DOES SEASON OF BURNING AFFECT FUEL DYNAMICS IN SOUTHEASTERN FORESTS?

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ABSTRACT:
Land managers in the southeastern United States (U.S.) have actively used prescribed fire, primarily in the winter or dormant season, as a tool to control the growth of understory vegetation since the middle of the last century. There is evidence, however, that burning during the growing season may have different, and in some cases more desirable effects on ecosystem processes, vegetation structure, vegetation composition and, by virtue of these factors, understory fuels and potential fire behavior.

We conducted an experiment to document and test for potential differences in the rate of fuel re-growth and accumulation following prescribed fires during the dormant and growing seasons. In other words, as a fuel management treatment, do growing season prescribed fires have a different lifecycle than dormant season prescribed fires? We tested the hypotheses that fuels re-grow and accumulate more slowly following growing season fires, and that growing season fires change the structure and composition of the understory fuelbed to a larger degree when compared to dormant season fires.

Our study measured fuel amount and composition annually following dormant and growing season prescribed fires for approximately two years in longleaf pine (*Pinus palustris*) flatwoods ecosystems in western (Eglin Air Force Base) and north-central (Apalachicola National Forest and St. Marks National Wildlife Refuge) Florida. We attempted to confirm anecdotal observations that fuel reduction that results from growing season burns lasts longer and also that the structure and composition of the post-fire fuelbed differs between growing season and dormant season fires. Confirmation of these observations could allow fire managers to adjust the intervals between fuel-reduction burns for the landscapes they manage, enabling treatment of more area for the same amount of effort and expense. As well, results from this study could suggest which treatments are most effective for restoring the structure and composition of understory fuels in flatwoods communities that have experienced a departure from desirable, historical conditions.

Prescribed fires at our managed, mesic longleaf pine flatwoods sites maintained reduced shrub and herbaceous fuel loading, coverage and height at least two years post-fire. Our experiment showed very little difference in post-fire fuel dyanamics related to season of burn, although the temperature of the fire did appear to affect shrub regrowth, with hotter fires producing a larger and longer-lasting reduction in shrub loading and coverage. We observed differences in post-fire fuel dynamics between the western and north-central Florida study regions and suspect those differences are related to regional variations in species composition.

BACKGROUND AND PURPOSE:

1. Introduction

Longleaf pine forests are a widely occurring fire-adapted vegetation type in the southeastern U.S. A formerly extensive type (Fig. 1), after nearly 400 years of intensive land use longleaf pine forests are currently found on less than two percent of their presettlement range (Frost 2006). Remaining tracts harbor some of the highest recorded

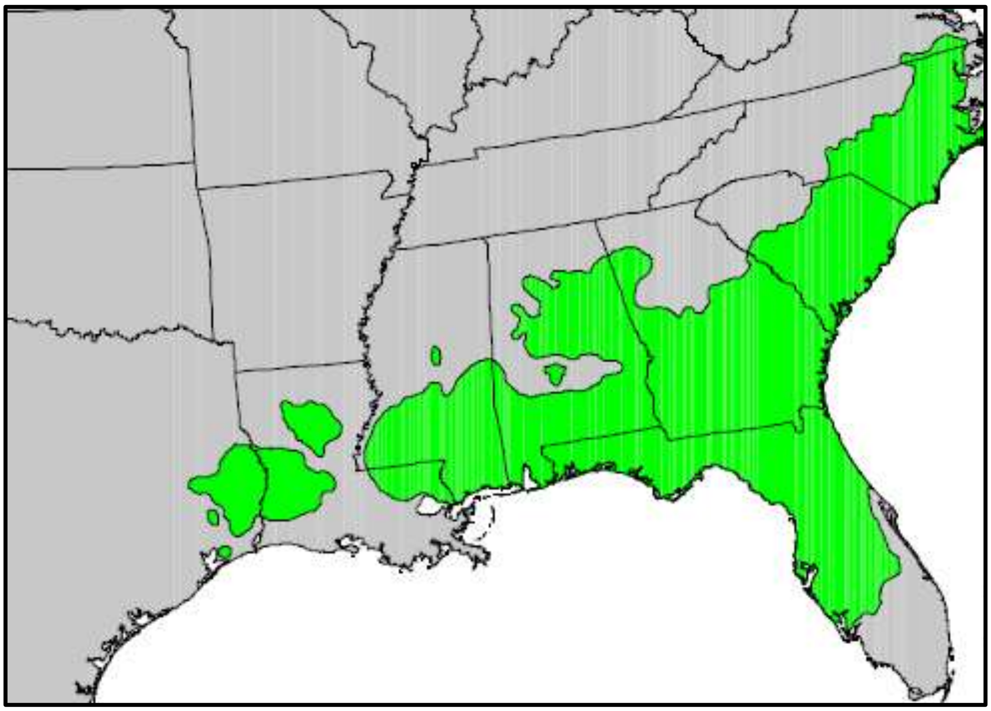

Figure 1. Historical range of longleaf pine forests in the southeastern United States. Map from Little (1971).

biodiversity in North America (Estill and Cruzan 2001, Hardin and White 1989, Stein et al. 2000, Walker and Peet 1984), serve as habitat for several threatened and endangered plants and animals (Krusac et al. 1995, Means 2006, Trani 2002), provide environmental services, and are important recreational areas (Cordell and Tarrant 2002, Holmes 2002). The fire regime, as in many southeastern U.S. ecosystems, is defined by frequent, low-intensity surface fire.

Fires occurred throughout the year but historically were concentrated during the lightning season (late spring and summer) in areas along the coast of the Gulf of Mexico where lighting is more frequent. In the past, fires were ignited by a combination of humans and lightning and there is debate concerning the role humans had in shaping the historical fire regime (Komarek 1968). It has long been known that in the absence of regular, frequent prescribed fire surface fuels can build to hazardous levels in as little as five years (Brose and Wade 2002, Davis and Cooper 1963). Since at least the middle of the twentieth century, frequent (1-5 year intervals) prescribed burning has been used as a tool to manage the rapid re-growth and accumulation of live vegetation (grasses, forbs, and shrubs), dead and down wood, and needle cast fuels that occurs following fire in longleaf pine forests in the southeastern U.S. (Fig. 2.; Robbins and Myers 1992). The average annual area that is prescribe burned for the period 2002-2011 in the southeast was 0.57 million ha (range: 0.44 – 0.72 million ha; National Interagency Fire Center 2013). This accounts for 62 percent of area burned nationally and is especially notable given that only 4.7 percent of the land area in the 13 southeastern states is under federal ownership (Gorte et al. 2012).

Figure 2. Prescribed burn demonstration plot at St. Marks National Wildlife Refuge showing biannually burned (L) and unburned (R) plots in longleaf pine flatwoods. Photo credit: J.B. Cronan.

Although wildfires mostly occur during the spring and summer in the region, much of the prescribed burning occurs during the winter months or dormant season. Because wildfires historically occurred during the spring and summer months, growing season burning has been promoted as more ecologically appropriate, however, there is a lack of consensus within both the management and research communities regarding the effects and merits of prescribed burning during the growing season (Robbins and Myers 1992).

