

GERMINATION AND ESTABLISHMENT OF WOODY SPECIES IN ASSOCIATION
WITH BARRIER ISLAND INTERDUNAL SWALES

By

SARAH THANKFUL LUMBAN TOBING

A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE

UNIVERSITY OF FLORIDA

2009

© 2009 Sarah Thankful Lumban Tobing

To my family for cultivating my love of nature.

ACKNOWLEDGEMENTS

My deepest gratitude goes to my committee members for their guidance and insight. I especially thank Dr. Debbie Miller for her enthusiasm for both teaching and nature and for her endless patience. I thank Dr. Mack Thetford for his zeal for teaching and everything green. I thank Dr. Carrie Reinhardt-Adams for her commitment to learning and for her support.

My most heartfelt appreciation goes to Lesley Atwood, Jude Groniger and Marti Occapinhi for all of their help in the greenhouse and at the beach and their support. I thank Nancy Steigerwalt for her support. I also thank Gregory Owen and James Duncan for help in the greenhouse in Gainesville and Morgan Morillo for her help crafting cages. Finally, I am thankful for my family and dear friends for all of their support and encouragement.

TABLE OF CONTENTS

	<u>page</u>
ACKNOWLEDGEMENTS	4
LIST OF TABLES	8
LIST OF FIGURES	10
ABSTRACT	12
 CHAPTER	
1 INTRODUCTION	14
2 EVALUATION OF <i>Quercus geminata</i> AND <i>Quercus myrtifolia</i> GERMINATION IN INTERDUNAL SWALES	18
Introduction	18
Barrier Island Vegetation	19
Oak Regeneration	20
Wildlife Implications.....	22
Study Objectives.....	22
<i>Quercus</i> Field Study	23
Study Site.....	23
Methods	24
Acorn Collection.....	24
Field Recovery and Germination Trial	25
Harvest	26
Analysis.....	26
Soil Evaluation.....	27
Greenhouse Study.....	27
Experiment 1: Evaluation of seed placement, soil moisture and salinity on germination of <i>Quercus geminata</i> in Milton, Florida.....	27
Experiment 2: Evaluation of seed placement, soil moisture and salinity on germination of <i>Quercus geminata</i> in Gainesville, Florida	29
Experiment 3: Evaluation of seed placement, soil moisture, salinity and insecticide application on germination of <i>Quercus geminata</i> in Milton, Florida.....	29
Experiment 4: Evaluation of seed placement, soil moisture and salinity on germination of <i>Quercus myrtifolia</i> in Milton Florida.....	30
Experiment 5: Evaluation of the effects of seed placement, cold storage, and salinity on Germination of <i>Q. myrtifolia</i> in Gainesville, Florida	30
Results and Discussion.....	31
Soil Evaluation.....	31

Field Recovery and Germination Studies	31
<i>Quercus geminata</i> recovery and germination	31
<i>Quercus myrtifolia</i> recovery and germination	32
Greenhouse Evaluations	32
Greenhouse Conditions	32
Experiment 1: Evaluation of seed placement, soil moisture and salinity on germination of <i>Quercus geminata</i> in Milton, Florida.....	33
Experiment 2: Evaluation of seed placement, soil moisture and salinity on germination of <i>Quercus geminata</i> in Gainesville, Florida	34
Experiment 3: Evaluation of seed placement, soil moisture, salinity and insecticide application on germination of <i>Quercus geminata</i>	34
Experiment 4: Evaluation of seed placement, soil moisture and salinity on germination of <i>Quercus myrtifolia</i>	36
Experiment 5: Evaluation of the effects of seed placement, length of cold storage, and salinity on Germination of <i>Quercus myrtifolia</i>	37
Discussion.....	37
<i>Quercus geminata</i> Greenhouse Studies	39
<i>Quercus myrtifolia</i> Greenhouse studies	39
Acorn Weight.....	41
3 EVALUATION OF <i>Morella cerifera</i> ESTABLISHMENT IN INTERDUNAL SWALES	56
Introduction	56
Study Site.....	59
Methods	60
Saplings	60
Cuttings	60
Soil Evaluation.....	61
Experiment 1: Evaluation of swale location, vegetation cover and water regime	61
Experiment 2: Evaluation of Season of Planting, Swale location, Vegetation coverand a modified watering regime	62
Experiment 3: Evaluation of location, vegetation cover and container shape.....	63
Data Collection	63
Analysis.....	64
Results and Discussion	64
Results	64
Experiment 1	64
Necrosis	64
Survival.....	65
Experiment 2.....	65
Necrosis	65

Survival.....	66
Experiment 3.....	66
Discussion.....	66
4 MANAGEMENT AND RESTORATION IMPLICATIONS	85
<i>Quercus</i>	85
<i>Morella cerifera</i>	86
APPENDIX 1 SAS 9.1 CODES USED FOR ANALYSIS	88
LIST OF REFERENCES	92
BIOGRAPHICAL SKETCH	98

LIST OF TABLES

<u>Table</u>	<u>page</u>
2-1. Average soil moisture and salinity (8 and 15cm) for 6 swales.....	43
2-2. ANOVA for the effects of location, vegetation and seed placement on germination of <i>Quercus geminata</i> in association with barrier island swales; Field Experiment.....	44
2-3. ANOVA for the effects of location, vegetation and seed placement on germination of <i>Quercus geminata</i> in association with barrier island swales; Field Experiment.....	44
2-4. ANOVA for the effects of salinity, soil moisture and seed placement on germination of <i>Quercus geminata</i> in Milton, Florida; Experiment 1	45
2-5. Fresh weight (grams) of <i>Quercus geminata</i> acorns 64 days after planting; Experiment 1.	45
2-6. ANOVA for the effects of salinity, soil moisture and seed placement on germination of <i>Quercus geminata</i> in Gainesville, Florida; Experiment 2	46
2-7. ANOVA for the effects of salinity, soil moisture, length of insecticide soak and seed placement on germination of <i>Quercus geminata</i> in Milton, Florida; Experiment 3.	47
2-8. Fresh weight (grams) of <i>Quercus geminata</i> acorns 80 days after planting (Experiment 3).	48
2-9. ANOVA for the effects of salinity, soil moisture and seed placement on germination of <i>Quercus myrtifolia</i> in Milton, Florida; Experiment 4	48
2-10. Fresh weight (grams) of <i>Quercus myrtifolia</i> acorns 90 days after planting (Experiment 4).	49
2-11. ANOVA for the effects of salinity, soil moisture, length of cold storage and seed placement on germination of <i>Quercus myrtifolia</i> in Gainesville, Florida; Experiment 5.	49
3-1. Average soil moisture and salinity (8 and 15cm) for 6 swales	72
3-2. ANOVA for the effects of vegetation cover, watering regime and week after planting on necrosis (%) <i>Morella cerifera</i> ; Experiment 1.	72
3-3. ANOVA for the effects of vegetation cover and watering regime on survival after the first growing season (binomial) <i>Morella cerifera</i> ; Experiment 1	73

3-4. ANOVA for the effects of season of planting, vegetation cover, watering regime and week after planting on necrosis (%) *Morella cerifera*; Experiment 2 74

3-5. ANOVA for the effects of season of planting, vegetation cover and watering regime on survival after the first growing season (binomial) *Morella cerifera*; Experiment 2 75

3-6. ANOVA for the effects of season of planting, vegetation cover and watering regime on survival after the first growing season (binomial) *Morella cerifera*; Experiment 2 76

LIST OF FIGURES

<u>Figure</u>	<u>page</u>
2-1. Santa Rosa Island, a barrier island in the western Florida panhandle, is the site of this field study.	49
2-2. Map view of a representative swale replication showing how treatment combinations were randomly assigned to split plots... ..	50
2-3: Percentage of <i>Q. geminata</i> acorns present (%) among six swales 87 days after placement in the field.....	51
2-4. Germination (%) of <i>Quercus geminata</i> (Experiment 1) 64 days after planting.. ..	52
2-5. Germination (%) <i>Quercus geminata</i> (Experiment 3) pretreated with Permethrin (2oz./gal) 80 days after planting.... ..	53
2-6. Germination (%) <i>Quercus myrtifolia</i> (Experiment 4) 80 days after planting	54
2-7. Germination (%) of <i>Quercus myrtifolia</i> (Experiment 5) cold storage germination trial 60 days after planting.....	55
3-1. Santa Rosa Island, a barrier island in the western Florida panhandle, is the site of this field study.	75
3-2. Map view (Experiments 1 and 2) of a representative swale replication showing how treatment combinations were randomly assigned to split plots.....	76
3-3. Map view (Experiment 3) of a representative swale replication showing how treatment combinations were randomly assigned to split plots.. ..	77
3-4. Percent necrosis (%) through time (1-5 weeks post planting) for <i>Morella cerifera</i> (Experiment 1) planted in the center of swales in September.	78
3-5. Survival (%) 248 days after planting in September for <i>Morella cerifera</i> (Experiment 1) planted in the center of swales.....	79
3-6: Necrosis (%) through time (weeks 2 – 5 post planting) for <i>Morella cerifera</i> (Experiment 2) planted in November.. ..	80
3-7. Necrosis (%) through time (weeks 2-5 post planting) of <i>Morella cerifera</i> (Experiment 2) planted in March.	81
3-8. Experiment 2. Survival (%) for the November wax myrtle (202 days after planting).	82

3-9. Survival (%) 72 days after planting in March for <i>Morella cerifera</i> (Experiment 2).	83
3-10. Survival (%) 72 days after planting in March, for <i>Morella cerifera</i> (Experiment 3)... ..	84

Abstract of Thesis Presented to the Graduate School
Of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Master of Science

GERMINATION AND ESTABLISHMENT OF WOODY SPECIES IN ASSOCIATION
WITH BARRIER ISLAND INTERDUNAL SWALE ECOSYSTEMS

By

Sarah Thankful Lumban Tobing

May 2009

Chair: Debbie Miller
Cochair: Mack Thetford
Major: Interdisciplinary Ecology

Germination of *Quercus geminata* and *Quercus myrtifolia* and the establishment of transplanted saplings of *Morella cerifera* were examined in association with interdunal swale ecosystems in the western panhandle of Florida. Statistical analysis was conducted to determine influence of 1) swale microsite (location), vegetation cover and seed placement on presence and germination eight weeks after placement of *Quercus geminata* and *Quercus myrtifolia* acorns in the field, Chapter 2; 2) soil moisture, salinity and seed placement on *Quercus geminata* and *Quercus myrtifolia* germination in the greenhouse, Chapter 2; and 3) location, vegetation cover and watering regime on necrosis rates through time and survival after the first growing season of *Morella cerifera* planted in the field, Chapter 3. There was a high rate of acorn loss in the field; *Quercus geminata* had 16.7% presence without cages and was influenced by location, vegetation and burial. *Quercus myrtifolia* had less than 1% presence without cages. Germination of *Quercus geminata* was 15% of acorns present and was not influenced by seed placement, location or vegetation cover. Germination of *Quercus myrtifolia* was 75% of acorns present and was marginally increased by burial. Germination of *Quercus* in the

greenhouse was influenced by salinity and burial with 0 ppt salinity having higher germination rates than 8 ppt, 15 ppt and 22 ppt salinities and buried acorns having higher germination than acorns placed on the surface of the soil at low salinities. Soil moisture increased germination at higher salinities (15 and 22 ppt). *Morella cerifera* necrosis was influenced by season, location, vegetation cover and watering. Necrosis was not a predictor of survival after the first growing season; indicating that monitoring of plant establishment should be longer than 5 weeks. *Morella cerifera* survival was influenced by season, location, vegetation cover, watering regime and container shape. Plants had higher survival when planted in 1) the spring than the fall; 2) the center than the ridge 3) vegetation than bare soil and 4) with supplemental watering. Information on woody plant ecology is essential to barrier island conservation and restoration because these species stabilize dunes, provide valuable wildlife habitat and help maintain species diversity.

CHAPTER 1 INTRODUCTION

The dynamism of barrier island ecosystems is influenced by natural disturbances and the variable, harsh environment. Barrier islands on the Gulf of Mexico and elsewhere develop zonal vegetation communities parallel to the coast according to steep environmental gradients with pioneering plants adjacent to the beach and an increasing diversity of plants farther inland (Ehrenfeld 1990). Two plant communities found in the interior and on the backside of barrier islands in the Florida panhandle are interdunal swales and scrub. Interdunal swales comprise a matrix of periodically inundated wetlands with organic sandy soils which are marsh like in quality, and xeric developing dune ridges which are created by the movement of sand (Kindell et al.1997). Scrub systems on barrier islands are similar to those found on mainland Florida and are unique to the southeastern United States with the highest concentration in Florida. These communities are characterized by well drained nutrient poor sandy soils (Menges and Hawkes 1998) and occur on back island dunes and on ridges surrounding interdunal swales.

In addition to harsh and variable daily environmental conditions, barrier islands in the eastern United States are subject to the brunt of tropical storms. Barrier islands throughout the Gulf of Mexico have recently experienced an increased frequency and intensity of hurricanes, potentially associated with climate change (Saunders and Lea 2008). Overwash events caused by storms can alter dune structures and environmental gradients across barrier islands (Miller et al. 2008) in addition to killing vegetation. Foredunes are most heavily impacted by storm surge. Loss of foredunes increases impact of subsequent storms on back barrier island plant communities (Pries et al. 2008).

Increased storm frequency also limits natural regeneration of vegetation and rebuilding of dunes. This can lead to changes in community composition including shifts in diversity.

Natural environmental disturbances change barrier island communities. Another major factor in barrier island change is anthropogenic disturbance. Many barrier island systems are fragmented by roads and buildings. This fragmentation disrupts natural processes such as sand movement and plant community establishment. Additionally, erosion prevention such as beach armoring prevents natural sand movement.

It is assumed that the diversity of barrier island vegetation is controlled by mortality of plants during the stages of germination and establishment from salinity, desiccation, sand movement and other stresses (Ehrenfeld 1990). The existence and regeneration of these plant communities is influenced by water availability, salt spray, sand movement and microsite conditions (Oosting 1945, Boyce 1954, Ehrenfeld 1990). Water availability is an indicator of plant community stability on barrier islands (Snyder and Boss 2002). The intensity of salt spray on dunes and ridges prohibits the growth of plants which would be found on these exposed areas in the absence of salt spray (Boyce 1954). As a result, tolerance of salt spray is correlated with succession and zonation of coastal vegetation (Oosting 1945).

Studies on germination and establishment of barrier island plants concentrate on foredune species (Ehrenfeld 1990). While the pioneering foredune grasses *Uniola paniculata* (sea oats) and *Panicum amarum* (bitter panicum) act as rapid sand accumulators (Dahl Woodard 1977), herbaceous plants and woody species provide long term stabilization of dunes (Brown and Hafenrichter 1962). Woody plants provide a diversity of structure and food for wildlife on barrier island landscapes (Preis 2006).

Germination and establishment of woody species is less commonly researched on barrier islands. Yet, the development of communities by woody species is one of the most significant stages of succession on barrier islands (Young 1995b). In addition, woody plants can increase species diversity; bird attracting structures such as perches can increase the diversity and abundance of bird dispersed seeds (Chambers and MacMahon 1994).

Morella cerifera Small (wax myrtle), *Quercus geminata* Small (sand live oak) and *Quercus myrtifolia* Willd (myrtle oak) are three woody species found on interdunal swale and scrub systems on Santa Rosa Island (SRI), Florida. Recruitment of these species on SRI has rarely been noted since Hurricanes Ivan (2004) and Dennis (2005) impacted the island. Regeneration of these systems following hurricanes may not occur because of lack of a seed source or lack of an appropriate seed bed (Clewell 1997 and citations within).

Research on interdunal swale vegetation ecology is crucial for understanding regeneration and potential restoration of this part of the landscape. The fragmentation of the landscape from anthropogenic disturbance adds justification for restoration of plant species. The following study examines establishment of *Morella cerifera* in association with different landscape positions, vegetation cover, watering regimes and container shapes. In addition, it evaluated germination of *Quercus geminata* and *Quercus myrtifolia* in association with different landscape positions, vegetation covers, seed placements and protection from predation and movement on barrier island interdunal swale. It also examines germination of *Quercus geminata* and *Quercus myrtifolia* under different seed placements, salinity levels and cold incubation periods in the greenhouse. This research

will increase information on woody species ecology on barrier island systems and potentially support ecosystem management.

CHAPTER 2
EVALUATION OF *Quercus geminata* AND *Quercus myrtifolia* GERMINATION IN
INTERDUNAL SWALES

Introduction

Scrub communities of Florida are unique and found only sparsely in other southeastern states. Defining characteristics of this ecosystem are low species richness and dry, sandy soils which are deficient in nutrients (Clewell 1997 and citations within). There are two hypotheses which contend the origin of this ecosystem: 1) scrub species establish on dunes which have been stabilized by grasses 2) scrub species establish near the water table in low elevation interdunal swales and that dunes form around them (Clewell 1997). Following hurricanes, scrub can be absent or nearly absent on barrier islands; it is hypothesized that regeneration may not occur because of lack of a seed source or lack of an appropriate seed bed (Clewell 1997 and citations within).

Quercus geminata Small (sand live oak), and *Quercus myrtifolia* Willd (myrtle oak) (here after referred to as *Q. geminata* and *Q. myrtifolia*, respectively) are dioecious, woody, scrub-oak species found in xeric ecosystems in the southeastern United States. Though both species can have either a tree or shrub growth habit; on barrier islands both more commonly grow in the shrub form. Individual shrubs are located on protected microsites on the backside of barrier islands. The clonal nature of both species allows these shrubs to form thickets on established back dunes and form coastal scrub communities.

Reproductive phenology differs among the two *Quercus* species. *Q. geminata* is a member of the white oak group with staminate floral buds initiating in the spring of the year prior to flowering and pistillate buds initiating in the late summer of the year prior to flowering. The following year, catkins are produced in spring which if fertilized will

develop fruit in the fall of the same year making this a 2 year cycle of acorn production (Abrahamson 2003 and citations within). *Q. geminata* is viviparous indicating that the growth of the embryo is continuous while on the parent plant

Q. myrtifolia, a member of the red oak group, initiates staminate and pistillate floral buds with the same seasonality as *Q. geminata*. However, fruit development and maturation for *Q. myrtifolia* occurs in the fall of the year following spring flowering (Abrahamson 2003 and citations within) making *Q. myrtifolia* acorn production a 3 year cycle. In contrast to members of the white oak group, members of the red oak group generally have a dormancy period before germination can occur (Hopper et al. 1985).

Barrier Island Vegetation

Barrier island vegetation develops along zones established by varying abiotic conditions (Ehrenfeld 1990). Two of the abiotic conditions that characterize barrier islands are salt spray and water availability. Soil moisture levels can be determined by the capacity of the soil to retain water and the availability of water within the landscape. Soils of barrier islands often consist of well drained sands and vegetation relies on the height of the water table and precipitation for needed moisture. The ground water on barrier islands is consolidated in a fresh or brackish water lens which floats above saline water. Terrain and vegetation patterns are the controlling factors for these lenses; variability in both promotes lens formation (Schneider 2003).

Tolerance of salt spray is correlated with growth form, succession and zonation of coastal vegetation (Oosting 1945). The intensity of salt spray on dunes and ridges prohibits the growth of plants which would be found on these exposed areas in the absence of salt spray (Boyce 1954). Salt spray causes the accumulation of chloride ions in the tissues of coastal plants which leads to necrosis of leaves and twigs and sometimes

death (Boyce 1954). Abrasion of leaves from wind creates traumata which are areas of entry for the salts (Boyce 1954). Broad leaved species on barrier islands are subject to constant salt spray and assume a salt-pruned, bonsai appearance (Kindell et al. 1997).

Oak Regeneration

The transition from seed to seedling in large seeded species such as oaks plays a crucial role in tree recruitment (Perez-Ramos et al. 2008). Influences on oak regeneration include plant interactions with seed predators and herbivores, flooding tolerance and wind disturbance (Collins and Bataglia 2008). Contributors to oak seedling establishment are seed dispersal, seed predation and microsite conditions (Collins and Bataglia 2008).

Seed availability may influence oak regeneration. Acorns are desirable food for wildlife due to their relatively high concentrations of fat and carbohydrates in addition to, calcium and proteins (Goodrum 1971). In addition, acorns can be plagued by insect infestations from the acorn moth (Lepidoptera: Olethreutidae), gall wasp (Hymenoptera: Cynipidae), and the acorn weevil (coleopteran: Curculionidae). Of these insects the weevil is the most significant and has been reported to destroy over 90% of acorns in eastern hardwood forest. The adult weevil deposits an egg in a developing acorn; the larvae grow and feed inside the pericarp. Once the seed matures it is unable to germinate or it produces a seedling of low vigor (Lombardo 2008 and citations there in).

