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# Do terraces and coconut mats affect seeds and submerged aquatic vegetation at Sabine National Wildlife Refuge?

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# DO TERRACES AND COCONUT MATS AFFECT SEEDS AND SUBMERGED AQUATIC VEGETATION AT SABINE NATIONAL WILDLIFE REFUGE?

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## Abstract

Terraces are a widely used wetland restoration tools in coastal Louisiana, yet the benefits of terraces are poorly documented. Like terraces, coconut mats also may increase abundance of submerged aquatic vegetation (SAV), but their benefits are undocumented. I compared SAV and seed abundance in a marsh pond among three treatments: terrace, coconut mat, and marsh.

I evaluated terraces constructed in 1999 and coconut mats installed in 2001 in portions of unit 7 of Sabine National Wildlife Refuge that converted from emergent marsh to open water between 1956 and 1978. I randomly selected 3 terrace, marsh, and coconut mat stations. I evaluated transects 0 meters, 5 meters, and 50 meters (here after open water) from emergent vegetation at each station. Submerged aquatic vegetation was evaluated on the terrace and marsh by harvesting SAV from 10-cm diameter cores, harvesting SAV from 1-$m^2$ plots, and raking: only 1-$m^2$ plot sampling was conducted on coconut mat treatments. I evaluated seed abundance on terrace and marsh transects with 10-cm diameter cores, which could not be used on the coconut mats.

Submerged aquatic vegetation biomass differed between treatments and sampling dates. Biomass of SAV, as estimated by the cores, was greater on the marsh transects than the terrace transects. The SAV biomass, as estimated by 1-$m^2$ plots, was greatest during September 2002. Biomass of SAV, as estimated by 1-$m^2$ plots, was greater on coconut mats than terrace or marsh transects. Raking indicated that in September 2002, the percent occurrence of SAV was greater on the marsh transects than on the terrace transects.

Seed biomass was greater adjacent to marsh than to terraces, which was similar to that in open water. Seeds of sawgrass (*Cladium jamaicense* Crantz) accounted for 87% of the seed biomass but did not germinate in a greenhouse.

My results indicated that terraces failed to increase SAV abundance above levels found in open water as was predicted. I concluded that restoration planners should no longer assume that terraces increase SAV abundance. Coconut mats increased SAV abundance. Additional studies on a variety of areas and configurations are needed to determine if my observations are typical.

# Introduction

The Gulf coast of the United States contains almost half of the nation's coastal wetlands and a large percentage of those wetlands are in Louisiana (Chabreck 1988). From the 1780's to the 1980's, 46 percent of Louisiana's wetlands were lost (Dahl 1990). The loss of marsh threatens wildlife and fish populations, many of which are important for their recreational, aesthetic, and economic value. Canal dredging related to the oil and gas industry, in particular, has impacted many wetlands (Boesch et al. 1994).

Restoring wetland vegetation requires understanding the factors that control vegetation establishment and growth. Emergent vegetation presence is controlled primarily by two factors: flooding and salinity, and availability of seed and vegetative propagules. McKee and Mendelssohn (1989) found that increased water level (i.e. simulated flooding) decreased live above-ground biomass and stem density in many freshwater marsh plants. In many gulf coast marshes, increases in salinity have been observed to coincide with a decrease in plant survival, biomass, and seed germination (Palmisano 1972, McKee and Mendelssohn 1989). Increased water level and salinity may decrease the recruitment of plant species from seed banks and decrease diversity in tidal marshes (Baldwin et al. 1996, Baldwin et al. 2001).

In many restoration studies (Combroux et al 2002, Seabloom and van der Valk 2003) seeds of desired species did not become established for several years following restoration. Seabloom and van der Valk (2003) found that restored wetlands in the prairie potholes did not achieve the vegetative cover or species richness of natural wetlands because the seeds and propagules of many species take years to disperse into restored areas. Seabloom and van der Valk (2003) found that dispersal limitation was the

primary cause of vegetation differences between restored and natural wetlands. According to Combroux et al. (2002), “vegetation management will be successful only when: (1) the seeds or vegetative propagules of required or preferred species are present in the propagule bank or can be created by breakage during restoration, (2) the seeds or vegetative propagules of unwanted species are not present or are, at least, uncommon or can be physically excluded, (3) conditions suitable for seed germination or the sprouting of vegetative propagules of preferred species can be established or maintained, and (4) conditions promoting the germination or sprouting of unwanted species can be avoided.”

Despite the importance of the seed bank for marsh restoration, Jemison and Chabreck (1962) found little relationship, in 1959 and 1960, between vegetative stand composition and the seeds available in the soil. Their study area included an area of major sawgrass mortality which occurred from 1957 to 1961 (Valentine 1978). Sawgrass occurs in areas adjacent to the study area today.

Submerged aquatic vegetation (SAV) species presence also is controlled primarily by two factors: light availability and salinity, and the availability of seed and vegetation propagules. Nutrient levels in sediments also are key in SAV propagation (Duarte 1995, Rybicki et al. 2001). Improving water quality has been linked to SAV restoration (Cerco and Moore 2001, Gallegos 2001) and is frequently the focus of SAV restoration efforts.

Submerged aquatic vegetation cover decreases as water depth increases (Penfound and Hathaway 1938, Hunter 2000), and the establishment of many species of SAV is controlled by turbidity and water depth (Penfound and Hathaway 1938, Joanen and Glasgow 1965). Rates of photosynthesis decrease as water depth increases, but the reduced photosynthetic rate does not decrease as rapidly as the decrease in light intensity

(Meyer et al. 1943). Established vegetation reduces turbidity by reducing underwater energy, but high water levels decrease effectiveness of vegetation to reduce turbidity (Ward et al. 1984).

In addition to turbidity, high salinities inhibit growth of many SAV species. Seed germination and plant growth of widgeon-grass (*Ruppia maritima* L.) is inhibited by high salinities (Joanen and Glasgow 1965, Mayer and Low 1970, Palmisano 1971). Thus, canals and other features that increase salinities need to be reduced if SAV is to become well established on some sites. The sensitivity of SAV to salinity changes can be used to establish minimum and maximum freshwater inflows for restoration in some systems (Doering et al. 2002).

To establish SAV where absent but where water depth and salinity are suitable, viable seeds must be present in the seed bank, or plant fragments must be present in water entering the site. If viable seeds or vegetative propagules are unavailable, then planting of site suitable species of SAV will be needed. Planting makes marsh restoration much more expensive. In some areas waterfowl herbivory limits SAV planting success unless plantings are protected until establishment (Hammerstrom et al. 1998, Harwell and Orth 1999).

