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Abstract approved:

John A Tanaka

The last five decades of research in arid land ecology cites Invasive species as a source of imbalances in biodiversity through habitat destruction and reductions of native species through ecosystem alterations in favor of non-native species. Invasive species are known to damage not only the surrounding ecosystem but also cause economic and non-economic losses to society.

This study focuses on economic and social impacts of controlling cheatgrass (*Bromus tectorum* L.) on the public rangelands of the Great Basin region. This research seeks to examine the economic and social impacts of adopting different restoration strategies (herbicide use, fire, grazing and re-seeding of native grasses). The economic study seeks to assess the cost-effectiveness of adopting any versus none of the restoration strategies using a linear programming multi-period optimization framework.

In order to understand if restoration of cheatgrass is socially acceptable and whether the spatial context influences economic decisions, a parallel social attitudinal study examines the perceptions held by ranchers, interest groups, agency personnel and informed public with regard to restoration, the ongoing collaborative project and expected costs of undertaking restoration.

The bio-economic study incorporates ranch production and ecological site specific data into representative optimization models and solves to maximize net ranch income subject to market and resource constraints. The economic study found restoration to impact the ranches financially as the degree of restoration increased. Costs of restoration were lowest under baseline conditions and increased in magnitude with use of grazing, fire, herbicide and the integrated strategy respectively. Attitudinal data indicated that the meaning of restoration and social acceptability towards restoration strategies differed within and across stakeholder groups in the Great Basin states of Oregon, Idaho, Nevada and Utah.

Economic and Social Impacts of Restoration:

A Case Study of the Great Basin Region

by

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I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes the release of my dissertation to any reader upon request.

Vijayanand H Satyal, Author

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Chapter 1. Introduction

1.1 Background

Ecological invasion is often described as alterations in an ecosystem caused by a replacement of existing populations of native plants and/or animal species by more dominant non-native species. Invasive species in the United States are ranked second only to habitat destruction in causing species endangerment nationwide (Brooks and Pyke 2001). Invasive species are known to damage not only the surrounding ecosystem and host species, but also cause economic and non-economic losses to society. The U.S. Office of Technology Assessment (OTA) in 1993 estimated damage costs from 79 selected harmful species over the preceding 89 years to be $97 billion (Perrings et al. 2000). More recently, Pimentel et al. (2004) estimated that in the U.S. approximately 50,000 introduced (non-indigenous) species caused major environmental damage and economic losses totaling roughly $120 billion per year.

Understanding invasion as a process and its effects is critical and offers a logical continuity to subsequent details on invasion and its potential socio-economic impacts. D'Antonio and Vitousek (1992) offered an ideal and concise definition of invasions and their effects (page 64):

> Invasions that alter ecosystem processes are important to ecological theory because such effects are less well characterized than are population or community level effects of invasion, and

> they represent a clear example of single species control over ecosystem processes. In addition, invasions that alter ecosystems threaten existing populations of native species and communities, affecting environmental conditions and resource availability and finally, also have widespread and long-term impacts on climate, atmosphere and land use.

Invading species continue to adversely affect aquatic, terrestrial, and aerial communities and species worldwide. Such invasions are often a result of either intentional human introduction of species or accidental dispersal of species through other means of transport. Anecdotal evidence cites aerial invasion to occur mostly through entry of non-native species of birds resulting in changed wildlife composition and feeding habitat. The most common types of aquatic invasions include arthropods, mollusks, microbes, and infectious disease carrying bacteria while terrestrial invasion is common in plants or animals.

A seminal empirical study by Elton (1958) provided the earliest well documented research on invasions by plants and animals and inferred that excessive human practices most often accelerated the rate and degree of survivability of invasive species. Over time invasive species have continued to gradually cause declines in populations of native species, damage to ecosystem balance and overall biodiversity, economic losses primarily in the form of decreased forage availability, contamination of newer ecosystems through cross-border trade, and non-economic impacts in the form of decline in ranching partly influenced by failure to deal with invasive species.

Internationally, the Global Invasive Species Programme (GISP) was created in 1997 to promote a global coordination of all nations to ensure increased awareness and develop tools to manage and contain invasive species. In 1999 the U.S. government responded to increasing evidence of significant harm that invasive species could inflict and Presidential Executive Order 13112 was issued to establish the National Invasive Species Council (NISC). This Executive Order called for all federal agencies to collaborate with the NISC to develop a cost-efficient management plan to track, monitor, and eradicate invasive species. Creation of the NISC indicated a vital shift in thinking and explicit recognition by society at large of the growing threat of invasive species to ecosystem and human health.

This study focuses on the invasion by exotic annual grasses on the arid rangelands of western U.S. The focus is specifically on cheatgrass (*Bromus tectorum* L.) invasion on public rangelands of the Great Basin region. The goal of this study is to assess the social and economic impact of adopting restoration strategies that are being studied as part of a multi-agency, multi-university research project – Integrating Weed Control and Restoration (IWCR) for Great Basin rangelands. Increasing complexities in growth and multiple effects of invasive species often demands an integrated systems-based analysis that requires an inter-disciplinary approach.

The next section elaborates on the research problem and rationale for conducting this study.

1.2 Research Problem: Significance and Motivation for Study

Understanding the significance of invasions by annual grasses is most helpful in the context of plant succession and climax. Over the past six decades, rangelands of the western U.S. have been managed using the traditional “Clementsian” principles of plant succession (Clements 1916) that considered plant communities to naturally reach a final and stable state of composition called a climax[1] (Sheley et al. 1996). Over time, there has been a paradigm shift in ecological theory from the standard Clementsian succession model of plants (where succession is a steady change) to a “state-and-transition” model wherein succession takes place through disturbances and there exists multiple stable plant communities in non-equilibrium states or plant successions in transitions (Westoby et al. 1989, West and Young 1988, Bestelmeyer et al. 2003, Stringham et al. 2001). A detailed synthesis of existing studies on the “state-and-transition” model applied to rangeland health was completed by Briske et al. (2005).

Sheley et al. (1996) further added that invasions are a case of secondary succession, where invasive species throw the natural succession process into disorder as a result of any site disturbance and/or other factors. Consequentially, invasive species dominate the site adequately enough to attain a steady state. Currently, biological invasions have caused more species extinctions than have resulted from human-caused climatic change or the changing composition of atmosphere. Furthermore, human-caused biological invasions in particular have resulted in a breakdown of bio-geographic barriers leading to self-maintaining and evolving populations in regions that could not otherwise have been reached (D’Antonio and Vitousek 1992). According to Kauffman and Pyke (2001), livestock are not only a good medium for seed dispersal of undesirable exotic organisms, their grazing preference for desirable native species may further improve the competitive advantage of less desired weeds, thus increasing the probability of exotic species establishment and dominance.

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[1] Plant community that no longer undergoes change in species composition due to succession.

A number of ecological studies have analyzed the concept of invasion and its dynamics; however, only a couple of studies are selected to explain the ecological underpinnings to the research problem. Cronk and Fuller (1995) proposed a general ecological framework to better understand the various inter-related hypotheses about invasive species and site specific characteristics which are provided in Table 1.1.

Table 1.1. Various scenarios of potential hypotheses and drivers of invasions (Cronk and Fuller 1995).

If potential hypotheses is . . .	**Then driver of invasion is…**
Absence of a predator	Successful utilization of resources due to lack of competition from native species
Greater reproductive potential	Invasive species possess high rates of reproduction
Poor adaptation by natives	Lower tolerance by natives plants to natural resource constraints
Chemical change	Better adaptation by invasive species to altered chemical conditions of site
Balance of change	Lack of diversity in native species influences easy survival of non-natives
Empty niche	Quick dominance by invasive species of available empty niches
Disturbance produced gaps	Disturbance (natural and/or human) creates ideal environment for entry

Table 1.1 provides insights into various scenarios of invasion using likely causes and processes of invasion. Olson (1999) evaluated the ecologic and economic impact of noxious weeds using a thematic classification. Table 1.2 depicts the complex inter-relationship among soils, plants, and animals and how a change in one can affect the others and eventually the entire ecosystem. It also highlights how accidental or intentional entry or spread of an invasive species affects soils, plants, and animals.

Table 1.2. Ecologic and economic impact of invasive weeds.

Impact areas	**Type of Impact**			
	Structure	**Organization**	**Function**	**Economics**
Soils	• Low levels of organic matter • Increase soil erosion	• Affect soil micro-organisms • Increase in litter layers and slows nutrient cycling	• Reduce infiltration and increase runoff • Increase aridity of soils	• Decline in land values with poor soil conditions • Decline in productivity
Plants	• Alter plant compositions and succession • Increase runoff	• Out-compete native species • Reduce species diversity and richness	• Litter from invasive weeds reduces growth of natives • Alter fire and grazing cycle	• Noxious range weeds have lower forage value • High costs of restoring native species
Animals	• Affects reproduction • Fall in animal diversity	• Ecosystem imbalance due to change in animal densities	• Reduced productivity • Affects rumen	• Affect grazing capacity • Decrease wildlife habitat

Findings similar to those above were also found by Masters and Sheley (2001), Brooks and Pyke (2001), and Laycock (1991). Effects of invasions in the Great Basin are widespread and complex. Cheatgrass is the chosen species of interest in this study for two key reasons: the species unique ecological characteristics (high degree of plasticity and reproductive potential) and its economic value as a source of forage for livestock during its early spring growing season. An annual grass and aggressive invader from Eurasia, cheatgrass already dominates approximately 25 million acres of the Great Basin region (roughly one-third of the land in the area) (Pellant 2004). The plant was first introduced to the western U.S. arguably in the late 1800’s in various regions of the western U.S. and southern Canada. As an aggressive invader, cheatgrass is capable of quickly establishing in areas already subject to disturbance (e.g., fire and overgrazing) (Mack 1985). Numerous ecological studies have analyzed the causes, mechanisms, and effects of invasions by exotic annuals on the arid rangelands of the western U.S. (Hull 1949, Mack and Pyke 1984, West and Young 1988, Melgoza and Novak 1991, Pellant 1990, Emmerich et al. 1993, D’Antonio and Vitousek 1992, and Brooks and Pyke 2001). Specifically analyzing the Great Basin region, Young et al. (1972) identified the factors that influenced a change from pristine landscapes comprised of big sagebrush communities and natural wildfire cycles to modern landscapes of exotic annual grasses and woody species. Some of the key causes that led to this change were:

- *Loss of perennial grasses* – Overgrazing and changing livestock patterns led to the increased density of big sagebrush communities. This in turn depleted perennial grasses and increased bare ground that were ideal conditions for establishment of alien species.
- *Competitive characteristics of aliens* – Cheatgrass and other Eurasian annual grasses were extremely competitive, i.e., a high degree of plasticity, capable of adapting to low precipitation climates and scarce soil nutrients, and well developed seed dispersal mechanisms.

Mack (1981) provided a detailed account of the successful entry of cheatgrass and other exotic alien annuals on the arid rangelands:

- *Unlimited access to public land and introduction of exotic species* – Intensive exploitation of the remote land occurred through the period of 1850 to the 1920's due to homesteading and gold mine discoveries. In addition, the intentional introduction of exotic species from various parts of the world, without complementary inclusion of other native species from their environment to help maintain the ecological balance, contributed to the explosive growth of cheatgrass in a foreign environment.
- *Exploitation of the open range and habitat modification* – Homesteading, travels for trade, and open range grazing resulted in disturbed soils and altered fire regimes that allowed for easy seed entry and dispersal of cheatgrass that also provided ideal conditions for growth of cheatgrass and similar species.

All of the above have identified the inherent complexity in biological invasions on arid rangelands. There is a damaging chain of sequential effects on the entire ecosystem that eventually has economic and social consequences. These studies also inferred a common conclusion: adopting a restoration strategy is critical (and often necessary) for effective control of an established invasive species that has crossed an ecological threshold and displaced the native species to attain a newer stable state.

1.3 Research Objectives

The aim of this study is to assess the economic and social impact of restoration based on an ecological framework developed by the consortium of universities and federal agencies in and around the Great Basin region. The framework is provided by an ongoing ecological research project that explores the use of varied restoration strategies to interrupt the cheatgrass induced fire cycle and to select the restoration technique(s) that would control primary weeds like cheatgrass and secondary weeds like rush skeleton weed (*Chondrilla juncea* L.), medusa head wildrye (*Taeniatherum caput-medusae* L.), and yellow star-thistle (*Centaurea solstitialis* L.).

Two study sites in each of eastern Oregon, western Idaho, northern Utah, and northern Nevada were selected for experimental ecological treatments. Wyoming big sagebrush (*Artemisia tridentata* subsp. *wyomingnesis)* is the only dominant native species on each site. The first experiment tested native grass and forbs species that may successfully compete with cheatgrass. The second experiment evaluated the role of nitrogen availability through treatments of herbicide use, grazing, and fire, each followed by re-seeding with perennial grasses selected from the first experiment. Surviving native species that successfully out-competed cheatgrass would then be selected and used in the third and final experiment located in northern Nevada.

Over the past five decades, there has been a surge in ecological research focusing on the growing threat of biological invasions from cheatgrass. However, little to no research has been conducted on the social and economic impacts of cheatgrass invasion and restoration efforts on ranching and communities supported by ranching. This study assumes significance in the light of a research problem involving a public good and a unique invasive species. Everyone in the U.S. has an equal right to access the public lands (non-exclusionary property), but these users also want conflicting uses resulting in a society possessing mixed views with regard to the use and/or management of the public lands. The goal of this study is to address the economic costs of undertaking restoration and social attitudes of various stakeholders (users) who could possibly have an affect on the support for and/or conduct of restoration activities.

This dissertation is organized as follows. The second chapter consists of relevant literature review of selected bio-economic and social attitudinal studies. The third chapter details the research methods, questions, and data. The fourth chapter provides the findings and related analysis. The final chapter summarizes the key conclusions and future recommendations for land managers and suggests further research.

1.4 Expected Results and Policy Implications

Since cheatgrass is the dominant source of forage during the early grazing season for the representative ranches, it is expected that adopting restoration strategies to control cheatgrass growth will impact the ranches financially. Furthermore, it is possible that the ranches will reduce their herd size to ensure that the ranch is economically viable. Attitudinal data is expected to show a wide range of views with regard to controlling cheatgrass using existing strategies from the various stakeholders. Demographic factors like age, number of years of affiliation with rangelands, and level of education may also influence the general social acceptability of restoration. Overall, information derived from the economic and social components may provide critical insights into the efficient utilization of federal funds for the restoration of native species on public rangelands.

Chapter 2. Literature Review

This chapter consists of a literature review of select studies for the two components of economic and social impact assessments of managing cheatgrass.

2.1 Review of Bio-Economic Studies

There exists an abundance of literature on optimizing the rate of weed control by maximizing economic profits in row crop agricultural systems. However, there are fewer studies on the economics of invasive exotic weeds in arid ecosystems. A number of bio-economic studies have explored the cost-effectiveness of managing invasive species using optimal control and linear programming techniques.

Pandey and Medd (1991) developed a stochastic multi-period dynamic economic model to examine the economic costs of managing wild oats (*Avena fatua* L.) that infested a continuous wheat cropping system. Their study combined a dynamic programming procedure with a bio-economic simulation model to generate transition probabilities to cope with multi-period effects of herbicide use and its effects on crop yield, weed density, and herbicide effectiveness. Such a process enabled the derivation of optimal dose amounts and inferred that a long term application of herbicide was more effective than a short term one. Motivated by the growing threat of cattle losses from larkspur (*Delphinium* spp.) poisonings, Nielsen et al. (1994) used net present value analysis (NPV) to estimate the economic feasibility of controlling tall larkspur (*Delphinium occidentale* S. Wats.) on BLM grazing lands using 3 different herbicides (glyphosate, picloram, and metsulfuron benzoic acid), different application methods, and a 10 year life for each treatment. Application of all three herbicides was economically feasible, as each internal rate of return (IRR) was higher (14.23% to 133.38%) than the interest payments on money borrowed to finance the treatments.

Higgins et al. (1997a and 1997b) used the simulation based systems model STELLA to develop an ecological-economic model to determine the economic costs and benefits of controlling the invasive weed *Acacia saligna* (Labill.) using a biological control agent *Uromycladium tepperianum* (Sacc.) McAlp. Benefits were assessed using the planting of a commercially valuable flower, *Protea repens* (L.), and harvesting commercial fuel wood. Population growth and production curve information was modeled to explore the reduction (and increase) in biomass of the weed (and the desired flower) in response to implementation of alternative control strategies. The dual studies indicated that although bio-control techniques were expensive, long run use and simultaneous fuel-wood harvesting would be economically and ecologically beneficial.

Johnson et al. (1999) used NPV analysis to examine the economic feasibility of using chaining as an initial treatment followed by repetitive burns to reduce the growth of redberry juniper (*Juniperus pinchotti* Sudw.) in the Rolling Plains and Edwards Plateau regions of Texas. Over a 30 year period, the study found juniper control was economically feasible across a wide range of economic and environmental scenarios and prescribed burns were found to be optimal at 7 year intervals.

A study conducted by Radtke and Davis (2000) for the Oregon Department of Agriculture (ODA) estimated economic impacts from 21 key noxious weeds in Oregon alone through losses in total personal income to be about $83 million and total economic value of existing and potential invasive weeds to cost Oregonians $100 million annually. The study did not include cheatgrass in its analysis. Knowler and Barbier (2000) conducted an economic analysis of invasive species by using optimal control techniques to explore prior and post invasion impacts due to introduction of ctenophore (*Mnemiopsis gardeni* L.) into the Black Sea. Introduction of the comb jelly not only reduced existing native stocks of commercially profitable anchovy fisheries but also impaired its biological growth process. Using a discrete time dynamic bio-economic framework, the authors derived pre-invasion and post-invasion relationships and used a two-stage linear estimation procedure to solve for optimal anchovy recruitment rates. The study concluded that the introduction of comb jelly into the Black Sea inflicted a loss of $16.7 million to the neighboring nations.

Bangsund et al. (2001) developed a deterministic bio-economic model to evaluate the economic costs of using sheep grazing as a means to control growth of leafy spurge (*Euphorbia esula* L.), an exotic and perennial weed in the upper Great Plains. Another study on the Texas rolling plains was done by Teague et al. (2001) using a NPV based simulation analysis. The study examined the economic costs of managing honey mesquite (*Prosopis glandulosa* Torr.). Their study evaluated the differences in NPV and benefit/cost ratios for treating mesquite using prescribed fire burns (5-7 year intervals) and an aerial spraying of a root-killing herbicide. The analysis included income from ranching and wildlife activities and found use of fire to be most effective if fine fuel loads were less than 1,700 kg ha $^{-1}$year $^{-1}$. In response to the development of “state-and-transition” models in the ecological literature with regard to management of rangelands, Babatyal and Godfrey (2002) developed a purely theoretical framework to explore the dynamic issues related to rangeland management. The authors classified rangeland to exist in four states: excellent, good, fair, and poor. They developed a transition probability matrix to examine the changes between any of the four states and the available decision choices that were dependent on the probabilities of occurrence of available events. However, no empirical analysis was undertaken.

To overcome the lack of accurate biological data on dose-response relationships, a number of researchers have developed methods to create relationship data or assumed hypothetical functions. Eiswerth and Johnson (2002) developed an optimal control model to examine the economic costs of managing invasive species from a social planner's perspective. The authors concluded that ecological and human factors (carrying capacity of the land, invader's intrinsic growth rate, and control techniques) are analytically ambiguous in sign and depend on the values assigned to the state variables and parameters. Eiswerth and Van Kooten (2002) explored the use of fuzzy membership functions using expert judgment surveys to obtain relevant data, which in turn was used in a stochastic dynamic programming (SDP) model to evaluate the costs of controlling yellow starthistle. The authors found that as land productivity and discount rates were increased, expected net return ($/acre) increased only if the best practice was adopted with follow up management in subsequent years. Aldrich et al. (2005) analyzed the economics of managing western juniper (*Juniperus occidentalis* Hook) in north-central Oregon by two representative ranches in two precipitation zones. The goal was to assess the economically optimal level of juniper control for ranching and estimate changes in deer, elk, and quail populations and the level of soil erosion. Using a multi-period linear programming approach, the research showed the 350 cow/calf and 1,000 cow/calf operations to have increases in economic profits and herd sizes as a result of adopting juniper control strategies. The study also showed an increase in quail and elk densities for both ranches in all four precipitation zones. Torell et al. (2002) analyzed ranch level impacts of changing grazing policies on BLM lands in Idaho, Nevada, and Oregon with the aim of protecting the greater sage-grouse (*Centrocercus urophasianus* Bonaparte, 1827*)* using linear programming techniques. Reducing or eliminating grazing permits from the Bureau of Land Management (BLM) had a negative impact on net returns and generally resulted in the reduction of the optimal herd size.

