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The relative success of restoration practices on cheatgrass infested sagebrush steppe lands in the Great Basin can affect the probability of crossing an ecological threshold and have economic effects on cattle ranches using federal rangelands. Cheatgrass invasion implies an increase in the risk of fire, which in turn increases the likelihood that ranchers will be denied temporary access to public lands. No study to date has incorporated forage availability constraints imposed on public grazing allotments by cheatgrass wildfires into ranch-level economic models. As cheatgrass is known to cause frequent fires, ignoring this constraint could overestimate the benefit of cheatgrass as a spring forage source.

The purpose of this project is to determine the importance of considering specific ecological effects of cheatgrass-associated wildfires on a ranch-level economic model. This study assumes that a representative Oregon 300 cow-calf ranch possesses a Bureau of Land Management (BLM) allotment that exhibits ecological characteristics typical of sagebrush steppe sites that are vulnerable to continued cheatgrass invasion. This project utilizes biological data gathered as part of the on-going Sagebrush Steppe Treatment Evaluation Project (SageSTEP) from a high desert land type in eastern Oregon. The grazing allotment is assumed to have a 15% percent cover of cheatgrass with an associated 20 to 40 year fire return interval. Results from a ranch economic impact analysis of cheatgrass associated fires on a ranch's public grazing allotment may exhibit directional bias if the baseline model does not consider both the economic contribution of cheatgrass to spring forage and the economic cost of a typical minimum two-year grazing exclusion following a wildfire. These two forage availability constraints are added to the public forage component of a ranch

bioeconomic model to address how the representative ranch reacts to the temporary loss of permitted AUMs in terms of forage substitution and/or herd size reductions as the result of the assumed fire return interval; under what circumstances will this temporary loss of AUMs force a representative ranch out of business; and whether there is an economic impact associated with changes in late spring AUMs under the assumed fire regime.

A baseline “No Fire Model” is compared to a “Fire Model” using a forty-year planning horizon with a 7% discount rate. All assumptions regarding a perfectly competitive industry hold in these models, including perfect information. The “Fire Model” is subject to randomly generated fire regimes using a Monte Carlo approach. Precipitation and cattle prices are held constant in order to isolate wildfire effects. Grazing on the BLM allotment is allowed during the fire year and is excluded for the following two years. During these two post-fire years, the representative ranch is forced to choose a substitute forage source and/or limit its herd size.

Results indicate that the ranch impacts of a fire go beyond the time-line of the two years of exclusion from the BLM allotment. This decrease in access to BLM AUMs results in an even greater decline in the average use of deeded range AUMs over time when compared to the No Fire Model. This decline occurs regardless of the fact that the ranch increases its use to the maximum available deeded range AUMs during the two years of the BLM allotment exclusion. Average Net Present Value (NPV) is also lower compared to the No Fire Model. Within the results of the Fire Model, NPV decreases and the probability of bankruptcy increases as the number of fires experienced within the planning horizon increases. As policy makers deal with the impending risk of an increase in cheatgrass associated wildfires in the Great Basin sagebrush steppe, this study shows that failing to include ranch impacts of fire on BLM land will likely result in an overestimation of the benefits or an underestimation of the costs of further invasion.

The Economic Impacts of Sagebrush Steppe Wildfires on an Eastern Oregon Ranch

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1 Introduction

More than one million people derive some portion of their income from grazing activities on the rangelands that comprise 80% of the land in the 17 western states (James et al. 2003). The conversion of western rangelands from native vegetation to the invasive annual grass cheatgrass (*Bromus tectorum* L.) occurred at an accelerated rate during the 20th century (Young and Allen 1997). In 1958, at the 11th Annual Meeting of the American Society of Range Management, an assistant area land officer from Utah imparted this sentiment regarding cheatgrass as a forage species:

> We try to utilize cheatgrass *(Bromus tectorum)* so as to take advantage of its late spring production peak without at the same time destroying the perennials which we hope gradually will regain their old dominance (Platt 1958, p. 64).

At that time, survey results from 36 U.S. and Canadian land managers indicated that approximately 25 million acres of rangelands were adversely affected by cheatgrass (Platt 1958). Today, at least 40 million hectares (98 million acres) in the U.S. are estimated to be affected by cheatgrass and its associated fires (Link et al. 2006).

The magnitude of this invasion and its characteristic grass-fire cycle effects on native ecosystems have led some to consider this as possibly the most significant plant invasion in North America (Chambers et al. 2007). The ecological impact of this invasion on the sagebrush steppe in the Great Basin region of the western United States is currently receiving a great deal of attention (USDA 2007, SageSTEP 2007). Cheatgrass converted millions of hectares of the sagebrush steppe in this region to annual communities by increasing the fire frequency and out-competing native perennial grasses (Anderson and Inouye 2001). Over 40% of the current area of sagebrush is estimated to be at moderate to high risk of displacement by cheatgrass within the next 30 years (Chambers et al. 2007).

Maintenance or restoration of native perennial herbaceous species is thought to be a requirement for ecological sustainability of these rangeland ecosystems (Chambers et al. 2007). As ranchers directly depend upon the quality and quantity of the forage on public lands, management strategies that enhance and promote rangeland sustainability are also considered to be important to the economic well being of livestock producers (James et al. 2003). Pellant (1996) perceived the curtailment of cheatgrass on native rangelands to be of the highest management priority.

Although cheatgrass can degrade native ecosystems (Pellant 1996), over the last century it has become an important forage resource for both domestic cattle and some wildlife species in many areas of the western U.S. (Knapp 1998). For example, cheatgrass provides more forage for livestock operations in Nevada than any other single plant species (Knapp 1998). While the nutritional content and reliability of cheatgrass as a livestock forage source has been debated (Young and Clements 2003, Young and Allen 1997), its flammability, once cured, remains uncontested.

Young and Clements (2003) cited ignitability as the major drawback of cheatgrass as a forage. They described a reserve of standing dry cheatgrass as "one spark away from disaster." Shortened fire return intervals in the Intermountain West have been linked to the spread of cheatgrass (Knapp 1998). This grass not only ignites easily, but its continuous fuel load enables fire to spread rapidly and grow large (Knapp 1998, Link et al. 2006). Wildfire in the Great Basin is becoming an increasingly important topic due to several catastrophic fire years. In 1999, wildfires in this region burned approximately 1.7 million acres (SageSTEP 2007).

The occurrence of fire on public lands is important to ranchers who hold public grazing permits since post-fire conditions on these public lands preclude domestic livestock grazing for at least two growing seasons (Knapp 1998). Lack of access to public forage forces ranchers to choose substitute sources and/or limit their herd size during these post fire years. Numerous ranch-level studies regarding the economic implications of reducing the availability of federal grazing land indicate that a number of ranchers depend upon their grazing permit to stay in business (Satyal 2006, Torell et al. 2002, Rowe and Bartlett 2001).

Cheatgrass invasion on federal rangelands implies an increase in the risk of fire, which in turn increases the likelihood that ranchers will be denied temporary access to public lands. This is an additional source of risk to the ranching enterprise that has not previously been explored. Interpreting the costs and benefits of public policies and land management practices that influence cheatgrass growth on federal rangelands requires knowledge of the costs and benefits of cheatgrass as a forage source. This necessitates quantifying not only the benefit of early spring cheatgrass forage production but also the cost of cheatgrass fires and the potential increase in the frequency of such fires as cheatgrass production increases. As cheatgrass continues to invade public lands in the Great Basin region, including the risk of wildfires into such models will become an increasingly important aspect to public land managers who wish to understand the impact of restoration policies on the ranching community.

The goal of this project is to determine the ranch-level economic impact of fire on a representative ranch's public grazing allotment. For the purposes of future evaluation and study of areas vulnerable to continued cheatgrass invasion, the ecological characteristics of the allotment are assumed to be representative of those ecological sites in the Great Basin sagebrush steppe region that are vulnerable to continued cheatgrass invasion. This study will provide a better understanding of the ranch-level economic impacts that result when ranchers cannot utilize their public lands as the result of wildfire. This could help prioritize public management restoration efforts. In addition, information regarding the influence of fire on forage availability may be important to ranchers evaluating the trade-offs of cheatgrass restoration efforts not only on public lands but on their deeded rangelands as well.

1.1 Problem statement

Cheatgrass is a unique exotic invasive species in that it provides economic value as a forage resource for grazing livestock while at the same time disrupting native ecosystems. This implies that there may be both costs and benefits for a ranching enterprise possessing a public forage allotment that is experiencing cheatgrass invasion. It should be noted that whether or not cheatgrass successfully invades a given area over time depends upon the site's invasibility which in turn depends upon a variety of factors including climate, degree of disturbance and relative competitiveness of natives and exotics (Chambers et al. 2007).

If a given ecological site is vulnerable to invasion, the introduction of cheatgrass results in decreased native species and increased wildfire frequency over time. Increased late spring forage is one possible benefit of this invasion. Increased risk of wildfires that limit access to public land for a two year period is one possible cost. The loss of native forage and thus the decrease of early summer forage is another potential cost. In the final state of cheatgrass invasion, the ecological site begins to exhibit the following characteristics: cheatgrass becomes a monoculture often referred to as annual rangelands; native forage is all but eliminated; fires occur frequently; and, in the case of public grazing lands, public land ranchers become wholly dependent upon the only available and often variable spring forage that has displaced the previously native public forage allotment.

One previous policy paper evaluated the ranch-level economic impact of denied access to spring forage (Torell et al. 2002). Another study sought to understand the ranch-level economic impacts of a variety of cheatgrass treatments on public grazing land with forage production consisting of roughly 80% cheatgrass and 20% native grasses (Satyal 2006). (Satyal 2006) successfully incorporated public forage constraints that designated the timing of available AUMs according to native grass and cheatgrass production in the spring and summer seasons. Other studies have included a great deal of biological information into ranch-level economic models (Aldrich et al. 2005; Stillings et al. 2003).

No study to date, however, has incorporated forage availability constraints imposed on public grazing allotments by cheatgrass wildfires. Furthermore, no study has included forage information typical of a mixed cheatgrass, native grass and sagebrush state rather than that of a nearly homogeneous cheatgrass state. As cheatgrass is known to cause comparatively frequent fires over time, ignoring these forage constraints could overestimate the benefit of the early spring forage provided by cheatgrass. Conversely, failing to attribute available AUMs in the early spring to cheatgrass could underestimate the potential benefit of cheatgrass. The following ecological constraints and research questions have been chosen to address these information gaps which will aid future ranch-level economic studies regarding ecological transitions on a rancher's public grazing allotments.

