RESTORING FIRE SUPPRESSED TEXAS OAK WOODLANDS TO HISTORIC CONDITIONS USING PRESCRIBED FIRE

Jeff C. Sparks, Michael C. Stambaugh, and Eric L. Keith

Wildland Fire Program Manager (JCS), Texas Parks and Wildlife Dept., 12016 FM 848, Tyler, TX 75707; Research Assistant Professor (MCS), University of Missouri-Columbia; Project Manager (ELK), Raven Environmental. JCS is corresponding author: to contact call 903-566-0535 ext. 237 or email at Jeff.Sparks@tpwd.state.tx.us.

Abstract.—Comparable to many oak ecosystems across the eastern United States, oak woodlands in Texas display characteristics of changing composition and structure due to altered fire regimes. Information describing historic fire regimes suggests woodlands underwent relatively frequent and repeated burning prior to major Euro-American influence in the early 19th century. Oak woodland management is a central goal of the Texas Parks and Wildlife Department natural community management; however many questions and challenges exist related to habitat loss and fragmentation, human populations, and prescribed fire implementation. In this paper we: 1) review information describing the historic fire regimes and community structures of Texas oak woodlands; and 2) detail fire prescriptions and challenges related to restoring long unburned sites.

INTRODUCTION

A goal of many land management agencies is to restore existing vegetation communities to resemble the vegetation composition and structure prior to industrialization or Euro-American settlement. The timing of major landscape and fire regime changes varied spatially but generally occurred in Texas during the mid-19th century or earlier. Restoring oak woodlands that have undergone decades of fire exclusion and become invaded by a dense understory and midstory can require intensive management and high cost inputs.

Using prescribed fire with standard published prescription parameters in these invaded oak woodlands often results in intermediate fire spread and relatively low intensity fires, thus not meeting objectives of reducing the stature of the invading understory and increasing the coverage of herbaceous species. It is often recommended that a combination of higher cost management tools such as mechanical and chemical treatments be used initially followed by prescribed fire as a maintenance tool. These more intensive management efforts greatly increase the cost for restoring these invaded woodlands, thus limiting the area that can potentially be restored. Based on 13 years of experience, we have begun to develop prescriptions for effectively restoring these vegetation communities to historic conditions by using fire as the primary management tool.

CONDITIONS OF HISTORIC TEXAS OAK WOODS AND PRAIRIES

Composition and Structure

Aside from anthropogenic features (roads, towns, agricultural lands), the major difference between the pre-Euro-American settlement vegetation and the current vegetation in Texas Oak Woods and Prairies (Fig. 1) is the increase in woody species biomass and resulting reduction in herbaceous species biomass (Diggs and others 2006). In the absence of fire (natural

