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NOAA COASTAL OCEAN PROGRAM
Decision Analysis Series No. 2

TECHNOLOGY AND SUCCESS IN RESTORATION, CREATION, AND ENHANCEMENT OF *SPARTINA ALTERNIFLORA* MARSHES IN THE UNITED STATES

Volume 1 -- Executive Summary and Annotated Bibliography

Geoffrey A. Matthews
Thomas J. Minello

August 1994

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Coastal Ocean Office

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Note to Readers

The NOAA Coastal Ocean Program (COP) provides a focal point through which the agency, together with other organizations with responsibilities for the coastal environment and its resources, can make significant strides toward finding solutions to critical problems. By working together toward these solutions, we can ensure the sustainability of these coastal resources and allow for compatible economic development that will enhance the well-being of the Nation now and in future generations. The goals of the program parallel those of the NOAA Strategic Plan for 1995-2005.

A specific objective of COP is to provide the highest quality scientific information to coastal managers in time for critical decision making and in a format useful for these decisions. To help achieve this, COP inaugurated a program of developing documents that would synthesize information on issues that were of high priority to coastal managers. To develop such documents, a three-step process was used: 1) to compile a list of critical topics in the coastal ocean through a survey of coastal resource managers and to prioritze and select those suitable for the document series through the use of a panel of multidisciplinary technical experts; 2) to solicit proposals to do research on these topics and select principal investigators through a rigorous peer-review process; and 3) to develop peer-reviewed documents based on the winning proposals.

Seven topics and associated principal investigators were selected in the initial round. *Technology and Success in Restoration, Creation, and Enhancement of Spartina alterniflora Marshes in the United States* by Geoffrey A. Matthews and Thomas J. Minello of the NOAA National Marine Fisheries Service's Galveston Laboratory is the second document in this Decision Analysis Series to be published and is presented in two volumes. Information on Decision Analysis Series No. 1 is shown on the inside back cover. Other volumes will be published over the next two years on the following topics: seagrass restoration technology, coastal watershed restoration, restoring streams and anadromous fish habitat affected by logging, eutrophication and phytoplankton blooms, and management of cumulative coastal environmental impacts.

As with all of its products, COP is very interested in ascertaining the utility of the Decision Analysis Series particularly in regard to its application to the management decision process. Therefore, we encourage you to write, fax, call, or Internet us with your comments. Please be assured that we will appreciate these comments, either positive or negative, and that they will help us direct our future efforts. Our address and telephone and fax numbers are on the inside front cover. My Internet address is DSCAVIA@HQ.NOAA.GOV.

Donald Scavia
Director
NOAA Coastal Ocean Program

VOLUME 1

EXECUTIVE SUMMARY

SECTION I-- ANNOTATED BIBLIOGRAPHY OF SELECTED LITERATURE ON RESTORATION, CREATION, AND ENHANCEMENT OF *SPARTINA ALTERNIFLORA* MARSHES IN THE UNITED STATES

Technology and Success in Restoration, Creation, and Enhancement of *Spartina alterniflora* Marshes in the United States

EXECUTIVE SUMMARY

Introduction

Extensive losses of coastal wetlands in the United States caused by sea-level rise, land subsidence, erosion, and coastal development have increased interest in the creation of salt marshes within estuaries. Smooth cordgrass *Spartina alterniflora* is the species utilized most for salt marsh creation and restoration throughout the Atlantic and Gulf coasts of the U.S., while *S. foliosa* and *Salicornia virginica* are often used in California. Salt marshes have many valuable functions such as protecting shorelines from erosion, stabilizing deposits of dredged material, dampening flood effects, trapping water-born sediments, serving as nutrient reservoirs, acting as tertiary water treatment systems to rid coastal waters of contaminants, serving as nurseries for many juvenile fish and shellfish species, and serving as habitat for various wildlife species (Kusler and Kentula 1989). The establishment of vegetation in itself is generally sufficient to provide the functions of erosion control, substrate stabilization, and sediment trapping. The development of other salt marsh functions, however, is more difficult to assess. For example, natural estuarine salt marshes support a wide variety of fish and shellfish, and the abundance of coastal marshes has been correlated with fisheries landings (Turner 1977, Boesch and Turner 1984). Marshes function for aquatic species by providing breeding areas, refuges from predation, and rich feeding grounds (Zimmerman and Minello 1984, Boesch and Turner 1984, Kneib 1984, 1987, Minello and Zimmerman 1991). However, the relative value of created marshes versus that of natural marshes for estuarine animals has been questioned (Cammen 1976, Race and Christie 1982, Broome 1989, Pacific Estuarine Research Laboratory 1990, LaSalle et al. 1991, Minello and Zimmerman 1992, Zedler 1993). Restoration of all salt marsh functions is necessary to prevent habitat creation and restoration activities from having a negative impact on coastal ecosystems.

This project was undertaken to provide resource managers, habitat researchers, coastal planners, and the general public with an assessment of the technology and success in restoration, enhancement, and creation of salt marshes in the United States. The objective was to be accomplished through the development of three products: 1) an annotated bibliography of the pertinent literature, 2) an inventory of restored, enhanced, or created *Spartina alterniflora* marshes, and 3) a directory of people working in salt marsh creation and restoration. This executive summary describes these products and provides an overall assessment of our understanding regarding restoration, enhancement, and creation of salt marsh habitats. In particular, we have stressed *Spartina alterniflora* marshes and habitat functions related to the support of fishes, crustaceans, and other aquatic life.

Products

Section I. An Annotated Bibliography of Selected Literature on Restoration, Creation, and Enhancement of *Spartina alterniflora* Marshes in the United States.

What was included. This annotated bibliography summarizes the literature on created *Spartina alterniflora* salt marshes, particularly for the last decade. Literature on planting techniques and the establishment of vegetation is included, along with assessments of habitat value and functional equivalency. Publications that involve other species of *Spartina* such as *S. foliosa* have been included if they discuss marsh functions. A particular effort was made to include all studies involving nutrients, sediment organics, infaunal populations, and utilization of created *Spartina* marshes by aquatic and fisheries species.

The annotations were written to assist in determining whether a paper is pertinent to one's needs. Annotations were much like abstracts or summaries, but also included some interpretation on our part, particularly for articles that discussed the use of created salt marshes by fishery or related aquatic organisms.

Articles and project reports were requested from everyone we identified working in the field of salt marsh creation and restoration or conducting functional comparisons of created and natural marshes. Scientific literature was searched using Current Contents.

Lists of reports from various organizations and agencies were searched for articles concerning coastal marsh restoration activities. Articles were also obtained from proceedings of symposia on wetlands restorations, particularly those sponsored each spring by Hillsborough Community College in Florida, and those published by the Association of State Wetland Managers.

Endnote Plus, a computer reference program (Niles and Associates, Inc. Berkeley, CA), was used to create the directory. Entries are in alphabetical order according to the first author's last name. The directory is available in hard copy or as an electronic data file in Endnote Plus, Pro-Cite, Refer/BibIX, and text formats.

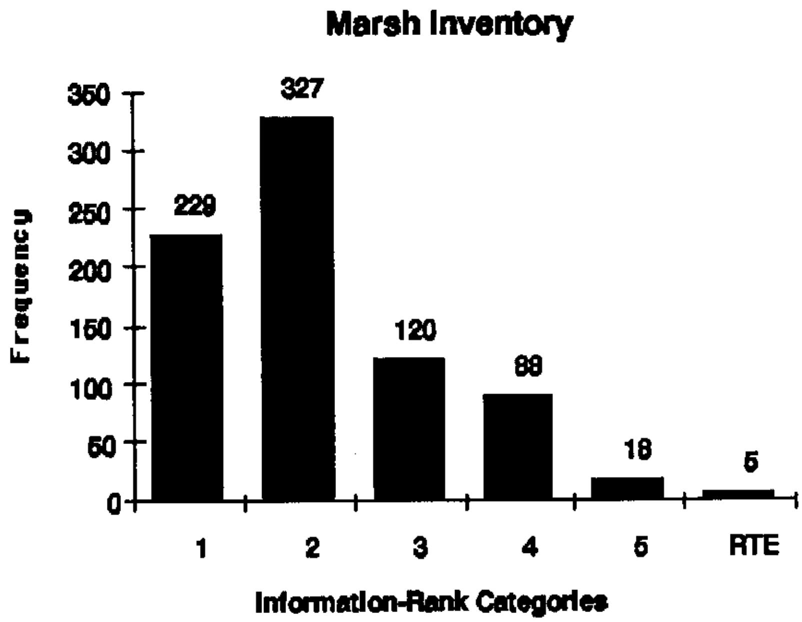
Limitations. A natural limitation of this annotated bibliography is that some important articles may have been missed, and new articles will have been published before the bibliography is printed. A few entries were included although their subject matter was tangential to the main focus. This distraction was considered more desirable than excluding the articles, because the entries showed some of the directions that salt marsh restoration activities were heading. Very few entries include quantitative comparisons of faunal utilization in created and natural salt marshes. This paucity of published research limits our ability to assess whether created marshes have attained functional equivalence; fortunately such studies are increasing in number.

Potential Benefits. This bibliography provides a comprehensive collation of literature on coastal salt marsh restoration, enhancement, and creation activities in the U.S. Although the focus was on evaluation of created salt marshes, the bibliography also covers construction techniques, mitigation requirements, sources of information about regional requirements of salt marshes, nutrient requirements and nutrient pools, and even a few articles on regional management practices for coastal zones. Thus, the bibliography should serve anyone looking for documentation on various aspects of coastal salt marsh restoration and coastal-zone wetlands restoration research needs.

Section II. An Inventory of Restored, Created and Enhanced *Spartina alterniflora* Marshes in the United States.

Development. This database contains information about restored, enhanced and created salt marshes in the coastal U.S. and was created using Microsoft Excel. Available data on location, planting techniques, and success of each marsh was entered via 20 variables. A total of 787 marshes was located and entered in the database over our 1-year study period. Each marsh was assigned a unique inventory number and was also ranked in relation to the amount of available information on the marsh. These information rankings included 1) very little information available, a marsh was planned and permitted but may never have been constructed, 2) a marsh was planted but the location was not precisely identified, 3) a marsh was planted and the exact location is known, 4) a planted marsh was evaluated for successful establishment, 5) a marsh was successfully established and animal utilization was evaluated. The inventory also includes a few entries for marshes where no planting had been done, but restored tidal flow had allowed a marsh to develop (Information Ranking = RTE). Contractors throughout the U.S. provided information for the inventory on *Spartina alterniflora* marshes that they had designed or built. Site information on created marshes was also garnered from publications, reports, conference proceedings, and even assorted notes obtained from research ecologists working in this field. State environmental and fisheries agencies were consulted for their records about man-made salt marshes. Area and district offices of the U.S. Army Corps of Engineers (COE), Soil Conservation Service (SCS), U.S. Fish and Wildlife Service, and the Habitat Protection Branch of the National Marine Fisheries Service (NMFS) were also contacted for information about created *Spartina alterniflora* marshes in their respective coastal areas.

Limitations. The people we contacted in the field of restoration science were generally receptive toward our requests and provided available information. Frequently, however, data required to evaluate salt marsh construction and utilization by animals were never originally recorded, were incomplete, or were not readily available with a reasonable search effort. Thus, many of the marshes in the inventory have low information rankings. For example, some projects that were issued COE permits were not located, and it is unclear whether these marshes were failures or had never been constructed. In addition, we obtained some information from design or initial work plans for projects, and these plans may not have accurately described the actual planted marsh. In situations where we only suspected that a marsh had been created, the inventory entry was given an Information Rank of 1 (see frequency diagram below). For other marshes, only a general description of the marsh location was available (Information Rank 2).



(Rank categories are based on amount of information available [p.4., above], with 5 representing marshes for which the most information was available. RTE refers to marshes with restored tidal exchange.)

Information on created *Spartina alterniflora* marshes on the West Coast was not recorded. A few *Spartina alterniflora* marshes were planted in West Coast estuaries several decades ago, but this species is considered an exotic and is no longer used in that region.

Potential Benefits. Information on locations of created salt marshes is widely scattered, often making it difficult to study the progression of plant and animal populations and the functional development of these habitats. It may take many years for a created marsh to attain the functions of a natural marsh. After a few years, created marshes are often superficially identical to natural marshes, and precise location information is required to continue studying such sites for development of marsh functions. This computerized database is designed to help locate such marshes and to provide basic information about each marsh.

Despite data-collection limitations, the number of marshes in the inventory demonstrates the extent of marsh creation in the coastal areas of the United States. The inventory also demonstrates the amount of data lacking for most of these created marshes. In many cases, these data are relatively easy to record at marsh creation sites (for example the exact location of the marsh), and perhaps the existence of an inventory may stimulate better record keeping. Coastal managers should consider requiring such data records as part of the permitting process. Much of the missing data on marshes included in the inventory may be available somewhere, and we would like to solicit user's help in making the inventory as complete as possible. We anticipate updating the inventory periodically with the addition of new marshes and the inclusion of additional information on the marshes already entered.

Section III. A Directory of Human Resources Involved in the Restoration, Creation, and Enhancement of *Spartina alterniflora* Marshes.

Participants. Participation in the directory was strictly on a voluntary basis. Those included, therefore, have expressed their willingness to interact with the community of people interested in salt marsh restoration. Authors of pertinent research articles were solicited, and many notable estuarine ecologists are participating. The directory also includes staff of various federal permitting, regulatory, and research agencies including: U. S. Army Corps of Engineers, Waterways Experiment Station, National Marine Fisheries Service, U. S. Fish and Wildlife Service - National Biological Survey, and the U. S. Department of Agriculture - Soil Conservation Service. Staff of various state and municipal agencies involved in salt marsh restoration are included. In addition, the directory includes many contractors and others with hands-on knowledge of marsh design and construction. There are over 300 participants in the directory.

Directory Structure. An index lists individuals alphabetically by their last name, but the main contents are organized alphabetically by state. Individuals are listed first in each state, followed by companies and organizations. Each entry includes the person's name, firm/institute/agency, address, telephone number, FAX number, position and specialty, and a description of some of the participant's latest marsh related projects. The directory was created using Endnote Plus, and is available in hard copy or as an electronic data file in Endnote Plus, Pro-Cite, Refer/BibIX, and text formats.

Limitations. This directory is not a "complete" listing of all persons and organizations involved in preserving and restoring salt marshes and coastal wetlands. A large number of people were contacted and asked to participate. Not everyone chose to participate, and undoubtedly we failed to contact some important potential participants. The directory is dynamic and is intended to be updated periodically. We are still soliciting additional participants and updates to entries. Keywords about each individual were not included, but most reference programs can search all fields for descriptive key words; one might focus on the "specialty" or "projects" sections of each person's entry.

Potential Benefits. This directory provides a nucleus of concerned people involved in salt marsh restoration ecology. People from a variety of disciplines are included, and they can provide information about how to manage coastal salt marsh areas, how to create marshes, and how to assess whether the marshes are fulfilling their projected functions. The directory should facilitate information exchange among ecologists working in this field, lay people and managers concerned about their local estuary or marsh, coastal landowners interested in preserving their property from erosion, and companies needing assistance with habitat mitigation.

Conclusions and Recommendations

Smooth cordgrass *Spartina alterniflora* is the dominant salt marsh vegetation along shorelines of Atlantic and Gulf coasts of the United States. Techniques for seeding, planting, and transplanting *S. alterniflora* have been sufficiently developed so that the establishment of vegetation is highly likely when the prescribed conditions are met (Woodhouse 1979, Knutson et al. 1981, Webb and Newling 1985, Allen et al. 1986, Earhart and Garbisch 1983, Broome et al. 1988, Broome 1989, Nailon and Seidensticker 1991). The following key factors have been identified for successfully establishing *S. alterniflora*. 1) Young healthy plants should be used and should be obtained from as close to the planting area as possible. Plants from the project vicinity have the best chance for survival and good growth because they are adapted to the local conditions. 2) Planting should be conducted early in the growing season to provide an adequate length of time for establishment. 3) The soil must contain adequate nutrients. Graded down upland soils often need additions of fertilizer to supply sufficient nutrients, while dredged material or natural bay sediments usually have sufficient nutrients already. 4) Proper elevation

(0.2–0.5 m above Mean Low Water) at the site is critical. Reference should be made to the nearest flourishing natural marsh whenever possible. Smooth cordgrass will grow over a wider tidal range than where it grows best. Success has also been achieved when plants are placed at the higher end of the elevation range and allowed to grow into lower elevations on their own. 5) A gentle slope of 1-10% grade provides sufficient width and drainage for the marsh to develop. This slope should continue seaward from the planted area to reduce wave height and erosive forces. 6) Good water flow and tidal exchange are needed to supply nutrients and to prevent salt build-up in the sediment. 7) Protection from waves is particularly important for a new planting. The fetch should be less than 2 km; shorter fetches are required if the shoreline faces the direction of high winds during stormy weather. 8) Protection of the new plants from pests such as herbivorous fish, insects, small mammals, and man is often needed. Each marsh has a unique suite of potential pests. 9) Protection from activities on adjacent lands has become increasingly important as coastal development continues, and monitoring such activities can protect newly planted marshes from destructive abuse. Although following these nine guidelines and sound planting principles should result in the successful establishment of a *S. alterniflora* marsh, consultation with local experts will often provide technical refinements that will facilitate and insure a greater probability of success.

Above-ground biomass in created *Spartina alterniflora* marshes quickly reaches parity with natural marshes if these basic conditions for marsh establishment and survival are met (Cammen 1975, Webb et al. 1978, Seneca et al. 1985, Webb and Newling 1985, Broome et al. 1986, Broome 1989, and LaSalle et al. 1991). The presence of vegetation in itself is generally sufficient to provide the functions of erosion control, substrate stabilization, and sediment trapping (Knutson et al. 1982). The nutrient-rich sediments trapped by smooth cordgrass aid in maintaining and extending the vegetative zone for the species (Allen and Webb 1982). Apart from above-ground biomass, however, created salt marshes appear to differ from natural marshes in a number of characteristics. Created marshes generally have lower sediment organic content, below-ground biomass, densities of benthic infaunal prey organisms, and densities of nekton on the marsh surface. There is some evidence that these characteristics are linked, and that trophic support for nekton is relatively low in newly created salt marshes.

Below-ground biomass and sediment organic content appear to develop slowly in created salt marshes, and levels may take years to become comparable to natural marshes

(Cammen 1975, Webb et al. 1978, Lindau and Hossner 1981, Craft et al. 1988, Sacco 1989, Langis et al. 1991, LaSalle et al. 1991, Moy and Levin 1991, Minello and Zimmerman 1992). The origin of the sediment used to create the marsh is important, and organic content is generally lower in graded down uplands and sandy dredged material compared with fine-grained dredged material. Low initial levels usually increases the time to reach parity with natural sediments.

The density of benthic infauna such as annelid worms, insect larvae, and small crustaceans is generally lower in created marshes than in natural marshes. These prey organisms are important in supporting the food web of estuarine nekton. In Atlantic coast marshes Cammen (1976), Sacco (1989), and Moy and Levin (1991) found lower densities and generally different species composition for infaunal organisms in created salt marshes. In Texas, Minello and Zimmerman (1992) found that mean amphipod densities in transplanted marshes were only 20-40% of densities in natural marshes, and diversity of infaunal organisms was significantly lower in the transplanted marshes. Although polychaete densities in their study were not significantly different between the natural and transplanted marshes, there was some indication that the abundance of this group was related to the age of the marsh; differences from natural marshes were greatest for the youngest transplanted marsh (2 years old) and smallest for the oldest transplanted marsh (5 years old). LaSalle et al. (1991) also reported a positive relationship between the density of benthic infauna and marsh age. In most of the above studies, a positive relationship was observed between sediment organic content or macro-organic matter and the density of benthic infauna.

Quantitative sampling of nekton densities in salt marsh vegetation is difficult (Zimmerman et al. 1984, Kneib 1991, Rozas 1992), thus comparisons of surface utilization between created and natural marshes are limited. Relative abundance in pit traps or Breder traps is unreliable in making such comparisons, because the sampling area of these devices cannot be accurately defined. Minello and Zimmerman (1992) used a drop sampler to compare springtime densities in three created and three natural *S. alterniflora* marshes (3-5 years in age) on the Texas coast and found overall densities of large macrofauna and decapod crustaceans were significantly lower in the transplanted marshes. These differences were due mainly to daggerblade grass shrimp and young brown shrimp. Diversity of decapod crustaceans was also higher in the natural marshes. Densities of fish (mainly the darter goby and pinfish) as a group were not significantly different between natural and transplanted marshes. In addition, fish diversity was consistently higher in the transplanted marshes. In a larger study of ten created salt marshes (3-15 years in age) in Galveston Bay, Texas, Minello and Webb (1993) also found reduced densities of commercially important crustaceans (brown shrimp, white shrimp, and blue crabs) when the marshes were compared with five natural marshes. In North Carolina, Meyer et al. (1993) used block nets to compare densities of fishes, shrimps, and crabs in a planted and natural *Spartina alterniflora* marsh. Two years following planting, overall mean densities of shrimp (mainly daggerblade grass shrimp and brown shrimp) were about three times higher in the natural reference marsh compared with the planted marsh, but differences were not statistically significant apparently due to high sample variability. Mean crab densities were two to three times higher in the created marsh, but again the differences were not significant. Fishes collected included spot, mummichog, pinfish, and pigfish, and the mean density for total fish was twice as high in the natural marsh as in the created marshes. This difference was statistically significant during two of the three sampling periods. These conflicting results in marsh utilization patterns may be the result of different sampling gears and techniques or may reflect regional differences in the way salt marshes function for nektonic organisms. The results may also be attributable to the natural variability in populations of organisms that occur from year to year and the natural variability in carrying capacity of habitats. Until a substantial number of such quantitative comparisons are available, it will be difficult to assess functional parity between created and natural salt marsh habitats.

Understanding the functional development of created marshes requires an understanding of how natural salt marsh systems function. There is evidence, for example, that salt marshes function differently for shrimp, crabs, and fishes in different coastal regions. Direct exploitation of the marsh surface is extensive in many marshes of the northern Gulf of Mexico (Zimmerman and Minello 1984, Thomas et al. 1990, Baltz et al. 1993, Rozas and Reed 1993, Peterson and Turner 1994), thus densities of decapods and fishes and their prey on the marsh surface should reflect habitat value for marshes in this region. Direct use of the marsh surface may be lower in marshes along the Atlantic coast, and nekton densities in these marshes appear to be substantially lower than in the Gulf (Hettler 1989, Mense and Wenner 1989, Kneib 1991, Fitz and Wiegert 1991). Atlantic coast marshes have relatively less edge, higher elevations, and different tidal inundation patterns, and all of these factors may affect utilization patterns of nekton (Rozas 1993). These regional differences increase the necessity for functional studies comparing natural and transplanted salt marshes in various parts of the country.

Indications of long-term retarded functional development in created salt marshes suggest that some habitat functions may never fully develop. However, under the assumption that most created marshes can eventually develop into fully functional habitats, there has been considerable interest in methods for stimulating marsh development rates. The correlative relationships identified between sediment organic content and infaunal populations have inspired work on the addition of organic amendments to sediments before planting. This work has shown promise for increasing the rate of marsh development, but success may be related to local and regional conditions (Currin, C.; Zedler, J.; Broome, S.; personal communications). The value of increasing sediment organic matter through the addition of soil amendments may depend upon the causal relationships between infaunal abundance and the development of marsh sediments. For example, if infaunal populations increase because sediment organic matter is used as food by deposit feeders, the relative amount of refractory organic matter may be important. However, sediment organics may also alter the physical structure of the sediment improving the habitat for infauna. Thus, factors such as porosity, bulk density, size of detrital particles, and inorganic grain size distribution may be important. In addition, the oxygenation of sediments by live plant roots may be a factor in increasing infaunal abundance. Controlling development rates of marsh sediments, therefore, may be difficult without a better understanding of sediment/infaunal relationships. Other research on improving functionality of created marshes indicates that the addition of edge through the construction of channels and creeks can dramatically increase use of the marsh surface by nekton (Minello et al. 1994). The value of adding edge, however, may also be a regional phenomena, and adding edge in Atlantic coast marshes may not be beneficial. Natural salt marshes in the northern Gulf of Mexico have relatively more edge and are apparently used more extensively by aquatic animals than marshes along the Atlantic coast (Rozas 1993).

Despite a great deal of rhetoric regarding functional equivalency in created marshes, quality research on the problem has been limited. Important questions that still must be addressed center on how natural salt marshes function for fishery and aquatic species and how these functions vary regionally. Without this basic understanding of salt marsh ecosystems, comparisons of natural and created systems will continue to be limited in scope. Comparisons of natural and created marsh use by fishery species and other aquatic nekton are needed, but these comparisons must be based on quantitative samples in marsh creeks and within the vegetation itself. The use of enclosure samplers is generally required for measuring animal densities in these vegetated habitats. A variety of such devices have now been developed including throw traps and drop samplers (Kushlan 1981, Zimmerman et al. 1984), flume and block nets (McIvor and Odum 1986, Hettler 1989), and lift nets and flume weirs (Rozas 1992, Kneib 1991). Comparisons of functional equivalency in created and natural marshes may also require experimental measurements of animal growth and predation risk in these habitats.

A basic and pervasive problem in functional comparisons is a limited replication of study marshes. The development of our marsh inventory may be useful in this regard by helping to identify additional created marshes for analysis. Sound inferences concerning relative functioning of marshes require an estimate of variability among both natural marshes and created marshes. If for example, only one created marsh is examined in the study area, conclusions can only be made regarding that marsh and not created marshes in general. In a similar manner, variability among natural marshes is often great and should also be assessed. Data on spatial variability within marshes and seasonal and annual variability are also important (Zedler et al. 1986), but information on marsh to marsh variability will be most useful in assessing the overall value of created marshes compared with natural marshes.