In the past, numerous marsh restoration techniques have been proposed and applied: vegetative plantings, fences and barriers, weirs, impoundments, canal plugs, redistribution of dredge and slurry material, and herbivore control (Turner 1998). A common goal for marsh remediation techniques is establishment and promotion of emergent vegetation and SAV. Traditional vegetative planting is a viable option in many situations, but many SAV species do not propagate well when planted. A 47% planting

unit loss of planted seagrass was observed in Tampa Bay, Florida (Fonseca et al. 1996). Therefore, vegetative plantings are not a panacea and will not work in all restoration situations. Fences and barriers are effective at disrupting wave energy, but some require frequent maintenance.

Marsh terraces and coconut mats are two relatively new marsh restoration techniques that have not been fully evaluated. Marsh terraces have been touted as relatively cheap and permanent (Turner 1998). Terraces consist of sediment dug from a pond and placed in a row in the pond to an elevation of approximately 60 to 100 cm above mean water level. Terraces are expected to (1) create emergent wetlands, (2) slow erosion of adjacent natural marsh, (3) increase the abundance of SAV, and (4) perhaps initiate growth of emergent vegetation in shallow open water by reducing wave fetch (Boesch et al. 1994).

The expected impacts of marsh terraces on emergent vegetation stem from the impacts terraces have on the two of three controlling factors, but then again, terraces should create some inter-tidal areas suitable for emergent vegetation. The terraces bring seeds inundated on the marsh pond bottom to the inter-tidal terrace surface which should promote seed germination and subsequent vegetative propagation. Emergent vegetation that establishes on terraces should also produce seeds that would be available for waterfowl foraging in waters adjacent to terraces.

One goal of restoration is to increase the habitat value for fish and wildlife because many SAV seeds and plants are important foods for several waterfowl species wintering in Southwest Louisiana (Chamberlain 1959), and because winter habitat quality may influence subsequent breeding population size in ducks (Raveling and Heitmeyer

1989, Cox and Afton 1997). In particular, SAV is important to the diet of Gadwall (*Anas strepera*) in Louisiana (Paulus 1982). A decline in migrating waterfowl populations in the Chesapeake Bay during the early 1980's showed a strong correlation with decreases in SAV distribution (Kemp et al. 1984).

Marsh terraces are also thought to positively impact SAV by affecting the two controlling factors of light availability and seed and vegetative propagule availability. Turbidity should be reduced because wave energy in the environment is reduced. Terrace impacts on seeds and other vegetative propagules of SAV should be minimal because seeds and propagules should be recruited from surrounding areas.

The effectiveness of terraces at promoting SAV abundance has been evaluated only once (see Steyer 1993). In that study, SAV was planted and percent survival was determined over one three-month period (June 1991 thru August 1991) in 2 terraced ponds and 1 non-terraced pond. The survival rate for SAV was low, attributed to low water clarity and retention of suspended sediments. Steyer's data failed to demonstrate an effect of terraces on SAV, yet terraces are generally anticipated to increase SAV abundance (Nyman, Louisiana State University, personal communication). If terraces are observed to be less effective than previously thought, mitigation and restoration funding may be used more efficiently in other marsh restoration techniques.

Rozas and Minello (2001) evaluated the effects of terraces on fish using the same terraces as Steyer (1993). Terrace fields supported higher standing crops of most fishery species than natural marsh ponds of similar size; however, the fish community in terraced ponds was not equivalent to natural marsh at Sabine NWR (Rozas and Minello 2001).

Submerged coconut mats are woven mats of coconut tree fiber anchored to the marsh bottom. Mats may serve as a substrate for SAV establishment in areas where marsh damage has removed natural substrate layers. The mats are relatively inexpensive; ours cost $500 for a 2 m by 50 m roll, and may be used alone or in conjunction with terraces or other structures.

Coconut mats are used to restore upland grasses in small disturbed areas, and have been tested as a tool for increasing SAV abundance (see Boustany 2000). The logical impacts of submerged coconut mats on SAV are similar to the impacts of terraces. Submerged coconut mats are hypothesized to decrease turbidity by holding down loose sediments and protecting SAV from wave disturbance. The mats are not anticipated to impact salinity. Submerged aquatic vegetation seeds and propagules available in the restoration area should colonize coconut mats, because they potentially provide better substrate, as observed by Boustany (2000).

I conducted a field experiment to determine the effects of terraces and submerged coconut mats on SAV and seeds. I also conducted a greenhouse experiment to compare the effects of flooding, salinity, and shading on germination of the most common seed in marsh ponds where terraces were constructed. I was interested in SAV because it provides food for wintering waterfowl, and because it’s predicted response to terraces is one reason that terraces are currently a popular restoration tool. I was interested in seeds because they provide food for waterfowl and because they are essential when restoration planners restore suitable environmental conditions and rely upon natural recruitment to restore desired vegetation.

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# Chapter 1: Do Terraces and Coconut Matting Affect Submerged Aquatic Vegetation Associations on Unit 7 of Sabine National Wildlife Refuge?

Many Louisiana coastal marshes have converted to open water over the last fifty years. Several techniques have been proposed to slow or reverse this loss (see Boesch et al. 1994). Terraces consist of sediment dug from a pond and placed in a row in the pond to an elevation of approximately 60 to 100 cm above mean water level. Terraces are intended to (1) slow erosion of adjacent marsh, (2) increase the abundance of Submerged Aquatic Vegetation (SAV) in the adjacent pond, and (3) initiate growth of emergent vegetation on the terraces and in adjacent shallow open water (Boesch et al. 1994). Terraces have become a common restoration technique in recent years and have been installed in a diverse array of locations including two coastal wetlands planning, protection, and restoration act (CWPPRA) authorized projects in construction. The wetland value assessment (WVA) community models, used in the process to rank CWPPRA projects for funding, weigh aquatic vegetation heavily. Aquatic vegetation is weighted heavily in the model because SAV provides food and cover to fish and wildlife (EWG 1998). Terraces are generally assumed to positively impact SAV and other aquatic vegetation when applying the WVA (Nyman, Louisiana State University, personal communication).

The effect of terraces on SAV was evaluated once before (Steyer 1993). In the Steyer (1993) study, SAV was planted adjacent to those terraces, and percent survival was determined over the subsequent three-months. SAV survival was higher in the non-terraced pond than in the ponds where terraces were constructed.

Coconut mats might provide another method of increasing SAV abundance. Coconut mats also are relatively untested, but may serve as a substrate for SAV establishment in areas with suitable water salinity and light availability but where substrate is unsuitable. In order for coconut matting techniques to be effective, vegetative components of the marsh must be restored from either the seed bank or vegetative plantings. The mats are relatively inexpensive and could be used in conjunction with terraces or other structures.

The effects of coconut mats on SAV were studied once before (Boustany 2000). Boustany (2000) found that coconut mats at Cameron Prairie National Wildlife Refuge (NWR) were an effective way of increasing SAV abundance. The invasive species, water-milfoil (*Myriophyllum spicatum* L.), was the primary species to occur on the mats, though it was not one of the species pre-vegetated on the mats.

