Evaluation of a New Method of Restoring a Salt Marsh by Channelization of a Highway Spoil Barren

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A bare coastal Georgian spoil area located in a smooth cordgrass (*Spartina alterniflora* Loisel.) salt marsh was channelized by using an amphibious rotary ditcher to evaluate its use in marsh restoration. The method has been found to offer an inexpensive and rapid, yet safe, technique of wetland mitigation in salt marshes that exhibit the proper hydrological and elevational characteristics. Amphibious rotary ditching has been found to have less of an impact on the marsh than excavation, which usually requires large earth-moving equipment, earth mats, site access, and traffic control. The surcharge is dispersed evenly to either side of the ditcher onto the marsh; thus, an upland disposal site is not required. In this case, the impact from the rotary ditcher's tracks and sidecast material to the existing salt marsh communities surrounding the spoil was temporary. Recovery and even enhancement of existing *S. alterniflora* communities has been rapid. Compared with an unchannelized (reference) spoil area, the marsh restoration channel has increased tidal frequency, duration, and flushing during ebb tide. In spite of drought, *S. alterniflora* coverage on the channelized spoil zone more than doubled over the first 2 years after the construction of the channel. Remote sensing using aerial photography has revealed a 42 percent decrease in unvegetated area on the channelized site.

The value of wetlands is now known and appreciated (*1*). In 1973 it was estimated that the total life support value per acre of salt marsh equaled $83,000 [income-capitalization value per acre at an interest rate of 5 percent (*2*)]. In 1986 it was estimated that fish production and waste assimilation values of wetlands were $10,333 and $6,225 per acre, respectively (*3*).

With the addition of two lanes to Torras Causeway, which connects St. Simons Island to the mainland in Glynn County, Ga., filling of some of the adjacent salt marsh could not be avoided. To mitigate this wetland loss, the U.S. Army Corps of Engineers and the reviewing agencies recommended (a) restoration of the spoil sites paralleling the causeway to smooth cordgrass (*Spartina alterniflora* Loisel.) marsh, (b) retention and modification of some of the existing bridges for fishing piers with access, and (c) construction of a paved bicycle path parallel to the causeway. *S. alterniflora* has been used extensively on the East Coast to stabilize intertidal spoil disposal sites (*4*).

The most widely accepted method in the past of stimulating marsh restoration was removal of a sufficient amount of spoil from the surface of a disposal site to reduce elevations and increase the frequency of tidal inundation. Recent investigations suggest that, in addition to tidal frequency and duration, the retention time of standing water after a high-tide cycle can influence the productivity of a salt marsh (*5*). Standing water can reduce the availability of oxygen to plant roots and rhizomes, but, even more devastating, it may increase soil salinities as a result of evaporation. This investigation explores the use of a different restoration technique to achieve an increase in the frequency of tidal flooding and a decrease in the retention time after a high-tide cycle.

In both Glynn and Chatham counties on the coast of Georgia, the Mosquito Control Department has employed an innovative method of ditching mosquito breeding areas. This method entails the use of an amphibious rotary ditcher that is able to simultaneously traverse and ditch areas of unstable substrates such as salt marshes. Depending on the composition of the substrate and the speed and design of the rotary ditcher, depths of 3 to 4 ft can be achieved with a single pass. Over several years of using this method of mosquito control, the Mosquito Control Department in both counties noted not only a reduction in mosquitos in recently ditched sites but, in some instances, an enhanced growth of salt marsh vegetation along and adjacent to the ditches (J. Carter, personal communication, 1985). Investigation of the potential of amphibious rotary ditching in salt marsh restoration had not been fully explored before this study. The investigation was designed to address the following questions:

1. Has channelization increased tidal frequency and duration?
2. Is channelization able to promote and maintain *Spartina*?
3. Will channelization provide additional growth and habitat diversity to the existing short *Spartina* found on the spoil fringe area and the marsh restoration channel (MRC) connectors?

SITE DESCRIPTION

Located on the coast of Georgia in Glynn County (Figure 1), the mitigation site parallels Torras Causeway, which connects St. Simons Island to the mainland at Brunswick. During construction of the original causeway in 1950, spoil from the

