ECONOMIC FEASIBILITY AND RISK OF USING PRESCRIBED EXTREME FIRE AS AN INVASIVE BRUSH MANAGEMENT TOOL IN TEXAS

A Thesis

by

DUSTIN BRUCE VAN LIEW

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2007

Major Subject: Agricultural Economics

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Approved by:

Chair of Committee,	J. Richard Conner
Committee Members,	Urs P. Kreuter
	David Anderson
Head of Department,	John P. Nichols

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ABSTRACT

Economic Feasibility and Risk of Using Prescribed Extreme Fire

as an Invasive Brush Management Tool in Texas. (August 2007)

Dustin Bruce Van Liew, B.S., California Polytechnic State University

Chair of Advisory Committee: Dr. J. Richard Conner

This component of the Conservation Innovation Grants Summer Burning project evaluates the economic feasibility of using prescribed fire that exceeds the current Natural Resource Conservation Service (NRCS) technical standards as a rangeland restoration practice on privately owned land in Texas. This study has four objectives: (1) Evaluate the economic effectiveness of using prescribed extreme burns as a rangeland restoration tool compared to other rangeland restoration strategies. (2) Provide economic research results that will facilitate a review of the technical standards, specification, and potential policy changes by the NRCS with respect to the use of prescribed extreme burning. (3) Assess economic effects of extreme fire when used in combination with other treatment practices over a 20 year planning horizon. (4) Through modeling, forecasting, and simulation assess the risk associated with the use of extreme prescribed fire, with respect to weather (rainfall) conditions. The research covers four contiguous counties in each of three eco-regions in Texas: Rolling Plains, Edwards Plateau, and the South Texas Plains. Focus group meetings with landowners and NRCS/Extension personnel were held in each region to obtain preliminary information including common rangeland uses, most problematic invasive brush species, and the

most commonly used treatment methods and associated costs. The primary invasive species in each region include: Rolling Plains – Prickly Pear (*Opuntia phaecantha*); Edwards Plateau – Redberry and Ashe Juniper (*Juniperus ashei* Buchh. And *J. pinchotii* Sudw., respectively); South Texas Plains – Huisache (*Acacia smallii* Isely). Mesquite (*Prosopis glandulsa* Torr.) was identified as a common invasive brush species across all three regions.

When extreme fire was compared to the most commonly used invasive brush treatments, assuming the treatment was instituted in year one, it was economically superior in all cases and feasible (Net Present Value > 0 and Benefit/Cost Ratio >1) in all but two cases. The inclusion of forecasted rainfall figures with the combination of using the most commonly used brush treatment with extreme fire proved to substantially reduce the risk of instituting the treatment regimes. The probability distribution of NPVs was significantly smaller when treatment practices were spread over ten years and parcels than when treatment was restricted to the first year and whole ranch.

DEDICATION

The time, effort, and ability to complete this study and the opportunity to pursue a master's degree at Texas A&M University have been contributions from our creator and Lord Jesus Christ; without him none of which would have been possible. This work is also dedicated to my parents, Dana and Jan Van Liew whose support is unwavering and eternal. To my grandparents, Gene and Elanora Davis, whose work ethic and conservative values contributed to my desire to pursue this achievement and Vernon and Lavonda Van Liew, whose sense of country gave me reason to be thankful for the opportunity afforded us in our great nation. Finally, to my sister, Jill Van Liew, who is always supportive of my decisions.

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To the landowners and NRCS representative who graciously took time from their busy schedules' to meet with our group and provide vital information for the study, thank you. Dr. Richard Teague, Dr. Lynn Drawe, Dr. Wayne Hanselka, and Dr. Charles (Butch) Taylor (the pioneer of extreme fire in Texas), thank you for the expertise provided in contribution to this study.

Finally, thank you to everyone in the Agricultural Economics Department at Texas A&M for their support and friendship while completing this thesis. I have been blessed with friendship of fellow aggies in the graduate program, specifically Amanda Leister, Brandon Leister, Crystelle Miller, Chris Elrod, Hart Bise, Crystal Mathews, and Lindsay Higgins and for that I am thankful. To my non-Aggie friends, thanks for being at the other end of my phone calls and to Forrest Mangan who is a great friend.

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CHAPTER I

INTRODUCTION

Over the last two centuries, rangeland in Texas, from the Rolling Plains in the north to the South Texas Plains, has been transformed; what was once pristine grassland savanna to mixed brush prairies by invasive brush species (Hamilton et al. 2004). Historically, the principle source of income from rangeland has been domestic grazing livestock and, in more recent times, wildlife lease-hunting. Thus, in order for the landowners or range managers to directly benefit from the land, the rangeland must support both livestock production and wildlife habitat. The presence of invasive brush can drastically reduce the carrying capacity (head of livestock per acre) of rangeland by diminishing the amount of forage for grazing livestock. Likewise, dense stands of brush in excess of that needed for browse and screening cover are detrimental to wildlife habitat.

Over the past century, many methods of managing invasive brush on Texas rangelands have been developed. In general, the methods can be classified as mechanical, chemical, biological and prescribed fire. Many of these practices are expensive and landowners operating with small margins are hard pressed to afford them. Rates of return on investments in the brush management practices vary widely; thus when landowners are operating with small margins it is imperative they use the most effective and efficient treatment option in terms of plant mortality and enterprise revenue.

This thesis follows the style of the *American Journal of Agricultural Economics.*

Prescribed fire is used to mimic historical fire regimes to manage brush on grassland and savanna rangeland (Scifres and Hamilton 1993). The practice has been used for decades. However, only in the recent past has the treatment been used in extreme weather conditions, and this study compares the economic returns of extreme fire with other commonly used range management practices. Current NRCS guidelines define extreme fire as burning that takes place when: temperature exceeds 95 degrees Fahrenheit, relative humidity is less than 20 percent, wind speed is greater than 15 miles per hour, and less than 6 percent fuel moisture. Benefit Cost (B/C) analysis and Net Present Value (NPV) can be used by landowners to show which treatment investments are the preferred method for the brush species they are managing.

Investment in brush management practices can be costly. In addition exogenous variables such as weather can impact what treatments are available to the landowner. The variability in rainfall alone can dictate whether the right conditions will be present for an extreme fire; therefore, it is usually a combination of the available management practices over an extended period that offers the desired results. This paper will compare the associated costs, returns, and risk of common brush management practices with extreme fire.

Problem Statement

The goal is to assess the economic feasibility of restoring rangeland health in the Southern Plains, in Texas using extreme prescribed fires compared to the other most commonly used brush treatment methods. In addition, OLS regression and stochastic simulation are used to assess the efficiency of including extreme fire in a brush treatment regime. The results will facilitate a review of current NRCS technical standards with regard to prescribed extreme fire. Current standards seem arbitrary and could be restricting landowners from using extreme burns to manage their land.

The hypothesis to be tested in this study is that extreme fire is economically superior to other commonly used brush management practices. This hypothesis does not infer that alternatives are not effective brush treatments, but that extreme fire will provide comparable, or superior, vegetative results at lower total cost. It is also important to note that like most other mechanical or chemical brush management practices, extreme fire is often most effective when combined with follow-up management practices, usually over a multi-year period. The objectives are designed to accomplish an economic analysis that maximizes the benefit of the study for the NRCS, and private landowners.

Objectives

1. Evaluate the economic effectiveness of using prescribed extreme burns as a rangeland restoration tool compared to other rangeland restoration strategies: Herbicide, mechanical and cool season fire.
2. Provide economic research results that will either support or discourage revisions of the technical standards, specifications and potential policy changes by the NRCS with respect to the use of prescribed extreme burning.
3. Use response curve analysis, cost benefit analysis and NPV, provided via the software program Grazing Systems Analysis Tool (GSAT) to assess the

economic effects of extreme fire when used in combination with other brush management practices over a 20 year planning horizon.

4. Through modeling, forecasting and simulation with the software program Simulation Econometrics to Analyze Risk (SIMITAR), assess the risk associated with the use of extreme fire as a tool to manage brush, with respect to weather (rainfall) conditions.

Structure of Remaining Chapters

The rest of the thesis is divided into four chapters. Chapter II is a review of relevant literature. The comparative economic analysis and mesquite sensitivity analysis are described in Chapter III. Chapter IV consists of risk analysis with regard to weather, through the use of stochastic modeling. Finally summarization and discussion will take place in Chapter V.

CHAPTER II

REVIEW OF LITERATURE

In the last 100 to 200 years Texas rangeland has changed from open savannas and grasslands to land with vast areas of woody plant cover. This transition of Texas rangeland was mostly due to overgrazing and suppression of wildfire by European settlers over the last two centuries (Hamilton et al. 2004). Brush management on Texas rangeland is one of the most important issues facing rangeland owners in the state. The woody species of Honey Mesquite (*Prosopis glandulsa* Torr.), Huisache (*Acacia smallii* Isely), Redberry Juniper (*Juniperus pinchotii* Sudw.), and Ashe Juniper (*Juniperus ashei* Buchh.), along with the cactus species Brownspine Prickly Pear (*Opuntia phaecantha*), are particularly problematic for landowners in the regions of this study. These species have converted certain regions of Texas rangeland from savanna and grassland steady states to brush-dominated woodland steady states (Archer 1989). There are many reasons for brush control; livestock production, water yield, wildlife habitat, carbon sequestration, and overall aesthetic value are a few (Hamilton et al. 2004). The four most commonly used brush management methods are mechanical, chemical, biological, and prescribed fire.

Economics of Brush Management

Economic benefits from brush control are based on an increase of the NPV and rate of return though an increased carrying capacity for livestock production and or wildlife enterprises (Hamilton et al. 2004). This method assumes that ranchers will adjust their herd sizes to realize the benefit from the improved forage production resulting from the brush control (Bach and Conner 1998). Another potential benefit of brush control that is not normally realized by the rancher is off-site water yield. The greatest potential for increasing water yield seems to be on Juniper dominated rangelands due to the high interception of moisture and the shallow, permeable soil and parent material where Juniper is usually found. Mesquite dominated uplands show little potential for increased water yield with brush control due to factors such as deep soil, and vigorous re-growth following eradication (Wilcox 2002). The use of brush control to increase off-site water yield is one practice that the government will consider when providing EQIP funds (Bach and Conner 1998). Currently the accepted methodology for measuring the benefits of implementing a brush management practice is through the use of estimated response curves, which show the increase in forage due to brush control and the effective life of the treatment (Hamilton et al. 2004). The use of NPV is considered superior to other ways of measuring economic gains from range improvement practices because it takes into account the time value of money.

The implementation of alternate methods of brush control offer different costs and benefits depending on many variables. Scifres and Hamilton (1993) state, “The relatively low cost for installation, compared to other range improvement practices, is one of the most attractive features of prescribed burning.” Generally the highest costs associated with prescribed burning are the planning and preparation costs. This includes the time and the training by the burn manager, and is typically greater for the initial burn when compared to maintenance burns (Scifres and Hamilton 1993). In addition, deferring grazing from land prior to prescribed fire can be costly. Currently the prescribed Burn Board of the Texas Department of Agriculture requires a minimum of one million dollars of liability insurance for hired burn managers when executing a prescribed burn (Sec. 153.082). Costs can increase further if insurance companies see summer fire as a higher risk practice they might charge more for coverage.

Invasive Brush Species in Texas

In the Southwest U.S.A., honey mesquite is pervasive over much of the rangeland; this is especially true in the North Texas Rolling Plains. Prickly pear in the Rolling Plains and huisache in the Southern Plains have become the target species for range managers to treat. Ashe juniper and redberry juniper are the most problematic invasive native species in the Edwards Plateau area of Texas (Ansley and Rasmussen 2005). These three regions of Texas rangeland have decreased carrying capacity for livestock production and in some cases have reduced wildlife enterprise income and water yield due to the proliferation of brush.

Rolling Plains

In the case of treating mesquite in north Texas, Teague et al. (2001) said, “There is an economic advantage to using fire wherever possible and restricting use of herbicides to those instances that fire is not a viable option.” Though not proven to be economically comparable to prescribe fire, herbicide treatment of mesquite is another effective treatment method. According to Teague, the cost of herbicide treatment would have to be less than half of what it is before it would be economically competitive with the use of prescribed fire. In a study by Whitson and Scifres (1981), the use of aerial applied

2,4,5-T for dense mesquite treatment in deep soils was economically feasible when compared to mechanical treatment options. In more recent years, chemical and mechanical treatments for mesquite have decreased due to increased costs and environmental concerns (Ansley and Jacoby 1998). This means more economically feasible treatment options are needed for mesquite in the Rolling Plains of North Texas.

Another species that has become very problematic to landowners in the Rolling Plains is prickly pear, and according to NRCS representatives a greater concern than Mesquite (Jerry Gleason, NRCS rep. Rolling Plains, TX., Personal Communication). Recently, extreme fire has been effectively used to treat prickly pear in the Rolling Plains. Ansley and Castellano (2007), found that with extreme fire, motte mortality increased by at least 80 percent by three years postfire. In addition, cool season (low intensity) fire had little to no effect on reducing motte cover.

Edwards Plateau

Juniper was present on about 10.1 million acres of western Texas rangeland in 1982, a 60 percent increase from 1948 (Ansley, Pinchak and Ueckert 1995). Juniper has a particularly negative impact on herbaceous plant development and soil erosion because they are evergreens and have shallow root systems. More specifically herbaceous production declines significantly with as little as 10-20 percent juniper canopy cover (Ansley, Wiedemann, Castellano, and Slosser 2006). Juniper management options are limited, mainly to mechanical and prescribed burning techniques. Broadcast herbicide treatments are not available when controlling juniper (Lyons, Owens, and Machen 1998). It is, however, possible to use Individual Plant Treatment (IPT) with herbicide for juniper if there are no more than about 300 plants per acre (Lyons, Owens, and Machen 1998). Many economists and range managers agree that mechanical control of juniper is expensive relative to the cost of using prescribed fire; it can be anywhere from two to six times the cost. Ansley, Wiedemann, Castellano, and Slosser (2006) noted that mechanical clearing of woody plants often stimulates recruitment of seedlings and thus for mechanical treatment to be successful it may need to be followed by a prescribed fire before the seedlings mature. In addition, Ueckert et al. (2001) confirmed that conversion of juniper woodlands back to grasslands will not only require a reclamation treatment but also maintenance treatments. In the absence of treatment, juniper canopy cover will increase at the rate of 1.01 percent per year (Ueckert et al. 2001).

South Texas Plains

In the past most wildfires in the South Texas Plains have been caused by lightning strikes during hot summer conditions (Scifres and Hamilton 1993). This allowed South Texas to maintain grassland dominated steady state. In the last 100 to 350 years South Texas has gone from predominantly tall-grass prairies and savannas to areas with large amounts of brush (huisache and mesquite), mostly due to climate change and the alteration in the use of fire by man (Archer 1989). When managing brush in South Texas, prescribed fire has been shown most effective when used following a herbicide or mechanical treatment. As Scifres and Hamilton (1993) show, the probability of installing a successful burn is increased after an initial brush control method, because it allows for an adequate load of continuous fuel to be established. The use of herbicide alone for managing mesquite can be very costly because it takes repeated applications at fairly close intervals to achieve a significant reduction (Scifres and Hamilton 1993).

Huisache is the most problematic invasive brush species in South Texas (Robert Gibbens, NRCS rep, South Plains TX, Personal Communication 2006). Huisache can form nearly pure stands, especially following mechanical treatment, thus decreasing efficiency of range livestock and greatly hampering management (Bovey and Meyer 1974). Seedlings grow rapidly and resprout following damage or top removal and can form dense stands in just two to three growing seasons following mechanical treatment (Bontrager, Scifres and Drawe 1979). A study by Ruthven III et al. (1993) concludes that root plowing in South Texas results in a huisache dominated rangeland. When root plowed (17years earlier) rangeland was compared to untreated land, there was a 72 percent increase in huisache canopy cover compared to 10 percent on the untreated site. The response of huisache, along with the costs of mechanical brush treatment, makes it the least used treatment method in South Texas.

The most commonly used Huisache treatment methods in South Texas are herbicide and prescribed fire (Lynn Drawe, Welder Wildlife Foundation, Sinton TX, Personal Communication 2006). The most effective chemical IPT treatment for huisache is oiling (.25 – 2 liters of diesel or kerosene, around the base of each plant) (Scifres 1980). Prescribed burning for huisache management holds the most promise when applied following a reduction of the brush stand by an initial treatment (Scifres, Mutz and Drawe 1982).

Managing Risk

OLS Regression

Simple regressions can be used to establish a relationship between two variables, while multiple regression estimates how several explanatory variables are related to a dependent variable (Woolridge 2003). Ordinary least squares (OLS) regression, a multiple regression method, will be used to estimate the relationship between the dependent variable and the explanatory variables.

OLS regression is a basic econometric method which explains a dependent variable (Y) in terms of one or more independent variables (X). The relationship between the variables can be defined as follows:

$$Y = \beta 0 + \beta 1X + u$$

Where:

Y =Dependent Variable,

$\beta 0$ =Intercept Parameter,

$\beta 1$ =Slope Parameter(s),

X =Explanatory variable(s), and

u =Error Term.

The intercept parameter represents the expected value of Y when X is equal to zero (Woolridge 2003). The slope parameter is a more significant indicator in an OLS model, as it shows the relationship between X and Y when the factors contained in the error term are held constant. The error term (residual) accounts for extraneous factors besides X that effect Y. The residual is the difference between the actual value of Y and predicted value of Y.

The following is a list of the five Gauss-Markov assumptions that must be fulfilled for regression to be the appropriate technique (Woolridge 2003):

1. Linear in parameters: the time series process follows a linear model,
2. Zero conditional mean: for each observation, the expected error term is zero,
3. No perfect collinearity: no independent variable is constant or a perfect linear combination of the others
4. Homoskedasticity: conditional on the independent variable(s), the variance of the error term is equal for all time periods
5. No serial correlation: conditional on the independent variable(s), the errors in two separate time periods are uncorrelated

The OLS estimator is overwhelmingly the preferred "optimal" estimator when the estimating problem is accurately characterized by the classic linear regression model (Kennedy 1998). If the explanatory variables are statistically significant, they will improve the accuracy of the model. Ordinary least squares also minimizes the sum of squared residuals which aids in the accuracy of the model (Kennedy 1998).

Time series analysis is the most comprehensive forecasting technique. It is based on the premise that future values are a function of historical observations for the same series (Richardson 2006).

The steps for estimating a time series model are:

1. Test for stationarity using the Dickey-Fuller test. If the series is not stationary, make it stationary by differencing the data.

2. Once the data is stationary determine the number of lags to include in the model. The number of lags can be based on the Schwarz Criterion and the autocorrelation lag function.
3. Estimate the time series model based on the number of lags indicated by the tests (Richardson 2006).

Risk and Simulation

All decisions have consequences and managers can seldom be sure of all aspects of those decisions. As defined by Richardson (2006), "Risk is the part of a business decision, the manager cannot control." Due to the many variables in agriculture, risk can play a large role in any decision, thus it should be the objective to minimize that risk as much as possible. In the past methods of reducing risk in agriculture have be generally based on budgeting methods (Hardaker et al. 2004).

Most people are risk averse when making decisions regarding significant expenses and/or incomes. An individual who is risk averse will forgo benefits for a reduction of risk. Thus, when evaluating risk, the average or expected consequence of a decision may not always be the most preferred option (Hardaker et al. 2004).

One way to reduce risk is through simulation, this allows for returns of alternative strategies to be estimated. Simulation estimates a probability distribution of stochastic (random) variables such as NPV, which gives a manager all possible outcomes for a specific model. According to Richardson (2006), "The purpose of simulation in risk analysis is to estimate distributions of economic returns for alternative strategies so the decision maker can make better management decisions." With simulation, a model is "solved" many times to produces a distribution of possible outcomes. The model contains stochastic variables and should describe the real system as close as possible.

Repetitive Monte Carlo or Latin hypercube sampling is used to generate values from specified input distributions (Hardaker et al. 2004). Monte Carlo sampling is a procedure which randomly selects values from the probability distribution, and thus samples a greater percent of the random values about the mean than samples under the tails (Richardson 2006). Latin hypercube sampling; this procedure segments the distribution into intervals and makes sure at least one value is sampled from each interval (Richardson 2006). This ensures that all areas of the distribution are sampled from and that the simulation is not weighted toward the mean.

Stochastic simulation is very flexible and offers a way to analyze risk in complex systems which otherwise would be unknown. The limits to simulation are limited only by the manager's knowledge of the real system. Hardaker et al. (2004) warn, "Too much complexity makes a model difficult to build, debug and use, and may give results very little better than could have been obtained from a simpler representation." Thus, the simplest model that accurately reflects the real system is usually preferred to very complex.

