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Legal barriers to effective ecosystem management: exploring linkages between liability, regulations, and prescribed fire

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Abstract. Resistance to the use of prescribed fire is strong among many private land managers despite the advantages it offers for maintaining fire-adapted ecosystems. Even managers who are aware of the benefits of using prescribed fire as a management tool avoid using it, citing potential liability as a major reason for their aversion. Recognizing the importance of prescribed fire for ecosystem management and the constraints current statutory schemes impose on its use, several states in the United States have undertaken prescribed burn statutory reform. The stated purpose of these statutory reforms, often called "right to burn" or "prescribed burning" acts, is to encourage prescribed burning for resource protection, public safety, and land management. Our research assessed the consequences of prescribed burn statutory reform by identifying legal incentives and impediments to prescribed fire application for ecosystem restoration and management, as well as fuel reduction. Specifically, we explored the relationship between prescribed burning laws and decisions made by land managers by exploiting a geographic-based natural experiment to compare landowner-prescribed fire use in contiguous counties with different regulations and legal liability standards. Controlling for potentially confounding variables, we found that private landowners in counties with gross negligence liability standards burn significantly more hectares than those in counties with simple negligence standards ($F_{6,72} = 4.16$, $P = 0.046$). There was no difference in hectares burned on private land between counties with additional statutorily mandated regulatory requirements and those requiring only a permit to complete a prescribed burn ($F_{6,72} = 1.42$, $P = 0.24$) or between counties with burn ban exemptions for certified prescribed burn managers and those with no exemptions during burn bans ($F_{6,72} = 1.39$, $P = 0.24$). Lawmakers attempting to develop prescribed burning statutes to promote the safe use of prescribed fire should consider the benefits of lower legal liability standards in conjunction with regulatory requirements that promote safety for those managing forests and rangelands with fire. Moreover, ecologists and land managers might be better prepared and motivated to educate stakeholder groups who influence prescribed fire policies if they are cognizant of the manner in which policy regulations and liability concerns create legal barriers that inhibit the implementation of effective ecosystem management strategies.

Key words: liability; local geographic ignorability; natural experiment; negligence; open burning law; prescribed fire; right to burn act.

Introduction

An emphasis on fire suppression has altered fire regimes in many ecosystems worldwide (Reinhardt et al. 2008, Moreno et al. 2014). Historical fire regimes played an important role in maintaining many natural systems (Pyne 1982) and regime alterations can have numerous detrimental effects. For instance, a change from frequent low-intensity fires to infrequent high-intensity fire in forests of the southeastern United States has resulted in the replacement of many loblolly pines by less valuable forest species (Drewa et al. 2002). Suppression of frequent fires in semiarid rangeland and mesic grasslands leads to shrub encroachment, lowering forage productivity and degrading habitat for grassland birds and mammals, many of which are threatened and endangered worldwide (Knapp et al. 2008, Van Auken 2009, Twidwell et al. 2013). Often, fire regime alterations also facilitate invasion by nonnative species (D'Antonio 2000, Mooney and Hobbs 2000).

In many systems, fire suppression results in vegetation structures that promote more intense fires (Stephens and Ruth 2005, Keane et al. 2008). Severe fires in systems adapted to low-intensity fires can lead to structural and compositional alterations within the plant community, which often reduce ecosystem resilience (Stephens et al. 2014). Often such plant community shifts following severe fire contribute to soil erosion and sedimentation in streams and reservoirs (McNabb and Swanson 1990). Intense fires can also lead to property loss, injury and

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loss of life, and may require enormous expenditures to bring them under control.

Prescribed fire is a cost-effective tool for range and forest restoration and management (Van Liew et al. 2012). It allows managers to impose a fire regime tailored to their management objectives. However, despite the benefits of prescribed burning for land and fuels management, landowners often choose not to use fire due to fear of liability (Haines et al. 2001, Yoder et al. 2004, Yoder 2008, Sun and Tolver 2012, Toledo et al. 2012).

Generally, civil liability standards in the United States for prescribed fire fall into three categories: strict liability, simple negligence, and gross negligence. A rule specifying strict liability holds burners liable for any property damage caused by an escaped prescribed fire, regardless of the action of the burner; it creates the highest level of liability for anyone using prescribed fire. Only five states have standards that suggest the stringency of strict liability, although the statutes do not all explicitly state that strict liability is the standard. Hawaii, for example, makes escape of fire evidence that, if unrebutted, is sufficient to prove willfulness, malice, or negligence (HRS §185-7). Simple negligence standards require the burner to practice reasonable care in applying a prescribed burn; they are the most common rules for prescribed fire and require the plaintiff to show negligence by the defendant in order for the burner to be liable for damage caused by escaped wildfire. They can either be explicitly stated statutorily as in Texas (Tex. Nat. Res. Code §153.081), or established through case law as in New Mexico. Gross negligence liability standards provide that, if a burner follows a set of codified regulations regarding burning, a plaintiff must show reckless disregard of the duty of care owed others by the burner. Usually, in states with gross negligence rules, simple negligence will apply if the regulatory requirements are not fulfilled (Sun 2006, Yoder 2008, Sun and Tolver 2012). Statutes identifying gross negligence liability standards have recently been enacted in several states (e.g., Florida Prescribed Burning Act (590,125(3)); Sun 2006; and see Coalition of Prescribed Fire Councils, *available online*).[2]

