

# SPATIAL AND SEASONAL FLAMMABILITY COMPARISONS OF NATIVE AND EXOTIC PLANTS IN THE POST OAK SAVANNAH, BLACKLAND PRAIRIE, AND PINEYWOODS ECOREGIONS OF TEXAS

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**Abstract**—Greater knowledge of plant flammability can improve prescribed fire effectiveness and wildfire mitigation strategies by improving fire behavior predictions in physics-based fire models and supplementing Firewise plant listings with flammability indices. Seasonal and regional changes in flammability parameters were estimated for yaupon (*Ilex vomitoria*), Chinese privet (*Ligustrum sinense*), greenbrier (*Smilax* spp.), and Chinese tallow (*Triadica sebifera*) within the Post Oak Savannah, Blackland Prairie, and Pineywoods Ecoregions of Texas. Foliage (yaupon, privet, and greenbrier) and wood (tallow) samples were collected in the dormant (February) and growing (August) seasons. Wood samples were collected from Chinese tallow due to dormant season leaf-off. Samples were evaluated using thermogravimetric analysis to estimate relative spontaneous ignition temperature (RSIT) and gas-phase maximum mass loss rate (GP-MMLR). RSIT and GP-MMLR are estimates of plant ignitability and combustibility. Yaupon was the most ignitable species during both seasons and across all three ecoregions. Chinese privet dormant season ignitability was similar to yaupon in the Post Oak Savannah and Blackland Prairie. Greenbrier exhibited the greatest growing season combustibility combined with moderate ignitability. Chinese tallow wood exhibited substantially greater ignitability and combustibility in the growing season. Collectively, all species exhibited seasonal and ecoregion variances in ignitability, while combustibility varied little relative to season and ecoregion. These data provide insight into potential species-specific contributions to fire behavior that may aid in more informed fire management planning.

## INTRODUCTION

Hazardous fuels reduction and restoration and maintenance of fire-adapted ecosystems in Texas continue to be management priorities. Texas' year-round fire season adds to fire management complexity in terms of wildfire suppression in both dormant and growing seasons (Texas A&M Forest Service 2012). Prescribed fire continues to play an important role in reducing woody fuel loads in forest and grassland ecosystems. Subsequent reductions in fuel loads reduce fire intensity and spot fire potential leading to improved fire containment, decreased heat exposure to desired species, and less ignition risk to adjacent residential and commercial buildings. Therefore, improved knowledge of wildland fuel flammability could aid fire managers in meeting prescribed fire prescriptions and potentially reduce losses associated with wildfires.

Active fire suppression and passive and poor management have allowed prolific growth and expansion of invasive and weedy native species that contribute to increased regional fuel loads. For example, yaupon (*Ilex vomitoria*) is considered a weedy native often found in great densities in unmanaged forests and pine (*Pinus* spp.) plantations (Shadow 2011), as well as mixed grass woodland ecosystems, especially the Post Oak Savannah (Mitchell and others 2005). Chinese privet (*Ligustrum sinense*) and Chinese tallow (*Triadica sebifera*) are exotic invasive species that exhibit prolific growth, vigorous resprouting when damaged, high reproductive capacity, and are abundant along waterways, fence lines, and forest edges (Greene and Blossey 2012, Pile and others 2017). Greenbrier (*Smilax* spp.) has been known to outcompete native grasses in oak woodlands, and is often targeted by prescribed burning in prairie and savannah restoration projects (Sparks and others 2012).

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The objective of this study was to estimate spatial and seasonal ignitability and combustibility trends for yaupon, greenbrier, Chinese privet, and Chinese tallow in three east Texas ecoregions for the purpose of quantifying key plant flammability indices for possible inclusion into Firewise plant listings, and identifying potential risks or opportunities associated with prescribed burn programs. To our knowledge, flammability estimates have not been conducted on Chinese privet or Chinese tallow, and new insight into their spatial and seasonal flammability could be useful for improving prescribed fire effectiveness and hazard classification. Since flaming combustion is the primary driver of fire spread, our study focused on estimating ignitability and gas-phase combustibility. Thermogravimetric analysis (TGA) was used to evaluate oxidative thermal degradation profiles to estimate ignitability and combustibility parameters for select species.

