CONSERVATION INNOVATION GRANTS
Final Report

Grantee Name: TEXAS AGRICULTURAL EXPERIMENT STATION	
Project Title: ECOLOGICAL, ECONOMIC AND SOCIAL DIMENSIONS OF USING SUMMER FIRE TO RESTORE ECOSYSTEMS IN THE SOUTHERN PLAINS OF THE US **(NRCS Grant Agreement 68-3A75-5-180)**	
Project Director: URS P. KREUTER	
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Period Covered by Report: October 1, 2005 – August 31, 2010	
Project End Date: September 28, 2009 (extended under no-cost extension agreement in letter of July 5, 2007 from Sheila Leonard, NRCS Washington, D.C.)	

Summary of work performed during the project

The primary goal of the research project was to provide rigorous scientific data for the NRCS to review and revise its technical standards and specifications for the applications of prescribed fire on Texas rangelands. This research was driven by the growing application of extreme fires, i.e., fires that are applied under conditions exceeding the NRCS's guidelines for prescribed fire. The five specific objectives were:

1. Quantify ecological impact of fire when air temperature exceeds 95^{o} F and/or when relative humidity is less than 20%.
2. Evaluate economic effectiveness of using prescribed summer burns as a rangeland restoration tool, compared to other restoration strategies.
3. Evaluate landowner interest/concerns about using prescribed summer fires, and their interest in using EQIP funds to implement summer burns.
4. Through modeling, provide an objective means for examining the implications of including prescribed summer fire in alternative livestock and wildlife production systems over an extended range of management options, physical conditions and weather sequences.
5. Provide research results to support revisions of the technical standards and specifications and potential policy changes by the NRCS.

During the four-year funding period for the project, progress was made towards accomplishing all five objectives. Research started in 2006 under this CIG supported project is ongoing using additional funding sources to more comprehensively address three of the studies objectives. First, ecological evaluations are being conducted beyond this project to quantify longer-term effects of using extreme prescribed fires. Second, the social dimension has been expanded to evaluate perspectives regarding the use of prescribed fire in two Mexican communities to address cultural differences in such perspectives. Third, the predictive model is being refined to better predict the effects on rangeland productivity of alternative landowner perspectives regarding the risk of using of fire. The Human/financial resources and research activities encompassed by the project since October 1, 2005 are summarized below:

Human and Financial Resources:

The project activities were supported by a NRCS CIG in the amount of $376,534 of which $332,430 (90%) was spend on direct costs associated with the research project. The remaining 10% was paid to Texas A&M University for indirect costs.

Personnel who contributed to the project are listed below with seven having been paid for their contributions with project funds:

1. Urs Kreuter PhD: Project Director, principle investigator for social study (Obj. 3, 5)
2. William Rogers, PhD: Principle investigator for ecological study (Obj. 1)
3. Dirac Twidwell: PhD graduate student involved with ecological study (Obj. 1)
4. Richard Conner PhD: Principle investigator for economic study (Obj. 2)
5. Dustin van Liew: MS graduate student involved in economic study (Obj. 2)
6. David Toledo: PhD graduate student involved with social/modeling studies (Obj. 3, 4)
7. Richard Teague PhD: Principle investigator for modeling study (Obj. 4)
8. William Grant PhD: Assistance with modeling study (Obj. 4)
9. Michael Sorice PhD: Assistance with statistical analysis and social component

Research Activities:

The timeline for the project, which included an approved 12-month no-cost extension, is attached at the end of the summary report.

The primary research activities pertaining to each of the first four objectives were:

- Objective 1: Field experiments with whole plot fire treatments and sub-plot herbicide treatments in three locations – Harris Ranch in Breckenridge, Texas Agrilife Research Center in Sonora and Welder Wildlife Refuge in Sinton.
- Objective 2: Focus group meetings with key informants and investment feasibility modeling to compare alternative woody plant treatments.
- Objective 3: Mail survey of 1200 landowners in 12 Texas counties – Stephens, Sutton, Throckmorton, and Young in the Rolling Plains; McMullen, Menard, Schleicher and Shackleford in the Edwards Plateau; and Bee, Duval, Kimble and Live Oak in the South Texas Plains.
- Objective 4: Development of Texas Fire Integration in Rangeland Ecosystems (TEXFIRE) using the STELLA® 9.0 software from ISEE System®.

As previously reported, the start and progress of the project were delayed for three reasons but all of the objectives for the project were nevertheless acheived. The three reasons for delays are:

- Delayed receipt of project funding
- Withdrawal of graduate student (Emily Dacy) who was initially hired to work on the modeling component of the project
- Unsuitable fuel and weather conditions for applying the initial extreme fire treatment in August/September 2007. This resulted in the deferment of the initial burn treatment to the summer of 2008, at which point suitable burns were applied at all three study sites.

Significant results, accomplishments, and lessons learned

A summary of the accomplishments and key findings are described for each of the five project objectives. The first four objectives correspond to the four primary research elements described above, while the fifth relates to overarching objective of providing scientifically rigorous research results for a review of the NRCS' technical standards and specifications for the application of prescribed fire as a tool for restoring and maintaining rangeland condition. Summary reports for each of the four primary research elements (Objectives 1 through 4) are provided below and detailed reports are appended. The key indicators emanating from this project that will help the NRCS review and revise its technical standards and specifications for the applications of prescribed fire are provided under Objective 5 in the summary below. A list of publications and presentations associated with this project is also included.

Objective 1 - Evaluate ecological impacts of applying extreme fire:

In the field experiments conducted to address the ecological dimensions of the study we have demonstrated that prescribed extreme fire (i.e., fire that exceeds the NRCS' traditional guidelines for applying prescribed fire) can be an effective restoration strategy in rangelands heavily invaded by woody plans. Specifically, our study showed that the application of fire alone can cause substantial mortality among resprouting woody plants. At present, confirmed cases of mortality have been observed for resprouting mesquite (*Prosopis glandulsa* Torr.) and huisache (*Acacia smallii* Isely), and non-resprouting trees such as Ashe juniper (*Juniperus ashei* Buchh.).

At the Welder Wildlife Refuge, up to 30% of mature mesquite trees were killed in the fire only treatments. Our initial observations suggest this mortality is the result of conducting extremely high intensity fires during periods of severe water limitations. This led to similar results at the Texas Agrilife Research Center in Sonora. At both sites, no mortality of mesquite was observed in the unburned plots. However, fire intensity and drought severity were lower at Harris Ranch, located on the Rolling Plains, and failed to cause any mortality in burned or unburned areas. This suggests that some fire intensity threshold exists that enables fire to cause mortality in resprouting plants, such as mesquite. Researchers and managers are reluctant to burn in the types of conditions that can lead to mesquite mortality due to the perceived risks of igniting extreme fires, legislation and policies that prevent burning in extreme conditions (e.g. burn bans) and a lack of understanding of biophysical processes that dictate fire behavior in rangelands. Nevertheless, this study clearly shows prescribed extreme fire can cause mortality among several invasive woody plants and it has the potential to be a useful tool for restoring rangelands.

While the primary ecological experiment focused on determining the effects on woody plants of applying high-intensity fires in rangeland communities, our study of herbaceous plant community responses to prescribed extreme fire and our long-term comparative analysis of high-intensity growing season fires versus dormant season fires and unburned areas also show favorable results for the application of prescribed extreme fire. Many landowners, agency personnel, and scientists are concerned that conducting high-intensity fires during periods of extreme drought will potentially lead to decreased species richness and increased invasion by exotic grasses. While our results are preliminary, one-year post burn results demonstrated that native forbs increased in species richness, leading to greater overall biodiversity in burned areas compared to unburned areas. All other plant functional groups did not differ between burned and unburned treatments. We are continuing to collect herbaceous species data, and we are identifying how the biomass of native forbs, native grasses, exotic forbs, and exotic grasses change over time in response to burned and unburned treatments. A 12-year study at the Texas Agrilife Research Center in Sonora that we have also analyze as part of this study shows that fire was not the dominant driver of herbaceous composition or dominance. Rather, changes in precipitation and removal of livestock herbivory were causing shifts in the herbaceous plant community. In this long-term study, prescribed extreme fires were implemented in the growing season, resulting in greater control of the woody plant community while the herbaceous community did not differ functionally among growing season, dormant season, and unburned treatments. These results corroborate our current study and suggest that the greatest amount of variation in herbaceous species composition and dominance is driven by changes occurring as a function of climatic variability, livestock herbivory, and legacy effects of pre-existing variability, and not the application of prescribed extreme fire.

One key element that should also be addressed is the need for scientists, managers, policy makers, and fire practitioners to be better informed about the biophysical mechanisms that drive fire behavior in rangelands. For example, rangeland fire practitioners have long used temperature and relative humidity as critical indicators of safe burning conditions. However, these variables were established for dormant season fuels to serve as a proxy for fuel moisture. Our study clearly demonstrates that fire behavior is not determined by changes in temperature and relative humidity when fire is fueled by live herbaceous plants during the growing season. Temperature and relative humidity are largely irrelevant when the fuel bed is dominated by live fuel rather that dead plant matter, herbaceous litter, or dormant grasses. Regardless of the season, fuel moisture is the most important variable affecting fire behavior. During the dormant season, fuel moisture is largely driven by changes in relative humidity. However, fuel moisture is also driven by soil-water limitations following extended periods of drought. This should be considered by all fire practitioners. The aforementioned mechanism is clearly shown in physical models of fire behavior in forest and grass fuel types. We are currently developing a manuscript that shows how the physics of fire dictates fire behavior and fire ecology in rangelands.

Deciding whether to burn above 95^{o} Fahrenheit or below 20% relative humidity (Objective 1) is, therefore, not relevant to understanding the ecological response of rangelands to growing season fires because those variables are not critical determinants of fire behavior during the growing season, when extreme fires are most commonly applied. However, temperature may be important for agencies to consider; heat stress and heat stroke are potential problems when prescribed fires are applied when air temperatures exceed these levels – although a more relevant indicator might be heat index. In terms of fire behavior or fire ecology, however, we recommend that fire practitioners focus on fire intensity, and the factors that directly affect it, when they develop burning guidelines. It is not our intention to determine what appropriate burning conditions should be for different organizations or for the NRCS. Rather, we intend to show that temperature and humidity thresholds that are currently used as guidelines are inappropriate predictors of fire behavior and fire effects during the growing season. We need to develop a better understanding of the factors that directly drive fire behavior and fire effects under those conditions. We are currently undertaking this challenge and, upon completion, we will disseminate this information and publications to the NRCS.

In addition, certain aspects of the hydrologic, carbon and nitrogen cycles, and soil formation processes, respond at different levels of fire intensity. Although significant research efforts have been undertaken to understand the effects of fire on ecosystem processes, much of this work has not included prescribed extreme fire. The following questions need to be addressed: 1) Can prescribed extreme fires, by reducing woody plants, increase overall net primary productivity and shift aboveground biomass to higher herbaceous proportions and belowground to more shallow soil horizons? 2) How do net nitrogen mineralization rates respond to prescribed extreme fire and how long will it take for mineralization rates to return to pre-fire levels? 3) How do prescribed extreme fires and herbivory interact to influence herbaceous production and nitrogen mineralization? 4) How do prescribed extreme fires and precipitation pulses interact to influence herbaceous production and nitrogen mineralization? 5) How is water infiltration influenced or inhibited by prescribed extreme fire through the formation of a somewhat transient hydrophobic layer? 6) How do grazing and precipitation interact with prescribed extreme fire to influence soil hydrophobicity?

Objective 2 - Assess economic efficiency of applying extreme fire:

The second part of the project was to ascertain the economic efficiency of using extreme fire as a rangeland restoration tool compared to other more traditional mechanical, chemical and fire treatments to reduce woody plant densities. The results of the economic analysis are reported in a manuscript that has been submitted for publication. The economic evaluation was conducted in four counties in each ecoregion included in the study: Stephens, Sutton, Throckmorton, and Young in the Rolling Plains; McMullen, Menard, Schleicher and Shackleford in the Edwards Plateau; and Bee, Duval, Kimble and Live Oak in the South Texas Plains.

Baseline information for the economic evaluation was derived through focus group meetings in each ecoregion that included a broad spectrum of landowners and NRCS and Texas AgriLife Extension personnel. The information obtained focused on the most common economic uses of rangeland resources by landowners in each ecoregion, the dominant invasive brush species, and the most commonly used practices and associated costs for controlling these invasive plants.

Based on this input, the most commonly targeted species are: prickly pear (*Opuntia phaecantha*) in the Rolling Plains; ashe and redberry juniper (*Juniperus ashei* Buchh. and J. *pinchotii* Sudw., respectively) in the Edwards Plateau; and Huisache (*Acacia smallii* Isely) in the South Texas Plains. Mesquite (*Prosopis glandulsa* Torr.) was considered to be a problematic invasive species in all three ecoregions and was, therefore, included as a second species in the analysis. Chemical and fire treatments are frequently used to treat prickly pear infested areas in the Rolling Plains, juniper treatments are limited to mechanical and prescribed fire techniques in the Edwards Plateau, and a combination of herbicide and fire is commonly used to treat huisache in the South Texas Plains. Due to its resprouting characteristics, mesquite is generally treated with herbicides followed by fire. Cool season maintenance burns were included in the analysis in all cases.

An investment feasibility model was used to compare the economic efficacy of extreme fire and the other commonly applied woody plant treatments. The economic analysis indicated that extreme fire was economically superior to all other woody plant treatments in all ecoregions; it was the only treatment that provided positive returns on investments without cost sharing. We also analyze the effect of including cost sharing to offset treatment costs to landowners. This resulted in even greater returns on investment for extreme fire and it resulted in less negative returns on investments for the more commonly used practices. However, our analysis did not support the assumption that 50% cost sharing would provide at least break-even returns to landowners for their investments in the commonly applied woody plant treatments.

Our study indicates that extreme fire followed by periodic cool season maintenance burns is the only method that can be used to efficiently reduce (produce positive returns on investment without cost-sharing) invasive woody plants in the study area. Despite this apparent economic superiority, two caveats must be added. First, we did not account for weather-related risks of not being able to apply fire, especially extreme fire, when necessary. Such risks could reduce the economic efficacy or even feasibility of applying extreme fire, especially when drought reduces fuel loads. Protracted delays in applying fire may necessitate the use of alternative treatments to contain invasive woody plants. Second, many landowners are reluctant to apply fire on their land. If it is socially desirable to maintain biodiverse, ecologically resilient and productive rangelands, it may be necessary to use public funding to help landowners implement rangeland restoration practices that are perceived to be less risky even if they are economically inefficient.

Objective 3 - Determine social issues about the application of extreme fire:

This element of the project explored landowner attitudes and perceptions about prescribed fire. The study area for the landowners survey included the same 12 counties as those included in the economic study. A self-completion survey questionnaire was sent in July 2008 to 1,200 landowners (100 in each selected county) to obtain information about landowner attitudes and perceptions regarding the use of prescribed fire as land management tool in general, and the use of extreme fire in particular. The selected landowners all owned at least 50 acres of land and they included members of prescribed burn associations (PBA members, 16% of total sample) and non-members who were randomly selected from county tax records (84% of total sample). The associations included in the survey were the Edwards Plateau Prescribed Burn Association, Hill Country Prescribed Burn Association, and Coastal Bend Prescribed Burn Association. We identified factors that affect landowner attitudes and perceptions about prescribed fire to help decision makers better understand behavior in relation to the use of this land management tool.

When asked about invasive woody plants, responses varied but overall the main species of concern were mesquite (*Prosopis glandulosa*) and prickly pear (*Opuntia* spp.) followed by juniper (*Juniperus* spp.) and huisache (*Acacia smallii*). In general, the survey respondents had positive attitudes towards the value of prescribed fire including warm season fires, and they believed that prescribed fire is easier to implement, less costly, and more effective than other brush control methods. When asked about prescribed extreme fires, responses were still positive, but less so than for milder fires. Despite this generally favorable attitude towards prescribed burns and the majority belief that the best season to apply prescribed fires is during dry warm months, the respondents were neutral to slightly concerned about applying prescribed fire on their land and only 32.6% had actually performed burns. In general, Edwards Plateau respondents had more positive attitudes towards prescribed fire than Rolling Plains and South Texas Plains respondents, the latter of which had the least positive attitudes coinciding with their greater level of concern about using prescribed fire. In addition, logistic regression analyses indicated that property size and length of ranching experience were significant positive predictors for a positive attitude towards prescribed fire, for previously applying prescribe fire, and for concerns over the availability of labor and equipment to safely apply prescribed fire.

Of relevance for this study were the results of the comparison of PBA members and non-members. We found PBA members to be more favorably predisposed to the application of prescribed fire than non-members. Given this, we were interested in learning more about factors influencing membership in these associations. To achieve this we conducted logistic regression analyses with PBA membership as the dependent variable and the predictor variables being attitude towards the use of prescribed fire, concerns over negative effects of prescribed fire on roads, urban areas, and neighbors, and concerns over lack of knowledge and equipment. The likelihood of PBA membership increased with more positive attitude towards the use of prescribed fire and decrease with level of concern over the negative effects of prescribed fire, lack of knowledge and lack of fire management equipment. We also used the following variable as predictors for PBA membership: attitude towards the use of extreme prescribed fire, effects of prescribed fire on roads, urban areas, and neighbors, and fire ecology knowledge as the covariates. PBA membership was positively related with more positive attitude towards use of prescribed extreme fire and greater fire ecology knowledge and negatively related with all of the potential negative effects of prescribed fire, suggesting that membership reduces such fears.

Finally, our survey corroborated the findings of other researchers that measures of social capital (trust, reciprocity and collective action) are high among members of landowner associations, such as PBAs. This indicates that PBAs play a positive role in enhancing cooperation among neighboring landowners, which could facilitate coordination of land management decisions across the landscape. PBAs may be especially useful in this regard because they focus on an issue that is targeted, is of widespread interest, and that generates shared experiences among neighboring landowners during burn days. Therefore, if the objective is to promote the use of fire across the landscape, educating people about the advantages of PBA membership and promoting membership in these associations is a good way of getting people informed and equipped to apply prescribe fire safely.

Objective 4 - Systems modeling:

This element of the project was included to develop a model for predicting the ecological implications of applying alternative prescribe fire strategies depending on the level of risk aversion towards using fire. The model is called Texas Fire Integration in Rangeland Ecosystems (TEXFIRE). TEXFIRE is being developed using the STELLA® 9.0 software from ISEE System® (Lebanon, NH, USA). This is a compartment model based of a range of functional equations with a one-month time step. Parameterization and evaluation of the model are based upon data from peer reviewed literature, existing models, Ecological Site Descriptions (ESD), and ongoing field experiments that are being performed as part of this project.

With each month, tree and shrub densities in the first size class increase based on seed establishment. Progression though state variables occurs monthly and progression into a different size class occurs based on time (years) a cohort of plants remains in one size class. Herbaceous plant growth occurs based on previously develop growth curves, and stochastic rainfall and temperature patterns based on historic data. Density of trees and shrubs affect themselves through intra-specific density dependent competition and together with cacti cover also have a cumulative effect on herbaceous biomass growth because of increased canopy cover that reduces availability of resources to understory vegetation (solar radiation, water uptake, nutrient uptake, etc. are all implicit in this variable). In addition, loss of tree and shrub density occurs by burning, chemical treatments, or mechanical treatments and loss of tree and shrub diameter occur by canopy scorch due to fire, herbicide defoliation and browsing.

All treatment effects are controlled by a decision making tree in which a landowner inputs the desired maximum woody cover and whether or not the landowner is willing to apply fire or other treatments. Mechanical and chemical treatment effects are dependent on having enough woody cover to warrant them and whether or not the landowner wishes to apply them. Fire treatment effects depend on fire intensity, which depends on the amount of herbaceous biomass and season of occurrence, and on the landowner's willingness to burn at higher intensities. The main output of TEXFIRE are the vegetation dynamics through time based on different brush treatment scenarios. By simulating stochastic weather patterns we can account for climatic uncertainties, which leads to a range of predicted results and a confidence band that may aid decision-making according the landowners' risk perceptions.

The delay in the initial fire treatments in this project also delayed the availability of data required to parameterize the model. Once it has been parameterized, the model will be validated so that it can be effectively used as a land management decision support tool. Additionally, because STELLA® 9.0 software is not object based, the model limits the flexibility of the tree and shrub submodels. Therefore, we are also exploring the use Visual Basic software to model tree and shrub attributes, which would allow us to add a spatial component to vegetation dynamics represented in TEXFIRE.

Objective 5 – Support for revision of technical standards and specifications:

The research that was conducted in this project has generated several indicators for consideration by the NRCS in its periodic review and revision of the technical standards and specifications for the applications of prescribed fire on Texas rangelands. These indicators are summarized for each of the four main elements of the research project:

Ecological indicators:

1. The field experiments demonstrated that applying extreme fire alone during the growing season can significantly increase the mortality of invasive woody plants including resprouting trees, such as mesquite and huisahce. This suggests that application of extreme fire is indeed a useful tool for reducing the density of invasive woody plants in formerly open grassland and savanna ecosystems in Texas.

2. The field experiments also showed that the application of extreme fire does not appear to harm herbaceous plant communities. This finding needs to be corroborated with further data that are currently being obtained and other questions also need to be addressed including the effect of extreme fire on hydrological, carbon and nitrogen cycling characteristics and herbaceous plant biomass production. Nevertheless, our study suggests that extreme fire can be safely applied without apparent harm to the herbaceous understory.

3. Most importantly, our study suggests that the temperature and relative humidity thresholds previously used to guide the application of prescribed fire primarily during the dormant season are of little relevance for understanding the ecological response of rangelands to growing season fires because those variables do not determine fire behavior during the growing season, when extreme fires are most commonly applied. Much more critical for predicting the behavior of fires that are fueled by live plant matter is ***fuel moisture***. That is not to say that air temperature is not an important consideration from a human health perspective when applying summer fires.

Economic indicators:

4. Our analysis demonstrated unequivocally that the application of prescribed extreme fire as an initial woody plant treatment followed by periodic cool season maintenance burns was economically far superior to all other commonly use woody plant reduction treatments. This analysis was based on information about invasive woody plants and treatments to reduce them that was obtained during focus group meetings from NRCS and Texas AgriLife Extension personnel and landowners and on treatment cost data obtained from the NRCS. It was also based on the assumption that the initial extreme fire treatment and subsequent maintenance fire treatments could be applied in any year.

5. Our analysis also showed that, based on our assumptions and data, the commonly used woody plant treatments remained economically inefficient (do not produce a positive return on investment for private landowners) even when 50% cost sharing was applied.

6. The use of the more commonly used woody plant treatments may still be necessary when prevailing weather conditions do not provide the fine fuel loads or fuel moisture conditions necessary for the application of prescribed fire, especially extreme fires (as was the case in the first year of our study) or when landowners are averse to applying fire on their land.

Social indicators:

7. The landowner survey showed that landowners in the 12 counties surveyed generally have favorable perspectives about the concept of applying prescribed fire, including extreme fire. However, many have concerns about applying fire on their land due to a lack of knowledge about applying fire safely, a lack of fire management equipment and labor on burn days, and concerns about negative effects of fire and smoke on their neighbors, and nearby roads or settlements. This indicates an opportunity for intervention to reduce these concerns, thereby increasing the probably of prescribed fire, including extreme fire, being applied more widely.

8. Our study also found that members of prescribed burning associations (PBSs) were significantly more favorable towards the application of prescribed fire on their land than non-members. Furthermore, members were less concerned about the lack of labor and equipment and they were more knowledgeable about the use and ecology of fire. This suggests that support for the establishment of PBAs across Texas could encourage more landowners to apply prescribed fire as a rangeland restoration tool on their land.

9. Our study also showed that PBA members exhibited greater social capital (ability to cooperate with others) than non-member landowners. This suggests that supporting the establishment of PBAs across Texas could facilitate more integrated decision making by landowners at the landscape level with respect to rangeland management. PBAs may be especially well suited to achieve this because of the compelling and broadly applicable issue that they focus on (i.e., the safe application of prescribed fire including extreme fires) whereas other landowner associations may focus on more localized or less compelling issues or they may not require landowners to interact in the same way as PBA members do during burn days.

Modeling indicators:

10. The modeling component of the study is still in process due to the need to parameterize the model using data derived from ongoing field experiments and the need to subsequently validate the model. However, progress with the Texas Fire Integration in Rangeland Ecosystems (TEXFIRE) model indicates that it is feasible to develop a decision support tool to stochastically predict the ecological outcomes of alternative woody plant treatment scenarios based on the level of landowner willingness to apply prescribed fire. TEXFIRE should be a useful tool for helping NRCS personnel, extension agents and landowners educate others about the implications of using or not using prescribed fire, including extreme fires, as an integral element of their land management strategy.

Environmental Quality Incentives Program (EQIP) and CIG grant agreement provisions

List of EQIP-eligible entities involved in the project: Not applicable – This is a research oriented project not an EQIP Project implementation initiative. However, the Welder Wildlife Foundation property at Sinton, Texas, which will be on of the field sties for the project, is an EQIP eligible entity.

Payments made to EQIP eligible entities: Not applicable – Payment to such entities was not part of project proposal or project budget.

Self-certification statements: Not applicable – No payments were made to any entities for land improvement projects.

Scientific Output for this Project

The following is a list of publications and other scholarly activities based on the results of this project:

Publications In Press

Twidwell, D., S.D. Fuhlendorf, D.M. Engle, C.A. Taylor, Jr. 2019. Surface fuel sampling strategies: Linking fuel measurements with fire effects. *Rangeland Ecology and Management*

Publications In Review

Taylor, Jr., C.A., D. Twidwell, N.E. Garza, C. Rosser, J.K. Hoffman, T.D. Brooks. Long-term effects of fire, livestock herbivory removal, and climatic variability in Texas semiarid savanna.

Twidwell, D., S.D. Fuhlendorf, C.A. Taylor, Jr., W.E. Rogers. Social risk versus ecological restoration: Which will determine the application of prescribed extreme fire?

Van Liew, D., J. R. Conner, U. P. Kreuter and Richard Teague. Economic feasibility of using prescribed extreme fire as an invasive brush management tool in Texas.

Publications In Preparation

Meza, J., D. Twidwell, C. J. Turney, W.E. Rogers. Using prescribed fire to locate fire ant mounds: implications for management.

Toledo, D., U.P. Kreuter, W.R. Teague, W.E. Grant. A comparative scenario based simulation of the ecological and socio-economic effects of applying different brush control practices.

Toledo, D., U.P. Kreuter. Human dimensions of using extreme prescribed fire to restore rangeland ecosystems in Texas: Evaluating the role of Prescribed Burn Associations

Toledo, D., U.P. Kreuter, M.G. Sorice: To burn or not to burn: confronting issues of ecological degradation, ranch economics, cultural norms, and burning risk.

Toledo, D., W.E. Grant, W.R. Teague, U.P. Kreuter. TEXFIRE: Modeling extreme prescribed fire effects and post-fire vegetation regrowth on Texas rangelands.

Twidwell, D., S.D. Fuhlendorf, W.E. Rogers, C.A. Taylor, Jr., D.M. Engle. Fire behavior in rangelands: a reassessment of traditions.

Twidwell, D., B. McMahon, B. Thomas, W.E. Rogers. Restoration of grassland using prescribed extreme fire: Initial effect on herbaceous species richness and invasion.

Twidwell, D., W.E. Rogers, W.R. Teague, U.P. Kreuter. Fire and herbicide effects in *Prosopsis-Opuntia* Texas savanna.

Presentations

Bruton, R.K., D. Twidwell, C. Wonkka, U.P. Kreuter. 2010. Drivers of decision: a review of grassland management techniques. 16th International Symposium on Society and Resource Management. Corpus Christi, TX, June 2-6, 2010.

Bruton, R.K., D. Twidwell, C. Wonkka, U.P. Kreuter. 2009. Balancing risk and return in sustaining environmental services: a review of resource management techniques. 94th Ecological Society of America Annual Meeting, Albuquerque, NM, August 2-7, 2009.

Delgado, A., D. Twidwell, R.A. Washington-Allen, W.E. Rogers, S.C. Popescu. 2009. Evaluating cross-scale resilience of an invaded savanna using field-based pulsed lidar. 94th Ecological Society of America Annual Meeting, Albuquerque, NM, August 2-7, 2009.

Herrin, J., D. Twidwell, C.A. Taylor, Jr. 2009. Why is there a burn ban? An evaluation of indices used for their establishment. 62nd Annual Meeting of the Society of Range Management: Merging Trails. Albuquerque, NM, February 8-12, 2009.

Hoffman, J.K., D. Twidwell, C.A. Taylor, Jr., N.E. Garza, C. Rosser, T.D. Brooks. 2009. Long-term analysis on the restoration potential of savanna using fire in different seasons. 94th Ecological Society of America Annual Meeting, Albuquerque, NM, August 2-7, 2009.

Hoffman, J.K., C.A. Taylor, Jr., D. Twidwell, N.E. Garza, C. Rosser, T.D. Brooks. 2009. Reintroduction of the historic fire return interval after grassland-savanna conversion to juniper woodland: long-term analysis. 10th Annual Ecological Integration Symposium. College Station, TX, March 6-7, 2009. **Best undergraduate presentation – 2nd place poster.**

Kreuter, U.P, J.R. Conner, W.E. Rogers, C.A Taylor, Jr., W.R. Teague. 2009. Ecological, economic and social dimensions of using extreme fire to restore ecosystems in the southern Plains. 62nd Annual Meeting, Society for Range Management, , Albuquerque, New Mexico, February 8-12, 2009.