Recognizing the considerable ecosystem changes that have resulted from prolonged fire suppression policies and the need to make prescribed burning available as a management option, many states, especially in the southeastern United States, have undergone statutory reform in order to promote the safe use of prescribed fire. The stated purpose of these statutory reforms, often called "right to burn" or "prescribed burning" acts, is to encourage prescribed burning for resource protection, public safety, and land management (e.g., Georgia Prescribed Burning Act [O.C.G.A. §12-6-146], Tennessee Prescribed Burning Act [T.C.A. §68-102-146]). These reforms usually include a statutory statement of the liability standard to be applied in case of loss of control over a prescribed fire. In some cases, simple negligence is applied, but in several states, gross negligence standards have been adopted. Most of the statutes also include regulations that ensure that the burn is carried out safely, and limited liability in the form of a gross negligence standard can be used to incentivize prescribed burn practitioners to receive training and undertake various safety precautions prior to burning. For instance, in Florida, burners who have been certified by the state-certified prescribed burn program and have written burn plans and adequate personnel and firebreaks will be subject to a gross negligence standard in court, whereas, those not certified to burn or lacking the requisite preventative measures during the burn will face the more stringent simple negligence standard in the event of an escape.

It is uncertain that these reforms are achieving their intended purpose of encouraging greater use of prescribed burning while maintaining safety and limiting escapes. Stringent regulations included in statutory reforms and mandated for protection under the gross negligence standards might serve as a disincentive to burning (McCullers 2013). Additionally, many states have adopted stringent regulatory requirements for protection under prescribed fire acts, but have not suitably incentivized burners to receive training and follow regulations by providing limited liability for those appropriately trained and prepared. While it might be easier to prove negligence if a burner has not followed all regulatory precautions outlined in the statute, he would still be subject to the same level of liability as a burner who had undergone training and planned for the burn following statutory mandates in states that have opted for simple negligence standards for all burners. Therefore, there is little incentive for a land owner to undergo time-consuming training in states that retain the same liability standard for certified and noncertified prescribed burn practitioners. Furthermore, some regulations might be more restrictive than others. For instance, burn ban regulations that allow counties to ban all burning during periods of high fire danger could limit prescribed fire use more than those with exemptions for certified prescribed burn managers (CPBMs; e.g., V.T.C.A., Natural Resources Code §153.004).

Resistance to the use of prescribed fire is strong among private land managers despite the advantages it offers. Even managers who are aware of the benefits and desirous of inexpensive means to achieve management objectives avoid using prescribed fire, often citing potential liability as a major reason for hesitation (Brenner and Wade 2000, Yoder 2008). Several recent studies have examined prescribed fire liability (Haines and Cleaves 1999, Haines et al. 2001, Yoder et al. 2004, Sun 2006, Yoder 2008), but none have explored the relationships between liability, regulation, and landowner use of prescribed fire. Specifically, none of these

[2] http://www.prescribedfire.net/

studies included the amount of private land treated with prescribed fire as a variable. In addition, these studies include an examination of state burning laws as of 2005 at the latest, but there have been additional state reforms since 2005 (e.g., Tennessee Prescribed Burning Act [T.C.A. §68-102-146]) that must be included for an up-to-date exploration of legal drivers of burning private land.

Herein, we attempt to assess the impact of statutory reforms that apply to prescribed burning and identify legal incentives and impediments to prescribed fire application for range and forest restoration and management, as well as hazardous fuel reduction. Specifically, we explore the relationship between prescribed burning laws and the decisions land managers make about fire. To achieve this, we took advantage of a natural experiment created by state-level regulatory reforms utilizing different liability standards and regulatory requirements between states to compare the use of prescribed fire by landowners in different states in the southeastern United States. This approach relied on the assumption that the decision to adopt less stringent liability is not related to increased incidence of wildfire in a state and attendant increased reliance on prescribed fire for fuels management. This assumption is more plausible if there is a method for controlling for differences in observed and unobserved variables related to incidence of wildfire across treatments. Local geographic ignorability design, where experimental units are located in a narrow area surrounding the border separating treatments, has been shown to increase the likelihood that such an assumption holds (Lee and Lemieux 2010, Keele and Titiunik 2014*b*, Keele et al. 2015). By employing a local geographic ignorability design, the border between states acts to arbitrarily assign counties to one of the two treatments of interest, statutory reform employing simple negligence standards and reform with gross negligence standards. Using this geographic approach to natural experiments increases the likelihood that treatment assignment is "as-if random" and therefore, the two treatment groups are similar with regards to all variables (Sekhon and Titiunik 2012). Indeed, many of the variables important to the decision to utilize prescribed fire for land management and for fuel reduction are directly related to climatological, ecological, and geographical conditions that are likely to be similar for counties located in a narrow band around state borders. Given this, contiguous counties across a state border with different liability standards are good counterfactuals. While the legal variables of interest in this study are discontinuous at the state boundary, variables not included in the model that drive the amount of area burned should be very similar for counties sharing a border. Therefore, the percentage of land area burned should be independent of the assignment of counties into a gross or simple negligence liability standard, the primary treatment of interest in this study. Many recent studies have employed research designs exploiting geographic discontinuities, such as geographic regression discontinuity design, where the probability of assignment into a certain treatment group changes discontinuously with distance from the border separating the treatments, and the local geographic ignorability design employed here, to determine the effects of legal reform, economic incentives, and social programs (Lee and Lemieux 2010, MacDonald et al. 2012, Cattaneo et al. 2015, Keele et al. 2015). This prevalence in research is a reflection of the ability of geographic-based natural experiments to overcome issues of selection bias and endogeneity, subsequently heightening the credibility of causal inferences based on these types of designs relative to other types of natural experiments (Keele and Titiunik 2014*a*).