1.2 Ecological constraints and research questions

As current estimates indicate that over 40% of the Great Basin sagebrush steppe is at moderate to high risk of displacement by cheatgrass (Chambers et al. 2007), the goal of this analysis is to provide baseline information that will eventually benefit those who wish to understand the ranch-level economic impacts of such a transition occurring. Due to the fact that at-risk areas are of primary interest in this study, the model assumes the representative ranch's public grazing allotment exhibits ecological characteristics that are typical of sagebrush steppe sites that are vulnerable to continued cheatgrass invasion. The grazing allotment is therefore assumed to have the following two ecological constraints which in turn impact forage availability: 1) the percent cover of cheatgrass is 15%, and 2) the site experiences a 20 to 40 year fire return interval (David A. Pyke, personal communication, June 2007).

By incorporating these ecological constraints into a ranch-level economic model, this study will address the following research questions.

1. How does the representative ranch react to the temporary loss of permitted AUMs in terms of forage substitution and/or herd size reductions as the result of the assumed fire return interval?
2. Under what circumstances will this temporary loss of AUMs force a representative ranch out of business?
3. Is there an economic impact associated with changes in early spring AUMs under the assumed fire return interval?

2 Literature Review

Results from a ranch economic impact analysis may exhibit directional bias if the baseline model does not consider both the economic contribution of cheatgrass to spring forage and the economic cost of grazing exclusion due to cheatgrass associated wildfires. As a result, this section reviews the ecological and economic aspects of cheatgrass on public lands. It begins with the background information necessary to understand the costs and benefits of cheatgrass invasion and of cheatgrass as a forage species. Total ranch-level costs of cheatgrass invasion and associated fires depend upon the degree of the ranch's reliance on public grazing. Thus, the latter part of this review is dedicated to the various methods used to determine the value rancher's place on public forage.

2.1. Cheatgrass and sagebrush steppe ecology

Over the last 30 years or more, cheatgrass wildfires have resulted in the loss of rangeland diversity, productivity and private structures (Pellant 1996). These costs along with fire suppression and rehabilitation costs have changed the common perception of cheatgrass from an unwanted but useful component of rangelands, to a threat to the health of rangeland ecosystems in a majority of the Great Basin (Pellant 1996). First reported in the Intermountain region of western North America in the late nineteenth century, this annual grass gradually spread into the formerly big sagebrush/bunchgrass areas where perennial grasses are thought to have been particularly vulnerable due to excessive grazing by domestic livestock (Young and Clements 2003). Today, while a majority of rangelands in the U.S. are touted to be in the best condition in 100 years, the extensive areas of cheatgrass-dominated sagebrush lands in the Great Basin are cited as one exception (Laycock 2003).

The following sections explore the general factors that promote cheatgrass growth and how these factors, along with the invasibility of a given site, influence the relative ability of cheatgrass to thrive in areas of the Great Basin Region. This is followed by a discussion of the grass-fire cycle that aids in cheatgrass establishment and leads to declines in native species. These grass-fire cycles can result in significant environmental consequences that are briefly summarized at the end of this ecological review.

2.1.1 Cheatgrass growth: climate and elevation factors

Cheatgrass above ground growth initiates in the early spring and continues until soils dry in early summer (David A. Pyke, personal communication, September 2007). It is particularly well adapted to environments with mild wet winters, early springs, and early hot dry summers (Swanson et al. 2006). It can tolerate seasonal drought, as seeds in the soil survive for up to five years (Pellant 1996). The annual invades both low elevation salt desert shrub communities and higher elevation zones ranging from 457 to 2,743 meters and from 15 to over 50 centimeters of average annual precipitation (Pellant 1996). While cheatgrass is not as well adapted to higher elevation range sites, dominance can occur as the result of disturbance (Swanson et al. 2006). High plant densities and prolific seed production allows cheatgrass to invade and dominate disturbed rangelands (Pellant 1996). The ability of cheatgrass to evolve and survive in new environments implies that it could increase in the future (Pellant 1996). Whether or not this invasive annual is able to successfully invade a given site has as much to do with the characteristics and disturbance regime of the site as it does with growth factors of the species itself.

2.1.2 Ecological framework

State-and-transition models provide an organizational framework for rangeland vegetation dynamics (Stringham et al. 2003). These models are particularly useful for describing changes in natural ecosystems due to the introduction of invasive species. A generic state-and-transition model for a shrubgrass ecosystem (Pellant et al. 2005) is presented in Figure 1 at the end of this chapter along with a detailed description of the its' basic components. This general model, based on models presented in Bestelmeyer et al. (2002) and Stringham et al. (2001), is directly applicable to public rangelands that are vulnerable to cheatgrass invasion.

In this model (Fig. 1), an ecological site is considered initially to possess characteristics associated with its natural state or reference state (State A). A state is considered to be relatively stable even though reversible transitions between communities do occur. Once an invasive species is introduced to the site, depending upon the site's level of exposure to a given disturbance regime and various climate factors, the site can cross an irreversible threshold or transition into the next ecological State (State B). The site is then considered to be more vulnerable to crossing an additional irreversible threshold or transition to the final state of invasion, State C.

2.1.3 Site invasibility

Species invasion is typically divided into three phases: introduction, colonization and naturalization (Brooks and Pyke 2001). These phases are associated with states A, B and C, respectively (See Figure 1 at the end of this Chapter). If eliminating cheatgrass is a management goal, whether or not an ecological site can be restored by simply removing the disturbance regime or whether perennial seeds must be planted, depends upon the level or particular state of invasion (Laycock 1991). If the characteristics of the site have changed significantly from those in the reference state (state A), it is assumed that an ecological threshold has been crossed and the site is in an alternative state (state B or state C).

It is not yet well understood what determines that any given site will cross the threshold out of the reference state (State A) into the colonization state (State B). Factors that influence this threshold typically vary by site, depending upon climate, management, and disturbance regime (Pellant 1996). Similarly, an ecosystem's susceptibility to invasion, or invasibility, depends upon climate, the degree of disturbance, competitiveness of resident species, and the particular traits of the invasive species (Chambers et al. 2007). The ability for invaders to spread may also depend upon the degree of species diversity on a given site as open ecological niches provide opportunities for establishment (Brooks and Pyke 2001). Disturbances that reduce community complexity can therefore allow exotic plant species to invade (Brooks and Pyke 2001). Likewise, plots exhibiting greater species richness tend to vary less in cover and provide adequate cover of native species which appears to render semi-arid areas less susceptible to invasion (Anderson and Inouye 2001).

It has been found that mature native grasses can effectively exclude or limit cheatgrass production and establishment (Chambers et al. 2007). However, under a disturbance regime and/or a low relative proportion of native grasses to cheatgrass, cheatgrass has been known to out-compete native grasses and shrubs for soil resources, including water (Brooks and Pyke 2001). Cheatgrass utilizes soil moisture during its growing period in the early spring before native perennial grasses can complete their growth (Swanson et al. 2006). One study involving bottlebrush squirreltail (*Elymus elymoides* (Raf.) Swezey; syn. Sitanion hystrix (Nutt.) J.G. Smith) competition concluded that mature perennials may be less susceptible to cheatgrass competition than seedlings (Humphrey and Schupp 2004). This result is a possible explanation for the persistence of certain perennial plant communities even when cheatgrass is present (Humphrey and Schupp 2004).

Maintaining a specific ratio of cheatgrass to native plants is believed to help prevent the site from crossing an ecological threshold from introduction to colonization (Pellant 1996). Available research has led to a few predictions as to the relative species composition required to prevent this transition. It is speculated that the potential for cheatgrass invasion should be considered a threat if perennial shrubs and forbs and larger native grasses number less than 3 plants per m^2 and cheatgrass is adaptable to the site (Pellant 1996). Young and Evans (1978) determined a density of 2.5 perennial grass plants per m^2 to be necessary to prevent invasion by cheatgrass.

Once the site has moved beyond the reference state, if the site is not managed for active restoration, it is more likely that a second threshold will be exceeded in which case naturalization results (State C). This second threshold is considered to be irreversible in the sense that biotic and abiotic factors and financial resources typically limit the ability of the site to return to its previous ecological state (State B). Within this final stage of invasion, seeding of native perennials typically fails to restore the site (Humphrey and Schupp 2004). In the Great Basin, there are areas in the sagebrush zone in which the degree of invasion is such that cheatgrass has become well established and, therefore, these communities are essentially closed to reoccupation by native perennial species (Swanson et al. 2006, Pellant 1996). Rangelands in this state (State C) are often termed annual rangelands in the literature to reflect the ecosystems homogeneous species composition of invasive annuals.

2.1.4 The great basin region vegetation, climate and invasibility

Semiarid ecosystems and plant communities with relatively low cover characterize the Great Basin Region (Chambers et al. 2007). It should be noted that cover in the sagebrush steppe has been found to be higher in areas having greater richness of vascular plants (Anderson and Inouye 2001). Depending upon elevation, sagebrush-grass and salt desert shrub communities comprise the typical vegetation types of the valleys and lower slopes in the Great Basin (Brooks and Pyke 2001). Sagebrush steppe features few trees over large, dry, open areas (Chambers et al. 2007). Higher elevations primarily consist of pinyon-juniper woodlands (Brooks and Pyke 2001).

This region is characterized by a semi-arid climate with precipitation occurring mostly as snow during the winter (Brooks and Pyke 2001). As a result, the primary determinant of plant establishment is water availability (Chambers et al. 2007). Ecosystems subject to large fluctuations in resources have been predicted to be more susceptible to invasion than systems with more stable resources (Chambers et al. 2007). The climatic characteristics of this region may partly explain how cheatgrass has come to be a major and permanent part of the vegetation in drier parts of the sagebrush zone (Swanson et al. 2006). It is currently widespread throughout woodlands at lower elevations (Miller and Tausch 2001).

These lower elevations also experience more frequent fires, a disturbance regime that aids in the invasion of cheatgrass. Although cheatgrass invades a range of biotic communities in this region, this "cheatgrass-wildfire cycle" infers that the Wyoming big sagebrush (*Artemisia tridentata* Nutt. subsp. *wyomingensis* Beetle & Young (Asteraceae)) and more mesic salt desert shrub plant communities are currently at the highest risk (Pellant 1996). Native shrub species are unable to survive shorter fire intervals and this can hinder their reestablishment (Brooks and Pyke 2001). To the north, the Columbia and Snake River plateaus experience similar issues with fire and invasive plants (Brooks and Pyke 2001). This cycle is an important aspect of successful cheatgrass establishment. The cheatgrass-wildfire cycle is described in more detail in the following section.