The role of fire in maintaining biodiversity and ecological structure and function of longleaf pine forests has been well documented (e.g., Boyer 1990, Lotti 1956, Maliakal et al. 2000, Olson and Platt 1995, Outcalt and Foltz 2004, Sparks et al. 1998, Van Lear et al. 2005, Waldrop et al. 1992, Walker and Peet 1984, Willcox and Guiliano 2010), however, no research that we know of has explicitly examined the effect of seasonality on the lifecycle aspects of prescribed burning as a fuel management treatment.

2. Objectives

There is evidence (both published and anecdotal) that prescribed fires during the spring and summer or growing season have different effects on a number of ecosystem processes and properties (Robbins and Myers 1992, Waldrop et al. 1987). Our primary research addressed the question:

Do prescribed fires conducted during the growing season have longer lasting and/or greater impacts on live fuel re-growth and overall fuel accumulation?

We were particularly interested in how fuels re-grow and accumulate over time following different fuel treatments (i.e., dormant season vs. growing season prescribed fires) in ecosystems where live vegetation comprises a substantial portion of the total available fuel load, such as is found in longleaf pine flatwoods ecosystems. We hypothesized that season of prescribed burning could affect the fuel treatment lifecycle, but that treatment effects could be site- or species-specific:

H_1: Growing season fires will reduce the rate of fuel re-growth and accumulation (i.e., increase the longevity of the treatment) when compared to dormant season fires.

H_2: Growing season fires will cause a greater change to the structure and composition of the understory fuel layer compared to dormant season prescribed fires.

We expect that a better understanding of the effects of season of prescribed burning will contribute to more effective and efficient employment of prescribed fire treatments for surface fuel management and ecosystem maintenance and restoration. For example, use of longer lasting fuel treatments in longleaf pine/wiregrass (*Pinus palustris/Aristida stricta*) habitats that have a contemporary overabundance of saw palmetto (*Serenoa repens*), gallberry (*Ilex glabra*) and other flatwoods-associated shrubs could allow managers to effectively treat a larger proportion of their landscape in cases where management resources or opportunities for using fire as a fuel management tool are limiting.

STUDY DESCRIPTION AND LOCATION:

1. Study Areas

Locations in pine flatwoods forests in western and north-central Florida were selected as study sites for this project (Fig. 3, Appendix A). All sites in western Florida were located at Eglin Air Force Base (Eglin) in Niceville. Eglin encompasses 187,555 ha making it the largest forested military reservation in the United States (DoD 1993), a substantial fraction of which (146,000 ha) is comprised of fire-dependent ecosystems. To manage the installation, the natural resources management section for Eglin operates an ambitious, nationally recognized, fire management program (DoD 2011, Hager 2010, Stevens 1996). Sites in north-central Florida were split between the Apalachicola National Forest (6 sites) and St. Marks National Wildlife Refuge (2 sites), two adjoining federal properties in the vicinity of Tallahassee. The Apalachicola National Forest is the largest national forest in Florida at 256,130 ha (USFS 2012); the Forest treats approximately 40,000 ha of fire-adapted ecosystem types annually with dormant and growing season prescribed fire. St. Marks National Wildlife Refuge occupies a 27,520 ha area along the Gulf Coast that is adjacent to the southeastern boundary of the Apalachicola National Forest. Upland forest composition and management (regular, repeated prescribed burning) at St. Marks are similar to the neighboring national forest. St. Marks averaged 5,316 ha of dormant and growing season prescribed fire from 2002 to 2011 (USFWS 2012).

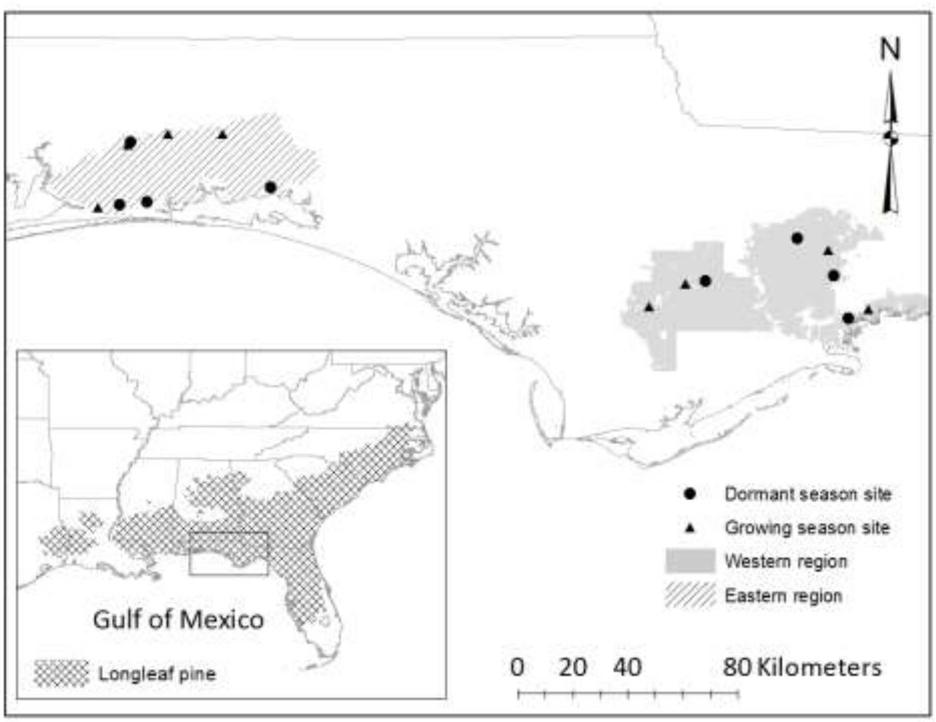

Figure 3. Map of site locations. Experimental design involved replicated, repeated measures (change in fuel characteristics 1 and 2 years after prescribed burning) of treatment effects (dormant vs. growing season prescribed fires) within blocks (western vs. north-central Florida).

The sites selected for this study were in what would be considered mesic pine flatwoods in which the overstory is typically composed of longleaf (*Pinus palustris*) and slash pine (*Pinus elliottii*). Flatwoods are characterized by a shrub-dominated understory, although herbaceous species do occur, can be abundant, and are important habitat components for many wildlife species. Understory vegetation is frequently dominated by mixtures of saw palmetto (*Serenoa repens*), gallberry (*Ilex glabra*), and wiregrass (*Aristida stricta*); various species of shrubby oak (*Quercus* spp.) and blueberry (*Vaccinium* spp.) also occur commonly.

Table 1. Site data for dormant and growing season prescribed fires in pine flatwoods in the Gulf Coastal Plain of Florida. Sampling occurred within the boundaries of operational burns. Sites were located at Eglin Air Force Base (E…), St. Marks National Wildlife Refuge (S…), and the Apalachicola National Forest (A…). Sampling occurred before, immediately after, one-year after, and two-years after fires.