When intact acorns are available, safe sites must be present for successful germination. Safe sites are zones with favorable resources such as water and oxygen, a favorable light source and absence of predators (Harper 1977). On Santa Rosa Island, Florida the two oak species are observed rarely as seedlings. The seedlings which have been detected are near established scrub dunes at lower elevations with flatter slopes (such as the toe of a dune) sometimes on the edge of or in shallow, interdunal swales. At

such sites, seedlings are within the proximity of a mature individual of the same species and herbaceous vegetation is lacking (Personal Observation). This suggests that the previous description fulfills the safe site requirements for *Q. geminata* and *Q. myrtifolia*.

An increase in the number of tropical storms on the Gulf coast could contribute to the decline in oak regeneration. Tropical storm occurrence has increased within the past three decades on Florida's Gulf coast (Miller et al. 2008). It is hypothesized that regeneration of scrub systems following hurricanes may not occur because of lack of a seed source or lack of an appropriate seed bed (Clewel 1997 and citations within). Oak thickets and individual shrubs add to the structural diversity of barrier island habitat. This type of woody structure can be important for both wildlife habitat and forage. Disturbance events, such as those created by tropical storms, have decreased the amount of woody structure of both alive and dead (snags) plants on Santa Rosa Island.

In addition to periodic natural disturbances such as storm events, oak regeneration can be affected by climate change. Low lying barrier islands are particularly vulnerable to a suite of climate change impacts including sea level rise, increase in the intensity of storms and shifts in species composition of biological communities. Within 130 years the global atmospheric concentration of CO₂ has increased by 37% from 270 PPM in 1870 to 370 PPM in 2000 (Tangley 2001). In a laboratory experiment, increased levels of CO₂ significantly increased reproductive output and biomass of *Q. myrtifolia* and did not increase either reproductive output or biomass of *Q. geminata*. Having accelerated the recruitment of *Q. myrtifolia*, increased CO₂ levels will lead to a scrub oak system with lower diversity (Stalling 2004). Thus, understanding of the germination ecology of these species is essential to their conservation.

Main contributors to oak seedling establishment are seed dispersal, seed predation and microsite conditions (Collins and Bataglia 2008). A past study showed that recruitment of *Quercus* seedlings is strongly suppressed by grasses (Callaway 1998 and citations within). However, vegetative cover such as grasses may create favorable microsite conditions in barrier island ecosystems. Regeneration of oaks is affected by plant interactions with seed predators and herbivores, flooding tolerance and wind disturbance (Collins and Bataglia 2008).

Wildlife Implications

In addition to providing food for wildlife on barrier islands, woody species such as oaks also provide structure. As stated in the previous chapter, it has been proven that bird attracting structures such as perches can increase the diversity and abundance of bird dispersed seeds (Chambers and MacMahon 1994). This could then increase the recruitment of a higher diversity of plant species.

Scrub dune systems are of particular importance to trans-Gulf migratory birds (Moore 1990). The highest diversity and number of individuals of these migrants is found in habitats where scrub oaks occur (Moore 1990). Scrub oaks and other woody species are also crucial components of beach mouse (*Peromyscus polionotus* sp.) habitat as beach mouse occupancy was higher in frontal dunes with established woody species following Hurricane Ivan in 2004 (Pries 2006).

Study Objectives

This study seeks to increase the breadth of information on germination of *Q. geminata* and *Q. myrtifolia* in relation to the barrier island landscape. This study evaluated the seed ecology and germination of *Q. geminata* and *Q. myrtifolia* in the field in relation to landscape position, vegetation cover, seed placement and protection from

movement. In addition, it evaluated, under greenhouse conditions, *Q. geminata* and *Q. myrtifolia* germination in response to differing moisture, salinity and seed placements. It also evaluated effects of different insecticide levels on *Q. geminata* germination and effects of different dormancy periods (cold storage) on *Q. myrtifolia* germination.

***Quercus* Field Study**

Study Site

The study was conducted on Santa Rosa Island (30°24'N, 81°37'W) an approximately 60km long and 1km wide Holocene barrier island within the Gulf coast lowlands (NRCS 2004) (Fig 1). The island supports a system of sand dunes and beach ridges with undulating elevation from mean sea level to 15m. Soil on the island is characterized as quartz sand and shell beds (NRCS 2004). Accumulation of organic matter occurs in low elevation, ephemerally inundated swales (from now on referred to as interdunal swales or swales) (NRCS 2004). The climate of Santa Rosa Island is subtropical with average temperature and humidity of 20.6°C and 41.5%, respectively during the study (May 2007 to June 2008). (National Weather Service, Inc. 2008) Total precipitation during the study year was 171 cm; mean annual precipitation was 152cm. Specific planting sites were located in the interdunal swale system of the barrier island in an area owned and managed by Escambia County Parks near Pensacola Beach, Florida.

Like most barrier islands, Santa Rosa Island has linear zones of vegetation beginning from the Gulf to Santa Rosa Sound including beach dunes, coastal grasslands, interdunal swales and maritime hammocks or scrub (Ehrenfeld 1990, Kindell et al. 1997). Beach dunes are ever changing with rapid deposition and erosion of sand and are dominated by grasses including *Uniola paniculata* L. (sea oats), *Panicum amarum* Elliot (bitter panicum) and *Schizachyrium maritimum* Nash (Gulf bluestem) and other salt

tolerant vegetation such as *Iva imbricata* Walter (beach elder), *Cakile constricta* Rodman (sea rocket) (Kindell et al. 1997). Coastal grasslands occur on gently undulating or flat terrain and are dominated by *U. paniculata*, *P. amarum*, *S. maritimum*, and *Dichantheium aciculare* Gould & Clark (needle-leaf panic grass). Interdunal swales are marsh-like in quality are dominated by *Fuirena scirpoidea* Michx. (umbrella sedge), *Cyperus lecontei* Torr. Ex. Stud. (LeConte's flatsedge), *Xyris* sp. (yellow-eyed grass), *Lachnanthes caroliniana* Lamarck (red-root), *Juncus megacephalus* Curtis (big-head rush), *Juncus roemerianus* Scheele (black needlerush), *Andropogon virginicus* var. *glaucus* L. (glaucus broomsedge), *Panicum tenerum* (Bey ex. Trin) (bluejoint panic grass) and *Spartina patens* Aiton. (marsh hay) and can be colonized by woody species such as *M. cerifera*. The maritime forest has a species composition similar to Florida's xeric scrub communities and scrubby flatwoods. The dominant species in the scrubby flatwood canopy is *Pinus elliottii* Elliot (slash pine) with a variable understory of *Q. geminata*, *Q. myrtifolia*, *Magnolia grandiflora* L. (Southern magnolia) or other shrubs (Kindell et al. 1997).

Methods

Acorn Collection

Acorns were collected from Eglin Air Force Base (EAFB), Santa Rosa Island, Florida on September 28-29, 2007 (*Q. geminata*) October 16, 2007 and November 14, 2007 (*Q. myrtifolia*). Timing of acorn harvest was based on observed vivipary in *Q. geminata* and evidence of natural dispersal of *Q. myrtifolia* from the trees. *Quercus geminata* acorns were not collected from the ground due to the high numbers of these acorns with evidence of herbivory. *Quercus myrtifolia* acorn collection consisted of picking acorns that were medium in size, free of cracks or holes and either green or

brown in color directly from the tree. Caps were left on if they did not pop off when initially picked. A float test was conducted to determine acorn viability by placing acorns in a bucket of water and discarding the ones that floated (Korstian 1927).

Field Recovery and Germination Trial

Germination of *Q. geminata* and *Q. myrtifolia* acorns was tested at two positions within shallow ephemeral swales under various manipulated conditions. Shallow swales and adjacent ridges were chosen using random stratification. Swales were stratified by observed elevation, hydrology, soil composition, plant composition and vegetation cover density so that only shallow swales, similar in most respects, were placed in a pool for selection. Of the available shallow swales with adjacent ridges, six were randomly selected. Each swale was split into vegetated or unvegetated cover types (subplots). To establish unvegetated subplots, vegetation was killed by placing black plastic over 3 m² plots for 1 month or more in each swale at the two swale locations. Half of each subplot was either covered by a cage to reduce herbivory and movement or not caged. Cages were constructed from 0.635cm (1/4 inch) wire mesh. Each cage was approximately 10cm tall, 30cm wide and 60cm long. Each cage was divided by a 10cm tall partition. Cages were not totally enclosed; the bottom had an opening to allow for placement over vegetation. Caged and non caged subplots were placed parallel to each other and the ordinal direction of the orientation of each subplot recorded. Within caged or non caged subplots acorns were buried at depth equal to the diameter of the acorn on one side of the partition or placed on the soil surface on the opposite side of the partition. *Quercus geminata* acorns were placed on October 19, 2007 and *Q. myrtifolia* acorns were placed on January 4, 2008 under 16 treatment combinations (Figure 2-1). Fifteen acorns

were buried or placed approximately 5 cm apart within each vegetation cover, cage, seed placement treatment combination in each of the replications for a total of 1440 acorns.

Harvest

Percent germination was determined at time of harvest approximately two months after placement. *Quercus geminata* acorns were harvested on January 3, 2008 and *Q. myrtifolia* acorns harvested on March 13, 2008. All sand was carefully removed from each acorn. Then acorns were placed in paper bags marked with their treatment number, a found acorn was recorded to have germinated if the radical had emerged. Acorns found outside of cages was counted as recovered. Acorns with signs of predation such as small mammal herbivory and non-germinated acorns were also recorded.

Analysis

This study utilized a split, split plot design with a $2 \times 2 \times 2 \times 2$ factorial arrangement of treatments, where the main plot is the replication (swale) with the following treatment combinations: location (center or ridge), vegetation cover (vegetated and not vegetated), cage protection (caged and non caged) and seed placement (buried and surface).

Statistical analyses were performed using binomial probability through general linear mixed models procedure (PROC GLIMMIX) of SAS 9.1 (SAS Institute Inc. 2008) to determine whether the predictor variables (location, vegetation cover, protection and placement) or interactions influenced recovery and germination. Statistical analysis of treatment effects on recovery is for non caged acorns only. Analysis of treatment effects on germination is for all recovered acorns, caged and non caged.

Soil Evaluation

Soil moisture and salinity were measured at each of the 6 replicates under the following hierarchical treatments: center or ridge, vegetated or unvegetated and 8cm or 15cm below the soil surface. Gravimetric water content was determined to measure soil moisture. Soil salinity was determined using the HI 9813 Portable pH/EC/TDS/°C Meter (Hanna Instruments, Sarmeola di Rubano, Italy). Samples were taken on six occasions and at uneven intervals. Hence, dates were not compared during analysis. Statistical analysis was performed using mixed models procedure (PROC MIXED) (SAS Institute Inc. 2008) to analyze differences in soil moisture and soil salinity for the different treatment combinations.

Greenhouse Study

Experiment 1: Evaluation of seed placement, soil moisture and salinity on germination of *Q. geminata* in Milton, Florida

This experiment evaluated the effects of seed placement, soil moisture and salt level on the germination of *Q. geminata*. Seeds were planted on October 12, 2007 at the Milton, Florida greenhouse after being refrigerated at 2°C for 15 days. Acorns were harvested on December 13-14, 2007. This experiment was arranged in a randomized complete block design with ten blocks (replications). Each block contained 16 one gallon nursery containers. Ten lots of 15 seeds (N = 150) were subjected to each of the 16 treatments for a total of 2400 seeds. Thus, each block contained a 2 × 2 × 4 factorial arrangements of treatments (a total of 16 treatments) with the following: seed placement (surface or buried), soil moisture (wet or dry) and salinity (0 ppt, 8 ppt, 15 ppt or 22 ppt)

The effect of seed placement on germination was evaluated by placing acorns at one of two depths: on top of the soil (surface) or below the soil surface (buried) at a depth

equal to the diameter of the acorn. The effect of moisture on germination was evaluated by imposing a moist or dry soil moisture level within each of four salinity treatments throughout the germination period. The moist soil moisture level represented the soil at field capacity (FC) and the dry was maintained at 25% FC. Soil moisture was monitored weekly for and returned to FC on a weekly basis. Field capacity was determined previously using test pots (n=10) which were saturated to the point that water seeped out of them and then weighed after draining overnight. The 25% FC treatment was returned to 25% FC on a weekly basis by returning the pots to 25% of the weight of pots at FC. This procedure for maintaining the two soil moisture levels was employed for all experiments located in Milton. The four salinity levels were derived from dissolving 0, 8, 15, and 22 g synthetic sea salt (Aquarium Systems, Mentor, Ohio 44060 USA)/L of deionized water[0-22 ppt; up to 63% full strength seawater salinity (35 ppt)]. Pots were watered alternately with salt solutions one week and deionized water the following week to prevent high concentrations of salt. If water was applied soil salinity was monitored using the HI 9813 Portable pH/EC/TDS/^oC Meter (Hanna Instruments, Sarmeola di Rubano, Italy) (Milton Experiments only).

At the termination of all Milton experiments, all acorns (ten replications) were destructively harvested and assessed for germination and of insect infestation. Insect presence was determined by presence of holes on the surface of the seed. In addition, all acorns and seedlings from two replications were weighed fresh to the nearest 0.01 grams.

Statistical analysis was preformed using mixed models procedure (PROC MIXED) SAS 9.1 (2008 SAS Institute Inc.) to determine whether the seed placement, soil moisture and salinity influenced the following: germination (10 replications), fresh and dry weight

(2 replications) presence of insects. Analyses were performed with a 95% probability for significance. Additionally, instances of probabilities between 93 and 95% are noted as marginally significant.

Experiment 2: Evaluation of seed placement, soil moisture and salinity on germination of *Q. geminata* in Gainesville, Florida

This experiment followed a similar design as Experiment 1 except, soil moisture began and was returned to saturation. The initial planting was on November 11, 2007 and harvest on December 20, 2007. Prior to planting acorns were refrigerated at 2°C for 45 days. This experiment used five lots of 15 seeds (N = 75) subjected to each of the 16 treatments for a total of 1200 seeds. There were four test pots which did not contain seed per replication which were used to monitor soil moisture and salinity. Test pots were refilled to saturation weekly to determine the amount of water required to replace water loss (refilled until water leaked from the bottom of the pot). Each week, 25% of the volume of water necessary to return pots to saturation was applied to pots maintained at 25% saturation.

At the termination of this experiment, all acorns and seedlings (5 replications) were assessed for germination and cut open to detect presence of insects. Acorns and seedlings were dried for 24 hours at 190°C prior to weighing to the nearest 0.01 grams. The same statistical analysis was used for this experiment as in Experiment 1.

Experiment 3: Evaluation of seed placement, soil moisture, salinity and insecticide application on germination of *Q. geminata* in Milton, Florida

This experiment followed a similar design to Experiment 1, except an insecticide treatment was applied to the acorns before planting. Insecticides were used in this experiment because a high rate of insect infestation was observed at the time of collection in the field. This experiment was planted on November 28, 2007 and harvested on

February 15, 2008. Acorns were refrigerated at 2°C for 62 days prior to planting. This experiment was arranged in a randomized complete block design with 5 blocks (replications). It contained a $2 \times 2 \times 2 \times 4$ factorial arrangement of the following treatments within each complete block: seed placement (buried or surface), soil moisture (wet or dry), salinity (0, 8, 15, or 22 ppt) and of insecticide (1 hour or 2 hour Permethrin soak) ($C_{21}H_{20}Cl_2O_3$) (2oz./1gal). The same statistical analyses were used as performed in Experiment 1.

Experiment 4: Evaluation of seed placement, soil moisture and salinity on germination of *Q. myrtifolia* in Milton Florida

This experiment followed a similar design as Experiment 1 except *Q. myrtifolia* was the study species. *Q. myrtifolia* were planted on October 17, 2007 at the Milton, Florida greenhouse and harvested on January 15, 2008. Prior to planting acorns were refrigerated at 2°C for one day. The same analysis was used as in Experiment 1.

Experiment 5: Evaluation of the effects of seed placement, cold storage, and salinity on Germination of *Q. myrtifolia* in Gainesville, Florida

This experiment followed a similar design as Experiment 2 except it was conducted using *Q. myrtifolia*, soil of all pots was maintained at 25% soil saturation and length of time of cold storage was evaluated. Acorns were harvested on October 16, 2007 and November 14, 2007 and refrigerated at 2°C until planting for 96 days and 67 days. *Q. myrtifolia* were planted on January 19, 2008 and the experiment terminated on March 19, 2008. Data collection included germination and dry weight.

This experiment was arranged in a randomized complete block design with 5 blocks (replications). It contained a $2 \times 2 \times 4$ factorial arrangement of the following treatments within each complete block: 2 levels of seed placement- (buried or surface), 4

levels of salinity- (0, 8, 15, or 22 ppt), 2 levels of cold storage- (early or late). The same analysis was used for this experiment as Experiment 1.

Results and Discussion

Soil Evaluation

Soil moisture was greater in the center than the ridge for September 28, 07 (P=0.0101), October 19, 07 (P=0.0027), and March 18, 08 (P=0.0007) with no interaction between location and vegetation cover except on March 18, 08 (P=0.0049) (Table 2-1). For this date, soil moisture was greater in the center than the ridge regardless of level of vegetation cover. However, the presence of vegetation decreased soil moisture on the ridge (P=0.0034) but did not influence soil moisture in the center.

Soil salinity was not influenced by vegetation or depth for any date, and soil salinity was influenced by location only on March 18, 08. For this date, salinity was greater in the center than on the ridge (P=0.0374) and greater at 8cm than at 15cm (P=0.0489).

***Q. geminata* recovery and germination**

Acorn loss was significant for *Q. geminata* with only 48.4% (677 out of 1440) total recovery of acorns. Of the acorns present, 64.4% (415 acorns) were caged and 35.6 % (262 acorns) were not caged. Recovery of *Q. geminata* acorns outside of cages was influenced by location, vegetation and seed placement (Figure 2-3). Recovery was higher on the ridge than in the center (P=0.0387) (Table 2-2). Overall, recovery was greater for buried acorns (P<0.0022). Vegetation cover contributed to a marginal decrease in the recovery of acorns (P=0.0566).

Germination of recovered acorns (caged and non caged) was marginally influenced by seed placement (P=0.0575) (Table 2-2). Germination was not influenced

by location or vegetation cover. Of the acorns present approximately 15% (100 out of 674) germinated.

***Q. myrtifolia* recovery and germination**

Acorn loss was also high for *Q. myrtifolia* with 7% (107 out of 1440) total recovery of acorns. Of the acorns present, 97.2% were caged and 2.8% were not caged. There was only one treatment combination (center, vegetated, non caged, buried) where acorns were recovered without cage protection, therefore, statistical analysis was not performed on presence of *Q. myrtifolia* acorns.

Of the acorns present (caged and non caged) 75% germinated. Seed placement marginally influenced germination ($P=0.0714$), with buried acorns having a greater probability of germinating (Table 2-3). Vegetation and location did not influence germination. No acorns had presence of insects and only one acorn exhibited signs of predation by something other than an insect.

Greenhouse Evaluations

Greenhouse Conditions

Greenhouses at two locations were used in the following studies: University of Florida's West Florida Research and Education Center in Milton, Florida and University of Florida's Environmental Horticulture Department in Gainesville, Florida. The Milton, Florida greenhouse average maximum low temperature was 23.3°C and the average maximum high temperature was 27.8°C. The Gainesville, Florida greenhouse average maximum low temperature was 22.1°C and the average maximum high temperature was 27.3°C.

Experiment 1: Evaluation of seed placement, soil moisture and salinity on germination of *Q. geminata* in Milton, Florida

Germination was influenced by salinity ($P < 0.0001$), soil moisture ($P < 0.0001$) and seed placement ($P < 0.0001$) and there was an interaction among salinity, soil moisture and seed placement ($P = 0.0002$) (Table 2-4). Although germination percentages generally decreased with an increase in salinity levels, the moisture level and placement of the seed also influenced the germination percentage (Figure 2-4). In the absence of salinity (0 ppt) the greatest germination, 43.0%, occurred with buried seed regardless of soil moisture level. However, with salinity at 0 ppt and seeds placed on the surface, germination was 25.3% with soil moisture at FC while germination was 6.0% with soil moisture at 25% FC. With an increased concentration of salinity (8 ppt) seed burial provided an advantage over surface placement ($P < 0.0001$) and soil at FC provided an advantage over soil at 25% FC ($P = 0.0002$). However, once the concentration of salinity exceeded 8 ppt germination of seeds placed on the surface and seeds in soil at 25% FC did not germinate. Seed buried in soil at FC continued to germinate in the presence of salinity at 22 ppt but germination decreased by 30.7 % compared to germination in soil of 0 ppt salinity.

