UNDERSTORY FUEL VARIATION AT THE CAROLINA SANDHILLS NATIONAL WILDLIFE REFUGE: A DESCRIPTION OF CHEMICAL AND PHYSICAL PROPERTIES

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Abstract—Upland forest in the Carolina Sandhills National Wildlife Refuge is characterized by a longleaf pine (*Pinus palustris*) canopy with a variable understory and ground-layer species composition. The system was historically maintained by fire and has been managed with prescribed fire in recent decades. A management goal is to reduce turkey oak (*Quercus laevis*) stem density and maintain the natural biodiversity in the understory. The patchy understory of this forest type creates several fuel complexes on a small within-stand scale. We measured chemical content (energy and ash) of five common species, identified three fuel complexes based on dominant vegetation and fuels [longleaf pine litter, turkey oak, and wiregrass (*Aristida stricta*)], and described the fuels present in each fuel complex. Longleaf pine litter contained the highest energy (21,716 J/g) and little bluestem (*Schizachyrium scoparium*) the lowest (19,202 J/g). Among the fuel complexes, turkey oak-dominated sites had the highest potential fuel weight (12.4 tons/ha) and wiregrass-dominated sites the lowest (6.9 tons/ha). Both turkey oak- and wiregrass-dominated sites had a more aerated fuel bed than longleaf pine litter-dominated sites. We concluded that the plant community structure creates different fuel conditions, suggesting that fires will burn heterogeneously, creating spatial diversity in postfire conditions.

INTRODUCTION

Fire is an integral part of the longleaf pine (*Pinus palustris*) ecosystem in the Southeastern United States, with 3- to 5-year fire intervals found in areas where pine litter accumulation is sufficient (Christensen 1981, Platt 1999). Fires at such intervals encourage the regeneration of longleaf pine and many herbaceous species (Brockway and Lewis 1997, Christensen 1981). Consequently, land managers throughout the Southeast commonly use fire as a management tool. At the Carolina Sandhills National Wildlife Refuge (CSNWR), controlled burning is used to reduce fuel loads, maintain an open understory, and encourage longleaf pine regeneration.

The primary ecosystem at the CSNWR is the xeric sandhills ecosystem, an upland longleaf pine forest characterized by a longleaf pine overstory, turkey oak (*Quercus laevis*) in the shrub and midstory, and a wiregrass (*Aristida stricta*) and mixed forb ground layer. However, plant cover has changed in the past two centuries due to land and resource use, resulting in decreased pine and grass cover and increased hardwood cover (Christensen 1981), and accordingly, new fuel complexes that may change the way fire behaves within the ecosystem.

Understanding how fuels affect fire behavior and desired fire effects is a necessary component of using controlled burns (Johnson and Miyanishi 1995). Fire behavior is affected by both the chemical (intrinsic) and physical (extrinsic) properties of a fuel (Pyne 1984). The chemical property of a fuel is best described by its energy and mineral (ash) contents, where the energy content affects the amount of heat released and the mineral content affects the ignitability of the fuel. Physical properties include fuel load, morphology, and arrangement.

Several studies have found differences in chemical properties among fuel species within an ecosystem (Dickinson and Kirkpatrick 1985, Dimitrakopoulos and Panov 2001) and among ecosystems (Dickinson and Kirkpatrick 1985, Golley 1961), as well as between native and nonnative invasive species (Dibble and others 2007, Lippincott 2000). Several of these studies couple chemical analysis with laboratory or field studies on fire behavior to suggest that intrinsic properties are related to other measures of flammability, such as rate of flame movement. Moreover, there is evidence that chemical properties of species in fire-prone environments are more likely to encourage fire (Mutch 1970). The dependence of the longleaf pine ecosystem on fire provides an ideal setting for further studies on fuel chemistry.

The patchy distribution of vegetation in the longleaf pine ecosystem creates numerous fuel complexes on a small within-stand scale. Previous studies on fuel variation in the sandhills concentrated on the heterogeneity in pine canopy cover and pine fuel loading. Small-scale variation in pine fuels was shown to affect fire intensity and shrub abundance, with areas of increased fuel loading causing higher temperature burns and increased shrub mortality (Thaxton and Platt 2006). Several studies looked at the effect of distance to nearest pine, pine density, or canopy species on fire temperature and turkey oak mortality (Platt and others 1991, Rebertus and others 1989, Williamson and Black 1981). Fuel arrangement and architecture, such as the positions of oak leaves and longleaf pine needles in the fuel bed, may also affect fire behavior (Rebertus and others 1989, Williamson and Black 1981), but differences in fuel arrangement have not been measured in sandhills ecosystems. Even though the presence of varying fuel complexes on the small scale has been used for fire behavior and fire effects studies in

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the sandhills, a comprehensive description of those fuel complexes is still missing.

