The rising Great Plains fire campaign: citizens' response to woody plant encroachment

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Despite years of accumulating scientific evidence that fire is critical for maintaining the structure and function of grassland ecosystems in the US Great Plains, fire has not been restored as a fundamental grassland process across broad landscapes. The result has been widespread juniper encroachment and the degradation of the multiple valuable ecosystem services provided by grasslands. Here, we review the social–ecological causes and consequences of the transformation of grasslands to juniper woodlands and synthesize the recent emergence of prescribed burn cooperatives, an extensive societal movement by private citizens to restore fire to the Great Plains biome. We discuss how burn cooperatives have helped citizens overcome dominant social constraints that limit the application of prescribed fire to improve management of encroaching woody plants in grasslands. These constraints include the generally held assumptions and political impositions that all fires should be eliminated when wildfire danger increases.

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The behavioral evolution of humans to harness and apply fire has shaped the structure and function of grasslands on Earth for tens of thousands of years, but many modern societies have evolved past this legacy (Pyne 2001, 2007). This change in human behavior, combined with other sources of anthropogenic change – such as climate change, the introduction and spread of species to new areas, and the modification of top-down (eg herbivory) and bottom-up (eg water, nutrients) controls – have resulted in a worldwide shift from grass-dominated to woody-dominated ecosystems (a process referred to as woody encroachment) and the depletion of valuable grassland ecosystem services (Scholes and Archer 1997; Bachelet *et al.* 2001; Bond and Midgley 2001; Bond *et al.* 2004; Bond 2008). Although there is a clear need to restore fire as a fundamental process in grassland landscapes at broad spatial scales (Fuhlendorf *et al.* 2012), many citizens lack the knowledge, experience, training, and equipment to control fires in nature (Yoder *et al.* 2004; Kreuter *et al.* 2008).

In a nutshell:

- The lack of fire in the Great Plains region has resulted in increased woody plant encroachment and degradation of grassland ecosystem services
- A new movement is underway whereby private citizens form cooperative associations that use fire to improve grassland management
- These burn cooperatives provide a social network that has increased the application of fire across broad landscapes in the Great Plains
- Laws and regulations have changed in some areas to allow members of burn cooperatives to use prescribed fire when other outdoor burning practices are banned
- We recommend burn cooperatives as a mechanism for helping citizens become agents of sociopolitical change in ecosystems dependent on fire

Here, we present an overview of an emerging citizen-driven campaign to reintroduce fire to combat woody encroachment in the US Great Plains. We first review how the transformation from grassland to woodland has altered ecosystem services in this region. We then synthesize the evolving story of prescribed burn cooperatives and how this social network is empowering private citizens to restore fire throughout the Great Plains biome (Figure 1). We specifically highlight how burn cooperatives have helped citizens become agents of sociopolitical change and to overcome the dominant social constraints that normally limit the use of prescribed fire.

The transformation of Great Plains grasslands to juniper woodlands

Long-term social–ecological interactions among climate, vegetation, fire, herbivores, and humans are responsible for the creation and maintenance of the grasslands that typify the Great Plains biome, but changes in these interactions are leading to a biome-level shift from grassland to woodland throughout the region (Engle *et al.* 2008). Based on evidence collected from stable carbon isotope data, opal phytolith (microscopic, fossilized silica particles of plant tissue) assemblages, burnt phytoliths, micro-

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scopic charcoal, and pollen and fossil records, woody plants were a dominant component of vegetation in the region now known as the Great Plains 11 000 years ago, when the climatic conditions that followed the last glacial maximum (ca 19 000 years ago; Clark *et al.* 2009) provided a more favorable environment for woody plants (Nordt *et al.* 2002; Cordova *et al.* 2011). As a result of changes in climate in the early Holocene, the abundance of C_3 woody plants declined steadily in favor of C_4 grasses (Fredlund and Tieszen 1994; Baker *et al.* 2000; Holliday *et al.* 2008; Cordova *et al.* 2011). Grasses have therefore been a dominant vegetation type in the Great Plains for the past 5000 to 8000 years (Bryant 1977; Hall and Valastro 1995; Nordt *et al.* 2002, 2008; Cordova *et al.* 2011), with brief resurgences in woody vegetation occurring only periodically (Nordt *et al.* 2002; Cordova *et al.* 2011).