Site	Region	Season of burn	Latitude	Longitude	Burn date
E100B-E	West	Dormant	N30° 39.40′	W86° 43.12′	12 Jan 2010
E501B	West	Dormant	N30° 27.36′	W86° 45.64′	23 Dec 2009
E505	West	Dormant	N30° 27.63′	W86° 40.12′	23 Jan 2010
E807D	West	Dormant	N30° 30.28′	W86° 15.50′	21 Feb 2010
E100B-W	West	Growing	N30° 39.09′	W86° 43.55′	8 May 2010
E103B	West	Growing	N30° 40.84′	W86° 35.62′	30 Mar 2010
E403	West	Growing	N30° 41.00′	W86° 25.25′	8 May 2010
E508A	West	Growing	N30° 26.50′	W86° 49.74′	19 Mar 2010
A034	East	Dormant	N30° 12.09′	W84° 50.20′	18 Feb 2010
A213	East	Dormant	N30° 20.52′	W84° 32.43′	11 Feb 2010
A319	East	Dormant	N30° 13.14′	W84° 25.22′	14 Jan 2010
S330	East	Dormant	N30° 04.72′	W84° 22.41′	17 Feb 2010
A032	East	Growing	N30° 11.69′	W84° 54.23′	19 May 2010
A071	East	Growing	N30° 07.07′	W85° 01.38′	2 Jun 2010
A302	East	Growing	N30° 17.91′	W84° 26.29′	22 Jul 2010
S209	East	Growing	N30° 06.57′	W84° 18.49′	9 Jul 2010

2. Study Methods

All study sites were located within the boundaries of operational prescribed fire burn compartments that had a history of regular, recurrent prescribed fires that were scheduled for burning in the winter of 2009-2010 and the spring and summer of 2010 (Table 1). Fire management personnel were interested in testing whether anecdotal observations that growing season prescribed fires: (1) have a longer lasting effect (i.e., that growing season fires slow re-growth of live understory fuels in comparison to dormant season fires), and (2) are a more effective tool for restoring the historical structure and composition of the understory fuel layer in longleaf pine/wiregrass communities currently dominated by saw palmetto and gallberry (i.e., that saw palmetto and gallberry cover and biomass are more effectively reduced and that wiregrass and other herbaceous species are favored in growing season prescribed fires).

a. Sampling Design:

The sampling design employed repeated measures with replicated treatments nested within blocks or locations (Figure 4). Treatments included a dormant season (December-February) and a growing season (late March-July) prescribed fires. Selection of study sites and assignment of treatments was dictated by management history and operational burning plans. At each location we identified management units with comparable vegetation composition and management history (i.e., season and time since last fire). We selected our study sites from among all management units that were scheduled for dormant and growing season prescribed burning in 2010 with comparable vegetation composition that had been most recently burned during the dormant season in 2008.

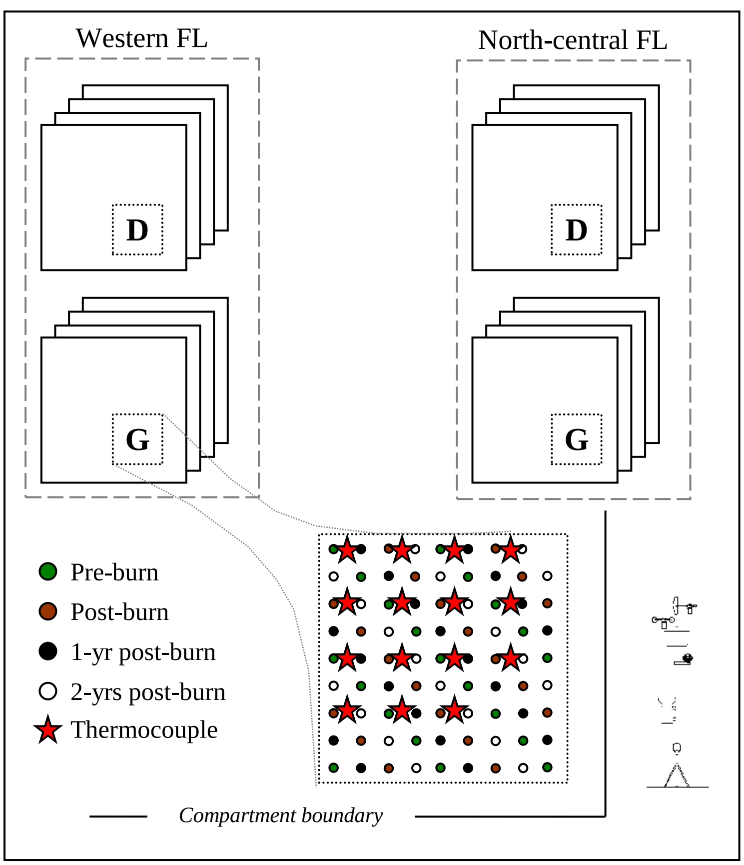

Figure 4. Schematic illustration of project sampling design for locations in western and north-central Florida. A grid of destructively sampled plots was used to assess changes in fuel composition and amount in response to dormant and growing season prescribed fires. A portable weather station was set-up adjacent to the compartment being burned to record ambient weather conditions, and an array of 15 thermocouples was deployed during fires to characterize in-fire temperature and duration. Sensors recorded temperature 5 cm above the surface as a proxy for fire intensity. G = growing season prescribed fire treatment unit; D = dormant season prescribed fire treatment unit.

Fuel loading and composition were measured before the treatment burns (December 2009-February 2010), immediately after the burns, one year after the burns, and two years after the burns to evaluate the differences in the fuel treatment lifecycle; that is, the rates of fuel accumulation that result from the different treatments. As frequent (i.e., every three years) prescribed burning is commonplace in flatwoods ecosystems, we felt that the duration of this study encompassed a typical fuel treatment lifecycle and would provide a useful estimate of potential differences between dormant season and growing season prescribed burning at a timescale that was relevant for management.

b. Field Measurements:

A 3-4 person field crew from the Pacific Wildland Fire Sciences Laboratory conducted pre-burn, day-of-burn, and post-burn fuel inventory measurements at each location; field personnel worked in close cooperation with fire managers at the selected locations to coordinate pre-burn and day-of-burn sampling activities. All research personnel present during burning operations were fireline qualified and equipped with the appropriate personal protective equipment for fireline duty.

Fuel amount – Fuels were inventoried using standard destructive methods (Wright 2013). Our previous work in this type and that of others (e.g., Outcalt and Foltz 2004, Sparks et al. 2002) has shown that numerous (~20) relatively small (1-4 m^2) destructive sample plots work well for characterizing fuel loading (fuel mass per unit area) in longleaf pine flatwoods ecosystems. Given the need to collect samples at four different times during the course of the experiment, eighty plots were established on a 20-m grid. Each plot grid encompassed a 2-ha area within each management unit. One-quarter of the plots were sampled during each sampling episode: pre-fire, immediately post-fire, 1-year post-fire, and 2-years post-fire.

All standing vegetation rooted within the boundaries of each plot was cut at ground level, separated by species and status (live and dead), ovendried at 70 °C for at least 48 hours and weighed to determine dry weight loading. Saw palmetto and tall-stature shrubs were sampled in 4-m^2 plots. Grasses, forbs, vines, and short-stature shrubs were sampled in two 1-m^2 subplots nested in opposite corners of the larger 4-m^2 plot. Litter and small woody fuels were collected in two 0.25-m^2 subplots that were also nested within the larger plot. Litter and small woody fuels were ovendried at 100 °C for at least 48 hours and weighed.

Large (i.e., >2.5 cm in diameter) woody fuel loading was estimated by using a planar intersect inventory (Brown 1974). Two 20-m planar intersect transects of random azimuth originated from each of the 20 pre-burn grid points (800 m total per site); the same 40 transects were re-measured during all four sampling episodes. Azimuths were constrained to a 270 degree horizon that did not overlap with the destructive sample plots that were co-located with the transect origins. Transect end points were marked with steel rods to facilitate re-measurement. In addition, the distance from the transect origin to each piece of intersected woody material was noted during the inventory in order to distinguish existing woody fuel particles from those that were newly contributed between sampling episodes.