Data and Methods

Legal variables

We performed a detailed analysis of the legality regarding prescribed fire for the states of the southeastern United States. We focused our analysis in this region because the state forest services and prescribed fire councils of the southeastern United States maintain complete records of prescribed burn permitting on private land that provided highly reliable data. Few other areas keep such complete and reliable records of prescribed burning on private land. Additionally, some states, such as Nevada and California, where some data were available, had additional layers of regulations for certain counties related to water and air quality control that would complicate an analysis of state-level statutory law.

We completed a search of state statutes and state appellate case law in the Westlaw legal database (Thomson Reuters, New York, New York) using the keywords "prescribed burn," "prescribed burning," "prescribed fire," "controlled burn," "controlled burning," and "controlled fire" for six southeastern states: Florida, Georgia, Alabama, South Carolina, North Carolina, and Tennessee. We then reviewed each statute and case to determine the applicable legally relevant variables, including civil liability standard as stated in statutes and applied in case law, regulations, and the use of burn bans to limit prescribed burning during potentially dangerous fire weather.

We identified four requirements for prescribed burning from the state statutes: written burn plans, presence of a CPBM, adequate personnel and firebreaks, and burn permits. Written burn plans prescribe the conditions under which the burn will occur. They define the weather conditions under which the burn will take place, the equipment and personnel that will be on hand during the prescribed fire, and illustrate the ignition technique that will be employed. Some states require a CPBM to remain at the site of the burn until the burn is completed. Some also require that adequate personnel and firebreaks be in place at the time of the burn,

although few statutes define what is meant by "adequate." Burn permits are required for burning in all states included in the study. They are applied for electronically or via telephone and require the applicant to list the date, type, location, and areal extent of the burn. They are always issued if there is no burn ban in place in the county. We categorized counties into those requiring only a burn permit for a prescribed burn and those requiring a permit plus one or more of the three additional requirements.

Prescribed fire data

We collected county-level permit data for prescribed burning on private land from 2008 to 2013 in the six southeastern states. However, we excluded Tennessee from the analysis because complete data on private land prescribed burning per county were unavailable. In addition, we included only counties that share a state border with a county in a state with a different liability standard (Fig. 1) as required by the local geographic ignorability design employed in this study. For instance, Alabama has a simple negligence standard and Georgia has a gross negligence standard, so the counties that form the border between Alabama and Georgia are included in the analysis. Focusing the analysis on contiguous counties separated by a state border provides a control on observable and unobservable factors influencing the use of prescribed fire that are unrelated to state regulations and liability standards (Lee 2001, Holcombe and Lacombe 2004, Huang 2008). This control is necessary because weather, land cover, vegetation type, topography, and many other variables are likely to play a role in a landowner's decision to conduct a prescribed burn. Natural experiments based on geographic separation between treatments, such as the one utilized in this study, provide a plausible comparison between experimental units haphazardly assigned. This approach limits concerns regarding model specification, including the potential for omitted variable bias and improper functional form (Hahn et al. 2001, Imbens and Lemieux 2008).

Burn permit data provide a proxy for the number of fires and acres burned in a given county for a given year. While not every burn permitted is necessarily carried out, the percentage of burns completed should not differ between matched counties. The permit application processes in the states selected are similar with none more onerous than others, so a decision not to follow through with a burn would most likely be related to weather or other factors controlled for through matching counties. Acres permitted per county per year were analyzed as a percentage of total privately owned forest, range, and pasture land for that county and are hereafter referred to as the percentage of land area burned. Number of fires per county per year includes range, forest, and pasture burns permitted and does not include pile burns, agricultural burns, or burning for land clearing associated with construction.

FIG. 1. Study area in the USA. Gray counties are included as matched pairs in the analysis. Study focused on the southeastern United States and included matched pairs of contiguous counties with different liability standards (gross negligence and simple negligence) applicable in the case of damage resulting from escaped prescribed fires.

Other data

We collected data for several control variables in order to avoid incorrect estimates from omitted variable biases: the amount of privately owned forest, pasture, and rangeland in each county, average household income of each county, average county education level, and county population density (from U.S. Census Bureau and the USDA Economic Research Service). We also explored the potential for additional municipal layers of law governing prescribed fire use, but found no evidence of additional regulatory requirements for landowners within city limits in any of the major municipalities in the study area. Finally, we identified the existence of prescribed burn associations in each study county as such burn associations have been shown to influence the amount of land burned by private landowners (Kreuter et al. 2008, Twidwell et al. 2013, Toledo et al. 2014).

Statistical analysis

To examine the effect of legal variables on private landowner use of prescribed fire, we used general linear mixed-effect models. The dependent variable in one set of regressions was the percentage of area burned per year per county; this was expressed as area permitted to be burned on private land in a given year for a given county, divided by the total amount of privately owned forest, range, and pastureland in the county. The independent legal variables were included as sets of binary dummy variables (0 = simple negligence, 1 = gross negligence; 0 = permit only required, 1 = permit plus

additional precautions required; 0 = no burn ban exemptions, 1 = burn ban exemptions). Strict liability was not included as a variable because none of the states included in the analysis had strict liability rules for prescribed burning. We also included average income, education, and county population density as covariates. We included an identifier for matched counties in the model as a variable with random intercepts, and used a compound symmetrical covariance matrix for the error term associated with the county identifier in order to account for correlated errors in dependent variables obtained from matched counties. We performed likelihood ratio tests to compare full models with the fixed effects of interest to reduced models without the effects to determine the significance of each variable in the model.