The importance of fire in maintaining the sandhills longleaf pine ecosystem, and the role of fuels in determining fire behavior, necessitate a better understanding of the chemical and physical properties of dominant fuels in the ecosystem. The objectives of this study were to: (1) quantify chemical properties (energy and ash content) for five common species (four native, one nonnative) found in the sandhills and (2) compare physical fuel properties (potential fuel weight, litter depth, and fuel arrangement) of three fuel complexes found within longleaf pine stands in the sandhills. A stronger understanding of fuel properties will improve our use of prescribed fire as a management tool, especially where altered understory species composition has led to new fuel complexes.

METHODS

Study Area

The study site was located in CSNWR (34.58° N, 80.23° W), which is situated on the fall line of the Upper Atlantic Coastal Plain in Chesterfield County, SC. Elevations for this area range from 70 m along Black Creek to 180 m on the highest ridges. Soils are well-drained sands of the Alpin-Candor series. Mean annual precipitation is 110 cm and mean annual temperature is 15.6 °C. Although several plant communities are found within CSNWR, all study sites were located in the upland longleaf pine-wiregrass community.

We established two experiments (one on fuel chemistry and one on the physical properties of fuels) to meet our two objectives and described the experimental design of each separately.

Fuel Chemistry

We used a complete block design with six blocks, and to account for variability among individuals, we sampled at least 10 individuals of each species per block, using composite samples for the analyses. In November 2007 we collected plant matter from five species [needle litter from longleaf pine, dead leaves of turkey oak, and leaves of wiregrass, little bluestem (*Schizachyrium scoparium*), and weeping lovegrass (*Eragrostis curvula*)] for chemical analysis. The first four species are common native species and are the dominant fuel in the system; the fifth is an exotic species, recently increasing in cover at CSNWR. Prior to lab analysis, we separated live and dead tissue for the three grass species (wiregrass, little bluestem, and weeping lovegrass) and analyzed each separately.

To prepare samples for analytical tests, we oven dried the plant matter at 65 °C for 48 hours and ground it to 60-mesh using a Thomas Model 4 Wiley® Mill (Thomas Scientific, Swedesboro, NJ). We measured energy content with an IKA® C 200 oxygen bomb calorimeter (IKA®, Wilmington, NC) in isoperibol mode, running three subsamples of each species per block. Subsample weights ranged from 0.8 to 1.3 g, depending on the species. We calibrated the calorimeter with certified benzoic acid to determine the heat capacity of the system. Energy content was measured in J/g.

Mineral ash analysis was performed by the Agricultural Service Laboratory at Clemson University. Ash content was determined by heating samples for 2 hours at 600 °C in a Thermo Scientific muffle furnace (Thermo Scientific, Barrington, IL). Two subsamples (each approximately 1 g) were analyzed for each sample.

Physical Descriptions of Fuels

In our second experiment we identified three fuel complexes according to the natural fuel distribution to describe physical differences in the variation of understory fuels. Fuel complexes were identified visually based on the dominant species. The first was dominated by longleaf pine needle litter, with live fuels nearly absent, the second by turkey oak stems and litter, and the third by wiregrass. Longleaf pine needle litter was present in all fuel complexes. The frequency of each fuel complex across the landscape was not determined.

We used a complete block design with seven blocks; four blocks contained one plot of each fuel complex, and three blocks had two plots of each. We selected sites with all three fuel complexes present and in close proximity to each other within each block. We installed 4- by 4-m plots for each fuel complex, because at this scale, fuels were relatively uniform; on a larger scale there would have been significant variation within a fuel treatment plot. All plots were located in areas with a mature longleaf pine canopy over Alpin soils. Finally, all sites were selected to have a similar burn history, with the last prescribed burn conducted in the spring of 2003 or 2004.

In February and March 2008 we sampled all plots to estimate potential fuel weight by measuring all standing vegetation (live and dead) <2 m in height and all ground litter. The fuel components measured for all fuel complexes included turkey oak stems, wiregrass plants, and litter (separated into needle litter, turkey oak litter, and unidentified fractions).

