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Tree species influence woodland canopy characteristics and crown fire potential

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ABSTRACT

Differences in canopy structure and biomass of trees are due to evolved morphologies particular to each species, interactions with neighboring trees during stand development, and environmental constraints on growth. In this paper we examine, how foliage shape and size coupled with distribution within the canopy are important theoretical factors affecting crown fire rate of spread. To accomplish this, we sampled leaves and measured leaf area index within woodland canopies dominated by four tree species (*Juniperus ashei*, *Quercus buckleyi*, *Quercus fusiformis*, and *Quercus sinuata* var. *brevifolia*). We found that mean leaf mass per unit area (*LMA*) of the four species were significantly different affecting maximum estimated canopy mass ranging in value between 41.61 and 85.46 $g\,m^{-2}$ for *Q. buckleyi* and *J. ashei*, respectively. We found no evidence that *LMA* was affected by whether a tree was grown with same species or different species indicating that this was an intrinsic, species character. Canopy mass, and therefore fuels, was calculated by multiplying *LMA* and leaf area index at different levels within the canopies. From this we found significant differences between the species measured, particularly *Q. buckleyi* and *J. ashei* ranging between 208.2 and 572.2 $g\,m^{-2}$ and canopy bulk density (*CBD*) ranging between 15.21 and 26.06 $g\,m^{-3}$, respectively. Using a canopy fire behavior model, we found that all canopies could potentially sustain active crown fires based on recent average wind speeds (1997–2015); however a large range in critical wind speed values for these fires was found with *J. ashei* having the lowest value of 14.8 $km\,h^{-1}$ and *Q. buckleyi* the highest, 44.4 $km\,h^{-1}$ indicating importance of the dominance of different species in the canopy. Current management of these woodlands may be increasing dominance of *J. ashei* thereby impacting potential crown fire behavior.

1. Introduction

Crown fire initiation and rate of spread are affected by forest species composition as a function of leaf morphology, foliar distribution in the canopy, and growth form of individual trees (Fulé et al., 2004). Foliage morphology is typically characterized by leaf mass per unit area (*LMA*; $g\,m^{-2}$), which is the ratio of the dry matter mass of a leaf and its projected surface area. The inverse of *LMA* is the specific leaf area (*SLA*; $m^2\,g^{-1}$) that was originally derived to capture differences in leaf expansion to mass accumulation rates (Hughes, 1959). Changes in *LMA* within a plant canopy are generally associated with light transmission with leaf shape changing in response to the plant balancing photosynthetic gain through radiation interception and carbon allocation (Givnish, 1988). Plant species with higher variable *LMA* within their canopies have higher canopy-level photosynthetic rates (Gutschick and Wiegel, 1988).

Leaf area index (*LAI*; m^2 leaf area m^{-2} ground area) is a well-established plant biophysical trait which is defined as the ratio of foliar area per unit ground area represents an individual tree or stand canopy leaf surface area available for interception of radiation (Watson, 1947), water (Carlisle et al., 1967), and gas exchange (Monteith, 1965). The correspondence of *LAI* and *LMA* vertically within a canopy profile has been demonstrated for single and mixed-species forests indicating the ability of plants to adjust foliar shape under differing light regimes (White and Scott, 2006). Typically, total aerial fuels (*TAF*; $g\,m^{-2}$) and canopy bulk density (*CBD*; $g\,m^{-3}$) are canopy components that are important for assessing fire behavior in tree canopies (Van Wagner, 1977; Keane et al., 2005; Dickinson et al., 2007). These essential fuel characteristics can be derived by taking measurements of *LAI* and *LMA* at different height intervals in a canopy

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$$CM_i = LAI_i \times LMA_i \quad (1)$$

where crown mass (CM; g m^{-2}) is at each calculated at each interval (i) in the canopy then summed:

$$TAF = \sum CM_i \quad (2)$$

to calculate TAF. Because evergreen, coniferous tree species have high and deciduous broad-leafed species have low average LMA values as evolutionary adaptations to different light, water, and nutrient requirement (Niinemets, 2007), forest species composition may affect TAF. Stand TAF may also vary with site productivity, microsite differences, and disturbance regimes (Riaño et al., 2004; Cruz et al., 2010).

The volumetric distribution of foliar mass within canopies is represented by CBD (g m^{-3}) calculated by:

$$CBD = TAF/CL \quad (3)$$

where CL is the canopy length in meters (Cruz et al., 2005). Stand CBD represents the live fuel per unit volume of a canopy and is used to determine the likelihood of torching and rate of crown fire spread (Scott and Reinhardt, 2001). CBD has been also used to determine whether enough live fuel is available to sustain a crown fire (Van Wagner, 1977; Scott, 2006) and the intensity of an active crown fire (Rothermel, 1972). Species interaction and composition of a stand may also affect LMA and CBD. Crown shapes of individual trees are affected by canopy crowding, as a function of initial density of trees, indicating individual growth effects among species influenced by differences in shade tolerance (Canham et al., 2004). Canopy crowding increases physical interaction of branches among adjacent trees leading to abrasion as branches collide during wind events that results in asymmetrically-formed canopies as species differ in growth of terminal stems, regrowth of damaged tissues, and hardness of branch material (Hajek et al., 2015). In contrast, stands with species that have different crown shapes due from inherent growth habits (e.g. determinant, indeterminant) have reduced interactions with each other by filling space through complementary geometry (Pretzsch, 2014).

