RECOVERY OF CYPRESS DOMES IN NORTH CENTRAL FLORIDA 10 YEARS AFTER HARVEST

By

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This thesis is dedicated to my parents, Daniel and Catherine Ricci, for their never-ending support throughout my academic career.

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Pondcypress (*Taxodium distichum* var. *nutans* (Ait.) Sweet) can naturally regenerate via stump sprouting, which is considered an important component of regeneration following harvesting because sprouts produce cones within two years that provide a seed source for additional seedling recruitment. However, there are few studies on the long-term success of pondcypress stump sprouts and their potential to act as a seed source. In this study I examined the effect of felling equipment (sawhead vs. shearhead) on the long-term success of stump sprouts and the likelihood of sprout vs. shrub development on cut stumps in relation to felling treatment, stump height and stump diameter in seven harvested cypress domes located in north central Florida, USA. Each of the study sites was harvested in spring of 1999 and re-examined in summer of 2009. I measured stump sprout characteristics such as numbers of sprouts per stump, sprout height and diameter, and cone presence on stumps tagged during the original study. I evaluated proportions of stumps with sprouts and cones using a two-factor Anova with felling equipment and time as the main effects. I also determined whether stump characteristics and felling treatment affected the probability of a stump containing a sprout, shrub, or being bare using a general linear mixed model.

Long-term sprouting success varied by site, ranging from15%-42% of stumps having at least one sprout. The type of felling equipment used did not significantly affect the proportion of stumps producing sprouts or sprouts producing cones, and the proportion of stumps with at least one sprout changed very little over time. This study confirmed initial findings that sprouts were more likely to develop on smaller diameter stumps (< 30 cm) and stumps cut 20 cm below or near the mean high water. The occurrence of shrubs or another tree species on a stump increased as both stump diameter and stump height increased.

Survival of sprouts over ten years shows that initial sprout success after two growing seasons can be used as an indicator of coppice regeneration. Recommendations for harvesting to maximize sprouting include cutting in close proximity of the historic mean high water mark and on stumps smaller than 30 cm.

CHAPTER 1
INTRODUCTION

Adequate regeneration of second-growth cypress is important for both ecological and economical reasons. Cypress timber has long been valued for its use as cross ties, ladders, pilings, stakes, post wood and narrow boards (Wilhite and Toliver 1990) and more recently as mulch for gardening. However, cypress swamps have multiple values beyond timber production, including wildlife habitat, ground water recharge, flood control, and water quality improvement (Ewel 1998). Recently, concerns over ecosystem recovery following harvesting have prompted a need for better understanding of regeneration dynamics in a variety of forested wetland systems in order to ensure a quick recovery of these systems following harvesting disturbance.

While baldcypress (*Taxodium distichum* (L.) Rich.) was highly valued for its high proportion of decay-resistant heartwood (Wilhite and Toliver 1990), most of the large older baldcypress trees that contained valuable heartwood has been harvested and much of the remaining cypress is pondcypress (*Taxodium distichum* var. *nutans* (Ait.) Sweet). With the sustained demand for cypress timber, and the improvements in harvesting equipment, loggers have been able to access a variety of forested wetland systems including small isolated cypress domes where pondcypress is frequently found. These domes are typically embedded within pine flatwood communities and occasionally intermixed within hardwood hammocks. The pondcypress is found in association with swamp tupelo (*Nyssa sylvatica* var. *biflora*), slash pine (*Pinus elliottii* Englem.), and various bays (*Gordonia lasianthus* (L.) Elis, *Persea palustris* (Raf.) Sarg., *Magnolia virginiana* L.) which regenerate on hummocks or along shallow edges (Wharton et al. 1977, Brandt and Ewel 1989).

Additionally, it is now common for trees of all merchantable sizes to be harvested because trends in the commercial usage of cypress have converted from lumber to pulp and mulch for gardening (Ewel 1998). Logging operations typically involve whole-tree harvesting of cypress (Duryea and Hermansen 1997). Though some studies have documented that that pondcypress domes can regenerate back to their original basal area and species composition by 50 years after harvesting (Terwilliger and Ewel 1986), the majority of the literature has focused on baldcypress regeneration. Early survival of pondcypress regeneration has been addressed in previous studies (Terwilliger and Ewel 1986, Ewel et al. 1989, Ewel 1996), but the long-term success has not been evaluated.

One unique characteristic of cypress is that it is one of the few conifer species that can naturally regenerate via seed germination or vegetatively by stump sprouting after harvest (Wilhite and Toliver 1990). Seed dissemination occurs during the fall to early winter, and water and wildlife movement are the main dispersal mechanisms within cypress domes. Seedlings need saturated but not submerged soil to germinate and prefer full sun for vigorous growth. Competition from shrubs or a dense understory can inhibit cypress regeneration by decreasing sufficient light and nutrients (Ewel 1989). Limited seedling recruitment across a site can also be attributed to factors like poor seed viability from parent stock, lack of seed sources after harvest, inability of seed to be dispersed, and hydrologic limitations (Gunderson 1984, Schneider and Sharitz 1986, Conner et al. 1986).

Stump sprouts are considered an important mechanism for immediately regenerating a cypress stand after harvesting (Ewel et al. 1989, Randall et al. 2005). In species that stump sprout, initial growth of sprouts is likely to be greater than seedling regeneration due to the root systems of established trees and the amount of stored carbohydrates in the root system (McCreary et al. 2002). Stump sprouts have vascular connections between the sprouts themselves and the parent tree root system, with each stem helping to sustain a portion of the root system (Kramer and Kozlowski 1979). Conner et al. (1986) found that baldcypress seedling regeneration grew on average to 91 cm and stump sprouts grew to 152 cm in height after four growing seasons. Additionally, since stump sprouts can produce cones as early as two years after sprouting, this could provide an additional seed source for seedling recruitment when environmental conditions are conducive for germination, so long as the seed source is viable (Ewel 1998, Randall et al. 2005).

There are still several concerns regarding the long-term success of sprouting as a mechanism for regenerating pond cypress in wetland systems. It is not clear whether sprouts can survive to be recruited into the main canopy, and low sprout survival between 17 and 23% has been observed in some cases (Conner et al. 1986, Conner 1988, Ewel 1996). In comparison, survival of bare-root pondcypress seedlings planted in eight harvested swamps in north Florida ranged from 37% to 89% after four years (Vince, Duryea and Randall unpub. data). Additionally, poor stem form and mechanical damage from ground-based logging can limit vegetative reproduction (Hook and DeBell 1970, Lockaby et al. 1997). Stump decay could compromise sprouts although decay may not necessarily move into the new sprout, particularly where the sprouts develop off the side of the stump (Shigo, 1986). Moreover, sprout regeneration can be spatially heterogeneous and sometimes insufficient in providing a continuous seed source across the entire stand (Kennedy 1982, Keim et al. 2006).