## METHODS

### Study Sites

Regional flammability influences were based on selection of ecoregions where two exotic invasive species, Chinese privet and Chinese tallow, and two native species, yaupon and greenbrier, were present. All species have naturalized populations within the Pineywoods, Post Oak Savannah, and Blackland Prairie ecoregions of Texas (Diggs and others 1999, Diggs and George 2006, Oswalt 2010, Wang and Grant 2014). Pineywoods sample sites were on the Stephen F. Austin State University campus and Stephen F. Austin Experimental Forest near Nacogdoches, TX. Post Oak Savannah sites were located at the Texas A&M University Equine Center and Veterans Park in College Station, TX. Blackland Prairie sites were located at the Trinity River Audubon Center and White Rock Lake in Dallas, TX.

Pineywoods sites consisted of mixed pine and hardwood forests on Alfisol and Inceptisol soils with little topographic relief. Post Oak Savannah sites consisted of mixed post oaks (*Quercus stellata*) and live oaks (*Quercus virginiana*) on Alfisol and Inceptisol soils with gently rolling terrain. Blackland Prairie sites exhibited a mix of live oak, cedar elm (*Ulmus crassifolia*), sugarberry (*Celtis laevigata*), and eastern red cedar (*Juniperus virginiana*) on Alfisol, Mollisol, Inceptisol, and Vertisol soils with flat rolling terrain.

### Sampling

Chinese privet, yaupon, and greenbrier foliage samples were collected from the same five plant specimens in each ecoregion ranging from 0 to 2 m in height during both seasons, and Chinese tallow wood samples were collected using the same parameters. Samples were collected in the dormant (February) and growing

(August) season. Seasonal sampling was coordinated across three study ecoregions to account for spatial influences on flammability. Foliage samples were flash frozen with liquid nitrogen and ground using a standard coffee grinder, while wood samples were ground in a standard Wiley mill. Ground samples were dried in an air convection oven at 40 °C for 48 hours and passed through a standard series of sieves to obtain the 35 mesh fraction for TGA analysis.

### Processing

Thermogravimetric analysis is a common method used to estimate plant flammability through the use of ground samples that focus on chemical composition, while reducing combustion variability associated with plant physical properties (White and Zipperer 2010). Anderson (1970) defines ignitability as the time-to-ignition and combustibility as the rapidity of combustion. Thermogravimetric estimates of ignitability are based on relative spontaneous ignition temperature (RSIT) in an air atmosphere under a predetermined linear heating rate up to 650 °C, with higher RSITs representing lower pilot ignition temperatures and flash points and are therefore more ignitable (Liodakis and others 2008, Liodakis and Kakardakis 2008). Combustibility estimates are a function of maximum mass loss rates (MMLR), meaning samples with greater MMLR are more combustible.

Thermogravimetry was conducted using a Perkin Elmer Simultaneous Thermal Analyzer (STA) 6000. Samples were weighed to ~20 mg and placed in a porcelain crucible. Heating range was 35–650 °C with a 10 °C min<sup>-1</sup> linear heating rate. Purge gas was air (~21% O<sub>2</sub>) set at 20 ml min<sup>-1</sup>. Differential thermogravimetric (DTG) peaks were evaluated by measuring the mass loss as a function of temperature and time at the onset, maxima, and endset peaks to yield flammability parameters using Pyris 13.2 software. Second derivative peaks were also used to inform onset and endset reaction peaks corresponding to the first derivative (DTG). Five individual species samples underwent TGA analysis according to the above specifications. Descriptive statistics were used to compare seasonal and regional differences in RSIT and GP-MMLR.