Another set of regressions examined the number of fires per county per year. The same dummy variables, covariates, and a county identifier were used as independent variables in these regression models. In this latter set of regressions, we also included an independent variable for total area of private forest, range, and pasture land in the county to account for land area because the dependent variable was not a percentage of the total land area as in the first set of regressions. We determined which legal variables had an influence on the dependent variables with likelihood ratio tests that compared the full model to a model with the dummy variable for the legal parameter of interest excluded.

In addition to the regression analyses performed, we used Wilcoxon matched-pairs signed-rank analysis of unadjusted, simple means for the available covariates (education, population density, and income) to compare levels of the covariates between counties with simple and gross negligence liability standards. Similarity between these covariates for the two different treatments provides evidence that the research design effectively reduces heterogeneity between treatment groups (Keele and Titiunik 2014*a*). We also used Wilcoxon matched-pairs signed-rank analyses to explore differences between unadjusted, simple mean proportion of land area burned between contiguous pairs of treated and untreated counties, pooling across years and for each year individually, for counties with gross vs. simple negligence standards.

Because the prescribed burn data were collected along state borders, and thus, each observation represents a contiguous county, we also tested for possible autocorrelation among observations with a Durban Watson analysis for each study year and for the data averaged over all study years. All data were analyzed using R version 3.0.2 (R Development Core Team 2013).

Results

Statutory review

Florida was the first state to undergo statutory reform in 1990, with the other southeastern states following suit between 2000 and 2012. The Florida Prescribed Burning Act of 1990 (Fla. Stat. Ann. §590.125) required a written prescription for a burn and a CPBM to be on site during burning to obtain a permit. In 1999, the act was amended to include requirements for adequate personnel, equipment, and firebreaks, and also to change the liability standard from simple to gross negligence if all regulatory requirements are met; if regulatory requirements are not met, simple negligence applies. Georgia followed in 2000 with an amendment to its prescribed fire statute that included a gross negligence standard (Ga. Code Ann., §12-6-148). However, unlike Florida, the Georgia statute does not include a list of regulatory hurdles for protection under the statute. It requires the burner only to obtain a permit from the division of forestry before burning. A Georgia appellate court upheld the standard, suggesting that slight diligence was all that a landowner was required to exercise in carrying out a burn given the gross negligence liability standard stated in the statue (*Morgan v. Horton* 2011). Alabama and North Carolina passed right to burn laws in 2011 (Ala. Code 1975 §9-13-271, N.C.G.S.A. §106-968) with requirements of a written prescription and the presence of a CPBM, but they maintained a simple negligence standard rather than adopting gross negligence. South Carolina's statute (Code 1976 §48-34-10), passed in 2012, has the same requirements as Alabama and North Carolina and also has a simple negligence standard. All states allow county commissioners, governors, and forestry division leaders to establish open burning bans during times of dangerous fire weather, but Alabama, Georgia, and North Carolina provide exemptions for CPBMs during burn bans. Georgia provides an exemption for any landowner burning for pasture and field management, silvicultural, and ecological purposes. An overview of legal variables is presented in Table 1, and the liability standard for each state is shown in Fig. 2.

Effects of liability and regulations

Mean percentage of land area burned was lower for simple negligence counties than their matched gross negligence counterparts for each year explored (2008–2013) and when averaging over the six-year study period ($F_{6,72} = 7.2$, $P = 0.009$; Table 2, Fig. 3a). This result was corroborated by the nonparametric analysis of simple unadjusted mean differences between simple and gross negligence counties (Table 3). However, there was no difference in land area burned between counties that require only permits and counties with additional regulations ($F_{6,72} = 2.38$, $P = 0.13$), and there was no difference between counties with burn ban exemptions for ecological burning and those without ($F_{6,72} = 0.08$, $P = 0.78$). None of the covariates differed at $\alpha = 0.05$ between counties with simple and gross negligence liability standards (Table 4). However, population density was slightly higher at $\alpha = 0.10$ for counties with gross negligence than those with simple negligence ($V =$

TABLE 1. Regulatory requirements and liability standards mandated by statute for each U.S. state included in the study.

Standard and requirement	State				
	Alabama	Florida	Georgia	North Carolina	South Carolina
Liability standard	simple negligence	gross negligence	gross negligence	simple negligence	simple negligence
Requirement					
Burn permit	yes	yes	yes	yes	yes
Certified prescribed burn manager	yes	yes	no	yes	yes
Written prescription	yes	yes	no	yes	yes
Adequate personnel and firebreaks	no	yes	no	no	yes
Burn ban exemptions	yes	no	yes	yes	no

431.0, $P = 0.057$). This difference in demographic parameters between gross and simple negligence are not likely driving the results of the overall model, however. The model includes these covariates in order to control for potential differences in demographic parameters that could be related to the amount and acreage of private land prescribed burns but are not controlled by the contiguous county design.

