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Initial Ecosystem Restoration in the Highly Erodible Kisatchie Sandstone Hills

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Abstract - Restoration of the unique and diverse habitats of the Kisatchie Sandstone Hills requires the re-introduction of fire to reduce fuel accumulation and promote herbaceous vegetation, but some soils in the area are extremely erodible, and past fires have resulted in high erosion rates. Overstory and understory vegetation, downed woody fuels, and other stand attributes were measured on sites that received either no management or two prescribed burns after >20 years of fire exclusion. The two burns (one dormant season and one growing season) reduced the live fuel-load (understory biomass) and forest floor (litter and duff mass) by 90 and 71%, respectively, but did not change the downed woody fuel load. Understory plant diversity was not affected by burning, but burning stimulated both colonization and sprouting for most plant species. Habitat for *Picoides borealis* (Red-cockaded Woodpecker) was improved; understory plant height was reduced by 2 m, and herbaceous vegetation was found in 40% of the areas sampled in the burned sites but it was found in only 6.7% of the reference (unburned) sites. Erosion risk was still elevated due to the sparse vegetative cover on the forest floor. Future management should consider erosion prevention, and plan the timing and intensity of additional burns to maximize plant cover on the forest floor and to improve the habitat by converting the woody understory to an herbaceous understory.

Introduction

The Kisatchie Sandstone Hills is a unique and diverse landform in west-central Louisiana that supports a number of fire-dependent ecosystems, but management of this area is confounded by the area's highly erosive soils and low inherent productivity. The region has a long management history, and past practices have degraded the ecosystem and pursued priorities and goals different from those of today's land managers. Because the soils are sensitive to management actions, including mechanical impacts and prescribed fire, ecosystem restoration will require careful adaptive management that incorporates research and monitoring to produce the conditions necessary for all ecosystem functions and services.

A century of timber harvest and fire suppression in the *Pinus palustris* (Longleaf Pine) forests in the West Gulf coastal plain, including the Kisatchie Hills, has resulted in massive ecosystem changes. Many unique habitats have been degraded, and changes in plant and animal species composition have been widespread (Van Lear et al. 2005). Many species characteristic of fire-maintained pine forests have become endangered or rare due to changes in the fire regime (Phillips and Hall 2000, Rudolph and Burgdorf 1997). The Kisatchie Hills area is home to several

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sensitive terrestrial and aquatic habitats for both flora and fauna (Van Kley 1999). Hillside bogs, sandstone glades and barrens, and sandy woodlands are all found in relative abundance in the Kisatchie Hills.

This area represents some of the best potential habitat for the endangered *Picoides borealis* Vieillot (Red-cockaded Woodpecker) (RCW), and rare *Pituophis ruthveni* Stull (Louisiana Pine Snake) (LPS) (Kisatchie National Forest Staff 1999a). Past management for timber production and open-range cattle grazing included fire suppression, which allowed woody fuels to accumulate and reduce habitat quality for RCW, LPS, and other open woodland animals. The management goal is restoration of the type of open-canopied woodland with an understory dominated by diverse herbaceous and low woody species that would provide excellent habitat for several target wildlife species including RCW and LPS (Kisatchie National Forest Staff 1999b). The Kisatchie National Forest plans to use prescribed fire to restore this natural community.

The fire return interval in the Kisatchie Hills was 2.1 yrs from the 1600s until the mid-1900s, and included both dormant and growing-season burns (Stambaugh et al. 2011). Dormant-season burns are commonly prescribed to reduce downed woody and forest floor fuels, but generally have little effect on woody vegetation. Growing-season burns, while difficult to manage under heavy fuel conditions, are more effective at controlling recruitment and sprouting of woody species (Drewa et al. 2002, 2006). Erosion losses are likely to be greatest following removal of the soil cover by fire, resulting in exposure of mineral soil (Larsen et al. 2009).

Soils on the study site are both quite infertile and highly erodible. The Kisatchie soil series is of specific interest due to its prominence in the area and its erosivity. It is widely mapped in an eroded phase, where the original Bt horizon has become the surface layer. This soil is a very slowly permeable, smectitic soil with a low Ca:Mg ratio, which increases clay dispersion, reduces soil structural stability, and increases erosivity (Dontsova and Norton 2002). Runoff is high on areas with steep slopes, and the dispersing nature of the soil and lack of soil cover due to infertility creates conditions resulting in extensive particle displacement. Wildfire-induced soil erosion is well-documented in the western US, (Larsen et al. 2009), whereas it is rarely recognized as a severe problem in the southeastern US (Callaham et al. 2012). However, many of the same conditions observed in forests of the western US are present in the Kisatchie Hills area: i.e., impaired hydrology, steep topography, and slow plant growth. Schoelerman (1981) measured soil loss for 15 months following a single prescribed fire on Kisatchie soils after 20 years of fuel accumulation, and found twice as much loss in burned areas as on unburned areas.

The objectives of this study were to 1) determine the effectiveness of the initial reintroduction of prescribed fire using a combined dormant and growing season fire regime for hazardous fuels reduction and habitat restoration goals, and 2) assess the soil condition following two prescribed burns and the potential for subsequent soil loss.

Methods

The study was conducted on the Kisatchie Ranger District near Gorum, LA (31.46°N, 93.005°W; Fig. 1). The climate is humid subtropical with a mean annual temperature of 19.4 °C and 1270 mm of precipitation, which is relatively evenly distributed throughout the year (Soil Conservation Service 1990). No forestry operations had been conducted on the 1600-ha area for 60–70 yrs and no extensive burns (wildfire or prescribed) had occurred in at least 20 years. Cattle grazing may have occurred in the area, but not for at least 20 years.

