RESTORATION OF *RESACA* WETLANDS AND ASSOCIATED WET PRAIRIE HABITATS AT PALO ALTO BATTLEFIELD NATIONAL HISTORIC SITE

A Thesis

by

MICHAEL RAY MARGO

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2006

Major Subject: Rangeland Ecology and Management

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Approved by:

Co-Chairs of Committee,	Steven G. Whisenant
	X. Ben Wu
Committee Member,	Ann L. Kenimer
Head of Department,	Steven G. Whisenant

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ABSTRACT

Restoration of *Resaca* Wetlands and Associated Wet Prairie Habitats at Palo Alto Battlefield National Historic Site.

(May 2006)

Michael Ray Margo, B.S., Texas A&M University

Co-Chairs of Advisory Committee: Dr. Steven G. Whisenant
Dr. X. Ben Wu

Cultivation and drainage projects associated with livestock production have substantially disturbed *resaca* wetlands and wet prairie habitats in southern Texas. As a consequence of the anthropogenic disturbances, the area of these wetlands has been reduced and the ecological integrity of the remaining wetlands has been compromised. The goal of this study was to explore effective strategies for ecological restoration of coastal prairie and *resaca* ecosystems in south Texas and provide restoration recommendations to the National Park Service at Palo Alto Battlefield National Historic Site (NHS). Field experiments were conducted to evaluate the effectiveness of different approaches for restoring *Spartina spartinae* on disturbed saline flats. A *resaca* hydrologic study was initiated to evaluate the groundwater hydrology in disturbed versus undisturbed *resaca* wetlands and explore potential restoration strategies. Transplanting *S. spartinae* in the fall season was more successful (80% survivability) than seeding (0% initial establishment), spring transplanting (0% survival), spring and fall mechanical transplanting (0% and 6% survivability, respectively). Soil disturbance significantly affected ($p \leq 0.05$) survival of transplanted tillers and basal diameter of both the bare-root and container-grown transplants in the fall manual treatments. The initial hydrologic study of the *resaca* wetlands found that vegetation rooting zone hydrology was likely dependent on surface water rather than groundwater. These findings suggest that strategies that restore surface hydrologic regimes will likely restore the ecosystem structure and function of disturbed *resacas*. Manually transplanting bare-root stock of *S. spartinae* in the late fall season without soil disturbance will increase the likelihood of successful saline flat restoration.

DEDICATION

To my beautiful wife Suzanne.

ACKNOWLEDGEMENTS

I would like to thank my committee co-chairs, Dr. Steve Whisenant and Dr. X. Ben Wu, and my committee member, Dr. Ann Kenimer, for their guidance and support throughout the course of this research. I also want to extend my gratitude to the National Park Service, specifically Joel Wagner, Luis Krug, Doug Murphy, Rolando Garza, and Karen Weaver, all of whom made this project possible.

Thanks also to my friends and colleagues and the department faculty and staff for making my time at Texas A&M University a great experience. Finally, thanks to my mom and dad for their love and support.

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CHAPTER I

INTRODUCTION

BACKGROUND

The primary focus of this research was to explore effective strategies for ecological restoration of coastal prairie and *resaca* ecosystems in south Texas and provide restoration recommendations to the National Park Service (NPS) at Palo Alto Battlefield National Historic Site (NHS) in Brownsville, Texas, USA. The site is 13.7 square kilometers and is the only National Park unit that preserves and commemorates resources related to the Mexican-American War of 1846. During the postwar period, private landowners utilized the area for agriculture until the establishment of the NHS in 1991. Agricultural use impacted vegetative communities, soils, and hydrology within the battlefield preservation subzone. One of the primary resource management goals of the NPS is to restore portions of the battlefield to 1846 conditions. This will facilitate the interpretation of events during the battle and to preserve diverse habitats for the variety of wildlife that reside on the NHS. Some of the wildlife species on the NHS include Roseate Spoonbills (*Platalea, ajaja*), Great Kiskadees (*Pitangus sulphuratus*), Northern Bobwhites (*Colinus virginianus*), jackrabbits (*Lepus californicus*), javalinas (*Sus scrofa*) , fiddler crabs (*Uca longisignalis*), and coyotes (*Canis latrans*). This restoration research was designed to provide specific information on restoration

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This thesis follows the style of Restoration Ecology.

practices that could accelerate the ecological recovery process through the establishment of a late seral species and specific surface manipulations to create appropriate hydrologic conditions. These restoration practices could then be used by the NPS to restore disturbed sites.

RESEARCH OBJECTIVES

Two restoration studies were initiated in 2001. The first was implemented to test restoration techniques to convert an early seral and non-native coastal prairie to a late seral *Spartina spartinae* (gulf cordgrass) community. The second was to study the relationship between hydrology, topography, and vegetation in a *resaca* (Spanish for oxbow lake) during and after surface manipulation. The following objectives were addressed by the research: determine the effects of 1) seeding versus transplanting, 2) container-grown versus bare-root stock, 3) manual versus mechanical planting, 4) spring versus fall planting, 5) soil disturbance on *S. spartinae* seedling survival and growth, and 6) analyze the relationship between hydrology, topography, and vegetation in a disturbed and undisturbed *resaca.*

RESEARCH HYPOTHESIS

Transplanting versus Seeding (H1)

It has been documented that transplanting container-grown seedlings or bare-root seedlings increases establishment success compared with direct seeding (Whisenant 1999). In addition, in the most unpredictable and inhospitable environments, 50 to75%

of all direct seeding operations fail and transplanting whole plants is the most viable option (Holden & Miller 1993; Whisenant 1999). Similarly, Broome et al. (1988) reported that transplanting is successful over a wider range of conditions than is seeding. Since the NHS is located in a semiarid climate (Thornthwaite 1948) with high evaporation rates, extreme variability in precipitation (Fulbright et al. 1990), and high temperature, transplanting *S. spartinae* may be the only viable option.

H1: Transplanting *S. spartinae* is more effective than seeding.

Bare-root versus Container-grown Stock (H2)

Methodologies for restoring *Spartina* seedlings include sprigs (bare-root), plugs (substrate intact), or container-grown (Broome et al. 1988). On the North Carolina coast, transplanting sprigs or single-stem plants of *Spartina alterniflora* stabilized substrates and began marsh development by the end of the second growing season (Woodhouse et al. 1974). Container-grown stock was more successful on sites with irregular flooding regimes, due mainly to the moisture retention capacity of the potting medium, which is also an advantage in establishment during periods of low rainfall (Broom et al. 1988). The Kika de la Garza Plant Materials Center in Kingsville, Texas has been restoring coastal saline sites with container-grown stock of *S. spartinae* (Lloyd-Reilley 2001, personal communication). Since major offsite drainage projects have altered the hydrology on the NHS, container-grown stock may be more effective than bare-root seedlings.

H2: Container-grown stock of *S. spartinae* will have a higher survivability than bare-root seedlings.

Manual versus Mechanical Planting (H3)

Transplanting can be accomplished manually or mechanically, depending on the size of the operation and the accessibility of the site (Broome et al. 1988). Farm tractors with a transplanter are effective particularly where labor is expensive and large areas must be planted during short planting periods (Whisenant 1999). Under good conditions mechanical equipment plants 1000 seedlings per hour (Stoddard and Stoddard 1987). A mechanical transplanter used for tobacco or vegetable plants proved satisfactory on certain sandy sites (Woodhouse et al. 1974). While rapid, economical, and effective, the straight-line planting patterns do not recreate natural-looking communities (Whisenant 1999). Hand implements designed for transplanting seedlings include dibbles, KBC bars, and hoedads. While more labor intensive and less rapid, manual planting can produce more natural-looking communities. In addition, hand planting allows additional care that may increase seedling establishment (Whisenant 1999).

> **H3:** Transplanting *S. spartinae* manually will increase survivability when compared to mechanical planting.

Timing (Spring versus Fall) Affects the Success of Transplanting (H4)

Since seedling establishment requires ample soil moisture and favorable temperatures, the best time for seeding or planting is just prior to the longest period of favorable growing conditions (Whisenant 1999). Seasonal temperatures and precipitation patterns dictate the most optimal time for planting or seeding in an area. The NHS is characterized by hot and dry summers and mild winters. During the summer months in 2001 and 2002, Brownsville averaged a high temperature of 34° C (NWS 2004). Milder temperatures during the winter should provide the most opportune time to establish transplants or planted seed at the NHS.

H4: Fall planting will increase *S. spartinae* establishment.

Soil Manipulation (H5)

Strategies that increase infiltration, reduce runoff, and increase nutrient cycling should improve seedbed conditions and increase seedling establishment (Whisenant 1999). Seedbed preparation may involve mechanical treatments such as plowing, chiseling, disking, or harrowing. Selecting from among the many types of disturbance depends on the kind and amount of existing vegetation and soil factors such as susceptibility to erosion, slope, salinity, stoniness, texture, and depth (Whisenant 1999). Bare and crusted soil surfaces are common on disturbed locations within the NHS. Soil manipulation may have the potential to increase infiltration and increase seedling establishment.

H5: Mechanical seedbed preparation will increase *S. spartinae* establishment.