The average annual number of fires was also lower for simple negligence counties than their matched gross negligence counterparts ($F_{7,71} = 18.74$, $P = 0.0001$; Table 3, Fig. 3b). As with acres burned, there were no differences in the number of fires between counties requiring permits and those with regulatory requirements additional to permits ($F_{7,71} = 0.82$, $P = 0.36$), and between counties with burn ban exemptions and those without ($F_{7,71} = 0.58$, $P = 0.45$)

We examined the correlation coefficients associated with gross and simple negligence to determine differences in land area burned between matching counties. The difference in land area burned between matched counties averaged over the six study years was 9.72% greater for gross negligence counties than simple negligence counties ($F_{5,53} = 7.2$, $P = 0.009$). This represents an additional 7919 ha of private land burned, on average, in counties with a gross negligence liability standard.

Fig. 4 shows the trend in the percentage of land area burned yearly, separated by liability standard. Gross negligence counties experienced greater percentage of land area burned than simple negligence counties did for the entire study period, but the difference was reduced during the last several years of the study. This is likely due to increasing drought conditions from 2009 to 2012 that could have constrained burning enough to diminish the effects of liability. Regardless of legal framework, prescribed burning was likely limited by low fuel accumulation in 2011, which is considered to be the peak of the 2000s drought (NOAA 2014).

Autocorrelation

There was no autocorrelation found among the 79 observations included in this study. This is a concern where data are collected from spatially contiguous units of observation, but a Durbin-Watson test for autocorrelation showed no correlation among the percentage of land area burned or the number of fires per county for any of the study years (Table 5).

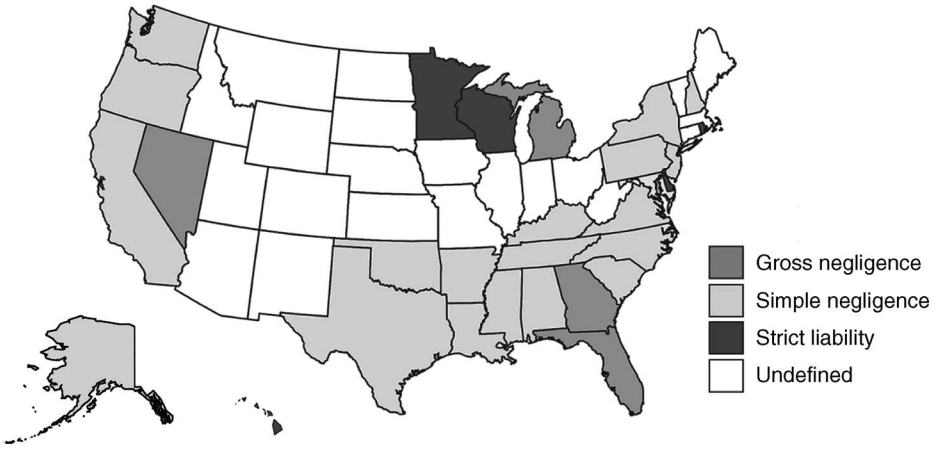

FIG. 2. Map of prescribed fire liability standard applicable in each state. Medium gray states statutorily prescribe a gross negligence standard, light gray states statutorily prescribe simple negligence for certified prescribed burners, dark gray states have case law or statutory language supporting strict liability for escaped prescribed fires, and white states have a liability standard undefined statutorily and usually follow simple negligence rules as established by case law.

TABLE 2. Regression estimates and standard errors of estimates for each model term for regressions of percentage of range and forest land burned in contiguous counties with different regulatory requirements.

Year and term	Parameter estimate		Likelihood ratio	
	Estimate	SE	*F*	*P*
2008				
Liability	932.2	151.4	37.907	0.0001
Permit+	358.7	206.4	3.0197	0.0866
Burn ban exemption	−268.5	151.6	3.1379	0.0808
Education	9.895	8.724	...	...
Income	−0.0098	0.0066	...	...
Density	−0.4355	0.3422	...	...
Land area	0.0011	0.0004	...	...
2009				
Liability	764.5	151.6	25.422	0.0001
Permit+	367.8	206.7	3.1652	0.0795
Burn ban exemption	−82.56	151.8	0.2959	0.5882
Education	14.08	8.737	...	...
Income	−0.0135	0.0066	...	...
Density	−0.5437	0.3427	...	...
Land area	0.0012	0.0004	...	...
2010				
Liability	704.2	151.3	21.65	0.0001
Permit+	254.5	206.3	1.5218	0.2214
Burn ban exemption	−92.07	151.5	0.3693	0.5453
Education	15.81	8.720	...	...
Income	−0.0141	0.0007	...	...
Density	−0.6043	0.3421	...	...
Land area	0.0012	0.0004	...	...
2011				
Liability	717.0	212.7	11.359	0.0012
Permit+	84.83	29.00	0.0856	0.7708
Burn ban exemption	−97.91	213.0	0.2114	0.6471
Education	17.91	12.26	...	...
Income	−0.0185	0.0092	...	...
Density	−0.7869	0.4808	...	...
Land area	0.0012	0.0006	...	...
2012				
Liability	587.8	172.8	11.567	0.0011
Permit+	42.78	23.56	0.033	0.8564
Burn ban exemption	−107.9	173.0	0.3892	0.5347
Education	11.06	9.957	...	...
Income	−0.0111	0.0075	...	...
Density	−0.7091	0.3906	...	...
Land area	0.0011	0.0005	...	...
2013				
Liability	488.8	161.9	9.1139	0.0035
Permit+	88.73	22.07	0.1616	0.6889
Burn ban exemption	−91.32	162.1	0.3175	0.5749
Education	13.72	9.328	...	...
Income	−0.0148	0.0070	...	...
Density	−0.6419	0.3659	...	...
Land area	0.0009	0.0005	...	...
Total				
Liability	699.1	161.5	18.738	0.0001
Permit+	199.6	220.2	0.8215	0.3648
Burn ban exemption	−123.4	161.7	0.5824	0.4479
Education	13.74	9.305	...	...
Income	−0.0136	0.0070	...	...
Density	−0.6202	0.3650	...	...
Land area	0.0011	0.0005	...	...