Figure 1. *Private citizens are organizing into prescribed burn cooperatives to combat woody plant encroachment in the Great Plains. (a) Members of burn cooperatives pool money and resources, (b) organize training opportunities and workshops, and (c) conduct prescribed burns on each other's properties, while (d) teaching upcoming generations of land stewards the value of fire in grassland conservation.*

The relative abundance of woody plants has been closely linked to the occurrence of fire following the late glacial maximum and the rise of the Great Plains biome (Cordova *et al.* 2011). Many woody plant species in the Great Plains have the propensity to resprout following defoliation. However, the biome shift from grassland to woodland is primarily associated with the encroachment of two non-resprouting, fire-sensitive trees, Ashe juniper (*Juniperus ashei*) and Eastern redcedar (*Juniperus virginiana*; Briggs *et al.* 2005; Van Auken 2009). Increases in these two juniper species are the result of changes in human and biophysical feedbacks that have reduced the incidence, intensity, and spatial extent of fires, thereby increasing the competitive advantage of these two species in Great Plains grasslands (Panel 1). The elimination of anthropogenic fire and the removal of the herbaceous layer needed to sustain grassland fire spread (as a result of overgrazing by domestic livestock) have led to widespread fire exclusion and juniper encroachment (Briggs *et al.* 2002; Briggs *et al.* 2005; Fuhlendorf *et al.* 2008; Allred *et al.* 2012; Taylor *et al.* 2012). Societal policies dictate when fire managers can use prescribed fires to restore and manage grasslands (Hawbaker *et al.* 2013), thereby limiting the biophysical process of fire to conditions that produce low-intensity fires that fail to kill junipers (Twidwell *et al.* 2013a). Anthropogenic fragmentation of the Great Plains for agriculture, resource extraction, and residential development, and the construction of windbreaks around houses using juniper trees (a volatile fuel source) have reinforced the need to protect people, property, and infrastructure from fire. Moreover, climate warming and intensifying droughts in the growing season have the potential to increase the competitive advantage of juniper over other species (Twidwell *et al.* 2013b; Volder *et al.* 2013) and may reinforce juniper dominance even during times of high drought-induced tree mortality (Twidwell *et al.* 2013b). As a result of these feedbacks, woody encroachment has emerged as the dominant threat to grassland ecosystem services in the Great Plains biome (Engle *et al.* 2008).

■ Degradation of grassland ecosystem services in the Great Plains

The ecological transformation from grassland to juniper woodland has led to profound changes to the ecosystem services provided by grasslands in the Great Plains (Table 1); some of these are discussed below.

Grassland biodiversity

The conversion of Great Plains grasslands to communities dominated by woody plants has led to tremendous declines in grassland obligate species across multiple trophic levels. Vegetation structure has been drastically altered and plant biodiversity has decreased by more than 90% in areas that have been transformed into juniper woodlands (Knapp *et al.* 2008; Van Auken 2009). Grassland birds are the most rapidly declining avian guild in North America (Fuhlendorf *et al.* 2012) and are rarely observed once juniper exceeds 10% of land cover

Panel 1. The role of humans in shaping the Great Plains biome

Humans can alter the occurrence of fire beyond its natural potential (Figure 2; solid line shows natural occurrence, dashed lines show human impacts; modified from Whitlock *et al.* 2010; McWethy *et al.* 2013). In the Great Plains region, humans have altered fire most dramatically in subhumid areas (Figure 2a), where high grassland productivity and continuity allow more rapid recovery of fuels following fire than occurs in the more arid western grasslands. Humans have had less effect in more arid regions, where fires were less frequent and natural processes (eg climate) had a greater effect on juniper retraction and expansion (Barger *et al.* 2009; Romme *et al.* 2009).

