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Strategies for establishing Spartina alterniflora on newly constructed marsh terraces in coastal Louisiana

Ashley Wilson Mullens
Louisiana State University and Agricultural and Mechanical College

STRATEGIES FOR ESTABLISHING *SPARTINA ALTERNIFLORA* ON NEWLY CONSTRUCTED MARSH TERRACES IN COASTAL LOUISIANA

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Ashley Wilson Mullens
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ABSTRACT

Marsh terracing is an innovative restoration technique being used in shallow, open water marshes in coastal Louisiana. When properly constructed and planted with an applicable plant species, terraces promote sediment deposition and accumulation by reducing wave energy. Although used extensively for marsh creation, little published information is available on techniques for establishing vegetation on marsh terraces.

The goal of this research was to determine the optimal planting season and most effective plant growth form of *Spartina alterniflora* for establishing vegetation on newly constructed marsh terraces. Study objectives were to: 1) compare survival and growth rates of different plant growth forms based on planting season, 2) determine the optimal method of handling/storing seed to maximize germination and survival on terraces, 3) characterize soil composition and terrace elevation as compared to ambient marsh, and 4) monitor water depth and salinity of an adjacent water body to determine any relationship to plant response.

This research was conducted on a large-scale terracing project on the Pointe aux Chenes Wildlife Management Area. Vegetative transplants of *S. alterniflora* were established on the terraces and were quantitatively sampled to examine differences in survival and growth. Treatments included plant growth form: containered plants (trade-gallon) and vegetative plugs; planting season: spring and fall planted; and growth period: 6 and 12 months. There was no significant difference in survival among planting seasons ($p=0.0933$) or growth forms ($p=0.5396$). Vegetative plugs and trade-gallons had similar growth rates when comparing aboveground biomass (944.79g/m^2 and 1173.39g/m^2, respectively) and belowground biomass (1187.82g/m^2 and 1262.60g/m^2, respectively). In a separate seeding study, there was little germination of *S. alterniflora* seed on the terraces (less than 1%), though the seed proved to be

viable under in controlled germination tests. Although direct seeding is not a viable option on marsh terraces, vegetative transplants of *S. alterniflora* are effective in establishing vegetation on terraces. This study will add to the knowledge base of coastal restoration technology by evaluating the variability in terrace construction and the hydrologic-soil-plant relationship that is essential to terracing success, thus providing restoration project planners with additional strategies that will better incorporate vegetative establishment into terrace engineering.

INTRODUCTION

Wetland deterioration is a significant environmental problem in coastal Louisiana, with rates of wetland loss averaging 61.3 km^2y^{-1} (Barras et al. 2003). Numerous techniques have been used to restore subsided areas in coastal Louisiana by transporting sediments to increase elevation within deteriorating marshes. Marsh terracing is one of the restoration techniques being used in shallow, open water marshes in coastal Louisiana. Research has shown that when properly constructed and located in heavy sediment fields, terraces can reduce wave energy, decrease turbidity, promote sediment deposition and accumulation, and create additional marsh edge habitat (Steyer 1993, Rozas and Minello 2001, Gossman 2005, Cannaday 2006). First used at Sabine National Wildlife Refuge in Cameron Parish, terracing has become widespread and is used heavily by the Louisiana restoration community (Purkey 2003). At least 700,000 linear feet of terraces have been constructed in coastal Louisiana since 1990 (Good et al. 2005).

Typically, marsh terraces are constructed with a marsh buggy equipped with a long-arm, backhoe shovel that dredges material from the bottom of the marsh and forms it into a segmented ridge or levee. The *in-situ* sediments used to construct terraces typically consist largely of silts and clays with varying levels of organic content. These dredged soils are highly disturbed, and natural vegetative colonization on the terraces is slow to establish (Louisiana Department of Natural Resources 2003), so it is common for some type of vegetative establishment to be artificially established in conjunction with terrace construction. Many of the restoration projects in Louisiana utilizing marsh terraces have been constructed within brackish or saline environments where salinity is typically greater than 8 parts per thousand (ppt), so *S. alterniflora*, the dominant clonal salt grass that occurs naturally within low, intertidal marshes in coastal Louisiana, has been transplanted on the majority of these systems.

Although terraces are being used extensively for marsh creation in Louisiana, little published information is available on techniques for establishing vegetation on marsh terraces. The primary goal of this research was to determine the optimal planting season and most effective plant growth form of *S. alterniflora* for establishing vegetation on newly constructed marsh terraces. The objectives of this study were: 1) to compare survival and productivity (growth) rates of different plant growth forms of *S. alterniflora* based on planting season, 2) to determine the optimal method of handling and storing *S. alterniflora* seed to maximize germination and survival on marsh terraces, 3) to characterize soil composition and elevation of the terraces as compared to ambient marsh, and 4) to monitor water depth and salinity of a water body adjacent to the marsh terraces to determine any relationship to plant response.

LITERATURE REVIEW

Wetland Loss

Wetland deterioration is a significant environmental problem in coastal Louisiana with current rates of loss averaging 61.3 km^2y^{-1}, which is a significant increase from the 25 km^2y^{-1} average between 1990 and 2000 (Barras et al. 2003). Marsh degradation in coastal Louisiana is generally characterized by extensive plant mortality, large areas of shallow, relatively unproductive open water, and exposed and unprotected bare marsh soils (Mendelssohn and McKee 1988). Marsh soils in degraded areas are generally fluid, organic, and highly susceptible to erosion and scouring from tides, frontal passages, storms, and from catastrophic events, such as hurricanes. Exposed soils are readily eroded by tidal flood waters and small ponds develop that may expand and coalesce into larger areas of open water (Mendelssohn and McKee 1988, Turner and Rao 1990).

Louisiana contains approximately 40% of the nation's wetlands in the contiguous United States, but the state accounts for over 80% of the total national wetland loss (Boesch et al. 1994). Along with the ecological significance of continued loss of coastal wetlands, there are numerous economic implications. It is estimated that over two million residents live and work in Louisiana's coastal parishes and the national economy is dependent on the productivity of the area. For example, 25% of the oil and gas consumed and 30% of the nation's seafood industry comes from Louisiana's coastal zone (Committee on the Future of Coastal Louisiana 2002). Consequently, continued coastal erosion and wetland deterioration will deprive the nation of vitally important fish, wildlife, and other wetland-related economic and environmental benefits.

Wetland loss is attributed to a variety of biotic and abiotic factors such as subsidence, sea level rise, hydrologic modification, and herbivory that operate on various temporal and spatial scales. Several anthropologic impacts, such as the dredging of oil and gas canals, heavily contribute to the increasing rates of coastal deterioration, but are considered secondary to natural subsidence (Bourne 2000). Rapid sea level rise exacerbated by localized subsidence (also known as relative sea level rise) is the dominant factor contributing to the deterioration of Louisiana's coastal marshes (Broome et al. 1988, Ramsey and Penland 1989, Day et al. 2004). Subsidence is defined as the downward displacement of the delta plain surface with respect to a vertical datum, and on the Louisiana coast is primarily caused by sediment compaction and tectonics (Walker et al. 1987, Penland et al. 1988, Gagliano 2005). A eustatic rise in sea level is currently estimated at 1 mm per year in most tectonically stable coastal states, but because of subsidence in Louisiana, rates in these coastal marshes can exceed 1 cm per year in some areas (Campanella et al. 2004). For marsh vegetation to survive and remain productive during this period of rising sea level and subsidence, it is necessary that the marsh vertically accrete enough sediment at its surface to support vegetative growth (Patrick and DeLaune 1990). Along the Louisiana coast, marsh accretion has generally not kept pace with relative sea level rise (DeLaune et al. 1978, Callaway et al. 1997). When marsh elevation becomes too low, emergent vegetative growth is limited even if all other growth conditions, such as salinity and nutrient availability, are favorable (Turner and Cahoon 1987). However, it is possible to mediate much of Louisiana's wetland loss through sediment availability (Boesch 1982, Mendelssohn et al. 1983) and a sound approach for reducing wetland loss and restoring deteriorated wetlands is the addition or retention of sediment to increase marsh elevation to a level that will support wetland plants (Mendelssohn and McKee 1988, DeLaune et al. 1990, Wilsey et al. 1992).

The Louisiana coast is divided into two geomorphic regions: the Mississippi River Deltaic Plain and the Chenier Plain (Visser et al. 1998). The Deltaic Plain is generally characterized by interdistributary marshes that are separated by abandoned river channels (Coleman and Gagliano 1964, Wright 1985). The soils in the Deltaic Plain are generally poorly drained, fluid, and highly organic and contribute to higher rates of land loss in the Deltaic Plain then in the Chenier Plain (Dunbar et al. 1992). Wetland loss in the Chenier Plain has historically been much lower than that of the Deltaic plain because of smaller subsidence rates associated with the more mineral soils found within the Chenier complex (Dunbar et al. 1992). Throughout the time period of 1978-1990, the Deltaic Plain accounted for 80% of the total coast wide land loss, while the Chenier Plain accounted for the remaining 20%. Numerous projects involving wetland restoration or creation in coastal Louisiana have been constructed within the Chenier plain (Coastal Wetlands Planning Protection and Restoration Act 2006). However, projects involving advanced engineering components have now begun to spread to the Deltaic Plain as new techniques are being developed to account for the generally unstable soils found there (organic matter content approximately 86%) (Visser et al 1998).

Restoration Techniques

Numerous techniques have been used to restore subsided areas in coastal Louisiana by transporting new sediments to increase elevation within deteriorating marshes. Some of the more commonly used restoration methods to create or enhance wetlands using sediments have been the construction of fresh water diversions (Caernarvon and Davis Pond), segmented breakwaters (Holly Beach and Raccoon Island), Christmas tree fencing (in both the Deltaic and Chenier Plains), and beneficial-use sediment dredging (Moger and Faust 1991, DeLaune et al. 2003). Of these restoration techniques, beneficial-use dredging has the greatest potential to restore or create the largest amount of wetlands and it is not uncommon for beneficial-use dredging projects to result in the creation (or enhancement) of several hundred acres of marsh. The Bayou LaBranche wetlands project, completed in 1994, was one of the first successful marsh creation projects using beneficial-use sediments. Bay islands, such as Queen Bess, and Grand Terre, several of the Isle Dernieres barrier islands, and interior marshes, such as West

Belle Pass, Little Lake, and Fourchon are excellent examples of successful beneficial-use sediment projects. In addition, beneficial-use sediment has the added value of resolving spoil disposal issues generally associated with maintenance dredging of navigable waterways. Consequently, numerous studies have been completed on the effects of beneficial-use sediments (Woodhouse et al. 1972, Turner and Cahoon 1988, Landin et al. 1989, Ford et al. 1999, Streever 2000) and the addition of sediments has shown to restore and enhance the productivity of deteriorating wetlands (Woodhouse et al. 1972, Chabreck 1989, Landin et al. 1989, Streever 2000).

Although beneficial-use sediments have been used to create or enhance wetlands, there are a number of major limitations that will continue to restrict the large-scale use of hydraulic dredge operations to distribute sediments across Louisiana's deteriorating coast. For example, many of the interior marshes suffering from wetland loss in Louisiana are often remote and inaccessible to sediment sources, sediment transport technology is presently limited to relatively short distances, and the per-acre construction costs of a dredge operation are significantly high. Still, as noted previously, there have been numerous successful beneficial-use sediment projects constructed in coastal Louisiana. Since inception in 1990, the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA) has constructed fifteen beneficial-use projects by hydraulic dredge. Over 20 million cubic yards of sediment have been used to create (or benefit) approximately 3,100 acres of marsh, at a cost of one hundred million dollars (Miller 2003). Although it has been demonstrated that the beneficial-use sediments have significant potential for creating and enhancing large areas of wetlands, the cost per acre will continue to be a limiting factor. For this reason, it is important to conduct research using methods that increase sediment distribution, but are more economical and efficient in their implementation.

Marsh Terracing

Marsh terracing, also known as bay bottom terracing, is a relatively new restoration technique being used in shallow, open water marshes in coastal Louisiana. The construction of marsh terraces combines several existing marsh restoration concepts into one innovative approach, i.e. construction of breakwaters, sediment dredging, and vegetative establishment on dredge spoil (Underwood et al. 1991). First used at Sabine National Wildlife Refuge in Cameron Parish, terracing has become widespread and increasingly popular with Louisiana's restoration community, especially within the Chenier Plain (Purkey 2003). Many groups are implementing terrace systems throughout coastal Louisiana, with at least 700,000 linear feet of terraces constructed since 1990 (Good et al. 2005). Marsh terraces have been characterized as a relatively inexpensive and effective means of reducing open water fetch, and consequently, shoreline erosion and bottom scouring. By reducing wind generated wave energies within the system, terraces cause suspended sediments to settle out, improving water quality and submerged and emergent vegetative environments. Additional benefits are derived by increasing marsh edge habitat, increasing overall primary and secondary productivity, and maximizing access for marine organisms (Underwood et al. 1991).

Typically, marsh terraces are segmented ridges or levees that are constructed with a marsh buggy equipped with a long-arm backhoe. *In-situ* materials are dredged from the bottom of the marsh and formed into ridges or levees approximately two to three feet above the surrounding ambient marsh elevation (Underwood et al. 1991, Louisiana Department of Natural Resources 2003). The dredge material is dug from alternating sides of the terrace to prevent continuous borrow canals immediately adjacent to the terraces, thus reducing the probability of current scouring and sloughing along the base of the terrace. Terrace systems have been constructed throughout Louisiana coastal marshes in various patterns, with openings between individual levees to allow for tidal exchange and the ingress/egress of marine organisms (Rozas and Minello 2001). Once constructed, the terraces are then planted at mean water level with an applicable emergent plant species, depending on the salinity of the area. Successful establishment of vegetation on newly created marshes depends on proper location of the dredged sediment and the planting of appropriate material (Lewis 1982). The use of vegetation offers an erosion control method that is compatible with natural processes and relatively inexpensive (Woodhouse et al. 1974, Dodd and Webb 1975, Broome et al. 1983). Many restoration projects in Louisiana utilizing marsh terraces have been constructed within brackish or saline environments (parts per thousand (ppt) > 8); therefore, *S. alterniflora* has been the species of choice for the majority of these systems.

Vegetative Establishment

Spartina alterniflora Loisel, commonly known as smooth cordgrass or oystergrass, is the dominant clonal salt grass found within the low, intertidal zone of the Atlantic and Gulf coasts (Mitsch and Gosselink 1986). Where salinity is approximately 20 ppt, *S. alterniflora* occurs in nearly monospecific stands, forming distinct ecological zones (Dai and Weigert 1996). Because *S. alterniflora* has been proven to survive inundation for extended periods and elevated salinity levels, it is selected for planting in many restoration projects in coastal Louisiana (Mooring et al. 1971, Landin 1991).

The establishment of *S. alterniflora* on newly constructed salt marshes has been studied extensively (Chabreck 1989, Landin et al. 1989) and these studies have shown that this species has the ability to rapidly colonize barren areas (Smart 1982). Although *S. alterniflora* is a critically important species in Louisiana's coastal marshes, it is considered an invasive species along the Pacific coast (Aberle 1993). However, because of its intrinsic growth rate, vigorous spreading ability, and strong rhizomatous growth, *S. alterniflora* has been used in restoration projects throughout Louisiana to create estuarine habitat, stabilize dredge material, and reduce shoreline erosion (Matthews and Minello 1994, Craft et al. 1999). Previous research has shown that when *S. alterniflora* is established on a newly created marsh that the aboveground biomass is equal or greater than that of the ambient marsh after only two growing seasons (Broome et al. 1988), but that planting date and elevational differences may have an effect on survival and productivity (Broome et al. 1975, DeLaune et al. 1983, Webb and Dodd 1989).

Studies conducted by Webb and Dodd (1976, 1989) in Galveston Bay, Texas, show that *S. alterniflora* can be planted year-round, but that vegetative success varies by season. Woodhouse and Knutson (1982) and Webb and Dodd (1976) suggest that the practical planting season for southern regions begins in late winter, more specifically, in the month of February. However, Steyer (1993) conducted a monitoring study on the Sabine National Wildlife Refuge marsh terraces that had been planted with *S. alterniflora* in the month of October and the vegetation had over an 80% survival rate. These results suggest that a number of other environmental characteristics, such as soil moisture, salinity, and site elevation, may also impact the survival and productivity of *S. alterniflora* in coastal marshes (Howes et al. 1986, Callaway 1992, Seliskar et al. 2002, Proffitt et al. 2003).

The influence of subtle differences in elevation on vegetative growth in coastal marshes is well documented (Lessman et al. 1997, Ford et al. 1999, Proffit et al. 2003). Studies have shown that the ability of *S. alterniflora* to colonize some, but not all, intertidal areas can be determined by differences in the microenvironment (Wijte and Gallagher 1996, Seliskar et al. 2002). Consequently, stands of *S. alterniflora* transplanted out of elevational range appear to decline in both height and vigor with changes in elevation only a few centimeters. Since marsh elevations are generally only slightly above mean Gulf level (Chabreck 1989), salt marshes that fall below sea level are subject to excessive inundation and waterlogging, which has been shown to adversely affect vegetative growth (Mendelssohn and Seneca 1980, Mendelssohn and McKee 1988, Bertness 1991).

Research has shown that differential tidal inundation of salt marsh habitats generates severe gradients in soil anoxia and salinity (Jefferies 1977, Mendelssohn et al. 1981). Wetland vegetation is sensitive to hydrological conditions and submergence can stress vegetation, ultimately leading to plant mortality (Mendelssohn et al. 1981, DeLaune et al. 1983). However, a study done by Teal and Teal (1969) showed that *S. alterniflora* not only survived periods of inundation, but that the plant flourished under the saline and anoxic soil conditions that are associated with flooding in coastal marshes.

Coastal wetland soils in Louisiana are typically waterlogged soils that are essentially devoid of oxygen and completely full of water (DeLaune et al. 1979). These soils can rapidly become anaerobic around the roots of wetland plants and shift from an oxidizing to a reducing environment (Teal and Kanwisher 1961). Reducing environments may lead to levels of hydrogen sulfide and soluble ferrous iron in the soil that can be toxic to wetland vegetation (Koch and Mendelssohn 1989, Mendelssohn and Morris 2000). When sediment in a reduced environment from a water bottom is dredged and deposited in the marsh, a series of abrupt alterations take place that cause important changes in the sediment chemistry (Dunstan et al. 1975). The dredged material contains heavy metals that, once oxidized, can be either stimulatory or inhibitory to wetland vegetation systems (Dunstan et al. 1975). Many of the metals present at low concentrations, such as zinc and copper, are essential for plant life, but can become toxic at higher concentrations (DeLaune and Pezeshki 1988). Nitrogen and phosphorus are essential elements that most commonly influence plant productivity in wetland systems (Valiela and Teal 1974, Broome et al. 1975, Mendelssohn 1979) and because nitrogen limitation appears to be the dominant factor controlling growth, the addition of nitrogen fertilizer to a natural salt marsh is thought to stimulate plant growth (Mendelssohn et al. 1982). However, past research has shown that nutrient supplies in regularly flooded marshes are usually adequate for plant growth of *S. alterniflora*, and that fertilizer virtually has no effect on its success (Webb and Dodd 1989).