While long-term survival of sprouts is affected by a multitude of factors, initial establishment of sprouts are often a function of stump dimensions. Stump height and diameter can influence the vigor of sprouting success regardless of species (Hook and DeBell 1970, Kennedy 1982, Ewel 1996, Gardiner et al. 2000). For flood-prone species stump height in relation to mean water depth has shown a strong correlation to sprout establishment (Terwilliger and Ewel 1986) though relationships may vary by species. Kennedy (1982) found that water tupelo cut 76 cm above the mean high water mark had the highest survival of sprouts; while Ewel (1996) indicated stump less than 70 cm tall from the ground yielded greater pondcypress sprout survival. Parent tree size can also influence stump sprouting. Early sprout survivorship is greatest on smaller stumps (Ewel 1996), while larger stumps over 40 cm in diameter did not show cypress sprout survival after harvest (Keim et al. 2006).

Stumps may also provide a safe site for germination and establishment of other plants such as shrubs or other tree seedlings which could potentially interfere with sprout development. Most shrub species cannot tolerate being submerged in the early stages of development and would naturally be recruited on stump surfaces above water. Wetland shrub species such as *Itea sp.* prefer stumps because they are elevated above floodwaters (Anderson et al. 2009), and dead or decaying stumps have also been observed to serve as a foundation for shrub or bay establishment (Schlesinger 1978, Casey and Ewel 2006). Furthermore, shrub invasion was noted on stumps in Louisiana cypress-tupelo swamps decades after harvest (Conner et al. 1981). Whether a shrub is recruited is on a stump may also be a function of the parent tree size. However, there has been no definitive quantification of relating stump size and shrub occurrence.

Long-term monitoring is needed to better understand the recovery of cypress domes after logging, yet there are few studies that have monitored sprouts or regeneration success longer than six growing seasons (McCreary 2002). This work builds upon initial two-year results reported by Randall et al. (2005). That study examined, parent tree size, height of stump cut, and felling equipment on stump sprouting (Randall 2001). Stump heights were cut below, at, or above mean high water, with either a hydraulic shear-head or continuous disk saw-head on the interchangeable head of the feller-buncher. The saw-head cuts with a disk blade and the shear-head, which can be compared to pruning shears, snips the tree off at the appropriate stump height. Using the saw-head attachment creates a smoother cut across the stump, while stumps cut with a shear-head may increase damage by splitting or shattering stumps (Porter et al. 1984). In general, two seasons after harvest, results indicated that greater sprouting occurred on smaller diameter stumps close to the mean high water mark, and sprout establishment was not significantly affected by felling equipment (Randall et al. 2005). These study sites were reinvestigated to assess the long-term survival of cypress stump sprouts ten years after harvest in relation to felling method (sawhead type) and to quantify the proportion of stumps with cone-bearing sprouts. An additional objective of this study was to determine the likelihood of sprout vs. shrub development as a function of felling equipment, stump diameter, and stump height.

CHAPTER 2
METHODS

Study Area and Experimental Design

This investigation was conducted in sites that were selected in 1999 to evaluate factors that influenced stump sprouting in pondcypress trees in eight isolated cypress domes. In 2009, the eight logged pondcypress domes were re-visited in north-central Florida (Figure 1) (latitudes: 29° 05' to 29° 55'; longitudes: 82° 10' to 82° 35'). However, after field investigations were completed, one site in Lafayette County was dropped due to difficulty in stump identification and relocation. Prior to harvest, pondcypress and swamp tupelo were the predominant species, along with slash pine, myrtle holly and various bays in the canopy. Historical climate data ranging from 1950 – 2010 in each county that contained a field site indicated that mean annual precipitation varied from 124 cm to 150 cm (Southeast Regional Climate Center 2010).

The original study used a split-plot design (Figure 2). Two 0.05 ha circular plots were established on each half of the pondcypress dome and each half of the dome was cut using a sawhead or shearhead harvesting technique. This was the whole-plot treatment. Within each 0.05 ha plot, 45 trees were chosen to be cut at one of three stump cutting heights as the subplot treatment. Heights were based on mean high water level within that swamp. This was determined from stain and lichen lines on the cypress trees (Randall et al. 2005). Stump heights were categorized as being cut low (20 cm below mean high water), medium (at mean high water), and high (40 cm above mean high water). Within each plot, permanent aluminum tags were used to mark each study stump, and locations within each plot were mapped.

The pondcypress domes were clearcut in February and March of 1999 in accordance with Florida's Best Management Practices in forested wetlands at that time, which left 12 reserve trees per hectare. Trees outside the research plots were harvested under operational standards. Stump height and diameter were recorded after logging, and sprouting success was initially monitored in the summer of 1999 through fall of 2002 (Randall et al. 2005).

Stump Sprout Remeasurements

The relocation of stumps from the previous study was conducted in May-July of 2009 using hand drawn plot maps and leave trees for orientation. We recorded whether stumps were bare, had cypress sprouts, or had other vegetation growing on the stump. If vegetation other than cypress was growing on the stump, the species was noted. For stumps with sprouts, we recorded the number of live sprouts on each stump, the height of all sprouts, and the dbh of stems > 5 cm (2 in) (stem diameter was measured at 1.4 meters from ground). We also noted whether or not each sprout was producing cones.

Eighty-seven percent of the initial stumps were relocated across all sites using plot maps from the original study. Out of the 168 missing stumps from the original study, 75 (45%) were from sawhead treatment and 93 (55%) were from shearhead treatment out of the total stumps in each category. A t-test confirmed that differences in numbers of missing stumps across sites were not significantly different by treatment so were not considered to be confounding factor in the subsequent analyses. Not surprisingly, water level affected our ability to relocate some stumps. Stump cut height of missing stumps was predominantly around mean high water level (65%), with the remaining amount being cut at the 20 cm below mean high water (30%) and 5% cut 40 cm above mean high water.

Data Analysis

Proc Glimmix (SAS 9.2) was used for all data analysis because this particular model properly assesses random (swamp and plot) and fixed effects (treatment, time, stump characteristics), and has the ability to estimate the appropriate standard errors for binary response data. Individual swamps were used as a blocking factor All statistical tests were run at $\alpha = 0.05$.

To assess the number of sprouts per stump, the proportion of stumps with sprouts and proportion of sprouts with cones, we used a generalized mixed model with treatment and time as fixed-effect factors (Appendix A). The two time periods were from the field observations in 2002 and 2009. Proportions of stumps with sprouts in 2009 were calculated only based on the total number of relocated stumps. Adjusted means were plotted to visualize the change in sprouts or cones in time.

A mixed model with a binomial distribution was analyzed to determine the probability of a stump having sprouts, other vegetation or nothing on it as a function of stump height, diameter, treatment, and interactions of those factors across all sites, (Appendix B). Stump diameters were broken into 5 categories that contained approximately the same number of stumps. Diameter categories were ≤ 20 cm, 20-29 cm, 30-39 cm, 40-49 cm, and > 50 cm. Sprouting was not evident on stumps over 50 cm, and used as a cut off point for categorical analysis. Additionally, stump height was categorized in the three cut height classes of the original study: 20 cm below mean high water, at mean high water, and 40 cm above mean high water.