Kreuter, U.P., W.R. Teague, W.E. Rogers, C.A. Taylor, Jr., J.R. Conner. 2009. Using extreme fire to restore rangelands in the Southern Plains: Ecological, economic and social evaluation. SWRI World Conference on Ecological Restoration. Perth, Australia, August 23-27, 2009

Meza, J., D. Twidwell, W.E. Rogers. 2010. Can ecological restoration reverse human-driven changes in fire ant and native harvester ant numbers? 16th International Symposium on Society and Resource Management. Corpus Christi, TX, June 2-6, 2010.

Rogers, W.E., D. Twidwell, G. Sosa, C.A. Taylor, Jr. Restoring shrub invaded rangelands with prescribed extreme fires. 95th Ecological Society of America Annual Meeting, Pittsburgh, PA, August 1-6, 2010.

Toledo, D., U.P. Kreuter, M.G. Sorice. 2010. To burn or not to burn: confronting issues of ecological degradation, ranch economics, cultural norms, and burning risk. 16th International Symposium on Society and Resource Management, Corpus Christi, Texas, June 6-10, 2010.

Toledo, D., U.P. Kreuter, W.R. Teague. 2009. Human and ecological dimensions of using extreme prescribed fire to restore rangeland ecosystems in Texas. SWRI World Conference on Ecological Restoration. Perth, Australia, August 23-27, 2010.

Toledo, D.P., U.P. Kreuter, W.E. Grant, D. Twidwell. 2009. Ecological and social dimensions of using extreme prescribed fire to restore rangeland ecosystems in Texas. 62nd Annual Meeting of the Society of Range Management: Merging Trails. Albuquerque, NM, February 8-12, 2009.

Turney, C.J., D. Twidwell, W.E. Rogers. 2009. Small threats, big challenges: using prescribed fire to locate and manage for fire ant (Solenopsis invicta) invasion in Texas. 94th Ecological Society of America Annual Meeting, Albuquerque, NM, August 2-7, 2009.

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Revised Timeline for Completion of Work for CIG Award # 68-3A75-5-180:

Project Objectives

6. Quantify ecological impact of fire when air temperature exceeds 95° F and/or when relative humidity is less than 20%.
7. Evaluate economic effectiveness of using prescribed summer burns as a rangeland restoration tool, compared to other restoration strategies.
8. Evaluate landowner interest/concerns about using prescribed summer fires, and their interest in using EQIP funds to implement summer burns.
9. Through modeling, provide an objective means for examining the implications of including prescribed summer fire in alternative livestock and wildlife production systems over an extended range of management options, physical conditions and weather sequences.
10. Provide research results to support revisions of the technical standards and specifications and potential policy changes by the NRCS.

Table 1: Original proposed timeline for accomplishment of the preceding five objectives.

Objective description	2005				2006												2007												2008								
	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
Evaluate ecological impacts	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Assess economic efficiency					■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■									
Determine social issues								■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■									
Systems modeling																	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■						
Report for NRCS TS&S revisions																													■	■	■	■	■	■	■	■	■
Produce Publication																																	■	■	■	■	■

Table 2: Revised Timeline for accomplishment of the five objectives.

Objective description	2005*				2006												2007												2008												2009								
	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
Evaluate ecological impacts					■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Assess economic efficiency									■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■																					
Determine social issues									■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■									
Systems modeling																	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Report for NRCS TS&S revisions																																													■	■	■	■	■
Produce Publication																																													■	■	■	■	■

* Funding for this project was received only in October 2006, which delayed the start of the project, especially the establishment of the field experiments. The need for three years field data is the primary reason for the request for a no-cost extension of 12 months from the end of September 2008 to the end of September 2009.

Objective 1 - Evaluate ecological impacts:

Final Report **August 2010**

ECOLOGICAL DIMENSIONS OF PRESCRIBED EXTREME FIRE IN TEXAS

The stated objectives of the ecological component of this project were to:

1. Quantify the ecological impact of fire when air temperature exceeds 95 degrees Fahrenheit and/or when relative humidity is less than 20%

2. Collate and analyze existing and new data regarding the effects of summer fires on rangeland plant communities

In addition to meeting the objectives stated in the grant, we:

3. Empirically tested the so-called "critical variables in rangeland fire behavior" – including temperature and relative humidity and evaluated the appropriateness of those variables in growing season fires

Overviews of the ecological projects are summarized as follows:

I. **Prescribed extreme fire and herbicide manipulations**
II. **Initial impacts on Herbaceous Species Richness and Invasion**
III. **Re-evaluating fire behavior in rangelands**
IV. **Long-term Fire Manipulation in Juniperus-Quercus Savanna**
V. **Additional Project Deliverables**
VI. **Future Research Needs**
VII. **References**

I. Prescribed Extreme Fire and Herbicide Manipulations in Thorn-Scrub Woodland

Project Status: Data collection and analysis is ongoing.

Introduction

An emerging benefit of fire to society is its potential use as a restoration technique in fire dependent ecosystems heavily invaded by woody plants. Successful restoration with fire requires overcoming the resilience of an undesirable, "degraded" ecosystem to promote the resilience and sustainability of an ecosystem that supports large amounts of environmental services. This is a particularly important consideration among resource managers in grassland and savanna environments that have transformed to woody dominated ecosystems. Landowners and resource managers are beginning to implement prescribed extreme fires (i.e. high intensity fires conducted in periods of severe drought) for restoration purposes in some post-grassland woodland ecosystems, especially since the economic considerations of resource management are becoming increasingly important. However, since little to no scientific evidence is available to show prescribed fire can cause high levels of woody plant mortality and overcome the resilience of these ecosystems (but see Twidwell et al. *in review*), strong debate exists concerning the ecological effectiveness of prescribed extreme fire in restoration efforts.

We established a fire-herbicide experiment across three ecoregions of Texas to determine the potential for grassland and savanna restoration from a heavily invaded woodland state. The three sites include (1) Rob and Bessie Welder Wildlife Refuge located near Sinton, Texas, (2) Texas A&M Agrilife Research Center located near Sonora, and (3) Harris Ranch near Breckenridge, Texas. The primary objective is to compare woody plant response to a series of treatments that use fire and herbicide in various combinations. The common tree species linking each site is honey mesquite, but numerous native invasive woody plants dominate individual sites, enabling us to determine if a universal restoration strategy can be developed for plant communities with varying invasive problems. This experiment is scheduled to be complete at the end of 2011. We therefore are only able to present initial experimental observations. More complete analyses will be presented in peer-reviewed publications; such publications are forthcoming.

Experimental Design and Treatments

Eighteen plots (30 m x 20 m) were established at each site and assigned random fire treatments of burned repeatedly, burned once, or unburned (3 burn treatments x 6 replications). Whole plots were subdivided into three subplots of equal area (20 m x 10 m) and assigned an herbicide treatment of herbicide then burn, burn then herbicide, or no herbicide. Livestock herbivory was excluded from all treatment units for the duration of this experiment.

Initial burn treatments were implemented across all three sites in 2008. In 2009, fire treatments were conducted at Welder Wildlife Refuge, thereby finalizing the treatment design for that site. The other two sites were unable to be burned in 2009 due to a lack of fuel accumulation resulting from the prolonged droughts after the 2008 fires. Both sites are scheduled to be burned in the 2010 growing season.

Herbicide treatments were conducted using 25% Remedy Ultra, 75% diesel. In 2007, all woody plants were sprayed across all sites in 'herbicide then burn' subplots. After the initial fire treatments and once resprouting mesquite exceeded 0.5 m in length, woody plants were sprayed across all sites in 'burn then herbicide' subplots.

Sampling

Within each plot, each individual woody plant was sampled (n ~ 5000 total; n ~ 3000 @ Sonora; n ~ 1600 @ Welder; n ~ 400 @ Breckenridge). Measurements included maximum canopy cover (m2), tree height (m), and number of stems. Within subplots, plant community and fuel characteristics were measured visually for total herbaceous (%), total woody (%), total bare ground (%), total leaf litter (%), and total juniper duff (%). Total canopy cover of select species were also recorded, including: mesquite (%), huisache (%), juniper species (%), persimmon (%), prickly pear (%), and lote bush (%). Additional subplot measurements included slope, slope location, and aspect. Within each subplot, herbaceous species composition and production were measured in three, randomly located quadrats.

During the fire, temperature, relative humidity, wind speed, flame length, flame depth, and rate of spread were measured within each subplot. Flame length, flame depth, and rate of spread will be used to calculate the mean fire intensity within each subplot. The amount of area burned was estimated for each subplot immediately after conducting the fires.

All woody plants were resampled in the summer of 2010. Each individual woody plant was assessed for mortality, presence of resprouting, and basal or apical dominance. Future sampling will collect maximum canopy cover, tree height, and number of stems for each individual woody plant. Pre-fire plant community and fuel characteristics were also re-measured. At this point, sampling has been completed for Welder Wildlife Refuge and Harris Ranch. Texas Agrilife Research Center in Sonora will be burned in September, after which, sampling will be finalized.

Preliminary Findings

Preliminary findings from this experiment reveal that prescribed extreme fires can be more effective at killing resprouting invasive woody plants than traditional prescribed fire applications. At the Welder Wildlife Refuge, mortality of mature mesquite trees (> 2 m tall) was 10% to 30% in the burned only treatments after 2 years. A similar amount of mortality was also observed for huisache. Likewise, approximately 10% of mature mesquite trees were killed by fire in the initial burn treatments at Sonora. However, no mortality was observed at Harris Ranch. Harris Ranch experienced the least drought stress of all three sites, and subsequently, fire intensity was much lower at this site compared to Welder and Sonora. At all sites, no mortality was observed in the unburned control treatments.

We are currently finalizing our data analysis to determine the causal relationships driving fire induced mortality of resprouting woody plants at Welder and Sonora. Observationally, all mortality cases appear to be large, single stemmed trees. We believe the increased mortality is a result of conducting fires at intensity levels that exceed the heat tolerance thresholds of mature, single stemmed mesquite trees. Further analyses and continued data collection will determine the validity of this hypothesis. Publications from these findings are forthcoming.

It is too early to compare the effects of fire and herbicide in various combinations but we can discuss the initial impact of the treatments. Across all three sites, the ‘herbicide only’ treatment resulted in approximately 60% mortality on mesquite. It appears that higher mortality results when burning after the herbicide treatment and even higher mortality appears to occur when applying herbicide on mesquite resprouting from fire. However, we need an additional sampling period to confirm these initial results and to ensure that we are not simply observing a prolonged lag in mesquite resprouting. Further data was collected in 2010 and will provide more complete comparisons among treatments, but we have yet to analyze these data. Any conclusions or recommendations from fire-herbicide combinations are therefore inappropriate at this time; however, we can definitively state that prescribed extreme fire, by itself, did cause substantial mortality on mature, resprouting trees at multiple sites.

II. Initial impacts on Herbaceous Species Richness and Invasion

Project Status: Part 1 is currently finished and will be submitted for peer-review publication by October 2010. Part 2 is a long-term project; field sampling will continue until at least 2011.

Introduction

Showing that prescribed extreme fire can kill both non-resprouting trees (e.g. Ashe juniper; Twidwell et al. 2009, Twidwell et al. *in review*) and resprouting trees (e.g. mesquite; see Part I results) provides the first evidence that prescribed fire has the potential to restore grassland and savanna ecosystems across a broad range of plant communities. While this result is desirable to many land managers, those individuals are equally interested in how prescribed extreme fire is impacting the herbaceous plant community. In particular, the effects of prescribed extreme fire on species richness, biomass, and exotic species invasions in the herbaceous community are entirely unknown. Here, we report the initial impacts of prescribed extreme fire on the species richness and exotic invasions of the herbaceous community and outline the current and future features of this project.

This experiment was located at the Rob and Bessie Welder Wildlife Refuge, located approximately 5 km north of Sinton, Texas. Primary native perennial grasses include vine mesquite (*Panicum obtusum*), little bluestem (*Schizachyrium scoparium*), buffalograss (*Buchloe dactyloides*), bristle grass (*Setaria* spp.) among others. Common native forbs include noseburn (*Tragia* spp.), *Ruellia strepens*, yellow neptune (*Neptunia lutea*), and blue mist flower (*Eupatorium coelestinum*). Introduced species include bindweed (*Convolvulus arvensis*), wood sorrel (*Oxalis* spp.), and KR bluestem (*Bothriochloa ischaemum*). Cattle were removed prior to initiation of this experiment and were excluded for its duration.

Experimental Design and Treatments

Eighteen plots, each 20 m x 30 m, were randomly assigned prescribed burn and herbicide treatments. Prescribed burn treatments of burned once, burned repeatedly and unburned were randomly assigned to each plot. The initial burn treatments were conducted in June 2008. Data from the two burn treatments were therefore pooled since only one fire had been conducted at this point of the analysis. Herbicide treatments consisting of herbicide before fire, herbicide after fire, or no herbicide were sprayed in 10 m x 20 m subplots within each main plot. In appropriate subplots, herbicide was applied to all woody plants by spraying a diesel-Remedy Ultra mix at the base of individual woody stems.

Vegetation Sampling

Vegetation sampling was preformed one year after the burn-herbicide treatments by randomly clipping all the herbaceous material within 3, 0.25 m2 quadrats in each subplot. Each herbaceous individual was identified to species, except for *Carex* spp., *Eragrostis* spp., *Oxalis* spp., *Croton* spp., *Tragia* spp., *Setaria* spp. and *Paspalum* spp., which could only be identified to genus. Plants identified to genus did not have the necessary reproductive structures and vegetation characteristics to allow for further identification. After species identification, samples were dried to measure dry weight biomass.

Statistical Analysis

Testing for differences in herbaceous species richness and total herbaceous biomass as a result of the application of herbicide on woody plants showed no significant differences among groups so data were pooled to compare burned (n = 12) and unburned (n = 6) treatments. Species richness data were analyzed using an independent samples t-test with unequal sample sizes of equal variance and normal distribution. Herbaceous biomass data were square-root transformed due to unequal variances and then analyzed using an independent samples t-test. Non-metric multidimensional scaling (NMS) was used to visualize differences in the herbaceous plant community between burn treatments. NMS ordinations were produced with PC-ORD (McCune and Meford 1999) using Bray-Curtis distances with random starting configurations, three dimensions, 100 runs of real data with 500 iterations per run, and a stability criterion of 0.00001. Individual species were not included if they occurred in less than 5% of all samples, following the recommendations by McCune and Grace (2002).

Results

Overall this herbaceous plant community was comprised of relatively few species. *Bothriochloa ischaemum* was the most commonly recorded plant of the species listed in this study. Other common species included *Panicum obtusum*, *Tragia* spp., *Eupatorium coelestrium* and *Krameria lanceolata*.

The herbaceous plant community significantly differed in species richness and total biomass after one year of treatment. Overall species and forb richness increased significantly in burned areas compared to unburned areas (Fig. 1 c). The species richness of perennial grasses was not significantly affected between burned and unburned treatments (Fig. 1 c). The increase of species richness was instead driven by native forbs (Fig. 1 a). No other native or introduced functional group showed significant differences between treatments (Fig. 1 a;Fig 1 b). Total live and dead herbaceous biomass was significantly lower in burned treatments (Table 2 or Figure 2). Bothriochloa ischaemum is the only introduced perennial grass found at the site. After one year, it did not significantly differ in the frequency of burned plots to unburned plots.

NMS ordination supported the finding that the increase in total species richness in burned treatments was largely driven by an increase in the number of native forbs. While the NMS ordination did not show strong separation among burned and unburned treatments, units were generally separated by an unburned-burned gradient along a NMS axis 1 (Fig. 2). Total species richness and native forb species richness were positively correlated in the direction of burned plots along axis 1 (r = 0.482 and 0.643, respectively). The dominant native forbs that accounted for this trend were Neptunia lutea, Tragia spp., and Krameria lanceolata (Table 2). However, some forbs, such as Eupatorium coelestrium, decreased (Table 2). Other forbs, including introduced species, were found at minimal relative frequencies and were not major drivers of the observed increase in total species richness in burned treatments.

NMS ordination also revealed an inverse relationship between total live and dead herbaceous biomass and species richness along axis 1 (Fig. 2; Table 3). Total biomass was negatively correlated with axis 1 whereas total species richness was positively correlated with axis 1 (Table 3). Treatment units with the highest amount of total herbaceous biomass were therefore generally lower in richness, while units with lower biomass were generally higher in richness. This relationship indicates that while some grass species were positively or negatively correlated with axis 1 (Table 1), their relative frequency is not a good corollary for their contribution to the total live and dead herbaceous biomass in this plant community.

Summary and Future Directions

This project provides preliminary findings on the effect of prescribed extreme fire on species richness and exotic species invasion of herbaceous plants. We found native forb richness was significantly greater in the prescribed extreme fire treatment, resulting in a significantly greater total herbaceous species richness compared to the control. Meanwhile, prescribed extreme fire did not cause an increase in *Bothriochloa ischaemum* abundance. Thus, the initial findings of this experiment are favorable for the application of prescribed extreme fire. However, we should note that these findings are preliminary and this analysis only looked at species richness and not the biomass of individual species.

Ongoing research at this site will provide a more detailed account of the response of the herbaceous community to prescribed extreme fire treatments. In the summer of 2010, vegetation was again sampled at Welder Wildlife Refuge. Samples were identified according to species, sorted, dried, and weighed, enabling us to calculate a wider range of community metrics (e.g. species richness, species biomass, total biomass) and compare them across treatment combinations. Vegetation will be sampled again in the summer of 2011 at Welder Wildlife Refuge and plans are in place to expand the project to the Texas Agrilife Research Center at Sonora to provide a cross-site comparison.

Table 1. Pearson correlations (*r*) with NMS axis 1 and relative frequencies of each plant species in burned (*n* = 12) and unburned (*n* = 6) treatments.

Species	*r*	Relative frequency (%) Burned (Mean ± SE)	Unburned (Mean ± SE)	Total
Introduced				
Perennial grasses				
Bothrichloa ischaemum	0.517	1.42 ± 0.16	1.16 ± 0.86	23.97
Forbs				
Convovulus arvensis	-	< 0.10	< 0.10	≤ 1
Oxalis spp.	-	< 0.10	0	≤ 1
Native				
Perennial grasses				
Bothrichloa laguroides	-	0	< 0.10	≤ 1
Buchloe dactyloides	0.329	0.17 ± 0.08	0.13 ± 0.06	2.84
Chloris x subdolichostachya	-0.562	0.11 ± 0.05	0.21 ± 0.08	2.58
Coelorachis cylindrica	-	0	< 0.10	≤ 1
Dichanthelium oligosanthes	-	< 0.10	0	≤ 1
Hilaria berlangeri	-	< 0.10	0	≤ 1
Nassella leucotricha	-0.403	0.13 ± 0.05	0.39 ± 0.13	3.87
Panicum obtusum	-0.518	0.69 ± 0.13	0.86 ± 0.13	13.40
Panicum hians	0.379	0.26 ± 0.07	< 0.10	3.61
Paspalum spp.	-	< 0.10	0	≤ 1
Schizachyrium scoparium	-	< 0.10	0	≤ 1
Setaria spp.	0.353	0.21 ± 0.05	0.13 ± 0.09	3.35
Tridens albescens	-	< 0.10	< 0.10	< 1
Annual grasses				≤ 1
Aristida oligantha	-	< 0.10	0	≤ 1
Forbs				
Ambrosia psilostachya	-	0	< 0.10	≤ 1
Eupatorium coelestrium	-0.471	0.28 ± 0.07	0.47 ± 0.12	6.19
Krameria lanceolata	0.454	0.37 ± 0.09	0.26 ± 0.09	5.93
Neptunia lutea	0.586	0.86 ± 0.16	0.43 ± 0.13	12.89
Ruellia stepans	-	< 0.10	0	≤ 1
Rubus trivialis	-	0	< 0.10	≤ 1
Solanum elaeagnifolium	-	< 0.10	< 0.10	≤ 1
Tragia spp.	0.534	1.01 ± 0.14	0.21 ± 0.12	13.40

Notes: Only correlations with axis 1 are shown since other axes did not separate groups according to differences in burn treatments.

Table 2. Pearson correlations (*r*) of species richness and total live and dead herbaceous biomass with each NMS ordination axes.

	r	
Response variable	NMS Axis 1	NMS Axis 2
Richness		
Total	0.482	-0.033
Total native	0.392	-0.095
Native forb	0.643	-0.087
Native grass	-0.209	-0.050
Introduced forb	0.528	0.147
Introduced grass	-0.303	-0.061
Biomass	-0.678	0.120

Figure 1. Species richness (mean + SE) of forbs and perennial grasses in burned (dark gray) and unburned (light gray) treatments for (a) native plants, (b) introduced plants, and (c) all plants. *, ** indicate significant differences at *P* < 0.10 and 0.05, respectively, compared to the unburned controls of each functional group.

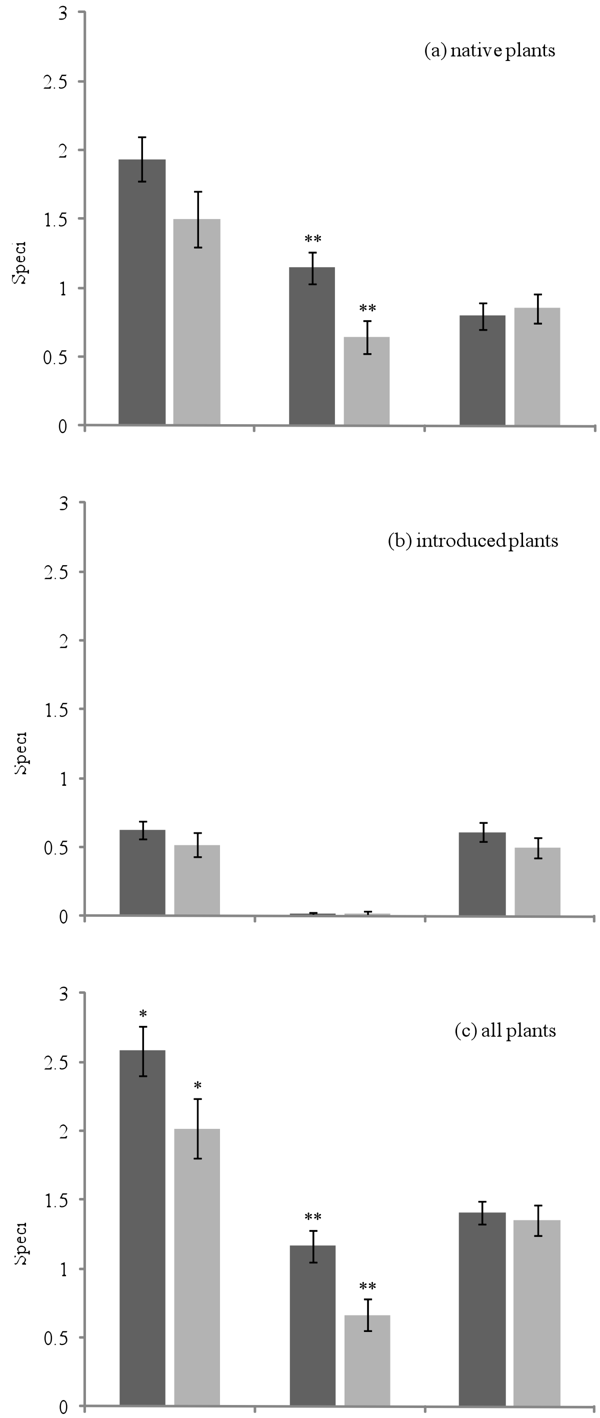
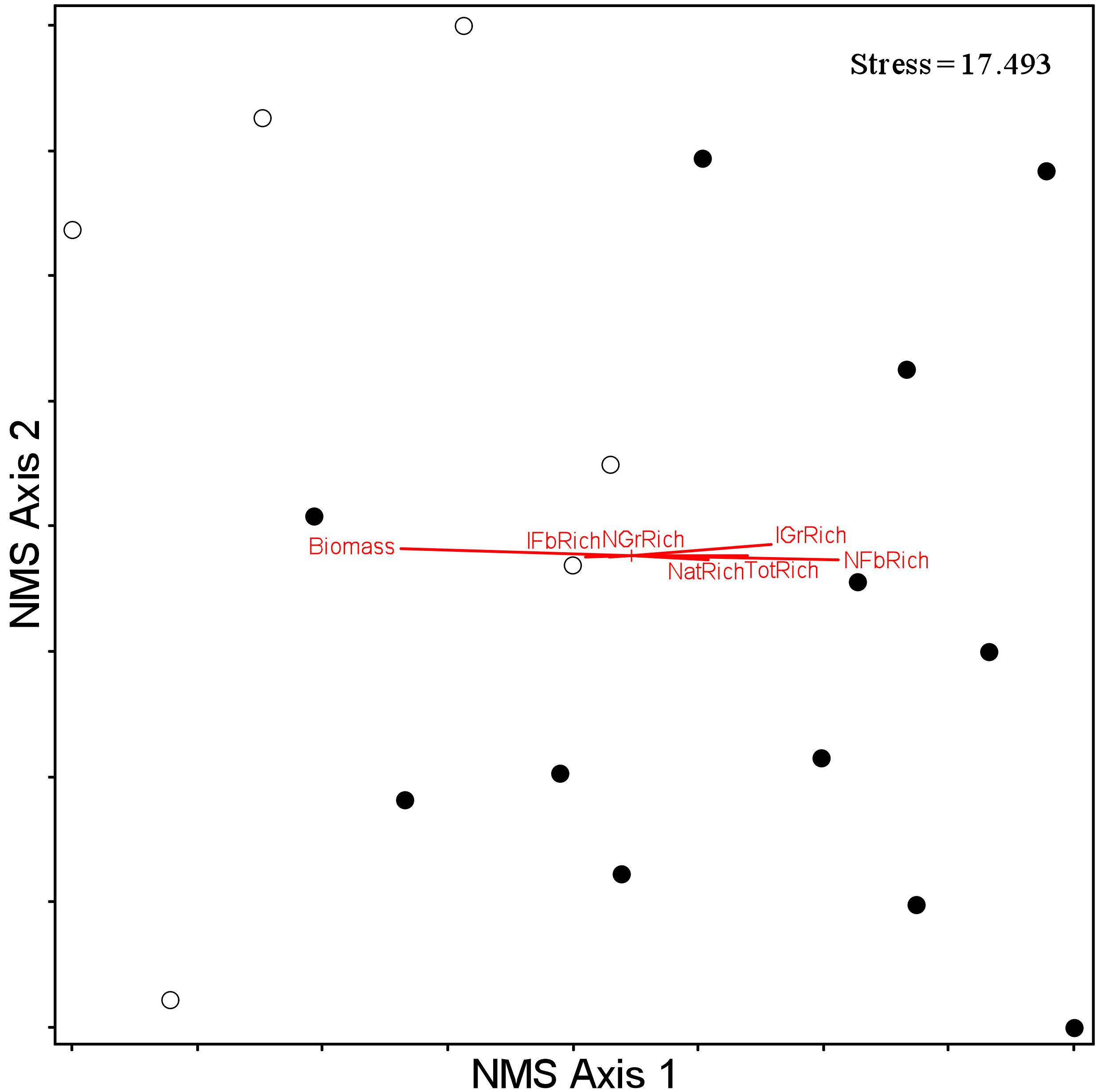


Figure 2. NMS ordination showing the differences in the distribution of the herbaceous plant community in burned (filled circles) and unburned (hollow circles) treatments. NMS ordinations were rotated in the direction of total richness. Biplots show the direction and strength of relationships between ordination scores and total richness (TotRich), native richness (NatRich), native grass richness (NGrRich), native forb richness (NFbRich), introduced grass richness (IGrRich), and introduced forb richness (IFbRich).



III. Re-evaluating fire behavior in rangelands

Project Status: Manuscript in preparation.

Introduction

Five critical variables are traditionally used to predict fire behavior in rangelands. They are temperature, relative humidity, wind speed, fuel load, and fuel moisture (Wright and Bailey 1982). In application, the number of variables is condensed further. Most often fire practitioners use only three easily measured variables, temperature, relative humidity, and wind speed, to determine safe, appropriate burning conditions in rangelands, leading to the commonly utilized 80˚F-20%-20mph Rule in West Texas and 60˚F-40%-15mph Rule in Oklahoma. If temperatures are over 80˚F, less than 20% relative humidity, or greater than 20 mph wind speed then conditions are deemed too risky for prescribed fires in Texas.

Indeed, understanding how various fuels and weather factors influence fire behavior is important. Fire intensity, the amount of heat released by the fire per unit space and time, and rate of spread, the amount of time required for the propagating flaming front to cover a given distance, are important for fire practitioners to determine the controllability of a fire. It is therefore important to ensure that the five critical variables identified in previous rangeland fire research continue to account for differences in fire behavior across a variety of fuel and weather conditions.

While these rules are used extensively throughout rangelands, there are a couple issues emerging that suggest a more robust rangeland fire model should be developed. First, the five critical variables were entirely established by fire behavior research conducted in dormant fine fuels. Historically, most prescribed fire activity was relegated to dormant periods of plant growth. More recently, however, prescribed fires are being conducted in both growing and dormant periods. Those fires conducted in the growing season are continuing to use the 80˚F-20%-20mph Rule or the 60˚F-40%-15mph Rule, even though no study has validated the use of these rules outside of the dormant season. In addition, the five variables identified in rangeland fire research are considered to be "critical" because they are assumed to directly influence fire behavior (e.g., fire intensity; Figure 1). This type of empirical model is inconsistent with some of the more biophysical based models used extensively in fire behavior predictions employed elsewhere (Rothermel and Deeming 1980).