Fresh weight was influenced by salinity ($P < 0.0001$) and burial ($P < 0.0001$) and an interaction between salinity and burial ($P = 0.0026$) was also present (Table 2-5). There was a significant difference between the fresh weights of acorns at 0 ppt and 22 ppt salinity ($P = 0.0027$). In the absence of salinity (0 ppt), buried acorns were significantly heavier than those at higher salinities (8 ppt, 15 ppt, 22 ppt) ($P < 0.0001$). Acorns placed on the surface in the absence of salinity (0 ppt) were significantly heavier than those placed on the surface with low salinity (8 ppt) ($P = 0.0427$). However, the weight of acorns placed on the surface in the absence of salinity (0 ppt) did not significantly differ from

those with higher salinities (15 ppt and 22 ppt). Mean dry weight of acorns was 0.60 g and was not influenced by seed placement, soil moisture or salinity. Insects were present in 1.3% of acorns; infestation was not influenced by seed placement, soil moisture or salinity.

Experiment 2: Evaluation of seed placement, soil moisture and salinity on germination of *Q. geminata* in Gainesville, Florida

Germination was influenced by salinity ($P < 0.0001$) (Table 2-6). In the absence of salinity (0 ppt) seeds germinated at 21.9%, this was significantly greater than at any other salinity. There was no difference in germination among acorns in salinities of 8 ppt (12.0%), 15 ppt (3.0%) or 22 ppt (4.7%).

Mean dry weight of acorns was 0.55 g and was not influenced by seed placement, soil moisture or salinity. Insect presence was influenced by salinity. The highest rate of infestation was at 22 ppt salinity (4.3%) and differed from all other salinities.

Experiment 3: Evaluation of seed placement, soil moisture, salinity and insecticide application on germination of *Q. geminata*

Germination was influenced by soil moisture ($P < 0.0001$), salinity ($P < 0.0001$) and insecticide ($P = 0.0010$) (Table 2-7). An interaction was present among soil moisture, seed placement and salinity ($P = 0.0062$) and between salinity and insecticide ($P = 0.0500$) (Table 2-5). In the absence of salinity (0 ppt), germination was significantly greater with the two hour insecticide level (40.7%) than the one hour level (17.3%) (Figure 2-5). Without the influence of salinity the percentage of germinated acorns in soil at field capacity (buried and on the surface) and buried acorns at 25% FC moisture were consistently greater than germination of acorns placed on the surface of soil at 25% FC. This pattern of germination was similar for both rates of insecticide although the magnitude of germination was greater for seeds soaked for 2 hours. With presence of

salinity (8, 15 and 22 ppt) germination of acorns placed on the surface was less than 5% regardless of insecticide application or soil moisture. At 8 ppt germination decreased more than 50% for acorns placed on the surface at both insecticide rates. At 15 ppt germination was less than 15% for all acorns but those treated with insecticide for two hours and buried in soil at FC which germinated at 40%. At 22 ppt no acorns germinated at greater than 5%.

Fresh weight of acorns was influenced by, salinity ($P=0.0495$), placement ($P=0.0104$) and soil moisture ($P<0.0001$) and there were interactions between salinity and moisture ($P<0.0001$) and burial and moisture ($P=0.0056$) (Table 2-8). In the absence of salinity (0 ppt) at FC, fresh weight was significantly heavier than the same moisture treatment for all other salinities (8 ppt, 15 ppt and 22 ppt) and there was no difference in fresh weights at other salinities. In addition, acorns were significantly heavier at 0 ppt ($P<0.0001$), 8 ppt ($P=0.0058$) and 22 ppt ($P=0.0082$) at FC than 25% and moisture did not have an effect on acorns at 15 ppt salinity regardless of soil moisture ($P=0.1230$). Buried acorns had greater fresh weights than surface acorns. Fresh weight was greater at FC compared to 25% FC. Moisture at FC in combination with burial increased fresh acorn weight ($P=0.0002$), however, fresh weight did not differ between surface and buried acorns at 25% FC.

Insect presence was detected in only one acorn. This acorn was treated with the 1 hour insecticide, placed on the surface, and kept at 25% of field capacity in the absence of salinity.

Experiment 4: Evaluation of seed placement, soil moisture and salinity on germination of *Q. myrtifolia*

Germination was influenced by salinity ($P < 0.0001$), moisture ($P < 0.0001$) and placement ($P < 0.0001$) and there was an interaction among salinity, soil moisture and seed placement ($P < 0.0001$) (Table 2-6). The three way interaction occurred because of the differing responses to soil moisture and seed placement with differing levels of salinity. In the absence of salinity (0 ppt) seeds germinated at 75.4% (buried) and 37.3% (surface) with soil at FC but no germination occurred with the soil at 25% FC regardless of seed placement (Figure 2-9). Although germination was at 12.0% buried and 6.0% surface, the response to soil moisture was similar with salinity at 8 ppt. With salinity levels greater than 8 ppt germination failed regardless of placement or soil moisture.

Fresh weight of acorns was influenced by, salinity ($P = 0.0495$), placement ($P = 0.0104$) and soil moisture ($P < 0.0001$) and there were interactions between salinity and moisture ($P < 0.0001$) and seed placement and moisture ($P = 0.0056$) (Table 2-10). In the absence of salinity (0 ppt) at FC, fresh weight was significantly heavier than the same moisture treatment for all other salinities (8 ppt, 15 ppt and 22 ppt) and there was no difference in fresh weights at the other salinities. In addition, acorns were significantly heavier at 0 ppt ($P < 0.0001$), 8 ppt ($P = 0.0058$) and 22 ppt ($P = 0.0082$) at FC than 25% FC and moisture did not have an effect on acorns at 15 ppt salinity regardless of soil moisture ($P = 0.1230$). Buried acorns had greater fresh weights than surface acorns. Fresh weight was greater at FC compared to 25% FC. Moisture at FC in combination with burial increased fresh acorn weight ($P = 0.0002$), however, fresh weight did not differ between surface and buried acorns at 25% FC. Mean dry weight was greater at FC (0.72 g) than 25% FC (0.68 g) ($P = 0.0030$). Salinity and seed placement did not influence dry weight.

Experiment 5: Evaluation of the effects of seed placement, length of cold storage, and salinity on Germination of *Q. myrtifolia*

Germination was influenced by salinity ($P < 0.0001$) and seed placement ($P < 0.0001$), the interaction between seed placement and cold storage ($P = 0.0527$) and the interaction among salinity, seed placement and cold storage ($P = 0.0162$). (Table 2-11). In the absence of salinity, germination was 25.2% for surface acorns and 37.9% for buried acorns (Figure 2-7). There was significantly greater germination in the absence of salinity (0 ppt) compared to all other salinity levels (8 ppt 15 ppt and 22 ppt). In addition, germination was higher for low salinity (8 ppt) than high salinity levels (15 ppt and 22 ppt). Germination did not differ among seeds stored at 67 or 96 days ($P = 0.7430$).

Acorn dry weight was influenced by cold storage ($P < 0.0001$). Acorns which were stored longer had significantly lighter weight than those stored for the shorter amount of time, 0.77g versus 0.84g, respectively. Dry weight was not influenced by soil moisture or salinity.

Discussion

Soil Evaluation

Salinity was influenced by location on March 18, 08. The difference between salinities on the center and ridge was 0.1 ppt and while statistical different this difference may not be biologically significant.

***Quercus* Field Studies**

Acorn recovery in the field was higher with cage protection for both species; there was 36% presence of *Q. geminata* and less than 1% presence of *Q. myrtifolia* without cages. This gross loss of acorns indicates a potentially high rate of herbivory for acorns in this environment. Briggs and Smith (1989) have shown other members of the red oak

group to have higher concentrations of fats, proteins and tannic acids. Higher loss of *Q. myrtifolia* acorns, suggests that these fruit are more desirable to herbivores. Presence was lower with vegetation cover than lack of vegetation for both *Q. geminata* and *Q. myrtifolia* acorns. This is consistent with a study which found the probability of seed removal by herbivores to be increased with thicker vegetation cover (Perez-Ramos et al. 2008).

Cages were utilized to ensure availability of field germination information. Though acorn presence was higher with cage protection, cages were not totally effective in preventing acorn loss. For *Q. geminata* there was 58% presence within cages and only 14% presence within cages for *Q. myrtifolia*. Cages were not totally enclosed; the bottom had an opening to allow for placement over vegetation. The lack of protection from all sides of the cage allowed access for burrowing herbivores to enter the cage. Since the cages were constructed with 0.635cm (¼ inch) wire mesh, it would not have been possible for acorns to move out of cages unless the acorns were removed from the bottom opening. *Quercus* acorns are a food source for many mammals (Silvertown 1980). Herbivores present on SRI which would be capable of burrowing include: beach mice (*Peromyscus polionotus* sp.) and cotton rats (*Sigmodon hispidus*). In the treatment where cages were moved, there was presence of raccoon (*Procyon lotor*) tracks. This indicates that raccoons may have removed acorns outside of cages as well. Germination of *Q. geminata* was only 15% in the field. There was a major rain event the fourth week post planting (October 24, 2007) where the site received 35.6cm of rain over a five day period (National Weather Service 2008). This rain event caused center swale locations to be inundated, causing plots to be submerged for a period of days. Standing water was

sampled in the center of the swales for salinity the day following the rain event; 0 ppt salinity was found at all six swale replications. This long period of inundation could have negatively affected germination rates. A study on Mediterranean oaks found that excess soil moisture reduced germination and lengthened time of emergence (Urbieta et al. 2008).

In contrast, the significant rain event may have decreased potential for acorn movement. In a study of seed movement in tidal marshes, it was found that water logged seeds were more likely to be retained at the site (Chang et. al 2008). The increase in seed mass caused by water logging could have decreased potential for seed movement caused by wind for surface seeds.

In comparison, both *Q. myrtifolia* recovery and germination were greatly different from that of *Q. geminata*. Recovery of *Q. myrtifolia* was much lower with less than 1% recovery for uncaged acorns at the end the study. However, germination of *Q. myrtifolia* was higher at 75%. Burial increased germination and recovery for both species in the field.

***Quercus geminata* Greenhouse Studies**

Burial increased germination in the greenhouse studies. This coincides with findings that burial of both *Quercus ilex* (Holm oak) and *Quercus rubra* (red oak) promote germination (Gomez 2004 and Garcia et al. 2004). In addition to deterring seed predation, burial can provide seeds with more favorable edaphic conditions for germination (Gomez 2004). Unfavorable edaphic conditions faced by unburied acorns included exposure to constant sunlight with a potentially high loss of moisture and, on barrier islands, exposure to salt spray.

Greenhouse experiments demonstrated that salinity had a negative effect on germination. Salinity of 8 ppt reduced germination while salinities of 15 ppt and 22 ppt severely reduced or prevented germination. Similar negative effects of salinity on germination have been illustrated in a natural setting. Storm surges and overwash events introduce sea water and create a punctuated disturbance which is an important factor in the mortality of seedlings and saplings (Smith 1997). Storms are important in regulating the distribution of maritime forest communities (Oosting 1954).

Yi and Zhang (2008) found that germination of *Quercus mongolica* is negatively influenced by insect infestation. Insecticides were effective in eliminating insect larvae in all but one acorn. The 2 hour application of insecticide increased germination. This could be because all insects were not effectively killed with a one hour soak or because a two hour soak provided more moisture retention, preventing dehydration of the seed.

***Quercus myrtifolia* Greenhouse studies**

Only Experiment 4 explored germination of *Q. myrtifolia* in soil at field capacity in comparison to 25% field capacity. In this case, soil moisture was a significant factor in the germination of *Q. myrtifolia*. The greatest germination rates were in the absence of salt at FC for buried acorns. Germination for buried acorns at all other salinities at FC was 0-12%. The pattern of germination was similar for surface acorns at FC, where there was significantly greater germination in the absence of salinity (0 ppt), 37.3%, and a steep drop in germination for all other salinities, 0-6.0%. In contrast, only buried acorns germinated at 25% FC (1.3%) and only in the absence of salinity (0 ppt).

The two germination experiments for *Q. myrtifolia* had the 25% FC moisture level, seed placement treatments, and the four salinity levels in common. In Experiment 4 no germination occurred with the soil at 25% field capacity regardless of placement and

in the presence of salinity germination failed regardless of burial or placement. However, in Experiment 5, germination was 25.2% for surface acorns and 37.9% for buried acorns, in the absence of salinity and the soil at 25% FC. This improvement in germination from 0% (Exp. 4) to 25-37% (Exp. 5) suggests the effects of cold storage warrant a further investigation since this was a major difference in the comparison of this data between the two experiments.

Although seed successfully germinated in the soil at 25% field capacity there was not sufficient moisture to support subsequent growth and establishment and 100% of germinated acorns in Experiment 5 died.

Acorn Weight

Quercus greenhouse studies found that acorn fresh weight was influenced by soil moisture, salinity and burial. The absence of salinity, higher soil moisture, and burial allowed retention of moisture within the seed. Bonafil (1998) found a correlation between seed fresh and dry mass for *Quercus rugosa* ($r^2=0.995$) and *Quercus laurina* ($r^2=0.992$) and showed that fresh mass is an indicator of the amount of reserves available for seedling growth. Sensitivity of acorns to edaphic conditions such as soil moisture influence seedling development and reiterate Harper's (1977) view that seeds require safe sites for germination.

Table 2-1. Average soil moisture and salinity (8 and 15cm) for 6 swales. Samples were taken at center and ridge locations and within vegetated and unvegetated subplots within each location. Means within a row followed by the same letter do not differ (alpha=0.5).

Date	Center				Ridge			
	Vegetated		Unvegetated		Vegetated		Unvegetated	
	8 cm	15 cm	8 cm	15 cm	8 cm	15 cm	8 cm	15 cm
Moisture (%)								
15-Sep	11.1 a	9.5 a	10.1 a	20.7 a	1.5 a	3.0 a	4.5 a	3.9 a
28-Sep	13.1 a	13.7 a	12.6 a	14.0 a	3.4 b	2.3 b	3.1 b	3.5 b
17-Oct	100.0 a	100.0 a	100.0 a	100.0 a	13.6 b	15.7 b	13.0 b	16.5 b
17-Nov	.	3.6 a	4.0 a	2.9 a	1.2 a	1.3 a	1.4 a	1.6 a
17-Dec	5.6 a	5.6 a	7.0 a	7.0 a	7.0 a	2.5 a	1.5 a	5.6 a
18-Mar	7.7 a	7.7 a	7.7 a	7.7 a	0.1 c	0.0 c	2.1 b	2.0 b
Salinity (ppt)								
28-Sep	0.2 a	0.3 a	0.2 a	0.2 a	0.1 a	0.1 a	0.1 a	0.1 a
17-Oct	0.0 a	0.0 a	0.0 a	0.0 a	0.1 a	0.1 a	0.1 a	0.1 a
17-Nov	0.3 a	0.1 a	0.2 a	0.1 a	0.1 a	0.1 a	0.1 a	0.0 a
17-Dec	0.1 a	0.1 a	0.2 a	0.1 a	0.1 a	1.5 a	0.1 a	0.1 a
18-Mar	0.2 a	0.1 b	0.2 a	0.1 b	0.1 b	0.1 b	0.1 b	0.1 b

Table 2-2. ANOVA for the effects of location, vegetation and seed placement on germination of *Quercus geminata* in association with barrier island swales; Field Experiment.

Source	Degrees of Freedom	ANOVA Sums of squares	Mean Square	F Value	Pr > F
Location	1	0.52	0.52	0.15	0.6978
Vegetation	1	0.02	0.02	0.01	0.9380
Location*Vegetation	1	0.19	0.19	0.06	0.8156
Seed Placement	1	13.02	13.02	3.82	0.0575
Location*Seed Placement	1	0.19	0.19	0.06	0.8156
Vegetation*Seed Placement	1	0.19	0.19	0.06	0.8156
Location*Vegetation*Seed Placement	1	1.02	1.02	0.30	0.5871

Table 2-3. ANOVA for the effects of location, vegetation and seed placement on germination of *Quercus geminata* in association with barrier island swales; Field Experiment.

Source	Degrees of Freedom	ANOVA Sums of squares	Mean Square	F Value	Pr > F
Location	1	37.69	37.69	0.94	0.3686
Vegetation	1	108.02	108.02	2.71	0.1510
Location*Vegetation	1	0.00	0.00	0.00	1.0000
Seed Placement	1	12.62	12.62	0.32	0.5942
Location*Seed Placement	1	54.05	54.05	1.35	0.2886
Vegetation*Seed Placement	1	4.52	4.52	0.11	0.7470

Table 2-4. ANOVA for the effects of salinity, soil moisture and seed placement on germination of *Quercus geminata* in Milton, Florida; Experiment 1.

Source	Degrees of Freedom	ANOVA Sums of squares	Mean Square	F Value	Pr > F
Salinity	3	16155.78	5385.26	44.73	<.0001
Soil Moisture	1	2722.58	2722.58	22.61	<.0001
Salinity*Soil Moisture	3	143.01	47.67	0.40	0.7561
Seed Placement	1	9506.58	9506.58	78.96	<.0001
Salinity*Seed Placement	3	3016.37	1005.46	8.35	<.0001
Soil Moisture*Seed Placement	1	33.61	33.61	0.28	0.5981
Salinity*Soil Moisture*Seed Placement	3	2027.36	675.79	5.61	0.0011

Table 2-5. Fresh weight (grams) of *Quercus geminata* acorns 64 days after planting on the surface or buried in soil watered with 4 levels of salt water; Experiment 1. Means within a column followed by the same letter do not differ (alpha=0.5).

Salinity (ppt)	Buried	Surface	P value
0	1.9 a	1.3 a	<.0001
8	1.5 b	1.1 b	<.0001
15	1.5 b	1.2 a	<.0001
22	1.4 b	1.2 a	0.0021

Table 2-6. ANOVA for the effects of salinity, soil moisture and seed placement on germination of *Quercus geminata* in Gainesville, Florida; Experiment 2.

Source	Degrees of Freedom	ANOVA Sums of squares	Mean Square	F Value	Pr > F
Salinity	3	7802.21	2600.74	14.49	<.0001
Soil Moisture	1	160.55	160.55	0.89	0.3478
Salinity*Soil Moisture	3	1294.89	431.63	2.41	0.0755
Seed Placement	1	293.88	293.88	1.64	0.2053
Salinity*Seed Placement	3	654.96	218.32	1.22	0.3109
Soil Moisture*Seed Placement	1	67.18	67.18	0.37	0.5428
Salinity*Soil Moisture*Seed Placement	3	339.45	113.15	0.63	0.5980

Table 2-7. ANOVA for the effects of salinity, soil moisture, length of insecticide soak and seed placement on germination of *Quercus geminata* in Milton, Florida; Experiment 3.

Source	Degrees of Freedom	ANOVA Sums of squares	Mean Square	F Value	Pr > F
Salinity	3	17472.36	5824.12	16.15	<.0001
Soil Moisture	1	7111.02	7111.02	19.72	<.0001
Salinity*Soil Moisture	3	2495.66	831.89	2.31	0.0797
Seed Placement	1	1067.71	1067.71	2.96	0.0877
Salinity*Seed Placement	3	414.41	138.14	0.38	0.7653
Soil Moisture*Seed Placement	1	111.12	111.12	0.31	0.5798
Salinity*Soil Moisture*Seed Placement	3	4597.95	1532.65	4.25	0.0067
Soak	1	3999.80	3999.80	11.09	0.0011
Salinity*Soak	3	2846.50	948.83	2.63	0.0529
Soil Moisture*Soak	1	1210.00	1210.00	3.36	0.0693
Salinity*Soil Moisture*Soak	3	401.17	133.72	0.37	0.7741
Seed Placement*Soak	1	444.29	444.29	1.23	0.269
Salinity*Seed Placement*Soak	3	188.83	62.94	0.17	0.9134
Soil Moisture*Seed Placement*Soak	1	134.40	134.40	0.37	0.5426
Salinity*Soil Moisture*Seed Placement*Soak	3	498.82	166.27	0.46	0.7099

Table 2-8. Fresh weight (grams) of *Quercus geminata* acorns 80 days after planting on the surface or buried in soil watered with 4 levels of salinity at field capacity (FC) or 25% FC (Experiment 3). Means within a column followed by the same letter do not differ (alpha=0.5).