CHAPTER 3
RESULTS

Characteristics of 10-yr old Pondcypress Sprout Regeneration

The average number of sprouts per stump decreased over time (Table 2-1). In 2002, the number of sprouts per stump averaged 15 sprouts on sawhead stumps and 12 on shearhead stumps. High values were due to an anomaly at one site (F1), which had an unusually large number of sprouts per stump, particularly for the sawhead treatment (Table 2-1). Removing this site would result in similar numbers of sprouts per stump (about 11) for both treatments in 2002. In 2009, the mean number of sprouts per stump decreased to 7 for both harvest treatments. Changes in the number of sprouts per stump with the removal of site F1 were not statistically significant between felling treatments.

Individual swamps showed great variability in sprout dimensions and proportion of stumps with sprouts. The mean diameter of the largest sprout per stump ranged from 7.1 to 18.1 cm across all of the sites, and mean height ranged from 5.3 to 7.1 m (Table 2-2). There was no correlation between the three stump heights used in the original study and sprout characteristics such as the number of sprouts on a stump, sprout dbh or height. The percentage of stumps with live sprouts varied between 10-40% in 2002 and between 11-41% in 2009.

Treatment Effect on Sprouts and Cones through Time

Time had a statistically significant effect on stump sprout success but felling treatment did not (table 2-3). However, the change in proportion of stumps with sprouts was likely not ecologically relevant, as the percentage of stumps with live sprouts in 2002 was 28% and rose only slightly to 31% in 2009, primarily because of additional stumps with sprouts found on the sawhead cut stumps (Figure 2-3). This indicated that stump sprouts primarily develop only within the first two years after harvesting.

The percentage of sprouts with cones increased significantly (p=0.0002) from the last period of monitoring in 2002 to 2009, but was not significantly influenced by treatment (Table 2-4). The proportion of sprouts with cones was between 10 and 13% for shearhead and sawhead stumps in 2002 and 17 and 26% for those treatments in 2009 (Figure 2-3).

Influence of Stump Characteristics on Likelihood of Sprouting

We calculated the probability, and tested the significance, that a stump of a given size (diameter and height class) and felling treatment would have sprouts, other vegetation or nothing growing on it 10 years after harvesting. Diameter was broken into 5 classes based on the range of diameters of sprouts that the majority of stump sprouts occurred. Height classes were based on the initial study categories related to mean water depth. Initially the interaction between stump diameter x height was tested, but it was dropped when all insignificant and were removed from the final analysis.

Evaluation of stump characteristics (diameter and height classes) and harvesting technique were conducted using only those stumps relocated in 2009 since that is the only time period for which data on other vegetation on stumps was recorded. A significant interaction effect between treatment x stump height was only found for stumps with sprouts (Figure 2-5, Table 2-5) (p=0.048). Multiple comparisons indicated that stumps cut with the shear head at mean high water and 40 cm above mean high water were significantly different from each other and significantly different from the sawhead stumps cut at the same heights. Harvesting technique did not significantly affect the likelihood of a stump being bare or having a shrub growing on it. (Table 2-6, Table 2-7).

Stump diameter significantly affected the probability of a stump having a cypress sprout growing on it ($p<0.0001$). There was a decrease in the likelihood of a sprout occurring on a stump as the stump diameter increased (Figure 2-6). Sprouting was more likely to occur on stumps within a diameter range of 0-20 cm. Stump diameter also significantly affected the likelihood of a stump being bare ($p=0.0004$) or having other vegetation ($p<0.0001$). The likelihood of a stump being bare nearly doubled as diameter increased from less than 20 cm wide to 21 cm and greater (Figure 2-6). There was no statistical difference in the likelihood of a stump being bare for stumps between 21 and 50 cm. The likelihood of a stump having other vegetation on it increased significantly with diameter (Figure 2-6). The highest probability of a shrub occurring on a stump was at stump diameters of 30 cm and greater. *Lyonia lucida* and *Myrica cerifera* were the dominant shrub species found on stumps (Figure 2-7).

Stump height had no significant effect on the likelihood of stumps being bare (Table 2-6) but did significantly affect the likelihood of having a shrub occur on a stump ($p<0.0001$) (Figure 2-8). Stumps cut at 40 cm above mean high water were the most favorable for shrub recruitment.

CHAPTER 4
DISCUSSION

Sprouting Response after 10 years

Cypress stump sprouts are an important source of regeneration following logging in forested wetlands. Stump sprouts can have an early growth advantage over regeneration by seeds; however, there has been concern about the longevity of coppice sprouts in other species,and their ability to be recruited into the overstory (Mostacedo et al. 2009). Additionally, it is not clear how survivorship and growth of pondcypress sprouts compares to that of baldcypress sprouts. Visser and Sasser (1995) found that the recruitment of baldcypress second growth trees did not keep up with mortality; however, findings from our study suggest that 10 years after harvesting, survival of coppice sprouts was high. All stumps that sprouted immediately following harvesting still had at least one if not several dominant sprouts 10 years later. Pondcypress sprout sizes measured in this study were consistent with those reported for baldcypress of a similar age. On average, dominant pondcypress sprouts in our study sites were 10 cm in diameter and over 4.7 m tall. Keim et al. (2006) found that baldcypress coppice sprouts from 10-50 years after harvesting averaged 10 cm in diameter and 6.8 m tall. Additionally, the number of sprouts per stump decreased over time though this was expected because dominant sprouts will eventually outcompete the others. Kennedy (1982) found a decrease in water tupelo stump sprouts over 6 growing season that led to an average of 5 sprouts per stump.

It has been suggested that sprouts originating from the top or cut surface of the stumps will not develop into quality timber producing trees (Conner et al. 1986). Tree form was not analyzed in our study, but casual observation suggested that the majority of surviving sprouts did, in fact, regenerate as a top sprout. The cypress sprouts in our field sites appeared to be growing in good form at this time, but it is too soon to determine their potential as a timber source.

Harvesting technique did not have a significant impact on sprout regeneration and survival. The average number of sprouts per stump was virtually the same for both treatments. It had been originally hypothesized that long-term survival would be notably higher on sawhead cut stumps due to shear-related damage by the shearhead feller. The stumps of trees can be damaged by a shearhead in the form of ring-shake, stump-pull, shatter, and splitting resulting in an increased risk of disease and decay because of the amount of damage caused by the blades (Porter et al. 1984). The severity of splitting damage can damage the stump, providing an entry-way for pathogens that eventually translocate to the coppice sprouts. However, our results indicate that at least 10-year survival of coppice sprouts was not affected by felling technique.

