RESEARCH ARTICLE

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Response of Willow (*Salix caroliniana* Michx.) in a Floodplain Marsh to a Growing Season Prescribed Fire

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ABSTRACT: In marshes, fire is considered vital in restricting woody invasion and maintaining herbaceous dominance. However, many shrub species are not killed by fire and respond to this disturbance by resprouting. We assessed the response of coastal plain willow (*Salix caroliniana* Michx.), a common shrub in southeastern wetlands, to a growing season prescribed fire using three metrics: stem density, stem basal area, and cover. We sampled burned and unburned sites before the fire and annually for four years thereafter. Cover of understory species were sampled before the fire and annually for two years after the fire.

The initial response of willow was prolific resprouting. However, stem density returned to pre-fire levels by the second year. Basal area and canopy level (>1.5 m) cover decreased after the fire and remained lower throughout the duration of the study. Basal area and canopy cover declined significantly in the unburned site, but the cause of these declines could not be identified. Despite these declines, basal area and canopy cover in the burned sites were lower than in the unburned sites for each of the four years after the fire, although differences were not always significant at the $p<.05$. Cover of dominant understory species, sawgrass (*Cladium jamaicense* Crantz) and cattail (*Typha domingensis* Pers.) declined after the fire and did not recover to pre-fire levels within two years after the fire. Understory species richness increased after the fire.

Index terms: fire, resprouting, *Salix caroliniana*, shrub, wetlands, willow

INTRODUCTION

Fire is often viewed as critical to the maintenance of herbaceous wetland plant communities (DeAngelis 1994), and the absence of fire can cause shifts in community types (White 1994). In peat-based wetlands, intense fires that consume the peat determine vegetation patterns by creating deeper areas with longer hydroperiods. For example, in the Okefenokee Swamp, the herbaceous marsh areas that are surrounded by hardwood swamp are created and maintained by peat fires (Cypert 1973). Peat fires also are responsible for the mosaic of deeper water sloughs throughout sawgrass (*Cladium jamaicensis* Crantz) communities in the Everglades (Davis et al. 1994) and for the patchwork pattern of sawgrass and maidencane (*Panicum hemitomon* Schult.) in the upper St. Johns River basin marsh in Florida (Lowe 1986).

However, effects of surficial fires, where only the vegetation is consumed, are often not long lasting. Fires may have the short-term effect of mobilizing nutrients (Faulkner and de la Cruz 1982, Miller et al. 1998) and increasing light to the soil surface. However, many herbaceous wetland species rapidly regrow after a fire so that shifts in community composition following a surficial fire rarely persist (Forthman 1973, VanArman and Goodrick 1979, Wade et al. 1980, Schmalzer et al. 1991, Lee et al. 1995). Nevertheless, some species may be reduced in cover or even eliminated if a fire is followed by flooding (Ball 1990, Herndon et al. 1991, Rolletschek et al. 2000).

In marsh communities, fire can restrict shrub invasion and maintain dominance by herbaceous species (Craighead 1971, Wade et al 1980, Wade 1989, Kushlan 1990, Nyman and Chabreck 1995). However, in shrub species that resprout, fire may result in increased stem density if the fires are not sufficiently intense to cause plant mortality (Terry and White 1979, Rooney 1990, Pendergrass et al. 1998, Clark and Wilson 2001).

Willow (*Salix caroliniana* Michx.) is widespread in southeastern wetlands and can expand to convert herbaceous dominated marshes to shrub swamps. Prescribed fire is often suggested as a management tool to limit willow expansion (Craighead 1971, Wade et al. 1980, Florida Natural Area Inventory and Department of Natural Resources 1990), although data on the response of willow to fire is lacking. In this study, we investigated the response of willow to a prescribed fire during the growing season in order to better understand the role of fire in controlling expansion of this species.

STUDY SITE

This study was conducted in the upper St.

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Johns River basin, which encompasses over 40,000 ha of floodplain marsh, hardwood swamp, and lakes comprising the headwater region of the river. This is the largest wetland in east central Florida and one of the largest in the state (Kushlan 1990). The conversion of herbaceous dominated marsh to willow shrub swamp has been documented in the upper St. Johns River basin, and variously ascribed to changes in hydrology, nutrient status, and fire regimes (Hall 1987, Kinser et al. 1997).