Population viability of individual tree species within a forest is sustained across environmental gradients where multiple species are present (Grumbine, 1994) may increase resilience to endogenous disturbances (Knoke et al., 2008), and buffer climate-change influences on ecosystem services (Ford et al., 2011). Management of multiple species within forests may be needed to balance objectives for wildlife, watershed protection, carbon accumulation, and fire risk (Hansen et al., 1991; Bullock et al., 2011). However, because wildfires may modify habitat (Yao et al., 2012), remove canopies to increase soil erosion (Yao et al., 2014), and consume site carbon (Sommers et al., 2014), addressing fire risk precedes consideration of all other management goals. Characterizing canopy fuel is an important first step for assessing fire risk because crown fire spread prediction may be predicted based on total canopy mass (Dickinson et al., 2007) and mass density (Van Wagner, 1977). Coarse estimates of canopy fuels and structure may be derived from measurement of leaf area that when coupled with averaged LMA provide stand level values. Stand species composition potentially influences variation in fire-related canopy characteristics due to intrinsic differences in foliage shape and mass. More information is necessary to understanding the linkage between tree species and canopy characteristics that potentially affect crown fire behavior.

2. Materials and methods

2.1. Site description

The Balcones Canyonlands National Wildlife Refuge (BCNWR) (Lat. 30.32°N, Long. 97.73°W) and the Balcones Canyonlands Conservation Preserve (BCCP) (Lat. 30.63°N, Long. 98.04°W) are located in the central Texas hill country of the Edward's Plateau Region. The BCNWR is managed by the U.S. Fish and Wildlife Service (USFWS) and is comprised of 6500 ha. The BCCP is comprised of 5300 ha and is managed jointly by the City of Austin, Texas and Travis County, Texas. Both of these preserves are comprised of land tracts that are actively managed for endangered species. The refuges serve as breeding grounds for two federally listed endangered species of birds: the golden-cheeked warbler (*Setophaga chrysoparia*), and the black-capped vireo (*Vireo atricapilla*) (USFWS, 1992). The refuge tracts are interspersed within private lands, primarily comprised of grazing operations surrounding BCNWR, and urban development for BCCP creating a definitive wildland urban interface.

The geology of the Balcones region is dominated by outcropping of the Glen Rose (upper Cretaceous), Walnut (lower Cretaceous), and Edwards (lower Cretaceous) limestone formations. Well-drained, clay loam soils have developed from this parent material that covers a distinctive plateau and valley topography with over 300 m of relief. The valleys are dominated by grasslands comprised of *Andropogon gerardii*, *Bouteloa gracilis*, *Schizacyrium scoparium*, and the introduced invasive *Bothriochloa ischaemum*. Riparian forests are found in creek bottoms composed of by tree species including: *Quercus buckleyi*, *Prunus serotina* var. *eximia*, *Juglans major*, *Ulmus crassifolia*, *Juniperus ashei*, and *Quercus fusiformis*. *J. ashei* and *Q. fusiformis* are found on mid-slopes on most aspects, with north-facing slopes dominated by the deciduous oaks *Q. buckleyi* and *Quercus sinuata* var. *brevifolia*, including sub-dominant species such as *P. serotina* var. *eximia*, *Diospyros texana*, *U. crassifolia*, *Celtis laevigata*, and *Ilex vomitoria*. The plateaus are partially covered by short, scrubby *J. ashei* groves (colloquially known as cedar brakes), grasslands (with same species as in the valleys), *Opuntia* spp. thickets, shrubby *Q. sinuata* var. *brevifolia* stands, and/or and bare limestone.

Four dominant woodland tree species were examined for this study including: *J. ashei*, *Q. fusiformis*, *Q. buckleyi*, and *Q. sinuata* var. *brevifolia*. *J. ashei* is a scaled-leaf evergreen conifer that grows to around 10 m in height, tolerates drier soils, and is probably shade intolerant (Adams, 1977; Diamond, 1997). This species does not resprout following fire or cutting and reproduces by large crops of berries dispersed by mammals and birds. *Q. fusiformis* is an evergreen broad-leaved oak that can grow 12 m, can tolerate dry slopes, and is moderately shade tolerant (Lin et al., 2001). It regrows vigorously post-fire from lateral root-sprouting. *Q. buckleyi* is a deciduous, broad-leaved oak that grows to around 12 m, grows rapidly in large canopy gaps (shade intolerant) (Murray et al., 2013a), prefers well-watered, loamy soils, and sprouts vegetatively from the root ball following fire (Andruk et al., 2014). *Q. sinuata* var. *brevifolia* is a deciduous, broad-leaved oak that is shade and competition intolerant (Reemts and Hansen, 2008). It can grow to height of 12 m in deeper soils or form a copse that is less than 4 m (known as shinneries) in shallow soils.

2.2. Canopy measurement

For this study, we measured mature, healthy dominant, trees located in forested stands with contiguous canopy cover (>80%) and were separated from other sampled trees by a minimum distance of 30 m. Individual crowns of trees sampled were considered