Odom et al. (2003) developed a dynamic programming model to derive optimal control rules for managing scotch broom (*Cystisus scoparius* L.). The dynamic programming model was developed for a planning horizon of 45 years and found that a mix of control treatments: exclusion of tourists, manual pull, herbicide use, pig control, and biological control was most effective. The average cost of controlling scotch broom was estimated at $22,836 per hectare.

All of the above studies have provided valuable insights into available methods to model and evaluate economic costs of invasive species. Availability of accurate dose-response relationships allowed for some studies to use optimal control techniques while the rest of the studies mainly used either linear programming techniques, simulation methods, or both. However, there is no formal study that has evaluated the economic costs of controlling cheatgrass dominated public rangelands of the Great Basin region.

2.2 Social Attitudinal Assessment: Review of Select Literature

A large body of literature exists on social attitudinal and acceptability studies of restoration within the disciplines of forestry and fisheries and a relatively smaller number with regard to range and wildland restoration. Therefore, this review of literature selects only those studies from forestry and other areas that fit the themes relating to social acceptability analysis that capture human-environment interaction.

2.2.1 Attitudinal analysis (meaning and/or perception of restoration)

Mitchell et al. (1996) used an open-ended questionnaire to analyze visitor perceptions to cattle grazing on national forest lands of the Big Cimarron Watershed in the Uncompahgre National Forest in Colorado. The researchers found that livestock grazing was a source of interference to some visitors' enjoyment of the Big Cimarron watershed with 10% of all respondents wanting cattle removed while 60% felt that no changes were needed. DeMillion and Lee (2001) assessed the need for ecological wilderness restoration and presented options for managers with the help of an attitude measurement study that evaluated the local acceptance of various restoration strategies. Their study found that mechanical efforts to manage forests were favored (74%) over non-mechanical (54%) or prescribed fire (55%) methods. The authors hypothesized from the findings that the respondents were more familiar with mechanical treatment as an option over the other two resulting in expressed support for the former management option. In response to a large body of literature on the "value-attitude-behavior" inconsistency, Tarrant and Cordell (2002) took a novel step further and assessed the value-attitude relationship with regard to the influence of four indicators of population diversity on the amenity values of forests, environmental attitudes, and forest value-attitude correspondence. Moreover, the authors used a scale to test the respondent's views over the New Environmental Paradigm (NEP): balance of nature, existence of a steady state economy, harmony between humans and nature, and limits to growth. Respondents' views indicated that individual characteristics played a significant role in explaining why people held certain views of the environment.

A number of attitude measurement studies have been conducted on riparian and forestry related issues, where stakeholders' acceptance of various restoration strategies were analyzed. While Williamson (1989) stressed the need for understanding what users of public rangelands think, Brunson and Steel (1994) conducted a national survey to assess public attitudes towards federal policies to manage rangelands. The telephone based random survey of 2,000 households exhibited a strong lack of interest in federal management of rangelands and general concern for over-grazing of rangelands. Brunson and Steel (1996) followed up that study with an assessment of variation in attitudes between the urban versus rural communities across the eastern versus western U.S. coastal regions with regard to rangelands, their use, and policies to manage them. The study found very low evidence for differences in the views of the public towards rangelands between the two coastal regions. However, they did find increased evidence of a dichotomy in attitudes between rural and urban areas with regard to rangelands and grazing policies and suggested future research on rural versus urban resource use differences.

2.2.2 Effects of non-rational perceptions on rational outcomes

While mainstream neoclassical economics assumes rationality in its analysis of efficient allocation of scarce resources (capital, labor, land, and management), there have been an increasing number of economic studies highlighting non-rational economic behavior influencing decision making. Gentner and Tanaka (2002) and Teague et al. (2001) found profit motivation to be a low ranking objective as part of the goals of ranchers and ranch owners. There could also be a possibility of economically non-rational decisions on the part of the rancher who is willing to use a lesser amount of available grazing land under his/her grazing permit and permitting some of the BLM allotted land to be used for restoration.

2.2.3 Contextual social acceptability analysis: wildland fuel management

In order to test for differences in perceptions between urban (recreational) and rural visitors, Brunson and Shindler (2004) explored variation in the social acceptability towards wildland fuels management in the western United States. The study used a mail survey to examine whether contextual factors such as geographical location and evaluator characteristics influenced values, attitudes, and end behavior of households in the Central Arizona highlands, Colorado Front Range, Central Oregon, and Utah Great Basin. Survey results indicated higher levels of knowledge about control treatments to influence respondent’s acceptability of those treatments. Brunson and Wallace (2002) explored the perceptions of ranchers and ranching communities from the public (non-ranching) perspective and suggested ways for ranchers and non-ranching rural residents to bridge closer ties in the context of differing views of public land and ranching in general.

Bergmann (2001) examined the opportunities and challenges to private ranches and public land managers as they adopted prescribed fire as a tool for reducing fire fuel loads (and thereby ensure healthy timber stands) in and around the John Day Valley area of eastern Oregon. The study also sought to explore the social acceptability of a cooperative fire management program by public land managers and private ranch owners. A grounded theory based combination of case study and ethnographic analysis was adopted to examine the data in efforts to build inferences that could later be tested as hypotheses. The study developed a thematic pyramid and inferred that “fundamental” themes like tenure, ideology, power, and change supported “consequential” factors like trust and cooperation. Moreover, the author suggested that for the stakeholders (private ranchers and public land managers), the fundamental themes set the stage for trust building and possible cooperation in developing a collaborative fire management program and using natural resources under mixed ownership scenarios.

Bergmann’s study did not examine the perceptions of interest group representatives and informed citizens with regard to issues of cooperative fire management and mixed ownership of landscapes (and resulting resource use). Moreover, the study was limited to the John Day Valley area of eastern Oregon and did not analyze differences in opportunities and challenges across a larger spatial region.

In summary, the reviewed studies neither explored attitudes of all stakeholders, nor did they assess differences in perceptions of restoration due to geographical differences in restoration sites. The studies did however suggest that attitudes towards restoration efforts vary by geographical factors and were possibly also motivated by general environmental conservation intentions.

Chapter 3. Research Questions and Methods

3.1 Research Questions and Methods – Cost-Effectiveness Analysis

Linear programming was selected to evaluate the cost-effectiveness of the chosen restoration strategies. The existence of inequalities in the linear resource constraints and the lack of sufficient biological data on secondary weeds (growth, resource use, and dose-response relationships) results in the use of linear programming over Stochastic Dynamic Programming (SDP) or optimal control techniques. The least cost based economic assessment approach is used to determine which strategy is the most cost effective. Since all of the benefits of restoration are not easily quantifiable, this study evaluates only the cost-effectiveness of each treatment and identifies the optimum states of restoration given a range of costs. Representative ranches are constructed for each of the four states: Oregon, Idaho, Nevada, and Utah. The linear programming based profit maximization approach accounts for ecological data and stochastic cattle prices.

The economic research questions are stated below followed by their respective rationale and hypotheses.

3.1.1 What are the Minimum Economic Costs of Controlling Cheatgrass Infested Rangelands?

Rationale: This research question seeks to address the economic costs of restoration that would be the same whether incurred by public agencies or private ranchers (producers). Since the ecological component of this project seeks to adopt an integrated restoration management approach, it is appropriate to use an economic method that integrates the biological and economic data. The restoration strategies consist of herbicide use, grazing, and fire each followed by reseeding of native species, and an integrated strategy consisting of use of herbicide, fire, grazing, and reseeding.

Economic analysis is undertaken using a multi-period bio-economic model that maximizes ranch income by ensuring that site-specific demand for forage by various livestock classes is less than or equal to its supply. Restoration is enforced through the use of STELLA generated forage data that results in changes in forage availability over time. Seeking to maximize profits, the bio-economic model balances seasonal forage demand and supply through adjustments in the herd size. Thus, the overall net profitability of the ranch is affected by the adoption of alternative restoration strategies. This information should be relevant to land managers and policymakers and also offer a basis for exploring cost-sharing alternatives.

Hypotheses:

H_o^1: There are no tradeoffs between ecological benefits achieved from undertaking restoration and resulting economic impacts.

H_o^2: There are no differences in costs of restoration when multiple restoration strategies are adopted over independent adoption of any single strategy.

3.1.2 Is the Adoption of an Optimum Mix of Restoration Strategies Economically More Cost Efficient than Not Adopting Any Restoration Strategy At All?

Rationale: This question seeks to conduct a sensitivity analysis by exploring a range of optimal costs to derive restoration cost functions given each strategy and a mix of multiple strategies. Specifically, information on the costs of the optimum mix of strategies would allow a comparison of economic costs of adopting restoration strategies with a managerial decision to not undertake any restoration strategy at all. Cost information calculated in this form would provide a producer and/or agency personnel with a wider set of alternatives to choose from as they try to balance an ecological-economic tradeoff. This information may be valuable to the BLM since this study assumes a private producer is permitted to allocate a certain proportion of his/her allotted BLM grazing permit to be used for restoration. An estimated range of costs based on a mix of different strategies would provide BLM with critical information on the economic costs of restoration on its lands and also facilitate an exploration of ways to develop cost-sharing partnerships between the public agency and private producer in order to satisfy mutual goals of economically and ecologically sustainable use of the land's resources.

Hypothesis

H_o^3: There are no differences in the long-run costs of restoration for ranch operations as integrated strategies are adopted.

3.2 Research Methods and Data for Bio-Economic Analysis

The economic problem characterized by this study is a firm-level constrained cost (revenue) minimization (maximization) type. The study evaluates the economic costs of adopting or not adopting restoration strategies by representative ranches in the Great Basin region. The study does not involve an assessment of all the benefits to a ranch due to the adoption of the restoration practices, so a cost-effectiveness approach is used. This approach assumes that the decision to implement a practice has been made and the search is to find the least cost way of achieving the restoration goal.

Furthermore, the study will compare the costs of adopting any restoration strategy (management changes) with the costs of not adopting any restoration practices. This comparison would provide useful information on not only the range of economic costs due to the adoption of a restoration strategy, but also determine the opportunity costs of not using the available land for restoration. Moreover, under specific ecological site-specific conditions, it can also be argued that the costs of not adopting any restoration strategy could also represent the costs of allowing secondary weeds to become established on cheatgrass dominated range sites.

The following sections summarize the restoration strategies, the use of a simulation model for dose-response data, and the empirical linear programming model.

3.2.1 Restoration strategies and related assumptions

Four restoration strategies that were used in the economic analysis are explained below (Personal communication with David Pyke and Paul Doescher, Oregon State University, 2005).

a) **Use of herbicide Roundup Ultra (3L) (glyphosate)[2]**

This strategy consists of an application of Roundup Ultra herbicide at the rate of 0.421 kg a.i. ha^{-1} (0.375 lbs a.i.$acre^{-1}$). This herbicide is applied in early spring

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[2] Trade-name products and services are mentioned as illustrations only. This does not mean that the Oregon State University Agricultural Experiment Station either endorses these products and services or intends to discriminate against products and services not mentioned.

during the active growing season of cheatgrass following 20% to 30% emergence of cheatgrass seed heads. The main purpose of this strategy is to reduce the rapid growth of cheatgrass through reduction in the cheatgrass seed bank resulting in lower cheatgrass stands. This in turn results in increased water and nutrient availability for the perennial grasses through the winter and early spring seasons of the following year. This strategy is considered most effective over the other stand alone strategies.

b) Prescribed fire application

Prescribed fire is used as a management strategy in efforts to reduce cheatgrass growth in late fall through reductions in the cheatgrass seed bank and resulting density. Use of prescribed fire right after herbicide application allows for elimination of any residual surviving cheatgrass seed heads to mature through the winter and spring seasons of the following year.

c) Grazing

Grazing as a restoration strategy is selected to explore the effects of cattle consuming cheatgrass stands as forage. While grazing is expected to be effective in controlling cheatgrass populations through reduced levels of reproduction, there is anecdotal evidence of disagreements as to the overall effectiveness of the treatment as cattle may continue to disperse cheatgrass seeds to distant regions and further facilitate invasion through their travels and waste.

d) Integrated strategy

The integrated strategy consists of the various combinations of herbicide, grazing, and prescribed burning with re-seeding as a means to control cheatgrass dominance across the study sites and allows for the use of nutrients to surviving perennials species. For the purpose of this study, in the absence of clear and consistent data, it is assumed that the integrated strategy is the most effective in limiting cheatgrass growth.

3.3 STELLA Model of Cheatgrass-Native Species Production

Since the above mentioned strategies are currently being adopted at various stages across the Great Basin sites, dose-response data is preliminary and limited. The lack of dose-response data is compensated for by developing a simulation model. We are using the simulation software STELLA (Ford 1999 and Deaton and Winebrake 2000) that allows for construction of a simplified competitive ecosystem to simulate the interaction between cheatgrass and the native species.

3.3.1 Working of the STELLA Simulation Model

STELLA is based on the underlying logic of systems thinking (Richmond 2001). It allows for modeling various systems to generate simulated data that would account for the interconnections between the components. Essentially, it consists of three distinct layers: the interface layer, the map or model layer, and the equations layer. The model layer is where the modeler can use specific tools to create the model. The specific tools include stocks, flows, converters, connectors, and decision process diamonds. The interface layer is a tool to provide a graphical understanding of the overall research task. Through the appropriate choices of dialogue boxes and tools, the modeler can show the simulation results. The equation layer provides an alternative way to code the model through use of equations that get generated as a result of using the model layer.

3.3.2 STELLA Model and Dose-Response Relationships

Specifically, STELLA is used to simulate the interactions between cheatgrass and the native species with the control strategies given a constrained supply of water so as to generate pre-treatment and post-treatment biomass information. Simulated results of pre and post-treatment biomass information from STELLA are used as forage availability constraints in the economic optimization model. Figure 3.1 shows the graphical cheatgrass-native ecosystem model.

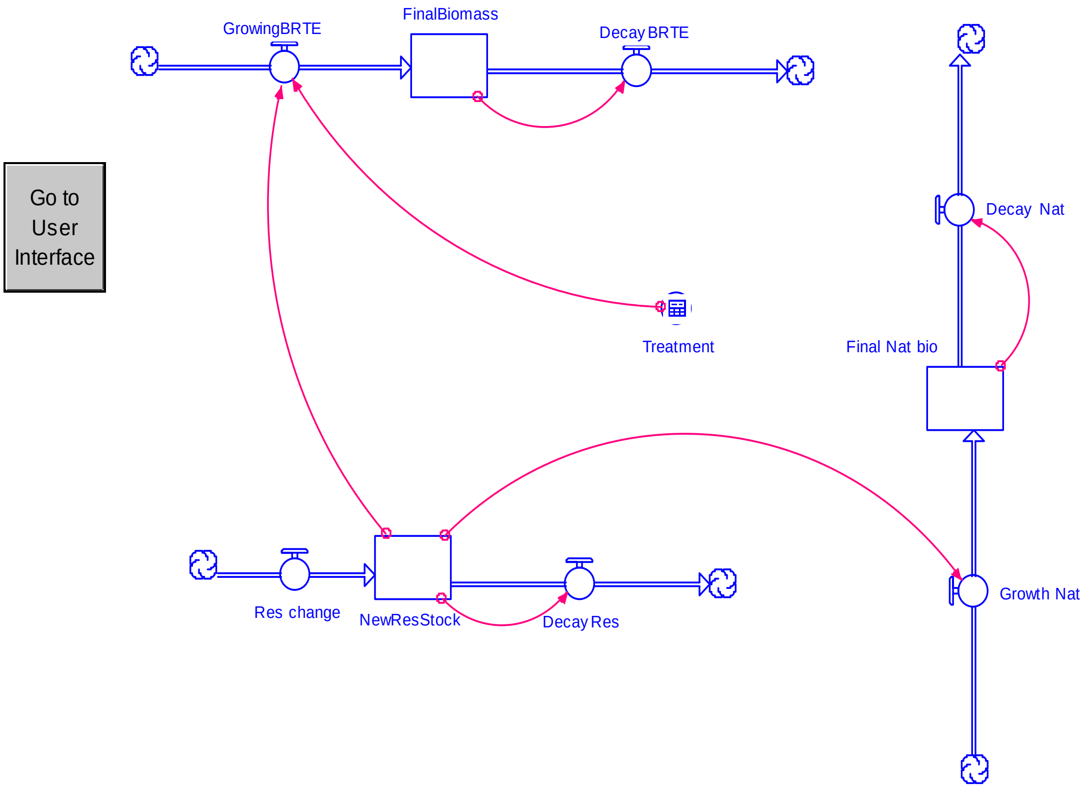


Figure 3.1. STELLA model of the cheatgrass-native ecosystem.

In figure 3.1, the cheatgrass sub-model is at the top with the native sub-model to the right and the limiting resource of water is at the bottom which connects to each of the other sub-models. The treatment icon in the center is used to select any cheatgrass treatment and is kept at “0” for the baseline conditions. The model produces a framework that could later be custom designed for specific native species as additional information becomes available. Detailed codes of the system are provided in Appendix A. Two assumptions are made in the STELLA model:

1. The vegetation across the sites which consist of 449 kg ha^{-1} (400 lb $acre^{-1}$) and 168 kg ha^{-1} (150 lb $acre^{-1}$) of aboveground cheatgrass and native species biomass, respectively and
2. Weather variation is accounted for using site specific rainfall patterns across the four sites of the Great Basin region and rainfall is the limiting nutrient.

Since precipitation is considered to be the key limiting nutrient, the STELLA model is designed so that any change in precipitation influences the final levels of cheatgrass and native species biomass. 120 years of precipitation data for the four states are collected from the OSU based Spatial Climate Analysis Service’s web site. A range of the minimum and maximum of precipitation data for each of the four states is calculated and then STELLA is used to generate a random and replicable stream of precipitation values for each simulation run. Allocation of the annual precipitation to the native species, cheatgrass, and general losses (i.e., runoff and evaporation) is modeled in the baseline and treatment models. To simulate real world conditions, two precipitation allocation conditions are used in modeling precipitation flow into the STELLA models.

The first condition is that if a randomly selected precipitation value is less than the average precipitation value, then 30% of precipitation is allocated to cheatgrass, 40% to perennial grasses, and 30% in overall losses across the site. The rationale for this condition is that in times of low precipitation or drought conditions there is more moisture in the deeper parts of the soils across the Great Basin arid lands than there would be in the upper regions. This allows for the deeper rooted native grasses to draw water more efficiently than the relatively shallower rooted cheatgrass plants would from the drier sub-surface soils. In general, it is assumed that in drier conditions, more often than less, native grasses have better access to moisture in the soils than cheatgrass.

The second condition is that if the randomly selected precipitation value is greater than the average precipitation value, then 50% of total precipitation is allocated to cheatgrass, 20% of total precipitation is allocated to perennial grasses, and 30% remains in overall losses. This condition of precipitation allocation is expected to be at work during times of higher than average precipitation conditions.

In addition to the precipitation allocation conditions, dose-response estimates are modeled in STELLA model to generate no-treatment versus treatment simulated biomass levels for cheatgrass and native species (Personal communication with Paul Doescher, David Pyke, and John Tanaka, Oregon State University, Robert Novak, University of Nevada, Reno, Jeanne Chambers and Eugene Schupp, Utah State University, and Mike Pellant, Bureau of Land Management, 2005). The dose-response relationships that were used for the simulation model are summarized below.

Table 3.1. Type of treatment used and changes in cheatgrass and native biomass.

Treatment used	Percent change in BRTE	Percent change in natives
Herbicide + re-seeding	60% decrease	20% increase
Fire + re-seeding	20% decrease	10% increase
Grazing + re-seeding	25% decrease	10% increase
All of above - Integrated	70% decrease	30% increase

Table 3.1 highlights the representative levels of responses due to adoption of each treatment in terms of biomass of cheatgrass and any typical perennial species across the sites. It is expected that these hypothetical estimates could change as current and future research activities deliver site specific results.

3.4 Bio-Economic Model and STELLA Generated Data

Optimal control and linear programming techniques are two feasible ways to explore the economically optimal restoration strategies. Various factors motivate the selection of the linear programming (LP) method that incorporates mathematical programming techniques to seek an optimal solution. LP models are best suited for production processes like agricultural operations where there exists a known set of decision variables, processes, and definite objective function to maximize or minimize. Use of LP analysis also allows for solving a problem that has inequalities in the objective function, resource constraints, or both.

3.4.1 Representative Ranches and Modeling Assumptions

Representative ranches are considered to be profit maximizing firms that have a certain amount of cropland and rangeland available for raising crops and grazing cattle, respectively. Representative ranches are developed for Idaho, Nevada, Oregon, and Utah. Herd size for each representative ranch is chosen after taking an average across all herd sizes across all of the counties for each of the four Great Basin states using the inventory on beef cattle farms from the U.S. Census of Agriculture (2000). Site-specific information enables all representative ranches to be heterogeneous in their financial structure and forage availability. It is assumed that these firms (ranches) operate with a goal to ensure year round forage availability for their cattle that translates into an economic goal of maximizing NPV of the firm’s gross margin subject to its resource constraints. Representative ranches are modeled in a multi-period framework so that long run implications for resource availability and transfers due to the adoption of any management decisions during a year are measurable. It is also assumed that ranchers use their grazing permits with the BLM to graze their cattle on public rangelands and meet their forage needs in certain seasons. Figure 3.2 provides a graphic overview of a typical ranch operation that was modeled in GAMS. A detailed review of GAMS is available in the user manual by Brooke et al. (1998).