There have been many studies conducted on the productivity and biomass of *S. alterniflora* (Stroud and Cooper 1968, McIntyre and Dunstan 1975, Kirby and Gosselink 1976, Linthurst and Reimold 1978, White et al. 1978, Hardisky et al. 1984, Gordon et al. 1985) and the majority of research only monitors aboveground productivity. Mueller-Dombois and Ellenburg (1974) developed specific methodology to estimate aboveground vegetation when conducting plant productivity assessments in a field environment. They developed the widely used clip-plot method that uses a quadrat to assess aboveground relative plant abundance. Quadrat sampling is a standard approach for estimating aboveground density, biomass, and other characteristics of a population (Mueller-Dombois 1974, Krebs 1989). However, measurements of belowground biomass have been shown to be equally as important in obtaining an unbiased estimate of *S. alterniflora* productivity (Gross et al. 1991).

Studies have shown that the belowground biomass is often much larger than that of the aboveground material and may be a more accurate measurement of plant biomass and primary productivity (Gallagher 1974). To estimate belowground biomass in wetlands, sediment cores are taken, the material is washed and strained, living and dead matter are separated from one another, and all material is weighed, dried to a constant weight, and re-weighed (Gallagher 1974). Soil coring may be difficult in wetlands because the soil is usually flooded and soft, and the separation of organic matter from soil is difficult (Hopkinson and Dunn 1984, Schubauer and Hopkinson 1984). Therefore, belowground biomass coring devices must be adapted based on specific conditions of the project site (Gallagher 1974, Hopkinson and Dunn 1984, Hopkinson 1984).

Seed Establishment

Numerous studies have been conducted on the efficiency and effectiveness of establishing *S. alterniflora* using clonal or vegetative transplants. However, because of the increasing size of restoration projects, there is significant interest in determining if vegetative cover can be established through the use of seed. Although *S. alterniflora* can be established by seeds, rhizomes (bare-root slips), or whole plants (Daehler and Strong 1994), most restoration projects primarily utilize colonial transplants because of the high resilience of the vegetative plant material to environmental stressors and reports on low germination and viability of *S. alterniflora* seed (Chapman 1960, Larimer 1968). However, past research by Mooring et al. (1971) and Broome et al. (1974) shows that viability of *S. alterniflora* seed can be maintained for several months after harvest if seeds are properly handled and stored. In fact, studies done by Broome et al. (1986, 1988) and Seneca et al. (1976) demonstrated that direct seeding can be successful in establishing vegetative cover of *S. alterniflora* when planted in a protected area in the upper half of the intertidal zone. A study by Webb et al. (1984) demonstrated the success of seeding plots by reporting a higher number of aboveground shoots in the seeded plots when compared to the number of shoots in the transplanted plots. Keeping seeds in place until they germinate is the main challenge when seeds are sown in an intertidal location (Woodhouse et al. 1972). In intertidal areas of high wave energies establishment has generally been with transplants since they are more tolerant of waves and currents than seeds and young seedlings (Lewis 1982). Unfortunately, the high cost of vegetative material and intense labor involved with establishment limits their potential for use in the stabilization of created wetlands. Although transplants are vigorous and appear to perform better under adverse site conditions than seeds, when conditions are optimal, seeding has been shown to be the most economical method of plant establishment on dredged material (Woodhouse 1979).

As Mooring et al. (1971) and Broome et al. (1974) demonstrated there are numerous factors that influence the viability and germination of *S. alterniflora* seed. A number of studies have shown that viability of *S. alterniflora* seed is significantly influenced by site variables (Mooring et al. 1971, Broome et al. 1974). Site selection is critical, as it has been shown that seed quality, as well as quantity, varies greatly from one stand to another. It is generally accepted that the best quality and greatest seed production are found on young, vigorous plants on recently colonized sites (Broome et al. 1974).

Past research has shown that seed collections should begin at the first sign of shattering, usually from late October to mid November in southeastern United States (Stalter 1972). The flowering sequence of *S. alterniflora* originates at the distal tip of the inflorescence and proceeds basally (Fang et al. 2004). Because the first seeds to shatter are those located at the seedhead tip, *S. alterniflora* seeds can be can be hand-harvested by cutting the entire inflorescence just below the bottom floret. Germination studies have shown that harvesting seed as near to maturity as possible will increase germination rates. Seed viability, which is the ability of the seed to germinate, can be maintained for several months after harvest if seeds are properly stored (Broome et al. 1974, Baskin and Baskin 1998). However, it is often necessary to compromise on complete seed maturity since large amounts of seed will be lost from natural shattering if harvesting is delayed too long.

An acceptable method for harvesting seed prior to natural shattering is to clip the entire seedhead and store it in a high moisture environment under cool (approximately 18° C) temperatures for thirty to sixty days (Seneca 1974, Chappell and Cohn 2006). This post-harvest storage is generally termed after-ripening and facilitates a continuation of maturation of immature seed (Broome et al. 1974). Seed moisture is critical during the after-ripening phase and seed moisture should remain at approximately 34 – 36% (dry weight basis) to maintain seed viability (Chappell and Cohn 2006). After-ripening also accelerates the deterioration of the seed pedicel, the rachilla, and other points of seed attachment, and greatly assists in separating seed from the rest of the inflorescence (Broome et al. 1974).

Spartina alterniflora seeds are both dormant and recalcitrant (Plyler and Carrick 1993, Chappell and Cohn 2006) and post-harvest treatments are required to break seed dormancy. Seed dormancy is a state of "suspended animation", or quiescence, when a living, viable seed will not germinate even though all the environmental conditions for growth are optimal (Farnsworth 2000). Recalcitrant seeds have high moisture content at maturity (30 – 70%), low longevity, limited storage capabilities, and are internally damaged by drying (Chin et al. 1980, Berjak and Pammenter 2001). It has been well documented that *S. alterniflora* seeds possess site-specific dormancy in the scutellum, a modified cotelydon that influences germination (Plyler and Carrick 1993, Plyler and Proseus 1996, Chappell and Cohn 2006). Although dormancy can be broken by surgically altering the scutellum or applying a growth-regulating substance, such as fusicoccin (FC) (Plyler and Carrick 1993), it is generally accepted that a cold-wet stratification (2° to 5 °C) for at least thirty days is necessary for the germination of *S. alterniflora* seeds. Seeds can be held under these conditions for approximately eight months, but they will begin to germinate even under cold-wet storage conditions if held too long. Most researchers estimate the shelf life of *S. alterniflora* seed at approximately nine months from harvest (Broome et al. 1974, Chappell and Cohn 2006).

Spartina alterniflora seed viability can be monitored by determining a baseline germination through testing at the time of collection and retesting seed germination at pre-selected intervals, usually thirty days. Since full emergence of the epicotyl (shoot) precedes hypocotyl (root) emergence in *S. alterniflora* seed, epicotyl emergence should be used to measure the onset of germination (Mooring et al. 1971). Controlled germination tests in a laboratory are designed to complement field studies and to help interpret response in the field (Seneca 1974). Mooring et al. (1971) developed the basic requirements for storage and germination of *S. alterniflora* seed and determined that the seeds cannot withstand drying and must be stored in cold temperatures to maintain viability. Mooring's study also indicated that *S. alterniflora* seeds germinate best in fresh water and that a gradual decline in germination occurs as salinity is increased. It is important to note that in most published results on *S. alterniflora* germination rates, researchers only include whole, filled seeds in the germination trials (Broome et al. 1974, Plyler and Carrick 1993, Plyler and Proseus 1996). When dealing with large-scale restoration projects, such as marsh terracing, it is not practical to separate empty or damaged seed from filled seed. Field application and germination tests from unsorted, randomly selected seed will result in a "relative" germination percent of an entire seed collection (Materne et al. 2003) instead of a biased rate based on only filled seed.

Numerous studies using seeding as the primary method of plant establishment on dredge material have been attempted and all of the techniques involved logistical access to the area with heavy equipment and mobility around the site (Mooring et al. 1971, Seneca 1974, Broome et al. 1974). Since many coastal marshes in Louisiana cannot physically support a ground-based seeding operation, or are simply inaccessible, these past seeding techniques would not be suitable for many deteriorating wetlands. Aerial seeding of *S. alterniflora* offers non-invasive alternative to current planting technology and would permit these inaccessible areas to be planted at a fraction of the cost of manual transplanting.

Aerial application of rice seed (*Oryza sativa*) is the primary means of planting rice in Louisiana and virtually all aspects of aerial seeding are well-established. Louisiana farmers, on average, plant 350,000 to 400,000 acres of rice annually by air (Materne 2003). *Oryza sativa* and *S. alterniflora* are similar in that they are both grasses, both are physiologically adapted to aquatic and semi-aquatic environments, and both produce large quantities of seed, although rice seed is significantly larger and heavier than that of *S. alterniflora* (Materne et al. 2003).

Because of the similarities of the rice and *S. alterniflora* seed, Materne et al. (2003) developed a *S. alterniflora* seeding formula based on well-established rice seeding rate models. Within their study, it was estimated that *S. alterniflora* produced approximately 90,000 seeds per pound with an average germination rate of 56%, which was considerably lower than that of rice at 80% (Materne et al. 2003). To compensate for a lower germination differential between *S. alterniflora* and rice varieties, Materne et al. (2003) modified the rice seeding formula by using a pure-live-seed (PLS) factor as opposed to a germination percentage.

Based on the study by Materne et al. (2003) and using the same variables as the rice formula, but including the PLS element, the formula to determine a *S. alterniflora* seeding rate is as follows:

50 (target seeds/ft^2) x 43,560 (ac ft^2) = 2,178,000 (seeds/ac^2)

2,178,000/90,000 (*S. alterniflora* seeds/lb) = 24 (lb of seed/ac^2)

24/.56 (germination %) = 43 (seeding rate in lb/ac^2 based on PLS)

43 (lb/ac^2) x 90,000 (seeds/lb)/43,560 (ac ft^2) = 89 (calculated seeds/ft^2)

Although *S. alterniflora* has a relatively large seed, it lacks significant endosperm density (Farnsworth 2000). Consequently, seeds are generally thin-walled and light in weight relative to their volume (Farnsworth 2000). *Spartina alterniflora* seeds must be stored under aqueous conditions to maintain viability, so they become cohesive and form sticky clumps when drained. To compensate for excessive seed moisture and clumping, the seeds must be blended with an inert clay carrier (palygorskite) at a 1:2 ratio that will absorb moisture, provide additional weight, and facilitate uniform distribution when released (Materne et al. 2003).

Previous attempts at coastal marsh creation or restoration have shown that the most effective technique is an integrated approach that works with natural processes to create wetland hydrology and establish hydrophytic vegetation (Kusler and Kentula 1989, Craft et al. 2003). In nature, *S. alterniflora* spreads by rhizomes within established populations, but colonization of new areas is mainly done by seed (Seneca 1974). For this reason, direct seeding should be examined as a possible method of vegetative establishment on marsh terraces, but because of planting specifications established by project sponsors, many terracing projects are restricted to transplanted material even though seeding may be a viable option.

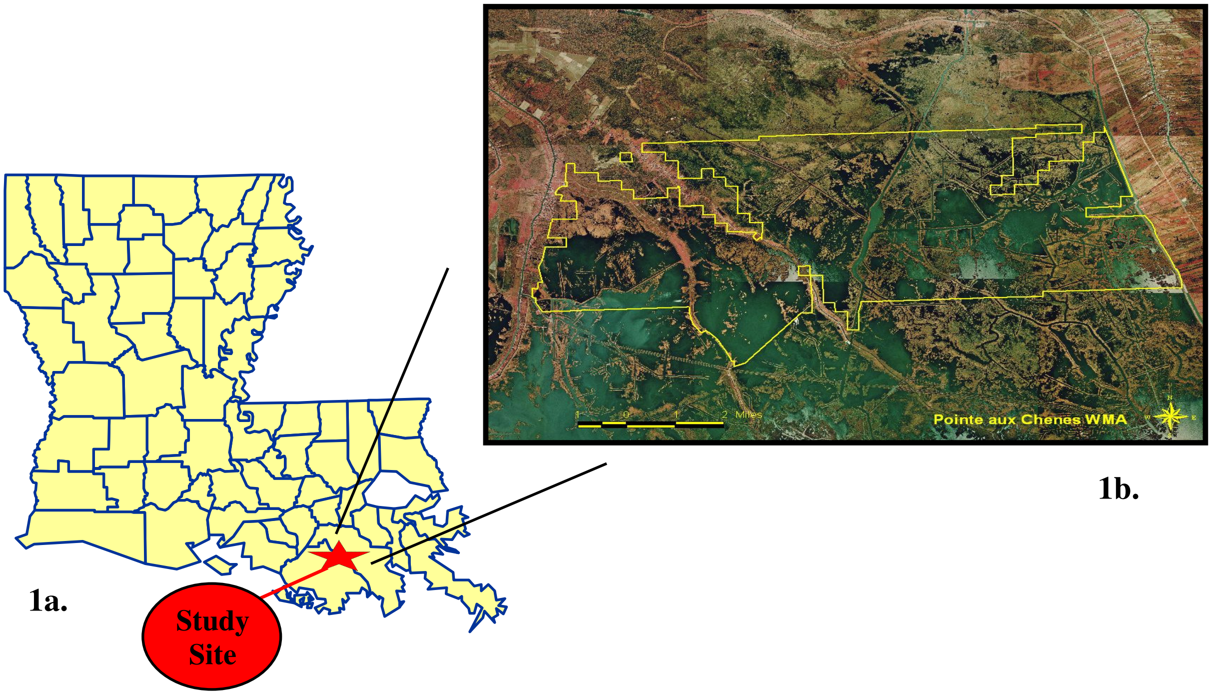
Because of a lack of long-term monitoring after project construction, evaluation of wetland restoration success has been limited (Race and Fonseca 1996, Zedler 2000). Quantitative measurements of marsh terraces are necessary to evaluate terrace stability and vegetative success. While there has been an abundance of research conducted on nekton populations in terraced ponds (Rozas and Minello 2001, Bush Thom et al. 2004, Gossman 2005, Cannaday 2006), studies that quantify the success or failure of vegetation on the terraces are rare (Underwood et al. 1991, Steyer 1993). Marsh terraces have proven to be a cost-effective technique with the potential of preserving and restoring significant portions of Louisiana's coastal marshes, but further research is needed before terracing can approach the scientific standards required for large-scale wetland restoration projects.

MATERIALS AND METHODS

Study Site Description

This research project was conducted over a two-year period, beginning in the spring of 2004 and ending in the fall of 2006. The field research was completed on the Pointe aux Chenes WMA located approximately fifteen miles southeast of Houma, Louisiana (Figures 1a. and 1b.). Pointe aux Chenes WMA is a state managed wildlife refuge located in both Terrebonne and Lafourche Parishes, and is considered part of the Terrebonne Basin.

Like the vast majority of marshes found in coastal Louisiana, Pointe aux Chenes WMA has been heavily affected by marsh subsidence, saltwater intrusion, extremes in tidal amplitudes, and extended hydroperiods that have resulted in a system of fringe vegetation and large expansion of shallow open water (Penland et al. 1990). Chabreck and Linscombe (1997) mapped Pointe aux Chenes WMA as a brackish marsh with *Spartina patens* (marshhay cordgrass), *Scirpus olneyi* (three-cornered grass), and *Eleocharis parvula* (dwarf spikerush) as the dominant plant species. However, based on current site assessments, the plant community is transitioning into more saline and emergent species, with *S. alterniflora* in the open and intertidal areas, and *S. patens*, *Distichlis spicata* (saltgrass), and *Batis maritima* (saltwort) co-mingled at slightly higher intertidal elevations. *Iva frutescens* (marsh elder) is the dominant shrub species found on spoilbanks and other high ground, with some *Baccharis halimifolia* (groundsel-tree), *Pluchea odorata* (stinkweed), *D. spicata, Paspalum vaginatum (seashore paspalum), and Amaranthus tamariscina* (waterhemp) as community members. The present brackish/saline plant community currently found within the project area is in stark contrast to the former freshwater swamp habitats found on the Pointe Aux Chenes WMA in the 1950's. A survey of the remaining ridges on the western boundary shows numerous standing dead trees (*Taxodium distichum,* baldcypress), the remaining artifact of a once thriving freshwater wetland forest community.



Figures 1a. and 1b. – Location of Pointe aux Chenes WMA in Louisiana and the Pointe aux Chenes WMA boundary. The refuge is located approximately fifteen miles southeast of Houma, Louisiana, in both Terrebonne and Lafourche Parishes. The area consists of approximately 35,000 acres of shallow, open water, brackish marsh. (Source: modified from the U.S. Geological Survey).

This research was conducted on a large-scale terracing project completed by the Louisiana Department of Wildlife and Fisheries in 2002. The construction of this terrace system was made possible through a grant provided by the Environmental Protection Agency and in-kind work provided by Louisiana Department of Wildlife and Fisheries. The primary objectives of the construction and design of the Pointe aux Chenes terraces were to reduce wave energies, promote sediment deposition, improve water quality, thus, promoting productivity of both submerged and emergent vegetation.

Terrace design and configuration is still an evolving science within the coastal engineering community and terraces have been constructed in a number of design configurations, such as checkerboard (i.e. Pecan Island Terracing) and duck-wing design (i.e. Little Vermilion Bay Sediment Trapping). The terraces within the Pointe Aux Chenes WMA system were constructed in a linear and parallel design, and grouped into three discrete terrace units. Where possible, individual terraces were anchored to existing vegetative marsh and each terrace group placed strategically within the tidal regime to achieve maximum baffling of water movement, reduce fetch length, and provide a greater degree of control of the hydrologic/sediment dynamics normally associated with open water systems. The Pointe aux Chenes WMA terracing system consists of twenty-six segmented terraces, with an average length of 400 feet and a total systems length of 11,658 linear feet (6.1 acres of elevated marsh) (Linscombe 2005). See Figure 2 for an aerial view of the system design, individual terraces, terrace groupings, and the proximity of terraces to the existing ambient marsh complex.

Although the successful completion of any large-scale restoration project is important, the Pointe aux Chenes WMA terracing project is especially significant because it represents the first terrace system constructed within the Deltaic Coastal Plains. Although widely used in the Chenier Plains, terrace construction was generally thought to be unfeasible within the Deltaic Plain because of its predominantly high organic content and relatively fluid soils. However, construction of the Pointe aux Chenes WMA terraces was possible by utilizing remnants of the more mineral soils associated with two natural ridges that parallel the management area.