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SECTION I

ANNOTATED BIBLIOGRAPHY OF SELECTED LITERATURE ON RESTORATION, CREATION, AND ENHANCEMENT OF *SPARTINA ALTERNIFLORA* MARSHES IN THE UNITED STATES

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Section I -- Annotated Bibliography

Foreword

Coastal development, sea level rise, and land subsidence have resulted in extensive losses of estuarine salt marsh habitat throughout much of the United States. Concomitant with this habitat loss is the loss of salt marsh functions. These functions include the stabilization of shorelines, prevention of erosion, flood control, sediment trapping, nutrient cycling, and removal of toxic wastes in watersheds. In addition, salt marshes provide valuable habitat for estuarine animals including economically important fishery species.

Efforts to implement a "no net wetland loss" policy in the United States will require a continuation and expansion of programs to restore and create salt marshes in regions of deteriorating coastal wetlands. These restoration projects frequently involve transplanting marsh vegetation on graded-down uplands or on dredged material. Although many of these efforts have failed, the establishment of vegetative growth in this manner often has been successful, and marsh planting techniques have been developed for a variety of coastal conditions.

Replacing or creating vegetative cover, however, is only the first step in creating a functional salt marsh. Habitat functions such as providing food, protection from predators, and reproductive sites for estuarine animals must also be replaced. The development of these habitat functions does not appear to parallel the growth of macrophytes, yet it is the growth of the plants that has been the usual measure of marsh creation success. This retarded functional development has raised serious questions about the relative value of created salt marshes. Few direct studies of animal growth, survival, or reproductive success have been conducted in created salt marshes. The abundance of animals in a salt marsh is generally used as an indicator of relative habitat value, although valuable habitats do not always support high densities of animals. Comparing animal abundance in natural and created salt marshes, however, is in itself a difficult problem, and the importance of collecting quantitative samples in assessing use of salt marshes by fishery and other aquatic organisms cannot be overemphasized. Sampling techniques often include the use of breeder traps, seines, trawls, or simple qualitative visual estimates. These techniques are generally not quantitative, and thus results based on their use must be weighed accordingly.

Resource managers, habitat researchers, and coastal planners need assistance in developing marsh restoration projects. The literature documenting efforts in this area is scattered and not readily available, and a synthesis of these data should be valuable for determining the most appropriate restoration and creation techniques applicable to different coastal conditions. Of special interest is an analysis of the importance of regional differences in successful restoration techniques. In addition, an assessment of whether these projects have replaced salt marsh functions is of primary importance.

This annotated bibliography is intended to summarize the literature on created *Spartina alterniflora* salt marshes. Although papers that deal with planting techniques and the establishment of the vegetation itself are included in the collection, special emphasis is placed on publications that assess habitat value and investigate the replacement of natural salt marsh functions. Some papers that involve other species of *Spartina* such as *S. foliosa* have been included in the bibliography if the papers relate to functional values. We tried to include all studies involving nutrients, sediment organics, and infaunal populations and studies that examined utilization of created *Spartina* marshes by fishery species or other aquatic or terrestrial fauna. The annotations was written to assist the reader in determining whether a paper was pertinent for their needs; annotations were not designed to substitute for reading the papers themselves. In contrast to abstracts or summaries, the annotations include some interpretation on our part. This is especially true in relation to the use of created salt marshes by fishery or related aquatic organisms. In the annotations, we have adopted the practice of abbreviating elevation references using the capitalized first letter of each word, included are: MHW for mean high water, MHT for mean high tide, MSL for mean sea level, MLT for mean low tide, MLW for mean low water, MLLW for mean lower low water, MTL for mean tide level, and NGVD for national geodetic vertical datum. These abbreviations are defined in a glossary of terms in the Tide Tables 1994 High and Low Water Predictions, East Coast of North and South America Including Greenland (DOC/NOAA/NOS, Washington, DC).

This bibliography is not totally comprehensive, rather it contains a wide selection of papers that we thought were important in advancing the science of salt marsh restoration. Undoubtedly, we have missed some significant contributions to the literature. The reader may wish to consult annotated bibliographies by Wolf et al. (1986) and by the U.S. Fish and Wildlife Service (see Miller et al. 1991); these bibliographies are much broader in scope and cover most studies involving created wetlands.

Acknowledgments

Creating this bibliography was greatly facilitated by the many scientists who kindly sent us reprints of their articles and reports of their projects, and who discussed the projects with us when possible. We are very grateful for their aid and interest. Four regional assistants helped obtain much of the gray literature reviewed here, and we thank them for their work: Chris L. Sardella (Northeast Coast), Andrew L. Bunch (South Atlantic Coast), Joseph L. Staton (Gulf of Mexico), and Russell E. DiFiori (West Coast). Thanks are also extended to Mark E. Pattillo who also reviewed articles and wrote their annotations. This work was funded by the National Marine Fisheries Service, Southeast Fisheries Science Center, and by a Resource Information Delivery grant from NOAA Coastal Ocean Program.

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Allen, H. "Biotechnical stabilization of dredged material shorelines." In: Beneficial Uses of Dredged Material, ed. M. C. Landin. 116-128. January 1988. Baltimore MD: US Army Corps of Engineers, 1988.

This review covers the efforts of the U.S. Army Corps of Engineer's Waterways Experiment Station in Vicksburg, Mississippi to develop biotechnical techniques for the stabilization of dredged material shorelines. Biotechnical stabilization combines the use of mechanical structures with biological elements (plants). Mechanical structures, including breakwaters and biodegradable mats, are useful in high energy (fetches over 9 km) environments for reducing erosion until plants such as *Spartina alterniflora* can become established.

Breakwaters are only necessary for 2-3 years until plants become established. The use of sand bags, floating tires, and tire-pole breakwaters is discussed. These techniques reduced shoreline energy under proper conditions. Other devices useful in the stabilization of plant stems include fibrous erosion control mats and burlap plant rolls. Techniques employing these devices are described and show promise in allowing the establishment of plants in high-energy areas. In general, the use of mats and plant rolls is more economical than breakwaters.

Allen, H. H., E. J. Clairain, R. J. Diaz, A. W. Ford, L. F. Junt, and B. R. Wells. "Habitat development field investigations--Bolivar Peninsula Marsh and upland habitat development site, Galveston, Texas: summary report." 73. City: U.S. Army Corps Eng. Waterways Experiment Station, Environmental Lab., 1978.

This report described an experiment to establish salt marsh and upland vegetation on a 2-yr old dredged material deposition site of about 7.3 ha on the Galveston Bay side of Bolivar Peninsula, Texas. The report also described the construction of a sandbag dike to reduce wave impacts, and a fence to keep large mammals out, including goats, raccoons and people out.

Most of the grading and sand moving on the site was accomplished with a small bulldozer and a rubber tire frontend loader. Intertidal planting were in 3 elevation tiers. Winter, spring and summer plantings, various fertilizers and application methods, several plant species, and planting techniques were tried. Monthly samplings recorded changes in plant height, density, # stems/plant, # of stressed plants, # of stable plants, % foliar cover, vegetative reproduction, # of plants with flowers, seed heads and new growth, and above and below-ground biomass.

Spartina alterniflora grew best in 0.06-0.21 m above MSL. At this elevation, tidal inundation occurred 69-87% of the time from Feb.-Aug'77. *Spartina patens* grew best at 0.37 m above MSL; inundation was less than 30% of the time. Sprigging was much more successful thanseeding, but seeding (more economical) was used successfully in the upper third of the intertidal zone, where inundation frequency was low but soil remained moist, and there was less washing out by even small waves. Fertilizers were not particularly effective. It was thought that the nutrient-rich fine sediments that became deposited in the marsh planting area promoted enough growth to mask the action of the fertilizers.

Sampling for fish and aquatic animals was conducted before and after marsh construction. No major changes were detected in fish diversity or abundance after marsh planting, however, no adequate sampling devices were available for sampling the marsh grass at that time. Increases were noted in the polychaetes and oligochaetes in the benthos in the marsh area protected by the dike, After marsh construction, some increases in bird and mammal use of the area were noted. More marsh birds were noted once the cordgrasses developed. Also, more rats and mice were noted when sufficient leaf growth was established to provide covered habitat. Marsh rabbits ate the new growth, but did little damage.

The overall results from this marsh establishment project were that a salt marsh could be created on dredged material, and that it could function like a natural marsh provided certain precautions were taken. Wave energy had to be greatly reduced to prevent erosion of plants, and new growth had to be protected from foraging mammals.

Allen, H. H., S. O. Shirley, and J. W. Webb, Jr. "Vegetative stabilization of dredged material in moderate to high wave-energy environments for created wetlands." In: Proceedings of the thirteenth annual conference on wetland restoration and creation, in Hillsborough, FL, edited by F. J. Webb, Jr. Hillsborough, FL: Hillsborough Community College, 19-35, 1986.

This paper reports the results of several attempts to stabilize shorelines using *Spartina alterniflora*. High wave energy erodes shoreline vegetation, and special devices to reduce waves must be used before cordgrass can be established to reduce erosion. Two breakwater designs and four planting enhancement treatments were tested using four test locations. The breakwaters were a 3-tier floating tire fence and a fixed tire-pole design that was two tires high by two tires wide. The enhanced treatments were: (1) multiple stemmed clumps, (2) roots and lower stems of clumps were wrapped in a piece of burlap, (3) a "plant roll" was made by rolling a 3.7 x 0.9 m burlap cloth around sandy soil with six clumps of *Spartina* spaced in it at 0.5-m intervals, and (4) single stems of *Spartina* sprigged in a woven natural fiber mat which was then anchored to the substrate. Results showed a breakwater was needed if a transplant project was to be successful in areas of high wave energy. Clumps proved as effective as the other more expensive treatments behind the breakwaters. Plant rolls functioned to protect single stems planted to landward of the rolls in areas of only moderate wave energy.

Allen, H. H. and J. W. Webb, Jr. "Influence of breakwaters on artificial salt marsh establishment on dredged material." In: Proceedings of the ninth annual conference on wetland restoration and creation, in Tampa, FL., edited by F. J. Webb, Jr. Tampa, FL.: Hillsborough Community College, 18-35, 1982.

Cordgrass was transplanted to a site with high wave energy to stabilize a dredged material dike and to provide marsh habitat. The site was located on the northwest side of a recently deposited dredged material island situated in the center of Mobile Bay, Alabama. Wind fetches were 4.8 to 6.4 km. An unprotected planting of 1.5 ha with *Spartina alterniflora* single stems on 1.0-m centers was a complete failure. A second planting was made in the same area, this time behind two types of wavebreaks. Two months after planting there was a 55% survival behind the floating-tire-breakwater, and a 24% survival behind a fixed-fence-breakwater. The fixed-fence-breakwater, however, was coming apart, and additional losses of transplants were expected due to washout. Use of a fertilizer during the planting did not appear to be of benefit. Spacing of transplants was also tested. Transplants set on 1.0-m centers yielded 34% survival versus 22% survival for those set on 0.5-m centers. A reason for the difference in survival was not offered.

In areas with significant wave energy, transplanting success will depend on a functional breakwater. The floating tire breakwater design appears to be successful though somewhat costly (about $126 per linear meter). This breakwater can be partially disassembled, moved to another location and reassembled to protect another transplanting, thus making it a little more cost-effective.

Although the area receiving transplants on 1.0-m centers had slightly better survival, it did not have the coverage afforded by the area planted on 0.5-m centers. Coverage on the latter area was twice that of the 1.0-m centers. It depends on how fast one needs coverage as to which density of transplanting one should use. If you can wait three or four years for a stand to form, the 1.0-m center regimen would be less expensive and faster to plant.

Allen, H. H. and J. W. Webb, Jr. "Bioengineering methods to establish salt marsh on dredged material." In: <u>Coastal Zone '93 in New Orleans, LA</u>, edited by S. Laska and A. Puffer, New Orleans, LA: Amer. Soc. Civil Eng., 118-132, 1993.

This paper describes a test of low-cost wave stilling devices along with five transplanting treatments, all for use in establishing a fringe *Spartina alterniflora* marsh along a shoreline that is subject to moderate to high wave action (energy). The study was done on Bolivar Peninsula in the Galveston Bay area, Texas. Two breakwaters were used, one was a modified floating tire design (FTB) and the other was a fixed tire design. Transplanting treatments were: single stem, multi-stem clumps, multi-stem clumps wrapped in burlap, multi-stem clumps on 0.5-m intervals in a burlap roll with substrate between, and single stems planted through slits in an erosion control fiber mat that was anchored in the substrate. Only single stems were planted behind the breakwaters. Four test plots of each of the planting treatments were done outside the breakwaters.

Planting occurred in July 1984. In a January 1985 census only about 8% of the plants in the plots outside the breakwaters were surviving, and most was in two of the erosion control mat plots. However, 2.5 years later, there was at least a 25% cover in 3 mat plots, 2 multi-stem plots, and 1 burlap wrapped multi-stem plot. Growth continued in these plots, but the shoreline receded, leaving them as small islands out from shore. The fixed tire breakwater failed after about a year, and the 50% cover that had become established disappeared after about four years. The FTB worked well, and the stand of *Spartina* expanded well beyond the initial plot by the end of five years, despite an initial sediment build-up behind the FTB which buried many transplants.

Athnos, D. L. "Compensatory mitigation in the Gulf coast states: Can we achieve "No net loss" of wetlands?" City: Inst. for Coastal and Estuarine Research, Univ. W. Florida, 1993.

This report summarizes wetland laws and regulations for each of the Gulf coast states, assesses the success of these regulations in achieving no net loss of wetlands through a review of recent literature, and presents recommendations which would help attain a "no net loss" status. Federal and state laws and regulations governing wetlands along the Gulf of Mexico coast were succinctly and clearly presented. Because the nation and many states do not have comprehensive laws protecting wetlands, wetlands are tentatively protected under the Clean Water Act, Section 404, which is under the administration by the U.S. Army Corps of Engineers and the Environmental Protection Agency.

The author concluded the system appeared to be failing and wetlands were being lost. A major portion of the loss was due to activities that are exempt for the 404 permitting process. But the process was not replacing the loss even when mitigation was available. The author offered 15 recommendations to assist in wetlands protection.

Baca, B. J. and T. W. Kana. "Methodology for restoring impounded coastal wetlands." In: <u>Proceedings of the thirteenth annual conference on wetlands restoration and creation, in Hillsborough, FL</u>, edited by F. J. Webb, Jr., Hillsborough, FL: Hillsborough Community College, 36-44, 1986.

This paper emphasizes the importance of water flows and tidal elevations at which various species of marsh plants are found, as the important factors to consider when restoring impounded intertidal areas. South Carolina has about 70,000 acres of coastal impoundments, and many of these could be reclaimed for tidal wetlands in the near future. Appropriate plants should be selected based on elevation and flushing patterns at a site.

Banner, A. "Revegetation and maturation of restored shoreline in Indian River, Florida." In: <u>Proceedings of the fourth annual conference on restoration of coastal vegetation in Florida, in Tampa, FL</u>, edited by R. R. Lewis, III and D. Cole, Tampa, FL: Hillsborough Community College, 13-42, 1977.

Restoration activities at a site just north of Vero Beach, Florida, are described. This was mitigation for destruction of natural waterfront and a slough. *Spartina alterniflora* (smooth cordgrass), *Rhizophora mangle* (red mangrove), *Laguncularia racemosa* (white mangrove), and *Avicennia germinans* (black mangrove) were transplanted to the site the same day they were dug from nearby donor sites along the Indian River. The substrate at the site was a coarse yellow sand that was mined locally, transported and dumped on the site, and smoothed to a slope of 7.5%. A breakwater was built to prevent erosion by storm waves. Plugs, 15 cm in diameter containing 30 cm tall cordgrass plants were planted on 0.5-m centers. Mangrove seedlings 40-90 cm tall were used. Planting was done in May, 1976.

Within two months after transplanting, about 75% of the red and black mangroves had lost their leaves. These plants never recovered. Mangrove plants continued to die through the remainder of the year. The four white mangrove seedlings that were transplanted survived. On the other hand, *Spartina* transplants survived and grew, and by November many had set seed. In December, young *Spartina* seedlings were found on control (bare) areas and on areas where mangroves had been planted but had died. The seedlings were volunteers from the seed from nearby natural marshes. Although the combination planting of red mangroves with cordgrass did not help the red mangroves survive, the following year red mangrove propagules colonized the cordgrass stands.

Halodule and *Halophila* developed lush beds just subtidal to the mitigation site but on the coarse yellow sand. These were not planned, but offered a chance to observe bed development.

This simple experimental restoration project showed *Spartina alterniflora* was a valuable plant for stabilizing bare intertidal shoreline. Cordgrass grew rapidly and spread, forming stands that also assisted in the establishment of red mangroves by trapping and holding the propagules. Mangrove transplants were not as hardy nor as useful for shoreline stabilization.

Beeman, S. "Techniques for the creation and maintenance of intertidal saltmarsh wetlands for landscaping and shoreline protection." In: <u>Proceedings of the tenth annual conference on wetlands restoration and creation, in Tampa, FL</u>, edited by F. J. Webb, Jr. Tampa, FL: Hillsborough Community College, 33-43, 1983.

This paper describes techniques for establishing and maintaining an intertidal salt marsh along the Atlantic coast of Florida, based on literature and 10 years of experience (make that 20 years today) in the field of marsh creation. Factors considered important included: soil composition, elevation and slope of the shoreline, size of the plants used, planting density, time of year of installation, and proper choice of plant species.

Best results were achieved where a breakwater was constructed at the MLW seaward edge of the flattened slope, and a berm was constructed above the planting site to prevent erosion due to upland runoff. An intertidal marsh slope between 5° and 15° and a high marsh slope between 15° to 25° were recommended. Large plugs (rather than single sprigs) of *Spartina alterniflora* were planted on 1-ft centers between MLW and MHW. Plugs of *Spartina patens* were planted above MHW, and plugs of *Distichlis spicata* and *Sporobolus virginicus* were planted at even higher elevations. These elevations matched the zonation of natural marshes in the area. Planted areas filled in within 2-3 months, and were able to prevent erosion. Planting of mangroves was not necessary, because natural recruitment usually became established within three years.

Maintenance action was recommended to prevent the natural 3-4 yr cycle of growth and die-back. Actions consisted of removing flotsom wrack (prolonged shading by wrack killed cordgrasses), creeping vines, and dead tops after seed set.

Benner, C. S., P. L. Knutson, R. A. Brochu, and A. K. Hurme. "Vegetative erosion control in an oligohaline environment, Currituck Sound, North Carolina." <u>Wetlands</u> 2 (1982): 105-117.

Nine species of coastal marsh plants were tested for their use in stabilizing a shoreline in an oligohaline bay in North Carolina. Plants were sprigged (0.9-m interval) along transects from the shore-berm out 30.5 m into the intertidal zone. Two side-by-side transects of each species were planted in four adjacent, replicating plots on a block of bare beach. A similar and adjacent bare area was used as a control.

Only four species survived (*Typha latifolia, Phragmites australis, Juncus roemerianus,* and *Spartina alterniflora*). Once they became fairly established, they were joined by 20 volunteer species that increased the vegetative cover substantially. As plant cover increased, erosion of the area decreased. Additional plant cover led to accretion of sediments and expansion of the marsh. A balance between erosion and accretion was finally established, and a year's net gain or loss of sediments then varied as weather and water conditions varied. The bare control area only experienced erosion through the eight years of the study.

Berger, J. J. ed. Ecological Restoration in the San Francisco Bay Area. Berkeley, CA: Restoring the Earth, 1990.

This is an excellent compendium of restoration projects of all types of habitats in the counties bordering San Francisco Bay. Plus, it contains a directory (Appendix A) of people, companies, and organizations (including governmental) that are involved in restoration activities and regulations.

Habitats covered include forests, grasslands, coastal dunes and prairies, mined lands, creeks, lakes, and marshes. Other restorations focused on wildlife such as fish, butterflies, birds, and mammals, and some focused on native plants. Each restoration project was summarized as to location, beginning date, current status, site characteristics, purpose of the project, procedures used, results to date (1990), monitoring activities, future plans, support, budget, contact people, and volunteer needs.

Appendix E explains how to create a restoration directory including a database of projects. This is a useful guide that can be used for many different types of directories.

Bernstein, P. G. and R. L. Zepp, Jr. "Evaluation of selected wetland creation projects authorized through the Corps of Engineers Section 404 program." 80. City: U.S. Fish and Wildlife Service, Permits/Licenses Branch, Annapolis, MD, 1990.

The goal of this study was to evaluate the success of mitigation for lost wetlands. Each of 66 randomly chosen mitigation projects located in the Baltimore, Norfolk, and Philadelphia Districts of the U.S. Army Corps of Engineers were reviewed, visited and evaluated. A short written report was included for each.

Four projects of the 66 permitted had not been done (no mitigation required), 44 of the 62 remaining were deemed failures according to the permit specifications, 9 were deemed successes, and 9 were still under construction. Among the failures were partial success--projects where wetlands were established but were inadequate to fulfill the permit requirements.

The authors concluded the permitting system was losing wetlands under its current system of operation. It needed modification if it was to preserve our wetlands. One recurring problem was the lack of thorough planning. Rarely was an approved design for the mitigated wetland (to be created or restored) submitted at the time of the permit request. Recommended improvements for the system were: (1) Standardize permitting requirements for all projects requiring compensation. (2) Implement a tracking system for all permits requiring mitigation. (3) Require a greater than 1:1 replacement ratio for some critical

types of wetland habitat. (4) Require routine follow-up investigations including comparisons of pre-construction and post-creation data. (5) Enforce permit requirements with prosecution.

Blair, C. "Successful tidal wetland mitigation in Norfolk, VA." In: Coastal Wetlands., ed. H. S. Bolton. 463-476. New York: American Society of Civil Engineers, 1991.

In 1984, a 2.8 ha man-made *Spartina alterniflora* marsh (Monkey Bottom marsh) was created on a scrape-down area connected to Willoughby Bay in Norfolk, VA. This mitigation area had four lateral ditches that drained into one main canal that connected with the bay via a culvert. Planting of *S. alterniflora* was done on 2-ft centers and at elevations that ranged above and below the expected marsh establishment zone.

The mitigation marsh was evaluated as to its sediments, vegetation, invertebrates, fish and birds four years after its construction. A comparison of Monkey Bottom marsh with two local natural *S. alterniflora* marshes found no significant differences in density, cover and standing crop of *S. alterniflora* among the three. Fish and crabs were found in abundance, though not quantitatively compared. *Mugil* and *Callinectes* accounted for 55% and 20% of the catch by numbers, respectively, at Monkey Bottom. *Brevoortia Fundulus* and *Menidia* were the dominants at the natural marsh, where mullet were seen but not captured. Hard, soft and razor clams were the three main benthic organisms at Monkey Bottom, but polychaetes were also common. The control marsh had many fiddler crabs and nematodes. Bird utilization was similar for the marshes, with the exception of more suburban species frequenting the control marsh which was surrounded by a long-established residential neighborhood. The overall conclusion was that the mitigation marsh was a success, and was functioning as a typical estuarine marsh.

Bolton, H. S., ed. Coastal Wetlands. Coastlines of the World. New York: American Society of Civil Engineers, 1991.

This is a collection of papers presented at Coastal Zone '91 held in Long Beach, CA. Topics run from political and legal considerations of coastal wetlands to environmental design and monitoring considerations.

Bontje, M. P. "The application of science and engineering to restore a salt marsh." In: Proceedings of the fifteenth annual conference on wetlands restoration and creation, in Tampa, FL, edited by F. J. Webb, Jr. Tampa, FL: Hillsborough Community College, 16-23, 1988.

The report compares the use of a 63-acre man-made *Spartina alterniflora* marsh by birds, mammals and fish, to that of a 113-acre neighboring, *Phragmites communis* (common reed) marsh. The report also briefly describes the creation of the *Spartina* marsh.

The cordgrass marsh was established by clearing the common reed by spraying with glyphosate, excavating and grading the area by digging wide, gently sloping, canals. Excavated material was piled into raised berms for shrubs and trees. Once the surface was at the proper slope and elevation (0.15-0.45 ft below mean high water), *Spartina alterniflora* was seeded into the area. The canals were connected with Mills Creek of the Hackensack River. Within a few growing seasons the cordgrass was well established.

Birds, mammals, fish and water were sampled for 11 months. Monthly bird counts were made by walking or boating through the entire site for 1-hr. Mammals were trapped with bait for 24-hr each month. Tracks and burrows were also recorded. Fish were collected bimonthly by pulling a 3-m seine once for 15 m.

Based on this sampling regime, results showed twice the diversity and seven times the abundance of birds were using the *Spartina* marsh as were using the larger *Phragmites* marsh. Muskrat burrows were twice as dense in the *Spartina* marsh as in the *Phragmites* marsh. *Fundulus heteroclitus* was the common fish in both areas. Fish diversity was low, reportedly due to poor water quality in the adjacent rivers and creeks where diversity was also low. Benthos was three times as plentiful and twice as diverse in the *Spartina* marsh as in the *Phragmites* marsh. Water quality was nearly identical for the two marshes.

The goal to improve wildlife habitat in the area was achieved by removing the common reed and establishing a cordgrass marsh. The cordgrass marsh apparently developed quite quickly in the area which had minimal wave stress, proper elevation, and a good inundation-drainage design.