Potential for Sprouts to Provide Seed Source

Cypress sprouts are also considered important for providing and additional seed source for seedling recruitment after harvesting. At our study sites, approximately one quarter of the sprouts were cone-bearings, and a preliminary seed viability test from cone samples taken in early October of 2009 indicated that on average 41% of the seeds were viable (varying from 20% to 58% across sites). Both pondcypress and baldcypress are considered to have similar reproductive characteristics, and several factors may contribute to variability and magnitude of seed viability of these trees in any given year. Mattoon (1915) stated that baldcypress produces a larger crop of seeds approximately every 3 years. Other factors such as drought or overall health of the tree may also affect seed viability in any given year. There is very little literature on viability of cypress seeds in reference conditions, although at least one other study has reported bald cypress seeds had consistently low viability over a three-year period (Sharitz et al. 1986). Although few naturally recruited seedlings were observed in the study sites, additional studies would be needed to determine if this was due to inadequate seed source, inadequate safe sites for germination, or some other factors.

Predictors of Vegetative Development on Cypress Stumps

Stump dimensions were better predictors than felling technique alone on the probability that the stump would have a cypress sprout versus some kind of other vegetation growing on it. For instance, stump diameter was a significant predictor of whether a stump would have a sprout or a shrub on it. My results were not unexpected as this trend had already been documented for cypress in several stands (Ewel 1996, Randall 2005) and for many other hardwood species (Golden 1999, Sands and Abrams 2009). Pondcypress of saw-timber size with a diameter larger than 40 cm produce fewer sprouts (Keim et al. 2006). Diameter is an important factor because older and larger trees have fewer basal dormant buds (Kauppi et al. 1988).

Stump height in relation to mean high water level has also been noted to be an important predictor of successful sprouting in swamps and flood-prone sites, and in this study stump height was also a significant predictor of the presence of either sprouts or other vegetation on stumps. Bald cypress stump sprouts were more likely to survive on shorter stumps (Keim et al. 2006), and in this study pondcypress sprouts were successful on stumps both at or 20 cm below mean high water. Water levels were not monitored under the duration of our study, but drought conditions were present during the initial study when most sprouts regenerated (Randal 2001). The low cut stumps may be submerged in years with typical precipitation, but typical effects of inundation on stump sprout survival and growth on those cut stumps may not have occurred on our study sites. Stump sprouts at our study sites had an opportunity to establish before normal to high water levels occurred again. Perhaps a higher mortality for low cut stump sprouts due to inundation stress would have been evident across all sites if these dry conditions did not occur (Ewel 1996). Because of those conditions, Randall (2001) suggested from observations outside the study plots, to cut cypress around the mean high water mark.

One concern of logging is that cypress swamps may convert to hardwood or shrub dominated swamps due to human and environmental influences. Most of the understory plants and shrubs in cypress and tupelo forests occur on elevated sites, which protect susceptible seeds and seedlings from flooding (Huenneke and Sharitz 1986). In Louisiana cypress-tupelo swamps, shrub invasion occurred where the canopy opened over elevated micro sites, including stumps or logs (Conner et al. 1981). Short-term studies suggested that harvesting in baldcypress and water tupelo swamps could lead to a conversion to hardwood species (Gellerstedt and Aust 2004). Conner et al. (1986) also found that after logging, all sites were dominated by small, shrubby, non-timber species after 1 to 4 growing seasons. On the other hand, other studies, such as those in Okefenokee Swamp indicate that shrubs only rooted on dead stumps and did not invade the entire site (Schlesinger 1978). At our study sites, shrub or other tree species tended to grow on stump heights greater than 40 cm above the mean high water level. *Lyonia lucida* and *Myrica cerifera* were the most prevalent shrubs found on stumps, and these species are typical of pondcypress stumps in the southeast.

Shrubs are faster growing, and may have an advantage over cypress seedlings or might compete with sprouts on stumps. However stumps that do contain sprouts usually do so because of the rapid early growth of stump sprouts (Johnson 1978). In this study, we found relatively few, if any stumps that had both sprouts and shrubs growing on them. It is possible that the shrubs developed on taller stumps that were simply not conducive to sprout development early on; however we do not have data from 2002 to determine whether competition existed during the early phases of vegetation development.

Management Recommendations

In our study, cypress coppice sprouts survived over ten years past harvest. These results suggest that early coppice regeneration counts during the first few years post-harvesting should provide an appropriate assessment of the coppice regeneration potential of that stand. The position of sprouts on stumps, and the condition of sprouts were not recorded in this study. Future condition and establishment position may result in additional sprout mortality in the future as sprouts develop into mature trees.

Our recommendations regarding the size of trees to cut in order to increase the probability of stump sprouting remain consistent with those of previous studies. Trees of a smaller diameter (< 30 cm) should have a better sprouting response than larger trees. If a site contains only larger cypress trees, sprouting may occur at low levels. Other recommendations suggest that he greatest likelihood of sprout success will occur when stumps are cut at or near the high water mark; although sprout success on stumps cut below the mean high water mark were high in this study, we attribute this to the extreme drought conditions immediately following harvest. Still, cutting at mean high water levels appears to be a safe recommendation unless accurate predictions of climate within the few years following harvesting (when sprouts develop) could be obtained.

Table 2-1. Mean number of pondcypress sprouts per stump during 2002 and 2009 in stumps of seven pondcypress sites in north central Florida (Figure 2-1).

		Number of sprouts per stump						
Year	Cutting Method	AC	F1	F2	G	P1	P2	R
2002	sawhead	9	43	9	12	12	10	11
	shear	8	23	8	17	12	11	13
2009	sawhead	3	8	7	10	7	7	10
	shear	6	7	5	10	8	8	8

Table 2-2. Summary statistics by site for proportion of pondcypress stumps with live sprouts, proportion of sprouts with cones, mean, dbh, and height of sprouts in 2009.

	Mean measurement by site						
Sprout Measurement	AC	F1	F2	G	P1	P2	R
Proportion stumps w/ sprouts (2002)[a]	10%	40%	27%	39%	31%	24%	28%
Proportion stumps w/ sprouts (2009)[a]	11%	39%	34%	41%	32%	27%	29%
Proportion sprouts w/ cones (2002)[c]	17%	9%	49%	19%	47%	54%	68%
Proportion sprouts w/ cones (2009)[c]	55%	40%	67%	56%	46%	70%	71%
Mean/ SE dbh of largest sprout (cm)[b]	8.7 (0.61)	8.5 (0.37)	11.1 (0.43)	7.1 (0.25)	8.5 (0.31)	18.1 (1.65)	9.5 (0.34)
Mean/ SE height of tallest sprout (m)[b]	5.8 (0.36)	5.0 (0.20)	7.1 (0.18)	5.3 (0.15)	6.0 (0.17)	6.2 (0.16)	6.1 (0.19)

a (n=1222)
b (n=1070)
c (n=1070)

Table 2-3. The effects of harvesting treatments, time, and their interaction, on the proportion of pondcypress sprouts per stump in seven pondcypress sites in north central Florida.