Following millennia of human-driven increases in fire activity (red arrows) in the Great Plains, fire activity decreased (blue arrows) following Euro–American settlement and forcible displacement of Plains Indians (circa 1850), fragmentation of grasslands to encourage settlement and cultivation (circa 1862, Homestead Act), overstocking and mass-marketing of domestic livestock (circa 1866, first cattle drives involving millions of cattle), and organized efforts to completely eradicate wildfires (circa 1935, US Forest Service). Decreases in human fire activity, coupled with human-mediated dispersal and planting of juniper trees (circa 1872, Arbor Day created in Nebraska), have enabled juniper trees to spread from the small patches of rock outcrops and valleys or depressions where fire was less likely to occur, leading to widespread juniper encroachment and the most dramatic changes in the Great Plains biome (Figure 2b) since the Dust Bowl era (Engle *et al.* 2008).

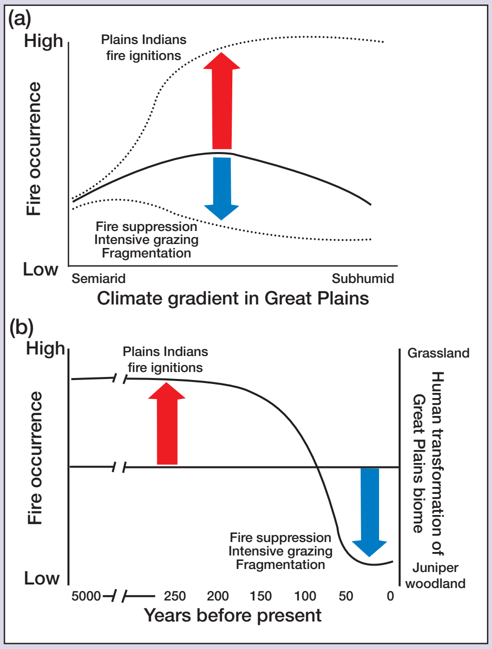

Figure 2.

(Chapman *et al.* 2004). Woody encroachment is also the primary reason for the decline of the lesser prairie chicken (*Tympanuchus pallidicinctus*; Fuhlendorf *et al.* 2002), which is now being considered for listing under the Endangered Species Act. Small mammals that inhabit Great Plains grasslands often benefit from moderate increases in woody cover, but diversity is lowest after conversion to closed-canopy woodlands (Horncastle *et al.* 2005).

Carbon sequestration and loss

It has been suggested that juniper encroachment in the Great Plains has greater potential as a carbon (C) sink than other ecosystems experiencing woody encroachment in North America (Barger *et al.* 2011). Juniper encroachment increases aboveground C stocks and belowground soil organic C (Knapp *et al.* 2008; McKinley and Blair 2008). However, aboveground biomass comprises approximately 90% of C storage gains in juniper woodlands (Barger *et al.* 2011) and given the susceptibility of these woodlands to rapid losses of aboveground C following wildfires, drought, disease, and insect outbreaks, gains in C storage are potentially short-lived (Breshears and Allen 2002). This is particularly true when such disturbance events cause unanticipated feedbacks to soil C storage that further facilitate C loss (eg loss of soil C from erosion; Johansen *et al.* 2001; Breshears and Allen 2002).

Stream flow and groundwater recharge

The effect of the grassland-to-juniper-woodland transformation on stream flow and groundwater recharge continues to be debated. Juniper has decreased stream flow and groundwater recharge in many cases (Huxman *et al.* 2005; Wine *et al.* 2011), and juniper trees have extensive root systems that appear to reduce water storage in soils important to aquifer recharge (Schwinning 2008). However, increases in water infiltration and recharge have also been documented in juniper-dominated systems (Wilcox *et al.* 2008). Differential hydrological responses to juniper encroachment should therefore be expected (Huxman *et al.* 2005; Wilcox *et al.* 2005), with positive and negative responses dependent on the interrelationships of juniper trees with temperature, precipitation, physiography, geology, and runoff and infiltration mechanisms (Jackson *et al.* 2008; Huxman *et al.* 2005; Wilcox *et al.* 2005; Schwinning 2008).

