CONSERVATION OF FOUR AT-RISK PLANT SPECIES IN SANDHILL ECOSYSTEMS OF THE SOUTHEASTERN COASTAL PLAIN

by

JACLIN A. DURANT

(Under the Direction of Rebecca R. Sharitz)

ABSTRACT

Conservation and restoration of herbaceous plant species endemic to the longleaf pine sandhills ecosystem of the southeastern United States are essential for maintaining diversity in this habitat. This study focuses on four at-risk species that represent a variety of plant life forms associated with this ecosystem. Natural populations were surveyed for density and reproduction, and experiments were conducted to determine how varying environmental conditions affect germination. In addition, the growth and survival of these four species planted into experimental gardens under a variety of post-disturbance conditions were studied. Results suggest that these four plant species can survive disturbed conditions that are likely to be found in sandhills ecosystems and that restoration efforts can be optimized by the pre-treatment of seeds using heat, cold stratification, or scarification techniques.

INDEX WORDS: Sandhills, Plant Conservation, Longleaf Pine Ecosystem, *Baptisia lanceolata, Carphephorus bellidifolius, Nolina georgiana, Stylisma pickeringii,* Disturbance, Rare Plants

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DEDICATION

This work is dedicated to my parents, Linda J. DuRant and Billy DuRant. Without them, there's no way I would have gotten this far. Also to Jenny and Mel who always make time for me no matter what; to Dave who has supported me through this entire process, and finally, to Ed who changed my life and the way I look at the world in so many ways. Thank you all.

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CHAPTER 1

INTRODUCTION

The southeast is one of the fastest growing areas of the United States in terms of human population and development. Native plants of this region face the combined pressures of habitat modification and destruction, as well as encroachment of introduced species and climate changes. Anthropogenic disturbances in this region include hundreds of years of agriculture, open range grazing by hogs and other livestock, logging, urbanization and the alteration of the natural fire regime (Ware et al. 1993). Although the Coastal Plain of the southeast is not alone in facing habitat fragmentation, the impacts of human induced change in this region are "magnified by the importance of natural disturbance and successional change" (Christensen 2000) to the maintenance of diversity and sustainable ecosystems.

The sandhills region of the southeastern US runs along the Fall Line (the interface between the Coastal Plain and Piedmont provinces) through North and South Carolina and Georgia (Figure 1). Sandhills are classified as having coarse sandy soils poor in water retention and high in irradiance (Christensen 2000). Hot spots of plant endemism often occur on such extremely xeric sites with sandy soils that are poor in nutrients and have relatively low tree cover (Loehle 2006).

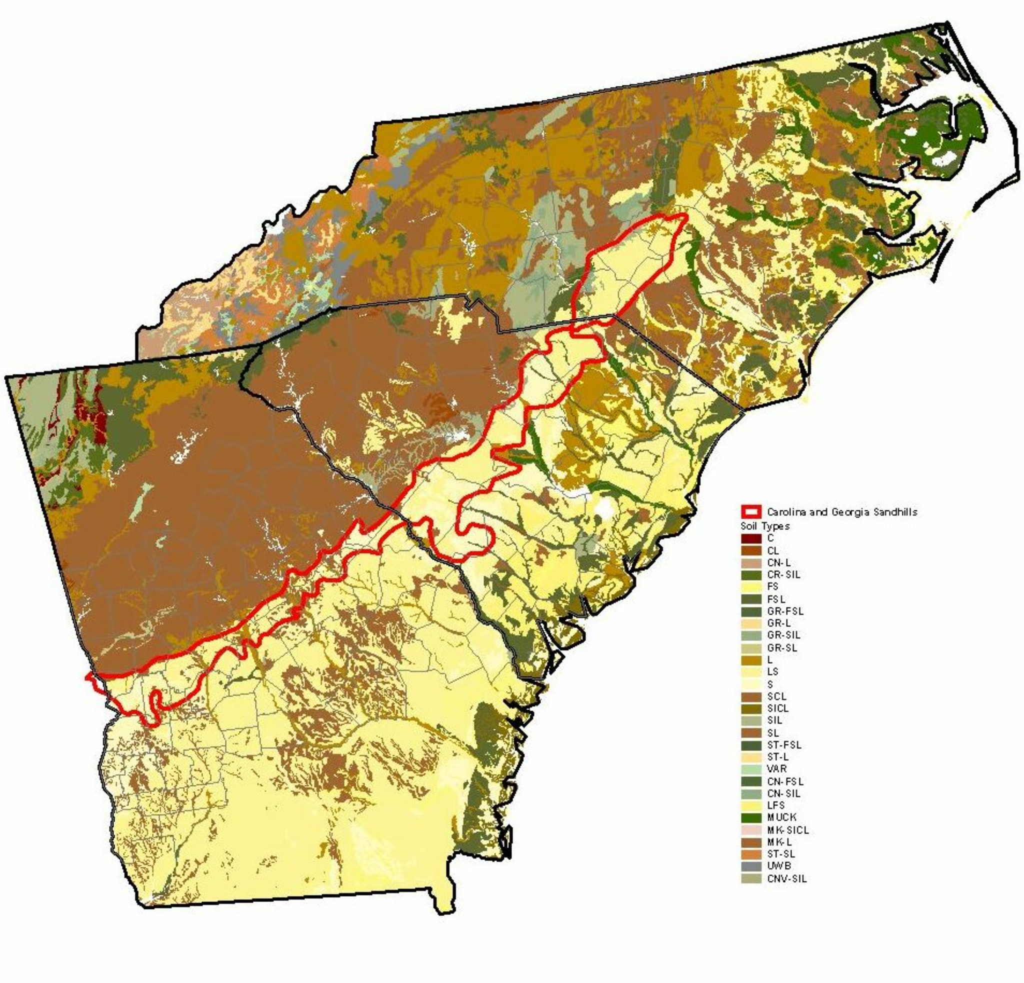

Figure 1. Soil profiles of North Carolina, South Carolina, and Georgia (State Climate Office of North Carolina). The sandhills region is outlined in red.

Southeastern sandhills ecosystems support numerous rare and endangered animal species such as the red-cockaded woodpecker (*Picoides borealis*), gopher tortoise (*Gopherus polyphemus*), and indigo snake (*Drymarchon corais*). These ecosystems also are habitat for a variety of threatened, endangered, or sensitive (TES) plants listed as state species of concern (Nelson 1986). In an analysis of the geographic trends of plant endemism in the southeastern US, Georgia was second and South Carolina fifth of fourteen states in the number of rare endemics occurring in each state, while Georgia was second and South Carolina fourth in the proportion of counties containing endemics (89% and 85%, respectively; Estill and Cruzan 2001).

The sandhills portions of Georgia and South Carolina are part of the dwindling longleaf pine (*Pinus palustris*) ecosystem in the southeast. The majority of the diversity within the longleaf pine ecosystem is present in the understory, while the canopy essentially consists of a monoculture (Simberloff 1993). "Of the 1630 total vascular plant taxa endemic to the entire Coastal Plain, one thousand are obligate associates of the *Pinus palustris* ecosystem" (Sorrie and Weakley 2006). There is a wide range of variation in community structure, understory composition, fire influence and soil moisture regime within this ecosystem (Ware et al. 1993). Also, many of the parcels of land large enough to support intact longleaf pine are under federal jurisdiction on sites such as the Department of Energy's Savannah River Site (SRS) in South Carolina, and military bases such as Fort Gordon in Georgia (Outcalt 2000; Sorrie and Weakly 2006). These areas are subject to multiple uses, including military training, industry, and research. These factors combined with the small remaining area of intact longleaf pine habitat represent a variety of challenges to conservation and restoration efforts in this region.

Although many native and endemic sandhills plant species are currently listed as TES in both state and global rankings, little is known about the life histories, germination, or establishment requirements of many of these plants. Brockway et al. (2004) state that a major difficulty in restoring longleaf pine ecosystems of the sandhills region is the restoration of understory plants and that this area of study lacks both knowledge and experience. Thus, the conservation and protection of remaining populations of rare plant species of the sandhills may be essential to retaining stability and function of the longleaf pine ecosystem.

Ecological restoration efforts should focus on both structure and function of the ecosystem including natural disturbances such as a regular fire regime (Covington et al. 1999, Walker 1999). The longleaf pine ecosystem has a long history of maintenance by fire, and many of these forests are now managed through controlled burns that benefit some rare and endangered animal species such as the red-cockaded woodpecker and the gopher tortoise (Outcalt 2000). The effects of burning as a management tool for longleaf pine have been well studied, but non-target species such as insects necessary for pollination, some animals, and small herbaceous plant species may be harmed by thorough burns or improper timing of burns (Sorrie and Weakley 2006).

Fire is a cue for germination for many plant species, especially those that have evolved in ecosystems that have a history of frequent burns. However, a more thorough understanding of the effects of heat and smoke on the seeds of plants associated with longleaf pine and sandhills ecosystems will aid future conservation and restoration efforts in these areas. Furthermore, alteration of the longleaf pine ecosystem through years of logging, grazing, and fragmentation has caused degradation in the herbaceous layer that fire alone will not be adequate to restore (Ruth et al. 2007). Though management plans must address the establishment and growth of longleaf pine seedlings, the replacement or enhancement of native herbaceous plant species with seeds or seedlings may also be necessary for the conservation and restoration of these ecosystems. Understanding conditions necessary for the germination and survival of these species, especially TES plants, will enhance conservation efforts.

For this research, I focused on four perennial sandhills species :*Baptisia lanceolata, Carphephorus bellidifolius, Nolina georgiana,* and *Stylisma pickeringii* (Table 1). These species were selected based on population location, seed availability, and to support research conducted through the Strategic Environmental Research and Development Program (SERDP) funded project, *Impacts of Military Training and Land Management on Threatened and Endangered Species in the Southeastern Fall-line/Sandhills Community* as representatives of a variety of life forms and life histories of sandhills TES plants (Sharitz 2009).

Table 1. Sandhills TES plants listed as Species of Conservation Concern for Georgia and South Carolina and chosen for study.

TES Species	**Common Name**	**Global[1] Status**	**State Status[1]**
Baptisia lanceolata	lanceleaf wild indigo	G4	GA-S4, SC-S3
Carphephorus bellidifolius	sandy woods chaffhead	G4	GA-S1, SC-SNR
Nolina georgiana	Georgia beargrass	G3, G5*	GA-SNR, SC-S3
Stylisma pickeringii	Pickering's dawnflower	G4, T3	GA-S2, SC-S2

[1]1= critically imperiled, 2 = imperiled, 3 = vulnerable, 4 = apparently secure, 5 = secure, SNR = species not ranked, T = sub-taxon. *numeric range indicates uncertainty about the global status of the species. Status from NatureServe, December 2008

Recent plant surveys performed on Fort Gordon and the SRS suggest a lack of young plants in natural populations of these species (K. Madden, personal communication). Thus, this research focused on the following goals:

1) Determine whether the absence of TES seedlings in natural populations is due to low reproduction, seed predation, poor germination, and/or low seedling survival.

2) Evaluate germination requirements for TES species.

3) Analyze growth and survival of planted TES seedlings following disturbance conditions commonly found on federal installations.

Two experiments and a survey of population density and reproductive success in natural populations on the SRS and Fort Gordon were conducted. The first experiment was a greenhouse study to analyze seed germination response to a variety of treatments designed to mimic common environmental factors known to influence germination. The second study was a common garden experiment set up to examine the survival of focal species transplanted to sites subjected to a variety of man-made disturbances mimicking military training activities and land management for red-cockaded woodpecker habitat. I analyzed survival, growth, and reproduction of TES species over four growing seasons to determine whether transplantation into disturbed areas would be a viable restoration technique for TES plants on the SRS and Fort Gordon.

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CHAPTER 2

POPULATION DEMOGRAPHY AND GERMINATION OF FOUR AT-RISK HERBACEOUS SANDHILLS PLANT SPECIES IN GEORGIA AND SOUTH CAROLINA

Abstract

Understory plants represent the majority of diversity within the longleaf pine ecosystem of the southeastern United States. An understanding of population demography and germination requirements is essential for the creation of ecologically meaningful conservation plans for at-risk understory species in this fire-prone ecosystem. This study quantified density, reproductive success, and seed predation of four herbaceous plants and examined effects of temperature and smoke on germination. No seedlings were found in natural populations surveyed, suggesting that seed germination or seedling establishment may be a limiting factor in population growth. Germination of *Baptisia lanceolata* was low under all treatments and significantly decreased in response to 15 days of cold stratification and to a combination of smoke and heat. Germination of *Carphephorus bellidifolius* increased in response to the application of heat, cold and smoke treatments. The greatest increase was in response to 30 days of cold stratification, suggesting an optimal threshold of cold exposure for maximum germination of this species. Although *Nolina georgiana* had the highest germination percentage of all four species under control conditions, cold stratification for 30 and 45 days increased germination. *Stylisma pickeringii* had very low

germination that significantly increased following scarification, suggesting that penetration of the seed coat is the limiting factor in its germination. Integration of such data from germination tests with population demographic surveys can provide managers with the tools to determine current population statistics, develop monitoring recommendations, and undertake species restoration efforts.

Introduction

Conservation of threatened, endangered, and sensitive (TES) plant species is a growing concern as many native habitats become increasingly threatened by degradation and alteration. Although surveys of rare plant population demographics and habitat characterization studies have provided valuable ecological data about TES plants, more information is needed to develop management plans to aid in conservation and restoration of at-risk species. The collection of demographic data (Schemske et al. 1994) and ecologically meaningful germination studies (Baskin and Baskin 1998) are essential to understanding the population biology and ecology of TES plants and the creation of management and restoration plans.

Within the southeastern Coastal Plain of the United States, 1630 endemic vascular plant species have been identified (Sorrie and Weakley 2006), of which 1000 taxa are associated with the longleaf pine (*Pinus palustris*) ecosystem. Longleaf pine forests in the southeast occupy less than 14% of their original area (Simberloff 1993) and fewer than 7% of the original longleaf pine ecosystems are in “good condition” signifying the presence of an intact understory layer and an existing fire regime essential for maintaining understory diversity (Frost 1993). Much of the remaining land suitable for long term conservation of longleaf pine communities is under federal jurisdiction on sites such as the Department of Energy’s Savannah River Site (SRS) in South Carolina, and military bases such as Fort Gordon in Georgia (Outcalt 2000; Sorrie and Weakly

2006). The restoration and conservation of understory plants in this ecosystem is lacking in knowledge and experience (Brockway et al. 2004).

The longleaf pine ecosystem experiences frequent surface fires (Outcalt 2000). Many plants historically associated with fire have evolved adaptations for survival including underground perennating structures, meristems surrounded by insulating tissues, basal sprouting capability, and fire induced flowering and seed production (Walker 1993). Plants native to fire-prone ecosystems such as the chaparral and fynbos produce seeds that germinate in response to either heat-shock or charred wood and smoke (Van Staden et al. 2000). In the fynbos, species that respond to smoke are most likely to be non-sprouting herbaceous perennials or low shrubs. The compound butenolide 3-methyl-2*H*-furo[2,3-c]pyran-2-one, isolated from burned plant material increases germination in a wide range of plant taxa (Flematti et al. 2004).

Longleaf pine ecosystems along the southeastern Fall Line region are closely associated with sandhills which are xeric nutrient-poor sites with deep, sandy, highly weathered soils that are a residual product of underlying sediment from the Cretaceous period (Christensen 2000). Management plans for these longleaf pine and sandhills ecosystems often include prescribed burns or mechanical (shredding, thinning) or chemical (herbicides) treatments used to facilitate burning as a restoration tool for longleaf pine and associated fire-tolerant plants (Brockway et al. 2004). The effects of these management treatments on TES plants of the sandhills are poorly understood, however.

Conditions that facilitate the survival of adult TES plants also may not be suitable for germination or establishment of seeds and seedlings. For example, high levels of seed predation or seedling herbivory may be found in an area otherwise suitable for establishment and survival (Schupp 1995). Seed predation may have significant effects on seedling recruitment and population growth of rare plants (Munzbergova 2005, Hegazy and Eesa 1991). Thus, it is important not only to study existing populations of TES plants, but also to understand the conditions that promote seed germination and survival. An integration of these components is essential for successful conservation and restoration efforts.

The goal of this study is to further our understanding of natural population demography and germination requirements of herbaceous sandhills TES plant species associated with the longleaf pine ecosystem. We surveyed three to five natural populations each of four focal TES plants for demographic characteristics and evidence of seed predation. We also applied heat and smoke to the seeds of these species to determine whether conditions simulating low intensity surface fires, the most common in sandhills ecosystems (Van Lear et al. 2005), would have an effect on germination rates. Since these four species disperse seed in late summer to autumn, cold stratification treatments were used to simulate winter conditions and to determine whether low temperatures are a prerequisite for germination (Baskin and Baskin 1998).