We established this study to (1) test the validity of critical factors for prescribed fires conducted in a variety of fuel and weather conditions in the growing season, and (2) evaluate the usefulness of the traditional framework in the growing season and, if needed, develop a universal framework that can be applied in all seasons. Here, we present the results from the first objective; we are currently developing a biophysical model for use in rangelands to satisfy the second objective. A manuscript including that biophysical model is forthcoming.

Sampling

General plant community characteristics, non-herbaceous plants, weather, fire behavior, and fire effects were measured in sixty-five 10 x 10 m plots at the Texas A&M Agrilife Research Center located near Sonora, Texas. The following variables were measured: total herbaceous plant cover (%), total woody plant cover (%), total bare ground cover (%), prickly pear cover (%), dead woody cover (%), fine fuel load (g m^{-2}), fine fuel moisture (%), temperature (˚C), relative humidity (%), and wind speed (km hr^{-1}). Cover estimates were made to the nearest 5%. Fine fuel load was quantified by clipping and weighing the total plant material in five 0.25 m^2 quadrats located randomly within each plot. Samples were then oven-dried at 70˚C for 48 hours, and reweighed to calculate fuel moisture on a dry-weight basis. Temperature, relative humidity, wind speed, rate of spread, and fireline intensity were measured from the time the fire was ignited to the time the fire reached the end of the plot.

Statistical Analysis

Principal components analysis (PCA) and multiple regression were used to assess relationships among environmental variables, determine redundant measurements, and identify important drivers of fire behavior. To evaluate relationships among fuel and weather characteristics, a Varimax rotation of the PCA on the correlation matrix was performed using CANOCO ver. 4.5. Variables included in the PCA were herbaceous cover (HERB), woody cover (WOODY) , bare ground cover (BG), temperature (TEMP), relative humidity (RH), mean and max wind speed (WINDAVG; WINDMAX), fuel load (FL), and fuel moisture (FM). A Varimax rotation identified variables correlated with each axis of the PCA to identify redundant measurements. The Pearson product correlation coefficient (r) was found for all combinations of variables to verify results from the PCA. Stepwise multiple regression was used to determine the fuel and weather characteristics related to fire intensity and rate of spread.

Results

PCA axis 1 explained 33.7% of the variability in these data, 21.5% was explained by PCA axis 2 (55.2% cumulative), 16.1% by PCA axis 3 (71.3% cumulative), and 12.4% by PCA axis 4 (83.7% cumulative). Measures related to weather were associated with high PCA axis 1 and PCA axis 3 scores (Figure 2, Table 2). Fuel moisture and wind speed were correlated greatest with PCA axis 1, whereas temperature and relative humidity were related to PCA axis 3. PCA axis 2 and PCA axis 4 were associated with descriptive measures of vegetation (Figure 2, Table

2). PCA axis 2 was related to herbaceous cover, woody cover, and fuel load. PCA axis 4 was correlated predominantly with bare ground.

Correlations were found for variables along similar axes to confirm measures of redundancy. Woody and herbaceous cover were negatively correlated (r = -0.657, $P < 0.05$), and both exhibited a slight negative association with bare ground (r = -0.274 and -0.300, respectively). Temperature and relative humidity were also negatively correlated (r = -0.877). Mean and max wind speed were positively correlated with each other (r = 0.715) and fuel moisture (r = 0.777 and 0.598, respectively). All other correlations were not significant ($P > 0.05$).

Fire intensity and rate of spread were dependent on various components of fuel and weather. Fire intensity was predicted by variability in fuel moisture ($R^2 = 0.489$, $P < 0.05$). All other fuel and weather components were not significant ($P > 0.05$) Rate of spread was predicted by bare ground, mean wind speed, and woody cover ($R^2 = 0.447$, $P < 0.05$). The variables that did not significantly predict any aspect of fire behavior were temperature, relative humidity, fuel load, and herbaceous cover (Table 2).

Summary

Temperature, relative humidity, and fine fuel load were not good predictors of fire intensity or rate of spread in the growing season when live fuels dominate the fuel bed (Table 2). Except for fine fuel load, our findings agree with physics-based models (e.g., Rothermel 1983). In our study, fine fuel load was not a significant predictor of fire spread because fuel load was averaged over a 10 m x 10 m area for this analysis and fuel load influenced fire intensity at fine scales, not at the 10 m x 10 m scale (Twidwell et al. 2009). The reason temperature and relative humidity are not good predictors of fire behavior in the growing season is because the relationship between relative humidity and fine fuel moisture content is decoupled in live fuels. In dead fuels that typify the dormant season, relative humidity directly influences fine fuel moisture content. As a result, practitioners should limit their use to fires conducted in dead fuels. More importantly, this shows that using temperature as the sole determinant of whether or not to burn is not only irrelevant in the growing season, but it also ignores numerous variables that are important drivers of fire behavior. We are currently developing a more robust rangeland fire model that provides a consistent framework across all fire conditions. Institutions can then use such a framework in future fire management and prescribed fire planning.

Table 1. Weather and fuel present at the time of burning 65, 10 m x 10 m quadrats on Edwards Plateau, Texas.

Variable	Minimum	Maximum	Mean	SE
Ambient air temperature (˚C)	28.3	38.5	35.5	0.3
Relative humidity (%)	12.4	44.7	23.7	1.0
Wind speed (km hr^{-1})	0.6	11.6	4.0	0.3
Fuel moisture (%)	3.8	29.6	16.9	1.1
Fuel load (g m^2)	23.7	406.2	166.0	20.6

Table 2. Principal component analysis (PCA) axes scores and the proportion of explained variation (r^2) for weather and fuel characteristics deemed to influence fire behavior. Axes scores represent correlations after Varimax rotation of the PCA. Significant values are shown for the proportion of explained variation (r^2) in fire intensity and rate of spread.

Variable	PCA Axis 1 Scores	PCA Axis 2 Scores	PCA Axis 3 Scores	PCA Axis 4 Scores	Intensity	Rate of spread
Herbaceous cover	0.055	0.886**	0.117	-0.210	n.s.	n.s.
Woody cover	-0.266*	-0.800**	0.012	-0.449**	n.s.	6.27*
Bare ground	-0.156	-0.071	-0.033	0.973**	n.s.	26.61**
Temperature	-0.149	-0.075	-0.949**	0.076	n.s.	n.s.
Relative humidity	0.083	0.230	0.944**	0.030	n.s.	n.s.
Mean wind speed	0.907**	-0.012	0.236	-0.137	n.s.	11.79*
Maximum wind speed	0.860**	0.110	0.033	-0.003	n.s.	n.s.
Fuel load	-0.101	0.648**	0.184	-0.047	n.s.	n.s.
Fuel moisture	0.890**	-0.018	0.030	-0.041	48.94**	n.s.

*$P < 0.10$, **$P < 0.05$; n.s., not significant

Figure 1. Depiction of the traditional framework used in rangelands to relate critical factors directly to fire intensity.

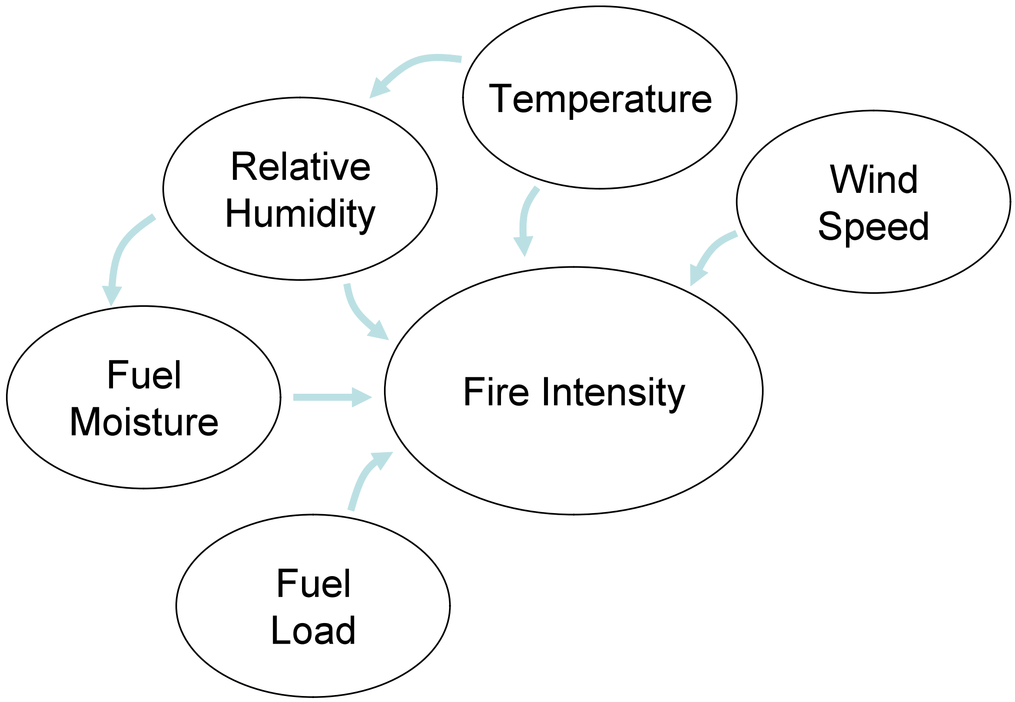
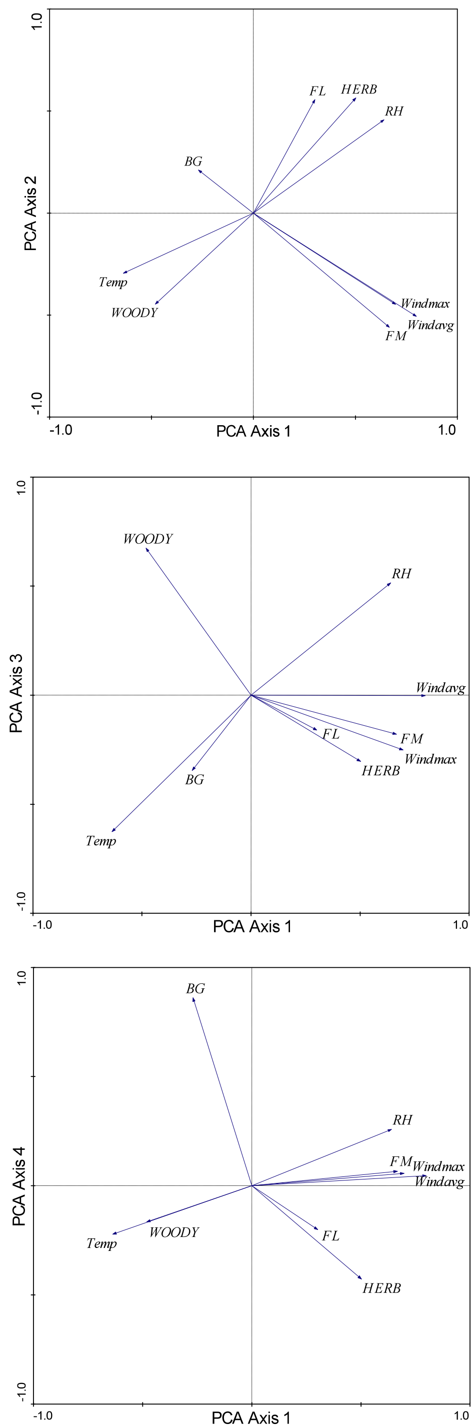


Figure 2. Fuel- and weather-centered principal component analysis of sixty-five 10 m x 10 m quadrats. Multiple figures are provided to demonstrate three-dimensional rotation of the data along axis 1.



IV. Long-term Fire Manipulation in *Juniperus-Quercus* Savanna

Project Status: Manuscript is currently in review (for details see references; Taylor et al. *in review*)

Introduction

Semiarid savannas once covered greater than 10% of the global terrestrial land surface but many are currently transitioning away from the grass-tree codominance that long-characterized these ecosystems toward economically and aesthetically less desirable shrub-dominated woodlands. Such changes have been linked to problematic or invasive plant species, climate change, and human-induced alteration of top-down (e.g., fire, herbivory) and bottom-up (e.g., water, nutrients) controls. Understanding the relative contributions and interactions among these causal drivers is therefore essential if rangeland managers are to maintain the desired proportion of grasses and trees that are essential to rangeland enterprises, livestock operations, and a variety of unique plant and animal species in semiarid environments.

This section presents the findings from an ongoing, long-term study on the Edwards Plateau that reintroduced the frequency and intensity of the historic fire regime (high intensity, 4-6 years) in different seasons (i.e. repeat summer versus repeat winter burn treatments). We use fire season as a proxy for fire intensity in this study since summer fires were specifically conducted in extreme drought conditions to promote the types of high intensity fires reported historically in this region. During early settlement, summer fires were often observed to be of greater intensity than winter fires due to the periodic occurrence of severe droughts that occur in this region during the summer. To our knowledge, this represents the first long-term study in semiarid savanna to reintroduce prescribed fire at frequencies and intensities consistent with the seasonal differences of the historic fire regime. An additional contribution of this paper is that we use statistical techniques unutilized in the rangeland literature to test for significant differences among treatments in a data set with low replication (e.g., N = 2) rather than relying on pseudoreplication and potentially producing unreliable results. The primary objective of this study is to determine if reintroducing the frequency and intensity of the historic fire regime can maintain codominance of grasses and trees in the absence of livestock herbivory. In other words, can solely reintroducing the historic fire regime prevent increases in woody plants without causing long-term change to the composition and dominance of the herbaceous community?

Methods

This research was conducted in the Edwards Plateau ecological region on the Texas AgriLife Research Station (31oN; 100oW) located 56 km south of Sonora, Texas. Plant communities range from oak savanna, dominated by small clusters of live oak (*Quercus virginiana*) and Vasey shin oak (*Q. pungens*), to closed-canopy juniper woodland, consisting of Ashe juniper (*Juniperus* *ashei*) and redberry juniper (*J. pinchotii*), depending on management history (Kuchler 1964, Hatch et al. 1990, Fuhlendorf and Smeins 1998). Herbaceous vegetation is dominated by common curly mesquite (*Hilaria belangeri*), Wrights threeawn (*Aristida wrightii*), sideoats grama (*Bouteloua curtipendula*), hairy grama (*Bouteloua hirsute*), Texas wintergrass (*Stipa leucotricha*), Texas cupgrass (*Eriochloa sericea*), and to a lesser extent, little bluestem (*Schizacyrium scoparium*).

A twelve ha portion of the station was fenced in 1994 to implement a long-term fire study. This section was chosen because it was one of the most homogenous units on the station. The area was characterized by consistent soils, flat topography, consistent grazing and brush management history, and similar vegetation patterns (i.e., oak savanna). Sheep, goats, and cattle were removed from the unit prior to this experiment and all livestock have been excluded for the duration of this study.

Six experimental units of equal area (2 ha) were established in the 12 ha section. Each unit was randomly assigned a long-term seasonal burn treatment of repeated summer burn, repeated winter burn, or control. Fire treatments were designed to replicate the frequency and intensity of the historic fire regime of this region. As a result, fire treatments were repeated every 6 years, on average, to match the estimated historic mean fire frequency of this region while allowing enough flexibility to conduct high-intensity fires by skipping burns scheduled during seasons of high precipitation or to burn sooner than scheduled if ideal conditions became available. Summer burn units were burned in August 1994, July 2000, and July 2006. Winter burn units were burned in January 1996, January 2000, and February 2006. Although fire treatments were initiated in different years at the start of this experiment, this study provides a more realistic portrayal of the effects of the historic fire regime on plant community dynamics. Historically, it was common for the amount of time between two successive fire events (i.e. fire return interval) to deviate from the historic mean fire frequency of 6 years. This long-term, ongoing experiment will therefore provide unique insights regarding the role of a variable, high-intensity fire regime in shaping community composition, abundance, and structure across different seasons.

Vegetation Sampling

The composition and abundance of graminoid species, woody plant species, and prickly pear cactus (Opuntia spp.) was sampled in each experimental unit along 10 randomly established and 'permanently' marked 50 m transects. Prior to fire treatment in 1994 and again in 2006, a 0.25 m2 quadrat was placed at 2 m increments along each transect to record the three most dominant graminoid species according to canopy cover. In 1994 and 2006, the abundance of overstory (> 1.5 m) and understory (< 1.5 m) woody plant species and prickly pear cactus was measured along the transects. In 2006, total woody canopy cover was measured using the line intercept method. Pre-treatment woody plant canopy cover was not available.

Data Analysis

The overall experimental design consisted of three factors: burn treatment (B; repeat summer burns, repeat winter burns, unburned control), time (T; 1994 and 2006), and height (H; < 1.5 m and > 1.5 m, representing understory and overstory vegetation, respectively) with two replicate plots for each factorial combination. To test for differences in the overall plant community, data from the complete experimental design were analyzed using permutational multivariate analysis of variance (PERMANOVA). We also performed canonical analysis of principal coordinates (CAP) to visualize differences in the plant community among treatments over time.

Discussion of Results

Entire plant community: Results from PERMANOVA revealed the plant communities were significantly different after 12 years of treatment (Table 1, $F = 12.38$, $P < 0.01$). While a significant treatment x height interaction was not found (Table 1), pair-wise comparisons between treatments showed the overstory plant community was significantly different in summer burn and winter burn treatments compared to the control, although summer burn and winter burn treatments were not significantly different from one another (Table 2). The understory plant community did not differ between treatments (Table 2).

Woody plant (and cactus) community: Reintroducing the frequency and intensity of the historic fire regime in this experiment preserved the structural integrity of savanna while decreasing or eliminating most woody plant and cactus species. Invasive woody plants decreased or were no longer observed in the understory and overstory after reintroducing the historic fire regime in the summer (Table 4), whereas repeatedly burning in the winter generally prevented invasion in the overstory (Table 4) and slowed the rate of invasion in the understory compared to unburned areas (Table 4). However, repeatedly burning in the summer was the only treatment to maintain grass-tree codominance over the 12 year duration of this study (Table 4). A lack of fire resulted in rapid invasion by Ashe juniper in the overstory and prickly pear cactus in the understory, more so than other problematic plants (Table 4). The continued absence of fire will eventually produce a closed canopy Ashe juniper woodland interspersed with dense clusters of prickly pear cactus and little to no herbaceous surface fuels. Such ecosystems are extraordinarily difficult to restore with fire alone, but the communities can be collapsed if fires are of sufficient intensity (Twidwell et al. 2009).

Live oak was the only species to increase over time in the understory and overstory across all treatments and increased in abundance more than any other woody plant. This is likely a response to the removal of livestock grazing and browsing. Live oak is highly preferred as browse forage by goats in this region, and thus an increase in live oak is generally viewed positively. Nevertheless, large populations of live oak are currently being crippled in Texas by *Ceratocystis fagacearum*, a fungal pathogen that causes oak wilt. An increase in the density and regeneration of live oak has led to highly interconnected root systems that facilitate the spread of oak wilt through common root systems and root grafts. Reducing current live oak densities or maintaining densities at pre-settlement levels is therefore a high priority. However, fire is not currently listed as a preventative strategy for oak wilt management. While in this study high intensity summer fires only slowed the rate of increase in the overstory compared to other treatments (Table 4), a combination of high-intensity fires and livestock browsing is likely to provide an effective means of maintaining overstory and understory densities at desired levels, similar to studies conducted elsewhere (Trollope 1974; Holdo et al. 2009; Staver et al. 2009).

Grass community: In contrast to the woody plant response, reintroducing the historic fire regime in different seasons did not explain the observed variability in grass dominance in this study. While significant differences were detected among treatments (Table 1), the greatest amounts of variation in the data are explained by changes occurring over time and legacy effects resulting from pre-existing variability(figures not shown here; pending manuscript acceptance). All dominant grass species except little bluestem either increased or decreased across all treatments over the 12 year duration of this study (Table 5). Livestock herbivory and precipitation variability, including the occurrence of the second most severe, prolonged drought in the history of the research station (Palmer Drought Severity Index < -4, 2000; Station Records 1919-2006), therefore played a larger role in shaping grass dominance over this time period than whether sites were burned repeatedly in the summer, burned repeatedly in the winter, or unburned. This conclusion is supported by a previous long-term study that evaluated grass community composition and abundance for 25 years after exclusion from grazing at the Sonora Research Station. Similar to our findings, the study found sideoats grama and Texas cupgrass increased in basal area and dominance after a severe drought in the 1950's whereas common curly mesquite and wrights threeawn sharply decreased in basal area and dominance (Smeins et al. 1976).

Coupling these findings to an earlier, 40+ year experiment on the Sonora Research Station (Fuhlendorf and Smeins 1997; Fuhlendorf et al. 2001) provides a clearer picture of the relative importance of fire, grazing, and climatic variability on the composition and dominance of this grassland community. Grazing and climatic variability were both shown to be important drivers of herbaceous vegetation change, but operated at different temporal scales. Grazing intensity explained the long-term direction of herbaceous vegetation change whereas climatic variability explained the short-term rate and direction of change. Fire operates and imposes changes at a different temporal scale. Yet, it is unclear whether fire is causing short-term oscillations within the long-term trajectory of this grass community or if fire is driving the grass community along a long-term, incremental trajectory that is being masked by other drivers. As a result of the 12 year sampling interval and duration of this study, we did not detect short-term oscillations that may have occurred and the duration of the study is insufficient to determine if drought masked a long-term, fire-driven directional influence on the grass community.

Summary

Fire, herbivory, and climatic variability are important determinants of the composition and structure of grasses and trees in semiarid savanna. In this study, we examined how reintroducing the frequency and seasonal intensity of the historic fire regime changed plant community composition and structure after 12 years of a fire-herbivory removal manipulation at the Texas AgriLife Research Station on the Edwards Plateau. Reintroducing a high intensity fire regime in the summer preserved the structural integrity of this live oak (Quercus virginiana) savanna while decreasing or eliminating numerous problematic plants in the understory and overstory, such as prickly pear cactus (Opuntia spp.), sacahuista (Nolina texana), Ashe juniper (Juniperus ashei), redberry juniper (J. pinochotti), and honey mesquite (Prosopsis glandulosa). In the less-intense repeat winter burning treatments, undesirable woody plants were generally maintained at pre-treatment levels in the overstory but all woody plants except Ashe juniper increased in the understory. Alternatively, unburned areas rapidly transitioned from a grass-tree co-dominated savanna environment to one that is heavily dominated by woody plants. In the grass community, dominance of grass species in the winter burn treatment significantly differed from summer burn and unburned treatments, whereas the summer burn treatment was not significantly different from the control. However, unlike the woody plant response, differences in grass dominance were not the result of reintroducing the historic fire regime in different seasons. All grass species except little bluestem (Schizacyrium scoparium) either increased or decreased in dominance across all treatments over time. Instead, the greatest amounts of variation were explained by changes occurring as a function of climatic variability, the removal of livestock grazing, and legacy effects resulting from pre-existing variability.

Table 1. PERMANOVA of the abundances of woody plants and dominant grasses in 1994 and 2006.

Source	df	1994			2006		
		MS	*F*	*P*	MS	*F*	*P*
All plants							
Treatment (T)	2	672	2.48	0.1262	1230	12.38	**0.0016**
Height (H)	1	18391	67.93	**0.0002**	17465	175.89	**0.0002**
T X H	2	129	0.48	0.6900	209	2.10	0.1614
Residual	6	271			99		
Total	11						
Woody plants							
Treatment (T)	2	1032	2.05	0.1490	1779	8.66	**0.0014**
Height (H)	1	6898	13.69	**0.0014**	6265	30.50	**0.0002**
T X H	2	142	0.28	0.8848	207	1.01	0.4324
Residual	6	504			205		
Total	11						
Grasses							
Treatment (T)	2	91	4.38	0.0618	6719	322.91	**0.0002**
Residual	3	21			21		
Total	5						

Notes: Bold *P*-values indicate statistically significant results ($P < 0.05$).

Table 2. Pair-wise comparisons of differences in plant community abundances between treatments in 2006.

Source	Statistic	SB versus WB	SB versus C	WB versus C
All plants				
Understory	*t*	1.93	2.01	1.88
	P	0.1152	0.1042	0.1074
Overstory	*t*	1.62	3.96	2.84
	P	0.1864	**0.0308**	**0.0480**
Woody plants	*t*	0.92	2.14	1.21
	P	0.4420	**0.0296**	0.3438
Grasses	*t*	18.06	2.47	124.55
	P	**0.0018**	0.0864	**0.0004**

Notes: Bold *P*-values indicate statistically significant results ($P < 0.05$).

Table 3. PERMANOVA investigating differences in the total cover of woody plants among fire treatments in 2006.

Source	df	MS	*F*	*P*
Treatment (T)	2	91	11.98	**0.0268**
Residual	3	7		
Total	5			
*Pair-wise comparisons			*t*	*P*
SB vs WB			1.83	0.1582
SB vs C			4.02	**0.0420**
WB vs C			2.66	0.0838

Notes: Bold *P*-values indicate statistically significant results ($P < 0.05$).

Table 4. Mean abundances ± SE (and mean change from 2006-1994) in the understory (U) and overstory (O) of individual woody plant and cactus species after twelve years of repeated summer burn (SB), repeated winter burn (WB), and unburned control (C) treatments.

Woody species	Acronym	Understory (U)			Overstory (O)		
		SB	WB	C	SB	WB	C
U/O abundance increased (+) in all treatments							
Live oak	QUVI	27.5 ± 11.5 (+18.0)	28.0 ± 2.0 (+24.0)	25.5 ± 4.5 (+12.0)	44.0 ± 2.0 (+13.5)	68.0 ± 9.0 (+40.5)	68.5 ± 7.5 (+47.0)
U inc. (+); O dec. (-) in all treatments							
Texas persimmon	DITE	4.5 ± 0.5 (+4.5)	5.5 ± 1.5 (+0.5)	3.0 ± 2.0 (+0.5)	0 (-1.5)	0 (-2.5)	0.5 ± 0.5 (-0.5)
Different responses among treatments							
Ashe juniper	JUAS	0 (-2.5)	1.0 ± 1.0 (-2.0)	9.0 ± 3.0 (+7.5)	0 (-6.5)	1.5 ± 0.5 (-3.0)	23.0 ± 6.0 (+19.0)
Redberry juniper	JUPI	2.5 ± 1.5 (-1.0)	2.0 ± 1.0 (+1.5)	4.0 ± 2.0 (+4.0)	0 (-3.5)	0 (-0.5)	5.5 ± 1.5 (+5.5)
Honey mesquite	PRGL	2.5 ± 2.5 (0)	1.0 ± 1.0 (+0.5)	3.5 ± 0.5 (+2.0)	1.0 ± 1.0 (-3.0)	1.0 ± 1.0 (+1.0)	3.5 ± 1.5 (+3.5)
Prickly pear	OPSP	5.0 ± 3.0 (-4.5)	14.5 ± 2.5 (+6.0)	31.5 ± 5.5 (+19.5)	0 (-3.5)	0 (0)	0 (0)
Sacahuista	NOTE	0 (-10.5)	21.5 ± 16.0 (+6.0)	21.0 ± 9.5 (+11.0)	0 (-1.5)	0 (0)	0 (0)
Agarita	MATR	0.5 ± 0.5 (-0.5)	6.0 ± 4.0 (0)	4.0 ± 1.0 (-0.5)	0 (-0.5)	0 (-0.5)	2.5 ± 2.5 (+2.5)
Total mean change		+3.5	+36.5	+56.0	-6.5	+35.0	+77.0

Table 5. Dominance of grass species after twelve years of repeated summer burn (SB), repeated winter burn (WB), and unburned control (C) treatments. Values are percent means ± SE (and percent mean change from 2006-1994).

Grass species	Acronym	SB	WB	C
Dominance increased (+) in all treatments				
Sideoats grama	BOCU	35.0 ± 5.8 (+7.4)	34.6 ± 0.6 (+11.6)	16.0 ± 2.8 (+6.6)
Sedge spp.	CASP	16.6 ± 2.2 (+5.2)	26.4 ± 0.8 (+7.8)	25.6 ± 6.8 (+11.0)
Texas cupgrass	ERSE	3.0 ± 3.0 (+1.8)	0.6 ± 0.2 (+0.6)	0.6 ± 0.2 (+0.6)
Texas wintergrass	STLE	56.0 ± 4.0 (+15.4)	46.0 ± 2.6 (+14.0)	50.2 ± 2.2 (+13.4)
Dominance decreased (-) in all treatments				
Wrights threeawn	ARWR	8.2 ± 1.8 (-21.8)	26.0 ± 1.6 (-4.4)	20.4 ± 2.8 (-18.2)
Hairy grama	BOHI	2.6 ± 0.2 (-11.0)	22.4 ± 0.8 (-20.6)	8.0 ± 1.6 (-11.4)
Common curly mesquite	HIBE	51.8 ± 3.0 (-15.6)	44.6 ± 3.4 (-7.8)	56.2 ± 4.2 (-4.4)
Dom + in WB & SB. Dom – in C				
Little bluestem	SCSC	0.6 ± 0.6 (+0.6)	10.6 ± 0.2 (+4.2)	0.4 ± 0.4 (-2.6)

V. Additional Project Deliverables

A number of additional projects have been established and will be part of the ongoing field collection and data analyses. First, we have established a long-term project aimed at characterizing the effects of fire and herbicide treatments on herbaceous composition, production, and invasion over time. Second, we are tracking the effects of the treatments on the density of red-imported fire ants and harvester ants. Third, we are developing ways to quantify ecological thresholds associated with fire (e.g. fire induced mortality threshold for woody plants; e.g. Twidwell et al. *in review*). Finally, we are integrating our work into coupled social-ecological frameworks that will provide a more detailed understanding of the factors driving the application of fire and other rangeland management techniques, the magnitude of those drivers, their thresholds, and the approaches needed to overcome those thresholds (e.g. Twidwell et al. *in review*).