2.1.5 Cheatgrass wildfires in the great basin

Cheatgrass can grow and germinate under harsh conditions allowing it to establish in the interspaces between shrubs on sagebrush shrublands (Brooks et al. 2004). This increases horizontal fuel continuity that can increase the frequency and extent of fire (Brooks et al. 2004). Wildfire intervals in the shrublands of the Great Basin historically ranged from 30 to 100 years (Brooks et al. 2004). Pellant (1996) described the length of the fire return interval as 32 to 70 years in sagebrush types. Return intervals of less than 5 years are associated with rangelands heavily infested with cheatgrass (Pellant 1996, Brooks and Pyke 2001).

The length and timing of the fire season in the Great Basin has also changed in some areas as the result of cheatgrass invasion. Usually dry by mid-July, cheatgrass has been reported to become flammable 4-6 weeks earlier and remains susceptible to fire 1-2 months later than native perennials (Pellant 1996, Swanson et al. 2006). These fires reduce the diversity and cover of native species that aids in the increase of cheatgrass (Link et al. 2006). An invasive plant-fire cycle can result (Brooks et al. 2004). This cycle is sometimes denoted as the cheatgrass-wildfire cycle (Pellant 1996). Repeated fires can lead to a homogenous landscape dominated by exotic annuals (Miller and Tausch 2001) as is typical of state C.

Fire size can often be larger as the result of cheatgrass invasion as well (Link et al. 2006). A study done by Knapp (1998) looked at the occurrence of large grassland fires in the Intermountain West between 1980 and 1995. Landscape structure and human activities together were found to influence spatial patterns of fire, while the timing of fires was successfully linked to climactic conditions that relate to plant growth. The data showed these fires clustered in areas characterized by their abundance of alien annual grasses and suggested that the Snake River Plains Region, along with several other regions in the Intermountain West, have undergone an increase in fire size. Since the invasive plant-fire cycle is driven by a positive feedback loop (Brooks et al. 2004), Knapp (1998) predicted that these areas are to be repeatedly affected by large fires in the future.

Due to future threat of cheatgrass fires, prioritizing fire prevention measures will rely increasingly upon the ability to predict the probability of fires occurring on any given site. A recent study performed in the Saddle Mountain National Wildlife Refuge in Grant County, Washington determined the relationship between the risk of sustained fire and percent cover of cheatgrass and native perennial cover (Link et al. 2006). This semiarid region is dominated by a mixture of big sagebrush, Sandberg bluegrass (*Poa secunda* J. Presl), and cheatgrass. The probability of sustained fire on the study plots was determined in the field by igniting fires during the fall season and determining the number of sustainable fires. The study found that 45% cheatgrass cover resulted in a fire risk of 100%. Given ignition, the lowest probability of fire found in the study area was 46% which was associated with 12% cheatgrass cover and 30% native perennials. Predicting cheatgrass wildfires and targeting restoration methods in the Great Basin region may help to avoid future environmental impacts.

2.1.6 Environmental aspects of cheatgrass and related fires

Environmental impacts from cheatgrass result from related wildfires, erosion potential, and the susceptibility of cheatgrass communities to invasions by other non-natives. The loss of big game winter ranges, habitat supporting North America's densest concentration of nesting raptors, sensitive plant species and non-game bird occurrence, along with reduced plant diversity, have all resulted from wildfires in the Great Basin region (Pellant 1996).

Furthermore, while cheatgrass litter can provide adequate cover for watershed protection, the uncertainty of its presence on sites with erodable soils and moderate to steep slopes as well as those that experience drought or wildfires, reduces site protection and can increase the potential for erosion (Pellant 1996). Plantings of other species can displace cheatgrass following a fire. However, introduced perennial grass crested wheatgrass (*Agropyron cristatum* L. (Gaertn.)) monocultures sometimes result from plantings commonly used in the 1950's-1970s for other purposes (Pellant 1996). Finally, invasive communities are known to be susceptible to invasion by seedlings of other exotic invasive plants (Young and Clements 2003). Sites once infested with cheatgrass in small portions of the sagebrush/grassland of the Great Basin are now dominated by unpalatable species such as scotch thistle (*Onopordum acanthium* L.) and/or medusahead wildrye (*Taeniatherum caput-medusae* L.) (Young and Evans 1978). This limits a site's forage production potential compared to cheatgrass (Young and Evans 1978).

Pellant (1996) stressed the need to accept cheatgrass as a permanent component of many Great Basin rangelands, while at the same time exploring new management and rehabilitation/restoration approaches to prevent further loss of fiscal and natural resources. However, the successful treatment of cheatgrass on public land may impact ranchers who utilize it for early spring forage. The next section presents the economic benefits and costs of cheatgrass as a forage species to provide a comprehensive understanding of the interests at stake.

2.1.7 Views on cheatgrass as a forage species

Cheatgrass has been argued to have had a positive impact on the livestock industry in the western region of the U.S. (Pellant 1996). It has been documented that this species provided more than half of the forage on spring ranches in southern Idaho (Pellant 1996). In Nevada, it is likely that more livestock forage comes from cheatgrass than from any other species (Pellant 1996). This implies that as cheatgrass invades, ranchers become increasingly accustomed to its presence as a forage species.

In many western states, few inexpensive forage substitutes for early spring forage exist (Rowe and Bartlett 2001, Torell et al. 2002). In addition to timing of availability, the benefit of cheatgrass is its ability to produce large quantities of forage. It can produce more biomass in some years than either native vegetation or seeded grass (Pellant 1996). A study in the state of Washington found similar aboveground biomass between a sagebrush-bunchgrass community and a cheatgrass community; however, nearly 25% of the former was contributed by live or dead woody tissue (Pellant 1996). One final benefit of annual rangelands (cheatgrass dominant) is that they can be grazed more heavily each year than most perennials (Swanson et al. 2006).

The variability of cheatgrass along with its relatively short growing season are two potential drawbacks for a ranch that relies upon cheatgrass as a forage source. Cheatgrass is typically both palatable and nutritious from early spring to early summer but provides a much shorter grazing season than most native herbaceous plants (Pellant 1996). Production of cheatgrass varies with a tenfold difference in net primary production in a wet versus a dry year (Pellant 1996). Such variability can make regular, intense utilization difficult as years of low production sometimes result in the need to substitute costly forage alternatives to maintain a cattle herd (Swanson et al. 2006). Production in perennial grass-dominated communities also varies yearly with precipitation, but the amplitude of the variation is less than with cheatgrass (Young and Allen 1997). Young and Allen (1997) noted that the trade-off in variability between cheatgrass and perennial grasses may be minimal during extremely dry years as perennial grass production is likely to be low along with cheatgrass production. They argued that proper management implies preclusion from perennial range as well during these dry years. They also pointed out that basing cow and calf production on cheatgrass during sub-average years does imply an additional risk to the ranch over that of perennials. This conclusion is similar to that of Swanson et al. (2006) as cited above.

Allowing cheatgrass to colonize a site also has its costs in terms of native forage for those ranchers who currently utilize both early spring cheatgrass forage and early summer native forage on rangelands. Cheatgrass and native grass species compete for resources and the success of either type often comes at the expense of the other (Humphrey and Schupp 2004). In the absence of successful restoration management, once cheatgrass is introduced to a vulnerable site it is possible that it can approach a cheatgrass-dominated state within a forty year time horizon (Pyke, D., personal communication, February 2007). Thus, if the ecosystem reaches the final and irreversible ecological state (State C) of invasion, ranchers are faced with a new problem--very little production of native forage. These two goods can be thought of as substitutes, albeit imperfect ones, as they have different yet overlapping growing seasons. The following quote from Tanaka explains the trade-off between investing in successful native grass restoration practices versus practices that allow cheatgrass to grow unimpeded:

> In moving to cheatgrass pastures, the rancher is trading off more stable forage supply and extended season of use for more abundant early season production and rainfall-dependent production (Tanaka, J.A., personal communication, April 2007).

It has been argued that sustainable utilization of a site requires the optimization of the site's long-term productivity along with the profitability of the enterprise, all at the lowest risk of failure (Weltz et al. 2003). As such, a successful rancher is one that avoids crisis situations through detailed planning, monitoring, and evaluation of the entire enterprise (Weltz et al. 2003). Does the possibility of cheatgrass wildfires on public grazing lands present a potential crisis situation and therefore imply an additional source of risk to the rancher? To understand the costs of losing temporary access to public forage lands as the result of cheatgrass-supported wildfires, it is first necessary to understand the value of public forage to a ranching enterprise.

2.2 Ranch-level economics

2.2.1 Estimating the value of public grazing lands

Researchers have employed a number of methods to estimate the value of forage on public rangelands. While average private rangeland lease rates have been the primary method to value public forage, these rates may or may not reflect the total benefit received from the use of forage on federal lands (Bartlett et al. 2002). Ranch-level linear programming models that use enterprise budgeting have been criticized for their underlying assumption that livestock production potential provides the only value associated with public forage (Bartlett et al. 2002). These models ignore quality of life (QOL) values and underestimate the true value of public lands (Bartlett et al. 2002). The QOL attributes of ranching is one indication that western ranchers maximize utility rather than profit (Torell et al. 2001, Genter and Tanaka 2002).

Bartlett et al. (2002) reviewed a variety of techniques for estimating the full market value for forage on public land that accounts for these non-market values and suggested two favored valuation approaches, the contingent valuation method (CVM) and hedonic regression models. The authors pointed out that these models require additional refinement, application and testing. One drawback not addressed in this paper pertaining to the CVM is the high cost required to provide legally defensible passive use estimates which must meet the conditions put forth by the National Oceanic and Atmospheric Administration’s “blue ribbon” panel.