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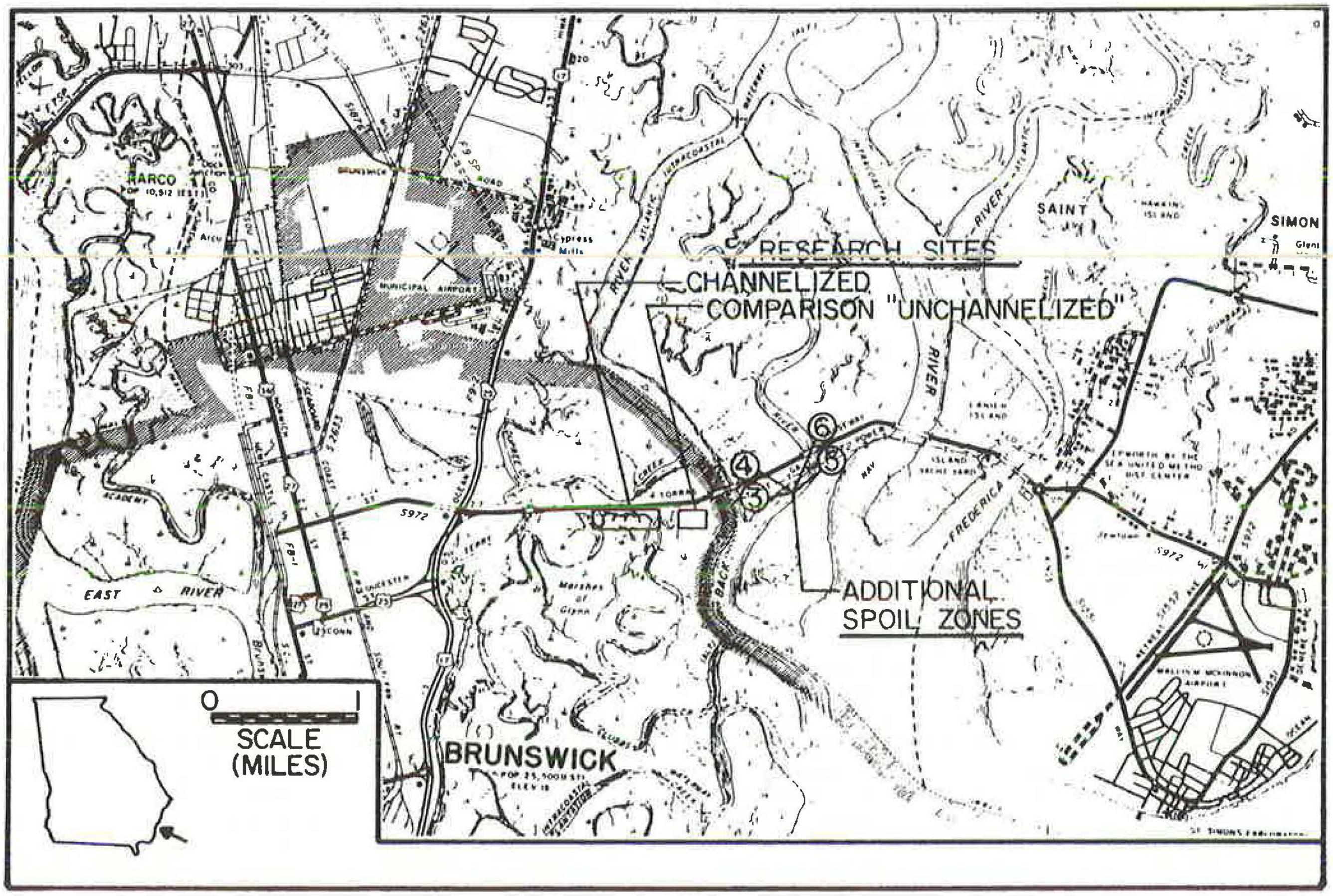


FIGURE 1 Project location (Torras Causeway, Glynn County, Georgia).

demucking process of the future roadbed was surcharged on the salt marsh adjacent to the highway. The spoil elevated the marsh and had an adverse effect on the smooth cordgrass (*S. alterniflora*) communities. *S. alterniflora* is the most frequent plant species in the salt marshes of Georgia (*6*). Because of the elevated condition, normal patterns of tidal frequency and duration of the spoil areas were interrupted, and the marsh was not able to regain its previous state of productivity. Salinity, tidal inundation, soil type and drainage, and competition by other species influence plant distribution within salt marshes (*7*). The resulting salt pans or salt barrens (*6*) have persisted for years, and soil salinities have become elevated evidently because of evaporation of standing water from an occasional spring high tide. Six spoil areas have been identified adjacent to the causeway and will require restoration as part of the mitigation (Figure 1).

MATERIALS AND SAMPLING METHODS

Channelization of the MRC began on August 28, 1985, but because of equipment failure, ditching was not completed until October 10, 1985. Approximately 1.5 km (0.93 mi) of channelization was completed, which included the main MRC (approximately 2,800 ft long); secondary MRCs (approximately 100 ft long); and the east, west, and intermediate connectors to the natural tidal creeks (Figures 2 and 3). Mean channel dimensions immediately after channelization ranged from 1.28 to 1.43 m (4.2 to 4.7 ft) wide and 0.7 to 0.79 m (2.3 to 2.6 ft) deep. The majority of the side-cast material was discharged 4 to 5 m from the rotary ditcher to either side of the MRC.

MRC Geomorphology

The MRC was monitored at predetermined stations for changes in width and depth due to erosion and deposition. Width and depth measurements were made to the nearest centimeter by using standard wooden meter sticks. The MRC width was measured from edge to edge of the MRC banks, and the depth was measured at the center while using an additional meter stick positioned level with the MRC edges.

MRC erosion-deposition stations were grouped for analysis on the basis of station location, soil composition, and presence or absence of vegetation. Additional categories included stations that received rhizomatous damage from the rotary ditcher during channelization and the mouths of the east and west connectors and the secondary MRCs.

Permanent Quadrats

A total of 16 permanent quadrats (PQ) were installed after channelization was completed. Twelve quadrats (PQ-0, PQ-00, PQ-1 through PQ-10) were located on the channelized

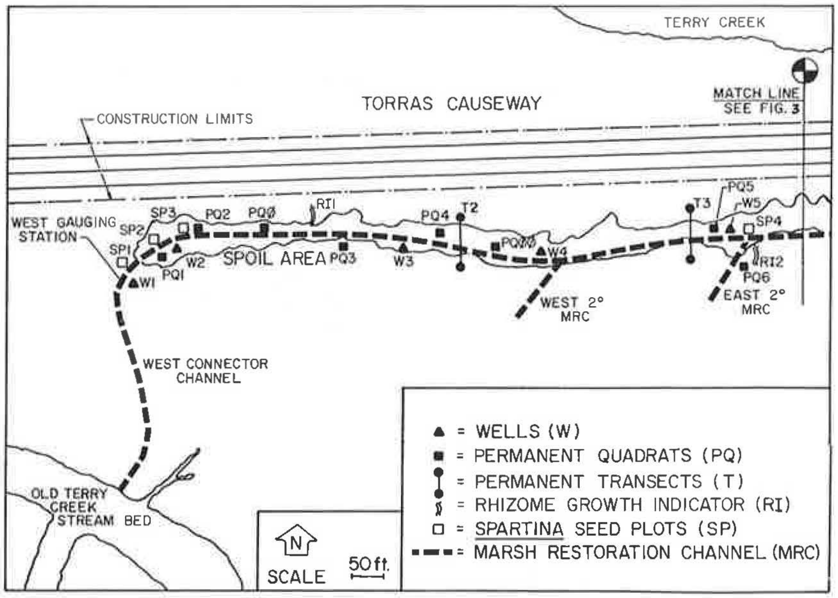


FIGURE 2. Channelized site (mitigation site 1): west connector.