Notes: Estimates were generated using linear mixed-effect models. The independent legal variables were included as sets of binary dummy variables. Average income, education, and county population density were included as covariates. We included an identifier for matched counties in the model as a variable with random intercepts, and used a compound symmetrical covariance matrix for the error term associated with the county identifier in order to account for correlated errors in dependent variables obtained from matched counties. Degrees of freedom for all *F* values are 6, 72. *P* values were obtained using Likelihood Ratio Tests to compare full models with the fixed effects of interest to reduced models without the effects to determine the significance of each variable in the model. Separate regressions were performed for each year and for all years pooled (total). Ellipses indicate that a likelihood ratio test with regard to those variables was not run.

Discussion

The Prescribed Fire Acts passed in southeastern United States have focused on the importance of fire as an historical part of southern forests and grasslands. The acts seek to promote the use of fire because of the broader benefits it provides to the general public, such as reducing wildfire risk and maintaining ecosystem health, as well as ecological and economic benefits, such as inexpensive brush control and grassland revitalization, which accrue directly to the burner. Prescribed fire stimulates essential ecosystem services, such as nutrient cycling (Noss et al. 2006), improved forage quality (Collins and Wallace 1990, Knapp et al. 2008), and disease and pest control (DiTomaso et al. 2006). Through the selective application of fire, land managers can increase spatial and temporal heterogeneity of plant and soil microbial communities (Turner et al. 1994, Chang 1996, Fuhlendorf and Engle 2001), diversifying natural areas, and improving wildlife habitat (Fuhlendorf et al. 2006). In addition, providing a low-cost land management option allows many land owners and managers to maintain forests and rangelands in ecologically functional states rather than converting them to land uses providing higher economic yield, such as development or agriculture (McCullers 2013). Maintaining land as ecologically functional forests and grasslands promotes biodiversity, nutrient cycling, carbon storage, water filtration, and other critical ecosystem services that benefit society at large.

The most broadly recognized social benefit of prescribed fire is its use in reducing hazardous fuels. For instance, fires in Yosemite National Park were most limited in spatial extent and severity where a "let-it-burn" policy had been adopted for naturally occurring wildfires (van Wagtendonk et al. 2012). Larger, more severe fires occurred in adjacent areas with a long history of fire suppression. Fire fuel models corroborate this outcome, with large reductions in fire intensity and average fire size in models that incorporate hazardous fuel reduction with prescribed fire (Fernandes and Botelho 2003). Similarly, prescribed burning lowered the incidence and extent of wildfires in Australian eucalypt forest (Boer et al. 2009). This reduction in hazardous fuels can lower the number and intensity of subsequent wildfires in the area, facilitating suppression efforts and limiting structural losses (Fernandes and Botelho 2003).

There are also some costs inherent in using prescribed fire. Prescribed fire causes smoke, which can present safety and health risks (Hardy et al. 2001). It can lead to substantial reduction in visibility and a loss of life and property if not properly controlled, as was the case in Florida in January 2008 when 70 vehicles collided due to reduced visibility from fog mixed with smoke from an escaped prescribed fire (McCullers 2013). Smoke also causes respiratory health issues in communities near large fires (Bowman and Johnston 2005). Such risks can, however, be reduced by timing prescribed fire to limit the amount of smoke reaching nearby communities and by taking precautions to reduce accidents caused by smoke on roadways (Hardy et al. 2001). In addition to the risks posed by the generation of smoke, the potential for prescribed fires to escape and cause losses of lives and property is the largest cost associated with its use. Ninety-nine percent of prescribed fires are successfully restricted to the intended area of burning, but the rare escapes can be catastrophic (Ryan et al. 2013). For