Plot, subplot, and transect loading values were averaged across each study site and sampling episode for use in statistical analyses. We were unable to fully inventory several sites; only sites with a complete data record were used in statistical analyses. A complete list of sites is included in Appendix A.

Fuelbed depth and vegetation height – The depth of the litter and duff layers was measured to the nearest millimeter at three points along each planar intersect transect during each sampling episode. Vegetation height by lifeform (i.e., grass, saw palmetto, and shrub) was also measured at three points along each planar intersect transect. Lifeform heights were only measured where a suitable plant was growing within 1 meter of the measurement point. Litter and duff depth and vegetation height were averaged across each study site and sampling episode for use in statistical analyses.

Vegetation composition – Transects established for large woody fuel sampling were also used for measuring vegetation coverage. Coverage by species of all understory vegetation present on a site was measured by using the line intercept method (Canfield 1941) during each sampling episode. Overstory canopy coverage was estimated by using a forest densitometer at 120 points in each stand that were co-located with litter, duff, and vegetation height measurements.

Day of burn – Portable weather stations were installed adjacent to each management unit prior to burning to record antecedent, day-of-burn, and subsequent weather conditions at 20-minute intervals. Weather stations were equipped with sensors located approximately 2 meters above the ground for measuring precipitation, wind speed, wind direction, temperature, and relative humidity. Grass, forb, shrub, and woody fuel samples were collected in heavy-gauge re-sealable plastic bags shortly before ignition to characterize day-of-burn fuel moisture content. Fuel moisture samples were weighed while wet within four hours of collection, ovendried for at least 48 hours (70 °C for live vegetation samples, 100 °C for litter and woody fuels), and re-weighed to determine gravimetric moisture content.

Fire behavior and fire intensity – Many researchers (Robbins and Myers 1992 provide a nice summary of research that has been conducted) have noted the difficulty in distinguishing the effects of fire behavior or fire intensity from season of burn on postfire vegetation responses (e.g., mortality, growth, flowering, productivity, etc.). Warmer ambient conditions are thought to contribute to elevated fire severity during growing season prescribed burns because less energy is required to raise plant tissue to lethal temperatures (Van Wagner 1973), although this phenomenon is not always observed (Sparks et al. 2002). Given the uncertainty regarding differences in fire intensity between dormant and growing season prescribed fires, we measured time series of temperature 5 cm above the ground at 15 locations within each prescribed fire treatment using a small array of type-K thermocouples (Figure 4). Thermocouples were located 3 meters from each pre-burn vegetation sampling point in undisturbed fuels and recorded temperature measurements at 5-second intervals. Average maximum temperature and average duration of flaming combustion in excess 60 °C were used as variables in statistical analyses to compare fire intensity among burns. In addition, we made visual observations of fire behavior (rate of spread, flame length) and lighting patterns (head, strip head, backing, flanking, etc.) as the study areas burned.

c. Data Analysis:

The experimental design allowed us to test for treatment and location differences using a repeated measures analysis of covariance (e.g., Green 1993, Quinn and Keough 2002, Laughlin et al. 2004). Ideally, treatment sites would have been split and each treatment would have been applied to the split site. Given operational constraints related to splitting management units, however, and the variable nature of fire in a field-applied, operational setting, we instead selected units with comparable vegetation and management history, and measured pre-fire fuel characteristics, fire behavior, and fire intensity (and used these measurements as covariates) to account and compensate for these limitations. This type of analysis allowed us to examine the potential difference among treatments and between locations while taking into account potential differences in fire intensity between the different treatments.

The data collected as part of this study, particularly species-level measurements of coverage and loading, will also allow additional analyses that are beyond the scope of this proposal using multivariate methods. Nonmetric multidimensional scaling (NMDS) may be used to explore potential differences among treatments, blocks, and sample times (McCune and Grace 2002).

KEY FINDINGS:

1. Postfire fuel regrowth marginally linked to season of burning

We hypothesized that growing season burns would produce a potentially longer lasting reduction in fuel amount and speculated that two primary mechanisms were behind this hypothesis. First, it is thought that fires during the growing season top-kill plants after they have expended their carbohydrate reserves producing the current year's growth leaving them fewer physiological resources to resprout and regrow and retarding overall recovery of live fuels (Matlack et al. 1993). Second, ambient conditions during growing season fires tend to be warmer and drier, which could produce fires of higher intensity and severity. Elevated severity, in particular higher levels of live understory plant mortality, would also slow live vegetation re-growth rates leading to longer recovery times for live understory fuels.

Table 2. Mean prefire, 1-yr postfire, and 2-yrs postfire loading, coverage, and height for understory shrub and herbaceous fuels burned during the dormant and growing seasons in western and eastern Florida.

	Region			
	West	East	West	East
	- - - - Shrub fuels (mean ± SD) - - - -		- - - Herbaceous fuels (mean ± SD) - - -	
Prefire				
		Loading (Mg ha^{-1})		
Dormant	3.18 ± 1.03	2.63 ± 0.76	1.01 ± 0.86	0.59 ± 0.57
Growing	1.98 ± 0.51	2.58 ± 1.85	0.94 ± 0.69	0.68 ± 0.12
		Coverage (%)		
Dormant	38.8 ± 5.0	43.64 ± 12.74	22.96 ± 18.16	15.02 ± 18.48
Growing	39.4 ± 3.9	45.73 ± 15.84	21.98 ± 12.92	21.36 ± 16.2
		Height (m)		
Dormant	0.65 ± 0.08	0.54 ± 0.04	0.30 ± 0.07	0.27 ± 0.04
Growing	0.64 ± 0.17	0.52 ± 0.08	0.24 ± 0.04	0.27 ± 0.01
1-yr Postfire				
		Loading (Mg ha^{-1})		
Dormant	1.75 ± 0.49	2.33 ± 0.77	0.77 ± 0.55	0.42 ± 0.45
Growing	1.40 ± 0.29	2.30 ± 1.20	0.88 ± 0.54	0.56 ± 0.29
		Coverage (%)		
Dormant	30.2 ± 8.1	41.68 ± 10.38	17.30 ± 10.00	7.24 ± 5.63
Growing	26.0 ± 3.6	36.38 ± 10.11	15.06 ± 6.89	9.73 ± 4.55
		Height (m)		
Dormant	0.48 ± 0.02	0.41 ± 0.03	0.22 ± 0.06	0.14 ± 0.05
Growing	0.49 ± 0.05	0.42 ± 0.05	0.20 ± 0.05	0.21 ± 0.05
2-yrs Postfire				
		Loading (Mg ha^{-1})		
Dormant	1.69 ± 0.44	2.45 ± 0.40	1.20 ± 0.91	0.48 ± 0.50
Growing	1.75 ± 0.17	2.38 ± 1.41	0.71 ± 0.41	0.68 ± 0.35
		Coverage (%)		
Dormant	29.6 ± 6.1	48.68 ± 12.53	19.75 ± 13.96	9.02 ± 7.92
Growing	33.2 ± 5.9	48.16 ± 12.34	15.62 ± 6.30	14.85 ± 6.98
		Height (m)		
Dormant	0.57 ± 0.05	0.46 ± 0.04	0.19 ± 0.05	0.14 ± 0.03
Growing	0.53 ± 0.06	0.46 ± 0.10	0.20 ± 0.07	0.19 ± 0.07