Salinity (ppt)	Buried		Surface		P value			
	FC	25%FC	FC	25%FC	FC buried vs.	25%FC buried vs.	FC buried vs.	FC surface vs.
					FC surface	25% FC surface	25%FC buried	25%FC surface
0	2.9 a	1.8 a	2.2 a	1.5 a	<.0001	0.9925	<.0001	<.0001
8	2.0 b	1.5 b	2.1 a	1.4 a	0.7830	0.0030	0.1996	<.0001
15	1.7 b	1.5 b	1.9 b	1.6 a	0.3014	0.0383	0.0785	0.0549
22	2.0 b	1.5 b	1.8 b	1.6 a	0.1884	0.7262	0.0004	0.057

Table 2-9. ANOVA for the effects of salinity, soil moisture and seed placement on germination of *Quercus myrtifolia* in Milton, Florida; Experiment 4.

Source	Degrees of Freedom	ANOVA Sums of squares	Mean Square	F Value	Pr > F
Salinity	3	21872.05	7290.68	119.20	<.0001
Soil Moisture	1	10999.17	10999.17	179.83	<.0001
Salinity*Soil Moisture	3	20811.17	6937.06	113.42	<.0001
Seed Placement	1	1482.31	1482.31	24.23	<.0001
Salinity*Seed Placement	3	2493.77	831.26	13.59	<.0001
Soil Moisture*Seed Placement	1	1323.65	1323.65	21.64	<.0001
Salinity*Soil Moisture*Seed Placement	3	2143.10	714.37	11.68	<.0001

Table 2-10. Fresh weight (grams) of *Quercus myrtifolia* acorns 90 days after planting on the surface or buried in soil watered with 4 levels of salinity at field capacity (FC) or 25% FC (Experiment 4). Means within a column followed by the same letter do not differ (alpha=0.5).

	Soil Moisture		
	FC	25%FC	P value
Buried	1.3	1.1	0.0002
Surface	1.2	1.0	0.0004
Salinity (ppt)			
0	1.4 a	1.0 a	<0.0001
8	1.2 b	1.1 a	0.0058
15	1.15 b	1.1 a	0.1230
22	1.15 b	1.1 a	0.0082

Table 2-11. ANOVA for the effects of salinity, soil moisture, length of cold storage and seed placement on germination of *Quercus myrtifolia* in Gainesville, Florida; Experiment 5.

Source	Degrees of Freedom	ANOVA Sums of squares	Mean Square	F Value	Pr > F
Salinity	3	10055.57	3351.86	62.40	<.0001
Soil Moisture	1	6.53	6.53	0.12	0.7284
Salinity*Soil Moisture	3	316.24	105.41	1.96	0.1285
Seed Placement	1	1087.52	1087.52	20.25	<.0001
Salinity*Seed Placement	3	152.74	50.91	0.95	0.4229
Soil Moisture*Seed Placement	1	234.96	234.96	4.37	0.0405
Salinity*Soil Moisture*Seed Placement	3	598.38	199.46	3.71	0.0162

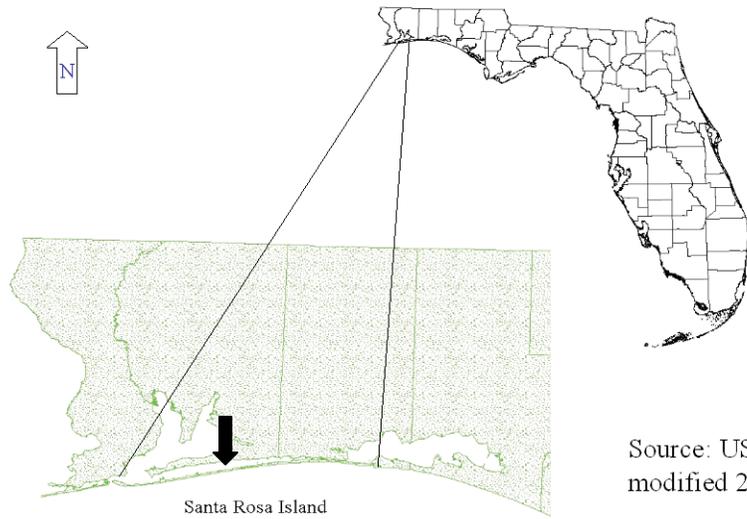
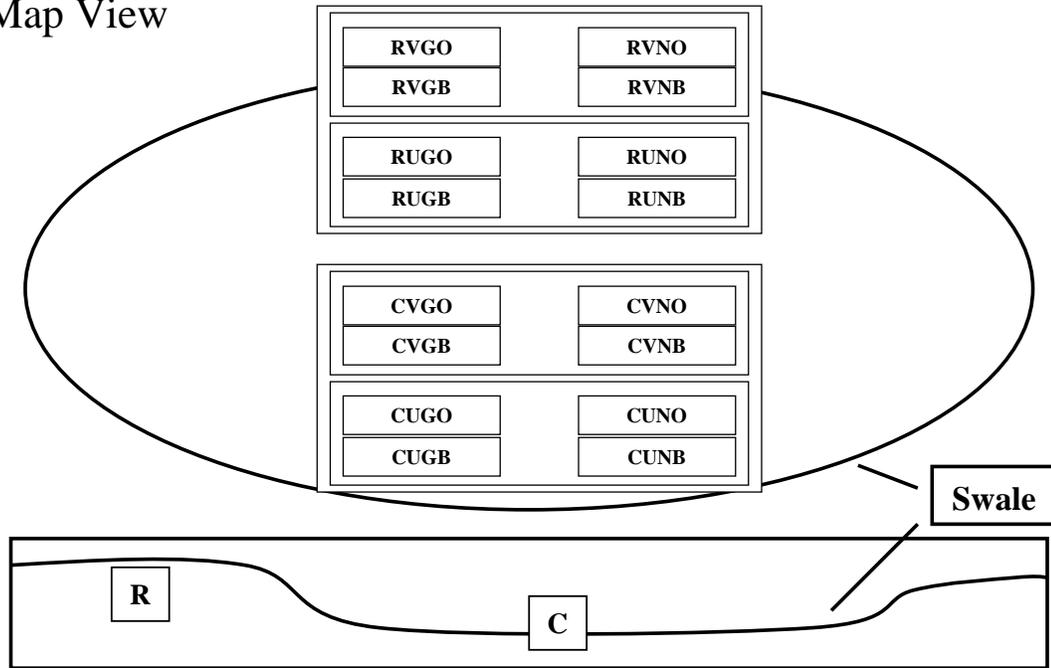


Figure 2-1. Santa Rosa Island field study. The black arrow indicates the approximate location of the study site.

Map View



Side View

Figure 2-2. Map view of a representative swale replication showing how treatment combinations were randomly assigned to split plots. The factorial arrangement of treatments included location (C = center, R= ridge) vegetation cover (V = vegetated, U = unvegetated), protection G = caged, N = non caged and placement (B = buried and O = unburied).

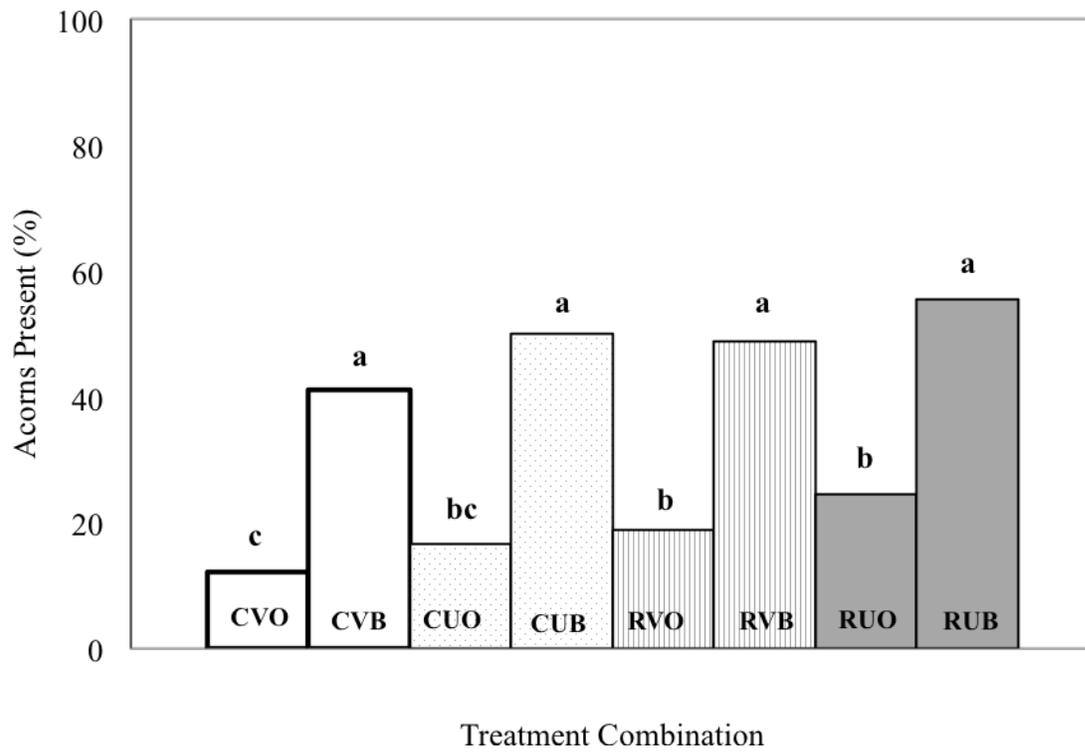


Figure 2-3: Percentage of *Q. geminata* acorns present among six swales 87 days after placement in the field where a factorial arrangement of treatments included location (C=center, R=ridge), vegetation cover (V=vegetated, U=unvegetated), and seed placement (O=surface and B=buried). Means with the same letter do not differ ($\alpha=0.5$).

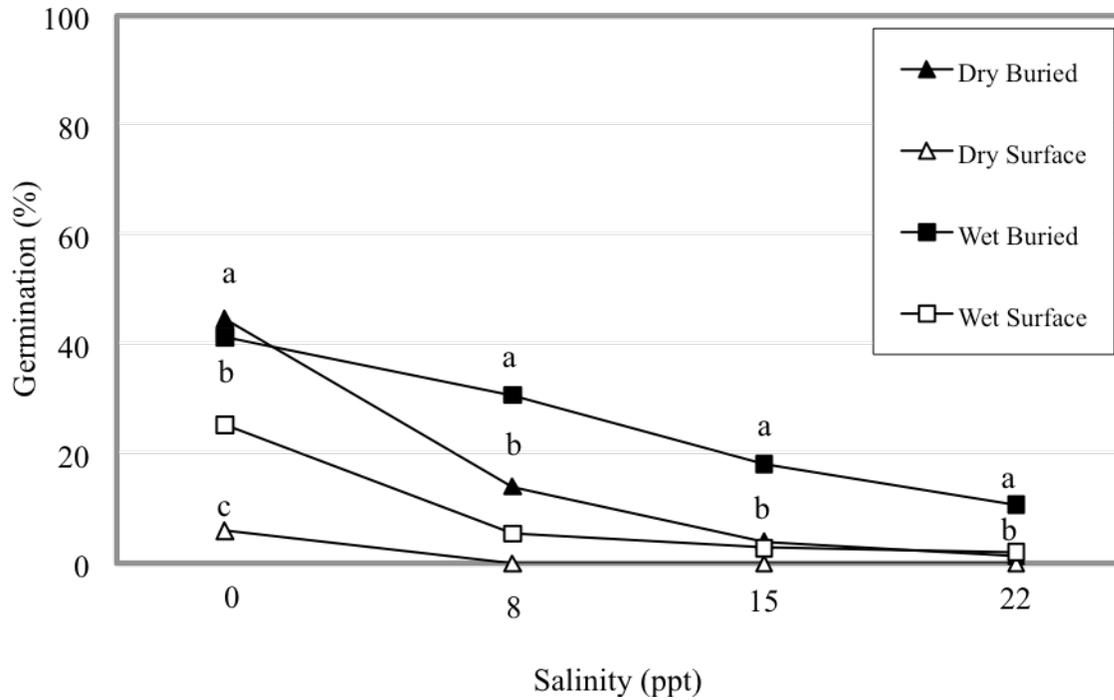


Figure 2-4. Germination (%) of *Quercus geminata* (Experiment 1) 64 days after planting for acorns (placed on the surface or buried), where Dry=25% field capacity Wet=field capacity and with four levels of salinity (parts per thousand). Means (within each salinity) followed by the same letter do not differ from each other (alpha=0.5).

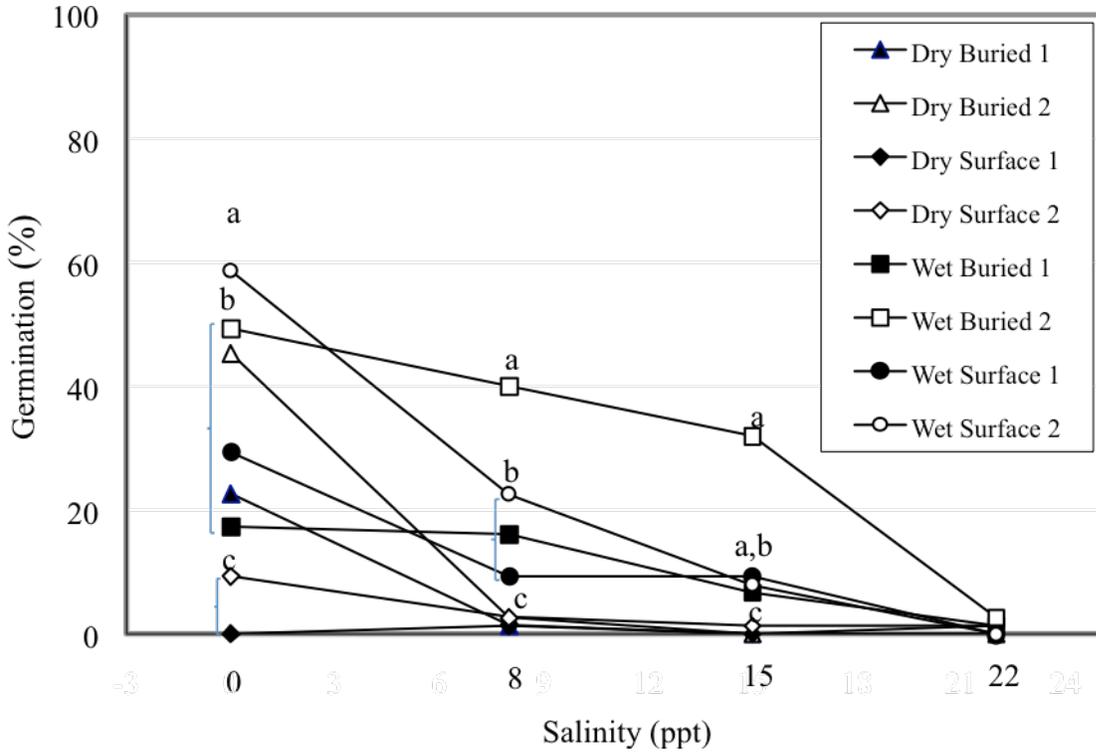


Figure 2-5. Germination (%) *Quercus geminata* (Experiment 3) pretreated with Permethrin (2oz./gal) 80 days after planting where 1= 1 hour soak (solid) and 2= 2 hour soak (hollow), acorns (placed on the surface or buried), where Dry=25% field capacity Wet=field capacity and with four levels of salinity (parts per thousand). Means (within each salinity) followed by the same letter do not differ from each other (alpha=0.5).

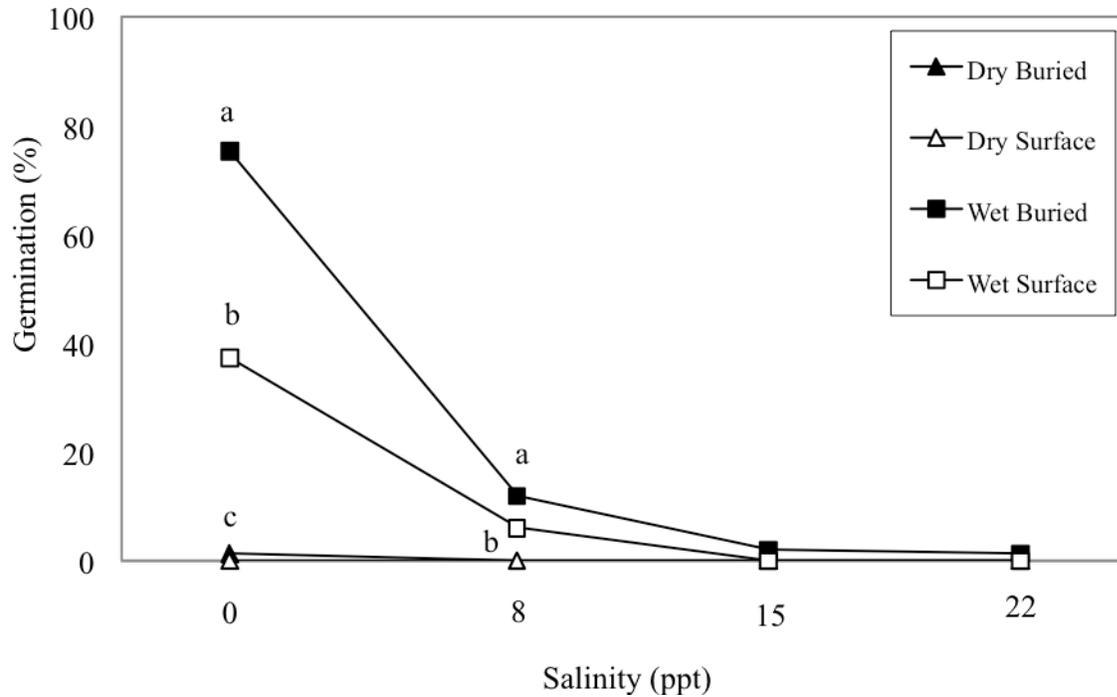


Figure 2-6. Germination (%) *Quercus myrtifolia* (Experiment 4) 80 days after planting for acorns (placed on the surface or buried), where Dry=25% field capacity Wet=field capacity and with four levels of salinity (parts per thousand). Means (within each salinity) followed by the same letter do not differ from each other (alpha=0.5).

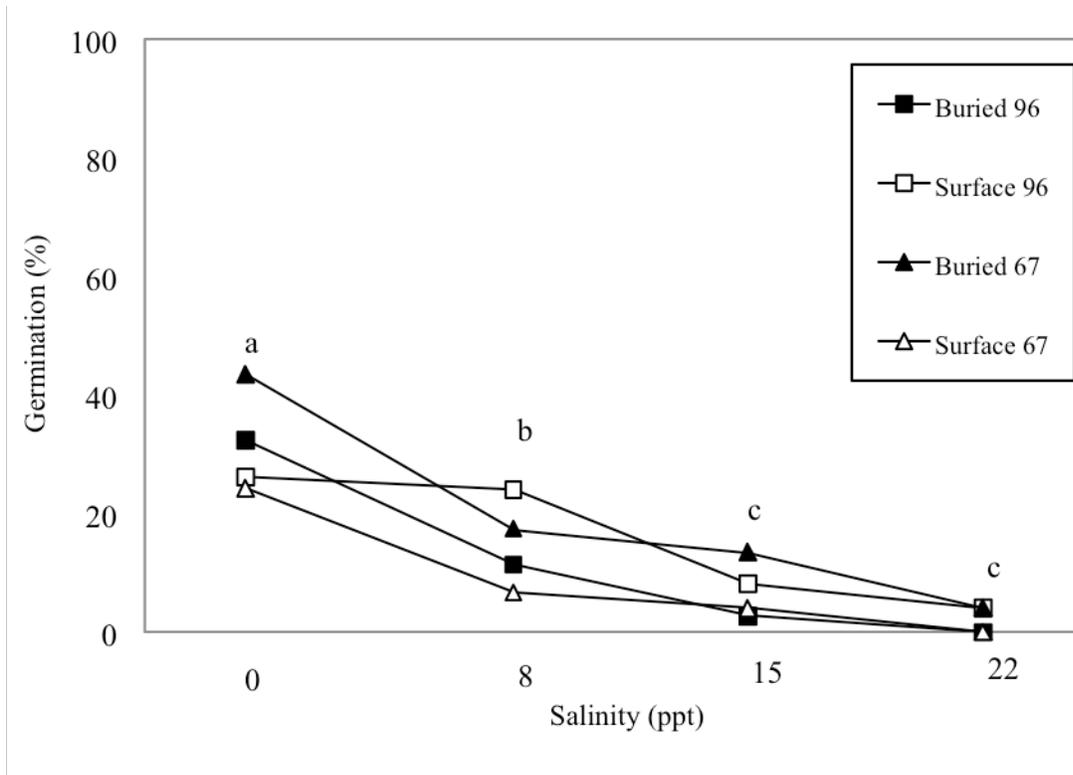


Figure 2-7. Germination (%) of *Quercus myrtifolia* (Experiment 5) cold storage germination trial 60 days after planting where 96= 96 days of cold storage and 67= 67 days of cold storage for acorns (placed on the surface or burried) and with four levels of salinity (parts per thousand). Means across salinities followed by the same letter do not differ (alpha=0.5).