We destructively sampled turkey oak stems outside the study plots to construct height vs. weight regressions, which we used to estimate stem weights of all stems within plots. Separate regression analyses were used for live stems zero to 70 cm, live stems >70 cm, dead stems zero to 70 cm, and dead stems >70 cm. We sampled wiregrass plants outside the study plots to develop relationships between wiregrass plant basal area and weight. Wiregrass basal area was estimated by taking two perpendicular measurements of plant crown diameter. Basal area and plant weight were estimated for all plants within each plot. Litter weight was estimated from samples collected adjacent to study plots. Litter samples from a 1- by 1-m area were used to estimate the litter weight of the longleaf pine litter- and wiregrass-dominated plots, and samples from a 1- by 2-m area were used to estimate the litter weight of the turkey oak-dominated plots. We sorted the litter samples into three components: longleaf pine litter, turkey oak litter, and unidentified. Oven-dry weights were obtained for each fraction. We took litter depth measurements from five points within each plot (plot center and 1 m in from each corner along diagonals). Pine and oak litter lodged in turkey oak stems were not considered in litter height measurements, though litter lodged in wiregrass plants was, due to its contact with the litter bed.

Dwarf huckleberry (*Gaylussacia dumosa*), little bluestem, splitbeard bluestem (*Andropogon ternarius*), and longleaf pine cones made up a minimal proportion of the fuels. Their presence was noted, but their weights were not estimated for the study.

Statistical Analysis

We used two-way analyses of variance using PROC GLM (SAS Institute Inc., Cary, NC) to test for significant differences among species for the chemical analysis, and among fuel complexes for the physical descriptions of fuels. For each model, a block term was included to account for location effects. For the analyses of physical fuel descriptions, weighting was used to account for the different number of plots in each block. We used least squares means tests in PROC GLM to make specific comparisons among species and fuel complexes, and linear contrasts to compare woody vs. grass species for energy and ash content.

RESULTS

Fuel Chemistry

Significant differences in energy content were found among the common fuel species ($P < 0.0001$), and mean energy values ranged from 19,202 J/g (little bluestem, live) to 21,716 J/g (longleaf pine needles) (table 1). Needle and leaf litter from the woody species contained more energy than the leaves from grass species ($P < 0.0001$). Of the native grass species, wiregrass had higher energy content than little bluestem, whereas the exotic grass species, weeping lovegrass, had a similar energy content as the dominant native grass species, wiregrass.

Mean ash content ranged from 1.36 percent (weeping lovegrass, dead) to 2.58 percent (little bluestem, live) (table 2). We found significant differences among species ($P < 0.0001$), although ash content of leaves and needles from woody species was not significantly different from that of leaves from grass species ($P = 0.4529$).

Table 1—Mean energy content of some sandhills species found on the Carolina Sandhills National Wildlife Refuge

	Energy content (J/g)	
Species	Mean	Standard error
Longleaf pine, needle litter	21,716 A	50.0
Turkey oak, leaf litter	20,389 B	64.6
Wiregrass, live	19,972 C	39.6
Weeping lovegrass, dead	19,658 D	92.8
Wiregrass, dead	19,587 D	103.4
Weeping lovegrass, live	19,578 D	55.4
Little bluestem, dead	19,277 E	97.1
Little bluestem, live	19,202 E	53.9

Test of significance is at the 95-percent confidence level; means with the same letter are not significantly different.

Table 2—Mean ash content of some sandhills species found on the Carolina Sandhills National Wildlife Refuge

	Ash content (percent)	
Species	Mean	Standard error
Weeping lovegrass, dead	1.36 A	0.199
Wiregrass, dead	1.48 AB	0.048
Longleaf pine, needle litter	1.72 BC	0.090
Wiregrass, live	1.97 CD	0.104
Weeping lovegrass, live	2.13 D	0.137
Turkey oak, leaf litter	2.14 D	0.062
Little bluestem, dead	2.53 E	0.195
Little bluestem, live	2.58 E	0.184

Test of significance is at the 95-percent confidence level; means with the same letter are not significantly different.

Physical Descriptions of Fuels

Mean potential fuel weight for each fuel complex was divided into five categories: turkey oak stems, wiregrass, longleaf pine litter, turkey oak litter, and unidentified litter (fig. 1). We found significant differences in total potential fuel weight among fuel complexes ($P = 0.0014$), with turkey oak-dominated plots containing greater fuel loads than longleaf pine litter- or wiregrass-dominated plots. For the individual fuel components, differences among fuel complexes were significant for turkey oak stems ($P < 0.0001$), wiregrass ($P = 0.0006$), and turkey oak litter ($P = 0.0002$). These differences in fuel components verified our fuel complex designations. For example, the turkey oak-dominated plots had the most turkey oak stems and litter, and the wiregrass-dominated plots had the highest wiregrass weights.