Livestock production

Juniper encroachment is a serious threat to the sustainability and economic profitability of livestock production (Scholes and Archer 1997; Limb *et al.* 2011; Taylor *et al.* 2012). The Great Plains accounts for nearly 50% of US beef production (Wishart 2004), a $79 billion industry

Table 1. Consequences of the transformation of grassland to juniper woodland in the Great Plains

Grassland	*Ecosystem service*	*Juniper woodland*
High	Grassland biodiversity	Low
Low	Aboveground C sequestration	High
Moderate	Resilience to rapid C loss	Low
Varies	Stream flow and groundwater recharge	Varies
High	Livestock production	Low
Varies	Wildfire suppression potential	Low to none

Figure 3. *The reduced ability of firefighters to suppress wildfires is an environmental service that has been lost throughout much of the Great Plains. (a) The low-intensity fires frequently observed in tallgrass prairie compared to (b) the tall flames and higher fire intensities that occur in juniper woodland. Wildfires in juniper woodland usually exceed firefighters' ability to use suppression techniques to extinguish the fire, as was the case for the August 2012 wildfires in Oklahoma juniper woodlands shown in panel (b).*

(USDA ERS 2011), but livestock production has decreased by 75% in areas where grasslands have been converted to juniper woodlands (Fuhlendorf *et al.* 2008).

Wildfire suppression potential

The potential for firefighters to suppress wildfires has markedly declined throughout the Great Plains (Figure 3). Guidelines developed by the US Forest Service indicate that fire suppression is unlikely to be successful in the presence of wildland fuels when flame lengths are greater than 3.4 m (Andrews and Rothermel 1982). In areas of long-term juniper encroachment, fires have shifted from frequent, grass-driven surface fires that vary in flame length (range = < 0.1 m to well over 3.4 m; Finney *et al.* 2011) to infrequent, juniper-driven crown fires that consistently exhibit extremely long flames (> 14 m) and are of increasing societal concern (Twidwell 2012). Such alterations to the fire regime and fire suppression potential are important contributors to the recent rise in housing losses, suppression costs, and human injuries and deaths resulting from wildfires in the Great Plains.

■ Citizen cooperatives: a novel solution to the woody plant problem

The degradation of grassland ecosystem services and the potential to use fire to improve management of encroaching woody plants has motivated citizens to organize themselves into prescribed burn cooperatives (also known as prescribed burn associations) throughout the Great Plains region (Figure 4). These organizations are composed primarily of private ranchers and landowners who help each other use prescribed fire to conserve and restore fire-dependent ecosystems (Taylor 2005). In 1995, the first prescribed burn cooperative in the Great Plains, the Prescribed Burn Task Force, was established in Nebraska. Since that time, prescribed burn cooperatives have grown to become the most prominent societal movement by private citizens to restore fire as an ecosystem process in the Great Plains biome (Figure 4). Fifty burn cooperatives are now in operation, with distributions ranging from southern Texas to Nebraska.

One burn cooperative, the Edwards Plateau Prescribed Burning Association (EPPBA; see Appendix 1), has grown from 35 founding members in 1997 to more than 300 members today, with over 150 000 ha of private land enrolled in the organization across 20 counties. Prior to forming a burn cooperative, few landowners had the