Experimental Design

A randomized block design with a 2 x 2 x 2 multi-factorial arrangement of treatments blocked by terrace was used to assess treatment effects. Treatments included two levels of plant growth form: containered plants (trade gallon) and vegetative plugs (bare-root); two levels of planting seasons: spring planted and fall planted; and two levels of growth period: 6 months and 12 months. In addition to the treatment and control plots established on selected terraces, an ambient marsh adjacent to treatment terraces was identified for productivity comparisons and

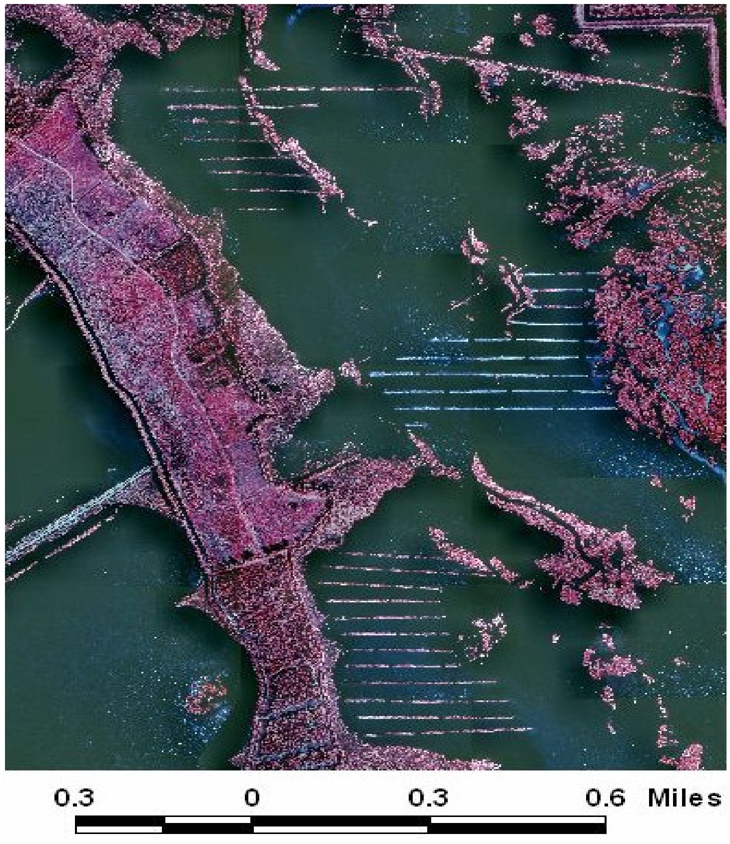


Figure 2 – Aerial photograph showing twenty-six terraces constructed in two phases that makeup the Pointe aux Chenes open water restoration project. Six terraces, each having similar elevation, salinity, wave energy, and fetch lengths were selected for this study.

a separate seeding study was conducted to determine if direct seeding of *S. alterniflora* was a viable option for establishing vegetation on constructed marsh terraces.

Analysis of Variance (ANOVA, Proc MIXED) was used to examine if there were differences between stem density, stem height, stem diameter, aboveground biomass, inflorescence, and belowground biomass among treatments. Where significant differences occurred, post-hoc comparisons were used to identify differences between specific treatments. All statistical analyses were conducted with SAS statistical analysis software (version 9.0; SAS Institute, Cary, North Carolina) and an alpha level of 0.05 was considered significant for all analyses.

Plot Design

Six marsh terraces were selected, three for the fall and three for the spring planting treatment (3 terraces x 2 planting seasons = 6 total terraces). Each treatment terrace was divided into three subplots; one subplot was planted with *S. alterniflora* vegetative plugs on three foot centers (n = 100, total plot length = 300'); another planted with *S. alterniflora* trade gallons on five foot centers (n= 100, total plot length = 500'); and the third subplot was left unplanted as a control (total plot length = 50'). Each of the two plant growth form treatment plots was replicated three times and the orientation of the plugs and trade gallons on the terrace was randomly selected. Each plant growth form/control treatment was planted under both fall and spring conditions.

A seeding study was conducted as a separate experiment by establishing five subplots total plot length = 90') along the crown and side slopes of the terrace. Each seeding subplot was constructed such that it encompassed not only the terrace crown, but also both side slopes extending from waters edge to waters edge. See Figure 3 for a schematic of the vegetative treatment design.

Site Characterization

Hydrology

To monitor changes in water depth and salinity throughout the study period, a YSI model 600LS sonde was installed in open water adjacent to the study terraces. The sonde was housed in a vertical structure consisting of a 16' treated 4"x 4" post driven into the marsh to resistance. The sonde was attached to a 2" PVC pipe that was then placed within a 3" perforated PVC pipe mounted to the 4"x 4" post with lag bolts. The bottom of the sonde rested on a 6" hitch-pin that was inserted through the 3" PVC and positioned approximately 2" off the marsh bottom. The 10' vented data cable was threaded through the top of the 2" PVC and secured in a covered hard-

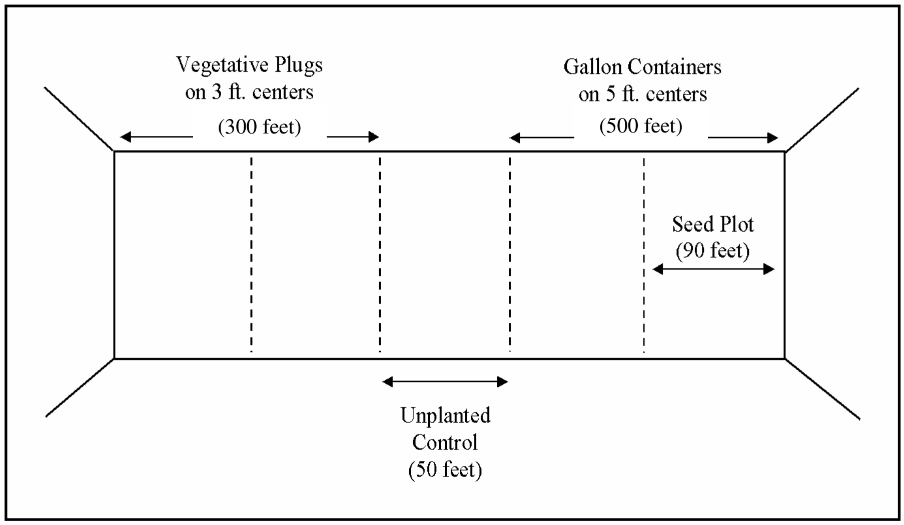


Figure 3 – Schematic of vegetative and seeding plots established on the marsh terraces. Each treatment terrace was divided into three subplots: one subplot was planted with *Spartina alterniflora* vegetative plugs on three foot centers, another planted with *S. alterniflora* trade gallons on five foot centers, and the third subplot was left unplanted as a control. For the seeding experiment, five subplots were established along the crown and side slopes of the

plastic electrical box, mounted by a flange on top of the 3” PVC. See Figure 4 for a schematic of the sonde field structure.

Before field deployment, the sonde was calibrated for atmospheric pressure using a vented level system and for specific conductance using a 10 mS/cm conductivity standard. Theconductivity calibration was checked using a YSI hand-held salinometer (Model NCT) to conduct a set of real-time measurements that were compared to sonde readings prior to leaving the structure. Once installed, the sonde was removed every three months for data collection, cleaning, maintenance, and recalibration. Field data were downloaded from the sonde using a YSI microcomputer based datalogger (YSI 650 Multiparameter Display System) and the data were imported into Microsoft Excel for analysis. The sonde collected data on water temperature (C), specific conductance (µm), salinity (ppt), and water level (cm) every thirty minutes for twelve months.

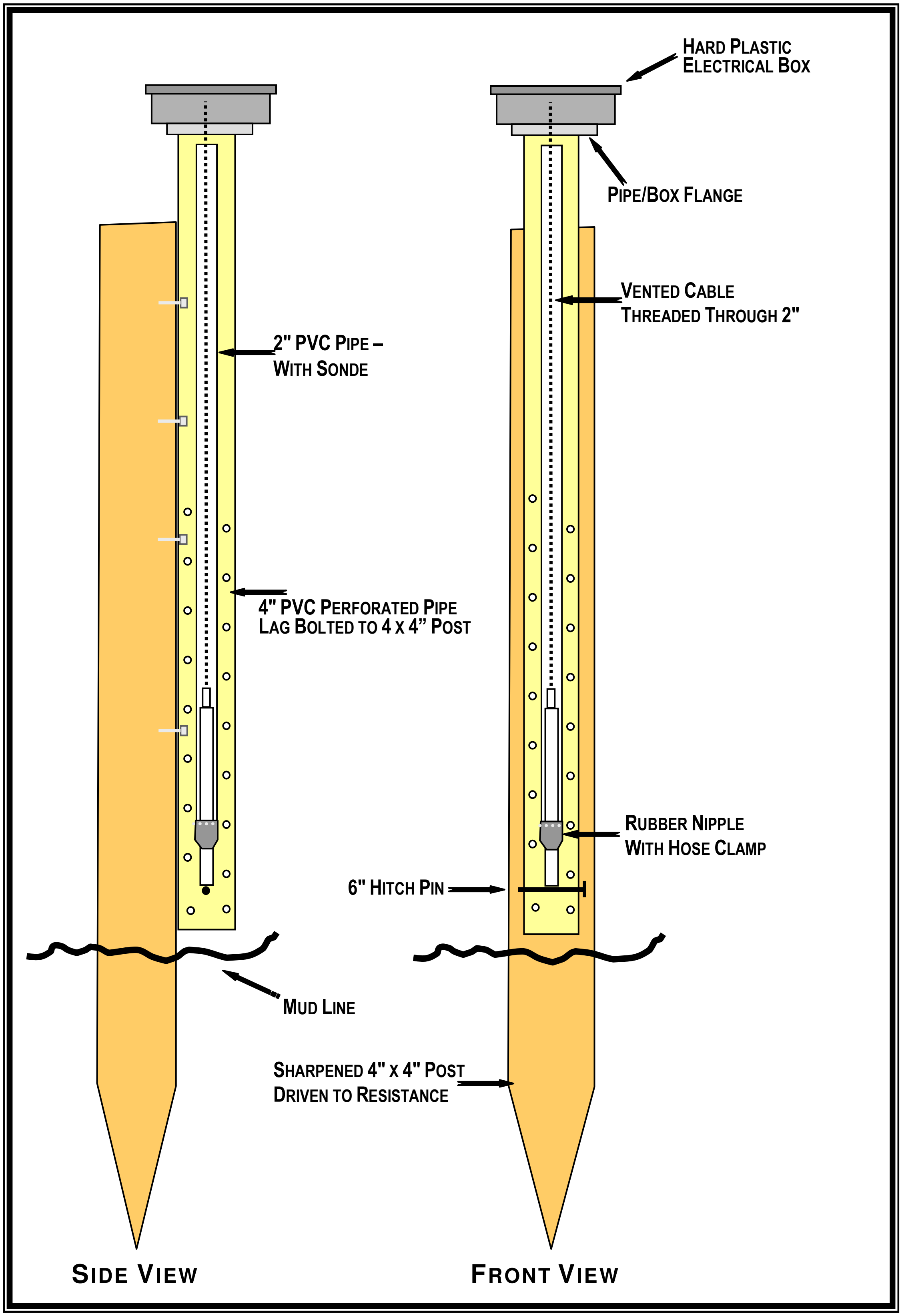


Figure 4 – Schematic of the YSI sonde (Model 600LS) field structure that was constructed in open water adjacent to the project site. (Source: used with permission Materne et al. 2005)

The sonde was attached to a stationary structure installed in an open water system adjacent to the terraces, as described earlier in this section. The sonde was positioned so that the bottom of the sonde was fixed approximately five centimeters off the marsh bottom and well below ambient marsh. Using standard elevational surveys that will be discussed later in this section, the height of ambient marsh was determined and used as the baseline elevation (assumed as zero). Consequently, it was necessary to correct the water level measurements to ambient marsh elevation; that is, to correct water level measurements to actual plus or minus levels above or below ambient marsh. This was accomplished by determining the elevation of the water level sensor relative to the elevation of the ambient marsh and subtracting the difference from each water level measurement.

Elevational Surveys

Environmental Systems Research Institute's ArcView 3.2 software was used to facilitate elevational surveys taken at the study site. Existing aerial imagery of the Pointe aux Chenes WMA (1998) was prepared by the U.S. Geological Survey and available online through the LaCoast website (http://www.lacoast.gov). Two additional base maps were flown specifically for this study in December 2004 and 2005 under a service contract with AeroData, Incorporated. The images were flown at low altitude (2,000 feet), are 1:4,000-scale, and are color-infrared photography. Images were scanned at a high resolution (2032 dpi) and have 0.076-meter pixel ground resolution.

The aerial photos allowed for more efficient field sampling by providing a method to locate important landmarks and interesting vegetative assemblages prior to going to the field. After further field evaluation of these areas of interest, the aerial photos were then used as a map to conduct elevational surveys on selected terraces. To facilitate the elevational surveys, a permanent benchmark was established on one of the marsh terraces by driving a ¾-inch galvanized pipe into the marsh to resistance. The permanent benchmark provided a system for measuring changes in the surface elevation of terraces relative to one another and to ambient marsh.

Elevations of the ambient marsh and the marsh terraces were established using a (Sokkia LP30A) self-leveling laser instrument and a surveying rod graduated in 3 mm (0.01 ft) intervals. An average elevation of ambient marsh was determined and used as the baseline elevation (assumed as zero). All elevational readings were then corrected to ambient marsh elevation. On each terrace, selected points were located three meters apart starting at the east end of the terrace and running length-wise along the crown of the terrace. Plant species composition was determined in a 1.5-meter radius centered at each sampling point. In addition, points of interest, such as areas of bare sediment, were selected on each terrace and a cross section was completed to determine elevations from the north side to the south side of the terrace. These measurements were used to create a complete profile image of the selected area of interest.

Sediment Analysis

Soil samples were collected from five different sampling sites: marsh terrace less than twelve months of age, marsh terrace approximately twelve months of age, marsh terrace greater than twelve months of age, undisturbed sediment on the marsh bottom, and ambient marsh. Soil samples were collected at each sampling plot, placed into labeled Ziplock bags, and transported on ice to the laboratory. These samples were divided into two portions: one portion was used for analysis on wet-soil basis, and the second portion was air-dried and then ground to pass a 2-mm sieve. The samples were analyzed at the Coastal Wetlands Soils Characterization Laboratory, Department of Agronomy and Environmental Management, Louisiana State University for pH (McLean 1982), electrical conductivity, salinity, bulk density, moisture content, and organic matter (Nelson and Sommers 1982). The samples were also analyzed for available phosphorus

(Bray and Kurtz 1945) and sulfur (Tabatabai 1982). Soil texture was determined using the pipette method (Soil Survey 1996). Extractable K, Ca, Mg, and Na (Thomas 1982) were analyzed by ICP (inductively coupled plasma emission spectrophotometer) after ammonium acetate extraction at the Soil Testing Laboratory, Department of Agronomy and Environmental Management, Louisiana State University.

Vegetative Work

Collection and Establishment

Plant material used in this study was collected from the USDA Natural Resources Conservation Service Golden Meadow Plant Materials Center in Galliano, Louisiana, and expanded in a greenhouse environment. Plant materials were collected from one production pond to minimize any intraspecific variability that may exist within the species. All materials were container grown (in 7" containers) and the vegetative plugs were split from the trade gallons before field planting. After transplanting, each plant was assigned a plant identification number (ID) based on its location along the terrace.

Productivity Assessments

Vegetation was monitored throughout the growing season and response variables of survival and growth were measured and recorded. Vegetative growth was assessed monthly for the first five months after transplanting on 25% of the population by conducting stem counts on randomly selected plants of both the vegetative plugs and trade gallons. All living stems of each selected plant were included in the count. Survival measurements were taken on 100% of the population and plants were considered live based on the presence of living, aboveground stems.

Destructive harvests were completed at six and twelve months after planting on a sample of the vegetative population using a clip-plot method to obtain aboveground biomass (Mueller-Dombois and Ellenburg 1974). The plants were randomly selected for harvest prior to going in the field using a random number assignment. During each of the harvest periods (6 and 12 months) of the respective treatments, fifteen vegetative plug samples and fifteen trade gallon samples were harvested. Aboveground vegetation was harvested by clipping materials within a 0.5 m^2 quadrat at approximately one-centimeter above the soil surface and placing the material in a labeled plastic bag. In the laboratory, individual samples were separated into living and dead material. The total number of stems was counted and the length and basal diameter of ten selected living culms were measured. In the fall, the total number of stems with visible inflorescences was also recorded. The clipped material was then placed in labeled, brown kraft bags, weighed, dried at 75° C to a constant weight, and re-weighed to determine dry weight of aboveground biomass.

Belowground biomass was sampled by taking eight-centimeter diameter by 45-centimeter long cores to a depth of 30-centimeters using thin-wall, aluminum irrigation pipe (Gallagher 1974). In the laboratory, each 30-centimeter long core was extruded and sectioned into five centimeter sections to measure the vertical distribution of root/rhizome development. The belowground material was separated by washing individual core sections through a 2-mm sieve and the remaining material was weighed, dried to a constant weight at 75° C, and re-weighed to determine biomass. Since the objective was to compare total biomass of the belowground samples, no attempt was made to separate live and dead material.

Above and belowground samples were taken concurrently from an ambient marsh adjacent to the terrace system. Ambient marshes were defined as emergent marshes not affected by project construction. Samples were also collected from the unplanted control terraces to determine if vegetation would, in fact, colonize naturally on untreated terraces. Vegetation samples (0.5 m^2 quadrat), as well as substrate cores, were taken during each harvest using the same methods as described above for the terraces.

Seed Experiment

To determine the effectiveness of seeding as a means of establishing *S. alterniflora* on marsh terraces, a series of seeding and controlled germination testing was completed in 2004 and 2005.

Seed Treatments

To assess the effects of handling and storage of *S. alterniflora* seed and the relationship to field germination, five seed treatments were examined: (1) seed sown immediately after-harvest (no after-ripening), (2) seed sown four weeks post-harvest (four weeks after-ripening), (3) seed sown eight weeks post-harvest (four weeks after-ripening and four weeks cold/wet stratification), (4) seed sown twelve weeks post-harvest (four weeks after-ripening and eight weeks cold/wet stratification), and (5) seed sown sixteen weeks post-harvest (four weeks after-ripening and twelve weeks cold/wet stratification).