Litter depth for each fuel complex is shown in figure 2. Differences among fuel complexes were significant ($P = 0.0214$), with longleaf pine litter-dominated plots having a lower litter depth than either wiregrass- or turkey oak-dominated plots. A density-related measure of litter arrangement is shown in figure 3. The ratio of litter weight to

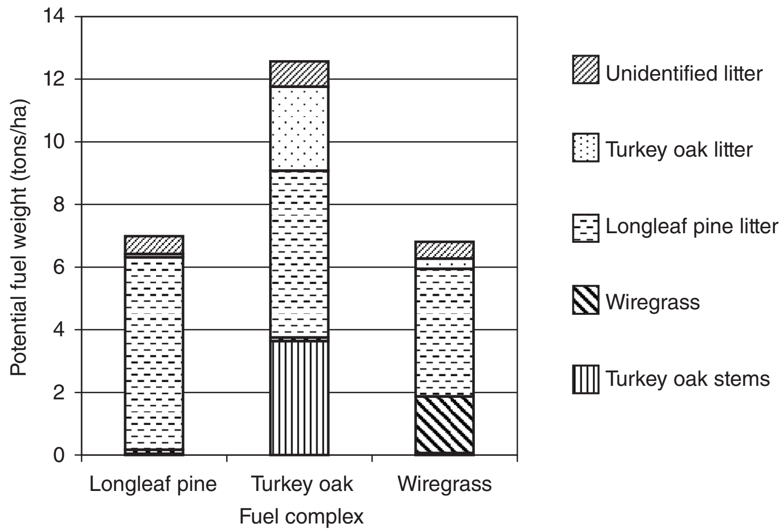

Figure 1—Effect of fuel complex on understory potential fuel weight (tons/ha), potential fuel weights are based on standing turkey oak stems <2 m tall, wiregrass plants, and all litter.

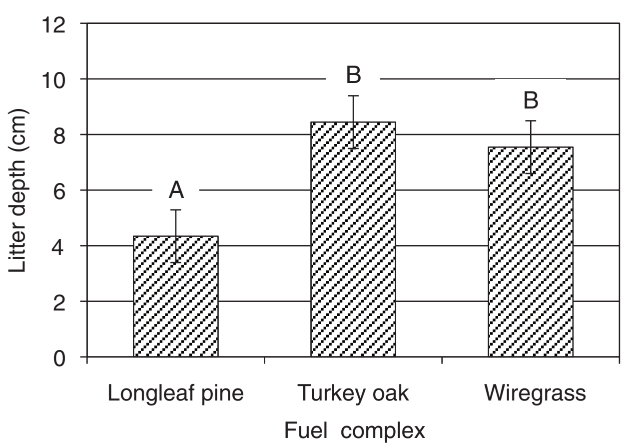

Figure 2—A summary of mean litter depth (cm) for three fuel complexes at the Carolina Sandhills National Wildlife Refuge. Different letters above bars show significant differences at a 95-percent confidence level.

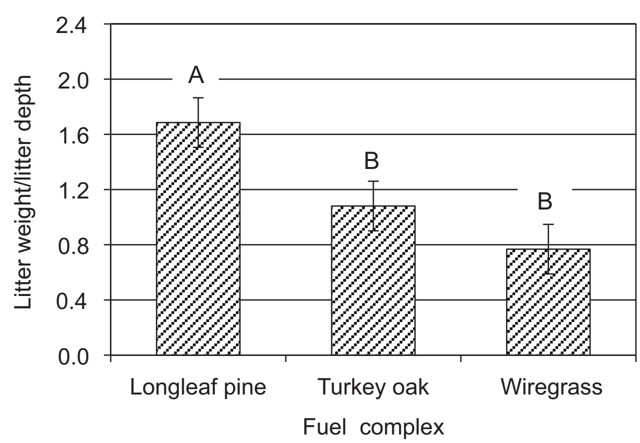

Figure 3—A measure of fuel bed aeration (the ratio of litter weight to litter depth) for three fuel complexes at the Carolina Sandhills National Wildlife Refuge. Different letters above bars show significant differences at a 95-percent confidence level.

litter depth was used to illustrate the aeration of the fuel bed. Longleaf pine litter-dominated plots had a higher weight to depth ratio than either turkey oak- ($P < 0.0001$) or wiregrass-dominated plots ($P < 0.0001$). No significant difference was found between turkey oak- and wiregrass-dominated plots ($P = 0.2331$).

