FLAMMABILITY OF LITTER FROM SOUTHEASTERN TREES: A PRELIMINARY ASSESSMENT

J. Morgan Varner, Jeffrey M. Kane, Erin M. Banwell, and Jesse K. Kreye[1]

Abstract--The southeastern United States possesses a great diversity of woody species and an equally impressive history of wildland fires. Species are known to vary in their flammability, but little is known about southeastern species. We used published data and our own collections to perform standard litter flammability tests on a diverse suite of 25 native overstory trees from the region. Flame heights, duration of flaming and smoldering combustion, and fuel consumption were measured for each species. Species spanned a wide spectrum of flammability, from highly flammable to fire-impeding. The southeast has several flammable species, including several *Pinus* and *Quercus* that rank among the most flammable species ever measured. In addition to these species, several species burned with poor flammability, notably eastern hemlock [*Tsuga canadensis* (L.) Carrière], Ocala sand pine [*P. clausa* var. *clausa* (Chapm. ex Engelm.) Vasey ex Sarg.], and eastern white pine (*P. strobus* L.), dampening local fire intensity and enabling these fire-intolerant species to survive in fire-prone landscapes.

INTRODUCTION

The southeastern United States encompasses a wide variety of fire-prone ecosystems. Within this diversity of ecosystems, individual species have traits that allow them to withstand heating (e.g., thick bark), recover damaged above-ground stems (e.g., via resprouting), or link reproduction or establishment to the season or frequency of fires. Another aspect of resilience to fire is litter flammability, whereby plants cast litter that elevates local flammability (the so-called "kill thy neighbor" strategy; Bond and Midgley 1995) or that diminishes local flammability (so-called "mesophiers"; Nowacki and Abrams 2008). Highly flammable species have litter that burns with great intensity, subjecting nearby plants to high temperatures and injury while diminishing local competition. Species with low flammability diminish local fire intensity, allowing them to escape injury or dampen intensity or overall fire spread. Differential flammability has been found across many plant communities in North America (de Magalhães and Schwilk 2012, Engber and Varner 2012, Fonda 2001, Fonda and others 1998), Australia (Scarff and Westoby 2006), and Europe (Curt and others 2011). In the southeastern United States, flammability research to date has focused on a narrow suite of pines (*Pinus*, four species) and oaks (*Quercus*, eight species). This low number of species is not reflective of the high tree diversity and frequent-fire history of the region.

The focus of flammability in forests is senesced litter, the primary carrier of fire in these ecosystems. Litter flammability can be evaluated in a number of ways that quantifies its ignitability (resistance or delay to ignition), fire intensity (energy release rate, as measured by flame characteristics), sustainability (the duration of flaming and smoldering phases of combustion), consumability (the proportion of the fuel consumed), or combinations of these four factors (Fonda 2001).

Understanding interspecific flammability has implications for land management in fire-prone southeastern forests. Prescribed fires are widely used in many southeastern ecosystems (Wade and Lunsford 1989) but have variable effects. Some of these differences may be due to variation in fuel flammability and its subsequent effect on fire behavior (Kane and others 2008, Wenk and others 2011). Distinguishing the flammability of species in southeastern forests can assist managers in targeting species for removal to better allow for the reintroduction of fire to these ecosystems (Kane and others 2008).

We sought to evaluate litter flammability of 25 native tree species common to many southeastern ecosystems. The specific objectives of this study were: (1) to evaluate and compare the flammability of the species, and (2)

[1]Assistant Professor, Mississippi State University, College of Forest Resources, Department of Forestry, Mississippi State, MS 39762; Assistant Professor and Research Assistant, respectively, Humboldt State University, College of Natural Resources, Forestry and Wildland Resources, Arcata, CA 95521; and Post-doctoral Research Scientist, Mississippi State University, College of Forest Resources, Department of Forestry, Mississippi State, MS 39762.

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to evaluate and compare the flammability of oaks and pines separately.

MATERIALS AND METHODS

Study Species and Collections

We collected leaf litter from 25 native species from several locations throughout the southern United States for this study and for those published in previous work (Fonda 2001, Fonda and Varner 2004, Kane and others 2008; table 1). For each species, we collected approximately 20 g (oven-dry weight) of recently fallen litter from beneath individual trees, with eight trees sampled per species. Collected litter was placed in paper bags, transported to the laboratory, sorted (removing non-leaf litter), and stored under laboratory conditions prior to burning experiments.

Laboratory Burning Experiments

Our analysis used data from published values from two laboratories, the Western Washington University combustion facility (Fonda 2001, Fonda and Varner 2004) and the Humboldt State University Wildland Fire Lab (Kane and others 2008). Both sites used identical methods in similar facilities, consisting of a 1- by 1-m steel platform mounted beneath an adjustable fume hood. In the Humboldt State University Wildland Fire Lab, we burned 13 additional species as part of this study (table 1). For all burning experiments, a 15 g oven-dry litter sample was spread across a 25-by 25-cm lattice of eight xylene-soaked cotton strings placed on the steel platform. Between five and eight replicates were burned for all 25 species. The string ends were ignited with a standard lighter, spreading to the interior litter. Maximum flame height was estimated by two trained observers (to the nearest cm) against a ruler mounted behind the platform. The duration of flaming and smoldering combustion was measured for all burns (to the nearest second). All residues following burning were sorted to remove unburned string and then weighed to calculate fuel consumption (percent).