Reintroduction of prescribed fire was initiated in 2004; a dormant-season burn was conducted in January on about half the overall study area to reduce fuel loading, and a growing-season fire was conducted in May 2007 to further control fuel loading and to control woody shrubs and understory trees. The remaining area was not burned. In 2009, we selected five sites ranging from about 10 ha to over 30 ha in the burned and unburned areas (Fig. 2). We based site selection on dominant species, condition class, stand age, soil series, and topography, with a focus on pine-dominated, mature (>50 yrs old) sites on Kisatchie-series or Kisatchie-

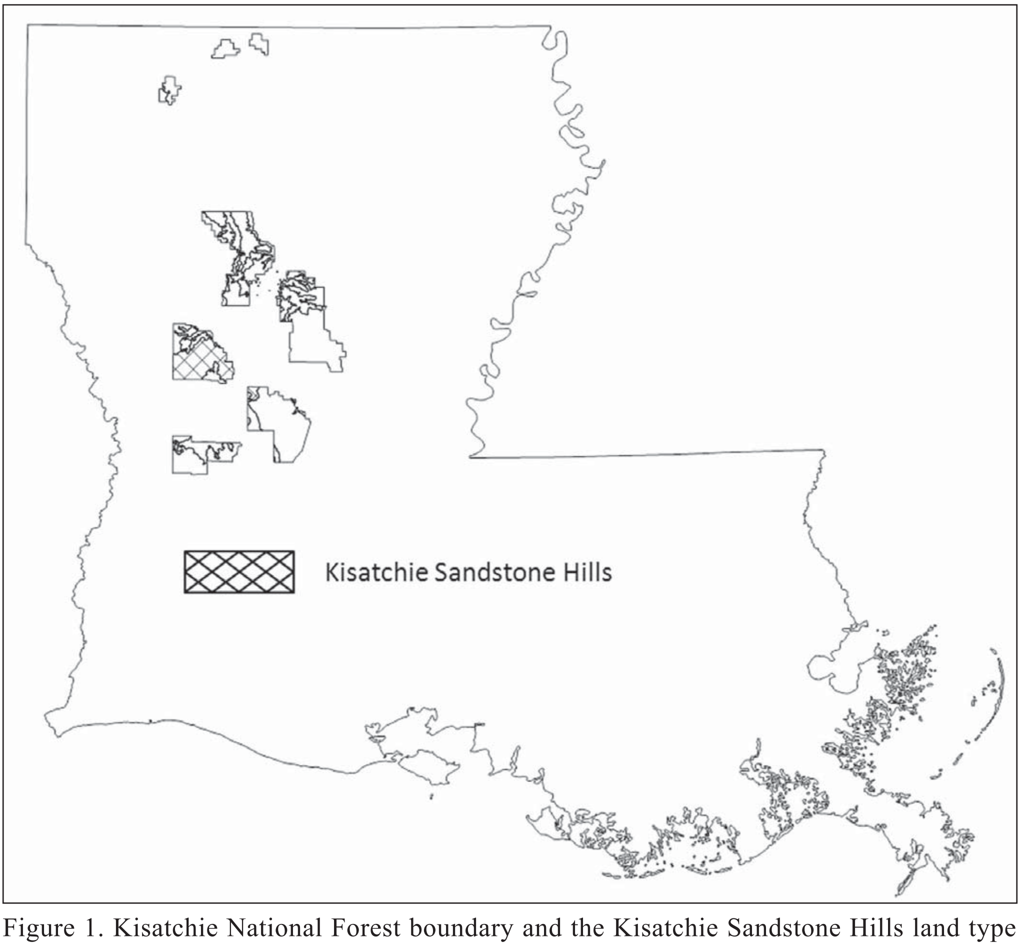

Figure 1. Kisatchie National Forest boundary and the Kisatchie Sandstone Hills land type area in LA.

dominated soil associations with moderate topography. Mature forests were selected to reduce inherent variability.