CHAPTER III

COMPARATIVE ANALYSIS

Introduction

Texas rangeland has been transformed by woody plant and cactus encroachment over the past two centuries. From prickly pear in the Rolling Plains, to juniper in the Edwards Plateau, huisache in the South Texas Plains, and mesquite state-wide, rangelands have suffered declining grazing capacity and economic returns. The increase in invasive brush encroachment has been attributed to overgrazing and fire suppression (Scifres 1980). In the past, naturally occurring fire would suppress brush and maintain a grassland steady state. Historically, rangeland has been managed to sustain grazing livestock but recently wild-life lease income has equaled or surpassed livestock on many ranches (Hamilton et al. 2004). Due to the tradeoff between grazing livestock and wild-life habitat that often incorporates some brush, landowners must manage brush for their unique operations. In the Edwards Plateau, a brush cover of about 30 percent would maximize the livestock and wild-life hunting lease value of the land (Thurow et al. 1997).

There are generally four methods of brush treatment used in Texas, mechanical, herbicide, biological, and prescribed fire. Many differences exist between the methods of brush treatment; the main focus of this study will be with regard to economic variance. Through the use of net present value (NPV) and benefit cost (B/C) analysis, landowners can compare the alternative brush treatments in order to maximize the net returns from their rangeland-based enterprises. For example, prescribed fire has been demonstrated, through these techniques, to be economically advantageous when compared to herbicide treatment (Teague et al. 2001).

In the past, most prescribed fire has been conducted during the winter (Ansley and Castellano 2007); but prescribed extreme fire is being used at an increasing rate (Hamilton et al. 2004 and Taylor 2005). Due to the relatively high costs of mechanical and herbicide treatments and the relatively low implementation costs of prescribed fire (both cool-season and extreme) it seems to be a more viable option for landowners. Though the implementation costs of fire are relatively low, there are other costs to consider; pre- and post-land deferment, planning, and labor availability (Scifres and Hamilton 1993).

This paper presents an analytical comparative economic analysis of using extreme prescribed fire or other commonly used brush treatment methods in the Rolling Plains, Edwards Plateau, and South Texas Plains. Through the use of NPV, BC ratios, break-even analysis and internal rate of return (IRR) the study quantifies the economic differences between alternative treatment methods and extreme prescribed fire.

Rolling Plains

The most problematic brush species in the Rolling Plains is prickly pear followed by mesquite (Jerry Gleason, NRCS rep. Rolling Plains TX, Personal Communication 2006). Recently, extreme fire has been effectively used to treat prickly pear in the Rolling Plains. Ansley and Castellano (2007), found that with extreme fire, motte mortality increased by at least 80 percent three years postfire. In addition, their study reported cool season (low intensity) fire had little to no effect on reducing motte cover.

Regarding the treatment of mesquite in north Texas, Teague et al. (2001) stated, "There is an economic advantage to using fire wherever possible and restricting use of herbicides to those instances that fire is not a viable option." If chemical treatment is the only option, the use of prescribed fire as a maintenance treatment is economically superior when instituted 10 years after an initial herbicide treatment rather than 15 or 20 years post treatment (Teague et al. 2003).

Edwards Plateau

The most targeted brush species in the Edwards Plateau is juniper (ashe and redberry), with mesquite being a secondary invasive species (Charles Anderson, NRCS rep. Edwards Plateau TX, Personal Communication 2006). Juniper management options are limited, mainly to mechanical and prescribed burning techniques. Broadcast herbicide treatments are not available for treating juniper (Lyons, Owens, and Machen 1998). Many economists and range managers agree that mechanical control of juniper is expensive relative to the cost of using prescribed fire; it can be anywhere from two to six times more costly (Workman 1986, Scifres and Hamilton 1993 and Ansley and Rasmussen 2005). According to Taylor (2005), extreme fire appears to be a viable treatment option for the Edwards Plateau, and he notes that it should be considered a reclamation treatment.

South Texas Plains

Huisache is the primary invasive brush species in the South Texas Plains, followed by mesquite (Robert Gibbens, NRCS rep. South Texas Plains TX, Personal Communication 2006). When managing brush in South Texas, prescribed fire has been shown most effective when used following a herbicide or mechanical treatment. As Scifres and Hamilton (1993) show, the probability of installing a successful burn is increased after an initial brush control method, because it allows for an adequate load of continuous fuel to be established. Due to its high costs and the fast resprouting of huisache after top removal, mechanical treatment is the least used treatment option.

Common Species

Mesquite is found on rangeland across Texas and considered a secondary problem in all three regions of this study. The use of herbicide alone for managing mesquite can be very costly because it takes repeated applications at fairly close intervals to achieve a significant reduction (Scifres and Hamilton 1993). A study by (Whitson and Scifres 1981), across many regions of Texas indicated that aerial application of herbicide produced higher annual rates of return on the investment than mechanical treatments.

Research in North Texas indicates that prescribed fire could treat mesquite at less cost than alternative brush treatments. However, to be effective, fire would have to be incorporated on a more frequent basis than other options (Teague et al. 1997).

In South Texas fall and winter burning will effectively reduce brush canopy and frequency in chaparral communities (Box and White 1969). The authors note that fall burning was slightly more effective than winter fire but that both options offered greater brush reduction when following an initial mechanical treatment.

Methods and Data

Study Sites

Research was conducted in four contiguous counties in each of three regions of Texas. The counties include: Rolling Plains – Shackelford, Stephens, Throckmorton and Young; Edwards Plateau – Kimble, Menard, Schleicher and Sutton; and South Texas Plains – Bee, Duval, Live Oak and McMullen. These sites were selected based on the brush species composition to reflect the region. Advice from Texas extension agents was used in the selection process.

Data

Primary data was collected through focus group meetings consisting of NRCS representatives, Texas extension personnel and landowners from each of the four counties in the three regions of Texas. These meetings took place in: Sonora TX, (Sutton County) July 25th 2006; Albany TX, (Shackleford County) August 1st 2006; and Beeville TX, (Bee County) August 3rd 2006. The primary data includes the most commonly used brush treatments with costs and average livestock grazing and wildlife hunting lease rates. Secondary data was reviewed from previous studies for the Forage response figures; Edwards Plateau and South Texas Plains (The Texas Water Resources Institute 2000) and the Rolling Plains (Richard Teague, Vernon TX, Personal Communication 2007).

Assumptions

For the Rolling Plains and Edwards Plateau, cool season fires are instituted every six years following the initial treatment (mechanical, chemical and extreme fire). In the South Texas Plains: the initial herbicide treatment is followed with a cool season fire the next year, then every four years after that; the initial extreme fire treatment is followed by cool season fire every four years. The difference is due the longer growing season in South Texas, thus more frequent maintenance treatments are needed (James Ansley, TAES Vernon TX, Personal Communication 2007).

Heavy brush cover is considered greater than 50 percent canopy cover for all species in the Edwards Plateau and South Texas Plains regions. Moderate brush cover in these two regions is considered to be between 20 and 30 percent cover. For the Rolling Plains: heavy prickly pear cover is considered to be greater than 20 percent canopy cover and moderate cover is between 10 and 20 percent; heavy mesquite cover is assumed as greater than 50 percent canopy cover and moderate cover as 20 to 30 percent.

Response curve analysis was based on measuring added livestock carrying capacity to the historical productivity base gained from previous research (The Texas Water Resources Institute 2000 and Richard Teague, Personal communication 2007). This analysis shows the increased animal units per acre due to the initial treatment and the life, in years, of that treatment. The response curve also illustrates how the maintenance treatments extend the life of the initial treatment. Additionally, the graphs show what will happen if brush management practices are not instituted (Graphs are listed in Appendix D). Data for this portion of the study were obtained from secondary sources published by the Texas Agricultural Experiment Station (TAES) and conversations with extension agents and TAES scientists.

Pretreatment carrying capacity estimates were also based on some assumptions for the three regions: Edwards Plateau and South Texas Plains for all brush species is, 50 ac/animal unit year (AUY) for heavy brush cover and 30 ac/AUY for moderate cover; Rolling Plains prickly pear is, 18.9 ac/AUY for heavy cover and 16.8 ac/AUY for moderate cover; and mesquite is, 20 ac/AUY for heavy cover and 17.25 ac/AUY for moderate cover (Richard Teague, Vernon TX, Personal communication 2007). In addition, forage response is assumed to be the same for extreme fire and the alternative treatments within a region for each canopy cover distinction. For example, in the Rolling Plains, heavy mesquite will have the same post treatment forage response for both an aerial applied herbicide treatment and extreme fire.

The analyzed ranch unit is assumed to be 1,000 acres in size, and the treatment planning horizon is a twenty year period. In addition, variable costs per acre were assumed to be .70 to .90 cents for taxes and .70 to .90 cents for liability insurance (Richard Conner, Texas A&M, College Station TX, personal communication 2007). A six percent discount rate (or opportunity cost) was used for all comparative analysis of the treatment options. This reflects a doubling or tripling of the inflation and risk -free rate commonly paid on simple savings accounts, which is commonly used for range management analysis (Richard Conner, Texas A&M University, College Station TX, Personal Communication 2007).

Brush Treatments

Within the three regions, extreme fire was compared to the most commonly used alternative brush treatment for the most problematic species along with mesquite for both moderate and heavy canopy cover of each. A table of treatment costs per acre and grazing and hunting-lease rates along with response curve data for all brush species in the three regions can be found in appendix A.

In the Rolling Plains, the initial prickly pear alternative treatment for moderate cover was chemical individual plant treatment (IPT) of 1 percent Surmount (manufactured by Dow AgroSciences) mixed with water and applied at the base. For heavy prickly pear cover, the alternative treatment was aerial application of ½ lb. Picloram (manufactured by Dow AgroSciences) per acre. The initial mesquite alternative treatment in the Rolling Plains was IPT using 0.5 percent each of Remedy and Reclaim (both manufactured by Dow AgroSciences) mixed with water for moderate cover, and helicopter applied ¼ lb. Remedy and ¼ lb. Reclaim mix per acre for heavy cover. These treatment alternatives are listed in Table 1 and will be referenced as "alternative" in the results section.

Table 1. Rolling Plains - Initial Brush Treatments

	Heavy Canopy Cover	Moderate Canopy Cover
Pickly Pear		
Fire	Extreme Fire	Extreme Fire
Alternate	Aerial Chemical, 1/2 lb. Picloram per acre	Chemical IPT 1% Surmount w/water
Mesquite		
Fire	Extreme Fire	Extreme Fire
Alternate	Aerial Chemical, 1/4 lb. ea./ac Reclaim & Remedy	Chemical IPT, 15% ea. Remedy/Reclaim mix

Cool season prescribed fire maintenance treatments every 6 years following initial treatment.

In the Edwards Plateau, initial redberry juniper alternative treatments were mechanical grubbing with stacking for both moderate and heavy canopy cover and additionally grubbing alone, for heavy redberry juniper canopy cover. Initial ashe juniper alternative treatments were mechanical tree sheer for moderate cover and both grubbing and grubbing with stacking for heavy canopy cover. The initial alternative treatments for mesquite were IPT mix of diesel and 15 percent Remedy applied at the base for moderate cover and helicopter applied mix of ¼lb. Remedy and ¼ lb. Reclaim per acre for heavy canopy cover. The alternative treatments being compared to extreme fire are listed in the following Table (2).

Table 2. Edwards Plateau - Initial Brush Treatments

	Heavy Canopy Cover	Moderate Canopy Cover
Redberry Juniper		
Fire	Extreme Fire	Extreme Fire
Alternate	Mechanical, Grubbing&Stacking	Mechanical,Grubbing&Stacking
Alternate	Mechanical, Grubbing	
Ashe Juniper		
Fire	Extreme Fire	Extreme Fire
Alternate	Mechanical, Grubbing&Stacking	Mechanical, Tree Sheer
Alternate	Mechanical, Grubbing	
Mesquite		
Fire	Extreme Fire	Extreme Fire
Alternate	Aerial Chemical, 1/4 lb. ea./ac Remedy & Reclaim	Chemical IPT, Diesel/Remedy mix

Cool season prescribed fire maintenance treatments every 6 years following initial treatment.

In the South Texas Plains the initial huisache alternative treatment was basal IPT mix of diesel and 15 percent Remedy for moderate cover and helicopter application of 3 pints/ac of Grazon P+D (manufactured by Dow AgroSciences) for heavy cover. The initial treatment for mesquite was IPT mix of diesel and 15 percent Remedy applied at the base for moderate cover and helicopter applied mix of ¼ lb. Remedy and ¼ lb. Reclaim per acre for heavy cover. The alternative treatment methods being compared to extreme fire in the South Texas Plains are presented in the following Table (3).

Table 3. South Texas Plains - Initial Brush Treatments

	Heavy Canopy Cover	Moderate Canopy Cover
Huisache		
Fire	Extreme Fire	Extreme Fire
Alternate	Aerial Chemical, 3 pints/ac Grazon P+D	Chemical IPT, 15% Remedy w/Diesel mix
Mesquite		
Fire	Extreme Fire	Extreme Fire
Alternate	Aerial Chemical, 1/4 lb. ea./ac Remedy & Reclaim	Chemical IPT, 15% Remedy w/Diesel mix

Cool season prescribed fire maintenance treatments every 4 years following initial treatment.

Economic Model

The analysis of using mechanical, chemical and prescribed fire was conducted using NPV, BC ratio and IRR over a 20-year planning horizon. Due to the fact that these economic measurements are correlated, the focus will be on NPV, which allows for analysis of future costs and returns to be analyzed in current terms. All figures are published to accommodate preferences for the values. Break even data for alternative management projects is presented for use by landowners and NRCS for potential cost share opportunities. This presents the amount of investment that would need to be subsidized to make the investment break even for the landowner.

> Definition: The Net Present Value (NPV) of a project or investment is defined as the sum of the present values of the annual cash flows minus the initial investment. The annual cash flows are the Net Benefits (revenues minus costs) generated from the investment during its lifetime. These cash flows are discounted or adjusted by use of a discount factor which represents the opportunity cost of investment capital. NPV is one of the most robust financial

evaluation tools to estimate the value of an investment (Odellion Research website 2007).

A management project is economically feasible if NPV is ≥ 0 (discounted returns equal or exceed discounted costs). When comparing brush treatments the option with the higher NVP is economically preferable (Workman 1986). The use of NPV is considered superior to other ways of measuring economic gains from range improvement practices because it takes into account the time value of money, and returns a dollar value to the landowner. The equation used for calculating NPV is:

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

Where V = future value
d = discount rate
n = planning horizon
i = years in planning horizon

The Benefit/Cost ratio is calculated by dividing the present value of returns by the present value of treatment (initial and maintenance) costs. The management project is economically feasible if the ratio is greater than 1. IRR is calculated to show the income earning potential. This is calculated by taking the average annual earnings or profits divided by the total amount of the investment and then expressed as a percent. The break even point was calculated by taking the difference of total investment cost and NPV. In addition, a break even point is shown that is calculated with the assumption that the land owner has received 50 percent cost share for the management project.

Results and Discussion

Rolling Plains

In three out of the four brush treatment scenarios, extreme fire proved to be economically feasible with NPV ≥ 0, and the benefit cost ratio greater than 1. The use of extreme fire for moderate canopy cover of prickly pear was marginally negative (Table 4). All four alternative treatment horizons had negative mean NPVs. For treatment horizons with negative NPV, the NRCS or some other source could pay that amount as cost share to allow the landowner to break even on total investment cost (Table 4).

Rangeland with heavy prickly pear cover was analyzed comparing aerial application of ½ lb. Picloram per acre herbicide, with extreme fire. The herbicide treatment has a NPV of -$21,811.51 (-$21.81 per acre) while the extreme fire treatment is positive with a NPV value of $5,311.13 ($5.31 per acre). However, assuming the landowner is eligible for 50 percent costshare, the herbicide treatment NPV becomes positive (Table 5). This allows choices between the two horizons to be based on variables other than strictly economic.

For rangeland with moderate prickly pear, both IPT with 1 percent Surmount and extreme fire produced negative NPV's. Extreme fire, however, was much closer to being economically feasible with a NPV of -$152.21 (-$.15 per acre) while the NPV for IPT with 1 percent Surmount was -$13,359.76 (-$13. 35 per acre) (Table 4). As illustrated in Table 5, both moderate pear treatments become positive when a 50 percent costshare is assumed.

Table 4. Rolling Plains Economic Measurements - Total Cost, Net Present Value, Benefit/Cost and Internal Rate of Return

Brush Treatment		Total Improvement Investment Cost	*Total NPV for Scenario	B/C Ratio	Total IRR
		$s per acre			
Heavy Prickly Pear:	Extreme Fire	15.00	5.31	1.536	18.43%
	Alternate	43.75	-21.81	0.411	-4.90%
Moderate Prickly Pear:	Extreme Fire	15.00	-0.15	0.985	5.62%
	Alternate	29.00	-13.36	0.422	-5.52%
Heavy Mesquite:	Extreme Fire	15.00	7.41	1.749	22.88%
	Alternate	45.00	-20.89	0.453	-3.85%
Moderate Mesquite:	Extreme Fire	15.00	1.67	1.169	9.94%
	Alternate	28.00	-10.59	0.522	-2.98%

The first column is the total cost for each of the brush management systems, the second is the net present value of each system. The third and fourth column are benefit cost ratio and internal rate of return for each management system.
* If NPV is negative; The NRCS or some other source could pay that amount as cost share to allow the landowner to break even on total investment cost and if NPV is positive, it is realized profit or amount that could be invested in further rangeland treatment.

On rangeland with heavy mesquite canopy cover, extreme fire was compared to the most commonly used alternative treatment of aerial applied herbicide, ¼ lb. per acre each of Remedy and Reclaim. Extreme fire is economically superior to the herbicide treatment with a NPV of $7,412.37 ($7.41 per acre) compared to -$20,889.52 (-$20.88 per acre) for the herbicide treatment (Table 4). In addition, the internal rate of return for the extreme fire treatment was over 3 ½ times greater than the discount rate (6 percent).

Finally, for rangeland with moderate mesquite cover, IPT of 0.5 percent each Remedy and Reclaim mix with water was compared to extreme fire. As with heavy mesquite, the extreme fire treatment resulted in a positive NPV and the herbicide treatment resulted in a negative NPV. Extreme prescribed fire for moderate mesquite offered an earning potential of 9.94 percent (Table 4). The Break Even (BE) point is figured by adding the initial NPV to the total improvement investment cost. The BE point illustrates the amount that would have to be provided by an external entity such as NRCS for a landowner to realize returns equal to the assumed 6% discount rate (Table 5). All four mesquite treatment horizons exhibited positive economic returns when a cost share of 50 percent was assumed (Table 5).

Table 5. Rolling Plains - Break Even Point & Cost-Share

	Brush Treatment	Total Investment Cost	Total Improvement Investment Break Even Point	50% Costshare	Economically Feasible w/costshare?
		$s per acre			
Heavy Prickly Pear:	Extreme Fire	15.00	20.31	7.50	12.81
	Alternate	43.75	21.94	21.88	0.06
Moderate Prickly Pear:	Extreme Fire	15.00	14.85	7.50	7.35
	Alternate	29.00	15.64	14.50	1.14
Heavy Mesquite:	Extreme Fire	15.00	22.41	7.50	14.91
	Alternate	45.00	24.11	22.50	1.61
Moderate Mesquite:	Extreme Fire	15.00	16.67	7.50	9.17
	Alternate	28.00	17.41	14.00	3.41

This table illustrates whether a treatment horizon would be economically feasible if a 50% costshare is assumed. The first column is the amount it would take for a rancher to break even, the second column is 50% of the treatment horizon's total cost and the third column is the difference between the first two. If the value in the third column is positive the treatment horizon is feasible, if negative it is still not feasible with costshare.

Edwards Plateau

In the Edwards Plateau, the four extreme fire treatments were economically feasible, with positive NPVs, B/C ratios greater than 1, and IRR above 6 percent. Alternatively, all the herbicide and mechanical brush management practices produced negative NPVs.

The treatment horizon with the least returns is grubbing and stacking of heavy juniper, with a NPV of -$107,263.07 (-$107.26 per acre). The same treatment method for moderate juniper cover produced a NPV of -$91,945.17 or -$91.94 per acre (Table 6). Grubbing alone on heavy juniper was better than the grub/stack treatment; however it also produced a negative NPV. Conversely the highest net present value treatment in the Edwards Plateau was extreme fire on heavy juniper rangeland (Table 6). Moderate juniper cover was broken into two treatment categories; ashe – tree sheering, and redberry – grubbing and stacking. This was done to reflect the resprouting characteristic of redberry juniper, thus rendering tree sheers ineffective for this species. Both moderate juniper alternative treatment methods produced negative NPVs. Even when assuming a 50 percent cost share, none of the alternative juniper treatments were economically feasible (Table 7).