Bontje, M. P. "A successful salt marsh restoration in the New Jersey meadowlands." In: Proceedings of the eighteenth annual conference on wetlands restoration and creation, in Tampa, FL, edited by F. J. Webb, Jr. Tampa, FL: Hillsborough Community College, 5-16, 1991.

This article provided a detailed account of a salt marsh restoration/creation project in Lyndhurst, NJ. An old dredged material deposition site had become overgrown with *Phragmites australis*. Wetland creation required killing the reed, decreasing the elevation of the site to match marsh levels, improving drainage across the site, and planting and establishment of *Spartina alterniflora*.

Innovative techniques were described that solved unforeseen problems that developed during the project. Rodeo was used to kill the *Phragmites*, via two aerial sprayings and one hand spraying of recruits. Earth moving was done by backhoes and dump trucks, saving money which would have been spent on specialized equipment.

This was a 14 acre site, in which about 9 acres of salt marsh, 2 acres of tidal channels, and 3 acres of upland berm were established. The salt marsh was established on a 1% slope that drained about 80% at low tide; only a few inches of water remained in the channels. At high tide only the dike and a central ridge were not submerged. *Spartina alterniflora* was planted as peat pots (3-4 stems/pot) on 3-ft centers. Fertilizer was added to the holes before the peat pots were inserted. No significant mortality occurred, and plant growth was good.

No scientific studies were done to test for use of the marsh by aquatic or land animals, but increased use of the area by birds was noted.

Boyd, M. J. "Salt marsh faunas: colonization and monitoring." In: Wetland restoration and enhancement in California, in Hayward, CA, ed. M. Josselyn, Hayward, CA: University of California Sea Grant College Program, 110, 1982.

This paper presents an overview of the marsh fauna found in California coastal marshes, and presents the needs for monitoring changes in the fauna at a restoration site.

Several species of invertebrates and vertebrates are listed. Detecting significant differences in population densities of various species was expected to require extensive sampling--well beyond what would be logistically or financially possible given current constraints. But some such assessment is needed if a restoration project is to be judged successful or not. A suggestion, by a participant in the discussion, was made to possibly use an indicator species.

Broome, S. W. "Creation and restoration of tidal wetlands of the southeastern United States." In: Wetland Creation and Restoration: The Status of the Science. Part 1, Regional Review., eds. J. A. Kusler and M. E. Kentula. 37-72. Washington, D.C.: Island Press, Inc., 1989.

This chapter includes descriptions and brief discussions of many facets of tidal salt marsh restorations and creations beginning with marsh functions, then project plans, and finally an evaluation of the success of a project. Smooth cordgrass, *Spartina alterniflora*, is one of the most important plants used in salt marsh restorations, particularly in the intertidal zone along the Atlantic and Gulf coasts of the U.S. The functions of these marshes are many, but the major ones eliciting restoration activities are shoreline erosion control, sediment stabilization, and fisheries and wildlife habitat development or replacement. Careful planning is required for success in such projects. Attention must be paid to elevation at the site, water circulation into and through the area, protection from erosive wave action, and adverse actions by pests, herbivores and man's activities in and around the site. Timing of the planting, health of the transplants, and fertility of the soil are also important factors. Monitoring is important for documenting the success of a technique. A photographic record can be valuable. Future research is needed on site selection, design and preparation, on plant propagation and culturing techniques, and on documentation of marsh development. Information and advice are offered on most of these subjects, and are based on the author's many years of first hand experience and reading.

Broome, S. W., S. M. Rogers, Jr., and E. D. Seneca. "Shoreline erosion control using marsh vegetation and low-cost structures." (1992).

This report describes the use of smooth cordgrass, *Spartina alterniflora*, marsh to control shoreline erosion. Suitable sites had a substantial tidal range and a regular diurnal tidal rhythm, and a gentle slope in the intertidal area. They were in estuaries where salinity ranged between 5 and 35 ‰ , wave action was light or reducible at least while plants are becoming established. Planting in the spring to obtain a full growing cycle the first year was recommended, as was the use of a time-released fertilizer. Selection of other plant species was recommended for elevations above the normal tidal zone.

Broome, S. W., E. D. Seneca, and W. W. Woodhouse, Jr. "Establishing brackish marshes on graded upland sites in North Carolina." Wetlands 2 (1982): 152-178.

The objectives of this study were to determine: 1) the most suitable marsh plant species to use in a marsh creation project; 2) each specie's elevation requirement; 3) the effectiveness of several fertilizers; and 4) which methods were most effective when more than one process was possible. The study was done at a Texasgulf Chemical Co. phosphate

mining site adjacent to Bond Creek, a tributary of the Pamlico River estuary near Aurora, NC. The site was a series of borrow pits that were graded to suitable elevation (matching a local natural marsh) and slope, and connected to Bond Creek. Diurnal tidal flows were minimal, wind being a dominant force of water height change.

A great variety of plantings and tests were done over three years. Because of the lack of tidal fluctuation in water levels, plant species were limited to narrow elevation bands. *Spartina alterniflora* ranged from 0.06 to 0.43 m above mean sea level (MSL). *S. patens*, and *S. cynosuroides* were limited to 0.18 to 0.43 m above MSL. For transplanting, greenhouse grown seedlings of *S. patens* and *S. cynosuroides* grew better than field dug plants, but no such difference was found for *S. alterniflora*. Survival was 80-100% when plants were planted at the proper elevations. Direct seeding was only partially successful; irregular water levels during germination and seedling growth were damaging.

Some fertilizers were of benefit, some were not, and some were detrimental. The application of fertilizer directly to the planting hole caused root burn. Residual fertilizer benefits could be found even into the second growing season. When all was working well, it took 2-3 yr for the planted marshes to equal the above-ground production of the natural marshes.

Broome, S. W., E. D. Seneca, and W. W. Woodhouse, Jr. "The effects of source, rate and placement of nitrogen and phosphorous fertilizers on growth of *Spartina alterniflora* transplants in North Carolina." Estuaries 6 (1983): 212-226.

This study evaluated the effects of fertilizer rate, type of fertilizer material, and application methods on growth and survival of *Spartina alterniflora* transplants. Changes in erosion rates of planted and unplanted shoreline were also noted. The test plots were along the Neuse River near Oriental, NC. Soil tests of the area showed no organic matter in the compacted sandy clay loam, a pH of 5.17, and low nutrient concentrations. Tidal fluctuation was wind dominated, and salinity varied from 5 to 23 ‰ . A previously attempted planting of *S. alterniflora* in the area showed fertilization was necessary for survival and growth, and that surface applications of fertilizers were ineffective. Subsurface application of fertilizers was tested in a randomized complete blocks design. Osmocote (3-4 month release), Mag Amp (medium texture), ammonium sulfate, urea, urea-formaldehyde, diammonium phosphate, concentrated superphosphate, and rock phosphate were used. Results showed the Osmocote fertilized plants survived significantly better than the others, and grew fastest. Plants with Mag Amp were slower to get started, but were doing well after 11 weeks. Test results also showed that both N and P were needed for satisfactory growth, and that K was not needed (probably enough was being supplied in the estuarine water). Phosphorous applied at a rate of 49 kg/ha produced maximum growth when adequate N was supplied. The maximum rate of N applied was 224 kg/ha, and growth continued to improve to this maximum. The most efficient and economical method of fertilizing was the time-released form of NH_4-N combined with concentrated superphosphate, both applied underground but not necessarily in the planting hole. Some carry over of fertilizers was noted during the second year of growth. A top-dressing of N and P fertilizers after a stand has become established was said to be beneficial. Roots have developed which can take up the nutrients before they are washed away. With the establishment of the plants, sediment accumulated along the landward margin of the stand. This build-up stimulated additional plant growth.

Broome, S. W., E. D. Seneca, and W. W. Woodhouse, Jr. "Long-term growth and development of transplants of the salt-marsh grass *Spartina alterniflora*." Estuaries 9 (1986): 63-74.

This paper reports about the effect of transplant spacing on growth and development of a *Spartina alterniflora* marsh, following the marsh development for 10 years, and comparing it with a nearby natural marsh. The test site was a Pine Knoll Shores, NC, on the barrier island of Bogue Banks. *Spartina alterniflora* plants of field (dug 11 km away) and greenhouse origins were planted on 45-, 60-, and 90-cm centers in three 15x12-m plots that were set in a randomized blocks design. Above-ground vegetative characteristics were measured from several 0.25 m^2 quadrats taken each October. Below-ground biomass was usually sampled by taking cores.

Results showed that 45- and 60-cm treatments were better for establishing a marsh in a marginal environment. Transplant survival rates at the end of the first growing season were 72%, 69% and 49% for the 45-, 60- and 90-cm treatments, respectively. Above-ground vegetation among the treatments was indistinguishable after two growing seasons, except that two of the 90-cm blocks had eroded away by the second year's monitoring. By the end of the fifth year, the planted marsh was as densely vegetated (above 600 stems/m^2) as the natural control marsh that was 200 m to the west. Below-ground biomass increased fastest in the 45-cm treatment. It reached an equilibrium around 2 kg/m^2 by the end of the third year, and was matching the natural marsh.

The failure of the two 90-cm spacing blocks reaffirms the need to plan a marsh planting based on the harshness of the environment. A thicker planting will be more effective in breaking the erosive action of waves, but of course, the cost will be higher as many more plants will be required.

Broome, S. W., E. D. Seneca, and W. W. Woodhouse, Jr. "Tidal salt marsh restoration." Aquatic Botany 32 (1988): 1-22.

This article summarized the techniques to restore *Spartina alterniflora* salt marshes in the Southeastern U.S. Results showed that the site must be at the proper elevation--between MSL and MHW, and have a gentle slope--less than 10%, preferably less than 5%. Although salt marshes occurred in a variety of substrates, a sandy substrate was easiest for restoration planting; fertilizer was usually needed as sandy substrates were often nutrient poor.

Vegetation was usually restored by transplanting sprigs or plugs, or by seeding. Young plants were commonly available from nearby, healthy, natural donor marshes, or from nursery stocks. Labor costs ran about 100 man-hours per hectare for manual planting of sprigs on 1-m centers, and half of that for mechanical planting. Timing of planting was important, and was best scheduled for early in the growing season (April-June). Restoration of an oil-contaminated marsh should not proceed for at least six months even if the oil was removed.

Because salt marshes are very valuable habitats that serve many functions, the authors recommended that policies to protect marshes and restore damaged ones should be strengthened. Restoration work should be guaranteed, and replanting should be required when deficiencies are detected during monitoring. Each project should be monitored for 3-5 years to determine its success. Documentation should be made of successes and failures, with reasons for failure being documented and discussed so future projects would not repeat mistakes.

Broome, S. W., W. W. Woodhouse, Jr., and E. D. Seneca. "The relationship of mineral nutrients to growth of *Spartina alterniflora* in North Carolina. II. The effects of N, P, and Fe fertilizers." Soil Science Society American Proceedings 39 (1975): 301-307.

Little is known about the effect of mineral nutrition on *Spartina alterniflora*. This study was initiated to evaluate the influence of N, P, and Fe on primary productivity by applying these nutrients to plots in natural marshes and on S. *alterniflora* seeded and transplanted on dredged material. In a marsh growing on a sandy substrate, additions of N alone increased yields of aboveground shoots significantly, and when P was also added, the yield increased about threefold. In a marsh growing on finer textured sediments, N fertilizer doubled the yield of short *S. alterniflora*, but there was no response to P. There was no growth response to applications of Fe to support previous speculation that iron nutrition might be a particularly important factor causing the chlorotic appearance of short *Spartina* and reducing its productivity. The results indicate that primary productivity of some S. *alterniflora* marshes is limited by the availability of N. When N is added, lack of P may become the factor limiting growth, particularly when the substrate is coarse in texture, indicating the importance of sediment as a factor in P supply to *S. alterniflora*. Lack of N is apparently one of a combination of factors which is responsible for producing the short form of *S. alterniflora*. The fact that N and P are the limiting factors in growth of S. alterniflora in some salt marshes has several ecological implications. Marshes may be acting as buffers for estuarine systems by providing sinks for excess nutrients from such sources as sewage and land runoff. The excess nutrients would produce increased growth of *S. alterniflora* thus providing and increased supply of food energy and nutrients to the detritus food chain of the estuary rather than altering energy pathways. The ability of salt marshes to utilize excess N and P may be important in managing estuarine systems. Nutrient-rich waste effluent dumped in marshes would have less impact on estuaries than that dumped in open estuarine waters.

Fertilization may be beneficial in propagating *S. alterniflora* on dredged material since establishing a full vegetative cover rapidly is important. Applications of N and P fertilizers enhanced growth of seedlings and transplants, but the response of *S. alterniflora* to fertilizer will depend on the inherent fertility of the substrate material.

Callaway, J. C. and M. N. Josselyn. "The introduction and spread of smooth cordgrass (*Spartina alterniflora*) in south San Francisco Bay." Estuaries 15 (1992): 218-226.

Spartina alterniflora was first introduced into south San Francisco Bay in the 1970's. Since that time it has spread to new areas within the south bay and is especially well established at four sites. The spread of this introduced species was evaluated by comparing its vegetative and reproductive characteristics to the native cordgrass, *Spartina foliosa* . The characters studied were intertidal distribution, phenology, aboveground and below-ground biomass, growth rates, seed production, and germination rates. *Spartina alterniflora* has a wider intertidal distribution and was more productive than the native cordgrass in all aspects studied. These results indicate that the introduced species becomes established more readily in new areas than the native species, and once established, *S. alterniflora* spreads more rapidly vegetatively than *S. foliosa*, thus out-competing it. *S. alterniflora* is likely to continue to spread to new areas in the bay and displace the native species. This introduced species may also affect sedimentation dynamics, available detritus, benthic algal production, wrack deposition and disturbance, habitat structure for native wetland animals, benthic invertebrate populations, and shorebird and wading bird foraging areas due to its different physical and ecological characteristics. The evaluation of the extent of these impacts, however, can only be made after *S. alterniflora* has become widely established and very difficult to eradicate.

Cammen, L. M. "Accumulation rate and turnover time of organic carbon in a salt marsh sediment." Limnology and Oceanography 20 (1975): 1012-1015.

Organic carbon in the sediments was measured near Drum Inlet, North Carolina in a natural *Spartina* alterniflora salt marsh and on both unvegetated dredged material and dredged material planted with *S. alterniflora*. The planted marsh was about 1 year old at the time of sampling. Grain size analyses indicated that sediment texture was sandy and similar among the three sites. Above-ground *Spartina* biomass in the planted marsh was comparable to the natural marsh, but below-ground biomass in the planted marsh was between 19% (unfertilized) and 43% (fertilized) of the natural marsh. The annual accumulation rates of organic carbon (g/m^2) in the upper 13 cm of sediment were 80.3 in the bare sediment, 87.0 in the planted marsh, and 96.8 in the planted and fertilized marsh. Organic carbon in the natural marsh sediment was 362.7 g/m^2. The data suggest that the dredged sediments would be comparable to the natural marsh sediment within 3-5 years, and that the presence of *Spartina alterniflora* did not appreciably increase the rate of organic matter accumulation. Bare sediment had accumulated almost as much organic carbon as planted dredged material, and the increases were attributed to detrital matter carried by tides and to benthic algae.

Cammen, L. M. "Abundance and production of macroinvertebrates from natural and artificially established salt marshes in North Carolina." American Midland Naturalist 96 (1976): 487-493.

Abundances of macro-infauna taken in core samples were studied from natural, man-made *Spartina alterniflora* marshes, and adjacent bare areas at two locations, one near Drum Inlet and one near Snow's Cut, North Carolina. At each location, a permanent set of sites were established along transects. The planted area transect ran from the upper extent of the cordgrass down the elevation gradient to the middle of the tidal creek at Drum Inlet, and to just above MLW at Snow's Cut. Transects through the bare areas ran parallel to the transect through the planted area. A similar transect crossed each natural marsh. Replicate samples, 1 m apart, were taken at each site with a piston corer that covered a surface area of 70.9 cm^2 and reached a depth of 13 cm.

Macro-infauna differed with the location. At Drum Inlet, insect larvae (Dolichopodidae) dominated the fauna in the bare and planted areas, while polychaetes (*Heteromastus filiformis* and *Capitella capitata*) dominated the natural marsh. At Snow's

Cut, polychaetes (*Laeonereis culveri, H. filiformis and C. capitata*) dominated the fauna in the bare area, while amphipods (*Lepidactylus dytiscus* and *Gammarus palustis*) and Dolichopodidae larvae dominated the fauna in the planted area. The natural marsh macro-infauna at Snow's Cut was dominated by polychaetes (*L. culveri* and *Nereis succinea*), an isopod (*Cyathura polita*), and a bivalve mollusk (*Arcuatula (= Modiolus) demissa*).

Annual macrofaunal production (excluding *Uca spp.*) was estimated to be equal to the maximum standing stock of the insect population, and twice the average standing stock of the rest of the macro-infauna. Production values (g dry wt./m^2/yr) at Drum Inlet were 1.4 for the bare area, 1.2 for the transplanted area, 7.7 for the natural marsh, and 23-34 in the adjacent tidal creek bottom. At Snow's Cut production values were 13.8 (bare), 0.5 (transplanted), 5.7 (natural marsh), and 8-17 (tidal creek).

The low faunal diversity at the sites was partly attributed to infrequent sampling. It is also possible that the habitat was not developed enough at that time to support other less opportunistic species. Winter sampling was not conducted, and would have been useful for improving accuracy of annual production estimates.

Cammen, L. M. "Macroinvertebrate colonization of *Spartina* marshes artificially established on dredge spoil." <u>Estuarine and Coastal Marine Science</u> 4 (1976): 357-372.

This study investigated population dynamics of macro-infauna taken in core samples from natural and man-made *Spartina alterniflora* marshes, and adjacent bare areas. Two location were studied, one near Drum Inlet and one near Snow's Cut, North Carolina. At each location, replicate core samples were taken at permanent sites that were established along transects that crossed the elevational plane from subtidal to the landward margin of the marsh.

Particle size analysis showed that the dredged material at the Drum Inlet was very similar to the natural marsh sediment. The dredged material at the bare and planted areas near Snow's Cut were similar to that at Drum Inlet, but differed from the natural marsh nearby. The natural marsh at Snow's Cut had much higher coarse-sand and silt-clay fractions.

The above-ground and below-ground biomass of *Spartina* differed for planted and natural marshes. The above-ground biomass values in g/m^2 were 709 (planted) and 1056 (natural) at Drum Inlet, and 984 (planted) and 637 (natural) at Snow's Cut. At each location, the planted marshes had only half the below-ground biomass that the natural marshes had, 605 and 2371 (planted) and 3169 and 4966 (natural) and the respective locations.

Macro-infauna differed between locations and among areas at the same location. At Drum Inlet, the macrofauna in the bare and planted areas had similar biomass, species composition, and numbers of taxa per sample. The bare area had higher densities of organisms during three of the five samplings. The natural marsh had a higher density, biomass, and diversity for two of the three dates when all three areas were sampled. At Snow's Cut, the macrofauna in the bare area consistently had greater biomass and density per date sampled. The natural marsh was only sampled once at Snow's Cut. The macro-infauna in the natural marsh had a greater density and diversity than the dredged material sites, but it had a biomass slightly less than that of the bare area and slightly greater than that of the planted area. Neither sediment characteristics nor the presence of *Spartina* were deemed

sufficient causes for these differences found in the fauna. Elevation levels, however, were different and were likely the cause of the infaunal differences.

Sufficient support for separating causes of differences in macro-infauna and in establishing statistically significant differences would have required an increase in sampling. Although the abundances of *Uca spp.* were not included, their presence could have impacted infauna abundances.

Cammen, L. M. "The macro-infauna of a North Carolina salt marsh." American Midland Naturalist 102 (1979): 244-253.

The community dynamics of the macro-infauna of a healthy *Spartina alterniflora* marsh near Beaufort, NC, were studied for one year. Monthly sampling involved taking at least 6 cores randomly in the marsh. These were processed through a 0.8 x 0.6-mm mesh sieve; the animals, macro-detritus and roots were caught and preserved in formalin. Greatest abundance was found during the late winter and early spring. Lowest abundance was during the summer and early autumn. Numbers of individuals ranged from 2200 to 15500 /m^2. There were 32 taxa identified in the samples, but only four dominated the community. These were: *Nereis succinea, Streblospio benedicti,* Capitellidae and Oligochaeta. They were present in over 93% of the cores. They accounted for 96% of the number of individuals caught, and averaged 85% of the monthly biomass. The low summer biomass was thought to be due to predation by juvenile fish and to mortality due to spring spawning. These taxa were also among the dominants in several other marshes in NC. The high numbers of infauna suggest that most of the marsh surface sediment and detritus is eaten and processed each year.

Chabreck, R. H. "Creation, restoration, and enhancement of marshes of the northcentral Gulf coast." In: Wetland creation and restoration: The status of the science. Volume I: Regional overviews. EPA/600/3-89/038., eds. J. A. Kusler and M. E. Kentula. 127-144. Corvallis, OR: U.S. Environmental Protection Agency, 1989.

Coastal marshes of the northcentral coast of the Gulf of Mexico encompass an estimated 1.2 million hectares. This is about half of all coastal marshes in the U.S., excluding Alaska. These coastal marshes are being threatened by subsidence, sea level rise, and erosion by wind generated waves. Efforts to protect and enhance the marshes in the northcentral Gulf involve use of dredged material and river water with its sediment. Weirs, dikes, and levees are also used around freshwater and brackish water marshes to protect them from saltwater intrusion. Information is given about things to consider when attempting to create or restore coastal marshes. Location, topography, hydrology, type of substrate, salinity, and wind and wave climates are all important factors to be considered in the planning process. Monitoring of a project is suggested to be a two level process. The first level is just a qualitative look to see if the project is developing as planned. The second level is a quantitative investigation of the project to assess the level of success attained.

Research is needed for developing marshes using diverted Mississippi River water. Opening channels in the banks of the larger delta channel of the river could allow mini-delta formation which could be planted or allowed to vegetate naturally. Dredged material use in marsh enhancement needs to be researched. Thin-layer deposition of dredged material may improve marshes that are deteriorating because of subsidence, but methods for this need to be developed.

Cobb, R. A. "Mitigation evaluation study for the south Texas coast, 1975-1986." City: Corpus Christi State University and U.S. Fish and Wildlife Service, 1987.

This report presents an evaluation of the level of acceptance, implementation, and success of the U.S. Fish and Wildlife Service's recommendations made to preserve fish and wildlife habitat, or to mitigate its loss along the south Texas coast. For 59 permitted waterfront projects, the USFWS recommendations were unconditionally accepted in 78%, rejected in 5%, and modified in 16%; 1% were unresolved. However, most of the accepted recommendations were those to avoid impact to wetlands or to assure adequate water quality within excavated canals. Projects requiring habitat compensation had more modifications, and they had more non-compliance by the permittee. Non-compliance with permit conditions was found at 31% of the sites inspected--78% of this was unfulfilled mitigation requirements and 22% was additional work performed beyond that permitted.

In the proposed mitigation work involving marsh restoration or creation there was substantial variation in describing the substrate elevations where *Spartina alterniflora* was to be planted. Rarely were details of the planting (stems/m^2, as-planted maps, etc.) provided in a report. Monitoring was never done by the permittee, and only once by the Texas General Land Office and Corps of Engineers. Completion reports were rarely filed. Only one performance bond was required. Of the 15 projects investigated, 6 were deemed failures, 4 were partial successes, and 5 were fully successful according to the permit requirements.

Many of the usual reasons for failure of transplanted marshes were found among these failed projects including: (1) no soil conditioning, (2) incorrect elevation, (3) excessive slope, (4) excessive wave action and inadequate protection, (5) bad weather, (6) poor drainage and excessive salinity, (7) human disturbance, and (8) improper site preparation. In a few cases where failure was due to insufficient plant cover within the specified time (two years), the marshes have since developed sufficiently to be rated successful.

Although almost 90% of the recommendations proposed by the USFWS were incorporated in the permits, the overall final results after implementation yielded a net loss of wetlands--only 50% were recovered through mitigation. The report offers 21 recommendations to enhance the chances of successful marsh restoration. And 21 more are given for seagrass restoration projects.

Courtney, F. X., S. A. Peck, and M. O. Hall. "Post-harvest recovery of a donor *Spartina alterniflora* marsh." In: <u>Proceedings of the eighteenth annual conference on wetlands restoration and creation, in Tampa, FL</u>, edited by F. J. Webb, Jr., Tampa, FL: Hillsborough Community College, 23-31, 1991.

A previously transplanted salt marsh at Spoil Island 2-D in Hillsborough Bay, Tampa Bay, FL, was used as a donor site for 300 m^2 of *Spartina alterniflora*. The harvest was made from 1/2 m or 1 m wide transects that were oriented either parallel or perpendicular to the shoreline. The cordgrass was hand pulled from the substrate. One half of the 24 harvest transects were fertilized shortly after harvest. After 17 months, mean culm

densities in donor transects were similar to those of the undisturbed marsh. Fertilizer made shoots more robust, but not more numerous. Limited harvest of planting material appears to cause only temporary damage to the vegetation of the donor marsh. No studies were done to assess changes in marsh utilization by aquatic fauna.

Covin, J. D. and J. B. Zedler. "Nitrogen effects on *Spartina foliosa* and *Salicornia virginica* in the salt marsh at Tijuana Estuary, California." Wetlands 8 (1988): 51-66.