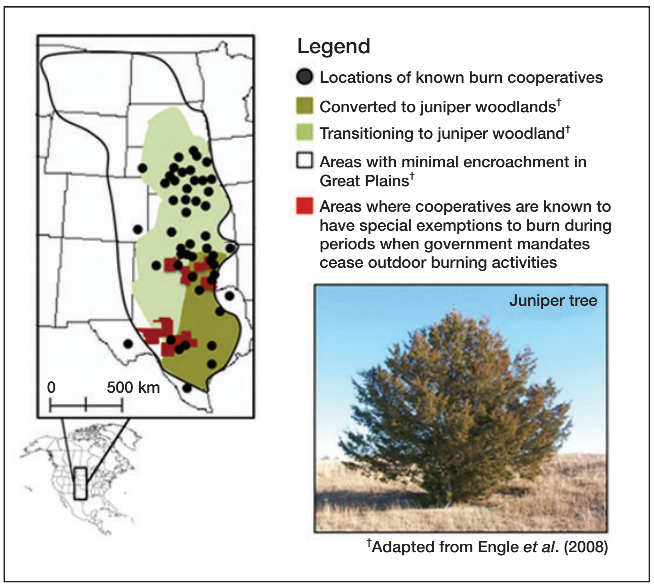

Figure 4. *Prescribed burn cooperatives have been formed throughout the Great Plains over the past 15 years. They represent an unprecedented citizen-driven effort to prevent further juniper encroachment into Great Plains grasslands and to restore areas that are already degraded (shown in green). In localized areas, burn cooperatives have led to sociopolitical reform that enables increased use of fire for the conservation and restoration of grasslands.*

Panel 2. Recommendations for monitoring and evaluation of the success of burn cooperative activities

(1) Site-specific recommendations for land ownerships with grasslands at early stages of juniper encroachment

- Determine juniper abundance prior to initiating a burning program. Ensure that burning activities are maintaining grassland dominance and preventing increases in juniper density and cover.
- Track changes in livestock production over time, with the recognition that factors other than fire and woody encroachment (eg stocking rate, climate, time since fire) drive changes in herbaceous production, forage quality, and livestock performance (Spalinger and Hobbs 1992; van Soest 1994; Allred *et al.* 2011).
- Monitor biodiversity of endemic flora and fauna species and compare with historical estimates (eg Axelrod 1985). Consider applying fire in ways that maximize variation in grassland structure to provide the diverse habitat requirements of multiple species (Fuhlendorf *et al.* 2006, 2009).
- Evaluate the effect of livestock management on herbaceous fuel loading and continuity. In areas where stocking rates are excessive, reduce grazing intensity so that prescribed burns will successfully spread across the burn unit. A minimum of 670–1120 kg ha^{-1} of fuel is typically needed for most prescribed burns (Wright and Bailey 1982).

(2) Site-specific recommendations for land ownerships with greater juniper abundance

- Determine whether burning activities are killing small juniper trees and preventing juniper encroachment from expanding.
- Look for fire-induced mortality among older, mature juniper trees and for signs that fires are being conducted in conditions capable of meeting restoration goals (sensu Twidwell *et al.* 2013a).
- Monitor long-term re-establishment of native grasses and forbs. Recognize that recovery is not immediate and requires a number of years once juniper has been removed (Alford *et al.* 2012).
- Monitor successional trajectory of vegetation following fire. Make certain fires are not facilitating the establishment and spread of exotic species (this is less of an issue in the Great Plains but is a considerable problem elsewhere; D'Antonio and Vitousek 1992).
- Track changes in potential livestock stocking rates (based on animals per unit of forage available rather than on animals per unit area) and evaluate whether changes are needed to fire or livestock management practices. Modify the number of animals based on changes in herbaceous production resulting from fire-induced decreases in juniper abundance.