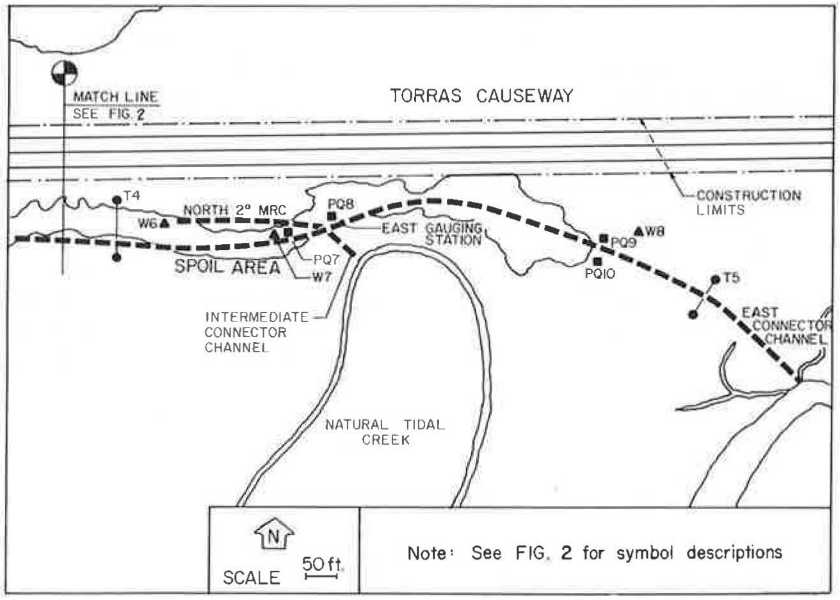


FIGURE 3 Channelized site (mitigation site 1): east and intermediate connectors.

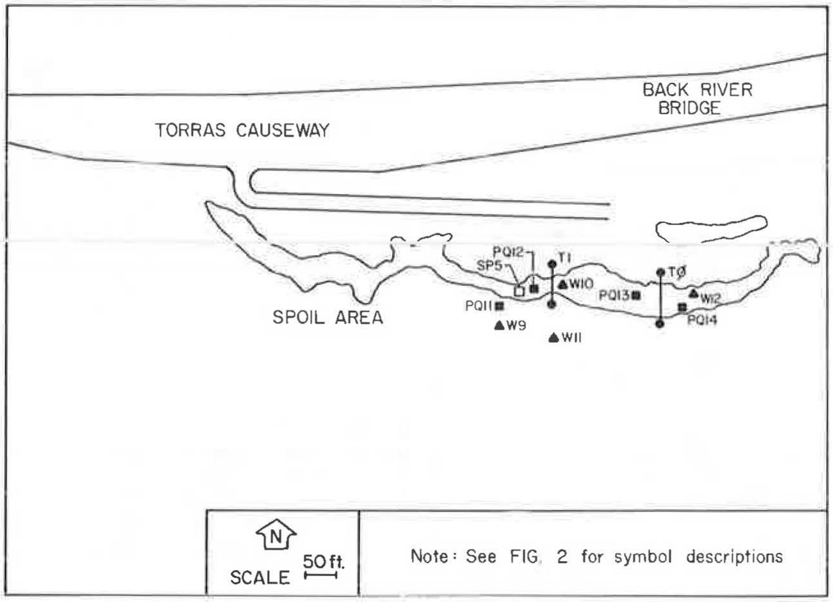
research site and four quadrats (PQ-11 through PQ-14) were located on the unchannelized research site. The quadrat location was permanently marked by installing a 0.5-in.-diameter schedule 40 polyvinyl chloride (PVC) pipe that was approximately 4 ft long. A 1-m^2 quadrat frame was positioned with the permanent PVC marker in the southwest corner of the frame. The quadrat frame was assembled from precut 0.5-in.-diameter schedule 40 PVC pipe and 90° elbows.

Rhizomatous Growth Indicator Plots

Two rhizomatous growth indicator plots were permanently positioned April 10, 1986, on the channelized research site. Wood stakes and surveyor's flagging were used to create a line of demarcation between *S. alterniflora* vegetation and unvegetated spoil. Any growth that obviously resulted from rhizomatous mitigation across the line of demarcation was noted during subsequent sampling excursions. Plant taxa, numbers, and heights were measured and logged.

Random Quadrats

Random quadrat sampling was conducted in the fall of 1986 and 1987. In fall 1986, random quadrat sampling was initiated on October 18 and was completed on October 19 and November 4. All random quadrat sampling was completed on Octo-



Note: See FIG. 2 for symbol descriptions

FIGURE 4 Unchannelized comparison site (mitigation site 2).

ber 31 during the fall 1987 period. The protocol of Kibby et al. (*8*) was followed for analysis of the random quadrats. A 0.2-m^2 quadrat was constructed from 0.5-in.-diameter schedule 40 PVC pipe and 0.5-in.-diameter schedule 40 PVC 90° elbows. Fiddler crab burrows were counted within each quadrat before vegetation was harvested. The vegetation was snipped at ground level, put into a plastic bag, and placed on wet ice for laboratory analysis. Before weighing, plant height measurements were logged. Live and dead plants of each species were weighed separately by using a trip balance. The observed wet plant weights were converted to dry weights by using conversion factors reported by Kibby et al. (*8*).