The results of our experiment do not show clear differences in postfire live fuel re-growth between growing season and dormant season fires (Table 2). Live shrub and herbaceous fuel loading, coverage, and height were not statistically significantly different for burns in the two seasons. Lack of significance is likely a function of the high level of variability in these measures of fuel characteristics within each seasonal and regional grouping of sites. Compared to other long-term studies that have observed a strong seasonal effect (e.g., the Santee Fire plots of Waldrop et al. (1987)), all of the sites in our study have been actively managed with regular, repeated prescribed fires through multiple fire cycles, whereas the Santee plots had not been burned for many decades prior to the initiation of the study. We suspect that the large-magnitude changes in fuel characteristics observed at Santee had already happened at our sites and that our sample size was not large enough to provide the statistical power necessary to detect the relatively small effect size.

2. Fire temperature is not necessarily a function of season of burning

It has been proposed that growing season fires are more intense and severe than dormant season fires owing to the fact that they occur when air temperatures are higher, which acts to: (1) increase the fuel temperature, reduce the fuel moisture, and therefore the proportion of the total fuel loading that is available for combustion, and (2) raise the ambient fuel temperatures thereby reducing the energy input necessary from the fire to reach lethal temperatures for plant tissues (Van Wagner 1973, Johnson 1992). Factors associated with seasonal fluctuations in live fuel moisture content and concentration of volatile extractives in the foliage of some species associated with phenological changes may also affect the intensity of fires burning at different times of the year in longleaf pine flatwoods where a significant portion of the available fuels are in the form of live shrubs and grasses (Philpot 1969, Philpot and Mutch 1971).

Peak in-fire temperatures spanned a roughly 200 °C range for our 16 prescribed fires. There was not a pattern to the temperatures observations (Figure 5). Neither region nor

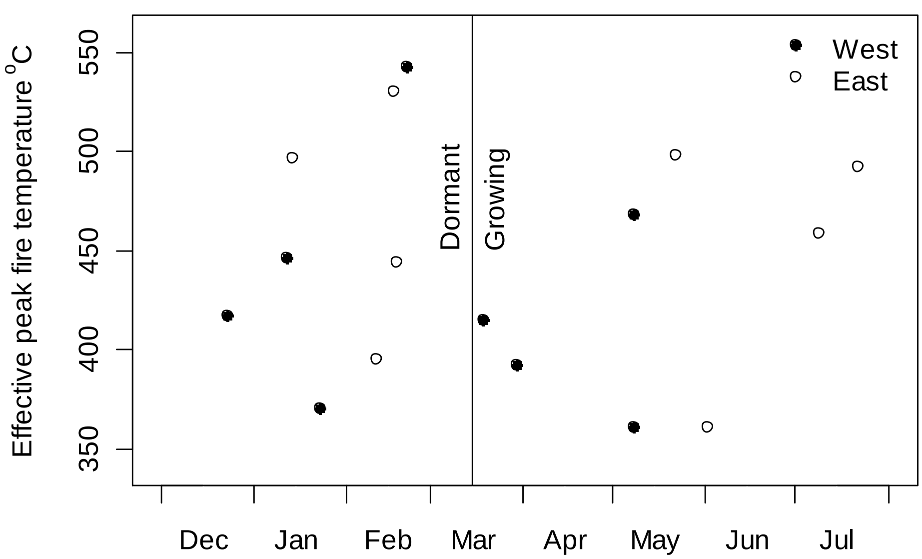

Figure 5. Distribution of effective peak fire temperature between dormant and growing season prescribed fires. Effective peak fire temperature is the sum of ambient temperature and average in-fire peak fire temperature.

season of burning affected the distribution of peak fire temperatures. It should be noted, however, that our sensors measured fire temperature near the ground surface; heat generated by burning shrubs and taller vegetation likely is not accounted for in these measurements as most heat from burning fuels is dispersed vertically. The fire temperature above the shrub fuel layer may be quite different from that at the ground surface. We chose to monitor fire temperature at the ground surface because we were interested in the potential effects of heating on shrub and herbaceous reproductive parts that are located at or belowground. Even though region and season of burning were not related to fire temperature, peak fire temperature was significantly correlated ($p<0.05$) with postfire shrub loading dynamics (Figure 6). No other measure of fuel characteristics, however, was significantly associated with fire temperature.

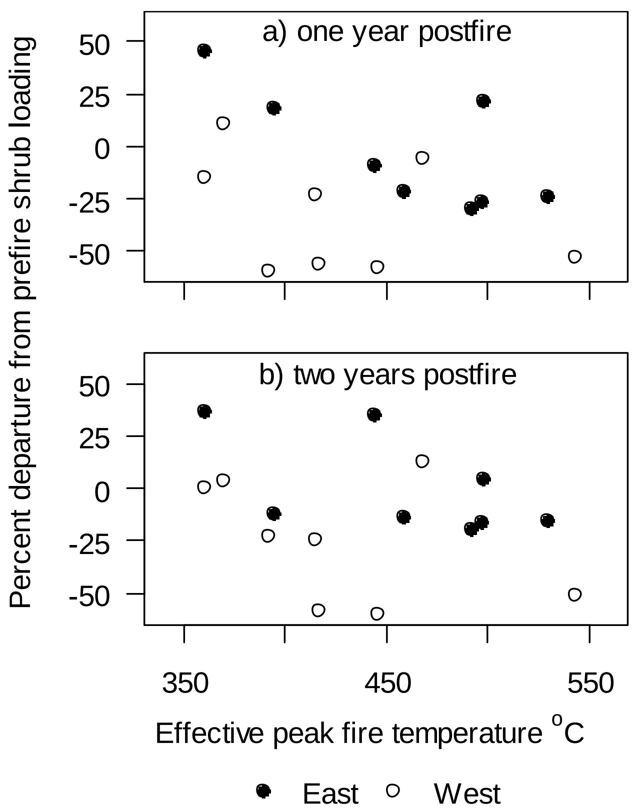

Figure 6. Relationship between fire temperature and shrub loading dynamics (a) one year and (b) two years postfire. Shrub loading on fires with higher effective peak fire temperatures tended to recover more slowly than fires in the lower end of the temperature range. Note that shrub loading for the majority of sites still had not recovered to prefire levels by two years following fire.

3. Regional differences in fuel dynamics

The experimental design of this study called for replicated, repeated sampling of fuel characteristics in a single broad ecosystem type under two treatments (growing season and dormant season prescribed fires) in two different locations. A location factor was incorporated into the design of the experiment in an effort to broaden the potential application of the study results. Study regions were both on the coastal plain of the

Gulf of Mexico and located at approximately the same latitude, but were separated by approximately 270 km of longitude. In general, soils in and around the western region tended to be well-drained, while those at the eastern site tended to be somewhat poorly drained, perhaps accounting for subtle differences in species composition between the two regions despite both being nominally mesic longleaf pine flatwoods.