Collection and Storage

Seeds were harvested during the second week in November for both the 2004 and 2005 seeding tests. Harvest was initiated with the first appearance of tip shattering, an indicator of seed maturation. All seeds were collected from Lafourche Parish in southeastern Louisiana. Seeds were hand-harvested by cutting the entire inflorescence just below the bottom floret, thoroughly wetting the seed heads, and placing them in 60-gallon plastic bags for transportation and storage. For the first seed treatment to be sown on the terraces, approximately 3 kg of seed were hand shattered from the seed heads immediately after harvest by tapping the seed head on a plastic sheet laid on the ground or against the inside wall of a large drum. Once the panicles and seed were separated, any remaining debris was removed from the seeds. To determine a baseline germination, a subsample of seeds was randomly selected from the 3 kg and these seeds were further separated into fifteen samples of fifty seeds.

In an open-ended shade house, the remaining seed heads were then spread out in a single layer on a concrete floor under a protected area and rehydrated as necessary. The seed heads were checked daily for the first thirty days to determine the degree of seed release from their panicles, and hand shattering of the remaining seed heads began thirty days after the beginning of the after-ripening process (Broome et al. 1974, Materne et al. 2005).

After all the seed heads were hand shattered, approximately 3 kg of seed was randomly selected for the second seed treatment. All remaining seeds were submerged in water in 5-gallon plastic tubs, sealed with a snap-on lid, and stored in refrigeration units at 2-5° C to undergo a period of cold-wet stratification. A random selection of approximately 3 kg of seed was made from the bulk seed amount four weeks, eight weeks, and twelve weeks after placement into cold-wet storage for the three additional seed treatments.

Field Trials

Prior to sowing, seed was hand-mixed with an inert clay based absorbent (palygorskite) that acted as a carrier to separate seeds and absorb excessive moisture (Materne et al. 2003). An Earthway Shoulder Spreader (Model 3100) was used to distribute the seeds uniformly on the terraces. To determine the number of seeds per square foot, ten samples were taken immediately after sowing using a 0.25 m^2 quadrat.

Seed germination and seedling survival measurements were conducted on the marsh terraces at thirty-day intervals after sowing. To determine seed germination and seedling survival, twenty-five samples were taken using a 0.25 m^2 quadrat. Seeds were considered germinated if the epicotyl (shoot) had emerged from the seed coat and was visible (Broome et al. 1974). Seedlings were determined as surviving if the plantlets had elongated past their primary shoot and the protective coleoptile (first shoot leaf stage) was upright, anchored, and developed to at least the third leaf stage (Materne et al. 2003). No attempt was made to count nongerminated seeds or non-surviving seedlings because of the uncontrolled conditions found on the marsh terraces (i.e. seed burial, predation).

Germination Assessments

Controlled germination testing was conducted throughout the collection and storage phases of the study to complement the field study and to help interpret response on the marsh terraces. Past research has used several different methods to test seed germination (Mooring et al. 1971, Seneca 1974, Linhart 1976, Seneca and Blum 1984, Daehler and Strong 1994, Plyler and Carrick 1993, Plyler and Proseus 1996). Because no optimal germination methodology had been established, three different germination mediums (Paper, Water, and Sand) were used to determine percent germination. Seed viability was monitored throughout the various phases of the study by determining a baseline germination at the time of collection and retesting at the thirty-day intervals. Prior to the beginning of any germination trials, seeds were soaked in a 10% Clorox solution for fifteen minutes and then rinsed with distilled water for an additional fifteen minutes to reduce pathogens (Seneca and Blum 1984). All tests were replicated five times for every seed treatment and germination counts were made at 7, 14, 21, and 28 days. The emergence of the epicotyl (shoot) was used as a germination indicator (Broome et al. 1974).

A number of standardized protocols developed by Mooring et al. (1971) and Broome et al. (1974) were followed to assess percent germination of *S. alterniflora* seed. For each seed treatment in the paper medium, five samples of randomly selected seed (n = 50) were evenly distributed on separate sheets of commercial grade (Anchor) germination paper that had been saturated with distilled water. A second saturated sheet was used as a cover to keep seeds from moving and to maintain moisture. Each sample was placed in a clear container with a lid with a small amount of distilled water in the bottom to maintain hydration. Containers were then placed in a germination chamber with alternating thermoperiods of 12 hours at 32°C and 12 hours at

28°C. Seeds received no supplemental lighting other than when samples were uncovered for germination counts.

Since the findings of Mooring et al. (1971) indicated that *S. alterniflora* seed must remain moist to maintain viability and will germinate best in freshwater, a second germination test was conducted that submerged seeds in water. For each seed treatment, five samples of randomly selected seed (n = 50) were placed into containers filled with eight ounces of distilled water. The containers were then placed in a germination chamber with alternating thermoperiods of 12 hours at 32°C and 12 hours at 28°C.

Based research by Linhart (1976) that demonstrated seeds would germinate in a moistened substrate, a third germination test was conducted that buried seeds in sand. For each seed treatment, five samples of randomly selected seed (n = 50) were placed onto a sand medium and covered with an additional thin layer of sand. The containers were then placed in a germination chamber with alternating thermoperiods of 12 hours at 32°C and 12 hours at 28°C.

RESULTS

Site Characteristics

Water Depth

Over a consecutive twelve-month period that the sonde was deployed, minimum water levels were 43.2 cm below ambient marsh and maximum levels were 46.8 centimeters above ambient marsh with an average water depth of 1.3 centimeters (± 14.9 centimeters) below ambient marsh. Figure 5 illustrates changes in water elevation over a twelve-month period (January 2005 – December 2005) with daily minimum, maximum, and average water levels plotted in relation to ambient marsh (assumed as zero). In this graph, Hurricanes Katrina and Rita (2005) were plotted for reference, but were excluded as outliers in the analysis of the complete data set to reduce skewness in the descriptive statistics.

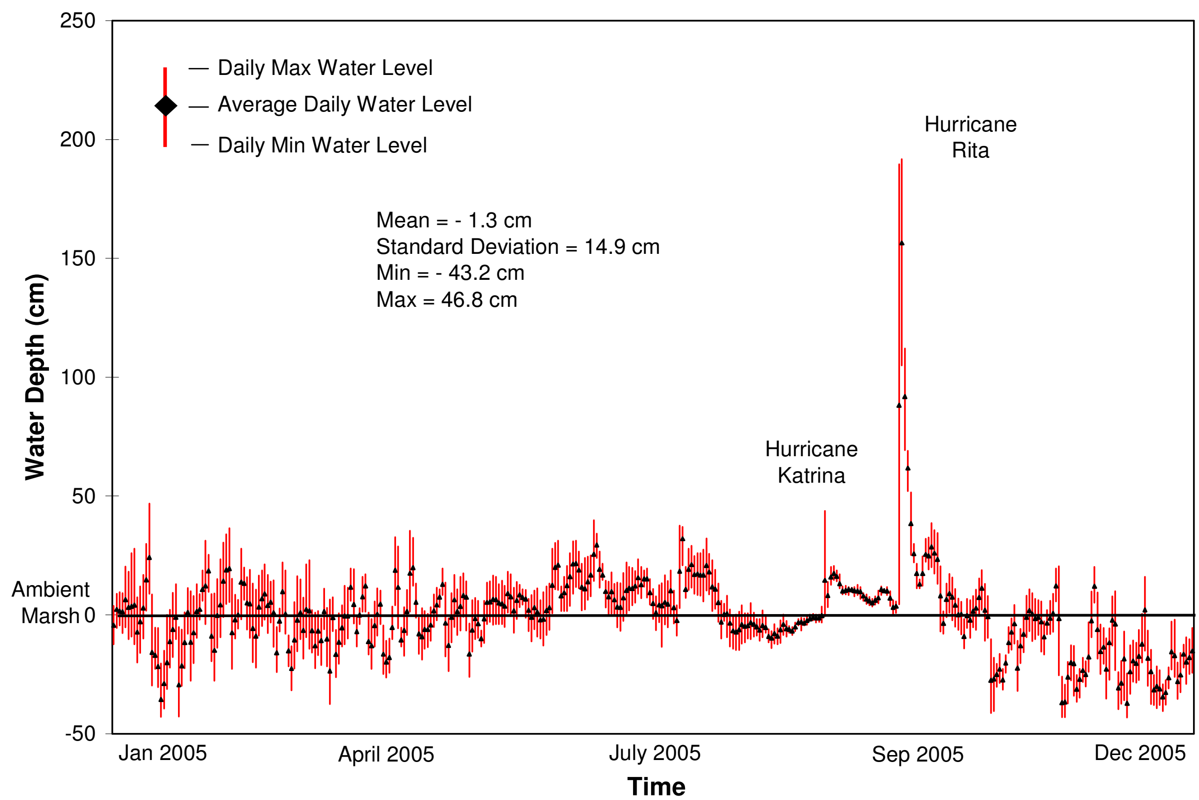


Figure 5 – Changes in water depth over a 12-month period. Individual datalines (red) represent daily minimum and maximum depth. Daily averages are plotted in black. Ambient marsh was used as the reference and is plotted as zero.

To determine water depth in a water body adjacent to the marsh terraces, flood frequency and duration were assessed. Flood frequency was defined as the number of flood events (expressed as percent of total) that flooding occurred at or above a reference elevation. A flood event is defined as a rising and falling water cycle that begins with water level below a reference elevation, rises to or exceeds the reference elevation, and ends when water falls below the initial elevation. One full cycle (regardless of the length of time) would constitute one flood event or frequency. Because vegetation was planted at the same elevation as ambient marsh, this was used as the reference elevation and assigned as zero. The frequency of flooding was determined at ambient marsh (0.0 centimeters) and it was found that there were 153 flooding during a twelve-month period.

Flooding duration was defined as the cumulative amount of time (expressed as percent of total) that standing water remained at or above a specific elevation. Since each recorded occurrence is equivalent to a thirty-minute duration, the cumulative sum of each occurrence at or above a specific elevation would equal to the total time (or percent) that the marsh was flooded.

Using 0.0 centimeters (ambient marsh) as the reference elevation, it was found that flooding of the ambient marsh (where vegetation was planted) was slightly skewed towards wet soils, with flooding occurring 56% of total and drying 44% of total. Table 1 is a summary of the amount of time flooded within a twelve-month period summarized by elevation and percent of total. Figure 7 is the cumulative percent time flooded plotted in approximately 2.54-cm (1-inch) increments.

Water Salinity

Over a consecutive twelve-month period, daily salinities varied, with a minimum of 1.2 ppt and a maximum of 17.3 ppt. With an average salinity of 7.3 ppt, the study site would be defined as an intertidal, brackish marsh environment (Chabreck and Linscombe 1997) (Figure 6).

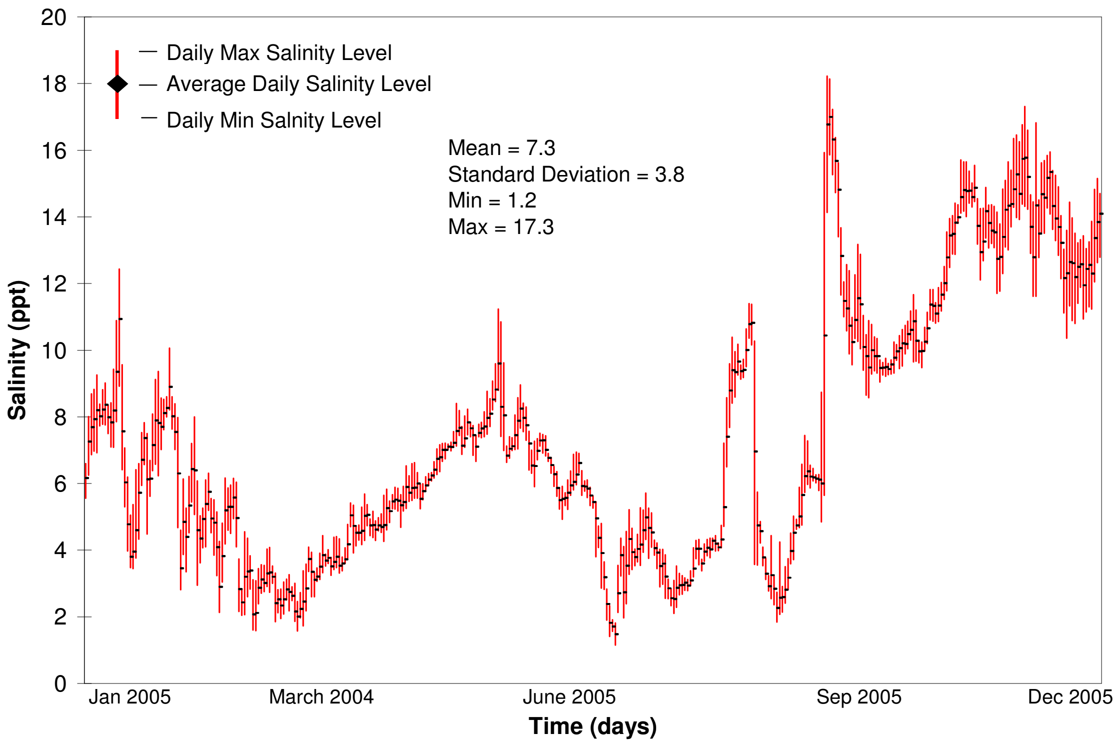


Figure 6 – Changes in salinity (ppt) over a 12-month period. Individual datalines (red) represent daily minimum and maximum depth. Daily averages are plotted in black.

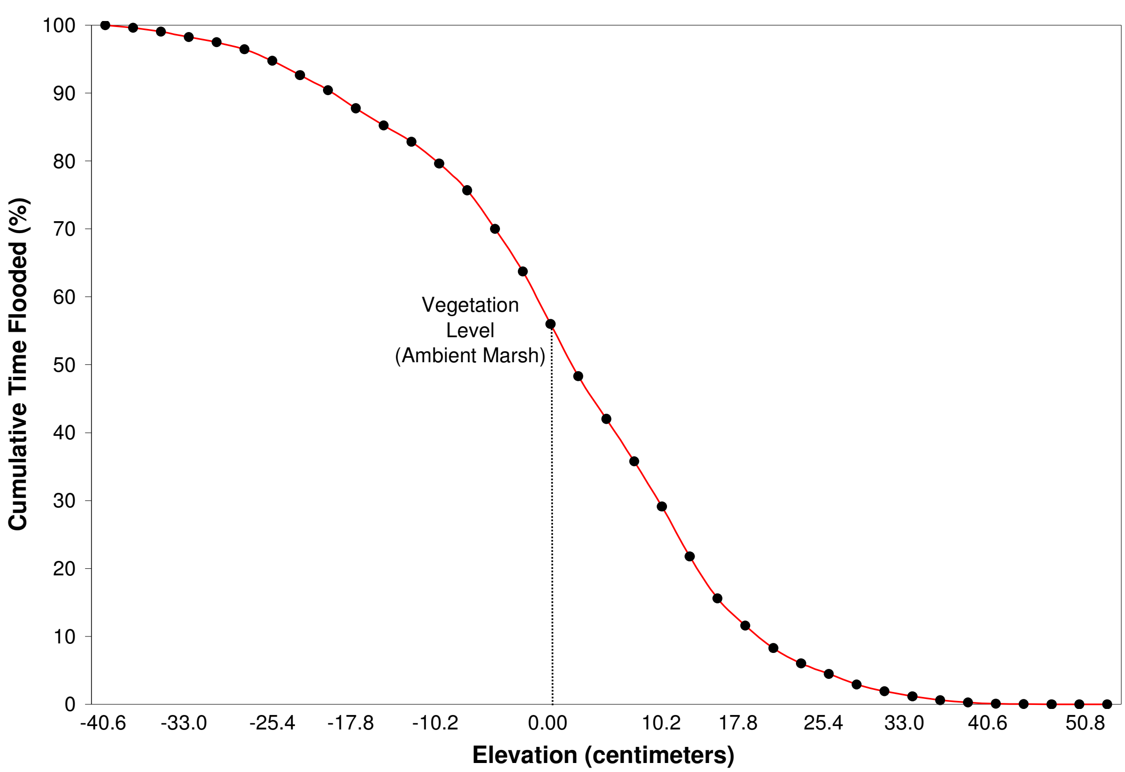


Figure 7 – Flooding duration, expressed as cumulative percent time flooded over a twelve-month period (365 days).

Table 1 – Summary of % time flooded by elevation over a twelve-month period (365 days).

Elevation (centimeters)	% of Total
-40.64	100.0%
-38.1	99.6%
-35.56	99.0%
-33.02	98.2%
-30.48	97.5%
-27.94	96.4%
-25.4	94.7%
-22.86	92.7%
-20.32	90.4%
-17.78	87.8%
-15.24	85.2%
-12.7	82.8%
-10.16	79.6%
-7.62	75.7%
-5.08	70.0%
-2.54	63.7%
0	55.9%
2.54	48.2%
5.08	42.0%
7.62	35.8%
10.16	29.1%
12.7	21.8%
15.24	15.6%
17.78	11.6%
20.32	8.3%
22.86	6.0%
25.4	4.5%
27.94	2.9%
30.48	1.9%
33.02	1.2%
35.56	0.6%
38.1	0.3%
40.64	0.1%
43.18	0.04%
45.72	0.01%
48.26	0.01%
50.8	0.0%

Elevation

For the elevational surveys, ten terraces were measured, but only results from two of the terrace transects are shown here to demonstrate the variation in terrace construction. Using ambient marsh as the reference elevation (0.0 cm), Terrace 1 was considered a high terrace with an average elevation of 46.7 cm (±6.8) above ambient marsh, with a minimum elevation of 19.3 cm and a maximum of 55.3 cm above ambient marsh. The consistently higher elevations on Terrace 1 had large, bare areas on the terrace crown where vegetative establishment was almost non-existent. Only one sampling station on Terrace 1 had vegetation present and it was located at a similar elevation to a marsh terrace fully vegetated with *S. alterniflora*. Terrace 2 was considered a lower terrace with an average elevation of 21.7 cm (±3.8) above ambient marsh, with a minimum elevation of 16.15 cm and a maximum of 30.48 cm. The lower elevations of Terrace 2 contained a dense, monospecific stand of *S. alterniflora* along the terrace crown and side slopes. Across all terrace transects, the average elevation of exposed bare sediment on the terrace crowns was 39.5 cm (± 9.85) above ambient marsh. Solid stands of *S. alterniflora* were found, on average, at 21.3 cm (± 5.6) above ambient marsh. As elevations increased, occurrence of *S. alterniflora* began to decline and volunteer colonization of *Distichlis spicata* and *Iva frutescens* was found. *D. spicata* was observed at 31.4 cm (± 6.82) above ambient marsh and *I. frutescens* was more commonly found in the higher elevations, at approximately 37.4 cm (± 11.17) above ambient marsh. See Figure 8 for transects of two terrace elevations.

To demonstrate the change in species composition with elevation, thirty terrace profiles (cross-sections) were completed. Transplants of *S. alterniflora* were planted at similar elevations to those of ambient marsh and had expanded from the lower elevational limit to upper elevational limit on the terrace. As the elevation increased, the occurrence of *S. alterniflora* declined and volunteer colonization of *D. spicata* was found on the top margins of the terrace.