Methods

Species of Interest

Four sandhills TES species were chosen for this study: *Baptisia lanceolata, Carphephorus bellidifolius, Nolina georgiana,* and *Stylisma pickeringii* (Table 2.1). These plants are listed as species of conservation concern in South Carolina and Georgia. The heritage G-ranks indicate rangewide status, while S-ranks indicate the status of the species within each state. These species were selected based on previous surveys that showed at least three populations on either the SRS, Fort Gordon, or both.

Table 2.1. Sandhills TES plants listed as Species of Conservation Concern for Georgia and South Carolina and chosen for study.

TES Species	Common Name	Global[1] Status	State Status[1]
Baptisia lanceolata	lanceleaf wild indigo	G4	GA-S4, SC-S3
Carphephorus bellidifolius	sandy woods chaffhead	G4	GA-S1, SC-SNR
Nolina georgiana	Georgia beargrass	G3, G5*	GA-SNR, SC-S3
Stylisma pickeringii	Pickering's dawnflower	G4, T3	GA-S2, SC-S2

[1]1= critically imperiled, 2 = imperiled, 3 = vulnerable, 4 = apparently secure, 5 = secure, SNR = species not ranked, T = sub-taxon. *numeric range indicates uncertainty about the global status of the species. Status from NatureServe, December 2008

Baptisia lanceolata (Walter) Elliott var. *lanceolata* (Fabaceae) is a perennial leguminous plant endemic to the southeastern Coastal Plain. Its native range is southern South Carolina to northeastern Florida and southwestern Georgia. The yellow flowers bloom from April to May and fruit from June to November (Weakley 2006). The fruit of is a ligneous legume (Melhman 1993). The seeds are dispersed locally when pods open while the plant is rooted, and by tumbleweed dispersal over long distances (up to 100+ meters) after the aboveground ramet dies and becomes uprooted, facilitated by contact with the ground (Melhman 1993). Seed predation may affect regeneration in this species. Horn and Hanula (2004) found both *Apion rostrum* Say (Coleoptera: Curculionidae) and an unidentified caterpillar (Tortricidae family) in seed pods of *B. lanceolata.* The caterpillar often exited the seed pod after consuming all of the seeds and leaving frass and silk behind (Horn and Hanula 2004).

Carphephorus bellidifolius (Michaux) Torrey & A. Gray (Asteraceae) is endemic to the southeastern Coastal Plain from southern Virginia to Georgia and occurs primarily in the sandhills. It has basal leaves and a corymbiform inflorescence and produces light purple flowers from August to October (Weakley 2006). The fruit of *C. bellidifolius* are achenes that are likely wind dispersed.

Nolina georgiana Michaux (Ruscaceae) is endemic to the southeastern Coastal Plain and occurs on dry and dry-mesic sandhills in South Carolina and Georgia. It has basal leaves, flowers from May to June, and produces indehiscent fruit from June to August (Weakley 2006). This species is typically dioecious.

Stylisma pickeringii (Torrey ex M.A. Curtis) A. Gray var. *pickeringii* (Convolvulaceae) occurs "usually in the driest, most barren, deep-sand areas, occasionally colonizing dry, disturbed areas in sandhills, such as sandy roadbanks" (Weakley 2006). *Stylisma pickeringii* grows from southern North Carolina through South Carolina, Georgia, Alabama and eastern Mississippi. It has a trailing growth form with multiple stems arising from a single point. It flowers from June to August and is in fruit from July to September (Weakley 2006).

Natural Population Survey

Transect surveys of populations of TES sandhills plants on Fort Gordon in Georgia and the Savannah River Site (SRS) in South Carolina were performed during 2003 and 2004 (Sharitz 2009). Data from that study were used to choose populations for this survey. Five populations of *B. lanceolata,* four populations of *N. georgiana,* and three populations each of *C. bellidifolius* and *S. pickeringii* were sampled.

Five GPS points where focal plants had been sampled previously were chosen randomly from each population. Each GPS point was relocated in the field, and the closest plant in a reproductive state (defined as a plant in either flower or fruit) within 20m was chosen as a focal plant. The height of *B. lanceolata*, the rosette radius (length of the longest leaf in the basal rosette) of *C. bellidifolius,* the longest basal leaf length of *N. georgiana,* and the longest vine length of *S. pickeringii* were measured. The flowers on the focal plant were counted, and the seeds were collected. Plants were vouchered at the University of Georgia herbarium.

A 100m^2 plot was created using the focal plant as the center point. For *S. pickeringii,* 1m^2 plots were used due to the trailing growth form and small size of these plants. Within each plot, the total number of plants of the focal species was counted, and the number of reproductive plants was recorded. Any non-focal TES species were also noted.

Additional seeds were collected from each population for germination experiments. Due to the sensitive nature of these species, no non-focal plant was entirely stripped of seeds, and an effort was made to collect from as many plants as possible. In the laboratory, seeds were placed on newspaper to dry, counted, and removed from the seed coats. Any damage to seeds was recorded, and damaged seeds were discarded. Seeds were then transferred to seed envelopes and stored at room temperature for germination experiments.

Statistical analysis

One-way ANOVA was used to compare variables between populations of focal species. Tukey's multiple comparison analysis was used to compare all pair-wise differences between populations.

Germination experiments

Imbibition testing was performed on groups of fifty seeds from each population. Seeds were weighed and placed on wet filter paper for eight hours. Each hour, seeds were patted dry and weighed to determine seed coat were permeability (Baskin and Baskin 1998). Since *S. pickeringii* did not imbibe water, a second imbibition test was performed on 50 seeds following scarification (nicking the seed coat with a razor blade). Additional seeds collected from each population were combined, mixed well, and then divided into groups of fifty. Each group was randomly assigned a number, and numbers were randomly assigned to germination treatments (Table 2.2).

For heat treatments, seeds were placed in seed envelopes and placed flat in drying ovens for 10 minutes. Time measurement began when the temperature of the ovens reached 40 or 60ºC. For cold treatments, seeds were placed on soil in flats, watered with a mist sprayer, and covered with clear plastic dome tops. These flats were then placed in a walk-in cooler (*c* 15°C) for the duration of the treatment (15, 30, or 45 days).

Stylisma pickeringii seeds did not imbibe water during imbibition testing unless scarified, so a scarification treatment was performed by rubbing seeds between sandpaper for ten minutes to mimic natural weathering of the seed coat. Other seeds of *S. pickeringii* were not scarified to determine if any germination treatments would cause seeds to become permeable.

Following treatment all seeds were planted in seed trays filled with soil that had been collected near a natural population on the SRS, sifted through a 0.5mm screen, and then steam sterilized. Planting was performed by lightly pressing the seeds into the sand. Seeds in the smoke treatments were given one drop of a ten percent commercially available liquid smoke solution from a pipette after planting. All seeds not in the smoke treatments were treated with one drop of water after planting. Control trays (unplanted) with sterilized soil from the natural habitat were also observed. Seed trays were placed in a greenhouse and watered daily with a misting wand as needed. All treatments contained five replicates of fifty seeds each. The number of germinated seeds in each tray was recorded once a day for 145 days. Germination day count for cold stratification treatments began the day after the trays were removed from cold storage (16, 31, and 46 days). New germinants were marked using plastic toothpicks.

Table 2.2. Treatments used in germination experiments. (BL = *Baptisia lanceolata,* CB = *Carphephorus bellidifolius,* NG = *Nolina georgiana*, SP = *Stylisma pickeringii*)

	40ºC	60ºC	smoke	40ºC smoke	Cold 15 d	Cold 30 d	Cold 45 d	Cold 15 d smoke	Scarify	Control
BL	X	X	X	X	X	X		X		X
CB	X	X	X	X	X	X	X	X		X
NG	X	X	X	X	X	X	X	X		X
SP	X	X	X	X	X	X		X	X	X

Statistical analysis

A logistic regression model was used to examine the effects of treatment on the proportion of germinated seeds. The Kaplan-Meier method (survival analysis) was used to analyze germination over the 145 day period of observation. The Log-rank test and Wilcoxon test were used to test whether all survival curves were equal.

NG	NG	NG	CB	CB	CB
NG	NG		CB	CB	
SP	SP		CB	CB	
SP	SP	SP	CB	CB	CB
	NG	NG	CONTROL	BL	BL
NG	NG	NG	BL	BL	BL
NG	NG	NG		NG	NG
	NG	NG	NG	NG	NG
BL	BL	BL	CONTROL	CONTROL	BL
BL	BL	BL	BL	BL	BL
	CB	CB		SP	SP
CB	CB	CB	SP	SP	SP
	SP	SP	CB	CB	CB
SP	SP	SP		C	CB
NG	NG	CB	SP	SP	SP
CONTROL	CONTROL	CONTROL	SP	SP	SP
SP	SP	SP	SP	SP	SP
SP	SP	SP	SP	SP	SP
SP	SP	SP	SP	SP	SP
SP	SP	SP	SP	SP	SP
CB	CB	CB	CB	CB	CB
CB	CB	CB	CB	CB	CB
CB	CB	CB	CB	CB	CB
CB	CB	CB	CB	CB	CB
NG	NG	NG	NG	NG	NG
NG	NG	NG	NG	NG	NG
NG	NG	NG	BL	NG	NG
NG	NG	NG	NG	NG	NG
BL	BL	BL	BL	BL	BL
BL	BL	BL	BL	BL	BL
BL	BL	BL	BL	BL	BL
BL	BL	BL	BL	BL	BL

KEY
45 Day Cold
30 Day Cold
15 Day Cold
15 Day Cold + Smoke
Smoke
Scarified
40 C
40 C + smoke
60 C
Control
Empty

Figure 2.1: Layout of germination experiment in greenhouse. Cells represent trays of 50 seeds. BL=*B. lanceolata*, NG=*N. georgiana*, SP=*S. pickeringii, and* CB=*C. bellidifolius*

Results

Natural population survey

For the five populations of *Baptisia lanceolata* surveyed in 100m^2 plots, the number of reproductive plants, plant size, and the number of damaged seeds per focal plant varied by location. No seedlings of *B. lanceolata* were found during this study, but average number of seeds/focal plant ranged from 7.8 to 47.6 (Table 2.3). Sixty-four percent of the focal plants studied showed evidence of insect predation in greater than half of their seed pods. The SRS 4 population had the greatest number of seeds damaged by seed predators. Seed predation was from the weevil *Apion rostrum* and an unknown lepidopteran larva. Intact seeds were recovered from pods that showed evidence of damage from the weevil but no intact seeds were found in pods that were damaged by the caterpillar.

For *Carphephorus bellidifolius,* natural populations did not differ in size, but differed significantly in the reproductive variables studied. The number of reproductive plants in a 100m^2 area varied by location as did the number of seeds and floral heads per focal plant. The SRS 1 population had the greatest density of reproductive plants and the greatest number of seeds and floral heads per focal plant (Table 2.4). No seedlings were found in the natural populations of *C. bellidifolius,* and no seed predation was noted although damage due to grazing of vegetative structures was observed.

Populations of *Nolina georgiana* did not show differences in population variables. Only female plants were counted as reproductive in this species, and no seedlings were found during the course of this survey. The majority of seed pods contained only one seed, but seed pods containing two and three seeds were also found. *Nolina georgiana* had the greatest population density of any TES species surveyed but a low proportion of reproductive plants in all populations (Table 2.5). No seed predation was observed.

Stylisma pickeringii populations had significantly different densities of reproductive plants. Populations of this species were found only on FG, mainly along roadsides. The road at location FG 6 had been graded prior to data collection, and this population had the lowest density of individuals per $1m^2$, although not significantly lower at the 95% confidence level. Seed predators were not identified, but evidence of seed predation (holes in the seed pod and damaged seeds) was noted. Average numbers of damaged seeds per focal plant were similar to average numbers of seeds per focal plant in each population (Table 2.6). Few intact seeds were recovered from the focal plants.

Populations of *B. lanceolata, C. bellidifolius,* and *N. georgiana* were all found at locations SRS 1 and SRS 3. Populations of *B. lanceolata* and *C. bellidifolius* were both found at location SRS 4. Location FG 1 had populations of *B. lanceolata, C. bellidifolius,* and *N. georgiana* but no reproductive individuals of either *B. lanceolata* or *C. bellidifolius. Carphephorus bellidifolius* individuals were also present at location FG 5, but no reproductive individuals were found. This was the only other focal species found in the same habitat as *S. pickeringii.*

Table 2.3: Comparison of population variables for *B. lanceolata* between locations. Values represent mean ± standard deviation. Within columns, values with the same superscripts were not significantly different at α = 0.05.

Location	Density (no. plants /100m^2)	No. reproductive plants / 100m^2	Height (cm)	No. seed pods / focal plant	No. seeds / focal plant	No. seeds per seed pod	No. damaged seed pods / focal plant
SRS 1	9.8 ± 7.01^a	4.2 ± 3.11^a	46.6 ± 5.9^{ab}	4.2 ± 3.03^a	11.2 ± 12.38^a	2.08 ± 1.38^a	1.4 ± 0.55^b
SRS 2	8.40 ± 3.78^a	1.8 ± 1.3^{ab}	42.0 ± 7.58^{ab}	2.8 ± 2.05^a	19.2 ± 22.9^a	6.17 ± 5.19^a	1.6 ± 1.34^b
SRS 3	4.6 ± 2.01^a	1.0 ± 0^b	52.6 ± 10.9^a	11.6 ± 9.81^a	47.6 ± 64.49^a	2.81 ± 3.15^a	6.2 ± 6.76^{ab}
SRS 4	4.4 ± 1.52^a	1.6 ± 0.55^{ab}	50.0 ± 9.35^{ab}	10.0 ± 6.04^a	43.0 ± 29.44^a	4.34 ± 1.4^a	8.2 ± 5.26^a
FG 1	3.8 ± 1.48^a	1.4 ± 0.89^{ab}	33.0 ± 14.83^b	5.2 ± 4.76^a	7.8 ± 8.9^a	1.23 ± 0.94^a	1.8 ± 1.1^b

Table 2.4: Comparison of population variables for *C. bellidifolius* between locations. Values represent mean ± standard deviation. Within columns, values with the same superscripts were not significantly different at α = 0.05.

Location	Density (no. plants /100m^2)	No. reproductive plants / 100m^2	Basal leaf length (cm)	No. seeds / focal plant	No. flower heads / focal plant	No. seeds per flower head
SRS 1	69.2 ± 51.81^a	59.8 ± 49.97^a	10.0 ± 1.23^a	397.4 ±348.6^a	28.2 ± 17.64^a	12.96 ± 3.42^a
SRS 3	51.2 ± 31.2^a	12.4 ± 10.29^{ab}	13.0 ± .95^a	62.0 ± 29.13^b	7.6 ± 3.21^b	9.01 ± 4.28^{ab}
SRS 4	13.4 ± 6.54^a	4.4 ± 4.83^b	11.6 ± .95^a	58.2 ± 61.57^b	9.2 ± 6.98^b	5.83 ± 3.27^b

Table 2.5: Comparison of population variables for *N. Georgiana* between locations. Values represent mean ± standard deviation. Within columns, values with the same superscripts were not significantly different at α = 0.05.

Location	Density (no. plants /100m^2)	No. reproductive plants / 100m^2	Basal leaf length (cm)	No. seed pods / focal plant	No. seeds / focal plant
SRS 1	271.5 ± 109.8^a	1.0 ± 1.72^a	60.0 ± 14.61^a	356.5 ± 83.3^a	396.5 ± 96.09^a
SRS 3	234.0 ± 77.64^a	2.75 ± 1.21^a	58.75 ± 10.33^a	148.0 ± 58.9^a	170.75 ± 67.94^a
FG 2	126.0 ± 69.44^a	5.0 ± 1.09^a	75.0 ± 9.24^a	94.2 ± 52.69^a	99.4 ± 60.77^a
FG 3	224.4 ± 69.44^a	5.0 ± 1.09^a	51.6 ± 9.24^a	147.2 ± 52.69^a	153.4 ± 60.77^a

Table 2.6: Comparison of population variables for *S. pickeringii* between locations. Values represent mean ± standard deviation. Within columns, values with the same superscripts were not significantly different at α = 0.05.