The study was conducted in the Blue Cypress Marsh Conservation Area, which is in the southern portion of the Upper St. Johns River Basin. The Blue Cypress Marsh Conservation Area is an 8600 ha floodplain marsh surrounding the 2600 ha Blue Cypress Lake (Figure 1). The soils are Histosols, Terra Ceia soil series (Euic, hyperthermic Typic Haplosaprists). Peat depths range between one and four meters. The principal plant communities are dominated by sawgrass, maidencane, cattail (*Typha domingensis* Pers.), tree islands with cypress (*Taxodium distichum* L.) and red maple (*Acer rubrum* L.), and shrub swamp dominated by willow. In deeper areas, white water lily (*Nymphaea odorata* Ait.) and bladderwort (*Utricularia* spp.) dominate (Lowe, 1986).

PRESCRIBED FIRE

The treatment site, approximately 265 ha, was enclosed by fire lines and subjected to an aerially ignited backfire on 1 June 1994. The fire was patchy, burning areas that had sawgrass and cattail as understory; however, areas dominated by maidencane or broad-leafed herbaceous species such as duck potato (*Sagittaria lancifolia* L.) and pickerel weed (*Pontederia cordata* L.) did not burn.

All sampling sites were burned, although the impacts varied. In most cases, large stems of willow were killed but not always consumed by the fire. Leaves and small stems were burned more completely.

At the time of the prescribed fire, mean water depth at the sampling sites was 12 cm. The site was flooded throughout the four years after the fire with depths ranging from 15 to 60 cm.

FIELD SAMPLING

Pre-fire vegetation data was collected in April and May 1994. Willow sampling was conducted annually for four years post-fire. Understory species composition was monitored annually for two years post-fire. All sampling was done in early summer (May-July). Sampling results one year after the fire were previously reported (Miller et al. 1998).

Sampling occurred in areas that had 40%-60% canopy cover of willow and understories dominated by sawgrass and/or cattail. Other commonly occurring species included buttonbush (*Cephalanthus occidentalis* L.), duck potato, and hemp vine (*Mikania scandens* L., Willd).

We used three different metrics to investigate willow response: (1) stem density, (2) stem basal area, and (3) cover. Unburned control sites were sampled to assess changes in willow in the absence of fire. We determined plant species composition, frequency, and cover in each site to assess how changes in willow affected understory species.

Sampling was conducted at six sites in the burned area and three sites in the adjacent unburned area. Two or three 1-m x 15-m belt transects were sampled at each site. Fifteen transects were sampled in the burned areas and seven transects in the unburned area. Because of the difficulty in distinguishing individual willows, we used number of stems as a measure of abundance. We determined stem density and diameter 0.5 m above the ground. Stem diameter was used to compute total basal area (the combined cross sectional area of all stems). Stems were categorized as mature or sprout. Small green stems without woody tissue were considered to be sprouts. No attempt was made to distinguish between seedlings and sprouts.

Willow cover was measured using the line-intercept method along the 15-m transect (Mueller-Dombois and Ellenberg 1974). Cover was measured in two height categories – canopy (>1.5 m) and subcanopy (<1.5 m). Understory plant species composition was recorded in 7-1 m^2 quadrats that were placed along the transect at 2-m intervals. Cover of each species was estimated by category (<5%, 5%-25%, 26%-50%, 51%-75%, >75%).

STATISTICAL ANALYSES

We used repeated measures ANOVA to evaluate post-fire changes in stem density, stem basal area, and canopy and subcanopy cover. Where significant differences were indicated, we used the Bonferroni/Dunn test to examine pair-wise differences between sampling events. To compare these metrics between burned and unburned sites we used simple ANOVA. Data for number of stems and stem basal area were transformed by square root to meet the normality assumptions of these tests. Number of sprouts, which was not normally distributed, was assessed using the Mann-Whitney U test. Simple correlation was used to investigate differences in sprouting response among transects. Response of understory species to the fire, which was measured as changes in cover categories, was analyzed using the Friedman test. Post-fire changes in species richness were analyzed with paired t test. All statistical analyses were performed using StatView™.

RESULTS

Before the fire, willow was the dominant species in both burned and unburned sites with canopy cover of 40%-60% and stem densities ranging between 0.5 to 3 stems per m^2. The majority of stems were mature. Density of sprouts was significantly higher in the control sites (p= 0.0158) where sprouts occurred along every transect and had densities ranging from 0.6 to 1.8 per m^2. Sprouts occurred in only six transects in the treatment sites with densities between 0.06 and 0.6 per m^2. Most transects had understory cover of >50% cattail and/or sawgrass.