Data Analysis

Burning experiment data were compared using principal components analysis (PCA) with standardized values (mean = 0, standard deviation = 1) for the each of the 25 species' four measured flammability variables: flame height (cm); flaming duration (seconds); smoldering duration (seconds); and fuel consumption (percent). When outliers were detected, we repeated the analyses after excluding those species. We only considered axes in PCA that resulted in cumulatively > 75 percent of the variation explained. Factors that were most related to the generated PCA axes were reported. We ran PCA for all 25 species and separately for the conifer (14 species) and oak (11 species) datasets.

RESULTS AND DISCUSSION

All Species

The southeastern tree species burned here are comparable to species burned using similar methods elsewhere in North America. The first PCA generated a two-axis solution that comprised 80.3 percent of the variation in the four variable dataset but detected three outlier species. These three species - eastern hemlock [*Tsuga canadensis* (L.) Carrière], Ocala sand pine [*P. clausa* var. *clausa* (Chapm. ex Engelm.) Vasey ex Sarg.], and eastern white pine (*P. strobus* L.) - were the least-flammable species evaluated and excluded from subsequent analyses. The analysis of the remaining 22 species resulted in a two-axis solution that explained 79.0 percent of the dataset, with no outliers. The first axis of this PCA, explaining 51.3 percent, was positively related to flame height and fuel consumption. Species at the high extreme of the first axis included longleaf pine (*P. palustris* Mill.), loblolly pine (*P. taeda* L.), pond pine (*P. serotina* Michx.), shortleaf pine (*P. echinata* Mill.), white oak (*Q. alba* L.), and turkey oak (*Q. laevis* Walt.), while those at the low extreme included sand live oak (*Q. geminata* Small), live oak (*Q. virginiana* Mill.), laurel oak (*Q. hemisphaerica* Bartr. ex Willd.), and Virginia pine (*P. virginiana* Mill.). The second axis explained an additional 27.6 percent and was positively related to flaming and smoldering durations. The extremes of this axis included turkey oak and southern red oak (*Q. falcata* Michx.) on the protracted burning extreme and pitch pine (*P. rigida* Mill.), longleaf pine, and

Table 1--List of southeastern tree species burned in laboratory flammability experiments. Code name refers to the abbreviated species name in all figures

Species	Code name	Collection location	Data source[a]
Pinus clausa var *clausa*	Ocala sand	Ocala NF, FL	1
Pinus clausa var *immuginata*	Choct sand	Eglin Air Force Base, FL	2
Pinus echinata	shortleaf	Sterrett, AL	2
Pinus elliottii var *densa*	S Fl slash	Archbold Biol. Station, FL	1
Pinus elliottii var *elliottii*	slash	Ichauway, GA	2
Pinus glabra	spruce	Tuskegee NF, AL	2
Pinus palustris	longleaf	Ichauway, GA	2
Pinus pungens	Table Mtn	Pisgah NF, NC	2
Pinus rigida	pitch	Pisgah NF, NC	2
Pinus serotina	pond	Ocala NF, FL	3
Pinus strobus	E white	Pisgah NF, NC	2
Pinus taeda	loblolly	Ichauway, GA	2
Pinus virginiana	Virginia	Sterrett, AL	2
Quercus alba	white	Sterrett, AL	2
Quercus falcata	So red	Ichauway, GA	4
Quercus geminata	sand live	Ichauway, GA	2
Quercus hemisphaerica	laurel	Ichauway, GA	4
Quercus incana	bluejack	Ichauway, GA	4
Quercus laevis	turkey	Ichauway, GA	4
Quercus margaretta	sand post	Ichauway, GA	4
Quercus marilandica	blackjack	Sterrett, AL	2
Quercus nigra	water	Ichauway, GA	4
Quercus stellata	post	Ichauway, GA	4
Quercus virginiana	live	Ichauway, GA	4
Tsuga canadensis	E hemlock	Pisgah NF, NC	2

[a]1 = Fonda (2001); 2 = collected, unpublished data; 3 = Fonda and Varner (2004); 4 = Kane and others (2008).

loblolly pine on the brief extreme. Oaks and pines generally overlapped, each having examples of highly flammable species and those with diminished flammability (fig. 1).

Conifer Litter Flammability

The most flammable pines in this study matched or exceeded published values for pines in the western U.S. (Fonda 2001, Fonda and others 1998). As in the overall PCA, eastern hemlock was an outlier in the conifer-only PCA. The remaining 13 conifers resulted in a two-axis PCA explaining 93.4 percent of the dataset (fig. 2). The first axis of this PCA explained 57.5 percent and was most related to flame height, fuel consumption, and flaming duration. Species at the positive extreme of this axis included longleaf, loblolly, pond, shortleaf, spruce (*P. glabra* Walt.), and pitch pines, while those at the negative extreme included Ocala sand, eastern white, and Virginia pines. The second axis explained an additional 36.0 percent and was negatively related to flaming and smoldering durations. The extremes of this axis included Virginia, Choctawhatchee sand [*P. clausa* var *immuginata* (Chapm. ex Engelm.) Vasey ex Sarg.], and Table Mountain (*P. pungens* Lamb.) pines on the protracted burning extreme and Ocala sand, eastern white, pitch, longleaf, and loblolly pine on the brief extreme. Eastern hemlock burned with lower intensity than any species in North America to-date.