Location	Density (no. plants /1m^2)	No. reproductive plants / 1m^2	Vine length (cm)	No. seed pods / focal plant	No. seeds / focal plant	No. damaged seeds / focal plant
FG 4	10.8 ± 2.25^a	7.8 ± 1.34^a	82.8 ± 11.27^a	19.2 ± 5.92^a	19.2 ± 5.92^a	14.8 ± 5.72^a
FG 5	10.2 ± 2.25^a	3.2 ± 1.34^{ab}	83.8 ± 11.27^a	12.0 ± 5.92^a	12.0 ± 5.92^a	11.0 ± 5.72^a
FG 6	5.0 ± 2.53^a	1.5 ± 1.5^b	67.25 ± 12.6^a	6.5 ± 6.62^a	6.5 ± 6.62^a	2.25 ± 6.39^a

Germination

In the 145 day germination study, the greatest number of seeds of *Baptisia lanceolata* germinated in the 60ºC treatment (total 24; 9.6%, Table 2.7). A total of 19 seeds (7.6%) germinated in the control treatment; however, the maximum number of seeds that germinated in any replicate occurred in the control treatment. The treatments of cold stratification for 15 days (P = 0.011, Table 2.8) and smoke + 40ºC heat exposure (P = 0.035, Table 2.8) had significant effects on the probability of germination of *B. lanceolata.* Both treatments decreased the probability of germination (odds ratio < 1) compared to control treatments. The highest percent germination of *B. lanceolata* occurred in the heat treatments (8.8% at 40ºC; 9.6%, Table 2.7) but these values were not significantly higher than the control. Overall germination of *B. lanceolata* was low; the average number of germinated seeds within treatments ranged from 1.2 to 4.8.

Under all treatments, *B. lanceolata* showed similar germination curves over time, with germination occurring slowly over the 145 day period (Figure 2.2). The 50 percentile germination day for *B. lanceolata* occurred the earliest for the smoke + 15 day cold stratification treatment, and the latest for the smoke treatment (Table 2.7).

Table 2.7: Results of germination study for *B. lanceolata.* Total, mean, and % seeds germinated are shown for each treatment. Max and min are the highest and lowest number of seeds germinated in replicates within treatments. Percentile germination day is the day at which 50, 75, and 95% of the total number of germinated seeds had germinated.

Treatment	Total	Mean	Std Dev	Max	Min	% Germinated	Percentile Germination Day		
							50%(G)	75%(G)	90%(G)
40ºC	22	4.4	1.52	6	2	8.8	25	45	58
60ºC	24	4.8	2.77	8	1	9.6	25	79	93
cold 15 days	6	1.2	1.30	3	0	2.4	21	79	95
cold 30 days	16	3.2	2.28	7	1	6.4	47	54	77
smoke +15 days cold	11	2.2	1.64	4	1	4.4	18	21	21
smoke + 40ºC	8	1.6	2.07	5	0	3.2	49	81	97
smoke	16	3.2	3.11	7	0	6.4	52	79	120
control	19	3.8	3.56	9	0	7.6	31	61	77

Table 2.8: Logistic regression results for germination probability of *B. lanceolata* seeds. Values are significant at P<0.05. Odds ratios are reported for treatment vs. control.

Treatment	Estimate	Standard error	Wald Chisquare	P	Odds Ratio
Intercept (Control)	-2.498	0.239	109.548	<.0001	-
40ºC	0.160	0.327	0.239	0.625	1.173
60ºC	0.256	0.321	0.634	0.426	1.291
cold 15 days	-1.207	0.477	6.402	0.011	0.299
cold 30 days	-0.185	0.352	0.276	0.599	0.831
smoke + 15 days cold	-0.581	0.390	2.217	0.137	0.560
smoke + 40ºC	-0.912	0.431	4.465	0.035	0.402
smoke	-0.185	0.352	0.276	0.599	0.831

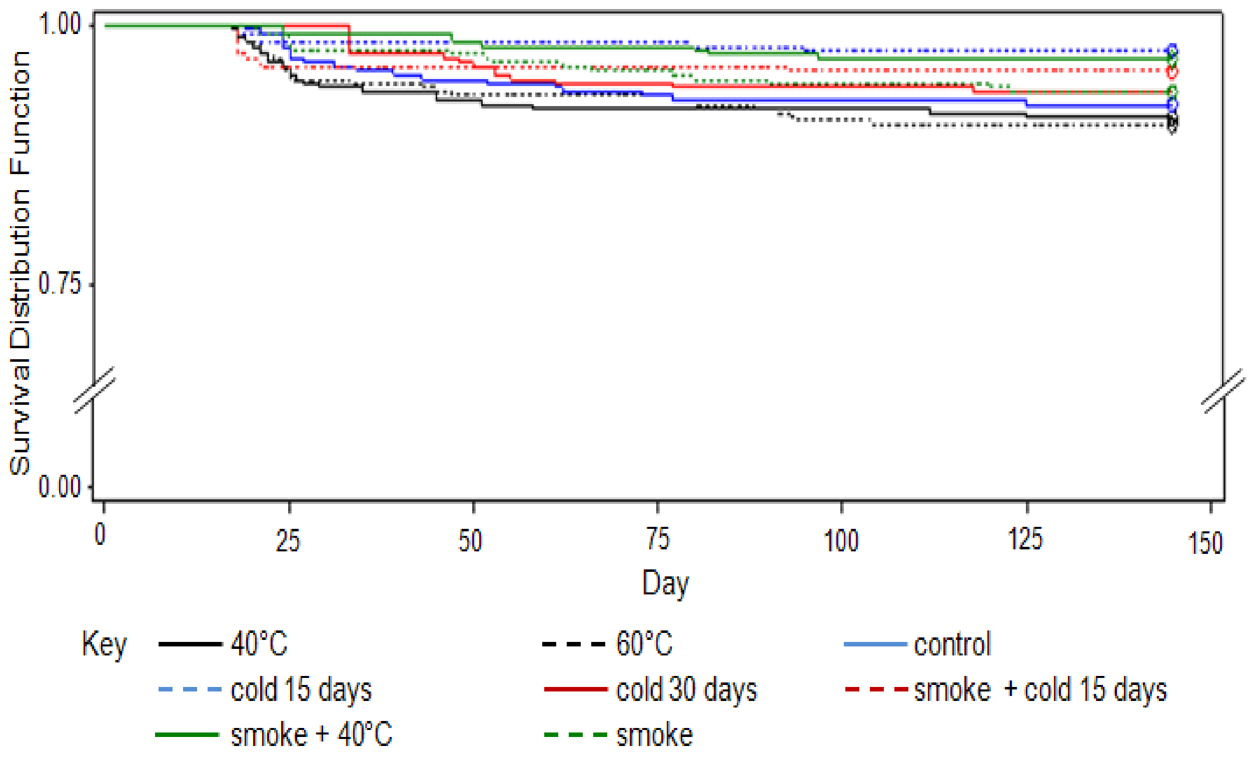

Figure 2.2: Curves of the proportion of ungerminated seeds over time for treatments of *B. lanceolata*. Ungerminated seeds were censored at day 145. Survival distribution function represents the proportion of ungerminated seeds.

Germination of *Carphephorus bellidifolius* seeds during the 145 day period ranged from 96 seeds in the control treatment to 164 seeds in the 30 day cold stratification treatment (Table 2.9). All treatments (except heat at 60ºC) significantly increased percent germination over the control treatment (Table 10, $P<0.05$). The odds ratio for the logistic regression was highest in the cold stratification for 30 days (65.6% germinated, Table 2.9) followed by the smoke + cold stratification for 15 days (58.4% germinated, Table 2.9) and the smoke + 40º C treatments (56.4% germinated, Table 2.9), indicating highest probability of germination under these conditions. Cold stratification for 30 days also had the maximum number of germinated seeds for any single replicate (35 seeds germinated, Table 2.9).

In all treatments except for cold stratification treatments that had not been removed from cold storage (30 and 45 day cold treatment), 75% germination of *C. bellidifolius* occurred prior to the fourth week of the experiment (Table 2.9). The control treatment had the smallest proportion of seeds germinated (38.4%) and took the longest amount of time to reach 90% germinated (52 days, Table 2.9). The control treatment also had the lowest number of seeds germinated for any one replicate (14 seeds germinated, Table 2.9).

The germination curves for *C. bellidifolius* were similar for all treatments except for cold stratification (Figure 2.3), which increased the germination rate. *Carphephorus bellidifolius* reached the 90 percentile germination day most rapidly after cold stratification: 10 days after removal from cold storage for cold 15 days and cold 30 days, 11 days after removal from cold storage for smoke + cold 15 days, and 7 days after removal from cold storage for cold 45 days (Table 2.9).

Table 2.9: Results of germination study for *C. bellidifolius.* Total, mean, and % seeds germinated are shown for each treatment. Max and min are the highest and lowest number of seeds germinated in replicates within treatments. Percentile germination day is the day at which 50, 75, and 95% of the total number of germinated seeds had germinated.

Treatment	Total	Mean	Std Dev	Max	Min	% Germinated	Percentile Germination Day		
							50%(G)	75%(G)	90%(G)
40ºC	122	24.4	1.52	26	22	48.8	20	26	47
60ºC	115	23	4.90	30	18	46	22	27	50
cold 15 day	123	24.6	2.88	28	20	49.2	21	23	25
cold 30 day	164	32.8	1.92	35	30	65.6	34	36	40
cold 45 day	127	25.4	4.51	33	22	50.8	48	49	52
smoke + 15 days cold	146	29.2	3.42	32	25	58.4	21	22	26
smoke + 40ºC	141	28.2	1.92	31	26	56.4	19	23	30
smoke	128	25.6	5.32	30	18	51.2	21	25	32
control	96	19.2	5.45	26	14	38.4	21	27	52

Table 2.10: Logistic regression results for germination probability of *C. bellidifolius* seeds.. Values are significant at $P<0.05$. Odds ratios are reported for treatment vs. control.

Treatment	Estimate	Standard Error	Wald Chisquare	P	Odds Ratio
Intercept (Control)	-0.4726	0.13	13.21	0.0003	-
40ºC	0.4246	0.18	5.4763	0.0193	1.529
60ºC	3.12E-01	0.1817	2.9534	0.0857	1.367
cold 15 days	0.4406	0.1814	5.90	0.0152	1.554
cold 30 days	1.118	0.19	36.0914	<.0001	3.059
cold 45 days	0.5046	0.1814	7.7359	0.0054	1.656
smoke + 15 days cold	0.8118	0.1827	19.75	<.0001	2.252
smoke + 40ºC	0.73	0.18	16.06	<.0001	2.075
smoke	0.5206	0.18	8.2332	0.0041	1.683

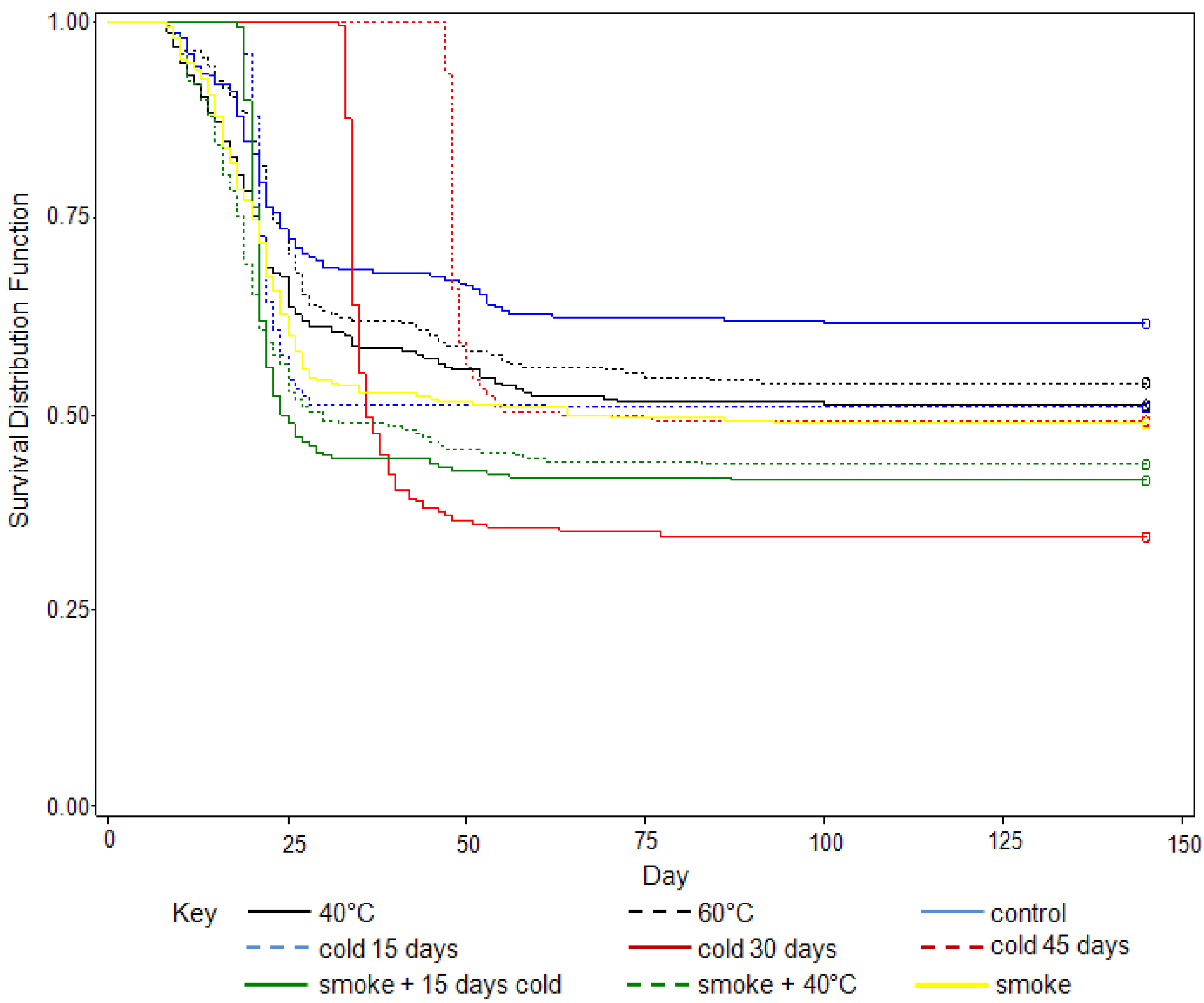

Figure 2.3: Curves of the proportion of ungerminated seeds over time for treatments of *C. bellidifolius.* Ungerminated seeds were censored at day 145. Survival distribution function represents the proportion of ungerminated seeds.

The germination percentage for *Nolina georgiana* following cold stratification for 45 days was the highest percent germination of any focal species in any treatment (73.2 %, Table 2.11), and the maximum number of germinants for any replicate also occurred under this treatment (46 seeds germinated, Table 2.11). Germination percentage increased significantly under cold stratification treatments at 30 and 45 days ($P<0.05$, odds ratio >1, Table 2.12). In the control treatment, 46.8 % of *N. georgiana* seeds germinated (Table 2.11). Percent germination decreased as compared to the control in the cold stratification at 15 days and the smoke + 40ºC treatments, but these values were not significant.

The germination curves for *N. georgiana* varied by treatment (Figure 2.4). Germination curves for the cold stratification treatment showed a trend of increased proportion of germinated seeds as the number of days spent in cold stratification increased. The cold stratification treatments for cold 45 days and smoke + cold 15 days reached the 90 percentile germination day the soonest, 23 days after they were taken from cold storage (Table 2.11). Seeds exposed to the low heat treatment of 40ºC took the longest to reach the 90 percentile germination day (66 days, Table 2.11).

Table 2.11: Results of germination study for *N. georgiana*.. Total, mean, and % seeds germinated are shown for each treatment. Max and min are the highest and lowest number of seeds germinated in replicates within treatments. Percentile germination day is the day at which 50, 75, and 95% of the total number of germinated seeds had germinated.

Treatment	Total	Mean	Std Dev	Max	Min	% Germinated	Percentile Germination Day		
							50%(G)	75%(G)	90%(G)
40ºC	127	25.4	5.86	30	17	50.8	34	55	66
60ºC	121	24.2	11.41	38	12	48.4	28	37	56
cold 15 day	100	20	5.79	26	11	40	33	64	80
cold 30 day	159	31.8	11.78	39	11	63.6	48	51	56
cold 45 day	183	36.6	11.52	46	17	73.2	58	62	68
smoke + 15 days cold	122	24.4	8.08	37	18	48.8	25	26	38
smoke + 40ºC	101	20.2	7.01	29	11	40.4	30	45	55
smoke	124	24.8	8.81	35	12	49.6	38	54	60
control	117	23.4	4.04	27	19	46.8	27	38	59

Table 2.12:Logistic regression results for germination probability of *N. georgiana* seeds. Values are significant at $P<0.05$. Odds ratios are reported for treatment vs. control.

