistils which remained undeveloped were distinguished by their small size. All values are based on an examination of 30 plants from each location. (Standard deviations are in parentheses.)

Location and date of collection	Length of flowering shoots (cm)	Number of pistils per plant		
		Total	Fertile	Aborted
Moriches Bay 14 June 1976	29 (±9)	61 (±37)	50 (±10)	10 (±7)
Northwest Creek 14 June 1976	53 (±6)	114 (±35)	94 (±25)	20 (±10)
Jessups Neck 14 June 1976	39 (±7)	77 (±31)	66 (±35)	10 (±5)
Montauk Lake 20 June 1976	34 (±14)	59 (±27)	47 (±17)	12 (±7)
West Fire Island 8 June 1976	21 (±6)	51 (±20)	41 (±17)	9 (±6)

specific location as indicated in Table 6. The reason for the variation in pistil number is unknown, but may be related to water depth.

The factors controlling floral shoot development and flower initiation remain unknown. At West Fire Island (Figure 1), approximately 6-9% of the shoots flower each year. These are recognizable as early as January (after microscopical examination), nearly four months before pollination. Anthesis, the opening of the flowers with subsequent pollination, seems strongly influenced by water temperature. It did not occur in either 1975 or 1976 until the water temperature had increased to 15°C (59°F).

Seed development from the time of pollination until seed release took approximately four weeks. All seeds, however, did not mature at the same time, since new flowers were constantly produced from mid-May until the third week in June. The shedding of seeds and the concomitant deterioration of the flowering shoots occurred continuously from mid-June until the first week in July (Table 7). This is the critical time for harvesting seeds, which I believe is best done while they are still present on the flowering plants.

Within this critical three-week period, however, I recommend that efforts to collect seeds be concentrated between the second and third weeks or in Long Island waters, approximately between June 26 and July 2. Although there are more seeds per plant during the first week, they are mostly immature or not viable. By the end of the third week, the plants have deteriorated to such an extent that they are hard to find and contain few seeds.

TABLE 7 *The decrease of female flowers (pistils) during the period of seed release*

Each pistil on the flowering plants contains a single seed and deteriorates after seed release.

Time of plant harvest	Number of pistils per plant	Cumulative loss (%)
3 June 1975	48	0
17 June 1975	44	8
23 June 1975	33	30
1 July 1975	14	70
9 July 1975	5	89

Seed Tape Production and Planting

A seed tape which can be placed intact beneath the sediment surface was designed to minimize the loss of seeds during planting. On 28 October 1976, six 20-meter (65 feet) strips of seed tape were planted on the east side of Sand Island (Figure 11). These tapes were lost during the course of the winter, so I can provide no data on seed germination and seedling growth. I believe the method, however, is of sufficient interest to warrant description.

The tape was manufactured in the laboratory using a toy called Knit Magic (Mattel Inc.) which produced a knitted tube from a single spool of cotton thread. As the machine knit the tape, seeds grasped by forceps were held above the unit and washed into the weblike weave of the tape by a gentle stream of seawater (Figure 15).

FIGURE 15 *Charging the seed tape made by the Knit Magic unit with seeds*

FIGURE 16 *Spool-winding the seed tape during production*

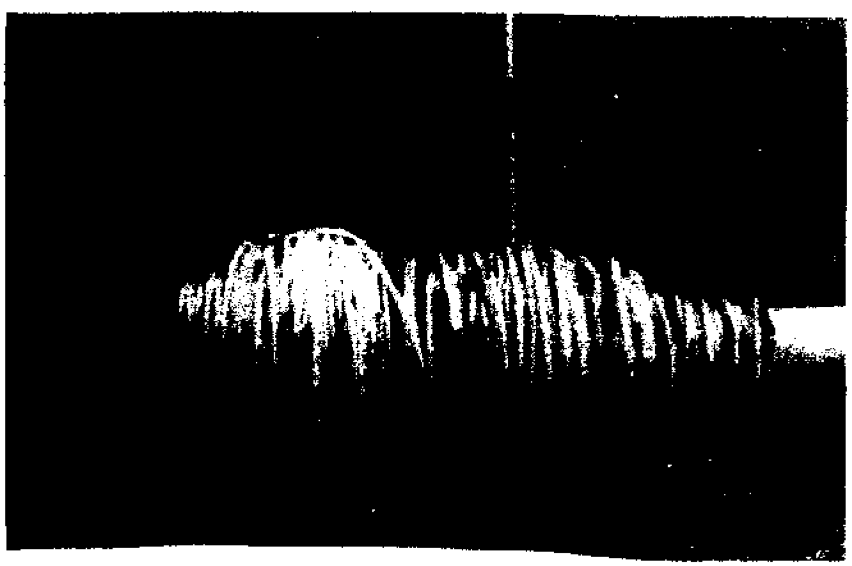

FIGURE 17 *Seed tape with entrapped seeds*

The regularity of grabbing and washing the seeds from the forceps determined the number and spacing of the seeds. In three separate 20-meter (65 feet) sections of tape, this number varied from 400 to 600 seeds, yielding a mean of one seed per 3.5 cm (1.3 inches) of tape. The end product resembled a spool of string with periodic bulges indicating the position of the seeds (Figures 16 and 17).