Nitrogen effects were examined by experimentally enriching plots of pure *Spartina foliosa* and mixed *Spartina-Salicornia virginica* at Tijuana Estuary, California. Even with large inputs of organic nitrogen from sewage spills during the experimental period, plants responded to experimental urea enrichment. In pure plots, the addition of nitrogen increased *Spartina* growth (as measured by total stem length and August biomass) and foliar nitrogen (TKN) concentration. However, this effect is eliminated if increased foliar nitrogen stimulates insect predation resulting in heavy plant mortality. In mixed plots, enrichment had no apparent effect on *Spartina* but increased the growth of *Salicornia*. The lack of an enrichment effect on *Spartina* may be due to underground rhizomes and roots of *Salicornia* continuing to take up nitrogen through connections with plants outside the removal plots. The experimental removal of *Salicornia* from mixed stands increased *Spartina* production, but removal of *Spartina* did not affect *Salicornia*. Thus, there was a strong competitive effect. In mixed stands, urea additions are detrimental to *Spartina* because *Salicornia* has a greater response capacity. *Salicornia* is a superior competitor for nitrogen and checks the growth of *Spartina* in enriched and unenriched conditions. These experiments show that nitrogen, through its complex effects on growth and competition, is an important cause of spatial and temporal variability seen in long term observations of *Spartina*.

Craft, C. B., S. W. Broome, and E. D. Seneca. "Nitrogen, phosphorus and organic carbon pools in natural and transplanted marsh soils." Estuaries 11 (1988): 272-280.

The objectives of this study were to compare the nutrient and organic pools of transplanted and natural coastal saline marshes. Marsh sediments were studied in five created and nearby natural marshes in diverse locations in North Carolina. A couple of the marshes compared differed in their vegetation. The created marshes ranged in age from 1 to 15 years. Sediments were sampled using an 8.5 cm diameter corer. Ten to 20 cores, 30 cm deep, were taken randomly from each marsh. Macro organic matter (MOM) was separated from the sediments by sieving on a 2-mm mesh sieve. MOM and soil nutrient reservoirs were smaller in transplanted marshes than in the nearby natural marshes. About 12% and 20% of the net primary production of emergent vegetation was buried in sediments of the regularly flooded and irregularly flooded transplanted marshes, respectively. MOM pools developed rapidly in transplanted marshes, and were expected to match the pools in natural marshes in 15-30 years. Soil nutrient pools in transplanted marshes, however, developed slowly and were expected to take much longer to match those of natural marshes.

Craft, C. B., E. D. Seneca, and S. W. Broome. "Porewater Chemistry of Natural and Created Marsh Soils." Journal of Experimental Marine Biology and Ecology 152 (1991): 187-200.

Physical and chemical properties of soils and porewaters were compared from a natural marsh and a man-made marsh that was created from graded down upland. Porewaters were sampled monthly for a year from established wells set in the marshes. Water level, temperature, salinity, DO, pH, Eh, Fe, Mn, organic C, N, P, NH_4, NO_3, and PO_4 concentrations were monitored in the pore water.

The created marsh soil had about 1% organic matter compared with about 50% for the natural marsh. DO, Eh, Fe, Mn and NO_3-N concentrations were significantly higher in the created marsh pore waters, but the dissolved organic C and N, NH_4-N, PO_4-P, and pH concentrations were lower. Even five years after creation of a saline estuarine marsh, the soil characteristics remained typical of the upland soil from which it was made.

This study suggests that we should not expect mitigated wetlands created on upland soils to gain characteristics of a natural marsh within even a decade. The authors recommended avoiding damage to natural wetlands because wetland soils are not readily replaced.

Crewz, D. W. and R. R. Lewis, III. "An evaluation of historical attempts to establish emergent vegetation in marine wetlands in Florida." 113 pp. Florida Sea Grant, Univ. of Florida,, 1991.

The authors' objectives were: (1) to compile a database of past marine wetland projects, (2) to then survey the sites for elevation and plant cover based on a random selection of sites from the database, and (3) to provide guidelines based on the observations made at the sites. These guidelines should help increase the success rate of marine wetland creation projects where emergent vegetation is planted. Objectives 1 and 2 were dismissed due to lack of available information and lack of access.

For objective 3, 33 sites were visited where salt marsh or mangroves had been planted. The sites were chosen based on accessibility (physical and legal), accuracy of site location information, species planted, and geographic location. All sites were visited in 1986. Twenty sites had been planted with *Spartina alterniflora* along with other species. Plant densities were measured along transects that extended from the seaward edge to the upland edge of the marsh or mangrove area. Transects were spread about 25 m apart.

Results of the survey showed that marsh establishment was at least partially successful in 65% of the cases. Planted *Spartina alterniflora* survived from +0.2 - +0.6 m NGVD. Older natural marshes nearby ranged down to -0.1 m NGVD. Marsh failures were attributed to: (1) poor design and planning, (2) poor planting technique, (3) poor monitoring and remedial action, and (4) insufficient regulatory review. Critical factors found for establishing a salt marsh were: elevation, slope, drainage, substrate, plant selection, installation techniques, fetch, wave climate, marine connection, and elimination of pests from the site (including humans). Monitoring the development of a planted marsh was recommended because problems could be quickly identified and corrected.

The authors commented that despite advances in planting techniques, continued poor planning and planting led to failures of mitigated marshes. It was highly recommended that degradation of natural marshes should be avoided whenever possible. It was also recommended that a strong monitoring program should be part of any wetland restoration or creation project.

Earhart, H. G. and E. W. Garbisch, Jr. "Habitat development utilizing dredged material at Barren Island, Dorchester County, Maryland." Wetlands 3 (1983): 108-119.

The objectives of this project were to stabilize a low island created by deposition of dredged material by planting *Spartina alterniflora* and to create a habitat for fish and wildlife. The project was done in the fall of 1981, in Chesapeake Bay just off the northeastern tip of Barren Island, Dorchester County, Maryland. About 135,831 m^3 of fine-grained sediments were hydraulically deposited in a single unconfined location. The discharge pipe remained at a site until the water depth reached 1.8 m above MLW, then the outlet was moved to an adjacent lower portion of the site. The dredge material was allowed to consolidate for about five months (Nov. - April) before *Spartina alterniflora* was seeded over 8.4 ha at a rate of 96 seeds/m^2. The seeded area was fertilized a month later. Peat pots of *Spartina patens* were planted on a 0.6-m grid over about 2 ha at elevations above the *S. alterniflora*. During the winter about 460 m^3 of oyster shell was placed in the center of the site to create nesting habitat for the least tern.

After eight months of growth, the shell island was nearly surrounded by 4.5 ha of flowering *Spartina alterniflora* at elevations ranging from 0.2 - 0.5 m above MLW, and 1.6 ha of *Spartina patens* at 0.4 - 0.7 m above MLW. A 4.1-ha pond, a 1.9-ha stretch of bare non-vegetated flatland, and a 0.1-ha area of oyster shell (tern nesting habitat) were also created.

This project required careful planning and diligence by the project team to keep the project on target. Constant monitoring by the project team was needed to keep the dredged material directed to the correct place. The project succeeded in creating *Spartina alterniflora* and *S. patens* marsh, plus some non-vegetated tern nesting habitat, but it did not create as much as was planned. When the project was completed, 69% of the designed marsh had become established. This paper provided a good comparison of project construction theory and construction reality, and it showed that even with a well planned design, circumstances during the construction phase can control the final success or failure of a project.

Earhart, H. G. and E. W. Garbisch, Jr. "Beneficial uses of dredged materials at Barren Island, Dorchester County, Maryland." In: Proceedings of the thirteenth annual conference on wetlands restoration and creation, in Hillsborough, FL, edited by F. J. Webb, Jr., Hillsborough, FL: Hillsborough Community College, 75-85, 1986.

Spartina alterniflora stems and clumps have been planted in dredged material to stabilize the material and establish salt marsh, but planting of large areas with sprigs of cordgrass can be very expensive. This paper describes a successful creation of 1.6 ha of *S. alterniflora* marsh using seeds. Judicious placement of the dredged material to specified elevations was required. This entailed constant monitoring of the additions of dredged material to the area. *Spartina alterniflora* marsh was made by broadcasting seed from an all-terrain-vehicle (ATV) during low tide over 5.3 ha. Broadcasting was followed by cultivating the substrate and seed by dragging a spiked metal mesh over it at low tide using the ATV. The site was fertilized four times during the summer. Seeding and fertilization

costs were only about one fifth those of single stem transplanting. *Ruppia maritima* voluntarily invaded the shallow waters between dredged material islands, establishing about 2.8 ha of *Ruppia maritima* beds. Natural beds were nearby.

Eleuterius, L. N. and J. I. Gill. "Long-term observations on seagrass beds and salt marsh established from transplants." In: Proceedings of the eighth annual conference on wetlands restoration and creation, in Tampa, FL., edited by R. H. Stovall, Tampa, FL.: Hillsborough Community College, 74-86, 1981.

This paper reviews seagrass and saltmarsh transplant projects that were initiated five to ten years earlier in Mississippi. The projects involved transplanting a wide variety of seagrass and salt marsh species. In seagrass projects, *Halodule beaudettei, Thalassia testudinum* and *Cymodocea manatorum* were transplanted. Only about 30% of the transplants survived at the end of one year, but 80% of these survivors had begun spreading. *Halodule beaudettei* survived best, and spread rapidly. As the beds grew, they constantly changed shape. At these particular test sites the seagrass beds spread only westward, leaving their original planting sites empty as the eastern shoots died. This migration occurred within only a few growing seasons and was attributed to the predominant westward current in the area.

In salt marsh studies, growth and spread of transplanted *Panicum repens, Spartina alterniflora, Juncus roemerianus, Spartina cynosuroides, Spartina patens, Distichlis spicata,* and *Phragmites communis* were measured over various periods up to 10 years. Propagation trials showed that preliminary rooting of these marsh plants in peat pots was unnecessary. Individual shoots successfully grew into stands in 60 and 80% of the marshes transplanted from November to February. In random plot tests *Panicum repens, Spartina alterniflora, Spartina patens,* and *Distichlis spicata* formed closed stands within a year. *Spartina cynosuroides* and *Phragmites communis* survived but did not spread during the three years of the tests, apparently because they were out competed by other plants. *Juncus roemerianus* was a slow grower and spreader, but it continued to spread even when crowded by other species. *Juncus* formed closed stands in five years when planted on 1.2-m centers. Stands of each species were found to move due to competition with each other and to the local changes in environmental conditions. After about seven years the mosaic pattern of the natural saltmarshes in the area was attained at the test site.

In another study of transplanted *Spartina alterniflora*, all transplants in the lower elevations died due to wave action and sediment erosion. The transplants in the upper zone survived and flourished. Observations of the stand eight years later found *Spartina alterniflora* had invaded the lower zone and was now growing well, even at the lowest elevation that had originally been planted. This spread extended 15 m down the intertidal slope in about eight years. From this observation, a transplanting principle was formed: plant the upper portion of the intertidal zone and allow the cordgrass to invade the lower portion on its own.

Espey Huston & Associates Inc. "Monitoring of transplanted *Spartina alterniflora* on an unconfined dredged material disposal site, Chocolate Bay, Texas." Espey, Huston and Associates, Inc. DACW64-87-D-0002, 1988.

A *Spartina alterniflora* marsh was planted on 8.09 ha of unconfined dredged material in Chocolate Bay of the Galveston Bay System, Texas. Sprigs were obtained from a nearby marsh (control marsh) in Halls Lake, and planted on 1-m centers in June 1983.

Sampling to monitor marsh development was performed March - August and October 1984, April, June and October 1985, April, July and October 1986, and October 1987. Percent cover, stem density and height, and above-ground biomass were measured at 8 sites along each of 3 elevational transects through each marsh.

By 1986, the planted marsh had increased to an average of 79% cover and 382 stems/m^2 that averaged 29 cm in height. The control marsh had fallen to an average of 64% cover and 297 stems/m^2 that averaged 22 cm high. In October 1987, average cover was down slightly at 66% and 44% for the planted and control marshes respectively. Total number of stems averaged 436 and 348 stems/m^2, 37 and 34 cm high, respectively.

Surveys made for wildlife found periwinkles, fiddler crabs, oysters, and birds to be common in both marshes. Observations on marsh use, however, were very limited.

Espey Huston & Associates Inc. "Monitoring of transplanted *Spartina alterniflora* on an unconfined dredged material disposal site, Pelican Spit, Galveston Bay, Texas." Espey, Huston & Associates, Inc. DACW64-89-D-0003, 1990.

This report describes the results of a salt marsh creation. In April, 1987, about 2.6 ha of shoreline were planted with *Spartina alterniflora* on 1-m centers on recently deposited unconsolidated dredged material at Pelican Spit in Galveston Bay, Texas. Planting was done between +0.5 and +0.9 m MLW. Planted and nearby donor (control) marshes were monitored in Nov. 1987, Nov. 1988 and Oct. 1989 for vegetative growth and general marsh development.

The planted marsh increased to 91, 258 and 210 stems/m^2 compared with the 405, 145 and 150 stems/m^2 in the control marsh in 1987, 1988 and 1989, respectively. Marsh periwinkles (*Littorina irrorata*) were the only typical marsh invertebrates observed at the planted marsh, while fiddler crabs, blue crabs and periwinkles were found at the control marsh. Sampling for invertebrates was only qualitative.

Faber, P., A. Shepherd, and P. Williams. "Monitoring a tidal restoration site in San Francisco Bay- the Muzzi Marsh." In: <u>Urban wetlands: proceedings of the national wetland symposium, in Oakland, CA</u>, eds. J. A. Kusler, S. Daly, and G. Brooks, Oakland, CA: Assoc. State Wetland Managers, 331-335, 1988.

Observations on tidal channel formation, sedimentation, and revegetation are reported for the Muzzi Marsh at Corte Madera, Marin County, California. A 53-ha portion of the marsh was opened to tidal flows in 1976 by breaching the seaward dikes. Revegetation was slow, and was thought to be due to a lack of tidal flows to the landward portion of the marsh. In 1981 additional channels were dug to increase tidal flows to the interior and peripheral areas. Revegetation rates increased, and a substantial coverage of the flats by *Salicornia virginica* and of the channel banks by *Spartina foliosa* developed. Seed source was a nearby natural marsh.

Faber, P. M. "The Muzzi marsh, Corte Madera, California: long-term observations of a restored marsh in San Francisco Bay." In: Coastal Wetlands., ed. H. S. Bolton. 424-438. New York: American Society of Civil Engineers, 1991.

This article reports on observations made of drainage channel formation, sedimentation, and revegetation of the 53-ha portion of the Muzzi Marsh at Corte Madera, California, on San Francisco Bay. The Muzzi Marsh was a 81 ha natural coastal marsh that was diked in 1959. Subsequently, the marsh dried out, killing all the marsh vegetation. In 1976, 28 ha were further diked to retain dredged material, but another 53 ha were opened for tidal circulation by breaching the dikes in two areas. Periodic observations and studies showed the development and spread of drainage channels across the flat plain. The deposition of sediments was greatest just outside these channels. *Salicornia virginica* and *Spartina foliosa* became established fairly rapidly from the water born seeds that were generated by the plants growing on the bayside of the dikes and in the 27-ha natural marsh just to the north of the Muzzi marsh. There was constant competition between *Salicornia virginica* and *Spartina foliosa* along the MHW elevation. The competition was influenced by yearly rainfall. In wetter years *Spartina foliosa* became established at slightly higher elevations, but in drier years *Salicornia virginica* invaded lower elevations.

Florida Department of Environmental Regulation. "Report on the effectiveness of permitted mitigation." Florida Department of Environmental Regulation. 1991.

As of 1984, any alteration of a wetland area in Florida required a permit from the Florida Department of Environmental Regulation (FDER). Between January 1, 1985 and December 6, 1990, FDER issued 1,262 permits involving a loss of 3,305 acres and a preservation of 7,587 acres of natural wetlands. The permits also required creation of 3,345 acres and enhancement of 7,301 acres of wetlands. An evaluation was made of the success rate of the mitigation process.

A sample of the permits was drawn which included about 10% from each wetland category. Each project was examined for compliance with permit specifications, and for ecological success. Compliance was poor. Only 6% of 63 examined projects were in full compliance, and 34% of the mitigation projects had not even been attempted. Ecological success among the projects being constructed was projected to be about 27%. Success rates were lower (12%) for freshwater projects than for coastal marsh projects (45%).

As FDER concluded, the permitting policy needed revising if the wetlands were to be preserved, or "no net loss" were to be achieved. Permits that were granted needed to be monitored and enforced. Such changes would do much to safeguard wetlands.

Fowler, B. K., G. R. Hardaway, G. R. Thomas, C. L. Hill, J. E. Frye, and N. A. Ibison. "Vegetative growth patterns in planted marshes of the vegetative erosion control project." In: Proceedings of the twelfth annual conference on wetlands restoration and creation, in Tampa, FL, edited by F. J. Webb, Jr. Tampa, FL: Hillsborough Community College, 110-120, 1985.

This paper reports some of the results of the Vegetative Erosion Control Project, a study of 24 marsh plantings in the Chesapeake Bay system in Virginia. Sites were chosen to maximize diversity of conditions, mainly fetch and direction faced. Seven sites were classified as having low wave energy (average fetch exposure < 1.8 km), 10 sites were

classified as having medium wave energy (average fetch exposure from 1.8 to 9.2 km), and seven sites were classified as having high wave energy (average fetch exposure > 9.2 km). *Spartina alterniflora* was planted on 0.5-m centers from MHW to just below MSL. *Spartina patens* was planted above *S. alterniflora* at a few sites. About 30 ml of Osmocote fertilizer having a 14-5.2-11.6 slow release formula, was placed in each hole just before each culm was planted. Osmocote was scattered over the marsh surfaces one or twice each summer to encourage vigorous growth of vegetation.

Growth comparisons through time and with natural marshes nearby showed that marshes on low energy shorelines were more productive than those on high energy shorelines. *S. alterniflora* was more productive in the higher intertidal zone than the lower intertidal zone, particularly when marshes were getting started. Stem densities were slightly greater in marshes that faced south, i.e. the sunniest side and the leeward side (strongest winds usually came from the northeast).

Several recommendations were given to improve chances of successful establishment of fringe marshes. 1) A breakwater should be used to protect a planting if the fetch is greater than 6 km. 2) The fringe marsh should be made as wide as possible from MSL to MHW. 3) *S. patens* should be used on bare beach areas above the *S. alterniflora* zone. 4) Maintenance planting for a new marsh should be done early in each growing season. 5) Newly developing marshes should be fertilized twice each summer using a slow release type fertilizer like Osmocote.

Frenkel, R. E. and L. M. Kunze. "Introduction and spread of three *Spartina* species in the Pacific Northwest." In: <u>Annual Meeting of the Association of American Geographers in Washington, DC</u>, Washington, DC: Assoc. Amer. Geographers 1984.

This paper describes the introduction and spread of *Spartina alterniflora, S. patens*, and *S. anglica* in the Washington and Oregon estuaries. The potential spread of *Spartina* and the consequent loss of intertidal mudflats are also discussed. *Spartina alterniflora* appears to have been accidentally introduced into Willapa Bay prior to 1911, perhaps associated with some facet of the oyster industry that was established there in 1904. *S. alterniflora* was purposefully transplanted to enhance duck habitat in Thorndyke Bay, Gibson Spit, Kala Point, and Padilla Bay, Washington. These colonies are well established, but are spreading slowly.

Spartina patens appears to have been introduced at Cox Island, Oregon, probably in the early 1920's. First records were of a small patch at that time, but present records show it has expanded exponentially to cover about 3000 m2. *S. patens* has since spread to the Dosewallips River in Washington.

Spartina anglica C.E. Hubbard, was planted on the eastern shore of Port Susan Bay near Stanwood, Washington. It has since spread to Livingston Bay, Iverson Spit, Triangle Cove, and Skagit Bay. *S. anglica* (sometimes call *S. townsendi*) is a fertile cross between *S. alterniflora* and *S. maritima* and is a vigorously spreading cordgrass. These three species are potential threats to native salt and brackish marsh plants in the Northwest, and to the bare mud and sand flats in the estuaries that are used by migratory birds.

Gallagher, J. L. "Salt marsh soil development." In: Rehabilitation and creation of selected coastal habitats: proceedings of a workshop. eds. J. C. Lewis and E. W. Bunce, U.S. Fish Wildl. Serv., 28-34, 1980.

This article reviews soil attributes that need be considered for successful planting of a salt marsh. The physical and chemical compositions of the soil are described in relation to five characteristics: stability, acidity, moisture, salinity and nutrients, with notes on interactions.

Stability is greater in sandy soils than in silt and clay oozes, but the latter can sometimes be improved by de-watering. Increasing stability increases the chance of plants staying in place and becoming established. Acidity was noted as a potential problem. Acidity is often caused by oxidation of the iron sulfides in dredged material when the material is pumped out and mixed with air and water. This is one reason for letting fresh dredged material sit and "age" for several months before planting; the acidity has a chance to be neutralized. Moisture content influences oxygenation of the soil. Soil, that was always saturated, became anaerobic. Plants capable of existing under anaerobic conditions (*Spartina alterniflora* being one) will grow in zones according to the lowest level of oxygen they can tolerate. Soil salinity influences plant establishment and zonation. Tidal inundation, salinity of the estuarine water, elevation, drainage, evapotranspiration and rainfall, all influence soil salinity. Nutrients are frequently limiting for plant growth in new marshes. Coarse sandy soils hold less nutrients than finer textured substrates, and fertilizers are often required to promote healthy plant growth when starting a marsh.

Gallagher, J. L., G. F. Somers, D. M. Grant, and D. M. Seliskar. "Persistent differences in two forms of *Spartina alterniflora*: A common garden experiment." Ecology 69(4) (1988): 1005-1008.

This paper provides a good review of the controversy around whether tall and short forms of *Spartina alterniflora* are genetically distinct, or whether these phenotypic differences are caused by environmental factors. Both tall and short form plants were transplanted from a Delaware salt marsh into common backyard garden plots also in Delaware. The plots were irrigated three times each week during the growing season with water (15-30 ‰) from a tidal creek. Initially the tall form was 30% to 100% taller than the short form. Differences between the height of the two forms persisted even after 9 years in the gardens. In addition, other morphological differences such as stem density, root-to-shoot ratios, and culm diameter varied between the two forms in a manner comparable to the differences in natural stands. Differences in productivity and underground reserves were also observed. The authors concluded that the phenotypic differences between tall and short form *S. alterniflora* are at least partially due to genetic differences between the forms. The possibility was also discussed that the forms are genetically similar, but certain genetic characters are turned on by environmental factors at the seedling stage, and that these differences persist despite long-term exposure to different environmental conditions.

Garbisch, E. W., Jr., P. B. Woller, and R. J. McCallum. "Salt marsh establishment and development." Fort Belvoir, VA.: U.S. Army Corps Eng., Coastal Eng. Research Center, Tech. Memo. 52, 114, 1975.

This study tested survival and growth of peat-potted *Spartina alterniflora, S. patens, S. cynosuroides, Distichlis spicata, and Ammophila breviligulata* seedlings that had been raised in a greenhouse. Seedlings were planted at inter-tidal and supra-tidal elevations. Grow-out sites were on natural beaches, sand and mud flats, and on dredged material beaches. Elevations, fertilizer applications, and planting dates were also investigated for influence on plant survival. Additional objectives were to determine shoreline stabilization potentials and sediment trapping potentials of the plants, and to determine the rate of macrobenthos colonization of the dredged material sites.

Seeds were harvested from natural stands near Assateague Island, VA during October, and grown out in sand filled peat pots the next spring. *Spartina alterniflora* was planted on 0.9-m centers; the others were planted on 0.6-m centers. All were in 10-cm diameter peat pots containing about five seedlings each. Plantings were made at four sites within a 40 km radius of St. Michaels, Maryland. All sites had gentle slopes of 1-6 degrees. Macrobenthos was sampled along four elevation contours at sites A, B, and #4. Elevations were +43 cm MLW (= MHW), +21 cm MLW (= MTL), MLW, and -15 cm MLW (= subtidal). Ten cores were taken at 0.5-m intervals along each elevation contour at each site. Cores were taken to a 15-cm depth using a corer with either a 21-cm^2 or a 46-cm^2 cross-sectional area. Organisms were separated from the substrate by washing the samples on 4.0, 1.0 and 0.5 mm sieves.

Results showed *Spartina patens, Distichlis spicata,* and *Ammophila breviligulata* all survived well at supratidal sites. *Spartina cynosuroides*, planted at MTL was completely killed within two years, most likely due to too much inundation. *Spartina alterniflora* suffered 60-90% mortality in areas from MHW to below MTL due to strong wave action. Those seedlings planted above MHW suffered about 10-40% mortality. Fertilizer applications to smooth cordgrass in moderate wave energy sandy areas increased net production135-860%. Net production of smooth cordgrass in the unfertilized dredged material area was similar to that in the fertilized sandy areas.

Macrobenthos invaded the dredged material area rapidly. After only three months, intertidal macrobenthos at the transplant site was as dense as that in the nearby natural marsh. There were four dominant taxa which accounted for about 90% of the intertidal macrobenthos by number: *Laeonereis culveri, Macoma balthica, Tubulanus pellucidus,* and Tubificid oligochaetes. Densities of macrobenthos tended to increase with time of inundation, i.e. from MHW to subtidal regions.

The use of peat pot plants in transplanting was recommended. This technique extends the planting season, reduces impacts on natural donor marshes, and allows transplant preparation. An important factor in transplant preparation is the acclimation of plants to site specific salinities prior to transplanting.

Hardaway, C. S., G. R. Thomas, B. K. Fowler, C. L. Hill, J. E. Frye, and N. A. Ibison. "Results of the vegetative erosion control project in the Virginia Chesapeake Bay system." In: Proceedings of the twelfth annual conference on wetlands restoration and creation, in Tampa, FL, ed. F. J. Webb, Jr. Tampa, FL: Hillsborough Community College, 144-158, 1985.