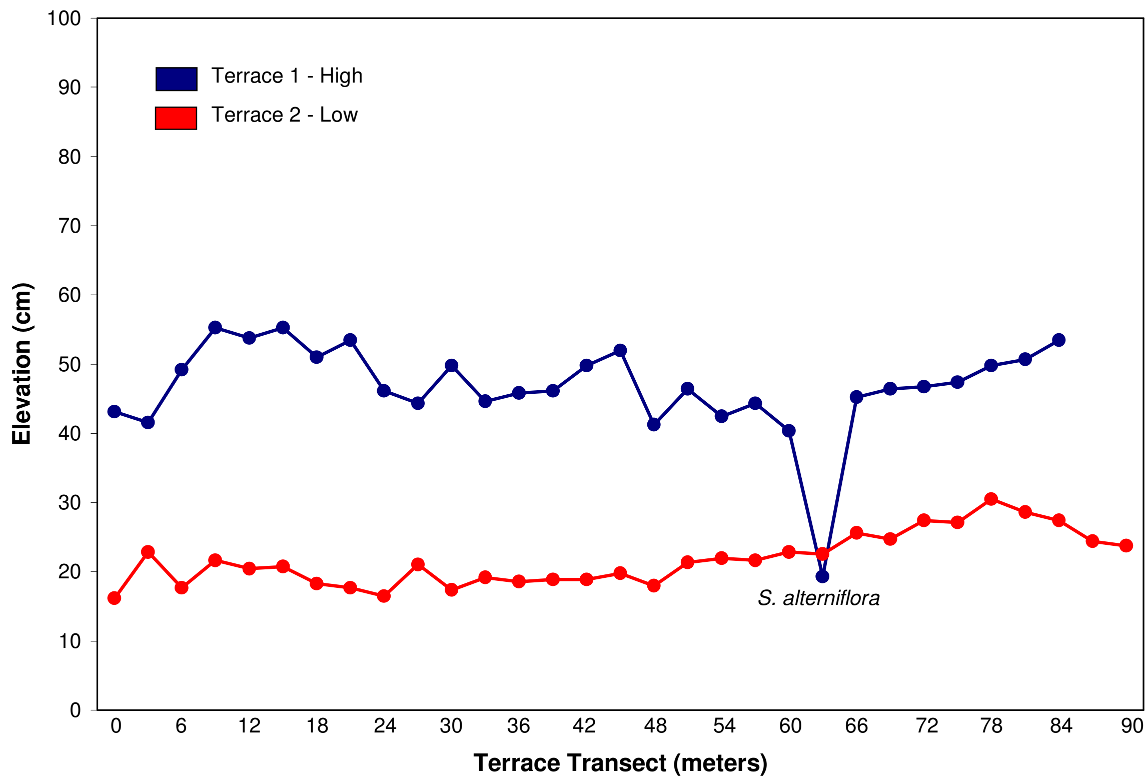


Figure 8 – Elevational transects surveyed length-wise along the crown of two separate terraces. Higher elevations on Terrace 1 contained bare areas on the terrace crown where vegetative establishment was almost non-existent. Only one station on Terrace 1 had vegetation present. The lower elevation of Terrace 2 supported a dense, monospecific stand of *S. alterniflora* along the terrace crown and side slopes. Ambient marsh was used as the reference and plotted as zero.

At the higher elevation, generally located on the crown of the terrace, there were bare areas of exposed sediment and scattered patches of *I. frutescens*. See Figure 9 for a schematic of a terrace profile; only one cross-section is shown to represent results that were consistently found at the project site.

Sediment Analysis

The texture of the marsh terraces on the project site were clay and silty clay. The texture of the nearby ambient marsh was clay loam and the texture of the undisturbed sediment dredged from the marsh bottom was clay. Soil bulk density was higher on the marsh terraces (1.08 g/cm^3, ± 0.05) than in the natural marsh (0.86 g/cm^3, ± 0.20) and the data indicated that the older the terrace, the lower the bulk density and the higher the organic matter. On average, the undisturbed sediment and ambient marsh (34.75%, ± 2.33) had a higher amount of organic matter than the marsh terraces (6.16%, ± 2.32). The primary macronutrients (N and K) and the secondary macronutrients (Ca, Mg, and S) measured increased with age in the marsh terraces. Phosphorus (P) decreased with terrace age and could indicate increased levels of nutrient removal by precipitation or plant uptake (Table 2).

Vegetative Response

All productivity data was analyzed using an analysis of variance (ANOVA) to determine if there were any differences in plant performance (survival and growth rate) between plant growth forms (vegetative plugs and trade gallons) of *S. alterniflora* when established on newly constructed marsh terraces on the Pointe aux Chenes WMA. Three areas were identified for sampling: marsh terraces, an unplanted control terrace, and a nearby ambient marsh. The unplanted control terrace areas remained completely void of vegetation throughout this study and were excluded from the statistical analysis.

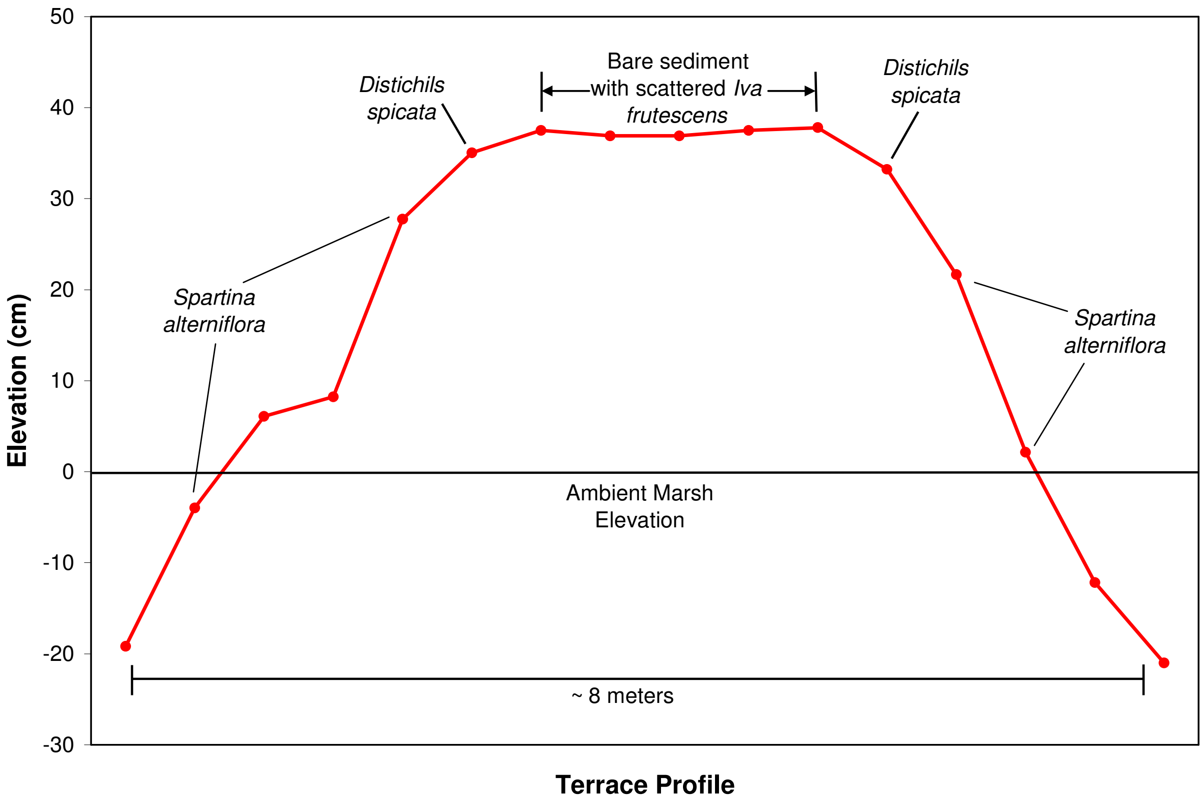


Figure 9 – Typical profile of a terrace at Pointe aux Chenes WMA. The terrace crowns had large areas of bare sediment with sporadic patches of *Iva frustescens*. The crown margins had volunteer colonization of *Distichils spicata* and the side slopes of the terraces down to the water line had dense, monospecific stands of *S. alterniflora*.

Table 2 – Average values for physico-chemical properties of sediments. Abbreviations include: E.C. (electrical conductivity), B.D. (bulk density), O.M. (organic matter).

Sample ID	pH	E.C. Wet (ppt)	E.C. Dry (ppt)	B.D. Field (g/cm^3)	B.D. Oven (g/cm^3)	O.M. (%)	Moisture (%)	N (%)	P (mg/m^3)	K (mg/m^3)	Ca (mg/m^3)	Mg (mg/m^3)	S (mg/m^3)
Terrace > 12 months	7.29	3.6	3.4	0.64	1.03	8.23	53.19	0.22	349.94	848.59	5387.32	2080.98	196.32
Terrace ≈ 12 months	7.53	2.3	2.7	1.13	1.13	3.65	34.31	0.10	387.98	760.86	2800.82	1193.62	252.60
Terrace < 12 months	7.12	4.0	3.2	0.70	1.10	6.6	51.0	0.2	292.88	1097.42	5307.16	2928.10	414.89
Undisturbed Sediment	7.29	3.4	4.2	0.30	1.00	33.1	74.2	1.1	95.09	1741.84	5768.51	3702.58	1251.21
Ambient Marsh	6.24	3.7	4.3	0.18	0.72	36.4	83.17	1.42	102.70	2107.12	4966.87	4308.22	2870.18

Survival

Survival did not significantly differ among planting seasons (p = 0.0933) or plant growth forms (p = 0.5396; Table 3). Since survival measurements were taken on 100% of the population, growth period was not included as a variable in this analysis. Also, it is noteworthy that all terraces contained vegetation after two major hurricanes passed through the area. Hurricanes Katrina and Rita (2005) made landfall, but no increase in mortality was observed in the vegetative transplants (Figure 10).

Monthly Stem Counts

In situ non-destructive, monthly stem counts were taken after transplanting and continued until the destructive harvest at six months. All plants had a similar number of stems at the time of transplanting and stem density increased over time for the first five months. The spring transplants had a faster rate of growth, with stem densities increasing after only ninety days (Figure 11). Within planting season, trade gallons and vegetative plugs had similar stem densities for the first five months after transplanting.

Stem Density

Stem densities varied significantly between growth periods (p = 0.0061; Table 4). The plants harvested after six months of growth had a significantly greater number of stems than those harvested after twelve months. There was also a significant interaction between planting season and growth period (p = 0.0009). After six months of growth, the spring transplants had a significantly greater number of stems than the fall transplants. In contrast, after twelve months, there was no significant difference between the fall and spring transplants (Figure 12).

Stem Height

Planting season and growth period had significant effects on stem height (Table 5). The plants harvested at twelve months after transplanting had significantly taller stem heights than

Table 3 – Analysis of variance indicating the effects of planting season and plant growth form on percent survival. There were no significant p-values; df signifies degrees of freedom.

Effects	Numerator df	Denominator df	F-value	p
Planting Season	1	4	4.81	0.0933
Plant Growth Form	1	4	0.45	0.5396
Planting Season * Plant Growth Form	1	4	0.08	0.7895

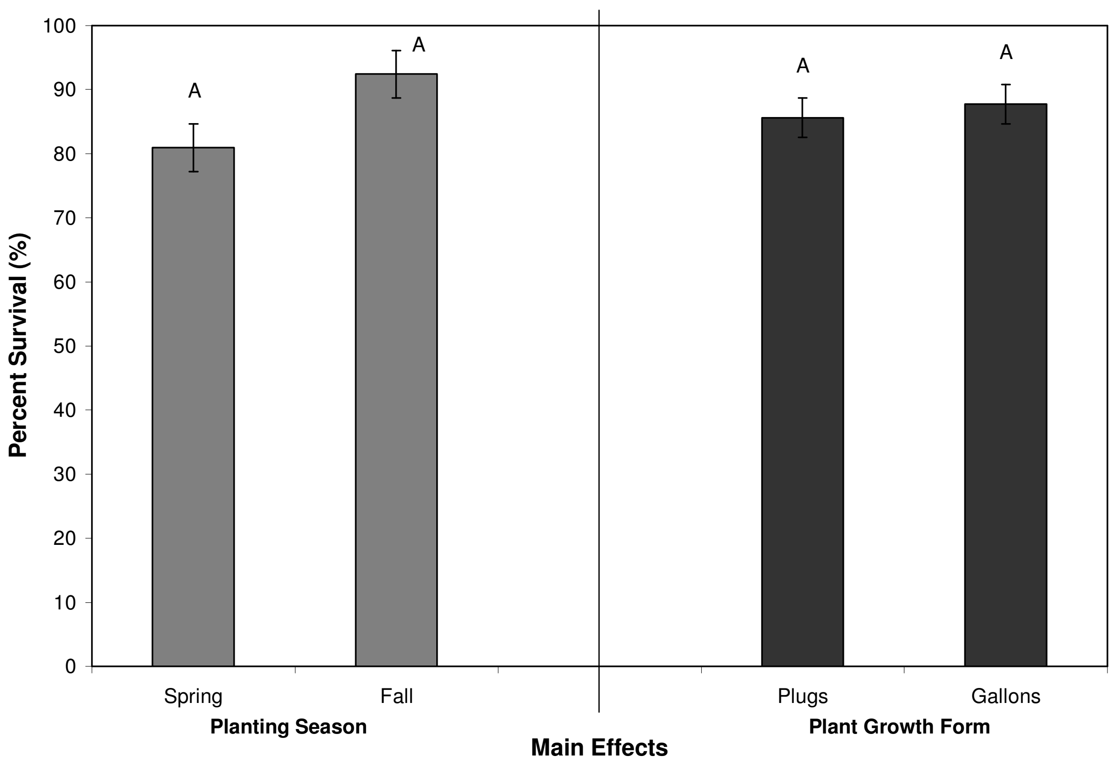


Figure 10 – Percent survival of vegetative transplants. There was no significant difference in survival between planting seasons or plant growth forms. Error bars represent standard error.

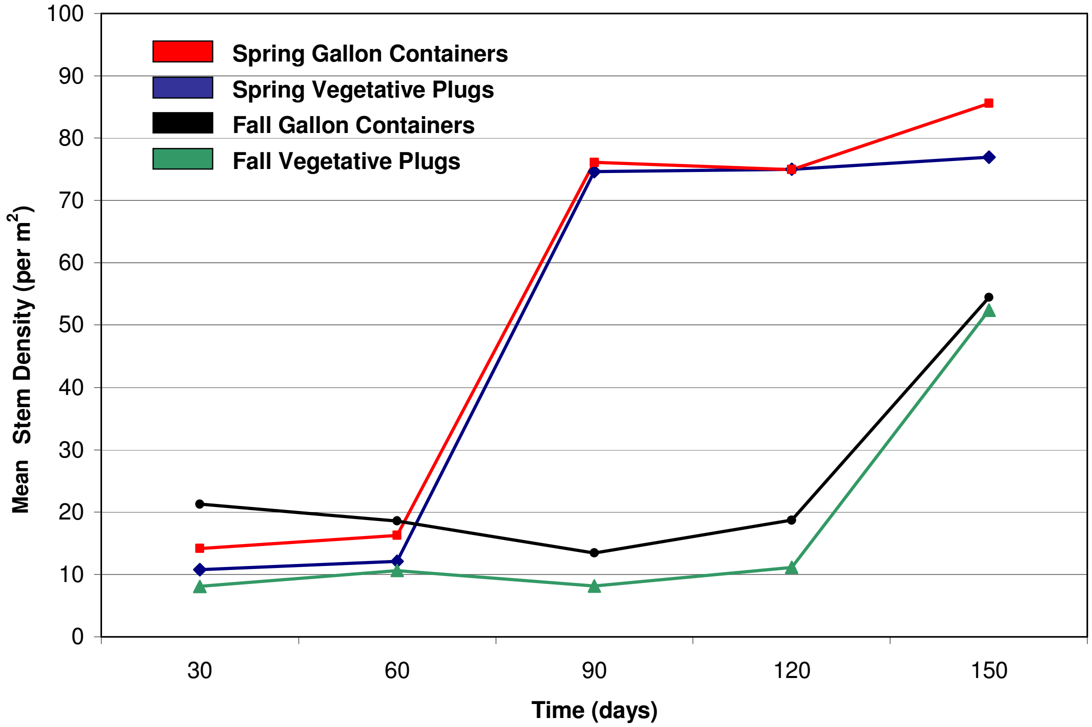


Figure 11 – Mean non-destructive stem density measurements after five months of growth. Within planting season, trade gallons and vegetative plugs had similar stem densities. When compared seasonally, the spring vegetative transplants had a higher number of stems at five months after transplanting.

Table 4 – Analysis of variance indicating the effects of planting season, growth period, and plant growth form on stem density. Significant p-values are in bold print; df signifies degrees of freedom.

Effects	Numerator df	Denominator df	F-value	p
Planting Season	1	4	0.43	0.5471
Growth Period	1	8	13.67	**0.0061**
Planting Season * Growth Period	1	8	26.62	**0.0009**
Plant Growth Form	1	4	0.69	0.4528
Planting Season * Plant Growth Form	1	4	0.35	0.5860
Growth Period * Plant Growth Form	1	8	2.61	0.1450
Planting Season * Growth Period * Plant Growth Form	1	8	0.10	0.7628

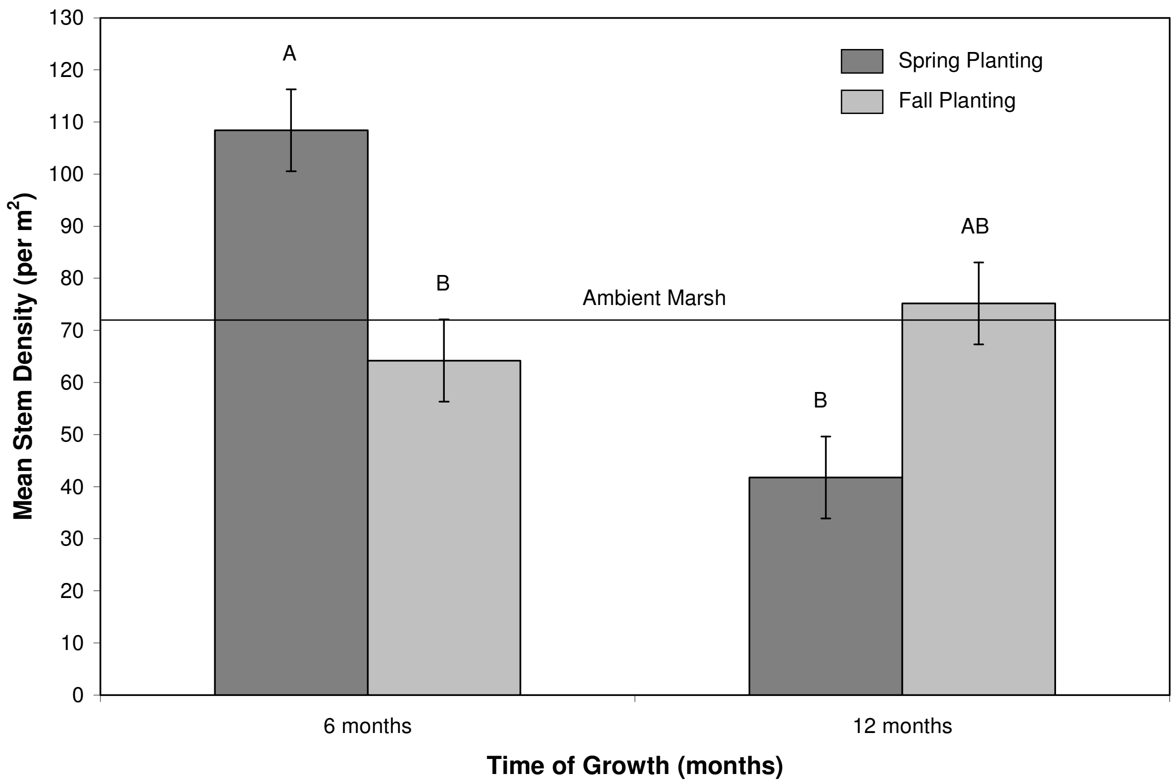


Figure 12 – The effects of growth period (months) and planting season on mean stem density. Error bars are standard errors; different letters indicate significant differences among means ($p \leq 0.05$). The solid horizontal line represents the average stem density of ambient marsh.

the six-month harvest (p = 0.0003; Figure 13). In addition, the stem heights of the fall transplants were significantly taller than the spring transplants (p = 0.0006; Figure 13). The interaction of planting season and growth period was also significant (p < 0.0001; Table 5). After six months of growth, the fall and spring transplants had similar stem heights. In contrast, after twelve months of growth, the fall transplants had significantly taller stems than the spring transplants (Figure 13).