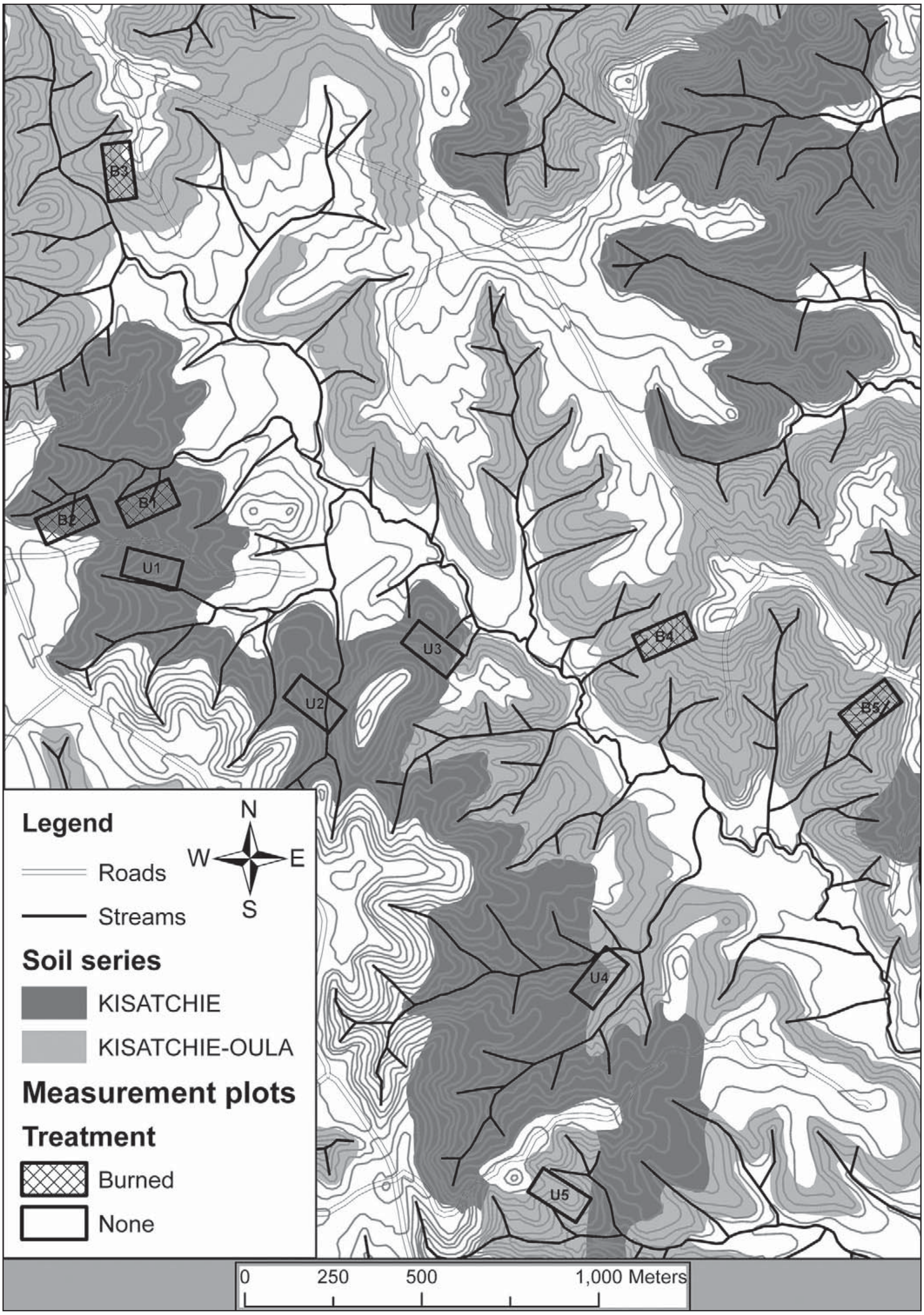

Figure 2. Burned and non-burned (reference) sites in the Kisatchie Hills area near Gorum, LA.

Within each site, six sampling points were arrayed on an 81-m x 161-m, randomly applied rectangular grid. Overstory vegetation, i.e., trees in dominant or codominant canopy positions, was tallied by species and sampled using variable-radius plot sampling with a 2.29-m^2 ha^{-1}-factor wedge prism. We used a laser hypsometer to measure height and height to the base of the live crown on a 20% random sample of all dominant and codominant trees, and we calculated live-crown ratio as the length of the crown (base of crown to top of the tree) to the total tree height. We measured diameter at breast height (DBH) and determined tree age with an increment borer. Species, total height (or length if not erect), and the number of stems per rootstock were tallied for all midstory and understory woody plants. We tallied individual plants >1.37 m tall within a 61.4-m^2 plot, and individuals <1.37 m tall within a 5.91-m^2 plot. Biomass (oven-dry equivalent) was calculated using equations developed for similar species and used to estimate live fuel loadings (Scott et al. 2006). Horizontal vegetation density at 2 m height, a habitat indicator for RCW (Rudolph et al. 2002), was determined at 15 m from the center point at 0°, 90°, 180°, and 270° from the transect azimuth (not cardinal directions) using a 50- x 50-cm density board with 10- x 10-cm squares. Woody plant diversity in the understory was calculated with Shannon's index (Shannon 1948).

At each sampling point, we established a 15.25-m transect from the sample center point in a random azimuth as determined by a random number generator. We measured forest-floor thickness to the interface with mineral soil, to the nearest 1 cm at 10 points along this transect (0.3, 1.5, 3.0, 4.6, 6.1, 7.6, 9.1, 10.7, 12.2, 13.7, 15.2 m, respectively). We determined forest-floor and herbaceous plant mass by sampling floor material within a 25-cm x 25-cm frame at 1.52, 7.62, and 13.7 m along the transect. Samples were dried at 70 ºC to a constant water content before weighing. At each of these three points, we measured the percent cover of herbaceous plants. Downed woody debris intercepts were noted for the 1- and 10-hour fuels within the first 1.83 m of the transect, the 100-hr fuel intercepts were documented within the first 3.66 m, and the 1000-hr fuels were recorded along the entire 15.25-m transect (Brown 1974).

We calculated means of multiple observations per site, and used univariate tests of normality to determine if transformations were needed to improve normality or variance homogeneity. Site-level means and standard errors are reported (n = 5 sites per treatment). Treatment differences were determined by t-test and considered significant at $P < 0.10$ (SAS Institute, Inc. 2004). The false discovery rate was controlled with the Benjamini-Hochberg method (Benjamini and Hochberg 1995).