This paper reports some of the results of the Vegetative Erosion Control Project conducted by the Virginia Institute of Marine Sciences. This was a study of 24 marsh plantings in the Chesapeake Bay system in Virginia. Sites were chosen to maximize diversity of conditions, mainly fetch and direction faced by the marsh. *Spartina alterniflora* was planted on 0.5-m centers from MHW to just below MSL. *Spartina patens* was planted above *S. alterniflora* at several sites. Osmocote fertilizer, a slow time-release type, was used; 30 ml was placed in the hole when each culm was planted. Osmocote was also broadcast into the marsh later when plants had started growing.

Results showed a fringe of marsh grass could be established with little or no maintenance on low energy shorelines, areas where the fetch was less than 1.8 km. Where wave energy was moderate (1.8-6.3 km fetch), the upper margin of the fringe marsh should be protected by establishing *S. patens* to trap sand and sediments, and preserve the back area from winter storm erosion. Areas with average fetches of 6.3-10 km need to be protected by a wave stilling device (breakwater). Fringe marshes should not be considered for beaches with average fetches greater than 10 km unless the beach is protected by a headland or spit. Also, maintenance planting of wash-out and die-back areas of the marshes should be required and anticipated.

Hartman, R. D., R. N. Reubsamen, P. M. Jones, and J. L. Koellen. "The National Marine Fisheries Service habitat conservation efforts in Louisiana, 1980 through 1990." Mar. Fish. Rev. 54 (1993): 11-20.

This article reviews the NMFS efforts to conserve habitat for fisheries and associated organisms in Louisiana from 1980 through 1990. During these years, NMFS reviewed 14,259 public notices to dredge, fill, or impound wetlands in Louisiana. The Habitat Conservation Division (HCD) of NMFS provided recommendations to the Corps of Engineers on 962 permit projects which would impact 240,000 ha of tidal influenced wetlands. Avoidance was recommended for about 113,000 ha, and mitigation was recommended for 63,5000 ha. Revisions or denials were recommended by HCD on only 12% of all proposed actions. The remaining permit applications were considered to have only minor impacts on marine fisheries. On a permit basis, 43% of HCD recommendations were accepted by the Corps, 34% were partially accepted, and 23% were rejected. Most of the permits involved oil and gas activities, followed by shoreline modifications, and then pipeline activities. A breakdown of permits and areas involved was given by drainage basins.

There is a need for greater awareness of coastal wetland loss through the Corp's Section 10/404 permitting program. An accurate continuing account of permitted wetland alterations and mitigation measures is needed to guide future decisions that will help preserve this important habitat.

Hoffman, W. E. and J. A. Rodgers. "A cost/benefit analysis of two large coastal plantings in Tampa Bay, Florida." In: Proceedings of the seventh annual conference on wetlands restoration and creation, in Tampa, FL, ed. D. P. Cole, Tampa, FL: Hillsborough Community College, 265-278, 1980.

This study compared costs of establishing a *Spartina alterniflora* marsh to those of establishing a mangrove stand. On the dredged material extension of Sunken Island in Hillsborough Bay of the Tampa Bay system, Florida, a 1.64 ha area was planted with smooth cordgrass using 12-cm diameter plugs planted in rows on 1.0-m centers with the rows being 2 m apart. This effort required 995 man-hours/ha, and a total cost of about $4,565/ha. About 93% survival was obtained, and after 14 months the plants had spread enough to almost hide the original planting layout. The mangrove planting was on a 0.52 ha plot on another dredged material island called CDA-D, also in Hillsborough Bay. Here *Avicennia germinans* (63%) and *Laguncularia racemosa* (37%) were planted on 2-m centers. Transplants were 30-190 cm tall. Survival was about 73% after 13 months. This planting required about 2541 man-hours/ha, and a total cost of about $11,459/ha. Labor costs were about 70% of the total cost of each planting, but did not include planning and supervision.

An interesting point made in this study was that the *Spartina* donor marsh had fully recovered within 12 months. Plants had been removed from the donor marsh at about 1 plug/m^2. Another feature that was unusual was the clipping of the cordgrass to leave only 10 cm above the substrate once the stems had been transplanted. Clipping was done to reduce transpiration and possible shock due to root damage. Impacts on mangrove donor stands can be longer lasting, but no particular mention was made of this study's donor stand.

Josselyn, M. J., ed. Wetland restoration and enhancement in California. La Jolla, CA: California Sea Grant College Program, 1982.

This report includes eight presentations presented at a California wetlands restoration workshop held in February 1982 at the California State University, Hayward, CA. Seven of the presentations were followed by panel and audience discussions through which concerns about restoration gains and losses were voiced. Presentations reviewed past, current and future wetland restoration actions and potentials including development of regional wetland restoration goals and legal (and institutional) constraints. Design strategy, engineering features of circulation, sedimentation and water quality, techniques for restoring vegetation and for monitoring were also presented and discussed. Poster session abstracts and an ample bibliography were also valuable inclusions.

Many of the problems and concerns voiced at this workshop are still valid though a decade has passed. It appears there will always be confrontation between ecological action to preserve a clean environment and the lure of economic riches possible through residential and municipal development of wetlands.

Josselyn, M. N., J. B. Zedler, and T. Griswold. "Wetland mitigation along the Pacific coast of the United States." In: Wetland creation and restoration: The status of the Science, Part 1, Regional review., eds. J. A. Kusler and M. E. Kentula. 1-36. Washington, DC: Island Press, 1989.

This article reviews west coast wetland types, reviews considerations that aid in making restorations successful, and reviews the kinds of projects that have been done. Some critical features of restoration plans are described, including: site history, topography, water control structures, hydrology, flood events, sediment budget, edaphic characteristics, existing wetland characteristics (vegetation and wildlife), and adjacent site features and conditions. Two levels of monitoring are recommended: (1) the enforcement monitoring to make certain implementation is following permit requirements, and (2) environmental monitoring to see if the design was correct and the functions are being realized. Several restoration projects are profiled including successes and significant findings.

Kentula, M. E., R. P. Brooks, S. E. Gwin, C. C. Holland, A. D. Sherman, and J. C. Sifneos. An Approach to Improving Decision Making in Wetland Restoration and Creation. Corvallis, OR: U.S. Environmental Protection Agency, Environmental Research Laboratory, 1992.

The objective of this book is to provide a guide that assists people in conserving, restoring, and creating wetlands successfully. The book presents a technique for analyzing an area of the country to determine types and amounts of existing wetlands, and the types of wetlands needed. An approach for their successful restoration or creation of wetlands is recommended along with variables to be monitored to determine the least harmful environmental impacts and best chances for project success.

Restoration projects should include: (1) precise objectives, (2) detailed plans including scheduled actions, (3) detailed maps or diagrams of the site, and (4) a checklist of variables to be monitored. Variables that should be monitored relate to morphometry, hydrology, substrate, vegetation, fauna, and sometimes water quality.

The authors also recommended the establishment of a permanent database that contains the important information for evaluating the success of each project. Data suggested to be entered regarding each project included: permitting agency, permit number, date of permit, type of mitigation, location of the mitigation site (state, county, city and address), date construction began, date construction was completed, map showing the as-built conditions, name of the contractor/builder, name of the contracting company, and specific objectives of the project. Entries should be included for mid-course evaluation of the construction and for corrections made based on the evaluation. Entries should also be included that describe conditions found during a final evaluation after planting was completed. Additional data to add would be expected to come from monitoring reports that evaluate the development of the plant and animal communities in the wetland at various intervals (six months to a year) after planting was completed.

Kiraly, S. J., F. A. Cross, and J. D. Buffington. The federal effort to evaluate coastal wetland mitigation: A report by the National Ocean Pollution Policy board's habitat loss and modification working group. NOAA Technical Memorandum CS/NOPPO 91-2. 10 p. plus Appendices., 1991.

This report summarizes results of a workshop on wetland mitigation, held at San Diego State University in January 1991. Federal efforts to evaluate coastal wetland mitigation were assessed including analyses of functional values in created wetlands and follow-up studies for federally-permitted mitigation projects. Conclusions were that federal efforts in these areas should be improved. Additional research should be conducted on understanding how coastal wetland ecosystems function. A system should also be established for evaluating the success (including functional success) of permitted mitigation projects.

Knutson, P. L., R. A. Brochu, W. N. Seelig, and M. Inskeep. "Wave damping in *Spartina alterniflora* marshes." Wetlands 2 (1982): 87-104.

Field experiments were conducted to test a model of wave damping and to determine how well a marsh can dampen waves. The model has been used to explain how a marsh damps waves and reduces waves' erosional forces. Two *Spartina alterniflora* marshes in Chesapeake Bay in Virginia were chosen as test sites: Wescoat Cove north shore marsh

(the oldest known man-made cordgrass marsh, planted in 1928 by Mr. Wescoat) and Kings Creek north shore marsh. The marsh vegetation was characterized by clipping 0.25 m^2 areas of vegetation out of the marsh where each sensor was to be placed. Stem density, length and thickness ranged from about 180-350 stems/m^2, 20-30 cm (stem length was about half the plant's total height), and 5-6 mm in diameter, respectively. In each marsh, wave sensors were placed along a transect. Sensors were placed at the seaward edge and 2.5, 5, 10, 20 or 30 m in towards shore. The research vessel, Virginia Dare, generated waves for the tests; waves ranged in height from 0.06-0.30 m. Controls were run on an adjacent non-vegetated beach.

Analyses indicated the model worked well, only requiring minor changes in the coefficients to adjust for the plants. Results also showed the marshes significantly reduced wave height and erosional energy. Wave height was reduced by about 50% within the first 5 m of marsh, and by about 95% after crossing 30 m of marsh. Wave energy was reduced in these cases by 65% and nearly 100%, respectively.

In theory, marshes are most effective at damping waves when waves were less than plant height (the condition during the tests) but would not be during storm tides. Under storm conditions, when water levels rise and waves frequently exceed plant height, marshes would be less effective against erosion by waves.

Knutson, P. L., J. C. Ford, M. R. Inskeep, and J. Oyler. "National survey of planted salt marshes (vegetative stabilization and wave stress)." Wetlands 1 (1981): 129-157.

This study describes a technique for evaluating a coastal site's potential for vegetative stabilization based on the site's shoreline characteristics that relate to wave-climate severity. Results were based on the study of 104 salt marsh plantings in 12 coastal states. All marshes studied were exposed to wind waves, were located in brackish and salt water environments, were planted with *Spartina alterniflora* or *S. foliosa* at least one year prior to the survey, and had no rubble or man-made structures in the planted areas.

Results of correlation analyses indicated that sediment grain size in the swash zone, longest or average fetch, and shore configuration were useful indicators of a site's suitability for vegetative stabilization. There was an 80% success rate in establishing a fringe marsh when sediment grain size was 0.4 mm or less, and there was an 80% failure rate when sediment grain size was 0.8 mm or greater. Failures increased when fetches increased. Successes increased as protection increased, with the greatest success rate found in coves. Another recommendation was that the site should have at least 6 m of intertidal width and be planted over 60% of this area; this should cause sufficient wave dampening to prevent erosion during most of the year. On the basis of these observations, a site evaluation form was developed to predict the success of a *Spartina* planting to control an area's erosion. This form was named the Vegetative Stabilization Site Evaluation Form.

Kraus, D. B. and M. L. Kraus. "The establishment of a fiddler crab (*Uca minax*) colony on a manmade *Spartina* mitigation marsh, and its effect on invertebrate colonization." In: National wetland symposium: mitigation of impacts and losses in Berne, NY, eds. J. A. Kusler, M. L. Quammen, and G. Brooks, Berne, NY: Assoc. State Wetland Managers, 343-348, 1986.

The objective of this study was to establish fiddler crab populations in a man-made *Spartina alterniflora* marsh at the Mills Creek mitigation site, and to compare the macrobenthos at this marsh with that in a natural marsh area on Sawmill Creek, both in the Hackensack River basin in northeast New Jersey. Fiddler crabs (*Uca minax*) were collected from a colony at Moonachie Creek (also in the Hackensack River basin), transported to the test sites (7-m^2 sites in the developing marsh), and deposited one crab per artificial burrow during 29-30 May 1986. Artificial burrows were made about 50 cm deep on 25-cm centers using a broom handle. Censuses of the number of burrows, types of burrows, and crabs seen in each of the two test sites (= colonies) were made in June, July, August and September. Benthic macrofauna were sampled at each colony, two control sites (30 m to the side of each colony), and in a *Phragmites* marsh using a bulb corer (300 ml) to a depth of 10 cm. Replicates were taken in May (before the crabs), June, July and September. Animals were separated from the cores using a 1 mm mesh sieve.

Results of censuses showed that many of the crabs remained in each test site, forming two colonies. One month after transplanting the crabs, about 42% of the burrows were occupied. A month later a few additional burrows were noted, and the presence of small burrows indicated that recruitment may have occurred. By September, colony densities achieved those of natural colonies elsewhere in NJ. Benthic macroinvertebrates were five to ten times more abundant in the developing marsh and natural marsh than in the crab colonies or in the *Phragmites* marsh. Although sampling was not robust, fiddler crabs appeared to decrease the number of benthic invertebrates in the substrate of the colonies, perhaps through predation.

Kruczynski, W. L. "Salt marshes of the northeastern Gulf of Mexico." In: Creation and restoration of coastal plant communities, ed. R. R. Lewis, III. 71-88. Boca Raton, FL: CRC Press, Inc., 1982.

Salt marshes along the northeast coast of the Gulf of Mexico are generally similar to those along the Atlantic coast and the rest of the Gulf coast. However, *Juncus roemerianus* is more important along the northeast coast where it displaces much of the *Spartina alterniflora* normally found in the intermediate marsh. Descriptions of marshes in the northeast Gulf include marsh plant zonation and productivity, marsh animal communities, and marsh destruction. Salt marsh creation activities are summarized, as are the related uses of the various dominant plant species for restoration purposes. Species reviewed are: *Spartina alterniflora, Spartina patens, Spartina cynosuroides, J. roemerianus, Distichlis spicata, Phragmites communis, Panicum repens, Panicum amarum, Uniola paniculata,* and *Ammophila breviligulata*. Although *Juncus* is an important species in natural marshes of this area, it is not easily transplanted. Best success has been achieved by transplanting clumps of *Juncus*, rather than single sprigs.

Additional information was given on handling transplant materials, use of fertilizers, planting methods, and factors affecting successful establishment of a transplanted marsh. The most important factors to consider for success were erosion control (water and wind) and soil characteristics (soil water, soil salinity, and soil nutrients).

Kusler, J. A. and M. E. Kentula, eds. Wetland Creation and Restoration, The Status of the Science, Washington, DC: Island Press, 1989.

This book is a collection of chapters that summarize the status of the restoration science for various wetland types. The executive summary describes the adequacy of our scientific understanding concerning wetland restoration and creation, offers recommendations for needed scientific research to fill the information pages, and gives recommendations to wetland managers as to restoration and creation potential based on current scientific knowledge.

Scientific knowledge and data has been developing, but much is still unknown. Some blame should be placed on poorly specified goals and the lack of monitoring for many of the early, and even current, restoration/creation projects. Some wetlands appear to be easier to restore than others, as are some of the wetland functions. Rarely is a restoration a complete success, with all functions of a natural system being obtained, but partial successes that restore some of the wetland functions are beneficial and may lead to additional functional development in the future. The long term success of a wetland restoration is even more uncertain than the short term success. Both often depend upon our abilities to manipulate the site and its surrounding land, to maintain close supervision during all phases of a project, and to keep pests and intruders away from sensitive areas. Fourteen recommendations are offered to wetland managers to assist them in creating and maintaining wetlands:

1. Wetland restoration must be viewed with some cynicism, particularly where promises are made to create a natural system in exchange for a permit to destroy or degrade a natural system that already exists.
2. Multidisciplinary expertise in planning and project supervision is needed in all project phases.
3. Clear, site-specific project goals should be established first.
4. A detailed plan concerning all phases of a project should be prepared in advance to help regulatory agencies evaluate the probability and achievement of success.
5. Site-specific studies should be done for the original system prior to wetland alteration.
6. Careful attention to wetland hydrology is needed in the project design.
7. Wetlands should be designed to be self-sustaining systems and persistent features in the landscape.
8. Wetland design should consider relationships of the wetland to water sources, other wetlands in the watershed, and adjacent upland and deep water habitats.
9. Buffers, barriers, and other protective measures are often needed for a successful restoration or creation of a wetland.
10. Restoration should be favored over creation.
11. A project should incorporated monitoring and methods for mid-course corrections when needed.
12. Long term management is needed for some types of wetland systems.
13. Risks inherent in restoration and creation of wetlands should be carefully evaluated and be reflected in project design.
14. Restoration action for artificial or already altered systems requires special evaluation as to regional needs.

Landin, M. C. and J. W. Webb, Jr. "Wetland development and restoration as part of Corps of Engineer programs: Case studies." In: National Wetland Symposium: Mitigation of Impacts and Losses, in New Orleans, LA, eds. J. A. Kusler, M. Quammen, and G. Brooks, New Orleans, LA: Association of State Wetland Managers, 388-391, 1986.

This paper presents an overview of the Corps of Engineers' work to use dredged material constructively, generally to create, restore or enhance wetlands. It also presents short reviews of seven projects. Since about 1970, over 130 wetland sites have been constructed using dredged material. Many of the sites were in coastal saline and brackish waters. Sites ranged in size from 0.4 to thousands of hectares. Results showed that most man-made wetlands were at least partially successful. These wetlands required about 3-5 years to develop into habitats comparable to natural marshes. Although above-ground vegetation generally could be established in the marshes within a couple of growing seasons, sediment organics and root biomass required more time, perhaps 10 years or more, to approach the conditions found in neighboring natural marshes.

Langis, R., M. Zalejko, and J. B. Zedler. "Nitrogen assessments in a constructed and a natural salt marsh of San-Diego Bay." Ecological Applications 1 (1991): 40-51.

Differences in nitrogen content in soil, soil water, and plant stems and leaves. were studied at a natural marsh (Paradise Creek) and a man-made marsh (Connector Marsh) in the San Diego Bay area, CA. Soil N pools and organic carbon were lower in the constructed marsh than in the adjacent natural marsh. Above-ground biomass and foliar N of *Spartina foliosa* were also lower in the constructed marsh. Rates of N fixation were lower in the surface (1-cm) sediments of the constructed marsh than the natural marsh, but not in the deeper sediments (down to 10 cm). Addition of organic matter to the soil increased N fixation rates in both marshes, more so when glucose was used than when ground-up dry *Spartina* plants were used. Nitrogen mineralization rates were high in both marshes. Results in general pointed to low import of nitrogen from tidal or stream flows, and high nitrogen demands by the marsh plants and ecosystem. Without a source of organics and nitrogen, constructed marshes will take a long time to develop production equivalent to natural marshes in the San Diego Bay area; longer perhaps than was estimated for Gulf and Atlantic coastal created marshes with *Spartina alterniflora* and *S. patens*.

LaPerriere, A. J. and M. M. Farmer. "Recent wetland restoration/creation actions in the New York District." In: Proceedings of the sixteenth annual conference on wetlands restoration and creation, in Plant City, FL., ed. F. J. Webb, Jr. Plant City, FL.: Hillsborough Community College, pp. 97-108, 1989.

Preliminary results of four New York District Corps of Engineers enforcement actions resulting in the restoration of one palustrine and three saltwater marshes are reported. The three saltmarsh restorations involved illegal fill being removed from sites in south central Long Island. At Site 1 (2.2 ha), the fill was removed within a few weeks of deposition, and was removed carefully so that about 25% of the original root mat was left intact and alive. At Site 2 (0.5 ha), the fill was removed a year after deposition, and all marsh plants and root matter had died. At Site 3 (0.04 ha), fill was removed two months after deposition, but conditions were such that the marsh was dead by the time removal was complete. At all three sites, substrate elevations matching those present prior to filling were carefully restored and the areas were allowed to revegetate naturally.

Revegetation was estimated subjectively to be 50% coverage during the first growing season at Site 1. During the second growing season, transects with 1-m^2 plots established at 30.5-m intervals were established in each site. Percentage cover by each plant species was estimated and all were summed for a total coverage percentage. Percentages of total cover for Site 2 and Site 3 after one growing season were about 37%. For Site 1 after two growing seasons, total cover was about 67%.

This paper showed how enforcement of wetland regulations, coupled with planned restorative action, can be effective. It also showed that in some cases, expensive transplanting operations may not always be necessary.

LaSalle, M. W., M. C. Landin, and J. G. Sims. "Evaluation of the flora and fauna of a *Spartina alterniflora* marsh established on dredged material in Winyah Bay, South Carolina." Wetlands 11 (1991): 191-208.

The objectives of this study were to compare floral and faunal characteristics of 4 and 8 year old *Spartina alterniflora* marshes that developed naturally on unconfined dredged material deposited in Winyah Bay, SC. Both marshes were tall form *S. alterniflora*, and samples were collected in September of 1988. Most samples were collected at 10 randomly chosen sites along a 50-m transect in each marsh. Above-ground vegetative characteristics were assessed from a 0.25 m^2 quadrat at each site. Sediment, benthos, and below-ground biomass were sampled by coring at these sites. Large (1 to 2 cm) macrobenthos were collected from adjacent 1 m^2 quadrats. Fish, shrimp and crabs were collected only in the 4-yr old marsh with Breder traps and block nets.

Marsh sediments were similar, and substrata were mainly silts and clays. The percent organics in all sediments examined was about 11%. Percent cover by *Spartina alterniflora* was about 50% in both marshes. Stem density (257 vs. 199 stems/m^2), below-ground biomass (3061 vs. 2204 g/m^2) and total biomass (3692 vs. 3061 g/m^2) were greater in the older marsh, but stem height (40 vs. 66 cm) and above-ground biomass (631 vs. 856 g/m^2) were greater in the younger marsh.

Total density of benthic macrofauna from sediment cores was significantly greater in the 8-yr old marsh compared with the 4-yr old marsh, with mean values of 150 vs. 35 organisms/75 cm^2. Species composition in the two marshes was similar, and the infauna was dominated by oligochaetes. Differences in infaunal density between the two marshes were attributed to marsh age, although the authors acknowledged that other factors such as distance to open water may have affected the populations.

The fish and shellfish collected from the 4-yr old marsh in Breder traps were typical estuarine fauna reported by others for the natural marshes in Georgia and North Carolina. The mummichog, *Fundulus heteroclitus*, and the daggerblade grass shrimp, *Palaemonetes pugio*, were the dominants. Block net data were not presented, but apparently confirmed that large numbers of mummichogs and daggerblade grass shrimp were present in the marsh channels along with blue crabs, *Callinectes sapidus*. Gut contents from mummichogs indicated that *Uca* and insects were dominant prey items.

Lewis, R. R., III. "Creation and restoration of coastal plain wetlands in Florida." In: Wetland creation and restoration: The status of the Science. Part 1. Regional review., eds. J. A. Kusler and M. E. Kentula. 73-102. Washington, DC: Island Press, 1989.

This chapter reviews past activities related to salt marsh and mangrove restoration in Florida. Restoration and creation projects were generally initiated to mitigate destruction of natural wetlands, to enhance existing habitat, and to stabilize eroding shorelines. Despite hundreds of restoration and creation efforts, there are few reports from which to draw information to make restorations a science rather than an art. The more successful projects had paid attention to many factors including: location, wave climate, tidal range, salinity, shading, time of planting, substrate quality, condition of the transplants, buffer zones, and monitoring with mid-course corrections if needed. On the basis of critical review of projects and of the sparse literature, five factors appeared to be the most important to successful restorations: correct elevation, adequate drainage, protection from wave damage, appropriate plant material, and protection from human impacts. Future needs are seen as: a centralized data bank for restoration projects, research on natural recruitment versus transplanting, rates of faunal recruitment to restoration sites, and regional planning for restorations.

Lewis, R. R., III. "Wetlands restoration/creation/enhancement terminology: suggestions for standardization." In: Wetland creation and restoration: The status of the Science. Part 2. Perspectives., eds. J. A. Kusler and M. E. Kentula. 417-419. Washington, DC: Island Press, 1989.

This document provides a glossary of terms frequently used in restoration, creation, and enhancement research. The terms defined are: mitigation, mitigation banking, restoration, creation, enhancement, and success. Restoration is defined as "returned from a disturbed or totally altered condition to a previously existing natural, or altered condition by some action of man." Creation is defined as "the conversion of a persistent non-wetland area into a wetland through some activity of man." Enhancement is defined as "the increase in one or more values of all or a portion of an existing wetland by man's activities, often with the accompanying decline in other wetland values."

Lewis, R. R., III. "Coastal habitat restoration as a fishery management tool." In: Stemming the tide of coastal fish habitat loss., ed. R. H. Stroud. Savannah: National Coalition for Marine Conservation, Inc., 1992.

In response to declines in both the commercial and recreational harvests of fishery species, a number of fishery management tools have been proposed and implemented. In the past, management methods concentrated on increasing survival of late juveniles and adults to restore or increase egg production. In recent years, methods which increase the survival of larval and juvenile fishes came to be considered more important to a species' reproductive success than egg production. Coastal wetland restoration is one such method, particularly for those estuarine-dependent species whose life histories include a resident period in shallow low-salinity marine habitats. A summary of the use of coastal restoration in past studies shows both its importance as a management tool, and the paucity of published information concerning its use. This lack of information is another reason that wetlands restoration is not generally listed or used as a fishery management tool. Another is the belief that restored wetlands can not reach a productive level equivalent to natural wetlands. Despite this generally negative attitude, restoration of coastal wetlands is generally acknowledged as being more predictable and assured of success if done correctly. Reviews of past projects show fish and wildlife populations closely approximating those found in natural wetlands, and suggest that this is an underutilized fishery management tool.