Treatment	Estimate	Standard Error	Wald Chisquare	P	Odds Ratio
Intercept (Control)	-0.128	0.127	1.023	0.312	-
40ºC	0.160	0.179	0.800	0.371	1.174
60ºC	0.064	0.179	0.128	0.720	1.066
cold 15 day	-0.277	0.181	2.349	0.125	0.758
cold 30 day	0.686	0.183	14.122	0.000	1.986
cold 45 day	1.133	0.191	35.210	<.0001	3.105
smoke +15 days cold	0.080	0.179	0.200	0.654	1.083
smoke + 40ºC	-0.261	0.181	2.079	0.149	0.771
smoke	0.112	0.179	0.392	0.531	1.119

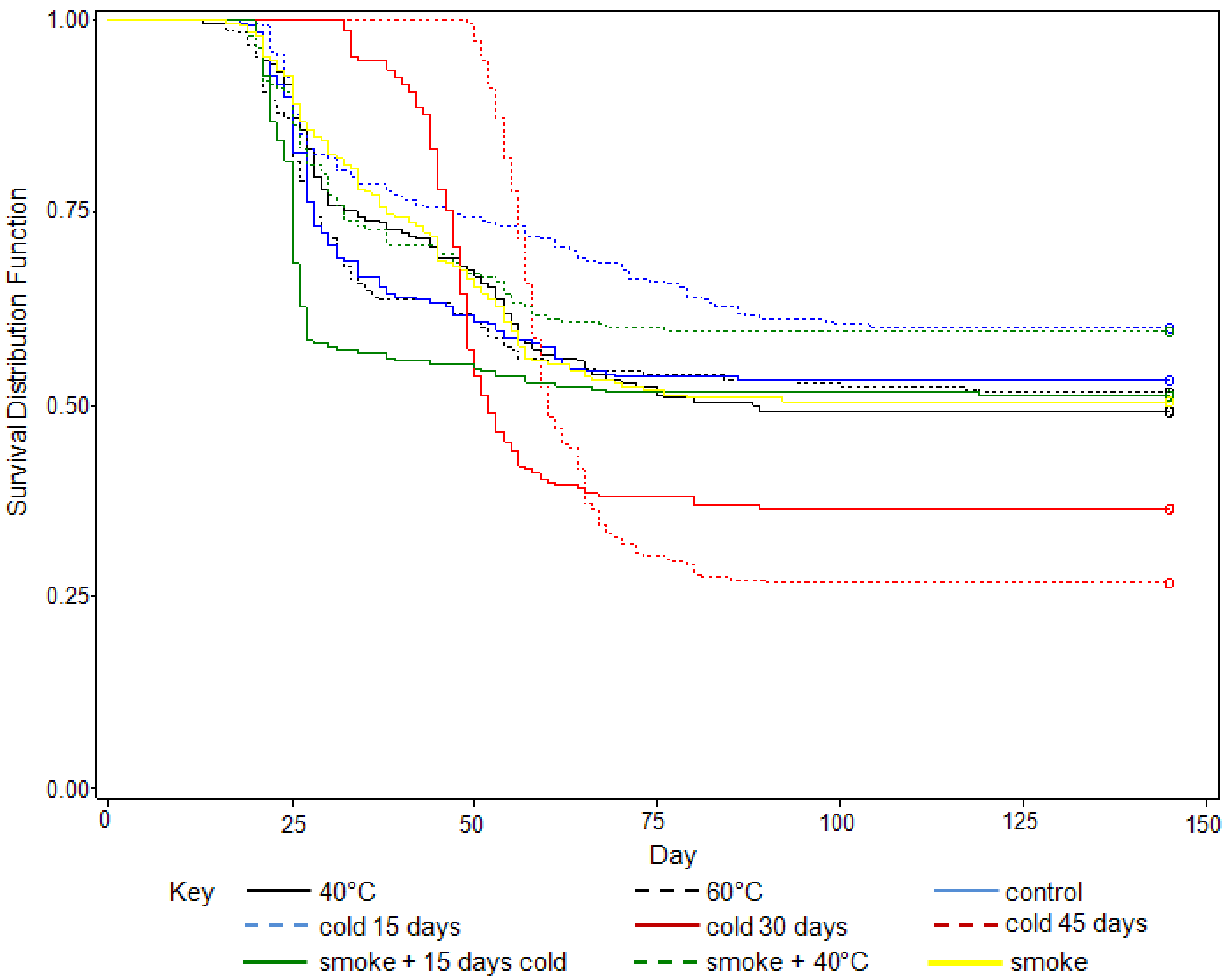

Figure 2.4: Curves of the proportion of ungerminated seeds over time for treatments of *N. georgiana*. Ungerminated seeds were censored at day 145. Survival distribution function represents the proportion of ungerminated seeds.

The only treatment that had a significant effect on the germination of *Stylisma pickeringii* was scarification with sandpaper (*P*< 0.05, odds ratio>1, Table 2.14). Scarification produced the highest percent germination (17.2%, Table 2.13) and the highest number of seeds that germinated for any one replicate (16 seeds, Table 2.13). Imbibition testing performed on *S. pickeringii* showed that seeds have an impermeable seed coat, and scarification resulted in both imbibition and germination.

All of the smoke treatments increased the proportion of germinated seeds of *S. pickeringii* as compared to the control (odds ratio >1, Table 2.14), but these results were not significant. Overall germination of *S. pickeringii* was low (Table 2.13) and germination curves for *S. pickeringii* appear linear (Figure 2.5).

Table 2.13: Results of germination study for *S. pickeringii.* Total, mean, and % seeds germinated are shown for each treatment. Max and min are the highest and lowest number of seeds germinated in replicates within treatments. Percentile germination day is the day at which 50, 75, and 95% of the total number of germinated seeds had germinated.

Treatment	Total	Mean	Std Dev	Max	Min	% Germinated	Percentile Germination Day		
							50%(G)	75%(G)	90%(G)
40ºC	12	2.4	1.52	4	1	4.8	15	49	118
60ºC	10	2	0.71	3	1	4	21	47	74
cold 15 day	7	1.4	0.55	2	1	2.8	22	56	86
cold 30 day	4	0.8	0.84	2	0	1.6	74	95	108
scarify	43	8.6	5.03	16	2	17.2	53	94	111
smoke +15 days cold	13	2.6	0.89	4	2	5.2	25	104	121
smoke + 40ºC	11	2.2	1.48	4	0	4.4	12	23	76
smoke	20	4	1.58	6	2	8	14	49	108
control	10	2	1.87	5	0	4	21	104	108

Table 2.14:Logistic regression results for germination probability of *S. pickeringii* seeds. Values are significant at $p<0.05$. Odds ratios are reported for treatment vs control.

Parameter	Estimate	Standard Error	Wald Chisquare	P	Odds Ratio
Intercept (control)	-3.1781	0.3227	97.0	<.0001	-
40ºC	0.2	0.4	0.1897	0.6632	1.210
60ºC	4.79E-16	0.4564	0	1	1.000
cold 30 day	-0.941	0.60	2.47	0.1159	0.390
cold 15 day	-3.69E-01	0.5011	0.54	0.4614	0.691
smoke + 15 days cold	0.2749	0.4305	0.4079	0.523	1.316
smoke + 40ºC	0.0995	0.4464	0.0497	0.8236	1.105
smoke	7.36E-01	0.3981	3.4146	0.0646	2.087
scarify	1.6066	0.36	19.5157	<.0001	4.986

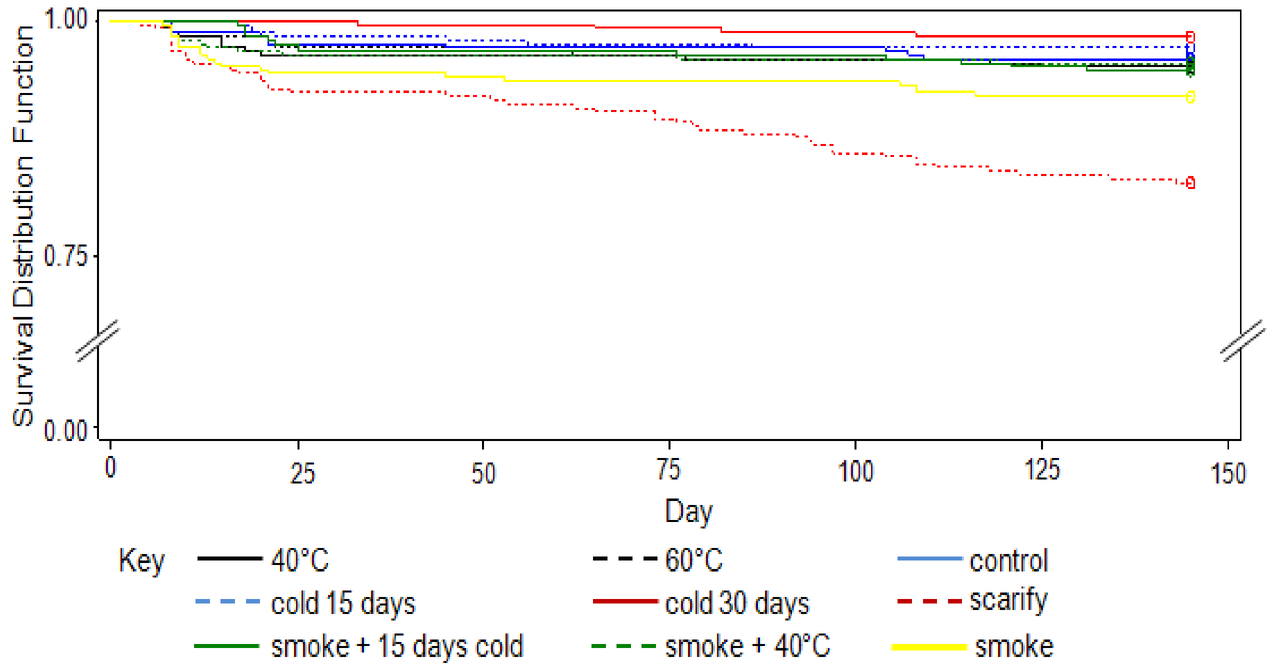

Figure 2.5: Curves of the proportion of ungerminated seeds over time for treatments of *S. pickeringii*. Ungerminated seeds were censored at day 145. Survival distribution function represents the proportion of ungerminated seeds.

Discussion

The conservation of native plants must take into account the natural demographics of native populations. An understanding of the natural variability of founder populations is essential to the successful reintroduction of native flora (Cochrane et al. 2002). Densities of reproductive plants varied across population location in all of our focal species except for *Nolina georgiana*. Neither plant size or plant density was related to variation in reproductive parameters for any of the species studied.

In a study of three populations of *Baptisia lanceolata*, Young et al. (2007) reported that less than 50% of seed pods were damaged by seed predators. They also found that pods damaged by the weevil predator *Apion rostrum* still contained viable seed and saw no evidence of the lepidopteran predator. In our study, seed predation rates averaged higher than 50%. There were intact seeds in pods damaged by the weevil seed predator, but no intact seeds were present in pods that sustained damage from the lepidopteran predator. The damage induced by seed predators is not limited to the actual consumption of seeds. Damage by insect predators has been shown to lead to mold and decay (Hegazy and Eesa, 1991). We saw evidence of this in *B. lanceolata* but did not quantify the damage due to fungal growth following attacks by insect predators.

Our finding of low germination of *B. lanceolata* is consistent with reports from other studies. In an examination of seed germination requirements in rare Australian plant species, Cochrane et al. (2002) found that seeds from Fabaceae species required either heat shock (pouring "near boiling" (*c* 90°C) water onto the seeds) or mechanical scarification for germination. Imbibition testing performed in conjunction with our study showed that water could permeate the seed coat of *B. lanceolata,* so no mechanical scarification treatment was performed, but the highest percent germination for this species was seen in the 60ºC heat treatment. Similarly, Young et al. (2007) found that fewer than 1% of *B. lanceolata* seeds germinated under greenhouse conditions and that average seed viability did not increase or decrease significantly in response to temperatures up to 100ºC. Young's study monitored germination for only three weeks, however. The number of treatments in our study was limited by the number of seeds available, but our results suggest that *B. lanceolata* germinates at a slow rate and that heat may increase germination percentage. Future germination studies should test germination of this species under a range of temperatures.

Natural populations of *Carphephorus bellidifolius* had the highest density of reproductive plants of any of our focal species. Common garden experiments show that this species will flower in the first growing season following establishment (DuRant, Chapter 3).

Germination of *C. bellidifolius* seeds increased significantly in response to all treatments except heat at 60ºC. The highest increase in germination was in response to cold stratification at 30 days. Though cold stratification at 15 and 45 days did increase germination, our results suggest that there is a threshold of cold stratification that will maximize germination.

Nolina georgiana had the highest population density of any of our species, but a low density of reproductive individuals. In a common garden experiment, *N. georgiana* took a minimum of four growing seasons to reach reproductive maturity, and this occurred only in open locations with high sunlight (DuRant, Chapter 3). Longleaf pine stands are relatively open with sparse tree density that allows high levels of sunlight to reach ground level (Van Lear et al. 2005). Thus, although *N. georgiana* seeds did not show an increase in germination in response to smoke or heat, this species may reach reproductive maturity most rapidly in habitats with intact longleaf pine ecosystems that have regular surface fires that inhibit growth of hardwood species.

Local abundance of this species suggests that seedling establishment may occur in cohorts following conditions that promote germination. Our experiments showed a significant increase in germination of *N. georgiana* following cold stratification of 30 and 45 days. Sandhills ecosystems in Georgia and South Carolina, where this species is native, do not often experience long periods of cold during the winter, so high levels of germination may occur rarely. Control treatments showed a germination percentage of 46.8%, the highest of any of our focal species; this suggests that even without optimal environmental conditions, *N. georgiana* seeds may germinate at a frequency high enough to maintain viable populations. Since no seed predation was noted in our study, our results suggest that current populations of *N. georgiana* may be stable, and that the absence of seedling recruitment in the field in one year of observation may not be cause for concern.

Stylisma pickeringii was shown to have an impermeable seed coat in imbibition testing for this experiment. Todd et al. (2002) found that scarification of *S. pickeringii* by shaking seeds in coarse sandpaper for 48 and 72 hours increased germination to 92% and 48%, respectively. Scarification in our experiment increased germination significantly over the control, but only to 17.2%. Exposure to smoke resulted in chemical scarification of the seed coat of *Emmenanthe penduliflora,* an obligate fire recruiter found in the chaparral ecosystem (Egerton-Warburton 1998). All of the smoke treatments and heat treatments in our study increased germination of *S. pickeringii* over the control, but the only treatment that significantly increased germination was mechanical scarification. These results suggest that permeation of the seed coat is the main limiting factor in the germination of *S. pickeringii*. The concentrations of liquid smoke and the methods used for applying liquid smoke to seeds need to be tested to determine whether smoke is a viable method to increase seed germination in restoration and management plans for this species.

Other studies of plant germination response in fire-prone communities have reported positive effects of heat exposure and smoke. In a study of heat shock effects on seed germination of plants native to savannas, temperature had a significant influence on the germination of all plant species tested (Gashaw and Michelsen 2002). Our heat treatments did not significantly increase the germination of any of the sandhills TES species tested, though *Baptisia lanceolata* did show an increase in average germination in response to both heat treatments. Keith (1997) examined germination of a fire prone Australian shrub and found an additive effect of smoke and heat treatments. Although germination of *Stylisma pickeringii* increased in response to smoke, heat, and smoke combined with heat, the increase in response to smoke alone was greater than the increase in response to smoke and heat combined. Overall, we found no evidence to suggest that germination response to smoke and heat may be additive in any of our focal species.

The absence of seedlings in the populations of these TES plants suggests that seed germination and seedling establishment may limit the growth of these populations. However, a more in-depth demographic analysis must be performed on these species (Schemske et al. 1994) to determine if population sizes are increasing or decreasing, as well as to determine which life history stages have the greatest effect on population growth. Furthermore, fire may affect vegetative reproduction in these plants. Studies of *Pityopsis gramifolia,* an abundant herbaceous species of the Florida sandhills, showed increased ramet production in response to fire and no seedling recruitment over a two year period (Hartnett 1987). Thus, seedling recruitment may not be important for population persistence, but a lack of seedling recruitment may lead to low genetic diversity.

Natural populations of *Nolina georgiana* and *Carphephorus bellidifolius* showed no evidence of seed predation, and high population densities suggest that these species may currently be stable. High rates of seed predation and low germination percentages under all treatments suggest that both *Stylisma pickeringii* and *Baptisia lanceolata* are at risk for population declines. In depth monitoring of these species should continue in order to develop management plans to conserve these populations.