Results and Discussion

The responses of primary interest were woody vegetative composition and height, total fuel loading, herbaceous community recovery, and soil cover. These variables are important for several interrelated reasons in an ecosystem management context. First, the total fuel-loading, especially tall ladder-fuel (senesced needles and dead woody debris), is of concern because it can indicate the potential damage that an uncontrolled wildfire could cause to the forest, soil, and watershed conditions. As fuel loads increase, the potential for uncontrolled wildfire to have severe fire effects, such as overstory tree mortality and severe erosion, increases. Erosion can lead to increased sediment delivery to streams, changes in hydrologic function, and soil loss and decreased site quality (Neary et al. 2008). Secondly, the understory vegetation structure is an important determinant of habitat quality for the endangered RCW and other significant wildlife. The restoration of herbaceous understory vegetation was a desired outcome of the study's treatments because its presence increases habitat integrity and value for a number of organisms in addition to the RCW (Rudolph and Burgdorf 1997). Finally, while prescribed fire will reduce fuel loading and increase the desired herbaceous understory, soil cover is needed to protect the area's erodible soils from rainfall impacts and to reduce runoff so that water infiltration is maintained. On many sites with Kisatchie soils, the coarser-textured topsoil has already eroded, leaving a relatively impermeable, fine-textured soil that is prone to runoff and further erosion unless it is covered by forest floor or herbaceous vegetation.

General stand characteristics

Sites were chosen that were similar with respect to landform, soil type, and slope. All sites were located on Miocene-aged sediments of the Catahoula and Fleming formations and included Kisatchie series (fine, smectitic, thermic Typic Hapludalf) or Kisatchie-Oula (fine, smectitic, thermic Vertic Hapludalf) complex. The topography of the sites was qualitatively quite similar; we did not observe differences in the general character of the sites. The mean slopes were similar (19% for reference sites and 13% for burned sites; Table 1). The measurement points occurred in all slope positions (ridge, midslope, toeslope) in both reference and burned sites.

Vegetative composition and habitat value

The overstory vegetation was very similar across both treatments (Table 1). Overstory tree age, as measured on dominant or codominant trees within a measurement point, averaged just over 63 years for both treatments, indicating that the even-aged stands originated in the mid-1940s. The specific mechanism of stand establishment is unknown, but likely included a mix of natural regeneration, direct seeding, and possibly some planting, although no rows were apparent. The mean arithmetic DBH and height of the dominant or codominant pines were similar and averaged about 38 cm and 23 m, respectively, across the treatments. The live crown and live-crown ratio were not different between treatments. Pine, hardwood, and total stand basal area were similar across treatments and averaged 16.5, 4.2, and 20.7 m^2 ha^{-1}, respectively. The basal area in standing dead trees was also similar between the treatments. The overstory was primarily composed of *Pinus taeda* (Loblolly Pine) or Longleaf Pine, but one site contained over 50% *Pinus echinata* (Shortleaf Pine), and nearly every site included all three pine species. Longleaf Pine was a more common dominant species on the burned sites (Table 2), and Loblolly Pine more commonly dominated the unburned reference sites, but these differences likely resulted from historical regeneration patterns rather than recent treatments. *Quercus marilandica* (Blackjack Oak) and *Quercus stellata* (Post Oak) were the predominant hardwood trees in the overstory; a variety of other oaks and hardwoods were also documented (Table 2).

We observed differences in the structure of the midstory and understory strata between the reference and burned sites. The understory plant density (plants ha^{-1}) was 79% greater in the burned sites, and the total stem density was more than 3-fold greater in the burned sites than in the unburned reference sites (Table 1). Over

Table 1. General site characteristics of reference and burned sites on highly erodible soils in the Kisatchie Hills area of LA.

	Reference		Burned		
Site characteristic	Mean	SE	Mean	SE	P[B]
Slope (%)	18.7	3.3	13.1	1.3	0.1525
Age (yrs)	63.2	5.5	63.8	3.9	0.9646[C]
DBH[A] (cm)	36.2	2.3	39.5	1.8	0.1576[C]
Height[A] (m)	22.8	0.8	24.3	0.7	0.2119
Height to live crown[A] (m)	12.9	0.6	14.8	0.7	0.0778
Live-crown ratio[A]	0.44	0.00	0.39	0.00	0.2162
Total basal area (m^2)	20.0	1.8	21.3	1.2	0.5884
Pine basal area (m^2)	14.8	1.7	18.1	2.2	0.2756
Hardwood basal area (m^2)	5.2	1.2	3.1	1.6	0.3390
Snag basal area (m^2)	0.2	0.6	0.9	0.2	0.3042[D]
Horizontal density at 2 m (%)[E]	89.6	3.7	17.6	9.7	0.0001
Understory density (plants ha^{-1})	16,269	3750	29,087	1673	0.0142
Understory density (stems ha^{-1})	26,162	6200	78,600	14,291	0.0098
Understory >1.37 m (stems ha^{-1})	9072	1310	2232	661	0.0016
Understory diversity (woody)[F]	2.83	0.19	2.35	0.19	0.1480
Understory height (m)	3.03	0.13	0.84	0.06	<0.0001
Understory biomass (Mg ha^{-1})	11.17	1.86	1.13	0.14	<0.0001
Downed fuel (1 hr) (Mg ha^{-1})	0.06	0.01	0.06	0.03	0.9090
Downed fuel (10 hr) (Mg ha^{-1})	0.74	0.14	0.79	0.17	0.8226
Downed fuel (100 hr) (Mg ha^{-1})	1.59	1.23	2.61	0.74	0.4985
Downed fuel (1000 hr) (Mg ha^{-1})	5.86	2.92	5.85	1.61	0.9974
Downed fuel (total) (Mg ha^{-1})	8.25	2.87	9.31	1.95	0.7681
Forest-floor depth (cm)	5.98	0.52	2.67	0.34	0.0007
Forest-floor mass (Mg ha^{-1})	24.3	2.0	7.0	0.2	0.0009[D]
Forest-floor density (kg m^{-3})	41.4	2.0	28.3	2.3	0.0026