CHAPTER 3
EVALUATION OF *Morella cerifera* ESTABLISHMENT IN INTERDUNAL SWALES

Introduction

The dynamism of barrier island ecosystems is influenced by natural disturbances and the harshness of the environment. Barrier island vegetation develops along zones established by varying abiotic conditions (Ehrenfeld 1990). Two of the abiotic conditions that characterize barrier islands are salt spray and limited water availability. Soil moisture levels can be determined by the capacity of the soil to retain water and the availability of water within the landscape. Soils of barrier islands often consist of well drained sands and vegetation relies on the height of the water table and precipitation for required moisture. The ground water on barrier islands is consolidated in a fresh or brackish water lens which floats above saline water (Schneider 2003). Terrain and vegetation patterns are the controlling factors for these lenses; variability in both promotes lens formation (Schneider 2003).

Tolerance of salt spray is correlated with succession and zonation of coastal vegetation (Oosting 1945). The intensity of salt spray on dunes and ridges prohibits the growth of plants which would be found on these exposed areas in the absence of salt spray (Boyce 1954). Salt spray causes the accumulation of chloride ions in the tissues of coastal plants which leads to necrosis of leaves and twigs and sometimes death (Boyce 1954). Necrosis is the localized death of living cells. Abrasion of leaves from wind creates traumata which are areas of entry for the salts (Boyce 1954). Broad leaved species on barrier islands are subject to constant salt spray and assume a salt-pruned, bonsai appearance (Kindell et al. 1997).

In addition to harsh, daily environmental conditions, barrier islands in the eastern United States are subject to the brunt of tropical storms. Barrier islands throughout the Gulf of Mexico have recently experienced an increased frequency and intensity of hurricanes, potentially

associated with climate change (Saunders and Lea 2008). Intense storms alter dune structure and kill vegetation. Foredunes are most heavily impacted by storm surge; loss of foredunes increases impact of subsequent storms on back barrier island plant communities (Pries et al. 2008). Increased storm frequency also limits natural regeneration of vegetation and rebuilding of dunes. The prediction of continuing climate change lends urgency to development of restoration strategies for barrier islands.

Wax myrtle (*Morella cerifera* Small) (here after referred to as *M. cerifera*) is a dioecious woody shrub species common on barrier islands on the Atlantic and Gulf coasts and areas on the mainland. *M. cerifera* has 5-10 cm catkins which flower from April to May and produce a 4mm drupe which is covered in resinous wax; this is where the common name wax myrtle is derived. Fruit of *M. cerifera* ripens from August to October. To germinate the waxy seed coat must be removed (U.S. Forest Service). This plant is most likely wind pollinated like other members of the oak superfamily (Fagales) (Erickson 2004 and citations within). Mature individuals can grow to 10m tall. However, shorter individuals are present on barrier islands.

Establishment of *M. cerifera* seedlings is limited by abiotic conditions (Shao et al. 1995). The sharp environmental gradients caused by proximity to the open ocean cause this species to be present behind the protection of foredunes (Ehrenfeld 1990). Fresh water availability is another important factor in *M. cerifera* establishment on barrier islands (Shao et al. 1995). A study done with transplants found coastal plant survival and growth can differ with differing container sizes (Thetford 2005). Plants produced in containers with a deeper rooting capacity will have greater root develop at the time of transplant, increased ability to reach available water and thus a better chance at establishment.

Once established, clonal growth, high photosynthetic potential, symbiotic nitrogen fixation and prolific seed production allows *M. cerifera* to rapidly form thickets within mesic interdunal swale communities, stabilized dunes and protected microsites (Young 1992, Stallins 1997). As a result of competition, the recruitment of this species is also negatively effected by presence of mature thickets (Young et al. 2007). Information on whether establishment of this species is negatively affected by competition of grasses and forbs which occur in interdunal swales is not currently available.

On Santa Rosa Island (SRI) *M. cerifera* provides woody structure within a matrix of herbaceous interdunal swales. However, *M. cerifera* is absent from interdunal swales found in sections of SRI most recently and severely impacted by saline overwash from tropical storms. Recruitment of *M. cerifera* into interdunal swales of SRI has rarely been noted since Hurricanes Ivan (2004) and Dennis (2005) impacted the island. Along with loss of shrubs, bird attracting structure has been lost on the SRI due to storm events. Tree mortality was near 100% in swales across much of SRI (unpublished data) after hurricane Ivan (2004) and Dennis (2005) as a result of salt water overwash coupled with strong winds. *M. cerifera* relies upon birds for dispersal. Bird attracting structures such as perches can increase the diversity and abundance of bird dispersed seeds (Chambers and MacMahon 1994). A decline in recruitment of this species could occur due to loss of bird attracting structures in combination with other anthropogenic habitat alterations. Restoration of *M. cerifera* may be necessary in disturbed areas to maintain natural diversity of plant species as well as enhancing altered wildlife habitat.

Evaluation of establishment of *M. cerifera* on barrier island interdunal swales is relevant to understanding the ecology of the species within this landscape and the potential for restoration of the species to the landscape. The objective of this study is to: evaluate of the effect of season

of planting, swale position, vegetation cover, watering regime and container shape on *M. cerifera* establishment.

Study Site

The study was conducted on Santa Rosa Island (30°24'N, 81°37'W) an approximately 60km long and 1km wide Holocene barrier island within the Gulf Coast Lowlands (NRCS 2004) (Fig 1). The island supports a system of sand dunes and beach ridges with undulating elevation from mean sea level to 15m. Soil on the island is characterized as quartz sand and shell beds (NRCS 2004). Accumulation of organic matter occurs in low elevation, ephemerally inundated swales (from now on referred to as interdunal swales or swales) (NRCS 2004). The climate of Santa Rosa Island is subtropical with average temperature and humidity of 20.6°C and 41.5%, respectively during the study (May 2007 to June 2008). (National Weather Service, Inc. 2008) Total precipitation during the study year was 171 cm; mean annual precipitation was 152cm. Specific planting sites were located in the interdunal swale system of the barrier island in an area owned and managed by Escambia County Parks near Pensacola Beach, Florida.

Like most barrier islands, Santa Rosa Island has linear zones of vegetation beginning from the Gulf to Santa Rosa Sound including beach dunes, coastal grasslands, interdunal swales and maritime hammocks or scrub (Ehrenfeld 1990, Kindell et al. 1997). Beach dunes are ever changing with rapid deposition and erosion of sand and are dominated by grasses including *Uniola paniculata* L. (sea oats), *Panicum amarum* Elliot (bitter panicum) and *Schizachyrium maritimum* Nash (Gulf bluestem) and other salt tolerant vegetation such as *Iva imbricata* Walter (beach elder), *Cakile constricta* Rodman (sea rocket) (Kindell et al. 1997). Coastal grasslands occur on gently undulating or flat terrain and are dominated by *U. paniculata*, *P.amarum*, *S.maritimum*, and *Dichantheium aciculare* Gould & Clark (needle-leaf panic grass). Interdunal swales are marsh-like in quality are dominated by *Fuirena scirpoidea* Michx.(umbrella sedge),

Cyperus lecontei Torr. Ex. Stud. (LeConte's flatsedge), *Xyris* sp. (yellow-eyed grass), *Lachnanthes caroliniana* Lamarck (red-root), *Juncus megacephalus* Curtis (big-head rush), *Juncus roemerianus* Scheele (black needlerush), *Andropogon virginicus* var. *glaucus* L. (glaucus broomsedge), *Panicum tenerum* (Bey ex. Trin) (bluejoint panic grass) and *Spartina patens* Aiton. (marsh hay) and can be colonized by woody species such as *M. cerifera*. The maritime forest has a species composition similar to Florida's xeric scrub communities and scrubby flatwoods. The dominant species in the scrubby flatwood canopy is *Pinus elliottii* Elliot (slash pine) with a variable understory of *Q. geminata*, *Q. myrtifolia*, *Magnolia grandiflora* L. (Southern magnolia) or other shrubs (Kindell et al. 1997).

Methods

Saplings

For experiments 1 and 2 *M. cerifera* saplings were used. Twelve hundred sixty *M. cerifera* saplings were purchased from Ornamental Plants Nursery in Hawthorne, Florida. These plants were conditioned outside of the greenhouse before planting in the field. For the purpose of this study, a sapling is defined as a plant which is no longer reliant on the seed for nutrients. Saplings were grown from seed in trays with 60 cavities; each cavities volume was approximately 100mL. There were multiple saplings in each cavity: up to 10. All but one of these saplings was cut to the soil level prior to field planting. The single remaining saplings were similar in stem width and height.

Cuttings

For experiment 3, *M. cerifera* propagated cuttings were used to assess the effect of container shape on establishment. Two container shapes were used: SR 225 rose pot (here after referred to as rose pot) [7.5cm deep and 4cm x 4cm wide at the base and

5cm x 5cm wide at the top (Lerio Corp., Kissimmee, FL)] and 164mL RLT (here after referred to as RLT [21cm deep and have a 1cm diameter at the base and a 4cm diameter at the top (Ray leach tube SC-10; Stuewe & Sons Inc)]. Both containers have approximately the same volume. *M. cerifera* cuttings were propagated vegetatively; 160 were grown in rose pots and 160 were grown in RLTs. Cuttings were taken on July 8, 2007 and August 11, 2007 from 5 mature individuals whose ecotype is native to SRI. The cuttings were placed in plastic bags and bags were placed in a cooler with ice. In the greenhouse, the clipped end of the cutting was clipped again, dipped in Dip and Grow root inducing concentrate [1.0% Indole Butyric Acid, 0.5% 1-Naphthaleneacetic acid, 98.5% inert ingredients (Dip and Grow, Inc., Clackamas, Oregon)] and stuck 1cm deep into rose pots or RLTs filled with Fafard 3B [45% peat, 25% bark, 15% perlite, 15% vermiculite (Conrad Fafard Inc., Agawam, Mass., 01001)] moist growing media. The cuttings were then placed on a mist bench for 4 weeks and misted for 5 seconds every 10 minutes and for 5 seconds every hour until roots were present. Once roots were present cuttings were removed from the mist bench and watered 1-5 times a week until planted in the field. These cuttings were not acclimated outside of the greenhouse before planting.

Soil Evaluation

Soil moisture and salinity were taken at each of the 6 replications under the following hierarchical treatments: center or ridge, vegetated or unvegetated and 8cm below the soil surface or 15cm below the soil surface. Soil moisture was determined by gravimetric water content. Soil salinity was determined using the HI 9813 Portable pH/EC/TDS/⁰C Meter (Hanna Instruments, Sarmeola di Rubano, Italy).

Experiment 1: Evaluation of swale location, vegetation cover and water regime

Necrosis and survival of *M. cerifera* saplings was assessed when planted in various environmental conditions in association with interdunal swales. Necrosis was assessed visually

by the percentage of non-living leaves and twigs on each plant. This experiment followed a $2 \times 2 \times 2$ factorial arrangement of treatments with the following: location (center or ridge of swale), vegetation (vegetated or unvegetated), watering regime (watered or unwatered).

A split, split plot experimental design was used (Figure 3-2). In each of six randomly selected swales (replications), saplings were planted under eight treatment combinations. Within each swale, two locations, the elevated ridge surrounding the swale and the concave, center of the swale, represented whole plot treatments. Whole plots were split into vegetated and unvegetated subplots. Unvegetated subplots were established when vegetation was killed by placing black plastic over 3 m² plots for 1 month or more at the two swale locations in each swale. The plastic was removed on the day of planting and remaining dead vegetation was removed manually. Vegetated subplots contained approximately 50% cover of interdunal vegetation. Sixteen saplings were planted 30 cm apart in each location and vegetation cover combination. Cover subplots were further subdivided by watering regime with eight saplings receiving no supplemental water and the remaining eight saplings receiving 500 ml of water the day of planting and weekly thereafter for 5 weeks. Placements of subplots were randomized at each site.

Saplings were planted September 23, 2007 (September planting). There was no watering on week 4 and 5 due to inundation of plots from a major rain event. Necrosis was assessed weekly beginning 1 week after planting and continued 5 weeks post planting.

Experiment 2: Evaluation of Season of Planting, Swale location, Vegetation cover and a modified watering regime

To assess the effect of planting season and a different watering regime, *M. cerifera* saplings were planted on November 8, 2007 (November planting) and again on March 18, 2008 (March planting) with the an experimental design similar to Experiment 1 (Figure 3-2).

Experiment 2 had a $2 \times 2 \times 2 \times 2$ factorial arrangement of treatments and utilized a split, split plot experimental design. The watering regime was modified to provide two treatments: saplings received 500 ml of water the day of planting and no supplemental water thereafter (unwatered) or they received 500 ml of water the day of planting, were watered daily for the first week and watered once weekly for the next 5 weeks (watered). Factorial treatment combinations included season of planting (November or March), location (center or ridge) and watering regime (watered or unwatered).

Experiment 3: Evaluation of location, vegetation cover and container shape

The effect of location within swales, vegetation cover and container shape on *M. cerifera* cuttings was evaluated at five replicate swale sites on March 18, 2008. The experimental design was similar to Experiments 1 and 2 except no supplemental water was supplied (Figure 3-3). Instead, half the saplings planted into the location/cover subplots were grown in rose pots (n=8) while half were grown in RLTs (n=8) (Figure 3-2). Experiment 3 utilized a split, split plot experimental design and had a $2 \times 2 \times 2 \times 2$ factorial arrangement of treatments: location (center or ridge), cover (vegetated or unvegetated) and container shape (rose pot or RLT).

Plantings were blocked according to the date when cuttings were propagated; swales 1-2 used cuttings from July 11, 2007 and swales 3-5 used cuttings from August 9, 2007. Subplot locations were randomized at time of planting. Cuttings were not acclimated outside of the greenhouse prior to being planted in the field.

Data Collection

Percent necrosis of each plant was estimated each week from 1-5 weeks after planting for both fall plantings for Experiment 1. Percent necrosis of each plant was estimated for weeks 2-5

after planting for Experiment 2 (data was not collected the first week after planting). Survival of each plant was determined for Experiments 1, 2 and 3 on May 28, 2008.

Analysis

Statistical analyses were performed using SAS 9.1 (2008 SAS Institute Inc.). Percent necrosis was analyzed using mixed models procedure (PROC MIXED) with repeated measures to determine differences in necrosis over time. Survival of plants was analyzed using binomial probability to determine the influence location, vegetation cover and container type through (PROC GLIMMIX).

Results and Discussion

Results

Soil Evaluation

Soil moisture was greater in the center than the ridge for September 28, 07 ($P=0.0101$), October 19, 07 ($P=0.0027$), and March 18, 08 ($P=0.0007$) with no interaction between location and vegetation cover except on March 18, 08 ($P=0.0049$) (Table 3-1). For this date, soil moisture was greater in the center than the ridge regardless of level of vegetation cover. However, the presence of vegetation decreased soil moisture on the ridge ($P=0.0034$) but did not influence soil moisture on the center.

Soil salinity was not influenced by vegetation or depth for any date, and soil salinity was influenced by location only on March 18, 08. For this date, salinity was greater in the center than on the ridge ($P=0.0374$) and greater at 8cm than at 15cm ($P=0.0489$).

Experiment 1

Necrosis

Location influenced necrosis, with all but one sapling 100% necrotic on the ridge after 2 weeks and no decrease in necrosis thereafter. As a result, further analysis was restricted to the

effects of vegetation, watering and time on necrosis of plants in the center of the swale. Necrosis increased with week ($P=0.0232$) after planting and decreased with the presence of vegetation ($P=0.0205$) and supplemental water ($P=0.0169$) (Table 3-2). Treatment interactions were not significant (Figure 3-4).

Survival

Location effected plant survival, with 100% mortality of plants on the ridge compared to < 10% mortality of plants in the center. Survival of plants in the center was not effected by vegetation cover ($P=0.3440$) (Table 3-3). Watering had a marginal effect with greater survival of watered plants ($P=0.0600$) (Figure 3-4). Treatment interactions were not significant.

Experiment 2

Necrosis

Necrosis was significantly affected by season, location, week, vegetation cover and watering regime (Table 3-4). Necrosis for March plantings ($P<0.0001$) was less than November plantings (Figures 3-5 and 3-6). Ridge plants were more necrotic than center plants ($P<0.0001$). Necrosis did not occur at a consistent rate for center and ridge plants within planting season. As a result, there was a significant three way interaction of season, location and week ($P=0.0167$). For November plantings, necrosis did not differ with location two weeks after transplant. However, ridge plants were more necrotic than center plants weeks 3 and 5 after transplant. Necrosis of center plants did not change from week 2 to 5 while necrosis increased for ridge plants from week 2 to 5. For March plantings, necrosis of ridge plants was significantly greater than center plants for all weeks post transplant. There was no significant change in percent necrosis with time (weeks) for March plantings except on week 5 when necrosis increased for ridge plants. Necrosis was diminished by the presence of vegetation but the magnitude of effect

was greater for November plantings as indicated by a significant vegetation by season interaction ($P=0.0020$). Applying water also decreased necrosis ($P<0.0001$).

Survival

Survival was significantly effected by season, location, vegetation cover and watering regime (Table 3-5). Survival for March plantings was greater than that of November plantings ($P<0.0001$) (Figures 3-7 and 3-8). Survival was greater in the center than the ridge ($P<0.0001$). Presence of vegetation cover had a positive influence on survival ($P<0.0001$) but only for November plantings as indicated by the interaction between season and vegetation cover ($P=0.0126$). In the center, there was higher survival for the March planting than the November planting ($P<0.0001$). However, planting season did not influence survival on the ridge ($P=0.0946$), as indicated by the interaction between season and location. Application of water increased survival ($P=0.0059$).

Experiment 3

Survival

Survival was influenced by location ($P<0.0001$) and container shape ($P=0.0218$) (Table 3-6). Plants in the center had greater survival than plants in the ridge and plants in RLT pots had greater survival than plants in rose pots (Figure 3-9). No plants in rose pots on the ridge survived and survival was low for plants in rose pots in the center (18.8%). No treatment interactions were significant.

Discussion

Soil Evaluation

Salinity was influenced by location on March 18, 08. The difference between salinities on the center and ridge was 0.1 ppt and while statistical different this difference may not be biologically significant.

Field Establishment

Water availability was a major limiting factor to wax myrtle establishment. Survival improved with supplemental water for both Experiment 1 and 2. In addition, survival was greater for all three experiments in the center of the swale where soil moisture was periodically higher. Swales are ephemeral wetlands and have brief periods (hours to days) of standing water immediately following rainfall events. A fresh water lens below the swale may also provide swale plants with moisture for longer periods than would be found on the ridge, which is elevated by deposited sand. RLT pots are twice the depth of rose pots which supported development of deeper root volume and depth compared to rose pots and may have increased accessibility to deeper sources of water also increased plant survival. This is similar to the Anderson et al. (1984) study which found that seedlings of *Pinus taeda* (loblolly pine) produced in RLT containers had higher survival when planted in the field than seedlings produced in open trays or with bare roots. Even in the relatively wet center of the swale, supplemental water and RLT increased survival. This further supports the importance of water availability as a limiting factor. Thus, establishment of *M. cerifera* saplings corresponds with establishment of seedlings which are also limited by fresh water availability (Shao et al. 1995). These results support the hypothesis that woody plants such as wax myrtle found on dunes may have established in swales that were later filled with sand (Clewell 1997)

Differences in moisture stress may have also influenced difference in survival with season of planting. Wax myrtle planted in September would have experienced higher moisture stress due to greater transpiration the first two weeks after plantings in comparison to the November and March plantings. For the first five weeks post planting (September 23, 2007-October 27, 2008), temperature averaged 27.9°C (max) and 18.9°C (min) and rainfall for the site

was 45 cm. There was a major rain event the fourth week post planting (October 24, 2007) where the site received 35.6cm of rain over a five day period. This major event may have occurred too late to prevent 100% loss of ridge plants. Rainfall the first two weeks following plantings was 3.7 cm and soil moisture on the ridge was 3.1%. Even with weekly watering almost all plants on the ridge had necrosis nearing 100% within two weeks. For the November planting for five weeks temperatures averaged 21.0 °C (max) and 9.8 °C (min) and the site received 5.4 cm of rain, with only 0.2cm within the first two weeks after planting. November plantings did not benefit from the major rain event two and a half weeks before planting because soil moisture was 1.4% on the ridge one week post planting. Higher survival rates are most likely due to lower transpiration from lower temperatures. In March, during the first five weeks post planting temperatures were 21.1 °C (max) and 10.7 °C (min) and there was 6 cm of rainfall with 5.5 cm within the first 2 weeks (National Weather Service 2008). Even without weekly watering survival on the ridge improved to 37% (November planting) and 52% (March planting). No plants survived on the ridge in rose pots (Experiment 3). The rose pot treatment was not comparable to unwatered treatments in the other experiments because these plants were not acclimated outside of the greenhouse prior to planting in the field. Since plants for Experiment 3 were not acclimated outside of the greenhouse, planting on a xeric microsite with no supplemental water may have contributed to mortality. The rain event in October caused the center of swales to be submerged for a period of days with water salinity at 0 ppt. Lower percent survival of center plants for this planting could have been caused by hypoxic aquatic submersion. *M. cerifera* fruit ripen from August to October and may develop into saplings by spring. Therefore, the March planting of saplings may be similar to the natural establishment of this species.