The paper by Torell et al. (2001) also suggested that non-market values make policy analysis difficult, arguing that QOL values lead ranchers to continue in business until they are forced to leave. As a result, standard budgeting and economic modeling techniques fail because they use a minimum acceptable investment return as the critical level that will cause a business to exit the industry (Torell et al. 2001). Due to the lack of a profit motive, this approach naturally reveals that most ranchers should not be in business regardless of the policy change under consideration (Torell et al. 2001). These authors suggested that for the sake of policy analysis, multi-period linear programming models with a profit maximizing objective provide a reasonable approach as long as these models include production alternatives, cash flow constraints, borrowing capacity, and off-ranch income. Assuming that ranchers will operate until they either fail to meet certain cash flow constraints or exceed their borrowing capacity, policy analysis is then limited to whether or not the ranch goes bankrupt (i.e., fails to meet the cash flow and borrowing constraints imposed by the model).

Both Torell et al. (2001) and Bartlett et al. (2002) criticized the use of ranch-level economic linear programming for the purposes of comparing profit-maximizing production estimates before and after a policy change. Such comparisons require numerous models to adequately describe the wide range of wealth, debt load, and economic positions of western ranches (Torell et al. 2001, Bartlett et. al. 2002). Genter and Tanaka (2002) were the first to systematically cluster ranchers by their numerous and common attributes, with each cluster representing different amounts of off-ranch income and motivations for ranching. The rationale of the hobbyists is particularly hard to capture as they are not typically dependent on ranching, yet this group comprises 50.4% of all public land ranch operators in the West (Genter and Tanaka 2002). This type of enterprise tends to be small with high variable costs and usually operates at a loss (Rowe and Bartlett 2001). Assuming strict profit maximizing behavior for these ranchers is clearly inaccurate. Therefore, because utility cannot be measured, economic models provide, at best, an incomplete assessment of land-use policies (Torell et al. 2001).

While the true value of public forage is difficult to quantify, ranch-level economic models that consider the seasonal dependency of ranches on public rangelands provide a better estimate of this value than those that do not. The seasonal forage source that is most limiting determines the carrying capacity of a ranch operation. This implies that the lack of federal forage for even a short time, in the absence of an economically viable alternative, can reduce the number of livestock on a ranch (Taylor et al. 1982). A study by Greer (1995) examined Bureau of Land Management (BLM) and United States Forest Service (USFS) permittee files for Grant, Malheur, Harney and Lake counties of southeastern Oregon and concluded that while the dependency of local ranches on public grazing appeared insignificant when calculated on an annual basis, its importance to the ranching community is evident when looked at on a seasonal basis. Between 1987 and 1992, total annual dependency for federal forage in this study area was estimated between 13% and 26%, yet in the grazing season from May through September federal range provided from 35% to 48% of the forage needs of the ranching community (Greer 1995). The reason for this may be in part due to the desert or semi-desert climate in southeast Oregon that limits the development of additional forage sources (Greer 1995).

Another example of the importance of timing of available public forage is demonstrated in the Torell et al. (2002) paper that evaluated the ranch impacts of eliminating spring use of BLM forage. The study employed a linear programming model to determine optimal production and economic returns for representative ranches in the areas of Owyhee County, Idaho, northeastern Nevada, and Lake County, Oregon. The specific ranches considered were medium sized, 300 cow ranches in Idaho, and large ranches, 720 and 500 cows in Nevada and Oregon, respectively. The model maximized net present value over a forty-year planning horizon with 100 different beef price scenarios. To evaluate the impact of spring public forage loss, only the season of use was restricted by moving the turn-out date for each representative ranch while the quantity of the BLM forage (as expressed on an AUM basis) remained unchanged. Two analyses were performed for each representative ranch to determine the range of possible economic impacts from eliminating spring forage. The first analysis included only winter hay feeding as a grazing alternative and herd size was allowed to vary according to profit maximizing conditions (Torell et al. 2002).

For the Idaho model, the turn-out date was moved from April 15th to May 15th and the optimal response was to reduce average herd size from 345 Animal Unit Years (AUY) to 274 AUY. An estimated 182 AUMs of hay were required to replace the AUMs lost by limiting the season of use. As spring grazing limited annual livestock production, AUMs in the other seasons were no longer economically useful to the ranch. The optimal solution reduced BLM AUMs used by 683 AUMs when compared to that of the non-restricted model. Torell et al. (2002) argued that in this case, eliminating spring grazing was economically equivalent to an allotment reduction. The economic loss associated with this exclusion from spring grazing was estimated in net returns to be $24.17/AUM removed. For the Idaho model, the economic value of the BLM forage during the spring period was found to be 5 to 10 times the value in other seasons.

The Oregon ranch model showed somewhat contrasting results (Torell et al. 2002). The typical March 1st turn out date was moved to April 1st. The optimal strategy was to extend winter hay feeding by one month. The AUMs removed during March were utilized later in the grazing season and herd size increased by 19 head. This result may be due to the substantial hay resources for the Oregon ranch in which the production cost of hay is nearly equivalent to the sale price. By contrast, the Idaho model had a defined profit margin of $22/ton for selling hay resources. In addition, developing the marginal hay meadows for grazing was an option included in the Idaho model that was not considered viable in the Oregon model. Limited alternatives for hay land in the Oregon model meant the opportunity cost of feeding hay was relatively low. Eliminating spring grazing reduced net income by $8.17/BLM AUM removed.

Results of the Nevada Model showed a reduction from 728 AUY to 589 AUY when the turn out date was moved from April 8th to May 8th. The only possible grazing alternative was to extend winter hay feeding. A 44% reduction in optimal BLM AUMs occurred, and net economic returns decreased by $17, 171 or $25.82/AUM removed from spring grazing.

The second analysis of the value of spring forage allowed the representative ranches to freely adjust their seasonal use of all deeded and private leased AUMs when BLM spring grazing was removed (Torell et al. 2002). Under this scenario, the Idaho ranch was allowed both the option to convert hay land to pasture and graze this pasture in the spring and to also lease additional private land during the spring. The economic impact of removing spring grazing under these circumstances was estimated to be a loss of $5.34/AUM removed. This is much lower compared to the $24.17/AUM lost in the first analysis when the ranch was not free to adjust deeded and private leased AUMs.

For the Oregon model, allowing leased private AUMs to substitute for grazing during the March period resulted in minimal economic consequences (Torell et al. 2002). Without the imposed reduction in season of use the ranch optimally used private leased forage between May 1 and October 1st. Therefore, under this second analysis of shortened spring grazing, the Oregon ranch was allowed the flexibility to use those private AUMs in March and graze BLM later in the summer. Under this optimal solution, economic returns and herd size remained unchanged and, as a result, there was no economic loss for the Oregon model associated with this season-of-use adjustment.

More seasonal flexibility of other forages decreased the loss to $18.76 per BLM AUM removed in the spring in the Nevada Model. Results showed additional hay land would be optimally converted to pasture and deeded AUMs would be allocated for spring grazing. Hay feeding would not increase. This is similar to the results of the Idaho model. In both cases grazing alternatives are cheaper than hay feeding.

While the Nevada and Idaho models results were similar, the contrasting results of the Oregon model demonstrates the importance of accurately representing the seasonal complement of forage and pasture resources available, along with the ranch's level of dependency on federal lands (Torell et al. 2002). If BLM grazing is removed, it is those ranches with restricted seasons of forage availability that will be less able to substitute alternative forage sources (Torell et al. 2002). These differences in availability of substitutes therefore determine the contributory value of the federal grazing permits for livestock production (Torell et al. 2002).

This same policy study by Torell et al. (2002) also considered the economic impact of year round BLM AUM allotment reductions of 50%, 75% and 100%. Ranch management strategies considered for this portion of the analysis included leasing outside private forage, converting native meadow hay land to irrigated pasture, extending the hay feeding period, and reducing the size of the cow herd. A 100% reduction in BLM grazing reduced optimal average herd size by 42% in the Idaho model and by 47% in the Nevada model (Torell et al. 2002). The Idaho representative ranch had an average 39% dependency on BLM annual grazing capacity which is close to the average herd size reduction. Both the Idaho and the Nevada ranch also reacted to the allotment reduction by converting hay land to pasture.

In contrast, with the elimination (100% reduction) of the BLM permit, the Oregon representative ranch substituted BLM AUMs by increasing amounts of private leased forage (Torell et al. 2002). Optimal USFS AUMs were also reduced by 11%. However, like the Idaho model, the primary response strategy was to reduce livestock production by 33%. As substantial hay land resources are assumed, the Oregon ranch switched to hay selling when the size of the BLM allotment was reduced with the subsequent reduction in herd size.

Annual average economic losses from removing AUMs were approximately \$3/AUM for the Idaho model, \$6/AUM for the Nevada model, and \$10/AUM for the Oregon model. In all cases, forage substitution minimized economic losses relative to feeding hay and reducing cow herd size.

This conclusion is also supported by Rowe and Bartlett's (2001) study of the impact of public grazing reductions for ranches in two Colorado counties that were experiencing varying levels of economic growth. This study found that in all cases, substituting forage for lost public grazing land resulted in lower economic impacts than the strategy of reducing herd size. Hence, additional leased land, if available, could always compensate for federal forage loss. However, cases in which increasing leased land was not an option and purchasing hay was the only available substitute, left herd reductions as the most cost-effective solution (Rowe and Bartlett 2001). These authors did note that considering only purchased hay may have overestimated hay costs as many ranchers produce their own hay.

While both studies concluded that forage substitution minimized economic costs the linear programming analysis used by Rowe and Bartlett (2001) differed from the Torell et al. (2002) in two key ways. Rather than using enterprise budgets in their linear programming models, Rowe and Bartlett (2001) used a sampling frame of 242 federal permittees in the two counties. This sample was stratified to create sets of ranch budgets that were compiled and averaged to use as representative budgets for different ranch sizes and livestock categories. In addition, results from thirty-five personal interviews of local ranchers were used to determine management response strategies to federal forage reductions. These ranchers indicated that if they were faced with a reduction in public grazing, they would choose to reduce herd size, lease additional land, or increase hay production.

Second, unlike Torell et al. (2002), Rowe and Bartlett (2001) considered the herd reduction management strategy separately from the federal forage substitution strategy in their linear programming models. The herd reduction strategy eliminated solely federal forage as a forage source and allowed herd size to vary. The other scenario allowed forage substitution to occur while herd size was held constant. Changes in herd size and contribution margins were evaluated to determine economic impacts. Contribution margins were calculated by subtracting variable costs from gross returns and fixed costs were not considered.