The objectives of this study were to determine the effectiveness of terracing and submerged coconut mats at increasing the abundance of SAV and seeds. The assumption that terraces increase SAV has never been substantiated. The information this project yielded should be considered in the appropriation of funds for coastal wetland restoration and provide information on the factors limiting SAV in coastal Louisiana.

## Study Area

My study took place on Unit 7 of Sabine National Wildlife Refuge (29°52’26”N, 93°43’58”W) in southwest Louisiana (Figure 1). Between 1956 and 1978, much of this area converted to open water from a marsh dominated by sawgrass (*Cladium jamaicense* Crantz) (Valentine 1978, O’Neil 1949). The study area was classified as intermediate

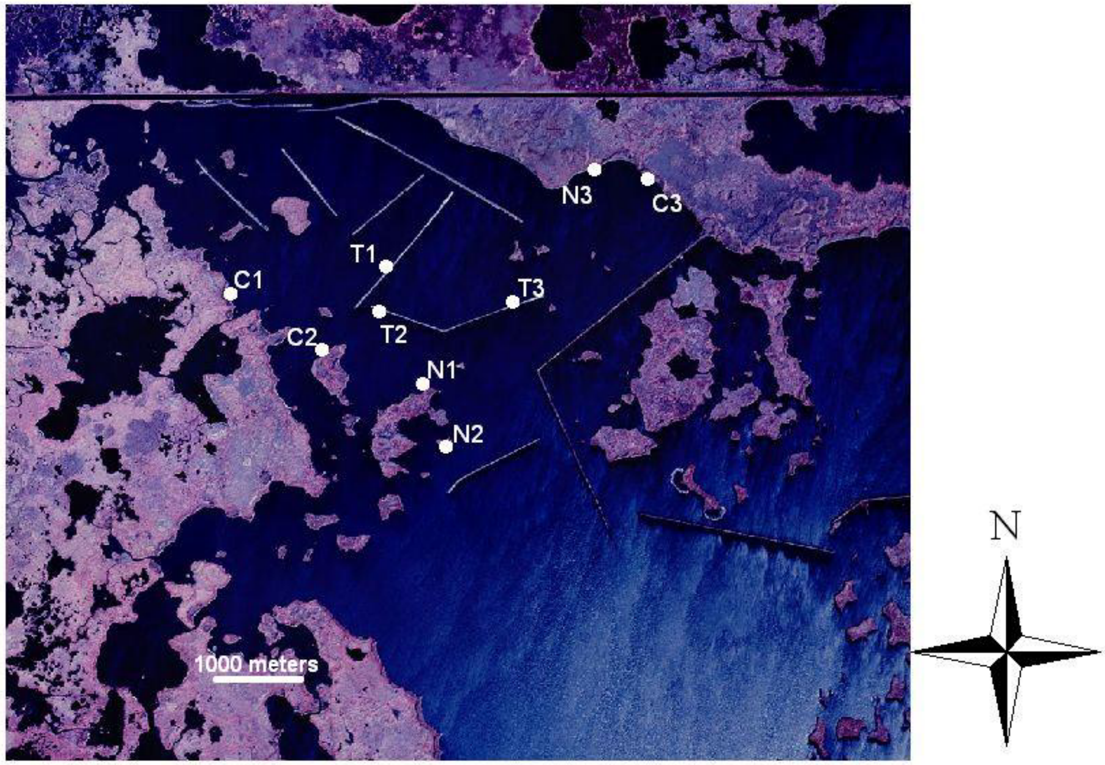


**Figure 1**: Photo of the study area in Unit 7 of Sabine NWR, Louisiana. Points denote shorelines from which transects project. C transects are coconut mat transects, N transects are natural marsh transects, and T transects are terrace transects. For the terraces, the side the label occurs is the side of the terrace the transect projects from.

and brackish marsh on vegetative type maps made between 1949 and 1997 (Chabreck et al. 1998). Terraces were constructed in the open water areas in 1997, 1998, 1999, and 2000; however I examined only the 1999 terraces. The terraces were approximately 3-m wide. I selected marsh transects in the area from shoreline adjacent to the 1999 terraces. The substrate on the terrace sites was largely unconsolidated clay, while the natural marsh and coconut mat transect's substrates were detritus and organic clays (Bush 2003). Emergent vegetation occurred along all shorelines (marsh and terraces) in Unit 7. During my study, major emergent species on adjacent marsh were sawgrass, phragmites (*Phragmites australis* (Cav.) Trin. ex Steud.), Olney three-square (*Schoenoplectus americanus* (Pers.) Volk), wiregrass (*Spartina patens* (Ait.) Muhl.), and smooth cordgrass (*Spartina alterniflora* Loisel.).

## Methods

### Field Procedures

I randomly selected three terrace transects, three coconut mat transects, and three marsh transects. The transects were selected by assigning numbers to shoreline areas and selecting them using a random number generator. Each transect had three stations: (1) one at the edge of the emergent vegetation (0 m), (2) one five meters from the edge of the emergent vegetation, and (3) one fifty meters from the edge of the emergent vegetation. I assumed that the 50 m station was far enough from the emergent vegetation to be free of any edge effect. Emergent vegetation was defined as vegetation which protrudes above the mean water level (such as wiregrass or smooth cordgrass). Biomass as well as percent occurrence of SAV was estimated because neither is effective at estimating SAV

abundance across the range of SAV abundance common to Louisiana coastal marshes (Hunter 2000).

I measured biomass of SAV at each station except coconut mat stations via two techniques: cores and 1-$m^2$ plots (Ellison et al. 1986). I collected cores at all terrace and marsh stations five times: September 2001, December 2001, February 2002, May 2002, and September 2002. All material retained by a 0.5 mm sieve were stored on ice and returned to the lab. Biomass of seeds and SAV were determined in the lab. On all transects, SAV was collected from 1-$m^2$ plots, sampled by Bush (2003) in her study of fish at these sites, as another estimator of SAV biomass. Those 1-$m^2$ plots were sampled at 0 m and 50 m, but not 5 m stations and were not made during the first visit in September 2001.

I measured percent occurrence of SAV using the rake method (Nyman and Chabreck 1996) at 5 and 50 m stations on terrace and marsh transects at each station. A rake was dropped to the pond bottom, dragged, and raised at twenty stations per transect parallel to the marsh edge. Percent occurrence of total SAV and each species of SAV was calculated from the number of stations containing SAV and the total number of stations on the transect. I measured salinity and depth (± 1 cm) on all transects at 0, 5, and 50 meters during sampling trips in September 2001, December 2001, February 2002, and May 2002. Salinity was measured using a YSI model 63 (YSI Incorporated, 1725 Brannum Lane, Yellow Springs, OH 45387 USA). Depth was estimated to the nearest centimeter as part of the coring process. Light availability data was obtained using a secchi disk.