Plant necrosis was a rapid indicator of water stress particularly on ridges. Supplemental water decreased necrosis for both ridges and swales plants however, after the first 2 weeks supplemental water was not able to prevent an increase in necrosis for plants on the ridge thereafter. Growth of new foliage in the spring is reflected in the decreasing necrosis with time after planting while fall plants did not develop new growth and necrosis increased or remained constant after planting.

Salt spray, wind speed and direction and soil salinity are also factors potentially influencing wax myrtle establishment. Wind speed and direction influence salt spray injury and moisture relations. Abrasion of leaves from wind creates traumata which are areas of entry for the salts (Boyce 1954). Plants are then susceptible to accumulation of salts which lead to necrosis and potentially mortality (Boyce 1954). Salt spray and drying winds may have more negatively impacted ridge plantings compared to center plantings which may explain lower survival on the ridge compared to the center with supplemental water. Generally, the rim of the swale has greater salt spray than the center of swales (unpublished data).

Differences in wind speed and direction, salt spray and soil salinity did not appear to differ with season of planting. On SRI, wind speeds are generally highest in association with cold fronts (Miller et al. 2001). During the period of the study, average wind speeds were 41mph for both the seven months following the fall planting and the three months following the spring planting (National Weather Service 2008). In addition, dominant wind direction was from the north for the duration of the study. This in combination with similar wind speeds indicates that that all experiments potentially received the same amount of salt spray.

Soil salinity did not generally differ between locations and did not appear to influence wax myrtle survival. At one date soil salinity was higher in the center of the swale compared to

the ridge. With highest survival in the center of the swale it would follow that soil salinity did not negatively influence wax myrtle survival in this study. Quartz sand is highly porous and deposited salts quickly leach out of the rooting zone with rainfall (Clewell 1997).

Table 3-1. Average soil moisture and salinity (8 and 15cm) for 6 swales. Samples were taken at center and ridge locations and within vegetated and unvegetated subplots within each location. Means within a row followed by the same letter do not differ (alpha=0.5).

Date	Center				Ridge			
	Vegetated		Unvegetated		Vegetated		Unvegetated	
	8 cm	15 cm	8 cm	15 cm	8 cm	15 cm	8 cm	15 cm
Moisture (%)								
15-Sep	11.1 a	9.5 a	10.1 a	20.7 a	1.5 a	3.0 a	4.5 a	3.9 a
28-Sep	13.1 a	13.7 a	12.6 a	14.0 a	3.4 b	2.3 b	3.1 b	3.5 b
17-Oct	100.0 a	100.0 a	100.0 a	100.0 a	13.6 b	15.7 b	13.0 b	16.5 b
17-Nov	.	3.6 a	4.0 a	2.9 a	1.2 a	1.3 a	1.4 a	1.6 a
17-Dec	5.6 a	5.6 a	7.0 a	7.0 a	7.0 a	2.5 a	1.5 a	5.6 a
18-Mar	7.7 a	7.7 a	7.7 a	7.7 a	0.1 c	0.0 c	2.1 b	2.0 b
Salinity (ppt)								
28-Sep	0.2 a	0.3 a	0.2 a	0.2 a	0.1 a	0.1 a	0.1 a	0.1 a
17-Oct	0.0 a	0.0 a	0.0 a	0.0 a	0.1 a	0.1 a	0.1 a	0.1 a
17-Nov	0.3 a	0.1 a	0.2 a	0.1 a	0.1 a	0.1 a	0.1 a	0.0 a
17-Dec	0.1 a	0.1 a	0.2 a	0.1 a	0.1 a	1.5 a	0.1 a	0.1 a
18-Mar	0.2 a	0.1 b	0.2 a	0.1 b	0.1 b	0.1 b	0.1 b	0.1 b

Table 3-2. ANOVA for the effects of vegetation cover, watering regime and week after planting on necrosis (%) *Morella cerifera*; Experiment 1.

Source	Degrees of Freedom	ANOVA Sums of squares	Mean Square	F Value	Pr > F
Vegetation	1	858.73	858.73	5.54	0.0205
Water	1	913.73	913.73	5.90	0.0169
Vegetation*Water	1	183.84	183.84	1.19	0.2786
Week	4	1836.67	459.17	2.96	0.0233
Vegetation*Week	4	29.64	7.41	0.05	0.9956
Water*Week	4	38.34	9.59	0.06	0.9928
Vegetation*Water*Week	4	47.36	11.84	0.08	0.9893

Table 3-3. ANOVA for the effects of vegetation cover and watering regime on survival after the first growing season (binomial) *Morella cerifera*; Experiment 1.

Source	Degrees of Freedom	ANOVA Sums of squares	Mean Square	F Value	Pr > F
Vegetation	1	0.08	0.08	1.12	0.2922
Water	1	0.52	0.52	6.97	0.0090
Vegetation*Water	1	0.02	0.02	0.28	0.5980

Table 3-4. ANOVA for the effects of season of planting, vegetation cover, watering regime and week after planting on necrosis (%) *Morella cerifera*; Experiment 2.

Source	Degrees of Freedom	ANOVA Sums of squares	Mean Square	F Value	Pr > F
Season	1	8643.15	8643.15	38.30	<.0001
Location	1	19441.36	19441.36	86.16	<.0001
Season*Location	1	29.71	29.71	0.13	0.7170
Vegetation	1	23602.69	23602.69	104.60	<.0001
Season*Vegetation	1	2643.09	2643.09	11.71	0.0007
Location*Vegetation	1	397.22	397.22	1.76	0.1855
Season*Location*Vegetation	1	254.40	254.40	1.13	0.2891
Water	1	12111.26	12111.26	53.67	<.0001
Season*Water	1	298.49	298.49	1.32	0.2510
Location*Water	1	583.73	583.73	2.59	0.1087
Season*Location*Water	1	221.20	221.20	0.98	0.3229
Vegetation*Water	1	833.68	833.68	3.69	0.0555
Season*Vegetation*Water	1	93.71	93.71	0.42	0.5198
Location*Vegetation*Water	1	195.79	195.79	0.87	0.3523
Season*Location*Vegetation*Water	1	2.30	2.30	0.01	0.9197
Week	3	5265.92	1755.31	7.78	<.0001
Season*Week	3	5204.15	1734.72	7.69	<.0001
Location*Week	3	2465.03	821.68	3.64	0.0131
Season*Location*Week	3	1910.68	636.89	2.82	0.0389
Vegetation*Week	3	117.41	39.14	0.17	0.9143
Season*Vegetation*Week	3	300.15	100.05	0.44	0.7221
Location*Vegetation*Week	3	160.32	53.44	0.24	0.8707
Season*Location*Vegetation*Week	3	72.63	24.21	0.11	0.9558
Water*Week	3	424.36	141.45	0.63	0.5981
Season*Water*Week	3	843.66	281.22	1.25	0.2930
Location*Water*Week	3	89.66	29.89	0.13	0.9407
Season*Location*Water*Week	3	250.17	83.39	0.37	0.7750
Vegetation*Water*Week	3	39.94	13.31	0.06	0.9812
Season*Vegetation*Water*Week	3	72.55	24.18	0.11	0.9559
Location*Vegetation*Water*Week	3	20.44	6.81	0.03	0.9929
Season*Location*Vegetation*Water*Week	3	76.91	25.64	0.11	0.9521

Table 3-5. ANOVA for the effects of season of planting, vegetation cover and watering regime on survival after the first growing season (binomial) *Morella cerifera*; Experiment 2.

Source	Degrees of Freedom	ANOVA Sums of squares	Mean Square	F Value	Pr > F
Season	1	3.66	3.66	18.06	<.0001
Location	1	16.63	16.63	82.12	<.0001
Season*Location	1	0.69	0.69	3.40	0.066
Vegetation	1	0.95	0.95	4.69	0.031
Season*Vegetation	1	1.25	1.25	6.18	0.013
Location*Vegetation	1	0.16	0.16	0.78	0.378
Season*Location*Vegetation	1	0.00	0.00	0.01	0.936
Water	1	1.73	1.73	8.56	0.004
Season*Water	1	0.06	0.06	0.28	0.599
Location*Water	1	0.37	0.37	1.83	0.176
Season*Location*Water	1	0.04	0.04	0.19	0.663
Vegetation*Water	1	0.25	0.25	1.22	0.27
Season*Vegetation*Water	1	0.30	0.30	1.48	0.224
Location*Vegetation*Water	1	0.20	0.20	0.99	0.32
Season*Location*Vegetation*Water	1	0.71	0.71	3.48	0.062

Table 3-6. ANOVA for the effects of season of planting, vegetation cover and watering regime on survival after the first growing season (binomial) *Morella cerifera*; Experiment 2.

Source	Degrees of Freedom	ANOVA Sums of squares	Mean Square	F Value	Pr > F
Location	1	5.25	5.25	34.53	<.0001
Vegetation	1	0.25	0.25	1.66	0.1981
Location*Vegetation	1	0.03	0.03	0.18	0.6675
Container shape	1	4.99	4.99	32.81	<.0001
Location*Container shape	1	0.19	0.19	1.27	0.2614
Vegetation*Container shape	1	0.29	0.29	1.93	0.1655
Location*Vegetation*Container shape	1	0.00	0.00	0.00	1.0000

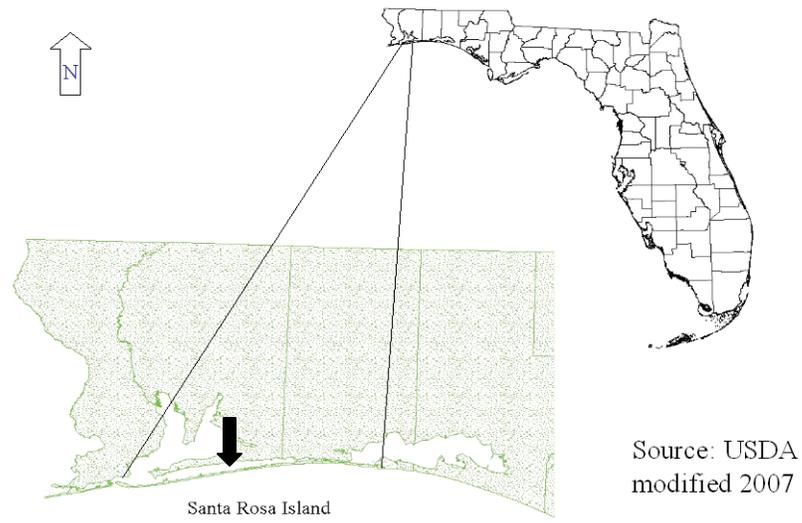
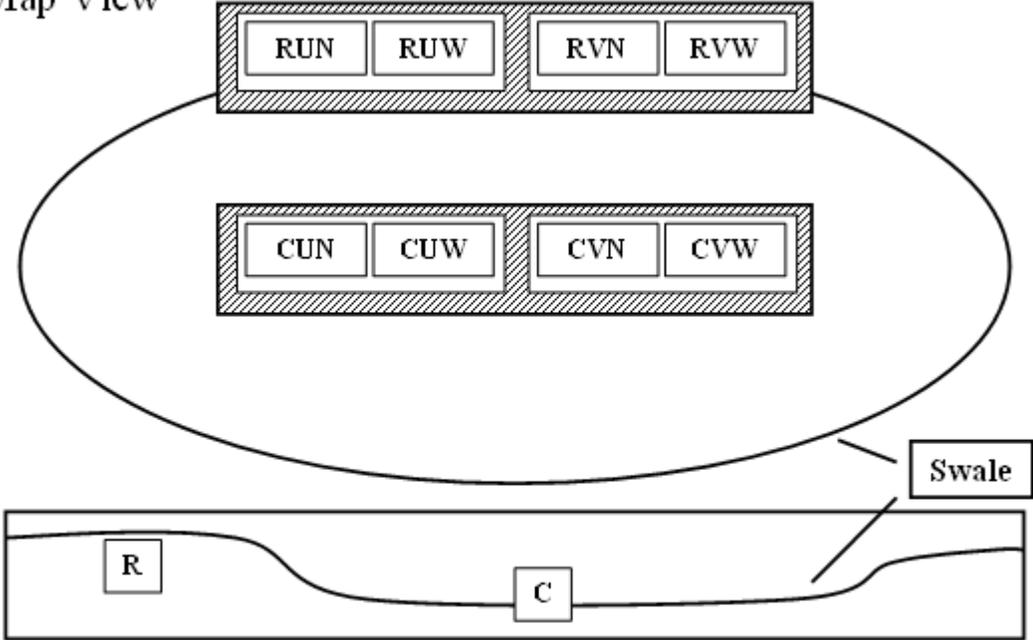


Figure 3-1. Santa Rosa Island, a barrier island in the western Florida panhandle, is the site of this field study. The black arrow indicates the approximate location of the study site.

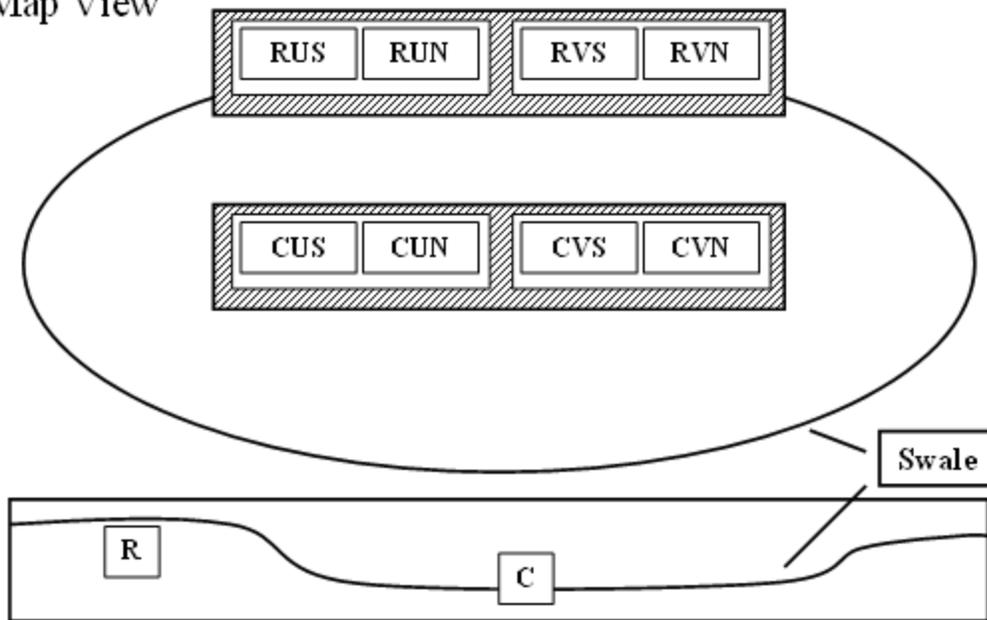
Map View



Side View

Figure 3-2. Map view (Experiments 1 and 2) of a representative swale replication showing how treatment combinations were randomly assigned to split plots. Eight saplings of *Morella cerifera* were planted in each treatment and the factorial arrangement of treatments included location (C = center, R= ridge), vegetation cover (V = vegetated, U=unvegetated) and water regime (W = watered, N = not watered).

Map View



Side View

Figure 3-3. Map view (Experiment 3) of a representative swale replication showing how treatment combinations were randomly assigned to split plots. Eight saplings of *Morella cerifera* were planted in each of 8 treatments and the factorial arrangement of treatments included location (C = center, R= ridge), vegetation cover (V = vegetated, U=unvegetated) and container type (S = rose pot, N = Ray Leach Tube).

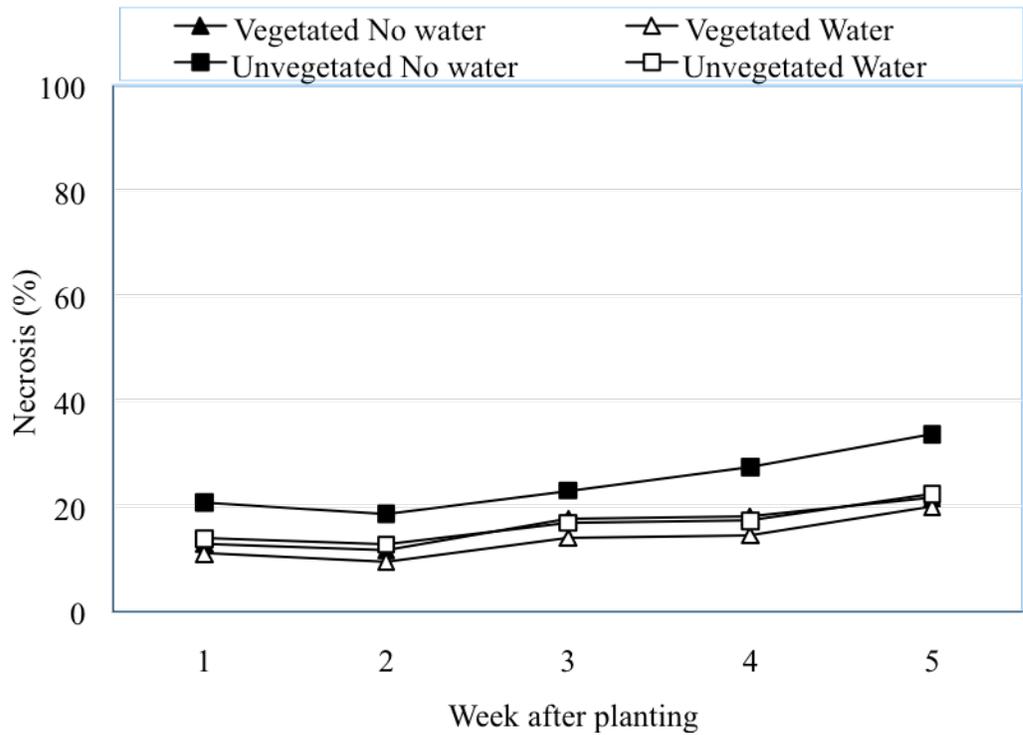


Figure 3-4. Percent necrosis (%) through time (1-5 weeks post planting) for *Morella cerifera* (Experiment 1) planted in the center of swales in September using a factorial arrangement of treatments with 2 levels of vegetation cover, vegetated or unvegetated and 2 levels of water regime, watered or not.