## RESULTS

Mean dormant season foliage RSIT yielded an ignitability ranking order of yaupon, Chinese privet, and greenbrier, with yaupon exhibiting greater ignitability (fig. 1). Interestingly, yaupon and Chinese privet had similar ignitability in the Post Oak Savannah and Blackland Prairie. Mean growing season foliage RSIT produced an ignitability ranking order of yaupon, greenbrier, and Chinese privet (fig. 2). Yaupon had the greatest growing season ignitability; however, greenbrier exhibited a considerable increase in ignitability, while Chinese privet had a moderate decrease. Substantial mean seasonal

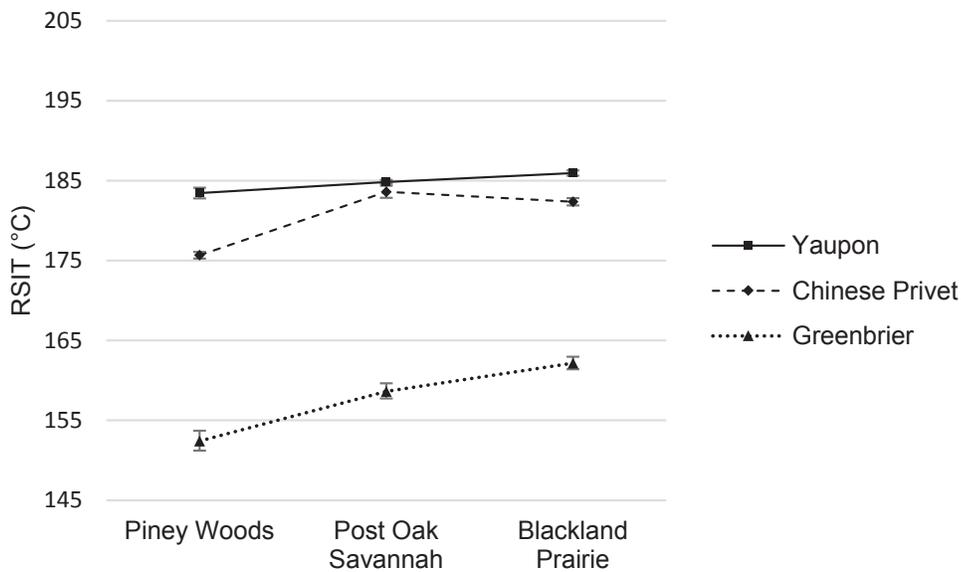


Figure 1—Mean dormant season relative spontaneous ignition temperature (RSIT) for yaupon, Chinese privet, and greenbrier foliage in the Piney Woods, Post Oak Savannah, and Blackland Prairie.