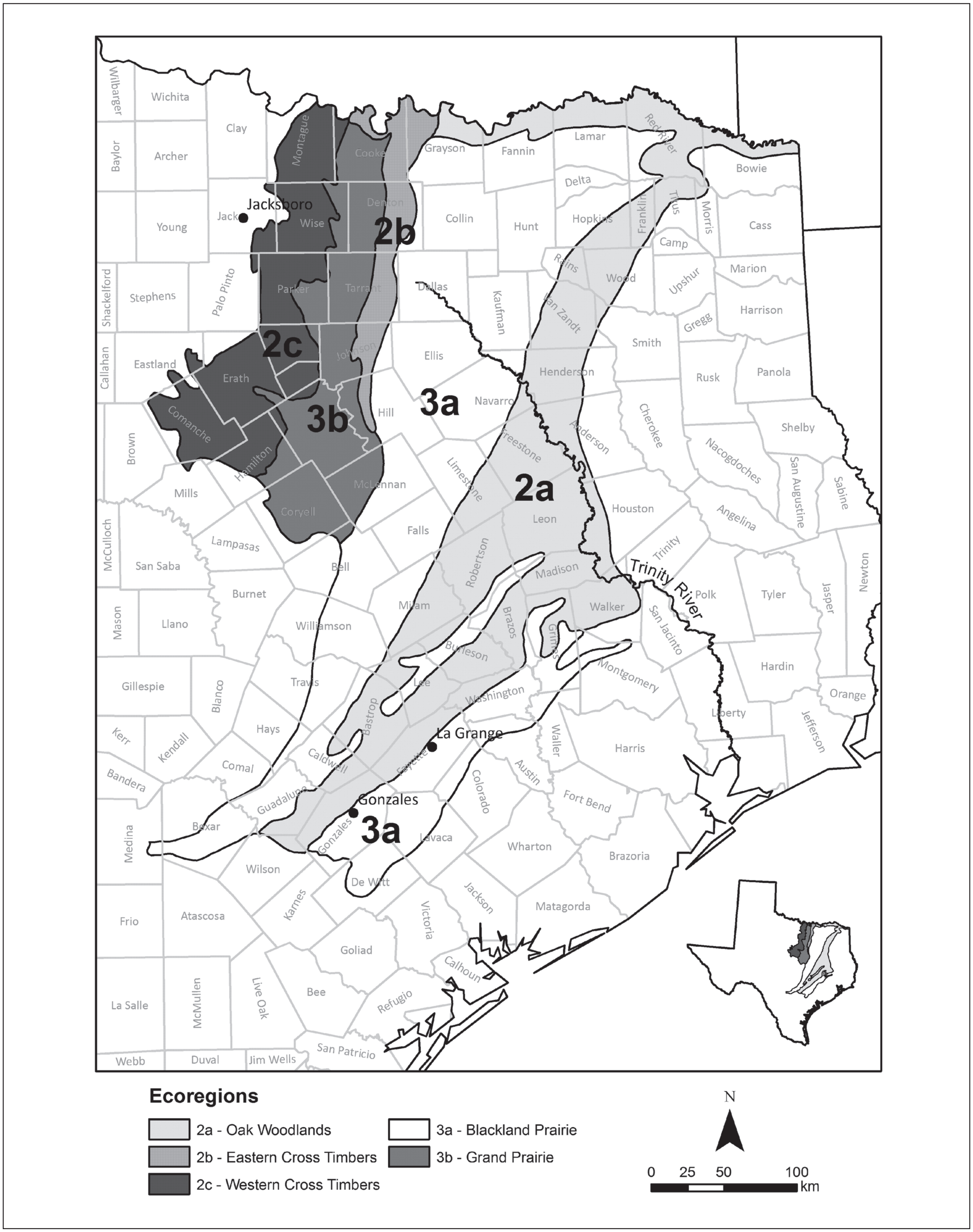

Figure 1.—Map of Texas ecoregions within the Oak Woods and Prairies region. Place names relate to the descriptions given for historic descriptions of vegetation and fire history.

and controlled), woody species have encroached into post oak (*Quercus stellata*) dominated communities that were historically open and park-like (Diggs and others 2006). The terms savanna and woodland do not accurately portray the region's current forest community structures, but according to early settler and explorer reports, they were accurate descriptors of pre-Euro-American settlement conditions (Diggs and others 2006).

Olmsted (1857) described an area most likely near the Houston County–Leon County line:

> "We came today upon the first prairie of any extent, and shortly after crossed the Trinity River. After having been shut in during so many days by dreary winter forests, we were quite exhilarated at coming out upon an open country and a distant view. During the whole day's ride the soil improved, and the country grew more attractive. Small prairies alternated agreeably with post-oak woods. The post-oak…forms a very prominent feature in Texas scenery and impressions. It is a somewhat small broad-leaved oak of symmetrical shape, and appears wherever the soil is light and sandy, in a very regular open forest growth. It stands in islands in the large prairies or frequently borders an open prairie through a large tract."

More densely forested areas would have occurred in association with natural fire breaks or in areas with lessened fire severities such as in rough terrain or low productivity sites. Roemer (1849) provides evidence for this vegetation patterning in his descriptions of an area between Gonzales and La Grange as "a sandy, hilly country, covered almost entirely with post oak forests."

Captain Domingo Ramón in 1716 described forests in what is probably present-day Burleson County as so dense that "there were not enough hatchets and knives to open a passage" (Foster 1995).

Olmstead (1857) described multiple community types and structures including the presence of fires in this description of Leon County:

> "During the first part of the day we went over small, level, wet prairies, irregularly skirted by heavy timber, with occasional isolated clumps and scattered bushes. Most of the prairies have been burned over. Both yesterday and to-day we have been surrounded by the glare of fires at night. After a few miles began post-oak, which changed to blackjack, and for the remainder of the day the country was as forbidding as a moor."

Approximately 100 km to the south (Colorado County), Roemer (1849) described the structure of post oak forests:

> "These forests …have a remarkable resemblance in winter to the cultivated German oak forests…. In other forests of North America many varieties of trees are usually found, but in the post-oak forests all are excluded with the exception of a few walnuts. Underbrush is also lacking. The soil upon which the post-oaks grow is usually of average fertility, but also often sterile and unproductive…. [There] is a wide zone where deposits of gravel and sand are found, and where farming cannot be carried on successfully. Here the land is covered with post-oaks."

In summary, the Texas Oak Woods and Prairies region was likely a complex mosaic varying from prairies and open savannas to forests with closed canopies (Diggs and others 2006; Keith 2008, 2009d, 2010a, 2010b; Keith and Leavitt 2008).

Fire Regimes

Since Euro-American settlement, fire regimes in Texas and throughout North America have been highly altered. Although fire is regarded as a principal historic disturbance to most of Texas' ecoregions (McNab and Avers 1994), relatively little work has been done to describe how fire regimes of Texas Oak Woods and Prairies varied spatially and temporally (Courtwright 2007, Diamond and others 1995). Here we describe fire regimes relevant to Texas Oak Woods and Prairies (Fig. 1).