Willow responded to the fire with a proliferation of sprouts. Before the fire, sprouts made up 7.2% of the total number of stems

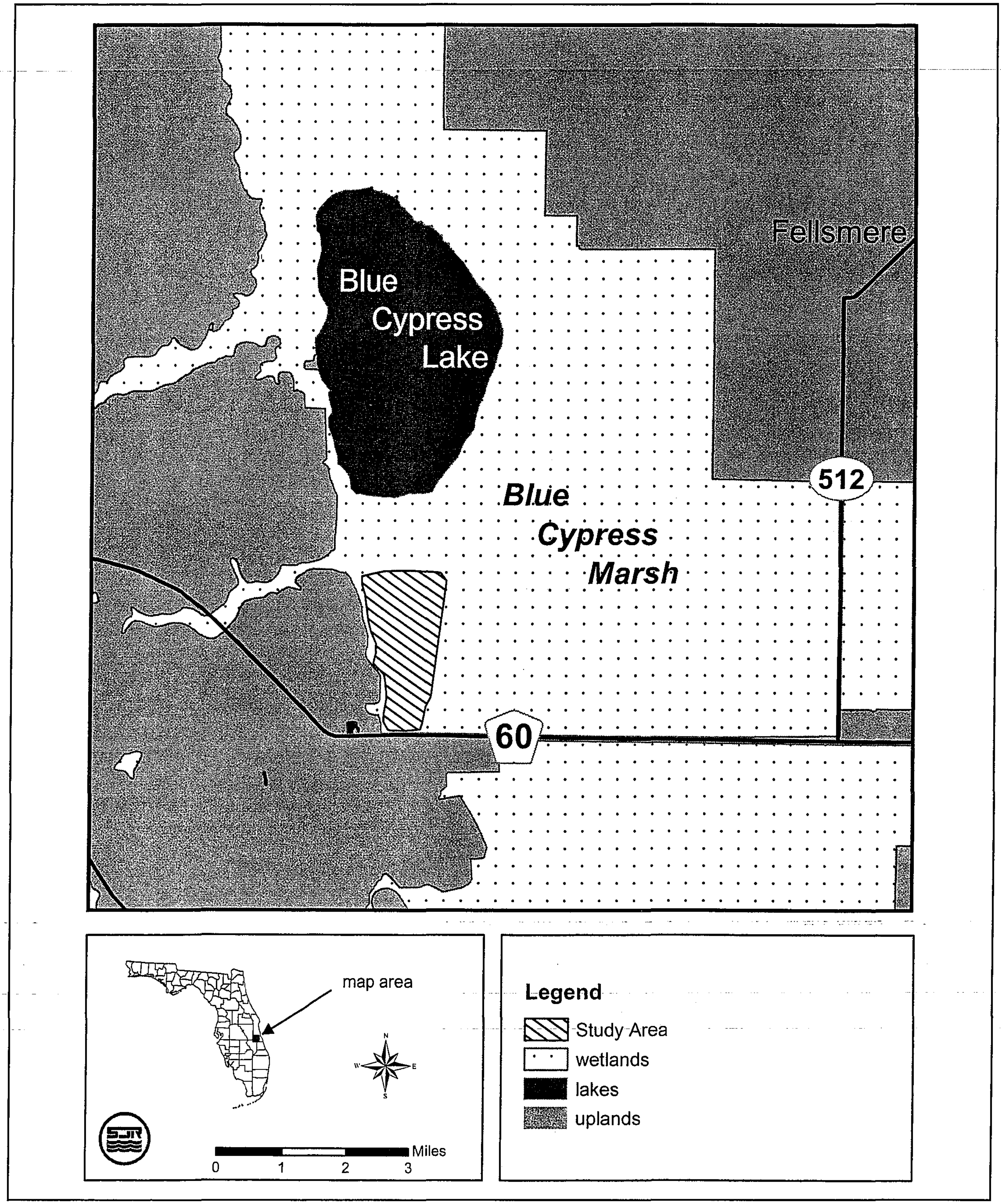

Figure 1. Upper St. Johns River Basin. Study site is indicated.

in the burned sites. One year after the fire, this had increased to 92.1%. The extent of sprouting was different among transects but the number of sprouts produced was not related to pre-fire stem density ($r^2 = .005$, $p = 0.79$) or to the number of mature stems that survived the fire ($r^2 = .012$, $p = 0.68$).