[A]DBH, height, and crown height and ratio were measured on 20% of the dominant or codominant pine trees in each plot, not all trees.
[B]P-values from pooled t-test unless noted. Comparisons with $P > 0.04$ were not rejected at alpha of 0.10 following control of Type I error with the Benjamini-Hochberg false discovery rate (Benjamini and Hochberg 1995).
[C]Age and DBH were transformed as log (DBH) to meet normality.
[D]P value from t-test with unequal variances (Satterthwaite).
[E]50-cm x 50-cm density-board read at 2 m height,15.24 m from plot center point.
[F]Woody plant species diversity calculated from Shannon's index.

28 species were recorded in the woody understory vegetation, but analysis with Shannon's index did not detect differences in woody plant diversity (Table 1). *Ilex vomitoria* (Yaupon) was the dominant understory species, followed by a number of *Vaccinium* spp. (blueberries), *Morella cerifera* (Wax Myrtle), and *Crataegus* spp. (hawthorns) (Table 3). While a few species were less abundant in the burned sites than in the reference sites, the only commonly found species with less abundance in the burned sites were hawthorns. Hawthorns averaged 617 plants ha^{-1} (825 total stems ha^{-1}) in the reference sites but only 169 plants ha^{-1} (225 stems ha^{-1}) in the burned sites. Otherwise, both the number of individual plants and the total number of stems were substantially greater for most species in the burned sites (Table 3, Fig. 3). Yaupon was especially prevalent in the burned sites, which had over 6000 more Yaupon plants ha^{-1} (35,000 total stems ha^{-1}) than the reference sites. Most species were not only more abundant in the burned sites, likely due to post-burn recruitment, but the number of stems per plant increased as well (Fig. 3). A few species had the same number of stems per plant regardless of treatment, but others, especially *Acer rubrum* (Red Maple), Blackjack Oak, *Quercus alba* (White Oak), and Yaupon, had 2- to 3-fold more stems per plant in the burned sites as in the reference sites. This increase in stem density was expected because repeated growing-season burns are generally required to reduce the sprouting ability of the understory shrubs in the area (Drewa et al. 2002). Horizontal density at 2 m was 90% in the reference sites but only 18% in the burned sites (Table 1). The stem density of understory plants greater than 1.37 m tall was more than 4-fold higher in the reference sites than in the burned sites. The understory averaged >3 m tall in the reference sites, and several species, e.g., Red Maple and Loblolly Pine, averaged 4 m tall (Fig. 4). The mean understory plant height was more than 2 m less in the burned sites compared to the reference sites (Table 1), and almost all species were

Table 2. Overstory basal area (m^2 ha^{-1}) by species in reference and burned sites on highly erodible soils in the Kisatchie Hills area of LA (n = 5 stands per treatment). Standard errors are in parentheses.

Species	Reference	Burned	P-value[A]
Pinus taeda L. (Loblolly Pine)	6.27 (2.39)	7.58 (2.45)	0.7139
P. palustris Mill. (Longleaf Pine)	11.30 (3.79)	4.59 (2.35)	0.1696
P. echinata Mill. (Shortleaf Pine)	0.54 (0.29)	2.68 (2.15)	0.3775[B]
Quercus marilandica Münchh. (Blackjack Oak)	0.77 (0.48)	1.22 (0.41)	0.4891
Q. stellata Wangenh. (Post Oak)	0.69 (0.46)	1.45 (0.49)	0.2874
Q. falcata Michx. (Southern Red Oak)	0.46 (0.22)	0.61 (0.61)	0.8202
Q. alba L. (White Oak)	0.15 (0.15)	0.38 (0.21)	0.4021
Q. nigra L. (Water Oak)	0.00 (0.00)	0.08 (0.08)	0.3739[B]
Liquidambar styraciflua L. (Sweetgum)	0.84 (0.33)	0.38 (0.24)	0.2936
Acer rubrum L. (Red Maple)	0.08 (0.08)	0.38 (0.24)	0.2839[B]
Carya alba (L.) Nutt. (Mockernut Hickory)	0.00 (0.00)	0.54 (0.45)	0.2962[B]
Nyssa sylvatica Marsh. (Black Gum)	0.00 (0.00)	0.15 (0.15)	0.3739[B]
Ulmus americana L. (American Elm)	0.08 (0.08)	0.00 (0.00)	0.3739[B]
Fraxinus pennsylvanica Marsh. (Green Ash)	0.08 (0.08)	0.00 (0.00)	0.3739[B]

[A]P-values from pooled t-test unless noted.
[B]P-value from t-test with unequal variances (Satterthwaite).

shorter on the burned plots (Fig. 4) than on the unburned plots. Herbaceous cover was distinctly greater in the burned sites compared to the reference sites (Table 4).