Oak Woodlands

Very little information is available describing the historic fire regime in the Oak Woodlands (Fig. 1). Many of the relict oak woodlands have experienced infill of woody vegetation suggesting that the disturbance regime (fire and/or grazing) has been altered. A recent fire scar history study developed in a relict sand post oak (*Quercus margaretta*) woodland in Van Zandt County provides one example of what the fire regime may have been (Stambaugh and others 2011). Here, the mean fire return interval for the 325 years from 1681-2005 was 6.9 years. Prior to 1850 (approx. timing of major Euro-American influence), fire intervals ranged from 2 to 16 years, with a mean fire interval of 5.9 years. Based on the presence and recruitment of trees, there was no evidence of stand replacing fire events, however two relatively severe fires occurred prior to 1850. During the Civil War era, fire frequency decreased and coincided with establishment of an oak cohort. Nearly all fires recorded at the site occurred when oaks were dormant.

Eastern and Western Cross Timbers

Fire is considered an important disturbance agent to maintaining the Cross Timbers ecosystem (Engle and others 1996) which extends from southeastern Kansas to central Texas (Francaviglia 2000). Dyksterhuis (1948) related that early settlers of the Jacksboro vicinity recalled no shrubby undergrowth in the western Cross Timbers, but instead remember a grassy understory which commonly burned during dry periods. They also stated that when the first white settlers arrived in the western Cross Timbers fringe, the Indians were known to regularly burn off the grass and had done so for years. Dyksterhuis (1948) described the uncertainty as to the pre-Euro-American settlement fire regime of the Cross Timbers, but several accounts by early travelers mention the incursion of adjacent prairie fires into the Cross Timbers as the mechanism for grassy understories and branch formations of the trees. A survey conducted in the Trinity River watershed by the U.S. Department of Agriculture in 1942 used fire scars to show that periodic fires were still occurring through the mid-20th century (Dyksterhuis 1948).

Recently, several fire scar history studies in more northerly Cross Timbers have contributed to characterizing the fire regime (Allen and Palmer 2011, Clark and others 2007, DeSantis and others 2010, Stambaugh and others 2009). Common among these studies are pre-Euro-American settlement period mean fire intervals of 3 to 6 years, a preponderance of dormant season fire events, and evidence for anthropogenic burning. These studies have had little to bear on the range of fire severity, however all sites had trees >200 years in age, suggesting no stand replacing events had occurred during at least the previous two centuries. Based on observations of fire scar heights in Cross Timbers post oaks, many of these sites likely experienced low- to moderate-severity fires. However, fires have the potential to be very high severity (e.g., stand-replacing) and widespread (>100,000 acres), particularly during drought conditions. In April 2011, wildfires burning through the western Cross Timbers in Palo Pinto County were stand replacing crown fires.

Blackland Prairie and Grand Prairies

As the southernmost extension of the “true prairie” (i.e., tallgrass prairie), the Blackland Prairie probably had a similar fire regime to other tallgrass prairie regions. The Blackland Prairie experiences higher temperatures and a longer growing season than the rest of the tallgrass prairie ecosystem, and its fire regime may have reflected these environmental differences (Smeins 1972). Smeins (2004) cites two reports from the 1840s (Gregg 1844, Kendall 1845) that assert that frequent fires and large grazing animals were the primary influences on vegetation in the Grand Prairie and Cross Timbers regions in pre-Euro-American settlement times. Considering the Blackland and Grand Prairie’s positions between the oak-dominated Cross Timbers and Oak Woodlands, it is likely that their fire regimes are strongly related. Like the Cross Timbers and Oak Woodlands, it is likely that these large prairie subregions burned at least every 3 to 4 years. With a dominance of grass surface fuels, the potential burning window of the prairies was likely larger, leading to an increased fire frequency compared to areas dominated by litter and woody fuels.

Current Structure

Post oak savanna habitats that historically burned regularly and have continued to burn to present day are very open and dominated by native grasses and forbs in the understory (Keith 2008, 2010b; Keith and Leavitt 2008). Examples of this habitat type are now extremely rare. Pre-Euro-American settlement upland habitat types can be characterized most prominently by the Post Oak (*Quercus stellata*)-Blackjack Oak (*Quercus marilandica*) Series and the Post Oak (including sand post oak [*Quercus margaretta*])-Black Hickory (*Carya texana*) Series (Diamond and others 1987). In addition, the Loblolly Pine (*Pinus taeda*)-Oak Series, Shortleaf Pine (*Pinus echinata*)-Oak Series, and Bluejack Oak (*Quercus incana*)-Pine Series can be found in uplands on the eastern edge of the Oak Woods and Prairies Ecoregion and in the Bastrop Lost Pines Subregion (Griffith and others 2007). Bluejack oak woodlands occur on xeric sandy soils in this region. In the western portion of the region, habitats in the Plateau Live Oak (*Quercus fusiformis*) Series, Plateau Live Oak-Midgrass Series, and Ashe Juniper (*Juniperus ashei*)-Oak Series also occur as part of the ecotone with the Edwards Plateau Ecoregion. The Coastal Live Oak (*Quercus virginiana*)-Post Oak Series occurs in the southern portion of the ecoregion. A complete list of common plant associations found throughout the region is found in Table 1 (Nature Serve 2011). Plant associations describe the most narrowly defined habitat types.