**Lab Procedures**

In the lab, cores were washed through a series of sieves with openings of 12.50 mm, 2.00 mm, 1.400 mm, 0.710 mm, and 0.500 mm respectively, with care being taken to remove all green, living plant material. The plant material was identified, sorted taxonomically, and placed by taxa into foil envelopes that were pre-weighed, recorded, and labeled. The foil envelopes and plant material were weighed together immediately. The foil envelopes with green plant material taken from the cores and 1-$m^2$ plots were placed in a drying oven for seven days at 65°C to achieve a constant weight (± 1 mg). To estimate SAV biomass, the dry material was then weighed and the value recorded.

Once the green plant material was removed, the material retained in each sieve was placed in pre-labeled bags by sieve. The sieved material was oven dried for seven days at 65°C, to achieve a constant weight, and the seeds were separated from debris using a seed blower and hand sorted with the aid of 70x power dissection microscopes (Jemison and Chabreck 1962). The seeds were then separated taxonomically and weighed. Five "subsamples" of seeds were taken for each taxa, weighed, and counted. Using these values a mean weight per seed was determined and this was multiplied by the mean seed weights to estimate seed numbers for comparison with other studies.

**Statistical Analysis**

Data were analyzed to answer the question: Do terraces support a SAV and seed community similar to the marsh or similar to the open water? Seed biomass, SAV percent occurrence (rake), SAV biomass (core), and SAV biomass (1-$m^2$ plot) were the response variables.

The response variables were compared among treatments with a randomization technique (Edington 1995) rather than with standard parametric statistics because the variance of the data was neither heterogeneous nor normally distributed. Randomization tests do not require random sampling or normally distributed data (Edington 1995). Randomization tests are extremely accurate; they are the benchmark against which parametric tests are compared when deciding if a parametric test is robust or not (Edington 1995). An ANOVA model was used to test the randomized variables. There were two factors, treatment and distance, with replication and repeated measures. Factors in the main plot were among treatments (TERRACE, MAT, and MARSH), distances (0 meters, 5 meters, and 50 meters), treatment X distance and replication transects (treatment X distance). Factors in the split plot were between sampling date, date X treatment, date X distance, and date X treatment X distance. Pond water salinity, water depth, and secchi depth were used as explanatory co-variables in the model. The addition of the co-variables in the model meant that 46 of 90 core observations, 70 of 96 1-$m^2$ plot observations, 46 of 60 of the percent occurrence observations, and 46 of 90 seed core observations were included in the model. The missing observations are due to missing data and the lack of 5 meter station data for secchi depth in the co-variable data set. The models using the co-variables had higher coefficients of variation than the models without the co-variables. The Type III sums of squares of the real data were selected as our test statistic. All treatment combinations were randomly re-assigned to the observed data and the test statistic was re-calculated 4,999 times. If the null hypothesis of no treatment effect was true, then the test statistic derived from the observed combination would rarely be exceeded by the randomly combined data. We used an alpha level of

0.05. Linear correlation procedures were run to test for associations among the vegetation species observed. SAS software (SAS Institute Inc. 1999) was used for all calculations and randomizations.

## Results

### Submerged Aquatic Vegetation

Eight species of SAV were observed: widgeon-grass (*Ruppia maritima* L.), eurasian milfoil (*Myriophyllum spicatum* L.), hornwort (*Ceratophyllum demersum* L.), najas (*Najas guadalupensis* (Spreng.) Magnus), lesser-pondweed (*Potamogeton pusillus* L.), nitella (*Nitella sp*.), chara (*Chara sp.*), and an unidentified species. Major vegetation species; i.e., those making up more that ten percent of SAV biomass or percent occurrence sampled, were correlated ($p>0.05$) regardless of the method used to estimate abundance.

Only three of the 90 cores contained SAV. All of the cores containing SAV were from the natural marsh transects. Biomass measured using the core method differed only among treatments ($p=0.0001$) (Table 1). The core biomass averaged $16\pm14$ g $m^{-2}$ (mean $\pm$ SE) on natural marsh transects and 0 g $m^{-2}$ on terrace transects.

Only 35 of the 96 1-$m^2$ plots contained SAV. Significant differences were found between treatments ($p=0.0001$) and sampling periods ($p=0.0001$) (Table 2). Biomass on the coconut mats averaged $2.2\pm0.7$ g $m^{-2}$ which was greater than on marsh ($0.9\pm0.8$ g $m^{-2}$) and terraces ($0.5\pm0.8$ g $m^{-2}$). During the September 2002 sampling period, marsh SAV biomass was $4.8\pm0.9$ g $m^{-2}$ which was greater than $0\pm0.8$ g $m^{-2}$ for all other treatment/sampling period combinations (Figure 2).

**Table 1**: Probability values from statistical tests on the submerged aquatic vegetation biomasses estimated with cores. The abbreviations used in the table are as follows: degrees of freedom (df), parametric ANOVA (parametric), and non-parametric randomization (resample).

| Source | df | Parametric | Resample |
|---|---|---|---|
| Treatment | 1 | 0.9102 | 0.0001 |
| Distance | 1 | 0.7475 | 0.1310 |
| Treatment*Distance | 2 | 0.5181 | 0.9730 |
| Sample(Treatment*Distance) | 12 | 0.4867 | 0.5165 |
| Sampling Period | 4 | 0.3014 | 0.4313 |
| Sampling Period*Treatment | 6 | 0.3300 | 0.1578 |
| Sampling Period*Distance | 4 | 0.5318 | 0.6633 |
| Sampling Period*Treatment*Distance | 6 | 0.4870 | 0.4685 |
| Salinity | 1 | 0.2087 | |
| Depth | 1 | 0.8072 | |
| Secchi | 1 | 0.5110 | |

**Table 2**: Probability values from statistical tests on the submerged aquatic vegetation biomasses estimated with 1-$m^2$ plots. The abbreviations used in the table are as follows: degrees of freedom (df), parametric ANOVA (parametric), and non-parametric randomization (resample).

| Source | df | Parametric | Resample |
|---|---|---|---|
| Treatment | 2 | 0.3620 | 0.0001 |
| Distance | 1 | 0.4225 | 0.6439 |
| Treatment*Distance | 2 | 0.2896 | 0.3965 |
| Sample(Treatment*Distance) | 12 | 0.4495 | 0.5823 |
| Sampling Period | 4 | 0.6719 | 0.0001 |
| Sampling Period*Treatment | 6 | 0.4478 | 0.2707 |
| Sampling Period*Distance | 4 | 0.2664 | 0.4263 |
| Sampling Period*Treatment*Distance | 6 | 0.1378 | 0.2527 |
| Salinity | 1 | 0.3668 | |
| Depth | 1 | 0.9041 | |
| Secchi | 1 | 0.1233 | |