VI. Future Research Needs

While this research provides a greater understanding of how various fuel and weather components influence fire behavior and how high-intensity fires, coupled with herbicide, can restore rangelands, we are unable to report on multiple other ecosystem components that are critical to understanding the role of fire in maintaining and restoring rangeland environments. Ecosystem processes, including aspects of the hydrologic cycle, carbon and nitrogen cycling, and even soil formation processes, respond at different levels of fire intensity. Although significant research efforts have been undertaken to understand the effects of fire on ecosystem processes, much of this work has not addressed the upper end of the fire response hierarchy by using prescribed extreme fire, thus resulting in a significant gap in understanding in Texas ecosystems. Future research should target key ecosystem functions (e.g., carbon, nitrogen, and water cycling) and how fires of different intensities can trigger changes in these ecological processes. To illustrate, the following questions still need to be addressed: 1) Can the use of prescribed extreme fires, by reducing woody plants, shift aboveground productivity to a higher herbaceous proportion and belowground to more shallow soil horizons, and greater overall net primary productivity? 2) How do net nitrogen mineralization rates respond immediately following prescribed extreme fire and how long will it take for mineralization rates to return to pre-fire levels? 3) How do prescribed extreme fires and herbivory interact to influence herbaceous production and net nitrogen mineralization? 4) How do prescribed extreme fires and precipitation pulses interact to influence herbaceous production and net nitrogen mineralization? 5) How is water infiltration from precipitation influenced or inhibited by prescribed extreme fire through the formation of a somewhat transient hydrophobic layer? 6) How do grazing and precipitation interact with prescribed extreme fire to influence soil hydrophobicity?

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Objective 2 - Assess economic efficiency:

Final Report **August 2010**

ECONOMIC FEASIBILITY OF USING PRESCRIBED EXTREME FIRE AS A RANGELAND RESTORATION PRACTICE ON PRIVATE LAND

Introduction

Our study addresses the following objective: To compare the economic efficacy of using extreme fire as a rangeland restoration tool compared to mechanical, herbicide, and cool season fire treatments. Specifically, we present an investment feasibility model comparison of applying extreme fire to other commonly used brush treatment methods in three eco-regions in Texas: Rolling Plains, Edwards Plateau, and South Texas Plains. These three eco-regions were selected for study because they represent a north to south transect across central Texas in which brush invasions have been pervasive. Specifically, our paper presents the model results of net present value (NPV), benefit cost ratio (BC), and internal rate of return (IRR) analyses of alternative brush treatments. Although our study focuses on invasive plant management in Texas, our findings have implications for rangelands across the Western USA and around the world where fires occur periodically. Before presenting these results, we describe the invasive brush characteristics of each of the three eco-regions included in our study.

Historically, rangelands in Texas have been used primarily to sustain livestock but in recent years there has been an increasing shift to supply of wildlife-based recreation. As a result, wildlife-related income has equaled or surpassed income from livestock on many Texas ranches [1]. Due to the comparative advantages of open grazing resources for livestock production and rangeland with some woody plants for wildlife ranching, landowners have had to become more selective about brush management according to their specific operational objectives. In the Edwards Plateau, brush cover of about 30% has been considered optimal for maximizing income from mixed livestock production and wildlife-related hunting operations [3].

In Texas, rangelands have been widely transformed by brush encroachment over the past two centuries [1, 2]. The most problematic brush species in the Rolling Plains eco-region is prickly pear (*Opuntia phaecantha*) (J. Gleason, NRCS, Rolling Plains TX, Personal Communication, July 2006). Recently, Ansley and Castellano [4], found that the use of extreme fire led to an 80% increase in prickly pear mortality three years after fire was applied, while cool season (low intensity) fire had little to no effect on prickly pear cover.

The most targeted invasive species in the Edwards Plateau are ashe and redberry juniper (*Juniperus ashei* Buchh. and J. *pinchotii* Sudw., respectively) (C. Anderson, NRCS, Edwards Plateau TX, Personal Communication, July 2006). Juniper treatments are limited to mechanical and prescribed fire techniques because broadcast herbicide application are ineffective for treating juniper [7]. Moreover, mechanical treatment methods for juniper have been found to be two to six times more costly than prescribed fire [6,8,9]. Accordingly, Taylor [5] concluded that extreme fire appears to be a viable rangeland restoration option for the Edwards Plateau.

Huisache (*Acacia smallii* Isely) is the main invasive brush species in the South Texas Plains, followed by mesquite (*Prosopis glandulsa* Torr.) (R. Gibbens, NRCS, South Texas Plains TX, Personal Communication, August 2006). Scifres and Hamilton [6] found that the probability of achieving brush mortality in South Texas with prescribed fire increased substantially when an initial mechanical or herbicide treatment was applied because this tended to increase the amount of flammable fine fuel to carry the fire. Mechanical treatments are seldom used for huisache because this species resprouts after aerial portions of the plant are removed.

Mesquite occurs on rangelands across Texas and in states to the north and west and in Mexico. It is considered a problem species in all three eco-regions in our study. The cost of using herbicides alone to manage mesquite can be high because repeated applications at about two year intervals are necessary to achieve significant mortality [6]. By contrast, aerial application of herbicide resulted in higher returns to investment in treatments than mechanical methods [10]. The effectiveness of using prescribed fire for treating mesquite has been substantially researched [11]. In North Texas, researchers found that prescribed fire could be used to treat mesquite less expensively than alternative brush treatments but that fire must be applied more frequently than other treatments [12,13]. Further, when herbicides were used as the initial treatment, application of prescribed fire as a maintenance treatment was found to be economically more effective when applied 10 years rather than 15 or 20 years after the herbicide treatment [14]. In South Texas, fall and winter burning were found to effectively reduce brush cover, and both options resulted in greater brush reduction when fire was applied after an initial mechanical treatment [15].

The three approaches most commonly used to treat brush in Texas include mechanical, herbicide (chemical), and prescribed fire. While these approaches vary with regard to topographic suitability, implementation techniques, and timing, the main focus of our study was their comparative economic efficacy as revealed by an investment feasibility model. In conducting this analysis, we were especially interested in evaluating the efficiency of using extreme fire to restore rangelands. In the past, most prescribed fires were applied during winter months [4]. However, fire is increasingly being applied during summer months when ambient temperatures and fuel loads tend to be higher and fuel moisture lower than during cooler seasons and the effect of fire on brush is reported to be more severe [1,5]. Due to the lower cost of applying fire compared to mechanical and herbicide treatments, the former approach to treating brush seems to be economically preferable for landowners. However, to fully evaluate the economic efficacy of alternative brush treatments, factors other than implementation costs must be considered [6].

Procedure

The study focused on four contiguous counties in the Rolling Plains, Edwards Plateau and South Texas Plains ecosystems of Texas as shown in Figure 1. The counties were selected, based on advice from Texas AgriLife Extension agents, because they represented a contiguous block of the dominant vegetation composition in each eco-region.

Data Collection and Analytical Scenarios

To achieve the objective of comparing the economic effectiveness of using extreme fire to other brush management practices, we first obtained relevant information for each of the three four-county study sites. Since substantial amounts of the required data are not published, we used focus group meetings [16] to obtain key informant consensus about the primary information required for each eco-region.

Focus group meetings were held in each eco-region during July and August 2006 and included NRCS representatives, Texas AgriLife Extension personnel, and landowners. Information obtained during these meetings and during follow-up communications with NRCS and Texas AgriLife Extension personnel included descriptions of the most common rangeland production systems, the most commonly used brush treatments, the costs of applying these treatments and the average livestock grazing and wildlife hunting lease rates prevailing in each eco-region. Herbaceous forage response data (i.e., changes in grazing capacity per unit area) following brush treatments were obtained from previous studies in the Rolling Plains (R. Teague, Texas AgriLife Research, Vernon TX, Personal Communication, February 2007) and the Edwards Plateau and South Texas Plains [17]. Based on the information thus obtained, the following treatment scenarios were established as the basis for the economic analysis.

In the Rolling Plains and Edwards Plateau, initial brush treatments selected for analysis consisted of mechanical, herbicide and extreme fire treatments, each followed by cool season fires every six years thereafter as a maintenance treatment. In the South Texas Plains, initial treatments included herbicide and extreme fire only (mechanical treatment for huisache and mesquite being largely ineffective). The initial herbicide treatment is followed with a cool season fire the following year and then every four years thereafter, while the initial extreme fire treatment is followed by cool season fire at four-year intervals. The difference in fire frequencies among the eco-regions is due the longer growing season and greater herbaceous production in the South Texas Plains and the associated need for more frequent maintenance treatments (J. Ansley, Texas AgriLife Research, Vernon TX, Personal Communication, February 2007).

Brush cover was categorized as heavy or moderate. Heavy brush cover is represented by greater than 50 % canopy cover, and moderate brush cover by 25 % cover for all woody species. By contrast, heavy prickly pear cover is represented by greater than 20 % canopy cover and moderate cover by 10 to 20 % cover.

Brush treatment response analyses were based on data from previous research aimed at estimating livestock carrying capacity changes following brush treatment. These analyses provide estimates of increases in livestock grazing capacity in animal unit years per hectare (AUY ha^{-1}) due to the initial treatment effect and the longevity of that treatment. They also illustrate how the maintenance treatments extend the life of the initial treatment and what will happen to carrying capacity if brush management practices are not instituted (Figure 2).

Pretreatment carrying capacity estimates were based on the expert opinion of long-term researchers in each eco-region (R. Teague, C. Taylor and W. Hanselka, Texas AgriLife Research and Extension, Personal communication, March 2007). For the Edwards Plateau and South Texas Plains the base carrying capacity was set at 20.23 ha AUY^{-1} (0.0494 AUY ha^{-1}) for land with heavy brush cover and 12.14 ha AUY^{-1} (0.0824 AUY ha^{-1}) for land with moderate brush cover for all brush species. For the Rolling Plains, base carrying capacity of rangelands with mesquite was set at 8.09 ha AUY^{-1} (0.1236 AUY ha^{-1}) for heavy cover and 7.00 ha AUY^{-1} (0.1429 AUY ha^{-1}) for moderate cover, and for rangelands with prickly pear it was set at 7.65 ha AUY^{-1} (0.1307 AUY ha^{-1}) for heavy cover and 6.8 ha AUY^{-1} (0.1471 AUY ha^{-1}) for moderate cover. The higher carrying capacities for the Rolling Plains reflects the relatively lower impact of brush cover on herbaceous forage production per unit area in this eco-region compared to the two other study areas. In addition, forage response within each canopy cover category is assumed to be the same for extreme fire and the alternative treatments (J. Ansley and C. Taylor, Texas AgriLife Research, Personal communication, March 2007).

In conducting the economic analysis, several assumptions were made to facilitate comparison of the alternative brush management treatments. First, the unit of analysis is an operating ranch of 404.7 hectares (1,000 acres) in size. Second the planning horizon for which the analysis was conducted is twenty years. Third, a discount rate of 6% was used to obtain the present value of all projected costs and revenues incurred during the 20 year planning period. The 6% rate is approximately two times the inflation rate and two to three times the risk-free interest rate commonly paid on simple savings accounts. Using a discount rate higher than the prevailing rate of return on risk free investments is warranted due to the higher risk associated with investments in range management practices [8]. A sensitivity analysis indicated that the choice of a lower discount rate (two or four percent) did not affect the relative economic efficiencies of alternative brush treatment options.

In addition, to simplify the comparative economic analysis of alternative brush treatment approaches, it was assumed that the entire ranch is operated by a livestock grazing lessee who is permitted to use a stocking rate that equals the livestock carrying capacity. Furthermore, it was assumed that the grazing lease rate paid by the lessee is based on the number of Animal Unit Equivalents (AUE) represented by the carrying capacity. Therefore, the annual revenue received by the landowner changes in direct proportion to the changes in livestock carrying capacity resulting from implementation of the brush control practices.

Analyses of each brush management treatment are conducted both with and without a 50% cost share to the landowner for implementing the brush treatments. This ratio assumes that half the brush treatment cost would be paid for by public funding, which is based on the cost-sharing ratio commonly used in federal conservation programs, such as EQIP.

Brush Treatments

Within each of the three eco-regions included in the study, extreme fire applications to both moderate and heavy canopy cover were compared with the most commonly used alternative treatment for the most problematic brush species previously identified and for mesquite. Details of each initial “alternate” brush treatment are provided in Table 1.

In the Rolling Plains, the alternate treatments evaluated for moderate and heavy prickly pear cover were individual plant treatment (IPT) using picloram plus flurozypyr (Surmount®) and aerial application of picloram, respectively. The alternate treatments for moderate and heavy cover of mesquite were basal IPT and aerial applications of triclopyr plus clopyralid (1:1 Remedy® + Reclaim®) mixes, respectively.

In the Edwards Plateau, the alternate treatment for moderate and heavy cover of redberry juniper, a basal sprouting species, was mechanical grubbing and stacking. Grubbing alone was also analyzed for heavy cover. The alternate treatments for ashe juniper, a non-sprouting species, included ground-level cutting and stacking for moderate cover and mechanical grubbing and stacking plus grubbing alone for heavy cover. The alternate treatments for moderate and heavy mesquite were IPT using a basally applied diesel/Remedy® mix and aerial application of 1:1 Remedy® + Reclaim® mix, respectively.

In the South Texas Plains, the alternate treatments for moderate and heavy cover of huisache were IPT using a basally applied diesel/Remedy® mix and aerially applied picloram and 2,4-D (Grazon® P+D), respectively. The alternate treatments for moderate and heavy mesquite cover were the same as those used for the Edwards Plateau eco-region.

Investment Feasibility Model

The comparative economic analysis of using prescribed extreme fire, mechanical and chemical treatments as brush control practices was conducted using NPV, BC ratio and IRR over a 20-year planning period as revealed by an investment feasibility model. NPV converts the values of future benefits and costs to present values as follows:

$$NPV = \sum_{i=0}^{n} \frac{V_i}{(1+d)^i} \qquad [18]$$

Where V = future value of a given benefit or cost, d = discount rate, n = planning horizon and i = the specific year during the planning horizon.

The investment feasibility model was parameterized for each specified brush species, brush density, and brush management combination in each eco-region. Data required to parameterize the model included costs and year incurred for initial and maintenance brush management actions, livestock carrying capacity for each year of the planning period both with and without implementation of the brush control practices, annual costs and revenues associated with operating the grazing lease and the appropriate discount rate for future costs and revenues. Once parameterized, the model was used with the specified data to calculate the NPV, BC, and IRR for the investment in the specific brush management scenario over the 20 year planning period.

An investment is considered to be economically feasible when NPV ≥ 0 (the sum of discounted future returns are equal to or exceed the sum of discounted future costs). NPV is considered superior to other metrics of economic gains from range improvement practices because it accounts for the time value of money and provides a dollar value for the investment [8]. By contrast, BC analysis provides a simple ratio of the present value of future benefits and costs (BC > 1 implies economic feasibility). IRR provides a measure of the income earning potential of an investment and is the ratio of the average annual earnings divided by the sum of discounted costs of the investment expressed as a percent. The IRR is an indicator of efficiency or quality of an investment, allowing for comparisons to alternate capital investments.

Break-even data for alternative brush treatments are also presented. These data provide the amount of subsidy that would be needed to allow the landowner's investment in brush management to break even. The breakeven point was calculated by adding the NPV to the total investment cost. In addition, a second breakeven point was calculated with the assumption that the landowner has received 50% cost share for implementing a brush management project.

Results

Economic Feasibility

Results from the investment feasibility model are presented in tabular format. Table 2 presents the total cost, NPV, B/C ratio, and IRR of applying extreme fire and the specified alternate brush treatments (described in Table 1) for the primary problem plant species and mesquite in each eco-region. NPV values are presented on a $ per hectare basis.

In the Rolling Plains extreme fire proved to be economically feasible for controlling heavy prickly pear cover, (NPV = $13.12 ha^{-1} [>0]; BC > 1; IRR > 6%) while for moderate prickly pear cover, extreme fire was economically marginal (NPV = -$0.38 ha^{-1}). By contrast, the alternative herbicide treatments for heavy and moderate cover prickly pear produced substantially negative NPVs (-$53.87 and -$33.00 ha^{-1}, respectively). Similarly, extreme fire was economically superior to the alternative herbicide treatments for heavy cover mesquite ($18.31 vs. -$51.60 ha-1) and for moderate cover mesquite ($4.13 vs. -$26.16 ha^{-1}).

In the Edwards Plateau, extreme fire treatments for heavy and moderate juniper cover were economically feasible (NPV = \$27.50 and \$18.73, ha^{-1}, respectively), while all four alternate mechanical treatments for heavy and moderate juniper cover resulted in substantially negative NPVs and are economically not feasible (Table 2). The application of extreme fire to heavy and moderate cover mesquite also produced positive NPVs (\$4.04 and \$6.08, respectively), while the alternate herbicide treatments produced substantially negative NPVs (Table 2).

In the South Texas Plains, neither extreme fire nor the alternate treatment for heavy huisache cover was economically feasible (NPV = -\$0.76 and -\$96.96 ha^{-1}, respectively). By contrast, extreme fire for treating moderate huisache cover was found to be economically feasible, (4.97 ha^{-1}) but the alternate treatment was not (Table 2). Extreme fire was found to be economically feasible for the treatment of both heavy and moderate mesquite cover (NPV = \$16.31 and \$11.64 ha^{-1}, respectively), but the alternate herbicide treatments produced negative NPVs (Table 2).

Effect of Cost Sharing for Primary Problem Species

Cost-sharing may be necessary to encourage landowners to adopt rangeland management practices that produce socially desirable outcomes in cases where private landowner benefits do not fully offset the associated costs of implementation. Table 3 presents the break-even value, 50% cost sharing value and NPV with 50% cost-sharing (adjusted NPV) for each woody plant treatment scenario previously described. The break-even value indicates the largest total cost for a treatment scenario that would allow a landowner to break even (NPV = 0), assuming a 6% discount rate. It is obtained by adding the NPV value to the Total Cost values shown in Table 2. The NPV values associated with each treatment, both with and without 50% cost-sharing, are compared for the primary problem species within and across each eco-region for mesquite.

When 50% cost share was applied to treatments for controlling prickly pear in the Rolling Plains, NPV of using extreme fire increased by 140% for dense prickly pear cover and for moderate prickly pear cover the NPV became positive (Table 3). In the case of the alternate herbicide treatments, a 50% cost share resulted in the NPV becoming just greater than zero for both heavy and moderate prickly pear cover.

The inclusion of a 50% cost-share for controlling juniper in the Edwards Plateau resulted in the NPVs associated with the use of extreme fires to increase by 67% for heavy cover and 104% for moderate cover. By contrast the NPVs for all alternate mechanical treatments remained negative and thus economically infeasible when 50% cost-sharing was incorporated (Table 3).

Similar to prickly pear in the Rolling Plains and juniper in the Edwards Plateau, the inclusion of a 50% cost-share for the application of extreme fire to treat huisache in the South Texas Plains resulted in all NPVs becoming positive (Table 3). By contrast, the alternate herbicide treatments for huisache produced a negative NPV even when a 50% cost-share was included thereby rendering it economically infeasible even with substantial cost sharing.

Comparative Economic Efficiency of Alternative Treatments for Mesquite

Mesquite was reported to be a problematic invasive species across all three of the eco-regions included in this study. Therefore, the economic efficiencies of alternative treatments for this species, both without and with 50% cost-sharing, are compared across the three eco-regions.

The use of extreme fire to treat mesquite was found to be economically feasible (NPV > 0) without cost-sharing in all three eco-regions (Table 2). However, while applying extreme fire to heavy mesquite cover produced a 450% greater NPV in the Rolling Plains than in the Edwards Plateau (\$18.30 vs. \$4.05 ha^{-1}), it produced a 60% greater NPV when extreme fire was applied to moderate mesquite cover in the Edwards Plateau than in the Rolling Plains (\$6.48 vs. 4.13 ha^{-1}). This difference is due to the greater forage response of using extreme fire to treat heavy mesquite in the Rolling Plains compared to forage responses under moderate mesquite cover in both eco-regions. In addition, because mesquite is generally less invasive in the Edwards Plateau than the Rolling Plains eco-region, the anticipated forage response to the use of extreme fire to treat dense mesquite is expected to be lower in the Edwards Plateau. The use of extreme fire for the treatment of moderate mesquite produced greater NPV (\$11.26 ha^{-1}) in the South Texas Plains due to higher grazing and hunting-lease rates than in either the Rolling Plains or the Edwards Plateau. When 50% cost share was included in the economic analysis, the economic efficiency of extreme fire treatments for mesquite increased in all three eco-regions.

In contrast to extreme fire, herbicide treatments for both heavy and moderate mesquite cover produced negative NPVs in all three regions when no cost-share was applied, although the Rolling Plains resulted in the least negative NPVs (Table 2). This suggests that it would be less costly to treat mesquite with herbicide in the northern most eco-region. However, when 50% cost sharing was added, herbicide treatments in the Rolling Plains became economically feasible (NPV > 0) (Table 3). By contrast, a 50% cost share would be insufficient to provide a positive return to landowners in the Edwards Plateau and the South Texas Plains with aerial herbicide treatment of heavy mesquite cover and the IPT herbicide treatment of moderate mesquite cover. With aerial herbicide application for dense mesquite in the South Texas Plains, 50% cost share is marginally insufficient to produce a positive NPV. These differences are due to the higher livestock carrying capacity in the Rolling Plains.

Discussion and Conclusion

Our comparative economic analysis of alternative methods for treating primary invasive plants and mesquite in the Rolling Plains, Edwards Plateau and South Texas Plains indicates that, based on the specified assumptions, the use of extreme fire is economically superior to all of the commonly used mechanical and herbicide-based methods. In many cases, the rates of return from investments in brush management using extreme fire were double or triple the assumed discount rate. Only in the case of moderate prickly pear cover in the Rolling Plains and heavy huisache cover in the South Texas Plains was the use of extreme fire found to be economically marginal and in both cases would be viable with a minimal amount of cost sharing. The use of extreme fire was found to be an economically efficient method for treating both heavy and moderate cover mesquite in all three eco-regions, especially in the Rolling Plains and South Texas Plains eco-regions. By contrast to the use of extreme fire, all of the alternative mechanical or herbicide-based treatments for prickly pear, juniper, huisache, and mesquite were found to be economically infeasible; all produced substantially negative NPVs when no cost share was added. Despite the clear economic superiority of using extreme fire to restore rangelands across all three eco-regions, two caveats need to be added.

First, we did not take into account weather-related risk of not being able to institute a fire regime, which could reduce the NPV and even make the practice infeasible in some cases. If rainfall is below average in the period leading up to the application of extreme fire, there is a good probability there will insufficient fuel load to carry fire. Protracted delays in the application of fires may necessitate the use of alternative mechanical or herbicide-based treatments to ensure that invasive plants are maintained at manageable levels. The effect of the probability of deferring fire on the economic efficiency of using this brush control tool needs to be further investigated. At the same time, weather-related risks of not being able to apply herbicides at optimal times also need further elucidation to provide a more comprehensive assessment of the relative economic efficiencies of extreme fire and alternate brush management treatments.

Second, even if the application of extreme fire is the only economically feasible option for restoring prickly pear or woody-plant invaded rangelands, the reluctance of many landowners to use this tool cannot be ignored. If it is socially desirable to maintain bio-diverse, ecologically resilient and productive rangelands, it may be necessary to use public funding to help landowners implement rangeland restoration practices that are perceived to be less risky. The implementation of land improvement programs, such as EQIP, already addresses this need. Accordingly, we also addressed the effectiveness of cost-sharing on the economic feasibility of alternative invasive plant management practices to the landowner. Assuming a 50% cost-share ratio, we found that cost sharing would make mechanical and chemical treatments for prickly pear and mesquite in the Rolling Plains economically feasible for the private landowner. However, in the Edwards Plateau and the South Texas Plains, a higher level of cost sharing would be necessary to ensure that landowners break even when applying the most commonly used juniper, huisache and mesquite control techniques. This is consistent with the higher cost-sharing that is commonly provided to landowners who are improving endangered species habitat in the Leon River watershed, for example, where cost-sharing of 80% is common.

In conclusion, from an economic perspective, our study suggests that extreme fire is efficient and economically superior to all other treatment options for restoring rangelands that have become infested with invasive brush species in all three eco-regions. The use of extreme fire as a rangeland restoration tool is still relatively new and minimally used but our results should contribute to the growing interest in using this method for restoring rangelands. The results should also assist NRCS's review of current technical standards with respect to prescribed fire.

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Table 1. Detailed description of initial alternate brush treatment for each of the three eco-systems included in the study.

Eco-region Species treated	Moderate cover	Heavy cover
Rolling Plains[1]		
Prickly Pear[5]	Basal Chemical IPT[2] 1% surmount[3]	Aerial Chemical 0.57kg. picloram[4] per hectare
Mesquite	Basal Chemical IPT[2] .27kg each of remedy[3] and reclaim[3]	Aerial Chemical 0.27kg each of remedy and reclaim ha^{-1}
Edwards Plateau[1]		
Redberry juniper	Mechanical Grubbing and stacking	Mechanical Grubbing and stacking Grubbing only
Ashe juniper	Mechanical Cutting/stacking using hydrologic shears fitted to skid steer equipment	Mechanical Grubbing and stacking Grubbing only
Mesquite	Basal Chemical IPT[2] 15% remedy mixed with diesel	Aerial Chemical 0.27kg each of remedy and reclaim ha^{-1}
South Texas[1]		
Huisahce	Basal Chemical IPT 15% remedy mixed with diesel	Aerial Chemical 3.51 liters/ha of grazon P+D[3]
Mesquite	Basal Chemical IPT 15% remedy mixed with diesel	Aerial Chemical 0.27kg each of remedy and reclaim ha^{-1}

[1] Cool season prescribed fires applied every 6 years after initial treatments in Rolling Plains and Edwards Plateau and every 4 years after initial treatment in South Texas.
[2] Individual plant treatment.
[3] Manufactured by Dow AgroSciences, LLC
[4] Manufactured by DuPont Agricultural Products
[5] Prickly pear heavy cover is greater than 20% and moderate cover is between 10 and 20%

Table 2: Total Cost, Net Present Value (NPV), Benefit-Cost ratio (B/C) and Internal Rate of Return (IRR) of applying extreme fire and alternate brush treatments to the primary problem plant species and mesquite in each eco-region.

Brush Type Cover density	Treatment[1]	Total Cost ($ ha^{-1})	NPV ($ ha^{-1})[2]	B/C ratio	IRR (%)
		Rolling Plains			
Prickly Pear					
Heavy	Extreme fire	37.05	13.12	1.536	18.43%
	Alternate	108.06	-53.87	0.411	-4.90%
Moderate	Extreme fire	37.05	-0.38	0.985	5.62%
	Alternate	71.63	-33.00	0.422	-5.52%
Mesquite					
Heavy	Extreme fire	37.05	18.31	1.749	22.88%
	Alternate	111.15	-51.60	0.453	-3.85%
Moderate	Extreme fire	37.05	4.13	1.169	9.94%
	Alternate	69.16	-26.16	0.522	-2.98%
		Edwards Plateau			
Juniper[3]					
Heavy	Extreme fire	37.05	27.50	2.125	29.3%
Ashe &	Alternate 1	347.04	-264.94	0.164	-11.26%
Redberry	Alternate 2	248.24	-171.73	0.232	-8.88%
Moderate	Extreme fire	37.05	18.73	1.766	23.60%
Ashe only	Alternate	242.06	-174.68	0.198	-10.20%
Redberry only	Alternate	297.64	-227.10	0.160	-----
Mesquite					
Heavy	Extreme fire	37.05	4.04	1.165	10.41%
	Alternate	100.04	-55.38	0.340	-7.60%
Moderate	Extreme fire	37.05	6.48	1.265	12.82%
	Alternate	192.66	-140.77	0.180	-----
		South Texas Plains			
Huisache					
Heavy	Extreme fire[4]	55.58	-0.76	0.978	5.07%
	Alternate	157.77	-96.96	0.259	-----
Moderate	Extreme fire	55.58	4.97	1.143	10.55%
	Alternate	213.35	-143.66	0.216	-----
Mesquite					
Heavy	Extreme fire	55.58	16.31	1.470	20.16%
	Alternate	156.54	-78.73	0.393	-6.22%
Moderate	Extreme fire	55.58	11.26	1.324	15.61%
	Alternate	219.52	-43.20	0.243	-9.92%

[1] See Table 1 for description of alternate treatments.

[2] If NPV < 0, some cost sharing would be necessary to allow landowner to break even on total investment cost; and if NPV > 0, the resulting “profit” could be invested in further rangeland treatment.