Table 6. Edwards Plateau Economic Measurements - Total Cost, Net Present Value, Benefit/Cost and Internal Rate of Return

	Brush Treatment	Total Improvement Investment Cost	*Total NPV for Scenario	B/C Ratio	Total IRR
		$s per acre			
Heavy Ashe/Redberry Juniper:	Extreme Fire	15.00	11.13	2.125	29.30%
	Alternate (grub/stack)	140.50	-107.26	0.164	-11.26%
	Alternate (grub)	100.50	-69.53	0.232	-8.88%
Moderate Juniper:	Extreme Fire	15.00	7.58	1.766	23.60%
Ashe	Alternate (tree sheer)	98.00	-70.72	0.198	-10.20%
Redberry	Alternate (grub/stack)	120.50	-91.95	0.160	-----
Heavy Mesquite:	Extreme Fire	15.00	1.64	1.165	10.41%
	Alternate	40.50	-22.42	0.340	-7.60%
Moderate Mesquite:	Extreme Fire	15.00	2.62	1.265	12.82%
	Alternate	78.00	-56.99	0.180	-----

The first column is the total cost for each of the brush management systems, the second is the net present value of each system. The third and fourth column are benefit cost ratio and internal rate of return for each management system.
* If NPV is negative; The NRCS or some other source could pay that amount as cost share to allow the landowner to break even on total investment cost and if NPV is positive, it is realized profit or amount that could be invested in further rangeland treatment.

The treatments for mesquite in the Edwards Plateau for heavy canopy cover were aerial application of ¼ lb. Reclaim and ¼ lb. Remedy mix per acre and extreme fire. Treatments for moderate canopy cover were IPT of diesel and 15 percent Remedy mix and extreme fire. Extreme fire had positive returns for both heavy and moderate mesquite, with NPVs of $1,636.82 ($1.63 per acre) and $2,622.78 ($2.62 per acre), respectively, and B/C ratios greater than 1 (Table 6). Alternately, the two chemical treatments both produced negative NPVs. When a 50 percent cost share is assumed, aerial herbicide treatment of heavy mesquite is nearly positive, but both alternative treatments still fall short of offering positive returns (Table 7).

Table 7. Edwards Plateau - Break Even Point & Cost-Share

	Brush Treatment	Total Investment Cost	Total Improvement Investment Break Even Point	50% Costshare	Economically Feasible w/costshare?
		$s per acre			
Heavy Ashe/Redberry Juniper:	Extreme Fire	15.00	26.13	7.50	18.63
	Alternate (grub/stack)	140.50	33.24	70.25	-37.01
	Alternate (grub)	100.50	30.97	50.25	-19.28
Moderate Juniper:	Extreme Fire	15.00	22.58	7.50	15.08
Ashe	Alternate (tree sheer)	98.00	27.28	49.00	-21.72
Redberry	Alternate (grub/stack)	120.50	28.55	60.25	-31.70
Heavy Mesquite:	Extreme Fire	15.00	16.64	7.50	9.14
	Alternate	40.50	18.08	20.25	-2.17
Moderate Mesquite:	Extreme Fire	15.00	17.62	7.50	10.12
	Alternate	78.00	21.01	39.00	-17.99

This table illustrates whether a treatment horizon would be economically feasible if a 50% costshare is assumed. The first column is the amount it would take for a rancher to break even, the second column is 50% of the treatment horizon's total cost and the third column is the difference between the first two. If the value in the third column is positive the treatment horizon is feasible, if negative it is still not feasible with costshare.

South Texas Plains

The treatments for heavy huisache cover both produced negative NPVs with aerial application of 3 pints/ac of Grazon P+D producing a NPV of -$39,254.24 (-$39.25 per acre) and extreme fire having a NPV of -$306.10 or -$.31 per acre (Table 8). However the IRR for extreme fire suggests if the discount rate was ≤ 5.07 percent the treatment would become positive. In the case of moderate huisache cover, the chemical IPT had a NPV of -$58,163.61 (-$58.16 per acre) while extreme fire was positive with a NPV of $2,010.94 or $2.01 per acre (Table 8). Of the four huisache treatments, extreme fire used on moderate cover was most profitable. Assuming a 50 percent cost share, the alternative huisache chemical treatments were closer to profitability, but were still negative (Table 9).

Table 8. South Texas Plains Economic Measurements - Total Cost, Net Present Value, Benefit/Cost and Internal Rate of Return

	Brush Treatment	Total Improvement Investment Cost	*Total NPV for Scenario	B/C Ratio	Total IRR
		$s per acre			
Heavy Huisache:	Extreme Fire	22.50	-0.31	0.978	5.07%
	Alternate	63.88	-39.25	0.259	-----
Moderate Huisache:	Extreme Fire	22.50	2.01	1.143	10.55%
	Alternate	86.38	-58.16	0.216	-----
Heavy Mesquite:	Extreme Fire	22.50	6.60	1.470	20.16%
	Alternate	63.38	-31.87	0.393	-6.22%
Moderate Mesquite:	Extreme Fire	22.50	4.56	1.324	15.61%
	Alternate	88.88	-57.97	0.243	-9.92%

The first column is the total cost for each of the brush management systems, the second is the net present value of each system. The third and fourth column are benefit cost ratio and internal rate of return for each management system.

* If NPV is negative; The NRCS or some other source could pay that amount as cost share to allow the landowner to break even on total investment cost and if NPV is positive, it is realized profit or amount that could be invested in further rangeland treatment.

The two highest returning treatment methods in the South Texas Plains were the use of extreme fire on heavy and moderate mesquite, with NVPs of $6,602.27 ($6.60 per acre) and $4,558.87 ($4.55 per acre) respectively (Table 8). In addition, they both exhibit IRRs well over two times the discount rate. The alternative treatment methods analyzed were aerial application of ¼ lb. Remedy and ¼lb. Reclaim mix for heavy mesquite and IPT of diesel and 15 percent Remedy mix. Neither of the alternative mesquite treatments were profitable, both exhibiting negative NPVs along with benefit cost ratios less than 1 (Table 8). If a landowner is eligible for 50 percent cost share, the chemical treatment of heavy mesquite (-$.19 per acre) is nearly feasible (Table 9).

Table 9. South Texas Plains - Break Even Point & Cost Share

	Brush Treatment	Total Investment Cost	Total Improvement Investment Break Even Point	50% Costshare	Economically Feasible w/costshare?
		$s per acre			
Heavy Huisache:	Extreme Fire	22.50	22.19	11.25	10.94
	Alternate	63.88	24.62	31.94	-7.32
Moderate Huisache:	Extreme Fire	22.50	24.51	11.25	13.26
	Alternate	86.38	28.21	43.19	-14.98
Heavy Mesquite:	Extreme Fire	22.50	29.10	11.25	17.85
	Alternate	63.38	31.50	31.69	-0.19
Moderate Mesquite:	Extreme Fire	22.50	27.06	11.25	15.81
	Alternate	88.88	30.90	44.44	-13.54

This table illustrates whether a treatment horizon would be economically feasible if a 50% costshare is assumed. The first column is the amount it would take for a rancher to break even, the second column is 50% of the treatment horizon's total cost and the third column is the difference between the first two. If the value in the third column is positive the treatment horizon is feasible, if negative it is still not feasible with costshare.

Mesquite Sensitivity Analysis

Mesquite is a pervasive brush species on many ranches across Texas, and was found to be a common problem in the three regions of this study. Due to this commonality, a sensitivity analysis of the discount rate was conducted to compare treatments across all three regions. As discount rate increases, more weight is put on the costs and returns occurring in the earlier part of the planning horizon, which is where most of the costs are incurred. This is illustrated in Table 10, where all NPVs and B/C ratios increase as the discount rate decreases.

In all three regions, the treatment of mesquite with extreme fire is economically feasible, with discount rates of six, four and two percent (Table 10). Conversely, all alternative treatments produced NPVs < 0 regardless of the discount rate used. Although this was the case, the more interesting analysis comes from comparing region to region. For example, using extreme fire for heavy mesquite in the Rolling Plains with a 6 percent discount rate is valued higher (NPV = $7,412.37 or $7.41 per acre) than the use of extreme fire on the Edwards Plateau at all three discount rates (Table 10). When the extreme fire treatment of moderate mesquite between the Rolling Plains and Edwards Plateau is analyzed the pattern is reversed. The three discount rate scenarios in the Edwards Plateau offered higher returns than the corresponding treatment methods in the Rolling Plains, mainly due to the greater forage response (Table 10).

Table 10. Mesquite Sensitivity Analysis of Discount Rates Across Three Texas Regions

		Rolling Plains			Edwards Plateau			South Texas Plains		
		6%	4%	2%	6%	4%	2%	6%	4%	2%
Heavy										
Alt	NPV	-$20.89	-$19.01	-$16.34	-$22.42	-$21.71	-$20.60	-$31.87	-$30.31	-$27.98
	B/C	0.453	0.525	0.614	0.34	0.392	0.456	0.393	0.453	0.526
Fire	NPV	$7.41	$9.83	$13.07	$1.64	$2.81	$4.40	$6.60	$8.94	$12.07
	B/C	1.749	1.877	2.015	1.165	1.25	1.342	1.47	1.552	1.637
Moderate										
Alt	NPV	-$10.59	-$9.50	-$7.91	-$56.99	-$56.69	-$55.90	-$57.97	-$57.21	-$55.76
	B/C	0.522	0.599	0.691	0.18	0.212	0.252	0.243	0.285	0.336
Fire	NPV	$1.67	$3.00	$4.84	$2.62	$4.03	$5.95	$4.56	$6.56	$9.28
	B/C	1.169	1.267	1.376	1.265	1.359	1.462	1.324	1.405	1.49

NPV and B/C ratio listed down the left side for alternative treatments and extreme fire for heavy and moderate canopy cover. The three tested discount rates are listed across the row under the three regions. NPV values are in dollars per acre.

The South Texas Plains was more profitable when extreme fire treatment of moderate mesquite was compared to both the Rolling Plains and the Edwards Plateau for all three discount rate scenarios; this was due to higher grazing and hunting-lease revenue per acre (Table 10).

Heavy mesquite alternative treatment was the same in all three regions; a chemical aerial application of ¼ lb. Remedy & ¼ lb. Reclaim mix per acre was used. Though they all produce negative economic values, the Rolling Plains had the least negative NPV followed by the Edwards Plateau then the South Texas Plains. This means it would be less costly for rangeland in the north to be treated with ¼ lb. Remedy & ¼ lb. Reclaim mix per acre than in the south. Extreme fire seems to be the most efficient treatment option at various discount rates and across all regions. This analysis, however, does not take into account the risk of not being able to institute a fire regime in any given year, which could reduce the NPV and possibly even make the practice economically infeasible in some cases.

Summary and Conclusions

Over a twenty year planning horizon, brush that is not treated can become an even more costly problem than what is present at the beginning. Brush encroachment for rangeland with moderate brush cover will move to or reach heavy cover over the next 20 years without treatment. This will reduce carrying capacity for grazing livestock and potentially negatively effect wildlife habitat, both will decrease economic returns from rangeland. Much of Texas rangeland has some sort of brush presence and encroachment is widespread; thus many ranchers face a choice of treatment options. This study has illustrated the economic benefits of using extreme fire as compared to treatments that are currently used.

Extreme fire, in all cases, was economically superior to the other commonly used brush treatment methods. In addition, extreme prescribed fire treatments were economically feasible, with two exceptions that produced only marginally negative NPVs. Extreme fire treatments of moderate prickly pear in the Rolling Plains and heavy huisache in the South Texas Plains would become feasible with a conservative amount of cost sharing. In many cases, extreme fire returns were double or triple the discount rate. Thus investing in extreme fire as a treatment method is better than many alternative investment activities.

Management Implications

From an economic perspective, this study suggests that extreme fire is efficient and superior to other treatment options across Texas. Extreme fire is still a relatively new and minimally used brush treatment; however this research should contribute to making the method more prevalent on ranches across Texas. In addition the results should contribute to the review of current NRCS technical standards for the use of extreme fire.

This study assumes initial treatment of ranches will take place during months with extreme fire conditions, thus it does not account for the weather risk involved with using herbicide and/or extreme fire. If rainfall is below average prior to the summer months (usually exhibit extreme fire conditions) there is a good probability there will not be enough fuel load to carry an extreme fire. Additionally broadcast herbicide is relatively ineffective if the target brush species is not growing when the treatment is applied.

CHAPTER IV

RISK ANALYSIS

Introduction

In the last 100 to 200 years Texas rangeland has changed from open savannas and grasslands to land with vast areas of woody plant cover. This transition of Texas rangeland was mostly due to overgrazing and suppression of wildfire by European settlers over the last two centuries (Hamilton et al. 2004). The woody species of honey mesquite, huisache, redberry juniper, and ashe juniper, along with the cactus species brownspine prickly pear, are particularly problematic for landowners in the regions of this study. There are many reasons for brush treatment; livestock production, water yield, wildlife habitat, carbon sequestration, and overall aesthetic value are a few (Hamilton et al. 2004). The four most commonly used brush management methods are mechanical, chemical, biological, and prescribed fire.

Risk is a part of most aspects in life, decisions made today have uncertain consequences in the future. When managers are faced with alternative investment choices, minimizing risk is important. One way to minimize risk is through simulation modeling. Richardson (2006) states, "The purpose of simulation in risk analysis is to estimate distributions of economic returns for alternative strategies so the decision maker can make better management decisions." Due to the advancement of technology and more efficient operating systems, risk analyses through modeling and simulation have become a more viable option. For economic analysis, risk can be divided into "risk" and "uncertainty". Risk can be taken into account when probabilities of occurrence can be calculated based on historical observations (i.e. weather patterns). Uncertainty, however, is when probabilities cannot be calculated, such as livestock prices in a freely fluctuating market (Workman and Tanaka 1991). In an economic sense, the one who exploits risk usually bears the profits but can also lose.

Stochastic simulation as defined by Hardaker et al. (2004), is "Selected variables or relationships incorporate random or stochastic components (by specifying probability distributions) to reflect important parts of the uncertainty in the real system." This allows for complex decisions to be analyzed while reducing the risk involved. Simulation "solves" (runs or iterates) a model many times, producing a distribution of all possible outcomes for the specified variables.

As with other decisions, the choice of invasive brush management treatment to be used in an Integrated Brush Management System (IBMS) involves risk. Decisions in the past regarding agriculture risk (Hardaker et al. 2004), and more specifically brush treatment alternatives have generally been based on budgeting methods. Though these methods are effective, they do not account for risky exogenous variables such as weather, forage load, stocking rates or timing of treatment. Various grazing related, stocking-rate, weather and range management studies have been conducted using risk related software (Bernardo, Engle and Mccollum 1988; Bernardo and Engle 1989; Riechers, Conner and Heitschmidt 1989; Workman and Tanaka 1991; Anderson et al. 1993 and Schumann et al. 2001). One study in particular (Kreuter et al. 1996), focused on Grazingland Alternative Analysis Tool (GAAT), and early version of Grazing

Systems Analysis Tool (GSAT), and concluded decision support software is becoming increasingly important in dynamic rangeland analysis.

The purpose of this study is to evaluate the long term implications of including extreme fire as part of a brush treatment program and also, to evaluate the use of one treatment for the whole ranch in the first year compared to using a combination of extreme fire with an alternate treatment over the first 10 years. Simulation offers a way to evaluate risk due to weather variations (rainfall variability) and produce NPV probability distributions of alternative treatment regimes. In addition, the results contribute to the limited existing research on extreme fire and the efficiency of using it as part of a brush program.

Methods and Data

Study Sites

Research was conducted in four contiguous counties in each of three regions of Texas. The counties include: Rolling Plains – Shackelford, Stephens, Throckmorton and Young; Edwards Plateau – Kimble, Menard, Schleicher and Sutton; and South Texas Plains – Bee, Duval, Live Oak and McMullen. These sites were selected based on the brush species composition to reflect the region. Advice from Texas extension agents was used in the selection process. For the rainfall risk analysis portion of this study, one representative county from each region was selected: Rolling Plains, Throckmorton; Edwards Plateau, Kimble; and South Texas Plains, Live Oak. The four counties in each region were very similar in rainfall quantities and thus only one county was needed to represent each region.

Data

Primary data was collected through focus group meetings consisting of NRCS representatives, Texas extension personnel and landowners from each of the four counties in the three regions of Texas. These meetings took place in: Sonora TX, (Sutton County) July 25th 2006; Albany TX, (Shackleford County) August 1st 2006; and Beeville TX, (Bee County) August 3rd 2006. Data included, the most commonly used brush treatment methods with costs per acre; and livestock-lease rates and wildlife hunting-lease rates on a per acre basis. Secondary data was used from previous studies of the forage response figures; Edwards Plateau and South Texas Plains (The Texas Water Resources Institute 2000) and the Rolling Plains (Richard Teague, Vernon TX, Personal communication 2007).

Historical bi-monthly rainfall data from January 1948 though November 2006, was obtained from the U.S. Department of Agriculture's Risk Management Agency website under the "Policies: pasture, rangeland, and forage; Historical Indices" URL (www.rma.usda.gov/policies/pasturerangeforage/).

Assumptions

For the Rolling Plains and Edwards Plateau, cool season fires are instituted every six years following the initial treatment (mechanical, chemical and extreme fire). In the South Texas Plains: the initial herbicide treatment is followed with a cool season fire the next year, and every four years after that; the initial extreme fire treatment is followed by cool season fire every four years. The difference is due to the longer growing season in

South Texas, thus more frequent maintenance treatments are needed (James Ansley, TAES Vernon TX, Personal Communication 2007).

Heavy brush cover is considered greater than 50 percent canopy cover for all species and in the Edwards Plateau and South Texas Plains regions. Moderate brush cover in these two regions is considered to be between 20 and 30 percent cover. For the Rolling Plains: heavy prickly pear cover is considered to be greater than 20 percent canopy cover and moderate cover is between 10 and 20 percent; heavy mesquite cover is assumed as greater than 50 percent canopy cover and moderate cover as 20 to 30 percent (Richard Teague, Vernon TX, Personal Communication 2007).

Pretreatment carrying capacity was also assumed for the three regions: Edwards Plateau and South Texas Plains for all brush species is, 50 ac/animal unit year (AUY) for heavy brush cover and 30 ac/AUY for moderate cover; Rolling Plains prickly pear is, 18.9 ac/AUY for heavy cover and 16.8 ac/AUY for moderate cover; and mesquite is, 20 ac/AUY for heavy cover and 17.25 ac/AUY for moderate cover. In addition, forage response is assumed to be the same for extreme fire and the alternative treatments within a region for each canopy cover distinction. For example, in the Rolling Plains, heavy mesquite will have the same post treatment forage response for both an aerial applied herbicide treatment and extreme fire.

Ranches are assumed to be 1,000 acres in size, and the treatment planning horizon is over a twenty year period. In addition, variable costs per acre were assumed to be 70 to 90 cents for taxes and 70 to 90 cents for liability insurance. A six percent discount rate (or opportunity cost) was used for all comparative risk analysis of the treatment options. This reflects a doubling or tripling of the inflation and risk -free rate commonly paid on simple savings accounts and is a common practice for range management analysis (Richard Conner, Texas A&M University, College Station TX, Personal Communication 2007).

The ranches are divided into ten 100 acre parcels. One parcel each year for the first ten years was treated with an initial treatment. All 1,000 acres are assumed to produce wildlife hunting-lease revenue each year, while grazing lease revenue was based on animal unit equivalents (AUE) per acre from forage response data generated with GSAT.

For the purpose of this study, extreme fire was instituted as an initial treatment when rainfall was forecasted to be above average from April though July. This assumes a large enough fuel-load would be present to carry an extreme fire and that weather conditions, in Texas, are most often favorable during the months of August and September. Fuel moisture is an important factor when planning an extreme prescribed fire (Dirac Twidwell, Texas A&M University, College Station TX, Personal Communication 2007), however, due to the lack of historical fuel moisture data we assume the weather conditions in August and September would exhibit fuel moisture content that would carry an extreme fire. If an extreme fire was instituted, parcels were deferred for two growing seasons post treatment and for one growing season if an alternative treatment was used to allow for forage response before livestock were re-introduced. All initial treatments are preceded with one growing season deferment.

A table of treatment costs per acre and grazing and hunting-lease rates along with response curve data for all brush species in the three regions can be found in appendix A.