The large number of sprouts produced after the fire led to a significant increase in stem density for one year; the loss of large diameter stems led to a significant decline in basal area throughout the four years of post-fire sampling (Table 1).

Willow cover at the canopy level (>1.5m) also decreased after the fire and remained 71% lower than pre-fire levels four years post-fire (Table 1). There were no significant changes in subcanopy (<1.5m) cover.

One year after the fire in the unburned site, stem density, basal area, and canopy cover were not significantly different from pre-fire levels. However all three measures declined significantly in the later years of the study (Table 1). These changes complicated the comparison of burned and unburned sites.

The differences between the burned and unburned site were greatest one year after the fire when basal area and canopy cover were both significantly lower in the burned area than the unburned (Figure 2). Stem density was significantly lower in the burned site before the fire, but one year after the fire, there was no significant difference (Figure 2).

For the remainder of the study, basal area and canopy cover were lower in the burned site than the unburned site, although the differences did not achieve a level of statistical significance of $p<0 .05$ (Figure 2). Stem density was not significantly different in burned or unburned sites for the remaining three years of the study (Figure 2).

The dominant understory species in the study site were sawgrass and cattail. These species had cover values of >75% in all the sampling transects before the fire. After the fire, cover of these species declined significantly in the burned sites, and remained below pre-fire levels for the two years of post-fire sampling (Friedman test, $p=0.002$). Cover values in the unburned sites did not change (Friedman test, $p=0.268$).

Few species demonstrated substantial changes in frequency after the fire. Buttonbush showed the sharpest decline in frequency (15.3%) the first year after the fire. Frequency of smartweed (*Polygonum* spp.) and cattail also showed substantial decline (6.7% and 8.5% respectively). However, by the second year after the fire, all three had regained pre-fire frequencies (Table 2), and smartweed had increased over pre-fire levels.

Although the overall number of species did not change greatly between sampling events, the number of species along each transect increased significantly (paired t test $p=.0014$). Average species richness increased from 5.5 species before the fire to 6.5 species one year after the fire and 8.3 species two years post-fire.

Changes at unburned sites included large increases in the frequency of *Bacopa* sp. and declining frequency of mosquito fern (*Azolla caroliniana*), duck potato, and bladderwort. There was no significant difference in species richness in the unburned sites after the fire.

DISCUSSION

As discussed by van Mantgem et al. (2001), it can be difficult to do rigorous scientific experiments with prescribed fires because of the lack of replication and controls. The current study exemplifies this problem in that there were significant changes in the control site, which confound interpretation of the results. These changes suggest that fire is not the only factor affecting the expansion of willow, although the cause of these changes could not be identified.

Table 1. Mean (SE) of willow basal area, stem density and canopy cover in Blue Cypress Marsh Conservation Area for each sampling event. Asterisks indicate significant differences (Bonferonni-Dunn) from pre-fire values, p<0.05.

	Pre fire	1 yr post fire	2 yr post fire	3 yr post fire
Burned Site				
Basal stem area (mm^2/m^2)	950 (169)	331 (107) **	533 (260) **	379 (169) **
Stem density ($\#/m^2$)	1.7 (0.2)	4.0 (1.1) **	1.9 (0.5)	1.2 (0.3)
Canopy cover (%)	44.9 (4.9)	17.6 (4.3) **	19.1 (5.6) **	14.3 (4.4) **
Sub-canopy cover (%)	3.4 (0.8)	8.2 (1.9)	2.3 (0.1)	3.4 (1.0)
Unburned Site				
Basal stem area (mm^2/m^2)	1014 (168)	901 (107)	908 (187)	575 (133) **
Stem density ($\#/m^2$)	2.8 (0.7)	2.6 (0.7)	2.9 (0.7)	1.5 (0.3) **
Canopy cover (%)	53.8 (6.1)	44.2 (6.6)	31.1 (5.1) **	27.2 (3.4) **
Sub-canopy cover (%)	4.4 (1.6)	3.7 (1.8)	3.6 (1.1)	4.2 (1.3)