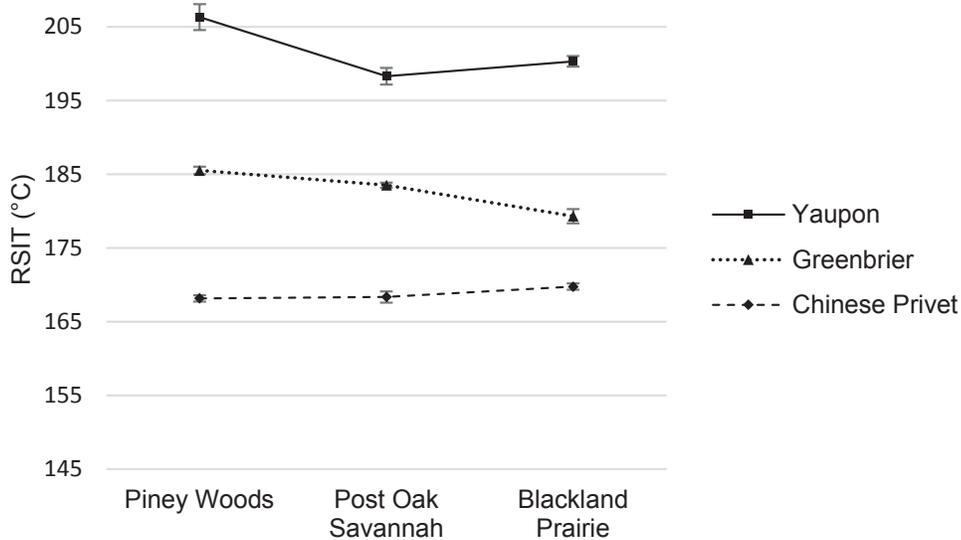


Figure 2—Mean growing season relative spontaneous ignition temperature (RSIT) for yaupon, Chinese privet, and greenbrier foliage in the Piney Woods, Post Oak Savannah, and Blackland Prairie.

differences in RSIT existed among species ranging from 11.8 to 25.0 °C (table 1). In contrast, mean regional differences in RSIT were greater in seasons associated with greater species-specific ignitability (table 2).

Mean dormant season foliage GP-MMLR yielded a combustibility ranking order of yaupon, greenbrier, and Chinese privet, with yaupon exhibiting greater ignitability (fig. 3). Pineywoods species yielded the greatest differences in combustibility. Mean growing season foliage GP-MMLR produced a combustibility ranking order of greenbrier, yaupon, and Chinese privet (fig. 4).

Greenbrier produced substantially greater growing season combustibility compared to yaupon, especially in the Pineywoods. Mean seasonal effects among species foliage combustibility produced little variance (table 1). Likewise, mean regional species foliage GP-MMLR slightly differed (table 2).

Mean seasonal RSIT for Chinese tallow wood exhibited substantially greater ignitability in the growing season as opposed to the dormant season (fig. 5). The Blackland Prairie yielded the greatest range in Chinese tallow wood ignitability, with the least dormant and greatest

**Table 1—Mean seasonal differences in relative spontaneous ignition temperature and gas-phase maximum mass loss rate within ecoregions by species**

Source/species	RSIT (°C)	GP-MMLR (%/min)
Foliage		
Yaupon	16.96 (5.26)	0.18 (0.03)
Chinese privet	11.80 (3.94)	0.15 (0.12)
Greenbrier	25.04 (7.98)	0.93 (0.42)
Wood		
Chinese tallow	22.91 (4.80)	2.28 (1.13)

Figures in parentheses are standard deviations.

RSIT = relative spontaneous ignition temperature and GP-MMLR = gas-phase maximum mass loss rate.

growing season RSIT. Similarly, Chinese tallow exhibited greater growing season combustibility compared to dormant season GP-MMLR (fig. 6). Chinese tallow exhibited the greatest GP-MMLR range in the Blackland Prairie. Differences in mean seasonal RSIT's were much greater as compared to GP-MMLR (table 1). Regionally, Chinese tallow exhibited greater differences in RSIT in the growing season, while differences in GP-MMLR remained relatively similar (table 2).

## DISCUSSION

Thermogravimetric analysis yielded similar mass decomposition profiles from past studies conducted in air atmospheres, which represent two distinct thermogravimetric peaks linked to gas- and solid-phase combustion (Jones and others 2015, Liodakis and Kakardakis 2008, Munir and others 2009). Analysis of gas-phase combustion peaks yielded reasonable ignitability and combustibility estimates relative to species respective RSIT and MMLR indices.

As expected, yaupon was the most ignitable species among foliage samples, and was consistent with previous studies and anecdotal accounts (Long and others 2006). Additionally, yaupon exhibited relatively high combustibility and was readily ignited; therefore, fire managers should exercise caution when prescribed burning and actively suppressing fires in fuel beds with dense yaupon. Dormant season Chinese privet ignitability was also comparable to yaupon in the Post

**Table 2—Mean ecoregion differences in relative spontaneous ignition temperature and gas-phase maximum mass loss rate among species with respect to season and ecoregion**