As Rowe and Bartlett (2001) used different methods from that of Torell et al. (2002), their study revealed additional aspects to consider when choosing a representative ranch for policy evaluation. The study indicated that public land dependency, ranch size, *and* efficiency seemed to determine the degree of impacts from federal forage reduction. While the county that was experiencing high levels of development pressure (Routt County) depended very little on leased land for forage and heavily on federal forage, ranchers in the less developed county (Moffat County) relied on an equal percentage of federal and leased land. This implies that Moffat County ranchers could compensate for forage loss more easily. While small and less efficient (hobby) ranches existed in both counties, all of which actually saw higher contribution margins as the result of reducing herd size, a higher percentage of hobby ranches existed in Routt County. The authors suggested that lower levels of efficiency in Routt County could potentially explain why contribution margins showed greater relative declines for Moffat County ranchers under the herd reduction scenario than declines in contribution margins in Routt County for the same scenario. The authors linked greater federal forage dependency, smaller ranch size, and lower efficiency to development pressures, decreasing land availability, and increasing costs, implying that Routt County may be relatively more vulnerable to future grazing cuts.

Results from the Rowe and Bartlett (2001) study as well as those from the other studies outlined above, demonstrate the problem with generalizing economic impacts for ranchers faced with public forage loss. Rancher motivation, seasonal dependency, efficiency, ranch size, the availability of economically viable substitutes, and the degree of development pressure in the region are all important aspects to consider when averaging ranch budget data to create a single representative ranch. Furthermore, unless separate models are created for ranches that have been clustered according to common attributes (Genter and Tanaka 2002), the results of ranch-level studies regarding loss of public forage should be treated with some degree of skepticism. Generalizations regarding economic impacts to ranchers as a whole group will likely be inaccurate for a significant percentage of ranchers.

Regardless of the pros and cons of various economic valuation methods, Bartlett et al. (2002) stressed the importance of considering the full economic value of public forage, considering it as an essential step to an accurate understanding of the value of range improvements, resource value comparisons, and impact assessment as public land forage is allocated to other uses. While no "best" method for determining the value of federal forage has been agreed upon, it is clear that for those ranchers that utilize public land, federal forage does possess some degree of value. Current economic methods may underestimate this value by ignoring QOL values, but assigning no value at all will bias the results.

The studies presented here exhibit a variety of methods and considerations for determining the ranch-level economic impact of permanent reductions in access to federal forage allotments. Yet, none of these approaches considered the implications of temporary periods of loss of public land that would result from wildfires. In addition, these studies ignored possible variations in the seasonal or annual forage availability and production according to forage species type or land management strategy. These ecological characteristics become important when more than one species comprises forage on grazing allotments and/or when restoration treatments are being applied. Certain biological information must be included into the ranch-level economic model in order to accomplish this level of specificity. The following section provides a discussion of bioeconomic models that have successfully integrated ecological characteristics into ranch-level economic models. These ecological characteristics are tied to the model through their influence on timing of forage availability and production.

2.2.2 Bio-economic models

Agricultural economists have created a number of firm level models that simulate behavioral and technical relationships for the purposes of evaluating optimal input use and output supply (Weersink et al. 2002). Rangeland economists have used these basic optimization (profit maximizing) frameworks to weigh numerous management options on a dynamic landscape. Tanaka and Workman (1988) developed usable mathematical and tabular approaches for investment in the control of undesirable vegetation and outlined a method to analyze biological and economic decisions that alleviated an identified seasonal (spring) forage bottleneck in a yearlong ranch-operation. They estimated the optimum (profit maximizing) rate of initial overstory kill for the purpose of increasing seasonal forage availability which has the potential of increasing red-meat production. Brush reduction benefits discussed, although not all implicitly considered in the model, included increased forage and livestock production, ease of working cattle, increased feed for wildlife, and improved watershed conditions. A linear programming model analyzed a "typical" 206 brood cow, cow-calf-yearling Utah ranch operation data set and calculated the value of additional crested wheatgrass forage obtained by the reduction of big sagebrush canopy cover. Cost of kill relationships were also included for each type of treatment method considered.

The results indicated that the Utah ranch, from an economic efficiency or profit maximizing view, should achieve the highest possible initial kill level (Tanaka and Workman 1988). A big sagebrush kill rate between 92 and 100% was found to be optimal, although the authors recognized that multiple use management may dictate less than 100% removal of big sagebrush. Tanaka and Workman (1988) also noted that the goal may not be complete control on other ranches or grazing lands that are more productive, as the same level of present net worth might be achieved for less investment.

Tanaka and Workman (1988) considered sagebrush strictly from a livestock production perspective and as such described sagebrush is an "undesirable" shrub. The limited one-year planning horizon of the model accounted only for immediate treatment benefits and costs without consideration for potential ecological change that may ultimately be undesirable in the long-run. Scientists have just recently begun to understand the relationship between percent cover of native species and the invasibility of a given site. As described in the ecological section, plots exhibiting greater species richness tend to render semiarid areas less susceptible to invasion, perhaps primarily due to the increased representation of cover by native species (Anderson and Inouye 2001). Furthermore, treatment methods examined in the Tanaka and Workman (1988) study were ecosystem disturbances which are now thought to open ecological niches and provide opportunities for the establishment of invasive species (Brooks and Pyke 2001).

New research has demonstrated that sustainable rangeland management requires an understanding of biological dynamics over planning horizons that include many years. An optimal strategy based on a single year may preclude use of this strategy in the future if irreversible biological damage results. Albers and Goldbach (1999) demonstrated the difference in economic efficiency strategies for farmers with dissimilar planning horizons due to the presence or absence of land tenure security. A model of optimal shifting cultivation was combined with a model of species competition to present a deterministic framework for examining farmers' decisions when faced with potential irreversible loss in forest cover (Albers and Goldbach 1999). Farmers in the model were assumed to value the contribution of fallow growth strictly in terms of its contribution to agricultural fertility. The "forward looking farmer" was assumed to have complete tenure security and might therefore manage to avoid irreversible ecosystem changes. In contrast, the "myopic farmer" might have a high discount rate or no tenure security. It was hypothesized that either farmer may find it optimal to invoke an irreversible ecological change and this might lead to an economic irreversibility as well.

The results of this model suggested that under certain conditions it is economically efficient from the perspective of both types of farmers to undertake ecologically irreversible actions (Albers and Goldbach 1999). However, the existence of a technical irreversibility, whether or not this results in an economic irreversibility, caused the forward-looking farmer to alter the previously chosen production path. This led the authors to conclude that there was danger in employing resource management strategies based on models that ignore impacts of resource use on resource regeneration. They argued that this could lead to an irreversible collapse of the ecosystem that produces the resource.

The results of the Tanaka and Workman (1988) study may not necessarily be applicable today due to additional information about ecosystem relationships and changing societal attitudes regarding what is considered “undesirable” vegetation. However the methods presented in that study coupled with dynamic models like that created by Torell et al. (1991) that determined future forage and livestock production based on intertemporal stocking rates, have paved the way for new, long-run bioeconomic models that address contemporary resource management issues. These models have the ability to quantify the indirect market benefits of ecological restoration management practices that may appear at first to have little or no market value. These models are able to provide such information by linking treatment methods to forage availability and subsequently to economic impacts, providing a biological and economic framework that assigns value to non-market goods.

In general, bioeconomic models combine biological dynamics with economic behavior to determine an optimal bioeconomic strategy (Stillings et al. 2003). The following is a discussion of recent, ranch-level bioeconomic models, all of which consider ranch operation decisions over extended time horizons. It has been found that lengthy time horizons are needed to fully evaluate the impacts of investment projects, including restoration methods, that change the long-term biological characteristics of the site and, in turn, future forage availability. Although Aldrich et al. (2005) and Stillings et al. (2003) evaluated projects on deeded rangelands while Satyal (2006) considered restoration treatment strategies on public lands, the lack of low-cost seasonal forage substitution opportunities resulted in ranch-level economic impacts regardless of ownership.

Stillings et al. (2003) determined optimal ecological management strategies through comparisons of the corresponding economic outcomes, allowing a quantified cost in the form of net returns to be assigned to the non-market value of riparian area restoration. A multi-period bioeconomic model was developed for the purpose of evaluating riparian area management practices for a 300 cow-calf ranch in northeastern Oregon. An off-stream water and salt dispersion project was the primary management strategy considered. The model was solved using a linear programming model developed using the General Algebraic Modeling System (GAMS) software (Brooke and Meeraus 1998). Comparisons were made between various management scenarios over a 60 year time-line with a 7% discount rate.

As the magnitude of net returns can vary depending on precipitation level and market prices, Stillings et al. (2003) considered high, medium, and low prices sets and dry, medium, and wet precipitation levels. This economic analysis used forage equations of motion to determine forage supply as a function of both precipitation and forage utilization levels achieved on private and public pasturelands. If the manager exceeded the 35% utilization level of riparian area use, the agency was assumed to lower the amount of total permitted AUMs in the following year. This allowed the model to link management strategies to forage availability that was then balanced with herd size and forage demanded for each year.

The dispersion project was found to have 3 significant impacts on the average annual gross margin. First, investment and increases in variable costs such as labor costs imposed additional direct costs on the ranch. Second, better cattle distribution allowed more forage to be consumed in the uplands that led to more animal units grazed or fewer AUMs purchased from other sources such as leased pasture or hay. Third, cows and calves grazing on the dispersion project saw significant weight gains that translated into additional revenue from the culled cows and sold calves. Regardless of the price set or precipitation level, the representative ranch saw a positive return from the dispersion project investment in the face of riparian area grazing concerns.

Aldrich et al. (2005) developed a quantitative evaluation framework for determining optimal ranch management practices for western juniper encroachment on rangelands and applied this framework to a set of representative ranches in the John Day Ecological Province of north-central Oregon. A discrete-time, dynamic economic model was developed and evaluated also using GAMS. Similar to the method employed in Stillings et al. (2003), Aldrich et al. (2005) used equations of motion to reflect ranch operations and the impact on available forage as the result of various juniper treatment methods. Boundary equations were used to connect available forage, which varies depending on juniper treatment, to the ranch operation by requiring the amount of forage produced or purchased to meet the year-long feed requirements of the herd.

The unique aspect of this model was to include accounting equations that reflected changes in sedimentation and wildlife populations as the result of multiple-year impacts from the various juniper management scenarios. While accounting equations accounted for wildlife population changes for quail, deer, and elk as a function of ranch size, precipitation, and the extent of juniper encroachment, economic values associated with these changes were not determined in the model nor were they considered in the profit maximizing objective function. The study found that ranch size and precipitation zones affected not only the profitability of the ranch but also the relative impact of juniper encroachment on erosion levels and some wildlife populations. The impact on wildlife and the environment was determined exogenously in the model but because no dollar value was assigned to these variables, they were not an endogenous part of the management decision. Regardless of ignoring these variables in the profit function, juniper management was found to positively impact simulated revenues over and above expensive juniper management costs.