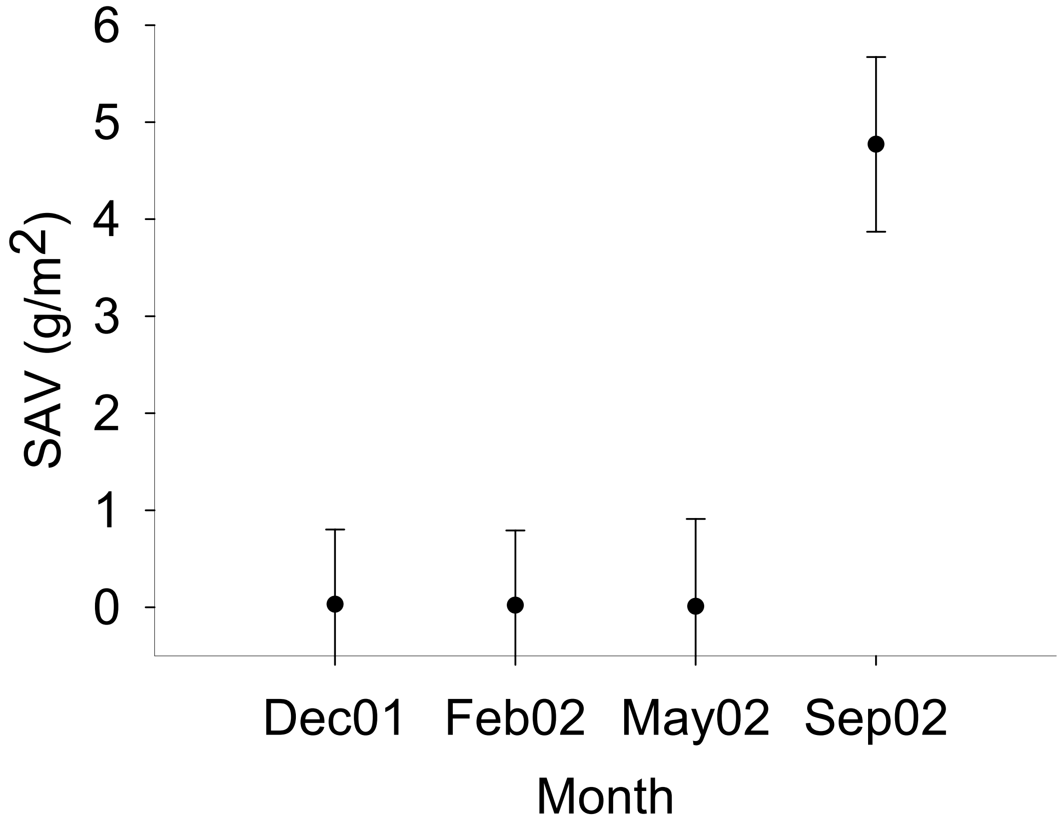


**Figure 2**: Submerged aquatic vegetation biomass (LS means and LS standard errors) estimated by the 1-$m^2$ plot method by sampling period. Submerged aquatic vegetation biomass was greater during September 2002 (p=0.0001).

Submerged aquatic vegetation occurred in 12 of the 60 transects. Percent occurrence differed among the sampling period by treatment combinations ($p=0.0001$) and with distance from emergent vegetation ($p=0.0001$) (Table 3). During September 2002, SAV percent occurrence on the marsh transects was 42±14%, which was greater than on the terrace transects (9±4%). At all other sampling periods, SAV percent occurrence did not differ between marsh transects and terrace transects (Figure 3). The SAV percent occurrence 5 m from the emergent edge was 9±4%, which was greater than the SAV percent occurrence at 50 m from the emergent edge: 4±2%.

**Seeds**

Seeds were found in all of the cores. The seeds were dominated by sawgrass and bulrush (*Scirpus sp.*) (Table 4). Both major vegetation species, each making up more that ten percent of the seed biomass, were correlated ($p>0.05$). Neither of these major species were SAV. There was a significant difference between seed biomasses estimated 0 meters from the emergent edge of the terrace treatments and the seed biomasses estimated at all other distance treatment combinations ($p=0.0001$) (Table 5). Seed biomass on all sampling period by treatment combinations averaged 1.93±1.16 g $m^{-2}$ except terrace 0 meters which averaged 0.05±0.02 g $m^{-2}$. The mean seed density for each treatment was 331,185±1,328,766 seeds $m^{-2}$ adjacent to natural marsh and 5,034±36,027 seeds $m^{-2}$ adjacent to the terraces. The natural marsh and terrace seed densities are both similar to those found in other tidal marsh studies (Table 6). The mean water depth covering these seeds was 54±3 cm on the natural marsh pond transects, 61±1 cm on terrace transects and 44±2 cm on coconut mat transects.

**Table 3**: Probability values from statistical tests on the submerged aquatic vegetation percent occurrence estimated with the rake method. The abbreviations used in the table are as follows: degrees of freedom (df), parametric ANOVA (parametric), and non-parametric randomization (resample).

| Source | df | Parametric | Resample |
|---|---|---|---|
| Treatment | 1 | 0.5773 | 0.0001 |
| Distance | 1 | 0.5696 | 0.0001 |
| Treatment*Distance | 1 | 0.0922 | 0.1168 |
| Sample(Treatment*Distance) | 8 | 0.8658 | 0.9478 |
| Sampling Period | 3 | 0.0007 | 0.0211 |
| Sampling Period*Treatment | 3 | 0.0118 | 0.0001 |
| Sampling Period*Distance | 3 | 0.5842 | 0.9104 |
| Sampling Period*Treatment*Distance | 3 | 0.4120 | 0.7407 |
| Salinity | 1 | 0.0023 | |
| Depth | 1 | 0.6568 | |
| Secchi | 1 | 0.3572 | |