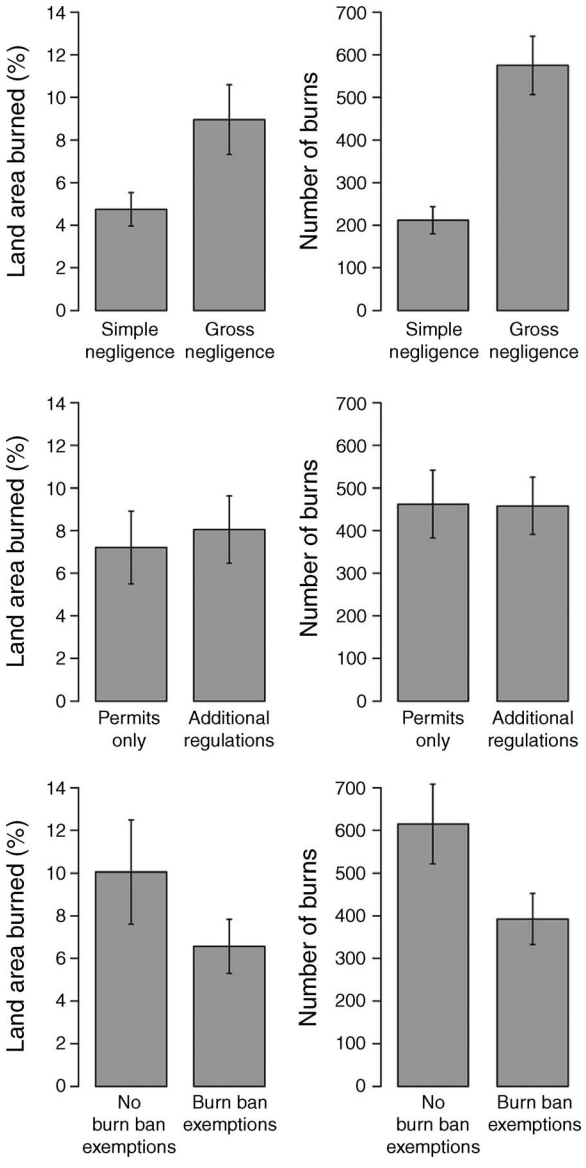

Fig. 3. Means and standard errors for average annual percentage of land area burned and average annual number of burns between contiguous counties with simple negligence and gross negligence (top row), permit requirements only and additional requirements (middle row), and burn ban exemptions for certified prescribed burn managers (CPBMs) or land management (bottom row). Means are based on data pooled across all years of the study and adjusted for covariates (education, population density, and income).

TABLE 3. Unadjusted simple differences in means for proportion of total range and forest land burned between contiguous pairs of gross and simple negligence.

Year	Gross negligence	Simple negligence	*V*	*P*
2008	0.066	0.017	550.0	<0.001
2009	0.089	0.048	451.0	0.025
2010	0.085	0.043	453.0	0.024
2011	0.077	0.043	374.0	0.041
2012	0.067	0.046	414.0	0.107
2013	0.069	0.048	397.5	0.037
Total	0.076	0.041	479.0	0.006

Notes: Table includes unadjusted means and standard errors, as well as the test statistic and *P* value obtained by performing Wilcoxon matched-pairs signed-rank tests for pairs of contiguous counties with different liability standards for each year of the study and pooled over all years (total).

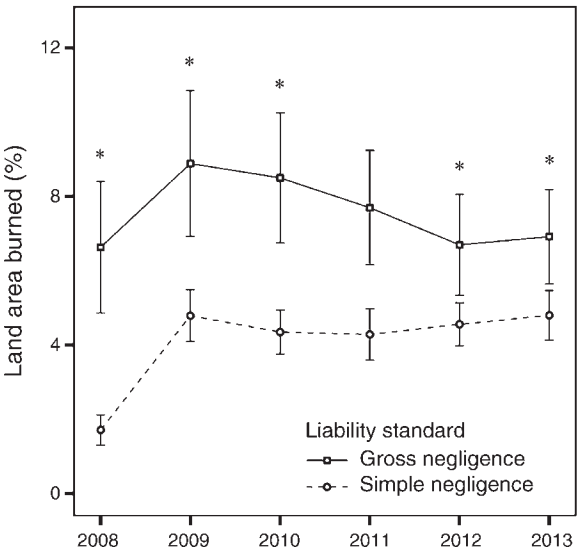

FIG. 4. Unadjusted means and standard errors for the percentage of range and forest land area burned each year for counties with gross negligence and simple negligence status for prescribed fire. Asterisks indicate years with significant differences in simple unadjusted mean percentage of land area burned between gross and simple negligence counties according to Wilcoxon matched-pairs signed-rank tests for each year ($\alpha = 0.05$).

instance, the Lower North Fork Fire in Colorado in 2012 was started by a spot fire from a nearby prescribed burn and resulted in three fatalities and $11.3 million in property damages (Colorado Legislative Council 2012).

Statutorily prescribed legal liability standards and regulations for prescribed burners seek to find an efficient and effective balance between the societal costs and benefits of prescribed burning. Gross negligence standards shift some costs of burning associated with escapes from the burner to the adjacent property owners. This reduced cost of burning provides an incentive encouraging prescribed burning on private land (Yoder et al. 2004). Our study reports an additional 9% (±4%) of total hectares of forest, pasture, and rangelands were burned in counties with gross negligence liability standards in 2013. When applied across the counties included in this study, a switch to gross negligence liability for the simple negligence states would result in an average additional 7388 ha burned per county per year. Gross negligence also functions as an incentive to follow statutory regulatory requirements and receive prescribed burn training. This lowers the risk of escape and the attendant costs for both burners and adjacent property owners as those applying fire are better trained to properly conduct safe and effective prescribed burns. In addition, the lower liability standard can incentivize the creation of defensible space and fire-wise construction because adjacent landowners are exposed to a larger portion of the costs attendant to prescribed burning escapes than the burners under gross negligence liability standards.

Yoder (2008) analyzed the relationship of liability standards and regulations to the occurrence and severity of escaped prescribed fire in the United States. He defined severity as a measure of the cost of suppression plus an estimate of damage costs resulting from the fire. He found that gross negligence states had more escapes than simple negligence states, but damage and suppression costs were not higher. Yoder's analysis does not include data on the total number or acreage of prescribed fires or an explicit control for potential omitted variable bias through the use of local geographic ignorability or a similar experimental design. Therefore, the higher number of escaped fires could potentially be the result of higher numbers of prescribed fires conducted in gross negligence states, or differences in driving variables omitted from the analysis. Regardless, the finding of no difference in damage or

TABLE 4. Unadjusted simple differences in means for covariates between contiguous pairs of gross and simple negligence.