(3) Recommendations for evaluation of broad social–ecological impacts

- Monitor juniper abundance and changes resulting from burn cooperative actions using satellite and remote-sensing data (Sankey and Germino 2008).
- Track changes in the rule and implementation of laws, policies, and other forms of social governance over prescribed fire, based on reviews of legislative statutes, common law, and administrative regulations, as well as natural resource policy statements and surveys involving multiple stakeholders.
- Evaluate the effect of burn cooperatives on the number and amount of acreage burned by wildfires. Document instances where the actions of cooperatives have improved, or failed to improve, fuels management and fire-suppression efforts.
- North American Breeding Bird Survey data can be used as a hierarchical metric of grassland avian biodiversity (Sauer and Link 2011) and possibly as a measure of conservation and restoration success.
- Determine the ability of burn cooperatives to conserve or recreate historical conditions using pollen, phytolith, and stable C isotope data. This should be done with the understanding that such data are best suited to identifying regional-scale vegetation changes over millennial timescales and are not suitable for establishing fine-scale references for an individual site (Cordova *et al.* 2011).

expertise or equipment to apply fires across large areas. However, a field tour of a pilot study convinced some local landowners of the potential to use high-intensity fires in times of drought to reduce juniper abundance and increase grassland dominance (subsequent experiments on this approach are discussed in Twidwell *et al.* 2009; Taylor *et al.* 2012; Twidwell 2012; Twidwell *et al.* 2013a). At the end of the tour, the 35 landowner participants organized into a prescribed burn cooperative with the aim of using fire to prevent juniper encroachment into remaining grasslands and savannas and to restore grassland services in areas where juniper encroachment had already occurred. As the EPPBA has grown over the past 15 years, members who had not previously used prescribed fire are estimated to have conducted over 300 burns on 100 000 ha.

It is likely that burn cooperatives elsewhere have analogous management goals and will see similar increases in membership numbers and area burned. However, burn cooperatives have only recently emerged in the Great Plains, so membership size, prescribed burning practices, and ecological impacts have yet to be determined for most cooperatives. Burn cooperatives would therefore benefit from monitoring programs that evaluate, refine, and support their long-term goals of conserving and restoring the grassland ecosystem services desired from this region. Such monitoring programs do not currently exist. With this in mind, we suggest (1) site-specific observations (self-evaluations or agency consultations, to determine whether members of cooperatives are meeting their land-management objectives) and (2) more regional assessments (external evaluations of the impact of burn cooperatives across broad landscapes), aimed at characterizing the social–ecological benefits and trade-offs associated with cooperative burning activities (Panel 2).

Social constraints

Although burn cooperatives have helped citizens increase the use of fire in the Great Plains, key social factors limit their potential success. The social–ecological system of the Great Plains operates under a stringent legislative umbrella. All states have formal policies and laws that forbid people from lighting fires when wildfire danger increases. The consequence of such risk-driven policies is that most cooperatives are forced to burn in conditions that produce low-intensity fires, with little potential for exceeding the juniper mortality threshold needed to meet management objectives (Twidwell *et al.* 2013a). In addition, landowners are confronted with increasing liabilities for using prescribed fire (Yoder *et al.* 2004; Kreuter *et al.* 2008). Regulations target prescribed fire practitioners with regard to air quality and health concerns in metropolitan areas and force fire managers to mitigate the effects of smoke along roadways (Yoder *et al.* 2004; Sun 2006). These legislative constraints greatly concern members of burn cooperatives, as they limit the adaptive capacity of private citizens and severely restrict usage of prescribed fire.

A burn cooperative provides landowners with a social network that resolves some of the social constraints that restrict the use of prescribed fire. Cooperatives overcome labor limitations because landowners help one another conduct prescribed fires; cooperative members have greater access to personnel and can form a complete fire crew, which improves efficiency and safety. Members of burn cooperatives have personally built fire suppression equipment and shared their equipment with neighbors, conducting prescribed burns on several properties. Those who have a long history of conducting burns on their own property partner with inexperienced individuals who are unfamiliar with prescribed burning procedures. Members participate in training and educational programs to improve their understanding of fuels, fire behavior, fire suppression, and fire effects (Taylor 2005), engage in open discussion, and provide an adaptive learning framework, which has been useful in reducing liability concerns associated with prescribed fire (Kreuter *et al.* 2008). Many members also include their children in burn cooperative activities, thereby raising awareness among future land stewards on the importance of fire in grassland conservation.