Each representative ranch has a finite set of cropland and rangeland. There exists a minimum and maximum limit on the availability of each land type and equations are used to ensure the transfer of forage and crop production to livestock producing and crop selling activities. Results from one year become inputs to the next year’s production cycle. The model has a planning horizon of 40 years. A seven percent (7%) discount rate is used in the analysis.

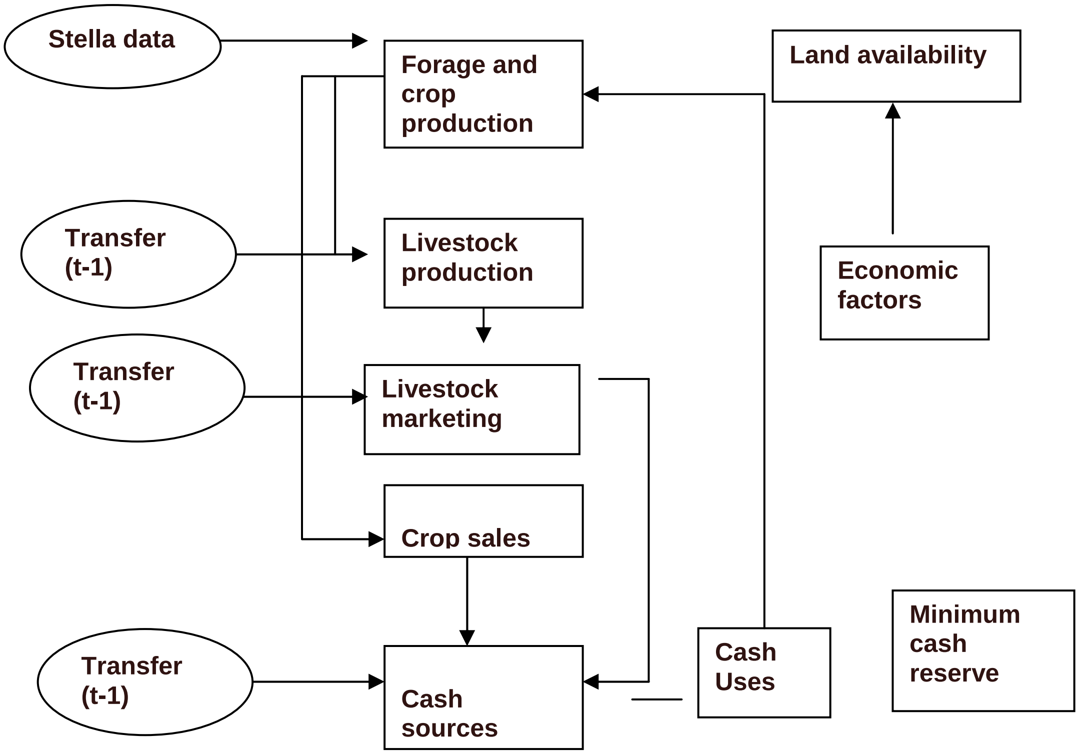


Figure 3.2. GAMS based LP model of a representative ranch (Torell et al. 2002).

A baseline optimization model is initially solved for each ranch model across the four study sites. The baseline model includes the economic costs of operating the ranch without adoption of any cheatgrass treatments, thus representing the status quo.

STELLA generated pre-treatment and post-treatment biomass data are incorporated into the GAMS model. A growth curve is used to select optimal levels of forage. Since cheatgrass and native species have varying growth trajectories, the representative ranch models do not utilize maximum levels of forage production from the two species. The result is that forage utilization may be lower than total annual production. Restoration strategies are then imposed in the STELLA simulation model and post-treatment biomass data of native species and cheatgrass and treatment costs are incorporated into the treatment ranch models. Changes in the forage availability due to the restoration practices cause the model to find a new economic optimum solution.

3.4.2 Empirical LP Model

The LP based optimization model used for this study is a modification of the original model developed by Torell et al. (2002) to evaluate ranch-level impacts of changing grazing policies to protect the greater sage-grouse on Idaho, Nevada, and Oregon BLM lands. Key components of the model are explained below and the GAMS code is provided in Appendix B.

A representative ranch is assumed to have the following objective function:

$$Max\ \pi \ = \ \sum_{t=1}^{40}[(TR_t - TVC_t)*(1+r)^{-t} + TValue] \tag{3.1}$$

Equation 3.1 maximizes the present value of ranch income which equals total revenues (TR_t) minus total variable costs (TVC_t) plus a terminal value (*TValue*). The terminal value is added into the equation to account for all future returns from the herd following the end of the 40-year planning period.

$$\mathrm{TR}_t = \sum_{t=1}^{40}[(liveclass_t * salewt * saleprice_t) + (crops_t * cropsale)] \tag{3.2}$$

Equation 3.2 is the total revenue equation and sums the income earned from the sales of animals (steer calves, heifer calves, yearlings, and cows) and sale of surplus crops. The first component of right hand side of equation 3.2 denotes the total income earned from the sale of cattle. *Liveclass* is the set for various classes of cattle consisting of cows, yearlings, heifer calves, and steer calves. The animal class times the standard selling weight *(salewt)* times the sale price *(saleprice)* yields total income earned from sale of animals on the ranch. Stochastic cattle prices are used in all four representative ranch models. Income from crops sold consists of *crops* times the market prices of crops *(cropsale)*.

Total variable costs are those incurred in the purchase of forage, animals, maintenance of animals, and adoption of restoration practices.

$$\mathrm{TVC}_{t} = \sum_{t=1}^{40}[(forage_t * fcst) + (animcst) + (Actreat_t * trtcst)] \tag{3.3}$$

Equation 3 represents the total variable cost function by summing the costs of forage *(fcst)* times forage used *(forage)*, the cost of raising a brood cow *(animcst),* and the cost of undertaking restoration activities on treatable BLM land *(trtcst)* times available BLM land *(Actreat)*. Although there are other constraints specified in model (e.g., loan payments and savings), they are not explicitly explained here but included in Appendix B.

3.4.3 GAMS LP Model and Growth Rates of Cheatgrass and Native Species

Growth curves representing the cumulative growth of native species and cheatgrass are modeled in the GAMS LP model. Figure 3.3 depicts the different growth rates of the two species.

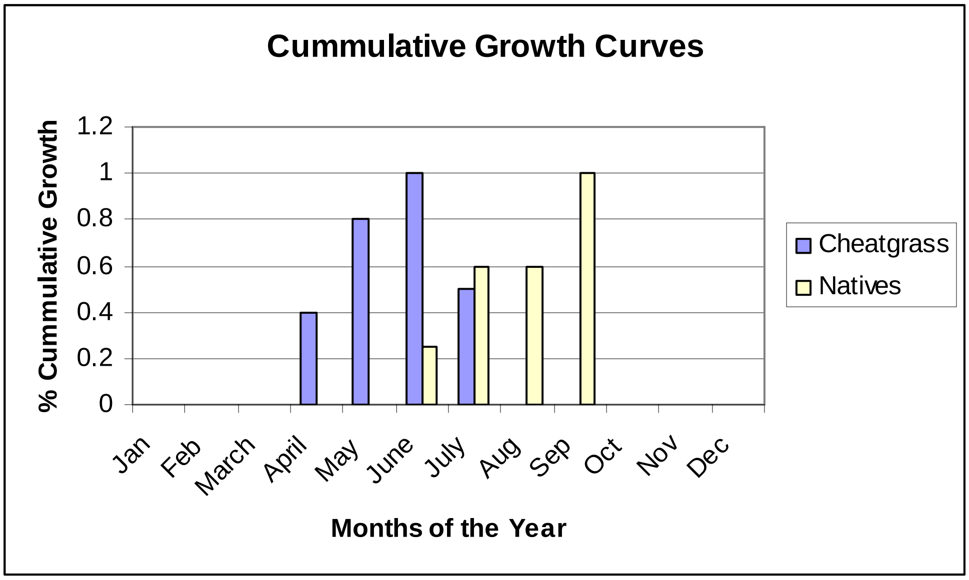


Figure 3.3. Typical growth curves of cheatgrass and natives species.

While cheatgrass starts to germinate in late fall and early winter, the native species only start to germinate later on during the spring season. Cheatgrass achieves peak maturity through the month of June and mortality by end July. The later germination by native seeds results in tissue and root growth during the summer season and peak growth in late summer and early fall. Such temporal differences in the growth curves of cheatgrass and native species result in varying forage production in each season from the two species. Moreover, a gradual decline in treatable land base during restoration (as treatment strategies do not have the same effects on both species) results in reduced forage production (and land availability) across all grazing seasons. The above two factors in combination influences the GAMS based LP model to adjust the herd size that balances forage demand with forage availability across all restoration scenarios.

In general, the empirical model maximizes ranch income (minimizes costs) given the production and economic constraints. The treatment model imposes restoration treatments on public lands that are typically used for grazing by representative ranches. Cattle prices are in 1997 dollars and are used in the simulations with 100 forty year sets of prices randomly generated based on historical prices for different livestock classes (Torell et al. 2002).

3.4.4 Data Sources

Development of representative ranches is accomplished using existing Extension Service budgets and studies conducted by Torell et al. (2002) and Capps and Workman (1982). Typical BLM grazing allotment use across each of the four Great Basin states and approximate costs of various restoration strategies are collected from respective BLM field offices. A simplified cheatgrass ecosystem and relevant dose-response relationship information is modeled in STELLA using restoration studies selected from the IWCR project. Initializing biomass values for STELLA modeling of cheatgrass and natives interaction is selected in consultation with ecologists. The Natural Resource Conservation Service (NRCS) Electronic Field Office Technical Guide (E-FOTG) is used to get typical growth curves for cheatgrass and native species. Weather data is collected from OSU based Spatial Climate Analysis Service (SCS) center and used to define the range for random generation of precipitation that drives the cheatgrass-native simulation model.

3.5 Social Impact Assessment – Research Questions and Methods

Public rangelands in the U.S. are a classic case of a public good – everyone has the right to access the lands (non-exclusionary property). Thus, the users of public lands often have conflicting motivations for using the land, resulting in society possessing mixed views about land use and therefore its management. Conducting a social impact assessment presents the opportunity to capture various attitudes and related perceptions that influence the nature and degree of restoration.

Such ecological issues have significant social implications with regard to the use and management of western U.S. rangelands. Diverse and competing uses of public rangelands of the western U.S. are a result of stakeholders possessing wide range of value systems and views that influence their final actions, including rational profit maximizing behavior. The scant available literature does propose the existence of non-rational behavior influencing economic actions directly and/or indirectly. Lackey (2001) suggested that natural resource issues that have competing societal values (implicit in preferences) cannot be resolved by economics alone. Such competing societal values (and resulting decisions) are often influenced by the context in which decisions are made. The appropriate inclusion of such a context (ecological, economic, and social) that refines the reality is critical for a holistic understanding of all factors that possibly could influence the perceptions of key stakeholders, which in turn determines their decisions. Contextual perceptions or attitudes of users and decision-makers with regard to public rangelands require adequate inclusion to explore any possible human-environment linkages.

Specifically, it is a proposition of this study that public rangelands are an example where human–environment interactions are based on value systems (either explicit or implicit) and these values are influenced by factors such as situational or geographical context. Furthermore, actions stemming from these contexts may often seem irrational to an economic profit maximizing individual. Adopting rangeland restoration strategies is one such case where changes in the landscape (floral and faunal composition) often influences (and is influenced by) stakeholders who possess varying perceptions. Such differences in perceptions, even if not ultimately translated into actual behavior, can significantly influence their willingness to support and/or assist in the restoration of rangelands. Additionally, the type and degree of feasible restoration techniques are often site and species specific, which calls for a cautious selection of a restoration strategy that fulfills ecologic, economic, and social concerns of acceptability.

Whisenant (1999) stresses this view by stating that not only the biotic and abiotic limitations influence wildland restoration objectives, but so do land use goals, social interactions, economics, and resulting management preferences. Restoration planners, managers, and final users of restoration project outcomes may have differing views based on their different value systems, knowledge, and experience with regard to overall goals, methods, and means of implementation. In addition, appropriately managed restoration of arid lands calls for a site and context based approach that evaluates not only the site conditions but also any past history of problems. Ignoring site and context specificity can result in conflicts. Conflicts may appear to be resolved in the short-term using traditional decision-making methods, but they generally resurface because societal attitudes change or the underlying values and interests of conflicting parties remain unchanged (Rasmussen and Brunson 1996).

Differing and often implicit value systems are often a result of attitudinal differences. Therefore, it is critical to have a clear understanding of the term *attitude*. Tindall (2001) defined an attitude as a general learned and relatively enduring tendency on the part of individuals to respond negatively or positively to a given phenomenon. Rasmussen and Brunson (1996) have stressed the need to understand societal attitudes so as to better understand ecological issues that are induced by humans and in turn have implications on humans. Public acceptance of decisions calls for an active interaction with citizens about their interests, which is the crux of this study.

The need to ensure that feasible restoration strategies are socially acceptable has been increasingly stressed by BLM scientists, extension agents, ranchers, and even the communities in whose neighborhood restoration is undertaken. However, no study has yet explored the social acceptability of managing cheatgrass on Great Basin rangelands using the above mentioned restoration strategies. Specifically, this study seeks to explore the perceptions of various stakeholders about management of cheatgrass across the public rangelands of the Great Basin states of Oregon, Idaho, Nevada, and Utah.

3.6 Research Questions and Propositions

This study is exploratory in nature and uses a case study approach to elicit attitudes and perceptions of diverse stakeholders who are directly or indirectly affiliated with restoration on public rangelands. The research questions are provided below followed by the propositions.

3.6.1 Research Questions

a) **Does restoration have different meanings to different stakeholders across the Great Basin region?**

b) **What are the key drivers that would enable current restoration strategies to be socially acceptable?**

3.6.2 Propositions Supporting the Two Research Questions

The following reasons justified the selection of above two research questions:

a) **Variations in perceptions.**

There could be a diverse set of attitudes and perceptions among all stakeholders – agency personnel, ranchers, non-ranching community, and interest groups – with regard to restoring cheatgrass on public rangelands. It is assumed that ranchers in the Great Basin depend on cheatgrass as an abundant source of forage for cattle due to its growth in late winter and early spring when forage sources are generally limiting to a year-round ranching operation (Capps and Workman 1982). While ranchers may value cheatgrass, its dominance on rangelands can be an ecological loss resulting in lower survival rates of perennial species, reduced levels of biodiversity, and general imbalances in the Great Basin ecosystem. Such ecological instability is often a concern to natural resource scientists, interest groups supporting restoration, and agency personnel. The view of informed citizens is not known, thus they are included as the fourth category for this research.

b) **Site and context specific factors (social, ecological, and economic).**

There is a possibility for conflict among stakeholders with regard to the selection of certain strategies for controlling cheatgrass in the Great Basin region. The second question seeks to explore if site and context specificity could be playing a role in restoration being a success or not. Knowing the views of various stakeholders in terms of their personal perceptions of the degree of the problem that warrants change (restoration) could influence the degree of adoption of the chosen treatments.

c) Differences in acceptability of restoration strategies.

It is expected that all stakeholders will have different views on the effectiveness and consequences of each restoration strategy. Therefore, the second research question explores the existence of any human dimension to restoration that typically is ignored or unaccounted for during restoration planning. Contextual factors include ecological history of the site and economic conditions of the region, demographic factors, level of awareness, and the degree of interaction and trust with resource professionals and agency personnel, all of which may influence the level of social acceptability towards restoring cheatgrass dominated rangelands.

3.7 Research Methods and Sampling Strategy

The upper Great Basin climate is typically characterized by extreme summers and winters and an arid environment. Moreover, rural communities with predominant occupations like ranching, agriculture, and fishing (resource dependent activities) are dominated by lower family income levels that are increasingly contributing to their poor social and economic conditions. At the same time, public lands in this region continue to be utilized by multiple users who often possess competing value systems; this can result in neighboring communities, the public-at-large, and regular users of the land harboring strong but potentially conflicting values about its use.

All of the above characteristics of the public rangelands in the Great Basin region form a unique “*context*” of ecological, social, and economic features. Interpreting the forestry literature and work done on contextual management of natural resources (Brunson 1992, 1993, Hansis 1995), such a context would be a mix of situational (geographical aspects), spatial (dynamics of surrounding locale), and social (influenced by demographics) characteristics. For the purpose of this study, I will ignore the specifics of different types of contexts, but rather highlight the importance of evaluating such a context consisting of interconnected factors that could significantly influence views and perceptions of stakeholders towards restoration. Knowledge of the existence of such a context that could influence the attitudes and implicit value systems of decision makers and that may eventually influence their actions is critical. Lack of any prior formal study or specific hypotheses with regard to stakeholders’ perspectives towards public rangelands and management of exotic annuals like cheatgrass constrained this study to be exploratory in nature.

An exploratory research design allows for a careful evaluation of social acceptability towards restoration and the related drivers and factors that influence acceptability. Furthermore, an exploratory research design facilitates an examination of respondents using pre-established propositions and seeks to draw inferences that could turn into potential hypotheses worthy of future investigation. The use of a case study analysis fit appropriately with the goal to conduct an exploratory qualitative analysis of the above stated research issues.

3.7.1 Case Study Analysis

According to Berg (2001) qualitative research allows researchers to share in the understandings and perceptions of others. A lack of prior studies with regard to attitudes towards restoration on public rangelands limits the ability to use or build any absolute hypothesis with regard to the subjects' impressions of public rangelands with regard to invasive species and restoration. Thus using qualitative research techniques is considered a better fit than a purely quantitative one. Specifically, evaluating a phenomenon within the context of the situation motivated the use of a case study analysis which is well suited to researching meanings in events, places, and changes.

Given the ecological, social, and economic context of the Great Basin region, a case study analysis allows for capturing the views of the respondents toward restoration and ongoing restoration strategies in particular. According to Yin (2002) a case study is an inquiry that essentially investigates a contemporary phenomenon within its real-life context, specifically when boundaries between the phenomenon and context are not clearly evident.

The context here represents unique ecological and socio-economic conditions. The phenomenon of interest in this study is the willingness to support or undertake restoration that can have multiple meanings to varied audiences. This study is a multiple case study design within a single context. Multiple cases exist in this study due to the need to assess attitudes of stakeholders in four different geographic locations. Thus, the unit of analysis (case) also is the meaning of restoration across different geographic locations (southeastern Oregon, southwestern Idaho, northwestern Utah, and northern Nevada).

Moreover, a case study analysis allows for better understanding of the stakeholders' perceptions given the context (setting) that influences not only their day-to-day decisions but also their relationship with the natural resources (land, flora, and fauna) and acceptability to change (restoration in this case). Information obtained from this study would complement the economic cost information on impacts of restoration by offering an insight into not only "what it costs to restore" but also "what their attitudes are" with regard to cheatgrass dominated rangelands.

3.7.2 Case Study Participants

The selection of relevant stakeholders for this study is largely motivated by their expected roles and professions that involve the management and use of public rangelands, on anecdotal evidence, and personal communications. The stakeholders identified for this study are ranchers, informed citizens, interest groups, and agency personnel.

1. **Ranchers**

This group consists of full-time ranchers who are engaged in traditional ranch operations with 80% or more income from ranching (Gentner and Tanaka 2002). It is essential to include ranchers as a stakeholder as they are the dominant users of the rangelands and ranching practices are often speculated as a facilitator of continual growth of invasive species.

2. **Informed citizens**

This category includes members of the public-at-large who are not only informed citizens of the community (thus actively involved or aware of activities and issues involving rangelands) but also whose primary source of income is not dependent on ranching. Knowing the views and preferences of informed citizens with regard to public rangelands and their use and restoration projects is critical as they often represent the general community in public hearings, official meetings, and petitions.

3. Interest groups in favor of restoration

The existence of interest groups that provide a voice for their members in support or opposition of issues cannot be ignored. Local members of interest groups engaged in restoration efforts or in favor of restoration on public rangelands are also interviewed.

4. Agency personnel from the BLM and/or USFS

The BLM as the managers of public rangelands and USFS with similar duties on National Forests and Grasslands made it essential to include the perspectives of personnel from these two agencies.

One respondent from each stakeholder group was interviewed in each of the four Great Basin states. Limiting the interviews to four categories across the four states is due to logistical constraints (time and expenses). According to Patton (1990), qualitative research often calls for use of inductive analysis of the data, meaning that the critical themes emerge out of the data. Key themes that were expected to emerge from these interviews were the degree of social acceptability to invasive species and cheatgrass control; the assessment of ongoing restoration, including usefulness and methods; and drivers and factors that could improve/affect restoration initiatives.