Resaca Hydrology (H6, H7, H8)

The natural shape of a *resaca* within the NHS preservation subzone was modified to provide a year-round water sources for cattle. These hydrologic changes are especially important in wetlands, where species composition is largely determined by hydrologic regime (Mitsch and Gosselink 2000). A process-oriented approach (Whisenant 1999) that explores the relationship between hydrology, surface topography, and vegetation can help develop effective approaches for restoring *resaca* ecosystems.

H6: The hydrology of the disturbed *resaca* is different from that of the undisturbed *resaca.*

H7: In *resaca* channels, plant assemblage is primarily determined by hydrologic regime (depth and variation of the water table).

H8: Reshaping the topography of *resaca* channels, without significant alteration of *resaca* levees, will restore the hydrologic regime as defined by that of a reference *resaca*. (Due to compliance restrictions caused by the potential for cultural resource damage this hypothesis was not tested)

CHAPTER II

RESTORATION OF *SPARTINA SPARTINAE* IN SALINE FLATS AT PALO ALTO BATTLEFIELD NATIONAL HISTORIC SITE

INTRODUCTION

Coastal marsh restoration has been a common practice in parts of the world for many years (Ranwell 1967; Dodd and Webb 1975; Knutson 1976; Garbisch 1977; Woodhouse 1979; Linthurst & Senaca 1980; Chung 1982; Senaca & Broome 1982; Broome et al. 1986; Broome et al. 1988; Boyer & Zedler 1999; Warren et al. 2002). Along the east coast of the U.S.A., *Spartina alterniflora* (smooth cordgrass) is the dominant angiosperm in regularly flooded marshes and is the principal species used in marsh restoration projects (Broom et al. 1988; Woodhouse et al. 1974). In more temperate climates, *Spartina spartinae* (gulf cordgrass) dominates, sometimes to the exclusion of other species (Hatch et al. 1999). Along some portions of the southern Texas Gulf Coast, U.S.A., the relative abundance and distribution of *S. spartinae* has changed as a result of both natural and anthropogenic disturbance. Methodologies for restoring *S. spartinae* are important since previous research was limited to its morphology, phenology, distribution, and response to fire (Shiftlet 1963; Nixon 1969; Gould 1975; McAtee et al. 1976; Oefinger & Scifres 1977; McAtee 1979; McAtee et al. 1979; Scifres et al. 1980; Lonard 1993; Stutzenbaker 1999; Lonard et al. 2004).

Restoring the structure and function of coastal marshes is often initiated by replacing the dominant native angiosperm, with the assumption that restoration of the dominant plants will lead to the spontaneous regeneration of other native plants and animals. Potential methodologies for restoring a dominant species such as *Spartina*, include transplanting sprigs, plugs, container grown seedlings, or seeding (Broom et al. 1988).

Transplanting large seedlings is usually more reliable than direct seeding (Whisenant 1999). In addition, in the most unpredictable and inhospitable environments, 50-75% of all direct seeding operations fail and transplanting whole plants is the most viable option (Holden & Miller 1993; Whisenant 1999). Similarly, Broome et al. (1988) reported that transplanting is successful over a wider range of conditions than is seeding. On the North Carolina coast, transplanting sprigs or single-stem plants of *Spartina alterniflora* resulted in substrate stabilization and marsh establishment by the end of the second growing season (Woodhouse et al. 1974). Broome et al. (1988) reported that container-grown stock are especially successful on sites with irregular flooding regimes, due mainly to the moisture retention capacity of the potting medium, which is also an advantage in establishment during periods of low rainfall.

Transplanting can be accomplished manually or mechanically, depending on the size of the operation and the accessibility of the site (Broome et al. 1988). Farm tractors with a tree transplanter are most effective where labor is expensive and large areas must be planted during short planting periods (Whisenant 1999). Under good conditions mechanical equipment plants 1000 seedlings per hour (Stoddard & Stoddard 1987). A mechanical transplanter used for tobacco or vegetable plants proved satisfactory on certain sandy sites (Woodhouse et al. 1974). While rapid, economical, and effective, the straight-line planting patterns do not recreate natural-looking communities (Whisenant 1999).

Hand implements designed for transplanting seedlings include dibbles, KBC bars, and hoedads. While more labor intensive and less rapid, manual planting can produce more natural-looking communities. In addition, hand planting allows additional care that increases seedling establishment.

Since seedling establishment requires ample soil moisture and favorable temperatures, the best time for seeding or planting is just prior to the longest period of favorable growing conditions (Whisenant 1999). Seasonal temperatures and precipitation patterns dictate the most optimal time for planting or seeding in an area.

Strategies that repair soil surface processes (infiltration, runoff, nutrient cycling) can improve seedbed conditions and increase seedling establishment (Whisenant 1999). Seedbed preparation may involve practices such as plowing, chiseling, disking, or harrowing. Selecting from among the many types of disturbance depends on the kind and amount of existing vegetation and soil factors such as susceptibility to erosion, slope, salinity, stoniness, texture, and depth (Whisenant 1999). Soil manipulation may have the potential to increase infiltration and increase seedling establishment.

Salinized soils are the result of hydrologic processes in arid and semiarid regions and occur through natural or human-caused (secondary salinization) processes (Whisenant 1999). Frequent rainfall tends to leach the upper soil of salts and when groundwater is close to the surface, soil water salinity fluctuations are less (Mitsch & Gosselink 2000). Artificial drainages which lowered the groundwater table and consistent droughts have lead to the unusually dry saline flats at the NHS. These two interactions may be the dominant factor preventing the natural regeneration of *S. spartinae* at the NHS. Gulzar et al. (2001) found that increased salinity inhibited seed germination of the halophytic grass, *Urochondra setulosa*. Gradients of disturbance and stress factors have been shown to change species composition and richness of herbaceous plants (Grime 1979). The extent to which increased salinity will influence restoration of *S. spartinae* at the NHS is unknown.

Since there have been no studies on the success of different methodologies for restoring *S. spartinae* along the southern Gulf Coast of Texas, the following objectives were addressed by this research: determine the effect of: 1) seeding versus transplanting, 2) planting season, 3) soil disturbance, 4) container grown versus bare-root stock, and 5) manual versus mechanical planting on seedling survival and growth.

METHODS

Study Area

The study area was located at the Palo Alto Battlefield National Historic Site (NHS), 8.0 km north of central Brownsville, in Cameron County, Texas, USA (26º 01’ N, 97 28’ W). The 3,400 acre NHS lies within the Matamoran district of the Tamaulipan Biotic Province (Blair 1950) and the Gulf Prairies and Marshes vegetation region (Schuster & Hatch 1990) of Texas (Fig. 2.1). Cameron County’s climate has been characterized as a subhumid-to-semiarid east-coast subtropical (Fulbright et al. 1990). Mean annual temperature for the region is 23.0º C (Tunnell & Judd 2002) with a mean frost-free

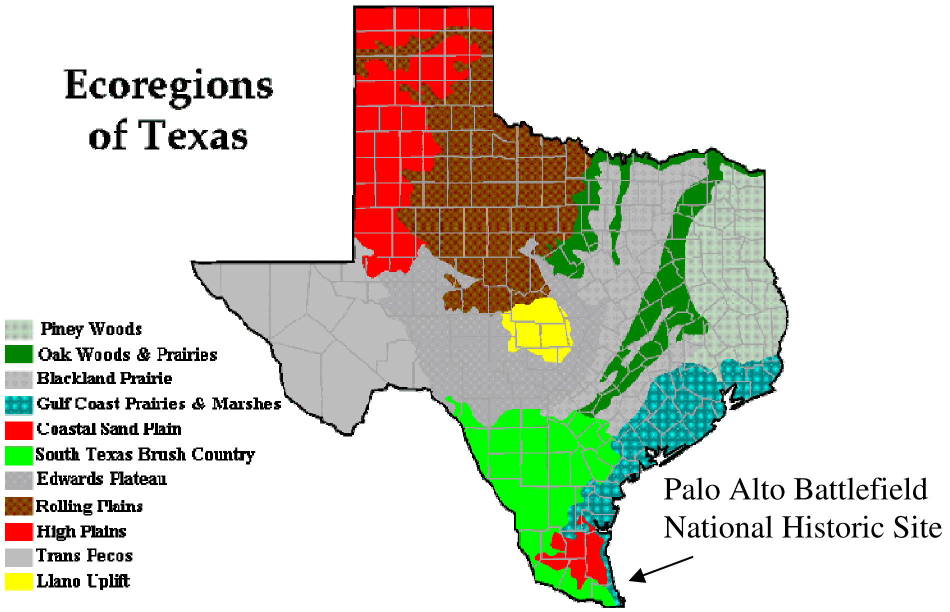

Fig 2.1. Palo Alto Battlefield National Historic Site is located within the southernmost portion of Gulf Coast Prairies and Marshes vegetation region of Texas. Map from the Texas Parks and Wildlife Department.

period of 330 days (Lonard et al. 1991). Mean annual precipitation and evaporation is 68.2-cm and 247-cm, respectively (Tunnell & Judd 2002). Precipitation distribution is bimodal, with the highest percentage falling during May and September.