Remote Sensing

Remote sensing by aerial photography supplied by the Georgia Department of Transportation was conducted to plot changes in the unvegetated surface area of the spoil zone. The causeway was flown over and photographed on May 5, 1984 (17 months before channelization), April 23, 1987 (18 months after channelization), and December 19, 1987 (25 months after channelization). An outline of the unvegetated surface was transferred manually to tracing paper. A Hewlett-Packard computer digitizer was used to determine the unvegetated surface area. The computer was programmed to digitize to the nearest one-thousandth of a square mile. The scales on the photography were estimated from measuring the causeway width.

Hydrology

A high-tide hydrological study was conducted on October 30, 1987. The time of arrival of sheet flow onto the comparison site was noted (Figure 4). Flow velocity, width, and depth were measured at three places in the MRC: the west connector, the east connector, and the intermediate connector (Figures 2 and 3). Flow measurements were made over a high-tide cycle at 10-minute intervals by standard stream gauging equipment. The measurement procedure outlined by Buchanan and Somers (*9*) was followed for flow data acquisition and discharge determination. Modified from Buchanan and Somers, the formula

$$Q(f) \text{ or } Q(e) = \text{sum}[(a)(v)(k)]$$

represents the computation where $Q(f)$ and $Q(e)$ are the total discharge in cubic feet per second (CFS) during flood and ebb, respectively, a is an individual cross-section area, and v is the corresponding mean velocity of the flow normal to the cross-section area. The constant (k) is the conversion factor from CFS to the interval between measurements. The constant k assumes that the flow increased or decreased at a constant rate.

RESULTS

MRC Geomorphology

Figures 5–7 compare arithmetic mean width and depth values of the MRC in vegetated muck (along the west connector) with unvegetated spoil. In Figure 5, ratios of mean width to depth (*W:D*) are plotted to illustrate an overall indication of erosion or deposition of the MRC, or both. An increase in the ratio can occur as a result of an increase in MRC width, a decrease in MRC depth (indicates deposition), or both. Between October 1985 and April 1987, mean *W:D* increased significantly in the spoil zone in unvegetated areas. A comparison of Figures 6 and 7 shows that the initial instability of the west connector MRC (vegetated muck) was not caused by an increase in MRC width, but instead was because of a decrease in MRC depth (note sharp decrease in mean depth between September and October 1985). Dense *S. alterniflora* rhizomes are responsible for soil stability and the retention

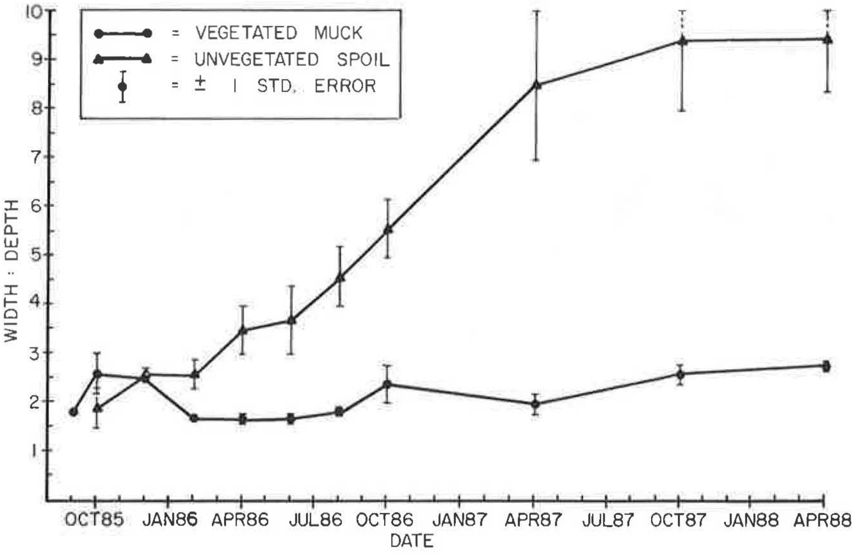


FIGURE 5 **Mean channel width-to-depth ratios in vegetated muck and unvegetated spoil.**

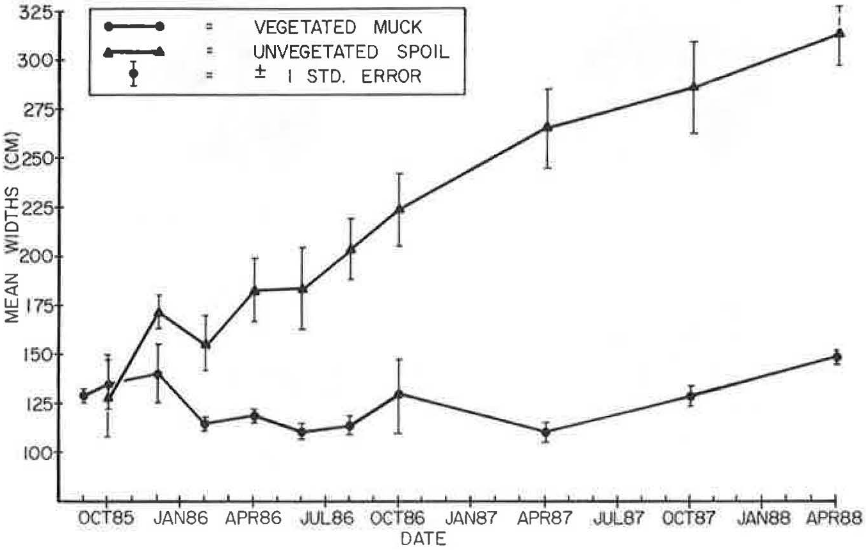


FIGURE 6 **Mean channel width in vegetated muck and unvegetated spoil.**

of the original cross-sectional profile of the west connector. With the exception of one length of channel in which the rotary ditcher damaged the rhizomes while attempting to make a sharp turn, track damage to *S. alterniflora* adjacent to the west connector occurred only aboveground during ditching.