Table 1.—Common plant associations including series and usual fuel model for habitats in the Post Oak Savanna and Cross Timbers and Prairies Ecoregions. See Table 2 for descriptions of fuel models.

Series	Association	Fuel Model
Post Oak-Blackjack Oak Series	Eastern Redcedar Forest	TL3
Coastal Live Oak-Post Oak Series	Live Oak-Post Oak-Cedar Elm-Water Oak Forest	TL6, TU2, TU3
Loblolly Pine-Oak Series	Loblolly Pine-Post Oak-Blackjack Oak Forest (Vernia or Jedd Rocky Upland)	TL6, TL8
Loblolly Pine-Oak Series	Loblolly Pine-Post Oak-Eastern Redcedar-Blackjack Oak-Black Hickory Forest	TL8
Loblolly Pine-Oak Series	Loblolly Pine-Sand Post Oak-Post Oak-Blackjack Oak Forest	TU2
Loblolly Pine-Oak Series	Loblolly Pine-Yaupon Ravine Forest	TL9
Plateau Live Oak-Midgrass Series	Plateau Live Oak / Little Bluestem Woodland	GR4
Ashe Juniper-Oak Series	Post Oak-Ashe Juniper-Purpletop-Virginia Wild Rye Woodland	TL6, TU3
Post Oak-Black Hickory Series	Post Oak-Black Hickory-Yaupon-Woodoats-(Little Bluestem)-Woodland	TL6, TU2, TU4
Post Oak-Blackjack Oak Series	Post Oak-Blackjack Oak / Little Bluestem Woodland	GR2, GR6, GS3, GS4, TU3
Post Oak-Blackjack Oak Series	Post Oak-Blackjack Oak Cross Timbers Woodland	TU3
Post Oak-Blackjack Oak Series	Post Oak-Blackjack Oak Woodland	TU3

(Table 1 continued on next page)

Table 1 (continued).—Common plant associations including series and usual fuel model for habitats in the Post Oak Savanna and Cross Timbers and Prairies Ecoregions. See Table 2 for descriptions of fuel models.

Series	Association	Fuel Model
Post Oak-Blackjack Oak Series	Post Oak-Blackjack Oak-American Ash-Winged Elm-Woodoats Forest	TU2, TU3
Post Oak-Blackjack Oak Series	Post Oak-Blackjack Oak-Black Hickory-Farkleberry Forest	TL6, TL9, TU2, TU3
Post Oak-Blackjack Oak Series	Post Oak-Blackjack Oak-Cedar Elm Forest	TL6
Post Oak-Blackjack Oak Series	Post Oak-Blackjack Oak-Cedar Elm-Little Bluestem-Coralberry Woodland	TU2, TU3
Post Oak-Blackjack Oak Series	Post Oak-Blackjack Oak-Eastern Redcedar Forest	TU2
Post Oak-Blackjack Oak Series	Post Oak-Blackjack Oak-Eastern Redcedar-Little Bluestem Woodland	GS3, TU2, TU3
Post Oak-Blackjack Oak Series	Post Oak-Blackjack Oak-Red Oak-Yaupon-Woodoats Forest	TL6
Post Oak-Blackjack Oak Series	Post Oak-Blackjack Oak-Rusty Blackhaw-Roughleaf Dogwood-Purpletop Forest	TL6, TU2, TU3
Post Oak-Blackjack Oak Series	Post Oak-Blackjack Oak-Winged Elm-Roughleaf Dogwood-Silver Bluestem-Little Bluestem Woodland	GS4, TU3
Post Oak-Blackjack Oak Series	Post Oak-Blackjack Oak-Yaupon Forest	TU2
Post Oak-Blackjack Oak Series	Post Oak-Cedar Elm Forest	TL6, TU2
Post Oak-Blackjack Oak Series	Post Oak-Cedar Elm-Blackjack Oak-Little Bluestem Woodland	GS3, GS4, TU3
Post Oak-Blackjack Oak Series	Post Oak-Cedar Elm-Blackjack Oak-Purpletop-Virginia Wild Rye Woodland	TU2, TU3
Coastal Live Oak-Post Oak Series	Post Oak-Cedar Elm-Cherokee Sedge-Purple Top Forest	TU2, TU3
Post Oak-Black Hickory Series	Post Oak-Cedar Elm-Coralberry-Caric Sedge Forest	TL6
Post Oak-Blackjack Oak Series	Post Oak-Gum Bumelia-Saw Greenbriar-Purpletop Woodland	GS3, TU3
Post Oak-Blackjack Oak Series	Post Oak-Little Bluestem-Longspike Tridens-Bushy Bluestem-Rush Spp Woodland	GS3
Post Oak-Blackjack Oak Series	Post Oak-Lovegrass-Silver Bluestem Woodland	GR3
Post Oak-Blackjack Oak Series	Post Oak-Mesquite Woodland	GR4
Post Oak-Blackjack Oak Series	Post Oak-Plains Love Grass-Longspike Tridens Claypan Savannah	GR3
Post Oak-Blackjack Oak Series	Post Oak-Plateau Live Oak-Cedar Elm-Caric Sedge-Virginia Wildrye Forest	TU3

(Table 1 continued on next page)

Table 1 (continued).—Common plant associations including series and usual fuel model for habitats in the Post Oak Savanna and Cross Timbers and Prairies Ecoregions. See Table 2 for descriptions of fuel models.