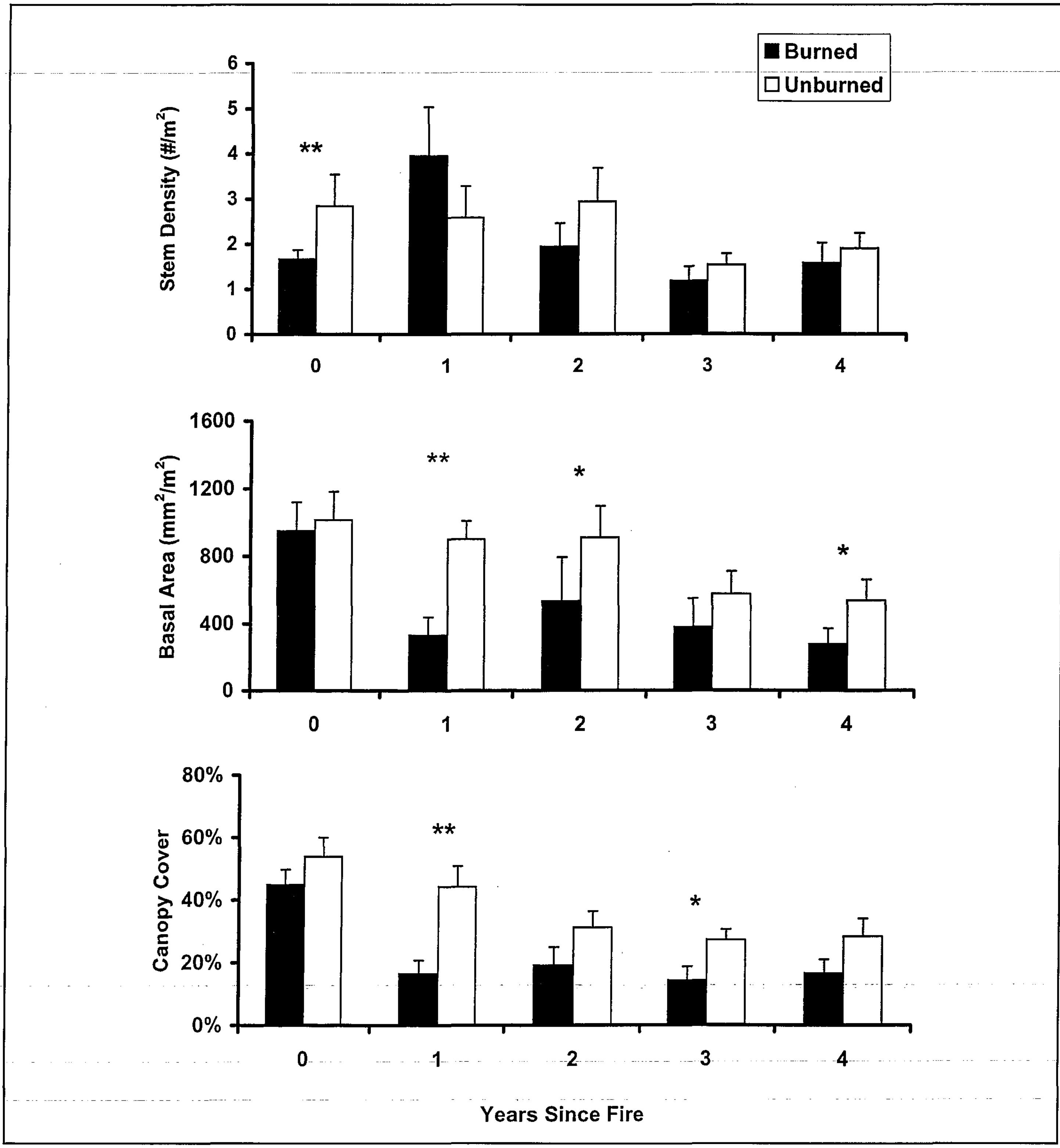

Figure 2. Comparison of burned and unburned sites. A. stem density, B. stem basal area, and C. canopy cover. Bars indicate +1 standard error. Stars indicate level of significance, * = p<0.10, ** = p<0.05.

Annual sampling showed no evidence of a wildfire, insect outbreak, or disease.