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CHAPTER 3

THE GROWTH AND SURVIVAL OF FOUR AT RISK SANDHILLS PLANT SPECIES IN POST DISTURBANCE ENVIRONMENTS

Abstract

The longleaf pine (*Pinus palustris*) ecosystem of the southeastern Coastal Plain and the associated sandhills is a hotspot of diversity and plant endemism that is rapidly dwindling in area and in quality in response to habitat alteration and degradation. Many of these pine forests are located on parcels of federal land and are thus subject to a variety of disturbances such as military machinery and troup movement in addition to prescribed fire and other habitat management practices. For this study, we monitored seedlings of four threatened, endangered, or sensitive (TES) plant species of the longleaf pine and sandhills ecosystem that were transplanted to experimental gardens that had been subjected to varying levels and types of disturbance. Disturbance did not decrease survival of any of these plant species over four growing seasons, and garden location was shown to have a greater effect on overall survival than disturbance treatment. Seedling establishment and first growing season survival were the most important factors in the long term survival of these TES species.

Introduction

The southeastern Coastal Plain and the sandhills ecosystems contained therein are a hotspot of plant endemism in the United States (Loehle 2006,). Many of the endemic plants are considered threatened, endangered, or sensitive (TES) at the state level, and are found in areas that were once dominated by longleaf pine (*Pinus palustris*) forests (Sorrie and Weakley 2006). These southeastern longleaf pine forests now occupy less than 14% of their original area (Simberloff 1993) and are still facing a variety of threats including habitat fragmentation, loss of area, and logging. According to Frost (1993), less than 7% of the original longleaf pine forest ecosystems are in "good condition," signifying the presence of an intact understory layer and a fire regime essential for maintaining understory diversity. There are at least 187 species of rare plants associated with longleaf pine forests (Walker 1993). In addition, several animal species found in these ecosystems are listed as federally threatened or endangered, including the red-cockaded woodpecker, (*Picoides borealis),* the eastern indigo snake (*Drymarchon corais couperi*), and the gopher tortoise (*Gopherus polyphemus).*

Many studies have focused on the conservation of rare animals in the sandhills, and on conservation and restoration of longleaf pine (Van Lear et al. 2005). Fewer studies have concentrated on the TES plant species within the sandhills ecosystem. The high plant species richness in the understory of the sandhills and longleaf pine ecosystems is a key element of the healthy function of these systems. Thus, restoration and conservation of understory TES plants is essential for maintaining ecosystem structure and function in sandhills and longleaf pine communities (Brockway et al. 2004).

The sandhills, located inland along the southeastern Coastal Plain, are xeric environments with highly weathered soils that are a residual product of underlying sediment from the

Cretaceous period (Christensen 2000). These areas are subject to a variety of natural disturbances, tropical storms being one of the principal large-scale disturbances (Brockway et al. 2004), and fire another. Furthermore, since European colonization, much of the land throughout the historic range of these ecosystems has been converted to urban and agricultural land use (Ware et al. 1993). Fire suppression in longleaf pine ecosystems has been shown to alter the vegetation profile, reduce the herbaceous plant layer, and prevent recruitment of longleaf pine seedlings (Ruth et al. 2007). The absence of fire in both longleaf pine and associated sandhills ecosystems results in changes in the vegetative community structure and succession to hardwood forest (Laessle 1958; Brockway et al. 2004).

Today, many of the parcels of land suitable for long term conservation of sandhills and longleaf pine communities are located on federal property, such as the Department of Energy's Savannah River Site (SRS) in South Carolina, and military bases such as Fort Gordon in Georgia (Outcalt 2000; Sorrie and Weakly 2006). Due to the nature of federal land use, in addition to forest management and conservation efforts, much of the remaining longleaf pine and sandhills ecosystem on these sites is subject to multiple uses including industry, research, hunting, and military training operations.

Even though the longleaf pine and associated sandhills communities have high local endemism of herbaceous plant species (Sorrie and Weakley 2006), management plans often focus on conservation and restoration of one key species such as longleaf pine or the federally-endangered red-cockaded woodpecker (single species habitat management). Management of these areas for woodpecker habitat is currently performed using tools such as prescribed burns and periodic thinning of hardwood understory species (Sorrie and Weakly 2006; Collins et al.

2006). It is not known how such single species habitat management may affect other TES species of the sandhills communities, especially TES plants.

Prescribed burning increases herbaceous species diversity and richness in sandhills sites (Heuberger and Putz 2003). Ruth et al. (2007) reported that although burning reduced species richness of herbaceous plants, species absent in long unburned areas were found in recently burned sites. Whether this was a result of increased germination from the seed bank in response to fire or an increase in sunlight due to the loss of canopy and litter layers is unknown and may be species dependent (Ruth et al. 2007). Many herbaceous species associated with longleaf pine and other fire dependent systems are shade intolerant (Frost et al. 1986), and thus may respond favorably to any disturbance that removes a portion of the canopy layer. McGuire et al. (2001) found that the herbaceous understory growth response was significantly increased in gaps and that this increase was positively correlated with light availability.

In addition to fire, other management techniques that simulate small-scale disturbances may be used to enhance recruitment of longleaf pine seedlings. Brockway et al. (2004) suggest that mechanical (shredding, thinning) or chemical (herbicide) treatments be used to facilitate burning as a restoration tool in longleaf pine ecosystems. Though these techniques aid pine establishment and restoration, they could have harmful effects on herbaceous TES plant species in the understory.

Effective conservation of rare sandhills plants requires a greater knowledge of the responses of different TES species to fire and other management techniques. Furthermore, conservation of TES sandhills plants also may require transplantation of populations to protected sites. Although the response of sandhills plants to disturbance *in situ* (especially managed burns) has been well documented (Hiers et al. 2000), their survival when transplanted into disturbed sites has been poorly studied. On sites such as military installations that have multiple land use demands, it may be necessary to translocate populations of TES plants to maintain their abundance. Thus, this study focuses on the survival of native TES species that have been planted into disturbed sites. The planting of seedlings also may be an effective technique for use in restoration of the herbaceous layer of longleaf pine communities and may be necessary in highly degraded ecosystems (Harrington et al. 2003; Brockway et al 2004). This experiment documents the survival and growth of four TES plant species that were transplanted to post-disturbance treatments that mimic land use practices likely to be found on government installations where these sandhills ecosystems occur.

Methods

Species of consideration

For this study, four herbaceous sandhills plant species that represent a variety of life forms and are found in populations on the Savannah River Site (SRS) and Fort Gordon (FG) were chosen. These species are listed as species of conservation concern in South Carolina and Georgia (Table 3.1).

Baptisia lanceolata (Walter) Elliott var. *lanceolata* is a perennial leguminous herb (Fabaceae) endemic to the southeastern Coastal Plain. Its native range of is southern South Carolina to northeastern Florida and southwestern Georgia. The yellow flowers bloom from April to May, and fruits from June to November (Weakley 2006).

Carphephorus bellidifolius (Michaux) Torrey & A. Gray (Asteraceae) is characterized by a rosette of basal leaves and a corymbiform inflorescence. It flowers from August to October

(Weakley 2006). It occurs primarily in the sandhills and is endemic to the southeastern Coastal Plain from southern Virginia to Georgia.

Nolina georgiana Michaux (Ruscaceae) is also endemic to the southeastern Coastal Plain and found on dry and dry-mesic sandhills in South Carolina and Georgia. This plant has elongated linear basal leaves, is dioecious, flowers from May to June, and is in fruit from June to August (Weakley 2006).

Stylisma pickeringii (Torrey ex M.A. Curtis) A. Gray var. *pickeringii* (Convolvulaceae) is found "usually in the driest, most barren, deep-sand areas, occasionally colonizing dry, disturbed areas in sandhills, such as sandy roadbanks" (Weakley 2006). It grows from southern North Carolina through South Carolina, Georgia, Alabama and eastern Mississippi, has a trailing growth form with multiple stems arising from a single point, flowers from June to August, and is in fruit from July to September (Weakley 2006)

Table 3.1. Sandhills TES plants listed as Species of Conservation Concern for Georgia and South Carolina and chosen for study.

TES Species	**Common Name**	**Global[1] Status**	**State Status[1]**
Baptisia lanceolata	lanceleaf wild indigo	G4	GA-S4, SC-S3
Carphephorus bellidifolius	sandy woods chaffhead	G4	GA-S1, SC-SNR
Nolina georgiana	Georgia beargrass	G3, G5*	GA-SNR, SC-S3
Stylisma pickeringii	Pickering's dawnflower	G4, T3	GA-S2, SC-S2

[1]1= critically imperiled, 2 = imperiled, 3 = vulnerable, 4 = apparently secure, 5 = secure, SNR = species not ranked, T = sub-taxon. *multiple rankings indicate uncertainty regarding global status of the species. Status from NatureServe, December 2008

Study design

Twelve sandhills sites were chosen for disturbance gardens, six on the SRS and six on FG. Two sites on each installation were located in areas that had recently experienced a high level of disturbance. The FG high impact gardens were located on sites that had been cleared and compacted by the movement of heavy machinery (mimicking track and motorized vehicle training), while the SRS high impact gardens were located in areas where the understory vegetation had been burned and shredded (mimicking intense forest management). Two sites on each installation were designated as low impact gardens. Two of these were subjected to human foot traffic meant to mimic military troup movement and two were disturbed to mimic fox-hole digging. In addition, two sites on each installation were designated as control gardens and not disturbed.

Gardens were laid out in 25m^2 plots in May of 2005. In each garden, 100 *Nolina georgiana*, 100 *Baptisia lanceolata,* 20 *Carphephorus bellidifolius,* and 20 *Stylisma pickeringii* seedlings were planted. These seedlings had been grown from seed in a greenhouse for several weeks before planting. A week after planting, all dead or dying seedlings were replaced. Each garden was watered every other day for a month to promote seedling establishment.

In August of 2005, gardens were sampled by counting and measuring each TES plant. Plant height and vine length for the largest ramet were measured for *Baptisia lanceolata* and *Stylisma pickeringii.* The length of the largest basal leaf (basal rosette radius) was measured for *C. bellidifolius* and the length of the longest leaf was measured for *N. georgiana.* The percent ground cover of other plant species within the gardens, the number of focal TES plants in flower or fruit, and any damage caused by herbivores were recorded. The gardens were resampled at the end of the growing season in 2006, 2007, and 2008.

Data Analysis

Growth values of each species within each garden were averaged for each year. Graphs were constructed using average height, rosette width, leaf length, and vine length for *Baptisia lanceolata, Carphephorus bellidifolius, Nolina georgiana*, and *Stylisma pickeringii,* respectively. Confidence intervals were constructed by multiplying the standard error of each value by the t-statistic using df = n-1 where n = # plants measured.

Total survival was determined by dividing the number of plants alive at the end of the study by the number of plants that were planted at the beginning of the study in May 2005. Confidence intervals for the proportion were determined using the formula

$$CI= z*stdev_p +/- .5/n$$

$$stdev_p = sqrt((p(1-p))/n)$$

where p is the proportion and n is the number of individuals planted at the beginning of the study. The CI values are adjusted by .5/n because survival is a discrete value. Annual survival percentages were calculated by dividing the number of plants alive at year X by the number of plants alive at year X-1. Reproduction was determined from a count of the number of individuals with either flowers or seed at the end of each growing season.

Results

The greatest variation in overall percent survival within treatments after four growing seasons was in the high disturbance gardens. Of the three treatments, none consistently showed a significantly higher or lower survival percentage at the 95% CI than any other in all four gardens for any of the focal species (Figure 3.1).

After four growing seasons, the percent survival of *Baptisia lanceolata* seedlings was highest in the FG disturbance gardens for all treatments except one of the control gardens. Total survival of *B. lanceolata* ranged from 13% to 66% in the high disturbance gardens, 8% to 75% in the low disturbance gardens, and 7% to 53% in the control gardens. In three of the control gardens and one low disturbance garden, total survival was less than 10% after four growing season.

Carphephorus bellidifolius and *Stylisma pickeringii* showed no significant differences in total percent survival between or among treatments at the 95% confidence level. Survival of *C. bellidifolius* after four growing seasons ranged from 15% to 70% in the high disturbance gardens, and 10% to 60% in both the low disturbance and control gardens. Total survival of *S. pickeringii* ranged from 5% to 55% in the high and low disturbance gardens, and 0% to 45% in the control.

The total percent survival of *Nolina georgiana* was significantly higher at the 95% confidence level in the FG high impact gardens than any other garden (Figure 3.1). Total survival ranged from 12% to 75% in the high disturbance gardens, 8% to 36% in the low disturbance gardens, and 1% to 29% in the control gardens.

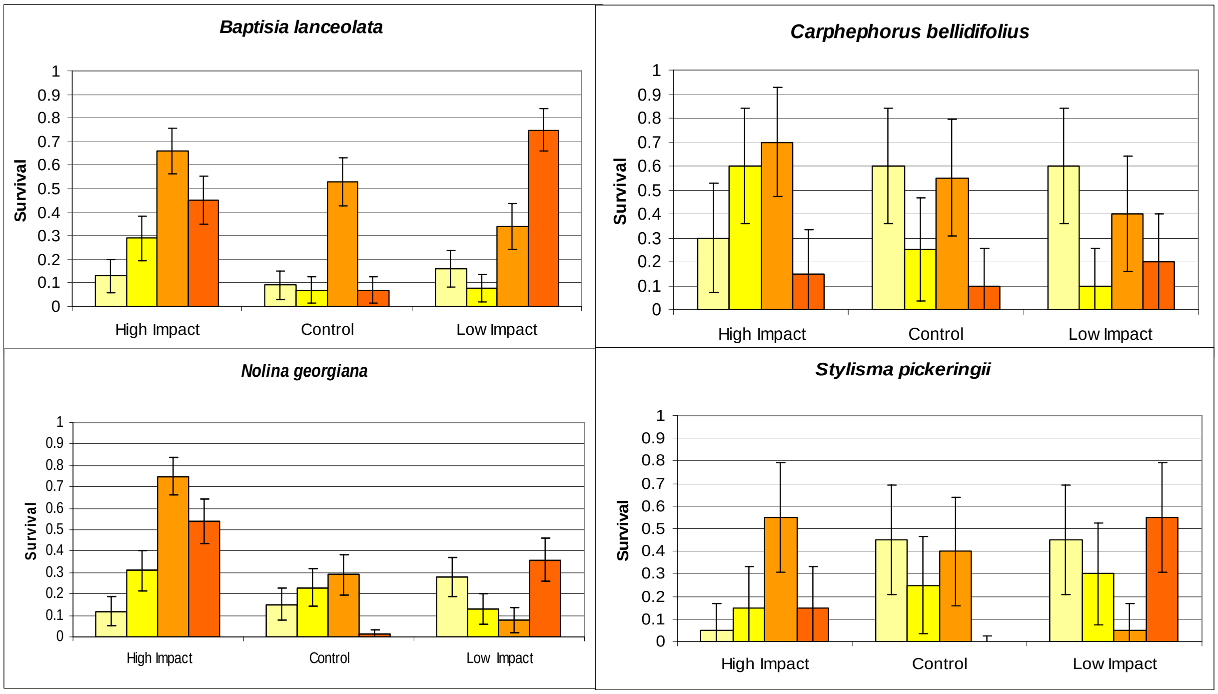
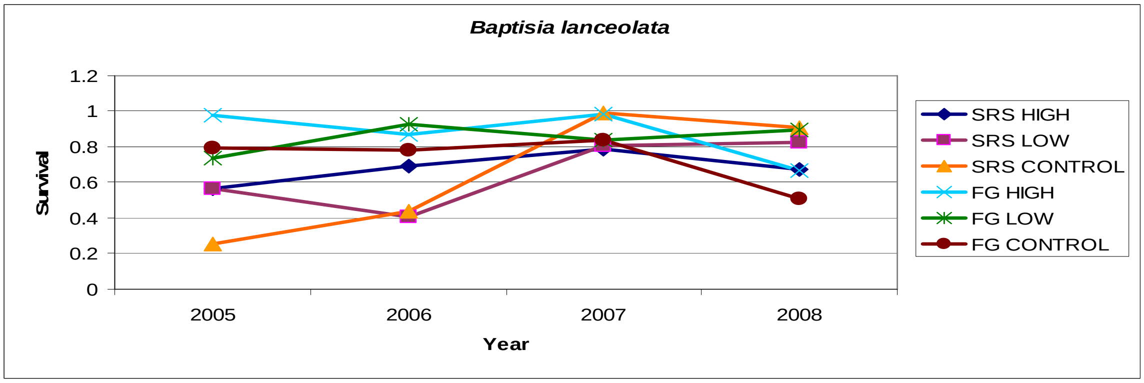


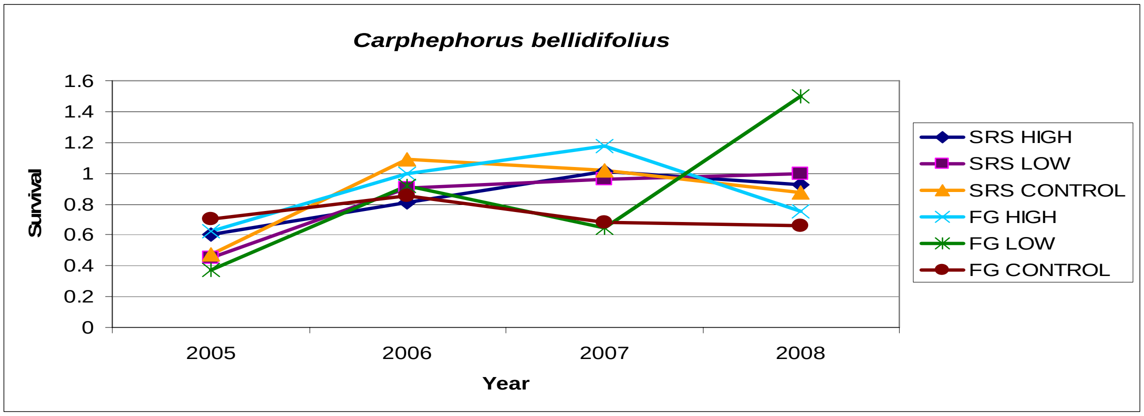
Figure 3.1: Proportion of plants surviving in the TES disturbance gardens after four growing seasons. The yellow bars are SRS gardens and the orange bars are FG gardens. Vertical lines represent 95% confidence intervals.