[3] Alternate treatments for heavy cover of both Ashe and Redberry juniper include grubbing only, and grubbing and stacking, whereas alternate treatments for moderate cover of these species include tree shears and grubbing and stacking, respectively.

[4] The higher cost for extreme fire in the South Texas Plains is due to more frequent maintenance fires.

Table **3.** Per hectare total treatment cost, break even, 50% cost sharing value and Net Present Value (NPV) with 50% cost-sharing (all in $ ha^{-1}) for extreme fire and alternate brush treatments for primary problem plant species and mesquite in each eco-region.

Brush Type Cover density	Treatment[1]	Total Cost	Break-even[2]	50% cost-share[3]	NPV with cost share[4]
			Rolling Plains		
Prickly Pear					
Heavy	Extreme fire	37.05	50.17	18.53	31.64
	Alternate	108.06	54.19	54.03	0.16
Moderate	Extreme fire	37.05	36.67	18.53	18.15
	Alternate	71.63	38.63	35.82	2.82
Mesquite					
Heavy	Extreme fire	37.05	55.36	18.53	36.83
	Alternate	111.15	59.55	55.58	3.98
Moderate	Extreme fire	37.05	41.18	18.53	22.65
	Alternate	69.16	43.00	34.58	8.42
			Edwards Plateau		
Juniper					
Heavy	Extreme fire	37.05	64.55	18.53	46.02
Ashe &	Alternate 1	347.04	82.10	173.52	-91.42
Redberry	Alternate 2	248.24	76.50	124.12	-47.61
Moderate	Extreme fire	37.05	55.78	18.53	37.26
Ashe only	Alternate	242.06	67.38	121.03	-53.65
Redberry only	Alternate	297.64	70.53	148.52	-78.29
Mesquite					
Heavy	Extreme fire	37.05	41.09	18.53	22.57
	Alternate	100.04	44.66	50.02	-5.36
Moderate	Extreme fire	37.05	43.53	18.53	25.00
	Alternate	192.66	51.89	96.33	-44.44
			South Texas Plains		
Huisache					
Heavy	Extreme fire	55.58	54.82	27.79	27.03
	Alternate	157.77	60.81	78.89	-18.07
Moderate	Extreme fire	55.58	60.54	27.79	32.75
	Alternate	213.35	69.68	106.67	-36.99
Mesquite					
Heavy	Extreme fire	55.58	71.88	27.79	44.10
	Alternate	156.54	77.81	78.27	-0.46
Moderate	Extreme fire	55.58	66.84	27.79	39.05
	Alternate	219.52	76.33	109.76	-33.44

1 See Table 1 for description of alternate treatments.
2 The break even value was calculated by adding the NPV of the treatment scenario to the total cost for instituting the specified brush treatment
3 The 50% cost share is half of the total treatment cost.
4 The difference between breakeven and the cost-share value provides the adjusted NPV. If adjusted NPV > 0, the treatment is economically feasible when a 50% cost share is applied.

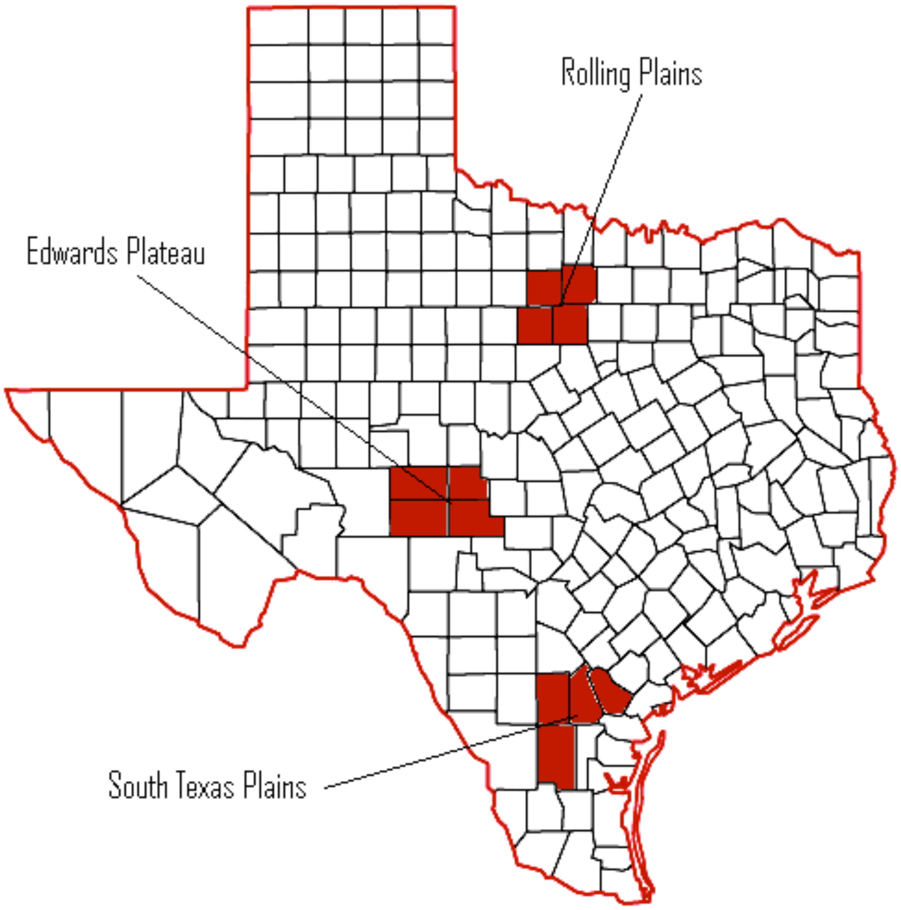
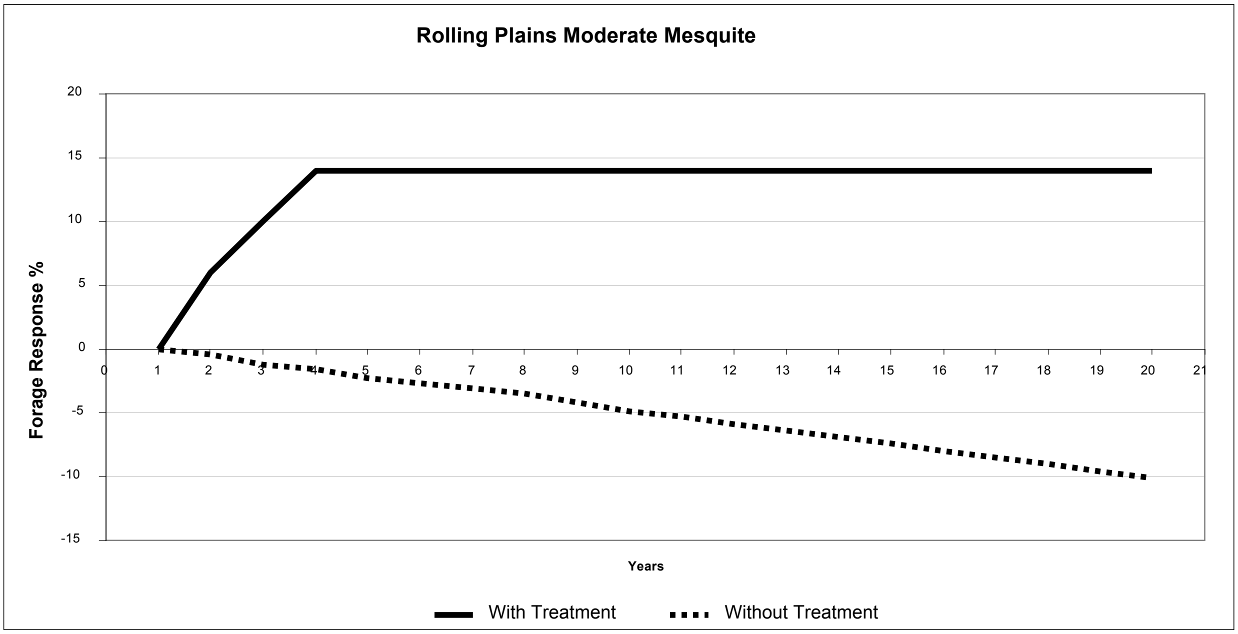


Figure 1: Study area counties in Texas: Rolling Plains – Shackelford, Stephens, Throckmorton and Young; Edwards Plateau – Kimble, Menard, Schleicher and Sutton; and South Texas Plains – Bee, Duval, Live Oak and McMullen.



Firgure 2: Response curve graph illustrating forage response with (solid line) and without (hashed line) treatment for moderate mesquite in the Rolling Plains, Texas.

Objective 3 - Determine social issues

Final Report **August 2010**

SOCIAL DIMENSIONS OF USING SUMMER FIRE TO RESTORE ECOSYSTEMS IN THE SOUTHERN PLAINS OF THE USA – ANALYSIS OF SURVEY DATA

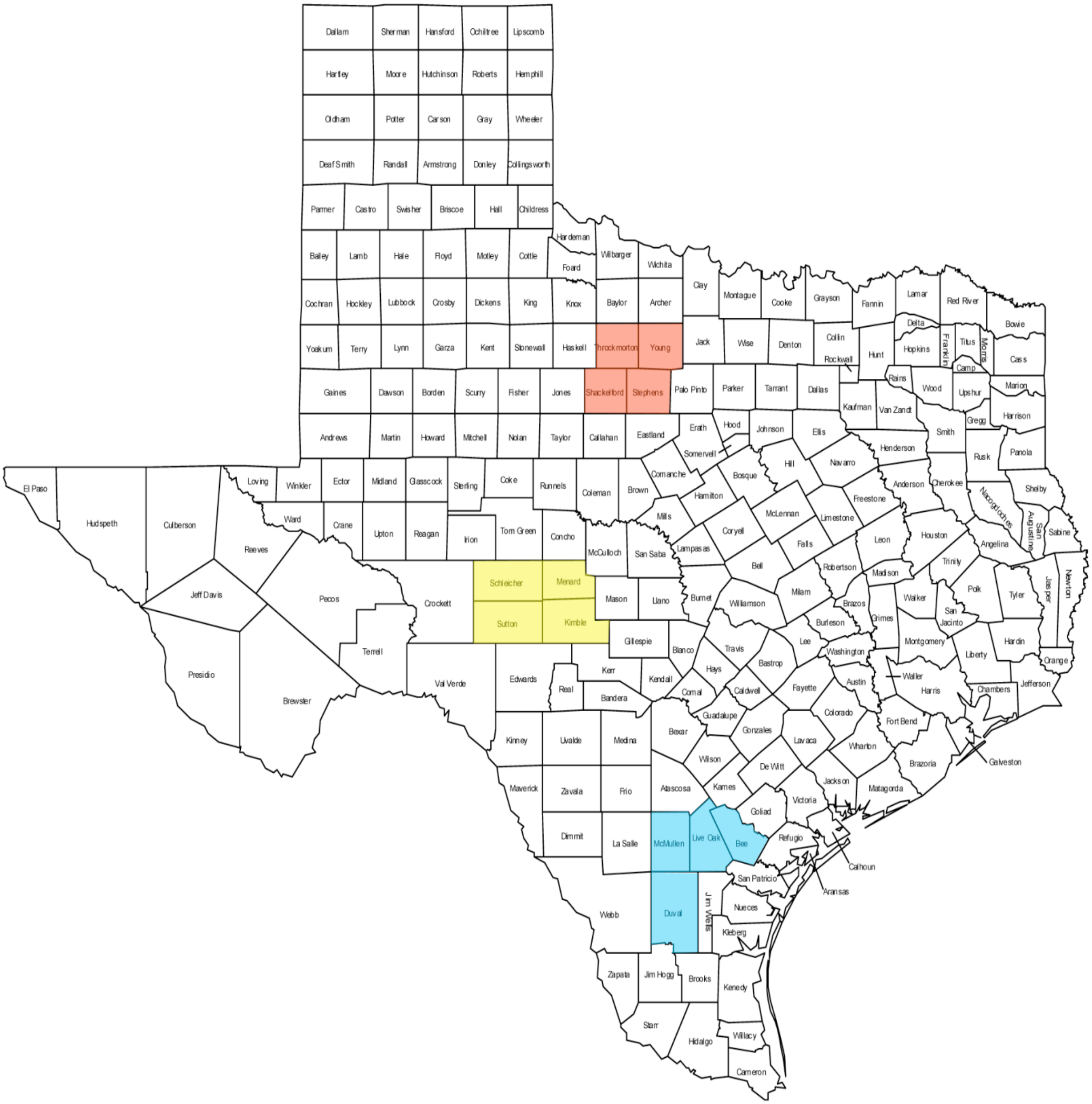
Introduction

Historically, the episodic occurrence of wildfires was a key driver for maintaining open grassland and savanna systems across most of the Southern plains and Western US. With increasing population densities in many of these fire prone areas, wildfires began to be controlled and in most cases extinguished. This lack of fire in systems that have typically evolved with fire, together with the occurrence of other natural and anthropogenic processes, have driven many of these grassland and savanna systems towards systems dominated by woody plant species.

Many studies exist on the use of fire to restore these ecosystems to their historic grassland state but little information is known about the use of prescribed extreme fires. Prescribed extreme fires occur under conditions that approximate of exceed the upper limits of standards and practices currently approved by federal agencies. Until now, no integrative research has been conducted to simultaneously evaluate the ecological, economic and social aspects of using prescribed extreme fires as a rangeland management tool. The objective of this project is to determine the socio-economic and ecological effects of using extreme prescribed fire to control woody plant encroachment in three different ecoregions of Texas.

This section of the project explores landowner attitudes and perceptions towards using extreme prescribed fires. The project area includes 12 different counties in Texas: 4 counties in each of the three ecoregions studied (Fig.1). A self-completion survey questionnaire was sent in July 2008 to 1200 landowners in order to gather information regarding landowner attitudes and perceptions towards extreme prescribed fire. The sample consisted of 100 landowners with more than 50 acres of land per county, and was selected by including members of prescribed burn associations (16% of total sample) and by randomly selecting landowners using county tax records (84% of total sample).

We explore landowner attitudes and perceptions towards using extreme prescribed fires and incorporate this information into a framework that will help researchers and decision makers



determine what factors influence or control landowners attitudes and perceptions towards fire, and will link these attitudes and perceptions to specific burning or not burning behaviors.

Figure 1. 12 Counties indentified as the study area – 4 counties in each of the three areas studied.

Survey Methods

The project area includes 12 different counties in Texas (4 counties in each of the three ecoregions studied). The counties sampled for the social component of the survey include: Bee, Duval, Kimble, Live Oak, McMullen, Menard, Schleicher, Shackleford, Stephens, Sutton, Throckmorton, and Young. A self-completion survey questionnaire was sent in July 2008 to 1200 landowners in order to gather information regarding landowner attitudes and perceptions towards extreme prescribed fire. The sample consisted of 100 landowners with more than 50 acres of land per county, and was selected by including members of prescribed burn associations (16% of total sample) and by randomly selecting landowners using county tax records (84% of total sample). Members from the following prescribed burn associations were included in the survey sample: Edwards Plateau Prescribed Burn Association (EPPBA), Hill Country Prescribed Burn Association (HCPBA), Coastal Bend Prescribed Burn Association (CBPBA). The sample was divided in non-association members and association members in order to compare the behavioral intentions and attitudes of landowners who approve and are experienced with burning with those who are opposed or have no or little experience burning.

The survey followed methods described in (Dillman 2000) and question format followed methods described in (Ajzen 2002), and (Fink 2003). Dillman (2000), proposes using multiple contacts and making the survey questionnaires as respondent friendly as possible. In order to achieve this, a pre-survey letter was mailed out on July 21, 2008; a survey questionnaire, cover letter, and a self addressed postage paid envelope were mailed out on July 28; a reminder card was sent on August 6; a follow up letter and second questionnaire were mailed out on August 18; and a final reminder/thank you card was sent out on September 1. The questionnaire consisted of a cover page and 10 pages of questions. In total there were 42 questions addressing 5 areas of inquiry: operational characteristics, attitudes and perceptions towards prescribed burning, attitudes and perceptions towards prescribed burn associations, attitudes and perceptions towards cost-share programs, and personal characteristics. When we stopped receiving survey questionnaires, a non-response bias survey was conducted by randomly selecting 50% of the non-respondents and administering one-page non-response bias surveys to these landowners.

Summary of Survey Data

The survey asked a variety questions regarding personal and operational characteristics of the respondents, the use of prescribed fire, the use of prescribed extreme fire, and landowner willingness to participate in cost-share programs. We summarize this information in the following tables. For additional information regarding the type of question asked and the available response categories, consult Appendix B.

Non-Response Bias Survey

Of the 1187 mailed surveys, we received 585 usable responses of which 22% were members of prescribed burn associations and 78% were non-members showing that we had slightly higher response rates from members that non-members.

50% of the first survey non-respondents (n=267) were sampled at random for the non-response bias survey. Of the 267 non-response bias surveys mailed, we received 21% (n=59) for a total of 11% response rate from the original non-respondents.

General comparisons between personal characteristics of respondents of main survey and non-response bias survey (Table 1) show that Gender and place of residence in for respondents of both surveys was very similar. There was a larger difference in whether respondents lived in rural or urban areas in Texas. To test whether this had an effect on people's attitudes, a logistic regression was ran on both surveys using rural or urban as a dichotomous dependent variable and an index of attitude towards burning as an independent variable to test whether we could predict if a person lived in rural or urban Texas based on their attitudes. The results from this test show that there is no effect in either survey (pseudo R-square < 0.1) between living in rural or urban Texas and respondents opinion towards prescribed fire (Table 2).

Table 1. Non-Response Bias Survey Personal Characteristics Comparison.

	Main survey		Non-response survey	
Gender	Female: 20%	Male: 80%	Female: 25%	Male: 70%
Live on a Ranch?	Yes: 40%	No: 60%	Yes: 41%	No: 54%
Live in rural or urban TX	Rural: 44%	Urban 54%	Rural: 63%	Urban: 30%

Table 2. T-test for differences in landowner characteristics that could lead to non-response bias.

	Main survey		Non-response survey		T-Test Signif.
	Mean	SD	Mean	SD	
Age	63.38	12.12	61.4	11.9	0.235
Consider prescribed burning to be a beneficial restoration tool	6.1*	1.35	5.9*	1.5	0.407
Years of formal education	14.2	4.3	14.2	4.2	0.981

* Where 1 = strongly disagree and 7 = strongly agree

Results from comparisons of both surveys show there are no significant differences between the main survey and non-response survey results related to age, attitudes of respondents towards prescribed fire, and years of education.

There are no statistically significant differences in responses to both the main survey and the non-response survey suggesting that we have a representative sample of the population of landowners with more than 50 acres of land in the 12 counties surveyed.

Personal Characteristics

In this section we describe general personal characteristics of landowners who responded to the survey and include supporting tables.

- 80% of the survey respondents were men and the average age was 63 ± 12 years (Tables 1 & 2).
- 40% of the landowners sampled reported living on the property for which they provided answers. Of these, mean years lived on a ranch was 30 years (Table 1).
- 12% of landowners had less than or equal to 12 years of formal education (up to high school degree), 65% had between 12-16 years (bachelors or some college), and 23% had >16 years (advanced degree or long bachelors*). Mean education among all landowners who responded was 14.2 ± 4 years (Table 2).
- 40% of the landowners who live away from their ranch reported living within 50 miles from their land (about an hour drive). The other 60% lived between 51 and 1200 mile away from their land.
- Mean landowner farming/ranching experience was 31 years and 8% of landowners reported having no farming/ranching experience (Tables 3).
- 78% of landowners sampled reported that they had owned the properties for which they were providing answers for more than 10 years (Table 4).
- Most (94.7%) landowners reported not planning to sell their property within the next five years, but 5.3% reported they were planning to sell (Table 5).
- 59.2% of landowners reported living away from their land, of these, 44.2% live in a rural area in Texas, 54.1% live in an urban area in Texas, and 1.7% live outside of Texas (Tables 6 and 7).
- Respondents invested a mean of $49,416 and median of $10,000 in land improvements on their properties in the last five years. 12.5% of landowners did not invest any money, 53% invested between $1 and $20,000, 24.4% invested less than $100.000 and about 8% invested more than $100,000 (Table 8).
- 23% of landowners reported not receiving any income from their properties in 2007 and 34% reported that 10% or less of their income was derived from their properties. Only 16% reported that more than 50% of their income comes from their rural property (Table 9).
- Landowner income was fairly normally distributed except for income category $100,001-500,000 which had the most (33.3%) responses (Table 10).
- In general respondents are experienced landowners who have time to manage their land but have financial constraints that limit the amount of land improvements they are able to implement. In general, respondents don't consider themselves to be risk takers and when asked if they trust extension and agency personnel, respondents are either neutral or have some distrust (Table 11).

These statements are generalization to indicate typical responses to the survey and should be fairly representative of the population of landowners with more than 50 acres of land in the 12 counties sampled based on our non-response bias survey. For further analysis of these data please refer to the *Analysis of Survey Data* section of the report.

Table 3. Responses to Q 35: How many years of farming/ranching experience do you have?

Number of Years	Number of Landowners	Percent
0-10	125	23
11-20	97	18
21-30	74	14
31-40	81	15
41-50	77	14
51-60	41	8
61-70	32	6
71-79	8	1
81-91	8	1
91-100	1	.2

Table 4. Responses to Q 36: How many years have you or your family owned the property?

Number of Years	Number of landowners	Percent
1-10	124	22
11-20	63	11
21-30	36	7
31-40	34	6
41-50	30	5
51-60	22	4
61-70	32	6
71-80	37	7
81-90	25	5
91-100	75	14
>100	73	13

Table 5. Responses to Q 37: Do you plan to sell your property in the next five years?

	Frequency	Percent
No	538	94.7
Yes	30	5.3

Table 6. Responses to Q 38a: Do you live in the property for which you provided answers?

	Frequency	Percent
No	342	59.2
Yes	236	40.8

Table 7. Responses to Q 38b: If you answered no to the above question, do you live in rural Texas, urban Texas, or out of Texas?

	Frequency	Percent
Rural	152	44.2
Urban	186	54.1
Out of Texas	6	1.7

Table 8. Responses to Q 39: About how much money did you invest in land improvements on your property during the last five years?

US Dollars Invested	Frequency	Percent
$0	65	12.5
$1-10K	204	39
$10,001-20K	73	14
$20,001-30K	37	7
$30,001-40K	17	3
$40,001-50K	32	6
$50,001-60K	12	2
$60,001-70K	5	1
$70,001-80K	7	1
$80,001-90K	2	0.4
$90,001-100K	21	4
$101-150K	11	2
$151-200K	16	3
$201-300K	7	1
$301-400K	4	1
$401-500K	2	0.4
$>500K	5	1

Table 9. Responses to Q 40: About what percentage of your total annual income in 2007 was derived from your rural property?

% Annual income derived from property	Frequency	Percent
0	121	23
1-10	179	34
11-20	37	7
21-30	37	7
31-40	17	3
41-50	45	9
51-60	13	2
61-70	12	2
71-80	22	4
81-90	18	3
91-100	25	5

Table 10. Responses to Q 41: Please check the category that best describes your total household income in 2007.

Income Category	Frequency	Percent
Less than $25,000	33	5.6
$25,000-50,000	82	13.9
$50,001-75,000	92	15.6
$75,001-100,000	102	17.3
$100,001-500,000	196	33.3
Greater than $500,000	40	6.8
Missing	43	7.3

Table 11. Responses to Personal Characteristics Statements in Section 42: Numbers represent percentage of landowners who responded on each category.

Question / Response Category	Strongly Agree	Agree	Somewhat Agree	Neutral	Somewhat Disagree	Disagree	Strongly Disagree
Off-ranch activities and/or employment limit my time to make land improvements.	10.2	16.8	3.6	11.6	16.1	25.4	16.3
I am unable to make as many land improvements on my property as I would like because of financial constrains.	3.8	10.3	4.1	14.8	17.5	26.7	22.9
I consider myself to be an experienced land manager.	4.8	9.1	4.5	17.9	22.2	27.4	14.1
I consider myself to be a risk taker.	7.6	13.1	10.3	21.8	22.5	18.9	5.9
I trust the County Extension Office personnel operating in my area.	2.7	3.1	2.0	29.5	16.4	31.3	14.9
I trust the Texas Parks and Wildlife personnel operating in my area.	3.8	1.5	3.6	25.1	16.8	35.0	14.2
I trust the NRCS personnel (i.e. Range conservationist) operating in my area.	2.7	1.3	2.0	30.2	13.2	31.8	18.8
I trust the USFWS personnel operating in my area.	5.8	2.6	1.5	47.2	12.5	21.7	8.7

Land and Operational Characteristics

In this section we describe general operational characteristics of landowners who responded to the survey and include supporting tables.

- Mean acres owned by respondents was 3036, the median was 500, minimum was 50 and maximum was 105,065. 51% own less than 500 acres, 24% own between 501 and 2000 acres, 23% own between 2001 and 20,000 acres and 2% own over 20,000 acres (Table 12).
- 76% of landowners who responded live within 15 miles of a town or urban area and 93% live within 10 miles of a highway or an interstate (Tables 13 and 14).
- 73% of survey respondents are the sole owners of the properties for which they provided answers, 20% are part owners and 4% are the managers of those lands (Table 15).
- Several respondents rated the importance of activities with respect to management decisions equally for all categories that make percentages add to more than 100%. Overall cattle grazing and wildlife ranching were the most important activities when it came to ranch management decision making (Table 16).
- Land use activities which derived the most income for landowners were cattle grazing (40%), fee hunting (14%), mineral sales and leases (9%) and crop production (6%) (Table 17).
- Overall, the species of most concern for landowners were Mesquite (50%) and Prickly Pear (23%), followed by the Junipers combined (22%) and Huisache (16%) (Table 18). Percentages add to more than 100% due to some landowners being equally concerned about some species. When looking at the 3 different eco-regions individually, the brush species of most concern in the Edwards Plateau are the Junipers combined (49%) followed by Prickly pear and Mesquite (Table 19a); for the Rolling Plains the brush species of most concern are Mesquite (76.5%) followed by Prickly Pear (26%) (Table 19b); and for the Coastal Plains the brush species of most concern are Mesquite (58.2), followed by Huisache (36%) and Prickly Pear (18%) (Table 19c)
- Vegetation cover in land owned or managed by respondents was predominantly native grassland (36%) followed by dense brush (23%) and mixed savanna (Table 20).
- When summarizing number of acres treated by different land improvement practices, mechanical brush clearing was the practice used the most followed by chemical and fire treatments (Table 21).
- When asked if they considered their land and the watershed their land is located in to be in excellent condition, very few landowners strongly agreed, and most were either neutral or disagreed reflecting either indifference or some degree of land degradation (Table 22).
- 54.4% of landowners reported their land was not in excellent condition and 47% reported the watershed their land was also in a less than excellent condition (Table 999).
- Respondents were mostly ranchers with cattle and wildlife operations.
- Invasive plant species of concern varied across regions but overall the main species of concern for respondents were Mesquite (*Prosopis glandulosa*) and Prickly pear (*Opuntia spp*.) followed by Juniper (*Juniperus spp*.) and Huisache (*Acacia farnesiala).*

These statements are generalization to indicate typical responses to the survey and should be fairly representative of the population of landowners with more than 50 acres of land in the 12 counties sampled based on our non-response bias survey. For further analysis of these data please refer to the *Analysis of Survey Data* section of the report.

Table 12. Responses to Q 2: How many acres do you own or manage?

Acres Owned	Frequency	Percent
50-100	80	14
101-200	94	16
201-300	46	8
301-400	45	8
401-500	28	5
501-1000	73	12
1001-2000	71	12
2001-3000	35	6
3001-4000	23	4
4001-5000	14	2
5001-6000	15	3
6001-7000	9	2
7001-8000	5	1
8001-9000	3	1
9001-10,000	10	2
10,001-20,000	20	3
>20,000	14	2

Table 13. Responses to Q 3: Approximately how many miles (as the crow flies) is the edge of your property from the nearest town or urban area?

Miles	Frequency	Percent
0	14	2
1-5	127	22
6-10	188	32
11-15	116	20
16-20	83	14
21-30	44	8
>30	7	1

Table 14. Responses to Q 4: Approximately how many miles (as the crow flies) is the edge of your property from the nearest highway or interstate?

Miles	Frequency	Percent
0	214	38
1-5	245	43
6-10	69	12
11-15	18	3
16-20	9	2
>20	9	2

Table 15. Responses to Q 5: How are you associated with the land.

	Frequency	Percent
Sole owner	422	72.9
Part owner	117	20.2
Manager	17	2.9
Other	23	4.0

Table 16. Responses to Q 6: Rank the following activities based on how important they have been with respect to management decisions on your land during the past 5 years.

	1	2	3	4	5	Not Applicable
Cattle grazing	63.9	12.8	5.7	0.5	4.4	12.6
Sheep grazing	5.3	4.0	1.8	4.0	7.2	77.6
Goat browsing	10.5	5.9	5.5	5.5	5.3	67.3
Wildlife ranching	29.5	18.9	12.6	3.1	3.5	32.4
Crop production	11.0	9.5	8.4	2.4	9.3	59.3

Table 17. Responses to Q 7: About what percentage of the gross income from your property was obtained from the following land use activities in 2007?