Brush Treatments

Within the three regions, extreme fire was combined with the most commonly used, initial, alternative brush treatment for the most problematic species along with mesquite for both moderate and heavy canopy cover of each.

In the Rolling Plains, the initial prickly pear alternative treatment for moderate cover was chemical individual plant treatment (IPT) of 1 percent Surmount mixed with water. For heavy prickly pear cover, the alternative treatment was aerial application of ½ lb. Picloram per acre. The initial mesquite alternative treatment in the Rolling Plains was IPT using 0.5 percent each of Remedy and Reclaim mixed with water for moderate cover, and helicopter applied ¼ lb. Remedy and ¼ lb. Reclaim mix per acre for heavy cover. Table 11 lists the two treatment methods available for each brush species and canopy cover in the Rolling Plains.

Table 11. Rolling Plains - Initial Brush Treatment Choice Variables

	Heavy Canopy Cover	Moderate Canopy Cover
Pickly Pear		
Fire	Extreme Fire	Extreme Fire
Alternate	Aerial Chemical, 1/2 lb. Picloram per acre	Chemical IPT 1% Surmount w/water
Mesquite		
Fire	Extreme Fire	Extreme Fire
Alternate	Aerial Chemical, 1/4 lb. ea./ac Reclaim & Remedy	Chemical IPT, 15% ea. Remedy/Reclaim mix

Cool season prescribed fire maintenance treatments every 6 years following initial treatment.

In the Edwards Plateau, initial redberry juniper alternative treatments were mechanical grubbing with stacking for both moderate and heavy cover with grubbing alone, additionally for heavy cover. Initial ashe juniper alternative treatments were mechanical tree sheer for moderate cover and both grubbing and grubbing with stacking for heavy cover. The initial alternative treatments for mesquite were IPT mix of diesel and 15 percent Remedy for moderate cover and helicopter applied mix of ¼lb. Remedy and ¼ lb. Reclaim per acre for heavy cover. The following table lists the choice treatment variables for the Edwards Plateau (Table 12).

Table 12. Edwards Plateau - Initial Brush Treatment Choice Variables

	Heavy Canopy Cover	Moderate Canopy Cover
Redberry Juniper		
Fire	Extreme Fire	Extreme Fire
Alternate	Mechanical, Grubbing&Stacking	Mechanical,Grubbing&Stacking
Alternate	Mechanical, Grubbing	
Ashe Juniper		
Fire	Extreme Fire	Extreme Fire
Alternate	Mechanical, Grubbing&Stacking	Mechanical, Tree Sheer
Alternate	Mechanical, Grubbing	
Mesquite		
Fire	Extreme Fire	Extreme Fire
Alternate	Chemical Aerial Chemical, 1/4 lb. ea./ac Remedy & Reclaim	Chemical IPT, Diesel/Remedy mix

Cool season prescribed fire maintenance treatments every 6 years following initial treatment.

In the South Texas Plains the initial huisache alternative treatment was basal IPT mix of 15 percent Remedy with diesel for moderate cover and helicopter application of 3 pints/ac Grazon P+D for heavy cover. The initial treatment for mesquite was IPT mix of diesel and 15 percent Remedy for moderate cover and helicopter application of ¼ lb. Remedy and ¼ lb. Reclaim per acre for heavy cover. Table 13 illustrates the brush treatment methods used in the South Texas Plains model.

Table 13. South Texas Plains - Initial Brush Treatment Choice Variables

	Heavy Canopy Cover	Moderate Canopy Cover
Huisache		
Fire	Extreme Fire	Extreme Fire
Alternate	Chemical Aerial Chemical, 3 pints/ac Grazon P+D	Chemical IPT, 15% Remedy w/Diesel mix
Mesquite		
Fire	Extreme Fire	Extreme Fire
Alternate	Chemical Aerial Chemical, 1/4 lb. ea./ac Remedy & Reclaim	Chemical IPT, 15% Remedy w/Diesel mix

Cool season prescribed fire maintenance treatments every 4 years following initial treatment.

Model

A stochastic Monte Carlo (with Latin hyper cube sampling) integrated brush management model was used to evaluate the effects of weather when incorporating extreme fire as a brush management tool. Monte Carlo, in general, refers to any simulation involving random numbers; the procedure randomly selects values from probability distributions (Law and Kelton 1991 and Richardson 2006). Latin hypercube sampling involves segmenting the distribution into intervals equal to the number of iterations (500 in this case) and makes sure at least one value is sampled from each interval (Richardson 2006).

Fifty eight years of bi-monthly historical rainfall data was used to forecast twenty years of annual rainfall. Through the use of seasonal indexing, the bi-monthly data were converted to annual rainfall. This process produced fractional contribution indices (FCI) for the six two-month periods in each year. Due to the removal of variability by using constant FCIs, the mean and standard deviation from each period along with the constant FCI were used as parameters in a truncated normal distribution to create stochastic FCIs.

An Ordinary Least Squares (OLS) time-series trend regression was used to forecast 20 years of annual rainfall. The forecasted annual rainfall data was distributed with a truncated normal distribution, where the parameters for this distribution were the mean and standard deviation with a minimum of zero, as negative rainfall is impossible. To create stochastic bi-monthly rainfall, the forecasted annual rainfall was multiplied by the stochastic FCI for each of the 20 years. Through the use of IF statements, a set of stochastic zero/one decision variables were created to find when rainfall would be above average for the periods of April-May and June-July in the same year. The zero/one decision variables were simulated 500 times (iterations) to obtain probability distributions of rainfall being greater than a historical average, for the two bi-monthly periods in any given year. When the two periods (April-May and June-July) exhibit greater than average rainfall, fuel load would be large enough to carry an extreme prescribed fire.

The probabilities generated were then used in an integrated brush management model for each of the three regions. Net revenue for each treatment system was generated using GSAT. The model was re-created 14 times to analyze all combinations of the alternative treatment and extreme fire regimes with respect to brush species and canopy cover. A Bernoulli distribution was used in combination with the rainfall probabilities to simulate whether extreme fire or the alternative treatment would be used on each parcel for each of the first ten years. The Bernoulli distribution is a special form of a conditional probability distribution; it is an on/off switch which activates another random variable or decision, it returns a 1, P percent of the time and 0, 1-P percent of the time (Richardson 2006). The treatment costs and deferment periods were tied to the Bernoulli distribution to reflect the differing costs and revenue depending on which initial treatment is selected, based on the forecasted rainfall probabilities.

Within the model, all treatments have a one season pre-treatment deferment; in addition, the alternative treatments are deferred during the season of treatment while extreme prescribed fire treatments are followed by a two-season deferment. This allows the net revenue for each of the first ten years to be stochastic. Through the use of a discount factor, the net revenues were converted and summed to get a stochastic net present value for the model.

A second alternative brush management model that treated the whole ranch in the first year was created to compare with the 10 parcel system. The model was restricted to treating the whole 1,000 acres in the first year. The same rainfall probability for the first year was used, and the same Bernoulli distribution was used for the stochastic brush treatment. This model was re-created 28 times for each of the regions and brush treatment systems, 14 of which assumed a 50 percent costshare for the initial treatments.

The stochastic NPV output variable for each of the 56 combinations was simulated 500 iterations to get a probability distribution. The derived distributions provide information with regard to relative profitability and the risk associated with instituting the brush management options. This allows for managers to analyze the economic efficiency of using extreme fire in combination with other commonly used brush management treatment options in today’s terms.

Results and Discussion

The forecasted rainfall probability distribution was applied to the simulation model to analyze the effect of rainfall risk on various brush treatment systems across the three regions of Texas. The profitability of using an integrated management system with 10 parcels being treated over the first 10 years of a 20 year management horizon (10 year system hereafter) were compared to the profitability of using a one time treatment of the whole ranch in the first year (1^{st} year system hereafter). This comparison was made to analyze the effect of spreading brush treatment of a ranch over years and parcels on investment risk. Due to the assumed two growing season deferment period for extreme fire, the alternative treatments have an advantage, as the landowner is able to use the land the year following initial treatment.

Rolling Plains

All eight treatment combination systems generated negative NPVs (Table 14). In each brush situation, spreading the treatment over 10 years, generated less negative mean NPVs than treating the entire ranch in year one. With an assumed 50 percent costshare, the 10 year system produced a positive expected value (mean) NPV, while all 1^{st} year systems remained negative.

The moderate mesquite 10 year system with IPT of 0.5 percent ea. Remedy and Reclaim and extreme fire, exhibited the highest mean NPV ($-4.18 per acre - Table 14). The 10 year system for Heavy prickly pear cover exhibited less financial risk (smaller NPV standard deviation) than the 1^{st} year system (Table 14). The first year system of treating heavy prickly pear had a 25.2 percent chance of producing positive economic returns, which reflects the initial treatment choice being extreme prescribed fire. Treating moderate prickly pear with the 1st year system exhibited a standard deviation of NPV 3 ½ times larger than the 10 year system with ($4.97 vs. $1.35 per acre). With 50 percent costshare, the 10 year system for treating prickly pear and mesquite in the Rolling Plains had greater than 50 percent chance of returning a positive NPV (nearly 95 percent for heavy and moderate mesquite – Table 14).

Table 14. Rolling Plains Net Present Value Statistics

	*Brush Treatment Combination	Mean	Standard deviation	Range Minimum	Range Maximum	Probability NPV > zero
		$s per acre				
Heavy Prickly Pear:	10 year system	-9.19	2.82	-14.46	1.28	0.001624
	1st year system	-15.54	10.66	-21.76	2.72	0.252222
	10 year system (50% costshare)	0.19	1.29	-2.22	4.99	0.532425
	1st year system (50% costshare)	-3.30	4.75	-6.07	4.84	0.252887
Moderate Prickly Pear:	10 year system	-6.29	1.35	-8.82	-1.26	0.000000
	1st year system	-10.41	4.97	-13.30	-1.90	0.000000
	10 year system (50% costshare)	-0.87	0.61	-2.01	1.40	0.090435
	1st year system (50% costshare)	-3.36	2.09	-4.58	0.23	0.252095
Heavy Mesquite:	10 year system	-7.94	2.91	-13.38	2.88	0.010190
	1st year system	-14.40	11.04	-20.83	4.51	0.252356
	10 year system (50% costshare)	1.78	1.32	-0.68	6.68	0.948169
	1st year system (50% costshare)	-1.72	4.88	-4.56	6.63	0.253185
Moderate Mesquite:	10 year system	-4.18	1.22	-6.46	0.36	0.001005
	1st year system	-7.96	4.41	-10.54	-0.40	0.000000
	10 year system (50% costshare)	0.98	0.53	-0.02	2.94	0.949880
	1st year system (50% costshare)	-1.27	1.74	-2.28	1.72	0.252859

The invasive brush species and canopy cover are listed on the left.
The treatment combinations are the same. The (10 yr) system is; one 100 acre parcel being treated each of the first 10 years. The (1st yr) system is; the entire 1000 acres being treated with extreme fire or the alternative treatment.
A 50% costshare is assumed for the two systems for each species and listed below the respective NPV figures.
*Maintenance cool season fire every 6 years following initial treatment. Both the 10 parcel system and the whole ranch system.

Heavy mesquite canopy cover 10 year system of aerial applied ¼ lb. ea/ac Remedy and Reclaim with extreme fire was compared to the 1st year system, using ¼ lb. ea/ac Remedy and Reclaim or extreme fire. The 10 year system exhibited a higher mean NPV of $-7.94 per acre, than the 1st year system which was $-14.44 per acre. In addition, the 10 year system had less risk (NPV standard deviation $2.91 per acre) compared to the 1st year system with a NPV standard deviation of $11.04 per acre (Table 14). Moderate mesquite treatment combination was chemical IPT of 0.5 percent ea Remedy and Reclaim with water and extreme fire for the 10 year and 1st year systems. The 10 year system offered higher returns, mean NPV $-4.18 per acre and less risk, standard deviation of $1.22 per acre compared to the 1st year system of mean NPV $-7.96 per acre and standard deviation of $4.41 per acre (Table 14).

While the mean NPV for each treatment for each brush scenario was negative, in 5 of the 8 scenarios a positive NPV was possible (heavy pear, heavy mesquite, and moderate mesquite with extreme fire), as shown by the maximum NPV. In the case of heavy pear and mesquite, the maximum NPV realized in simulation was from treating all range in year one, which reflects the use of extreme prescribed fire as the initial treatment.

Edwards Plateau

In all six comparisons between treatment horizons (10 year and 1st year systems) the 10 year system was economically superior, with greater mean NPVs and less risk, with lower NPV standard deviations (Table 15).

Heavy ashe and redberry juniper were analyzed together as they both had the same alternative brush treatments. The 10 year system of grubbing and stacking with extreme fire had a mean NPV of -$55.99 per acre, while the 1st year system exhibited a small probability of generating positive returns (maximum NPV of $7.60 per acre). The risk for the 1st year grubbing and stacking or extreme fire combination however, exhibited nearly four times the risk with a NPV standard deviation of $51.49 per acre, compared to the 10 year system (standard deviation $13.17 per acre).

Heavy juniper treatment systems of grubbing and extreme fire offered greater returns than the grubbing and stacking treatment horizons. While the 1st year treatment system had a small probability of being positive (maximum NPV of $7.60 per acre) it also had more than three times the risk (standard deviation of $34.56 per acre) of the 10 year system (standard deviation $8.87 per acre – Table 15). These results were expected as initial expense per acre for grubbing and stacking is higher than grubbing alone. The inclusion of both alternative options for heavy juniper is to account for landowner preferences of each treatment.

Moderate juniper cover was broken into two treatment categories; ashe – tree sheer, and redberry – grubbing and stacking. This was done to reflect the resprouting characteristic of redberry juniper, thus rendering tree sheers an ineffective treatment. These mechanical treatments were combined with extreme fire in the 10 year and 1st year systems.

Table 15. Edwards Plateau Net Present Value Statistics

	*Brush Treatment Combination	Mean	Standard deviation	Range Minimum	Range Maximum	Probability NPV > zero
		$s per acre				
Heavy Juniper:	10 year system	-55.99	13.17	-80.39	-7.80	0.000000
(Grubbing & Stacking)	1st year system	-75.29	51.49	-107.21	7.60	0.276132
	10 year system (50% costshare)	-20.65	6.42	-32.55	2.84	0.001653
	1st year system (50% costshare)	-30.43	24.94	-45.89	9.72	0.276350
Heavy Juniper:	10 year system	-34.52	8.87	-50.95	-2.08	0.000000
(Gubbing)	1st year system	-48.04	34.56	-69.47	7.60	0.276197
	10 year system (50% costshare)	-9.92	4.27	-17.83	5.70	0.026642
	1st year system (50% costshare)	-16.80	16.48	-27.02	9.72	0.276529
Moderate Ashe Juniper:	10 year system	-36.23	8.62	-52.20	-4.70	0.000000
	1st year system	-49.74	33.75	-70.66	4.59	0.276122
	10 year system (50% costshare)	-12.30	4.16	-20.00	2.90	0.008051
	1st year system (50% costshare)	-19.35	16.19	-29.39	6.72	0.276372
Moderate Red Juniper:	10 year system	-48.31	11.04	-68.76	-7.92	0.000000
	1st year system	-65.07	43.27	-91.89	4.59	0.276095
	10 year system (50% costshare)	-18.34	5.37	-28.28	1.29	0.000893
	1st year system (50% costshare)	-27.01	20.95	-40.00	6.72	0.276288
Heavy Mesquite:	10 year system	-10.46	2.55	-15.19	-1.12	0.000000
	1st year system	-16.22	9.91	-22.36	-0.28	0.000000
	10 year system (50% costshare)	-1.96	1.18	-4.15	2.36	0.057209
	1st year system (50% costshare)	-5.42	4.51	-8.21	1.85	0.276367
Moderate Mesquite:	10 year system	-29.77	6.56	-41.93	-5.76	0.000000
	1st year system	-40.85	25.66	-56.76	0.47	0.276017
	10 year system (50% costshare)	-11.21	3.18	-17.09	0.41	0.000472
	1st year system (50% costshare)	-17.27	12.34	-24.92	2.60	0.276189

The invasive brush species and canopy cover are listed on the left.
The treatment combinations are the same. The (10 yr) system is; one 100 acre parcel being treated each of the first 10 years. The (1st yr) system is; the entire 1000 acres being treated with extreme fire or the alternative treatment.
A 50% costshare is assumed for the two systems for each species and listed below the respective NPV figures.
*Maintenance cool season fire every 6 years following initial treatment. Both the 10 parcel system and the whole ranch system.

The moderate ashe juniper 1st year system exhibited a small probability of being positive, maximum NPV of $4.59 per acre while the 1st year system, had a negative mean NPV of $-36.23 per acre (Table 15). The 1st year treatment standard deviation was more than three times greater than the 10 year treatment with a NPV standard deviation of $33.75, compared to $8.62 per acre for the 10 year system (Table 15). The moderate redberry juniper systems both had negative mean NPVs; however, the 1st year system did have a small probability of being positive with a maximum NPV of $4.59 per acre.

The treatment combination for heavy mesquite cover was aerial applied herbicide of ¼ lb. ea/ac Remedy and Reclaim with extreme fire. Unique in the region, the 1st year system did not have a chance of being a positive NPV (Table 15). Though, it was still over three times as risky to use the 1st year system to treat heavy mesquite. The treatment of heavy mesquite produced the least risk (standard deviation $1.18 per acre) of any scenario in the Edwards Plateau (Table 15). Moderate mesquite treatment system included extreme fire and chemical IPT of 15% Remedy with diesel mix, for both 10 and 1st year. The 1st year system had a small probability of having a positive NPV (max NPV $.47 per acre). While the 10 year system had no chance of a positive NPV (max NPV $-5.76 per acre), it had less financial risk. Assuming a 50 percent costshare, all 12 scenario combinations did have a chance of producing a positive NPV.

South Texas Plains

In the South Texas Plains, all four huisache treatment systems yielded a negative NPV (max NPVs were negative), while three of the four mesquite treatment systems had a small probability of generating positive returns, with maximum NPVs being positive (Table 16). Even with the assumption of 50 percent costshare, the expected NPV (mean) remained negative for all scenarios but risk (standard deviation) was reduced when compared to initial scenarios. The treatment combination for heavy huisache cover was an aerial application of 3 pints/ac Grazon P+D and extreme fire. Though both negative, the 1st year system had potentially higher returns, maximum NPV of $-2.63 compared to maximum NPV of $-4.77 per acre for the 10 year system, but exhibits much more risk. Moderate huisache was treated with chemical IPT of 15 percent Remedy with diesel mix and extreme fire. The 10 year system for moderate huisache generated a negative mean NPV of $-31.53 per acre but had much less risk, with a standard deviation of $6.51 compared to $23.79 per acre for the 1st year system (Table 16).

Table 16. South Texas Plains Net Present Value Statistics

	*Brush Treatment Combination	Mean	Standard deviation	Range Minimum	Range Maximum	Probability NPV > zero
		$s per acre				
Heavy Huisache:	10 year system	-20.33	4.12	-27.83	-4.77	0.000000
	1st year system	-27.44	14.72	-36.16	-2.63	0.000000
	10 year system (50% costshare)	-8.36	2.11	-12.19	-0.39	0.000000
	1st year system (50% costshare)	-14.31	8.19	-19.16	-0.51	0.000000
Moderate Huisache:	10 year system	-31.53	6.51	-43.40	-6.94	0.000000
	1st year system	-41.20	23.79	-55.29	-1.10	0.000000
	10 year system (50% costshare)	-13.45	3.31	-19.48	-0.95	0.000000
	1st year system (50% costshare)	-20.22	12.60	-27.68	1.02	0.258071
Heavy Mesquite:	10 year system	-14.55	4.00	-21.84	0.57	0.000535
	1st year system	-20.50	13.98	-28.78	3.07	0.258193
	10 year system (50% costshare)	-2.72	2.02	-6.38	4.91	0.087316
	1st year system (50% costshare)	-7.54	7.56	-12.02	5.19	0.258603
Moderate Mesquite:	10 year system	-30.46	6.75	-42.77	-4.98	0.000000
	1st year system	-40.28	24.64	-54.88	1.25	0.258045
	10 year system (50% costshare)	-11.71	3.41	-17.93	1.19	0.001313
	1st year system (50% costshare)	-18.43	12.94	-26.09	3.37	0.258229

The invasive brush species and canopy cover are listed on the left.
The treatment combinations are the same. The (10 yr) system is; one 100 acre parcel being treated each of the first 10 years. The (1st yr) system is; the entire 1000 acres being treated with extreme fire or the alternative treatment.
A 50% costshare is assumed for the two systems for each species and listed below the respective NPV figures.
*Maintenance cool season fire every 4 years following initial treatment. Both the 10 parcel system and the whole ranch system.