The sedimentary deposits of the Holocene-Modern fluvial-deltaic system of the Rio Grande (Brown et al. 1980) has dictated the character of soils, vegetation, and other natural resources of the battlefield. Consequently, the NHS is characterized by meandering distributary channels (*resacas*), muddy floodplains, and saline interdistributary basins (Fig. 2.2).

The soils of the core battlefield and *resaca* wetlands are deep, poorly drained, and calcareous saline clays of the Lomalta series. Lomalta clay soils have a salinity range of 20-50-Mmhos/cm, a permeability rate of <0.06-in/hr, and a very high shrink-swell potential (Williams et al. 1977). Slopes in the wet prairie are < 0.5% and elevation is approximately 4-m.

Fig. 2.2. *Resaca* channels and saline interdistributary basins interspersed within NHS boundaries.

Dependent upon favorable edaphic factors (Johnson 1955) *S. spartinae* dominates the coastal prairie. Other species occurring in the wet prairie include *Borrichia frutescens, Suaeda* spp., *Salicornia virginica, Batis maritima, Limonium nashii*, and *Monanthochloe littoralis*. Several introduced grasses include *Dichanthium annulatum, Dichanthium, aristatum, Pennisetum ciliare, Urochloa maxima*, and *Urochloa panicoides* occur in the core battlefield and other disturbed sites (Lonard et al. 2004).

Study Design

Seeding Experiment

A seeding experiment was conducted in spring and fall of 2002 by sowing 0.11-kg of *S. spartinae* in ten M-shaped mounds mixed with peat moss. This seedbed configuration has been known to increase germination and establishment in western Australia by concentrating rainwater near the seed and leaching the salts (Malcolm 1991) (Fig. 2.3).

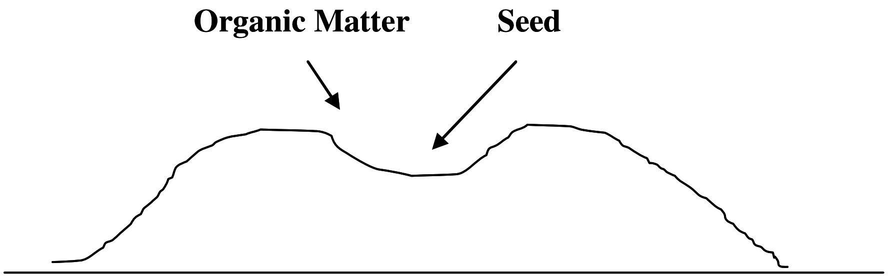

Fig. 2.3. Cross-section of M-shaped mound used to decrease the detrimental effects of saline soils.

Manual Transplanting Experiment – Planting Season, Soil Disturbance, and Seedling Preparation

The manual transplanting design included a 2x2 factorial experiment in a completely randomized split-plot design (Ott & Longnecker 2001) with five replications. Soil disturbance was identified as factor *A* and stock-type as treatment factor *T*. A total of 12 whole-plots split into two 3x3-m² sub-plots were established for $n = 6$ observations at each combination of soil disturbance and stock-type (Fig. 2.4). Factor *A* consisted of two levels: till (T) and no-till (NT). Treatment factor *T* also consisted of two levels:

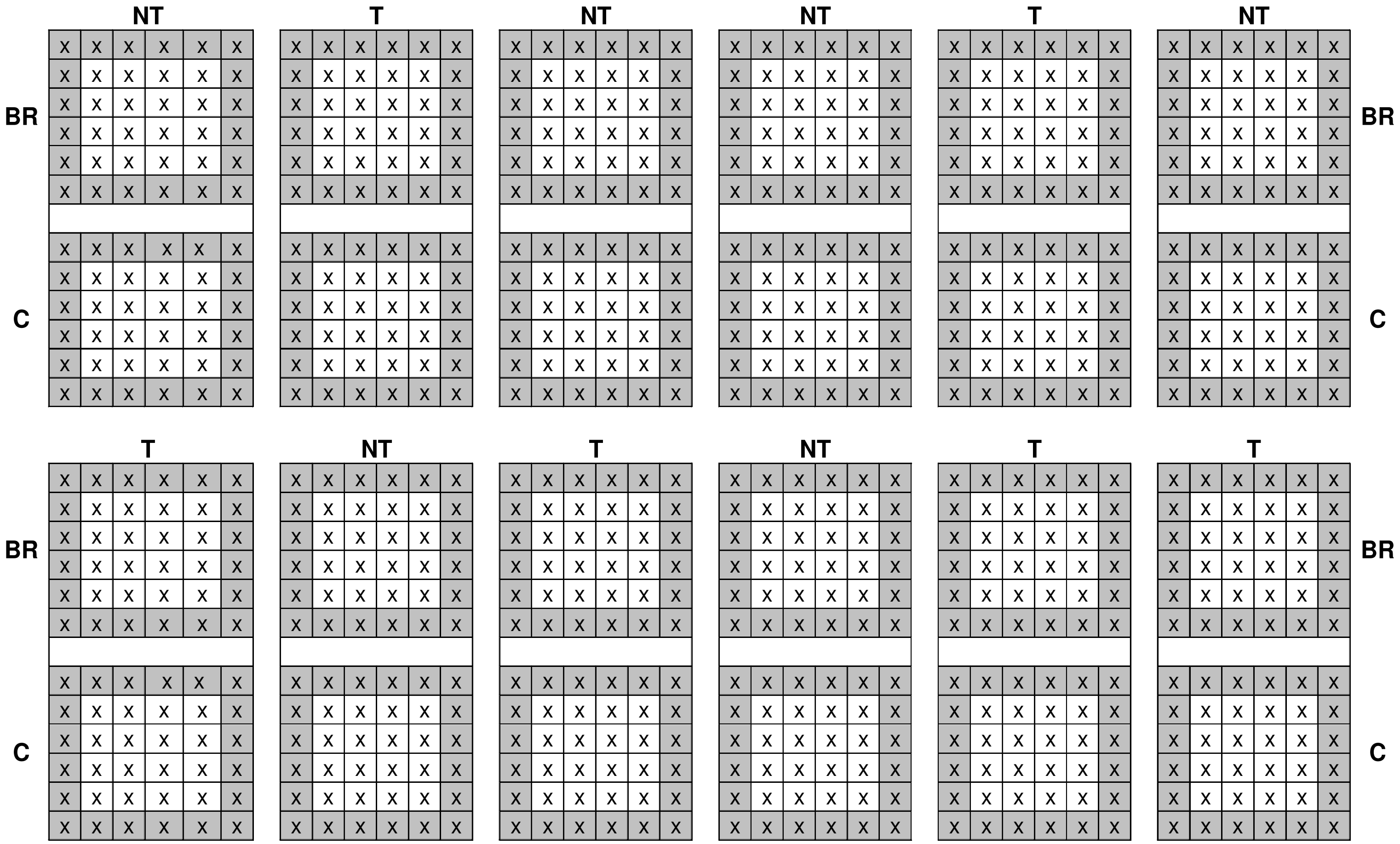

Fig. 2.4. Manual transplanting split-plot design. BR = bare-root, C = container-grown, NT = no-till, T = till.

bare-root (BR) and container-grown (C). The 2x2 factorial experiments consisted of four treatment types: till bare-root (TBR), no-till bare-root (NTBR), till container (TC), and no-till container (NTC). A total of 36 seedlings were planted in each sub-plot with a sample size of 16 (Fig. 2.5). This experiment was conducted in spring and fall of 2002.

Fig. 2.5. A manually transplanted *S. spartinae* seedling in a tilled plot.

A total of 864 bare-root seedlings were planted in both the spring and fall of 2002. Individual seedlings were gathered from an undisturbed gulf cordgrass community approximately 50-m from the experiment site. One bundle of vigorous tillers (~ 45-cm diameter) was harvested from an actively spreading and mature *S. spartinae* plant. This non-destructive harvesting method preserves the integrity of the donor plant. Individual seedlings were then separated from each bundle and wrapped in a wet burlap sack to prevent drying. Each seedling consisted of 3-7 tillers with a basal diameter range of 2.5-5.0-cm. Harvesting occurred in the fall, summer, and spring of 2002. The summer harvest of 300 seedlings was transplanted into 3.8 x 21-cm plastic cone containers with a growing media consisting of Canadian sphagnum peat moss, horticultural vermiculite, wetting agent, and a starter nutrient charge. The seedlings were kept in a wet environment by submerging the bottom ¼ of the containers in a trough of water for six months. Container-grown seedlings were only planted in the fall 2002 treatment due to readiness of plant material.

Soil manipulation was accomplished by tilling whole plots to a depth of 7-10-cm. A gas powered rotary tiller was used to disturb the soil. A total of 12 random whole-plots were tilled in both the spring and fall of 2002.

Mechanical Transplanting Experiment – Planting Season and Soil Disturbance

The mechanical transplanting design included a 2x1 factorial experiment in a completely randomized split-plot design (Ott & Longnecker 2001) with five replications. Soil disturbance was identified as treatment factor A and stock-type as treatment factor T. A total of two whole-plots split into 12.5 x 7.5-m subplots for $n = 6$ observation at each combination of soil disturbance and stock-type. Factor A consisted of two levels: till (T) and no-till (NT). Treatment factor T consisted of one level: bare-root (BR). Only bare-root seedlings were used for this experiment because the containerized seedlings were too large for the planter. Subplots consisted of six, 10-m rows with 25 seedlings spaced 30-cm apart in each. A total of 150 bare-root seedlings were planted in each sub-plot. A farm tractor with an attached planter was used to plant the seedlings in six, 10-m rows in each subplot (Fig. 2.6). Each row consisted of 25 seedlings spaced 30-cm apart. Plantings occurred in both the spring and fall of 2002.