Source/season/species	RSIT (°C)	GP-MMLR (%/min)
Foliage		
Dormant		
Yaupon	1.67 (0.74)	0.39 (0.24)
Chinese privet	5.29 (3.56)	0.23 (0.19)
Greenbrier	6.50 (3.11)	0.32 (0.18)
Growing		
Yaupon	5.35 (3.05)	0.35 (0.24)
Chinese privet	1.07 (0.77)	0.37 (0.28)
Greenbrier	4.14 (2.10)	0.49 (0.41)
Wood		
Dormant		
Chinese tallow	0.62 (0.27)	1.71 (0.80)
Growing		
Chinese tallow	5.76 (2.55)	2.03 (1.58)

Figures in parentheses are standard deviations.

RSIT = relative spontaneous ignition temperature and GP-MMLR = gas-phase maximum mass loss rate.

Oak Savannah and Blackland Prairie, and may allow for more effective control using prescribed fire. Conversely, greater Chinese privet densities may contribute to greater wildfire intensity, potentially leading to larger and more severe wildfires (Wang and others 2016). High growing season combustibility associated with greenbrier warrants caution during late dormant season prescribed burns. Greenbrier may also present a greater risk of torching and crown fire initiation in woodlands and forest stands where vines extend into the canopy, thus acting as a readily combustible ladder fuel.

Chinese tallow continues to be a regionwide problem in forests, grasslands, and riparian corridors. High growing season ignitability and combustibility of Chinese tallow wood may allow for more integrated management options using prescribed fire. Although ignitability and combustibility of Chinese tallow wood is quite variable, prescribed burning of growing season masticated wood residue may be an effective control for resprouting trees and seed bank management (Pile and others 2017).

Substantial differences in species ignitability with respect to season were potentially influenced by annual variation in photoperiod, temperature, and moisture regimes, as well as edaphic and minor topographic variation. In contrast, species combustibility did not appear to be greatly influenced by season or region. Regional ignitability results for yaupon, Chinese privet, and Chinese tallow exhibited greater differences in

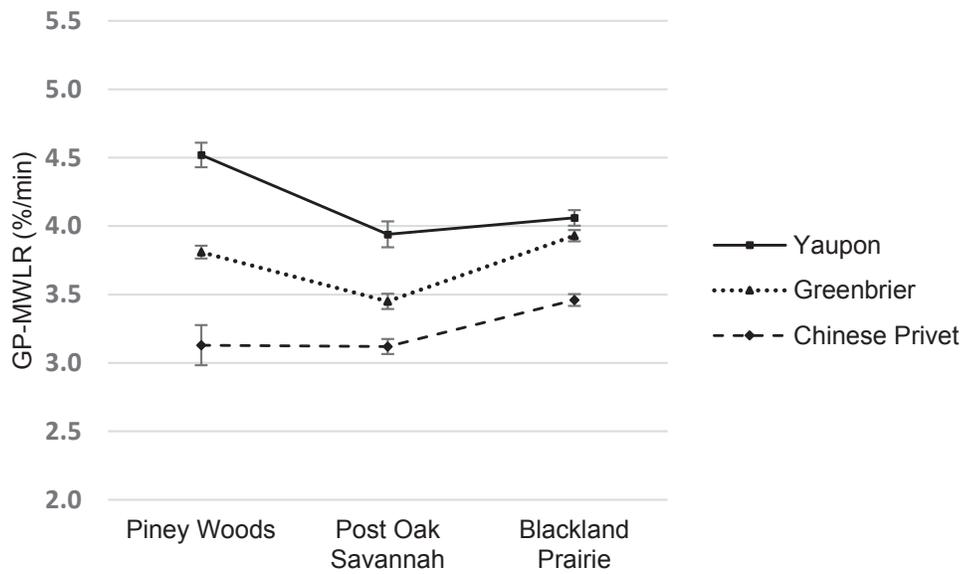


Figure 3—Mean dormant season gas-phase maximum mass loss rate (GP-MMLR) for yaupon, Chinese privet, and greenbrier foliage in the Piney Woods, Post Oak Savannah, and Blackland Prairie.