Satyal (2006) focused on the social and economic impacts of adopting restoration strategies to restore cheatgrass dominated public rangelands to native species in the western U.S. Treatment costs and loss of forage availability, or rather the discounted opportunity costs associated with foregone forage due to the assumed two year recovery period required from restoration, were considered together to comprise the total economic cost of restoration. It was assumed that restoration was needed on 75% of the total available BLM summer grazing allotment. While four representative ranches were considered, only the results from the Oregon and Idaho models will be highlighted here.

The Oregon ranch was a typical 300 cow/calf operation, assumed to use its BLM grazing permit annually from April 1st to July 15th. Specific information regarding the seasonal growth functions of cheatgrass and native species were utilized in the model. Because the seasons of peak production differed between these two species, the representative ranch used less BLM forage than the total that was available. Under the no change, or no treatment scenario, the Oregon ranch was economically viable with 300 brood cows and net annual returns of $61,827.

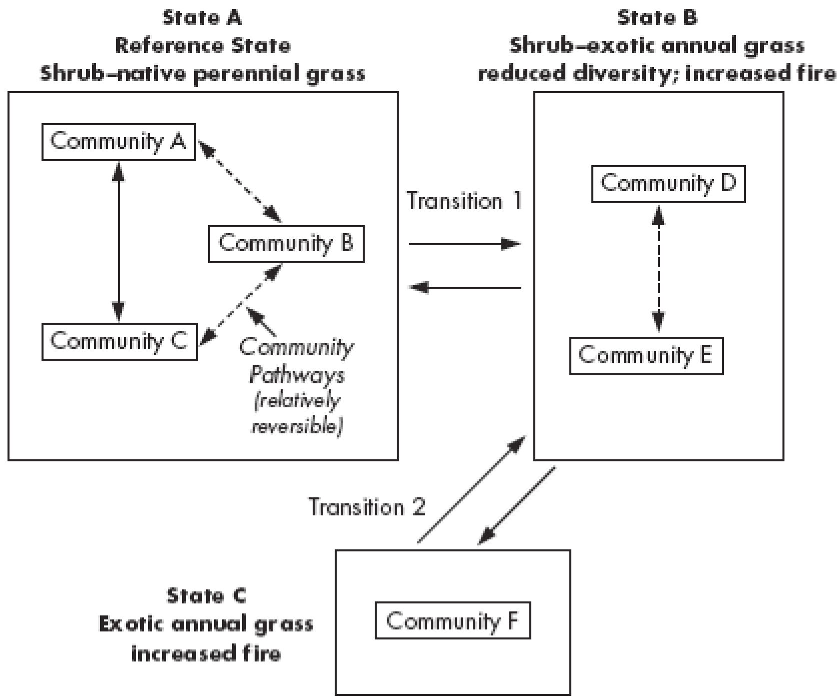
Each treatment strategy considered resulted in a different percentage decrease in consumption of AUMs and profit for the Oregon model over that of the baseline scenario. For example, the application of herbicide reduced forage availability by 33% due to a 60% reduction in cheatgrass biomass and reduced herd size from 300 to 276 brood cows. Subsequently, net annual returns fell by 7% to $57,123. The total economic cost of restoration over the 40 year planning horizon was calculated to be $82,815 or $197.60 per hectare. The greatest decrease in net returns resulted from the integrated strategy with a 70% decrease in cheatgrass growth, the highest decrease in cheatgrass of all considered strategies. A 30% increase in natives resulted, but this did not make up for the significant loss in cheatgrass forage. The Idaho ranch saw similar economic results. Again, the integrated strategy caused the greatest decline in net returns. All four representative ranches experienced greater financial impacts from restoration than from no restoration, regardless of the treatment strategy used.

Perhaps the most important implication of these models is their ability to internalize what could only previously be calculated as external costs through imposed constraints on forage availability. By doing this, these models get closer to determining the full benefits and costs of restoration. Quantifying these benefits and costs in terms of ranch-level economic gains or losses makes these additional risks of failure to a ranching enterprise more difficult to ignore. These risks are layered on top of those more typically considered including technology, price, and policy (Weersink et al. 2002). Yet, none of the bioeconomic studies presented here successfully integrated all sources of risk nor all relevant non-market values into the model as constraints or as part of the objective function.

Weersink et al. (2002) presented various methods to incorporate issues of sustainability into linear programming models with a profit maximizing objective. However, methods presented such as "nearly-optimal" linear programming were based on an underlying assumption that private enterprise interests were independent of social interests. While this may be the case, this ignores the possibility that ranchers may possess some value in promoting public benefits or that if public and private incentives differ that their respective optimal outcomes are more often than not misaligned. While the "nearly-optimal" method was specifically for circumstances in which the optimal solution for the enterprise was not that of society's, it was possible that the model was ignoring or failing to account for costs or benefits to the enterprise that may actually lead to an optimal solution that was congruent with that of society's. As biological factors involve thresholds, steady states, and transitions, it may be that the optimal solution was the same for both the enterprise and society, but only prior to crossing a given ecological threshold.

For example, Unterschultz et al. (2003), found that ranches possess positive economic incentives to maintain riparian zones that are in good range condition, yet riparian zones in fair to poor range condition may require additional economic incentives if ranchers were to adopt more costly management strategies. A similar scenario may be one explanation for the results of the study by Satyal (2006) as described above. The naturalized condition of these invaded rangelands was one possible explanation for why restoration was more costly than maintaining the status quo. These results may also reflect the failure to include all possible costs of this ecological state, such as the imposed risk of fire on the ranching enterprise or the vulnerability of these lands to other less palatable invasive species.

The common thread of these bioeconomic models is their ability to come closer to quantifying the full economic costs and benefits of various restoration strategies. Considering the upfront treatment cost alone is clearly not sufficient to provide a cost-benefit analysis because both ecosystems and economic systems are dynamic interconnected webs. Various management strategies send ripples that stem far beyond the initial point of contact. As ranchers are members of this web, modeling based on the assumption that impacts from management decisions impose more or less of a loss on individual ranchers than those that they impose on members of society should not go without question. It may be possible that with perfect information the optimal solution for a ranching enterprise is equal to, or at least closer to, that of society's solution than previously anticipated.



Community Pathways	Example
A	Shrubs and native perennial grasses co-dominate (historic climax plant community)
B	Native perennial grasses are dominant; shrubs subdominant
C	Shrubs dominate; perennial grasses subdominant
D	Shrubs dominate; exotic grasses subdominant
E	Exotic grasses dominate; shrubs subdominant
F	Exotic annual grasses dominate
Transitions (relatively non-reversible)	
1	Wildfire and introduction of exotic, invasive, annual grasses
2	Repeated wildfires that exceed natural fire-return interval

Figure 2.1. State and Transition Diagram (Pellant et al. 2005, p.16). Ecological transitions are represented by solid arrows to stress relatively permanent change and differentiate transitions between states from the relatively reversible community pathways.

States (Large Squares): States A, B and C are differentiated from each other due to relatively large differences in plant functional groups, ecosystem processes, vegetation structure, biodiversity and management requirements.

Biological Communities (Small rectangles): Biological communities that are functionally similar with respect to their soil/site stability, hydrologic function and biotic integrity are connected together by community pathways within a single state.

Community Pathways (Dashed arrows): These pathways connect plant communities within a state and represent reversible transitions between plant communities. A transition along a community pathway can be reversed by altering the factors/disturbance that produced the initial change from one community to another.

Transitions (Solid arrows): Transitions between states are *not* typically viewed as reversible by simply altering the factors or disturbance regime that produced the change. Such transitions may result in a physically-altered state in which potential soil loss may require revegetation or shrub removal to avoid future degradation of a given site. A return to a pre-existing state may require expensive restoration mechanisms.

Reference State (State A): The biological communities within this state are performing at or near the optimum level under the natural disturbance regime. Managers may choose to manage for communities other than those of the reference state if desired plant communities exist in another state. The desired plant community will likely be found in the reference state if sustainability is an objective.

3 Methods

3.1 Theoretical Model

A general discrete-time optimal control problem determines the optimal allocation of resources over time necessary to maximize the net present value (NPV) of a given objective function (Aldrich 2002). The objective function is subject to resource constraints. The general form for this problem is as follows:

$$\max_{\{u_t\}} \sum_{t=1}^{T} F(t, y_t, u_t)\delta^t \qquad [3.1]$$

subject to $y_{t+1} - y_t = f(t, y_t, u_t)$

$$y_0 = \overline{y}$$

$$u_t \in \Omega$$

where δ^t is the discount rate. The objective function is constrained by the state variable, y_t, which defines the state of the system at time t, the initial condition, y_0, which defines the level of the state variable at time t=0, and the control variable, u_t, which functions as a decision variable (also known as a choice or control variable). This is a dynamic optimization problem in that decisions made in one period affect the resources available in the subsequent period. This problem can be solved using dynamic first order conditions using a Hamiltonian function as long as neither the objective function nor the constraints contain inequalities.

The multiperiod ranching operation profit maximization problem is dynamic in the sense that production decisions in the current period affect not only the current period but also subsequent periods. This problem is best described by a dynamic discrete-time optimization problem in which the decision variables are constrained by inequalities rather than equalities. As a result, mathematical programming is employed to obtain a solution. The general form of this problem is as follows:

$$\max \sum_{t=1}^{T} F(t, y_t, y_{t-1})\delta^t \qquad [3.2]$$

subject to $y_{t+1} - y_t = f(t, y_t, u_t)$

$y_0 = \bar{y}$, and

$u_t \in \Omega$, where t=1, 2,…,T

where δ^t is the discount rate. The NPV of the objective function is maximized subject to the equations of motion, the initial conditions and the boundary condition. The equations of motion detail how the change in each state variable (the full set of state variables describe the stock of resources y_t), depends upon time (t), the state variable itself, and the control variables, u_t. The initial conditions, y_0, are constants that describe the resource stock at time t=0. The boundary condition is a generalization of the restrictions placed on the decision variables. The next section describes the empirical ranch model that is based on Eq. 3.2.