Covariate	Gross negligence	Simple negligence	*V*	*P*
Education (years completed)	16.95	14.99	308.5	0.287
Population density (no. people/km^2)	158.57	76.28	431.0	0.057
Income (average annual gross income)	40 931.17	37 410.63	409.0	0.127

Notes: Table includes unadjusted means and standard errors, as well as the test statistic and *P* value obtained by performing Wilcoxon matched-pairs signed-rank tests for pairs of contiguous counties with different liability standards.

suppression costs suggests that gross negligence standards are not leading to vastly greater losses than simple negligence standards.

In the absence of gross negligence standards, prescribed burn associations might provide a non-legislative mechanism for limiting liability associated with prescribed fire use by private landowners. These associations are cooperatives of landowners with a common goal of using fire to manage private lands, and they are established to share the costs of prescribed burning (Toledo et al. 2012, Twidwell et al. 2013). They provide shared labor and equipment on burn days, serve as a conduit for established knowledge related to prescribed burning, provide safety training for new members, and can potentially spread the costs of liability insurance among members (Toledo et al. 2014). In Oklahoma and Texas, prescribed burn associations have even driven legislation that allows for burning by certified prescribed burn managers during burn bans to meet land management objectives (Twidwell et al. 2013). However, the effectiveness of burn cooperatives to reduce liability concerns associated with prescribed burning is limited by risk-driven legislative and regulatory requirements as burn associations are still subject to the same level of liability as individual burners (Twidwell et al. 2013).

In 2012, the Tennessee House of Representatives voted almost unanimously (with one vote opposing) for the passage of the Tennessee Prescribed Burning Act. The act had been drafted by the Tennessee Wildlife Federation and the Tennessee Prescribed Fire Council with the hopes of developing a Certified Prescribed Burn Manager training program. The bill offered limited liability in the form of a gross negligence liability standard to CPBMs as an incentive to complete the training and use additional statutorily circumscribed precautions, such as developing a burn prescription and having a CPBM on site for the duration of the burn. It was drafted following the example of the Right to Burn Acts in other Southeastern states in order to promote safe use of prescribed fire to reduce hazardous fuels and increase ecosystem health. The bill faced a legislative battle in the Senate, however. It was attacked on grounds that gross negligence would leave burners unaccountable for damages. The debate was fueled by front page news of a catastrophic escaped prescribed fire in Colorado just days before the Senate hearing on the Prescribed Fire Act. Supporters of the act failed to effectively counter with the importance of the act for increasing safety in prescribed burning through incentivizing training programs, and in the end opted to settle for a simple negligence standard in order to move forward with the CPBM training program and have language regarding the value of prescribed fire for the ecosystems of Tennessee in the state statutes. Many supporters of the original bill felt the less stringent, gross negligence liability standard was essential to achieving the stated purpose of the statute to promote the use of prescribed burning for range and forest health, fuel reduction, and perpetuation of Tennessee's plant and animal populations (T.C.A. §68-102-146). Tennessee is not the only state struggling to develop appropriate statutes for reducing constraints on landowners who desire to include fire in their suite of management tools. Discussions of optimal liability and regulatory schemes for prescribed burning should be informed with data regarding the effects of these legal variables on land mangers' decisions.

TABLE 5. Durbin-Watson (DW) test for autocorrelation of observations.

Year	Durbin-Watson	Autocorrelation	$P <$ DW
2008	1.93	0.04	0.25
2009	2.00	−0.01	0.37
2010	1.87	0.06	0.18
2011	1.99	0.01	0.36
2012	1.96	0.02	0.30
2013	1.93	0.03	0.26
Average all years	1.94	0.03	0.27

Notes: Tests for autocorrelation between counties based on geographic distance.

Our results show that private landowners are more likely to use prescribed fire for managing their properties and burn a greater proportion of private land in counties where their state has adopted gross negligence liability standards compared with landowners in counties who are subjected to state-mandated simple negligence legal standards. Interestingly, regulatory requirements, such as adequate firebreaks, personnel, equipment, written burn plans, and CPBMs on site do not decrease the amount of burning on private land. In fact, these types of regulations, in conjunction with lower liability, will make prescribed fire more available to landowners and managers while providing some safety assurances for neighbors. Taken together with Yoder's (2008) finding of no additional damage or increased suppression costs in states with gross negligence standards, lawmakers struggling to determine the optimal legal framework for promoting burning should consider the benefits of a lower legal liability standard for those undertaking to manage fuel, forests, and rangelands with fire. Given the importance of fire to the maintenance of natural systems worldwide and our demonstration of the effects the legal landscape has on private land prescribed burning, liability-related disincentives to prescribed fire use will likely have a tremendous influence on the future structure and functioning of ecosystems (Twidwell et al. 2013). Ecologists and land managers also need to be aware that policy regulations and liability concerns may create legal barriers that inhibit the use of prescribed fire. Such recognition will allow them to better engage and educate both the public and policy makers regarding the essential role fire plays in these ecosystems. Opportunities to foster communication between related stakeholder groups should be promoted whenever possible. Indeed, a more comprehensive and thorough

understanding of these legal–ecological feedbacks is essential to increase the availability of effective ecosystem management strategies in fire-prone ecosystems worldwide and to provide solutions to management issues that address both social concerns and ecological perspectives.

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