Heavy mesquite cover was treated with an aerial application of ¼ lb. ea/ac of Remedy and Reclaim with extreme fire for both 10 year and 1st year systems. The 10 year and the 1st year systems had mean NPVs of -$14.55 and -$20.50 per acre, respectively. However both had the possibility of being positive NPVs. There was higher return potential for the 1st year system (max NPV $3.07 per acre), but less risk for the 10 year system (standard deviation $4.00) compared to a NPV standard deviation of $13.98 per acre for the 1st year system (Table 16).

The treatment combination for moderate mesquite cover was chemical IPT of 15 percent Remedy with diesel mix and extreme fire. The 10 year system offered less risk (standard deviation NPV $6.75 per acre) however, like heavy mesquite, there was higher return potential with a greater maximum NPV (Table 16). When costs are shared at 50 percent from an outside entity, the risk is greatly reduced for the landowner, which is reflected in the smaller NPV standard deviations in the previous three Tables (14,15,16).

Discussion

A deterministic version of the weather risk model was created using GSAT. The following Table (17) provides the NPV output from the deterministic model. The treatments were used in year one of a twenty year planning horizon for the whole ranch, without the option of using the alternative mechanical or herbicide treatment if extreme fire was not an option due to weather conditions.

Table 17. Three Texas Regions - Deterministic Model: Net Present Values

Rolling Plains	**Brush Treatment**	***Total NPV for Scenario**
		$s per acre
Invasive Species		
Heay Prickly Pear:	Aerial Chemical, 1/2 lb. Picloram/ac	-21.81
	Extreme Fire	5.31
Moderate Prickly Pear:	Chemical IPT, 1% Surmount w/water	-13.36
	Extreme Fire	-0.15
Heavy Mesquite:	Aerial Chemical, 1/4ea Remedy&Reclaim/ac	-20.89
	Extreme Fire	7.41
Moderate Mesquite:	Chemical IPT, .5% ea Remedy/Reclaim w/water	-10.59
	Extreme Fire	1.67
Edwards Plateau		
Heavy Ashe/Redberry Juniper:	Grubbing and Stacking	-107.26
	Gurbbing	-69.53
	Extreme Fire	11.13
Moderate Ashe Juniper:	Tree Sheer	-70.72
	Extreme Fire	7.58
Moderate Redberry Juniper:	Grubbing and Stacking	-91.95
	Extreme Fire	7.58
Heavy Mesquite:	Aerial Chemical, 1/4 lb. ea/ac Remedy&Reclaim	-22.42
	Extreme Fire	1.64
Moderate Mesquite:	Chemical IPT, 15% Remedy w/diesel	-56.99
	Extreme Fire	2.62
South Texas Plains		
Heavy Huisache:	Aerial Chemical, 3 Pints/ac Grazon P+D	-39.25
	Extreme Fire	-0.31
Moderate Huisache:	Chemical IPT, 15% Remedy w/diesel	-58.16
	Extreme Fire	2.01
Heavy Mesquite:	Aerial Chemical, 1/4 lb. ea/ac Remedy&Reclaim	-31.87
	Extreme Fire	6.60
Moderate Mesquite:	Chemical IPT, 15% Remedy w/diesel	-57.97
	Extreme Fire	4.56

*NPVs from using the stated tretment option in year one of a 20 year horizon for the three regions.
(figures from GSAT, Chapter III)

As Table 17 contains, all mechanical and herbicide treatments in the three regions generated negative NPVs. All but two extreme fire scenarios generated positive returns (the two being only marginally negative). The limitation with this analysis is that it provides no insight into the risk involved with the treatment options. If the figures in

Table 17 were the only information available to a landowner, he/she would always use extreme fire to treat brush. However, when weather risk is factored in and the option of using either treatment for a given brush species, the NPVs offer important decision information. The difference is due to the option of using extreme prescribed fire when weather conditions permit and limiting the alternative, more costly treatment methods for the other years. Additionally, when treatments are spread over years and parcels the landowner is more likely to get favorable weather conditions for extreme fire which is substantially cheaper on a per acre basis.

With the inclusion of forecasted weather data and stochastic choice variables of the alternative treatment and/or extreme fire, NPV risk is greatly reduced and probability of NPV amount can be obtained. The following figures contain NPV probability distributions for 10 year and 1st year mesquite treatment systems for all three regions.

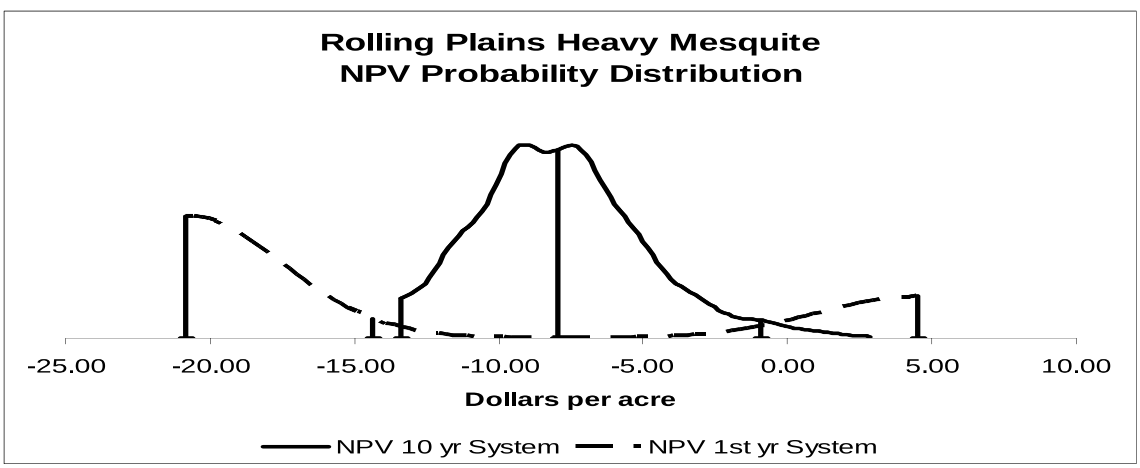

Figure 1. Probability distribution of NPVs for 10 and 1st year heavy mesquite treatment systems in the Rolling Plains. The values are expressed in dollars per acre.

Figure 1 illustrates the wider distribution of NPV for the heavy mesquite 1st year system compared to spreading out treatment over time and space. The outcome of using the 1st year system to treat heavy mesquite in the Rolling Plains is either about -$20.00 per acre or about $5.00, there's little chance for NPV to be between the two extremes. This is due to the Bernoulli distribution built into the model which is a choice variable that randomly selects either an alternative treatment or extreme fire in year one. The left side of the distribution reflects the probability of using the alternative treatment and the right side illustrates the NPV returns when extreme prescribed fire is used as the initial treatments.

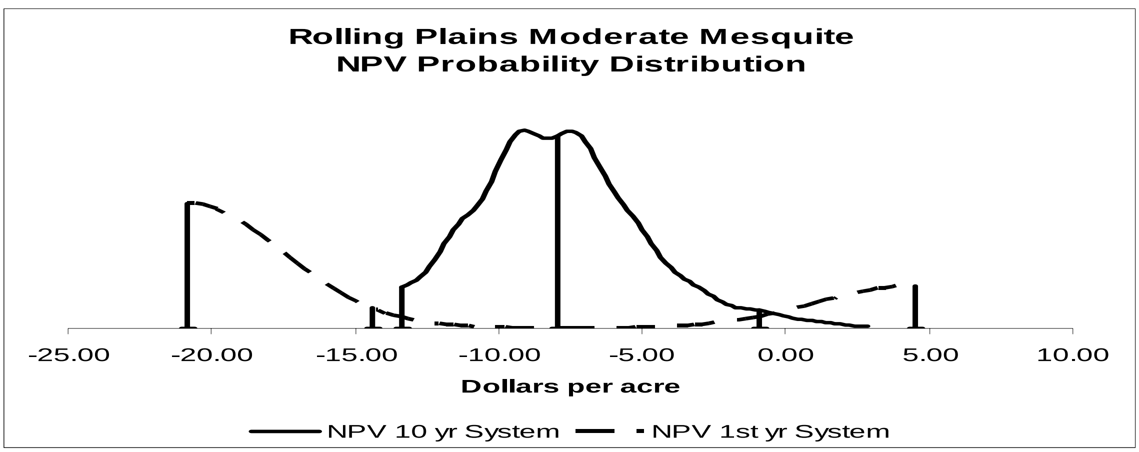

Figure 2. Probability distribution of NPVs for 10 and 1st year moderate mesquite treatment systems in the Rolling Plains. The values are expressed in dollars per acre.

As with treating heavy mesquite, moderate mesquite being treated over a 10 year period had less risk (Figure 2). While the distribution is mostly negative for the 10 year system, there is a small probability of getting positive NPV returns.

The Edwards Plateau exhibits the same characteristics as the Rolling Plains, as the 1st year system distributions are much wider (Figures 3 & 4).

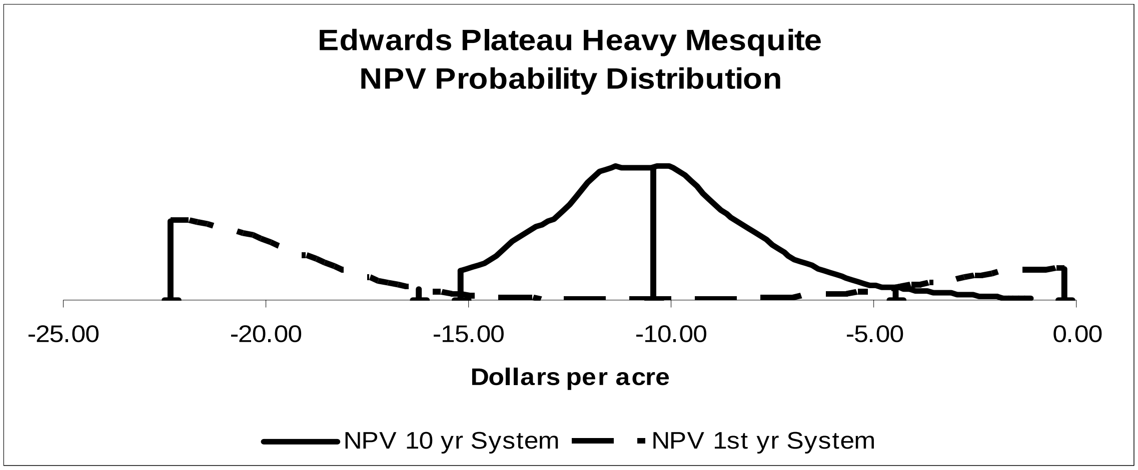

Figure 3. Probability distribution of NPVs for 10 and 1st year heavy mesquite treatment systems in the Edwards Plateau. The values are expressed in dollars per acre.

The 1st year treatment system for heavy mesquite in the Edwards Plateau has a more than $5.00 per acre wider distribution of NPV than the 10 year system (Figure 3).

The NPV distribution for moderate mesquite (Figure 4) is even more uncertain for a 1st year system than for treatment of heavy mesquite (Figure 3), this is mainly due to the higher cost of IPT treatment when compared to aerial.

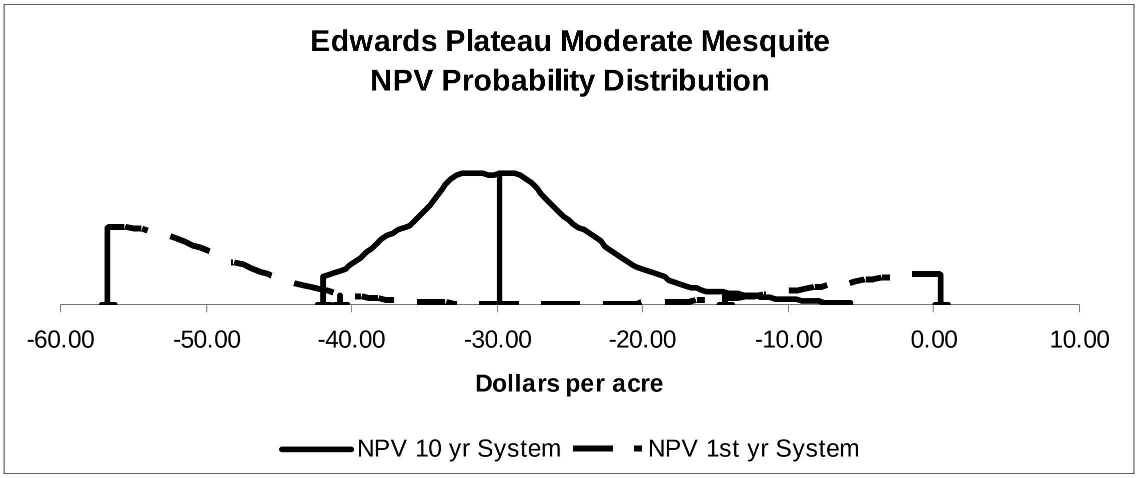

Figure 4. Probability distribution of NPVs for 10 and 1st year moderate mesquite treatment systems in the Edwards Plateau. The values are expressed in dollars per acre.

In the South Texas Plains, the NPV distributions for 10 year treatment systems of both heavy and moderate mesquite are wider than in the other two regions (Figures 5 & 6). The 10 year distribution however, is still smaller than the alternative 1st year systems.

Though the 1st year treatment of heavy mesquite in South Texas could offer higher NPV returns (greater max NPV), figure 5 illustrates that less risk is involved with using the 10 year system.

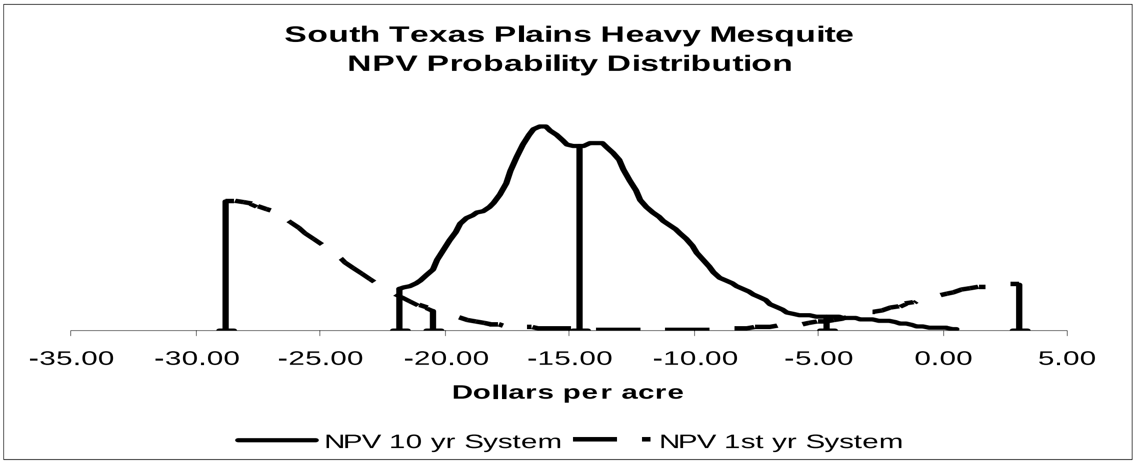

Figure 5. Probability distribution of NPVs for 10 and 1st year heavy mesquite treatment systems in the South Texas Plains. The values are expressed in dollars per acre.

As expressed in figure 6, the risk is much lower to institute a 10 year system for treating moderate mesquite in South Texas even though the 1st year system offers a slight chance of being positive.

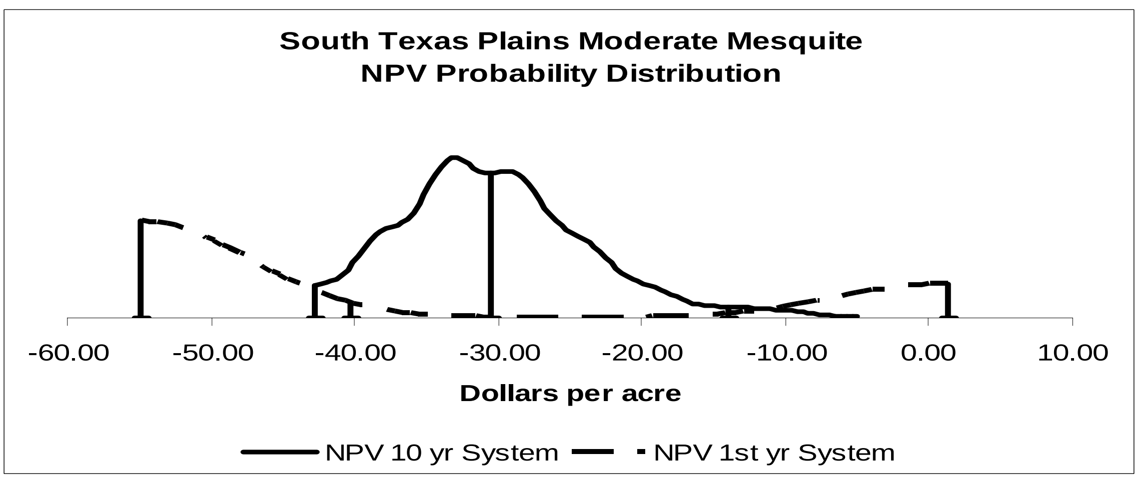

Figure 6. Probability distribution of NPVs for 10 and 1st year moderate mesquite treatment systems in the South Texas Plains. The values are expressed in dollars per acre.

Figures one through six represent visually, the data from the results section. The figures (graphs) allow a decision maker to see the range of possible NPV returns for the given treatment scenario. The graphs illustrate that across all regions and invasive brush species, it is less risky to manage brush over time and space (years and parcels) than to treat the whole ranch at one time in the 1st year.

Summary and Conclusions

Leaving invasive brush species untreated over a 20 year period can become a more costly problem than what it would take to begin treatment today. Left untreated, all the invasive species covered in this study would move from moderate cover to near heavy cover within 20 years. The increase of invasive brush species reduces carrying capacity and can hinder wildlife habitat, decreasing potential economic returns from the land. Landowners are faced with a choice of brush management practices. This study illustrates the economic benefit of including extreme fire in an IBMS over a multi-year period to account for the weather risk of using fire in any given year.

The inclusion of weather (rainfall) risk along with treating the representative ranch over the first 10 years of a 20 year planning horizon proved to reduce NPV risk for all treatment system comparisons, and with 50 percent costshare the reduction was even greater. An additional advantage to treating one parcel a year for 10 years is the option for rotational grazing. When treating only part of the ranch, a landowner would not have to lease alternative land for livestock, as would be the case for the 1st year treatment system. Though not included in this study, the cost of leasing land while treating an entire ranch, as the 1st year system assumes, would be costly.

This study assumed rainfall would have to be above average from April to July to generate enough fuel load to carry an extreme fire. The simulated rainfall data for the next 10 years exhibited about a one in four chance of having extreme fire conditions each year, thus the practice should be included in an IBMS and not relied upon completely.

Management Implications

This study illustrates that including extreme fire in an IBMS along with other commonly used treatment options, over a ten year period, significantly reduces risk. By spreading invasive brush treatment over time and acreage a landowner can use extreme fire when the weather conditions permit and use more costly alternative management practices when fire is not an option. In agreement with common knowledge (Dr. Charles Taylor, Texas A&M Experiment Station, Sonora TX., Personal Communication 2006) this study suggests that landowners use extreme prescribed fire opportunistically and other treatments if conditions for fire are not suitable. Additionally, costshare is an important component to reducing risk for the landowner and should be available to landowners when using extreme fire.

CHAPTER V

SUMMARY AND CONCLUSIONS

The increase of invasive brush species on Texas rangeland over the last two centuries requires that many landowners invest in management of the brush present in their region. The implementation of economically efficient and effective methods of brush treatment, that allow for maximum herbaceous forage, and wildlife habitat response is the goal of many Texas landowners. Due to exogenous variables such as weather, fuel prices, environmental concerns, brush response, and others, the costs and benefits from implementing some brush management practices can be difficult to estimate in advance. The cost of many brush treatment options are high, and in combination with exogenous variables, instituting any given treatment can be very risky. Through the use of software programs such as GSAT and SIMITAR, landowners can plan into the future and reduce overall risk. In addition, through publicly funded programs, like the NRCS EQIP program, landowners can, in many cases, receive costshare payments to partially off-set the expense and risk of implementing brush management practices on their rangeland.