Table 5 – Analysis of variance indicating the effects of planting season, growth period, and plant growth form on stem height. Significant p-values are in bold print; df signifies degrees of freedom.

Effects	**Numerator df**	**Denominator df**	**F-value**	**p**
Planting Season	1	4	93.53	**0.0006**
Growth Period	1	8	36.97	**0.0003**
Planting Season * Growth Period	1	8	120.59	**<.0001**
Plant Growth Form	1	4	0.00	0.9659
Planting Season * Plant Growth Form	1	4	1.29	0.3190
Growth Period * Plant Growth Form	1	8	2.90	0.1272
Planting Season * Growth Period * Plant Growth Form	1	8	1.21	0.3028

<u>Stem Diameter</u>

Plant growth form and growth period had significant effects on the stem diameter (Table 6). Stem diameter significantly increased over time (p = 0.0009), with the twelve-month harvest having significantly larger stem diameters than the six-month harvest. In addition to growth period effects, stem diameters varied significantly with plant growth form (p = 0.0226). Trade gallons had significantly larger stem diameters than vegetative plugs. Planting season was also marginally significant (p = 0.0590). The interaction of planting season and growth period was significant (p < 0.0001). After six months of growth, the spring transplants had significantly larger diameters than the fall transplants. In contrast, after twelve months of growth, the fall and spring transplants had reached similar stem diameters (Figure 14).

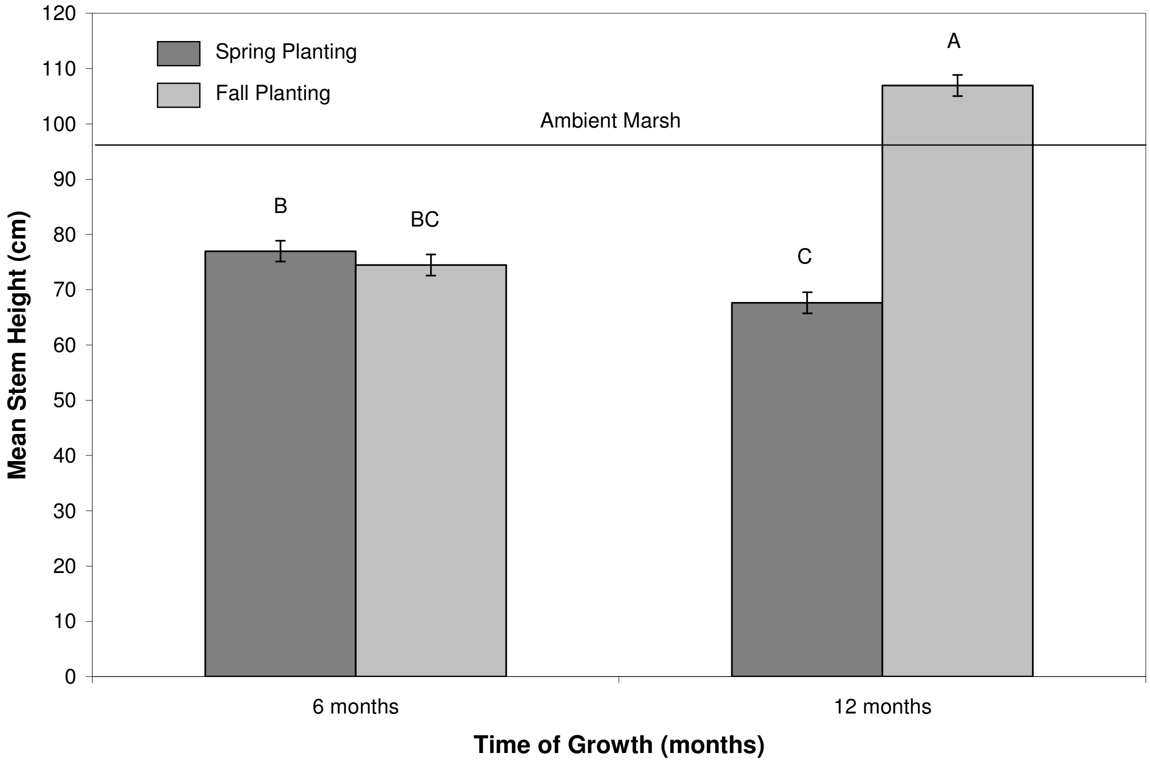


Figure 13. The effects of growth period (months) and planting season on mean stem height. Error bars are standard errors; different letters indicate significant differences among means ($p \leq 0.05$). The solid horizontal line represents the average stem height of ambient marsh.

Table 6 – Analysis of variance indicating the effects of planting season, growth period, and plant growth form on stem diameter. Significant p-values are in bold print; df signifies degrees of freedom. *: Planting season is marginally significant.

Effects	Numerator df	Denominator df	F-value	p
Planting Season	1	4	6.85	**0.0590***
Growth Period	1	8	25.94	**0.0009**
Planting Season * Growth Period	1	8	70.77	**< .0001**
Plant Growth Form	1	4	13.01	**0.0226**
Planting Season * Plant Growth Form	1	4	0.92	0.3919
Growth Period * Plant Growth Form	1	8	0.03	0.8637
Planting Season * Growth Period * Plant Growth Form	1	8	3.46	0.998

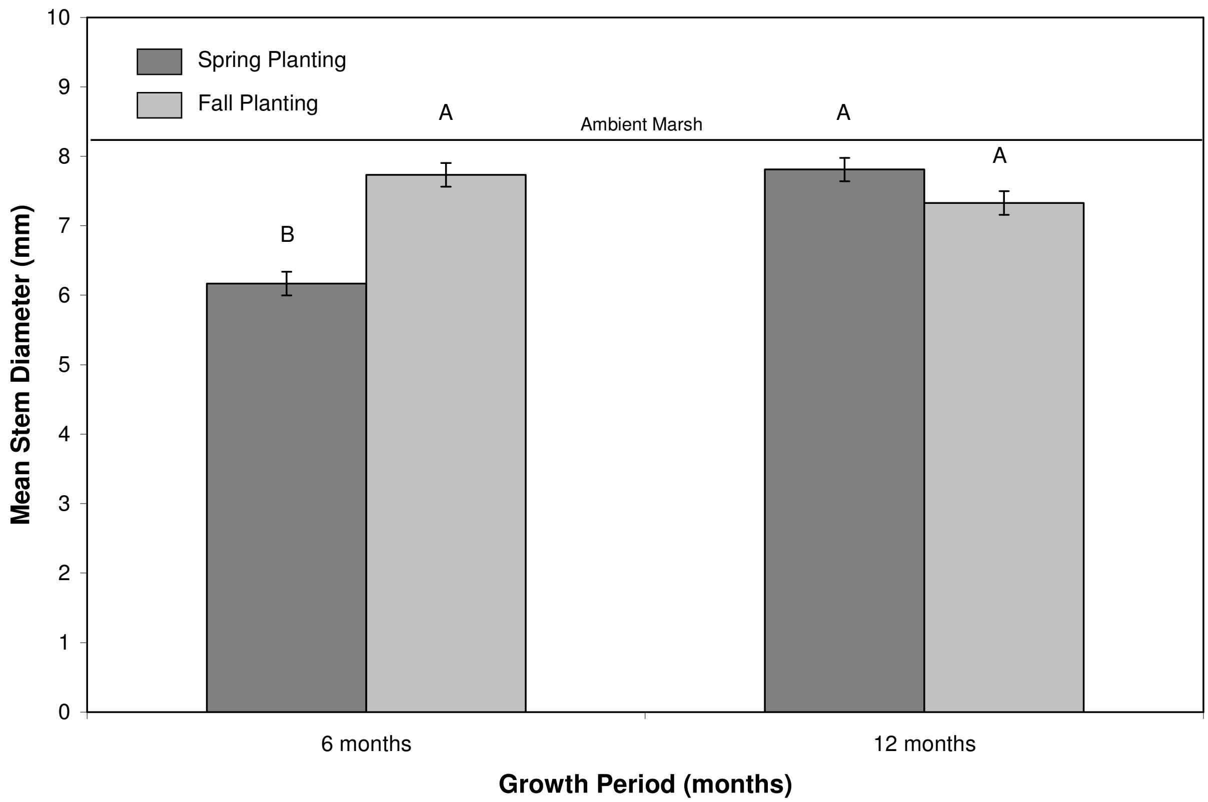


Figure 14 – The effects of growth period (months) and planting season on mean stem diameter. Error bars are standard errors; different letters indicate significant differences among means ($p \leq 0.05$). The solid horizontal line represents the average stem diameter of ambient marsh.

Dry Weight (Aboveground Biomass)

Aboveground biomass (expressed as dry weight) did not differ between plant growth forms (p = 0.0936; Table 7). There were no significant differences between trade gallons (1173.39 g/m^2 ± 73.79) or vegetative plugs (944.79 g/m^2 (± 73.73)). There was no significant difference (p = 0.4712) in biomass between growth period (6 months (1097.15 g/m^2 ± 72.44); 12 months (1021.03 g/m^2 ± 72.50). However, marginal significant differences (p = 0.0657, Table 7) existed between planting seasons (Fall (1190.30g/m^2 ± 73.79); Spring (927.88 g/m^2 ± 73.73).

Belowground Biomass

Belowground biomass (expressed as dry weight) did not differ significantly between plant growth forms (p = 0.3267) (gallon container (1262.60g/m^2 ± 47.37); vegetative plugs (1187.82g/m^2 ± 47.33)), planting seasons (p = 0.3102) (Fall (1264.08g/m^2 ± 47.37); Spring (1186.34g/m^2 ± 47.33)) or growth period (p = 0.3413) (6 months (1191.34g/m^2 ± 47.33); 12 months (1259.08g/m^2 ± 47.37)) (Table 8).

Across all samples, belowground biomass was statistically significant with depth (p<0.0001; Table 9). The largest amount of root/rhizome biomass was in the upper five centimeters of the soil profile (Figure 15).

Table 7 – Analysis of variance indicating the effects of planting season, growth period, and plant growth form on aboveground biomass. Significant p-values are in bold print; df signifies degrees of freedom. *: Planting season is marginally significant.

Effects	Numerator df	Denominator df	F-value	p
Planting Season	1	4	6.33	**0.0657***
Growth Period	1	8	0.57	0.4712
Planting Season * Growth Period	1	8	0.11	0.7519
Plant Growth Form	1	4	4.80	0.0936
Planting Season * Plant Growth Form	1	4	0.04	0.8596
Growth Period * Plant Growth Form	1	8	0.00	0.9676
Planting Season * Growth Period * Plant Growth Form	1	8	0.00	0.9484

Table 8 – Analysis of variance indicating the effects of planting season, growth period, and plant growth form on belowground biomass. No significant p-values existed in this analysis; df signifies degrees of freedom.

Effects	**Numerator df**	**Denominator df**	**F-value**	**p**
Planting Season	1	4	1.35	0.3102
Growth Period	1	8	1.02	0.3413
Planting Season * Growth Period	1	8	0.28	0.6093
Plant Growth Form	1	4	1.25	0.3267
Planting Season * Plant Growth Form	1	4	0.40	0.5636
Growth Period * Plant Growth Form	1	8	0.34	0.5757
Planting Season * Growth Period * Plant Growth Form	1	8	0.02	0.8820

Table 9 – Analysis of variance indicating the effects of planting season, growth period, plant growth form, and depth on belowground biomass. Significant p-values are in bold print; df signifies degrees of freedom.

Effects	**Numerator df**	**Denominator df**	**F-value**	**p**
Planting Season	1	4	1.35	0.3102
Growth Period	1	8	1.02	0.3413
Planting Season * Growth Period	1	8	0.28	0.6093
Plant Growth Form	1	4	1.25	0.3267
Planting Season * Plant Growth Form	1	4	0.40	0.5636
Growth Period * Plant Growth Form	1	8	0.34	0.5757
Planting Season * Growth Period * Plant Growth Form	1	8	0.02	0.8820
Depth	5	80	13.85	**<.0001**
Planting Season * Depth	5	80	0.23	0.9481
Growth Period * Depth	5	80	1.13	0.3514
Planting Season * Growth Period * Depth	5	80	0.18	0.9682
Plant Growth Form * Depth	5	80	0.18	0.9707
Planting Season * Plant Growth Form * Depth	5	80	0.11	0.9897
Growth Period * Plant Growth Form * Depth	5	80	1.57	0.1767
Planting Season * Growth Period * Form* Depth	5	80	0.29	0.9147

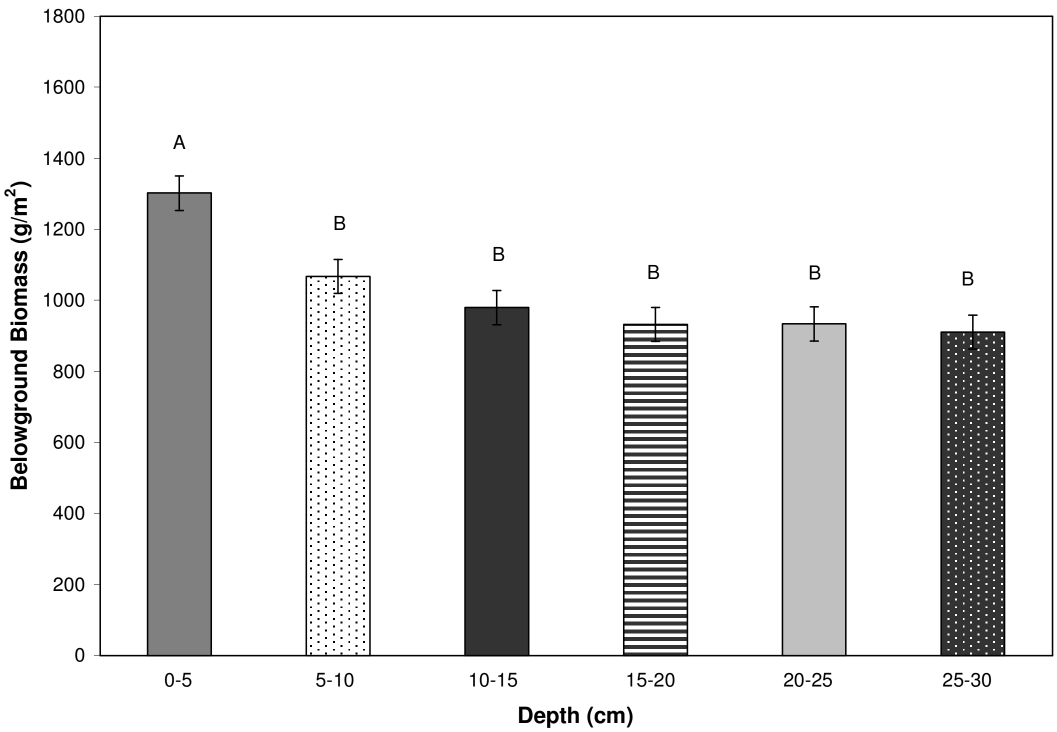


Figure 15 – Mean belowground biomass across all samples expressed as live dry weight (g/m^2) sectioned into five-centimeter depth increments. Root/rhizome biomass in the upper five centimeters of soil was statistically greater than any of the other soil zones. Error bars are standard errors; different letters indicate significant differences among means ($p \leq 0.05$).

Stem Inflorescence

Only planting season and plant growth form were analyzed in the ANOVA because *S. alterniflora* was only in flower during the fall harvest. There was no significant difference in plant growth form (p = 0.7633; Table 10). However, inflorescence number differed significantly between planting season (p=0.0295; Table 10), with the spring transplants having a significantly higher inflorescence number than the fall transplants (Figure 16).

Table 10 – Analysis of variance indicating the effects of planting season, growth period, and plant growth form on stem inflorescence. Significant p-values are in bold print; df signifies degrees of freedom.