Lewis, R. R., III and C. S. Lewis. "Tidal marsh creation on dredged material in Tampa Bay, Florida." In: Proceedings of the fourth annual conference on restoration of coastal vegetation in Florida, in Tampa, FL, eds. R. R. Lewis, III and D. Cole, Tampa, FL: Hillsborough Community College, 45-67, 1977.

Three experimental plantings of smooth cordgrass, *Spartina alterniflora*, were done on a 12 year old dredged material island in Tampa Bay, Florida. The tests were to assist in developing marsh creation techniques.

In the first planting, 36 single stems were dug from an adjacent natural marsh and planted in six rows of six plants on 1.0-m centers. The substrate was uneven and the elevation of the planted plot ranged from 49 to 61 cm above MLW, or just a little lower than the natural marsh (58-64 cm above MLW). Planting was in September, 1976, and the test area was well protected from waves and had a gentle slope. About 91% of the transplants survived and increased so that nine months later there were 267 stems. The control area showed no volunteer establishment of *Spartina alterniflora* during the course of this study.

The second planting was adjacent to the first. It involved only 15 seedlings sent to Tampa. The seedlings had been grown in Maryland from seeds harvested near Assateague Island, Virginia. The seeds were germinated and raised by Environmental Concern, Inc. in Maryland. These seedlings were also planted in October, 1976, on 1.0-m centers. No details of survival percentages were given, but eight months later there were 331 stems.

The donor marsh for the first planting went into flower in November, and 237,000 spikelets were harvested and shipped to Environmental Concern, Inc. Eleven percent of the spikelets contained seeds, and 63% of the seeds germinated. Many of the seedlings produced were sent back to Tampa Bay for the third planting experiment. The 500 healthiest (=tallest) seedlings were planted on 1.0-m centers in another area adjacent to the previous planting. This planting was in May, 1977. One month later there appeared to be at least 90% survival.

The successful establishment of cordgrass on the island showed that a salt marsh could be established much more rapidly if assisted by transplanting. In addition the study showed that a northern variety of smooth cordgrass could be successfully transplanted in Florida. The experiments also showed planting could be successful even in the fall in Florida, probably because of the year-round warm weather. In photographs the plants appeared to be sparse and short, even in the natural marsh, but no mention was made of these features in the paper.

Lindall, W. N., Jr. and G. W. Thayer. "Quantification of National Marine Fisheries Service habitat conservation efforts in the southeast region of the United States." Mar. Fish. Rev. 44 (1982): 18-22.

The objectives of this study were to determine how many acres of coastal marsh were impacted by permitted alterations in the southeastern U.S. in a year, and to determine to what extent National Marine Fisheries Service's recommendations to protect this coastal habitat were being followed. From Oct. 1980 through Sept. 1981, there were 6,399 permit applications from the Corps of Engineers available for review by NMFS in the Southeast. The permits covered about 1,300 ha to be dredged, 2,590 ha to be filled, and 3,360 ha to be impounded. NMFS did not object to about 73% of the desired alteration after preliminary review showed they involved only minor alterations to wetlands. NMFS contracted 1,380 permit applications for thorough review, and did not assess 368 permit applications. Of the 7,272 ha in the 1,380 permits thoroughly reviewed, NMFS objected to alteration of 5,412 ha, but did not object to 1,860 ha being altered provided there was mitigation involving 1,012 ha of restoration and 324 ha of creation to reduce the loss of wetlands.

Almost all (98%) of the recommendations submitted by NMFS were incorporated in the permits by the Corps of Engineers, however, only 72% of these were complied with by permitees. Even though the study did not tell the percentage (by area) of wetlands that were preserved or improved, and did not evaluate the losses of wetlands from permitted activities versus non-permitted activities, it did show NMFS was effective in protecting a substantial amount of the country's coastal wetlands. The article also showed, however, that in one year in the southeast at least 524 ha of coastal wetlands were lost through the permitting process.

Lindau, C. W. and L. R. Hossner. "Substrate characterization of an experimental marsh and three natural marshes." Soil Science, American Journal **45 (1981): 1171-1176.**

Changes were monitored in selected chemical and physical properties of dredged material used in the construction of a coastal marsh. Substrate properties were also compared with those of three natural marshes, all in the Galveston Bay area, Texas. The dredged material in all three elevational tiers at the transplant site contained about 97% sand, 2% clay, and 1% organic matter at the start of the study. Sixteen months later, the lowest tier had been covered by 2-30 cm of fine particles that had settled out of the water column due to a breakwater that had been constructed to protect the site from wave impacts. Baseline cores showed that organic matter, cation exchange capacity (CEC), total Kjeldahl nitrogen (TKN), and extractable phosphorus values were low, and nitrate and nitrite concentration were below detectable values. Ammonium was detected in half of the core samples, never exceeding 2.0 mg N/g. The clay content, CEC, TKN, extr-P, and sulfide values were highly variable due to the heterogeneity of the graded dredged material.

The intertidal and supratidal zones in the dredged material area were planted with *Spartina alterniflora, S. patens* and some other species. Trends of increasing concentrations of TKN, ammonium-N, organic matter, and extr-P, were found over the three post-planting samplings. These changes were mainly found in the lowest tier where most of the particulate matter accreted. Even with the increases found in the nutrients, their values were well below those for the natural marshes. Data suggest that concentrations of nutrients at the transplant site should approach those of the natural sites in a total of 2 to 5 years after

planting. The study also indicated that substrate concentrations of N and P did not show a response to the surface applications of fertilizer.

Lindau, C. W. and L. R. Hossner. "Sediment fractionation of Cu, Ni, Zn, Cr, Mn, and Fe in one experimental and three natural marshes." Journal of Environmental Quality 11 (1982): 540-545.

Clay mineralogical properties of a planted *Spartina alterniflora* marsh were compared with those of three natural marshes, all in the Galveston Bay area, Texas. At the transplanted marsh site the dredged material in all three elevational tiers sampled, contained about 97% sand, 2% clay, and 1% organic matter. A sequential chemical extraction procedure was used to obtain the concentration of the metals. Clay minerals found in the sediments of the experimental marsh were not significantly different form those in the natural marshes. Total elemental substrate concentrations of Cu, Ni, Cr, Zn, Mn and Fe averaged 7.9, 8.6, 25.5, 25.2, 123, and 12,200 ug/g, respectively, for the four marshes. About 30% of the total substrate Cu, Ni, and Zn was associated with the organic matter fraction in these marshes. About 53% of the experimental marsh Mn was associated with the easily reducible fraction, compared with only 11% in the natural marshes. Iron associated with the organic matter and sulfide fraction of the experimental marsh was about 10% lower than that for the natural marshes. The likelihood of heavy metals reaching toxic levels appears to be very low for these marshes.

Lyon, J. T., III. "A comparison of epiphytes on natural and planted *Spartina alterniflora* marshes." M.S. Thesis, North Carolina State University, 1975.

Epiphytic algae growing on stems of *Spartina alterniflora* were compared between two created salt marshes and nearby natural marshes at Beaufort and Snow's Cut, North Carolina. Comparisons were made through standing crop estimates and laboratory ^{14}C uptake rates. Neither standing crop nor primary production varied consistently between transplanted and natural marshes. The age of stems and the marsh elevation appeared to be more important than whether the marsh was transplanted in determining epiphyte growth.

Mager, A. and G. W. Thayer. "NMFS habitat conservation efforts in the Southeast Region of the United States from 1981 through 1985." Marine Fisheries Review 48 (1986): 1-8.

The U.S. Army Corps of Engineers (COE) in the southeastern region of the United States regulates development activities affecting thousands of acres of wetlands every year. The National Marine Fisheries Service (NMFS) makes recommendations to the COE that are designed to minimize the effect of these projects on wetland resources. The NMFS Habitat Conservation Division's Southeast Region quantifies those COE projects relating to water development in the Southeast Region of the United States in a computerized system that tracks permit recommendations and proposed habitat alterations. This project was begun in late 1980, and the first five years of data are summarized. Such data are necessary in order to maintain a comprehensive view of wetlands modification to determine cumulative loss of habitat. This information is necessary to prevent avoidable damages to fisheries production and judge the effectiveness of the NMFS recommendations.

NMFS recommendations on permit applications are made by the Southeast Regional Office and its area offices, but are dependent on up-to-date research information provided by research laboratories of the Southeast Fisheries Center. The close links between these facilities and NMFS fisheries habitat conservation efforts are described.

Meyer, D. L., M. S. Fonseca, D. R. Colby, W. J. Kenworthy, and G. W. Thayer. "An examination of created marsh and seagrass utilization by living marine resources." In: <u>Coastal Zone '93, Volume 2, Proceedings of the 8th Symposium on Coastal and Ocean Management.</u>, eds. O. Magoon, W. S. Wilson, H. Converse, and L. T. Tobin. 1858-1863. New York.: American Society Of Civil Engineers, 1993.

This paper summarizes the results of a study where fish, shrimp, and crab utilization of planted and natural *Spartina alterniflora* marshes and *Halodule wrightii - Zostera marina* seagrass beds was evaluated. Initially, *S. alterniflora* was planted in 1987 at three dredged-material sites in North Carolina in solid and reticulated (with access channels) patterns. By 1992, however, the marsh had coalesced into a solid vegetative stand. Habitat heterogeneity was then added by placing oyster cultch along certain areas of the marsh shoreline. Fishery utilization of the created marshes and nearby natural marsh was examined from 1987 through 1989 by the use of block and fyke nets that collected animals retreating off the marsh surface with the ebb tide.

Density data were presented from three collections of fisheries organisms made in the two years following transplanting. The overall mean density of shrimp (mainly daggerblade grass shrimp and brown shrimp) was 3.1 times as large in the natural reference marsh as in the planted marshes, but differences were not significant apparently due to high sample variability. Mean crab densities (mainly blue crabs) were twice as high in the planted marshes compared with the natural marsh, but again this difference was not statistically significant. Fishes collected included spot, mummichog, pinfish, and pigfish, and the mean density for total fish was twice as high in the natural marsh as in the created marshes. This difference was statistically significant during two of the three sampling periods. The results of this study highlight the difficulties encountered in collecting quantitative data from marsh surfaces in order to assess fishery utilization patterns in natural and created salt marshes.

The effect of depositing oyster cultch along the marsh shoreline was examined 3 months after cultch placement. Oysters, xanthid crabs, amphipods, and other reef organisms were found inhabiting this cultch. This addition appeared to increase animal diversity in the marsh because few of these organisms were collected in marsh areas where cultch was not added.

Miller, L., G. T. Auble, and K. A. Schneller-McDonald. "User's guide to the wetland creation/restoration data base, version 2." Wash. D.C.: U.S. Dept. Inter., Fish and Wildlife Service, Research and Development. 1991.

This is a guide to assist users in accessing a very large annotated bibliographical database about all types of wetland restorations and creations, and related topics. The guide facilitates finding articles about selected subjects in the database. The database (Wetland Creation/Restoration Data Base) contains about 500 entries referring to *Spartina alterniflora*, and should be of use to researchers.

Minello, T. J. and J. W. Webb, Jr. "The development of fishery habitat value in created salt marshes." In: Coastal Zone '93, Volume 2. Proceedings of the 8th Symposium on Coastal and Ocean Management., eds. O. Magoon, W. S. Wilson, H. Converse, and L. T. Tobin. 1864-1865. New York: American Society Of Civil Engineers, 1993.

This short paper describes preliminary results from a Coastal Ocean Program project in Galveston Bay, Texas, designed to compare ten created *Spartina alterniflora* marshes with five natural marshes. The created marshes were mainly transplanted on dredged material and ranged in age from 3 to 15 years at the time of sampling (fall 1990, spring 1991). Compared with natural marshes, above-ground plant biomass was equal or higher in most created marshes while below-ground biomass and sediment organic content was consistently lower in created marshes. Densities of juvenile fishery species within the marsh vegetation were estimated using a drop enclosure. Grass shrimp, commercial penaeid shrimp, blue crabs, pinfish, and gobies predominated. Created marshes generally supported lower numbers of natant macrofauna, especially juvenile brown shrimp, white shrimp, and blue crabs. Preliminary results from a caging study in the marshes indicated that growth rates of juvenile brown shrimp were similar in created and natural marshes, but survival in cages was significantly lower in created marshes than in natural marshes. A predator exclosure study in the marshes suggested production of benthic annelids was greater in natural marshes. There was little evidence in any of the results to indicate that utilization and value of the created marshes was increasing based solely on marsh age.

Minello, T. J. and R. J. Zimmerman. "Utilization of natural and transplanted Texas salt marshes by fish and decapod crustaceans." Marine Ecology Progress Series 90 (1992): 273-285.

The objective of this study was to compare three transplanted *Spartina alterniflora* salt marshes (2-5 years in age) with adjacent natural marshes on the Texas coast. Samples were collected only in the spring, limiting conclusions to this season, but the use of replicate marshes allowed a test of the null hypothesis that transplanted marshes on the Texas coast were equivalent to natural marshes. Quantitative drop enclosures (2.6 m^2 area) were used to collect juvenile fishes and crustaceans on the marsh surface. Above-ground density and biomass of macrophytes were also measured within these enclosures, and sediment cores were collected to examine sediment macro-organic matter (MOM) and benthic infaunal densities.

Mean values for stem density and above-ground biomass of *S. alterniflora* were consistently higher in the transplanted marshes, and the difference was statistically significant for stem density. Macro-organic matter in the upper 5 cm of sediment was significantly lower in the transplanted marshes. Densities of polychaetes and amphipods within transplanted marshes were positively correlated with this MOM. The transplanted marshes had significantly lower densities of decapod crustacea (primarily daggerblade grass shrimp, *Palaemonetes pugio,* and juvenile brown shrimp, *Penaeus aztecus*) compared with natural marshes. This reduced utilization may have been a response to low densities of benthic food organisms, and densities of decapods were positively correlated with densities of prey in sediment cores. In contrast to the utilization pattern of decapods, densities of fish (dominated by the darter goby, *Gobionellus boleosoma,* and pinfish, *Lagodon rhomboides*)

were similar between natural and transplanted marshes. These small fish may rely on salt marshes more for protective cover than for enhanced food resources, and above-ground structure in the transplanted marshes may have adequately provided this function.

The authors stressed that comparisons of functional equivalency between natural and transplanted salt marshes require adequate information on how salt marshes actually function for fish and decapod crustacea. For example, the use of prey density as an indicator of food value in a marsh can be misleading unless trophic pathways are well understood and access to the marsh surface is considered.

Minello, T. J., R. J. Zimmerman, and E. F. Klima. "Creation of fishery habitat in estuaries." In: Beneficial uses of dredged material: Proceedings of the first Interagency Workshop, 7-9 Oct. 1986, Pensacola, Florida., eds. M. C. Landin and H. K. Smith. 106-117. US Army COE, WES: Tech. Rep. D-87-1, 1987.

This paper discusses the importance of estuarine habitats, including salt marshes, in supporting the productivity of coastal fisheries. Extensive wetland losses have caused an increased willingness to create coastal salt marshes with dredged material. These marshes, however, are usually established over subtidal bay bottom. In order to properly assess the impacts of these habitat exchanges, the relative value of the involved habitats for fishery species must be known. Research conducted in fishery ecology and habitat functions at the Galveston Laboratory of the National Marine Fisheries Service is reviewed. Preliminary data is also reported indicating that transplanted *Spartina alterniflora* marshes support lower densities of nekton than natural marshes. Subsequently, these data have been analyzed fully by Minello and Zimmerman (1992). A cooperative program to create fishery habitat is also discussed; this program was in the initial stages of development between the NMFS and the U.S. Army Corps of Engineers.

Minello, T.J., R.J. Zimmerman, and R. Medina. "The importance of edge for natant macrofauna in a created salt marsh." Wetlands (in press, 1994).

The relationship between marsh edge and animal use was examined in a planted *Spartina alterniflora* marsh located in the Galveston Bay system of Texas. A completely randomized block experimental design was used with each of four blocks containing a control and experimental sector. Marsh edge was increased through the construction of channels in experimental sectors. Channel construction had no detectable effect on marsh surface elevation. Effects of these simulated tidal creeks on habitat use were examined by sampling nekton at high tide with drop enclosures both on the marsh surface and within the channels. Crustaceans dominated the nekton, and use of the marsh surface in experimental sectors was significantly higher than in controls; densities of brown shrimp *Penaeus aztecus*, white shrimp *P. setiferus*, and daggerblade grass shrimp *Palaemonetes pugio* were 4.6 to 13 times higher near the channels. Polychaete densities in marsh sediments were also significantly higher near channels, and densities of decapod predators were positively correlated with densities of these infaunal prey. Thus, channel effects on natant decapods may have been related to the distribution of prey organisms. However, increased densities of natant fauna along the channel edge may simply reflect a requirement for departure from the marsh surface at low tide. Marsh-surface densities of small bait fishes, bay anchovy *Anchoa mitchilli* and the inland silverside *Menidia beryllina*, also increased near channels, but highest densities of these fishes were in the creeks themselves. The abundance and distribution of juvenile blue crabs *Callinectes sapidus* and gulf marsh fiddler crabs *Uca longisignalis* were not affected by the addition of experimental channels. Overall, the study results indicate that habitat value of created salt marshes can be enhanced by incorporating tidal creeks into the marsh design.

Morrison, J. and P. Williams. "Warm Springs marsh restoration." In: Urban wetlands: proceedings of the national wetland symposium, in Oakland, CA, eds. J. A. Kusler, S. Daly, and G. Brooks, Oakland, CA: Assoc. State Wetland Managers, 340-349, 1988.

This paper discusses the design and monitoring of the 81-ha tidal restoration portion of a previously diked wetland, the Warm Springs marsh area near Fremont, California. The area is at the southern end of San Francisco Bay. The design was made by a team of a landscape architect, a biologist, and a hydrologist. The objectives of the restoration were: 1. to establish an Alkali bulrush marsh as is found outside the diked area, 2. to enhance *Salicornia virginica* growth for habitat for the salt marsh harvest mouse, an endangered species, 3. to provide fill and flood protection for the industrial park, 4. to improve tidal circulation and water quality to the area, and 5. to improve public access to the area for fishing, hiking, picnicking, and bird watching.

The planned topography for the area included terraces and peninsulas along the embayment which would provide area for pickleweed growth. Elevated areas along the dikes were retained as refugia during extremely high water events. A main channel was established connecting the embayment with Coyote Slough at the south end, and a minor connection with Mud Slough at the north end. Channel erosion deepened and widened the south entrance during the first year as expected in the design. This channel stabilized within 15 months. The tidal inflow brought in seeds from adjacent marshes and *Salicornia virginica* became established along the higher terraces as planned. *Spartina sp.* started growing among the pickleweed at its lower elevations, but Alkali bulrush did not invade the restoration area as was expected it would. Increased use of the area by bird, fish and mammals use of the area was documented.

Although the Alkali bulrush did not become established, this carefully designed project is likely to be considered a success. Most of the goals of the restoration project are being met, including restoration of many natural marsh functions. The project is a good example of what careful and knowledgeable planning can do for wetland restoration.

Moy, L. D. and L. A. Levin. "Are *Spartina* marshes a replaceable resource? A functional approach to evaluation of marsh creation efforts." Estuaries 14 (1991): 1-16.

This study compared a 1-3 yr old man-made *Spartina alterniflora* salt marsh in Dills Creek, North Carolina with two adjacent natural marshes. Comparisons were made of sediment properties, infaunal composition, and *Fundulus heteroclitus* use of the marshes. Sediments and infauna were sampled in spring and fall of 1987 and spring and summer of 1988 along three isobath transects (8, 28 and 48 cm above MLW) in each marsh. On each transect sediment cores (3.2 to 4.7 cm diameter) were taken to a depth of 4 to 5 cm. During three of the above sampling periods, pit traps, consisting of plastic wash tubs buried in the

sediment, were used to collect juvenile *Fundulus* at five sites in each marsh. Gut analyses were also conducted on the collected fish.

Sediment grain-size was similar in the planted marsh and the natural marsh that shared the same drainage system (east marsh), but sediments were finer in the west marsh. Detritus and sediment organics were higher in both natural marshes than in the planted marsh. Sediment macrofauna in the natural marshes were dominated by the oligochaete *Monopylephorus evertus,* while the macrofauna of the planted marsh was dominated by polychaetes that occur nearer the sediment/water interface such as *Streblospio benedicti* and *Manayunkia aestuarina.* Meiofauna species composition was similar between east and planted marshes, the only two compared. Total mean density of meiofauna was about twice as high in the east marsh, but high variances prevented the detection of statistically significant differences.

Fundulus collected in pit traps on the natural marshes had mainly detritus and insects in their guts, while fundulids in the planted marsh had polychaetes and algae. These dietary differences reflected the available infaunal prey in the marshes. The number of fish caught in the pit traps was consistently higher in the natural marshes than in the planted marsh. The authors suggested that this increased catch indicated that the natural marshes supported larger populations of fish despite the observed dietary differences. Low *Spartina* stem densities in the planted marsh may have provided inadequate protection from predators or insufficient spawning sites. The different catches of *Fundulus* in pit traps, however, may also have been the result of variable catch efficiency in the marshes. The surface area of marsh sampled by the traps was unknown and may have varied among the marshes. Differences in the occurrence of depressions (natural 'pit traps') on the marsh surface may also have affected catches. This problem with pit traps, however, probably had little effect on the study conclusions that the planted salt marsh was ecologically different from the natural marshes in the area, and that salt marshes should not be treated as a replaceable resource.

Munro, J. W. "Wetland restoration in the mitigation context." Restoration & Management Notes 9 (1991): 80-86.

The author reviews some of the problems encountered in the permitting and mitigation process for wetland alteration. The process was characterized as costly, slow, and not well regulated (little standardization, and little checking of mitigation projects). Guidelines for planning a restoration project have not been formally established by responsible agencies, but several important variables to be considered in the planning, execution, and monitoring processes for a project's success were suggested, defined and briefly discussed. They included: sizing up the area, describing or defining the site, modeling the project, establishing constant reference points for monitoring, maintaining authenticity, defining the goals, developing a conceptual plan, specifying net gain, defining the pattern of the system, setting the ecological context of the project, defining the education potential, describing the area hydrology, planning for the long-term, scheduling, allowing for setbacks, having buffer zones, maintaining holism and continuity, using innoculants, making wildlife structures, preventing erosion, keeping some flexibility in the plan, using horticulture, using planting patterns, having sufficient sock for the project, accepting providence, protecting against exotics, developing biodiversity, ordering supplies, recycling

plants and soil if possible, planning for transportation, using soil banks, keeping accurate records, and publishing reports to help others.

The author concluded that without continuity of the designer overseeing the construction and monitoring its progress, projects could fall short of their goals. Timing and scheduling of planting was underscored as very important for obtaining that initial growth and plant establishment. Documentation of the entire project was deemed worthwhile even if the project failed--a lesson learned, and hopefully not repeated. Better area-wide planning of restoration activities could be done if a list of mitigation areas and projects were accessible to the public.

Nailon, R. W. and E. L. Seidensticker. "The effects of shoreline erosion in Galveston Bay, Texas." In: Coastal wetlands, ed. H S. Bolton. 193-206. New York: Amer. Soc. Civil Engineers, 1991.

The use of planted *Spartina alterniflora* is discussed for shoreline erosion control in Trinity Bay and East Galveston Bay, Texas. *S. alterniflora* was planted at four sites, and about 1825 meters of shoreline were vegetated. Before planting, erosion rates at the four sites ranged from 0.5 to 2.6 m per year, and this rate appeared related to fetch length. Christmas trees, plastic snow fence, and used cargo parachutes were installed to reduce shoreline energy while young transplants became established. Survival of transplants ranged from 60 to 70% after a year for the three sites protected from wave energy. At the one site with no protection, none of the transplants survived.

Fishery species were sampled with bag seines and cast nets in the waters just offshore from one successful transplant site and from the site with no surviving plants. The samples were collected in August and October of 1988, about 2 years after transplanting. White shrimp, Gulf menhaden, and striped mullet were most abundant in the catches and 87% of the finfish and crustaceans were collected adjacent to the successful transplant site. Although gear catch efficiencies may have varied among sites, and the samples were not collected within the vegetation, the large differences in observed catches suggested that the shoreline area with transplanted *Spartina alterniflora* was utilized more by these fishery organisms than was the bare shoreline.

National Research Council. Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy. Washington D.C.: National Academy Press, 1992.

This book reviews historic degredation of aquatic ecosystems in the U.S. Of particular relevance were chapters 6 (Wetlands) and 8 (National restoration strategy: basic elements and related recommendations). The wetlands chapter included descriptions and discussion of the functions of wetlands, a brief history of the loss of wetlands in the U.S., a review of the potential for restoration actions, and a review of restoration research and technology. It also included a discussion of the difficulties that face wetland restorations, including ecological, biological and institutional constraints. Some discussion about what constitutes "successful" restoration was included, as was discussion about the research needs to assist wetland restoration. Among the most significant needs appeared to be the assessment of the restoration of functional equivalency, and what technology could be developed to accelerate the restoration process in each project.

Chapter 8 contains a proposal for a national restoration strategy. The elements come under four headings: (1) goal setting, (2) priority setting and decision-making principles, (3) redesign of federal policies and programs, and (4) innovation in financing.

This book provides an excellent base of information about the current status of restoration activities and thought in the U.S. It shows there is a large concern by ecologists, biologists, and naturalists that many important aquatic ecosystems are being destroyed with a consequent loss of associated fish and wildlife. It also shows how this loss of natural resources will continue if new policies are not established by state and federal agencies to offer better protection to aquatic ecosystems.