Fig. 2.6. Fesco tree planter being used to plant *S. spartinae* seedlings.

Data Collection and Analysis

Seedling survival and aboveground net standing crop were assessed in fall 2003 or after one growing season. In addition to seedling survival, basal diameter and number of tillers for each seedling were determined. Above-ground net standing crop of each seedling was determined by clipping the aboveground portion of each seedling, drying it at 60º C for 24 hours, and recording the weight. For the seedling and mechanical planting experiments, as well as the spring planting of the manual transplanting experiment, no basal diameter, number of tillers, or biomass data was collected because the survival was 0%.

Statistical analysis of the data from the transplanting experiment (fall planting only) was performed using a two-way Analysis of Variance (ANOVA) procedure with SPSS software version 11.0. Analysis of variance mean separation was determined at a ($p \leq 0.05$) significance level. The Bonferroni procedure for multiple comparisons was used to determine which treatment combination pairs were significantly different in their means.

RESULTS

Seeding Experiment

The seeding resulted in a 0% establishment rate in both spring and fall 2002 sowing (Fig. 2.7). Statistical analysis was not conducted on this experiment.

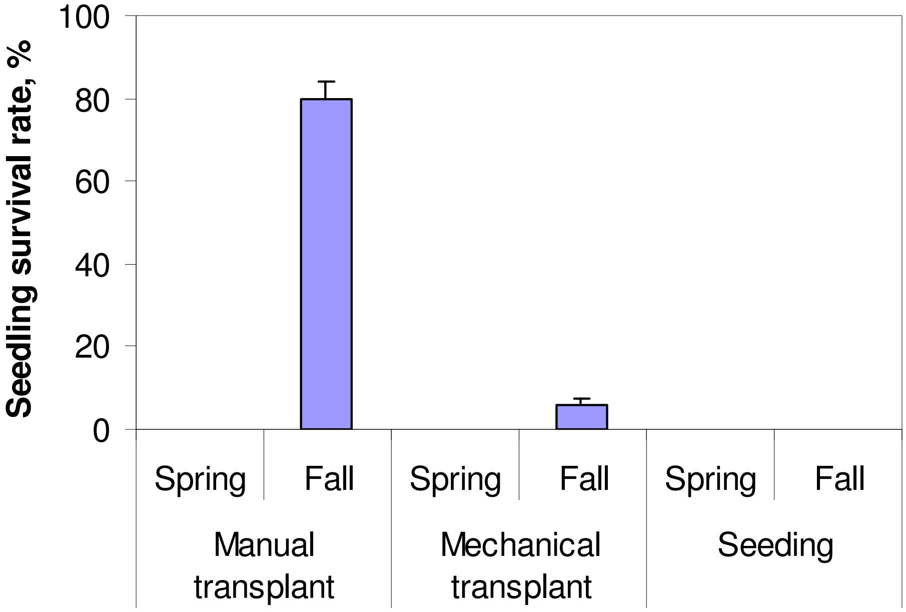

Fig. 2.7. Survivability of *S. spartinae* in all treatments.

Manual Transplanting Experiment

The spring 2002 manual transplanting of 684 bare-root seedlings resulted in a 0% survival rate in all treatment combinations. The fall 2002 manual transplanting resulted in an 80% survival rate of all sampled seedlings (Fig. 2.8). Between stock-types, the containerized seedlings had a higher rate of survival than the bare-root seedlings (81 and 79%, respectively). Among stock-type, the NTBR seedlings had a higher rate of survival (81%) than the TBR seedlings (77%). Contrastingly, the TC seedlings had a higher survival rate (85%) that the NTC seedlings (77%).

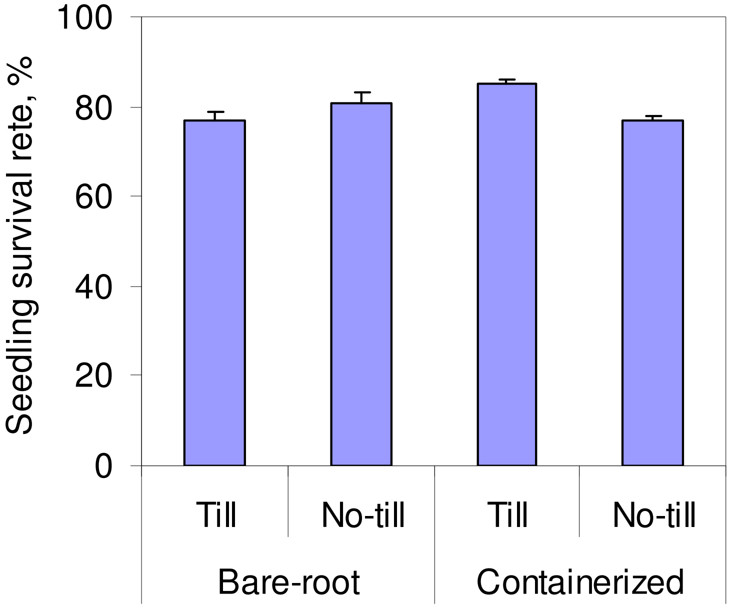

Fig. 2.8. Survivability of *S. spartinae* among stock-type during fall manual treatment.

The statistical analysis showed that the treatment (combinations of soil disturbance, stock-type, and seedbed preparation) had significant effects on the number of tillers (F = 19.63, p = 0.000; Fig. 2.9a) basal diameter (F = 25.78, p = 0.000; Fig 2.9b) and seedling weight (F = 16.90, p = 0.000; Fig. 2.9c) for fall manual transplanting.

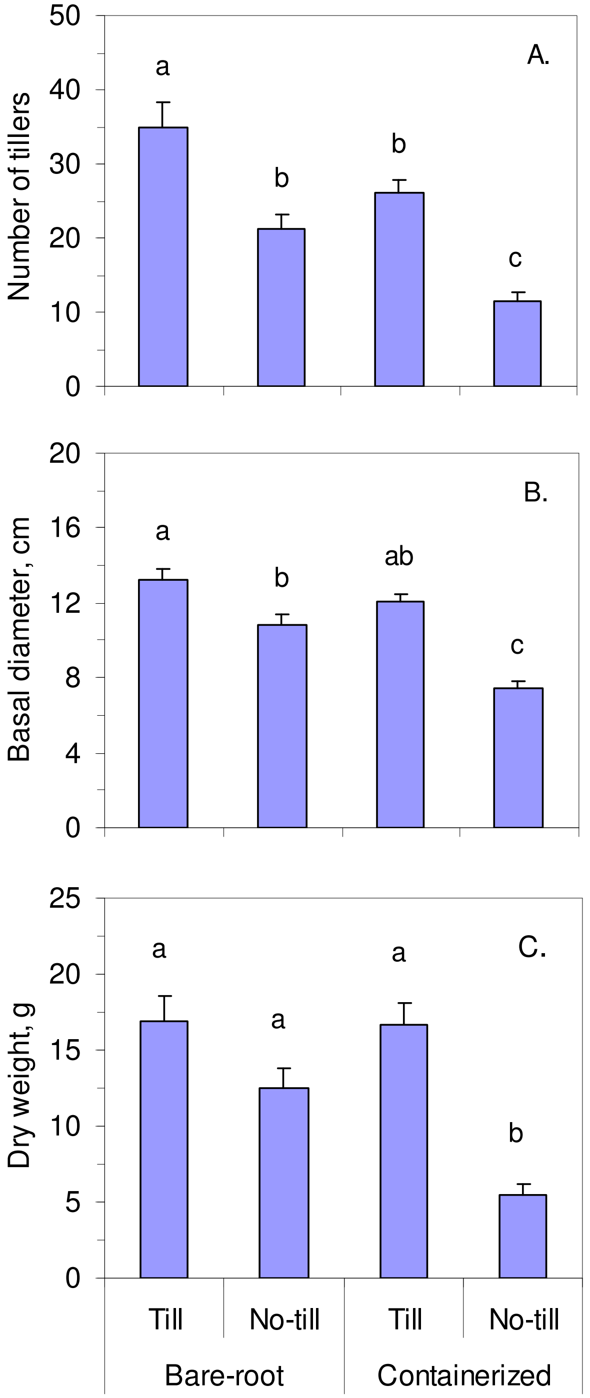

Fig. 2.9. Results of measured parameters of *S. spartinae* seedlings in fall 2002 manual treatment. Treatments with different letters were significantly different ($p \leq 0.05$).

Multiple paired comparisons among treatment combinations showed that mean number of tillers and basal diameter were significantly ($p < 0.05$) effected by tilling on both the container-grown and bare-root stock. Soil disturbance also had a significant affect on the mean weight among the containerized seedlings ($p = 0.000$). However, soil disturbance did not significantly affect the mean seedling weight among the bare-root seedlings ($p = 0.098$).