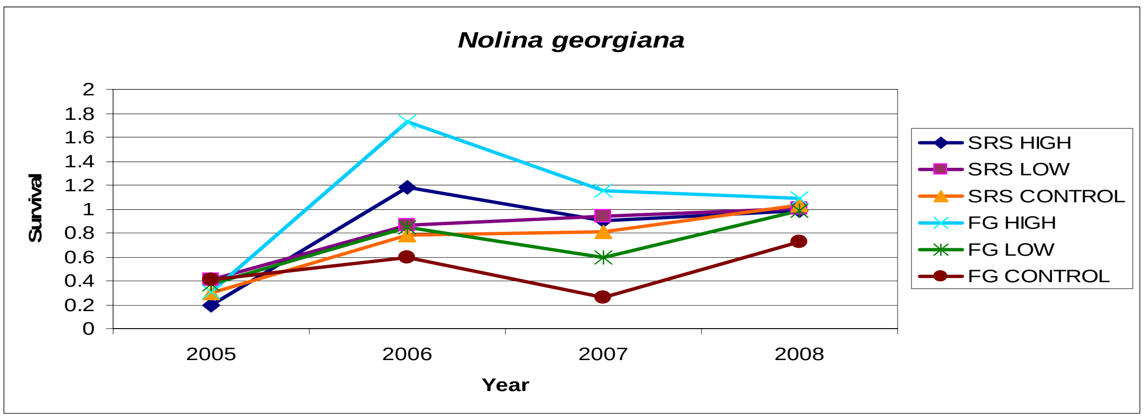
Baptisia lanceolata had highest initial survival (2005) in the FG high impact gardens (Figure 3.2), the most disturbed sites. Average survival in these gardens remained high through the third year but declined during the fourth growing season. Average annual survival in the other gardens generally increased through the third growing season and remained relatively high, although there was also reduced survival in the FG control gardens by the end of the study. Survival of this species was generally higher in the FG than the SRS gardens.

The proportion of *Nolina georgiana, Carphephorus bellidifolius* and *Stylisma pickeringii* plants surviving after the first growing season was the lowest average yearly survival for these species in all gardens except for *S. pickeringii* in the FG control garden (Figure 3.2). Average yearly survival of these species generally increased during the second growing season in all treatments for *C. bellidifolius* and *N. georgiana,* and in all gardens.

During the fourth growing season, *Noliana georgiana* average survival was higher than 70% in all gardens on both installations and *Carphephorus bellidifolius* average survival exceeded 65% in all gardens (Figure 3.2). Fourth season average survival of *S. pickeringii* was greatest in SRS low disturbance and control gardens. These values were greater than 100%, representing resprouts of these perennial plants.


Baptisia lanceolata
1.2
1
0.8
0.6
0.4
0.2
0
Survival
2005
2006
2007
2008
Year
SRS HIGH
SRS LOW
SRS CONTROL
FG HIGH
FG LOW
FG CONTROL


Carphephorus bellidifolius
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Survival
2005
2006
2007
2008
Year
SRS HIGH
SRS LOW
SRS CONTROL
FG HIGH
FG LOW
FG CONTROL


Nolina georgiana
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Survival
2005
2006
2007
2008
Year
SRS HIGH
SRS LOW
SRS CONTROL
FG HIGH
FG LOW
FG CONTROL

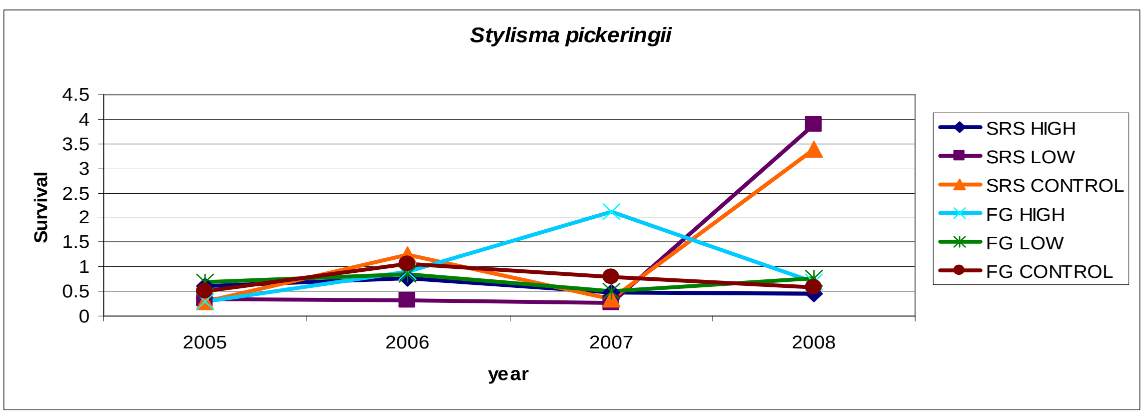

Stylisma pickeringii
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Survival
2005
2006
2007
2008
year
SRS HIGH
SRS LOW
SRS CONTROL
FG HIGH
FG LOW
FG CONTROL

Figure 3.2: Average yearly survival of focal plants in disturbance gardens. Values for each data series are the average of $N_{(t)}/N_{(t-1)}$ for two disturbance gardens at the end of the growing season.

Average yearly plant height of *Baptisia lanceolata* was significantly higher in the FG high impact gardens than in the SRS high impact gardens and all other gardens for all four years of the study. Plant height also was significantly greater in all of the FG gardens than the SRS gardens in each treatment at the end of the first growing season except for one of the control gardens. Height generally increased in 2006 and 2007, but there was no significant increase in *B. lanceolata* plant height in any garden from fall 2007 to fall 2008 (Figure 3.3).

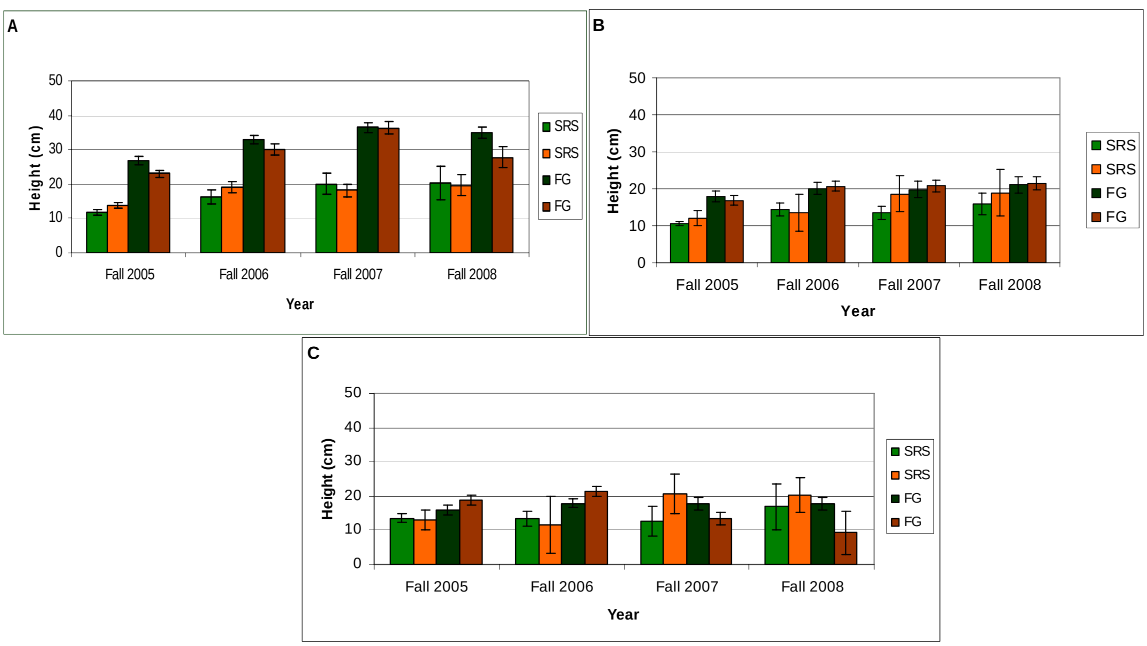


Figure 3.3 : Average yearly plant height of *Baptisia lanceolata* in disturbance gardens. Vertical lines represent 95% confidence intervals. A-high impact gardens, B-low impact gardens, C-control.

Carphephorus bellidifolius showed high variation in rosette radius, and there was no overall significant difference among treatments or by installation. Width did increase yearly in many gardens, but these values were not significant at a 95% confidence interval (Figure 3.4).

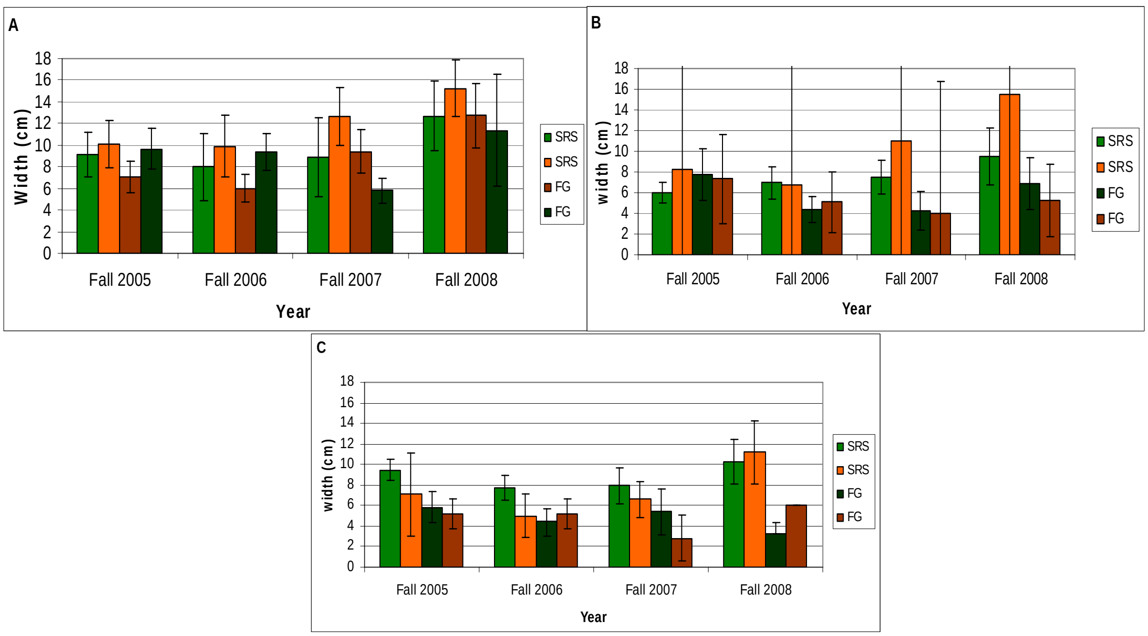


Figure 3.4: Average yearly rosette radius width of *Carphephorus bellidifolius* in disturbance gardens. Vertical lines represent 95% confidence intervals. A-high impact gardens, B-low impact gardens, C-control.

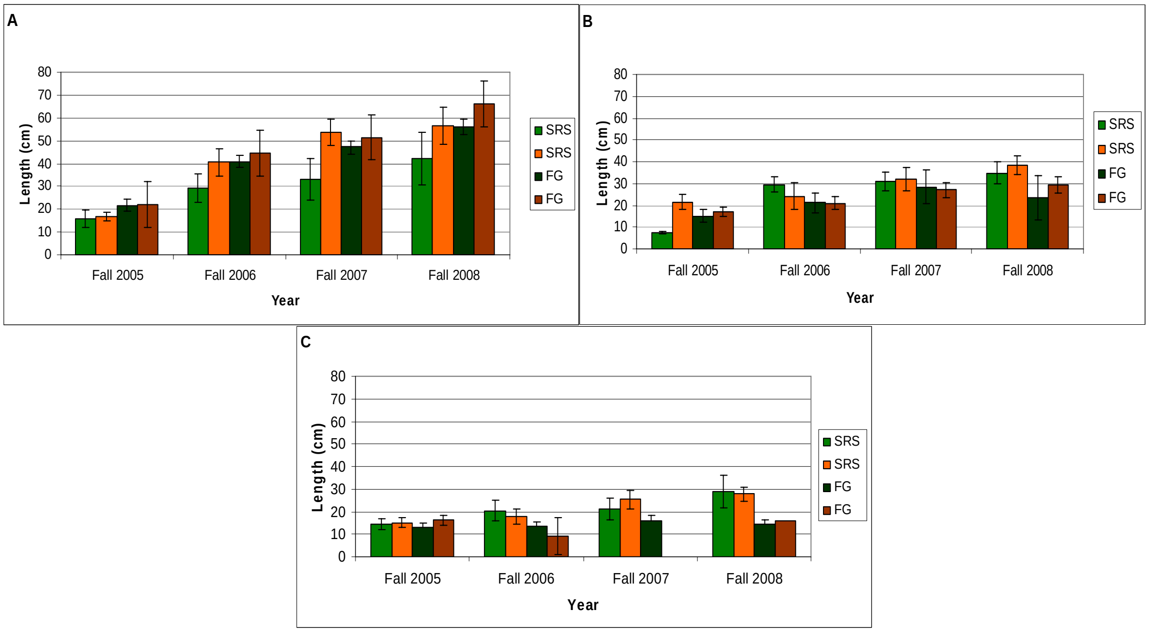


Figure 3.5: Average yearly leaf length of *Nolina georgiana* in disturbance gardens. Vertical lines represent 95% confidence intervals. A-high impact gardens, B-low impact gardens, C-control.

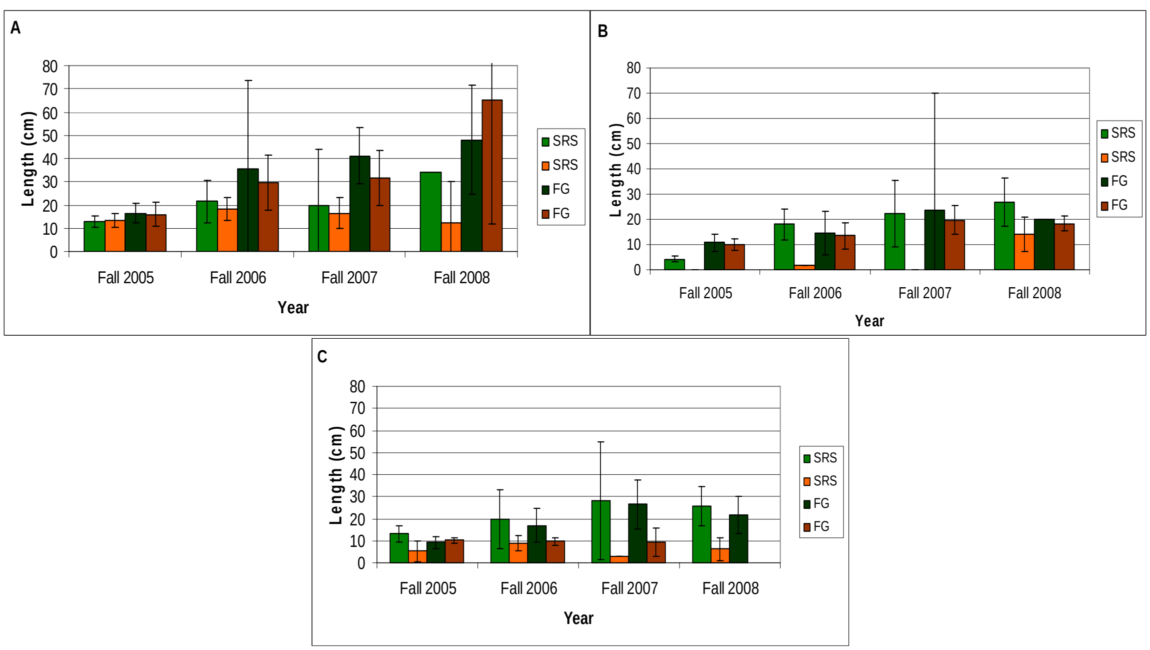


Figure 6: Average yearly vine length of *Stylisma pickeringii* in disturbance gardens. Vertical lines represent 95% confidence intervals. A-high impact gardens, B-low impact gardens, C-control.