Series	Association	Fuel Model
Post Oak-Black Hickory Series	Post Oak-Sand Post Oak-Black Hickory-Blackjack Oak-Southern Red Oak-Woodoats Forest	TL6
Post Oak-Black Hickory Series	Post Oak-Sand Post Oak-Black Hickory-Blackjack Oak-White Ash-Woodoats Forest	TL6, TU2
Post Oak-Black Hickory Series	Post Oak-Southern Red Oak-Black Hickory-White Ash-Shortleaf Pine Forest	TU2
Post Oak-Blackjack Oak Series	Post Oak-Southern Red Oak-Blackjack Oak-Shortleaf Pine Forest	TL6, TU3
Post Oak-Blackjack Oak Series	Post Oak-Southern Red Oak-Water Oak-Nutmeg Hickory-American Ash Forest	TU2
Post Oak-Blackjack Oak Series	Post Oak-Texas Ash-Plateau Live Oak-Ashe Juniper Slope Forest	TL6, TU2, TU3
Post Oak-Blackjack Oak Series	Post Oak-Water Oak-Cedar Elm-Sugarberry Forest	TU2, SH9
Post Oak-Blackjack Oak Series	Post Oak-Water Oak-Sand Post Oak-Winged Elm Forest	TL2
Post Oak-Blackjack Oak Series	Post Oak-White Ash-Blackjack Oak-Woodoats Forest	TL6
Post Oak-Blackjack Oak Series	Post Oak-Winged Elm Forest	TL6
Post Oak-Blackjack Oak Series	Post Oak-Winged Elm-Water Oak-Blackjack Oak Forest	TU2, TU3
Post Oak-Blackjack Oak Series	Post Oak-Winged Elm-White Ash-Beautyberry-Woodoats-Nutrush Forest	TL6, TU2
Post Oak-Black Hickory Series	Sand Post Oak-Black Hickory-Loblolly Pine Forest	TU2, TU3
Post Oak-Black Hickory Series	Sand Post Oak-Black Hickory-Red Oak-Little Bluestem Woodland	TU3
Post Oak-Black Hickory Series	Sand Post Oak-Black Hickory-Red Oak-Yaupon-Woodoats Forest	TL6
Post Oak-Black Hickory Series	Sand Post Oak-Black Hickory-Southern Red Oak Forest	TU2
Coastal Live Oak-Post Oak Series	Sand Post Oak-Live Oak-Black Hickory-Yaupon Forest	TU2
Loblolly Pine-Oak Series	Sand Post Oak-Loblolly Pine-Black Hickory-Eastern Redcedar-Yaupon Forest	TL6, TL9, TU2
Shortleaf Pine-Oak Series	Shortleaf Pine-Southern Red Oak-Cherrybark Oak-Loblolly Pine-Post Oak-White Oak-White Ash Forest	TL6, TU2, TU3
Post Oak-Black Hickory Series	Southern Red Oak-Sand Post Oak-Post Oak-Eastern Redcedar-Water Oak Forest	TL6

Most of the natural vegetation that has not been cleared for agriculture or urbanization is generally characterized by a mature overstory of post oak and a dense understory dominated by woody species. The most common woody species in these dense understories within its range is yaupon (*Ilex vomitoria*) (Keith 2009a, 2009b, 2009c, 2009d). In many areas, yaupon often creates a near monoculture in the understory, shading and virtually eliminating all native herbaceous vegetation. In the native yaupon range, post oak woodlands and forests are noticeably dense and difficult to restore to habitats with open herbaceous understories. Common community types or plant associations of this type (Nature Serve 2011) include the Loblolly Pine-Yaupon Ravine Forest, Post Oak-Black Hickory-Yaupon-Woodoats-(Little Bluestem)-Woodland, Post Oak-Blackjack Oak-Red Oak-Yaupon-Woodoats Forest, Post Oak-Blackjack Oak-Yaupon Forest, and Sand Post Oak-Black Hickory-Red Oak-Yaupon-Woodoats Forest (Table 1).

Outside the native yaupon range, woodlands are noticeably more open and easier to restore to habitats with herbaceous understories. Woody species that also encroach into upland habitats within and outside the native yaupon range include winged elm (*Ulmus alata*), American beautyberry (*Callicarpa americana*), eastern redcedar (*Juniperus virginiana*), saw greenbriar (*Smilax bona-nox*), Small's greenbriar (*Smilax smallii*), roughleaf dogwood (*Cornus drummondii*) (on clay soils), upland privet (*Forestiera ligustrina*), Alabama supplejack (*Berchemia scandens*), coralberry (*Symphoricarpos orbiculatus*), Virginia creeper (*Parthenocissus quinquefolia*), and poison ivy (*Toxicodendron radicans*). The latter four species are often as effective as yaupon in out-competing native herbaceous vegetation outside the dominant range of yaupon (Keith 2006, 2010b; Keith and Leavitt 2008). Common plant associations include Eastern Redcedar Forest, Post Oak-Blackjack Oak-Eastern Redcedar Forest, Post Oak-Winged Elm Forest, and Post Oak-Winged Elm-White Ash-Beautyberry-Woodoats-Nutrush Forest (Nature Serve 2011) (Table 1).