Independent pairwise comparisons among soil disturbance and stock-type were also evaluated. In comparing no-till versus till, regardless of stock-type, all three dependent variables were significantly ($p < 0.05$) different. Similarly, in comparing bare-root versus containerized seedling, regardless of soil disturbance, all three dependent variables were significantly ($p < 0.05$) different.

Mechanical Transplanting Experiment

Spring 2002 mechanical, bare-root plantings resulted in a 0% survival rate in both the tilled and no-till plots. A 6% survival rate resulted in the fall 2002 mechanical plantings with all surviving seedlings occurring in the tilled plots.

DISCUSSION

Seeding

Salinized soils often require special seedbed requirements prior to seeding. Site preparation in salizined soils should reduce the salt accumulations on the surface and encourage downward movement (FAO 1989, Whisenant 1999). The use of M-shaped mounds to increase leaching was unsuccessful at the NHS. McAtee (1979) found that high temperatures detrimentally affected *S. spartinae* germination. He further discovered that possibly a cool wet period is needed to break seed dormancy. Past drainage projects within the NHS have undoubtedly resulted in a drier coastal prairie. Since 50-75% of direct seeding operations fail (Whisenant 1999), transplanting whole plants is the more viable option.

Manual versus Mechanical Transplanting

The mechanical transplanting using a farm tractor with an attached planter proved to be ineffective on the no-till plots. The heavy clay soils separated into large aggregates when chiseled with the planter. This caused poor root-to-soil contact which decreased seedling survival. Tilling the soil prior to mechanical transplanting did increase seedling survival slightly in the fall treatment, but survival was very low (6%).

Spring versus Fall Transplanting

The timing of transplanting had a pronounce effect on *S. spartinae* survival. In 2002, the mean daily maximum temperature exceeded 30º C for seven months (April-October) with significant rainfall occurring during the fall months (Fig. 2.10). The spring planting preceded a hot and dry period, which likely contributed to the seedling survival rate (0%) significantly lower than those of fall transplanting. Mild temperatures during fall and winter provide optimum conditions for seedling survival in southern Texas and likely contributed, together with the higher rainfall, to the success of fall manual transplanting.

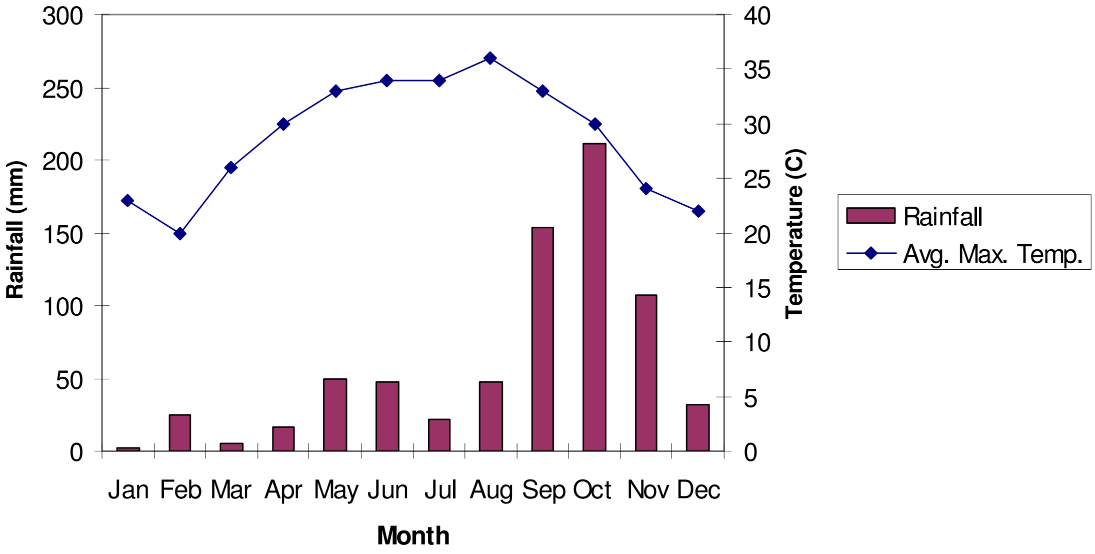

Fig. 2.10. Average maximum temperature and monthly rainfall for 2002 in Brownsville, Texas. Data from the National Weather Service, Brownsville, Texas.

Effect of Soil Disturbance and Stock-type

Within the fall manual transplants, container-grown stock had a 2% higher survival rate compared to the bare-root stock, but had lower productivity. The mean aboveground biomass and basal diameter were lower in the container-grown seedlings. A root-bound index exceeding 27% in container-grown stock has been shown to effect survival rate and growth in *Pinus* seedlings (South et al. 2005). The results of the *S. spartinae* study suggest that root bound seedlings may have slowed growth during the first growing season when compared to bare-root stock.

The significant effect ($p < 0.05$) of tilling on bare-root and container-grown stock during manual transplanting suggests that loosed soil may provide more permeability necessary for plant growth, especially on crusted saline soil types. Sinclair and Catling (2003) found that soil disturbance prior to transplanting increased herbaceous plant size compared to undisturbed plots.

Restoration Recommendations

The results of this study clearly indicate that transplanting should be preferred over direct seeding for the restoration of *S. spartinae* in this experiment. Fall transplanting appears to be preferable to spring transplanting. Although no planting time guarantees success, choosing a time followed by the longest period of the most favorable growing conditions increases restoration success (Whisenant 1999).

Since container-grown stock are costly to grow and maintain and only increased survival rate by 2% compared to bare-root stock, the most economic choice would be transplanting bare-root stock. Although soil disturbance had a significant ($p < 0.05$) effect on the transplants, no-till survival rate was at an acceptable 79%. With the cultural sensitivity of a National Historic Site, tilling large areas is not recommended. Manually transplanting bare-root stock during the mild fall season with adequate soil moisture can increase the success of restoring *S. spartinae* at the Palo Alto Battlefield National Historic Site. Restoring a few acres at a time can help avoid large failures and provide valuable information for future plantings.

CHAPTER III

RESACA WETLAND RESTORATION

INTRODUCTION

The biotic composition, structure, and function of aquatic, wetland, and riparian ecosystems depend largely on the hydrologic regime (Gorman & Karr 1978; Junk et al. 1989; Sparks 1992; Mitch & Gosselink 2000; Richter et al. 1996). A change in hydrology affects species composition and richness, primary productivity, organic accumulation, and nutrient cycling in wetlands (Mitsch & Gosselink 2000). Assessing the impact of perturbation on the hydrologic regime requires characterization of hydrologic parameters in order to restore or sustain ecological integrity (Richter et al. 1996).

The hydrological alterations that occurred within a historically significant *resaca* at Palo Alto Battlefield National Historic Site (NHS) during the early twentieth century include pond excavation, trenching and other drainage projects. The consequences of these alterations have yet to be determined. The relationship between hydrology, surface topography, and vegetation will provide both the key to understanding the damage and a tool for directing ecological changes during restoration. The objectives of this study was to 1) utilize a process-oriented approach to analyze the hydrology, topography, and vegetation within a disturbed *resaca* at the NHS, 2) conduct a small-scale channel restoration experiment and assess its influence on hydrology and vegetation, and 3) develop a restoration plan for the National Park Service based on the research findings.

RESACA HYDROLOGY

Resacas (oxbow lakes) are former channels of the Rio Grande found mostly in the southern portion of Cameron County, Texas (Handbook of Texas Online, 2005). Changes in river hydrology have separated *resacas* from Rio Grande waters. They now receive water almost exclusively from runoff and rainfall (Mora et al. 2001). *Resacas* are widely used by wildlife in the region (Jahrsdoefer & Leslie, 1988). According to the National Biological Service, *resacas* "may be the key to the high biodiversity" found in the region, providing habitat for such aquatic creatures as the Amazon molly (*Poecilia formosa*) and the Rio Grande siren (*Siren intermedia*) (Environmental Protection Agency 1998). Development of *resacas* as reservoirs and channels for irrigation began in 1906 (Handbook of Texas Online, 2005). They now serve important functions as both water delivery systems to cities and farms and as flood control during heavy rainfall (Farmer 1992).

Remnant *resacas* are a prominent feature of the NHS (Farmer 1992). Efforts to drain the salt prairie towards small excavated ponds created by individual landowners are evident throughout the NHS. The excavation of shallow ditches along *resaca* beds apparently held and drained runoff toward the ponds that were typically established within *resacas* (Fig. 3.1). Ponds were important for increasing water retention during dry summer months (Fig. 3.2). The historically significant north/south *resaca* located along the western boundary of the NHS, exhibits the typical drainage projects created by livestock producers. The hydrologic consequences of these disturbances have yet to be determined.