Average leaf length of *Nolina georgiana* was significantly greater in three of the high impact gardens than all other gardens in fall of 2006, 2007, and 2008. Final leaf length of *N. georgiana* was significantly higher than first growing season leaf length in all gardens except both FG controls (Figure 3.5). Vine length of *S. pickeringii* was highest in 2008 after four growing seasons in the high impact gardens, but no trends were significant for average vine length at the 95% confidence level due to high variation in length and low population size (Figure 3.6).

All focal plants showed evidence of reproductive maturity by the presence of flowers or fruit after four growing seasons. Only *Carphephorus bellidifolius* flowered during the first growing season. *Nolina georgiana* flowered only during the fourth growing season in the FG high impact gardens; both male and female plants flowered. The high impact gardens supported the greatest number of flowering plants of all species. *Carphephorus bellidifolius* and *Stylisma pickeringii* were the only plants that flowered in the control gardens (Table 3.2).

Table 3.2: Total number of individuals in flower or fruit in disturbance gardens at the end of the growing season.

Species	Year	Treatment		
		High Impact	Control	Low Impact
B. lanceolata	2005			
	2006	1		
	2007	18		1
	2008	3		1
C. bellidifolius	2005	7	2	3
	2006	20	2	3
	2007	24	12	11
	2008	10	7	9
N. georgiana	2005			
	2006			
	2007			
	2008	5		
S. pickeringii	2005			
	2006		1	1
	2007	4		
	2008	5		

FG high impact gardens had the highest ground cover of non-focal herbaceous plants during all years (Table 3.3), while SRS high impact gardens had a yearly increase in woody understory plants. Most of the woody plant biomass in these gardens was associated with resprouts of shredded hardwood species including turkey oak (*Quercus laevis*) and blueberry (*Vaccinium sp.*) All other gardens remained primarily bare ground or covered with pine or hardwood leaf litter throughout the study.

Table 3.3: Yearly percent ground cover of disturbance gardens. Estimates do not include focal plants.

High Impact

	SRS	SRS	FG	FG
2006	50% bare ground, 5% shrubs, 5% woody, 1% herbaceous	50-75% pine litter, 5% woody, 5% shrub/vine, 5% herbaceous	90% herbaceous, <5% shrubs, 5% bare ground	95% herbaceous, <5% shrub/vine/woody
2007	50-75% bare ground, 10-25% woody, 5% herbaceous and vines	50-75% pine litter, 5-25% woody, <1% herbaceous	75-100% herbaceous, 5% woody	75-100% herbaceous, <5% shrub/vine/woody
2008	50% woody, 50% pine and leaf litter, <5% bare ground	90-100% pine litter, 15-25% woody	75-100% herbaceous, 5-10% leaf litter, <5% woody	75-100% herbaceous, 5% leaf litter, <5% woody

Low Impact

	SRS	SRS	FG	FG
2006	60% bare ground, 10% woody, <5% shrub/vine, 5% herbaceous	95% bare ground, <5% herbaceous, <5% woody	95% pine litter, >5% herbaceous, <5% woody	50% pine litter, <5% woody, <5% herbs
2007	25-50% leaf litter, 5-10% herbaceous, 25% woody	90-95% pine litter, 5-10% herbaceous	100% pine/leaf litter, <5% seedlings	75-100% pine litter, <5% woody, <5% herbs
2008	50% leaf litter, 25% woody, 25% bare ground	100% pine litter, <5% herbaceous/grasses	100% pine litter, <1% herbaceous	75-100% pine litter, 5-15% herbaceous, <5% bare ground, <1% woody

Control

	SRS	SRS	FG	FG
2006	90% bare ground, <5% woody, <5% shrub, <5% herbaceous	95% pine litter, <5% herbaceous, <5% woody	90% bare ground, >5% herbaceous, >5% woody	95% pine litter, <5% woody, <5% herbaceous
2007	75-90% bare ground, <5% woody, <5% herbaceous, 10% pine and leaf litter	90% pine litter, <5% woody, 5% herbaceous	25-50% pine litter, >1% woody	100% pine and leaf litter, <5% herbaceous,
2008	50% bare ground, 25-50% pine and leaf litter, <1% herbaceous, <1% woody	100% pine litter, <1% woody, <1% herbaceous	75% bare ground, 15-25% pine litter,<5% herbaceous	100 % pine and leaf litter, <1% herbaceous and woody

Discussion

Disturbance treatments in our study had an overall positive impact on transplanted focal plant survival and growth. Survival percentages of these four sandhills TES species were associated more strongly with installation location than with treatment, however. The FG high impact disturbance gardens were in a location that had been cleared of all canopy plants; *Baptisia lanceolata*, *Nolina georgiana,* and *Stylisma pickeringii* plants grew largest in these gardens during most growing seasons. Percent canopy openness in these two gardens ranged from 64-78% at the time of transplanting; whereas values for the low disturbance gardens ranged from 30-36% and for the undisturbed gardens from 24-30% (Appendix 3, Sharitz 2009).

Light is a major limiting resource for herbaceous plants in sandhills ecosystems. In a study of the reproductive ecology of *Baptisia lanceolata*, Young (2007) found that populations typically occurred in sites with relatively open forest canopy. Similarly, Hainds (1999) reported that basal area of pines was related to abundance of leguminous species in the understory of a longleaf pine forest and attributed this to pine overstory effects on light quality and quantity. In our study, the FG high impact gardens were associated with highest average yearly survival for all of the TES plants during at least one growing season. These gardens also had the greatest amount of herbaceous ground cover of other species. Competition for resources, especially light, with these other plants may have led to the decrease in average survival rates during the fourth growing season that occurred for all TES species in the FG high impact gardens.

Annual survival percentages of the four TES species tended to increase after the first growing season, suggesting that seedling survival may be a limiting factor in the success of reintroduction of these plants into natural habitats. Conditions appropriate for the survival of adult plants may not be suitable for seed germination or seedling establishment (Schupp 1995). Although all four TES species flowered by the fourth growing season, there was no noticeable seedling recruitment over four years. Annual survival values greater than 100% for *Nolina georgiana* represent resprouts since this species did not flower until the final growing season. Values of over 100% survival for *Stylisma pickeringii* were most likely attributed to resprouts as well, since the very few reproductive individuals produced few seeds. Survival values for *Carphephorus bellidifolius* greater than 100% may have resulted from newly recruited plants or resprouts. These plants suffered from the greatest amount of grazing by herbivores of any of our focal species, which may have lead to losses of above ground vegetation prior to survey dates. Ramet production was not quantified, but plant size and seed production were greater and grazing by herbivores was lower in the high impact gardens than in other treatments.

All of these TES plants are long-living perennial species, and long term demographic studies are needed to determine how important seedling recruitment is relative to clonal ramet production. In addition, since controlled burning is a management tool in longleaf pine ecosystems, studies should also examine the response of these plants to fire. For example, studies in the Florida sandhills of populations of *Pityopsis graminifolia,* an abundant rhizomatous herbaceous species, showed increased ramet production in response to fire and no seedling recruitment over a two year period (Hartnett 1987). Of our focal plants, only *Baptisia lanceolata* is rhizomatous, although the leaf bases of *Nolina georgiana* form a bulb-like structure just below or at the surface of the ground. These two species might be less susceptible to burning than other sandhills plants with more shallow root systems.

Previous studies documenting the response of understory plant species to military training activities in longleaf pine forests at Fort Benning, GA, found that species diversity was highest in areas of low level disturbance and control sites and lowest in areas with history of heavy disturbance such as from tanks or other track vehicles (Dale et al. 2002). Even though such military training activities can have a negative effect on understory plant populations, our study suggests that herbaceous plants reintroduced into areas of previous high disturbance have a chance of survival that is equal to or higher than plants introduced into undisturbed areas.

Military and federal installations such as the SRS and Fort Gordon may be ideal sites for restoration and conservation of sandhills communities and their TES species. Disturbances on these sites are heterogeneous, varying in size, frequency, duration, severity and type. The heterogeneous disturbance hypothesis suggests that this variation in disturbance may allow for high biodiversity (Warren et al. 2007). Since survival and growth of the TES plants varied widely based on installation location and disturbance treatment, a heterogeneous landscape may provide the most options in restoration of viable populations of these species.

Disturbances introduce stochastic influences on the vegetative structure of an ecosystem. Responses to disturbance will vary in response to a variety of factors (White and Pickett 1985). Our main concern in this experiment was the survival of planted seedlings into post-disturbance gardens for future restoration efforts, but the survival of adult plants in response to disturbance was not analyzed. Due to the stochastic nature of the longleaf pine and sandhills ecosystems, the effects of disturbance on intact ecosystems also must be taken into account when planning a management or restoration strategy.

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CHAPTER 4

SUMMARY

Conservation planning for southeastern longleaf pine and sandhills ecosystems faces a unique suite of challenges (Ware et al. 1993). Management plans for these areas currently focus on maintaining habitat for the red-cockaded woodpecker and other federally endangered species as well as on regeneration of longleaf pine. Such management usually consists of prescribed burns or other hardwood understory control practices (Sorrie and Weakly 2006; Collins et al. 2006). Tracts of longleaf pine that remain intact and are large enough to sustain viable populations of these species often occur on lands owned by the federal government (Outcalt 2000; Sorrie and Weakly 2006). Thus, resource managers of these sites must balance conservation needs against multiple uses such as military training, industry, and research.

Although understory species account for the majority of plant diversity in longleaf pine ecosystems (Loehle 2006, Sorrie and Weakley 2006), there has been limited research on the population demography and germination and establishment requirements of these species (Brockway et al. 2004). Included among these understory plants are numerous species considered threatened, endangered, and sensitive (TES) but that are not federally listed as rare or endangered and thus are not afforded protection. To create ecologically viable conservation and restoration plans for longleaf pine and sandhills ecosystems, an understanding of the natural population dynamics of these TES plant species must be combined with knowledge of seed germination requirements and of the ability of these plants to survive when transplanted into sandhills habitats.

The four focal species chosen for our study (*Baptisia lanceolata, Carphephorus bellidifolius, Nolina georgiana,* and *Stylisma pickeringii*) represent a variety of growth forms common to herbaceous sandhills plants. Natural population densities ranged from relatively high numbers of individuals (*Nolina georgiana*) to relatively sparse (*Baptisia lanceolata*). All four species flowered and produced seed, but no seedlings were observed over the course of the study. Furthermore, high levels of seed predation was found in two of the species, *B. lanceolata* and *Stylisma pickeringii.* These species also had the lowest germination percentages under greenhouse conditions. Since all four of these TES species are long-lived perennial plants, more detailed long-term demographic surveys are needed to determine the importance of seedling recruitment versus ramet production in maintaining populations of these species

Transplantation of seedlings may be required in order to restore species diversity within degraded habitats and to maintain populations of rare plants. Our studies show that planted seedlings of these sandhills TES plants have a higher probability of survival in disturbed habitats with open canopies than in undisturbed habitats, making these species ideal candidates for restoration projects. First growing season survival percentages tended to be lowest for these species, however, and this suggests that restoration using older seedlings may be the more successful.

A more in-depth understanding the germination requirements for TES plants also can benefit conservation and restoration plans. Cold stratification techniques maximized germination of *Carphephorus bellidifolius* and *N. georgiana,* while scarification resulted in the highest germination of *S. pickeringii.* These treatment techniques should be useful in obtaining the maximum number of seedlings for transplantation. This is especially important given the at-risk conservation status of these species and the relatively small numbers of seeds available for collection in natural populations. Knowledge of how varying environmental factors affect germination also may suggest management activities that support viable populations of these species. Integration of data from population demographic surveys, germination studies and *in situ* plant growth experiments provide managers with more in-depth knowledge of at-risk plant species and can increase the effectiveness of conservation and restoration programs.

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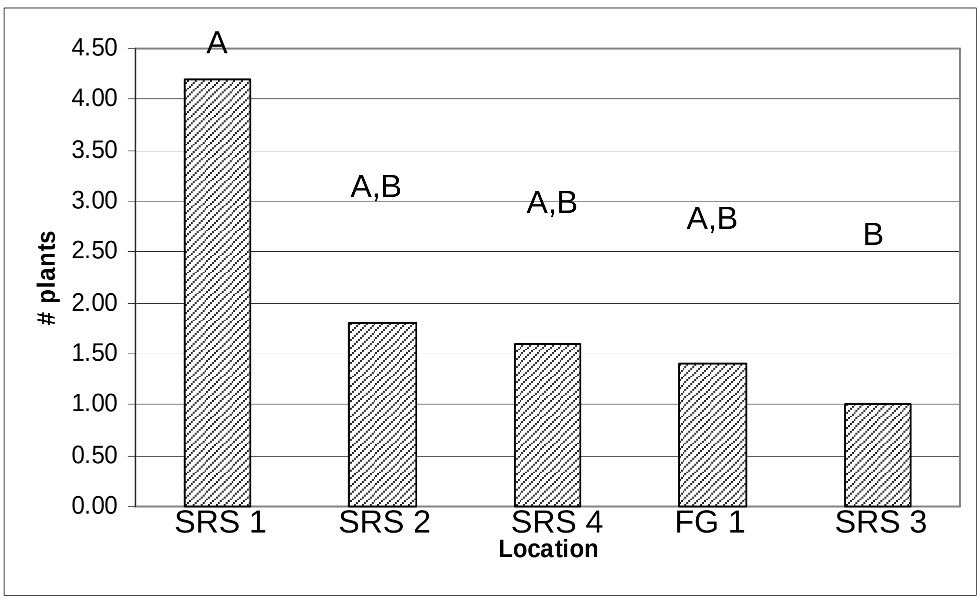
APPENDIX A

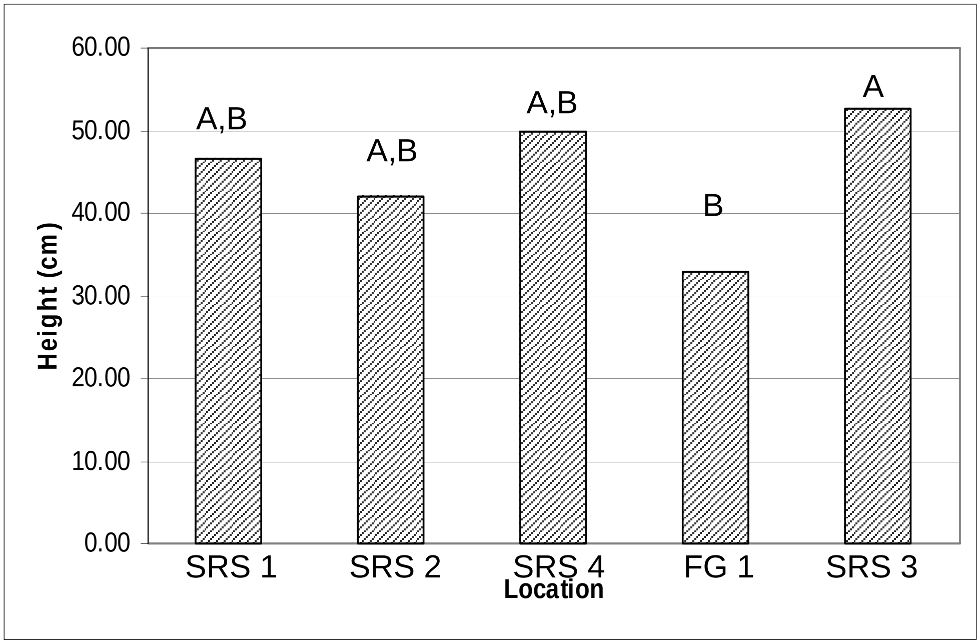
FIGURES OF POPULATION VARIABLES FROM NATURAL POPULATION SURVEYS OF TES SPECIES THAT VARY SIGNIFICANTLY (P<0.05)

Figure 5.1



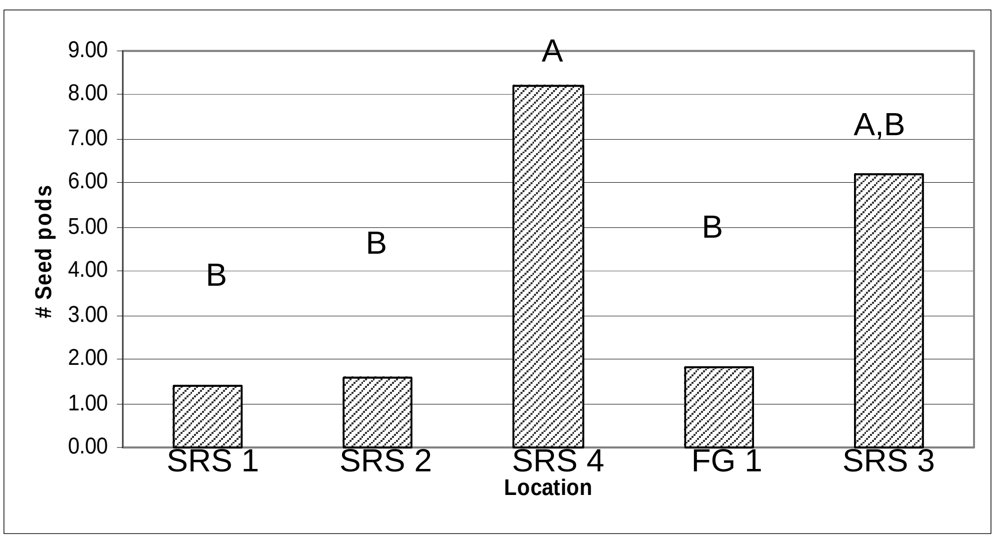
Average reproductive plant density per 100m^2 of *Baptisia lanceolata*.. Different letters represent values that are significantly different at α 0.05.