	Cattle Grazing	Sheep Grazing	Goat Browsing	Fee Hunting	Exotic Wildlife	Crop Prod.	Recreation (other than hunting)	Mineral Sales and Leases	Other
Mean	39.8	2.7	4.6	14.0	2.5	6.4	1.5	8.9	4.9
Median	30.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
St. Dev.	38.0	10.9	14.6	24.9	12.2	19.4	9.4	22.5	19.3

Table 18. Responses to Q 8: Rank the following plant species based on their relative abundance on your land.

All Counties	1	2	3	4	5	Not Applicable
Ashe Juniper	15.6	5.4	6.0	6.2	9.4	57.4
Red-Berry Juniper	6.7	4.9	5.6	7.6	7.1	68.1
Huisache	11.6	4.5	8.5	3.8	12.5	58.9
Mesquite	50.1	17.2	12.3	7.3	7.6	5.4
Prickly Pear	23.2	31.2	20.7	6.7	10.3	7.8

Table 19a Responses to Q 8 by Geographic Area - Edwards Plateau

Edwards Plateau	1	2	3	4	5	Not Applicable
Ashe Juniper	33.5	11	9.3	12.3	10.1	23.8
Red-Berry Juniper	15.9	11	9.3	11	8.4	44.5
Huisache	2.2	0.9	1.3	4	17.3	74.3
Mesquite	25.1	18.1	18.5	12.8	14.5	11
Prickly Pear	25.1	27.3	23.8	6.2	11.5	6.2

Table 19b. Responses to Q 8 by Geographic Area – Rolling Plains

Rolling Plains	1	2	3	4	5	Not Applicable
Ashe Juniper	4.8	3	6.6	2.4	11.4	71.7
Red-Berry Juniper	0.6	0.6	6	6.6	7.8	78.3
Huisache	1.2	0.6	5.4	2.4	12	78.3
Mesquite	76.5	10.8	6	3	2.4	1.2
Prickly Pear	25.9	42.2	11.4	7.2	6.6	6.6

Table 19c. Responses to Q 8 by Geographic Area – Coastal Plains

Coastal Plains	1	2	3	4	5	Not Applicable
Ashe Juniper	1.3	0	0.6	1.3	6.3	90.5
Red-Berry Juniper	0	0.6	0	3.8	4.4	91.1
Huisache	36.1	13.9	22.2	5.1	6.3	16.5
Mesquite	58.2	22.8	10.1	3.8	3.2	1.9
Prickly Pear	17.7	25.3	25.9	7	12.7	11.4

Table 20. Responses to Q 9: About what percentage of your property is currently covered by each of the following types of land cover?

	Native Grassland	Planted Pasture	Mixed Savanna	Dense Brush	Woodlands	Water Bodies	Other
Mean	35.7	9.7	21.5	22.7	4.8	2.1	3.0
Median	30.0	0.0	2.3	10.0	0.0	0.0	0.0
St. Dev.	31.4	18.5	29.1	27.1	11.7	6.8	11.8

Table 21. Responses to Q 10: About how many acres of your land were treated with each of the following land improvement activities during the last five years?

	Manual Brush Clearing	Mech. Brush Clearing	Chem. Brush Control	Prescribe d Burning	Wildlife Habitat Improved	Planting Improved Pasture	Erosion Control	Other
Mean	89.1	258.4	244.1	209.9	53.2	170.4	4.9	15.1
Median	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
St. Dev.	404.9	1317.2	1450.7	1590.3	307.7	3216.5	33.6	158.3

Table 22. Responses to Operational Characteristics Statement in Section 42:

Question / Response Category	Strongly Agree	Agree	Somewhat Agree	Neutral	Somewhat Disagree	Disagree	Strongly Disagree
I consider my land to be in excellent condition.	3.2	10.4	15.4	16.6	27.9	18.6	7.9
The watershed in which my land is located is in excellent condition.	4.2	10.5	12.3	26.0	18.8	21.0	7.2

Prescribed Burning

General Attitudes and Perceptions

Landowners were asked to what extent they agreed or disagreed with a set of statements regarding prescribed burning. In this section we describe general attitudes and perceptions towards prescribed burning of landowners who responded to the survey and include supporting tables.

- From our survey data we can see that landowners generally agree with the use of prescribed fires. When asked if they agreed with the idea of using prescribed burning or if they would consider using it, a grand majority of landowners considered prescribed burning to be a beneficial tool and they would in fact consider using it (Table 23a).
- When asked about concerns over lack of labor and/or equipment needed and about lack of knowledge and/or experience about fire safety, landowners agreed that they were concerned but these concerns are not strong enough to be the main constraints to applying prescribed fire (Table 23b).
- In general, respondents said that prescribed burning was easier to implement, more effective, and less costly than other brush control measures (Table 23c).
- 35% of landowners samples believe that the best season to implement a prescribed burn in order to control woody vegetation is the dry warm season, while 28% believe that the best season is the wet cool, 25% the dry cool, and 12% the wet warm season.
- 33.7% of landowners reported suppressing fire on their land while 66.3 said they did not suppress fire.
- 32.6% of landowners reported performing prescribed burns on their land while 67.4 reported they had not performed prescribed burns on their land.
- 58 of landowners have not applied any prescribed burns on their land in the **last five years**. 42% have performed at least 1 prescribed burn and 32% report having participated in prescribed burns in somebody else's property during the last 5 years (Tables 25 and 26).
- When asking people who had burned if they had well defined objectives for burning on their land, 64% reported they had well defined objectives and 36% did not.
- When asked about how well landowners accomplished their burning objectives, the mean response was 74 ± 22.5, and the median was 80%.
- Landowner attitude towards prescribed fire varies depending on risk level of prescribed fires. At low risk levels, attitudes towards prescribed fire are very positive (79%) and as risk becomes higher, attitudes level off and there are no clear differences in attitudes (48% positive attitude, 52% negative attitude).
- 42% of people with positive attitude towards fire conducted a burn without considering risk. This increased to 44% if risk was low, but when risk is high, only 17% of people with positive attitudes conducted a burn.

These statements are generalization to indicate typical responses to the survey and should be fairly representative of the population of landowners with more than 50 acres of land in the 12 counties sampled based on our non-response bias survey. For further analysis of these data please refer to the *Analysis of Survey Data* section of the report.

Table 23a. Responses to Prescribed Burning Attitude Statements in Section 12:

Question	Mean[1]	SD	Percent Agree[2]	Percent Disagree[3]
I consider the use of prescribed burning to be a beneficial tool for restoring rangelands.	6.1	1.4	88.9	5.4
I agree in principle with the idea of using prescribed burning on my land when needed.	5.9	1.5	85.7	8.2
I am in favor of applying prescribed burning on my land occasionally.	5.6	1.7	79.3	11.5
I am in favor of applying prescribed burning on my land whenever it is needed and there is sufficient fuel to burn.	5.6	1.7	77.9	10.8

Table 23b. Responses to Concerns over Using Prescribed Fire Statements in Section 12:

Question	Mean[1]	SD	Percent Agree[2]	Percent Disagree[3]
I am concerned about applying prescribed burning because of lack of labor and/or equipment needed.	4.6	2.1	59.7	29.7
I am concerned about using prescribed burning because I lack knowledge and/or experience about fire safety.	4.0	2.1	47.0	40.0

Table 23c. Responses to Opinion Towards the Practical Use of Prescribed Fire Statements in Section 12:

Question	Mean[1]	SD	Percent Agree[2]	Percent Disagree[3]
Prescribed burning is easier to implement than other methods for controlling woody plant encroachment.	5.1	1.6	64.0	12.8
Prescribed burning is more effective than other methods for controlling woody plant encroachment	4.9	1.6	58.9	13.8
Prescribed burning is less costly that other methods for controlling woody plant encroachment.	5.6	1.3	78.2	3.5

[1] 1 = Strongly disagree, 7 = strongly agree.

[2] 5, 6, or 7 on a 7-point Likert scale

[3] 1, 2, or 3 on a 7-point Likert scale

Table 24. Responses to Q 13: Based on your knowledge and experience, what season is best for burning in order to control woody vegetation?

Best Season for Burning?	Frequency	Percent
Dry Cool	125	25.2
Wet Cool	140	28.2
Dry Warm	172	34.7
Wet Warm	59	11.9

Table 25. Responses to Q 17: How many prescribed burns have been applied on your land over the last 5 years?

No. of Burns	Frequency	Percent
0	207	57.8
1	43	12.0
2	45	12.6
3	22	6.1
4	16	4.5
5	12	3.4
6	1	0.3
10	7	2.0
>10	5	1.0

Table 26. Responses to Q 18: How many prescribed burns covering more than 10 acres have you participated in during the last 5 years on **your** property and on **somebody else's** property?

No. of Burns	My property		Someone else's property	
	Frequency	Percent	Frequency	Percent
0	195	57.5	201	67.9
1	40	11.8	21	7.1
2	40	11.8	14	4.7
3	25	7.4	11	3.7
4	16	4.7	9	3.0
5	9	2.7	9	3.0
6	2	0.6	4	1.4
7	1	0.3	1	0.3
8	0	0.0	4	1.4
10	5	1.5	9	3.0
>10	6	2.0	13	4.4

Attitudes and Perceptions towards Extreme Prescribed Burns

In this section we describe general attitudes and perceptions towards extreme prescribed burning of landowners who responded to the survey and include supporting tables.

- When asked about the use of extreme prescribed fires, landowners did not agree with the use of these fires as much as with the use of more mild fires, but response was still more in favor of burning that not (Table 27a).
- 47.4% of landowners agree that based on their experience, warm season prescribed burns are favorable for their land (Table 27a).
- 21% of landowners have participated in a warm season prescribed burn while 79% have not.
- Responses regarding the use of Certified Prescribed Burn Managers were close to neutral, but in general landowners believe that Certified Prescribed Burn Managers can burn during burn bans and must have liability insurance (Table 27b).
- In general, 44% of respondents agree that they would be willing to pay more in order to hire a Certified Prescribed Burn Manager (Table 27b).
- In general proximity to roads or urban areas does not keep landowners from using prescribed fire (Table 27c).

These statements are generalization to indicate typical responses to the survey and should be fairly representative of the population of landowners with more than 50 acres of land in the 12 counties sampled based on our non-response bias survey. For further analysis of these data please refer to the *Analysis of Survey Data* section of the report.

Table 27a. Responses to Q 21: Attitudes towards extreme (intensely hot) prescribed fires.

Question	Mean[1]	SD	Percent Agree[2]	Percent Disagree[3]
I am in favor of applying prescribed burning on hot days (up to 100° F) when there is a lot of fuel and little wind.	4.5	1.9	53.3	28.0
I am in favor of burning using warm season prescribed burns as a land restoration tool.	4.8	1.7	58.0	19.2
I would be willing to apply warm season prescribed burns on my land if I was shown it benefited my land.	5.2	1.7	70.9	14.7
Based on my knowledge and experience, warm season prescribed burns are favorable for my land.	4.5	1.7	47.3	21.2

Table 27b. Responses to Q 21: Perceptions towards the Use of Certified Prescribed Burn Managers.

Question	Mean[1]	SD	Percent Agree[2]	Percent Disagree[3]
I can perform a prescribed burn during a burn ban if a certified prescribed burn manager is in charge of the fire.	4.1	2.0	41.1	33.3
Affordable liability insurance is currently available for certified prescribed burn managers.	4.1	1.3	21.0	13.3
Certified prescribed burn managers must have liability insurance.	5.2	1.5	56.3	5.7
I would be willing to pay more in order to hire a certified prescribed burn manager.	4.4	1.8	43.8	24.3

Table 27c. Response to Q 21: Concerns over Effects of Prescribed Fires on Nearby Urban Areas or Roadways.

Question	Mean[1]	SD	Percent Agree[2]	Percent Disagree[3]
The proximity of my property to urban areas keeps me from using prescribed burning.	2.3	1.5	8.3	76.0
The proximity of my property to major roadways keeps me from using prescribed burning.	2.5	1.5	10.9	72.2

[1] 1 = Strongly disagree, 7 = strongly agree.

[2] 5, 6, or 7 on a 7-point Likert scale

[3] 1, 2, or 3 on a 7-point Likert scale

Prescribed Burn Association Data

Prescribed burn associations are groups of voluntary individuals who form an association to promote the safe and effective use of fire. Prescribed burn Associations members benefit from educational opportunities, the use of a shared pool of fire suppression equipment and, most importantly, association members benefit from having a labor pool composed of other members of the association. Our analysis confirms research that has shown that measures of social capital such as trust, reciprocity, and collective action are high among members of landowner associations (Kreuter et al. 2008).

- 23% of survey respondents were members of burn associations. This is not representative of the population of the 3 areas studied because when separating response rate between members and non-members, there was a higher survey response rate by members of prescribed burn associations than non-members.
- 70% of members of prescribed burn associations report that there was a written burn plan for the burns they have participated in which leaves 30% without a written burn plan.
- Of the respondents who were a part of a prescribed burn association, 74% where part of the Edwards Plateau Prescribed Burn Association (EPPBA), 18% were part of the North Central Prescribed Burn Association, 7% were part of the Central Bend Prescribed Burn Association, and 1% were part of the Hill Country Prescribed Burn Association. The EPPBA is the largest association with more than 400 members and an increasing number of chapters throughout their operating area. This is reflected in the fact that most of the respondents who were a part of a prescribed burn association were part of the EPPBA.
- Table 30 measures responses regarding trust, reciprocity, and collective action, which are all measures of social capital. Most responses to all of these questions were clearly favorable (>5).
- 70% of respondents who were part of prescribed burn associations reported that it was important for them to belong to a PBA.
- Most respondents who were part of prescribed burn associations know the other members of the association and consider many to be friends.
- More that 60% of respondents who were part of prescribed burn associations report that they would help their non-kin association members and even lend or borrow equipment from them. And most agreed that being a member of a PBA would help them guide and implement management decisions.

These statements are generalization to indicate typical responses to the survey and should be fairly representative of the population of landowners with more than 50 acres of land in the 12 counties sampled based on our non-response bias survey. For further analysis of these data please refer to the *Analysis of Survey Data* section of the report.

Table 28. Response to Q 22 and 26.

	Yes	No
Are you a member of a Prescribed Burn Association?	23.2%	76.8%
Was there a written burn plan for the burns you participated in?	70.1%	29.9%

Table 29. Responses to Q 23.

What is the name of your prescribed burn association?	Edwards Plateau PBA	Central Bend PBA	North Central PBA	Hill Country PBA
Percentage	74.1	7.4	17.6	0.9

Table 30. Responses to Q 28. Please indicate to what extent you agree or disagree with the following statements about burn associations.

Question	Mean[1]	SD	Percent Agree[2]	Percent Disagree[3]
It is important for me to belong to a burn association.	5.4	1.7	70.5	9.8
I know most members of my burn association.	4.6	1.9	54.1	22.4
I consider many members of my association to be friends.	4.9	1.7	56.6	14.3
I socialize with members of my burn association.	4.4	1.8	41.2	20.9
I trust members of my burn association.	5.2	1.5	62.1	7.7
I would spend time helping non-kin association members.	5.3	1.6	66.3	7.1
I would loan equipment to non-kin association members.	5.2	1.6	66.3	8.7
Non-kin members would spend time helping me.	5.3	1.5	67.2	6.6
Non-kin association members would loan me equipment.	5.1	1.5	59.0	7.1
I care what other association members think I should do.	5.1	1.6	66.3	9.8
I have gotten my money's worth from participating in my prescribed burn association.	5.1	1.7	59.0	10.1
Being a member of a prescribed burn association will help me achieve my land management objectives.	5.3	1.7	65.2	10.3
If my association urged its members to adopt certain conservation practices, most would likely comply.	5.1	1.5	66.5	8.2
If my association urged members to follow specific burn guidelines, most would likely comply.	5.5	1.4	75.8	6.0
Prescribed burn association members may be able to burn during burn bans imposed by county commissioners.	5.1	1.8	63.5	14.0

[1] 1 = Strongly disagree, 7 = strongly agree.
[2] 5, 6, or 7 on a 7-point Likert scale
[3] 1, 2, or 3 on a 7-point Likert scale

Cost Share Programs

In this section we describe general landowner responses regarding cost-share programs and include supporting tables.

- Of the cost share programs available to landowners, the Environmental Quality Incentives Program is the one that landowners have participated in the most, followed by the Conservation Reserve Program. 18% of landowners who have participated in a cost share are currently enrolled in EQUIP and 13% have been enrolled in the past. For the CRP 5% of these landowners are currently enrolled and 10% have been enrolled in the past.
- 32% of landowner reported they had not participated in a cost-share program because they did not know about these programs, 16% were not interested, 13% did not know hot to apply, 10% did not think they were not sufficiently flexible for their land management needs, 7% though they were to difficult to enroll in, and 4 thought they did not qualify for these.
- 71% of landowners believe that participation in a cost-sharing program would benefit their land.
- 68% believe that participation in a cost-sharing program would help them apply management actions they could not otherwise apply but 57% believe that participation in a cost-sharing program would make it easier for public agencies to regulate activities on their land.
- 50% agree that if available, they would participate in a cost-sharing program to implement management actions on their land.
- More than 50% agree that their family, friends, and neighbors would approve of their participation in a cost-share program.

These statements are generalization to indicate typical responses to the survey and should be fairly representative of the population of landowners with more than 50 acres of land in the 12 counties sampled based on our non-response bias survey. For further analysis of these data please refer to the *Analysis of Survey Data* section of the report.

Table 31. Responses to Q 29: Have you participated at any time in any of the following federal or state funded cost-sharing land improvement programs?

Cost-Share Program	Currently	In the Past	Never
Environmental Quality Incentives Program	17.9	13.2	68.9
Conservation Reserve Program	5.2	9.8	84.9
Wildlife Habitat Incentives Program	1.9	3.3	94.8
Wetland Reserve Program	0.4	0	99.6
Landowner Incentive Program	1.2	5.2	93.6
Other	1.7	1.9	96.4

Table 32. Responses to Q 30: If you have not participated in cost-share programs, please indicate why.

Reason	Percentage
I don't know about them	32.0
I don't know how to apply	13.2
I am not interested	15.9
I am not qualified	3.9
It is too difficult to enroll in them	6.7
They are not sufficiently flexible for my land management needs	9.7
Other	18.1

Table 33. Responses to Q 31: Please indicate to what extent you agree or disagree with the following statements about cost-sharing programs.

			Percent	
Question	Mean[1]	SD	Agree[2]	Disagree[3]
Participation in a cost-sharing program would benefit my land.	5.38	1.55	70.70	7.94
Participation in a cost-sharing program would help me apply management actions I could not otherwise apply.	5.24	1.58	68.44	9.13
Participation in a cost-sharing program will make it easier for public agencies to regulate activities on my land.	4.78	1.76	56.62	17.47
If available, I plan to participate in a cost-sharing program to implement management actions on my land.	4.63	1.71	50.00	18.39
My family and friends would approve of my participation in a cost-sharing program.	5.09	1.47	59.58	7.47
Most of my neighbors whose opinion I value would approve of my participation in a cost-sharing program.	4.98	1.47	54.55	8.12

[1] 1 = Strongly disagree, 7 = strongly agree.
[2] 5, 6, or 7 on a 7-point Likert scale
[3] 1, 2, or 3 on a 7-point Likert scale

Analysis of Survey Data

Prescribed Burn Data

In general, landowners sampled had positive attitudes towards prescribed fire, positive attitudes towards warm season fires and were neutral to slightly concerned over the use prescribed fire (Table 34). Mean responses between the three geographic areas sampled were similar, but when tested for differences, were significantly different. Edwards Plateau residents in general had more positive attitudes towards prescribed fire than Rolling Plains or Coastal Plains. Coastal Plains residents also had positive attitudes towards prescribed fire but had the least positive of the three areas, which coincides with this area having the highest concerns over using prescribed fire.

Table 34. Comparison of attitudes and concerns of using prescribed fire with respect to geographic area.

Descriptive Statistics					ANOVA	
	Study Area	N	Mean	Std. Dev.	F	Sig.
Attitude towards burning	Rolling Plains	166	5.63	1.553	9.420	0.000
	Edwards Plateau	221	6.12	1.195		
	Coastal Plains	154	5.54	1.552		
Attitude towards warm season fires	Rolling Plains	155	4.74	1.429	3.326	0.037
	Edwards Plateau	213	4.97	1.496		
	Coastal Plains	148	4.56	1.524		
Concerns over using prescribed fire	Rolling Plains	167	4.14	2.014	5.098	0.006
	Edwards Plateau	224	4.12	1.983		
	Coastal Plains	155	4.72	1.807		

1 = Strongly disagree, 4= neutral, 7 = strongly agree.

A Principal Components Analysis (PCA) with a varimax rotation was used in order to reduce the number of variables used in the analysis of survey data. The sample size is large enough to reliably run PCA (n=585). Question 12 – related to attitudes, perception, and concerns regarding prescribed fire - was reduced to 3 components (Table 35), and question 21 –related to attitudes and perceptions toward extreme prescribed fires – was reduced to 4 components (Table 36). A reliability analysis - Cronbach's alpha – was run on each of the three components to know how reliable these components were.

Table 35. Principle Components Analysis using varimax rotation for question 12.

	Component			Cronbach's alpha
	1	2	3	
I agree in principle with the idea of using prescribed burning on my land when needed.	.887			0.906
I am in favor of applying prescribed burning on my land occasionally.	.869			
I consider the use of prescribed burning to be a beneficial tool for restoring rangelands.	.867			
I am in favor of applying prescribed burning on my land whenever it is needed and there is sufficient fuel to burn.	.862			
Prescribed burning is more effective than other methods for controlling woody plant encroachment.	.721			
Prescribed burning is easier to implement than other methods for controlling woody plant encroachment.	.677			
I am concerned that if I use prescribed burning it might negatively affect nearby roadways.		.870		0.812
I am concerned that if I use prescribed burning it might negatively affect nearby urban areas.		.835		
I am concerned that if I use prescribed burning it might have negative effects on my neighbor's property.		.788		
I am concerned about applying prescribed burning because of lack of labor and/or equipment needed.			.908	0.816
I am concerned about using prescribed burning because I lack knowledge and/or experience about fire safety.			.896	

Table 36. Principal Components Analysis using varimax rotation for question 21.

	Component 1	2	3	4	Cronbach's alpha
If my land needs it, I will perform a prescribed warm season burn on my property.	.871				
I would be willing to apply warm season prescribed burns on my land if I was shown it benefited my land.	.806				
My family and friends would support me if I decide to implement a warm season prescribed burn on my property.	.794				
I am in favor of burning using warm season prescribed burns as a land restoration tool.	.770				0.904
I am prepared to burn under whatever conditions are necessary to achieve my land management objectives.	.743				
The chance of attaining desired management objectives using warm season prescribed burns outweighs the risks.	.734				
Most of my neighbors whose opinion I value would support me if I decide to implement a warm season burn on my land.	.705				
The proximity of my property to urban areas keeps me from using prescribed burning.		.920			0.866
The proximity of my property to major roadways keeps me from using prescribed burning.		.909			
Most naturally ignited fires on rangelands in the Southern Great Plains occur during the summer months.			.868		0.637
Warm season fires maintain the dominance of open grasslands and savannas.			.759		
Certified prescribed burn managers must have liability insurance.				.806	0.449
I would be willing to pay more in order to hire a certified prescribed burn manager.				.779	

All 3 principal components for question 12 were reliable (>0.7) as well as the first two components of question 21 (Tables 35 and 36). These components will be used in subsequent analysis.

Bivariate correlation and regression analysis aimed at trying to find relationships between landowner/property characteristics and their perceptions towards the ecological role and use of hot prescribed fires were performed but even though relationships were significant due to the large sample size, the strength and the effects of the relationships were very poor or nonexistent (Appendix D). Based on the lack of bivariate relationships, multivariate regression analysis were performed, aimed at trying to find relationships between landowner/property characteristics and their perceptions towards the ecological role and use of hot prescribed fires that we could not find from using bivariate techniques alone.

Table 37. Logistic regression analysis for "having burned in the past" as the dependant variable.

	Dependant	Independent	Nagelkerke R Square	B	S.E.	Sig.	Exp(B)
Prescribed Fire Analysis 1	Has burned in the past	Log (Acres)	0.306	.242	.077	.002	1.274
		Consider to be an experienced land manager		.612	.075	.000	1.843
		Constant		-6.059	.561	.000	.002
Prescribed Fire Analysis 2	Has burned in the past	Attitude towards prescribed fire	0.394	.989	.152	.000	2.689
		Concerns over labor and equipment		-1.139	.123	.000	.320
		Constant		-.992	.123	.000	.371

The first logistic regression in table 37 shows how the log of the acreage and experience were significant predictors of having burned in the past. For this analysis, we used “landowner has applied prescribed burning in the past” as the dependent variable and the predictor variables of interest are acreage and whether a landowner considers him/herself to be an experienced land manager. Acreage is heavily skewed to the left so it was transformed logarithmically.

I am interested in the factors that influence whether or not a landowner will apply prescribed burning. I cannot predict future outcomes, but I can use whether they have burned in the past or not as a proxy for whether they would burn in the future. The response variable is binary: 0=has not burned or 1=has burned.

The likelihood ratio chi-square of 562.785 with a p-value of 0.0001 tells us that our model as a whole fits significantly better than the empty model (the model is better than just relying on a best guess). All components are statistically significant. For a one unit increase in **log(acres)**, the odds of having burned in the past increased by a factor of 1.274 (27%), and for a one unit increase in **experience**, the odds of having burned in the past increased by a factor of 1.843 (84.3%). Landowner experience and acreage predicted whether a landowner has burned or not and therefore should be able to predict whether a landowner will burn in the future, but we have no way of testing this with the available data.

The second model in table 37 shows how attitude towards prescribed fire and concerns over labor and equipment were significant predictors of having burned or not in the past. For this analysis, we used “landowner has applied prescribed burning in the past” as the dependent variable and the predictor variables of interest are attitude towards prescribed fire and concerns over labor and equipment.

The likelihood ratio chi-square of 481.109 with a p-value of 0.0001 tells us that our model as a whole fits significantly better than the empty model. All components are statistically significant. For a one unit increase in **attitude towards prescribed fire**, the odds of having burned in the past increased by a factor of 2.689 (168.9%), and for a one unit increase in **concerns over labor and equipment**, the odds of having burned in the past decreased by a factor of 0.32 (-68%).

Prescribed Burn Association Data

When we look at PBA membership and landowner attitudes and perceptions regarding fire, there is a significant difference in attitudes between members and non-members. In general PBA members are more in favor of prescribed burning (Table 38).

Table 38. Comparison of mean response values of attitudes and characteristics of Prescribed Burn Association (PBA) members versus nonmembers.

Respondent characteristics	PBA member vs. nonmember		
	Members	Non-members	Difference
Are in favor of prescribed burning	6.7	5.5	1.2 *
Are in favor of extreme prescribed fires	5.6	4.5	1.1 *
Favor burning over other brush control methods	5.8	5.0	0.8 *
Have ranching experience	5.7	4.6	1.1 *
Have performed extreme prescribed burns	62%	38%	24%*

1 = Strongly disagree, 4= neutral, 7 = strongly agree.
* Statistically significant at $P < 0.05$.

Since membership in a prescribed burn association influences whether or not a landowner will burn, we are interested in learning more about factors influencing association membership. We ran a second set of logistic regression analysis for a bivariate dependant variable with membership in a PBA as our dependent variable (Table 39). The predictor variables of interest are attitude towards the use of prescribed fire (Q. 12, PCA Component 1), concerns over negative effects of prescribed fire on roads, urban areas, and neighbors (Q. 12, PCA Component 2), and concerns over lack of knowledge and equipment (Q. 12, PCA Component 3).

The likelihood ratio chi-square of 123.258 with a p-value of 0.0001 tells us that our model as a whole fits significantly better than the empty model and all components are statistically significant. For a one unit increase in **attitude towards the use of prescribed fire**, the odds of being a member of a prescribed burn association increased by a factor of 3.10 (210%), for a one unit increase in **concerns over negative effects of prescribed fire**, the odds of being a member of a prescribed burn association decreased by a factor of 0.733 (-26.7%), and for a one unit increase in **concerns over lack of knowledge and equipment**, the odds of being a member of a prescribed burn association decreased by a factor of 0.40 (-60%)*.

Question 12 PCA Components 1, 2, and 3 were significant predictors of membership in a prescribed burn association. Attitude towards the use of prescribed fire was a better predictor of membership in a PBA, concerns over negative effects of prescribed fire and concerns over lack of knowledge and equipment also predicted someone not being part of a PBA.

We also ran this analysis using attitude towards the use of extreme prescribed fire (Q 21, PCA Component 1), effects of prescribed fire on roads, urban areas, and neighbors keep me from burning (Q 21, PCA Component 2), and fire ecology knowledge (Q 21, PCA Component 3) as the covariates. The likelihood ratio chi-square of 82.324 with a p-value of 0.0001 tells us that our model as a whole fits significantly better than the empty model (the model is better than just relying on a best guess).

All components are statistically significant. For a one unit increase in component 1, the odds of being a member of a prescribed burn association increased by a factor of 2.49 (149%), for a one unit increase in component 2, the odds of being a member of a prescribed burn association decreased by a factor of 0.534 (-47%), and for a one unit increase in component 3, the odds of being a member of a prescribed burn association increased by a factor of 1.4 (42%).

Components 1, 2, and 3 were significant predictors of membership in a prescribed burn association. Attitude towards the use of prescribed extreme fire (Q 21, PCA Component 1) was a better predictor of membership in a PBA, potential negative effects of prescribed fire (Q 21, PCA Component 2) predicted not being part of a PBA and fire ecology knowledge (Q 21, PCA Component 3) also predicted someone being part of a PBA.