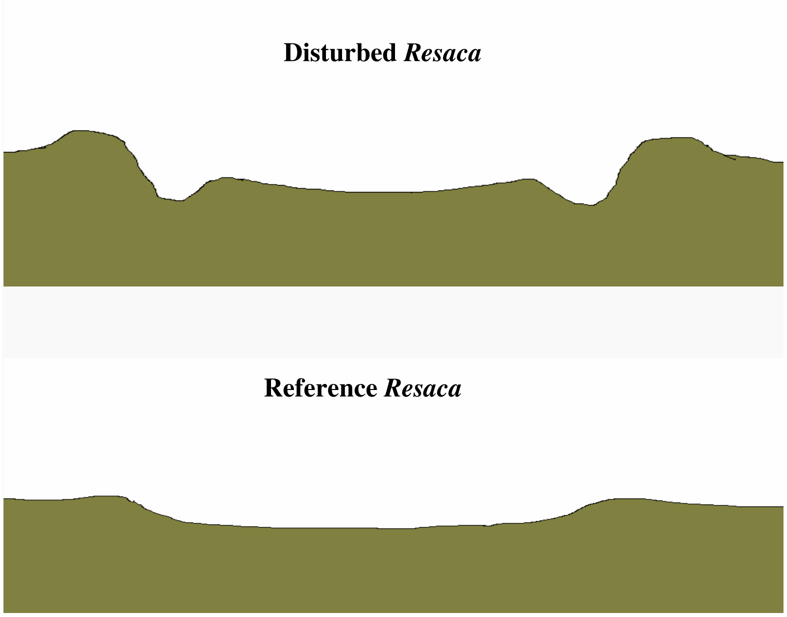

Fig. 3.1. Cross section of the disturbed *resaca* (top) with ditches and an undisturbed/ reference *resaca* (bottom).

Fig. 3.2. Aerial view of an artificial pond within a *resaca* channel.

HYDROLOGIC STUDY

In August of 2003, Enercon Services, Inc. (Enercon) was contracted to install 35 groundwater monitoring wells at the NHS. The wells were installed along transect lines crossing *resacas* to obtain data for assessing the relationship between subsurface hydrologic regime and overlying vegetation. The data collected would be used to monitor seasonal shallow groundwater patterns and dynamics.

A total of 15 shallow monitoring wells were installed within a 100-m section of a disturbed *resaca* (Group 1) (Fig. 3.3) The wells were installed in three transects spanning the width of the *resaca*. This location was the designated site for the subsequent channel restoration (plugging the ditches) experiment. Another 10 wells (Group 2) were scheduled for installation in a second disturbed *resaca* site that was not to be restored. These wells could not be installed due to unanticipated access restrictions in the *resaca*. The remaining 10 wells (Group 3) were installed in an undisturbed (reference) *resaca* located in the eastern parcel of the NHS (Fig 3.4). These wells were installed in two transects spanning the width of the *resaca*. The distribution of the groups of wells at the NHS can be seen in Fig. 3.5.

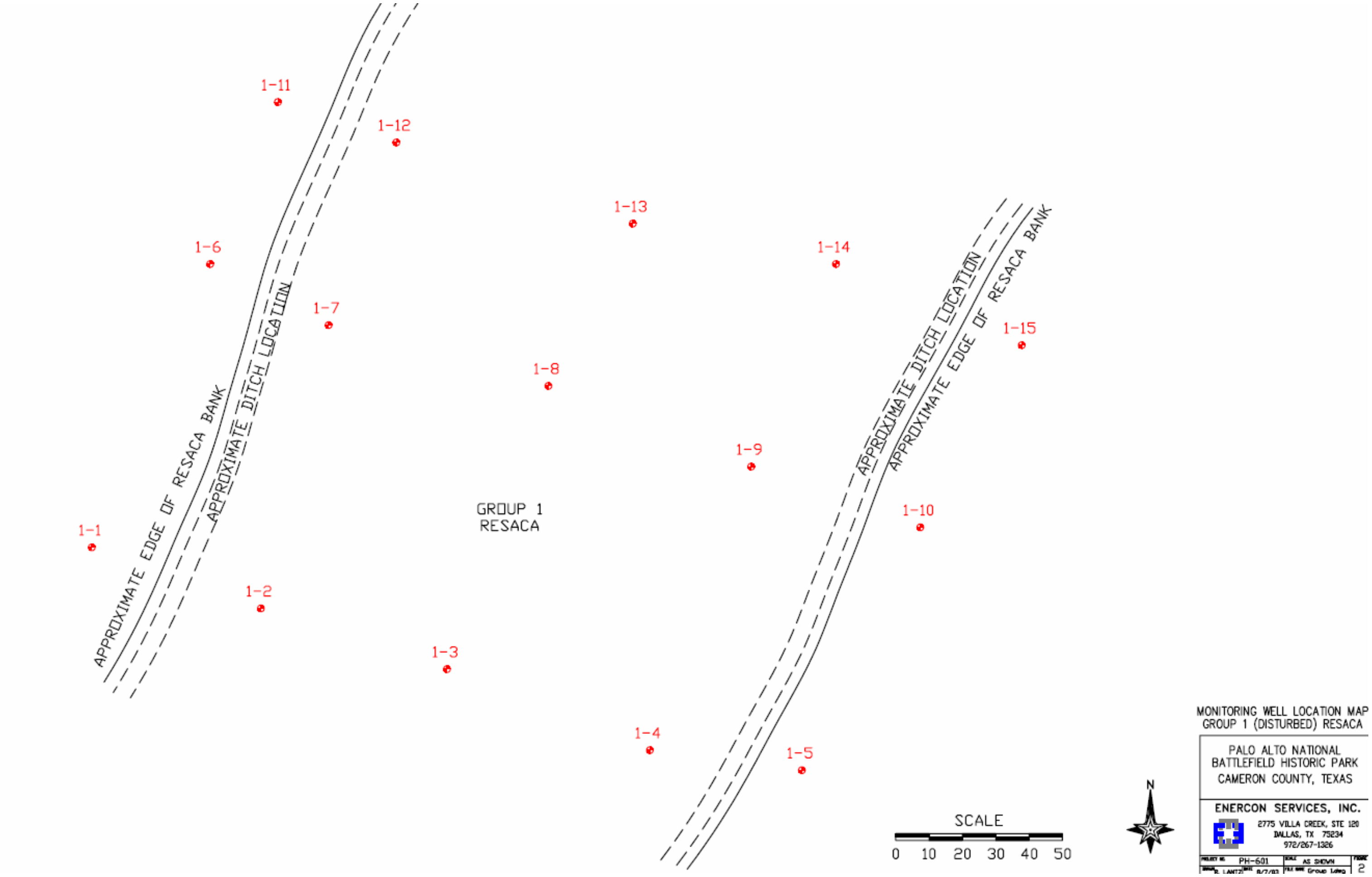

Fig. 3.3. Monitoring well location map for Group 1. A total of 15 wells were installed along three transects spanning the width of the disturbed *resaca*. Location map from Groundwater Monitoring Well Installation Report, Enercon Services, Inc. 2003.