Figure 5.2



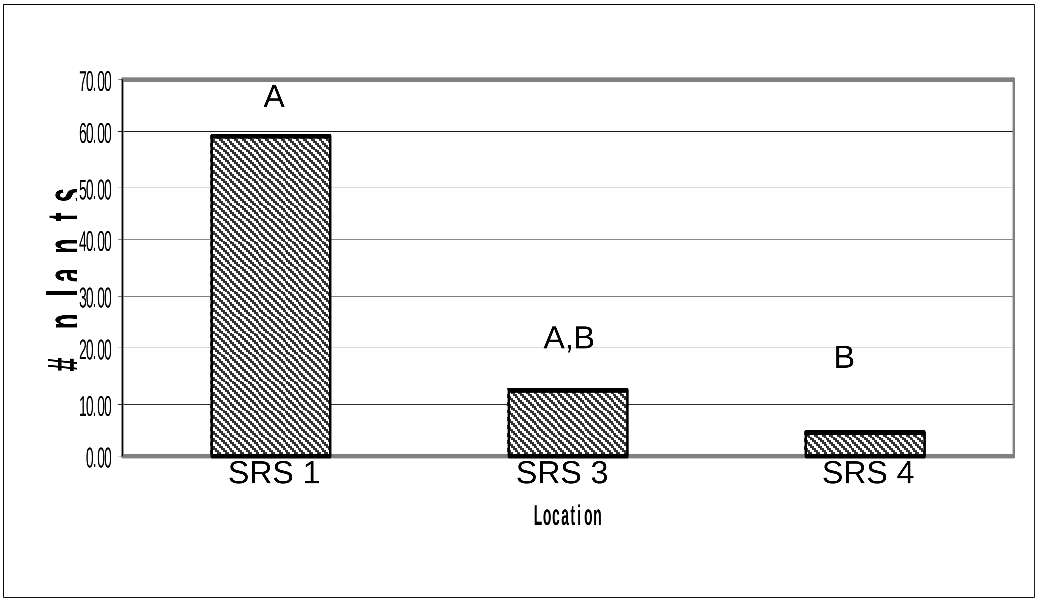
Average height (cm) of focal plants for *Baptisia lanceolata.* Different letters represent values that are significantly different at α 0.05.

Figure 5.3



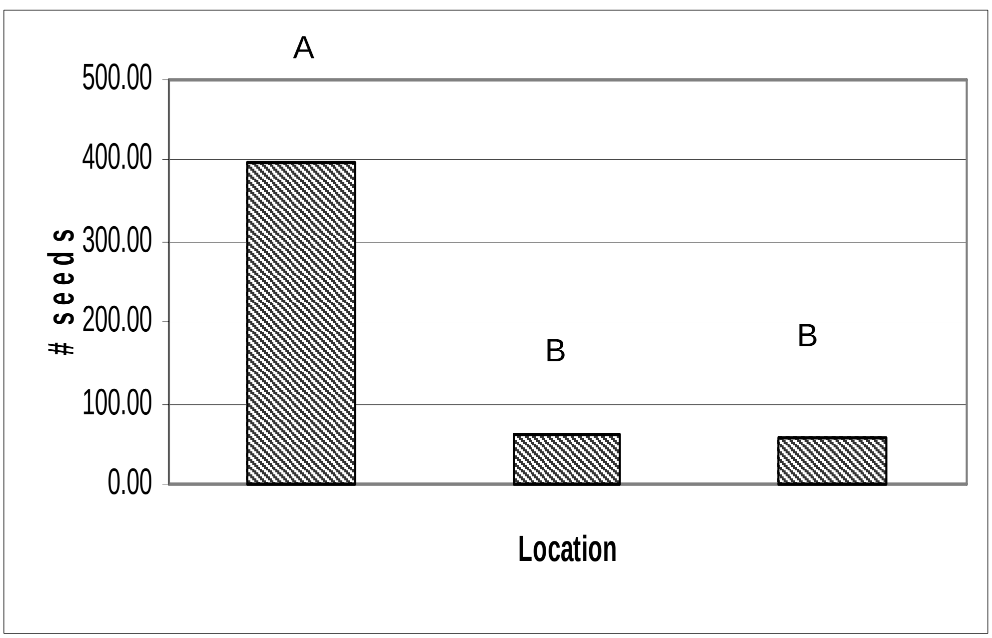
Average number of damaged seed pods of focal plants for *Baptisia lanceolata.* Different letters represent values that are significantly different at α 0.05.

Figure 5.4



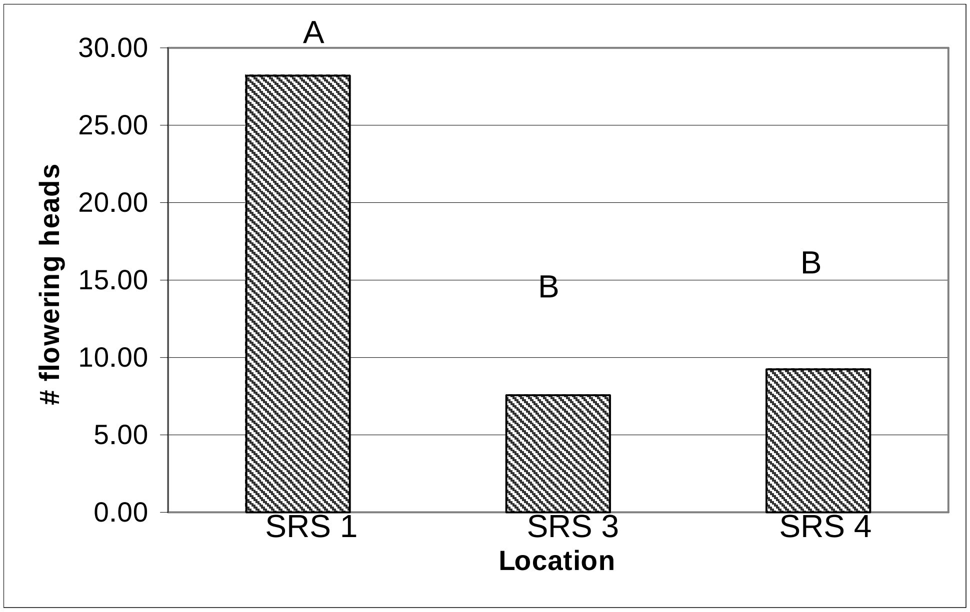
Average reproductive plant density per 100m^2 of *Carphephorus bellididfolius.* Different letters represent values that are significantly different at α 0.05.

Figure 5.5



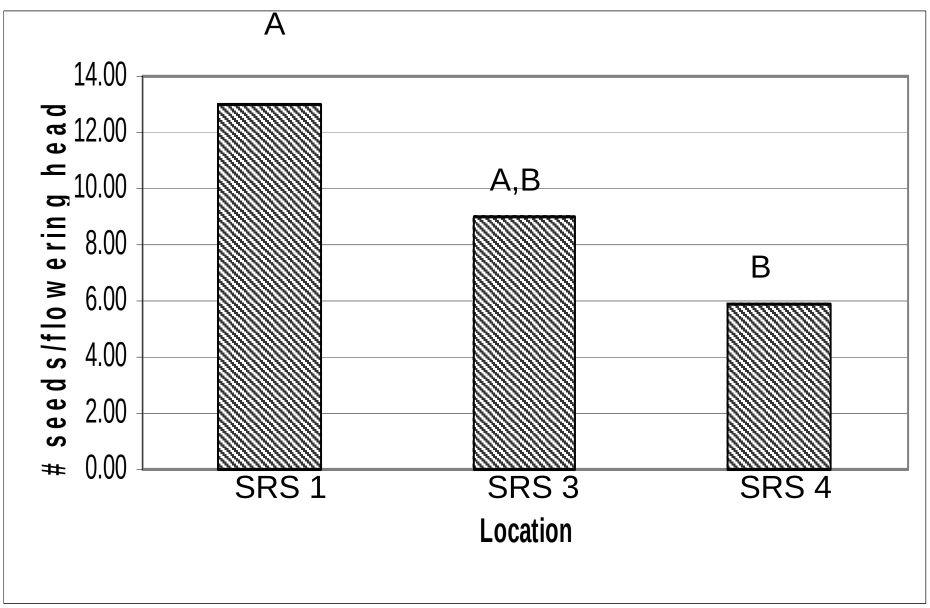
Average number of seeds per focal plant for *Carphephorus bellididfolius.* Different letters represent values that are significantly different at α 0.05.

Figure 5.6



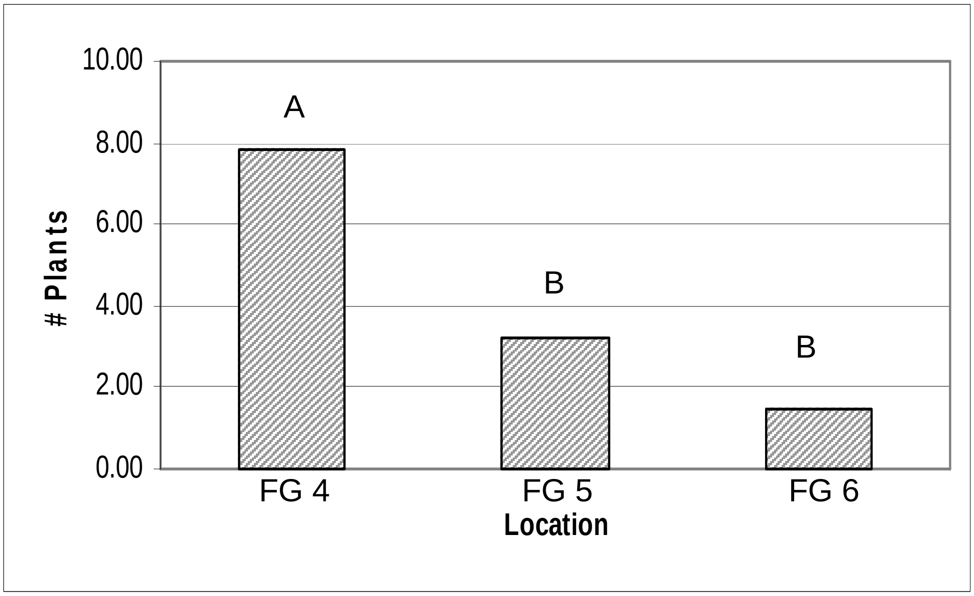
Average number of flowering heads per focal plant for *Carphephorus bellididfolius.* Different letters represent values that are significantly different at α 0.05.

Figure 5.7



Average number of seeds per flowering head of focal plants for *Carphephorus bellididfolius.* Different letters represent values that are significantly different at α 0.05.

Figure 5.8



Reproductive plant density per $1m^2$ of *Stylisma pickeringii*. Different letters represent values that are significantly different at α 0.05.

APPENDIX B

NON FOCAL PLANT SPECIES FOUND IN TES DISTURBANCE GARDENS

SRS A

Crataegus flava
Nyssa sylvatica
Prunus serotina
Quercus laevis
Quercus stellata
Vaccinum stamineum
Vitis rotundifolia

SRS B

Quercus laevis
Crataegus flava
Rhus copallina
Vaccinium stamineum

SRS C

Diospyros virginiana
Opuntia humifusa var. humifusa
Quercus laevis
Quercus incana
Vaccinium stamineum

FG A

Aureolaria pectinata

FG B

Juncus sp.
Pinus palustris
Moss

FG C

Andropogon sp
Areolaria pedicularia
Dichanthelium
Diospyros virginiana
Panicum sp.
Pinus palustris
Stylisma patens

FG D

Diospyros virginiana
Quercus laevis
Tephrosia sp

SRS D	FG E
Areolaria pectinata	*Andropogon sp*
Quercus laevis	*Centrosema virginianum*
Vaccinuim stamineum	*Desmodium sp*
	Dichanthelium
SRS E	*Eupatorium capillifolium*
	Panicum sp
Juncus sp.	*Rubus sp*
Stipulicida sp.	*Rhus copallina*
Stylisma patens	*Sassafras albidum*
Tephrosia virginiana	*Solidago odora*

SRS F	FG F
Baptisia perfoliata	*Andropogon sp*
Cnidoscolus stimulosus	*Centrosema virginianum*
Juncus sp	*Desmodium sp*
Panicum sp	*Dichanthelium*
Pinus palustris	*Eupatorium capillifolium*
Quercus falcata	*Panicum sp*
Quercus laevis	*Rubus sp*
Sassafras albidum	*Rhus copallina*
Stipulicida sp.	*Sassafras albidum*
Stylisma patens	*Solidago odora*
Tephrosia sp	*Tephrosia sp*
Vaccinium arboretum var. arboreum	*Vaccinium arboretum var. arboreum*
Vitis rotundifolia	

APPENDIX C

ENVIRONMENTAL CHARACTERISTICS OF TES DISTURBANCE GARDENS

Environmental characteristics (canopy openness, soil sand and organic matter content, and soil nutrients) of each experimental treatment garden. SRS = Savannah River Site, FG = Fort Gordon.
* Data are from the top 10 cm of soil, reported in parts per million

Treatment	% Canopy Openness	% Sand	% Organic Matter	Ca*	K*	Mg*	Mn*	P*	Zn*
No Disturbance									
SRS 1	29.53	88.0	1.48	32.25	10.97	6.86	0.45	3.31	2.08
SRS 2	30.47	92.0	1.90	9.76	8.18	2.97	9.02	10.69	2.81
FG 1	25.04	98.0	1.56	10.27	8.32	2.92	3.51	2.17	1.28
FG 2	23.94	92.0	1.90	11.05	10.36	3.28	0.56	1.88	3.25
Low Disturbance									
SRS 1	36.47	90.0	1.24	13.26	8.69	2.88	0.60	2.91	2.86
SRS 2	34.79	90.0	1.88	8.18	8.37	2.72	7.70	11.26	2.75
FG 1	35.79	92.0	1.34	7.54	8.41	2.50	0.01	1.86	3.29
FG 2	30.27	92.0	1.58	8.95	7.62	2.08	0.07	1.88	2.45
High Disturbance									
SRS 1	37.95	90.0	1.22	27.42	11.94	5.52	3.33	4.05	3.94
SRS 2	36.99	88.0	1.80	25.30	14.49	7.18	0.41	3.05	3.70
FG 1	78.05	90.0	1.84	58.70	16.56	10.31	8.65	3.26	0.73
FG 2	64.17	88.0	3.43	67.70	16.65	12.02	8.47	3.13	0.60