Table 39. Logistic regression analysis with membership in a Prescribed Burning Association quantified as a bivariate dependant variable.

	Independent	Nagelkerke R Square	B	S.E.	Sig.	Exp(B)
PBA Analysis 1	Attitude towards use of prescribed fire	0.33	1.131	0.201	0.000	3.100
	Concerns over negative effects of prescribed fire		-0.310	0.130	0.017	0.733
	Concerns over lack of knowledge and equipment		-0.915	0.124	0.000	0.400
	Constant		-1.650	0.157	0.000	0.192
PBA Analysis 2	Attitude towards the use of extreme prescribed fire	0.248	0.912	0.145	0.000	2.489
	Effects of prescribed fire on roads, urban areas, and neighbors keep me from burning		-0.628	0.150	0.000	0.534
	Fire ecology knowledge		0.353	0.129	0.006	1.423
	Constant		-1.454	0.140	0.000	0.234

Conclusions and Management Implications

In terms of income obtained from their property, cattle and wildlife are the most important land use activities to landowners in the three regions. Cattle and wildlife were also the most important land use activities take into account when making decisions about land management.

Woody plant species of concern varied throughout the sites but overall the main species of concern for survey respondents were Mesquite (*Prosopis glandulosa*) and Prickly pear (*Opuntia* spp.) followed by Juniper (*Juniperus* spp.) combined and Huisache (*Acacia smallii).*

In general, landowners in the counties sampled have positive attitudes towards prescribed fire and believe it is easier to implement, less costly, and more effective than other brush control methods. When asked about prescribed extreme fires, attitudes were less positive than with milder fires. Even though landowners in the sample area are generally in favor of prescribed burns, only 32.6% have actually performed burns on their land. Landowner attitude towards prescribed fire varies depending on risk level. At low risk levels, attitudes towards fire are very positive and as risk becomes higher, attitudes level off. 42% of people with positive attitude towards prescribed fire conducted a burn not considering risk. When risk was low, this increased to 44% of people with positive attitude, but when risk was high, only 17% of people with positive attitude conducted a burn, highlighting the importance of prescribed burn associations.

When asked about the best season to perform prescribed fires, a majority of landowners believe that the best season to apply prescribed fires was in dry, warm months.

In general, landowners are not kept from burning because of proximity to urban areas or roadways even though most report their land being in close (<10 miles) proximity to these.

Landowner experience, attitude towards the use of prescribed fire, concerns over negative effects of prescribed fire, concerns over lack of knowledge and equipment and acreage predicted whether a landowner has burned or not and therefore should be able to predict whether a landowner will burn in the future, but we have no way of testing this with the available data.

Concerns over negative effects of prescribed fire, and concerns over lack of knowledge and equipment also predicted someone not being part of a PBA.

Our research and the research of others have shown that measures of social capital such as trust, reciprocity, and collective action are high among members of landowner associations.

Prescribed burn association members have more positive attitudes towards prescribed fire while non-members are more concerned about fire effects and lack of knowledge and equipment. If our objective is to promote the use of fire across the landscape, educating people about the advantages of PBA membership and promoting membership to these associations is a good way of getting people informed and equipped to deal safely with fire.

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Appendix A: Letters Sent to Landowners Requesting Data

Pre-Survey Letter

AgriLIFE RESEARCH & EXTENSION
Texas A&M System

TEXAS A&M UNIVERSITY
COLLEGE OF AGRICULTURE AND LIFE SCIENCES
DEPARTMENT OF ECOSYSTEM SCIENCE AND MANAGEMENT

July 21, 2008

Dear Landowner,

Within the next few days you will receive a questionnaire in the mail requesting your participation in a study about the use of prescribed fire in Texas. This survey is being conducted by the Department of Ecosystem Science & Management at Texas A&M University. The purpose of the study is to gain information about landowner interests and concerns regarding the use of prescribed fire to restore rangelands. The results of the study will help us make recommendations to the Natural Resources Conservation Service (NRCS), which helps landowners off-set the cost of implementing land improvement practices through programs such as the Environmental Quality Improvement Program (EQIP).

To effectively promote public policies that better support individual landowners and land management associations to which they might belong, it is important for policy makers and land management agency personnel to better understand your interests and concerns about land management. Our study is designed to **let landowners, like you, voice their views about the use of prescribed fire and the role that Landowner Associations might play in facilitating its use.** Your responses will be used to develop a report for distribution to prescribed burning associations in Texas, the NRCS, other state and federal agencies, and Texas policy makers.

You are among a group of randomly selected landowners in 12 states in Texas who we are asking to help with the study by completing and returning the questionnaire as soon as it arrives.

We know you are busy, but we hope that you will be willing to participate in this study. Our research can succeed only through the generous help of people like you.

If you have any questions please contact me by phone at 979-845-5583 or e-mail at urs@tamu.edu or you can also contact my research assistant, David Toledo at 979-458-2044 or david_toledo@tamu.edu. Thank you in advance for your help.

Sincerely,

Urs P. Kreuter

Urs P. Kreuter
Associate Professor, Texas A&M University

225 Animal Industries Building, 2138 TAMU, College Station, Texas 77843
Tel. 979.845.5579; Fax. 979.845.6430; http://essm.tamu.edu

Survey Cover Letter

AgriLIFE RESEARCH & EXTENSION
Texas A&M System

TEXAS A&M UNIVERSITY

COLLEGE OF AGRICULTURE AND LIFE SCIENCES

DEPARTMENT OF ECOSYSTEM SCIENCE AND MANAGEMENT

July 28, 2008

Dear Landowner,

A few days ago we sent a letter about a study aimed at gaining a better understanding of **landowner perspectives regarding the use of prescribed fire to restore rangelands and the role that Landowner Associations might play in helping them apply fire on their land**. This survey is being conducted by the Department of Ecosystem Science & Management at Texas A&M University. Results from the study will be used to make recommendations for policy changes and landowner association improvements that will make it easier for landowners to apply prescribed fire on their land. The results from this study may also enhance the availability of support and the availability of publicly funded cost-sharing opportunities for landowners who wish to apply fire on their land.

To better understand landowners' concerns and interests about management practices that improve the health of their rangelands, such as the use of prescribed fire, it is important to **let landowners, like you, voice their views about such practices.** For the survey results to allow us to make meaningful policy recommendations that benefit landowners, we need to hear from everyone included in the survey.

Over the past few years, we have conducted several studies to evaluate landowner perceptions about land improvement practices and the role of landowner associations in promoting improved land management. In June 2004 we conducted a preliminary study to understand landowner perceptions about prescribed fire. If you participated in this study, we thank you. The current study is much larger covering 12 counties in three eco-regions of Texas and the questionnaire is different from the previous one.

We ask that you complete the attached questionnaire as soon as possible and return it to us in the attached postage paid return envelope. The questionnaire should take about 30 minutes to complete and your responses will be kept confidential. Individual landowners will not be identified in any reports or publications associated with this study and only aggregated statistics will be presented. The cover of each survey questionnaire includes a code number that allows us to identify respondents and remove them from the list for follow-up mailings.

This study has been reviewed and approved by the Institutional Review Board-Human Subjects in Research, Texas A&M University. For research related problems or questions regarding 'subject' rights, contact the Institutional Review Board through Melissa McIlhaney, Human Subjects Protection Program Coordinator, Office of Research Compliance at 979-458-4067.

If you have any questions or comments, please feel free to contact me by telephone (979-845-5583) or e-mail (urs@tamu.edu). Thank you in advance for your help!

Sincerely,

Urs P. Kreuter

Urs P. Kreuter
Associate Professor, Texas A&M University

225 Animal Industries Building, 2138 TAMU, College Station, Texas 77843
Tel. 979.845.5579; Fax. 979.845.6430; http://essm.tamu.edu

First Reminder Card

Dear Landowner:

One week ago, we mailed a questionnaire asking for **your views about prescribed fire.** If you have completed and returned the questionnaire, please accept my sincere thanks.

If you have not yet completed the questionnaire, please do so today and return it in the supplied postage-paid envelope. It is only by asking people like you to share your experiences and opinions that we can help policy makers better understand landowners' views and concerns about such issues. We need a high response rate for our study to be most meaningful. If you did not receive a questionnaire, or if it was misplaced, please contact David Toledo by phone or email (979-458-2044 or david_toledo@tamu.edu), and we will send you another one immediately. Thank you in advance for your help!

Sincerely,

Urs P. Kreuter, Associate Professor, Texas A&M University

Second Mailing Cover Letter

AgriLIFE RESEARCH & EXTENSION
Texas A&M System

TEXAS A&M UNIVERSITY

COLLEGE OF AGRICULTURE AND LIFE SCIENCES
DEPARTMENT OF ECOSYSTEM SCIENCE AND MANAGEMENT

August 18, 2008

Dear Landowner,

About three weeks ago you were sent a questionnaire in which we asked you about your perspectives regarding the use of prescribed fire to restore rangelands in Texas and the role that Landowner Associations might play in helping landowners apply fire on their land. Results from the study will be used to make recommendations for policy changes and landowner association improvements that will make it easier for landowners to apply management actions on their land.

As of today, we have not received your completed questionnaire. If you mailed it back recently, please accept our sincere thanks. If you have not yet completed the questionnaire, please help us by filling it out now. A second copy of the questionnaire is enclosed in case you misplaced the one that was mailed earlier.

We are writing again because your response is very important. It is only by hearing from nearly everyone in the sample that we can be sure that the results are truly representative.

As previously indicated, your answers will be kept **COMPLETELY CONFIDENTIAL**. Protecting the confidentiality of people's answers is very important to us, as well as the University.

A few people have informed us that they no longer own land in the counties sampled. If this applies to you, please let us know on the cover of the questionnaire and return it in the enclosed envelope so we can delete you from the mailing list. In addition, if you prefer not to answer the questionnaire, please let us know by returning a blank questionnaire in the enclosed stamped envelope.

If you have any questions please contact me by phone at 979-845-5583 or e-mail at urs@tamu.edu or you can also contact my research assistant, David Toledo at 979-458-2044 or david_toledo@tamu.edu. Thank you in advance for your help.

Sincerely,

Urs P. Kreuter

Urs P. Kreuter
Associate Professor, Texas A&M University

225 Animal Industries Building, 2138 TAMU, College Station, Texas 77843
Tel. 979.845.5579; Fax. 979.845.6430; http://essm.tamu.edu

Final Reminder Card

Dear landowner,

During the last six weeks we have sent you several mailings about an important research study that we are conducting. The purpose of the study is to understand **landowners' views about prescribed fire in Texas.** The study is drawing to a close and this is the last time that we will contact you about the study. Hearing from everyone in our small sample helps assure that that the survey results are as accurate as possible. Therefore, if you have not yet had the opportunity to complete the survey questionnaire, we ask you to please do so. We assure you that your response is completely confidential.

We appreciate your willingness to consider our request for assistance. If you did not receive a questionnaire, or if it was misplaced, please contact David Toledo by phone or email (979-458-2044 or david_toledo@tamu.edu), and we will send you another one immediately. Again, thank you for your help!

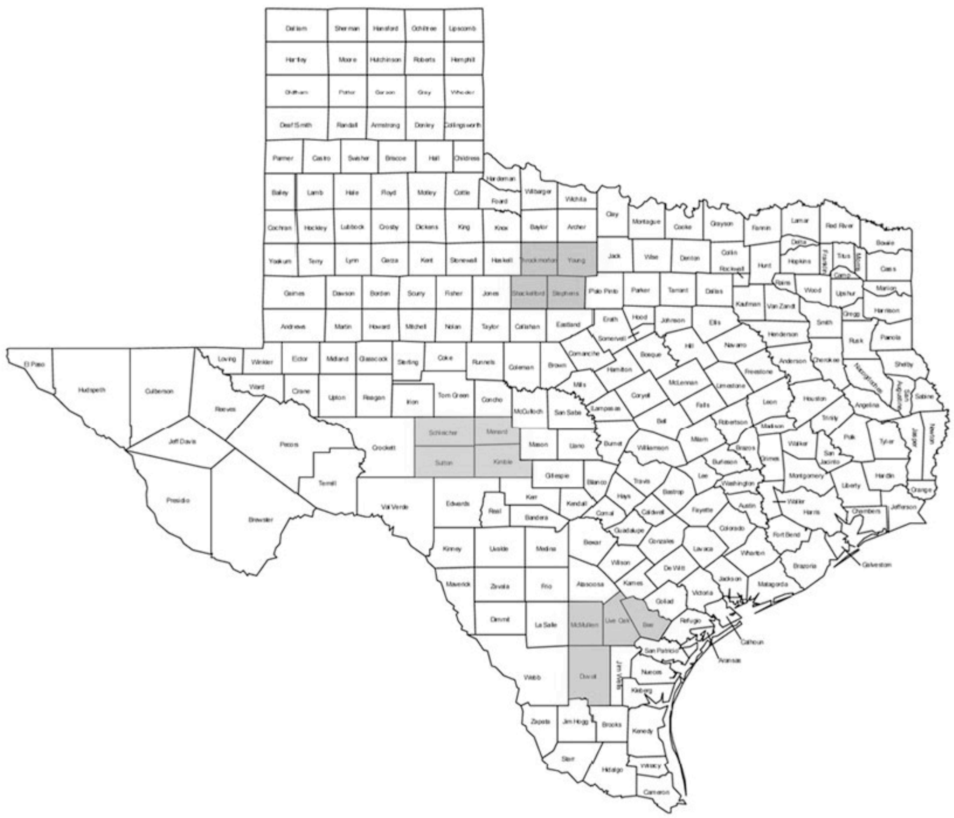
Sincerely,

Urs P. Kreuter, Associate Professor, Texas A&M University

Appendix B: Mail Survey Instrument

The Role and Application of Prescribed Burning in Texas:

A Mail Survey of Landowners in 12 Texas Counties



Results from this survey will provide information to landowner associations and policy makers about the use of prescribed burning to improve private rangelands.

Department of Ecosystem Science & Management
Texas A&M University
TAMU 2138
College Station, TX 77843-2138

July 2008

We are asking that this questionnaire be completed by the person who is currently most involved in making decisions about land management on the property. If you have any questions, please contact Dr. Urs Kreuter (phone: 979-845-5583 or email: urs@tamu.edu).

COMPLETING THE QUESTIONNAIRE

Please make sure that you answer all questions that apply to your property. Incomplete questionnaires create problems for conducting proper statistical analysis.

If you encounter a question that does not apply to your property, please indicate this by writing "NA" in the margin next to the question.

If you encounter a question for which you do not know the answer, please indicate this by writing "DK" in the margin next to the question.

Many of the questions in this survey use a rating scale with 7 options. Please circle the number that best describes your opinion. For example, if you were asked to use such a scale to indicate the extent to which you agree or disagree with the statement that "Texas is the best state in the USA" and you strongly agree, you would circle *number 1*, as follows:

	Strongly Agree	Agree	Somewhat Agree	Neutral	Somewhat disagree	Disagree	Strongly Disagree
Texas is the best state in the USA	(1)	2	3	4	5	6	7

In making your markings, please remember the following points:

- Your identity will remain anonymous.
- Please answer all items – do not omit any.
- There will not be any financial compensation for answering this survey.

FIRST QUESTION

Do you own and/or operate at least 50 acres of private land in one or more of the following 12 counties: Bee, Duval, Kimble, Live Oak, McMullen, Menard, Schleicher, Shackelford, Stephens, Sutton, Throckmorton, or Young? Please check (☑) one.

☐ No - Please stop here and return questionnaire in the attached postage-paid envelope. It is important that we hear back from everyone who receives a questionnaire. We thank you for taking the time to place the questionnaire in the enclosed envelope and returning it to us.

☐ Yes - Please proceed to complete the whole questionnaire.

OPERATIONAL CHARACTERISTICS

This section is designed to obtain information about your property and land management objectives in order to help us analyze the survey data more effectively.

1. In which COUNTY is your land predominantly located? ________________________

2. How many acres do you own or manage? __________acres

3. Approximately how many miles (as the crow flies) is the edge of your property from the nearest town or urban area? __________miles

4. Approximately how many miles (as the crow flies) is the edge of your property from the nearest highway or interstate? __________miles

5. How are you associated with the land?

☐ Sole owner
☐ Part owner
☐ Manager
☐ Other (please describe) ____

6. Rank the following land use activities based on how important they have been with respect to management decisions on your land during the past 5 years. (1 = most important … 5 = least important; Enter 0 if not applicable).

__Cattle grazing __Sheep grazing __Goat browsing __Wildlife ranching __Crop production

☐ Check here if you do not use your land for any kind of animal or crop production.

7. About what percentage of the gross income from your property was obtained from the following land use activities in 2007? (Please make sure your answers add to 100%)

Cattle grazing	_________%
Sheep grazing	_________%
Goat browsing	_________%
Fee hunting	_________%
Exotic wildlife production and/or hunting	_________%
Crop production	_________%
Recreation related activities (other than hunting)	_________%
Mineral sales and leases	_________%
Other (Please describe) ___________________________________	_________%

☐ Check here if you did not derive any income from your land in 2007.

8. **Rank the following plant species based on their relative abundance on your land. (<u>1 = most abundant … 5 = least abundant. Enter 0 if species not present</u>)**

   __Ashe Juniper/cedar __Red-berry Juniper/cedar __Huisache __Mesquite __Prickly Pear

9. **About what percentage of your property is currently covered by each of the following types of land cover? (<u>Please make sure that your answers add to 100%)</u>**

   Native grassland __________%
   Planted pasture __________%
   Grass and tree mixed savanna __________%
   Dense brush __________%
   Woodlands __________%
   Water bodies (ponds, tanks, lakes, etc.) __________%
   Other (Please describe) ____ __________%

10. **About how many acres of your land were treated with each of the following land improvement activities during the last five years.**

    Manual brush clearing (includes manual pesticide application) _____________ acres
    Mechanical brush clearing _____________ acres
    Chemical brush control _____________ acres
    Prescribed burning _____________ acres
    Wildlife habitat improvement _____________ acres
    Planting of improved pasture or forage crops _____________ acres
    Erosion control _____________ acres
    Other (Please describe) ________________________________ _____________ acres

11. **Please circle the option that best describes how often you monitor the following variables.**

I keep close track of rainfall on my property	Regularly	Occasionally	Never
I keep close track of temperature on my property	Regularly	Occasionally	Never
I keep close track of relative humidity on my property	Regularly	Occasionally	Never
I keep close track of wind speed on my property	Regularly	Occasionally	Never
I keep close track of forage production on my property	Regularly	Occasionally	Never
I keep close track of fuel load on my property	Regularly	Occasionally	Never
I keep close track of fuel moisture on my property	Regularly	Occasionally	Never

<u>PRESCRIBED BURNING</u>: This section is designed to obtain information about your attitudes and perspectives towards prescribed burning.

12. Please indicate to what extent you agree or disagree with the following statements. (<u>Circle only one number to the right of each statement</u>)

	Strongly Agree	Agree	Somewhat Agree	Neutral	Somewhat disagree	Disagree	Strongly Disagree
I consider the use of prescribed burning to be a beneficial tool for restoring rangelands.	1	2	3	4	5	6	7
I agree in principle with the idea of using prescribed burning on my land when needed.	1	2	3	4	5	6	7
I am in favor of applying prescribed burning on my land occasionally.	1	2	3	4	5	6	7
I am in favor of applying prescribed burning on my land whenever it is needed and there is sufficient fuel to burn.	1	2	3	4	5	6	7
I am in favor of applying prescribed burning on hot days (up to 100° F) when there is a lot of fuel and little wind.	1	2	3	4	5	6	7
I am against using prescribed burning as a management tool to control woody vegetation.	1	2	3	4	5	6	7
I am concerned that if I use prescribed burning it might negatively affect nearby urban areas.	1	2	3	4	5	6	7
I am concerned that if I use prescribed burning it might negatively affect nearby roadways.	1	2	3	4	5	6	7
I am concerned that if I use prescribed burning it might have negative effects on my neighbor's property.	1	2	3	4	5	6	7
I am concerned about using prescribed burning because I lack knowledge and/or experience about fire safety.	1	2	3	4	5	6	7
I am concerned about applying prescribed burning because of lack of labor and/or equipment needed.	1	2	3	4	5	6	7
Prescribed burning is easier to implement than other methods for controlling woody plant encroachment.	1	2	3	4	5	6	7
Prescribed burning is more effective than other methods for controlling woody plant encroachment.	1	2	3	4	5	6	7
Prescribed burning is less costly that other methods for controlling woody plant encroachment.	1	2	3	4	5	6	7
Prescribed burning has potentially greater risk than other woody plant control methods.	1	2	3	4	5	6	7
I feel the financial advantages of prescribed burning out-weigh the risk associated with it.	1	2	3	4	5	6	7
Local government officials in my area generally support the use of prescribed burning to restore rangelands.	1	2	3	4	5	6	7
I have designed my ranch management plan to include periodic application of prescribed burns.	1	2	3	4	5	6	7

13. **Based on your knowledge and/or experience, what season is best for burning in order to control woody vegetation?**

☐ Dry cool season ☐ Wet cool season ☐ Dry warm season ☐ Wet warm season

Please elaborate if you have any comments:

____

____

Current guidelines set forth by government agencies recommend against burning when air temperature is above 100° F, relative humidity is below 20%, and wind speed exceeds 20 miles per hour. Warm season prescribed burns are usually conducted under conditions close to these guidelines. Based on this, please answer question 14:

14. **Have you participated in any warm season prescribed burns?** ☐ Yes ☐ No

15. **Do you actively suppress the use of fire on your land?** ☐ Yes ☐ No

16. **Have you ever applied a prescribed burn on your land?** ☐ Yes ☐ No

If No, please explain why not and then SKIP TO NEXT PAGE.

____

____

17. **How many prescribed burns have been applied on your land over the last 5 years?**

____

18. **How many prescribed burns covering more than 10 acres have you participated in during the last 5 years on your property or somebody else's?**

________ Burns on my property
________ Burns on somebody else's property

19. **Did you have well defined objectives for burning your land?** ☐ Yes ☐ No

20. **On a scale of 0 to 100%, how well did you accomplish your objectives for the prescribed burns you conducted?**

______% Please elaborate if you have any comments:

____

____

21. Please indicate to what extent you agree or disagree with the following statements about the use of prescribed burning, including warm season prescribed burns, to restore rangelands. **(<u>Circle only one number to the right of each statement</u>)**

	Strongly Agree	Agree	Somewhat Agree	Neutral	Somewhat disagree	Disagree	Strongly Disagree
Most naturally ignited fires on rangelands in the Southern Great Plains occur during the summer months.	1	2	3	4	5	6	7
Warm season fires maintain the dominance of open grasslands and savannas.	1	2	3	4	5	6	7
Based on my knowledge and experience, warm season prescribed burns are favorable for my land.	1	2	3	4	5	6	7
I am in favor of burning using warm season prescribed burns as a land restoration tool.	1	2	3	4	5	6	7
I would be willing to apply warm season prescribed burns on my land if I was shown it benefited my land.	1	2	3	4	5	6	7
I am prepared to burn under whatever conditions are necessary to achieve my land management objectives.	1	2	3	4	5	6	7
If my land needs it, I will perform a prescribed warm season burn on my property.	1	2	3	4	5	6	7
I can perform a prescribed burn during a burn ban if a certified prescribed burn manager is in charge of the fire.	1	2	3	4	5	6	7
Affordable liability insurance is currently available for certified prescribed burn managers.	1	2	3	4	5	6	7
Certified prescribed burn managers must have liability insurance.	1	2	3	4	5	6	7
I would be willing to pay more in order to hire a certified prescribed burn manager.	1	2	3	4	5	6	7
Most of my neighbors whose opinion I value would support me if I decide to implement a warm season burn on my property.	1	2	3	4	5	6	7
My family and friends would support me if I decide to implement a warm season prescribed burn on my property.	1	2	3	4	5	6	7
I worry greatly about my neighbors implementing warm season prescribed burns.	1	2	3	4	5	6	7
I worry greatly about my neighbors implementing any type of prescribed burns including cool season burns.	1	2	3	4	5	6	7
The proximity of my property to urban areas keeps me from using prescribed burning.	1	2	3	4	5	6	7
The proximity of my property to major roadways keeps me from using prescribed burning.	1	2	3	4	5	6	7
The chance of attaining desired management objectives using warm season prescribed burns outweighs the risks.	1	2	3	4	5	6	7

PRESCRIBED BURN ASSOCIATIONS

This section is designed to obtain information about your perspectives regarding landowner associations that focus on prescribed burning in Texas.

22. Are you a member of a prescribed burn association? ☐ Yes ☐ No
If No, why not? ________________________________ please SKIP TO NEXT PAGE.

23. What is the name of your prescribed burn association? ________________________

24. How many years have you been a member? ______________Years

25. How many burn association meetings do you attend per year? ___________Meetings

26. Was there a written burn plan for the burns you participated in? ☐ Yes ☐ No

27. Was there a designated Certified Prescribed Burn Manager for the burns that you participated in? ☐ Yes ☐ No ☐ Don't know

28. Please indicate to what extent you agree or disagree with the following statements about burn associations. (Circle only one number to the right of each statement)

	Strongly Agree	Agree	Somewhat Agree	Neutral	Somewhat disagree	Disagree	Strongly Disagree
It is important for me to belong to a burn association.	1	2	3	4	5	6	7
I know most members of my burn association.	1	2	3	4	5	6	7
I consider many members of my association to be friends.	1	2	3	4	5	6	7
I socialize with members of my burn association.	1	2	3	4	5	6	7
I trust members of my burn association.	1	2	3	4	5	6	7
I would spend time helping non-kin association members.	1	2	3	4	5	6	7
I would loan equipment to non-kin association members.	1	2	3	4	5	6	7
Non-kin members would spend time helping me.	1	2	3	4	5	6	7
Non-kin association members would loan me equipment.	1	2	3	4	5	6	7
I care what other association members think I should do.	1	2	3	4	5	6	7
I have gotten my money's worth from participating in my prescribed burn association.	1	2	3	4	5	6	7
Being a member of a prescribed burn association will help me achieve my land management objectives.	1	2	3	4	5	6	7
If my association urged its members to adopt certain conservation practices, most would likely comply.	1	2	3	4	5	6	7
If my association urged members to follow specific burn guidelines, most would likely comply.	1	2	3	4	5	6	7
Prescribed burn association members may be able to burn during burn bans imposed by county commissioners.	1	2	3	4	5	6	7

COST-SHARING PROGRAMS

This section is designed to obtain information about your perspectives about existing cost-sharing programs, such as EQIP, or future programs that may be offered by federal, state, and/or local land management agencies. These questions do not imply any new programs and your response will not influence your opportunity to participate in such programs.

29. Have you participated at any time in any of the following federal or state funded cost-sharing land improvement programs? (Check all that apply in each row)

	Currently	In past	Never
Environmental Quality Incentives Program (EQIP)	☐	☐	☐
Conservation Reserve Program (CRP)	☐	☐	☐
Wildlife Habitat Incentives Program (WHIP)	☐	☐	☐
Wetland Reserve Program (WRP)	☐	☐	☐
Landowner Incentive Program (LIP)	☐	☐	☐
Other (Please describe) ____________________________	☐	☐	☐

30. If you have not participated in cost-sharing programs, please indicate why:

- ☐ I don't know about them
- ☐ I don't know how to apply
- ☐ I am not interested
- ☐ I am not qualified
- ☐ It is too difficult to enroll in them
- ☐ They are not sufficiently flexible for my land management needs
- ☐ Other (Please specify) ____

31. Please indicate to what extent you agree or disagree with the following statements about cost-sharing programs. (Circle one number to the right of each statement).

	Strongly Agree	Agree	Somewhat Agree	Neutral	Somewhat disagree	Disagree	Strongly Disagree
Participation in a cost-sharing program would benefit my land.	1	2	3	4	5	6	7
Participation in a cost-sharing program would help me apply management actions I could not otherwise apply.	1	2	3	4	5	6	7
Participation in a cost-sharing program will make it easier for public agencies to regulate activities on my land.	1	2	3	4	5	6	7
If available, I plan to participate in a cost-sharing program to implement management actions on my land.	1	2	3	4	5	6	7
My family and friends would approve of my participation in a cost-sharing program.	1	2	3	4	5	6	7
Most of my neighbors whose opinion I value would approve of my participation in a cost-sharing program.	1	2	3	4	5	6	7

PERSONAL CHARACTERISTICS

To understand differences among landowners regarding their interest and concerns about prescribed burning and cost-sharing programs, we ask you to provide some information about yourself. YOUR RESPONSES WILL BE KEPT STRICTLY CONFIDENTIAL.

32. In which year were you born? ________________

33. Gender: ☐ Male ☐ Female

34. How many years of formal education have you had? ____________ years

35. How many years of farming/ranching experience do you have? ____________ years

36. How many years have you or your family owned the property? ____________ years

37. Do you plan to sell you property in the next five years? ☐ Yes ☐ No

38. Do you live on your property for which you provided answers? ☐ Yes ☐ No

If Yes, how many years you have lived on a ranch? ____________ years

If No, about how far by road do you live from your property? _____________miles

If No, do you live in: ☐ a rural area in Texas ☐ an urban area in Texas ☐ out of Texas

39. About how much money did you invest in land improvements on your property during the last five years? $_______________

40. About what percentage of your total annual income in 2007 was derived from your rural property? ______________ %

41. Please check the category that best describes your total household income in 2007. We remind you that your identity will remain anonymous and your answers are confidential.