The semi-structured questionnaire (Appendix C) allows for the respondent to share his or her views freely and for newer questions to evolve that were not preplanned. Demographic information (age, gender, income, education level, and political orientations) of the participants is collected in an effort to conduct a richer analysis of the data. Moreover, the demographic data in conjunction with attitudinal data allows for looking at the influence of demographic factors on the perceptions and social acceptability of the participants towards restoration. Yin (2002) warned of limitations to using such a technique, including response bias, inaccuracies in recalling, and reflexivity – interviewee response is what interviewer seeks to hear. For a targeted audience, as in this study, with the possible different meanings of restoration and its overall acceptability embedded in the participant's insights, such a technique was found most appropriate to use.

3.7.3 Sampling Strategy

The site and context specificity in the study and its special focus on a specific set of subjects for assessing their attitudes to a phenomenon (restoration) implies that choosing a sample based on probabilistic methods (e.g., random sampling) may not be feasible. Moreover, it is critical to ensure that the subjects chosen match their respective stakeholder category and identify with the contextual conditions of the Great Basin region that influences the study design. In such instances, a purposive sampling technique is used initially as it ensures the inclusion of certain types of individuals or persons displaying certain attributes (Berg 2000). In this study, after interviewing the initial contacts, a snowball sampling approach is adopted. Snowball sampling enables the researcher to ask the first set of subjects for additional contacts across each of the four states who possess similar expertise and/or occupation and fit the context. The next set of respondents is identified in consultation with existing ones who are in touch with each other through professional affiliation in groups or networks. The process is repeated until one participant per category in each of the four regions of the Great Basin is interviewed.

3.7.4 Interviews

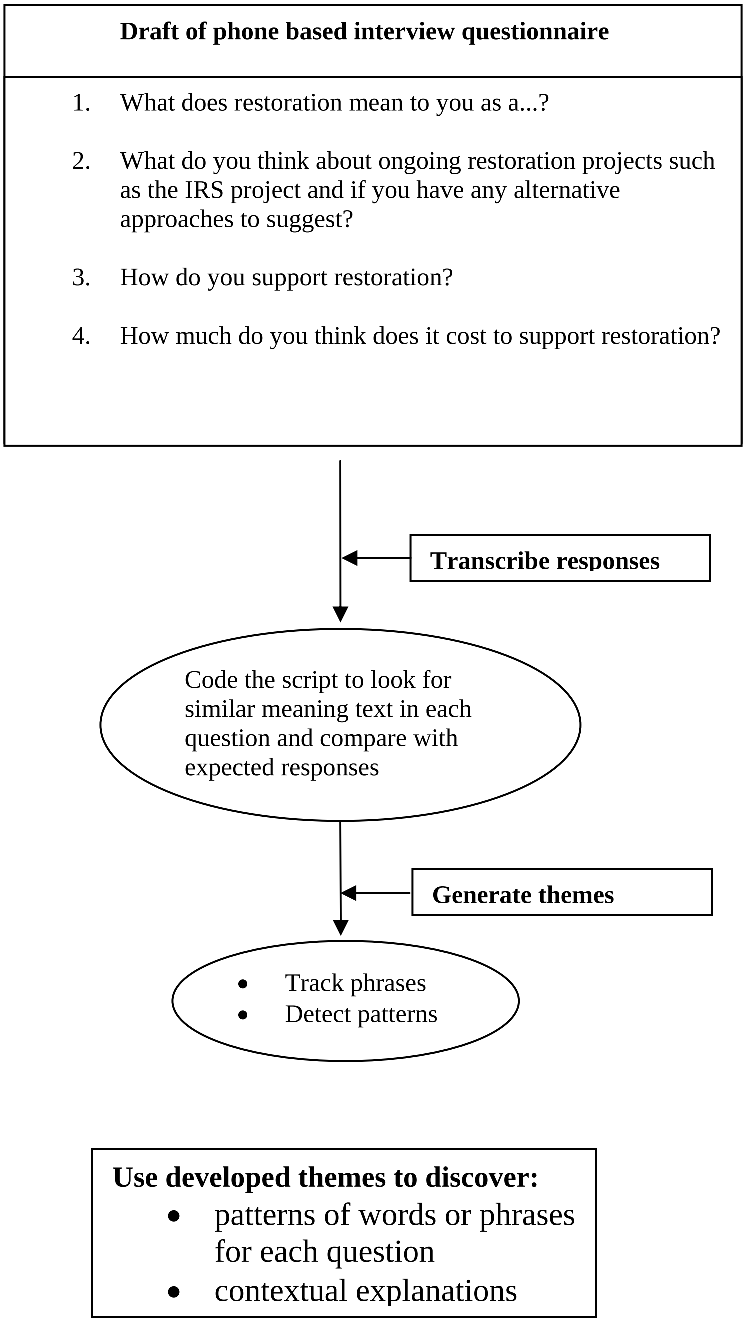
Since this research is qualitative in nature, semi-structured interviews are used to undertake a realist approach (inductive probing) to understand the data. According to Taylor and Bodgan (1998) interviews can be especially useful when the investigators are interested in understanding the perceptions of participants or learning how participants come to attach certain meanings to phenomena or events.

Phone interviews are conducted in accordance with Oregon State University's (OSU) Institutional Review Board (IRB) procedures of informed consent and confidentiality of contact information. Required certification to conduct such research was obtained. Appendix C also documents the IRB protocol that was approved by the OSU Ethics in Human Subjects Board.

Data collection through interviews is primarily a three step process. In the first step, informed contacts are used to acquire a list of key informants since the issue is not only very specific in its scope but also limited to the geographical context of Great Basin rangelands of Oregon, Idaho, Nevada, and Utah. Oregon State University's rangeland resource extension agents and rangeland resource scientists not engaged with this study are asked to provide names of key informants as they are frequently in close contact with the larger community on general range management issues. OSU extension agents can also provide names of their colleagues in other land grant universities of the four Great Basin states as part of the effort to solicit case study participants. The key informants across all four states consist of retired federal and/or state agency personnel, active community members, and rangeland resource consultants. In the second step, the key informants are contacted and read the IRB protocol that explains the reason for the interviewer's request to receive names of potential interviewees for each of the four Great Basin states. In general, each key informant should be able to provide names that match any of the stakeholder categories. Interest group representatives and informed citizens may be difficult to obtain from the initial set of approximately 10 key informants. Snowball sampling is thereafter used to gather names of other potential interviewees for the other states if information from key informants is lacking. The initial sampling pool across all categories for each state will average two names per group although only one person per category will be called for a phone interview. The third and final step involves contacting the interviewees and reading the IRB protocol to them and asking them of their willingness to participate. Those who choose to participate (100% acceptance rate), will be either interviewed right then or at another convenient time. Interview time should vary from 15 to 45 minutes and responses will be recorded through note taking.

3.7.5 Data Analysis

Qualitative data analysis according to Strauss and Corbin (1990) begins with the identification of themes emerging from the raw data, a process also referred to as “open coding.” The transcribed responses from the interview based data offers an extensive and accurate source of layers of meanings that warrant interpretation. Emerging main and sub-themes are used in the analysis of the data through a rigorous and repetitive evaluation of the text and searching for phrases and matching patterns. Such an interpretation or content analysis calls for the development of an objective coding scheme (Yin 2002). Coding is done by grouping the responses into categories that bring together similar or opposing themes or ideas that otherwise would go unnoticed. These codes in turn allow for systematic assessment of collected material through analysis of similar words, phrases and anecdotal examples or stories expressed by the interviewee. The similar words or phrases are then highlighted which represented the various developed themes. Figure 3.4 provides a flowchart of the process of theme development. Additional demographic data as provided in Appendix C are used to compare all responses to evaluate if demographics influence a certain view or position of the respondents.



Draft of phone based interview questionnaire

1. What does restoration mean to you as a...?
2. What do you think about ongoing restoration projects such as the IRS project and if you have any alternative approaches to suggest?
3. How do you support restoration?
4. How much do you think does it cost to support restoration?

Use developed themes to discover:

- patterns of words or phrases for each question
- contextual explanations

Figure 3.4. Process of transcribing interview responses and developing themes.

Chapter 4. Results and Discussion

This chapter provides the results and related analysis of the economic and social implications of adopting restoration strategies to control cheatgrass.

4.1 Economic Impacts - Results and Discussion

Economic costs of undertaking restoration will be presented for each of the four Great Basin ranches under a baseline scenario (no changes) and four treatment scenarios of herbicide use, grazing, prescribed fire, and an integrated strategy consisting of all three. Each of the four restoration strategies is followed by re-seeding of perennial native species.

The economic model assumed that restoration was needed on 75% of the total available BLM summer grazing allotment. The remaining 25% of the BLM land was assumed to be in native species, thus not requiring treatment. For each restoration strategy, a 2 year post-treatment recovery period was required for the perennial seeded species to become established. The two year recovery period resulted in the rancher being faced with no BLM forage for the treated acres for those years. The resulting loss of forage availability or the discounted opportunity costs associated with forgone forage was added to the treatment costs to assess the total restoration costs to the representative ranches.

Each representative ranch has a different combination of resources, production rates, management practices, and costs. Table 4.1 summarizes the initial characteristics of representative Great Basin ranches.

Table 4.1. Initial productivity characteristics of representative ranches.

Characteristics		**Units**	**Oregon**	**Idaho**	**Nevada**	**Utah**
Land resources	BLM - natives	AUMs	481	231	550	301
	BLM – treatable	Acres	1,031	1,958	3,000	2,055
	Private lease	AUMs	200	200	200	200
	Deeded rangeland	AUMs	1,650	1,650	1650	1650
	Raised meadow	Acres	70	70	70	70
	Grazed meadow	Acres	350	350	350	350
Initial animal resources	AUY	AUY	410	513	555	538
	Brood cows	Head	300	330	340	384
	Cull cows	Head	52	57	73	51
	Bulls	Head	20	24	24	18
	Repl. heifers	Head	52	52	65	11
	Horses	Head	10	10	10	10
Required animal raising and transfer conditions	Calf-crop	%	0.84	0.88	0.85	0.80
	Cow replacement	%	0.15	0.15	0.18	0.13
	Bull replacement	%	0.25	0.25	0.20	0.25
	Heifers for sale	%	0.10	0.12	0.11	0.25
	Heifer calves kept	%	0.80	0.80	0.80	0.10
	Cow-bull ratio		20.00	18.00	20.00	24.00
Off ranch income		$	10,000	10,000	10,000	10,000
Family allowance		$	24,000	24,000	24,000	24,000
Fixed ranch expenses		$	17,446	24,430	33,361	23,920
Interest return on savings		%	3	3	3	3
Short term borrowing rate		%	10	10	10	10

It is evident from Table 4.1 that the representative Great Basin ranches have similar land resources and financial conditions but varying levels of animal herd size and required ratios between different animal classes. The economic impacts of adopting restoration strategies are explained below for each of the four representative ranches. The economic costs of restoration in this study are calculated as a summation of the total costs of treatment and discounted costs associated with the loss of two years of forage due to the recovery period from restoration. The selected economic measures are annual averages for each restoration scenario. Given the assumption that a rancher may adopt restoration only in year 1 which results in forage and resource adjustments in the initial years and the profit maximizing model's tendency to adjust herd size to maximize the terminal value, the economic analysis excludes results from years 1 to 4 and 37 to 40. By excluding these years that are model adjustment years, the study is able to focus on the economic implications of restoration strategies on the overall performance of the ranch operation.

4.2 Ecological and Economic Impacts of Restoration for the Oregon Ranch

A representative Oregon ranch is described using the productivity and resource use parameters as shown in Table 4.1. The ranch was assumed to replicate a typical 300 cow/calf operation with 52 cull cows, 20 bulls, 10 horses, and 52 replacement heifers. The rancher was assumed to be operating the ranch full time. The ranch used its annual BLM grazing permit from April 1st to July 15th each calendar year and restoration strategies were assumed to be needed on 417.4 ha of BLM land. The ranch at all times used 481 AUMs of native forage from its non-treatable BLM allotment. The following two sections summarize the ecological and economic impact to the representative Oregon ranch due to the adoption of the restoration strategies.

4.2.1 Ecological Impacts of Restoration Adoption for the Oregon Ranch

The ecological impact to the Oregon representative ranch under alternative restoration scenarios is shown in Figure 4.1. The different growth functions for cheatgrass and native species (i.e., seasonality) resulted in less forage used than total forage available. Total forage production from BLM "treatable" land was the highest at

1,471 AUMs and consumption was 837 AUMs. Selecting herbicide application resulted in treatable BLM forage availability declining to 821 AUMs and usage to 556 AUMs. Grazing and fire reduced forage availability to 708 AUMs each. A decision to adopt the integrated strategy impacted forage availability and utilization significantly. The integrated scenario resulted in production of 707 AUMs but only 491 AUMs were utilized or a 41% decline for the Oregon ranch model.

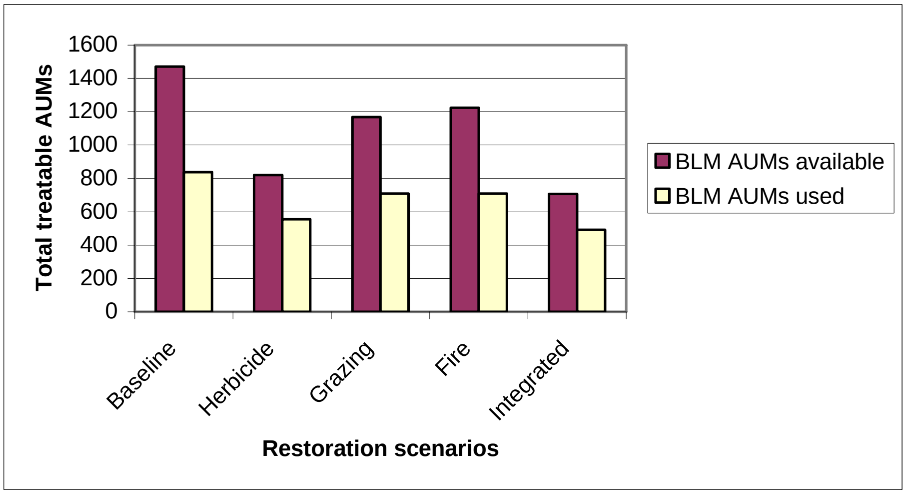


Figure 4.1. BLM forage availability and use for the Oregon model.

4.2.2 Economic Impacts of Restoration for the Oregon Ranch

The economic impacts of restoration adoption are summarized below using Table 4.2 and Figure 4.2.

Table 4.2. Economic impacts of restoration for the Oregon model.

Characterisitcs	Baseline	Herbicide	Grazing	Fire	Integrated

Animal units yearlong (t = 5 to 36)	462	428	447	449	420
Number of brood cows (t=5 to 36)	300	276	289	290	271
Annual net return (t=5 to 36)	$ 61,827	$ 57,123	$ 60,007	$ 59,767	$ 54,365
Total restoration costs	$ 0	$ 82,815	$ 41,575	$ 57,040	$ 134,365
Restoration costs per hectare	$ 0	$ 197.60	$ 98.80	$135.85	$ 321.10

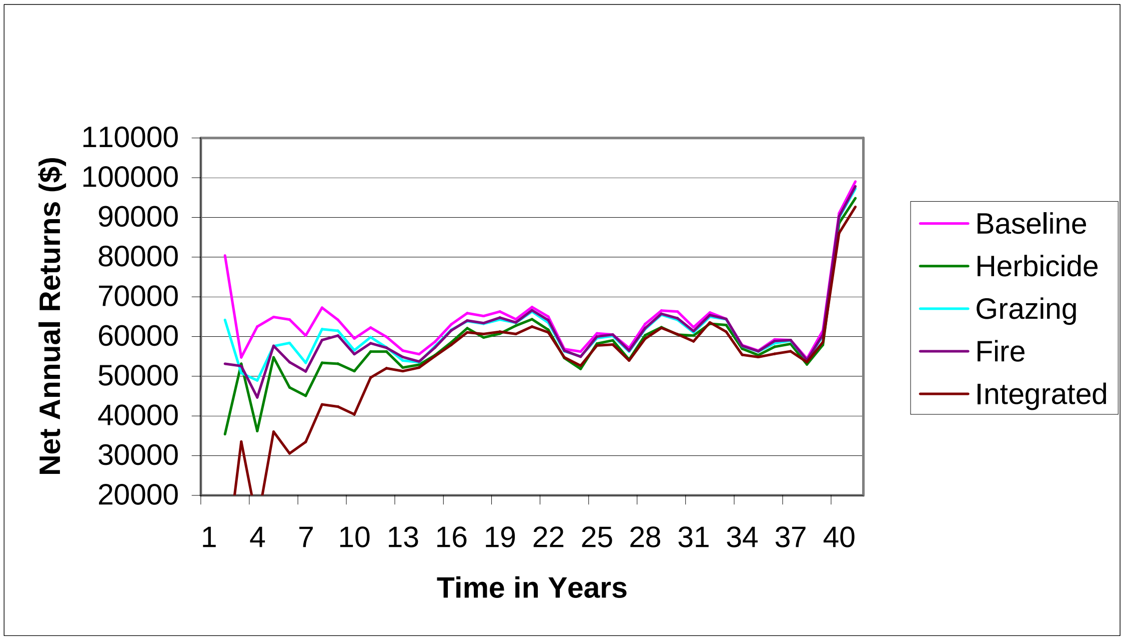


Figure 4.2. Annual net returns for the Oregon ranch model.

4.2.2.1 Baseline Conditions

Under the no change scenario, the Oregon ranch had an economically viable operation with 300 brood cows and 426 AUY and net annual returns of $61,827.

4.2.2.2 Herbicide Use

A decision to apply herbicide reduced forage availability by 33% (due to a 60% reduction in growth of cheatgrass biomass) for the Oregon ranch due to dissimilar seasonal growth rates of cheatgrass and native species. Consequentially, the Oregon ranch model adjusted its herd size from 300 brood cows to 276. AUY declines from 462 to 428. Net annual return of the ranch fell by 7% to $57,123. Total costs of restoration due to herbicide use on 417.4 ha of BLM land was $82,815 or $197.60 per hectare which matches anecdotal cost information received from BLM personnel.

4.2.2.3 Grazing

Grazing as a restoration strategy was simulated in STELLA to reduce the growth of cheatgrass during its initial growing season. STELLA was modeled to indicate a 20% decrease in cheatgrass biomass and a 10% corresponding increase in native biomass due to the adoption of grazing as a means to reduce cheatgrass reproduction capacity. Table 4.2 shows that the economic costs of grazing BLM lands is lower than that incurred by the rancher under the herbicide scenario. The reduced forage availability resulted in a herd size of 289 brood cows and 447 AUY. Annual net returns were $60,007, a 3% decrease over the baseline case. Total restoration costs consisted of $41,575 or a net cost of $98.80 per hectare.

4.2.2.4 Prescribed Fire

Use of prescribed fire was assumed to control cheatgrass by reducing its growth by 20% and increasing native biomass by 10%. AUY of the ranch was reduced to 449 with 290 brood cows. However, the ranch continued to remain economically viable with annual net returns of $59,767. Total restoration costs due to use of prescribed fire was $135.85 per hectare.

4.2.2.5 Integrated Strategy

The integrated strategy consisted of a one time sequential implementation of prescribed fire, herbicide, and reseeding of native species starting in late summer. A 70% decrease in cheatgrass growth with a 30% increase in natives resulted in the ranch falling short of the minimum forage needs in the earlier grazing seasons of April and May. Adopting an integrated strategy resulted in the ranch severely reducing its herd size to balance the reduced forage supply with the demand. This caused a reduction in herd size to balance the lower forage availability. Total annual AUY fell from 462 to 400 and herd size reduced by 9.6% to 271 brood cows. Total ranch restoration costs were $321.10 per hectare.

4.2.3 Discussion of Results

The economic analysis indicated that adoption of any restoration strategy impacted the ranch financially over not adopting any restoration strategies at all. This is verified by Figure 4.2 that depicts the net annual return for the Oregon ranch model.

Net annual returns for the Oregon ranch were highest under the baseline condition alone. Net annual returns were the lowest under the integrated and herbicide restoration scenario with average returns of $54,365 and $ 57,123, respectively. Use of grazing resulted in average net returns of $60,007 and $59,767 with fire. To conclude, grazing and fire proved to be the most cost-effective restoration strategies for the Oregon ranch.

4.3 Ecological and Economic Impacts of Restoration for the Idaho Ranch

The representative Idaho ranch is similar to the Oregon ranch in its general working and production practices. The ranch is a full time operation with over 1,958 acres in a BLM allotment available for treatment during the summer grazing months.