Permanent Quadrats

Six of the eight permanent quadrats located on the channelized site that had no growth in April 1986 had *S. alterniflora* growth in December 1987. Permanent quadrats PQ-0 and PQ-00 were positioned during the April 1986 sampling period in areas beside the MRC and adjacent to short-form *S. alterniflora*. Both PQs had no visual growth in April, but in the June 1986 sampling period, just 2 months later, 29 and 4 *Spartina* plants (live and dead total) were recorded, respectively, in those PQs. By December 1986, *S. alterniflora* had increased to 27 and 57 plants in PQ-0 and PQ-00, respectively. By December 1987, *S. alterniflora* had increased to 197 and 146 in PQ-0 and PQ-00, respectively.

Rhizomatous Growth Indicator Plots

Two boundary plots were positioned April 10, 1986 to monitor the growth of *Spartina* resulting from rhizomatous migration. There was no growth on one side of the boundary line in April, but by June 21, 1986, 18 and 21 plants were observed across the east and west boundary plots, respectively. By August 19, 1986, the plants had increased in number to 60 and 49 plants in the east and west plots, respectively. By

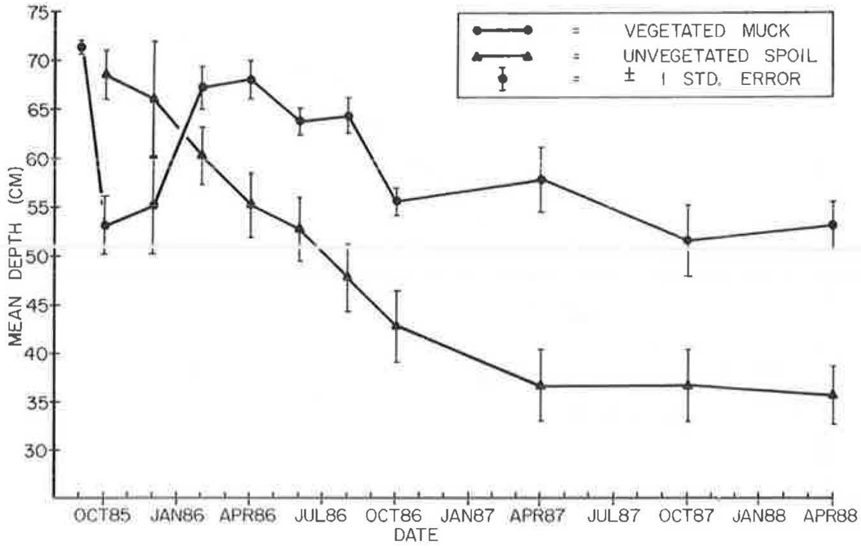


FIGURE 7 Mean channel depth in vegetated muck and unvegetated spoil.

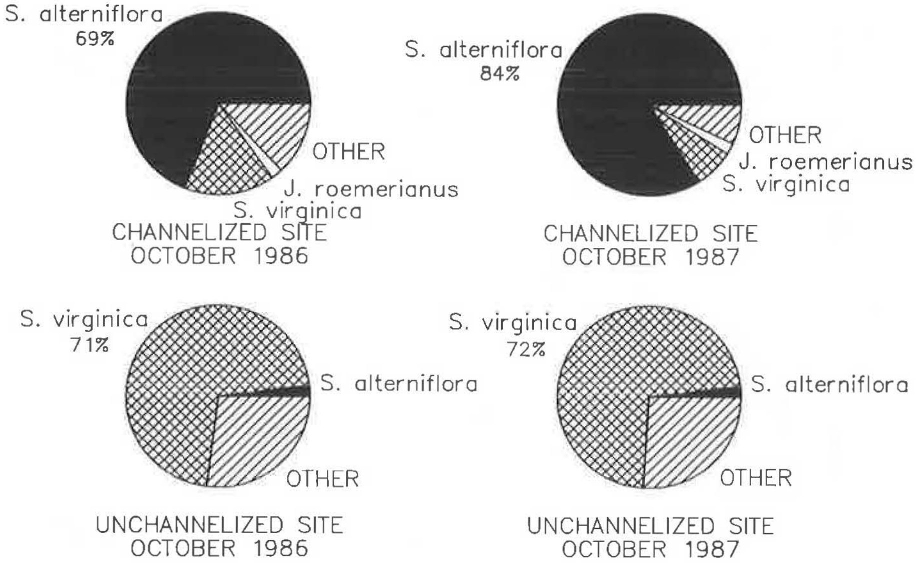


FIGURE 8 Relative plant abundance (by weight) from random quadrat sampling.

October, *Spartina* had further increased in numbers to 138 and 114 plants in the east and west boundary plots, respectively. Average height in the east plot increased from 21.7 to 22.0 to 29.9 cm during the three sample periods. Average height in the west plot increased from 14.2 to 16.0 to 22.3 cm during the three sample periods. All new growth in both plots was monospecific *S. alterniflora*.