Newling, C. J., M. C. Landin, and S. D. Parris. "Long-term monitoring of the Apalachicola Bay wetland habitat development site." In: Proceedings of the tenth annual conference on wetland restoration and creation, in Tampa, FL, ed. F. J. Webb, Jr. Tampa, FL: Hillsborough Community College, 164-186, 1983.

This paper describes changes in the man-made cordgrass marshes that occurred in the Apalachicola Bay wetland habitat development site, an area of dredged material deposition that was protected from wave action by dikes. The area, known as Drake Wilson Island, covers about 5 ha along the northern shore of Apalachicola Bay, FL. In 1976, *Spartina alterniflora* was planted in various configurations in the intertidal zone, and *Spartina patens* was planted in the supratidal zone. Based on randomly selected 0.5-m^2 quadrats, within two growing seasons all *S. alterniflora* plots that began with plants on 1-m centers or less had filled in for 100% coverage; those on larger centers had mostly been washed out, or were just surviving. Similar coverages were found for *S. patens* using 0.25-m^2 quadrats. By the second year, 42 species of plants had invaded the planted site; *Distichlis spicata* was the dominant invader in areas between the two cordgrasses.

By 1982, six years after the planting, several changes had occurred to the planted areas. *Scirpus robustus* was now found regularly interspersed with *S. alterniflora* along the landward margin. *S. patens* coverage had been greatly reduced by invading dune-type vegetation. Diversity in the dunes and marshes had increased to 97 species of plants by this time. The plant assemblage on the island was as diverse as those at the nearby natural marsh sites examined for comparison.

Based on visual observations, bird usage of the Drake Wilson Island was even greater than at the natural marshes. Wading birds were commonly found feeding at Drake Wilson Island, and included many clapper rails, plovers, herons, egrets and terns. No sampling was done for fisheries or fisheries food-chain organisms. Some concern was voiced about the eroding dikes and thus about the longevity of this marsh. Inferences were that repairs may become necessary to maintain the marsh.

Niering, W. A. "Vegetation dynamics in relation to wetland creation." In: Wetland creation and restoration: The status of the Science. Part 2. Perspectives., eds. J. A. Kusler and M. E. Kentula. 479-486. Washington, DC: Island Press, 1989.

Ecological concepts involved in the successional development of wetland vegetation are discussed. Discovering the hydrological basis of a wetland leads to a better understanding of how perturbations to water flow through a marsh will affect its vegetation. Disturbance is a natural part of coastal wetlands and depending on the severity of the

disturbance, the induced changes in wetland vegetation will vary from minor and short-termed to severe and persistent. Creating a wetland that will persist requires creating an area with an appropriate and stable topography and hydrology; once vegetation becomes established it should persist.

Pacific Estuarine Research Laboratory. A manual for assessing restored and natural coastal wetlands with examples from southern California. California Sea Grant Report No. T-CSGCP-021. La Jolla, California: 1990.

This manual discusses the problems encountered in assessing functional equivalency for created salt marshes. The basic premise is that man-made wetlands should be expected to replace natural wetland functions. Evaluation procedures are presented for wetland functions related to hydrology, water quality, sediment and nutrient dynamics, vegetation, and support of various animal populations. The main purpose of the manual is to standardize methods of assessing functions in created wetlands. Criteria for success need to be stated as testable goals that can be achieved through reasonable monitoring programs.

The assessment method recommended for fishery species was repetitive seining of enclosed areas in tidal creeks or ponds until populations decline. This seems extreme. Because salt marsh vegetation in southern California is infrequently flooded in comparison with other coastal regions, sampling of nonvegetated habitats within the marsh complex may be sufficient to assess fishery use. In other regions, however, where the vegetated areas in salt marshes are directly utilized by fishery species, animal densities on the marsh surface (within the vegetation) are important, and the quantitative sampling of this habitat requires different techniques.

Patience, N. and V. V. Klemas. "Wetland functional health assessment using remote sensing and other techniques: literature search." NOAA. Tech. Memo. NMFS-SEFSC-319, 114, 1993.

This report reviews techniques for determination of the functional health of wetlands using remote sensing and other techniques. It provides a concise review of concepts and technology, and points to areas of future research. Each section of the report is supported by an extensive review of pertinent literature. With improving technology and information transfer, system capabilities will make greater accuracy and timeliness possible for health assessments of many more wetlands and their functions. Remote sensing will also allow for monitoring of many more restored and created wetlands on an annual basis.

Reppert, R. "Wetlands mitigation banking concepts." U.S. Army Corps of Engineers. IWR Rep. 92-WMB-1, 33, 1992.

This report provides general and specific information about wetland mitigation banking. Mitigation banks that are functioning are reviewed and evaluated. The potential of mitigation banking for achieving "no net loss" of wetlands is also evaluated.

Wetland mitigation banks provide advanced compensation for unavoidable wetland losses by creation, restoration, enhancement or preservation of other wetlands of equivalent value. Such banks are usually large tracts whose tangible and intangible values are equated to credits. As wetlands are altered elsewhere, credits are withdrawn from the bank. When the credits are exhausted the bank is closed, and new projects must seek

mitigation credits elsewhere. Banks would appear to be very effective in mitigation efforts particularly when many small mitigation projects would not yield any one area of sufficient size to support some larger wetland animals that require a large area for a viable habitat.

Mitigation banks are sponsored by industries, highway departments, port authorities, federal projects, and commercial interests. Of the 37 banks identified in this report, 19 were sponsored by state highway departments, 8 by ports, and 7 by land developers. In 1988, there were only 12 banks, now there are 37, and there are plans for 65 new banks in the next couple of years. This shows a significant development towards banking for solutions to mitigation.

Banking has its good and bad features depending on your point of view, and such an increase in banks could be disturbing news. Some of the good features listed were:

1. A bank is generally a large block of land which can support more species, some requiring large areas as habitats, than small single mitigation projects.

2. A large unit in a bank should be more economical to manage than many small dispersed units.

3. A bank generally provides for mitigation before adverse impacts to wetlands occur, otherwise there could be loss of habitat and ecological functions for several years while a mitigation project develops to its full functioning state.

4. A bank can be more thoroughly planned, managed, and incorporated into regional wetland requirements because there is plenty of time for these actions.

5. A bank can serve more social value than small spread-out mitigation projects; elements for public appreciation and education can be offered in a larger area.

6. A bank can expedite conflict solution because it already exists and its costs are known.

7. A bank can provide a lifetime monitoring program to protect the habitat. The establishment of a bank indicates permanence for the habitat as far as man's actions are concerned.

The main negative features of banks were listed as:

1. The planning may be less than adequate for the entire area and lifetime of the bank.

2. The existence of a bank may make it too easy to allow other wetlands to be destroyed where there may have been alternative actions that could have preserved them. Banks may act as short circuits to the regulatory process.

3. There is uncertainty as to the real value of a bank in terms of credits. Credit value has been difficult to establish for ecological functions of wetlands, and thus, crediting and debiting will always be controversial.

4. A bank may not provide for in-kind replacement, thereby potentially allowing for a particular habitat to be eliminated from a watershed.

5. There are uncertainties about management techniques for wetland habitats in general, and, when applied to a large bank, poor management could prove ecologically and economically costly.

6. The preservation of wetlands in the bank would only be beneficial if the lands were subject to loss to begin with; if not, there would be no replacement benefit by preserving the bank lands.

7. When all bank credits are exhausted, there is always the question of who is going to own the land and be responsible for its maintenance.

Mitigation banking is likely to increase as we press to use wetlands. To obtain the benefits offered by mitigation banking, we must support excellence in planning each bank and excellence in maintaining each bank. Yearly credits should be issued to each bank that would go to support the maintenance and monitoring. Certainly, the presence of mitigation banks should not be used as an excuse to destroy natural wetlands; avoidance of damage to natural systems should be emphasized.

Reubsamen, R. N. "National Marine Fisheries Service efforts in Texas to tailor mitigation to specific wetland types." In: Proceedings of the National Wetland Symposium: Mitigation of Impacts and Losses, in New Orleans, LA, New Orleans, LA: Assoc. State Wetl. Manag., 424-425, 1986.

This paper briefly summarizes the NMFS perspective toward mitigation for loss of wetlands in Texas. Avoidance of impacts on natural wetlands is the goal. When that is not possible, replacement by creation or restoration of in-kind wetland habitat of equal or greater size is sought. The replacement wetland should be located as close to the impacted wetland as practical (without itself becoming impacted). Increased manpower will be needed to review permit applications to alter wetlands (processed by the Corps of Engineers) and to monitor all the wetland mitigation efforts. Such monitoring is currently being accomplished for only a few projects.

Riggs, S. "Distribution of *Spartina alterniflora* in Padilla Bay, Washington, in 1991." Washington Dept. Ecology, Padilla Bay National Estuarine Research Reserve. Tech. Rep. 3, 63, 1992.

The objectives of this study were to document the distribution and spread of *Spartina alterniflora* in Padilla Bay, Washington. Baseline maps and data were available from a 1987 study by Wiggins and Binney (1987). Cordgrass stands that had been mapped in 1987 were mapped again in August and September, 1991. Comparing maps showed the cordgrass spread 1-2 m/yr. Area surveys also located several additional stands of *S. alterniflora*. The total area now covered was estimated at 4.8 ha compared with about 2.7 ha four years earlier. Only very minor die-back was found in central portions of some of the stands, and *Salicornia virginica* was found inhabiting those areas. There was still no evidence of flowering by *S. alterniflora* in Padilla Bay. (Note: Although not included in this report, S. Riggs informed us that 1992 was an extra warm summer for Padilla Bay, and that *S. alterniflora* did flower.)

The impact of *S. alterniflora* in the estuaries of Washington is considerable. Studies are needed to examine the function of cordgrass in the northwest.

Roberts, T. H.. "Habitat value of man-made coastal marshes in Florida." In: Sixteenth annual conference on wetlands restoration and creation, in Plant City, FL., ed. F.J. Webb, Jr., Plant City, FL.: Hillsborough Commun. College, 157-179, 1989.

This study was undertaken to determine the quality of man-made wetlands as habitat for fish and wildlife, and therefore, the effectiveness of marsh creation as mitigation for losses of coastal wetlands. Fish, bird, and mammal populations at 21 man-made, established, coastal marshes of various ages and 6 natural marshes were sampled and compared for similarities. The majority of the sites were dominated by *Spartina alterniflora*. Created marshes were located throughout northern and central Florida and ranged in age from approximately 1 to 10 years old. Vegetation characteristics were highly variable, but man-made sites that were properly planned, constructed, and maintained, were considered to serve as viable habitat for animals normally associated with natural coastal marsh systems. Factors influencing site use by various animal groups, and suggestions for the design of future mitigation efforts are discussed.

A quantitative comparison of aquatic animal utilization in created vs. natural marshes was not possible with the data presented. Sampling methods used in the study were not quantitative, and variability in characteristics of the different marshes (size, configuration, location, etc.) may have influenced the results. However, results show qualitatively that established man-made wetlands have the ability to support the same animal species as natural wetlands.

Roberts, T. H. "Habitat value of man-made coastal marshes in Florida." Vicksburg, MS: U.S. Army Corps Eng., Waterways Experiment Station. Tech. Rep. WRP-RE-2, 42, 1991.

The objectives of the study were to determine the effectiveness of marsh creation as mitigation for losses of natural coastal marshes along Florida's Gulf and Atlantic coasts. Only 55% (21 of 38) of the man-made *Spartina alterniflora* marshes visited in Florida estuaries were identifiable or deemed successful enough to be sampled; 1 man-made *Juncus* marsh was also studied. The marshes ranged in size from 0.004 to 2.8 ha, and were compared with four *Spartina* and two *Juncus* natural marshes that ranged in size from 0.20 to 3.2 ha. The 22 man-made marshes ranged in age from 1 to 10 years old, but 7 were 1-2 yr old, 6 were 2-3 yr old, and 6 were 3-5 yr old. Data were gathered on soil characteristics such as substrate texture, particle size and organic content from 3 to 5 samples per site. Vegetation was sampled using stratified random transects with the point-intercept method, and data on species composition, percent cover, stem density, and height of *Spartina* plants were obtained. Below-ground biomass of *Spartina* was measured from 7-cm-diameter cores taken to a depth of 18 cm. Fish data were collected using fyke nets (2 per site), Breder traps, and a Wegener Ring net. The fyke nets were set at high tide, and fish and motile invertebrates were collected as they left the marsh with the ebbing water. The Wegener Ring net was used to collect fish in tidal channels in some marshes. Birds were surveyed in each marsh on three consecutive days, and bird calls were also identified and recorded. Mammals were trapped at each site using Sherman Box and Museum Special Snap traps, one each per station, 5-7 stations per marsh, and two nights in each marsh. Tracks and other signs of larger mammals were also noted.

Sufficiently large variability was found in the data for each variable sampled in each age group of man-made marshes that no differences could be detected among the age groups. The author attributed much of the variability to marsh size and shape. Organic matter averaged from 0.2 to 10.1 % in the man-made marshes, and showed no statistically significant increase with age (r^2=0.04). *Spartina alterniflora* cover in the man-made marshes ranged from 40% on a 2 yr old site to 80% on a 1 yr old site, and averaged about 60% for all. Many marshes had other species of plants growing in adjacent zones, and these added an average of 10% to the total marsh cover for the sites. Below-ground biomass estimates ranged from 831-3,429 g/m^2 among man-made marshes and varied widely among sites. The minor correlation found between the age of a marsh and its below-ground biomass (r^2=0.14) did not appear to be significant. Only 50% of the man-made marshes supported marsh-dependent birds, and abundances were relatively low when birds were observed. Size and configuration of the man-made marshes were limiting, as were nearby development activities that appeared to be intolerable for the birds. Raccoons and marsh rabbits were found using about 30% of the man-made and natural marshes. Small mammals such as the cotton rat, rice rat, Norway rat, black rat, and house mouse were collected in man-made marshes. Their use of the marshes was probably influenced more by vegetation and nearby source of colonists than by age of the marsh.

Many of the fish species found in natural marshes were found in the man-made marshes. Again, no correlation was found between similarity index values (of the fish communities in a man-made marsh and the nearby natural marsh), and the ages of the man-made marshes (r^2=0.003). Most man-made marshes had three to five of the common eight species characteristic of natural marshes. Abundances in the man-made marshes were within the range of the natural marshes. Because the sampling was not quantitative in the sense that it could provide numbers of fish per m^2 of marsh, the abundance values were only taken as general indicators of marsh use. Other aquatic macroinvertebrates found in both man-made and natural marshes included *Littorina irrorata* and *Uca* spp. Again, there was great site-to-site variation in abundances of these animals.

This report points out the great variability in man-made and natural marshes. This variability makes if difficult to generalize from a study of only one or two marshes. The study also points out the difficulties in obtaining quantitative samples of marsh fauna; despite the use of multiple gears to sample fish and motile invertebrates, quantitative comparisons could not be made among marshes. Causes for differences among all the marshes were not obvious, though size, shape, and surroundings were likely sources for differences.

An important finding of this study was that established techniques to create or restore *Spartina alterniflora* marshes frequently appeared to be neglected, improper elevation of the substrate and a lack of protection from erosive waves were common in created marshes. Even when marsh creation was successful, other infringements and destructive acts were common when almost any other use could be made of the marsh or the adjacent land. Only by carefully incorporating species habitat requirements into project design, and locating wetlands where their habitat value can be realized, will mitigation efforts be fruitful and the loss of natural wetlands be offset.

Sacco, J. "Infaunal community development of artificially established salt marshes in North Carolina." Ph.D. Thesis, North Carolina State University., 1989.

Benthic infaunal populations were examined at six locations along the North Carolina coast; at each location, a transplanted *Spartina alterniflora* marsh was sampled along with a nearby natural marsh. The created marshes ranged from 1 to 17 years of age. The six locations differed in tidal range, salinity, and substrate composition. Infauna were dominated by annelid worms; polychaetes made up over 53% and oligochaetes 35% of the infauna in samples. Taxonomic composition and trophic diversity appeared similar among

the marshes, but infaunal densities were generally lower in the transplanted salt marshes. Sediment organic matter was also lower in created marshes. There appeared to be a relationship between high organic matter and high infaunal densities, but this relationship varied with local conditions. There was no apparent relationship between marsh age and the development of the infaunal community.

Sampling in natural marshes was conducted along the entire elevational range within the marsh, while sampling in created marshes was restricted to the original area of planting. Because elevation affects infaunal densities, this sampling regime may have affected results.

Seneca, E. D. and S. W. Broome. "Restoring tidal marshes in North Carolina and France." In: Restoring the nation's marine environment, ed. G. W. Thayer. 53-78. College Park: Maryland Sea Grant College, 1992.

This review article covers various techniques used to restore and create tidal marshes. The important factors discussed include site selection, elevation, slope, tidal range, wave climate, salinity, soil properties, cultural practices, sedimentation, wildlife impacts, post-planting maintenance, and traffic. The authors conclude that the primary goal of most wetland projects is to assist the system so that it can eventually attain functional equivalency with a natural wetland. The initial objective, therefore, is to restore the dominant emergent vegetation. These macrophytes then serve as substrata for other organisms, produce organic matter for the food web, provide habitat for organisms, and buffer shorelines from waves. Macrophytes also cycle nutrients and trap and stabilize sediments. Thus, establishment of a thriving macrophyte stand provides the basis for establishing fish and wildlife functions. These functions may or may not follow, but the establishment of the macrophytes is a key step in any restoration or creation project.

Seneca, E. D., S. W. Broome, and W. W. Woodhouse, Jr. "Comparison of *Spartina alterniflora* Loisel transplants from different locations in a man-initiated marsh in North Carolina." Wetlands 5 (1985): 181-190.

The objectives of this study were to determine how height form and latitude of origin might influence the variability of *Spartina alterniflora* when plants are transplanted to other sites as they are in restoration projects. Plants from four locations (short and tall forms from Beaufort) were transplanted on 0.9-m centers in a randomized split-plot design planting at the southern-most site. The grow-out site was a recently deposited (60 days prior to planting) area of dredged material that was 96% sand, 1% silt and 3% clay. Height, basal area, aboveground dry weight, culm density, and number of flower heads were measured periodically over five growing seasons.

Results showed that height and time of flowering of each location-type were maintained at the new site for several growing seasons. However, under the influence of elevation, the short form became taller when grown at lower elevations, and the tall form became shorter when grown at higher elevations. Within two growing seasons, the transplanted marsh had the standing crop equal to local natural marshes. Results also showed that yearly standing crop could vary as much as 45% in the transplanted marsh, which was the same as has been found for natural marshes. This variability should be considered in evaluating the success of a restored or created marsh.

Seneca, E. D., S. W. Broome, and W. W. Woodhouse, Jr. "The influence of duration-of-inundation on development of a man-initiated Spartina alterniflora Loisel marsh in North Carolina." J. Exp. Mar. Biol. Ecol. 94 (1985): 259-268.

This study was conducted in a *Spartina alterniflora* salt marsh that was planted in 1971 near Snow's Cut in North Carolina. Above-ground growth parameters measured included plant height, culm density, dry weight, basal area, and the number of flowers. Below-ground biomass was also measured. These growth parameters were measured at different elevations that corresponded to daily tidal flooding durations of 4, 7, 9, and 11 hours. The marsh was sampled during growing seasons 2, 3, 4, 5, and 12. During the second growing season, maximum above-ground growth occurred in the 7-h inundation zone. During growing seasons three through five, all growth variables generally increased with tidal inundation. By the twelfth growing season, *S. alterniflora* was completely displaced in the 4-h inundation zone by other marsh plants. *S. alterniflora* maintained dominance in the 9 and 11-h inundation zones and spread into areas of even lower elevation than originally planted.

Shisler, J. K. "Creation and restoration of the coastal wetlands of the northeastern United States." In: Wetland creation and restoration: The status of the Science. Volume I: Regional overviews. EPA/600/3-89/038., eds. J. A. Kusler and M. E. Kentula. 145-174. Corvallis: U.S. Environ. Prot. Agency, 1989.

This chapter characterizes the wetlands in the northeastern U.S., and describes the types of wetland restoration activities prevalent in that region. Most of the intertidal zone in salt and brackish marshes is dominated by smooth cordgrass, *Spartina alterniflora*. The area just above the intertidal zone is dominated by saltmarsh cordgrass, *Spartina patens*, mixed with some salt grass, *Distichlis spicata*. Several thousand hectares of this upper zone was diked off from tidal flows and the area used to grow salt hay (a combination of *Spartina patens*, *Distichlis spicata*, and *Juncus gerardii*). A couple of thousand hectares have recently been reopened to tidal circulation, but on a controlled-flow basis so the areas can be managed for waterfowl.

Factors to be considered in the design of creation or restoration projects are briefly described in this chapter. Some of the factors are: location of the project, hydrology at the site, topography of the site (elevation, slope, size), texture and quality of the substrate, species of plants to be used (matched to the environmental parameters expected from the design), adequacy of buffer zones, protection from pests, and degree of monitoring that will be required for success.

Research is needed to make restoration projects even more successful than they have been. Fourteen topics for research are given. Some concern plant species environmental requirements, tolerances of transplanting practices, and propagation potential. Other topics range from understanding pest control to simple developing a decent inventory of the wetlands.

Sinicrope, T. L., P. G. Hine, R. S. Warren, and W. A. Niering. "Restoration of an impounded salt marsh in New England." Estuaries 13 (1990): 25-30.

Vegetation changes of a tidal marsh in Stonington, CT, were documented for a 20 ha marsh 9 years after the reintroduction of tidal flushing. Vegetation was examined in aerial photography by comparing data from a study of the area by Hebard in 1976, with data obtained in 1986. Hebard's transects were then revisited in 1987 and 1988 to determine current coverage by species using the same line intercept method. Two extensions were added to transects T-3 and T-4 to cover what were previously mudflats.

Typha angustifolia decreased from 74% to 16% coverage, due to increased salinities over much of the area. *Phragmites australis* increased slightly as some of the *Typha* began dying out, but it too was exhibiting signs of stress in its stunted new growth. *Spartina alterniflora* increased from <1% coverage to 45%, invading much of the mudflats and intertidal area vacated by *Typha*. High marsh species such as *Distichlis spicata, Spartina patens, Juncus gerardi*, and *Salicornia europaea* also increased in areas upland from the *S. alterniflora* zone.

No systematic survey of the marsh and creek was made to document changes in utilization by aquatic species. However, increased use by ducks, shorebirds, and migratory birds was noted.

Soil Conservation Service. "Wetland restoration, enhancement, or creation." In: Engineering Field Handbook, ed. Soil Conservation Service. 79. 13. Washington DC: U.S. Department of Agriculture, 1992.

This is chapter 13 in the US DOA Soil Conservation Service's Engineering Field Handbook. It discusses wetland processes, functions and characteristics, and describes (with example data) the planning that is needed for a successful restoration/creation project. Consideration must be given to site selection, design, implementation, monitoring, and management. A wetland planning checklist is given in Appendix A, as is a monitoring site visit checklist in Appendix B.

Steinke, T. J. "Hydrologic manipulation and restoring wetland values: Pine Creek, Fairfield, Connecticut." In: National wetland symposium: mitigation of impacts and losses, in New Orleans, LA, eds. J. A. Kusler, M. L. Quammen, and G. Brooks, New Orleans, LA: Assoc. State Wetland Managers, 377-383, 1986.

This article presents a history of Pine Creek marsh in Fairfield, CT, and a description of the restoration activities associated with reestablishing tidal flows to this marsh. A detailed plan incorporated information about the area from hydrologists, biologists, public health officials, and civil engineers. The restoration began with 28 ha of an almost pure stand of 3-4 m tall *Phragmites australis* and has resulted in reestablishing the *Spartina patens* upper marsh and the *S. alterniflora* lower marsh after only five years of tidal flow renewal. Restoration was accomplished by building new dikes containing self-regulated tide gates before removing the old dikes. The restoration has also maintained flood protection and has eliminated 25-30 annual peat and Phragmites fires that threatened adjacent homes. A greater variety of birds has been noted in the marsh, and hunting and fishing has increased. Another 81 ha of marsh is under consideration for restoration action.

Stout, J. P. "Evaluation of coastal wetlands mitigation, Alabama." Alabama Dept. Environ. Management. Tech. Rep., 45, 1990.

The objectives of this study were to evaluate coastal mitigation work in Alabama. Recommendations were made that should improve success rates of coastal wetland restorations.

Of 12 wetland mitigation sites visited: no mitigation work had been started in three, work was incomplete in one, three were failures, two showed partial success, and three were deemed successful. The survey found very little monitoring of this mitigation work, and in most cases little was done to correct deficiencies when they were discovered during monitoring.

Problems with the mitigation system were varied. There was no standard format for a permit request that included all the needed information about a project to enable proper evaluation of the permit request. The limited documentation that was required was not routinely cataloged or available for examination and evaluation when needed. There was no central control or plan that could help direct mitigation efforts in Alabama. Such a plan or organization might act to preserve some of each kind of ecosystem in each watershed. A list of 25 factors to include in a plan was included.

Concern was expressed about a growing attitude that losses of natural wetlands could be mitigated by restoring or creating wetlands of equal value. The author suggested that we may be accepting a loss of valuable natural wetlands for equal areas of inferior quality created wetlands. Monitoring for 3-5 years after the restoration planting was recommended for marshes and submerged aquatic vegetation, and for 5-7 years for forested wetlands. There were 15 recommendations for monitoring which included photographic surveys from fixed markers and the use of aerial photos. Monitoring of vegetative, topographic, and hydrologic changes were also among the recommendations, along with utilization by waterfowl and aquatic fauna.