A far-ranging goal of prescribed burn cooperatives is to secure more accommodating government regulations that provide special exemptions to qualified individuals or cooperatives. Laws have been changed to benefit burn cooperatives in localized areas; for example, some county officials in Texas have extended their enforcement of burning restrictions to grant cooperatives legal exemptions to conduct prescribed fires during government-mandated bans on fire use (as part of Texas Government Code Annotated, Chapter 352 §081). Similar exemptions in Oklahoma enable a small proportion of landowners in the southern Great Plains to use fire during environmental conditions that coincide with periods of high wildfire danger (Figure 4). These favorable changes in legislation show an increased awareness within some communities of the need for fire in the Great Plains, but the vast majority of burn cooperatives continue to operate under strict regulatory constraints. Unless more wide-ranging changes in regulation occur throughout the biome, burn cooperatives will be unable to restore grasslands that have been converted to juniper woodlands and their activities will be limited to preventing juniper encroachment in the few remaining patches of remnant grassland.

Conclusions

Human use of fire has dramatically changed in the Great Plains, contributing to a human-induced transformation from grassland to juniper woodland and the depletion of valuable ecosystem services throughout the region. Reversing the degradation caused by decreases in human fire activity and juniper encroachment depends ultimately on society's valuation of grassland services, the ability to adapt to new pressures within this social–ecological system, and the development of novel approaches that address both societal and resource management needs. Burn cooperatives have increased the adaptive capacity of prescribed fire practitioners in the Great Plains, thereby allowing them to overcome many of the social constraints that prevented burning for land-management purposes in recent decades. In localized areas, burn cooperatives with large memberships have gained the attention of regulators, leading to changes in the rules governing the use of prescribed fire. Yet most burn cooperatives continue to face numerous social–ecological challenges that dictate how citizens can use fire for grassland conservation and restoration. Even so, burn cooperatives are a unique mechanism for increasing fire activity in the Great Plains and can serve as a model for increasing fire use by private citizens in other fire-dependent ecosystems.

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Appendix 1. Edwards Plateau Prescribed Burning Association Inc (EPPBA) – the largest burn cooperative in the Great Plains

Established
1997

Legal status
501(c)(3) non-profit

Mission
To restore the productivity and ecological stability of Edwards Plateau, Texas, rangelands using a neighbor-help-neighbor prescribed fire cooperative.

Constituents
Over 300 ranchers, agency employees, and members of the general public with private landholdings of over 120 000 ha of rangeland across 20 counties of Texas.

Goals
To empower and equip ranchers to manage rangelands by sharing prescribed fire equipment and labor among constituents; to train constituents in the proper, effective, and safe application of prescribed fire; to foster good relations within local and regional communities on the use and benefits of prescribed fire.

Bylaws (at a glance)
A membership fee of $25 per year is required to cover the cost of equipment, administrative costs (eg correspondence, newsletters, educational material), and training.

Landowners must participate in at least one prescribed burn before they can schedule a burn on their own property.

A burn plan must be submitted to and approved by the appropriate authorities prior to scheduling of the burn.

Only landowners and members of the general public can serve on the EPPBA advisory board. Individuals affiliated with government agencies or academic institutions can only be members.

Dealing with risk
Experience, equipment, and money is pooled within the burn cooperative to provide education and training, to mitigate risk, and to establish a regional fire culture by fostering good relations among neighbors within the local community. Many counties now allow EPPBA members to burn during periods when fires are banned, to meet restoration objectives as a result of their long-established safety record.

Challenges to continued success
Continued success hinges upon the ability of EPPBA to conduct prescribed fires in a variety of conditions (from mild to extreme). Long-term and inflexible burn bans, emergency declarations, and a lack of education among the general public regarding the importance of fire can greatly disrupt EPPBA operations.

Awards and recognition
Lone Star Steward Award, 2010
Texas Environmental Excellence Award, 2002

