Are native plants all a fire hazard?: Canopy flammability of Texas shrubs.  
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# Chapter onE

# Introduction

The interaction between vegetation and fire has existed since the origin of land plants and fire is a dominant driver of change in many terrestrial ecosystems (Bond, 2005; Bowman, et al., 2009; Pausas & Keeley, 2009). However, fire can be life-threatening, brings many difficulties by destroying homes and can alter wildlife habitats. As a result, fire has been viewed as a destructive force and its ecological role has been overlooked to a great extent in the history of ecological science (Bond & Keeley, 2005; Pausas & Schwilk, 2012). Due to the failure of granting fire as an inseparable part of many ecosystems, fire had been suppressed in a massive scale in recent past, but fire is always influential no matter whether we repress it or not (Pyne, 2017). For instance, due to the fire suppression, an imbalance of total fuel load has been emerged in many fire-adapted ecosystems which were subject to periodic fire, and it is an important factor along with the climate change behind the frequent wildfire we have been experiencing in many parts of the globe now a days (Shang, et al., 2007; Steel, et al., 2015). Given the fact that, we have been witnessing an increasing trend of wildfire activity in various corners of the worlds (Dennison, et al., 2014; Salguero, et al., 2020; Williams, et al., 2019; Westerling, 2016), there is an increasing awareness of mitigating the detrimental effects of wildfire. For instance, there is an increasing awareness of fire-safe planting around homes (Moore-Gough, et al., 2001; Fitzgerald & Waldo, 2002; Detweiler, et al., 2006) and increasing regulations requiring clearing of fuels around structures. Therefore, for dealing with fire more effectively to maintain ecosystems’ health and reduce fire hazard, we need a better understanding of plant flammability and how plant traits influence fire severity.

The initiation of wildfire depends on the amount of plant material present in ecosystems to sustain fire and the different physical and chemical properties of plants determines how they interact with fire (Bond & van Wilgen, 1996). In addition, it is well recognized that plants have both inter and intra species specific differences in their ability to get burnt (Pausas, et al., 2012; Cui, et al., 2020; Cui, et al., 2022; Wyse, et al., 2016). Communities, dominated by few or even single species, the properties of individual plant species determine how and whether fire consumes the entire community or not (Bond & van Wilgen, 1996) and the flammability of dominant plant species strongly determines how vegetation burns in a community and therefore a fundamental element determining fire’s ecological effects (Bond & Midgley, 1995; Lavorel & Garnier, 2002; Bond, 2005). For instance, the shrublands, woodlands, and savannas of central Texas are fire prone ecosystems. There is already recognition that plant species have different contributions to fire hazard in this region. For example, increasingly continuous fuels that result from juniper expansion can lead to increased crown fire hazard and intense fires such as the 2011 Bastrop County Complex fires. However, measuring flammability of plant species and ranking them based on their flammability, is not always straightforward. One complication is that the concept of flammability of plants is subjective (Gill & Zylstra, 2005) and methodological differences on studies is prevalent (Weise, et al., 2005; Pausas, et al., 2012; Jaureguiberry, et al., 2011). Historically, flammability has been grouped into four different components: ignitibility, combustibility, consumability and sustainability (Anderson, 1970; Martin, et al., 1993) and viewed them as independent to one another. However, empirical evidence suggests that these metrics are intercorrelated and that view also fails to treat flammability as a plant trait which has ecological and evolutionary consequences. However, to quest for a holistic view which will offer an ecological and evolutionary perspective of plant flammability, (Pausas, et al., 2017) suggested that flammability has three major axes that are not necessarily correlated with one another: ignitability, heat release, and fire spread rate even though field experiment doesn’t support the existence of ignitability as a separate independent axis (Prior, et al., 2018). Nonetheless, past work in surface fire systems suggests that the flammability of leaf litter varies along two largely orthogonal dimensions, total heat release and flame spread rate (de Magalhaes & Schwilk, 2012; Cornwell, et al., 2015) and more recently, (Prior, et al., 2018) suggested that this is a more generalizable pattern and could be used to upscale the fire behavior in community level and to investigate evolutionary consequences of fire on plants. However, this framework has yet to be explored thoroughly in canopy level flammability experiment.