These changes in vegetative composition and structure had several positive effects on habitat quality for the endangered RCW and other wildlife. The Kisatchie Hills support high quality habitat for the RCW, *Geomys breviceps* Baird (Baird's Pocket Gopher), and LPS. Although not listed as threatened or endangered, LPS is very rare (Rudolph and Burgdorf 1997; Rudolph et al. 2006). Red-cockaded Woodpeckers require old, widely spaced dominant and codominant canopy pines for cavity excavation, and open pine habitat with a limited midstory for foraging. Baird's Pocket Gophers feed on the belowground portions of herbaceous plants (English 1932, Sulentich et al. 1991), and are the primary food source for the LPS (Rudolph and Burgdorf 1997). Thus, the presence of herbaceous vegetation is of prime importance for both species. The study area is within 20 km of a known LPS population at Peason Ridge Military Reservation and is part of the largest block of potential remaining habitat for this species (Rudolph et al. 2006). Baird's Pocket

Table 3. Understory vegetation density (plants ha^{-1}) in reference and burned sites on highly erodible soils in the Kisatchie Hills area of Louisiana, USA (n = 5 stands per treatment). Standard errors are in parentheses.

Species	Reference	Burned
Ilex vomitoria Ait. (Yaupon)	7632 (2399)	14,681 (3379)
Vaccinium spp. (blueberry)	2854 (1583)	3699 (998)
Morella cerifera (L.) Small (Wax Myrtle)	1975 (1124)	2662 (1051)
Pinus taeda L. (Loblolly Pine)	1022 (611)	2312 (1365)
Crataegus spp. (hawthorn)	618 (318)	169 (169)
Acer rubrum L. (Red Maple)	725 (523)	833 (581)
Halesia diptera Ellis (Two-winged Silverbell)	331 (331)	0 (0)
Quercus marilandica (Münchh.) (Blackjack Oak)	242 (162)	508 (383)
Quercus alba L. (White Oak)	247 (169)	293 (85)
Liquidambar styraciflua L. (Sweetgum)	111 (67)	756 (303)
Quercus nigra L. (Water Oak)	113 (69)	56 (56)
Rhododendron canescens (Michx.) Sweet (Mountain Azalea)	22 (22)	5 (5)
Quercus stellata Wangenh. (Post Oak)	78 (78)	0 (0)
Quercus falcata Michx. (Southern Red Oak)	62 (62)	846 (520)
Cornus florida L. (Flowering Dogwood)	56 (56)	0 (0)
Fraxinus pennsylvanica Marsh. (Green Ash)	56 (56)	0 (0)
Pinus echinata Mill. (Shortleaf Pine)	43 (43)	56 (56)
Nyssa sylvatica Marsh. (Black Gum)	27 (15)	5 (5)
Chioanthus virginicus L. (Fringetree)	16 (16)	0 (0)
Rhus copallinum L. (Winged Sumac)	16 (16)	889 (456)
Prunus serotina Ehrh. (Black Cherry)	11 (7)	0 (0)
Carya alba (L.) Nutt. (Mockernut Hickory)	5 (5)	5 (5)
Magnolia virginiana L. (Sweetbay Magnolia)	5 (5)	0 (0)
Pinus palustris Mill. (Longleaf Pine)	0 (0)	73 (73)
Serenoa repens (Bartr.) Small (Saw Palmetto)	0 (0)	56 (56)
Diospyros virginiana L. (Common Persimmon)	0 (0)	169 (169)
Sassafras albidum (Nutt.) Nees (Sassafras)	0 (0)	113 (113)
Viburnum spp. (viburnum)	0 (0)	56 (56)

Gophers cannot burrow in Kisatchie soils because of the clayey soil texture, but suitable soils occur nearby.

The reference sites included old, widely spaced pine trees in the overstory, which are required for RCW, but the understory had grown tall enough to be