Effect on proportion of stumps w/ sprouts	No. DF	F Value	Pr> F
Treatments	1	2.73	0.11
Time	1	14	<0.001
Treatments*Time	1	1.29	0.27

Table 2-4. The effects of harvesting treatments, time, and their interaction, on the proportion of pondcypress sprouts with cones per stump in seven pondcypress sites in north central Florida.

Effect on Proportion of Sprouts with Cones	No. DF	F Value	Pr> F
Treatments	1	1.71	0.21
Time	1	19.27	0.002
Treatments*Time	1	0.31	0.58

Table 2-5. The effects of harvesting treatments, stump characteristics, and the interaction of treatments*stump height classes, on the probability of pondcypress sprouts occurring on a stump in seven pondcypress sites in north central Florida.

Effect on probability of stumps w/ sprouts	No. DF	F Value	Pr> F
Treatments	1	5.8	0.02
Stump Diameter Classes	4	42.69	<0.001
Stump Height Classes	2	16.94	<0.001
Treatments*Stump Height Classes	2	3.06	0.048

Table 2-6. The effects of harvesting treatments, stump characteristics, and the interaction of treatments*stump height classes, on the probability of a stump being bare in seven pondcypress sites in north central Florida.

Effect on probability of bare stumps	No. DF	F Value	Pr> F
Treatments	1	0.5	0.49
Stump Diameter Classes	4	4.65	<0.001
Stump Height Classes	2	2.59	0.08
Treatments*Stump Height Classes	2	1.09	0.34

Table 2-7. The effects of harvesting treatments, stump characteristics, and the interaction of treatments*stump height classes, on the probability of other vegetation occurring on a stump in seven pondcypress sites in north central Florida.

Effect on probability of stumps w/ other vegetation	No. DF	F Value	Pr> F
Treatments	1	2.33	0.14
Stump Diameter Classes	4	27.76	<0.001
Stump Height Classes	2	19.1	<0.001
Treatments*Stump Height Classes	2	0.41	0.67

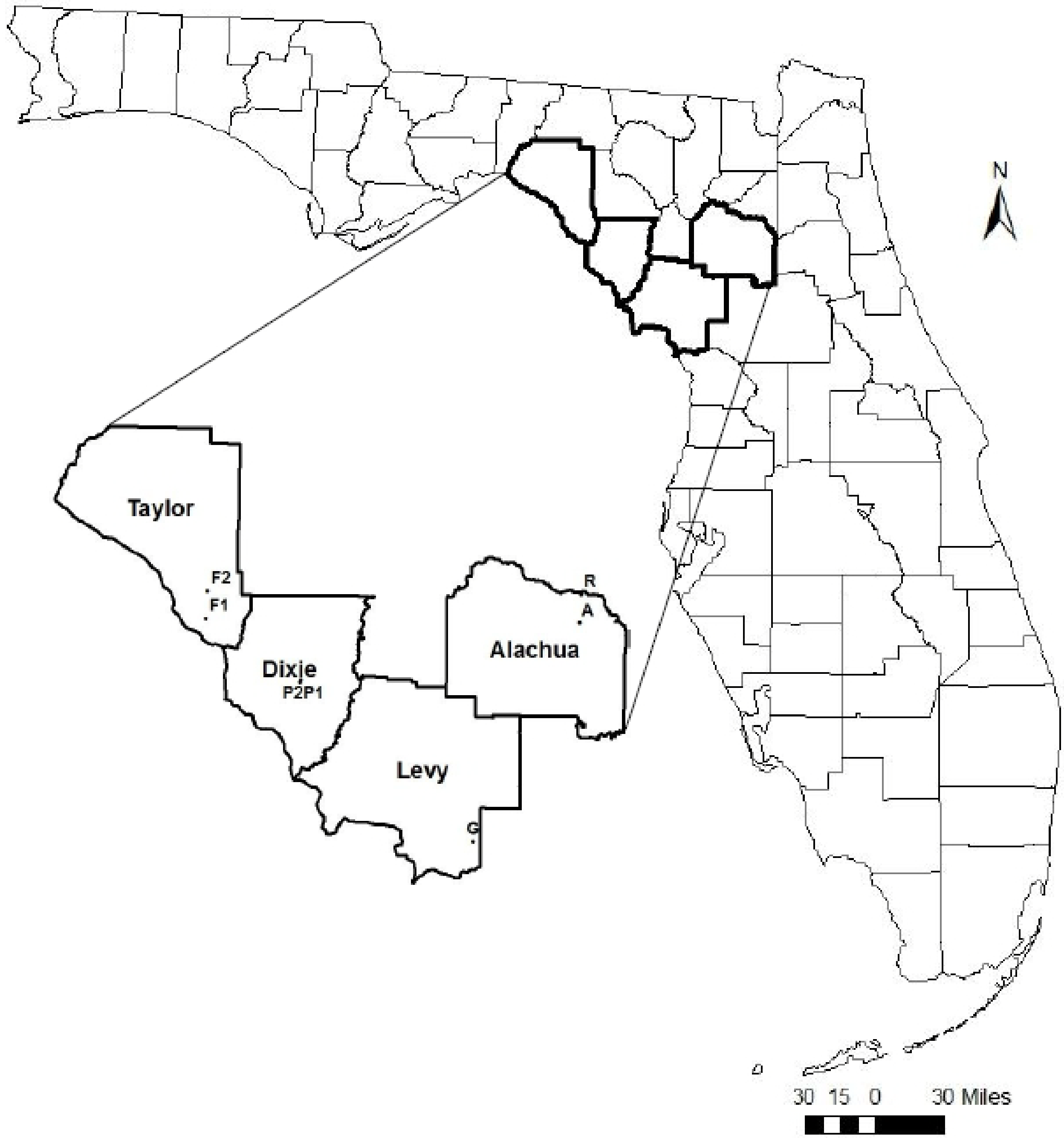

Figure 2-1. Locations of pondcypress wetland study sites in north central Florida by county.