Because failures are largely ignored at present, changes in the system are sorely needed. A detailed mitigation design plan with clearly stated goals should be required for a permit to be granted. Concerned agencies must find staff to perform the monitoring, and performance of the work required by the permit must be enforced. Innovative approaches for mitigating loss of wetlands should be pursued. The process of mitigating an acre-planted for an acre-used is resulting in lost wetland functions as well as loss of fish and wildlife and their habitat.

Tanner, G. W. and J. D. Dodd. "Effects of phenological stage of *Spartina alterniflora* transplant culms on stand development." Wetlands 4 (1985): 57-74.

This study tested three phenological types of *Spartina alterniflora* for differences in survival and growth when used for marsh creation. Plants were dug from three natural donor marshes that had seedling, dwarf-form, and tall-form stands of *S. alterniflora*. Plantings were conducted at a dredged material site in Galveston Bay, Texas, and two substrates and three fertilizer treatments were also tested. Roots of all transplants were kept moist using wet burlap bags. Single culms were planted on 0.5-m centers in plots of 5 rows of 10 plants each. Treatments were configured in a randomized block design.

The seedling phenotype had a moderately superior initial survival and more rapid tiller production and biomass accumulation than the other two phenotypes. Seedling culms came from a newly established natural stand of plants that was in the process of rapid expansion itself, while the other phenotypes came from mature stands that were in equilibrium.

The fine grain (silty) substrate supported more vegetative growth than the coarse grain (sandy) substrate, even though the sandy substrate had slightly better initial survival. Fertilizers had no apparent effects, but the root-stimulator treatment killed a significant number of transplants.

Thayer, G. W., ed. Restoring the Nation's Marine Environment. College Park, MD: University of Maryland Sea Grant College Program and DOC/NOAA/National Marine Fisheries Service, 1992.

This book brings together current philosophies, techniques, and recommendations for preserving, restoring, enhancing, and creating many kinds of habitats in the marine environment. Chapters on salt marsh restoration in southern California by Joy Zedler and in N. Carolina and France by Ernest Seneca and Stephen Broome emphasized the need to use appropriate techniques in the restoration and creation tidal marshes. Such techniques included detailed plans that considered many variables such as: site selection, elevation, slope, tidal range, wave climate, salinity, soil physical and chemical properties, sedimentation, variety of vegetation to be planted, and protective measures against herbivory and trampling.

Questions remained about how to restore all the functions associated with natural marshes. A particular concern was for restoration of faunal population dynamics, not just the habitat. Various studies indicated 2-10 years may be required for faunal dynamics of a created marsh to match those of a neighboring natural marsh. Long term marsh studies were expected to yield answers, and were recommended.

Underwood, S. G., G. D. Steyer, B. Good, and D. Chambers. "Bay bottom terracing and vegetative planting: an innovative approach for habitat and water quality enhancement." In: Proceedings of the eighteenth annual conference on wetland restoration and creation, in Hillsborough, FL, ed. F. J. Webb, Jr. Hillsborough, FL: Hillsborough Community College, 164-173, 1991.

This paper presented the results of a project to prevent further shoreline and marsh erosion by waves, and to increase water quality in three ponds in a marsh along the north shore of Calcasieu Lake in the Sabine National Wildlife Refuge, Louisiana. There were 128 shallow bay terraces constructed and laid out in a checkerboard design in the ponds. *Spartina alterniflora* was planted on both sides of the terraces to stabilize them, trap sediment, and reduce the size of the wind generated waves. Preliminary results indicated reduced water turbidity in the terraced ponds, reduced size of wind generated waves in the ponds (greatly reduced fetch due to terraces), and good growth of cordgrass to stabilize the terraces.

The terracing technique may prove very useful in other areas of Louisiana for reestablishing marsh. Marshes that are subsiding may benefit greatly from terracing.

US Army Corps of Engineers. Engineering and Design. Environmental Engineering for Coastal Protection. Vol. EM 1110-2-1204. Washington DC: U.S. Army Corps of Engineers, 1989.

This manual provides guidance in environmental engineering for the protection of coastal areas. It summarizes information about various means of protecting shores, including the use of *Spartina alterniflora* marshes to reduce erosion. Sampling techniques are given for use in monitoring the effects of various projects.

Watzin, M. C. and J. G. Gosselink. "The fragile fringe: coastal wetlands of the continental United States." Louisiana Sea Grant College Program, Louisiana State University, Baton Rouge, LA; U.S. Fish and Wildlife Service, Washington, DC; and National Oceanic and Atmospheric Administration, Rockville, MD. 1992.

This report is an informative presentation of the nature and value of coastal wetlands in a popular format. It gives definitions, functions and needs, illustrated by examples that will help anyone to better understand the values of coastal wetlands and why their preservation is important.

Webb, J. W., Jr. "Establishment of vegetation for shoreline stabilization in Galveston Bay, Texas." Ph.D., Texas A&M Univ., College Station, TX, 1977.

The objectives of this research were to isolate and test plant species that would stabilize bay shorelines, to develop planting technology, to test wave-stilling devices, and to calculate a time-effort budget for a transplanting project. The study area was the north shoreline of East Bay, on the Anahuac National Wildlife Refuge, Chambers County, Texas. This area had an eroding bank that was receding at 1-2 m/yr. The soil was classified as loam or clay-loam texture, structurally unstable and subject to erosion. Thirteen plant species, two wave-stilling devices, and three planting techniques were tested.

Spartina alterniflora was the most successful species in the intertidal zone below MHW, but it required protection from wave impact. Wave-stilling fences of hay bales contained in chicken wire and in 14-gage welded mesh wire were unsuccessful. Tires on cables held in place by metal posts were somewhat successful, but lost effectiveness when they partially sank into the substrate. *Spartina spartinae* and *Spartina patens* were the most successful above MHW. Fertilizer was beneficial to plant growth in a natural marsh (control), but showed no significant benefit to the planted blocks.

Seeding an area failed to establish plants. Hand planting of tillers or culms was effective when protected by the wave stilling device (tire fence). Mechanical planting of tillers was also successful at low tide and behind a wave-stilling device.

Mechanical grading down of the banks to a smooth slope for establishing the planted marsh was not useful. Erosion of the loosened substrate occurred within several months.

Webb, J. W., Jr. "Salt marshes of the western Gulf of Mexico." In: <u>Creation and restoration of coastal plant communities</u>, ed. R. R. Lewis, III. 89-110. Boca Raton, FL: CRC Press, Inc., 1982.

This chapter reviews coastal salt marsh restoration and creation activities in the western Gulf of Mexico. There are six sections to the chapter which give excellent coverage to the topic. They include descriptions of: the plant community, the various levels of productivity of the salt marsh, the loss of this habitat through modification, specific projects, recommended techniques, and research needs.

The coastal marsh plant community in the western Gulf is quite similar in species composition to that along the Atlantic coast of the U.S. Smooth cordgrass, *Spartina alterniflora*, is the dominant species intertidally. It grows best from MLW to MHW. At a slightly higher elevation *Distichlis spicata* (salt grass) occurs. Overlapping *Distichlis* and moving slightly higher still, *Spartina patens* (saltmeadow cordgrass) is found, sometimes forming broad meadows. The higher margins of the salt meadows are shared with *Scirpus maritimus* (leafy threesquare), *Scirpus olneyi* (Olney bulrush), *Borrichia frutescens* (sea oxeye daisy), *Monanthochloe littoralis* (salt flat grass), *Limonium carolinanum* (sea lavender), *Batis maritima* (saltwort), *Salicornia bigelovii* (annual glasswort), *Salicornia virginica* (virginia or perennial glasswort), and *Iva frutescens* (bigleaf sumpweed or marsh elder) which often form clumps in this infrequently flooded area.

These salt marshes are very productive areas. Production of *Spartina alterniflora* can be 500 to 2800 $g/m^2/yr$. Much of this production supplies the beginning material for a detritus based food web. The marshes act as feeding habitat that also offers protection for juvenile fish, shrimp and crabs of economic importance. Coastal marshes also serve as permanent habitat for otters, muskrats, nutrias, raccoons, and alligators, as well as winter habitat for thousands of ducks and geese.

Salt marshes are being lost every year through natural and man-induced causes. Subsidence and erosion are the two main natural causes, but man is contributing to these also. Dredging and filling operations are man's chief means of altering salt marshes. Now, sea level rise will add to the loss of salt marshes because much of the land on the higher side of the marshes is blocked. Thus, many of the marshes cannot migrate up the slope as the sea rises.

Eleven transplant projects are reviewed. Each gives insights and discoveries that led to improved restoration techniques. Tips on successful techniques are offered, among these were: 1. Select the proper species of plant for the elevation in the project area. 2. If possible, put transplants in the ground the same day as they are dug, and keep their roots moist at all times during the transfer. 3. Planting depth should be sufficient to allow the roots to extend normally. 4. Protect planting area from excessive wave energy by using a breakwater if necessary.

Several research needs were mentioned. Research is needed to develop ways to make transplanting less expensive. Combinations of transplanting and seeding might be developed for large areas to cut the costs. Research on "edge-effect" is needed. Does increasing the edge in a marsh increase production of fish, shrimp and crabs? Finally, research is needed to develop low-cost reusable wavebreaks.

In the ten years since this was written much research has been done, but many of the needs remain. The techniques given in the chapter are still used. Mitigation for loss of natural wetlands is not keeping up, and salt marsh is still being lost at a rapid rate in the western Gulf.

Webb, J. W., Jr. "Soil water salinity variations and their effects on *Spartina alterniflora*." <u>Contributions in Marine Science</u> 26 (1983): 1-13.

The effects of soil salinity on *Spartina alterniflora* were compared in a transplanted marsh and a natural marsh in the Galveston Bay area, Texas. soil salinity increased with elevation to a maximum at MHW, where it frequently reached 40 ‰. Highs

of 59 ‰ at the transplant site and 99 ‰ at the natural marsh site were found during the summer. The high salinity was damaging to *Spartina alterniflora*, and when combined with low soil moisture found above MHW was limiting to the cordgrass. High soil salinities were apparently caused by evaporation between tidal cycles.

Webb, J. W., Jr. and J. D. Dodd. "Wave-protected versus unprotected transplantings on a Texas bay shoreline." Journal of Soil & Water Conservation 38 (1983): 363-366.

Shoreline erosion is a dominant feature along many Texas bays. *Spartina alterniflora* has been planted along some stretches and effectively controlled further erosion. The objectives of this study were to see if a wave-stilling device would aid in establishment of transplanted salt marsh plants in an area where wave action was erosive, and to see at what elevations the various species of plants might become established.

The study site was along the north shoreline of East Bay in the Galveston Bay System, Texas. A 60-m stretch of shore bank was graded down to a 10% slope. The area was planted, but washed out within a few months. The area was re-graded to a 2% slope. A cable with tires threaded on it was suspended from poles driven into the bay bottom to act as a wave-stilling device. Plants were transplanted to the area, but within a few months the waves had washed them out again. The tires had sank partially, and waves were able to pass over them with minimum decrease in energy. A second string of tires was added, and the area replanted.

The two-tire cable was sufficient to break most of the wave action, and *Spartina alterniflora* survival was good (about 70% at the best elevation) after the first year. *Spartina spartinae, Spartina patens,* and *Distichlis spicata* also did well, surviving above mean high water much better than *S. alterniflora.*

After the tire line was removed there was some erosion of the *Spartina alterniflora*, but most of the marsh survived to prevent further erosion. The other species also acted to protect the shore at higher elevations, and were shown to be valuable in beach stabilization projects.

Webb, J. W., Jr. and J. D. Dodd. "*Spartina alterniflora* response to fertilizer, planting dates, and elevation in Galveston Bay, Texas." Wetlands 9 (1989): 61-72.

This study tested date, fertilizer rates, and elevation as they affected survival and growth of *Spartina alterniflora* transplants on a sandy dredged material deposition site on Bolivar Peninsula, Texas. Differences in seasonal tidal heights affected areas of best survival. Higher tides led to better survival at higher elevations (still below MHW). Better survival, tiller production, and growth was associated with the May planting versus the February planting. However, stem density was greater in the February planting area than in the May area after one full growing season despite the lower initial survival and tiller production. Fertilizer was of no apparent benefit. The use of a two-season planting was suggested where large expanses need to be covered. The lower elevations could be planted during the winter when water levels are usually lower, and the upper elevations could be planted during the spring when water levels are usually higher.

Webb, J. W., Jr., J. D. Dodd, A. T. Weichert, and B. H. Koerth. "*Spartina alterniflora* response to fertilizer rates, planting dates, and elevation in Galveston Bay, Texas." In: Estuaries. Second water quality and wetlands management conference. in New Orleans, LA, ed. N. V. Brodtmann, Jr., New Orleans, LA: , 379-399, 1985.

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Webb, J. W., Jr., M. C. Landin, and H. H. Allen. "Approaches and techniques for wetlands development and restoration of dredged material disposal sites." In: National wetland symposium: mitigation of impacts and losses. in New Orleans, LA, eds. J. A. Kusler, M. L. Quammen, and G. Brooks, New Orleans, LA: Assoc. State Wetland Managers, Inc., 132-134, 1986.

The possibilities of using dredged material and *Spartina alterniflora* to create salt marshes and stabilized shorelines are discussed. Techniques that have been tried and have shown promise are mentioned. Particular note is made of the erosion control mats with sprigs of *Spartina* planted through slits in the mat material. Breakwaters were found essential in areas of high wave energy.

Webb, J. W., Jr. and C. J . Newling. "Comparison of natural and man-made salt marshes in Galveston Bay complex, Texas." Wetlands 4 (1985): 75-86.

The vegetation of a man-made *Spartina alterniflora* marsh planted in 1976 on Bolivar Peninsula, Texas, was compared with three natural marshes in the Galveston Bay complex in 1978 and 1979. Samples for the analysis of above-ground biomass, live stem density, dead stem density, stem height, percent cover, and species composition were collected from 0.5 m^2 quadrats that were randomly placed along elevational transects. Below-ground biomass was collected in the same quadrats using about 8-10 cm diameter corers; core depths were 25 and 30 cm.

Spartina alterniflora dominated the sites below mean high water, but other plants (*Salicornia bigelovii, Spartina patens, Batis maritima, Sporobolus virginicus,* and *Distichlis spicata*) were more important above mean high water. The above-ground biomass of *S. alterniflora* and other species at Bolivar was within the variability shown among the three natural marshes. However, live biomass of *S. alterniflora* was significantly greater in 1978 in the man-made marsh than in the natural marshes. This difference was caused by greater stem heights in the created marsh which more than compensated for the generally lower stem densities.

At the lower elevations where *S. alterniflora* dominated, below-ground biomass was generally much lower in the man-made marsh than in the natural marshes. However, this biomass increased from 1978 to 1979. At the higher elevations, where other

species dominated, below-ground biomass at the created marsh was within the range of the natural marshes.

Overall, this study indicated that production of above-ground biomass in a 2-3 year old created salt marsh was comparable to production in nearby natural marshes. Below-ground biomass and species composition were changing in the created marsh, becoming more similar to the natural marshes of the area.

Wiggins, J. and E. Binney. "A baseline study of the distribution of *Spartina alterniflora* in Padilla Bay." Washington Dept. Ecology, Padilla Bay National Estuarine Research Reserve. Reprint Series 7, 28, 1987.

The objective of this study was to document the distribution of *Spartina alterniflora* in Padilla Bay, Washington. It is thought that S. alterniflora was transplanted into southern Padilla Bay sometime in the early 1960's. Stands of *Spartina* were located by walking the shoreline of all known salt marsh areas of the bay. Seven major stands were found in addition to the extensive stand on Dike Island, all still in southern Padilla Bay. The smaller stands were located south and east of Dike Island. All were mapped. There were also several small clumps (about 1 m^2 each) of *S. alterniflora* recorded in Telegraph Slough. The mapped area comprised over 2.4 ha. The elevation of the growing cordgrass ranged from 2.5 to 3.6 m above MLLW. *Salicornia virginica* intermixed with *S. alterniflora* at the higher elevation, and continued into the higher marsh where it was mixed with *Distichlis spicata*.

Based on comparisons of aerial photographs from 1968 and 1978, the spread of *Spartina alterniflora* in Padilla Bay appears to have been vegetative. It also appears that clumps may break off during storms, be transported onto other adjacent mudflats, and become established if the elevation is correct.

Williams, S. L. and J. B. Zedler. "Restoring sustainable coastal ecosystems on the Pacific coast: Establishing a research agenda." California Sea Grant College. Rep. T-CSGCP-026, 19, 1992.

This report lists prioritized research needs for Pacific coastal ecosystems, particularly estuarine wetlands. Priority weights were the averages of priorities determined by 15 scientists (most were from the West coast) who are familiar with coastal ecosystems and restoration potential. A prioritization was felt necessary to promote research in areas deemed critical for the perpetuation of coastal wetland ecosystems along the West coast. The West coast has probably lost 50% of its coastal estuarine wetlands already.

There were 25 research needs spread among four topics. Habitat specificity of organisms, habitat function determinants, and population dynamics were leaders in the conservation of biodiversity topic. Hydrology of the coastal wetlands was primary among physical processes research needs. Nutrient dynamics and establishing water quality criteria for vegetation were most important in water quality research. Habitat architecture, site selection criteria, and monitoring and evaluation of success were key needs under restoration research.

Wilsey, B. J., K. L. McKee, and I. A. Mendelssohn. "Effects of increased elevation and macro- and micronutrient additions on *Spartina alterniflora* transplant

success in salt-marsh dieback areas in Louisiana." Environmental Management 16 (1992): 505-511.

Extensive areas of salt marshes in coastal Louisiana are suffering dieback due to compaction, subsidence, and lack of sediment additions. The objectives of this study were to test elevation of the substrate and nutrient enhancement in an area of *Spartina alterniflora* degradation and dieback to see if the marsh could be restored by transplanting more *S. alterniflora* into the area given certain environmental modifications.

The test areas were dieback salt marshes in the lower Barataria Basin near Caminada Bay, Louisiana. Five sites, two elevations (0 and +30 cm), two macronutrient treatments (N, P, K; with and without), and two micronutrient treatments (Fe, Mn, Cu, Zn; with and without) were tested. One plant of *S. alterniflora* was used for each treatment at each site. All plants selected and dug from the nearby donor site were the same size.

After four months (i.e. on Nov. 17, 1989) the *S. alterniflora* in the elevated plots had twice the above-ground biomass and significantly more culms than the normal substrate level plots. The elevated plots were at the same height as the nearby, vigorously growing, *S. alterniflora* that lined the banks of the channels. Micronutrient addition appeared to inhibit growth, while macronutrient addition promoted growth only in the elevated plots. In these plots macronutrients increased culm density by about 61% over controls.

This paper reinforces the importance of planting at proper elevations in marsh restoration projects. Although elevations should generally match those of the nearest natural marsh, this study makes it clear that one should match elevations carefully, and should look to match the elevations of most vigorous growth in the natural marsh. The vigorous-growth area may be above the average elevation of the marsh.

Wolf, R. B., L. C. Lee, and R. R. Sharitz. "Wetland creation and restoration in the United States from 1970 to 1985: An annotated bibliography." Wetlands 6 (1986): 1-88.

This annotated bibliography covers studies concerning creation and restoration of salt and freshwater wetlands that were published between 1970 and 1985, and contains 304 citations accompanied by very brief annotations. Many of the cited studies are on the use of *Spartina alterniflora* in marsh creation or restoration activities. This bibliography will be useful in finding earlier articles about *S. alterniflora* restorations, or articles with a slightly different subject emphasis than our bibliography.

Woodhouse, W. W., Jr. "Building salt marshes along the coasts of the continental United States." Fort Belvoir, VA: U.S. Army Corps Eng., Coastal Eng. Res. Cent. Spec. Rep. 4, 96, 1979.

This report provides basic information about coastal marshes of the United States. Included are descriptions of the types of marshes, types of marsh plants, site requirements for establishing marshes, and plant propagation techniques. Also included are descriptions of planting and fertilizing techniques and their costs.

Woodhouse, W. W., Jr. and P. L. Knutson. "Atlantic coastal marshes." In: Creation and restoration of coastal plant communities, ed. R. R. Lewis, III. 45-70. Boca Raton, FL: CRC Press, Inc., 1982.

This chapter reviews various facets of salt marshes along the Atlantic coast of the U.S. There is a brief description of the loss of salt marshes and the need for their preservation. Much information is given to aid in creating or restoring salt marshes. Dominant coastal marsh plant species are discussed as to their shape, habitat, reproductive potential and timing, and as to techniques for harvesting, propagating, and culturing some of the species. The important species include: *Spartina alterniflora* (smooth cordgrass), *Spartina patens* (saltmeadow cordgrass), *Juncus roemerianus* (black needle rush), *Distichlis spicata* (saltgrass), *Spartina cynosuroides* (big cordgrass), and *Phragmites australis* (common reed). Planting procedures are described, and their costs estimated. A typical marsh creation project using *Spartina alterniflora* sprigs placed on 1-m centers requires about 10,000 sprigs and 100 man-hours to plant one hectare. This estimate does not include the planning and coordinating, obtaining of transplant material, nor the transport of material to the project site.

Recommendations are given for selecting a site, checking the soil, preparing the grade and elevation, selecting the planting time, and protecting the planted site. Protection must be established against grazing animals and trampling animals, including man and his off-road vehicles. Protection may also be necessary from erosive action by wind and wind and boat waves. The end product of a marsh creation project will be evaluated not only by the vegetation developed, but also by the wildlife and fisheries species that use the planted marsh as habitat.

Zedler, J. B. "Canopy architecture of natural and planted cordgrass marshes: selecting habitat evaluation criteria." Ecological Applications 3 (1993): 123-138.

Nesting requirements of the Light-footed Clapper Rail (*Rallus longirostris levipes*) were determined from its natural marsh habitat. Selected habitat criteria were identified for use in evaluating the value of created marshes as habitat for this bird. Height distribution and density of *Spartina foliosa* (California cordgrass) were preferred over percent cover for characterizing canopy architecture. Percent cover was found to be too subjective.

The bird appears to require a density of *Spartina foliosa* of at least 100 stems/m^2. Also, the required height frequency distribution of the stems has at least 90 stems over 60 cm tall, and of these at least 30 stems over 90 cm tall. Greater densities and taller plants make even better habitat. The size of the marsh is also important. The rail appears to need 0.8-1.6 ha of marsh with the specified architecture for its home range. There are additional requirements for the birds to use a marsh even if it appears to meet the vegetation requirements mentioned, but these other requirements have not yet been discovered.

Several associated recommendations were made based on work and observations made during this study. Destructive sampling of the cordgrass should be avoided; every stem is valuable. Densities and height frequency distributions to characterize a marsh should be based on 0.25 m^2 (or larger) quadrats. Long-term monitoring, 20 years, is recommended because establishment of planted marshes may meet the criteria for success for a year or two and fail thereafter.

Zedler, J. B., J. Covin, C. Nordby, P. Williams, and J. Boland. "Catastrophic events reveal the dynamic nature of salt-marsh vegetation in southern California." Ecology 9 (1986): 75-80.

Recent hydrological anomalies (flooding, dry-season stream flows, and droughts) were shown to greatly alter coastal wetland habitats in southern California in a six-year (1979-1984) study of the Tijuana Estuary. Permanent sampling sites (102) were set at 5-m intervals along 8 transects in lower intertidal marsh that was dominated by *Spartina foliosa*. During normally dry years (1979, 1981, 1982) interstitial soil salinities were between 35 and 45 ‰ , but during years with wet winters and rare flooding (1980 and 1983) interstitial salinities dropped to between 15 and 35 ‰ . During an extremely dry year (1984) the interstitial salinity reached 104‰ in September. *S. foliosa* reacted to these changes by increased growth during fresher years by mainly increased stem length when the freshwater inflow occurred early in the year (1980), and mainly by increased numbers of stems when freshwater inflow occurred later (1983). *S. foliosa* also responded quickly to the drought in 1984 with reduced stem density (62% from that found in1983 or 28% from that found in the other years) and reduced stem heights (50% from 1983 and 30% from other years).

The study showed the importance of soil salinity in governing rates and types of growth of western cordgrass. Variations in tidal circulation and weather were also found to be important for marsh growth and establishment. Long-term dynamics of a salt marsh should be understood before the marsh is used as a reference site or as a site for restoration.

Zedler, J. B., M. Josselyn, and C. Onuf. "Restoration techniques, research, and monitoring: vegetation.", pp 63-72 In: Wetland Restoration and Enhancement in California, in Hayward, CA., ed. M. Josselyn, Hayward, CA.: California Sea Grant College Program, 1982.

This article summarizes the goals and techniques most commonly associated with California coastal marsh and seagrass restorations, and it suggests items and actions for a follow-up monitoring program for such projects. The goals are the same as for Atlantic coast restorations, perhaps with the decreased need for shoreline stabilization and increased concern for increasing habitat diversity for additional wildlife support. Restoration techniques included a basic sequence of actions: map the site, develop a conceptual plan, develop a site plan with engineering features including hydraulics, do some test planting, develop a comprehensive planting design and map including any needed protective devices, describe a monitoring plan and a management plan based on results from monitoring, and finally, develop a plan to share the information about the results of the restoration project with others (researchers, restorers, creators, and the public). Suggestions for future restoration research included determination of: (1) optimal habitat sizes and configurations for wildlife utilization by various species, (2) the tidal and freshwater flushing requirements of marsh vegetation, (3) the nutrient requirements of the vegetation and impacts of nutrient load in waste waters, (4) rates of marsh establishment--natural colonization versus transplants, (5) the relationship between plant density, flushing, and mosquito control.

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