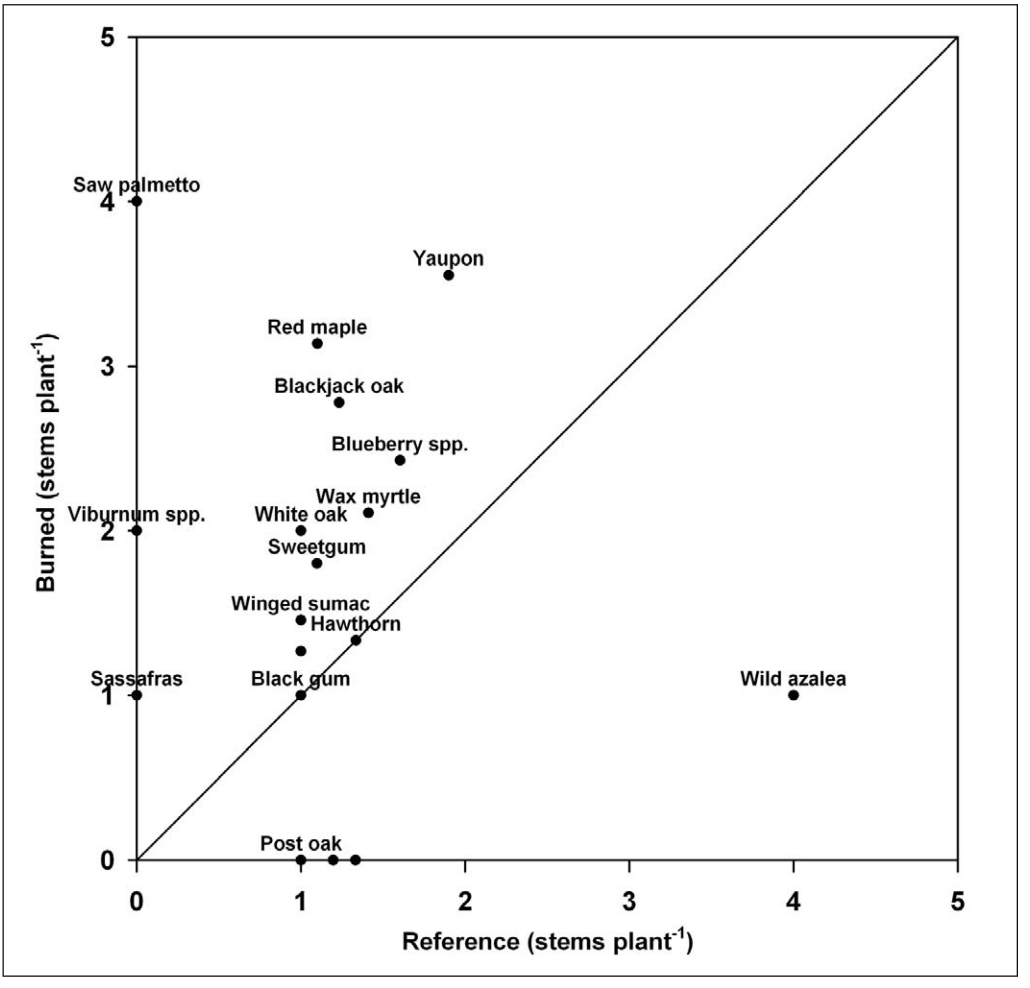

Figure 3. Understory woody plant sprouting in reference and burned sites in the Kisatchie Sandstone Hills area near Gorum, LA (*n* = 5 stands/treatment).

Table 4. Frequency (%) of herbaceous cover and bare soil by cover class (percent of sampling points with herbaceous or bare soil cover by class) in reference and burned sites in the Kisatchie Hills near Gorum, LA (*n* = 5 stands/treatment).

	Herbaceous		Bare soil	
Cover class	Reference	Burned	Reference	Burned
0% (no herb or bare)	93.3	60.0	87.0	67.0
1–10%	5.6	18.9	10.0	27.0
11–50%	1.1	8.9	3.0	7.0
51–100%	0.0	12.2	0.0	0.0

considered midstory (3 m), and was quite dense (90% horizontal density). The presence of midstory vegetation reduces habitat suitability for RCW (Rudolph et al. 2002, US Fish and Wildlife Service 2003), primarily by altering the birds' foraging behavior. In comparison, midstory vegetation was greatly reduced on burned sites, creating nearly ideal habitat conditions for RCW with respect to the midstory. Most importantly, plant height in burned areas averaged less than 1 m tall, and the horizontal density at 2 m was only 18%. The two burns conducted on this area clearly succeeded in top-killing the understory vegetation and removing the midstory and taller understory vegetation, thereby improving the foraging conditions for RCW and other important wildlife species. Herbaceous cover, while still not sufficient for Baird's Pocket Gophers or associated LPS, increased substantially after only two burns.

Fuel loadings

Live fuels in the understory decreased from over 11 Mg ha^{-1} in the reference sites to less than 2 Mg ha^{-1} in the burned sites, and the forest-floor mass was reduced by 71%. Ladder fuels were not quantified, but were prevalent in the tall woody understory in the reference sites (Fig. 5). These fuels were conspicuously absent in the burned sites. Not only was the ladder fuel likely consumed during the two fires, but the 2-m reduction in the mean height of the understory reduced the potential for ladder fuels to accumulate. Downed woody fuel levels were similar between both treatments for all fuel classes. Very little downed