DISCUSSION

Our analysis of energy content produced a range of values similar to those found in other studies from longleaf pine ecosystems (Golley 1961, Hough 1969) and within the range reported for other ecosystems (Dibble and others 2007, Dickinson and Kirkpatrick 1985, Dimitrakopoulos and Panov 2001). However, energy content for the same fuel type can vary by site (Hough 1969) and season (Golley 1961), and our values represent energy contents of sandhills species during the dormant season. It is possible that live tissue sampled midsummer could vary from that sampled in winter. Additionally, previous research has reported that energy content decreases as litter decomposes (Hough 1969). Because we sampled fresh litter for the woody species (longleaf pine and turkey oak), it is likely that litter deposited in the lower fuel bed may contain less energy than our reported values.

We expect that the energy content of fuels reported in this study play an important role in fire behavior when these fuels burn. The high energy content of longleaf pine needles supports previous field studies that report increased fire temperatures in areas with higher pine densities (Platt and others 1991, Williamson and Black 1981). The difference in energy and ash content between wiregrass and little bluestem is notable because of potential implications on fire behavior. Wiregrass, with higher energy content and lower ash content, would be more readily flammable and would generate a higher heat output than little bluestem. These differences could result in an increased rate of spread and higher fire temperatures in areas dominated by wiregrass as opposed to areas dominated by little bluestem.

Our study sites for quantifying the physical properties of fuels differed in many ways from sites used in earlier studies on fuels and fire in the sandhills. Williamson and Black (1981) considered only oak-dominated areas without a pine canopy; at CSNWR, turkey oaks are found throughout areas under a longleaf pine canopy. Excluding pine canopy cover would not be representative of the system we studied. In fact, we found longleaf pine litter was present in similar quantities across the landscape, with other fuel components differentiating the three fuel classes.

Potential fuel weight varied from 4.5 to 18.5 tons/ha in our plots, falling on the lower end of 2.1 to 59.0 tons/ha reported by Thaxton and Platt (2006). The smaller range of our values is likely due to the exclusion of sites containing 100-hour or larger pine fuels. The decision to exclude large fuels was made to minimize the influence of confounding factors in later studies on fire intensity and behavior.

Plots dominated by turkey oak stems had the highest litter weights. In addition, measures of fuel arrangement indicated a well-aerated fuel bed of litter with relatively high energy content. These results suggested the potential for increased fire intensity and temperature in turkey oak-dominated sites compared to longleaf pine litter-dominated sites, contrasting with studies noting decreased flammability of oak litter and lower temperature burns near oaks as compared to pines (Rebertus and others 1989, Williamson and Black 1981). However, comparisons with those studies are difficult to make because oaks were isolated from pines, which is not the case at CSNWR.

The significant differences found in our description of litter arrangement confirmed previous speculations about variation in litter placement (Rebertus and others 1989, Williamson and Black 1981). We showed that wiregrass- and turkey oak-dominated sites have an aerated fuel bed compared to longleaf pine litter-dominated sites. Pine needle litter lodges in the vegetation, and turkey oak leaves curl and pack loosely, also catching pine needle litter in a more elevated position. Due to the lack of vegetation in the longleaf pine litter-dominated plots, a denser fuel bed was recognized where needles are packed horizontally. It is likely that, if given similar weights of fuel, a looser arrangement will increase air flow prior to and during burns, reducing the moisture content of the litter and increasing the rate of spread of the fire.

Heterogeneity in vegetation and litter on a small scale has been shown to affect species composition and abundance (Platt and others 2006) and fire effects such as hardwood mortality (Rebertus and others 1989, Thaxton and Platt 2006). Fire is used at CSNWR to reduce fuel loads, suppress hardwoods in the understory (especially turkey oak), and maintain the natural biodiversity of the system. The observed presence of different fuel complexes (confirmed by differences in fuel loading, composition, and arrangement) and chemical differences of the fuels suggests that prescribed fires will burn heterogeneously within longleaf pine stands. However, monitoring fire behavior and fire effects would be necessary to determine the specific responses of prescribed fire to fuel variation.

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