Tape knitting was hastened by coupling the handle to a motor drive which turned the machine at approximately 10 revolutions per second and yielded about 1 m (3.2 feet) of tape per minute. A motor-driven spool continuously gathered the tape during production. The result was a small but constant tension on the tape during its manufacture. This tension was important, for it allowed the tape to tighten and twist on itself while winding on the spool, thus preventing the seeds from falling through the weave.

The seeds for the tape were gathered by hand-harvesting the flowering shoots, grinding the shoots briefly in a Waring blender, and then separating the seeds from the debris by washing and screening them with clean seawater. This method's rapidity outweighs the unavoidable loss and injury of seeds (between 15 and 20%) during the grinding process. Other seed preparation methods, such as removing them individually or allowing natural release to occur from plants floating in large aquaria, were either time-consuming or did not work.

After grinding, most seeds were still confined within the walls of the pistils. The final washing contained mature and immature seeds in approximately the same proportion as present on the flowering shoots.

By using a modified hand plow (Figure 18), the tapes were deposited several centimeters below the sediment surface. A crossbar was attached to hold and allow free turning of the tape spool. A metal tube was bolted to the plow frame so that one end was positioned behind but at the same level as the lower cutting edge of the plow.

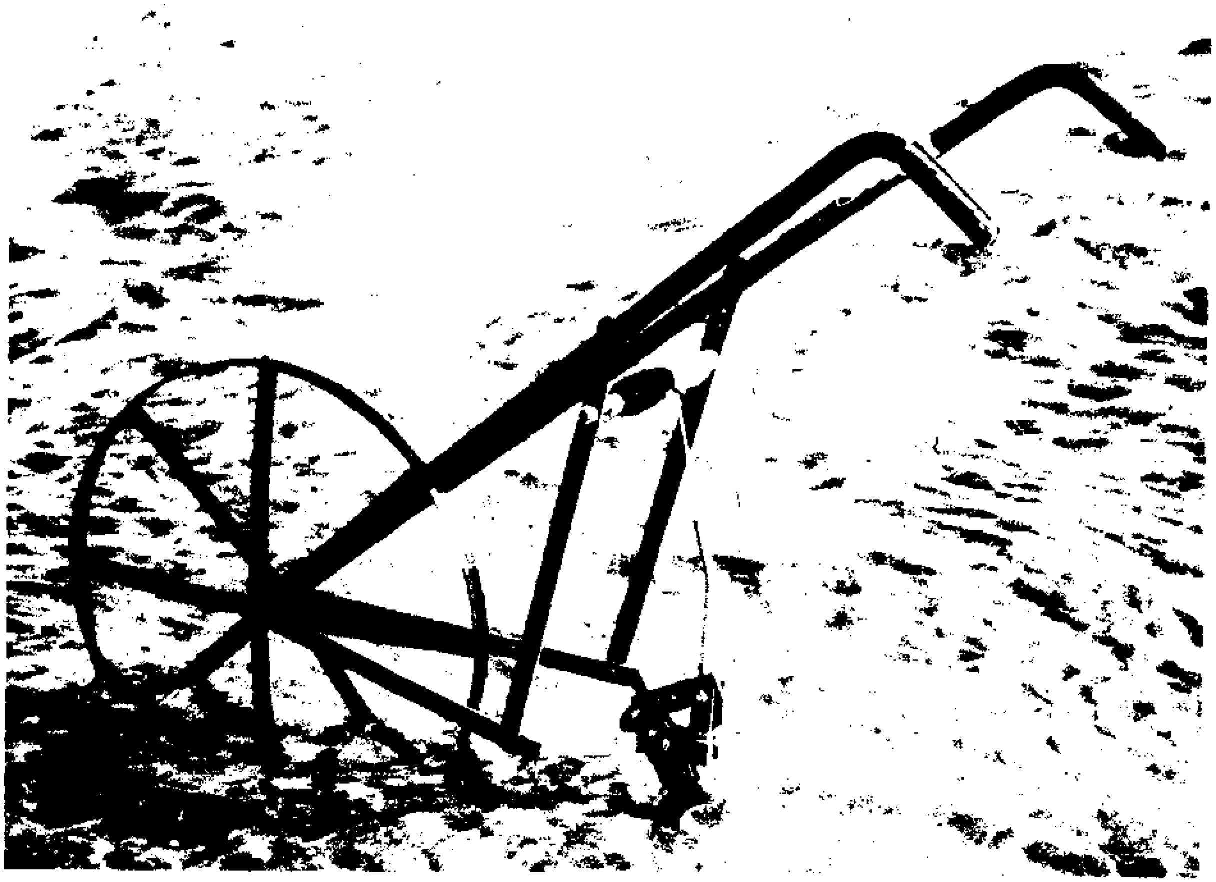

FIGURE 18 *Hand plow used in planting seed tapes*
Tapes are deposited close to the rear cutting edge of the plow.