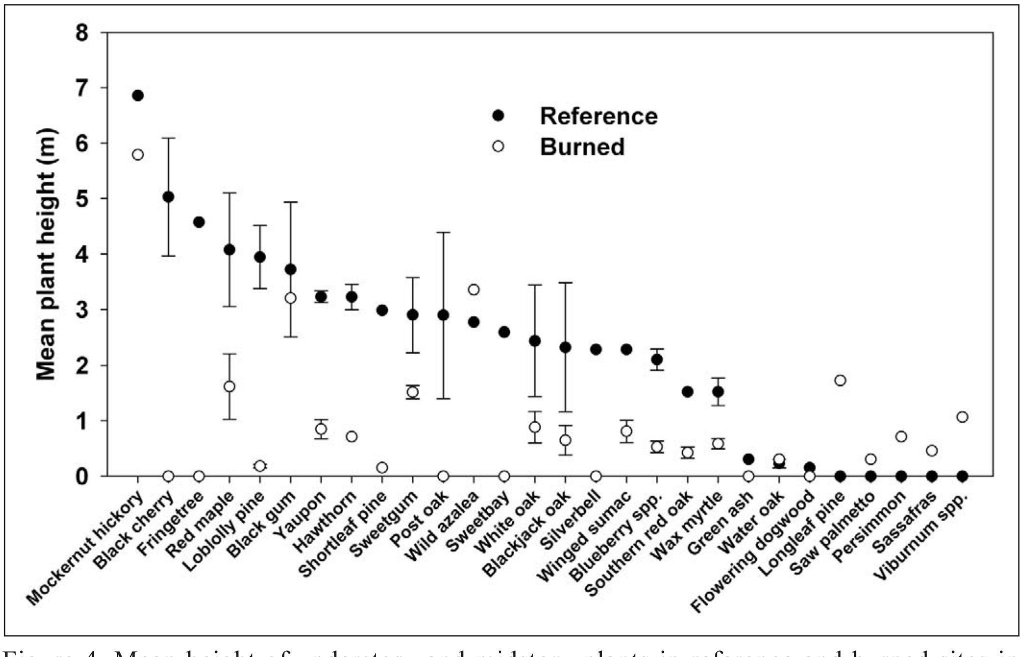

Figure 4. Mean height of understory and midstory plants in reference and burned sites in the Kisatchie Sandstone Hills area near Gorum, LA (n = 5 stands/treatment). Error bars are one standard error. Missing error bars indicate the species was found in only one site of the indicated treatment.

Figure 5. Understory conditions at representative locations in reference sites (A), and burned sites (B) in the Kisatchie Sandstone Hills area near Gorum, LA. Photo was taken approximately at 1.8 m, with the camera held level at the point of the photograph.

woody fuel was found in the 1-, 10-, or 100-hour fuel classes, which averaged 0.06, 0.77, and 2.10 Mg ha^{-1}, respectively. About 67% of the total downed woody fuel was contained in the 1000-hr fuels, which averaged 5.8 Mg ha^{-1} across the 2 stand types (Table 1). The forest-floor thickness averaged about 6 cm in the reference sites, while it averaged only about half that in the burned sites (Table 1). Similarly, forest-floor mass in the burned sites was less than a third of what was measured in the reference sites. Accordingly, the forest-floor density was also about 32% lower in the burned sites than the reference sites.

The management goal for these burns was to reduce 1- and 10-hr fuels by 60–80%, 100-hr fuels by 30–40%, and 1000-hr fuels (up to 23-cm diameter) by 10–20% (S. Staples, Kisatchie Ranger District Fire Management Officer, Provencal, LA, pers. comm.). The lack of fuel reduction in the 1000-hr fuels was not surprising, because both burns occurred before the normal extended dry period in late summer, when fuels would have been drier and burned more extensively. The absence of detectable differences in the levels of smaller fuels could be due to either an ineffective burn or to increased fuel production following the burns. Because the live fuels and forest floor were largely consumed, it is likely that these burns were initially effective at reducing the lighter fuels. However, the burns may have caused an increase in small branch senescence, thereby increasing these lighter fuels. If this occurred, it would not likely continue following another burn because the lower crown would have senesced. We observed little to no scorch on the smaller fuel classes, further suggesting that the original fuels were likely consumed but replaced by new fuel in the same class. Rideout and Oswald (2002) also noted little decrease in fuel loadings in three areas in East Texas and attributed the lack of response to ineffective burns, but the forest floor was not consumed in their burns as it was in this study's burns.

Soil erosion risk for physically undisturbed forests can be approximated by comparing soil cover and canopy height above bare soil. These two variables control erosion, and are affected by prescribed burning, especially where hydrophobicity and soil sealing are not likely (Larsen et al. 2009). Because the vegetation canopy intercepts rainfall before the droplets reach the ground, plant cover is an important factor in determining rainfall impact energy. Generally speaking, an overstory canopy that is >20 m tall reduces rainfall impact very little, but short, <2-m-tall vegetation is almost as effective as actual soil cover at reducing rainfall impact and the resultant soil detachment (Wischmeier 1975). The fires had no effect on the overstory canopy, but reduced the vertical stratification of vegetation. Our results suggest that soil protection by vegetative cover was likely the same after the burn as before, but the forest-floor material was reduced in the two fires. A sparse cover of recently fallen needles (Oi horizon) was maintained across most of the area, but no Oe or Oa horizons (fermentation or duff layers) were found in burned areas (Tables 1, 4). We observed some soil cover, but it was sparse enough so that rainfall impact would still be high and particle detachment would likely occur. This condition was magnified in areas with lower overstory basal area, where litterfall was low, and in areas where herbaceous vegetation was sparse. Although the extent of soil erosion that occurred after each fire was not quantified in this study, Haywood et al. (1995) found high erosion rates for burned and unburned glade vegetation communities with greater than 9.2 m^2 ha^{-1} overstory basal area on Kisatchie soils (56.9 and 49.1 Mg ha^{-1}, respectively). However, they found >25% bare soil or rock prior to burning, whereas bare soil and rock was <2% in this study, regardless of treatment. In our study, the post-burn reduction in the density of herbaceous species increased erosion potential, but the concurrent increase in short vegetation (woody and herbaceous) increased canopy cover.

Conclusions and Recommendations

Restoring the native vegetation and habitat on highly erodible soils in the Kisatchie Hills will require careful management actions. An initial two-burn plan, consisting of a cool dormant-season burn to reduce fuel loads, followed by a warm growing-season burn to top-kill undesirable woody vegetation and increase herbaceous vegetation reduced the overall fuel load, increased herbaceous vegetation, and improved the vertical structure for RCW habitat. However, this initial action resulted in increased total woody plant and stem density, and a reduction in forest-floor density. Soil erosion risk response was mixed—the increase in short woody and herbaceous vegetation reduced the canopy height, but density of the protective forest-floor layer was reduced. Future burns should be planned to continue to top-kill the undesired woody vegetation; further fuel-reduction burns are not needed at this time.

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