When brush is not controlled over a 20 to 30 year period, it can lead to levels of cover that reduce herbaceous production for livestock grazing and even hinder wildlife habitat (Teague et al. 2001). This is a serious concern to many landowners since the two main sources of income for Texas rangeland owners are livestock grazing and wildlife lease hunting. Thus, implementation of brush management practices is best not delayed; rather, canopy cover should be reduced in a timely manner so that the revenue producing aspects of the rangeland are improved as soon as possible. Landowners are faced with the choice of which brush management practice to use and since each ranch is unique, the conclusions from this study are not intended to be universal.

Problem Statement

The goal of this study is to assess the economic feasibility of restoring rangeland health in the Southern Plains, specifically Texas, using extreme fires compared to the other most commonly used brush treatment methods. An additional goal is to assess the difference in risk associated with including extreme fire in a brush treatment regime. The results will facilitate a review of current NRCS technical standards with regard to prescribed extreme fire. Current standards seem arbitrary and could be restricting landowners from using extreme burns to manage their land.

The hypothesis to be tested in this study is that extreme fire is economically superior to other commonly used brush management practices. This hypothesis does not infer that alternatives are not effective means of treating brush problems, but that extreme fire will provide comparable, or superior, vegetative results at lower total cost. It is also important to note that like most other mechanical or chemical brush management practices, extreme fire is often most effective when combined with other follow-up management practices, usually over a multi-year period. The objectives are designed to accomplish an economic analysis that maximizes the benefit of the study for the NRCS, and private landowners.

Objectives

The first objective of this study was to evaluate the economic effectiveness of using prescribed extreme burns as a rangeland restoration tool compared to other rangeland restoration strategies: Herbicide, mechanical and cool season fire. This was achieved through the use of GSAT and SIMITAR, by examining the costs, returns, and risk involved with the use of extreme fire for rangeland restoration. The second objective is to provide the results of this study to the NRCS to aid them in determining whether the technical standards of using extreme fire should be altered. The third and fourth objectives were to use GSAT results in combination with simulation risk modeling to evaluate the economic efficiency of using extreme fire as part of an integrated brush management system.

Results

Extreme fire, in all cases, was economically superior to the other commonly used brush treatment methods. In addition, extreme fire treatments were economically feasible, with exceptions, which produced only marginally negative NPVs. Extreme fire treatments of moderate prickly pear in the Rolling Plains and heavy huisache in the South Texas Plains would become feasible with a conservative amount of cost sharing. In many cases, extreme fire internal rates of return were double or triple the discount rate. Thus investing in extreme fire as a treatment method is better than many alternative investment activities.

When extreme fire was included with the most commonly used treatment methods in each region, assuming whole ranch treatment in year one, though negative, the NPVs were higher than just using the alternative treatment (mechanical or herbicide) alone. The inclusion of weather (rainfall) risk along with treating the representative ranch over the first 10 years of a 20 year planning horizon proved to significantly reduce NPV risk for all treatment systems compared to treating the whole ranch in the first year. All the 10 year systems exhibited negative mean NPVs; however, with cost share many became economically feasible and further reduced the risk.

Management Implications

These results suggest extreme fire should be adopted as an effective, economically efficient brush management option for Texas rangeland owners. Extreme fire is still a relatively new and minimally used brush treatment; however this research should contribute to making the method more prevalent on ranches across Texas. In addition the results should contribute to the review of current NRCS technical standards for the use of extreme fire.

By spreading invasive brush treatment over time and acreage a landowner can use extreme fire when the weather conditions permit and use more costly alternative management practices when fire is not an option. In agreement with common knowledge (Dr. Charles Taylor, Texas A&M Experiment Station, Sonora TX., Personal Communication 2007) this study suggests that landowners use extreme prescribed fire when they can and other treatments if conditions are not suitable. This study, along with others should increase the likelihood of using extreme fire more often in the future.

Additionally, the inclusion of costshare further reduces risk when combined with treating a ranch over 10 years and over 10 parcels. The NRCS should modify their technical standards to include extreme fire. Due to the lower cost of prescribed fire and the assumed forage response when extreme fire is used, the NRCS could treat much more land with costshare funds than when using alternative methods.

Further Research

Through the use of a more extensive simulation model, that includes specific data such as head of livestock, and target wildlife species (type of hunting-leases), and fuel moisture to name a couple, more detailed information could be provided to individual landowners. Fuel moisture content is something that should be included in future models when the data becomes available. Recent research indicates that moisture content of the fuel load may be more important than total fuel load when instituting an extreme prescribed fire (Dirac Twidwell, Texas A&M University, College Station TX, Personal Communication 2007).

Though the possibility of burn bans was assumed non existent in our study, there is the possibility of bans preventing the use of extreme fire. This must be taken into account when planning to use extreme fire in an integrated brush management system. One possible solution to the risk of being prevented from using extreme fire due to a burn ban is through membership of a prescribed burn association. A successful example of a burn association is the one in the Edwards Plateau, started by Dr. Butch Taylor where the members are able to burn during burn bans.

The brush treatment alternatives to prescribed fire were selected based on frequency of use in each region along with the average cost per acre for each method; further research could focus on different treatment alternatives. This study was limited to only the two most common invasive brush species for each region, when there are many brush species landowners confront on Texas rangeland.

The attitudes of landowners toward extreme fire was not accounted for in this study, however, could play a defining role in how widely the practice is accepted. It is human nature to be adverse to change, so a study which examined landowner attitudes toward extreme fire and offered answers to their concerns could be valuable in making the brush treatment practice a more commonly used tool in Texas.

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APPENDIX A

Table 18. Rolling Plains Cost and Revenue Statistics

Prickly Pear	**Moderate Canopy Cover 20-30%**	**Cost per acre**
Initial Treatment	Chemical IPT 1% Surmount	$18.50
	Extreme Fire	$4.50
	Cool Season Fire	$4.50
	Heavy Canopy Cover >50%	
	Aerial Chemical, 1/2 lb. Picloram per acre	$33.25
	Extreme Fire	$4.50
	Cool Season Fire	$4.50
Mesquite	**Moderate Canopy Cover 20-30%**	
Initial Treatment	Chemical IPT, Remedy/Reclaim mix	$17.50
	Extreme Fire	$4.50
	Cool Season Fire	$4.50
	Heavy Canopy Cover >50%	
	Aerial Chemical, 1/4 lb. ea. Reclaim Remedy	$34.50
	Extreme Fire	$4.50
	Cool Season Fire	$4.50
Lease Rates		
	Livestock - Grazing	$5.50
	Wildlife - Hunting Deer/Quail	$10.00

Brush treatments and costs per acre, extreme and cool season fire along with the most commonly used alternative prickly pear and mesquite treatments. The lease rates for grazing and hunting are listed at the bottom

Table 19. Edwards Plateau Cost and Revenue Statistics		
Redberry Juniper	**Moderate Canopy Cover 20-30%**	**Cost per acre**
Initial Treatment	Mechanical,Grubbing&Stacking	$110.00
	Extreme Fire	$4.50
	Cool Season Fire	$4.50
	Heavy Canopy Cover >50%	
	Mechanical, Grubbing	$90.00
	Mechanical, Grubbing&Stacking	$130.00
	Extreme Fire	$4.50
	Cool Season Fire	$4.50
Ashe Juniper	**Moderate Canopy Cover 20-30%**	
	Mechanical, Tree Sheer	$87.50
	Extreme Fire	$4.50
	Cool Season Fire	$4.50
	Heavy Canopy Cover >50%	
	Mechanical, Grubbing	$90.00
	Mechanical, Grubbing&Stacking	$130.00
	Extreme Fire	$4.50
	Cool Season Fire	$4.50
Mesquite	**Moderate Canopy Cover 20-30%**	
	Chemical IPT, Diesel/Remedy mix	$67.50
	Extreme Fire	$4.50
	Cool Season Fire	$4.50
	Heavy Canopy Cover >50%	
	Chemical Aerial Chemical, 1/4 lb. ea. Remedy	$30.00
	Extreme Fire	$4.50
	Cool Season Fire	$4.50
Lease Rates		
	Livestock - Grazing	$5.50
	Wildlife - Hunting	$8.00
	Deer/Turkey/Exotics/Hogs	

Brush treatments and costs per acre, extreme and cool season fire along with the most commonly used alternative juniper and mesquite treatments. The lease rates for grazing and hunting are listed at the bottom

Table 20. South Texas Plains Cost and Revenue Statistics

Huisache	**Moderate Canopy Cover 20-30%**	**Cost per acre**
Initial Treatment	Chemical IPT, Remedy/Diesel mix	$65.00
	Summer Fire	$4.50
	Cool Season Fire	$4.50
	Heavy Canopy Cover >50%	
	Chemical Aerial Chemical, Grazon P+D	$42.50
	Summer Fire	$4.50
	Cool Season Fire	$4.50
Mesquite	**Moderate Canopy Cover 20-30%**	
	Chemical IPT, Remedy/Diesel mix	$67.50
	Summer Fire	$4.50
	Cool Season Fire	$4.50
	Heavy Canopy Cover >50%	
	Chemical Aerial Chemical, 1/4 lb. ea. Remedy Re	$42.00
	Summer Fire	$4.50
	Cool Season Fire	$4.50
Lease Rates		
	Livestock - Grazing	$9.00
	Wildlife - Hunting Deer/Quail	$11.00

Brush treatments and costs per acre, extreme and cool season fire along with the most commonly used alternative huisache and mesquite treatments. The lease rates for grazing and hunting are listed at the bottom

APPENDIX B

Table 21. Regional Historical (bi-monthly) Rainfall Data

Rolling Plains		**Edwards Plateau**		**South Texas Plains**	
Year	Actual Rainfall	Year	Actual Rainfall	Year	Actual Rainfall
1948	2.646	1948	0.8856	1948	3.045
1948	3.509	1948	4.232	1948	2.9052
1948	8.8504	1948	5.2546	1948	4.6403
1948	0.9504	1948	3.9422	1948	3.8024
1948	2.688	1948	1.582	1948	3.7444
1948	3.508	1948	3.9425	1948	2.5648
1949	2.451	1949	3.06	1949	3.438
1949	6.677	1949	5.6488	1949	7.371
1949	5.3456	1949	4.6999	1949	7.0462
1949	7.5924	1949	6.6286	1949	2.8728
1949	4.076	1949	3.1955	1949	4.5816
1949	1.378	1949	2.7379	1949	2.4668
1950	1.011	1950	1.128	1950	1.89
1950	9.5425	1950	5.2118	1950	6.1776
1950	10.114	1950	6.3554	1950	5.047
1950	8.4294	1950	5.0554	1950	2.9288
1950	0.74	1950	0.1435	1950	0.4876
1950	0.214	1950	0.0323	1950	0.406
1951	1.524	1951	2.28	1951	3.234
1951	5.225	1951	2.093	1951	5.238
1951	4.6488	1951	2.6144	1951	2.4157
1951	6.2532	1951	2.484	1951	5.7008
1951	0.848	1951	0.672	1951	2.1344
1951	0.238	1951	0.3895	1951	0.3108
1952	1.602	1952	1.1616	1952	4.056
1952	6.116	1952	5.681	1952	6.372
1952	2.2568	1952	1.333	1952	2.9498
1952	0.7776	1952	2.5622	1952	6.8488
1952	1.848	1952	1.512	1952	3.335
1952	1.314	1952	1.4478	1952	2.2596
1953	3.432	1953	1.4304	1953	1.92
1953	2.9425	1953	1.9228	1953	5.7132
1953	5.0388	1953	1.6125	1953	1.0535
1953	5.6106	1953	2.0102	1953	6.6696
1953	6.288	1953	2.9225	1953	3.5098
1953	0.82	1953	0.7828	1953	1.9264
1954	0.123	1954	0.444	1954	0.147
1954	10.835	1954	4.2274	1954	5.7672
1954	1.8044	1954	1.6942	1954	5.439
1954	1.0206	1954	1.0718	1954	2.4192
1954	1.76	1954	1.9355	1954	3.6616
1954	3.61	1954	1.1324	1954	1.0276
1955	2.364	1955	0.624	1955	2.721
1955	6.369	1955	1.7756	1955	3.2832
1955	5.85	1955	4.601	1955	3.675
1955	5.8698	1955	5.6258	1955	4.3232
1955	2.444	1955	0.742	1955	1.8124
1955	0.572	1955	0.8626	1955	1.288
1956	1.206	1956	0.7752	1956	0.771
1956	3.212	1956	5.589	1956	2.673
1956	1.0192	1956	1.763	1956	1.3524
1956	1.2204	1956	0.4232	1956	2.1896
1956	2.64	1956	1.8585	1956	2.1252
1956	1.806	1956	0.8683	1956	1.8928
1957	3.609	1957	3.0144	1957	4.188
1957	12.452	1957	11.5276	1957	11.4102
1957	2.9952	1957	2.3349	1957	1.8179

Table 21 cont.

Rolling Plains		**Edwards Plateau**		**South Texas Plains**	
1957	1.755	1957	2.6128	1957	7.9744
1957	8.556	1957	9.695	1957	8.2708
1957	1.422	1957	3.1179	1957	7.5208
1958	2.631	1958	4.2864	1958	6.537
1958	6.4295	1958	3.4408	1958	5.0652
1958	5.2884	1958	3.6034	1958	3.6946
1958	4.8762	1958	6.762	1958	11.5136
1958	2.012	1958	3.199	1958	8.6066
1958	0.33	1958	0.3382	1958	2.646
1959	0.891	1959	1.428	1959	3.297
1959	5.181	1959	3.9882	1959	5.0328
1959	8.6476	1959	7.4648	1959	4.6109
1959	1.0746	1959	3.6524	1959	3.1136
1959	5.948	1959	5.047	1959	6.509
1959	4.022	1959	4.2978	1959	2.6432
1960	1.704	1960	2.1672	1960	3.321
1960	2.079	1960	1.1408	1960	4.2066
1960	6.5416	1960	4.6784	1960	7.7861
1960	3.483	1960	4.0204	1960	6.524
1960	7.708	1960	3.57	1960	11.8312
1960	3.724	1960	5.7361	1960	5.8016
1961	3.909	1961	1.3248	1961	2.898
1961	2.849	1961	1.2788	1961	2.808
1961	8.1796	1961	10.578	1961	6.5611
1961	3.9906	1961	2.5116	1961	2.5312
1961	3.952	1961	4.172	1961	5.2394
1961	1.004	1961	0.38	1961	1.022
1962	1.032	1962	1.1568	1962	1.311
1962	3.311	1962	3.2292	1962	4.8816
1962	9.8072	1962	4.6268	1962	4.2826
1962	11.6046	1962	4.6644	1962	3.8136
1962	5.256	1962	2.492	1962	2.0332
1962	1.092	1962	0.4123	1962	2.8392
1963	2.529	1963	1.344	1963	2.631
1963	5.8905	1963	6.5228	1963	2.8944
1963	4.7788	1963	1.2513	1963	5.0568
1963	2.8404	1963	3.8686	1963	2.1056
1963	3.6	1963	3.9165	1963	5.7546
1963	1.67	1963	3.1369	1963	4.4044
1964	3.33	1964	2.5056	1964	3.423
1964	3.2175	1964	2.7324	1964	2.8134
1964	4.29	1964	2.1113	1964	1.6562
1964	7.9326	1964	9.8578	1964	4.4408
1964	2.852	1964	2.3625	1964	1.8124
1964	1.552	1964	2.7607	1964	3.3852
1965	1.245	1965	3.3432	1965	5.949
1965	7.2985	1965	9.3518	1965	6.5988
1965	2.6624	1965	1.5394	1965	3.304
1965	3.6126	1965	2.3	1965	4.5448
1965	4.016	1965	1.547	1965	5.6056
1965	2.222	1965	1.9266	1965	2.445
1966	1.533	1966	1.8336	1966	8.0352
1966	6.875	1966	5.9478	1966	3.7142
1966	3.3956	1966	1.8103	1966	5.9472
1966	14.0454	1966	8.303	1966	0.5658
1966	1.008	1966	0.469	1966	1.1536
1966	0.074	1966	0.0551	1966	2.277
1967	0.828	1967	1.0392	1967	4.1148
1967	5.0985	1967	3.7628	1967	1.568
1967	6.7028	1967	4.128	1967	15.7864
1967	4.0068	1967	7.0058	1967	4.7978
1967	2.836	1967	3.822	1967	6.384

Table 21 cont.

Rolling Plains		Edwards Plateau		South Texas Plains	
1967	4.898	1967	4.8659	1967	6.384
1968	5.202	1968	3.1104	1968	2.946
1968	5.4285	1968	8.5652	1968	8.2242
1968	5.2572	1968	4.6139	1968	5.8457
1968	3.7368	1968	4.163	1968	5.5608
1968	4.364	1968	3.416	1968	4.554
1968	1.26	1968	0.6612	1968	1.6016
1969	3.876	1969	2.7696	1969	3.588
1969	7.326	1969	5.0508	1969	7.8246
1969	2.86	1969	2.494	1969	2.3961
1969	10.6542	1969	8.3766	1969	4.3512
1969	4.624	1969	7.3115	1969	7.4244
1969	1.52	1969	2.1413	1969	4.242
1970	5.025	1970	3.7152	1970	4.311
1970	3.0965	1970	6.4814	1970	8.0838
1970	0.442	1970	1.849	1970	3.9249
1970	4.8492	1970	5.5154	1970	6.9384
1970	3.012	1970	0.924	1970	0.5014
1970	0.392	1970	0.0456	1970	0.2772
1971	0.822	1971	1.4352	1971	1.02
1971	3.9655	1971	2.9854	1971	2.1384
1971	3.354	1971	5.6545	1971	4.3659
1971	9.8172	1971	8.5192	1971	11.6424
1971	4.7	1971	5.7575	1971	6.2974
1971	2.118	1971	1.4801	1971	3.7324
1972	0.744	1972	0.7536	1972	0.765
1972	5.6485	1972	6.555	1972	5.5674
1972	4.1756	1972	4.9622	1972	5.3214
1972	8.1594	1972	8.6618	1972	5.7232
1972	9.632	1972	2.2785	1972	2.3184
1972	2.938	1972	2.7227	1972	2.3884
1973	5.394	1973	4.1712	1973	4.377
1973	3.7345	1973	2.6864	1973	5.5188
1973	4.7528	1973	7.525	1973	10.2949
1973	6.372	1973	3.6754	1973	11.4184
1973	2.612	1973	6.4365	1973	4.1722
1973	0.358	1973	0.3211	1973	1.7892
1974	1.839	1974	1.236	1974	1.746
1974	4.0535	1974	7.6222	1974	3.8502
1974	3.9832	1974	1.075	1974	2.0972
1974	8.6508	1974	13.3998	1974	10.2368
1974	5.164	1974	4.536	1974	3.8548
1974	2.082	1974	1.9361	1974	0.8988
1975	3.114	1975	1.8672	1975	1.536
1975	7.458	1975	8.004	1975	8.1864
1975	7.0044	1975	5.7964	1975	4.0866
1975	6.5718	1975	3.013	1975	4.4296
1975	2.612	1975	3.514	1975	1.9688
1975	1.692	1975	0.5453	1975	1.2516
1976	1.605	1976	1.5696	1976	0.573
1976	5.401	1976	5.0002	1976	9.8982
1976	4.3524	1976	8.5398	1976	5.1842
1976	4.9896	1976	5.405	1976	6.7368
1976	7.44	1976	7.819	1976	12.1808
1976	1.662	1976	1.8107	1976	4.2588

Table 21 cont.