4.3.1 Ecological Impacts of Restoration Adoption for the Idaho Ranch

The ecological impacts to the Idaho representative ranch due to adoption of restoration strategies are shown in Figure 4.3. Under the baseline condition, the Idaho ranch maximized its use of available treatable forage, resulting in cattle grazing 1,450 AUMs of the total available 3,018 AUMs. Dissimilar seasonal growth rates resulted in forage availability never equaling forage production. A management decision to apply herbicide resulted in a reduction in available forage to 1,713 AUMs and final utilization of 1,186 AUMs of treatable BLM land. Adopting grazing as a restoration strategy reduced available forage to 2,536 AUMs and forage grazed to 1,394 AUMs. Prescribed fire use reduced forage availability to 2,526 AUMs and only 1,349 AUMs of those available were finally utilized. The integrated strategy as modeled in STELLA impacted forage availability significantly, resulting in only 1,027 AUMs being grazed (29% decline).

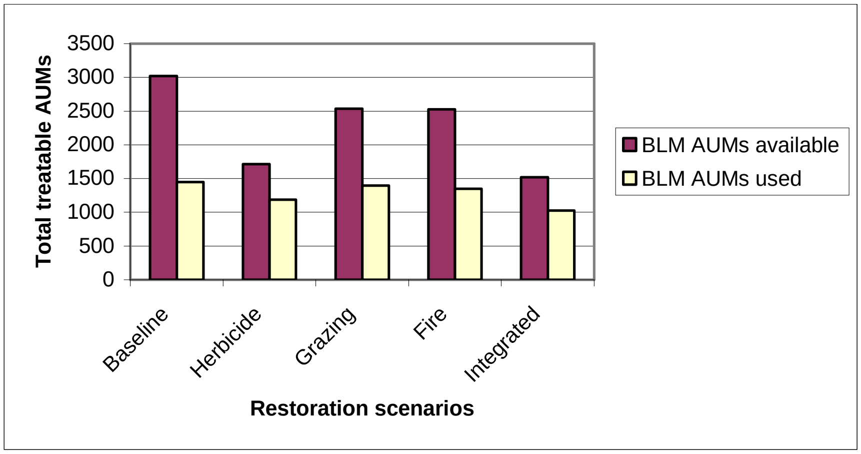


Figure 4.3. BLM forage availability and use for the Idaho model.

4.3.2 Economic Impacts of Managing Cheatgrass for the Idaho Ranch

The economic impact of restoration strategies to the Idaho ranch are summarized in Table 4.3. Following the summary of individual economic impacts of each restoration strategy, a general discussion reviews the net annual return of the ranch under various restoration scenarios.

Table 4.3. Economic impacts of restoration for the Idaho model.

Characteristics	**Baseline**	**Herbicide**	**Grazing**	**Fire**	**Integrated**
Animal units yearlong (t = 5 to 36)	513	483	513	508	460
Number of brood cows (t=5 to 36)	330	308	329	325	294
Annual net return (t=5 to 36)	71,571	67,326	70,701	70,210	62,305
Total restoration costs	0	$182,797	$104,477	$133,847	$280,697
Restoration costs per hectare	0	$229.71	$130.91	$167.96	$353.21

4.3.2.1 Baseline Condition

Under the no change or baseline condition, the number of brood cows was 330 with 513 AUY and net annual nominal return of the ranch was $ 71,571 allowed the ranch to maintain an economically viable operation.

4.3.2.2 Herbicide Use

Herbicide use in STELLA was modeled to yield a 60% decrease in cheatgrass growth and a 20% increase in native forage. The effects of this treatment are summarized in Table 4.3. As in the case for Oregon, the application of Roundup Ultra, though very effective, had a significant negative impact on the economic profitability of the Idaho ranch due to varying growth rates of cheatgrass and natives. This resulted in a reduction in herd size by 6.6% to 308 brood cows. Annual net return was reduced from $71,571 to $67,326 or a 6% decline with restoration costs totaling $182,797 or $229.71 per hectare.

4.3.2.3 Grazing

Grazing as a restoration strategy was implemented during the growing season of cheatgrass with the intent to reduce seed production before it gets dispersed into the soil. Grazing was modeled in STELLA to result in a 25% decrease in cheatgrass and a 10% increase in native biomass. Use of grazing resulted in a reduction in BLM treatable AUMs from 1,450 to 1,394 AUMs. Animal units yearlong and herd size were reduced to 513 and 329, respectively. Annual net returns were reduced to $70,701, or a 2% decline. Restoration costs over the 793 ha of treatable BLM land totaled $104,477 or $130.91 per ha.

4.3.2.4 Prescribed Fire

Using prescribed fire on 793 ha of BLM treatable land resulted in reductions in cheatgrass by 20% and an increase in native biomass by 10%. This translated into 1,349 BLM treatable AUMs being available to cattle in addition to the 231 AUMs of native forage. AUY of the ranch was reduced to 508. Annual net return of the ranch was $70,210 and restoration costs were $104,477 or $167.97 per ha.

4.3.2.5 Integrated Restoration

Adoption of the integrated restoration strategy impacted the Idaho representative ranch severely. The 330 cow-calf operation was forced to adjust to lower BLM treatable forage availability of 1,027 AUMs. Herd size declined to 294 brood cows and annual net return decreased by 13% to $62,305. Total restoration costs incurred by the ranch were $280,697 or $353.21 per ha.

4.3.2.6 Discussion of Results

Review of the Idaho ranch model indicates that adoption of restoration strategies had similar economic implications as the Oregon ranch model. Figure 4.4 shows the net annual returns of the Idaho ranch across the 40 year timeline. The baseline condition of no restoration resulted in the highest net return followed by grazing and then fire as cost-effective restoration strategies. Adoption of the integrated restoration strategy impacts the ranch severely in the initial years due to insufficient forage availability. This results in the ranch incurring negative returns until year 3 and then becoming profitable again with increased availability of forage.

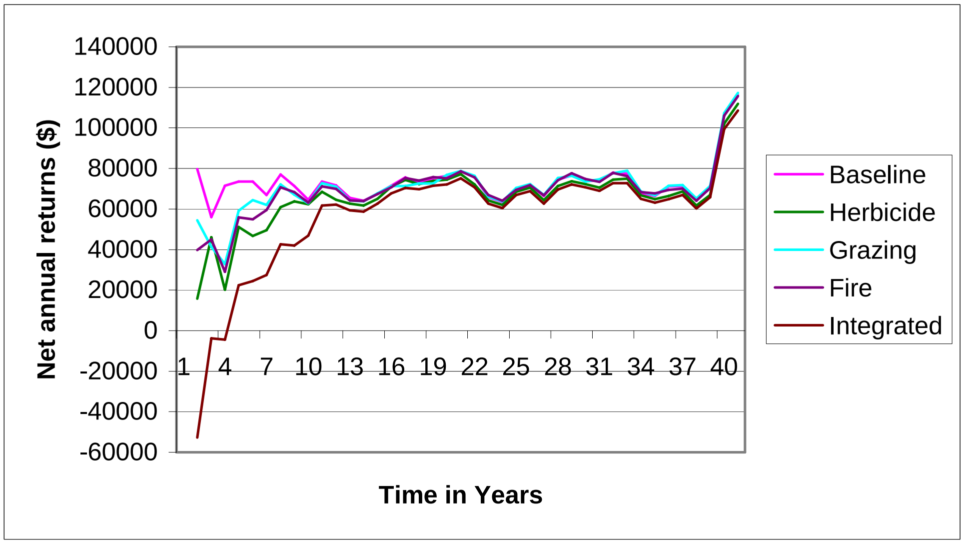


Figure 4.4. Net annual returns of Idaho ranch model.

4.4 Ecological and Economic Impacts of Restoration for the Nevada Ranch

The representative Nevada was based on a full time ranch operation consisting of 340 brood cows, 73 cull cows, 24 bulls, and 10 horses. The ranch was similar in other production and resource use characteristics as the other Great Basin state ranches (Table 4.1).

4.4.1 Ecological Impact of Restoration Adoption for the Nevada Ranch

The ecological impact of restoration to the Nevada ranch is shown in Figure 4.5 that compares available versus used BLM treatable forage. Under the baseline conditions, the Nevada ranch model had 3,225 AUMS of which 1,561 AUMs of BLM treatable forage were consumed. Herbicide use reduced cheatgrass growth significantly causing a decline in forage availability to 1,999 AUMs and net use to 1,165 AUMs. Adopting grazing and fire as restoration strategies resulted in the availability of BLM treatable forage to decline to 1,129 AUMs and 1,125 AUMs respectively. The integrated restoration strategy reduced forage availability to 1,682 AUMs and net usage declined to 1,087 AUMs.

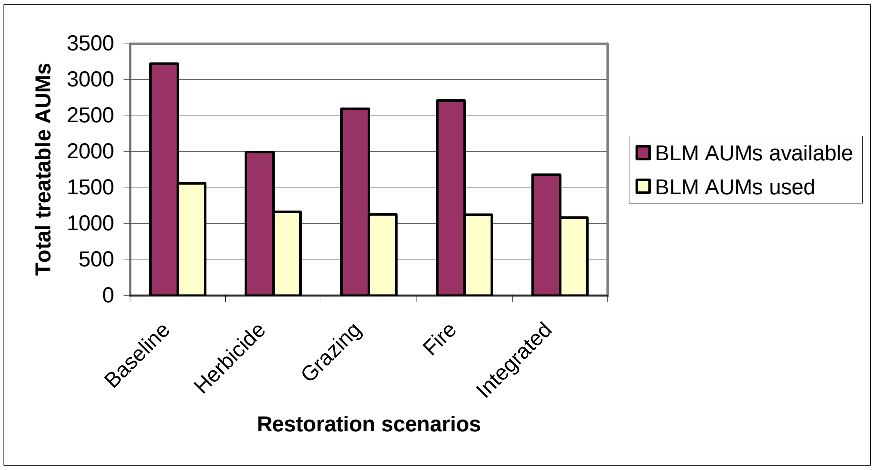


Figure 4.5. BLM forage availability and use for the Nevada model.

4.4.2 Economic Impact of Restoration Adoption for the Nevada Ranch

Table 4.4 summarizes the economic impact of cheatgrass control strategies.

Table 4.4. Economic impacts of restoration for the Nevada model.

Characteristics	**Baseline**	**Herbicide**	**Grazing**	**Fire**	**Integrated**
Animal units yearlong (t = 5 to 36)	555	502	490	485	500
Number of brood cows (t=5 to 36)	340	312	300	299	307
Annual net return (t=5 to 36) ($)	65,319	-121,762	51,748	17,274	-92,756
Total treatment costs	0	$ 214,639	$ 94,639	$ 139,639	$ 364,639
Treatment costs per hectare	0	$ 175.37	$ 76.57	$ 113.62	$ 298.87

4.4.2.1 Baseline Scenario

The Nevada based representative ranch had an average herd size of 340 brood cows and 555 AUY. Net nominal annual return of the ranch was $65,319.

4.4.2.2 Herbicide Use

Herbicide application on the Nevada representative ranch offered similar forage availability constraints as those experienced by the representative Oregon and Idaho ranches. A 60% decrease in cheatgrass and a 30% increase in natives resulted in significant reductions in forage availability for the ranch during its grazing seasons on treatable BLM land of 1,215 ha. The ranch was affected with a sharp decline of its herd to 312 brood cows, or 8.2%, and 502 AUYs. The annual net return was -$121,762 and total restoration costs were $214,639 or $175.37 per ha.

4.4.2.3 Grazing

Grazing as the second restoration strategy for the 340 brood cow operation proved economically more sustainable than application of herbicide. Average AUY fell to 490 and herd size declined from 340 brood cows to 300. Reduced herd size accordingly adjusted the annual net returns to $51,748, or a decline of 20%. Restoration costs for the ranch totaled $94,639 or $76.57 per ha.

4.4.2.4 Prescribed Fire

The Nevada representative ranch under a prescribed fire restoration scenario resulted in a reduced availability of treated forage to 1,125 AUMs. The ranch consequentially reduced its herd size to 299 brood cows and the annual net returns declined to $17,274, a decline of 73%. Restoration costs were $139,639 or $113.62 per ha.

4.4.2.5 Integrated Strategy

The decision to adopt an integrated restoration scenario resulted in a decline in AUY to 500 and herd size to 307 brood cows. Annual net returns of the ranch were a negative $92,756 with restoration costs of $364,639 or $298.87 per ha.

4.4.2.6 Discussion of results

Similar to the Oregon and Idaho representative ranch, the Nevada ranch was economically impacted by adoption of all four restoration strategies. Figure 4.6 provides a 40 year summary of the annual net returns of the ranch due to adoption of the different restoration strategies.

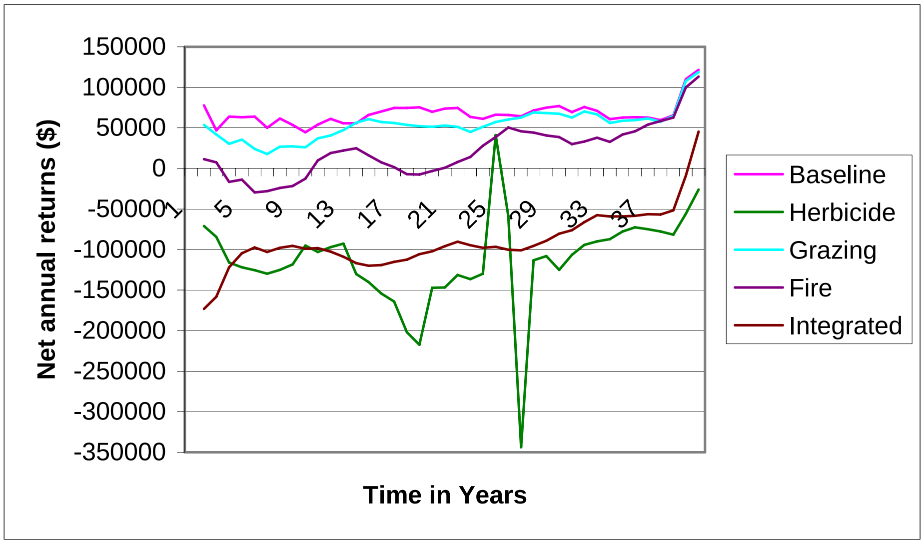


Figure 4.6. Annual net returns for the Nevada ranch model.

Although the Nevada representative ranch had a greater BLM allotment area than other representative ranches (1,214 hectare of treatable land), lower precipitation, and a lack of forage availability due to restoration impacted herd size of the ranch significantly. The Nevada ranch maintained an economically viable operation under the baseline and grazing scenarios, but faced the possibility of bankruptcy due to a negative annual net return under the herbicide, fire, and integrated scenarios.

4.5 Ecological and Economic Impacts of Restoration for the Utah Ranch

A typical Utah ranch was constructed using data from extension reports and Torell et al. (2002). Table 4.1 summarizes the productivity and resource parameters of the Utah representative ranch.

4.5.1 Ecological Impact of Restoration for the Utah Ranch

The ecological impact of cheatgrass control is provided below using Figure 4.7. The representative Utah ranch displayed similar forage availability and use responses to cheatgrass control strategies as did the other Great Basin representative ranches. Under the baseline condition with the higher precipitation range, the ranch's treatable BLM land produced 3,575 AUMs and 1,780 AUMs of those were used. Adoption of an herbicide strategy reduced forage availability to 2,261 AUMs and eventual consumption was 1,190 AUMs. Using grazing as a management strategy resulted in 2,902 AUMs being available and 1,485 AUMs were grazed. Adoption of prescribed fire resulted in the availability of 3,034 AUMs of which 2,023 AUMs were used and an integrated restoration strategy resulted in the ranch utilizing only 1,149 AUMs of the total available 1,897 AUMs.

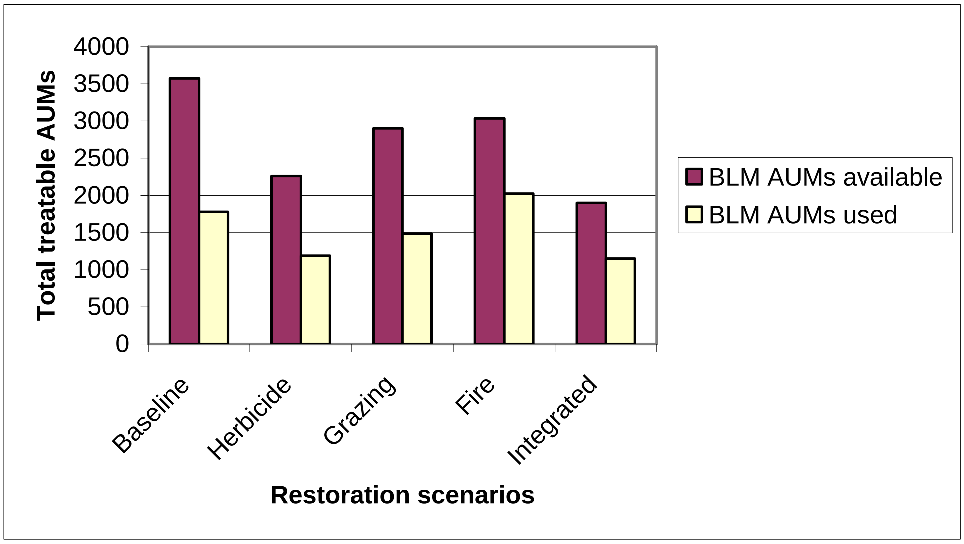


Figure 4.7. BLM forage availability and use for the Utah model.

4.5.2 Economic Impact of Restoration for the Utah Ranch

Table 4.5 summarizes the economic impacts to the Utah ranch choosing to adopt various restoration strategies.

Table 4.5. Economic impacts of restoration for the Utah model.

Characteristics	**Baseline**	**Herbicide**	**Grazing**	**Fire**	**Integrated**
Animal units yearlong (t = 5 to 36)	538	463	524	481	461
Number of brood cows (t=5 to 36)	384	330	374	343	329
Annual net return (t=5 to 36) ($)	51,502	-9,188	49,109	21,227	-30,910
Total treatment costs	0	$173,813	$91,613	$122,438	$276,563
Treatment costs per hectare	0	$207.48	$108.68	$145.73	$330.98

4.5.2.1 Baseline Scenario

Under a framework of not adopting any restoration strategy, the representative Utah ranch was able to utilize 1,780 AUMs of the treatable BLM forage in addition to the 550 AUMS of non-treatable BLM native forage sources. Economically, the ranch maintained a viable operation with a herd size of 384 brood cows, 538 AUY, and an annual net return of $51,502.

4.5.2.2 Herbicide Use

Herbicide use impacted post-treatment available forage resulting in the overall reduction in BLM treatable forage to 1,190 AUMs. The model adjusted ranch herd size to 330 brood cows, a decline of 14%, and AUY to 463. The ranch faced the risk of negative annual net return of -$9,188 or becoming bankrupt. Restoration costs for the entire 832 ha of treatable BLM land were estimated at $173,813 or $207.48 per ha.

4.5.2.3 Grazing

Grazing as a restoration scenario was modeled to reduce cheatgrass growth by 25% and increase native forage biomass by 10%. Solving for an optimal ranch income resulted in the use of 1,485 AUMs from BLM treatable land by 384 brood cows and an annual net return of $49,109. Higher precipitation resulting in increased productivity per hectare was a factor in the Utah ranch to have the lowest economic loss in comparison to other restoration strategies. Grazing restoration costs were $91,613 or $108.68 per ha.

4.5.2.4 Fire

Prescribed fire was assumed to reduce cheatgrass biomass by 20% and increase native biomass by 10%. Adopting fire as a restoration strategy increased the treatable BLM forage to 2,023 AUMs. Lack of enough forage availability through the early grazing seasons resulted in 481 AUY and herd size fell to 343 brood cows. Annual net return for the ranch was $21,227 with restoration costs of $122,438 or $145.73 per ha.

4.5.2.5 Integrated Strategy

Adopting the integrated strategy imposed significant restrictions on the ranch through reduced forage availability and high restoration costs. Optimal adjustments by the ranch resulted in BLM forage from treatable land being reduced to 1,149 AUMs and 461 AUY. Furthermore, the herd size declined to 329 brood cows resulting in the ranch operation with an annual net return falling to -$30,910 or a deficit in annual cash flow or experiencing bankruptcy.

4.5.2.6 Discussion of Results

Figure 4.8 shows the overall economic status of the Utah representative ranch as a result of adopting various cheatgrass control strategies. The Utah ranch model displays similar economic impacts as the other states. Grazing continued to remain the most cost-effective restoration strategy after the baseline condition. Adoption of herbicide and the integrated restoration strategies proved economically damaging as the ranch runs the risk of going bankrupt.