3.2 Empirical Model

A baseline “No Fire Model” and a “Fire Model” are evaluated for a representative 300 cow-calf Oregon ranch. It is assumed that the ranch’s BLM allotment forage component is comprised of native grass and cheatgrass AUMs as measured on a study site that is part of a current research project (SageSTEP 2007). Models are calibrated to ensure that the forage sources exactly meet the yearlong needs of the 300 cow-calf ranch. This study uses constant precipitation and constant cattle prices in order to isolate the wildfire impacts. Randomly generated fire regimes are analyzed and compared to the No Fire Model to determine the impact on the ranch using a Monte Carlo approach.

3.2.1 Baseline economic model (No Fire Model)

A ranch-level economic multi-period, linear programming model (Satyal 2006, Torell et al. 2002) is used as the baseline or No Fire Model. Livestock production is dynamic and considered to take place over T-years. The rancher's decision problem is assumed to be discrete rather than continuous which implies that variables may change only once within any given time period. In this model the ranch maximizes the present value of profit over a forty-year planning horizon using a 7% discount rate. The General Algebraic Modeling Systems software (GAMS) (Brooke and Meeraus 1998) is the mathematical programming tool used to solve this problem.

The model determines the profit maximizing number of livestock to produce and sell at time T for each class of animal subject to typical operating constraints, including forage supply and costs. It is assumed that the ranch starts within an initial quantity of mature cows (Table 3.1), that a minimum herd replacement requirement exists for cows and heifers (Table 3.1), and that these replacements comes from heifer calves and yearlings saved each year rather than from purchased brood cows. A description of the representative Oregon ranch in terms of key model parameters is presented in Tables 3.1-3.3. Costs and price information is based upon OSU Enterprise Budget EM8470 (Kerns et al. 1997). Brief descriptions of the operating constraints that are central to this study are also provided within this section. The complete model code can be found in Appendix A.

Table 3.1. Livestock characteristics for the Oregon representative ranch.

Livestock Class **(Model Name)**	Sale Weight **100 weight (cwt)**	Animal Production Costs **(2005 $)**	Number or %	Sales Price **(Appendix D) (2005 $)**		
				High	**Average**	**Low**
Mature cows maintained in the herd (BROODCOW)	**0.00**	**32.00**	**300**			
Cull cows (CULLCOW)	**11.00**	**32.00**		**50.65**	**42.98**	**35.30**
Bulls (BULL)	**5.00 (2000 lbs over 4 years)**	**0.00**		**63.96**	**54.50**	**45.03**
Steer calves for sale (SCALF)	**5.75**	**0.00**		**113.41**	**96.40**	**79.39**
Heifer calves for sale (HCALF)	**5.25**	**0.00**		**111.85**	**92.60**	**73.34**
Yearling steers for sale (SYEAR)	**0 (not raised on ranch)**	**0.00**				
Yearling heifers for sale (HYEAR)	**8.00**	**0.00**		**87.68**	**75.82**	**63.96**
Replacement heifer calves (REPHCALF)	**0.00**	**0.00**	**60.00**			
Replacement heifer yearlings (REPHYEAR)	**0.00**	**32.00**	**58.00**			
Brood cows sold (SELLBCOW)	**1.00**					
Minimum cow replacement rate (MINREPL)			**0.15**			

Minimum percentage of heifers for sale (MIN-HYEAR)			**0.10**			
Table 3.1 **(Continued)**						
Maximum percentage of heifer calves produced and saved as replacements (MAXREPL)			**0.80**			

Table 3.2. Forage quantity and costs for the Oregon representative ranch according to land type.

Land Type **(Model Name)**	Quantity Available **(Acres)**	Forage Cost/AUM **(2005 Dollars)**
BLM Allotment (ACBLM)	**2310**	**8.77**
Deeded Range (DEEDRANG)	**1700**	**11.55**
Raise Meadow (RMEADOW)	**500**	**130.00**
Graze Meadow (GMEADOW)	**500**	**13.75**

Table 3.3. Ranch fixed income and expenses (2005 $) for the Oregon representative full-time ranch.

Income and Savings Rate **(SCALER)**		Expenses and Borrowing Rate **(SCALER)**	
Off Ranch (OFFRANCH)	**12,168**	**Fixed ranch expenses (FIXED)**	**21,229**
Family Living Allowance	**24,000**	**Short Term Borrowing Rate (STLOANR)**	**0.04**
Interest Return on Savings account (SAVRATE)	**0.03**		

3.2.1.1 Seasonal forage demand and supply

Forage demand in each of seven seasons is constrained to be less than or equal to the amount of forage available in the corresponding season. This is one of many boundary conditions imposed on the various control variables (Section 3.1) that determine forage use. The representative ranch allocates forage (e.g., private lease, deeded range, the BLM allotment, and hay) by season to maintain the cattle herd. The seasons of use for each land type considered in the forage supply equations of the model are listed in Table 3.4.

Table 3.4. Seasons of use according to land type.

Season	Date Season Starts	Land Type (G)
Season 1	March 15	Deeded Range
Season 2	April 1	Deeded Range, BLM Allotment
Season 3	June 15	Deeded Range, BLM Allotment
Season 4	July 15	Deeded Range, BLM Allotment
Season 5	September 1	Deeded Range, BLM Allotment
Season 6	October 1	Deeded Range, Raised Meadow Hay
Season 7	November 15	Hay

This description of forage supply in the model is limited here to the constraints pertaining to the amount of BLM AUMs available. This is the only forage source in the model in which the available AUMs vary by season and grass type according to specific growth functions (Table 3.5). Table 3.5 shows the relative proportion of total annual AUMs for native grass (N) and cheatgrass (C) available in each season.

These growth functions are used within the system of seasonal BLM forage quantity constraints defined in Eq. 3.3.

Table 3.5. Native grass (N) and cheatgrass (C) rate of growth by season (S) (USDA 1996).

Growth Functions		
Season (S)	**Native Grasses** (N)	**Cheatgrass** (C)
2	0.0	0.4
3	0.25	0.8
4	0.6	1.0
5	1.0	0.5

$$BLMUSE_{S,t} \leq \sum_{N,C} (SOURCE_{N,C} * (GROWTH_{N,C})_S)_t * ACBLM \quad [3.3]$$

for each t=1,…,40

S=2, 3, 4, 5.

In Eq. 3.3 the number of AUMs used in each season (BLMUSE) in a given year is restricted to be less than or equal the number of acres available to the ranch (ACBLM) multiplied by both the proportion of annual AUMs ac^{-1} (SOURCE), as measured at the Hart Mountain study site, according to grass type and the corresponding proportion of the grass type available (GROWTH) in each season (S) according to Table 3.5. The model optimally allocates the total number of annual BLM AUMs available across seasons subject to this system of constraints. Section 3.2.1.4 outlines the methods and assumptions that were employed to attain the number of annual AUMs ac^{-1} available to the ranch according to grass type.

3.2.1.2 Production costs

Production costs are separated into forage harvesting expenses (FORCOST) (Eq. 3.4) and animal raising expenses (ANIMCOST) (Eq. 3.5). In Eq. 3.4, each forage quantity used for each land type is multiplied by the corresponding cost per unit of use and then summed over all available seasons. Costs for each land type are listed in Table 3.2. Table 3.4 lists the possible land types available for each season. The first term pertains to the amount of land used (LANDUSE) in a given year for each season according to land type (G), deeded range, raised meadow hay and hay (set "GRAZE" in the model code). The amount of each land type used is multiplied by the corresponding per unit forage harvesting costs (FORCOST1). The BLM land type is added separately for the purposes of this project, which is made evident in section 3.2.2. BLMUSE in each season, as calculated in Equation 3.3, is multiplied by the cost per AUM (BLMCOST). All forage costs are then summed together to get total forage costs within in a given year.

$$FORCOST_t = \sum_{S=1}^{S=7} \sum_{G} (LANDUSE_{G,S})_t * FORCOST1_G + \sum_{S=2}^{S=5} BLMUSE_{S,t} * BLMCOST \quad [3.4]$$

for each t=1,…,40.

Eq. 3.5 calculates animal raising expenses in year t by multiplying the optimal number of livestock raised (RAISE) for each livestock class (L) (set "LIVCLASS" in the model code) times per head animal production costs (ANIMCOST). Table 3.1 outlines the various livestock classes available to the ranch and the per head animal production costs. These production costs are based upon OSU Enterprise Budget EM8470 (Kerns et al. 1997). Costs per head were calculated by first subtracting grazing fees and other feed and forage costs from the total variable costs and then dividing by the number of brood cows, cull cows and replacement heifers.

$$ANIMCOST_T = \sum_{L} ANIMCOST_L * RAISE_{L,t} \quad [3.5]$$

for each t=1,…,40.

3.2.1.3 Forage supply constraints

While this baseline model is similar to that used by Satyal (2006), a few modifications were made. First, the original model incorporated results from a growth simulation program that determined changes in the relative amounts of AUMs available from cheatgrass and native grasses per year as a function of precipitation. The AUMs included in the No Fire Model are instead held constant over time. The methods used to determine the relative contribution of AUMs ac^{-1} per year from native grass and cheatgrass from the SageSTEP study site are discussed in section 3.1.2.

Second, overall quantities of forage available per year have changed as they were adjusted for each land type in order to calibrate the model. A total of 1700 acres of deeded rangeland, 2310 BLM allotment acres, and 500 acres of raised meadow hay allowed the model to maintain a 300 cow/calf equilibrium level for a majority of the planning horizon (Table 3.2).

Third, the BLM seasons of use are further constrained by the two following separate but similar equations.

$$BLMUSE_{S=2,t} / 2.5 \leq BLMUSE_{S=3,t} \qquad [3.6]$$

for each t=1,…,40.

$$BLMUSE_{S=3,t} \leq BLMUSE_{S=4,t} / 1.5 \qquad [3.7]$$

for each t=1,…,40.

These equations constrain BLM use to consecutive seasons. The choice to exclude a particular season of use is still allowed but alternating seasonal use within a given year is no longer an option. This forces the model to use at least as many BLM AUMs per month in season 3 as were used in season 2, or at least as many BLM AUMs per month in season 4 as were used in season 3. Divisors are used to convert unequal season lengths to a per month basis (season 2 is 2.5 times longer and season 4 is 1.5 times longer than season 3).