Rolling Plains		Edwards Plateau		South Texas Plains	
1977	2.439	1977	3.2976	1977	2.079
1977	8.206	1977	7.2496	1977	10.4436
1977	2.3972	1977	2.021	1977	3.1115
1977	2.6622	1977	1.288	1977	1.8648
1977	1.412	1977	3.2865	1977	4.9312
1977	0.586	1977	0.7695	1977	0.7476
1978	3.015	1978	1.9224	1978	1.608
1978	2.6015	1978	2.6358	1978	2.862
1978	3.1408	1978	2.6359	1978	5.3851
1978	8.8398	1978	7.0426	1978	9.716
1978	2.62	1978	3.2025	1978	3.381
1978	2.07	1978	0.7144	1978	3.9732
1979	3.342	1979	3.0048	1979	2.328
1979	3.795	1979	1.8354	1979	7.884
1979	6.058	1979	7.224	1979	7.2324
1979	5.1354	1979	3.8686	1979	4.2112
1979	1.816	1979	1.127	1979	0.7544
1979	2.704	1979	2.5422	1979	2.4108
1980	1.494	1980	1.1256	1980	1.605
1980	6.094	1980	5.1474	1980	6.1722
1980	0.9828	1980	2.7477	1980	1.1025
1980	9.0828	1980	5.9064	1980	8.8872
1980	3.356	1980	3.094	1980	4.002
1980	1.452	1980	2.0881	1980	2.8056
1981	4.209	1981	3.7896	1981	2.022
1981	5.4835	1981	5.6304	1981	6.8526
1981	3.1928	1981	4.4763	1981	8.0066
1981	2.7972	1981	2.8888	1981	5.7792
1981	5.772	1981	5.6315	1981	4.0296
1981	2.1	1981	0.741	1981	0.91
1982	1.518	1982	2.0088	1982	4.032
1982	12.518	1982	6.4584	1982	5.7294
1982	8.6684	1982	5.1729	1982	2.0384
1982	2.4354	1982	2.0562	1982	4.1776
1982	2.916	1982	2.905	1982	7.7096
1982	3.948	1982	3.6841	1982	1.904
1983	2.655	1983	2.8296	1983	5.043
1983	6.138	1983	2.0976	1983	2.079
1983	4.4096	1983	3.8614	1983	7.1932
1983	1.3284	1983	1.7342	1983	7.084
1983	7.968	1983	2.7685	1983	3.634
1983	0.844	1983	1.5181	1983	2.968
1984	2.388	1984	0.9576	1984	1.608
1984	0.7755	1984	1.8308	1984	2.1006
1984	2.4128	1984	3.9302	1984	1.8228
1984	3.8826	1984	1.0626	1984	2.0832
1984	6.232	1984	5.586	1984	6.9782
1984	3.938	1984	5.4929	1984	5.4376
1985	5.898	1985	2.448	1985	3.711
1985	5.94	1985	4.6506	1985	7.344
1985	4.3108	1985	7.1896	1985	5.831
1985	3.8772	1985	4.1078	1985	5.7736
1985	4.228	1985	2.072	1985	8.8688
1985	0.206	1985	0.2318	1985	2.1476
1986	2.304	1986	1.6656	1986	0.924
1986	5.6375	1986	5.5614	1986	4.3092
1986	7.02	1986	4.6698	1986	5.6497
1986	7.7166	1986	4.4068	1986	3.5672
1986	9.148	1986	8.008	1986	8.395
1986	2.482	1986	3.9539	1986	6.2188

Table 21 cont.

Rolling Plains		Edwards Plateau		South Texas Plains	
1987	5.121	1987	4.356	1987	4.674
1987	8.6185	1987	4.4206	1987	3.9798
1987	5.6992	1987	5.9426	1987	7.9968
1987	4.2984	1987	6.21	1987	4.06
1987	0.404	1987	1.2005	1987	2.6542
1987	3.93	1987	1.121	1987	2.198
1988	1.947	1988	0.8616	1988	1.032
1988	2.5245	1988	3.2522	1988	4.4496
1988	7.1916	1988	5.8609	1988	4.557
1988	6.7662	1988	3.9422	1988	3.388
1988	0.94	1988	0.6405	1988	1.3156
1988	1.71	1988	2.1755	1988	2.9512
1989	3.951	1989	5.3976	1989	1.359
1989	5.6375	1989	2.967	1989	3.2616
1989	6.1568	1989	1.6684	1989	3.0723
1989	9.315	1989	2.7554	1989	2.4192
1989	0.408	1989	2.2085	1989	4.2826
1989	1.638	1989	1.3471	1989	1.9068
1990	6.858	1990	5.2464	1990	4.407
1990	10.813	1990	6.3756	1990	4.941
1990	5.0232	1990	4.8461	1990	7.6979
1990	5.9238	1990	8.1328	1990	4.7208
1990	3.076	1990	4.375	1990	2.5576
1990	4.054	1990	2.5593	1990	3.542
1991	0.411	1991	1.0512	1991	4.488
1991	6.0445	1991	4.1032	1991	5.3244
1991	6.1932	1991	7.8776	1991	7.0707
1991	7.3926	1991	6.0766	1991	5.796
1991	2.364	1991	2.065	1991	1.3938
1991	6.122	1991	8.1719	1991	13.6164
1992	5.25	1992	5.5944	1992	7.269
1992	5.4835	1992	4.8898	1992	12.5982
1992	8.5696	1992	6.4113	1992	4.8804
1992	3.5316	1992	1.9366	1992	2.1952
1992	3.712	1992	2.184	1992	2.9486
1992	2.508	1992	2.2211	1992	2.5592
1993	5.364	1993	3.2376	1993	3.699
1993	4.8455	1993	4.531	1993	8.2944
1993	4.7476	1993	3.0229	1993	4.7334
1993	4.3902	1993	3.8594	1993	1.624
1993	2.912	1993	1.3965	1993	3.2476
1993	1.618	1993	2.5745	1993	2.4304
1994	2.589	1994	0.9936	1994	5.937
1994	6.6165	1994	5.5016	1994	8.9154
1994	1.014	1994	2.1672	1994	5.2234
1994	4.1526	1994	4.1952	1994	3.8248
1994	4.664	1994	5.362	1994	6.0214
1994	2.346	1994	2.9811	1994	3.2928
1995	1.923	1995	2.4696	1995	3.348
1995	8.646	1995	5.9938	1995	5.0652
1995	6.3232	1995	4.9106	1995	3.9935
1995	10.6758	1995	5.0002	1995	4.7488
1995	2.44	1995	2.59	1995	2.9808
1995	1.206	1995	0.5225	1995	2.3576
1996	2.118	1996	1.3872	1996	1.386
1996	1.441	1996	8.5928	1996	3.3912
1996	6.7392	1996	5.5126	1996	6.1005
1996	14.85	1996	7.1622	1996	9.352
1996	4.012	1996	3.0205	1996	2.8842

Table 21 cont.

Rolling Plains		Edwards Plateau		South Texas Plains	
1997	4.173	1997	5.7984	1997	2.982
1997	7.7165	1997	4.4344	1997	7.7598
1997	4.8308	1997	6.3554	1997	6.9531
1997	4.3578	1997	1.7204	1997	4.34
1997	4.756	1997	2.219	1997	5.5982
1997	4.118	1997	1.8354	1997	2.0888
1998	5.169	1998	3.5688	1998	5.838
1998	1.4465	1998	1.035	1998	0.864
1998	3.5412	1998	3.0315	1998	1.2789
1998	1.4796	1998	7.1392	1998	11.7712
1998	4.44	1998	3.955	1998	9.66
1998	3.514	1998	0.9823	1998	0.84
1999	5.058	1999	1.5696	1999	2.241
1999	7.788	1999	3.6846	1999	2.4732
1999	5.122	1999	4.3516	1999	6.9139
1999	1.998	1999	0.7774	1999	2.3744
1999	1.684	1999	1.4385	1999	0.4462
1999	1.25	1999	0.5263	1999	1.6044
2000	4.674	2000	1.1136	2000	2.736
2000	3.3825	2000	3.542	2000	4.3902
2000	4.6488	2000	5.0052	2000	4.6403
2000	0.0486	2000	2.4288	2000	2.4416
2000	8.508	2000	9.1105	2000	7.4336
2000	2.734	2000	2.1242	2000	2.2512
2001	7.518	2001	3.6912	2001	2.34
2001	3.454	2001	3.1326	2001	3.4884
2001	0.6188	2001	1.6469	2001	2.3373
2001	4.995	2001	5.7132	2001	10.8192
2001	4.26	2001	4.039	2001	5.7776
2001	1.648	2001	0.5814	2001	2.9484
2002	4.479	2002	2.5896	2002	0.732
2002	5.863	2002	1.7342	2002	2.943
2002	10.8368	2002	5.3793	2002	13.6122
2002	2.6352	2002	3.2246	2002	10.3544
2002	6.3	2002	6.4925	2002	9.9498
2002	2.87	2002	1.4193	2002	4.6984
2003	1.803	2003	3.12	2003	4.059
2003	4.2955	2003	2.461	2003	0.4536
2003	7.2488	2003	5.0611	2003	11.858
2003	4.374	2003	5.9248	2003	9.1896
2003	2.056	2003	3.192	2003	5.1382
2003	2.408	2003	2.3389	2003	2.1112
2004	5.82	2004	4.5936	2004	4.854
2004	3.5585	2004	5.0968	2004	8.964
2004	11.9496	2004	4.4849	2004	10.0401
2004	3.5748	2004	5.8742	2004	4.8328
2004	11.328	2004	9.2925	2004	8.4318
2004	1.682	2004	1.7708	2004	1.5344
2005	3.288	2005	3.6504	2005	5.295
2005	2.42	2005	5.7178	2005	3.2184
2005	8.1484	2005	5.375	2005	5.0568
2005	9.9522	2005	4.255	2005	1.5456
2005	3.036	2005	3.682	2005	2.7508
2005	0.484	2005	1.3091	2005	0.742
2006	2.928	2006	1.7112	2006	0.687
2006	4.587	2006	3.772	2006	1.6848
2006	2.5324	2006	3.0831	2006	3.2536
2006	3.0078	2006	2.7738	2006	4.6704
2006	6.676	2006	3.311	2006	1.058

APPENDIX C

Table 22. 20 Year Forecast of Rainfall Probabilities.

Probabilities that rainfall will be greater than average April - July in any given year.

Rolling Plains		Edwards Plateau		South Texas Plains	
2007	0.254	2007	0.278	2007	0.26
2008	0.282	2008	0.282	2008	0.26
2009	0.272	2009	0.274	2009	0.264
2010	0.28	2010	0.28	2010	0.268
2011	0.26	2011	0.256	2011	0.262
2012	0.268	2012	0.24	2012	0.242
2013	0.264	2013	0.256	2013	0.258
2014	0.274	2014	0.272	2014	0.276
2015	0.272	2015	0.28	2015	0.268
2016	0.266	2016	0.286	2016	0.274
2017	0.288	2017	0.258	2017	0.256
2018	0.276	2018	0.276	2018	0.27
2019	0.268	2019	0.26	2019	0.256
2020	0.256	2020	0.274	2020	0.272
2021	0.25	2021	0.258	2021	0.254
2022	0.254	2022	0.28	2022	0.274
2023	0.29	2023	0.256	2023	0.28
2024	0.262	2024	0.274	2024	0.264
2025	0.282	2025	0.262	2025	0.282
2026	0.27	2026	0.266	2026	0.276

APPENDIX D

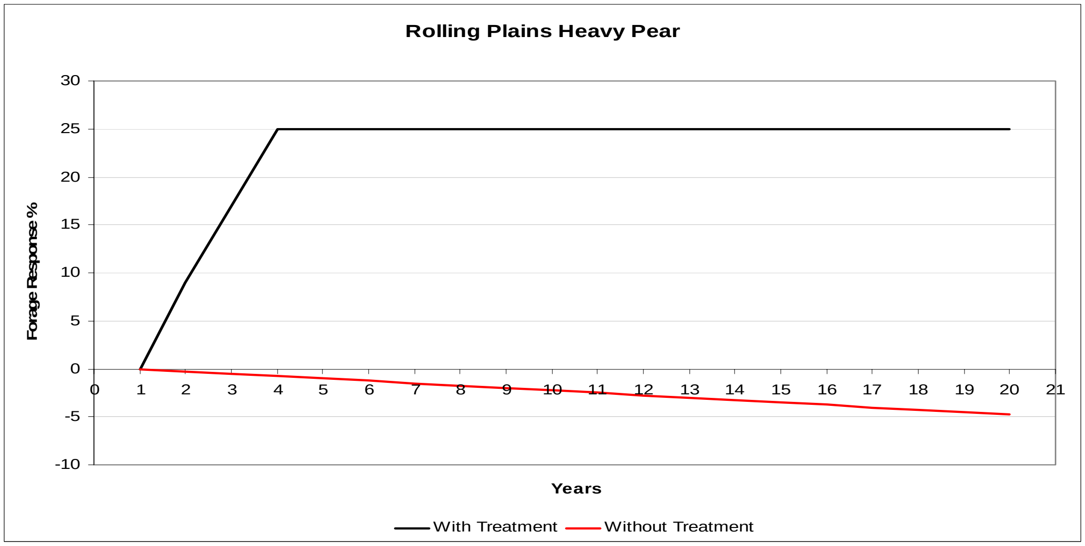

Figure 7. Response curve for heavy prickly pear in the Rolling Plains.

Table 23. Data Figures of % Forage Response for Heavy Prickly Pear in the Rolling Plains.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Rolling Plains Hvy Pear	9.00	17.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
Hvy Pear, NT	0.00	-0.25	-0.50	-0.75	-1.00	-1.25	-1.50	-1.75	-2.00	-2.25	-2.50	-2.75	-3.00	-3.25	-3.50	-3.75	-4.00	-4.25	-4.50	-4.75

NT - No Treatment

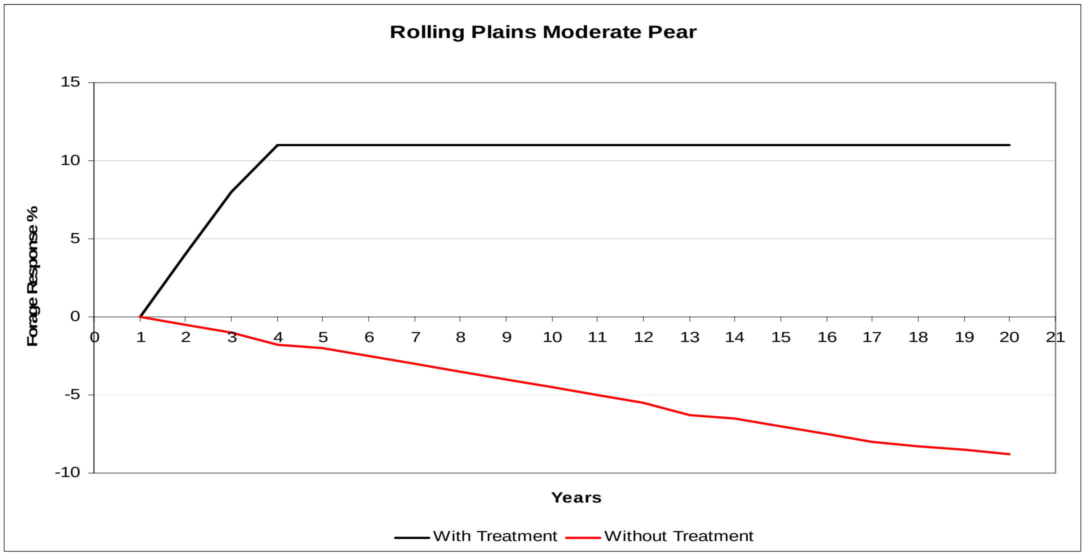

Figure 8. Response curve for moderate prickly pear in the Rolling Plains.

Table 24. Data Figures of % Forage Response for Moderate Prickly Pear in the Rolling Plains.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Rolling Plains																				
Mod Pear	4.00	8.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00
Mod Pear, NT	0.00	-0.50	-1.00	-1.75	-2.00	-2.50	-3.00	-3.50	-4.00	-4.50	-5.00	-5.50	-6.25	-6.50	-7.00	-7.50	-8.00	-8.25	-8.50	-8.75

NT - No Treatment

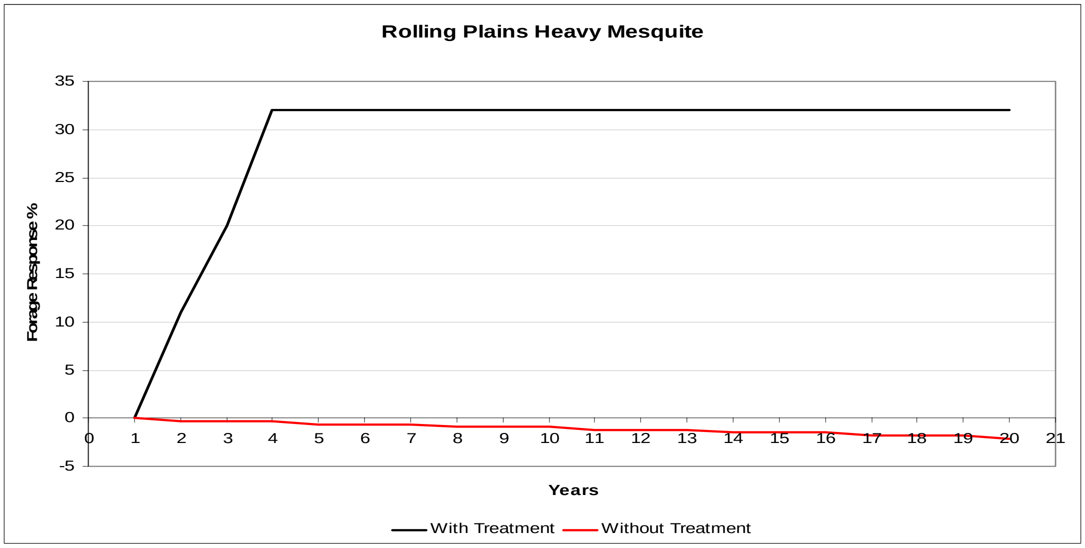

Figure 9. Response curve for heavy mesquite in the Rolling Plains.

Table 25. Data Figures of % Forage Response for Heavy Mesquite in the Rolling Plains

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Rolling Plains																				
Hvy Mesq	11.00	20.00	32.00	32.00	32.00	32.00	32.00	32.00	32.00	32.00	32.00	32.00	32.00	32.00	32.00	32.00	32.00	32.00	32.00	32.00
Hvy Mesq, NT	-0.31	-0.31	-0.31	-0.61	-0.61	-0.61	-0.92	-0.92	-0.92	-1.21	-1.21	-1.21	-1.50	-1.50	-1.50	-1.80	-1.80	-1.80	-2.09	-2.09

NT - No Treatment

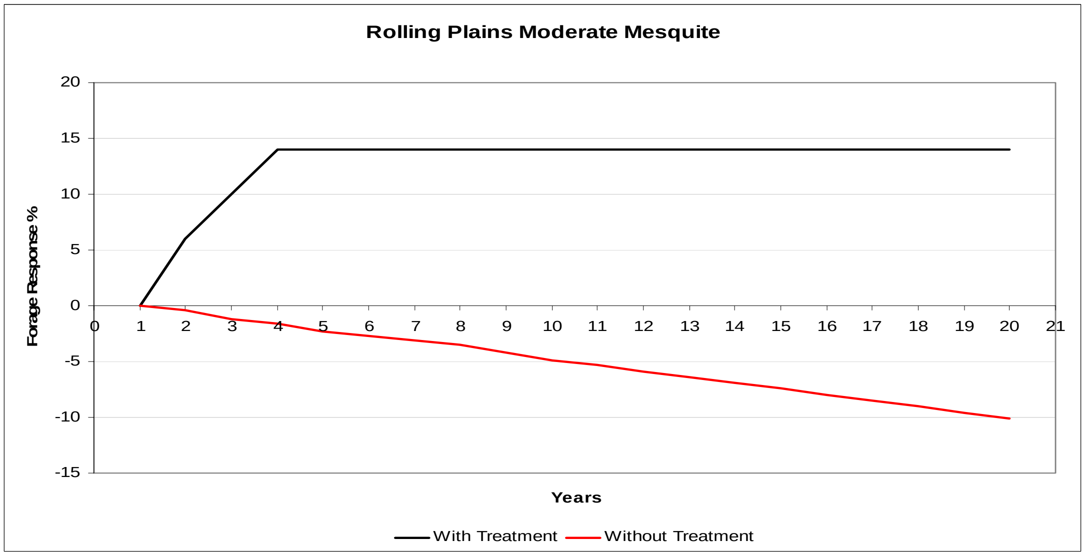

Figure 10. Response curve for moderate mesquite in the Rolling Plains.