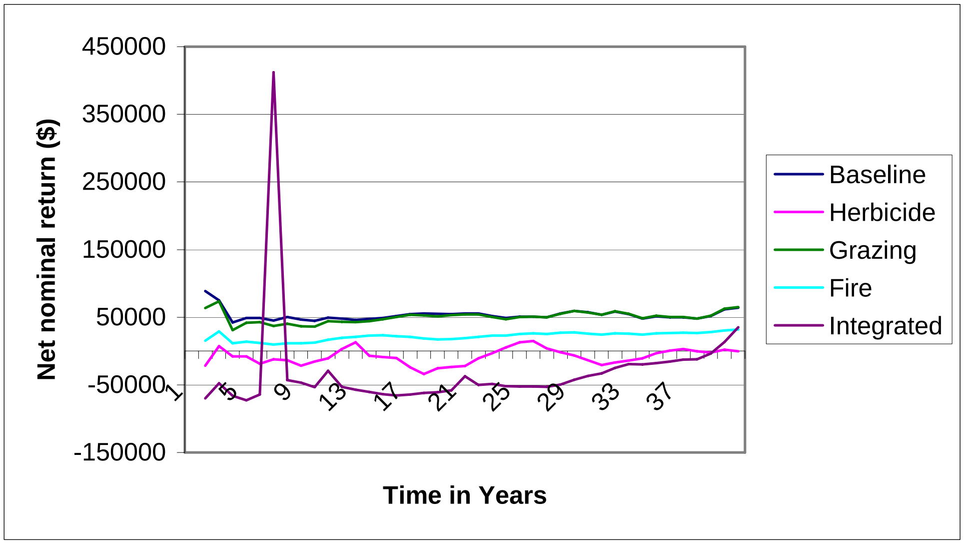


Figure 4.8. Annual net returns for the Utah ranch model.

4.6 Results and Analysis – Social Impact Assessment

This section is split into two parts. The first section provides an overview of the various themes that emerged from transcribing the phone interviews of each stakeholder across the Great Basin region. The next section provides the detailed findings from the transcribed data across all the four categories from Oregon, Idaho, Nevada, and Utah.

4.6.1 Findings from Phone Interviews

Stakeholder responses to each question and emerging themes are provided below with some elaboration on possible explanations for the respondents' views. The question below is taken from the phone interview survey as provided in appendix C.

4.6.1.1 What does restoration on public rangelands mean to you as a ….?

The key themes that emerged from coding all the responses included:

i. **perceptions of restoration**

ii. **differences in meaning of restoration versus rehabilitation**

iii. **barriers to restoration (ecological, economic, and / or social)**

a) BLM personnel

No major differences were found in the perceptions of four BLM respondents across the four Great Basin states. All of the respondents reported a consistently distinct difference between restoration and rehabilitation when dealing with cheatgrass and other exotic grasses.

i. Perception of restoration

All three BLM respondents echoed this respondent in describing restoration:

> Restoring function and structure so as to use native species
> to restore a site to its original state or where there is least
> runoff and threat from invasive species.

However all four respondents were also realistic about the threat posed by cheatgrass and described its management as a complex task. For example, a BLM interviewee from Idaho with 18 years experience said

> Restoration often requires use of native species but that is often not possible. One has to substitute with non-native species and restoration is a slow process.

ii. Differences in meaning of restoration versus rehabilitation

Almost all respondents felt that there was a distinct difference between restoration and rehabilitation and dealing with cheatgrass and other exotic grasses is essentially restoration. All the BLM respondents defined rehabilitation as some variation of

> Recovery from disturbance

The BLM respondent from Utah in particular said

> Dealing with cheatgrass requires restoration and not rehabilitation. Simply restoring a site to earlier site means rehabilitation.

Moreover, the respondents were also emphatic in their efforts to explain the difference in meaning, possibly trying to convey that the two terms are commonly misunderstood.

iii. Barriers to restoration

Barriers to restoration were cited by all the BLM interviewees. However, demographics appear to play a critical role in the respondents' views. The more experienced BLM personnel used very few scientific terms in their responses and in general were more expressive than the less experienced ones with regard to typical barriers relating to restoration. For example, a BLM interviewee from Nevada with over 33 years of experience in range restoration said

> My dealing with restoration involves the use of fire to allow for burnt areas to let reseeded native species to come in. Started using natives and even introduced species. Restoration to me means putting natives back with right soil type. Clearly more expensive.

While a BLM interviewee with 18 years of experience in range management said

> Restoration to me means restoring functionality and structure. This of course includes use of native species but that is often not possible.

b) Ranchers

Ranchers across the four Great Basin states generally shared similar views with regard to meaning of restoration and also felt that generally, restoration and rehabilitation were the same. Overall, demographic differences did not play a significant role in the respondents' responses.

i. Perception of restoration

In regard to the main theme of perceptions towards restoration, ranchers across the four Great Basin states had similarly clear views along the lines of one respondent:

> Getting the land into a natural state.

Specifically, for example, a full-time rancher from Idaho with a Bachelors education said -

> Restoration means that the rangeland might be degraded so there is a need to manipulate the land to restore it to a natural state.

While a rancher from Oregon with over 30 years of ranching experience indicated -

> It means getting the land into shape so that the water goes into the ground where it falls and then you have a tremendously ecologically diverse group of plants which are well suited for the land.

ii. Differences in meaning of restoration versus rehabilitation

All the rancher respondents were unanimous in their view that there is no difference between the terms "restoration" and "rehabilitation." The responses were consistent even though geographical factors varied for each respondent. For example, a rancher from Utah with high precipitation conditions and facing reduced levels of cheatgrass invasion said -

> Restoration to me from a rancher's perspective means rehabilitation of rangelands.

A rancher from Idaho where precipitation levels were much lower and cheatgrass is a significant issue, said -

> I think restoration and rehabilitation is somewhat same thing.

iii. Barriers to restoration

All the ranchers in general expressed reservations about restoration. Few responses dealt with the ecological barriers of doing restoration on public rangelands while some dealt with the economic concerns of undertaking restoration. Moreover, most ranchers explicitly or implicitly also tried to question the widely held understanding that cheatgrass is indeed a threat to rangelands. A comment made by a rancher from eastern Nevada where cheatgrass is highly dominant reflects this questioning:

> BLM thinks, cheatgrass is bad and helps them fill their budgetary requests for dollars. On drier sites, perennials are not always useful. Another problem with rehabilitation is where does the cattle go? Cannot go and buy grasses easily…basically, lack of economically feasible options.

No difference in views of the ranchers with varying demographic characteristics was found.

c) Interest groups favoring restoration

The interest groups in the four Great Basin states had similar responses but used more scientific terms than other groups to explain their views. There were mixed views with regard to the difference between restoration versus rehabilitation and demographic characteristics like experience seemed to influence the views of the respondents.

i. Perception of restoration

Interest group respondents favoring restoration in general had common attitudes towards what restoration exactly means. For example, an Oregon based interest group representative said -

> When I think of restoration, I think of vegetation structure, hydrological characteristics, changing fire, and grazing patterns and use of re-seeding and more active methods for completely invaded sites.

ii. Differences in meaning between restoration versus rehabilitation

The respondents had mixed views regarding restoration versus rehabilitation. It is possible that experience was influential in their views with regard to the presence of any differences in meaning between the two ecological terms. An interest group representative from Utah with only 1.5 years of experience, for example, said

> I had never thought about restoration versus rehabilitation. They seem the same to me.

On the other hand, a respondent from Idaho with over 6 years of experience in range issues had more to say about the distinction.

> Restoration to me means re-seeding of disturbed areas. Rehabilitation means – mining or reclamation, or some sort of reduced damage but is not necessarily the same as restoring to a natural condition.

iii. Barriers to restoration

The interest group had no views at all regarding barriers to restoration.

d) Informed citizens

Informed citizens across the four states shared similar attitudes about restoration with the interest group respondents. Informed citizens also felt that restoration and rehabilitation were two distinct concepts. Moreover, they also made explicit mention of social and economic barriers related to the conduct of restoration activities. Educational qualifications appeared to play a significant role in the type of responses shared by the interviewees across all three themes. Specifically, respondents with higher educational qualifications felt that restoration and rehabilitation are not the same and in general, were more critical of restoration than respondents with a lower educational level.

i. Perception of restoration

Educational qualifications influenced the language used by the respondents in defining their understanding of the term restoration. For example, a Nevada based informed citizen with a Bachelors degree said

> Restoration to me means restoring a land that you are looking at to the original state.

While an informed citizen from Idaho with a Ph.D. in Range Economics said

> Restore the ecological and hydrological functions of the system.

ii. Differences in meaning between restoration versus rehabilitation

Varying levels of educational qualifications also appeared to influence the respondents' views with regard to the meanings of restoration versus rehabilitation. A Nevada based informed citizen with a Bachelors degree in Education, for example, claimed that

> Restoration and rehabilitation are the same thing.

However, a respondent from Utah with a Ph.D. expressed a differing view.

> There is a difference between restoration versus rehabilitation. Rehabilitation to me means putting back the land into a functional system versus restoration means, putting it back into a natural state.

iii. Barriers to restoration

Barriers to restoration were most explicitly discussed by three of the four informed citizens; educational background again seemed to again influence perceptions. For example, the Utah informed citizen with a Ph.D. said

> The problem with restoration is we do not have a static system. Restoration is idealistic. What we need to do is put our environment / rangelands in a function in which it works at its optimum.

However, an Oregon informed citizen with only a Bachelors education said

> I am aware of the increasing efforts to grow native grasses on cheatgrass dominated rangelands and it seems pretty costly to control such grasses.

4.6.1.2 Discussion of Results: Variations in Meaning of Restoration

In general, the findings matched expected results with regard to the organizational responses on the meaning of restoration. All respondents across all groups for each state offered some perception of restoration and contextual factors (ecology and level of awareness and degree of professional involvement with other stakeholders).

4.6.1.3 What do you think about the ongoing restoration project to control cheatgrass growth and establish native plants instead? Are there alternative approaches that you could suggest?

The primary themes that emerged from responses to this question were:

- **i. Social acceptability of restoration**
- **ii. Barriers to restoration**

Summarized below are the stakeholder responses across the four Great Basin states.

a) BLM personnel

The BLM respondents across the four states were generally very supportive of the ongoing cheatgrass control project. All respondents were unanimous in sharing that a cheatgrass dominated site called for integrated treatments over the use of "stand-alone" treatments.

i. Social acceptability of restoration strategies

In response to the issue of whether currently undertaken restoration strategies were socially acceptable or not, all BLM respondents were supportive of the strategies being adopted. For example, the BLM interviewee from Idaho said

> I find the current strategies acceptable. We ourselves use prescribed fire and herbicide. By doing so, you first reduce the levels of cheatgrass. These two are very effective strategies.

ii. Barriers to restoration

Differences in perceived barriers to restoration were noticeable when demographic factors were taken into account. Results indicate that the older (and more experienced) BLM respondents explicitly expressed their concerns with the economic costs of undertaking control treatments and the composition of the people engaged in restoration. Below are two quotes from two BLM personnel that contradict the conclusion drawn from findings to the earlier question that: older (more experienced) personnel are more critical and/or realistic about using restoration treatments over their younger colleagues. A BLM interviewee from Nevada with over 28 years of experience said

> Fire is acceptable but grazing is not at all a viable option. Maybe flash grazing could be an alternative. Herbicide is also not okay. Tested in small plots but on a large scale there are too many constraints- costs, regulations, impact statements, etc.

On the other hand the BLM respondent from Utah with 10 years of experience said

> I have experimented with a couple of similar approaches (seeding, drilling, compacting, etc) and they are not effective. I would like to see non-traditional approaches like using of water sprinkler system to irrigate roughly 40 acres of arid lands to increase canopy of vegetation and root growth of natives. This is an out-of box approach.

b) Ranchers

All of the ranchers across the four Great Basin states shared attitudes in support and opposition to the selected restoration strategies. They also felt that the BLM was overly dependent on the use of native seeds.

i. Social acceptability of restoration strategies

Except for the rancher from Utah, all other ranchers expressed reservations about the selected restoration strategies. In large part the reservations were ecological in nature and revolved around the key issue of using perennial species when other introduced species like crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) could be used as part of the re-seeding efforts. The ranchers in general were critical of using fire and herbicides. A rancher from Idaho with over 30 years of experience conveyed this view chronologically.

> I think too many times, BLM or other agencies has too much of a bias in using other species as part of reseeding. Too much focus on getting back to natives. Exploring an intermediary step is essential. You cannot do directly back from cheatgrass to natives. They could go with crested wheatgrass which was used a lot in the past. They agencies know that seeding crested wheatgrass increases forage, which is viewed as something really negative. Now that thinking and practice is not acceptable.

The other three responses also included criticism of BLM restoration practices and described crested wheatgrass as a species to seriously consider for reseeding.

ii. Barriers to restoration

Ranchers described both ecological and economic concerns as barriers to restoration. A combination of ecological and economic issues is best summarized by a Nevada rancher.

> Restoration that involves the use of our grazing land could break some of us. I do not think BLM really cares to use grazing as an option much. Fire if used, results in the land not being available for 2-3 years after that and BLM does not care about our concerns and needs. Lack of water adds to the issues.
> Do not believe that on some sites, perennials will compete with cheatgrass and herbicide use is not logical. Environmental laws prevent further application of herbicide as well.

c) Interest groups

Interest groups supportive of restoration responded to the second interview question relatively positively and expressed support for the ongoing restoration activities. They also did not voice any criticism of the BLM or ranchers with regard to their land management and ranching practices. No significant patterns in perception were noticed between the respondents with varying levels of educational background, years of affiliation to rangelands, or income earned.

i. Social acceptability of restoration

Respondents approached the question with a holistic mindset and expressed high levels of support in favor of the selected restoration strategies. They felt that restoration projects like the ongoing project were ideal as was “comprehensive and implemented over a large landscape.” This was clearly evident in the response of Idaho based respondent.

> I am not a practicing scientist so to me the restoration projects sound like a comprehensive one and cover the entire gamut. The issue and scale at which we do, is needed. Of course the size should be larger.

i. Barriers to restoration

No specific barriers to restoration strategies were shared by any of the respondents.

d) Informed citizens

Similar to the ranchers, the informed citizen respondents expressed reservations with the use of native seeds as part of the re-seeding strategy to generate competition against cheatgrass. They were, however, largely critical of grazing on public rangelands as it was felt that it would be highly ineffective as a restoration strategy.

i. Social acceptability to restoration

The overall degree of acceptability to restoration was positive, however, respondents shared their concerns with use of some strategies. The following comment from the Nevada based informed citizen emphasizes the degree of skepticism towards grazing in particular on public rangelands.

> If you got stuff turning out of the soil that is full of cheatgrass, I wonder how effective is native reseeding. Grazing creates more disturbance and cows are not even supposed to be here. They are meant to be in Europe where the conditions are wetter. In my view if you want native seeds to get established, you need them to be left alone."

ii. Barriers to restoration

Barriers to restoration were implicit in some of the views of the respondents to the above mentioned theme. However, one response by an Idaho based informed citizen focused solely on the barriers.

> Anything you do to remove cheatgrass has to be followed up with planting. A combination of strategies is essential. Conduct it on most productive sites and compare cost-feasibility.

4.6.1.4 Discussion of results: acceptability to current restoration strategies

In general, BLM respondents across each of the four Great Basin states expressed a high degree of acceptability towards each of the restoration strategies. As inferred in the discussion of the first question, higher levels of precipitation appeared to influence the ranchers' overall social acceptability of adopting restoration strategies. Those ranchers in states with low precipitation were more likely than ranchers in high precipitation states to find restoration a barrier. The informed citizens seemed very well aware of pitfalls associated with cheatgrass invasion and thus the strong need for integrated strategies. All the respondents addressed the economic feasibility of adopting landscape level restoration strategies.

4.6.1.5 How would you personally support restoration?

The key theme that emerged from reviewing the responses to this question was:

i. Ways of supporting restoration: time, money, other ways

The responses of the various groups to this theme are summarized below followed by a general discussion.

a) BLM personnel

All BLM respondents indicated that they support restoration through their work and thus the use of time. For example, BLM respondents from Idaho and Oregon offer their time to review plants, inspect, and supervise pre and post prescribed fire activities.

b) Ranchers

All the respondents indicated that they were engaged in some form of restoration on their rangelands. The rancher from Utah especially offered his time and resources by not only allowing USFS to burn some of the heavy timber to reduce understory but also sought state grants to cost-share some of the restoration activities. The rancher from Idaho supported restoration by seeking financial assistance for ranchers from congressional leaders.

c) Interest groups supporting restoration

All interviewees from interest groups in favor of restoration expressed a high degree of support for restoration in the Great Basin and offer their time through direct restoration efforts and volunteering with pulling weeds, managing school tours, working with landowners to control exotic grasses, and conducting hands-on research.

Similar to the BLM category, professional specializations within the interest groups respondents did influence the ways that they supported restoration. For example, the Idaho based interest group respondent (policy and awareness specialist) offered his time by

> Increasing awareness and improving policy by working with the BLM to create a cost-share position for someone to work on restoration.

d) Informed citizens

All of the respondents were engaged in restoration in some way. The informed citizen from Oregon was affiliated with a local school board through which she attended state meetings involving state trust lands that often support restoration. The informed citizens from Utah and Nevada engaged in volunteer activities and the respondent from Utah conducted restoration work through his professional position.

4.6.1.6 Discussion of results

In general, most respondents supported restoration in various ways. No specific ecological, social, or economic contextual factor influenced their current efforts at supporting restoration.

Responses of the BLM and interest group interviewees indicated a possibility of differences in their areas of professional expertise and academic specialization to influence not only their views but also the ways in which they support restoration. Thus, if an intra-agency attitudinal analysis was considered, it might be appropriate to take occupational roles, academic background, and socio-economic information into consideration. Lastly, the informed citizens were active in giving time to support restoration; however, demographic factors did not influence their responses.

4.6.1.7 How much do you think it costs to support a mix of restoration strategies: herbicide, fire, grazing followed by reseeding?

The key theme that evolved from coding the responses to the above question was:

i. Comparison of costs perception of ranchers versus non-ranchers

a) BLM personnel

BLM respondents in general offered detailed perspectives of what they felt were the costs of undertaking a restoration project similar to the ongoing cheatgrass control project. Their costs ranged from $150 to $200 per acre. The BLM interviewee from Nevada offered detailed breakdowns for their estimates.

> A standard mix of native seeds would cost $80/100 per acre, $50 drill seeding, $5 per acre for aerial application, all totaling up to $150 per acre. The more the natives, higher the cost.

The BLM respondent from Idaho also shared an ecological factor to cost estimates.

> Cost varies based on type of seed used. Higher precipitation zones have lower cost while lower precipitation zones have higher reseeding costs.

b) Ranchers

Almost all of the ranchers offered no detailed responses to the question of cost estimate of undertaking any of the restoration treatments to control cheatgrass invasion. Only the rancher from Utah who had been engaged in restoration said

> At a landscape level, depending on the topography, type of forage or plant you want to grow, the costs may vary. An absolute minimum would be $500 per acre.

c) Interest group representatives

Interest group representatives across the four Great Basin states offered a range of cost estimates varying from \$100 to \$200 per acre. The typical average cost estimate was \$150 per acre. The interest group representative from Nevada specifically said

> Ideally one needs a minimum of roughly 1000 acres or more, to see any realistic effects.

d) Informed citizens

The informed citizens offered a wide range of responses ranging from not knowing anything about it to \$2,000 per acre. Most informed citizens felt that costs of restoration would depend on the proportion of the land that is desired to be native versus not.

4.6.1.8 Discussion of results

Seeking a response from all stakeholders with regard to their notion of costs of restoration resulted in a wide range of estimates. As expected, the BLM and interest group representatives were understandably more aware (due to their occupational specialization) about restoration projects and thus offered itemized breakdowns of costs. In contrast, the ranchers and informed citizens did not offer clear estimates of the costs of undertaking typical cheatgrass control treatments. Only the rancher from Utah emphasized that the ecological context (site specific conditions and history of the region) would influence the economic costs of undertaking restoration.

4.7 Conclusions

Respondents exhibited general support in favor of restoration and the need to restore arid rangelands of the Great Basin with less invasive grasses. Across all four groups, it was more often observed that restoration had different meanings to the different stakeholders, especially in the context of invasive species and socio-economic characteristics. Table 4.6 summarizes the entire range of responses from each organizational group across the four Great Basin study states.

All of the responses more or less matched expectations however, a few findings warrant future attention and research:

1. **Ecological context**

   Ecological factors like the level of precipitation and level of invasiveness were the key contextual variables influencing the perceptions of subjects.

2. **Demographic characteristics**

   Level and type of educational background, age, and income earned influenced the overall levels of acceptability towards arid rangeland restoration projects, especially among BLM and Interest group respondents.

3. **Ideology**

   It is also possible that the ideology of an interviewee with regard to the relationship between humans and the environment influenced their perceptions, thus warranting further examination.

Overall, all stakeholders had varying perceptions of restoration and degree of acceptability with regard to restoration. The study offers strong evidence for further research on “intra-stakeholder attitudinal analysis to restoration” with regard to demographic variables (education and experience) and ecological factors (precipitation and native versus introduced species).

Table 4.6. Summary of coded themes and regional responses across categories.