Regardless of this problem, it is evident from the data that the fire had an impact on willow canopy cover and basal area. Differences between burned and unburned sites were greatest the first year after the fire, and these differences are clearly the result of the fire. For subsequent years, it is not possible to attribute the differences from pre-fire values exclusively to the fire,

Table 2. Plant species composition at sampling locations in Blue Cypress Marsh Conservation Area. Table shows percent of sampled quadrats in which the species occurred. Only species with frequencies >15% during at least one sampling event are shown.

	Burned Sites (n=112 quadrats)			Unburned Sites (n=49 quadrats)		
Taxa	Pre-Fire	1-Yr Post	2-Yr Post	Pre-Fire	1-Yr Post	2-Yr Post
Azolla caroliniana	0.0	9.5	11.4	38.8	0.0	10.2
Bacopa spp.	0.0	4.8	0.0	24.5	36.7	36.7
Cephalanthus occidentalis	44.8	29.5	42.9	32.7	32.7	36.7
Cladium jamaicense	65.7	65.7	72.4	57.1	53.1	55.1
Mikania scandens	17.1	11.4	8.6	18.4	22.4	18.4
Peltandra virginica	7.6	6.7	8.6	16.3	12.2	2.0
Polygonum sp.	12.4	5.7	23.8	26.5	22.4	12.2
Pontedaria lanceolata	5.7	4.8	11.4	36.7	38.8	38.8
Sagittaria lancifolia	28.6	27.6	24.8	38.8	22.4	30.6
Salvinia spp.	32.4	30.5	38.1	0.0	0.0	0.0
Typha sp.	33.3	24.8	31.4	42.9	53.1	49.0
Utricularia spp.	10.5	42.9	22.9	34.7	20.4	2.0

since there were also changes in the control sites. However, throughout the four years of post-fire sampling, the burned sites had consistently lower values than the unburned sites in both canopy cover and basal area, and in half these cases, these differences were significant at the p<0.10 level. This suggests that in the absence of fire, these metrics might still have declined, but not to such a great extent. Because of the changes in the unburned sites, it is not possible to assess how long it took the willow to recover from the fire impact. The time needed for willow recovery is particularly important in order to determine appropriate frequencies for prescribed fires.

Willow responded to fire by prolific re-sprouting. Although we did not distinguish between seedlings and sprouts, we expect that most of what was termed "sprout" was regrowth from existing stems or roots and not seedlings. Willow seeds are short-lived, loosing viability within two or three weeks of dispersal (Young and Young 1992). Additionally, willow seeds do not germinate under inundated conditions (Lee, unpubl. data), and there was standing water on the sampling site throughout the entire study.

Sprouting occurred basally, and from the trunk or main stem when it was not killed by the fire. Sprouting along the stem may be an adaptation for getting leaves into the canopy early to recapture light (Hodgkinson 1998). Although the sprouting response varied across the site, factors controlling these differences could not be identified. The extent of sprouting was not related to pre-fire stem density or intensity of fire (measured as number of mature stems remaining alive after the fire). The post-fire increase in stem density caused by resprouting did not persist beyond the first year, suggesting that many of sprouts died between one and two years after the fire. High mortality of sprouts is not unusual (Hodgkinson 1998), although the reason for the large number of unsuccessful sprouts is not known.

Dormant season fires in similar plant communities in another area of the upper St. Johns River basin had results much like those obtained here (Lee et al., in press). In that study, however, unburned willow increased significantly through time resulting in large differences between burned and unburned sites. Nevertheless, some studies in wetlands have found increases in shrub density after fire (Pendergrass et al. 1998), presumably because of the increase in sprouts.

The effects of the fire on the understory were not as expected. We hypothesized that willow canopy was suppressing understory plants and its removal would result in an increase in herbaceous cover and richness. The fire did not produce the strong positive response that we had expected. Dominant understory species declined in cover after the fire. Most changes in frequency of occurrence and cover of non-dominant understory species were small. However, species richness did increase in the burned sites. This increase was likely the result of a decrease in the heavy litter layer characteristic of both cattail and sawgrass marshes. Reduction in litter may allow for increased recruitment of short-lived forbs (Lee et al. 1995, Pendergrass et al. 1998).

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Steven J. Miller is a senior environmental scientist working on the restoration of the upper St. Johns River basin. He received his B.S. and M.S. degrees in aquatic ecology from Eastern Illinois University. His areas of expertise include wetland hydrology and ecology.

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