Oak Litter Flammability

The most- and least-flammable oaks tracked values observed for California oaks (Engber and Varner 2012). No outliers were detected in the oak-only PCA, and the two-axis solution explained 95.1 percent of the dataset (fig. 3). The first axis of this PCA explained 69.1 percent and was negatively related to flame height, fuel consumption, and flaming duration. Species at the low-flammability extreme of this axis included live and sand live oaks, while those at the high-flammability end included turkey, southern red, and white oak. The second axis

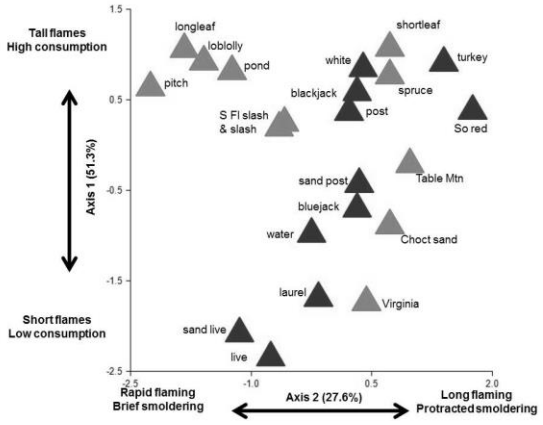

Figure 1--Principal components analysis of 22 southeastern tree species across litter flammability axes. Oaks are denoted with dark gray triangles and their common names. Pines are denoted with light gray triangles and their corresponding common names.

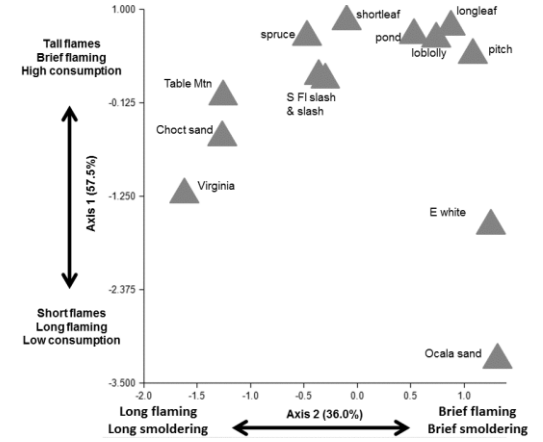

Figure 2--Principal components analysis of 13 southeastern pines across litter flammability axes.

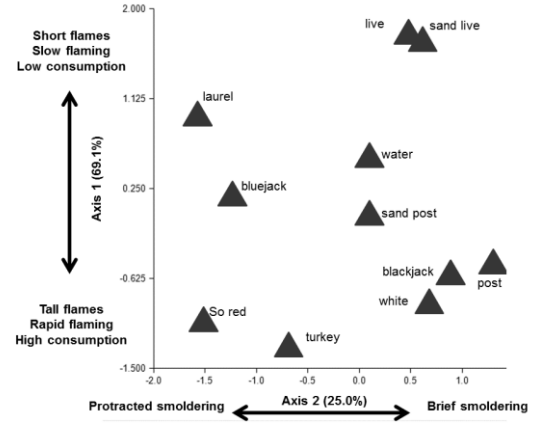

Figure 3--Principal components analysis of 13 southeastern oaks across litter flammability gradients.

explained an additional 25.0 percent and was negatively related to smoldering duration. The brief smoldering end of this axis included post oak (*Q. stellata* Wangenh.), blackjack oak (*Q. marilandica* Münchh.), and white oak, and the protracted smoldering extreme included southern red, laurel, and bluejack oak (*Q. incana* Bartr.).

Fire Management Implications

These results reveal that many southeastern trees cast highly flammable litter capable of facilitating fire spread and several that impede fire. Those highly flammable species facilitate the maintenance of fire-stable ecosystems, killing invading species that dampen flammability and decrease ecosystem integrity (Nowacki and Abrams 2006). Those species with low flammability are capable of diminishing fire intensity, enabling their persistence and the survival and persistence of other fire-impeding species that can degrade fire-prone plant communities. Future flammability work that scales these results to field fire behavior (e.g., Wenk and others 2011) will provide a stronger understanding of the consequences of fire or its exclusion on southeastern ecosystems.

CONCLUSIONS

Litter from the tree species burned in this study revealed that many southeastern species, both pines and several oaks, are highly flammable. These flammable species fuel fires that maintain open pine-oak forests and woodlands. Several species also burned with low intensity, perhaps enabling these fire-sensitive species to persist in these landscapes.

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