☐ Less than $25,000
☐ $25,000 - $50,000
☐ $50,001 - $75,000
☐ $75,001 - $100,000
☐ $100,001 - $500,000
☐ Greater than $500,000

42. Please indicate to what extent you agree or disagree with the following statements about personal characteristics that can affect land management and willingness to use assistance from state and federal agencies to improve the condition of Texas rangelands. (<u>Circle only one number to the right of each statement</u>)

	Strongly Agree	Agree	Somewhat Agree	Neutral	Somewhat disagree	Disagree	Strongly Disagree
Off-ranch activities and/or employment limit my time to make land improvements.	1	2	3	4	5	6	7
I am unable to make as many land improvements on my property as I would like because of financial constrains.	1	2	3	4	5	6	7
I consider myself to be an experienced land manager.	1	2	3	4	5	6	7
I consider myself to be a risk taker.	1	2	3	4	5	6	7
I consider my land to be in excellent condition.	1	2	3	4	5	6	7
The watershed in which my land is located is in excellent condition.	1	2	3	4	5	6	7
I trust the County Extension Office personnel operating in my area.	1	2	3	4	5	6	7
I trust the Texas Parks and Wildlife personnel operating in my area.	1	2	3	4	5	6	7
I trust the NRCS* personnel (i.e. Range conservationist) operating in my area.	1	2	3	4	5	6	7
I trust the USFWS* personnel operating in my area.	1	2	3	4	5	6	7

*NRCS - Natural Resources Conservation Service; USFWS - U.S. Fish and Wildlife Service

On the back cover, please write any other comments or suggestions that can help us better understand your perception about the use of prescribed burning as a rangeland management tool or other factors related to prescribed burning that affect your ranching or farming operation.

Your participation is greatly appreciated. Please send the questionnaire back to us in the enclosed postage-paid envelope.

Thank You!

Appendix C: Non-response Bias Survey Cover Letter and Survey Instrument

AgriLIFE RESEARCH & EXTENSION
Texas A&M System

TEXAS A&M UNIVERSITY

COLLEGE OF AGRICULTURE AND LIFE SCIENCES

DEPARTMENT OF ECOSYSTEM SCIENCE AND MANAGEMENT

March 26, 2009

Dear Landowner,

On July 2008 we sent a survey aimed at gaining a better understanding of landowner perspectives regarding the use of prescribed fire to restore rangelands and the role that Landowner Associations might play in helping them apply fire on their land. This survey was being conducted by the Department of Ecosystem Science & Management at Texas A&M University. Results from the study will be used to make recommendations for policy changes regarding prescribed fire.

We did not receive a completed questionnaire back from you during the initial mailing period and **we would really like to hear back from you**. For the survey results to allow us to make meaningful policy recommendations that benefit landowners, we need to hear back from everyone included in the survey.

We ask that you complete the attached **short questionnaire** as soon as possible and return it to us in the attached postage paid return envelope. The questionnaire should take less than 5 minutes to complete and your responses will be kept confidential.

If you have any questions or comments, please feel free to contact me by telephone (979-845-5583) or e-mail (urs@tamu.edu). Thank you in advance for your help!

Sincerely,

Urs P. Kreuter

Urs P. Kreuter
Associate Professor, Texas A&M University

This study has been reviewed and approved by the Institutional Review Board-Human Subjects in Research, Texas A&M University. For research related problems or questions regarding 'subject' rights, contact the Institutional Review Board through Melissa McIlhaney, Human Subjects Protection Program Coordinator, Office of Research Compliance at 979-458-4067.

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March 2009

Texas A&M University, Department of Ecosystem Science & Management

The Role and Application of Prescribed Burning in Texas

We are asking that this questionnaire be completed by the person who is currently most involved in making decisions about land management on the property.

YOUR RESPONSES WILL BE KEPT STRICTLY CONFIDENTIAL.

1. **In which year were you born?** ________________

2. **Gender:** ☐ Male ☐ Female

3. **How many years of formal education have you had?** ____________ years

4. **How many years of farming/ranching experience do you have?** ____________ years

5. **Do you live on a ranch?** ☐ Yes, I have lived on a ranch for ______ years ☐ No

6. **Do you live in:** ☐ a rural area in Texas ☐ an urban area in Texas ☐ out of Texas

7. **Please indicate to what extent you agree or disagree with the following statements. (<u>Circle only one number to the right of each statement</u>)**

	Strongly Agree	Agree	Somewhat Agree	Neutral	Somewhat disagree	Disagree	Strongly Disagree
I consider the use of prescribed burning to be a beneficial tool for restoring rangelands.	1	2	3	4	5	6	7
I am against using prescribed burning as a management tool to control woody vegetation.	1	2	3	4	5	6	7

8. **In order to assess the broader impact of this survey, please let us know why you did not respond. Check all that apply.**

☐ I did not receive the survey
☐ I did not believe the survey was really anonymous
☐ The survey did not pertain to me
☐ Lack of time
☐ Survey was too long
☐ I chose not to participate.
☐ Other ____

On the back cover, please write any other comments or suggestions that you think can help us in future surveys.

Your participation is greatly appreciated. Please send the questionnaire back to us in the enclosed postage-paid envelope.

Appendix D: Bivariate correlation and regression analysis tables discussed in page 38.

Table 37. Correlations table measuring the strength of the relationships between attitudes towards prescribed fires and personal/property characteristics (age, years experience, education, acres owned).

		Age	Acres owned or managed	How many years of farming/ranching experience do you have?	How many years of formal education have you had?
PCA Q12: In favor of burning	Pearson Correlation	-.105*	.118**	.007	.013
	Sig. (2-tailed)	.019	.007	.872	.772
PCA Q 21: In favor of hot burns	Pearson Correlation	-.141**	.241**	.083	-.009
	Sig. (2-tailed)	.002	.000	.081	.839

*Significant at $P < 0.05$; ** Significant at $P < 0.01$

Table 38. Correlations table measuring the strength of the relationships between years of experience and perceptions on ecological role of summer fire.

		Age	How many years farming/ranching experience do you have?	PCA Q12: In favor of burning	PCA Q 21: In favor of hot burns
PCA Q 21: Ecological role of summer fires	Pearson Correlation	.089	.172**	.146**	.000
	Sig. (2-tailed)	.057	.000	.002	1.000

*Significant at alpha 0.05; ** Significant at alpha 0.01

Table 39. Correlations table measuring the strength of the relationships between attitude towards prescribed fire and perception that fire is good based on knowledge and experience.

		Based on my knowledge and experience, warm season prescribed burns are favorable for my land.
PCA Q12: In favor of burning	Pearson Correlation	.339**
	Sig. (2-tailed)	.000

*Significant at alpha 0.05; ** Significant at alpha 0.01

Table 40. Correlation table measuring the strength of the relationships between years of farming/ranching experience (Q. 35) and perceived land condition (question 42e).

		I consider my land to be in excellent condition.
How many years of farming/ranching experience do you have?	Pearson Correlation	.126**
	Sig. (2-tailed)	.004

*Significant at alpha 0.05; ** Significant at alpha 0.01

Table 41. Correlation to tables measuring the strength of the relationship between distance from urban area/road and the perception that distance to urban or roadways keeps landowner from burning (Q. 21p and 21q) and.

		The proximity of my property to urban areas keeps me from using prescribed burning.	The proximity of my property to major roads keeps me from using prescribed burning.
Distance (miles) from urban areas	Pearson Correlation	-.115**	-.110*
	Sig. (2-tailed)	.008	.011
Distance (miles) from highway	Pearson Correlation	-.036	-.107*
	Sig. (2-tailed)	.414	.014

*Significant at alpha 0.05; ** Significant at alpha 0.01

Table 42. Correlations table measuring the strength of the relationships between land condition (question 42e) and financial constraints (question 42b).

		I consider my land to be in excellent condition.
I am unable to make as many land improvements on my property as I would like because of financial constrains.	Pearson Correlation	-.150**
	Sig. (2-tailed)	.000

*Significant at alpha 0.05; ** Significant at alpha 0.01

Table 43. Land condition (42e) vs time constraints 42A

		I consider my land to be in excellent condition.
Off-ranch activities and/or employment limit my time to make land improvements.	Pearson Correlation	-.068
	Sig. (2-tailed)	.112

*Significant at alpha 0.05; ** Significant at alpha 0.01

Table 44. Regression to test whether there was an effect between increasing brush cover (question 9) and willingness to burn (question 21e). Willingness to apply burn on my land was treated as the dependent variable and percent acres invaded by brush as the independent variable.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.047[a]	.002	.000	1.683

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3.233	1	3.233	1.142	.286[a]
	Residual	1489.010	526	2.831		
	Total	1492.242	527			

Table 45. Binary logistic regression results for whether landowner has suppressed fire or not as the bivariate dependent (question 15) and percent of land encroached by brush (question 9).

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	682.584[a]	.000	.000

Table 46. Binary logistic regression results for whether landowner has suppressed fire or not as the bivariate dependent (question 15) and distance in miles from urban area or roadway.

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	686.962[a]	.004	.005

Table 47. Binary logistic regression results for whether landowner is an urban dwellers or a ranchers as the bivariate dependent, and attitude towards hot prescribed fires PCA component.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.062[a]	.004	.002	4.943

Table 48. Binary logistic regression results for whether landowner is a member of a PBA as the bivariate dependent, and landowners perceived land condition (question 42e).

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	579.310[a]	.000	.000

Table 49. Binary logistic regression results for whether landowner suppresses fire or not as the bivariate dependent, and attitude towards prescribed fire.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.339[a]	.115	.113	1.571

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	158.628	1	158.628	64.248	.000[a]
	Residual	1224.617	496	2.469		
	Total	1383.245	497			

Objective 4 - Systems modeling:

Final Report **August 2010**

TEXFIRE: A SIMULATION MODEL FOR LONG-TERM STOCHASTIC SIMULATION OF GRASSLAND, SHRUBLAND, AND SAVANNA VEGETATION DYNAMICS UNDER DIFFERENT MANAGEMENT SCENARIOS

Introduction

The ecoregions studied in this project have generally increased in shrub canopy cover during the last century. As a result, quality of grazing pastures as well as wildlife habitat has declined. Systems exhibiting severe brush encroachment will only continue to get worst and past a certain point will become harder to revert back to historic grassland conditions. By implementing brush management practices such as reintroducing historical fire patterns, we can revert the system back to grassland state and maintain it that way with little restoration effort as long as follow-up treatments or historic fire regimes can be maintained.

Our model simulates tree, shrub, grass and forb dynamics and their interactions for a specific ecological site. The model takes into account different management scenarios including impact of livestock and wildlife as well as accounts for different brush management strategies including prescribed fire, chemical, mechanical, and a mix of chemical and fire treatments. These treatments are affected by the amount of plant material to be treated, physical and biological factors, and fire intensity. The model serves as a tool for landowners to determine if extreme prescribed fire can be an ecologically feasible land management practice that can be realistically applied to their land.

TEXFIRE was developed using the STELLA® 9.0 software from ISEE System® (Lebanon, NH, USA). The model has been represented as a compartment model based of difference equations with a time step of 1 month. Parameterization and evaluation of the model were based upon data from peer reviewed literature, existing models, Ecological Site Descriptions (ESD), and field experiments that are being performed as part of this project. Each month, new cohorts of trees and shrubs are established by seed, and existing cohorts progress through different size classes, with growth rates controlled by environmental factors. Herbaceous vegetation growth occurs based on growth curves taken from models created by Teague et al. (2008), Glasscock et al. (2005), and stochastic rainfall and temperature patterns based on historic data. By simulating stochastic weather patterns we introduce uncertainties that will lead to different results and a confidence band that may aid the process of decision making.

Density of trees and shrubs affect themselves through intra-specific density dependent competition and together with cacti cover also have an effect on herbaceous biomass growth because of increased canopy cover that reduces availability of resources to understory vegetation (solar radiation, water uptake, nutrient uptake, etc.) are all implicit in the intra-specific density dependent competition variable).

Model structure

The model represents the density and canopy diameter of trees and subsequent growth through five size classes (Fuhlendorf et al. 1996). Density and canopy diameter of shrubs is simulated for three size classes. Growth progression for trees and shrubs was simulated using cohorts of individuals. Cohorts were used in order to simulate treatment effects on different size classes. In this model a cohort is defined as a group of individuals characterized by having similar ages. Based on these ages, similar physical characteristics are assumed. To model different age classes, a cohort chain was used (Deaton and Winebrake 2000). A cohort chain (Fig. 1) allows us to simulate multiple attributes (density, canopy diameter, canopy cover) of successive age classes of trees and shrubs (Tixier et al. 2004).
Cactus growth in percent aerial cover was simulated using the model from Teague el al. (2008). According to Teague et al. (2008) cacti physically exclude herbaceous plants from growing in the same area where they are growing so the best way to simulate their effects on herbaceous growth is by subtracting the area occupied by cactus from the area available for herbaceous plants. Loss of tree and shrub density occurs by burning, chemical treatments, or mechanical treatments and loss of tree and shrub canopy diameter occur by canopy scorch due to fire, herbicide defoliation, and browsing.

TEXFIRE grass and forb growth have been simulated following Glasscock et al. (2005). The Glasscock et al. (2005) model simulates plant growth, senescence, death, and decomposition of different herbaceous plant communities (Fig.2). Cool and warm season herbaceous plants are modeled separately based of photosynthetic pathways (C_3 and C_4). Herbaceous plant net primary productivity depends on precipitation, maximum growth rate, and percent canopy cover of woody plants. Loss of herbaceous biomass occurs by burning, grazing and senescence.

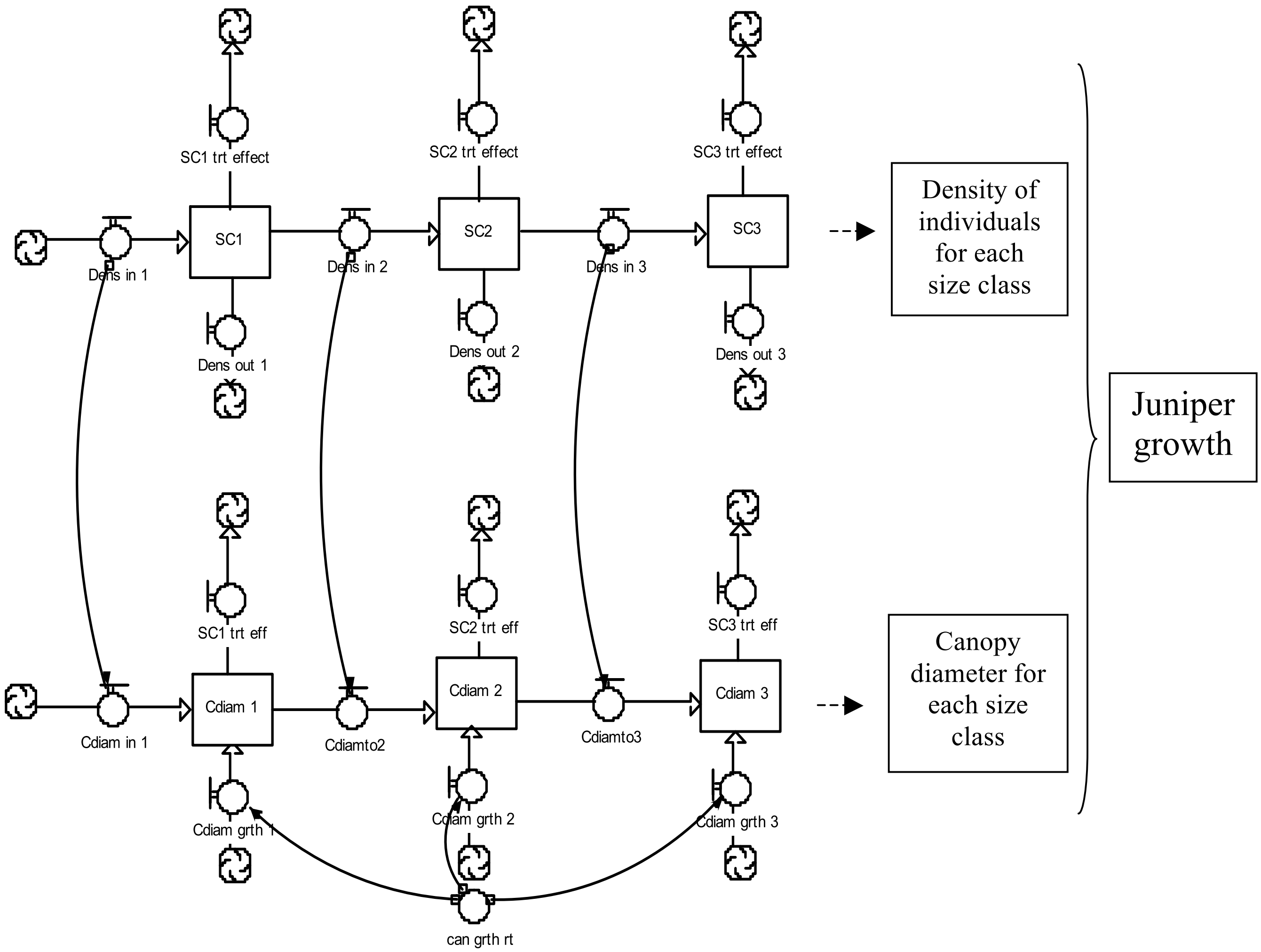

Figure 1. Cohort structure of TEXFIRE (Descriptions of abbreviations are presented in Table 1).

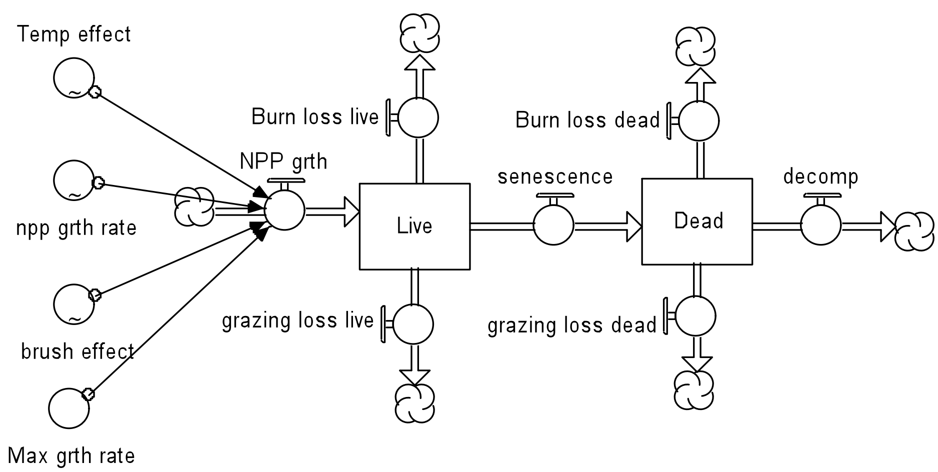

Figure 2. Conceptual diagram of the model structure used in TEXFIRE for herbaceous growth (Descriptions of abbreviations are presented in Table 1).

Submodel structure

TEXFIRE is structured in two linked chains of cohorts that represent the density and canopy diameter of juniper and mesquite. Other submodels include a prickly pear submodel and herbaceous growth models based on photosynthetic pathways. The inputs in the model are density of the different juniper and mesquite size classes, initial cactus biomass and initial C_3 and C_4 biomass for forbs and grasses. Outputs include the canopy cover of Juniper, Mesquite, and Prickly pear and the biomass of forbs and grasses for each time step.

<u>Herbaceous submodel</u>: Changes in herbaceous biomass for C_3 and C_4 grasses and forbs follow the Glasscock et al (2005) model. In this model, changes for each of these four vegetation types are represented by figure 3. In the herbaceous submodel, LH is live herbaceous, *npp* is the net primary productivity inflow which is affected by percent canopy cover of woody species and Prickly pear cactus, *gll* is loss of live biomass due to livestock, *glw* loss of biomass due to wildlife, *pbl* is the loss of biomass from prescribed burning, *sen* is the loss of biomass from senescence, and Δt is one month (Glasscock et al. 2005).

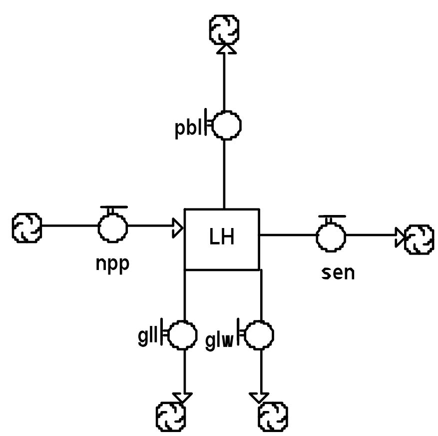

Figure 3. Live herbaceous vegetation dynamics.

<u>Cactus submodel</u>: Cactus growth and mortality due to fire follows Teague et al. (2008) in this model. Percent aerial cover of cactus grows monthly-based figure 4 using a cactus growth index. This model simulates the effect of prickly pear cacti on herbaceous production by subtracting the area occupied by prickly pear from the area available for grasses and forbs.

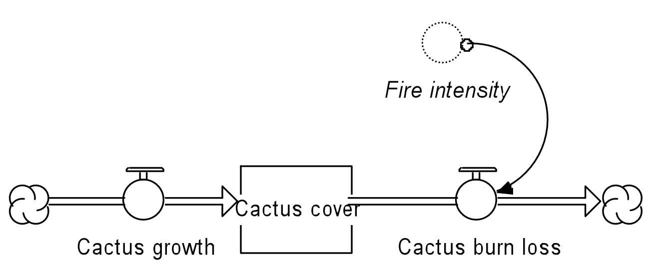

Figure 4. Cactus growth and burn loss based on fire intensity.

Juniper submodel (Figure 1): Previous research on Ashe Juniper separated the trees into size classes. According to this, trees remain in size classes 1-3 for 10 years each, and in size class 4 for 25 years, before accumulating in size class 5 as mature trees (Fuhlendorf et al.1996). In the juniper density by size class cohort, trees move at each monthly time step from one state variable to the next representing aging in months. Growth from one size class to the next occurs when a cohort of Juniper trees reaches the maximum age in months for its current size class. Loss of Juniper density in the model occurs by four methods: mechanical treatment, chemical treatments and/or prescribed burning at different intensities, or intraspecific competition. In the juniper canopy diameter growth cohort, the pool of the cohort grows at each time step if tree density is greater than 0. Loss of Juniper canopy cover in the model occurs by three methods: Scorch due to prescribed burning at different intensities, browsing by livestock and wildlife, or defoliation due to herbicides. Additional field data are required to address the treatment effects.

Mesquite submodel: The Mesquite submodel follows the age cohort structure of the juniper submodel. Treatment and browsing effects in the Mesquite model are also represented as in the Juniper model but parameterized to reflect growth, mortality and palatability differences.

Management Strategies

To simulate different management scenarios, data from the other project components were used to create criteria for applying prescribed fire based on landowner characteristics (Table 2):

- Burning Optimist: Plans for extreme prescribed burning whenever possible. Follow up treatments for optimal management.
- "Safe" Burner: Burns during dormant season only (avoids conditions for extreme prescribed fire: Summer, dry weather, high herbaceous fuel load, etc.),
- Fire Aversion: Does not use prescribed fire at any time. Uses ONLY chemical and mechanical alternative management strategies.

Situations to Test within each Management Strategy

- Stocking Rate: From low to high to determine optimal rate, or rate above which system is unsustainable (unburnable) or unprofitable.
- Initial Brush Conditions: From low to high. Especially the high condition to determine most effective pre-treatment options to prepare landscape for prescribed burning.

All treatment effects are controlled by a decision making tree in which a landowner inputs the desired maximum woody cover and whether or not he/she wishes to apply fire or other treatments. Mechanical and chemical treatment effects depend on having enough woody cover to need them and whether a landowner wishes to apply them. Effectiveness (brush reduction in individuals/ha or in m^2 of canopy) of fire treatments depends on fire intensity which depends on amount of herbaceous biomass and season of occurrence (Fuhlendorf et al. 1996), and on landowner willingness to burn at higher intensities. The main output of TEXFIRE are the vegetation dynamics through time based on different brush treatment scenarios (Fig 3).

Table 1. Description of variables used in Figures 1 and 2*.

Abbreviation	Variable description (units of measure)
Driving Variables	
Can grth rt	Canopy growth rate (m^2/month)
npp grth rate	Net primary productivity rate (kg/hect/month)
Temp effect	Temperature effect (Percent change in NPP)
Constants	
Max grth rate	Maximum growth rate (kg/hect/month)
State Variables	
Sc_i	Size Class (number of individuals/hect)
Live	Live tree (kg/hect)
Dead	Dead tree (kg/hect)
$Cdiam_i$	Canopy diameter of size class i (m^2)
Material Transfers	
SC_i trt effects	Treatment effects on density based on size class
Sc_i trt eff	Treatment effects on canopy diameter based on size class
decomp	Decomposition rate
Burn loss dead	Amount of dead plant matter burnt
Burn loss live	Amount of live plant matter burnt
grazing loss live	Amount of live plant matter grazed
senescence	Senescence
NPP grth	Net primary productivity growth
Dens in i	Density flowing into the system fro size class i
Cdiam in i	Canopy diameter flowing into the system for size class i
Cdiam grth i	Canopy diameter growth for size class i
Dense out i	Number of trees of size class i leaving the system
Auxiliary Variables	
Brush effect	Effects of woody material on herbaceous growth

Table 2. Landowner management strategies, environmental variables and fuel characteristics that determine whether a landowner will burn or not.

Landowner Management Strategies / Environmental Variables	Fine Fuel	Fuel Moist	Wind Speed (MPH)	Temp. (°F)	Burn?	Risk	Ecological risk if no alternate treatment implemented
Burning Optimist A	little	Low	>20	>100	Burn	High	Low
Burning Optimist B	little	High	>20	>100	Burn	Mod-High	Low
Burning Optimist C	lots	Low	>20	>100	Burn	High	Low
Burning Optimist D	lots	High	>20	>100	Burn	High	Low
Safe Burner A	little	Low	5<x<20	70<x<100	Burn	Moderate	Moderate
Safe Burner B	little	High	5<x<20	70<x<100	Burn	Low	Moderate
Safe Burner C	lots	Low	5<x<20	70<x<100	No Burn	None	High
Safe Burner D	lots	High	5<x<20	70<x<100	Burn	Moderate	Moderate
Safe Burner E	N/A	N/A	>20	>100	No Burn	None	High
Fire Averse	N/A	N/A	N/A	N/A	No Burn	None	High

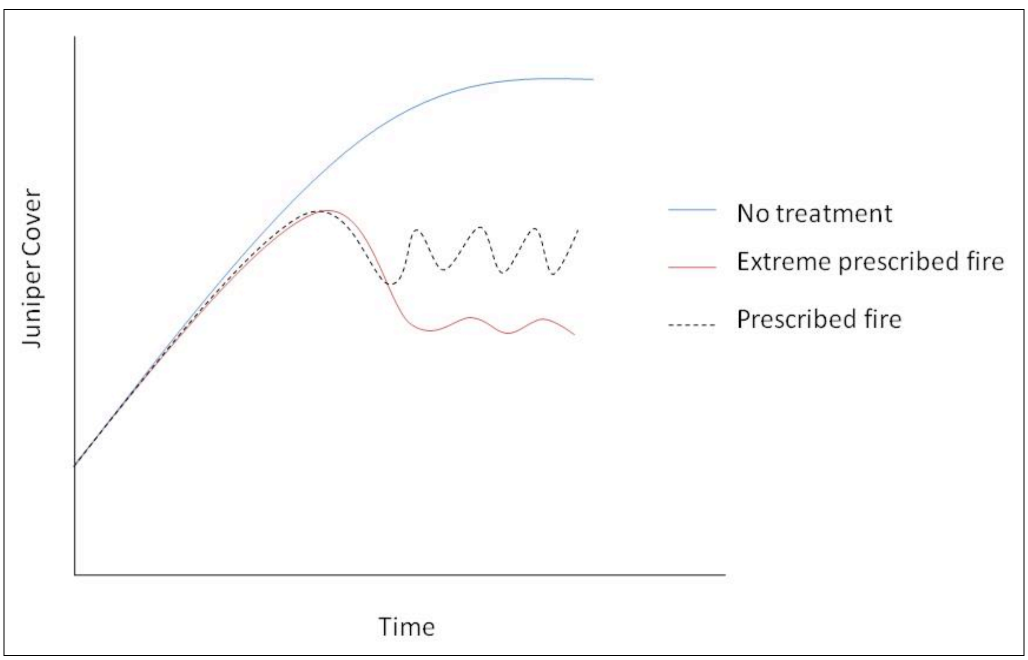

Figure 3. Hypothetical Graph of Juniper cover dynamics modeled through time with the inclusion of fire treatment scenarios.

Current Model Limitations

A delay in fire treatment applications has also delayed data required to parameterize certain portions of the model. Treatment effects of the model have not been properly parameterized to date. Once we can parameterize the model, we will still have to validate it before it can be used as a land management tool.

Future Work

STELLA® 9.0 software is not object based which limits our tree and shrub submodels. We are beginning to explore the use Visual Basic software to model tree and shrub attributes. This alternate approach will also allow us to add a spatial component to modeling the dynamics represented in TEXFIRE.

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