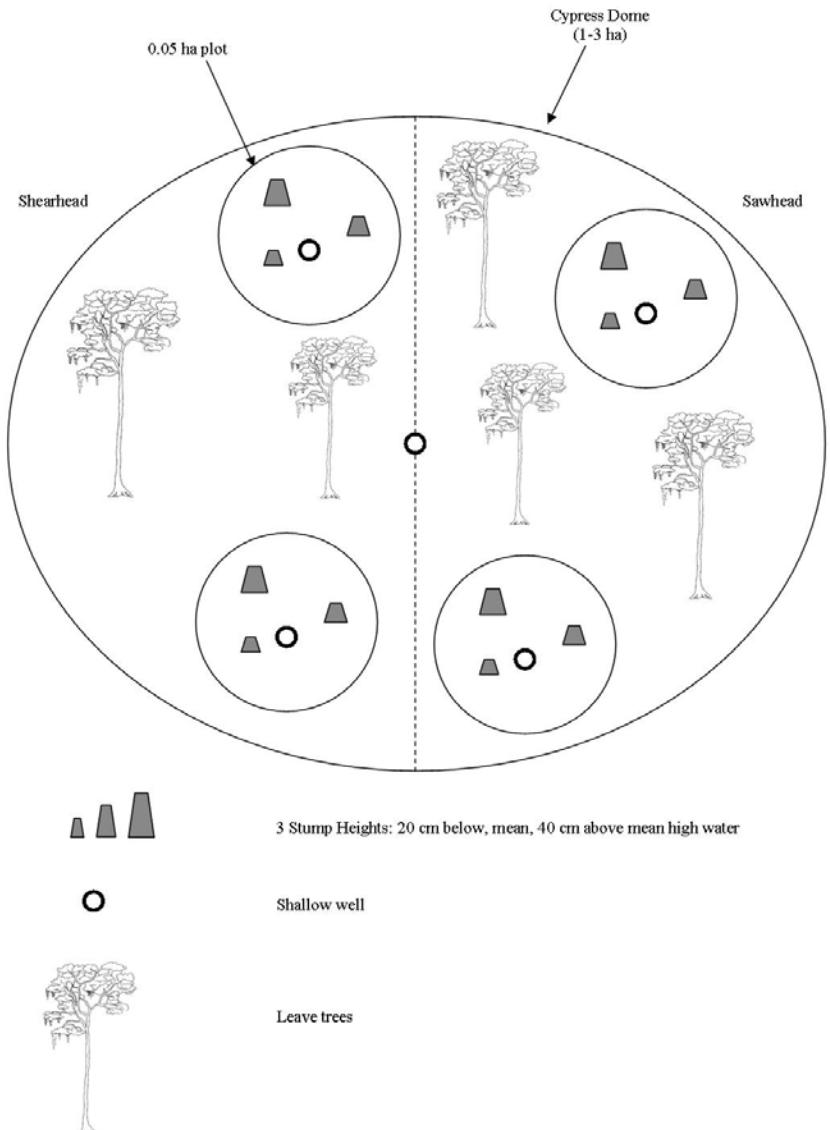

Figure 2-2. Study design two 0.05 ha circular plots to each harvesting method (sawhead or shearhead) and 3 stump heights per whole plot.

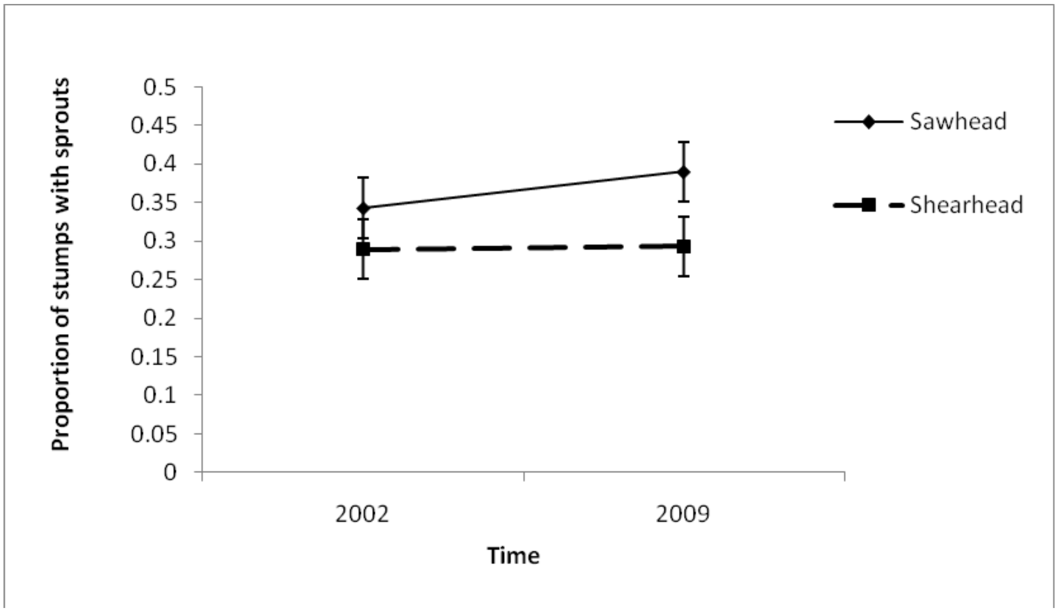

Figure 2-3. Mean and standard error of proportion of stumps with sprouts through time in seven pondcypress domes in north central Florida.

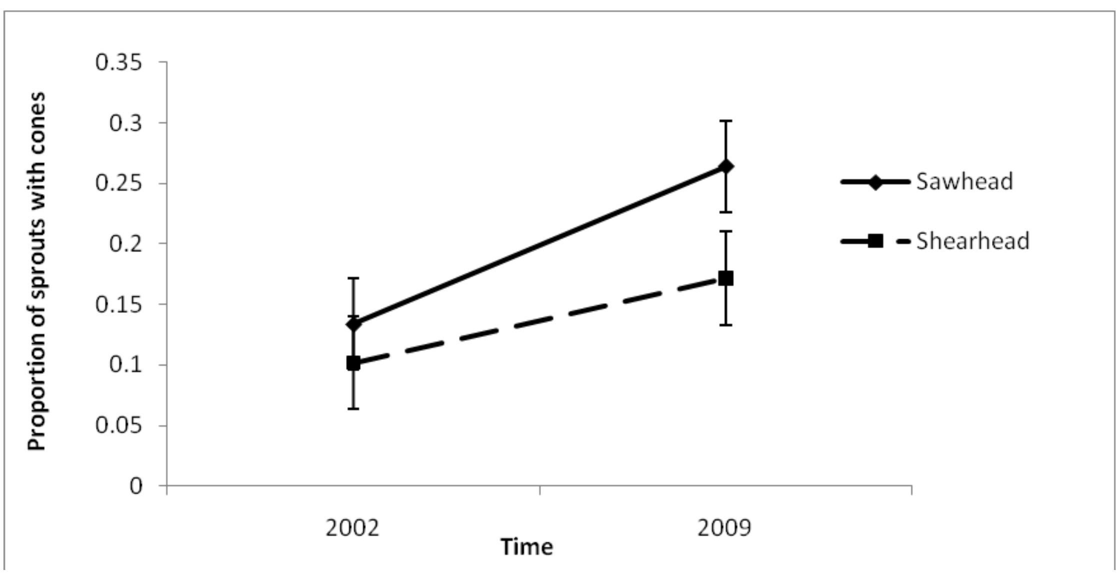

Figure 2-4. Mean and standard error of cone production through time in seven pondcypress domes in north central Florida.