Although our results do not suggest an effect on fuel dynamics associated with season of burn, we did observe statistically significant differences between the two regions ($p<0.05$). The sites in the western portion of the Florida panhandle (Eglin AFB) showed a greater and longer lasting reduction in shrub loading and coverage than the sites to the east (Apalachicola NF and St. Marks NWR). Several of the eastern sites recovered to and exceeded prefire shrub loading and coverage within two years, even when burns achieved higher peak fire temperatures (Figure 6). Both regions had many of the most frequently occurring and abundant species in common (e.g., saw palmetto, gallberry, wiregrass), so perhaps differences in species composition between regions for less common species is driving the differential rates of recovery of shrub fuel loading and coverage. A species-level analysis of the data are beyond the scope of the project as proposed; however, we plan to explore this possibility with future analyses.

4. Fuel characteristics still recovering after two years

Northern Florida and the rest of the Gulf and Atlantic coastal plains provide favorable growing conditions. Understory vegetation regrows rapidly following fires in this region (Davis and Cooper 1963, Brose and Wade 2002). Longleaf pine flatwoods fuel types are managed with frequent prescribed burning. Given their high productivity, mesic longleaf pine flatwoods can support fire spread one year after burning, however, typical burn rotations range from two to four years. Shrub and herbaceous species loading, coverage, and height was less than prefire levels on average for all regional and seasonal groupings, except for dormant season herbaceous loading in the western region and shrub coverage in the eastern region (Table 2), indicating that mesic longleaf pine flatwoods take longer than two years to fully revegetate following fires. Potential fire behavior reflects this change in live fuel loading, coverage and height after prescribed burning (Table 3). This suggests that repeated burning at intervals of two years or less could lead to overall reductions in shrub and herbaceous vegetation loading, potentially coverage, stature, and fire potential over time even in longleaf pine flatwoods stands that have been managed with prescribed fire for multiple fire cycles.

Table 3. Predicted mean prefire, 1-yr postfire, and 2-yrs postfire rate of spread, flame length, and reaction intensity as caculated by the Fuel Characteristic Classification System for understory fuels burned during the dormant and growing seasons in western and eastern Florida.

	Region	
	West	East
Prefire		
	Rate of spread (m min^{-1} ± SD)	
Dormant	1.6 ± 0.2	1.5 ± 0.5
Growing	1.5 ± 0.2	1.0 ± 0.1
	Flame length (m ± SD)	
Dormant	1.1 ± 0.1	0.9 ± 0.2
Growing	1.0 ± 0.1	0.7 ± 0.1
	Reaction intensity (kW m^{-2})	
Dormant	49,598 ± 15,456	35,311 ± 7,700
Growing	44,943 ± 12,446	31,064 ± 5,815
1-yr Postfire		
	Rate of spread (m min^{-1} ± SD)	
Dormant	1.3 ± 0.3	0.9 ± 0.3
Growing	1.0 ± 0.2	0.7 ± 0.2
	Flame length (m ± SD)	
Dormant	0.9 ± 0.2	0.6 ± 0.1
Growing	0.7 ± 0.1	0.5 ± 0.1
	Reaction intensity (kW m^{-2})	
Dormant	41,351 ± 13,248	25,585 ± 9,741
Growing	38,911 ± 11,317	27,713 ± 4,958
2-yrs Postfire		
	Rate of spread (m min^{-1} ± SD)	
Dormant	1.5 ± 0.4	0.7 ± 0.2
Growing	1.0 ± 0.4	0.8 ± 0.2
	Flame length (m ± SD)	
Dormant	1. ± 0.2	0.5 ± 0.1
Growing	0.7 ± 0.2	0.6 ± 0.1
	Reaction intensity (kW m^{-2})	
Dormant	48,444 ± 19,476	24,156 ± 12,305
Growing	31,230 ± 8,748	30,722 ± 5,745

MANAGEMENT IMPLICATIONS:

1. Manage fire temperatures

Skilled prescribed fire practitioners are able to exercise a remarkable amount of control over the spread and intensity of a fire during burning operations given that the combustion process is influenced by a large number of factors, including fuel type, amount, and arrangement, fuel conditions, environmental conditions, and micrometeorology (Wade and Lunsford 1998). Managers should carefully consider such factors as hourly, daily, and seasonal timing of prescribed fire projects (and the manner in which they relate to air temperature, wind speed, fuel moisture content, and fuel loading), pattern and method of ignition, and desired outcomes when implementing firing actions. Our results suggest that firing conditions designed to achieve a hotter fire may have the effect of retarding shrub coverage and loading recovery. Timing, pattern, and method of of ignition. Environmental conditions, including air temperature, wind speed, fuel moisture content, and fuel loading.

2. Expect regional differences in fire effects

This study begins to address how different aspects of place and time of burning are linked to fuel dynamics. Different aspects of fire management occur at multiple hierarchical levels and geographic scales, but ultimately, fire is applied at the very local site level. Although there are certainly general mechanisms that drive fire effects, our results (as well as the results of others) demonstrate that fire effects are best assessed on a case-by-case basis for each fire. It is, therefore, important for the prescribed fire practitioner to keep in mind that the specific characteristics of the place and time in which a fire is implemented will influence the fire's effects.

3. Monitoring of growing season burns necessary

This study highlights the difficulty and danger of uniformly applying principles learned at a single location. Additional data are needed to improve the scientific understanding of fuel succession in ecosystems that are managed with frequent prescribed fire. Basic fuel and fire effects monitoring programs on a selection of prescribed fire management units could contribute greatly to the scientific foundations upon which future fire management will be based.

4. Growing season fires have ecological value

Although the results of this study did not support our hypothesis that growing season fires have a longer-lasting effect on fuel reduction than dormant season fires in longleaf pine flatwoods forest types, neither did it suggest that fuel reduction effects are shorter following growing season fires. The research on seasonal effects of burning on fuel characteristics remains equivocal. there are reasons other than fuel reduction and fuel management, however, for conducting growing season prescribed fires. While burning in different seasons may not have marked effects on fuels, corollary ecological benefits, such as the promotion of wiregrass flowering (Figure 7) and the protection of sensitive species warrant continued use of growing season prescribed fire to achieve multiple resource benefits.

Figure 7. Increase in wiregrass flowering following a growing season fire in a longleaf pine flatwoods stand on the Apalachicola National Forest. Photo credit: J.B. Cronan.

Relationship to Other Recent Findings and Ongoing Work on This Topic:

To date research on the effects of prescribed burning in the growing season has focused on ecological responses. Data for comparing the fuel and fire behavior-related consequences of prescribed burning in different seasons has been lacking. This study attempted to fill this research gap. The results of this experiment, however, are rather inconclusive given its relatively short duration, especially in comparison to other well-established long-term studies such as the Santee Fire Plots (Waldrop et al 1987) and other repeated burn studies with a seasonal component scattered across the region.

Recently, Willcox and Giuliano (2010) have assessed the effects of season of burning on saw palmetto dynamics (coverage, height and density), however their narrow focus on saw palmetto limits the conclusions one can make regarding the rest of the pine flatwoods fuel complex. The proposed scope of this study prevents us from examining the effects of prescribed fires in different seasons on individual species or groups of species, although the manner in which we collected our data do allow for species-level assessments in the future. We greatly increased the sampling specificity over the level outlined in the original proposal. It is our intention to continue to analyze the data collected for this study on an ongoing basis. Specifically, a multivariate analysis of species level data will be undertaken by J.B. Cronan for his doctoral studies at the University of Washington. This analysis will contribute to his dissertation and also be written for publication in an appropriate peer-reviewed outlet.