Effects	Numerator df	Denominator df	F-value	p
Planting Season	1	4	10.99	**0.0295**
Plant Growth Form	1	4	0.10	0.7633
Planting Season * Plant Growth Form	1	4	0.82	0.4177

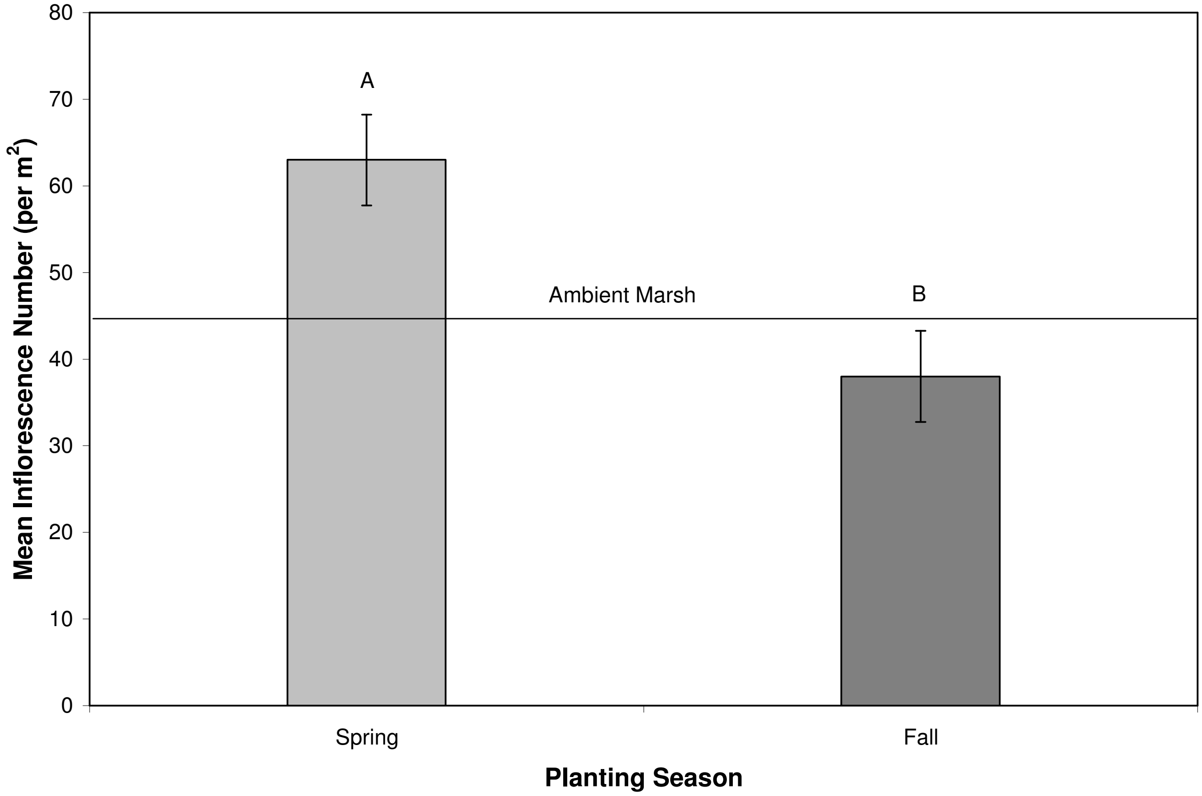


Figure 16 – Mean number of stem inflorescence across planting season. The spring transplants had a significantly larger inflorescence number than the fall transplants. Error bars are standard errors; different letters indicate significant differences among means ($p \leq 0.05$). The solid horizontal line represents the average inflorescence number in ambient marsh.

Benefits of Vegetation

This research was not only done to compare seasonal transplants of *S. alterniflora*, but to determine if the current planting window for coastal Louisiana could be extended or widened. A specific goal was to determine if there was any significance in transplanting vegetation for large-scale restoration projects in the fall. Many project specifications recommend that all transplanting occur after the last known frost date, approximately April 1st (Materne 2006). The results of the ANOVA from the destructive harvest showed that there was a significant difference in stem density when compared by sampling date (p = 0.0015; Table 11). The significant interaction between planting season and sampling date (p = 0.0033; Table 11) shows that the fall transplants have more stems when sampled at the beginning of the growing season (April) than those just recently installed in early spring (Figure 17). The fall transplants have grown over the winter months and are offering protection to the terrace at the beginning of the growing season. If vegetation is not transplanted until April 1, the terraces are unprotected for months and begin the growing season with a small number of stems. However, by the end of the growing season in November, the spring transplant stem counts exceeded the fall transplants (108 and 75 stems, respectively) (Figure 17).

Based on the same comparison, planting season and sampling date had a significant effect on aboveground biomass ($p = 0.0020$ and $p = 0.0129$, respectively; Table 12) and belowground biomass ($p = 0.0002$ and $p = 0.0004$, respectively; Table 13). In both variables, the significant interaction between planting season and sampling date (aboveground $p = 0.0055$; Table 12) (belowground $p = 0.0004$; Table 13) shows that at the beginning of the growing season, the fall transplants have greater biomass than the vegetation just transplanted in early spring. However, at the end of the growing season in November, biomass did not significantly differ between the fall and spring transplants (Figures 18 and 19).

Table 11 – Analysis of variance indicating the effects of planting season, plant growth form, and sampling date on stem density. Significant p-values are in bold print; df signifies degrees of freedom.

Effects	**Numerator df**	**Denominator df**	**F-value**	**p**
Planting Season	1	4	3.04	0.1563
Plant Growth Form	1	4	1.06	0.3615
Planting Season*Plant Growth Form	1	4	0.63	0.4705
Sampling Date	1	4	59.65	**0.0015**
Planting Season*Sampling Date	1	4	39.10	**0.0033**
Plant Growth Form*Sampling Date	1	4	0.01	0.9347
Planting Season * Plant Growth Form*Sampling Date	1	4	1.96	0.2338

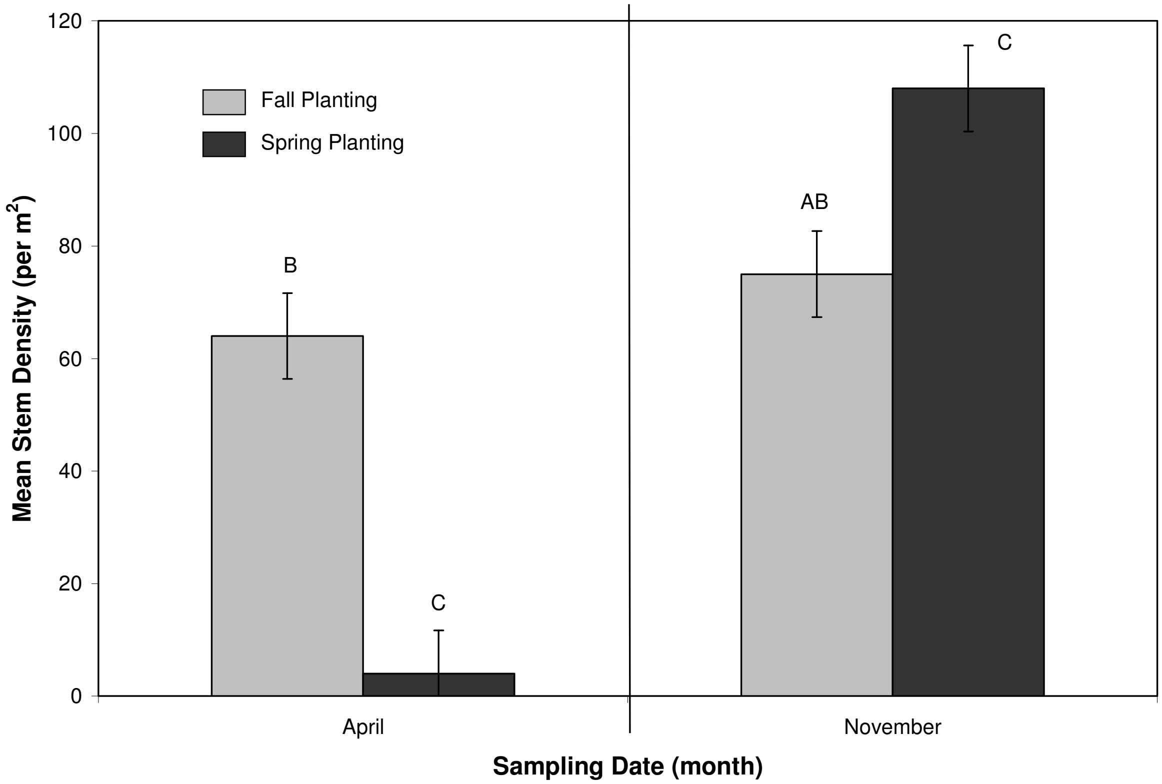


Figure 17 – The effects of planting season and sampling date on mean stem density. The error bars represent standard errors; different letters indicate significant differences among means ($p \leq 0.05$).

Table 12 – Analysis of variance indicating the effects of planting season, plant growth form, and sampling date on aboveground biomass. Significant p-values are in bold print; df signifies degrees of freedom.

Effects	**Numerator df**	**Denominator df**	**F-value**	**p**
Planting Season	1	4	51.78	**0.0020**
Plant Growth Form	1	4	3.68	0.1274
Planting Season*Plant Growth Form	1	4	0.45	0.5391
Sampling Date	1	4	18.29	**0.0129**
Planting Season*Sampling Date	1	4	29.84	**0.0055**
Plant Growth Form*Sampling Date	1	4	0.31	0.6072
Planting Season * Plant Growth Form*Sampling Date	1	4	0.28	0.6227

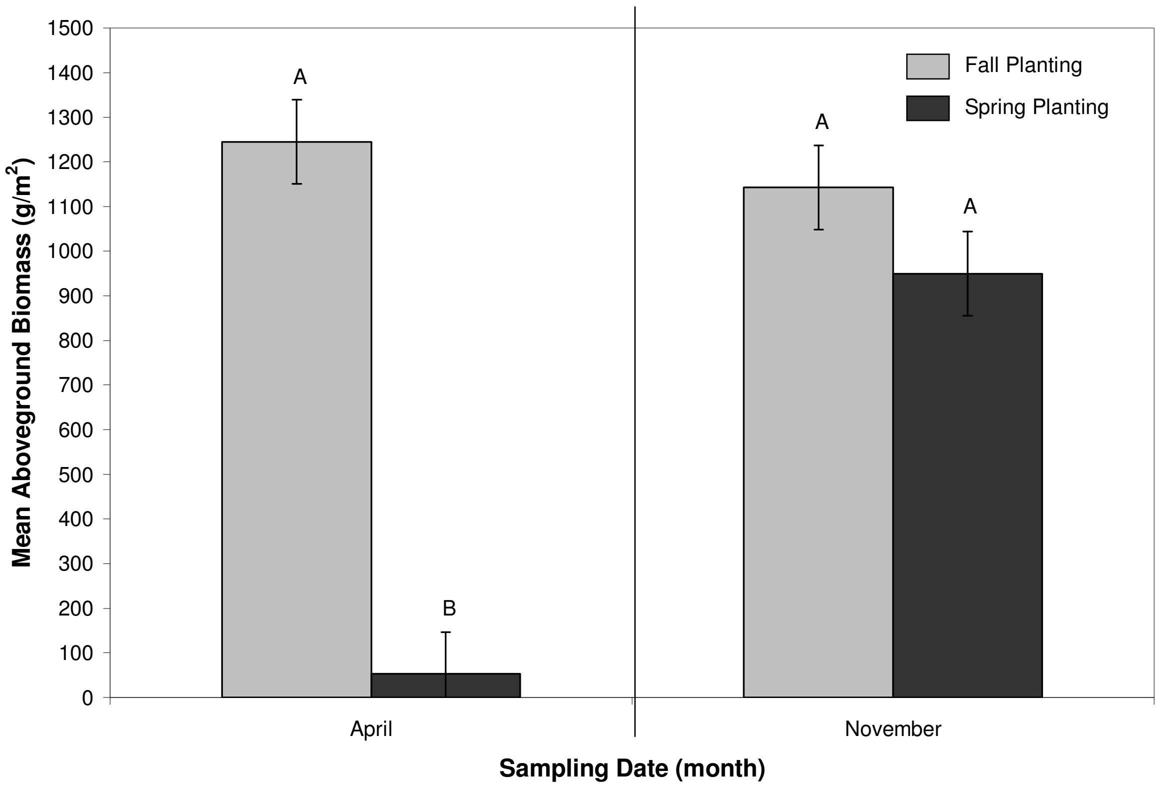


Figure 18 – Mean aboveground biomass per square meter. The fall transplants had greater aboveground biomass when sampled in April and are larger plants going into the growing season.

Table 13 – Analysis of variance indicating effects of planting season, growth form, and sampling date on belowground biomass. Significant p-values in bold; df signifies degrees of freedom.

Effects	Numerator df	Denominator df	F-value	p
Planting Season	1	4	180.55	**0.0002**
Plant Growth Form	1	4	1.09	0.3550
Planting Season*Plant Growth Form	1	4	0.75	0.4349
Sampling Date	1	4	122.71	**0.0004**
Planting Season*Sampling Date	1	4	115.58	**0.0004**
Plant Growth Form*Sampling Date	1	4	0.04	0.8482
Planting Season * Plant Growth Form*Sampling Date	1	4	0.09	0.7778

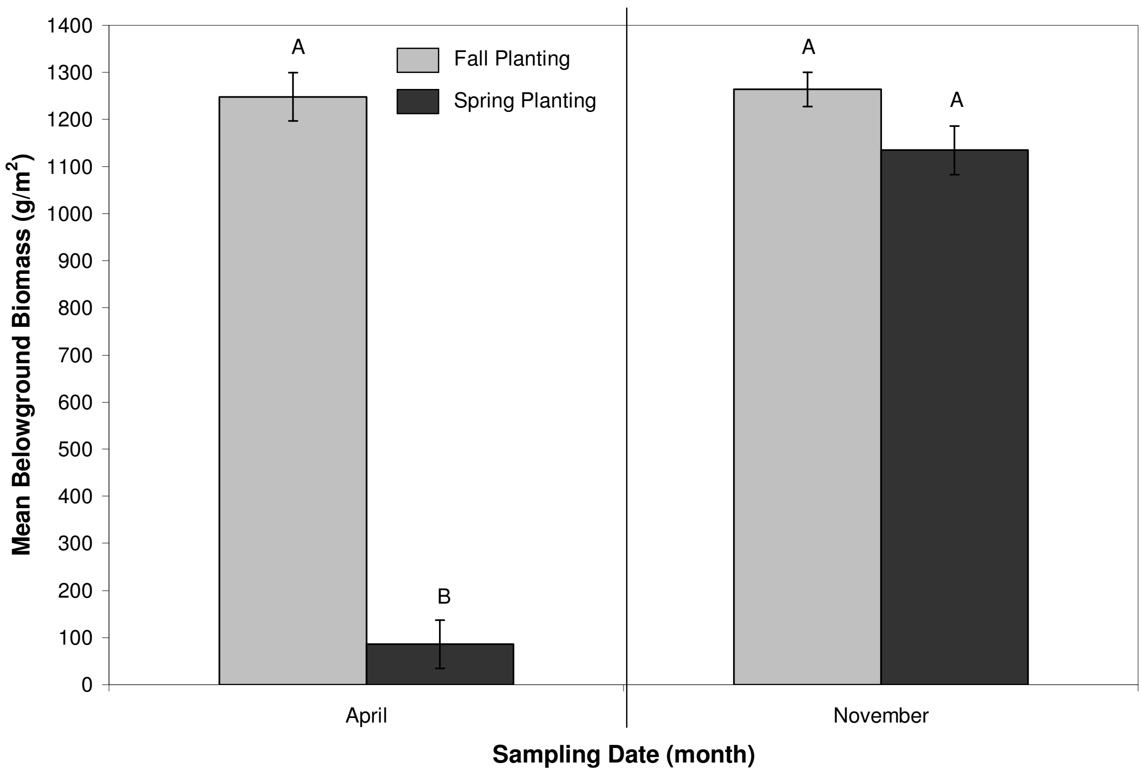


Figure 19 – Mean belowground biomass per square meter. The fall transplants had greater aboveground biomass when sampled in April and are larger plants going into the growing season.

Seed Establishment

<u>Controlled Germination Tests</u>

During the 2004 controlled germination testing, the *S. alterniflora* seeds in the water medium performed better, on average, than any other germination substrate used (Figure 20). Therefore, all other substrates were eliminated in 2005 and the water medium was used to determine percent germination. Overall, the seeds tested in 2004 had a higher percent germination than those tested in 2005 (Figure 21). The 2004 germination tests showed that extended periods of time in cold-wet stratification increased percent germination from 1.5% at 0 days to 23.9% at 120 days. The seeds tested in 2005 had very low germination rates and length in cold-wet stratification did not appear to affect their performance.

Germination tests from 2004 and 2005 showed that the majority of viable seeds germinated within the first 14 days of being placed in the water medium (Figure 22). Therefore, germination on the marsh terraces was thought to occur within the first two weeks after the release of seed.

<u>Field Trials</u>

Based on the quadrat sampling completed on the marsh terraces after the seed was released, there was an average of 141 seeds for every square foot, which is well above the optimal seeding rate of 89 seeds per square foot (Materne et al. 2003). Some germinated seeds were found on the marsh terraces, but the numbers were very low (less than 1% of those released). Therefore, no further germination or seedling survival measurements on the marsh terraces were completed or included in the results section. See Figure 23 for percent germination of field trials compared to controlled germination tests.

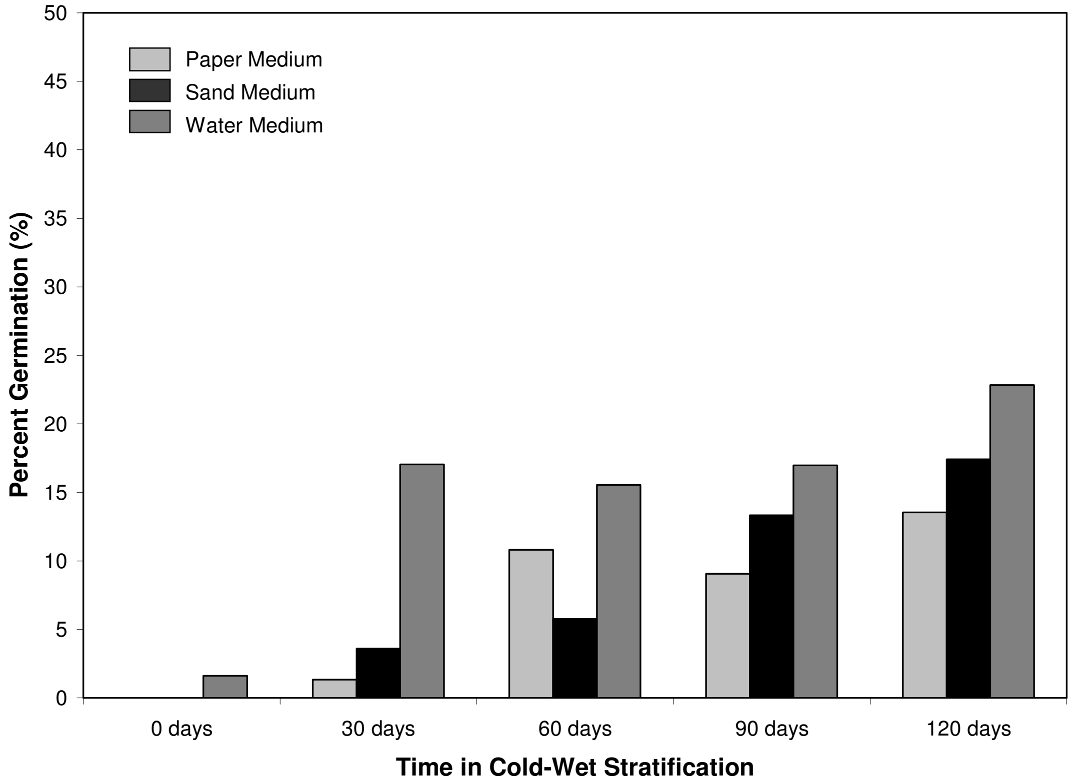


Figure 20 – 2004 percent germination of *S. alterniflora* seed in multiple germination substrates. During this controlled germination testing, the seeds in the water medium performed better, on average, than any other germination substrate used.