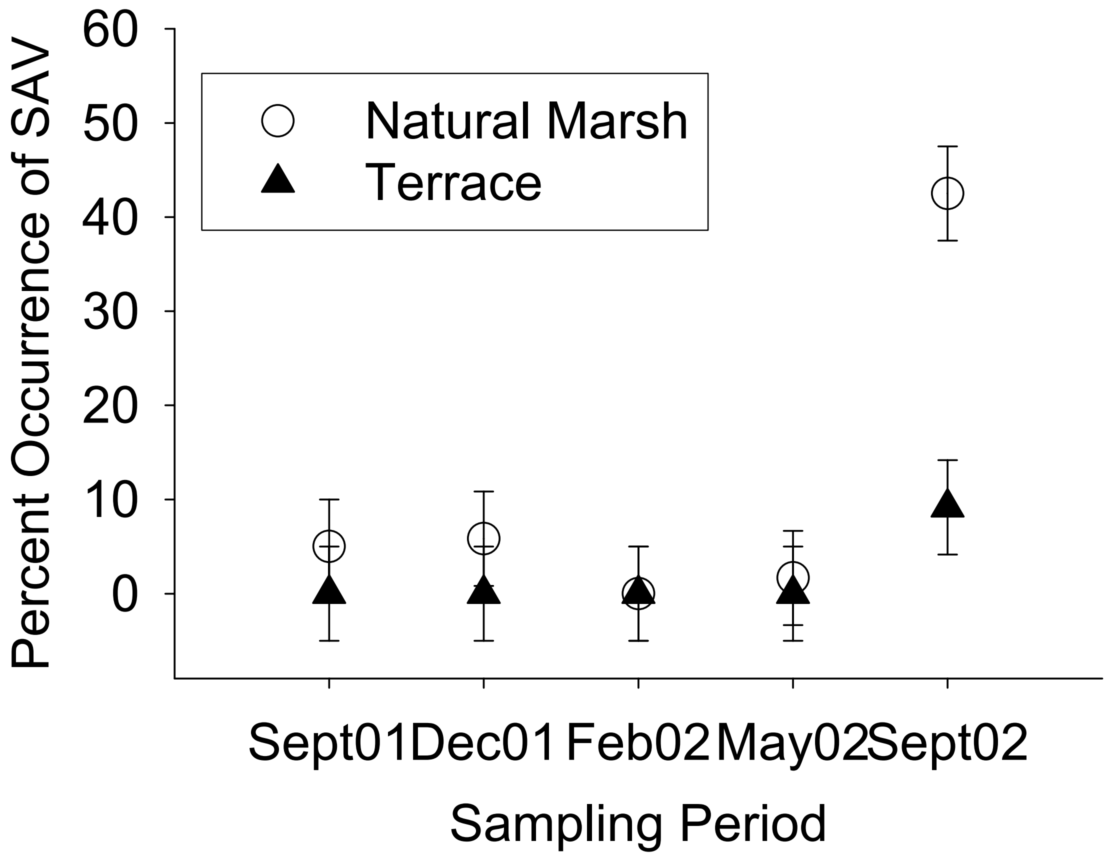


**Figure 3**: Submerged aquatic vegetation percent occurrence (LS means and LS standard errors) estimated by the rake method by treatment and sampling period. Submerged aquatic vegetation percent occurrence was greater on control stations than on terrace stations during September 2002 (p=0.0001).

**Table 4:** The percentage of total seed biomass found by taxonomic group and treatment (Mean ± SE).

| Taxa | Natural Marsh | | Terraced Marsh | |
|---|---|---|---|---|
| | Mean Seed Biomass ($g\ m^{-2}$) | Mean Percent Biomass | Mean Seed Biomass ($g\ m^{-2}$) | Mean Percent Biomass |
| *Cladium jamaicense* | 387.2 ± 1476.6 | 90 ± 2 | 5.2 ± 7.2 | 84 ± 3 |
| *Scirpus sp.* | 20.3 ± 102.8 | 10 ± 2 | 0.5 ± 0.6 | 12 ± 2 |
| *Polygonum sp.* | 1.8 ± 10.3 | 0 ± 0 | 0.0 ± 0.1 | 0 ± 0 |
| *Myriophylum sp.* | 2.2 ± 11.0 | 0 ± 0 | 0.0 ± 0.2 | 0 ± 0 |
| All Other Species | 0.1 ± 0.5 | 0 ± 0 | 0.1 ± 0.3 | 4 ± 2 |

**Table 5**: Probability values from the statistical test on the seed biomasses estimated with the core. The abbreviations used in the table are as follows: degrees of freedom (df), parametric ANOVA (parametric), and non-parametric randomization (resample).

| Source | df | Parametric | Resample |
|---|---|---|---|
| Treatment | 1 | 0.6758 | 0.0001 |
| Distance | 1 | 0.6965 | 0.1738 |
| Treatment*Distance | 2 | 0.2649 | 0.0001 |
| Sample(Treatment*Distance) | 12 | 0.7578 | 0.7215 |
| Sampling Period | 4 | 0.8856 | 0.0954 |
| Sampling Period*Treatment | 6 | 0.6953 | 0.3653 |
| Sampling Period*Distance | 4 | 0.7211 | 0.6835 |
| Sampling Period*Treatment*Distance | 6 | 0.5968 | 0.4997 |
| Salinity | 1 | 0.8727 | |
| Depth | 1 | 0.5114 | |
| Secchi | 1 | 0.3921 | |

**Table 6**: Seed densities of several tidal marshes and the study area adapted from Leck (1989).

| Wetland | Density ($m^{-2}$) | Range ($m^{-2}$) | Location | Reference |
|---|---|---|---|---|
| Sabine Unit 7 | | | | |
| Natural Marsh | 331,185 | 415-8,783,800 | Louisiana | |
| Terrace | 5,034 | 0-36,357 | Louisiana | |
| | | | | |
| Tidal marshes | | | | |
| Fresh | 9,293 | 1620-13,670 | New Jersey | Leck and Graveline (1979) |
| | 2,430 | 1645-3620 | New Jersey | Parker and Leck (1985) |
| | 26,957 | 14,805-41,010 | New Jersey | Leck and Simpson (1987) |
| Salt | 708 | 63-1,375 | California | Hopkins and Parker (1984) |

## Discussion

Conversion of emergent marsh to open water as seen on the study area and many areas of the Louisiana coast is the primary reason for restoration projects. Many of these projects are anticipated to increase SAV but are directed primarily at restoring emergent vegetation rather than SAV. This is different than other regions where SAV is being restored, such as Chesapeake Bay. Many restoration projects in Louisiana are attempting to establish SAV in areas formerly occupied by emergent vegetation but elsewhere, SAV restoration is attempting to re-establish SAV where it formerly occurred. In Louisiana and elsewhere, insufficient water clarity is believed to limit SAV abundance but in other areas along the Gulf of Mexico, the Atlantic coast of North America, and Western Europe SAV is frequently lost due to poor water clarity and urban development (Stevenson et al. 1993, Hammerstrom et al. 1998, Cerco and Moore 2001, Gallegos 2001, Rybicki et al. 2001 and, Doering et al. 2002). In Louisiana however, re-suspension of solids is believed to decrease water clarity, and hence, terraces are being used to reduce wave energy. Herbivory and seed predation are often cited to be major obstacles to restoration of SAV (Hammerstrom et al. 1998 and Harwell and Orth 1999), but those factors have not yet been addressed in coastal Louisiana.

Compared to other Gulf coast sites, my study area averaged lower SAV biomass and percent occurrence. In a study by Adair et al. (1994) at Trinity Bay, an oligohaline bay on the Texas Gulf coast, SAV biomass averaged 82 g $m^{-2}$ which is much higher than the average I observed (1 g $m^{-2}$). At Trinity Bay, mean najas and widgeon-grass occurrence was 22.0% and 28.0%, respectively (Adair et al. 1994). On my marsh sites, the mean percent occurrence of najas and widgeon-grass was 4% and <1%, respectively.

Trinity Bay is located near the delta of the Trinity River and is closer to the Gulf of Mexico than our study sites; therefore nutrient inflows may be higher, or turbidity lower.