High quality savannas and woodlands consist of areas that have been frequently burned, and these areas are often dominated by post oak and a diverse herbaceous ground cover layer (Keith 2008). The dominant herbaceous species is most often little bluestem (*Schizachyrium scoparium*). Other common species include purpletop (*Tridens flavus*), Virginia wildrye (*Elymus virginicus*), silver bluestem (*Bothriochloa laguroides*), meadow dropseed (*Sporobolus compositus*), black needlegrass (*Piptochaetium avenaceum*), rosettegrasses (*Dichanthelium* spp.), Texas ironweed (*Vernonia texana*), hairy sunflower (*Helianthus hirsutus*), and Georgia rockrose (*Helianthemum georgianum*). Areas that receive less frequent fire have developed into habitats best described as close-canopied forests (Keith 2010c). These forests are also dominated by post oak (and sand post oak) in the overstory, vary from sparse to dense in the midstory, and generally possess a sparse herbaceous understory. The most common herbaceous vegetation in these forests is woodoats (*Chasmanthium sessiliflorum*), nutrush (*Scleria oligantha*), rosettegrasses (*Dichanthelium* spp.), caric sedges (*Carex* spp.), and black snakeroot (*Sanicula canadensis*). Common plant associations include the Post Oak-Blackjack Oak/Little Bluestem Woodland in the Post Oak Savanna Ecoregion and the Post Oak-Blackjack Oak Cross Timbers Woodland in the East and West Cross Timbers Ecoregions (Nature Serve 2011) (Table 1).

PRESCRIBED FIRE MANAGEMENT

There are few published prescriptions for effective oak woodlands and savanna burns in Texas. Available prescription parameters are more applicable to meeting objectives in grass-dominated fuels or open restored woodlands where there are sufficient herbaceous fuels to carry fire. As fire is excluded from an area, the ingrowth of understory and midstory vegetation shelters the surface fuels, preventing grasses and other herbaceous species from growing. The primary carriers of fire become leaf litter or a combination of leaf litter and shrubs versus a grass leaf-litter combination. In these cases, fuel models change from a timber-understory (TU) to a timber litter (TL) fuel type (Scott and Burgan 2005). Fuel models in Texas fire suppressed oak woodlands, forests, and savannas can most commonly be categorized as either moderate load broadleaf litter (TL6) or moderate load, humid climate timber-shrub (TU2) (Tables 1 and 2) (Scott and Burgan 2005).

First entry burns in long unburned oak forest or savanna (Fuel Model TL6) can be difficult because the surface fuels are fully sheltered and have limited flammability. Under typical moderate prescriptions (RH >30, Winds <10 mph), we have observed only marginal, patchy burning with poor results for controlling woody invasive species in the understory and midstory. For restoration efforts to be effective, it is important to get a first entry burn intense enough to topkill the invading understory and midstory species.

Research in other forested communities has determined a fire line intensity of 500 kW/m is needed to control (topkill) woody understory stems ≥1 m tall of the same genus (Sparks and others 1999). Using BEHAVE to estimate fire behavior of specific burns where management objectives were successfully achieved, we determined the fireline intensity of these burns was near or above the 500 kW/m threshold

Table 2.—Fuel model descriptions relative to Texas oak communities. Prescription conditions are for initial burns with desired effects including topkill of understory woody vegetation.

Fuel Model	Description	Prescription
TL1	Forests with closed canopy juniper overstory and/or midstory. The understory is completely covered with juniper leaf litter and little or no woody or herbaceous fuels. Fire is carried predominantly by the juniper leaf litter.	No surface fire prescription Requires high input management such as mechanical or herbicide
TL6	Upland forests with closed canopy hardwood (predominantly post oak and southern red oak) overstory and a relatively sparse midstory. The understory is sparse and covered with hardwood leaf litter. Very few herbaceous plants are present. Fire is carried predominantly by the hardwood leaf litter.	Temperature: 40-90 °F Relative humidity: 12-30% Wind speed (mid flame): 6-18 mph 10-hour fuel moisure: ≤9%
TL8	Closed canopy forests dominated by pine. The midstory is sparse or composed of dense pine, and the understory is sparse and completely covered in a heavy layer of pine needles. Fire is carried predominantly by the pine needle litter.	Temperature: 40-75 °F Relative humidity: 20-50% Wind speed (mid flame): 4-12 mph 10-hour fuel moisure: 8-12%
TL9	Forests with a very close canopy overstory of hardwood or pine. The midstory is dense with woody species. This fuel type also describes midstory conditions with a dense pine needle drape primarily on yaupon. The understory is sparse with very dense hardwood litter or pine needles. Fire is carried by a combination of leaf litter and/or shrubs with heavy needle drape.	Temperature: 40-75 °F Relative humidity: 28-65% Wind speed (mid flame): 3-8 mph 10-hour fuel moisure: 9-15%
TU2	Closed canopy to moderately open canopy pine or hardwood forest overstories. The midstory is usually very dense with hardwood trees and/or shrubs. The understory is dense and dominated by woody shrubs and saplings. Grass and other herbaceous plants are sparse. Fire is carried by a combination of leaf litter and understory shrubs.	Temperature: 40-80 °F Relative humidity: 15-35% Wind speed (mid flame): 4-12 mph 10-hour fuel moisure: <10%
TU3	Moderately open to very open canopy forests or woodland with pine or hardwood overstories. The midstory is sparse with few or no stems that don't affect fire behavior. The understory is dominated by herbaceous species. Fire is carried by a combination of leaf litter and understory grass. This fuel model is often used to describe upland woodlands that are in a condition similar to those that existed prior to European settlement.	Temperature: 40-80 °F Relative humidity: 20-60% Wind speed (mid flame): 3-10 mph 10-hour fuel moisure: <12%