Random Quadrats

Random quadrat sampling was conducted between October 1986 and October 1987 for net primary productivity (NPP) and estimated end-of-season total (EOST; above-ground live and dead). EOST for *S. alterniflora* more than doubled (factor of 2.4) over the entire channelized spoil zone between October 1986 and October 1987. As a consequence, bare ground surface area was reduced by a factor of 0.5 over the same period. Parallel increases were observed in fiddler crab burrow count (factor of 2.4) and *S. alterniflora* seed head production (factor of 1.8). Relative abundance (by weight) of *S. alterniflora* increased from 69 percent in October 1986 to 84 percent in October 1987 (Figure 8). However, relative abundance of *S. virginica* decreased from 16 percent to 7 percent during the same period.

In contrast, unvegetated surface area on the comparison site increased by a factor of 3.3 between October 1986 and October 1987. In addition, no improvement in *S. alterniflora* seed head production was observed. Relative abundance of *S. alterniflora*, *S. virginica*, and *B. maritima* remained essentially unchanged.

Spatial variation in the rate of restoration was observed

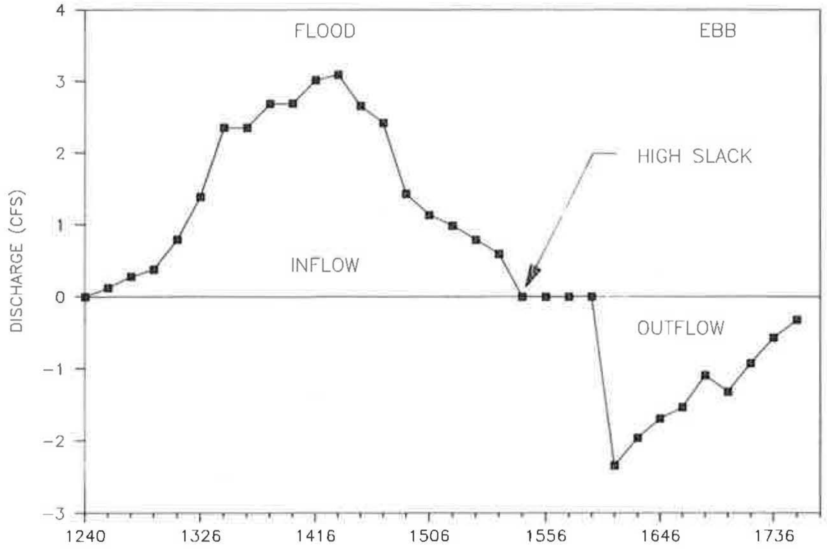


FIGURE 9 Tide cycle hydrograph from the west connector gauging station on October 30, 1987.

between the east and west sections of the channelized site. Causeway station 61 + 50 was the approximate center of the spoil zone. *S. alterniflora* on the west section (< 61 + 50) increased by a factor of 3.4 between October 1986 and October 1987. *S. alterniflora* on the east section (> 61 + 50) increased by a factor of 2.6 during the same time period.

Remote Sensing

A comparison of aerial photographs from May 1984, April 1987, and December 1987 revealed a reduction in unvegetated surface area on the channelized site. Between May 1984 and April 1987, a 25.2 percent decrease in unvegetated surface area was noted. Also, a comparison of photographs from May 1984 and December 1987 revealed a 42.1 percent decrease in unvegetated surface area. In contrast, a 57.0 percent increase in unvegetated surface area was measured between May 1984 and December 1987 on the unchannelized comparison site.

Hydrology

General

The channelized spoil zone was surveyed for elevations on August 19, 1985. The elevations varied along the bare spoil zone from 3.56 to 4.11 ft above mean sea level (MSL). Reported tides at the mouth of Frederica River range from 7.2 ft (mean) to 8.4 ft (spring) above mean low sea level [MLW (*10*)]. Based on an MSL elevation of 3.6 ft at the mouth of Frederica River and an elevation range of 3.56 to 4.11 ft above MSL, a tide of 7.16 to 7.71 ft above MLW was required to flood the spoil zone.

The following results are based on the hydrologic study of October 30, 1987. Even though the volume of estuarine water displaced in the MRC will vary according to different tidal cycles based on tidal amplitude, wind speed, and wind direction, the October 1987 study represents the general flow patterns during a typical high-tide cycle. The predicted tidal amplitude during the study was 7.3 ft (above MLW) which is only 0.1 ft higher than the average tidal amplitude of 7.2 ft reported at the mouth of Frederica River.

West Connector

Between 12:40 and 15:36, approximately 109,000 gal of seawater during flood tide flowed past the west connector gauging site to the spoil site (Figure 9). At approximately 13:56, the water left the banks of the MRC at the gauging station and flooded the adjacent marsh; thus the volume of seawater measured between 13:56 and 15:36 is a conservative estimation of the actual volume available. The flood tide continued until high slack occurred at the gauging site at 15:46. Between 15:56 and 16:06, seawater was observed to flow out the MRC, but the flow in the MRC was too slow to measure. From 16:26 to 17:46, 53,000 gal of seawater was measured until the flow in the MRC was reduced at 17:46 to 2 in. deep by 0.25 ft wide and was too low to measure accurately.

East and Intermediate Connectors

The east end of the spoil zone represents a much more complicated hydrologic regime. Between 12:24 and 15:15, approximately 155,000 gallons of seawater flowed during flood tide past the east connector gauging site onto the spoil zone (Figure 10). During this period, only 8,000 gal of seawater was introduced through the intermediate connector from the natural tidal meander adjacent to the east connector (Figure 11). However, 31,000 gal of seawater was lost during flood tide out the intermediate connector for a net loss of 23,000 gal from the MRC into the natural tidal meander. The direction of flow in the intermediate connector changed twice during the flood tide: from northwest (into the MRC) to southeast (into the natural tidal meander) to northwest again. High slack tide occurred at 15:25 at the east gauging sites.