Future Work Needed:

The effect size of single prescribed fires on fuel characteristics appears to be fairly small in forests with an established history of management with prescribed fire. Long-term studies of the ecological effects of burning in different seasons and at different intervals, however, have suggested that the effects on the fuel complex and the resulting fire potential could also be influenced by fires in different seasons. It would be useful to: (1) mine older data sets for fuel-related variables, and (2) establish long-term monitoring on a network of replicate sites in different regions and fuel types in the southeastern U.S. to better address questions related to how season of burning affects fuel characteristics in a region where prescribed fire is so widely used.

Our results suggest that fire temperature may be an important driver of fuel response following fire. Development and testing of methods for collecting better and more detailed measures of fire intensity and fire temperature is necessary. For example, measures of fire intensity or temperature at different heights above (and below) the ground, and above (and below) different types of wildland fuel could be very useful for understanding fire severity and effects.

Altered temperature and precipitation patterns associated with global climate change could affect individual species ranges. In highly disturbed ecosystems, such as the frequently burned forest types of the southeastern U.S., range shifts by species that define the mesic pine flatwoods fuel type could alter fuel re-growth and accumulation dynamics and create different conditions than those with which southeastern fire and fuel managers have become accustomed. In addition, potential climate change-related shifts in the lightning and wildfire seasons could affect the management options available to fire and fuel managers. Research and analysis to better understand the mechanisms that affect individual species' or species groups' response to fires at different times of the year and of different intensities will be necessary for effective resource management in a greenhouse world.

We used the Fuel Characteristic Classification System to assess fire behavior potential for this study. The FCCS is a useful tool for estimating likely fire behavior, however, there are numerous factors that are incorporated into the FCCS that are designed to improve estimates of fire behavior that are based on an anecdotal understanding of the manner in which various fuelbed characteristics affect combustion. For example, some shrub species are considered to accelerate combustion (Sandberg et al. 2007), but the factors used have not been validated with actual measurements of fire behavior. Similarly, the contribution of litter fuels to fire intensity is manipulated so that it works within the modified Rothermel (1972) framework proposed by Sandberg et al. (2007). Hough and Albini (1978) also proposed models for estimating fire behavior in long-needle pine forest types with understory vegetation dominated by saw palmetto and gallberry. Collection of detailed fuels and fire behavior data is necessary to validate our current fire behavior prediction models.

SCIENCE DELIVERY AND APPLICATION:

The Season of Burning study was proposed as a 3-year project. We have completed field data collection and the proposed analyses; results are summarized in this final report and included in the appended manuscript intended for *Forest Ecology and Management*. Results from this study have been presented at two international fire conferences (Table 4, Appendix B). Research findings will be presented to our collaborators at a mutually agreed upon date in 2013. Additional analyses will be completed in 2013-14 as part of the University of Washington Ph.D. dissertation of James Cronan (Table 5; Appendix C), which will yield both a dissertation chapter for Mr. Cronan and a manuscript for submission to *Ecological Applications* or a similar refereed outlet. Data gathered for this work will be archived on the U.S. Forest Service Research and Development Data Archive or similar repository and posted on the Fire and Environmental Research Applications website upon publication of research results.

Table 4. Deliverables crosswalk table. Proposed and delivered products for Season of Burn study.

Proposed	Delivered	Status
Refereed publication	*Effects of season of burning on postfire fuel dynamics and fire potential in longleaf pine flatwoods in northern Florida* (Forest Ecology and Management)	Draft in review
Poster	Poster documenting results following first year re-sampling to be presented at a regional or national fire science conference	Not completed
Field tour/ site visit	Visits to field study sites and presentations of research findings to fire management staff at the collaborating locations	Pending
Invited paper/ presentation	Present research findings at 5th International Fire Ecology and Management Congress. December 2012. Portland, OR	Completed
Website	Webpage documenting research design, results and archival data within the structure of the Fire and Environmental Research Applications team webpage (www.fs.fed.us/pnw/fera/research/fuels/burningseason.shtml)	Completed
Dataset	Fuel inventory, fire behavior, weather and fuel moisture data will be archived on the U.S. Forest Service Research and Development Data Archive (www.fs.usda.gov/rds/archive/) or similar repository and the Fire and Environmental Research Applications team webpage upon publication of results	Will be posted following publication
Annual reports	JFSP annual report of interim research progress and findings	Completed
Final report	JFSP final report documenting research findings and management implications.	Completed

Table 5. Delivered products that were not part of the original proposal.

Deliverable	Status
Refereed publication: *Effects of burn season and fire regime on frequently burned longleaf pine flatwoods community structure* (Ecological Applications)	Pending completion in June 2014
J.B. Cronan Ph.D. dissertation chapter	Pending completion in June 2014
Present research findings at 4th Fire Behavior and Fuels Conference. February 2013. Raleigh, NC	Completed
Repeat measurement dataset will be archived on the U.S. Forest Service Research and Development Data Archive (www.fs.usda.gov/rds/archive/) or similar repository and the Fire and Environmental Research Applications team webpage upon publication of results	Will be posted following publication

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APPENDIX A

STUDY LOCATIONS:

Fuel lifecycles were evaluated to assess fuel re-accumulation rates following application of prescribed fire during the winter (dormant season) and spring/summer (growing season) at the following locations in the southeastern United States. A total of 22 sites in mesic pine flatwoods were initially selected and sampled at the outset of the study prior to burning. Nineteen of the 22 initially sampled sites were burned. Data collection at three sites was compromised in some way (i.e., equipment failure, site re-burned prior to final sampling, etc.) leaving 16 sites with complete data sets that were inventoried during all sampling episodes (pre-burn, immediately post-burn [post-burn date 1], one year post-burn [post-burn date 2] and two years post-burn [post-burn date 3]). Only sites with a complete data set that were inventoried during all four sampling episodes were used in statistical analyses.

Eglin Air Force Base – Niceville, FL

Eleven mesic pine flatwoods sites were sampled before burning. Nine of 11 sites were burned (five dormant season and four growing season), and eight sites were sampled during all four sampling episodes. These sites were considered the western block in our experimental design.

Table A1. Information for study sites at Eglin Air Force Base, FL.