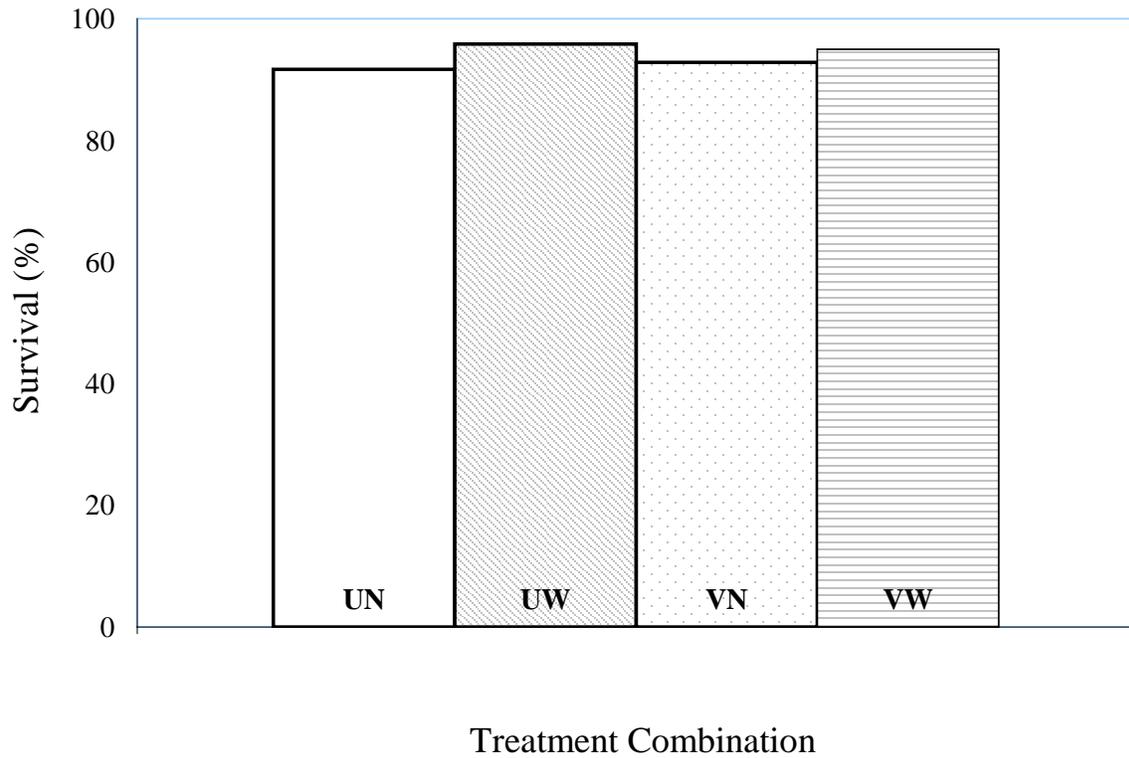


Figure 3-5. Survival (%) 248 days after planting in September for *Morella cerifera* (Experiment 1) planted in the center of swales using a factorial arrangement of treatments with 2 levels of vegetation cover, vegetated (V) or unvegetated (U) and 2 levels of water regime, watered (W) or not (N).

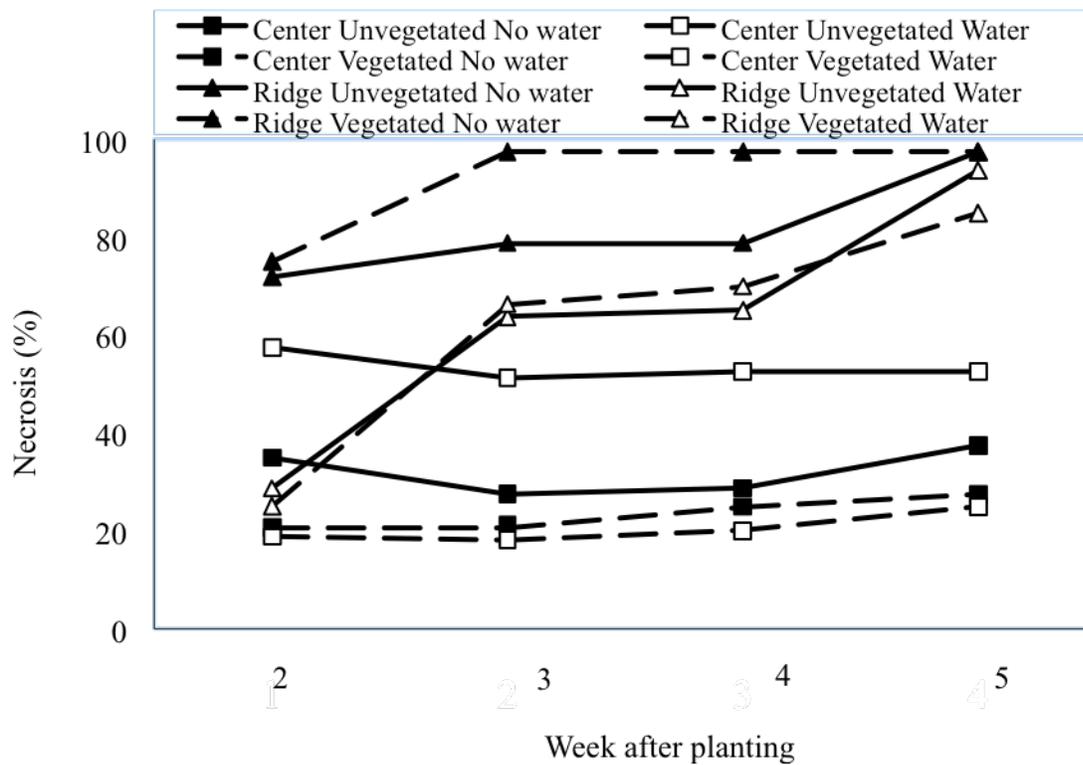


Figure 3-6. Necrosis (%) through time (weeks 2 – 5 post planting) for *Morella cerifera* (Experiment 2) planted in November using a factorial arrangement of treatments including location (center or ridge), vegetation cover (vegetated or unvegetated) and water regime (watered or not watered).

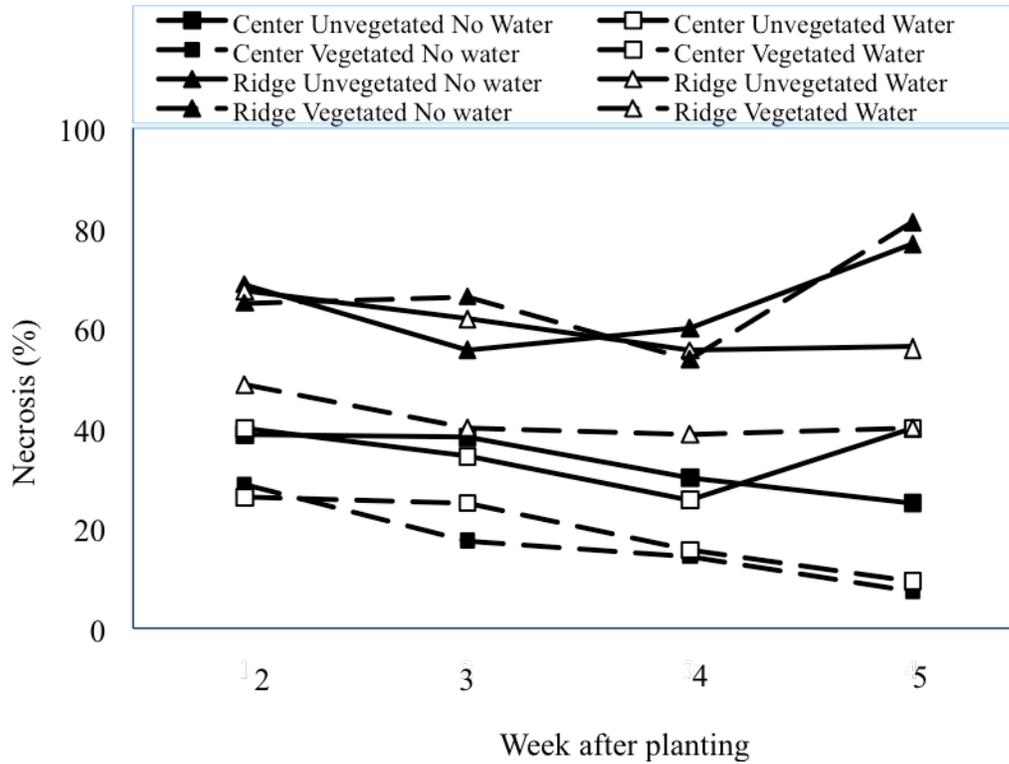


Figure 3-7. Necrosis (%) through time (weeks 2-5 post planting) of *Morella cerifera* (Experiment 2) planted in March using a factorial arrangement of treatments including location (center or ridge), vegetation cover (vegetated or unvegetated) and water regime (watered or not watered).

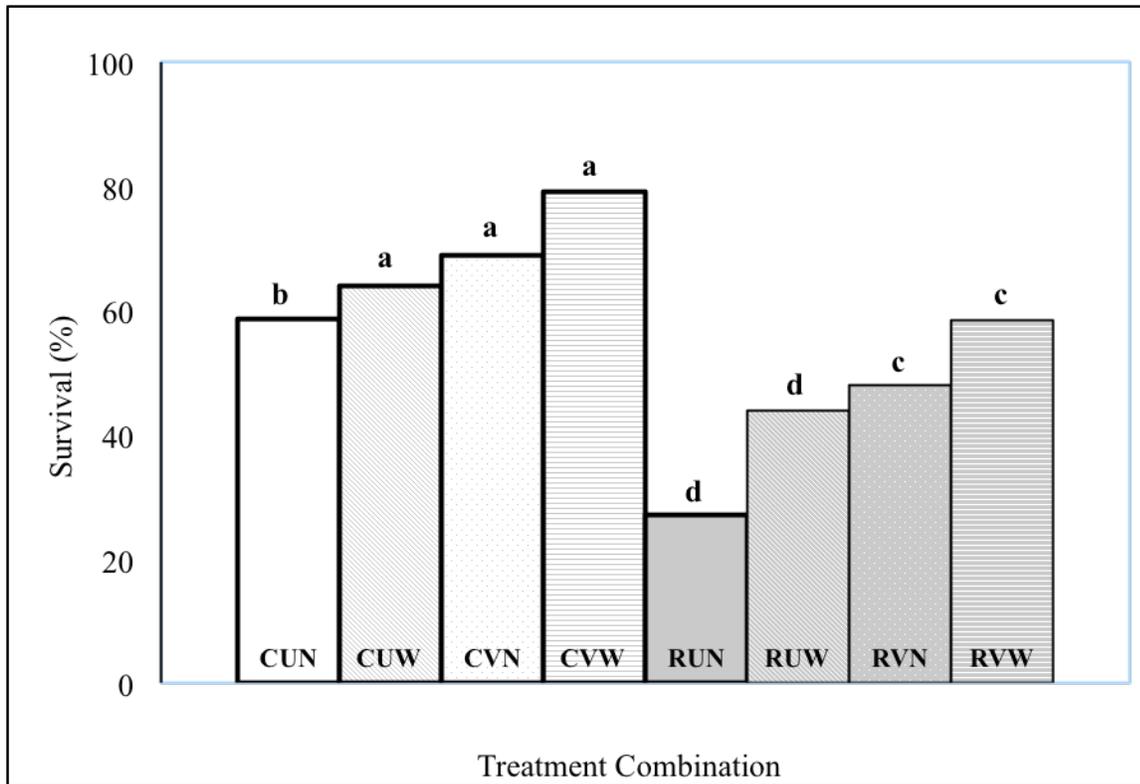


Figure 3-8. Survival (%) 202 days after planting in November for *Morella cerifera* (Experiment 2) using a factorial arrangement of treatments with 2 levels of location, center (C) and ridge (R), two levels of vegetation cover, vegetated (V) or unvegetated (U) and 2 levels of water regime, watered (W) or not (N). Bars with the same letter do not differ (alpha=0.5).

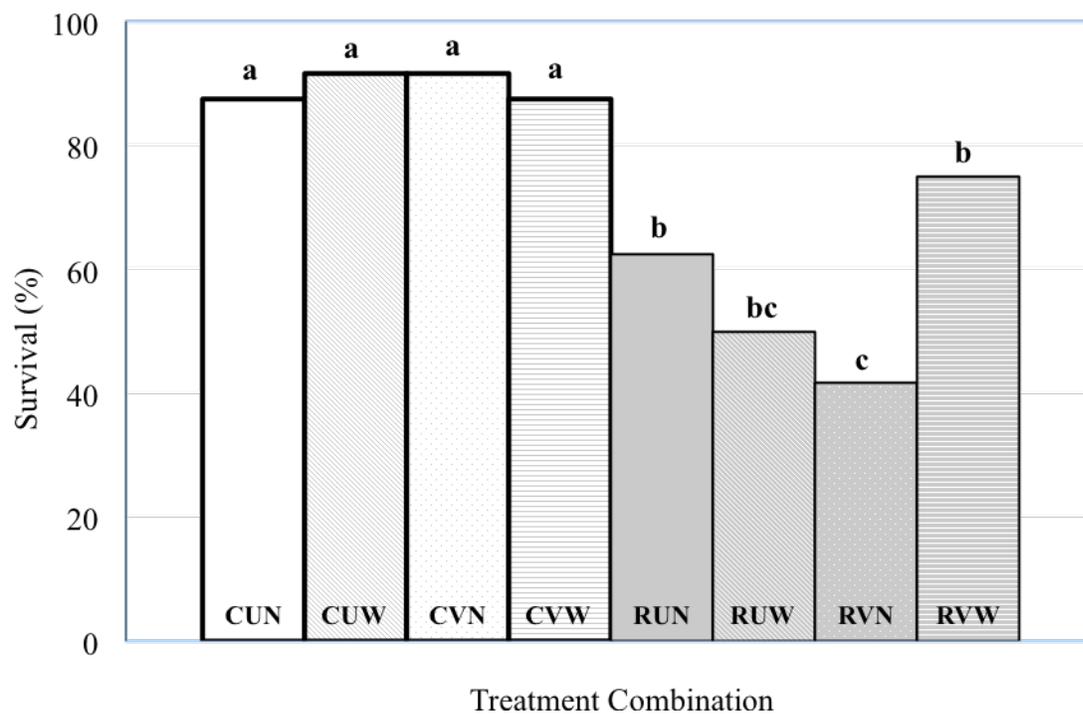


Figure 3-9. Survival (%) 72 days after planting in March for *Morella cerifera* (Experiment 2) using a factorial arrangement of treatments with 2 levels of location, center (C) and ridge (R), 2 levels of vegetation cover, vegetated (V) or unvegetated (U) and two levels of water regime, watered (W) or not (N). Bars with the same letter do not differ ($\alpha=0.5$).

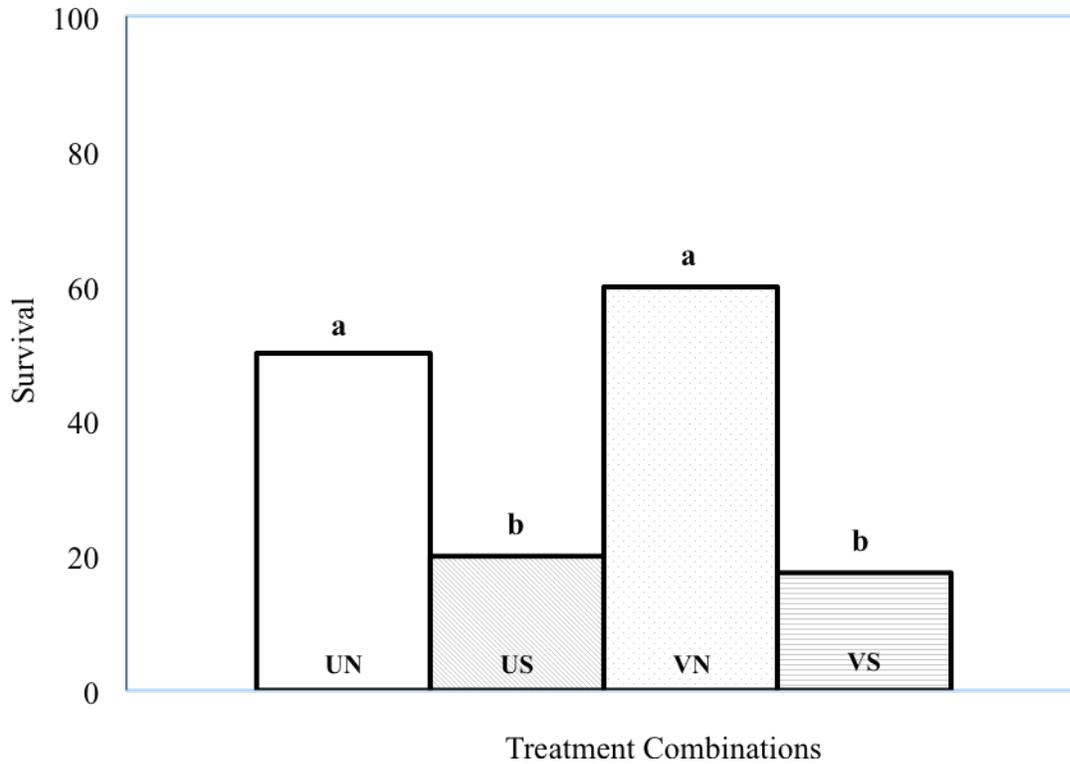


Figure 3-10. Survival (%) 72 days after planting in March, for *Morella cerifera* (Experiment 3) grown in rose pots (S) or Ray Leach Tubes (N) and planted in the swale center with 2 levels of vegetation cover, vegetated (V) or unvegetated (U). Bars with the same letter do not differ ($\alpha=0.5$).

CHAPTER 4 MANAGEMENT AND RESTORATION IMPLICATIONS

Quercus

Between high loss of acorns from herbivores and low germination of acorns under field condition, natural oak regeneration is limited on barrier islands. Field observation indicates germination and establishment occurs naturally in swale centers, the unelevated edge of swales where soil moisture is adequate, or in hollows between established trees on dunes. Across Santa Rosa Island, tree death following recent hurricanes was greatest in association with swales. As a result, planting may be necessary to restore sand live oak and myrtle oak to areas of barrier islands where severe storms or condominium developments have reduced the number of acorn producing trees.

Acorns of *Q. myrtifolia* and *Q. geminata* may be used in restoration if care is taken in collection and processing. Acorns should be screened for insect presence when collected. Acorns should be tested for viability using a float test (Korstain 1927) immediately following collection then again directly before planting. The float test insures that acorns with low masses are not used. Soaking in insecticide or in water prior to planting may increase germination. A two hour soaking in insecticide appears to eliminate any remaining insects, does not negatively impact germination but appears to imbibe the acorn which further increases the chances of germination in the arid environment of the barrier island landscape. Soaking of acorns in water may also increase acorn imbibition just prior to planting if pesticides are not needed.

Placement of acorns in the field should consider soil moisture, salinity and herbivores. On barrier islands, acorns should be planted in association with ephemeral swales located behind foredunes or on the back side of barrier islands. Acorns should be buried (length of acorn) in shallow swales, not on elevated ridges, and only in swales that are not susceptible to frequent

overwash such as from monthly high tides or high tides from winter storms. Soil salinity in these swales should be as near to 0 ppt as possible and should not exceed 8 ppt at time of planting. Preferably, planting should take place when swales have been recently saturated by rain but not where standing water is present. If water can be supplied, the soil associated with acorns should be maintained at 25% of field capacity. Thus, managers will have to determine the frequency and amount of water based on soil and field conditions. If cages are not used, acorns should be buried where vegetation is lacking and soil moisture is adequate. Vegetation provides cover for herbivores and may lead to increased loss of acorns. However, vegetation removal is both costly and time intensive, did not increase germination and is not recommended. When possible the use of cages, particularly for *Q. myrtifolia* is recommended. These cages can be removed after sapling development (when no seed material remains). Herbivory on seedlings has not been investigated but field observation on herbivory of saplings is not high. Germination and seedling establishment should have taken place prior to tropical storm activity.

. *Quercus myrtifolia* was greatly impacted by presence of salinity. Salinity levels below 8 ppt need to be tested on germination of this species. More research should be done on the influence of cold storage on *Q. myrtifolia*.

Morella cerifera

When planting 75mL cell transplants for restoration, the most limiting factors to establishment are water availability and season of planting. Results of this study suggests, late winter to early spring is the best season for planting of wax myrtle in the panhandle of Florida. Average monthly precipitation is lowest in May and October in the Florida panhandle (National Weather Service 2008). Soil water availability is critical and will limit planting success during hot, dry periods.

Water availability is higher in the center of the swale than the ridge and planting should not be attempted on the ridge unless supplemental water can be provided. Due to increased transpiration rates, daily supplemental water may be necessary for plantings under higher temperature conditions and on the ridge. The use of Ray Leach Tube containers to increase rooting depth of transplants is recommended to improve survival rates.

Necrosis was not a good predictor of plant survival. The differences in necrosis five weeks after planting and the survival of plants after the first growing season illustrate the importance of monitoring plant establishment for longer periods of time to determine survival.