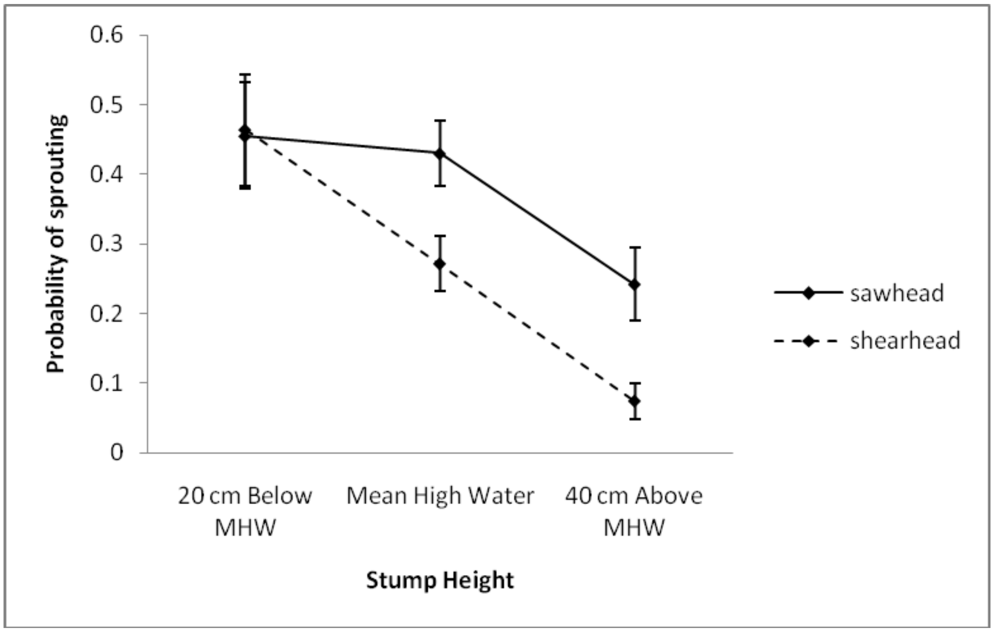

Figure 2-5. Treatment effect on stump height in seven pondcypress domes in north central Florida.

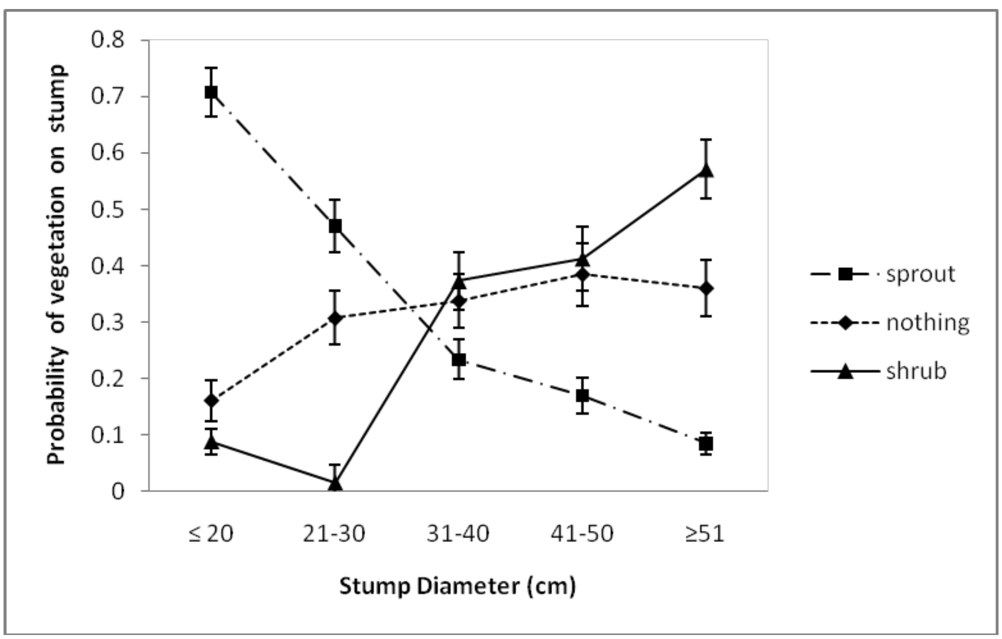

Figure 2-6. Effects of stump diameter on likelihood of having a sprout or shrub on a stump or being bare in seven pondcypress domes in north central Florida.

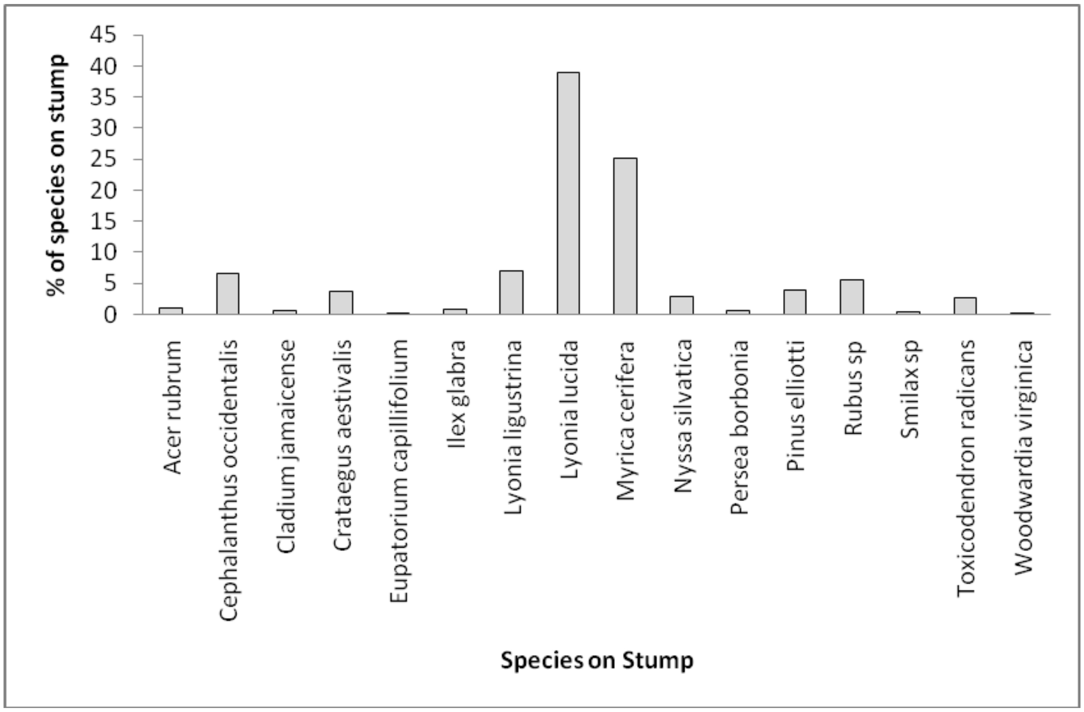

Figure 2-7. Percentage of species growing on stumps in seven pondcypress domes in north central Florida.