Hunter (2000) concluded that SAV abundance in Gulf Coast marshes usually is less abundant than in other regions and the SAV abundance that I observed were even lower than elsewhere on the Gulf Coast. Occurrence of SAV in non-managed marshes at Marsh Island, Louisiana averaged 13% between October 1958 and October 1988 (Nyman and Chabreck 1996). Hunter (2000) found SAV and algae occurrence to vary between months by as much as 80% cover during the time period from October 1998 through May 2000. A doubling of SAV abundance in September 2002 as compared to the means seen in previous sampling periods therefore agreed with previous observations of SAV variability in coastal Louisiana (Hunter 2000).

Due to the variability in SAV abundance anticipated at my study area, a suite of SAV estimation techniques was used. The core method detected a treatment effect. The 1-$m^2$ plots detected a treatment and a sampling period effect. The rake method worked best on these low density sites and detected differences in SAV percent occurrence between the terrace and marsh transects on one sampling date and effects of distance from the edge of emergent vegetation. Percent occurrence was a more suitable method to observe SAV due to the patchy occurrence of the vegetation, had the vegetation been more evenly distributed across the transects then the biomass measures would have been more effective.

In this study I sampled biomass, both the cores and 1-$m^2$ plots, of all plants within the upward projection of the sampling device. This method has been used in other studies (Nyman, Louisiana State University, personal communication, Hunter 2000,

Donnermeyer and Smart 1985). However, some studies have chosen to sample only vegetation material rooted within their sampling devices (Nyman, Louisiana State University, personal communication, Anderson and Kalff 1986, Downing and Anderson 1985).

Although the cores were the least effective SAV estimation method used in this study, I detected a significant treatment effect. SAV biomass near the natural marsh averaged 1.5 times more SAV biomass than near terraces. This effect and the absence of a distance effect suggest that terraces did not increase SAV biomass even when compared to open water.

The 1-$m^2$ plot also found a treatment effect, but not the same effect as the cores. No difference was detected between the terrace and natural marsh transects, however a two fold increase on the coconut mats was detected. The increase in SAV may be attributed to the mats providing a substrate which protected seedlings from wave action better than the natural substrate. The mats may have reduced turbidity thereby increasing light availability to SAV. The 1-$m^2$ plot was the only method used to estimate SAV on the coconut mats.

My percent occurrence estimates indicated that when SAV occurrence was low, there was no significant difference in SAV occurrence between the terrace and the marsh. When SAV was abundant in September 2002, I found that SAV percent occurrence was significantly higher on marsh transects than on terrace transects. Steyer (1993) also found that SAV abundance was lower in waters adjacent to terraces than near marsh. I detected higher percent occurrence near edge (9±4%) than in open water (4±2%) transects, which suggests that there is an edge effect of terraces and natural marsh that was not evident

with either of the biomass harvest methods. I conclude that the edge effect detected on the area was not ecologically significant because (1) it was only detected by my occurrence estimate method, and (2) the difference was less than 5% occurrence. None of the biomass estimation techniques found a significant distance effect or interaction.

Considering the results of all three SAV estimation techniques together indicated that the terraces did not increase SAV abundance in adjacent waters. The lack of a SAV increase near terraces means that either the terraces failed to decrease turbidity or disturbance by waves, or that those factors were not limiting to SAV during this study. If turbidity was limiting, then terraces failed to reduce turbidity as terrace designers anticipated. If wave action is limiting, then terraces failed to reduce wave action as terrace designers anticipated. If neither of the previous factors were limiting SAV then a third unknown factor such as lack of propagules or unsuited rooting conditions must be limiting SAV. However, this study was unable to determine the limiting factor.

The coconut mats increased SAV biomass. My results are not different from those of Boustany (2000). He observed that wild celery (*Vallisneria americana* Michx) did not increase on pre-vegetated coconut mats, but he noticed that water-milfoil invaded his mats and became more abundant than in areas lacking mats. Pre-vegetated species were not as well adapted for the habitat provided by the coconut mats as the milfoil which colonized them. Having no biomass on the mats to begin the experiment allowed me to observe milfoil move in without the competition of the less suitable species. The increase in biomass may be attributed to the mats providing a substrate which protected seedlings from wave action better than the natural substrate. The mats may have reduced turbidity thereby increasing light availability to SAV. Alternatively, the mats may have

provided a better substrate for rooting than the natural marsh substrate. Water-milfoil biomass on the mats may have increased due to reduced turbidity, reduced wave energy reaching the pond bottom, and/or better substrate for rooting.

The seed biomass estimates lead me to conclude that there were fewer seeds near the terrace than elsewhere. One explanation considered was seed predation; however, this was eliminated because the water depth found in the area discourages waterfowl use of any seeds. Dabbling ducks generally select areas with water depths of 5 to 25 cm for foraging, and many other wetland wildlife species select habitat within this range (Fredrickson and Taylor 1982). The mean depth on the site is twice as deep as the deepest depth recommended for dabbling ducks.

Once seed predation was eliminated, seed burial during terrace construction was probable. The construction of the terraces probably covered most of the seeds with deeper soils devoid of seeds. Most tidal marsh studies sample only seeds buried 10 cm deep or less (Leck 1989) and approximately 90% of seeds observed in a heathland can be found in the upper 4 cm of soil (Putwain and Gillham 1990). Apparently terraces have not created habitat for annual vegetation that could create a new seed source. The seeds detected were dominated by emergent vegetation, but those seeds were old and most likely not able to germinate (discussed further in chapter 2).

## Management Implications

On this particular area in unit 7 of Sabine NWR, terraces were ineffective at increasing SAV abundance. Increasing SAV abundance should not be a justification for terrace construction. Wetland value assessment (WVA) models should not predict an increase in SAV after terraces are constructed. This change might cause funds to be

appropriated for restoration techniques other than terraces. Coconut mats increased SAV biomass but it was unclear if the increase was ecologically significant and should be researched further.

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# Chapter 2: Does Salinity and Shading Affect Sawgrass (*Cladium jamaciense* Crantz) Seed Germination?

Much of southwest Louisiana's fresh water marsh was dominated by sawgrass (*Cladium jamaicense* Crantz) in the 1950s (Valentine 1978, O'Neil 1949). Between 1956 and 1978 many areas formerly dominated by sawgrass converted to open water. Despite this change, many sawgrass seeds can still be found in the marsh seed bank (see chapter 1). The viability of these seeds is unknown. Several studies have succeeded in germinating sawgrass seeds from the Everglades in Florida (Lorenzen et al. 2000, Ponzio et al. 1995, Ponzio 1998). Ponzio (1998) found that seed germination varies between sawgrass populations. Ponzio (1998) used fresh seeds collected from plants rather than seeds collected from soil. Sawgrass seeds collected from submerged sediments may have different germination characteristics than fresh seeds or older seeds collected from emergent or intermittently flooded sediments. Seeds can germinate even when completely inundated by deep or shallow water (Ponzio et al. 1995). Events that cause drying of pond bottom sediments, such as drought and artificial drawdown also may affect germination.