Table 26. Data Figures of % Forage Response for Moderate Mesquite in the Rolling Plains.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Rolling Plains																				
Mod Mesq	6.00	10.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00
Mod Mesq, NT	-0.41	-1.19	-1.60	-2.34	-2.72	-3.10	-3.50	-4.22	-4.94	-5.32	-5.85	-6.38	-6.90	-7.43	-7.96	-8.49	-9.02	-9.55	-10.08	-10.61

NT - No Treatment

APPENDIX E

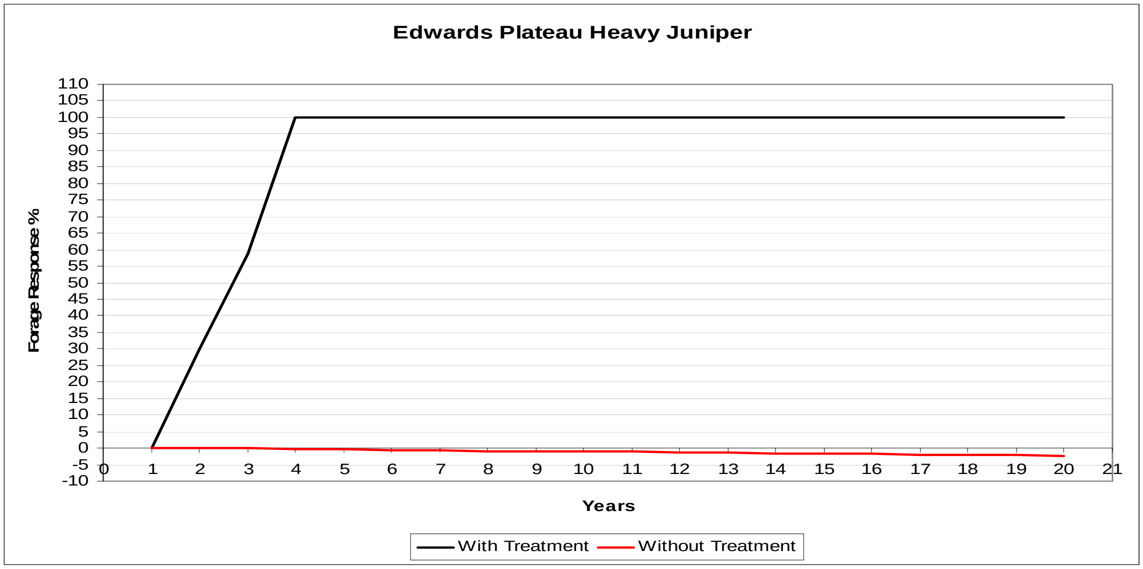

Figure 11. Response curve for heavy juniper in the Edwards Plateau.

Table 27. Data Figures of % Forage Response for Heavy Juniper in the Edwards Plateau.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Edwards Plateau																				
Hvy Jnpr	29.90	58.70	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Hvy Jnpr, NT	0.00	-0.14	-0.29	-0.43	-0.57	-0.71	-0.85	-1.00	-1.00	-1.13	-1.32	-1.44	-1.57	-1.70	-1.83	-1.96	-2.09	-2.21	-2.34	-2.47

NT - No Treatment

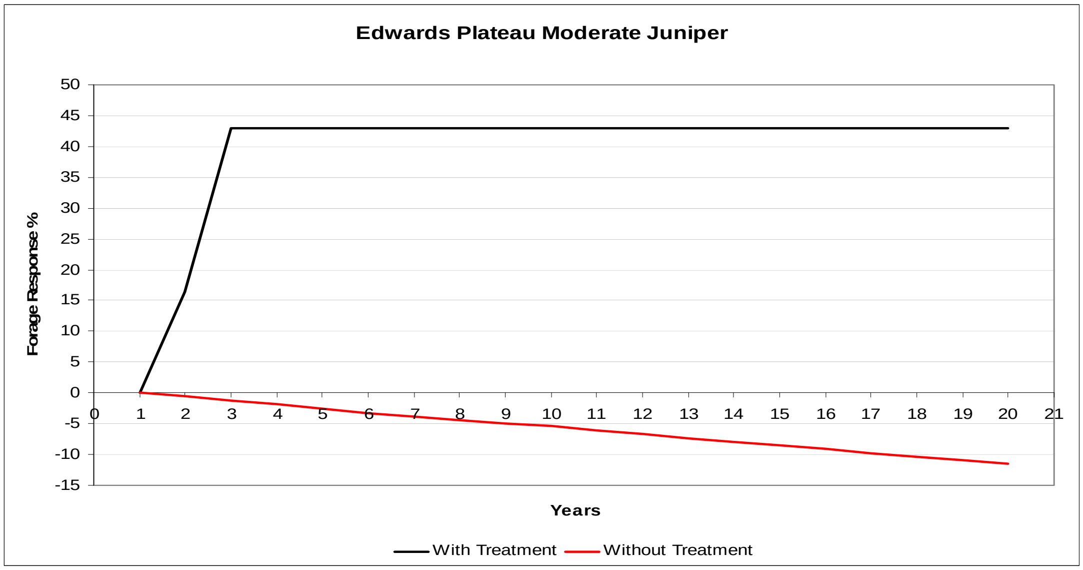

Figure 12. Response curve for moderate juniper in the Edwards Plateau.

Table 28. Data Figures of % Forage Response for Moderate Juniper in the Edwards Plateau.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Edwards Plateau																				
Mod Jnpr	16.30	42.90	42.90	42.90	42.90	42.90	42.90	42.90	42.90	42.90	42.90	42.90	42.90	42.90	42.90	42.90	42.90	42.90	42.90	42.90
Mod Jnpr, NT	-0.57	-1.33	-1.89	-2.60	-3.35	-3.90	-4.40	-4.90	-5.30	-6.13	-6.73	-7.33	-7.93	-8.53	-9.13	-9.73	-10.33	-10.93	-11.53	-12.13

NT - No Treatment

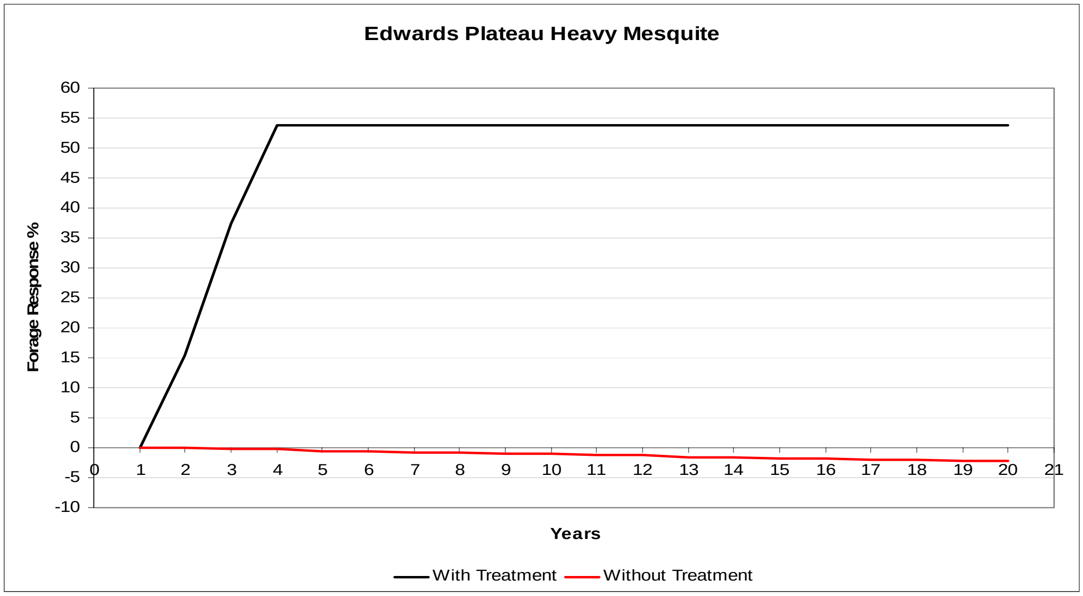

Figure 13. Response curve for heavy mesquite in the Edwards Plateau.

Table 29. Data Figures of % Forage Response for Heavy Mesquite in the Edwards Plateau.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Edwards Plateau																				
Hvy Mesq	15.40	37.50	53.90	53.90	53.90	53.90	53.90	53.90	53.90	53.90	53.90	53.90	53.90	53.90	53.90	53.90	53.90	53.90	53.90	53.90
Hvy Mesq,NT	0.00	-0.26	-0.26	-0.52	-0.52	-0.78	-0.78	-1.05	-1.05	-1.24	-1.24	-1.50	-1.50	-1.76	-1.76	-2.02	-2.02	-2.29	-2.29	-2.55

NT - No Treatment

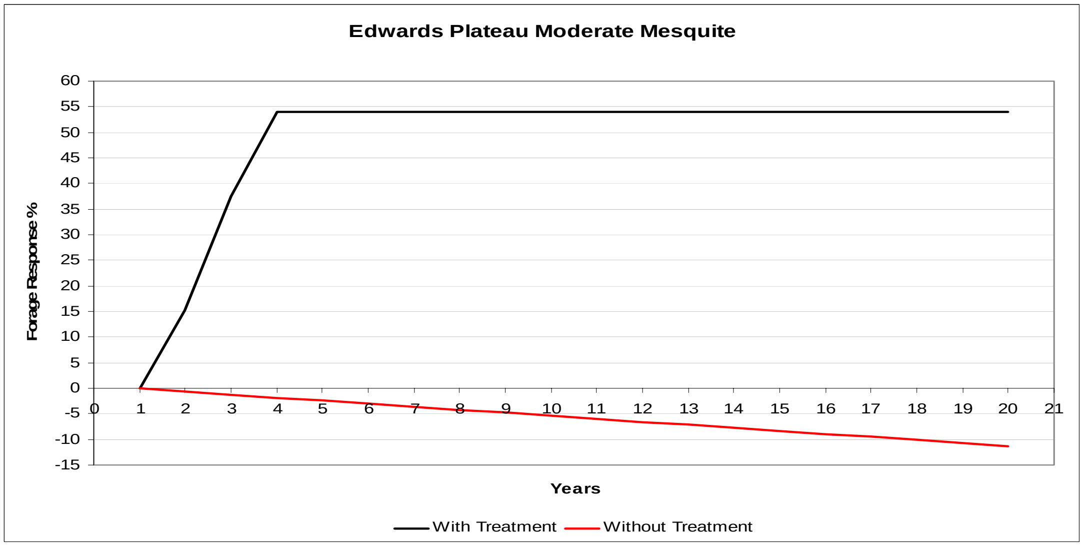

Figure 14. Response curve for moderate mesquite in the Edwards Plateau.

Table 30. Data Figures of % Forage Response for Moderate Mesquite in the Edwards Plateau.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Edwards Plateau																				
Mod Mesq	15.20	29.00	29.00	29.00	29.00	29.00	29.00	29.00	29.00	29.00	29.00	29.00	29.00	29.00	29.00	29.00	29.00	29.00	29.00	29.00
Mod Mesq,NT	-0.62	-1.22	-1.84	-2.44	-3.03	-3.61	-4.20	-4.76	-5.33	-5.95	-6.54	-7.13	-7.72	-8.31	-8.90	-9.49	-10.08	-10.66	-11.25	-11.84

NT - No Treatment

APPENDIX F

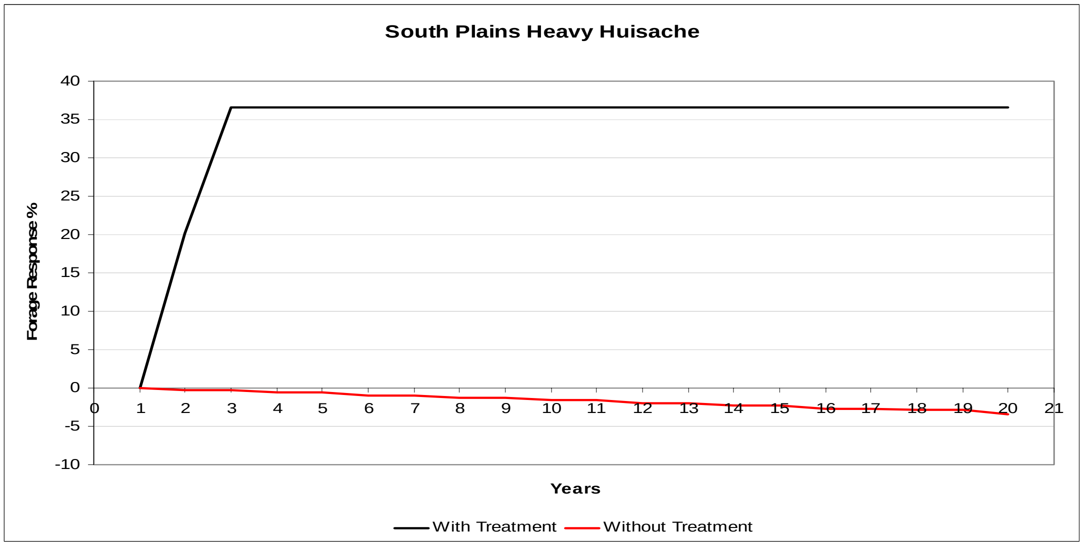

Figure 15. Response curve for heavy huisache in the South Texas Plains.

Table 31. Data Figures of % Forage Response for Heavy Huisache in the South Texas Plains.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
South Plains																				
Hvy Husc	0.00	20.20	36.60	36.60	36.60	36.60	36.60	36.60	36.60	36.60	36.60	36.60	36.60	36.60	36.60	36.60	36.60	36.60	36.60	36.60
Hvy Husc, NT	0.00	-0.33	-0.33	-0.59	-0.59	-0.97	-0.97	-1.30	-1.30	-1.60	-1.60	-1.98	-1.98	-2.25	-2.25	-2.66	-2.66	-2.90	-2.90	-3.40

NT - No Treatment

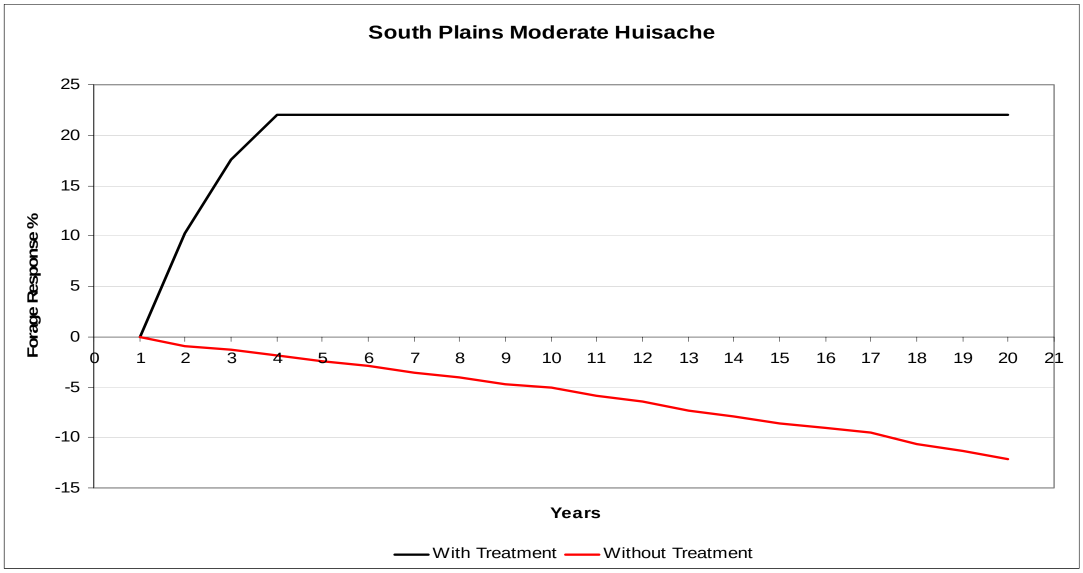

Figure 16. Response curve for moderate huisache in the South Texas Plains.

Table 32. Data Figures of % Forage Response for Moderate Huisache in the South Texas Plains

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
South Plains																				
Mod Husc	0.00	10.30	17.60	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00
Mod Husc, NT	0.00	-0.95	-1.30	-1.90	-2.40	-2.90	-3.60	-4.00	-4.70	-5.10	-5.90	-6.40	-7.30	-7.90	-8.60	-9.00	-9.50	-10.70	-11.30	-12.20

NT - No Treatment

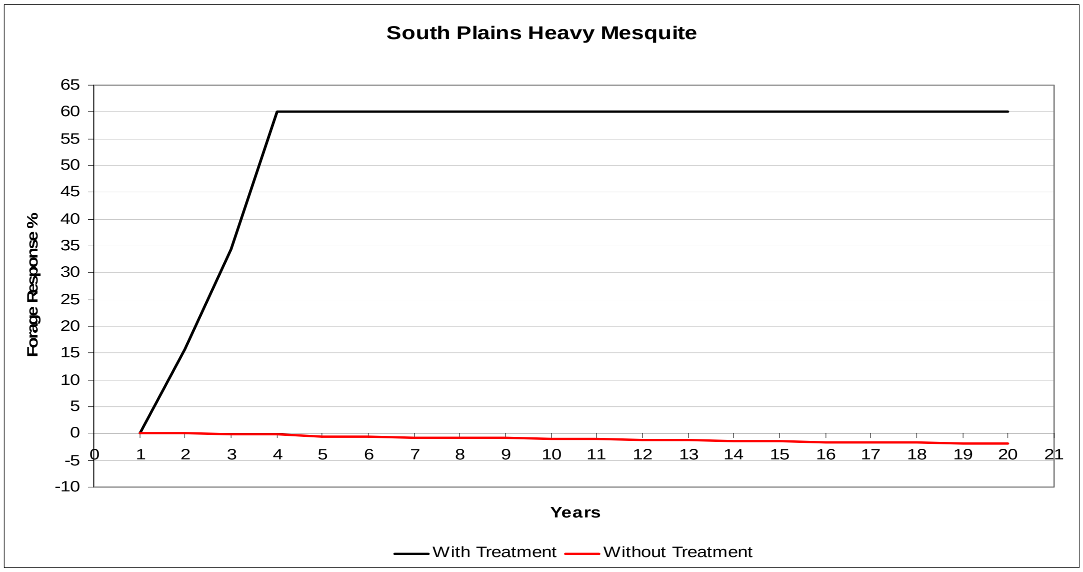

Figure 17. Response curve for heavy mesquite in the South Texas Plains.

Table 33. Data Figures of % Forage Response for Heavy Mesquite in the South Texas Plains.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
South Plains																				
Hvy Mesq	15.70	34.40	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Hvy Mesq, NT	0.00	-0.24	-0.24	-0.49	-0.49	-0.73	-0.73	-0.73	-0.97	-0.97	-1.17	-1.17	-1.39	-1.39	-1.61	-1.61	-1.61	-1.94	-1.94	-2.16

NT - No Treatment

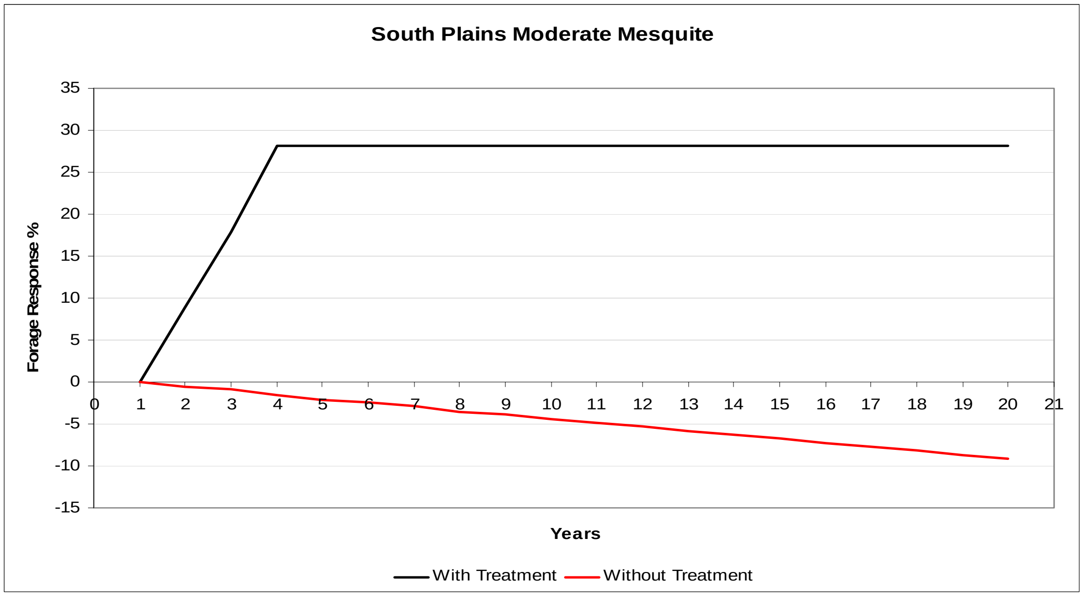

Figure 18. Response curve for moderate mesquite in the South Texas Plains.

Table 34. Data Figures of % Forage Response for Moderate Mesquite in the South Texas Plains.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
South Plains																				
Mod Mesq	8.90	17.80	28.20	28.20	28.20	28.20	28.20	28.20	28.20	28.20	28.20	28.20	28.20	28.20	28.20	28.20	28.20	28.20	28.20	28.20
Mod Mesq, NT	-0.60	-0.90	-1.50	-2.10	-2.40	-2.90	-3.50	-3.80	-4.40	-4.85	-5.33	-5.80	-6.28	-6.76	-7.24	-7.72	-8.20	-8.67	-9.15	-9.63

NT - No Treatment

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