(Sparks, unpublished data). It is important to identify weather parameters needed to achieve a fireline intensity of 500 kW/m in the most common fuel models. In these invaded oak woodlands, it appears that this type of fireline intensity is only achievable under very extreme conditions (RH ≤25 percent; Winds >10 mph).

Developing a Prescription for Long Unburned Oak Woodlands

We have spent the past 13 years attempting to use fire as the primary management tool for oak woodland/savanna restoration. In addition, based on this experience we have attempted to develop prescriptions for restoring these vegetation communities with fire as the primary management tool. Through trial and error we have developed a prescription that is effective at pushing an intense fire through degraded, long unburned oak woodlands and topkilling the invasive mid- and understory woody species represented by fuel model TL6 (Tables 1 and 2).

Early on we attempted fires with high winds (15-25 mph) and moderate humidity (RH 25-40 percent) with the thought that wind would push fire through the oak leaf litter. We discovered that this worked some days and not others. We then conducted burns at lowered relative humidity (20-30 percent) and observed that high winds and low relative humidity often were effective, but not always. We then began to closely monitor fuel dryness, specifically 10-hour fuel moisture contents and time since a precipitation event. After several burns, we discovered 10-hour fuel moistures to be a critical component of the prescription. Even with moderate winds (6-12 mph), if 10-hour fuel moistures are less than 9 percent and relative humidity <30 percent, fires were generally intense enough to meet management objectives. However, the larger the unit, the higher the winds needed to be to ensure burn out within a given operational period.

Timing

We have determined that exact timing of the burn is not as critical as is achieving the other prescription parameters needed to produce a fireline intensity of 500 kW/m. However, we have determined that we are more likely to meet prescription variables in late winter and early spring, when cold fronts drive down relative humidity, increase wind speeds and the longer days and warmer temperatures produce better drying conditions. Fall and early winter months can have days within prescription parameters, but leaf fall is often not until late November or early December, and days are short, reducing drying time between rain events. Longer days in early spring permit relative humidity to remain low and within prescription for several hours whereas in the winter it reaches its low in early afternoon hours after which it immediately begins to recover. In a typical year (during the last 10 years or so), there are only a handful of days meeting all of these prescription parameters. During drier years, typically during a La Niña mode, the number of potential days increases dramatically. For example, during winter and spring of 2010, observed fuel moistures rarely were within prescribed parameters, but in 2011 observed fuel moistures were within the defined prescription parameters nearly weekly and often for multiple days at a time. Because of rapidly changing conditions it is important to be ready and not pass up a potential burn day.

Monitoring 10-Hour Fuel Moisture

We used 10-hour fuel moisture sticks comprised of four connected ponderosa pine dowels and the Forester Fuel Moisture Scale (Model 11552) to measure 10-hour fuels (Davies and McMichael 2005). Through comparisons of our observed readings and those from Remote Area Weather Stations (RAWS) we have determined fuel moisture stick measurements to be less variable within a day, especially as fuel moistures are in the 6-15 percent range. Due to this variability, we recommend land managers utilize on site 10-hour fuel moisture to guide their prescribed fire planning instead of data derived from RAWS stations. With respect to planning, it is recommended to begin looking for an acceptable burn window when the on-site fuel moisture reaches 12 percent for more than 2 consecutive days.

Fire Control

The above prescription has proven to be very effective; however it can produce extreme fire intensities and carries greater risk and costs than typical cool-season maintenance burns. This prescription should only be attempted by experienced fire crews with substantial preparation such as using well established fire breaks (bare mineral soil) and having a contingency plan and on-site contingency resources.