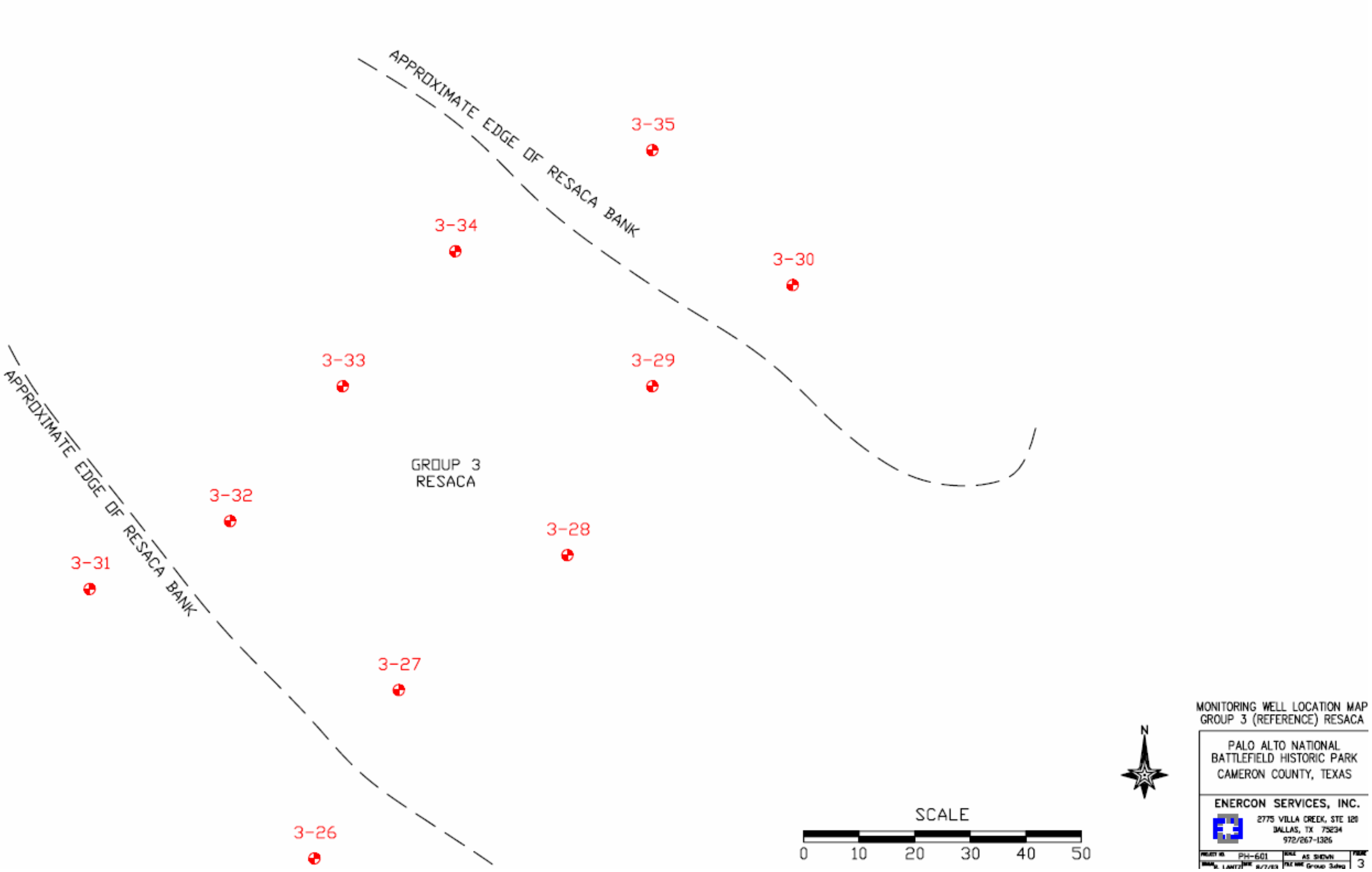

Fig. 3.4. Monitoring well location map for Group 3. A total of 10 wells were installed along two transects spanning the width of the reference *resaca*. Location map from Groundwater Monitoring Well Installation Report, Enercon Services, Inc. 2003.

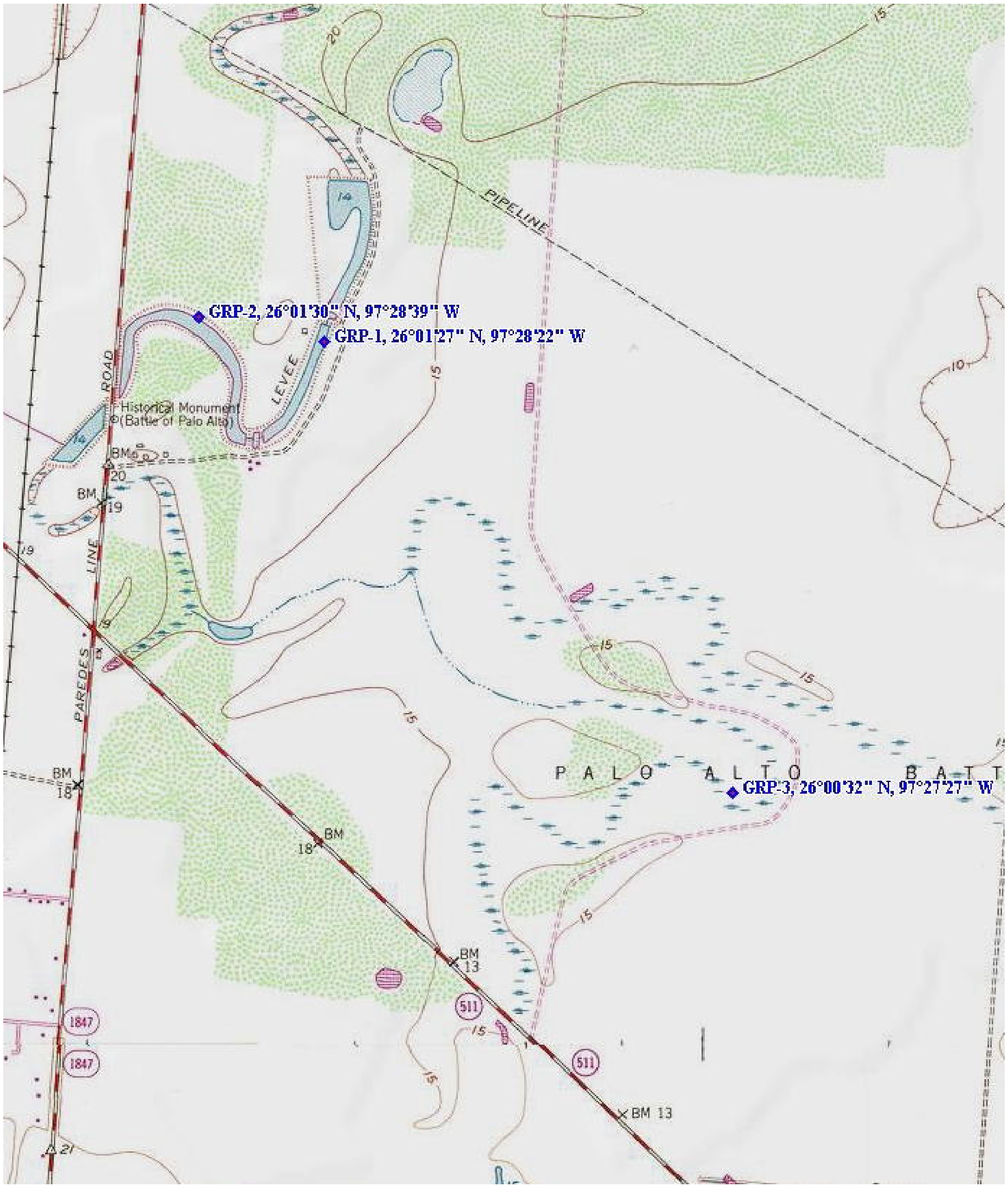

Fig. 3.5. Topographic map showing the monitoring well Groups 1, 2, and 3 at Palo Alto Battlefield National Historic Site. Map image from Groundwater Monitoring Well Report, Enercon Services, Inc. 2003.

The final well depths were reported by Enercon (2003): Group 1 soil borings were drilled using three-inch diameter, two-foot long steel Shelby tubes pressed into unconsolidated sediments. Wells 1-2, 1-3, 1-4, 1-7, 1-9, 1-12, 1-13, and 1-14 were drilled to 2.4-m below ground surface (bgs). Wells 1-1, 1-5, 1-6, 1-10, 1-11, and 1-15 were drilled to 4.5-m bgs. Well 1-8 was drilled to 5.4-m bgs. Group 3 included wells 3-27, 3-28, 3-29, 3-32, and 3-34 that were drilled to 2.4 bgs. Wells 3-26, 3-30, and 3-31, were drilled to 3.6-m bgs. The final two wells, 3-33 and 3-35, were drilled to 6.0 and 4.5-m bgs, respectively. Subsurface lithology and soil characteristics were recorded from each recoverable soil sample.

Each group of monitoring wells was surveyed to a relative benchmark elevation within the group. Group 1 wells were surveyed to a benchmark (BM) of 30.48-m at the surface pad of monitoring well 1-5. Group 3 wells were also surveyed to a BM of 30.48-m at the surface pad of well 3-35. Delta benchmark (Δ BM) was determined by subtracting the location reading (LR) from the BM. Relative top-of-casing (TOC) elevations were determined for each well in the group by adding the Δ BM and the BM. The relative groundwater table was determined by subtracting the well readings from the relative TOC elevation.

$\Delta \text{ BM} = \text{BM} - \text{LR}$

$\text{Relative TOC elevation} = \Delta \text{ BM} + \text{BM}$

$\text{Relative groundwater elevation} = \text{Relative TOC elevation} - \text{well readings}$

Varying drilling depths helped to identify different subsurface soil profiles among wells outside and within the *resacas*. The silty clay soils within the beds of both the disturbed and reference *resacas* averaged a depth of 5.7-m bgs. In comparison, silty clay soils reached a depth of only 4.5-m bgs outside both *resacas*. This can be attributed to the natural sedimentation of fine materials within the bed of river channels. Since clayey soils have lower hydraulic conductivity, it took 24 hours for the groundwater in the well casings located within the *resaca* channels to fill to a stable level, while the groundwater in the wells outside the *resacas* filled up in 2-3 hours.

The groundwater monitoring wells were gauged from August 2003 through January 2004 using an electric dipstick (Table 3.1). Well readings indicated a shallow groundwater table with low variability. Exceptional amount of rainfall during the month of September 2003, which was 285% above the 30 year (1970-2000) average, caused a drastic rise in groundwater level. *Resaca* channels were inundated from September until the end of the monitoring period. Fig. 3.6 compares the relationship between groundwater and precipitation for wells in both the disturbed and reference *resacas*. Wells 1-3, 1-9, 1-10, 1-13, 1-15, 3-28, and 3-29 were not graphed due to dry readings.

Table 3.1. Relative groundwater elevations (m) for all monitoring wells.