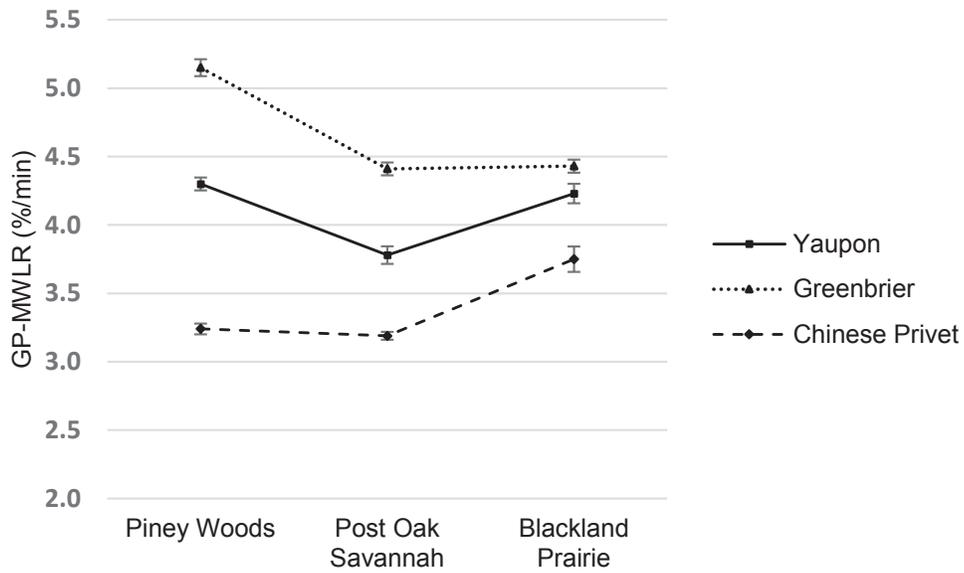


Figure 4—Mean growing season gas-phase maximum mass loss rate (GP-MMLR) for yaupon, Chinese privet, and greenbrier foliage in the Piney Woods, Post Oak Savannah, and Blackland Prairie.

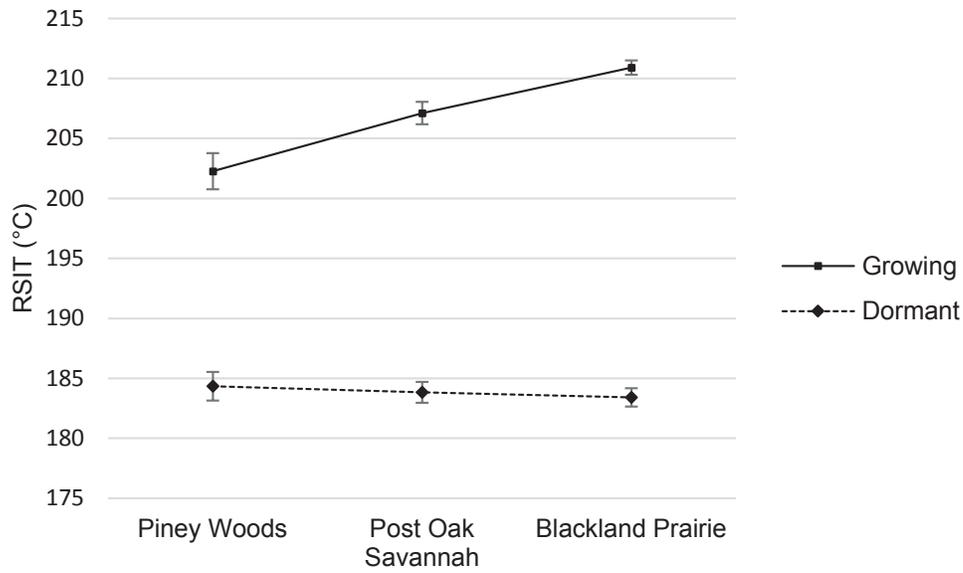


Figure 5—Chinese tallow wood mean dormant and growing season relative spontaneous ignition temperature (RSIT) for the Piney Woods, Post Oak Savannah, and Blackland Prairie.