Two factors that cause germination rates to vary are salinity and light availability. Human activities that impact salinity are channelization and freshwater diversion. Activities that affect light availability are marsh burning and natural and managed drainage. The effect of a combination of salinity treatments and light availability treatments on sawgrass seed germination has never been tested. The objective of this study was to determine if germination of sawgrass seeds from unit 7 of Sabine National Wildlife Refuge (NWR) varies with salinity, light, and water level adjustment.

## Methods

I conducted a study of sawgrass seed germination as affected by salinity, light, and water level in a greenhouse at LSU using seeds collected from Unit 7 of Sabine NWR (29°52'26"N, 93°43'58"W). I collected seeds from submerged sediments in May 2002 with a 10 cm diameter PVC coring tube to a depth of 20 cm. The water depth averaged 53 cm. Major emergent and submerged aquatic vegetation species in the area were described in Chapter 1.

Upon return to the lab, cores were refrigerated one week until they could be washed and sieved. I collected sawgrass seeds by hand under a 70x dissection microscope and placed them in glass Petri dishes. Eighteen 38 liter plastic bins were filled with water. Three sets of six bins were set at 0 ppt, 12 ppt, and 24 ppt, respectively, using Marine mix sea salt. I used a wide range of salinity and light reduction in the experiment because seed germination ecology differs between populations (Ponzio 1998) and because salinity and light availability vary greatly in coastal marshes. These methods were variations of those used in Ponzio et al. (1995), Baldwin et al. (1996), and Ponzio (1998). Two bins out of each salinity treatment were covered in 40% and 80% light level reduction cloths; two bins of each salinity treatment were left unshaded. Petri dishes containing fifteen seeds were covered with sand. Sand was used to keep the seeds from floating around the bins. Four Petri dishes were submerged in each of the plastic bins. Bins were monitored for seed germination three days a week for four weeks (June 1, 2002 to July 1, 2002). The salinity treatments used in this experiment do not simulate collection area conditions, but reflect speculated historic salinities at this site and have been observed at Marsh Island, Louisiana, which is also dominated by wiregrass

(*Spartina patens* (Ait.) Muhl.) (Nyman, Louisiana State University, personal communication). The light availability on the collection site was not quantified, so a wide range of light availability treatments was chosen.

After thirty days submerged in water the sand and seeds were transferred to humus filled 266-ml plastic cups with holes through which water could interchange between the cup and bin. Water levels were lowered to a point, approximately 1 cm to 3 cm below the soil surface, where the soil in the cups is moist in order to mimic natural drought and managed drawdown conditions that can completely drain marsh ponds, and exposure of seeds placed on terraces. Bins were monitored for seed germination three days a week for four weeks (July 1, 2002 to July 26, 2002).

## Results

No germination was observed during this experiment.

## Discussion

Sawgrass seeds in the seed bank on Sabine NWR site 7 terracing unit failed to germinate under a wide range of flooding, salinity, and light conditions. Even when exposed to low stress, drained freshwater conditions, the seeds did not germinate. No information on shading or salinity treatments could be obtained due to lack of seed germination.

Based on my results, sawgrass cannot be expected to re-establish simply by restoring lower salinity and water levels. Restoration of water salinity conditions similar to the area during the 1930's will not ensure sawgrass restoration. At Grand Lake, an area east of Sabine NWR, restorations of historic water salinity conditions have not restored the sawgrass marsh to a level near the abundance observed during the 1930's,

though the abundance of sawgrass has begun to reappear in that area (Visser et al. 2000) since it was virtually eliminated in the late 1950's. Experiments using cores from emergent marsh, rather than submerged sediments are needed to test the impact of salinity and light availability on germination of sawgrass. Viability of seeds could be tested. Experiments using fresh seeds are also needed to determine how long seeds remain viable.

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## Conclusions

On Unit 7 of Sabine National Wildlife Refuge, terraces constructed in 1999 did not increase submerged aquatic vegetation (SAV) biomass or percent occurrence as compared to areas of open water 50 meters from the emergent vegetation edge. The natural marsh had more SAV percent occurrence during peak production times than did the terraced marsh. Submerged coconut mats were effective at increasing SAV production on this area.

My results are different than hypothesized. Terraces did not have the vegetation propagation and seed regeneration potential predicted. The seed bank in the area was over 99% emergent vegetation species. Without planting, SAV cannot be expected to become widely established in the first two years, possibly longer, after terrace construction.

The abundance of SAV on the coconut mats is not different from abundance found in a previous study (Boustany 2000) using pre-vegetated coconut matting. Pre-vegetation matting was not an effective alternative to other restoration techniques, because no additional biomass was grown though the species pre-vegetated on the mat were quickly replaced with other species. My non-vegetated mat did increase SAV abundance on the mats, because there was no vegetation on the mats when they were installed. The mats increased SAV biomass more than terraces and more than untreated natural marsh ponds. More study of coconut mats is necessary if the potential of this technique is to be reached.

The most dominant seed on the study area was sawgrass. My study of sawgrass germination failed to produce any seed germination. It is likely that these seeds may not

be capable of germination due to age or some other factor, although viability was not specifically tested. If these seeds are not capable of germination, then plantings are advisable if a management goal is to re-establish the expansive sawgrass dominated marsh that existed during the early 1900's.

My study is reflective only of this particular area, and terraces and submersed coconut mats may have different results on other sites. More research on terraces and coconut matting is needed. Terraces of different designs should also be tested. Increasing the SAV abundance of an area should not be used to justify terrace construction: an increase in SAV abundance in areas adjacent to terraces should not be expected. Predictive models should not assume that terraces increase SAV abundance in adjacent ponds. Submerged coconut matting should be tested further on different sites and configurations.

# Vita

Aaron Bailey Caldwell was born on July 24, 1979, to parents Daniel and Nancy Caldwell. He grew up on a rural farm near Vivian, Louisiana, and spent many hours exploring the pine forest and bottomlands near his home. He graduated from Caddo Parish Magnet High School in Shreveport in 1997. The summer after high school graduation was spent taking classes at Louisiana Tech University in Ruston. During his third summer at Louisiana Tech, he took an internship with Southeast Louisiana Refuges in Slidell, Louisiana. His experience that summer sparked an interest in coastal ecosystems. During his time at Louisiana Tech, he also worked in the Louisiana Tech herbarium and on a vegetation research project. The exposure to plants broadened his ideas on ecological function and restoration. In 2000, he graduated from Louisiana Tech University with a Bachelor of Science degree in wildlife conservation. He began graduate school at Louisiana State University School of Renewable Natural Resources in 2001, where within the year he began a research project with Dr. John "Andy" Nyman. The degree of Master of Science will be awarded in August 2003.