Groups Themes	BLM				Ranchers				Interest Group				Informed Citizens			
	OR	ID	UT	NV	OR	ID	UT	NV	OR	ID	UT	NV	OR	ID	UT	NV
Perception of restoration	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Restoration versus rehabilitation	X	X	X	X		X	X			X	X	X			X	X
Acceptability of project strategies	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
Barriers	X	X	X		X	X	X	X	X	X		X	X	X		X
Ways of supporting	X	X	X	X	X	X		X	X	X	X		X	X	X	X
Sense of economic cost	X	X	X	X			X		X			X	X			

Chapter 5. Conclusions

This chapter discusses the findings from the economic and social impact assessments and offers recommendations for land managers and future research avenues for management of invasive species in the Great Basin region.

5.1 Economic Impacts of Restoration Strategies

The adoption of restoration strategies by representative Oregon, Idaho, Nevada, and Utah full time ranches had similar economic implications. All of the null hypotheses are rejected. The study finds that there is a tradeoff between ecological and economic benefits from restoration and the costs of adopting restoration strategies are significantly higher compared to the baseline. Moreover, the costs of adopting the integrated strategy across all four representative ranches are higher than any of the stand alone restoration strategies. Specifically, grazing remains the most cost-effective restoration strategy.

Restoration costs for the four ranches were the highest under the integrated scenario and lowest under a baseline condition. Figure 5.1 compares the net restoration costs per acre across the four Great Basin study states.

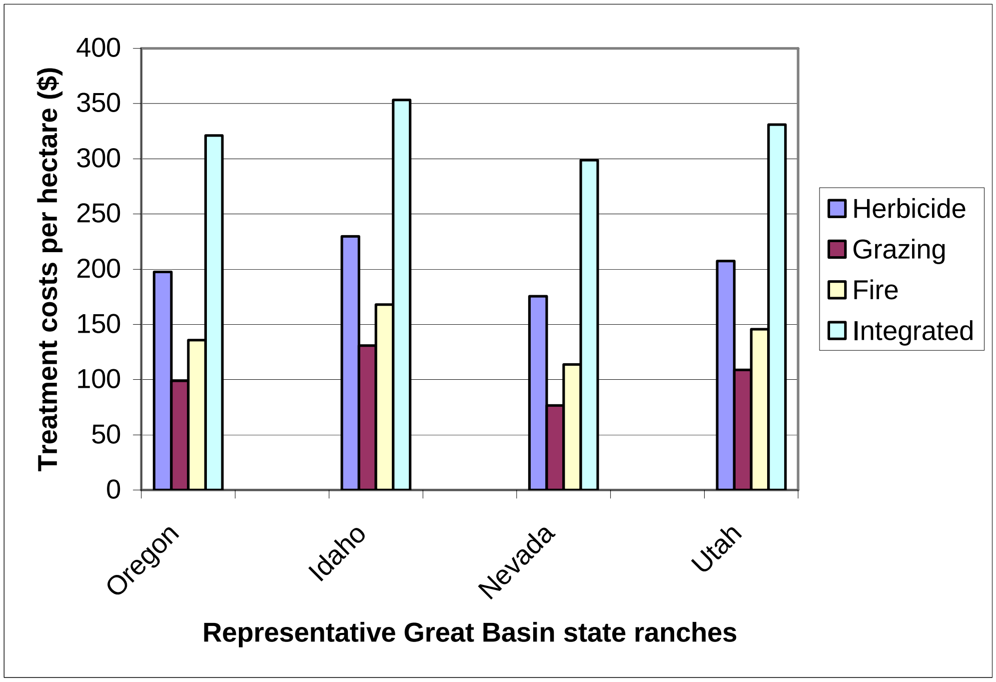


Figure 5.1. Comparative analysis of treatment costs.

As figure 5.1 indicates, restoration costs were generally higher for representative ranches in those states that had smaller sized BLM allotments and/or received low levels of precipitation (less than 200 mm). This is seen in the case of Oregon and Idaho representative ranches that had treatable BLM acreages that were smaller than those of Utah and Nevada and also experienced lower levels rainfall resulting in reduced forage availability per hectare. In the case of Nevada (with lower levels of average annual precipitation) and Utah (higher levels of precipitation), treatable BLM acreage was substantially larger, resulting in higher treatment costs.

In summary, the results identified three parameters that may strongly influence the economic costs to Great Basin ranchers due to the adoption of restoration strategies.

1. **Level of precipitation –** The amount of precipitation impacts forage availability and success of restoration (if reseeding is used) that in turn influences herd size and net returns of any representative full time ranch operation.
2. **BLM available "treatable" acreage –** The more of the BLM allotment that is treatable (i.e., infested with cheatgrass), the greater the potential for decreased forage being available if restoration should occur. This would likely cause a ranch to manage a smaller herd and have reduced profits.
3. **Order, type, and time period of restoration strategies –** The sequence of restoration strategies, type of native (or introduced) species used for reseeding, and time period allowed for natives to recover may individually and/or collectively influence total restoration costs. While this was not tested in this study, it is likely important.

5.2 Social Impacts of Restoration

In general, the findings matched expected results with regard to organizational responses of the meaning of restoration. All respondents across all groups for each state offered some perception of restoration and contextual factors (ecology, level of awareness, and degree of professional involvement with other stakeholders). There was a consistent response from all four BLM personnel across the four Great Basin states with regard to the existence of a scientific difference in the meaning of restoration versus rehabilitation. The ranchers, in contrast to the BLM respondents, did not think there were any major differences in the interpretations of restoration versus rehabilitation. They also felt that cheatgrass was not necessarily a “problem.” The views of the ranchers indicated that their willingness to support restoration was strongly influenced by geographic (levels of precipitation) and ecological (level of cheatgrass invasion) contexts. Moreover, the rancher from Utah was more supportive of restoration than ranchers from the other states, strengthening the hypothesis that higher levels of precipitation increases the overall social acceptability for undertaking restoration. Furthermore, there is also the possible existence of an underlying ideology that “nature’s resources is meant for humans to use” in support of the rancher’s views that restoration need not occur at the expense of reduced forage availability for cattle. Ranchers also listed economic costs of seeding native species and reduced land available for grazing as a result of restoration as common barriers.

Interest group respondents in support of restoration had similar views as those of BLM personnel with regard to restoration and felt rehabilitation to be a distinctly unique ecological concept. Informed citizens were most expressive about the possible barriers and issues involving restoration projects and educational background was significant in the nature and quality of their responses.

To conclude, across all groups, site specific ecological and demographic factors such as levels of precipitation and educational qualifications influenced interviewee responses. Surprisingly, variations in income levels did not play a critical role in the responses of the respondents. Lastly, findings from the phone interviews strongly supported the possibility that ecological aspects such as precipitation and type of species used in reseeding influenced the degree of social acceptability towards restoration of Great Basin rangelands.

5.3 Recommendations for Land Managers

Economic impact assessment of representative Great Basin representative ranches indicates that ranchers alone may not prefer to bear the total costs of restoration on public rangelands. Ecologically, there exists a lack of sufficient information on the accurate responses of cheatgrass to control strategies and the risks associated with seeding native species in low precipitation zones. Development of restoration plans for ranchers should take into account the lack of such dose-response data. The existence of ecological complexities like variation in climatic factors, risks of failure associated with restoration strategies, and spatial growth of invasive species may pose significant economic risks to ranchers. Assessing such risks as part of restoration efforts is appropriate.

Since public rangelands are a public good, it may not be economically efficient for ranchers to support federal and state agencies in undertaking restoration. In general, while there are some private benefits from restoration, it is likely that most of the benefits accrue to society. It may be appropriate to explore the use of (or develop) cost-share mechanisms or innovative policy tools to ensure that cheatgrass control efforts are not only ecologically feasible and socially acceptable but also economically equitable.

5.4 Avenues for Future Research

The economic assessment of controlling cheatgrass indicates that cost-effective restoration strategies will lead to reduced profits compared to the baseline scenario of doing nothing. This study, however, was undertaken under the assumption of homogeneity of cheatgrass growth under normal climatic conditions with no other invasive species interacting with cheatgrass when restoration strategies were adopted. Increasing anecdotal evidence of spatial and climatic changes in the Great Basin region calls for future research to explore the economic implications of controlling multiple arid land invasive species in the presence of stochastic events (e.g., rainfall variability and economic market distortions).

Social attitudinal analysis confirmed the existence of variations in perceptions and ideologies held towards restoration and nature of its conduct. Future research directed towards a larger scale survey based analysis of public land users would allow for a better understanding of stakeholders' opinions of invasive species, its management, and overall impression of whether cheatgrass is a "problem" or not. As part of a larger, comprehensive study, conducting an organizational analysis of various federal and state agencies with regard to management of public rangelands would allow for improved understanding of organizational influence on public land managers. Results from the social acceptability analysis also indicate a possibility of differences in perception with regard to use of public rangelands between urban versus rural residents which deserves future investigation.

A simultaneous review of the economic and social impact assessments infer the possible existence of ecological, economic, and social thresholds that influence not only the rate and degree of invasion but also the economic impacts of managing invasion and societal willingness to accept (or reject) such species and its management. An interdisciplinary effort to identify such thresholds and examine if they influence each other would allow for a holistic understanding of the ecology, economics, and human dimensions of arid land invasions by exotic grasses.

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APPENDICES

Appendix A STELLA Simulation Codes

FinalBiomass(t) = FinalBiomass(t - dt) + (GrowingBRTE - DecayBRTE) * dt
INIT FinalBiomass = 0

INFLOWS:
Base case: GrowingBRTE = IF (Treatment=0) AND (NewResStock<9.32) THEN 0.3*NewResStock*200 ELSE(0.5*NewResStock*200*(1-Treatment))
Herbicide: GrowingBRTE = IF (Treatment=0) AND (NewResStock<9.32) THEN 0.3*NewResStock*200 ELSE (0.5*NewResStock*200*(1-Treatment))
Grazing: GrowingBRTE = IF (NewResStock<9.32) THEN 0.3*NewResStock*200*(1-Treatment) ELSE(0.5*NewResStock*200*(1-Treatment))
Fire: GrowingBRTE = IF (NewResStock<9.32) THEN 0.3*NewResStock*200*(1-Treatment) ELSE(0.5*NewResStock*200*(1-Treatment))
Integrated: GrowingBRTE = IF (NewResStock<9.32) THEN .3*NewResStock*200*(1-Treatment) ELSE(0.5*NewResStock*200*(1-Treatment))

OUTFLOWS:
DecayBRTE = FinalBiomass
Final_Nat_bio(t) = Final_Nat_bio(t - dt) + (Growth_Nat - Decay_Nat) * dt
INIT Final_Nat_bio = 0

INFLOWS:
Base: Growth_Nat = IF(NewResStock<9.32)THEN 0.4*NewResStock*100 ELSE 0.2*NewResStock*100
Herb: Growth_Nat = IF (NewResStock<9.32) THEN 0.4*NewResStock*120 ELSE 0.2*NewResStock*120
Grazing: Growth_Nat = IF(NewResStock<9.32) THEN (0.4*NewResStock*110) ELSE(0.2*NewResStock*110) Fire: Growth_Nat = IF(NewResStock<9.32)THEN(0.4*NewResStock*110)ELSE(0.2*NewResStock*110)
Integ: Growth_Nat = IF (NewResStock<9.32) THEN(0.4*NewResStock*130) ELSE(0.2*NewResStock*130)

OUTFLOWS:
Decay_Nat = Final_Nat_bio
NewResStock(t) = NewResStock(t - dt) + (Res_change - DecayRes) * dt
INIT NewResStock = 0
INFLOWS:
Res_change = RANDOM(8,14,3267)
OUTFLOWS:
DecayRes = NewResStock, Treatment = 0