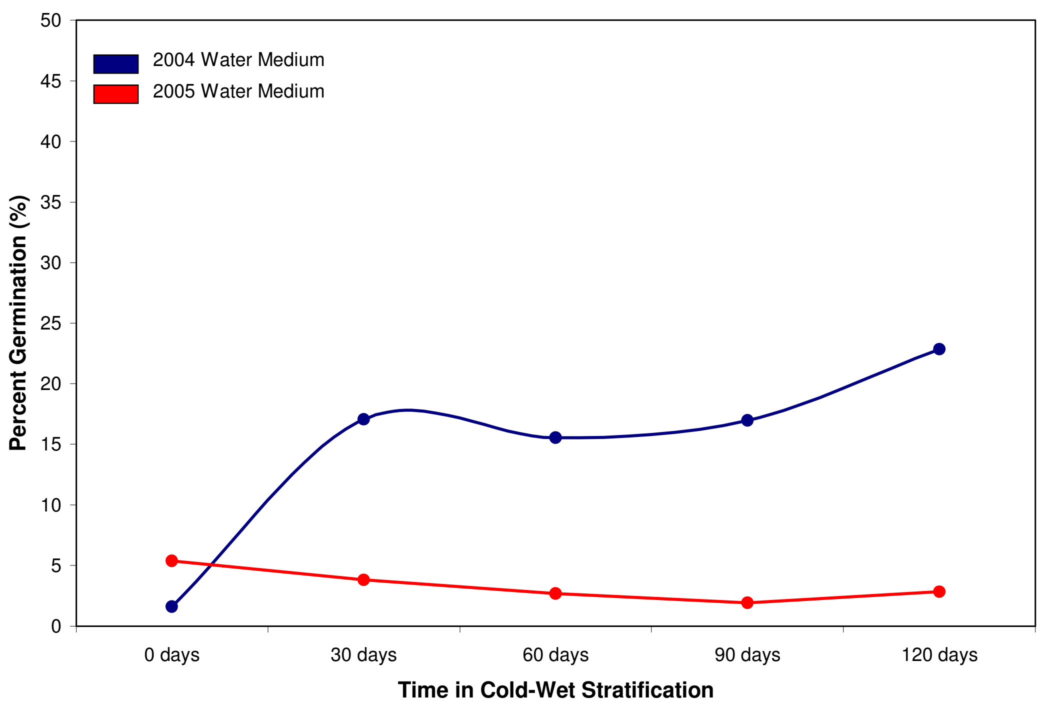


Figure 21 – 2004 and 2005 percent germination in the water medium. 2004 germination tests showed that extended periods of time in cold-wet stratification increased percent germination from 1.5% at 0 days to 23.9% at 120 days. Seeds tested in 2005 had very low germination rates and length in cold-wet stratification did not appear to affect their performance.

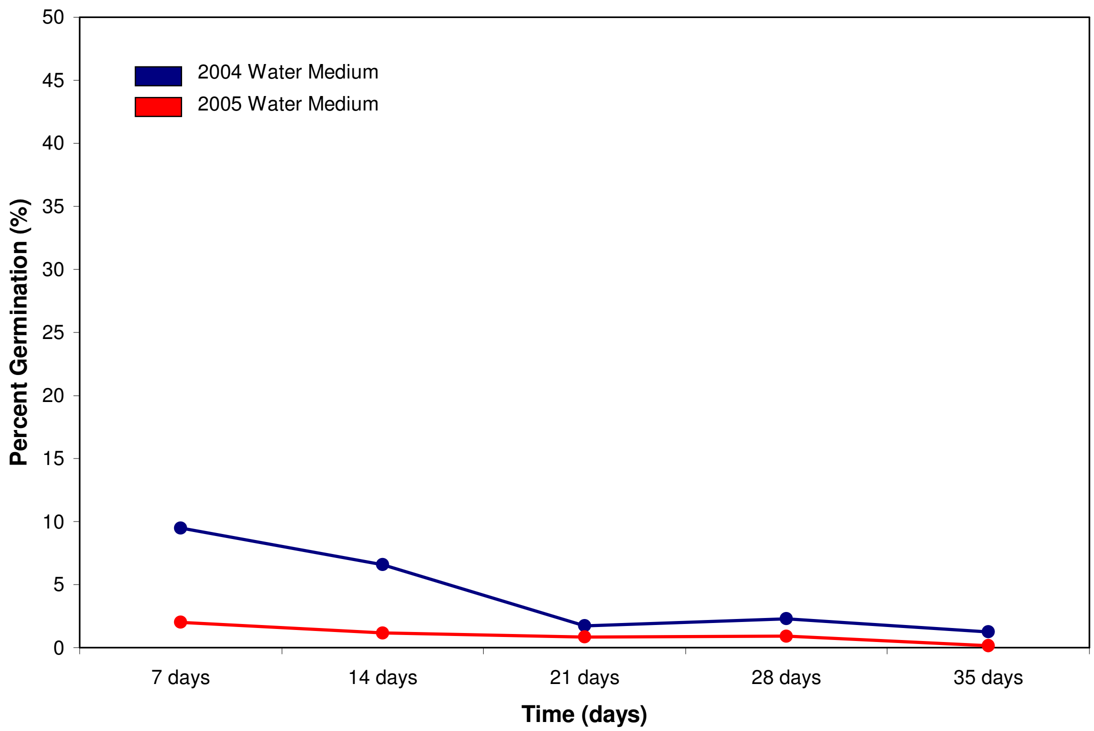


Figure 22 – 2004 and 2005 percent germination in the water medium. Results from both years showed that the majority of viable seeds germinated within the first 14 days of being placed in the water medium.

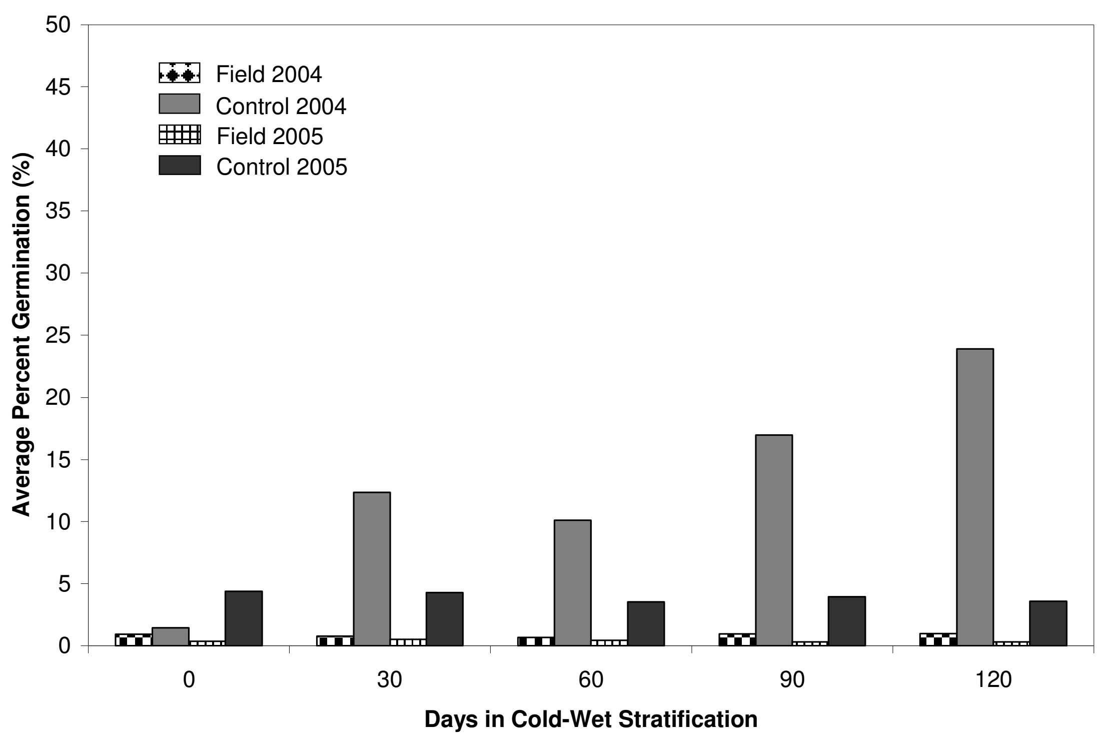


Figure 23 – Average percent germination of seed treatments in the field trials and controlled germination tests. Although the seed proved to be viable under controlled tests, there was little germination on the terraces.

DISCUSSION

Site Evaluation

The results of this study indicate that *S. alterniflora* can be successfully established on newly constructed marsh terraces, but that vegetative growth may be dependent upon elevation. Elevation, related to the frequency and duration of inundation of marsh soils (Mendelssohn and McKee 1988, Day et al. 1993), is a primary factor influencing plant productivity in coastal marshes (Webb 1982, DeLaune 1983, Bertness 1991, Edwards and Proffitt 2003). A 1:1 ratio of wetting to drying is optimal for plant growth and will provide a balanced oxidation-to-flooding regime that is critically important to intertidal plant species, such as *S. alterniflora*. Soil moisture is an important factor in plant growth and excess waterlogging may lead to highly reduced soils that affect the interaction of soil and root processes and result in lower plant survival and productivity (Mendelssohn and McKee 1988). Because vegetation was planted at the same elevation as ambient marsh, this elevation was used as the reference (0.0 cm). It was found that flooding at the elevation where vegetation was planted was slightly skewed towards wet soils, with flooding occurring 55.9% of total and drying occurring 44.0% of total. Under these flooding conditions, there is a slight probability of reduced soils that may result in lower plant survival and plant productivity. *S. alterniflora* is the dominant plant species in low, intertidal saline marshes, in part because of its complex oxygen transport mechanisms and high sulfide tolerance. As waterlogging (reduction) stress decreases with increased elevation, competitive interactions cause the replacement of *S. alterniflora* with other species. If transplants of *S. alterniflora* are planted at the correct elevation, terrace height is not necessarily important to plant productivity, but the height of the terrace will affect what species will grow out of the range of *S. alterniflora*, specifically on the terrace crown. The results of this study were similar to those reported by Webb (1982), which suggested plant productivity decreased as elevations increased. As terrace elevations increased, occurrence of *S. alterniflora* began to decline and it was replaced with *D. spicata* at 31.4 cm and *I. frutescens* at 37.4 cm above ambient marsh. The bare areas of sediment located at 39.5 cm and above on the marsh terraces suggest an upper threshold of hydrologic-soil-plant interaction. If a terrace covered with *S. alterniflora* is desired, an elevation no greater than approximately 21 cm above ambient marsh is needed to get vegetative coverage.

Vegetative Establishment

Throughout coastal Louisiana, terrace fields are being built to replace shallow open water areas in marsh ponds and many studies compare the productivity of marsh terraces to open water. However, the overall objective of most restoration comparisons is to determine whether created marsh begins to approximate structurally and functionally to that of natural salt marshes. Vegetative biomass provides an integrated measure of abiotic and biotic stress over time and is an indicator of overall marsh performance. The biomass on the terraces was comparable to other *S. alterniflora* standing live biomass figures reported for Louisiana coastal marshes. While the average aboveground biomass in this study was 1218.71 g/m^2, Kirby and Gosselink (1976) measured standing live biomass at 1018 g/m^2, while White et al. (1978) reported live biomass at approximately 1100 g/m^2. As the aboveground plant structures accumulate sediment and increase the elevation of the terrace, belowground biomass binds the substrate together and makes it less susceptible to wind and wave erosion (Mendelssohn et al. 1991). A study by Turner et al. (2004) examined biomass of multiple sites in the Terrebonne Basin in Louisiana, and found that the total amount of root biomass (live and dead) in the top 0 –30 centimeters ranged from 1612 to 6608 g/m^2. The vegetative transplants on the Pointe aux Chenes WMA marsh terraces averaged 1364.6 g/m^2. The difference in belowground biomass could be due to the younger age of the terrace stand.

In areas of high wave energies, restoration-project planners generally specify that containered material must be transplanted because of the greater biomass than vegetative plugs (Louisiana Department of Natural Resources 2003). However, a study done by Steyer et al. (1993) reported no significant difference in biomass after the second growing season when comparing vegetative plugs and trade gallons on marsh terraces. Vegetative plugs and trade gallons had similar rates of growth on the Pointe aux Chenes WMA marsh terraces. Average aboveground biomass of the trade gallons was 1173.4 g/m^2 while the vegetative plugs averaged 944.79 g/m^2. Average belowground biomass of trade gallons was 1262.6 g/m^2 and the vegetative plugs averaged 1187.8 g/m^2. Stem densities are also important in the accumulation of organic matter and will contribute to the stabilization of the sediment. The trade gallons and vegetative plugs had similar densities, 76 stems and 69 stems, respectively. These results suggest that vegetative plugs will, in fact, survive in high energy environments and can be used to establish a protective cover on the otherwise easily-eroded soils of marsh terraces. Because there is no difference in plant growth rates, vegetative plugs are just as effective as trade gallons when transplanted on marsh terraces.

There was no significant difference between the fall and spring transplants, suggesting that the planting window for coastal Louisiana can be expanded to include fall plantings (specifically in the month of October). Average aboveground biomass of the fall plantings was 1190.3 g/m^2, and spring averaged 927.9 g/m^2. Belowground biomass of fall plantings averaged 1264.1 g/m^2 and spring averaged 1186.3 g/m^2. Stem densities were also similar, with the fall plantings averaging 70 stems and spring plantings averaging 75 stems. The vegetation transplanted in the fall was actively growing and providing some protection to the terrace throughout the winter season. The fall transplants were well established at the beginning of the growing season on April 1st, and at the end of twelve months both seasonal plantings were approaching similar heights to those of the ambient marsh and appeared to be actively expanding with age.

Seed Establishment

Results of the controlled germination tests indicate that *S. alterniflora* seeds were viable, but that they had to go through a period of after-ripening to increase germination rates. It was assumed that there was no difference between harvest years, but under controlled tests, the germination results from the two different years suggested variability. The low germination percentages of the 2005 seed harvest support suggestions that the quality of seed produced in the natural marsh varies greatly from one stand of *S. alterniflora* to another (Broome et al. 1974)

According to past studies, seed are often the most important factor in establishing *S. alterniflora* on newly dredged sediments under natural conditions (Linthurst and Seneca 1980). However, the results from this study show that direct seeding is not feasible on newly constructed marsh terraces on the Pointe aux Chenes WMA. Although the native population of seed used in the seed treatments proved to be viable under controlled germination tests, when seeds were distributed on the terraces, there was very little germination. Some potential causes for poor seed germination on the terraces could be the high energies generated from both wind and tidal surge that would wash the seed away, predation, or the seeds could have died from desiccation over the thirty-day period (Chappell and Cohn 2006).

CONCLUSIONS

The low frequency of plant occurrence in the unplanted terraced control site demonstrates that there is little natural foundation material available in highly disturbed or dredged material soil. Consequently, naturally occurring vegetation is generally sparse and slow to establish. The establishment of vegetation through transplants of *S. alterniflora* will provide some protection to the otherwise easily-eroded soils of the terrace and is critical to terracing success. All vegetative transplants utilized in this study accelerated the process of revegetation on dredged soils. This study demonstrates that vegetative transplants are an economical, practical, and effective method of establishing a protective cover on marsh terraces. Although trade gallons are viewed as the most reliable means of establishment in areas of high wave energies, they have a higher per unit cost than vegetative plugs. For example, a Louisiana Department of Natural Resources Assessment Report (2001) states that installation costs for *S. alterniflora* transplants typically average approximately $4.00 per vegetative plug and $7.00 per trade gallon. The results of this study suggest that vegetative plugs of *S. alterniflora* can become established in areas of moderate to high wave energies, like those associated with marsh terraces. Since survival and growth rates were the same between the plant growth forms, vegetative plugs are more cost efficient than trade gallons and should be considered for use in large-scale restoration projects.

The results of this study indicate that late fall plantings in October can be successful, but faster shoot production of *S. alterniflora* can be achieved by planting in the warmer weather found during the spring months. Planting the terraces in the fall may protect the sediment from erosion caused by continuous wave action that is accelerated during the winter months by prolonged periods of winds from the northwest. Established vegetation on the terraces could act as a buffer to the strong winds, but the chance of increased plant mortality may not be worth the risk to some project planners.

Although direct seeding appears to be unsuccessful on the marsh terraces on the Pointe aux Chenes WMA, it has been demonstrated as a viable option in other areas with optimal seeding conditions, such as large beneficial-use areas or areas of marsh that have low wave energies and shallow water (Materne et al. 2003). At the initiation of this study, the use of direct seeding appeared to be a promising method, as it required the least investment in labor, facilities, and equipment. However, techniques to solve the low seed viability problem of *S. alterniflora* still need to be developed before direct seeding can be used in large-scale restoration projects in coastal Louisiana.

Vegetative establishment on marsh terraces is dependent upon the degree of inundation and changes in soil oxidation-reduction resulting from elevation differences (Mendelssohn and McKee 1988). This hydrologic-soil-plant interaction is important when designing marsh terraces and placement of the dredged material at marsh elevation is essential to terracing success. When properly constructed and planted at mean water level with an applicable emergent plant species, marsh terraces will promote sediment deposition and accumulation by reducing wave energy, increasing marsh edge habitat, thus increasing overall primary and secondary productivity.

This study documents the significant variability of marsh terrace design and construction. New terrace systems are continuously being constructed in coastal Louisiana in an attempt to improve previous designs. However, future studies of marsh terraces are necessary because there is not adequate information available to support one marsh terrace design over another. Restoration project planners should evaluate existing sediment characteristics of the area before selecting a site for terrace construction; sediments with extremely high water content and organic matter may not be suitable. Future marsh terracing designs should specify terrace elevations that are adequate for vegetative establishment and maximize vegetative growth. Finally, long-term post-construction monitoring is necessary before marsh terracing restoration can approach the scientific standards required for acceptance of expensive, large-scale wetland restoration projects in coastal Louisiana.

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VITA

Ashley Wilson Mullens was born August 21, 1980, in Baton Rouge, Louisiana. She was raised in New Roads, Louisiana, where she graduated from Catholic High School of Pointe Coupee in 1998. She graduated from Louisiana State University in December 2002 with a Bachelor of Science in wildlife management and a minor in forestry. In August 2003, Ashley began her graduate studies in The School of Plant, Environmental and Soil Sciences under the guidance of Mr. Michael D. Materne and Dr. Maud M. Walsh. The degree of Master of Science will be awarded in August 2007.