Site	Season of burn	Latitude	Longitude	Pre-burn date	Burn date	Post-burn date 1	Post-burn date 2	Post-burn date 3
E100B-E	Dormant	N30° 39.40′	W86° 43.12′	Nov 2009	12 Jan 2010	Jan 2010	Jan 2011	Jan 2012
E100B-W	Growing	N30° 39.09′	W86° 43.55′	Feb 2010	8 May 2010	May 2010	May 2011	Apr 2012
E103B	Growing	N30° 40.84′	W86° 35.62′	Jan 2010	30 Mar 2010	May 2010	Feb 2011	Jan 2012
E403B	Growing	N30° 41.00′	W86° 25.25′	Jan 2010	8 May 2010	May 2010	May 2011	Apr 2012
E501B	Dormant	N30° 27.36′	W86° 45.64′	Nov 2009	23 Dec 2009	Jan 2010	Jan 2011	Dec 2011
E503C	---	N30° 29.36′	W86° 41.76′	Feb 2010	Not Burned	---	---	---
E505	Dormant	N30° 27.63′	W86° 40.12′	Nov 2009	23 Jan 2010	Feb 2010	Jan 2011	Dec 2011
E507B	---	N30° 25.55′	W86° 45.74′	Feb 2010	Not Burned	---	---	---
E508A	Growing	N30° 26.50′	W86° 49.74′	Nov 2009	19 Mar 2010	May 2010	Feb 2011	Jan 2012
E807B	Dormant	N30° 29.08′	W86° 16.51′	Nov 2009	4 Jan 2010	Mar 2010	Jan 2011	---
E807D	Dormant	N30° 30.28′	W86° 15.50′	Jan 2010	21 Feb 2010	Feb 2010	Feb 2011	Jan 2012

Apalachicola National Forest – Crawfordville, FL

Eight mesic pine flatwoods sites were sampled before burning. Seven of eight sites were burned (four dormant season and three growing season), and seven sites were sampled during all four sampling episodes (site A18 was dropped from statistical anaylses for the benefit of a balanced design). These sites were considered part of the eastern block in our experimental design.

Table A2. Information for study sites on the Apalachicola National Forest, FL.

Site	Season of burn	Latitude	Longitude	Pre-burn date	Burn date	Post-burn date 1	Post-burn date 2	Post-burn date 3
A18	Dormant	N30° 12.52’	W84° 51.67’	Dec 2009	11 Feb 2010	Feb 2010	Feb 2011	Feb 2012
A32	Growing	N30° 11.69’	W84° 54.23’	Jan 2010	19 May 2010	Aug 2010	May 2011	Apr 2012
A34	Dormant	N30° 12.09’	W84° 50.20’	Feb 2010	18 Feb 2010	Mar 2010	Feb 2011	Feb 2012
A71	Growing	N30° 07.07’	W85° 01.38’	Feb 2010	2 Jun 2010	Aug 2010	May 2011	Apr 2012
A213	Dormant	N30° 20.52’	W84° 32.43’	Jan 2010	11 Feb-2010	Feb 2010	Feb 2011	Feb 2012
A302	Growing	N30° 17.91’	W84° 26.29’	Feb 2010	22 Jul 2010	Aug 2010	Jul 2011	Jul 2012
A314	---	N30° 14.21’	W84° 29.39’	Jan 2010	Not Burned	---	---	---
A319	Dormant	N30° 13.14’	W84° 25.22’	Nov 2009	14 Jan 2010	Jan 2010	Feb 2011	Mar 2012

St. Marks National Wildlife Refuge – St. Marks, FL

Three mesic pine flatwoods sites were sampled before burning. All three sites were burned (one dormant season and two growing season), and two sites were sampled during all four sampling episodes (site S411 was dropped from statistical anaylses because weather and fire temperature monitoring equipment was not successfully deployed during the burn). These sites were considered part of the eastern block in our experimental design.

Table A3. Information for study sites at St. Marks National Wildlife Refuge, FL.

Site	Season of burn	Latitude	Longitude	Pre-burn date	Burn date	Post-burn date 1	Post-burn date 2	Post-burn date 3
S209	Growing	N30° 06.57’	W84° 18.49’	Nov 2009	9 Jul 2010	Aug 2010	Jul 2011	Jul 2012
S330	Dormant	N30° 04.72’	W84° 22.41’	Nov 2009	17 Feb 2010	Feb 2010	Feb 2011	Mar 2012
S411	Growing	N30° 02.25’	W84° 27.17’	Feb 2010	21 Jul 2010	Aug 2010	Jul 2011	Jul 2012

APPENDIX B

PROPOSED DELIVERABLES:

The primary deliverables proposed for this project include a refereed publication, a poster, a presentation, a website, and a database of fuel characteristics and environmental measurements. With the exception of a poster documenting preliminary results and a pending presentation of research results to staff at collaborating agencies, all deliverables have been fulfilled and are detailed below.

Refereed publication:

Cronan, J.B.; Wright, C.S. Effects of season of burning on postfire fuel dynamics and fire potential in longleaf pine flatwoods in northern Florida. Manuscript in review, for submission to *Forest Ecology and Management*.

Attached to JFSP website: JFSP_09-1-01-2_Cronan_Wright_FEM_ms.pdf.

Presentation:

Cronan, J.B. 2012. Does season of burn influence fuel life cycle and fire behavior in longleaf pine flatwoods of the southeastern US? Presentation at 5th International Fire Ecology and Management Congress. December 3-7, 2012 in Portland, OR.

Attached to JFSP website: JFSP_09-1-01-2_Cronan_AFE_presentation.pdf.

Website:

http://www.fs.fed.us/pnw/fera/research/fuels/burningseason.shtml

Database:

Cronan, J.B.; Wright, C.S. Database of fuel loading, fuel depth, vegetation height, vegetation coverage data before, immediately after, 1 year after and 2 years after burning for study sites in northern Florida.

A database was created to organize and store project data. In addition to contributing to our understanding of fuelbed dynamics in southeastern pine flatwoods ecosystems, we plan to use this dataset to further our understanding of species responses to season-of-burning and improve our fuel consumption models for southern pine types in the region. Upon publication of research results, this database will be uploaded to the U.S. Forest Service R&D archive or a similar repository and posted on the Fire and Environmental Research Application Team's website: http://www.fs.fed.us/pnw/fera/.

Appendix C

Additional Deliverables:

In addition to the proposed data collection and science delivery products, we were also able to collect data that were beyond the scope of the orignal proposal, and will continue to conduct analyses that are also beyond the scope of the original proposal. Species-specific measures of loading and coverage will be analyzed and reported as part of J.B. Cronan's Ph.D. dissertation at the University of Washington, scheduled for completion in June 2014. The results of this dissertation chapter will also be written for publication in the peer-reviewed literature.

Dissertation:

Cronan, J.B. Effects of season of burning on fuelbed dynamics in mesic pine flatwoods. Chapter in Ph.D. dissertation; expected completion in June 2014. University of Washington, Seattle, WA.

File will be attached to JFSP website upon completion: JFSP_09-1-01-2_Cronan_dissertation.pdf.

Refereed publication:

Cronan, J.B.; Wright, C.S. Effects of burn season and fire regime on frequently burned longleaf pine flatwoods community structure. For submission to *Ecological Applications* or comparable outlet.

File will be attached to JFSP website upon completion: JFSP_09-1-01-2_Cronan_Wright_EA_ms.pdf.

Presentation:

Cronan, J.B. 2013. Does season of burn influence fuel life cycle and fire behavior in longleaf pine flatwoods of the southeastern US? Presentation at 4th Fire Behavior and Fuels Conference. February 18-22, 2013 in Raleigh, NC.

Attached to JFSP website: JFSP_09-1-01-2_Cronan_IAWF_presentation.pdf.

Database:

Cronan, J.B.; Wright, C.S. Database of sub-annual change in fuel loading, fuel depth, vegetation height, and vegetation coverage data two years after burning for study sites in northern Florida.

Data documenting changes in fuel characteristics at sub-annual time scales. Upon publication of research results, this database will be uploaded to the U.S. Forest Service R&D archive or a similar repository and posted on the Fire and Environmental Research Application Team's website: http://www.fs.fed.us/pnw/fera/.