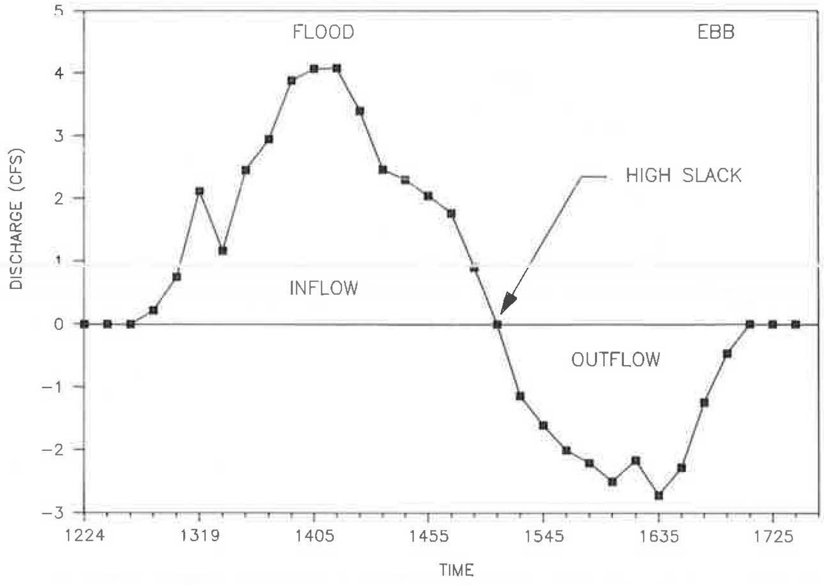


FIGURE 10 Tide cycle hydrograph from the east connector gauging station on October 30, 1987.

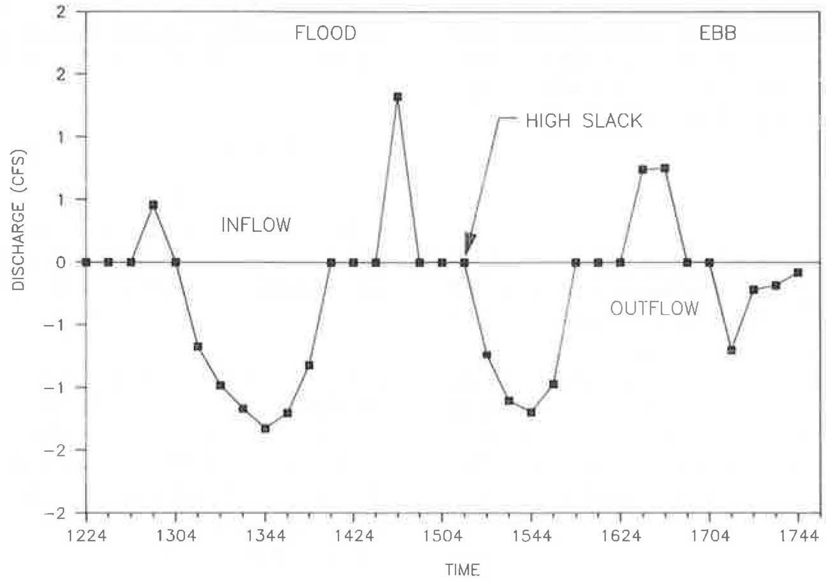


FIGURE 11 Tide cycle hydrograph from the intermediate connector gauging station on October 30, 1987.

During ebb tide, approximately 82,000 and 27,000 gal of seawater left the spoil zone via the east and intermediate connectors, respectively. Flow patterns in the intermediate connector during the ebb tide were observed to be just the opposite as were noted during the flood tide: from southeast to northwest to southeast.

Tidal asymmetry was noted in both the west and east gauging stations with tidal discharge (in CFS) during flood being greater than ebb. Pethick (*11*) reported that flood velocities on average in a natural tidal creek were 30 percent higher than those on the ebb.

Comparison Site

Aboveground estuarine water reached the comparison site approximately 2 hours later (14:40) than the MRC gauging sites. Even though interstitial flow is possible, estuarine water was not observed in any of the four sample wells located on the comparison site until the wells were filled from the aboveground flow. Bayliss-Smith et al. (*12*) reported that on upper marshes the majority of tides are below-marsh. When an infrequent over-marsh tide does occur on the comparison site, estuarine water has been observed to remain on the surface of the comparison site and in the sample wells between high tides.

DISCUSSION OF RESULTS

Analysis of permanent quadrat data, rhizomatous growth indicator plots, random quadrat data, and remote sensing has indicated that the MRC was successful in stimulating *S. alterniflora* growth, *S. alterniflora* seed-head production, and fiddler crab activity on the spoil site. The MRC not only increased tidal frequency and duration, it also reduced standing water and improved soil drainage after tidal cycles. Soil drainage has been found to be important in reducing soil anaerobiosis and increasing redox potential resulting in increasing *S. alterniflora* productivity (*13*). Also, soil flushing and drainage are essential in reducing free sulfides and salts (*14*), which can concentrate in toxic amounts causing plant mortality.

The amphibious rotary ditcher caused only temporary damage to existing soils and vegetation. Recovery of *S. alterniflora* that was damaged below ground was slow, but *S. alterniflora* that suffered only stem damage recovered rapidly. However, regardless of the degree of damage, enhanced growth of *S. alterniflora* adjacent to the MRC and damaged by the tracks was eventually evident. Also, no permanent damage from the side-cast material from the amphibious rotary ditcher was observed. Side-cast material could have even contributed to the enhancement of *S. alterniflora* growth to either side of the MRC. Based on random quadrat data, the estimated end-of-season total growth of *S. alterniflora* more than doubled in 1 year.