APPENDIX
SAS 9.1 CODES USED FOR ANALYSIS

Quercus Field

***Q. geminata* Presence**

```
proc glimmix data=qgem;  
  class bloc loc veg burial;  
  model n/total=loc|veg|burial /solution ;  
  random bloc;  
  lsmeans loc veg burial/pdiff;  
run;
```

***Q. geminata* Germination**

```
proc glimmix data=qgem;  
  class bloc burial;  
  model germ/n=burial/solution ;  
  random bloc;  
  lsmeans burial/pdiff;  
run;
```

***Q. myrtifolia* Presence**

```
proc glimmix data=qmyrt;  
  class bloc loc veg burial;  
  model Y/n = loc veg burial/solution;  
  random bloc;  
run;
```

Quercus Greenhouse

Experiment 1 Weights

```
proc mixed data=one;  
  class Rep salt burial water ;  
  model germper = salt|water|burial;  
  random Rep;  
  lsmeans salt water burial salt*burial salt*water*burial/pdiff;  
run;
```

Experiment 1 Germination

```
proc mixed data=two;  
  class Rep water salt burial water ;  
  model freshwt = salt|burial|water;  
  random Rep;  
  lsmeans burial salt/pdiff;  
run;
```

Experiment 2 Weights

```
proc mixed data=one;
```

```
class Rep salt burial water ;
model drywt = salt|burial|water;
random Rep;
run;
```

Experiment 2 Germination

```
proc mixed data=one;
class Rep salt burial water ;
model germper = salt|water|burial;
random Rep;
lsmeans salt water burial salt*burial salt*water*burial/pdiff;
run;
```

Experiment 3 Weights

```
proc mixed data=one;
class Rep salt burial water ;
model drywt = salt|burial|water;
random Rep;
lsmeans salt burial salt*burial*water/pdiff;
run;
```

Experiment 3 Germination

```
proc mixed data=one;
class Rep salt burial water pest ;
model germper = salt|water|burial|pest;
random Rep;
lsmeans water salt*burial*water water*pest;
run;
```

Experiment 4 Weights

```
proc mixed data=one;
class Rep salt burial water ;
model drywt = salt|burial|water;
random Rep;
lsmeans water/pdiff;
run;
```

Experiment 4 Germination

```
proc mixed data=one;
class Rep salt burial water ;
model germper = salt|water|burial;
random Rep;
lsmeans salt|water|burial/pdiff;
run;
```

Experiment 5 Weights

```
proc mixed data=one;
class Rep salt burial water ;
model drywt = salt|burial|water;
random Rep;
run;
proc mixed data=gnvqgem;
class Rep salin burial water ;
model germper = salin|burial|water;
random Rep;
lsmeans salin water /pdiff;
run;
```

Morella cerifera

Experiment 1 Necrosis

```
proc sort data=exp1 nec;
by bloc_no veg water week;
proc mixed data = exp1 nec;
class bloc_no veg water week;
model necrosis = veg|water|week;
repeated week;
lsmeans week veg water/pdiff;
run;
```

Experiment 2 Necrosis

```
proc sort data=exp2nec;
by bloc_no season loc veg water week;
proc mixed data = exp2nec;
class bloc_no season veg water loc week;
model necrosis= bloc_no season|loc|veg|water|week;
repeated week;
lsmeans season week veg loc water season*veg veg*water season*week loc*week
season*loc*week/pdiff;
run;
```

Experiment 1 Survival

```
proc sort data = eflsurv;
by bloc_no veg water;
run;
proc glimmix data=eflsurv;
class bloc_no veg water;
model surv= veg water water*veg/dist= binary link=logit;
random bloc_no bloc_no*water;
lsmeans water/pdiff;
run;
```

Experiment 2 Survival

```
proc sort data=exp2nec;
by bloc_no season loc veg water week;
proc mixed data = exp2nec;
class bloc_no season veg water loc week;
model necrosis= bloc_no season|loc|veg|water|week;
repeated week;
lsmeans season week veg loc water season*veg veg*water season*week loc*week
season*loc*week/pdiff;
run;
```

Experiment 3 Survival

```
proc sort data=contsurv;
by bloc_no loc veg conshp;
proc glimmix data= contsurv;
class bloc_no loc veg conshp;
model surv= loc veg conshp veg*conshp/dist= binary link=logit ;
random bloc_no;
lsmeans veg*conshp loc conshp/pdiff;
run;
```

LIST OF REFERENCES

- Abrahamson, W.G. and J.N. Layne 2003. Long-term patterns of acorn production for five oak species in xeric Florida uplands. *Ecology* **84**:2476-2492.
- Ainsworth, E. A., P. J. Tranel, B. G. Drake, and S. P. Long 2003. The clonal structure of *Quercus geminata* revealed by conserved microsatellite loci. *Molecular Ecology* **12**:527-532.
- Anderson R.L., Knighten J.L., Powers H.R. 1984. Field survival of loblolly and slash pine seedlings grown in trays and Ray Leach containers. *Tree Plant. Notes.* **35**(2):3-4.
- Battaglia, L. L., R. R. Sharitz, and P. R. Minchin 1999. Patterns of seedling and overstory composition along a gradient of hurricane disturbance in an old-growth bottomland hardwood community. *Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere* **29**:144-156.
- Bertness, M. D., P. J. Ewanchuk, and B. R. Silliman 2002. Anthropogenic modification of New England salt marsh landscapes. *Proceedings of the National Academy of Sciences of the United States of America* **99**:1395-1398.
- Bonfil, C. 1998. The effects of seed size, cotyledon reserves, and herbivory on seedling survival and growth in *Quercus rugosa* and *Q-laurina* (Fagaceae). *American Journal of Botany* **85**:79-87.
- Bond, W. J., and J. J. Midgley 2001. Ecology of sprouting in woody plants: the persistence niche. *Trends in Ecology & Evolution* **16**:45-51.
- Bourdeau, P. F., and H. J. Oosting 1959. The maritime live oak forest in North-Carolina. *Ecology* **40**:148-152.
- Boyce, S. G. 1954. The salt spray community. *Ecological Monographs* **24**:29-67.
- Briggs, J. M., and K. G. Smith 1989. Influence of habitat on acorn selection by *Peromyscus-leucopus*. *Journal of Mammalogy* **70**:35-43.
- Brown, R.L. and A.L. Hafenrichter 1962. Stabilizing Sand Dunes on the Pacific Coast with Woody Plants. Washington, U.S. Department of Agriculture and Soil Conservation Service (GPO) Miscellaneous Publication **892**:18.
- Callaway, R. M., and F. W. Davis 1998. Recruitment of *Quercus agrifolia* in central California: the importance of shrub-dominated patches. *Journal of Vegetation Science* **9**:647-656.
- Chambers, JC and J.A. MacMahon 1994. A day in the life of a seed – movements and fates of seeds and their implications for natural and managed systems. *Annual Review of Ecology and Systematics* **25**: 263-292.
- Chang, E. R., R. M. Veeneklaas, R. Buitenwerf, J. P. Bakker, and T. J. Bouma 2008. To move or not to move: determinants of seed retention in a tidal marsh. *Functional Ecology* **22**:720-727.

Clewell, A.F. 1997. Natural setting and vegetation of the Florida Panhandle. U.S. Army Corps of Engineers, Mobile District, Report.

Collins, B., and L. L. Battaglia 2008. Oak regeneration in southeastern bottomland hardwood forest. *Forest Ecology and Management* **255**:3026-3034.

Crawley, M. J. 1985. Reduction of oak fecundity by low-density herbivore populations. *Nature* **314**:163-164.

Dahl, B. E., and D. W. Woodard 1977. Construction of Texas coastal foredunes with sea oats (*Uniola paniculata*) and bitter panicum (*Panicum amarum*). *International Journal of Biometeorology* **21**:267-275.

Daws, M. I., C. S. Gamene, S. M. Glidewell, and H. W. Pritchard 2004. Seed mass variation potentially masks a single critical water content in recalcitrant seeds. *Seed Science Research* **14**:185-195.

Dobson, A. P., A. D. Bradshaw, and A. J. M. Baker 1997. Hopes for the future: Restoration ecology and conservation biology. *Science* **277**:515-522.

Ehrenfeld, J. G. 1990. Dynamics and processes of barrier-island vegetation. *Reviews in Aquatic Sciences* **2**:437-480.

Evans, C. E., and J. R. Etherington 1991. The effect of soil-water potential on seedling growth of some British plants. *New Phytologist* **118**:571-579.

Farmer, A. H., and A. H. Parent 1997. Effects of the landscape on shorebird movements at spring migration stopovers. *Condor* **99**:698-707.

Garcia, D., M. J. Banuelos, and G. Houle 2002. Differential effects of acorn burial and litter cover on *Quercus rubra* recruitment at the limit of its range in eastern North America. *Canadian Journal of Botany-Revue Canadienne De Botanique* **80**:1115-1120.

Gomez, J. M. 2004. Importance of microhabitat and acorn burial on *Quercus ilex* early recruitment: non-additive effects on multiple demographic processes. *Plant Ecology* **172**:287-297.

Goodrum, P. D., V. H. Reid, and C. E. Boyd 1971. Acorn yields, characteristics, and management criteria of oaks for wildlife. *Journal of Wildlife Management* **35**:520.

Hall, M. C., P. Stiling, D. C. Moon, B. G. Drake, and M. D. Hunter 2006. Elevated CO₂ increases the long-term decomposition rate of *Quercus myrtifolia* leaf litter. *Global Change Biology* **12**:568-577.

Harper J.L. 1977. *Population biology of plants*. Academic Press, London.

Helm, A. C., N. S. Nicholas, S. M. Zedaker, and S. T. Young 1991. Maritime forests on Bull Island Cape Romain, South-Carolina. *Bulletin of the Torrey Botanical Club* **118**:170-175.

- Higgs, E. S. 1997. What is good ecological restoration? *Conservation Biology* **11**:338-348.
- Hopper, G. M., D. W. Smith, and D. J. Parrish 1985. Germination and seedling growth of northern red oak – effects of stratification and pericarp removal. *Forest Science* **31**:31-39.
- Howe, H. F., and J. Smallwood 1982. Ecology of seed dispersal. *Annual Review of Ecology and Systematics* **13**:201-228.
- Iakovoglou, V., M. K. Misra, R. B. Hall, and A. D. Knapp 2007. The effect of seed size and parent tree on seed variables and seedling growth of *Quercus macrocarpa* and *Q. alba*. *Seed Science and Technology* **35**:771-777.
- Johnson, A. F. 1997. Rates of vegetation succession on a coastal dune system in northwest Florida. *Journal of Coastal Research* **13**:373-384.
- Kindell, C. E., B. J. Herring, C. Nordman, J. Jensen, A. R. Schotz, and L. G. Chafin. 1997. Natural community survey of Eglin Air Force Base, 1993–1996: Final Report. Florida Natural Areas Inventory, Tallahassee, Florida.
- Kolb, A., R. Leimu, and J. Ehrlén 2007. Environmental context influences the outcome of a plant-seed predator interaction. *Oikos* **116**:864-872.
- Korstian CF. 1927. Factors controlling germination and early survival in oaks. Yale University, School of Forestry Bulletin. **19**: 467-468
- Kozłowski, T. T., and S. G. Pallardy 2002. Acclimation and adaptive responses of woody plants to environmental stresses. *Botanical Review* **68**:270-334.
- Kramer, P. J., H. J. Oosting, and C. F. Korstian 1952. Survival of pine and hardwood seedlings in forest and open. *Ecology* **33**:427-430.
- Lombardo, J. A., and B. C. McCarthy 2008. Silvicultural treatment effects on oak seed production and predation by acorn weevils in southeastern Ohio. *Forest Ecology and Management* **255**:2566-2576.
- Mailly, D., P. Ndiaye, H. A. Margolis, and M. Pineau 1994. Stabilization of shifting dunes and afforestation along the northern coast of Senegal using the filao (*Casuarina-equisetifolia*). *Forestry Chronicle* **70**:282-290.
- Maun, M. A. 1994. Adaptations enhancing survival and establishment of seedlings on coastal dune systems. *Vegetatio* **111**:59-70.
- Mendelssohn, I. A., M. W. Hester, F. J. Monteferrante, and F. Talbot 1991. Experimental dune building and vegetative stabilization in a sand-deficient barrier-island setting on the Louisiana coast, USA. *Journal of Coastal Research* **7**:137-149.
- Menges, E. S., and C. V. Hawkes 1998. Interactive effects of fire and microhabitat on plants of Florida scrub. *Ecological Applications* **8**:935-946.

- Miller, D. L., M. Thetford, and M. Schneider 2008. Distance from the Gulf influences survival and growth of three barrier island dune plants. *Journal of Coastal Research* **24**:261-266.
- Miller, D. L., M. Thetford, and L. Yager 2001. Evaluation of sand fence and vegetation for dune building following overwash by hurricane Opal on Santa Rosa Island, Florida. *Journal of Coastal Research* **17**:936-948.
- Miller, D. L., L. Yager, M. Thetford, and M. Schneider 2003. Potential use of *Uniola paniculata* rhizome fragments for dune restoration. *Restoration Ecology* **11**:359-369.
- Moore, F. R., P. Kerlinger, and T. R. Simons 1990. Stopover on a Gulf coast barrier islands by spring trans-Gulf migrants. *Wilson Bulletin* **102**:487-500.
- Mulvania, M. 1931. Ecological survey of a Florida scrub. *Ecology* **12**:528-540.
- Nathan, R., and R. Casagrandi 2004. A simple mechanistic model of seed dispersal, predation and plant establishment: Janzen-Connell and beyond. *Journal of Ecology* **92**:733-746.
- Natural Resources Conservation Service (NRCS) 2004. Escambia County. Florida Online Soil Survey Manuscripts 149.
- Naumann, J. C., and D. R. Young 2007. Relationship between community structure and seed bank to describe successional dynamics of an Atlantic Coast maritime forest. *Journal of the Torrey Botanical Society* **134**:89-98.
- Navarro, F. B., M. N. Jimenez, M. A. Ripoll, E. Fernandez-Ondono, E. Gallego, and E. Simon 2006. Direct sowing of holm oak acorns: effects of acorn size and soil treatment. *Annals of Forest Science* **63**:961-967.
- Oosting, H. J. 1945. Tolerance to salt spray of plants of coastal dunes. *Ecology* **26**:85-89.
- Oosting, H. J. 1954. Ecological processes and vegetation of the maritime strand in the southeastern United-States. *Botanical Review* **20**:226-262.
- Penfound, W. T., and M. E. O'neill 1934. The vegetation of Cat Island, Mississippi. *Ecology* **15**:1-16.
- Perez-Ramos, I. M., I. R. Urbieto, T. Maranon, M. A. Zavala, and R. K. Kobe 2008. Seed removal in two coexisting oak species: ecological consequences of seed size, plant cover and seed-drop timing. *Oikos* **117**:1386-1396.
- Pries, A.J. 2006. Hurricane Impacts on Coastal Dunes and Spatial Distribution of Santa Rosa Beach Mice (*Peromyscus pounotus leucocephalus*) in Dune Habitats. Gainesville, Florida: University of Florida, Master's thesis.
- Ranwell, D. 1959. The dune system and dune slack habitat. *Journal of Ecology* **47**:571-601.

- Saunders, M. A., and A. S. Lea 2008. Large contribution of sea surface warming to recent increase in Atlantic hurricane activity. *Nature* **451**:557-U553.
- Schneider, J. C., and S. E. Kruse 2003. A comparison of controls on freshwater lens morphology of small carbonate and siliciclastic islands: examples from barrier islands in Florida, USA. *Journal of Hydrology* **284**:253-269.
- Shao, G. F., H. H. Shugart, and B. P. Hayden 1996. Functional classifications of coastal barrier island vegetation. *Journal of Vegetation Science* **7**:391-396.
- Shao, G. F., H. H. Shugart, and D. R. Young 1995. Simulation of transpiration sensitivity to environmental-changes for shrub (*Morella cerifera*) thickets on a Virginia barrier-island. *Ecological Modeling* **78**:235-248.
- Shao, G. F., D. R. Young, J. H. Porter, and B. P. Hayden 1998. An integration of remote sensing and GIS to examine the responses of shrub thicket distributions to shoreline changes on Virginia Barrier Islands. *Journal of Coastal Research* **14**:299-307.
- Shumway, S. W., and C. R. Banks 2001. Species distributions in interdunal swale communities: The effects of soil waterlogging. *American Midland Naturalist* **145**:137-146.
- Silvertown, J. W. 1980. The evolutionary ecology of mast seeding in trees. *Biological Journal of the Linnean Society* **14**:235-250.
- Smith, G. F., N. S. Nicholas, and S. M. Zedaker 1997. Succession dynamics in a maritime forest following Hurricane Hugo and fuel reduction burns. *Forest Ecology and Management* **95**:275-283.
- Snyder, R. A., and C. L. Boss 2002. Recovery and stability in barrier island plant communities. *Journal of Coastal Research* **18**:530-536.
- Stallins, J. A. 2005. Stability domains in barrier island dune systems. *Ecological Complexity* **2**:410-430.
- Stallins, J. A., and A. J. Parker 2003. The influence of complex systems interactions on barrier island dune vegetation pattern and process. *Annals of the Association of American Geographers* **93**:13-29.
- Stiling, P., D. Moon, G. Hymus, and B. Drake 2004. Differential effects of elevated CO₂ on acorn density, weight, germination, and predation among three oak species in a scrub-oak forest. *Global Change Biology* **10**:228-232.
- Tangley, L. 2001. Greenhouse effects - High CO₂ levels-may give fast-growing trees an edge. *Science* **292**:36-37.
- Thetford, M., D. Miller, K. Smith, and M. Schneider 2005. Container size and planting zone influence on transplant survival and growth of two coastal plants. *Horttechnology* **15**:554-559.

- Tommasi, F., C. Paciolla, M. C. De Pinto, and L. De Gara 2006. Effects of storage temperature on viability, germination and antioxidant metabolism in *Ginkgo biloba* L. seeds. *Plant Physiology and Biochemistry* **44**:359-368.
- Urbietta, I. R., I. M. Perez-Ramos, M. A. Zavala, T. Maranon, and R. K. Kobe 2008. Soil water content and emergence time control seedling establishment in three co-occurring Mediterranean oak species. *Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere* **38**:2382-2393.
- Yi, X. F., and Z. B. Zhang 2008a. Influence of insect-infested cotyledons on early seedling growth of Mongolian oak, *Quercus mongolica*. *Photosynthetica* **46**:139-142.
- Young, D. R., J. H. Porter, C. M. Bachmann, G. F. Shao, R. A. Fusina, J. H. Bowles, D. Korwan, and T. F. Donato 2007. Cross-scale patterns in shrub thicket dynamics in the Virginia barrier complex. *Ecosystems* **10**:854-863.
- Young, D. R., G. F. Shao, and M. M. Brinson 1995a. The impact of the October 1991 northeaster storm on barrier-island shrub thickets (*Morella-cerifera*). *Journal of Coastal Research* **11**:1322-1328.
- Young, D. R., G. F. Shao, and J. H. Porter 1995b. Spatial and temporal growth dynamics of barrier-island shrub thickets. *American Journal of Botany* **82**:638-645.
- Zedler, J. B., and J. C. Callaway 1999. Tracking wetland restoration: Do mitigation sites follow desired trajectories? *Restoration Ecology* **7**:69-73.
- Zedler, J. B., and J. M. West 2008. Declining diversity in natural and restored salt marshes: A 30-year study of Tijuana Estuary. *Restoration Ecology* **16**:249-262.

BIOGRAPHICAL SKETCH

Sarah was born in St. Petersburg, Florida. She grew up mainly in Pinellas County, except for a few years when her family lived in Pematang Siantar, Indonesia. During her childhood, she and her family traveled often. Whether traveling abroad or in her hometown, her parents often took her and her older brother to natural areas, especially the beach. She graduated high school with honors from Pinellas County Center for the Arts in 2002. There, she studied classical guitar. Since high school she has been playing music professionally. Sarah graduated from the University of Florida with honors with a B.S. in Forest Resources and Conservation in 2006. During her senior year, she took two studies abroad in Costa Rica and Central Europe. At UF she was an officer in both the School of Forest Resources and Conservation Student Council and Xi Sigma Pi Forestry Honor Society. She co-founded Gators for Tsunami Relief, a cooperative student organization which raised over \$12,000 for Direct Relief International's Indian Tsunami Fund in 2006.

Sarah has been involved in volunteerism since a young age. Some exciting community service activities she has participated in include: dog walking for the Society for the Prevention of Cruelty to Animals, picking up litter at Paynes Prairie State Preserve, removing invasive species in the Florida Keys and along the rivers of north Florida and performing music to raise money for charity.

Other than nature, Sarah's interests include teaching, writing and performing music, jewelry making, bike riding, vegetarian cooking and stamp collecting. She speaks fluent Indonesian and enjoys learning tidbits of other languages.