Well #	8/23/2003	9/3/2003	9/10/2003	9/24/2003	10/15/2003	11/7/2003	12/20/2003	1/8/2004
1-1	27.82	27.70	27.65	29.97	30.06	30.14	29.97	29.85
1-2	27.78	27.74	27.83	30.21	29.92	30.27	30.06	29.98
1-3	dry	dry	dry	30.28	30.21	30.28	30.19	30.07
1-4	27.77	27.76	27.68	30.44	30.09	30.54	30.02	29.94
1-5	27.85	27.72	27.67	30.11	30.10	30.20	30.02	29.90
1-6	27.83	27.68	27.65	29.98	29.99	30.15	29.96	30.00
1-7	27.79	27.70	27.64	30.18	30.13	30.24	30.05	29.92
1-8	27.83	27.71	27.64	30.10	30.16	30.36	30.06	29.96
1-9	27.61	27.61	dry	30.28	30.08	30.53	30.03	29.95
1-10	27.86	27.72	dry	30.13	30.09	30.21	30.05	29.93
1-11	27.82	27.67	27.62	29.99	29.97	30.18	29.98	29.89
1-12	27.67	27.71	27.66	30.14	30.08	30.24	30.02	29.94
1-13	dry	dry	dry	30.23	30.23	30.23	30.12	30.05

Table 3.1. Continued

Well #	8/23/2003	9/3/2003	9/10/2003	9/24/2003	10/15/2003	11/7/2003	12/20/2003	1/8/2004
1-14	dry	dry	dry	29.74	29.83	30.26	30.04	29.99
1-15	27.84	27.70	27.65	30.07	30.06	30.19	29.99	29.90
3-26	29.20	29.12	29.04	30.25	30.24	30.25	29.87	29.67
3-27	27.57	27.76	27.86	30.32	30.38	30.49	30.14	29.97
3-28	dry	dry	dry	30.43	30.41	30.43	30.31	30.20
3-29	dry	27.25	27.32	30.37	30.37	30.37	30.28	30.13
3-30	29.24	29.16	29.09	30.20	30.14	30.18	29.83	29.68
3-31	29.21	29.12	29.05	30.25	30.24	30.34	29.81	29.70
3-32	29.20	29.12	29.05	30.33	30.29	30.38	30.01	29.84
3-33	29.25	29.18	29.10	30.21	30.23	30.42	29.83	29.66
3-34	27.39	27.71	27.86	30.47	30.38	30.47	29.92	29.95
3-35	29.24	29.16	29.10	30.16	30.15	30.15	30.00	29.70

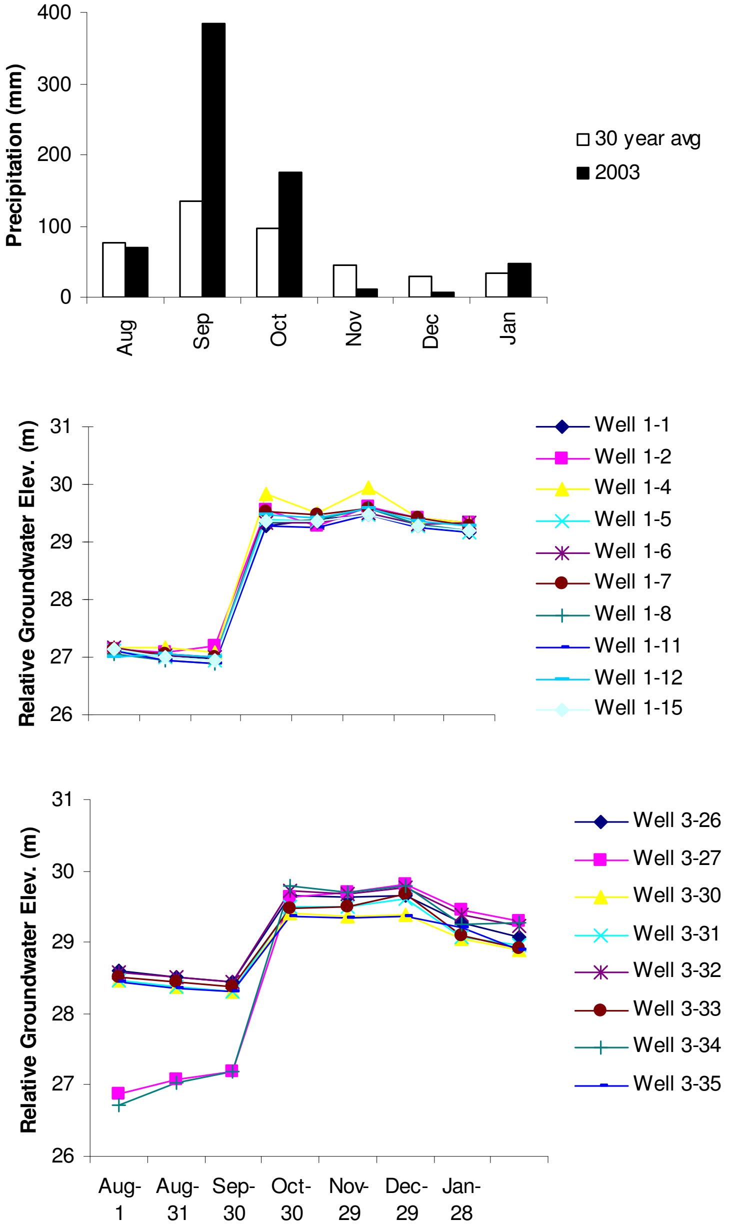

Fig. 3.6. Hydroperiod of groundwater response to rainfall: Disturbed *resaca* (middle), reference *resaca* (bottom). A 30 year (1970-2000) average monthly rainfall is compared with 2003. Rainfall data from the National Weather Service, Brownsville, Texas.

DISCUSSION

The shallow and flat groundwater table below the *resaca* channels fluctuates as a result of rainfall. The drainage ditches along the edges of the disturbed *resaca* channel at the NHS impedes surface water from reaching the center portion of the channel during minor rainfall events. Therefore, a drier environment exists in the central portion of the channel. Dense colonies of sea-ox-eye daisy (*Borrichia frutescens*) are commonly found in the central portion of the disturbed *resaca*. This species is typically found on saline wetlands that are infrequently flooded. In the drainage ditches along the interior portion of the *resaca*, wetland species more tolerant to flooding, such as cattails (*Typha spp.*), can be found.

The surface hydrology and the vegetation within the reference *resaca* are substantially different from the disturbed *resaca*. With the absence of drainage ditches, surface runoff from normal rain events is able to reach the central portion of the channel, thereby influencing vegetative communities. Wetland species that associated with infrequent flooding such as *B. frutescens* are not present in the central portion of the reference *resaca* channel. Aquatic plants such as *Nymphae elagas* and *Marsilea vestita* flourish during inundation. Bare and crusted clay soils are typically seen during dry periods. The frequency of inundation prevents *B. frutescens* from establishing. Interestingly, *Parkinsonia aculeate,* a fast growing woody shrub that tolerates saline soils and dry/wet environments, is commonly seen within the *resaca* beds during the dry periods. The strong influence of surface hydrology on *resaca* vegetation is clearly shown in the comparison of the disturbed and reference *resacas*.

Restoring surface flows will likely help restore the vegetative communities. This can be done by plugging/filling the drainage ditches and, if necessary, contouring the *resaca* channel to its natural shape.

Compliance issues prevented the occurrence of any surface manipulation experiments that would have reshaped the experimental section of the disturbed *resaca*. Since restoring the native vegetation, hydrologic regime, and topography are important objectives of the battlefield preservation subzone, it is vital that progress is made to actively restore the hydrologic regime of the disturbed *resaca*.

CHAPTER IV

SUMMARY

The purpose of this study was to develop effective strategies for ecological restoration of coastal prairie and *resaca* ecosystems in south Texas. This information enables the National Park Service at Palo Alto Battlefield National Historic Site (NHS) to meet their objectives of recreating site conditions present during the time of the battle. Field experiments were conducted that tested the following hypothesis regarding the restoration of the saline flats:

- Transplanting *S. spartinae* is more effective than seeding
- Container-grown stock of *S. spartinae* will have a higher survivability than bare-root seedlings.
- Transplanting *S. spartinae* manually will increase survivability when compared to mechanical planting.
- Fall planting will increase the success of *S. spartinae* restoration.
- Mechanical seedbed preparation will increase *S. spartinae* establishment.

Based on survivability and seedling production, manually transplanting bare-root stock of *Spartina spartinae* into untilled soil during the late fall season is recommended for *S. spartinae* restoration in the disturbed saline flats at the NHS. This methodology is likely the most effective and efficient when compared to spring season and mechanical plantings, container-grown stock, and direct seeding. Locations suitable for revegetation of *S. spartinae* at the NHS include disturbed saline flats that are not in the Chargo silty clay soil series, since they are less saline, higher than 4.6-m in elevation, and support brush-grassland vegetation (Lonard et al. 2004). In addition, restoring few acres at a time can help avoid large failures and provide valuable information for future plantings.

A *resaca* hydrologic study was conducted that evaluated the groundwater hydrology in a disturbed versus undisturbed *resaca* wetland and potential restoration strategies were explored. The hydrologic study was focused on two hypotheses:

- The hydrology of the disturbed *resaca* is different from that of the undisturbed *resaca*.
- In *resaca* channels, vegetation is primarily influenced by hydrologic regime (depth and variation of the water table)

Groundwater monitoring wells were established along transects spanning the widths of both the disturbed and undisturbed (reference) *resacas*. Readings from the wells showed that *resaca* vegetation is likely dependent upon surface water and the shallow groundwater table. By plugging or filling the artificial ditches within the disturbed *resaca* the structure and function of the wetland would likely be restored.

The disturbed saline flats and *resaca* wetlands at the NHS compromise the interpretation and preservation of the battlefield. This study helps provide necessary information required for the National Park Service to design and implement an ecological restoration plan that is based on the understanding of hydrology, soils, and vegetation at Palo Alto Battlefield National Historic Site.

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