In shrublands and grasslands, having insignificant amount of vertical fuel layer, is considered crown fire (Schwilk, 2015) and in different spatial-temporal scale, it is the most dominant fire in terms of total area burned annually and fire frequency (Mouillot & Field, 2005; Keeley, et al., 2011) and often cause more damage than other types of fire (Moore-Gough, et al., 2001). However, shrub fuels and transitions between grass fuels and shrubs are coarsely handled by most fire behavior models. In addition, a great deal of studies focused on single or few species and were limited to one or few plant traits, such as total biomass (Bond & van Wilgen, 1996). Additionally, most of the early flammability studies focused on burning individual leaves to upscale fire behavior and seldom consider special arrangements of plant parts which has a great influence on fire behavior (Bond & van Wilgen, 1996; Schwilk, 2003; Gao & Schwilk, 2018). Moreover, (Alam, et al., 2020) suggested that shoot level flammability is different than leaf level flammability and individual leaf flammability is a poor predictor of fire behavior in crown fire (Fernandes & Cruz, 2012). Therefore, it is important to use methods that measure flammability of whole or partial plant canopies which retains the special arrangement of plant parts and linking canopy traits to observed canopy flammability might help improve fire hazard mapping and fire behavior models.

Predicting from plant traits to fire behavior in ecosystem level is an important step in fire ecology (Schwilk, 2015) and decoupling the effect of plant traits on fire behavior from environmental factors has yet to be accomplished (Mutch, 1970; Troumbis and Trabaud, 1989; Bond and Midgley, 1995; Schwilk, 2003; Fernandes & Cruz, 2012; Pausas et al., 2012; Schwilk, 2015). For instance, total biomass (fuel load) is certainly a strong driver of fire behavior and often used to predict fire behavior model (Byram, 1959; McArthur, 1966; McArthur, 1967; Rothermel, 1972) but it is not the only one. Other plant traits are important to plant flammability including canopy architecture traits (leaf arrangement, canopy density, retention of dead branch, packing ratio). For example, some coniferous forests burn with high intensity because the crown of the trees are tightly packed and have low moisture content (Bond & van Wilgen, 1996). In dense canopies, rapid heat transfer allows fire to easily propagate from one branch to another and more susceptible to crown fire (Bradstock, et al., 2002; Keeley, et al., 2009). Apart from that, standing dead branch in the main trunk of tall tress might help the surface fire to reach the crown fire and dead branch retention is considered an influential canopy architecture traits in flammability (Schwilk, 2003). In addition, the proportion of dead biomass in the canopy is also significant to allowing further combustion (Bond & van Wilgen, 1996). Most importantly, dead biomass is also an influential factor for initiating ignition during fire occurrence. Likewise canopy density and dead biomass, the packing ratio as the ratio of fuel to air (surface area to volume ratio), has a great effect on availability of oxygen in fire (Bond & van Wilgen, 1996; Schwilk, 2015) and fire severity (Cornwell, et al., 2015; de Magalhaes & Schwilk, 2012) For instance, large diameter, bulky stems with spiny leaves lose moisture slowly than plant parts with small diameter and finely divided leaves (Bond & van Wilgen, 1996). However, compared to the surface fuel, canopy fuel characterization has not been explored thoroughly due to the unmanageable nature of shoot level flammability experiment (Schwilk, 2015). Therefore, to deal with the crown fire more effectively, characterization of the canopy fuel is required.

It is obvious that, burning the whole plant would be more insightful to understand the crown fire behavior (Stephens, et al., 1993; Etlinger & Beall, 2004) but it is harder to get enough sample size by burning the entire plants (Jaureguiberry, et al., 2011; Pausas, et al., 2012). Moreover, flammability experiment often criticized when it fails to replicate the real-world conditions (Fernandes & Cruz, 2012). For instance, laboratory-scale flammability experiment often chooses healthy plant parts to burn and ignore the catalytic influence of dead fuel which can’t imitate the real-world situation particularly when the ratio of dead and live fuel is high (Fernandes & Cruz, 2012). Therefore, it is important to use a method that can make measurements easily reproducible and can be more efficient in imitating the real-world situations.