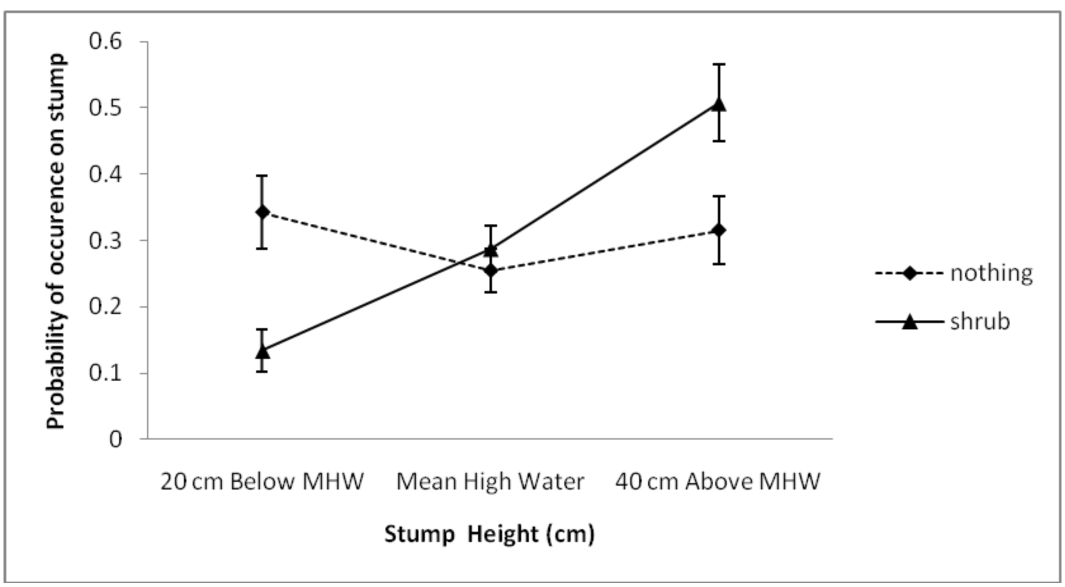

Figure 2-8. Probability of a stump being bare or having a shrub growing on a stump in seven pondcypress domes in north central Florida.

APPENDIX A
SAS CODE FOR GLIMMIX PROCEDURE ANALYZING SPROUTS AND CONES THROUGH TIME

```
PROC IMPORT OUT= proproportions
        DATAFILE= "e:\thesis\proportions.csv"
        DBMS=CSV REPLACE;
    GETNAMES=YES;
    DATAROW=2;
RUN;

ods rtf;
ods graphics on;

proc glimmix data=proportions plots=pearsonpanel;
weight stump_count;
title 'with time effect included swamp is random - sprouts';
class plot swamp treatments time;
model sprouts = treatments|time/ddfm=sat;
random swamp plot(swamp);
lsmeans treatments*time/slice=treatments plot=meanplot(cl join sliceby=time) pdiff;
lsmeans treatments|time/pdiff;
run;

proc glimmix data=proportions plots=pearsonpanel;
title 'with time effect included swamp is random - cones';
weight stump_count;
class plot swamp treatments time;
model cones = time|treatments time/ddfm=sat;
random swamp plot(swamp);
lsmeans treatments*time/slice=treatments plot=meanplot(cl join sliceby=time) pdiff;
lsmeans treatments|time/pdiff;
run;

title;
ods graphics off;
ods rtf close;
```

APPENDIX B

SAS CODE FOR GLIMMIX PROCEDURE ANALYZING STUMP CHARACTERISTICS

```
ods rtf;
ods graphics on;
PROC IMPORT OUT= b4
          DATAFILE= "e:\thesis\book4.csv"
          DBMS=CSV REPLACE;
    GETNAMES=YES;
    DATAROW=2;
RUN;
proc glimmix data= b4;
where  stump_ht < 300;
title 'sprouts';
class  size cat_diameter swamp treatment plot cat_depth cat_ht;
model sprout = treatment cat_diameter cat_depth treatment*cat_depth/dist=bin solution
ddfm=kr;
random swamp*plot;
lsmeans treatment cat_diameter cat_depth/ilink pdiff plots=mean(cl join ilink);
lsmeans treatment*cat_depth/ilink pdiff plots=mean(cl join sliceby=treatment ilink);
output out=p pred=p;
run;
proc glimmix data= b4;
title 'bare stumps';
where  stump_ht < 300;
class  size cat_diameter swamp treatment plot cat_depth cat_ht;
model bare  = treatment|cat_diameter|cat_depth@1  treatment*cat_depth/dist=bin
solution ddfm=kr;
random swamp*plot;
lsmeans treatment cat_diameter cat_depth/ilink pdiff plots=mean(cl join ilink);
lsmeans treatment*cat_depth/ilink pdiff plots=mean(cl join sliceby=treatment ilink);
output out=pb pred=p;
run;
proc glimmix data= b4 ;
title 'other stumps';
where  stump_ht < 300;
class  size cat_diameter swamp treatment plot cat_depth cat_ht;
model other = treatment|cat_diameter|cat_depth@1 treatment*cat_depth/dist=bin
solution ddfm=kr;
random swamp*plot;
lsmeans treatment cat_diameter cat_depth/ilink pdiff plots=mean(cl join ilink);
lsmeans treatment*cat_depth/ilink pdiff plots=mean(cl join sliceby=treatment ilink);
output out=po pred=p;
run;
ods graphics off;
ods rtf close;
```

APPENDIX C
PERCENTAGE OF SPECIES FOUND ON STUMPS

Species	Count	% of Species on Stump
Eupatorium capillifolium	1	0.2
Woodwardia virginica	1	0.2
Smilax sp	2	0.4
Cladium jamaicense	3	0.5
Persea borbonia	3	0.5
Ilex glabra	4	0.7
Acer rubrum	6	1.1
Toxicodendron radicans	15	2.7
Nyssa silvatica	16	2.9
Crataegus aestivalis	20	3.6
Pinus elliotti	21	3.8
Rubus sp	30	5.5
Cephalanthus occidentalis	36	6.6
Lyonia ligustrina	39	7.1
Myrica cerifera	138	25.1
Lyonia lucida	214	39.0

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BIOGRAPHICAL SKETCH

Nicole Ricci, a native to Macomb, Michigan, attended Macomb Community College as an Art and Design major, before transferring to Northern Michigan University to follow a bachelor's degree in Earth Science. During her studies at NMU, she earned the Farrell Cartography Scholarship for achieving the highest GPA in all mapping science courses.

After completing her Bachelor of Science, she attended Michigan Technological University in pursuit of a graduate degree in forestry and wetland science. She graduated with a course-work Master of Science in December of 2007.

In June of 2008, she entered the School of Forest Resources and Conservation at the University of Florida to pursue a thesis track Master of Science. Throughout her time at UF, she enjoyed learning many southern traditions, and gained lifelong friendships.