Burning under these prescription parameters will increase the likelihood of igniting snags and logs, thus increasing the time for mop-up and residual smoke. If maintaining snags and logs is a critical management objective, proper mitigation procedures should be established prior to ignition to protect them. The intensity of fires under these prescription variables will most likely generate new snags within the unit, and if the first entry fire is successful, subsequent fires can be conducted under less severe conditions, reducing risk of losing future snags and logs. Under these conditions embers generated by the fire can go unnoticed for hours or even days, increasing the chances for spotting well after an area has been burned. “Punky” downed logs or snags are more susceptible to glowing embers than surrounding oak leaf dominated fuels. Embers may smolder for up to 4 hours in these “punky” fuels before generating enough heat to start a fire and catch the surrounding area on fire. It is recommended that a crew remain on site to patrol for an extended period of time following one of these intense restoration burns.

Fuel Model Transition

Fuel models TL6 and TU2 (Table 2) best describe fire suppressed habitats with little to no herbaceous material in the understory that require severe conditions to produce a fire intense enough to meet management objectives during the first burn cycle or two. As the understory and midstory become suppressed by the initial fire treatments and light reaches the forest floor, grasses and forbs flourish, and the fuel model may transition into a TU3. The TU3 fuel model can be burned under more moderate conditions and still meet management objectives of woody control.

Fire Effects on Vegetation

The inherent abilities of plants to respond to fire depend partially on the fire regime to which the plant community has adapted (NWCG 2001). Based on rapid regrowth and ability of understory plants to resprout, most of the plant species common in the Oak Woods and Prairies have adapted to frequent and often intense fires. In these long unburned habitats, the amount of dead woody fuel, depth of litter and duff layers, and amount of dead material within or around a living plant may be greater than would have typically occurred historically when fires occurred relatively frequently. In this situation, the effects of fire on vegetation are likely very different than it would have been under historic conditions because of the higher temperatures and longer durations of fires.

Fire-related plant tissue mortality is dependent upon both the temperature reached and the duration of time the tissue is exposed to that temperature. The lowest temperature at which plant cells die is between about 50 to 55 °C (122 to 131 °F) (NWCG 2001). Killing all belowground reproductive structures usually occurs only where there is a long duration surface heat source, such as beneath a large pile of woody debris that sustains almost complete combustion (NWCG 2001). The severity of burn relates to the depth of the litter layer beneath the vegetation and its moisture content when the fire occurs (NWCG 2001). These high severity conditions of initial burns typically results in consumption of all litter and organic matter beneath shrubs and killing of all buds and roots in or near the organic layer. This kind of fire favors shrubs with buds and roots buried deep enough that they escape lethal temperatures. Fires which occur where there are deep accumulations of litter beneath shrubs and isolated trees or significant amounts of dead lower branches that burn off and smolder beneath a shrub crown are more likely to lethally heat roots and reproductive structures than a fire that occurs where there is sparse litter and few dead branches.

Tree mortality is often the result of injury to several different parts of the plant, such as crown damage coupled with a high percentage of cambial mortality. Mortality may not occur for several years following a fire. Death can occur from secondary infection by disease, fungus, or insects because the resistance of plants to these agents is often lowered by injury, and wound sites provide an entry point for pathogens (NWCG 2001). A tree weakened by drought, either before a fire or after wounding, is also more likely to die (Dickinson and Johnson 2001). A strong negative relationship exists between burn severity and postfire sprouting (based on personal observations).

High severity fires occur when large dead fuels and organic layers are dry (<12 percent 10-hour fuel moisture). These fires typically consume all litter, twigs, and small branches, most or the entire duff layer, and some large diameter dead, down woody fuels, particularly rotten material. Significant soil heating occurs, especially near fuel concentrations. Post oak often possesses relatively thick bark that will protect it from moderately intense fires that could damage the cambium. However, overstory post oak trees can be killed in high severity fires, particularly in areas where burning of dense fuel concentrations at the base of individual trees leads to localized intensities that kill the cambium and/or canopy buds.

Common woody species such as yaupon, American beautyberry, and saw greenbriar have thick, deep root caudices or tubers that aggressively resprout from the base of the plants following fire, including intense fires that occur in long unburned habitats. Other woody encroaching species such as winged elm and eastern redcedar rapidly colonize bare soil created by fire. Repeated and frequent fires (<2 years) are often necessary to kill the entire plants. Resprouting woody species after two or three fires continue to resprout but are often less vigorous and produce fewer stems. Reducing the total cover of these woody encroachers and creating open canopies under dead overstory trees then allows native perennial early successional herbaceous species such as broomsedge (*Andropogon virginicus*) and purpletop to begin to colonize. Herbaceous species adapted to these fire-suppressed habitats such as woodoats and nutrush also readily resprout from root bases and are seldom completely killed by these intense fires. Woodoats often becomes very dense in these severely burned areas immediately following fire. Early successional herbaceous species such as rosettegrasses, fireweed (*Erechtites hieracifolia*), and American pokeberry (*Phytolacca americana*) also colonize the bare soil created by these intense fires and often temporarily become the dominant understory plants. These annual species rapidly disappear in successive years following these high severity fires. As native herbaceous species gradually become more common and the woody encroachers are reduced, fire climax species such as little bluestem can slowly begin to colonize and eventually become common in the understory.

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