Before planting, the free end of the tape was threaded through the metal tube and secured in the sediments by a stake. The tape unwound as the plow was pushed in a straight line and was deposited 2 to 4 cm (approximately 0.8 to 1.5 inches) below the sediment surface. While the plow would have pushed aside the sediments on land, leaving a marked trough (Figure 19), they back-filled naturally under water so only a slight depression remained after planting. The speed of tape planting depended on how fast the plow was

FIGURE 19 *Testing the tape planter on dry sediments*

pushed. In 1 m (3.2 feet) of water, this was approximately 20 m (64 feet) per minute.

Evaluation of Seeding

The potential of seeding as a means of transplanting eelgrass requires further study. It certainly represents an alternative method when water depths are too great for the manual planting of shoots, although Eleuterius (1975) solved this problem in part by attaching shoots to heavy metal screens and dropping them from the side of a boat. Seeding also has been used as a successful alternative for sea grasses where vegetative growth is unreliable, as for *Thalassia* (Thorhaug 1974, 1976).

One of the biggest and most unexpected problems of using *Zostera* seeds, however, is the ability to collect large quantities of viable seeds. This was unexpected because eelgrass may produce over 100 seeds per plant. But only a fraction of these are mature and present on the plant at any one time. Furthermore, the germination of those seeds which are present is low, seldom exceeding 30%.

Garbisch (1976) recommended planting 10 viable seeds of the marsh *Spartina alterniflora* per square foot of sediment, which is equivalent to approximately 430,000 seeds per 0.41 hectares (1 acre). I estimate that to collect this many viable eelgrass seeds would require 368 man-hours to harvest the plants alone, at least in New York waters. Separating the seeds from the plants would require a similar number of man-hours unless a large-scale threshing mechanism were designed.

Seeding, therefore, does not necessarily involve less labor than miniplug planting, and in shallow waters may well be a more costly means of establishing eelgrass. But in deeper waters (> 122 cm, or 4 feet) where manual planting is difficult, seeding may represent the only practical means of transplantation. Seed tapes, such as designed in this study, provide a potential method for such deep-water planting.

CONCLUSIONS

1. Eelgrass (*Zostera marina*) may be successfully transplanted onto sandy dredge spoil in shallow waters. Successful transplantation, however, is unlikely in areas where water currents exceed 0.82 knots (0.42 m/sec).

2. Survival and growth of transplants depend on their initial size. Plugs with an average shoot number of 19 and an intact ball of sediments have a better survival rate than mini-plugs, which consist of four to six shoots and sediment-free roots and rhizomes. The production of new shoots by the mini-plugs after four months, however, is nearly equal to that of the plugs. Single shoot transplants have the poorest survival rate, and the amount of new growth is less than that of the miniplugs.

3. Miniplugs are recommended as the best method of transplantation. Survival after four months exceeds 80%. The amount of rhizome material and the number of shoots increase by factors of two and three, respectively. Anchoring devices are unnecessary, and the sediment-free nature of the miniplugs permits easy handling and transportation.

4. Treatment of transplants with the rooting hormone napthaleneacetic acid is unproductive and not recommended for improving survival and growth. The effect of fertilization requires further study. The addition of 0.49 g nitrogen per transplant has little effect, but higher doses should be tested.

5. Transplanting should be completed early in the growing season, or in New York waters during April and May. August plantings show little evidence of growth during the first two months and their chances of survival are reduced.

6. Using the recommended spacing of 66 cm (2 feet) between transplants, the planting of 0.41 hectares (1 acre) may be completed at a projected cost of $3,370.

7. Seeding represents an alternative method of establishing eelgrass, particularly in deeper water where hand planting is impractical. Seed planting, however, must be accomplished with a minimum of seed loss. Germination is poor and the continuous process of ripening and release over a period of three weeks reduced the availability of mature seeds.

8. Efforts to collect seeds in New York waters should be concentrated approximately between June 26 and July 2.

9. A seed tape provides a means of minimizing seed loss and implanting seeds several centimeters beneath the sediment surface.

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