A parallel increase in fiddler crab activity, as measured by the number of burrows, was also observed. Burrowing was observed on the bare areas on the channelized site before *S. alterniflora* colonization occurred. It is hypothesized that burrowing may be responsible for "conditioning" the soil before revegetation occurs. Katz (*15*) found that a population of the fiddler crab, *Uca pugnax*, can turn over approximately 18 percent of the upper 15 cm of sediment in a salt marsh. Katz also noted that burrowing increased the surface area of the marsh by 59 percent. Also, Allen and Curran (*16*) noted that burrowing resulted in a great deal of bioturbation. Montague (*17*) reported that fiddler crab burrows improve the growth of *S. alterniflora* by an average of 25 percent. The resulting increases in soil turnover, surface area, and bioturbation act to decrease subsurface anaerobiosis and improve the rate of redissolution, resuspension, and export of concentrated salts and sulfides, which may inhibit growth of *S. alterniflora*.

As compared with the unchannelized site, the MRC not only increased tidal frequency and duration, but also reduced standing water and improved soil drainage after tidal cycles. Even though the comparison site is located closer to the Back River (Figure 1), aboveground estuarine water reached the comparison site approximately 2 hours later than estuarine water reached the channelized site. In addition, standing water and water in sampling wells were observed on the comparison site long after the high-tide cycle.

Soil drainage has been found to be important in reducing soil anaerobiosis and increasing the redox potential that results in increased *S. alterniflora* productivity (*13*). Also, soil flushing and drainage are essential to reducing free sulfides and salts (*14*) which can concentrate to toxic amounts, causing a reduction in plant productivity or even mortality.

No hydrologic impact to adjacent natural tidal meanders from estuarine water entering or leaving the MRC via the east connector is suspected. The high-tide study addressed the closest natural tidal meander that could be affected hydrologically by the MRC (see Figure 3 at the intermediate connector). Stream capture by the MRC during ebb tide is not suspected.

The degree of erodability along the edges of the MRC depended on the soil composition, the degree of exposure to run-off, and the presence or absence of vegetation. For instance, the unvegetated sandy spoil located closest to the causeway was much more susceptible to erosion than the vegetated muck located on the west connector. Little or no bank erosion, as indicated by the MRC width measurements, was observed in muck stabilized with *S. alterniflora*. The extensive *S. alterniflora* root and rhizomatous mass on the west connector was responsible for the reduction of soil erodability and the retention of the original MRC morphology. During the first 3 months after channelization (October through December 1985), some sediment export was observed in the west connector. By January 1986, the mean channel depth of the west connector had nearly returned to its original depth profile. The MRC geomorphological data from the October 1987 sampling period may indicate a reduction in the rate of erosion-deposition in both the unvegetated spoil zone and the vegetated muck areas. New *S. alterniflora* growth within and adjacent to the MRC on the spoil zone is probably contributing to the reduction in the rate of erosion.

The unchannelized, comparison site remained visually unchanged with a reduction in *S. alterniflora* growth and vitality within the spoil zone. Interstitial salinity was observed to be significantly higher on the unchannelized site than on the channelized site. Growth of *S. alterniflora* is inversely related to the interstitial salinity of the soil (*18*). Sea salts were apparent on the unvegetated, comparison site causing crusty surface conditions and restricting growth to only salt-tolerant plants, such as *S. virginica*, along the fringe of the spoil zone. Even a reduction of salt-tolerant plants was observed on the comparison site during the summer and fall of 1986. The drought of 1986 probably contributed to the mortality. In contrast, an increase in growth and seed-head formation of *Spartina* on the channelized site was recorded during the same drought.

The following design considerations are recommended for future use of amphibious rotary ditching in salt marsh restoration:

1. Survey the potential restoration site for elevations.
2. Coordinate ditching with periods of low tidal amplitude (preferably neap tides during solstice) and growing seasons to allow for channel settling and stabilization and reduction of sediment export.
3. Make use of the best combination of rotor speed, rotor depth, and track speed of the ditcher to reduce subsurface damage to existing vegetation. Use only experienced equipment operators.
4. Before staking the channel path on site, mark the path on aerial photographs to determine the route of least impact to existing plant and animal communities.

5. Map ditcher access to the site and to each channel starting position to reduce superficial aboveground damage.
6. When possible, limit ditching to sandy substrates and avoid soft muck.
7. Connect the channel to the largest supply of estuarine water and the most direct route to the ocean.
8. Introduce meanders into the channel where possible.
9. Have personnel experienced in the use of rotary ditching in salt marsh restoration on-site to supervise channelization.
10. Establish a monitoring program after channelization. Have personnel with a background in wetland ecology monitor and report on the success or failure of the project.

Although the technique has certain limits, the use of rotary ditching as a method to obtain salt marsh creation and restoration has potential. The degree of success depends on elevation, tidal amplitude, access to natural tidal streams, and the soil type(s) of the area to be restored. Areas that are above the mean high water during spring tides (MHWS) probably would have only a limited rate of success when rotary ditching is used alone. When elevations are above the MHWS, the use of a combination of rotary ditching with excavation probably would have the best results. First, the elevation of the restoration site could be reduced by excavation. Next, the restoration site could be connected to a tidal stream(s) by channelization with rotary ditching, which would reduce the impact to existing salt marsh communities. Channelization would ensure proper flushing and drainage of the site into the tidal stream(s) and reduce the potential for mosquito breeding, anaerobiosis, and concentration of free sulfides and soluble salts in toxic amounts.

In addition to salt marsh restoration, amphibious rotary ditching has potential in the restoration of inland freshwater systems. However, this area needs further investigation.

ACKNOWLEDGMENTS

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