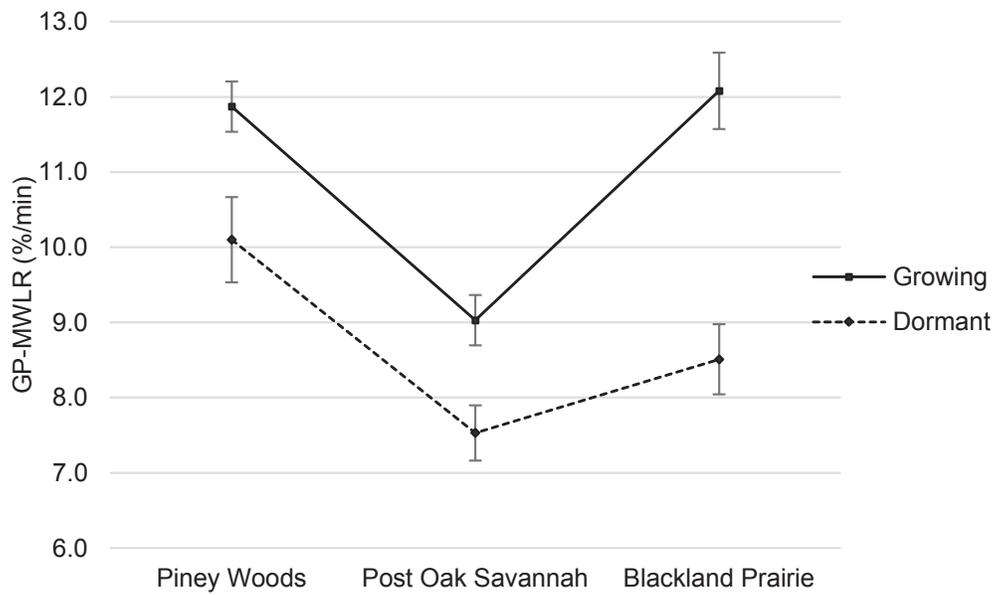


Figure 6—Chinese tallow wood mean dormant and growing season gas-phase maximum mass loss rate (GP-MMLR) for the Piney Woods, Post Oak Savannah, and Blackland Prairie.

ignitability associated with their respective season of greatest ignitability. Yaupon and Chinese tallow exhibited greater growing season ignitability across all three ecoregions suggesting greater differences in live fuel moisture or production of volatile compounds maybe linked to active growing conditions. Conversely, Chinese privet exhibited greater differences in dormant season ignitability suggesting active growth and subsequent changes in live fuel moisture or volatile compound production may occur opposite of its native associates. Greenbrier exhibited relatively high variation in ignitability with respect to region and season, suggesting ignitability maybe further influenced by associated cover type and edaphic conditions.

## CONCLUSIONS

This study focused on estimating spatial and seasonal flammability trends of four east Texas plant species. Thermogravimetric analysis was used to estimate ignitability and combustibility parameters by evaluating oxidative thermal decomposition curves associated with species foliage and wood samples. Mean seasonal and ecoregion RSIT estimates for ignitability varied considerably for all species, while mean seasonal and ecoregion combustibility estimates for GP-MMLR exhibited little variation among species, with the exception of Chinese tallow. These findings provide a preliminary estimation of spatial and seasonal trends in species-specific flammability, which may aid in greater prescribed fire effectiveness and improve species hazard classifications aimed at reducing wildfire risk. However, bench-scale flammability testing using TGA is limited to small ground samples, thus further large-scale flammability testing is needed to validate flammability estimates. Furthermore, ignitability estimates based on higher RSIT values require further testing and validation to confirm the accuracy of this methodology.

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