Appendix B GAMS CODE FOR ALL RESTORATION SCENARIOS

```
$Title Economic Impact Analysis-Cheatgrass Control
SIZE = Large
Debt = None
Grazing Fee = Current
Available Public AUMs = Current
Season of Use = Current
$OFFTEXT

*$OFFSYMLIST OFFSYMXREF
$onsymxref
file returns /c:\Cheatgrass\Oregon\output\Base_returns.txt/;          returns.pc=5;
file foragsum /c:\Cheatgrass\Oregon\output\Base_land.txt/;            foragsum.pc=5;
file raisesum /c:\Cheatgrass\Oregon\output\Base_raise.txt/;           raisesum.pc=5;
file risum /c:\Cheatgrass\Oregon\output\Base_objfn.txt/;              risum.pc=5;
file lndsum /c:\Cheatgrass\Oregon\output\Base_landuse.txt/;           lndsum.pc=5;
file feedsum /c:\Cheatgrass\Oregon\output\Base_feeduse.txt/;          feedsum.pc=5;
file haysum /c:\Cheatgrass\Oregon\output\Base_haysale.txt/;           haysum.pc=5;

Scalars  totdays        Total defined by various seasons
        calfcrop      Calf Crop Percentage at birth   /0.837/
        minrepl        Required min cow repl rate      /0.15/
        Bullrepl       Required bull replacement rate  /0.25/
        minhyear        Required min heifers for sale   /.10/
        maxrepl         Max % heifer calves kept        /0.80/
        cowbull         cow to bull ratio               /20.0/
        Rho            discount rate                   /0.07/
        Commiss         Commission % cost to sell cow   /0.03/
        Yardage         Yardage and trans Charge($ per day)  /1.50/
        Salefeed        Sale feed charge ($ per cwt)    /.30/
        Offranch        Off ranch income                /10000/
        Family          family living allowance         /24000/
        Fixed           Fixed ranch expenses            /17446/
        Iwealth         Initial cash position           /000/
        Endval          Last year return per AUY        /1/
        Stloanr         Short term borrowing rate       /0.10/
        Savrate         Interest return on Savings acct /.03/
        AcTreat         Acres of potentially treatable BLM land  /1031/
;
Set T Time periods /year01*year40/
    TLAST(T)  Last Period
    TFIRST(T) First Period
Set seasonON grazing season start date /seas1*seas8/
```

```
Set iter iteration /iter001*iter100/
Set season(seasonON) grazing season /seas1*seas7/
Set land types of land available /state, blm, trtable, usfs, privleas, deedrang, rmeadow,
     gmeadow, raisealf, purchalf, pmeadhay/
Set Crop(land) /rmeadow, raisealf, purchalf, pmeadhay/
Set Graze(land) /state, blm, usfs, privleas, deedrang, rmeadow, gmeadow, raisealf,
     purchalf, pmeadhay/
Set BLMT(land) /trtable/
Set landitem /number, aumac, cropyld, conver, usefac, forcost/
Set date1 /m, d, y, serial, days, months/
Set livclass /broodcow, cullcow, bull, horse, scalf, hcalf, syear, hyear,
     purscalf, purhcalf, rephcalf, rephyear, buybcow, sellbcow, buybull/
Set livecl(livclass) /cullcow, bull, scalf, hcalf, syear, hyear, purscalf,
     purhcalf, sellbcow/
Set livpara /buywt, salewt, deathlss, animcost, hayuse/
Set Costsum /forcost, animcost, loancst, treatcst, totcost, gross, repgross, net, netdisc,
     cashtr, accumsav, stborrow, repayst/
Set out1 /used, slack, total, shadow, value/
Set treatmnt /nochng, herb, grazing, fire, integ/
Set source /native, cheat/
;

parameter cropsale(crop) crop sale prices
   /rmeadow   65
    raisealf 100/;
parameter buypric(T,livclass);
parameter salepric(T,livclass);
parameter Econ(iter,T,costsum)          Economic Variables;
Parameter Landsum(iter,Land,T,out1)     Land Use Summary;
Parameter Landseas(iter,Land,T,season)  Seasonal land use summary;
Parameter Feedseas(iter,Crop,T,season)  Seasonal Crop use summary;
Parameter haysale(iter,Crop,T)          crop sales summary;
Parameter anim(iter,T,Livclass)         raised animals summary;
parameter AUY(iter,T)                   AUY on the ranch;
parameter ri(iter)                      Ranch Income Summary;
parameter MS(iter)                      Model status by iter;

parameter trtcost(treatmnt) Treatment costs dollars per acre
    /nochng     0
     herb       50
     grazing    10
     fire       25
     integ      100/;
```

```
$Include "C:\Cheatgrass\Oregon\Include Files\IDJordan100.txt"
$Include "C:\Cheatgrass\Oregon\Include Files\TreatORAUM.txt"
*Include "C:\Cheatgrass\Idaho\Include Files\TreatID.txt"
*Include "C:\Cheatgrass\NV\Include Files\NVAUM.txt"
*Include "C:\Cheatgrass\Utah\Include Files\UTAUM.txt"

*display salep;
*display treat;

table growth(season,source) forage growth curve
         Native   Cheat
Seas2     0.0      0.4
Seas3     0.25     0.8
Seas4     0.6      1.0
Seas5     1.0      0.5
;

table onday(seasonON,date1)
              m      d        y
seas1         3     15     2000
seas2         4      1     2000
seas3         6     15     2000
seas4         7     15     2000
seas5         9      1     2000
seas6        10      1     2000
seas7        11     15     2000
seas8         3     15     2001
;

onday(seasonON,"serial") = jdate(onday(seasonON,"y"),
  onday(seasonON,"m"),onday(seasonON,"d"));

onday(seasonON,"days") $ (ord(seasonON)LT card(seasonON)) =
   onday(seasonON+1,"serial") - onday(seasonON,"serial");

onday(season,"months") = onday(season,"days")/30.41667;

totdays = sum(season, onday(season,"days"));

if ((totdays = 365 or totdays = 366), display totdays;
else abort "Total season days not 365 or 366, adjust dates";
);
```

```
table avail(graze, season) seasonal forage availability

             seas1   seas2   seas3   seas4   seas5   seas6   seas7
state
blm                    1       1       1
usfs
privleas       1                               1       1
deedrang       1       1       1       1       1       1
rmeadow                                                1
gmeadow
raisealf
;

table availblm(BLMT,season) seasonal forage availability

             seas1   seas2   seas3   seas4   seas5   seas6   seas7
trtable                1       1       1
;

table cropaval(crop, season) seasonal crop feeding availability
              seas1   seas2   seas3   seas4   seas5    seas6    seas7
rmeadow         1                                                 1
raisealf        1                                                 1
purchalf        1                                                 1
pmeadhay        1                                                 1
;

table forage(graze,landitem) forage sources

             number  aumac  cropyld  conver    usefac  forcost
state            0.    1.0                        1.0     4.80
blm            481.    1.0                        1.0     7.19
usfs             0.    1.0                        1.0     9.46
privleas       200.    1.0                        1.0    13.75
deedrang      1650.    1.0                        1.0     3.25
rmeadow        350.    2.04    1.5      2.22      1.0     97.0
gmeadow        350.    4.46                       1.0    13.75
raisealf        70.    0.0     4.5      2.22      1.0    400.0
purchalf      1000.    0.0     1.0      2.22      1.0    120.0
pmeadhay      1000.    0.0     1.0      2.22      1.0     85.0
;
* Change blm "number" value to: 231 for ID, 550 for NV and 301 for UT
*display forage;
```

```
table forcrop(crop,landitem) forage sources

           number   aumac  cropyld  conver   usefac   forcost
rmeadow     350.     2.04    1.5     2.22     1.0       97.0
raisealf     70.     0.0     4.5     2.22     1.0      400.0
purchalf   1000.     0.0     1.0     2.22     1.0      120.0
pmeadhay   1000.     0.0     1.0     2.22     1.0       85.0
;

table aue1(livclass,season) AUE for animal classes by season in year T

             seas1   seas2   seas3   seas4   seas5   seas6   seas7
broodcow     1.00    1.00    1.00    1.00    1.00    1.00    1.00
sellbcow     1.00    1.00    1.00    1.00    1.00    1.00
buybcow      1.00    1.00    1.00    1.00    1.00    1.00    1.00
cullcow      1.00    1.00    1.00    1.00    1.00    1.00
bull         1.25    1.25    1.25    1.25    1.25    1.25    1.25
horse        1.25    1.25    1.25    1.25    1.25    1.25    1.25
scalf                                        0.50
hcalf                                        0.50
purscalf     0.50    0.50    0.75     0.75   0.75
purhcalf     0.50    0.50    0.75     0.75   0.75
syear                                                0.50    0.50
hyear                                                0.50    0.50
rephcalf                                             0.50    0.50
rephyear                                             0.50    0.50
;

table aue2(livclass,season) AUE for animal classes by season in year T+1

            seas1   seas2   seas3   seas4   seas5   seas6   seas7
broodcow
cullcow
bull
horse
scalf
hcalf
purscalf
purhcalf
syear        0.75    0.75    0.75    0.75    0.75    0.75
hyear        0.75    0.75    0.75    0.75    0.75    0.75
rephcalf
rephyear     0.75    0.75    0.75    0.75    1.00    1.00    1.00
;
```

```
table Animal(livclass,livpara) sale weights and costs by animal class

             buywt     salewt     deathlss   animcost   hayuse
broodcow                            0.01        9.88
cullcow                 11.00       0.01        9.88
bull                     5.00       0.01        0.0
scalf                    5.75       0.04        0.0        1
hcalf                    5.25       0.04        0.0        1
syear                    0.0        0.06        0.0        1
hyear                    8.00       0.06        0.0        1
purscalf      5.00       6.99       0.04     1500.0
purhcalf      5.00       6.59       0.04     1500.0
rephcalf                            0.04        0.0        1
rephyear                            0.02        9.88       1
buybcow       1.00
sellbcow                 1.00       0.02
buybull       1.00
;

*display Animal;

PARAMETERS
    DF(T)     Discount factor at time T;
    DF(T) = (1+RHO)**(-1*(ORD(T)));
    TLAST(T)  = YES$(ORD(T) EQ CARD(T));
DISPLAY TLAST;
    TFIRST(T) = YES$(ORD(T) EQ 1);
Display tfirst;

POSITIVE VARIABLES
    Landuse(land,season,T)      Acres or AUMS of land used in year T
    slacklnd(graze,T)              Unused land resources
    slackblm(BLMT,T)               Unused BLM treatable AUMs
    raise(livclass,T)              Raise livestock of class in year T (head)
    selllive(livecl,T)             Sell livestock of class in year T (cwt)
    sellcrop(crop,T)               Sell forage crop in year T
    feedcrop(Crop,season,T)        Feed forage crop AUMs in year T
    FORCOST(T)                     Forage harvest costs
    ANIMCOST(T)                    Animal production costs
    GROSS(T)                       Gross livestock returns
    STBORROW(T)                    Short Term Borrowing
    REPAYST(T)                     Repay Short Term Loan
    LOANCST(T)                     Principal and Interest Payments
```

```
   BLMSeas(season,treatmnt,T)  Acres of BLM treated Land used in different seasons
   BLMAcTrt(T)                 Total BLM treated land in acres
   BLMAcNT(T)                  Total BLM treatable land not treated in acres
   TREATCST(T)                 Total Cost of treating BLM acres
   BLMTTrt(T)                  Total treatable BLM land
   BLMuse(BLMT,season,T)       Acres of treatable BLM land grazed in year T
;

VARIABLES
   Ranchinc        Ranch Income
   NET(T)          Net livestock returns undiscounted
   NETDIS(T)       Net livestock returns discounted
   CASHTR(T)       Cash transfered to next period
   AccumSav(T)     Accumulated Savings
   TERM            Terminal Value
;

EQUATIONS

    LANDAVAL(GRAZE, T)      Land Use Equation
    MEADOW(LAND, T)         meadow use equation
    AUMAVAIL(T, season)     Total AUMS available
    CROPPROD(crop,T)        Production of crops
    HAYCALF(T,season)       Force calves to eat alfalfa
    HAYUSE(season, T)       Hay use ratio - 3 tons grass:1 ton alfalfa
    BULLRAT(T)              Set Bull to cow ratio
    CULLRATC(T)             Set cull cow to raised cow ratio
    COWTRAN(T)              Cow transfer between years
    BULLTRAN(T)             Bull transfer between years
    REPTRAN(T)              Calf replacement transfer to yearling replacement
    MINREPLC(T)             Minimum cow replacement rate
    MAXREPLC(T)             Maximum cow replacement rate
    MINHYRC(T)              Minimum additional replacements sold
    RSCALFC1(T)             Raise steer calf ratio year 1
    RSCALFC2(T)             Raise steer calf ratio year NE 1
    RHCALFC1(T)             Raise heifer calf ratio year 1
    RHCALFC2(T)             Raise heifer calf ratio year NE 1
    SALES(livclass,T)       Sales transfer
    COSTFORC(T)             Forage Production costs at T
    COSTANIC(T)             Animal production costs at T
    GROSSRET(T)             Gross Livestock returns at T
    NETRET(T)               Net Livestock returns at T
    NETRETD(T)              Discounted net returns at T
    INCOME                  Ranch Income definition
```

```
     CASHSOUR(T)                  Transfers of Cash
     SAVING1(T)                   Accumulated Savings at time 1
     SAVING2(T)                   Accumulated Savings at time T
     STREPAY(T)                   Force repayment of Short-term loans
     LOANPAY(T)                   Loan Repayment Calculation
     TERMVAL                      Terminal Value (Net R infinitely discounted)
     BLMNoT(T)                    Treatable BLM land that is not treated
     BLMSeas2(BLMT,season,T)      BLM Forage use in Season 2
     BLMSeas3(BLMT,season,T)      BLM Forage use in Season 3
     BLMSeas4(BLMT,season,T)      BLM Forage use in Season 4
     BLMSeas5(BLMT,season,T)      BLM Forage use in Season 5
     BLMAval(BLMT,T)              BLM acres of land available for treatment
     TREATBLM(T)                  Cost of treating BLM acres
     BLMTT(T)                     Total BLM treatable acres
;
*Forage demand and supply equations

MEADOW("rmeadow",T)..  SUM(season,landuse("rmeadow",season,T))+
SUM(season,landuse("gmeadow",season,T))=L=forage("rmeadow","number");

BLMTT(T)..                BLMAcTrt("year01") + BLMAcNT("year01") =e= AcTreat;
BLMNot(t)..              BLMAcNT("year01") =e= 0;

BLMSeas2(BLMT,"seas2",T)..  BLMuse(BLMT,"seas2",T) =L=
     SUM(source,treat(T,"nochng",source)*growth("seas2",source))*
     BLMAcTrt("year01") + SUM(source,treat(T,"nochng",source)*
     growth("seas2",source))*BLMAcNT("year01");
*BLMSeas2(BLMT,"seas2",T)..  BLMuse(BLMT,"seas2",T) =L=
     SUM(source,treat(T,"herb",source)*growth("seas2",source))*BLMAcTrt("year01")
     +SUM(source,treat(T,"nochng",source)*growth("seas2",source))*BLMAcNT("year
     01");
*BLMSeas2(BLMT,"seas2",T)..  BLMuse(BLMT,"seas2",T) =L=
     SUM(source,treat(T,"grazing",source)*growth("seas2",source))*
     BLMAcTrt("year01") + SUM(source,treat(T,"nochng",source)*
     growth("seas2",source))* BLMAcNT("year01");
*BLMSeas2(BLMT,"seas2",T)..  BLMuse(BLMT,"seas2",T) =L=
     SUM(source,treat(T,"fire",source)*growth("seas2",source))*BLMAcTrt("year01")
     +SUM(source,treat(T,"nochng",source)*growth("seas2",source))*
     BLMAcNT("year01");
*BLMSeas2(BLMT,"seas2",T)..  BLMuse(BLMT,"seas2",T) =L=
     SUM(source,treat(T,"integ",source)*growth("seas2",source))*BLMAcTrt("year01")
     +SUM(source,treat(T,"nochng",source)*growth("seas2",source))*
     BLMAcNT("year01");
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BLMSeas3(BLMT,"seas3",T)..  BLMuse(BLMT,"seas3",T) =L= SUM(source, treat
    (T,"nochng", source) *growth("seas3", source))*BLMAcTrt("year01")
    +SUM(source,treat(T,"nochng",source)*growth("seas3",source))*
    BLMAcNT("year01") - BLMuse(BLMT,"seas2",T);
*BLMSeas3(BLMT,"seas3",T)..  BLMuse(BLMT,"seas3",T) =L= SUM (source,treat
    (T,"herb",source)*growth("seas3",source))*BLMAcTrt("year01") + *SUM
    (source,treat(T,"nochng",source)*growth("seas3",source))*BLMAcNT("year01") -
    BLMuse(BLMT,"seas2",T);
*BLMSeas3(BLMT,"seas3",T)..  BLMuse(BLMT,"seas3",T) =L=
    SUM(source,treat(T,"grazing",source)*growth("seas3",source))*
    BLMAcTrt("year01")+SUM(source,treat(T,"nochng",source)*
    growth("seas3",source))* BLMAcNT("year01") - BLMuse(BLMT,"seas2",T);
*BLMSeas3(BLMT,"seas3",T)..  BLMuse(BLMT,"seas3",T) =L= SUM
    (source,treat(T,"fire",source)*growth("seas3",source))*BLMAcTrt("year01")
    +SUM(source,treat(T,"nochng",source)*growth("seas3",source))*
    BLMAcNT("year01") - BLMuse(BLMT,"seas2",T);
*BLMSeas3(BLMT,"seas3",T)..  BLMuse(BLMT,"seas3",T) =L=
    SUM(source,treat(T,"integ",source)*growth("seas3",source))*BLMAcTrt("year01")
    +SUM(source,treat(T,"nochng",source)*growth("seas3",source))*
    BLMAcNT("year01") - BLMuse(BLMT,"seas2",T);

BLMSeas4(BLMT,"seas4",T)..  BLMuse(BLMT,"seas4",T) =L=
    SUM(source,treat(T,"nochng",source)*growth("seas4",source))*
    BLMAcTrt("year01") +SUM(source,treat(T,"nochng",source)*
    growth("seas4",source))*BLMAcNT("year01") -BLMuse(BLMT,"seas2",T) -
    BLMuse(BLMT,"seas3",T);
*BLMSeas4(BLMT,"seas4",T)..  BLMuse(BLMT,"seas4",T) =L=
    SUM(source,treat(T,"herb",source)*growth("seas4",source))*BLMAcTrt("year01")
    + SUM(source,treat(T,"nochng",source)*growth("seas4",source))*
    BLMAcNT("year01") - BLMuse(BLMT,"seas2",T) - BLMuse(BLMT,"seas3",T);
*BLMSeas4(BLMT,"seas4",T)..  BLMuse(BLMT,"seas4",T) =L=
    SUM(source,treat(T,"grazing",source)*growth("seas4",source))*BLMAcTrt("year0
    1") +SUM(source,treat(T,"nochng",source)*growth("seas4",source))*
    BLMAcNT("year01") -BLMuse(BLMT,"seas2",T) - BLMuse(BLMT,"seas3",T);
*BLMSeas4(BLMT,"seas4",T)..  BLMuse(BLMT,"seas4",T) =L=
    SUM(source,treat(T,"fire",source)*growth("seas4",source))*BLMAcTrt("year01")
    +SUM(source,treat(T,"nochng",source)*growth("seas4",source))*BLMAcNT("year
    01") -BLMuse(BLMT,"seas2",T) - BLMuse(BLMT,"seas3",T);

BLMSeas5(BLMT,"seas5",T)..  BLMuse(BLMT,"seas5",T) =L=
    SUM(source,treat(T,"nochng",source)*growth("seas5",source))*BLMAcTrt("year0
    1") +SUM(source,treat(T,"nochng",source)*growth("seas5",source))*
    BLMAcNT("year01") -BLMuse(BLMT,"seas2",T) - BLMuse(BLMT,"seas3",T) -
    BLMuse(BLMT,"seas4",T);
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*BLMT,"seas5",T) =L= SUM(source,treat(T,"herb",source)*growth("seas5",source))*
    BLMAcTrt("year01") +SUM(source,treat(T,"nochng",source)*
    growth("seas5",source))*BLMAcNT("year01") -BLMuse(BLMT,"seas2",T) -
    BLMuse(BLMT,"seas3",T) - BLMuse(BLMT,"seas4",T);
*BLMSeas5(BLMT,"seas5",T)..  BLMuse(BLMT,"seas5",T) =L=
    SUM(source,treat(T,"grazing",source)*growth("seas5",source))*
    BLMAcTrt("year01")+SUM(source,treat(T,"nochng",source)*
    growth("seas5",source))*BLMAcNT("year01") -BLMuse(BLMT,"seas2",T) -
    BLMuse(BLMT,"seas3",T) - BLMuse(BLMT,"seas4",T);
*BLMSeas5(BLMT,"seas5",T)..  BLMuse(BLMT,"seas5",T) =L=
    SUM(source,treat(T,"fire",source)*growth("seas5",source))*BLMAcTrt("year01")
    +SUM(source,treat(T,"nochng",source)*growth("seas5",source))*
    BLMAcNT("year01") -BLMuse(BLMT,"seas2",T) - BLMuse(BLMT,"seas3",T) -
    BLMuse(BLMT,"seas4",T);

LANDAVAL(GRAZE,T)..  SUM(season,landuse(graze,season,T))+
    slacklnd(graze,T)=E=forage(graze,"number")* forage(graze,"usefac");

BLMAval(BLMT,T)..  SUM(season,blmuse(BLMT,season,T)) + slackblm(BLMT,T)
    =E= SUM(source,treat(T,"nochng",source))*BLMAcTrt("year01") +
    treat(T,"nochng","cheat")*BLMAcNT("year01");
*BLMAval(BLMT,T)..  SUM(season,blmuse(BLMT,season,T)) + slackblm(BLMT,T)
    =E= SUM(source,treat(T,"herb",source))*BLMAcTrt("year01") +
    treat(T,"herb","cheat")*BLMAcNT("year01");
*BLMAval(BLMT,T)..  SUM(season,blmuse(BLMT,season,T)) + slackblm(BLMT,T)
    =E=SUM(source,treat(T,"grazing",source))*BLMAcTrt("year01") +
    treat(T,"grazing","cheat")*BLMAcNT("year01");
*BLMAval(BLMT,T)..  SUM(season,blmuse(BLMT,season,T)) + slackblm(BLMT,T)
    =E=SUM(source,treat(T,"fire",source))*BLMAcTrt("year01") +
    treat(T,"fire","cheat")*BLMAcNT("year01");
*BLMAval(BLMT,T)..  SUM(season,blmuse(BLMT,season,T)) + slackblm(BLMT,T)
    =E=SUM(source,treat(T,"integ",source))*BLMAcTrt("year01") +
    treat(T,"integ","cheat")*BLMAcNT("year01");


CROPPROD(CROP,T).. sum(season,feedcrop(crop,season,T)) + sellcrop(Crop,T) =L=
   sum(season,landuse(crop,season,T)* forcrop(crop,"cropyld"));

AUMAVAIL(T, season).. SUM(livclass, raise(livclass,T)*aue1(livclass,season))*
    onday(season,"months") + SUM(livclass, raise(livclass,T-1)* aue2(livclass,
    season))*onday(season,"months") =L=
    SUM(graze,forage(graze,"aumac")*landuse(graze,season,T)* avail(graze,season)) +
    SUM(blmt,blmuse(BLMT,season,T)*availblm(BLMT,season)) +
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    SUM(crop,feedcrop(crop,season,T)*forcrop(crop,"conver")*
    cropaval(crop,season));

HAYUSE(season, T)..  SUM(crop,(feedcrop("rmeadow",season,T)
    +feedcrop("pmeadhay",season,T)))=L=
  SUM(crop,(feedcrop("raisealf",season,T)+feedcrop("purchalf",season,T)))*3;

HAYCALF(T, season)$ (ORD(Season) EQ 1 OR ORD(SEASON) EQ 7)..
    SUM(livclass, raise(livclass,T)*aue1(livclass,season)*animal(livclass,"hayuse")) *
    onday(season,"months")+ SUM(livclass, raise(livclass,T-1)*aue2(livclass, season)*
    animal(livclass,"hayuse"))*onday(season,"months")=L=
    feedcrop("purchalf",season,T)*forage("purchalf","conver")
    +feedcrop("raisealf",season,T)*forage("raisealf","conver");

COWTRAN(T)$(ORD(T) GT 1).. raise("broodcow",T) + raise("cullcow",T) +
    raise("sellbcow",T) =L= raise("broodcow",T-1)*(1-Animal("broodcow","deathlss"))
    +raise("rephyear",T-1)*(1-Animal("rephyear","deathlss")) + raise("buybcow",T);
BULLTRAN(T)$(ORD(T) GT 1).. raise("bull",T) =L= (1-bullrepl)*raise("bull",T-1)
    *(1-animal("bull","deathlss")) + raise("buybull",T) ;
REPTRAN(T)$(ORD(T) GT 1).. raise("rephcalf",T-1)*(1-
    animal("rephcalf","deathlss"))=E= raise("rephyear",T);
BULLRAT(T)..  raise("broodcow",T)+ raise("cullcow",T) + raise("rephyear",T)
  =E= cowbull*raise("bull",T);
CULLRATC(T)..  raise("cullcow",T) =e= minrepl*(raise("broodcow",T) +
    raise("rephyear",T));

MINHYRC(T)..  Raise("hyear",T) =G= minhyear*raise("rephyear",T);
MINREPLC(T)$(ORD(T) GT 1).. minrepl*(raise("broodcow",T)/(1-
    Animal("broodcow","deathlss"))+raise("cullcow",T)/(1-
    Animal("cullcow","deathlss"))) =L=raise("rephyear",T-1)*(1-
    Animal("rephyear","deathlss"))+raise("buybcow",T);
MAXREPLC(T).. raise("rephcalf",T) =L= maxrepl *(raise("hcalf",T) +
    raise("hyear",T)+ raise("rephcalf",T));
RSCALFC1(T)$(ORD(T) EQ 1)..  raise("scalf",T) + raise("syear",T) =L=
    calfcrop/2*(raise("broodcow",T) + raise("rephyear",T));
RSCALFC2(T)$(ORD(T) GT 1)..  raise("scalf",T) + raise("syear",T) =L=
    calfcrop/2*(raise("broodcow",T) + raise("rephyear",T-1));
RHCALFC1(T)$(ORD(T) EQ 1).. raise("hcalf",T) + raise("hyear",T) +
    raise("rephcalf",T) =L=calfcrop/2*(raise("broodcow",T) + raise("rephyear",T)) ;
RHCALFC2(T)$(ORD(T) GT 1).. raise("hcalf",T) + raise("hyear",T)
    +raise("rephcalf",T) =L= calfcrop/2*(raise("broodcow",T) + raise("rephyear",T-1));
SALES(livecl,T).. selllive(livecl,T) =L= (1-
    Animal(livecl,"deathlss"))*Animal(livecl,"salewt")* raise(livecl,T);
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COSTFORC(T)..    FORCOST(T) =E=
     SUM(season,SUM(graze,landuse(graze,Season,T)* forage(graze,"forcost")))+
     SUM(season,SUM(blmt,blmuse(blmt,season,T)*forage("blm","forcost")));

COSTANIC(T)..    ANIMCOST(T) =E= SUM(livclass,animal(livclass,"animcost")
     *raise(livclass,T)) + SUM(livclass,buypric(T,livclass)*animal(livclass,"buywt") *
     raise(livclass,T));
GROSSRET(T)..    GROSS(T) =E= SUM(livecl,selllive(livecl,T)*salepric(T,livecl)) +
     SUM(CROP,SELLCROP(crop,T)*cropsale(crop));
*Calculate total treatment costs
TREATBLM(T)$(ORD(T) eq 1)..    TREATCST(T) =E= BLMAcTrt(T) *
     trtcost("nochng");
*TREATBLM(T)$(ORD(T) eq 1)..    TREATCST(T) =E= BLMAcTrt(T) *
     trtcost("herb");
*TREATBLM(T)$(ORD(T) eq 1)..    TREATCST(T) =E= BLMAcTrt(T) *
     trtcost("grazing");
*TREATBLM(T)$(ORD(T) eq 1)..    TREATCST(T) =E= BLMAcTrt(T) *
     trtcost("fire");
*TREATBLM(T)$(ORD(T) eq 1)..    TREATCST(T) =E= BLMAcTrt(T) *
     trtcost("integ");

LOANPAY(T)..     LOANCST(T) =E= (1+Stloanr)*repayst(T);
CASHSOUR(T)..    CASHTR(T) =E= NET(T) + Offranch - family - fixed;
NETRET(T)..      NET(T) =E= GROSS(T)-FORCOST(T)-ANIMCOST(T)-
LOANCST(T)-TREATCST(T);
NETRETD(T)..     NETDIS(T) =E= NET(T)*DF(T);

INCOME ..        Ranchinc =e= sum(T, NETDIS(T))+TERM;

SAVING1(T)$(ORD(T) EQ 1).. AccumSav(T) =e= IWEALTH + NET(T) +
     OFFRANCH- Family - fixed + STBORROW(T);
SAVING2(T)$(ORD(T) GT 1).. AccumSav(T) =e= AccumSav(T-1)*(1 + savrate)
   + NET(T) + OFFRANCH - Family - fixed + STBORROW(T);
STREPAY(T)..     STBORROW(T-1) =L= REPAYST(T);

TERMVAL(TLAST).. TERM =E=
     ((raise("BROODCOW",TLAST)+raise("CULLCOW",TLAST)
     +raise("rephyear",TLAST)+raise("rephcalf",TLAST))*Endval)/RHO*(1-
     1/((1+RHO)** CARD(T)));

accumsav.lo(T)= 500.;
stborrow.up(T)$(ORD(T) EQ CARD(T)) = 0;
slacklnd.up("State",T)=0;
raise.up("sellbcow",T)$(ORD(T) EQ 1) = 0;
```