Lastly, costs and revenues in the original model were updated to 2005 prices and sale prices are held constant over time. One hundred sets of 2005 random livestock sale prices were averaged according to livestock class to create a set of "average sale" prices. Adding and subtracting one standard deviation from the mean resulted in a "high" and a "low" price set. The high, average, and low sale price sets are defined in Table 3.1 and read into the model as a GAMS include file (Appendix D). A separate iteration of the model occurs for each of the three price sets.

3.2.1.4 Ecological data

This model uses herbaceous biomass data that was gathered on four 200-acre plots in Lake County, Oregon on the Hart Mountain Grey Butte and Rock Creek study sites during the SageSTEP pre-treatment (control) year (SageSTEP 2007). Both sites are of the representative land base, High Desert Eastern Oregon. The elevation at the Gray Butte and Rock Creek sites is 4,910 ft. and 4,950 ft, respectively. The sites' common vegetation consists of primarily Wyoming big sagebrush, bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) A. Löve (Poaceae)), squirreltail, Sandberg bluegrass, Indian rice grass (*Achnatherum hymenoides* (Roemer & J.A. Schultes.) Barkworth), Thurber's needlegrass (*Achnatherum thurberianum* (Piper) Barkworth (Poaceae)), and cheatgrass. The Wyoming big sagebrush type is considered to be the driest of the sagebrush steppe communities and has historical fire return intervals of 50 to 100 years. The increase in fine fuels due to the introduction of cheatgrass has shortened this interval to less than 10 years in some of these sagebrush types.

Both sites are considered to be in reference state A (see section 2.1.2) although the level of cheatgrass invasion varies across each site. For the purposes of this project, the herbaceous biomass data used is that associated with the highest level of invasion, approximately 15% cheatgrass cover. Fifty percent of the herbaceous biomass on these study sites is assumed to be available as forage and is converted into Animal Unit Months (AUMs) ac^{-1} for use in the model. The herbaceous biomass data from the SageSTEP project included both native and non-native grasses and forbs. Percent cover information was the only available measurement separated into cheatgrass and native grasses. The relative percent cover of native grass to cheatgrass was therefore calculated and multiplied by the herbaceous biomass to determine the proportion of biomass attributed to cheatgrass and native grasses. The number of AUMs ac^{-1} for the two sites were then averaged. As a result of these methods, the model assumes the amount of AUMs ac^{-1} attributed to native grass and cheatgrass available on the ranch's BLM allotment is 0.37 and 0.28 respectively. In equation 3.3, AUMs ac^{-1} for each grass type is represented by the variable SOURCE. These values are entered into the model using a GAMS include file (Appendix B).

3.2.2 Fire impacts and the economic model (Fire Model)

Following are the methods used to create the "Fire Model" presented in terms of the changes made to the No Fire Model. While the No Fire Model incorporates only the first ecological constraint on the BLM allotment described in Section 1.2 (cheatgrass 15% cover), the Fire Model incorporates the additional fire regime constraint. Both ecological constraints are imposed exclusively upon the availability of the ranch's BLM grazing allotment.

3.2.2.1 Monte Carlo simulation

A 20 to 40 year fire interval implies a 100% chance of a single fire occurring within the time period of the model with the possibility of a second fire. A random number generator is used to draw from an integer set between one and 40 to determine the first fire year. The second number is randomly drawn from an integer set between 20 and 40 and added to the first fire year. If this second fire year lies within the 40 year planning horizon it is included in the model. 100 sets of random numbers are drawn in a Monte Carlo simulation of the ranch model. Grazing on BLM land is allowed during the fire year and is excluded as a forage source for the following two years. During these two post fire years, the representative ranch is forced to choose a substitute forage source and/or limit its herd size.

3.2.2.2 BLM Forage supply and cost equations

The random fire years are included in the model by adding the additional parameter (FIREPROD) to the No Fire Model using a table consisting of 100 columns of fire regimes and 40 rows which coincide with the 40 years of the model. Each year in which the BLM forage allotment is available is designated by the number 1. The two years immediately following the randomly generated fire year are designated by the number 0. This table is read into the model as a GAMS include file (Appendix C) through the use of the following two equations.

$$BLMUSE_{S,t} \leq \left(\sum_{N,C} (SOURCE_{N,C})_t * (GROWTH_{N,C})_{S,t} * ACBLM \right) * FIREPROD_t \qquad [3.8]$$

for each t=1, …,40

S=2, 3, 4, 5.

$$FORCOST_t = \sum_{S=1}^{S=7} \sum_{G} (LANDUSE_{G,S})_t * FORCOST1_G + \left(\sum_{S=2}^{S=5} BLMUSE_{S,t} * BLMCOST \right) * FIREPROD_t \qquad [3.9]$$

for each t=1,…,40.

Thus, the Fire Model eliminates BLM land as a decision variable during the two post-fire years by multiplying the right hand side of Equation 3.8 by the constant 0. This parameter also appears in the forage cost equation (FORCOST) as it is assumed that the ranch will not have to pay for their allotment during the two post-fire years.

3.2.3 Impact analysis

Three separate evaluations of this model were performed to address the three individual research questions.

Research Question 1: How does the representative ranch react to the temporary loss of permitted AUMs in terms of forage substitution and/or herd size reductions as the result of the assumed fire return interval?

A comparison between the two models in terms of changes in herd size and forage use is necessary to provide insight into the ranch management reactions to one or two, two-year periods of exclusion from their public grazing allotment in terms of herd size and forage use.

Research Question 2: Under what circumstances will this temporary loss of AUMs force a representative ranch out of business?

If the model results in an infeasible solution, this is considered equivalent to bankruptcy for the representative ranch. The probability of infeasibility in the No Fire Model varies with the price set and the discount rate. In the Fire Model, the probability of infeasibility varies not only on these two factors, but with changes in the characteristics of the randomly generated fire regimes as well. The three varying characteristics of any given fire regime are the number of fires, the time between fires, and the year of the fire. Each of these exogenous variables in the Fire Model has a combined and inseparable influence on ranch returns and costs which in turn directly influences the probability of an infeasible outcome. Understanding the relative influence of these variables on the probability of infeasibility therefore requires three comparative analyses that focus on the following: 1) costs, returns and NPV results as averaged over the 100 fire regime model iterations, 2) NPV results given different discount rates, 3) the cost and returns from individual fire regime iterations of the Fire Model.

The first part of this analysis compares the two models in terms of NPV, gross and net income, and animal and forage costs and considers the influence of these differences on the likelihood of bankruptcy. To understand the influence of the discount rate on the models' results, a sensitivity analysis compares NPV and infeasibility using a 4% and 10% discount rate in addition to the 7% discount rate assumed in the model. Finally, the probability of bankruptcy and the impact on NPV according to the three fire regime characteristics is considered.

Research Question 3: Is there an economic impact associated with changes in spring AUMs under the assumed fire return interval?

As the cheatgrass and native grass BLM AUMs utilized in the model are based on data from one specific level of invasion, referred to here as "Most Invaded", evaluating the sensitivity of the model results to other quantities of AUMs ac^{-1} by grass type will reveal whether or not the fire costs are biased by the use of this data. A sensitivity analysis considers AUMs ac^{-1} available by grass type from two lower levels of invasion. Ecological data for these two phases is obtained in the same manner as explained in Section 3.2.1.4. These two additional phases are referred to here for the purposes of this analysis as "More Invaded" and "Least Invaded". The available AUMs ac^{-1} for all three phases are shown in Table 3.6. This information is read into model using a GAMS include file (Appendix B).

Table 3.6. Native grass and cheatgrass annual AUMs ac^{-1} on Hart Mountain study site by level of cheatgrass invasion.

Grass Type	Least Invaded	More Invaded	Most Invaded
Native grass	**0.71**	**0.61**	**0.37**
Cheatgrass	**0.23**	**0.33**	**0.28**

4 Results

The Model results presented here are organized according to the specific research question they address. This is followed by a discussion of the implications of these results as they relate to the associated research questions. Although high, average, and low cattle sales prices were considered (Chapter 3.2.1), both models failed to return any feasible solutions when subject to the low sales price. As this was a result of the low sales price and not of the Fire Model itself, model results subject to the low sales price are not presented.

4.1 Results for research question 1

To address the first research question, forage substitution, intensity of land use, and herd size results from the Fire Model are presented in terms of their deviation from the No Fire Model.

4.1.1 Season of use

With the exception of season 5, the number of average yearly BLM AUMs used decreased in all seasons in the Fire Model when compared the corresponding season and sales price in the No Fire Model (Fig 4.1). The number of BLM AUMs used decreased by nearly 19% and 18%, given the high and average sales price, respectively. This percent decrease in use is larger than that of any other season. In season 3, the number of BLM AUMs used decreased by 8% for the high sales price and by less than 1% for the average sales price. In season 4, the reduction in BLM AUM's compared to season 4 of the No Fire Model is similar to that of season 3, with a reduction of 9% for the high sales price and by less than 4% for the average sales price.

In season 5, given the high sales price, the Fire Model showed an increase in the number of BLM AUMs used when compared to season 5 in the No Fire Model.

Given the high sales price, the No Fire Model utilized the least amount of BLM AUMs when compared to any other season within the same model. The Fire Model, however, employed more BLM AUMs than in any other season at an increase of 36% over that of the No Fire Model. For the average sales price, the difference between the No Fire and the Fire Model BLM use was negligible in season 5.

For both models, decreases in BLM AUMs used within any given season coincided with increases in the number of deeded range AUMs used. Fig. 4.2 gives a graphical representation of this inverse relationship over time in the Fire Model using season 2 as an example. Although the number of deeded AUMs used increased given seasons in which a decrease in BLM AUMs occurred, the number of yearly deeded range AUMs used on average per year decreased overall when compared to the No Fire Model. The decline in overall deeded and BLM AUMs used is discussed in the following section.

4.1.2 BLM and deeded range by year and planning horizon

The Fire Model used slightly fewer deeded and BLM AUMs on an average yearly basis when compared to the No Fire Model (Fig. 4.3). The amount of deeded land used in the No Fire Model was 1692 AUMs for both sales prices, but this amount decreased in the Fire Model to 1665 AUMs given the high sales price and to 1562, a 7.7% decrease, given the average sales price. The amount of BLM AUMs used decreased by 5% for the average sales price and by 6% under the high sales price.

Averaging AUMs used in the Fire Model makes it difficult to interpret the representative ranch's behavior in the two years following a fire. For this reason, the results of the Fire Model when subject to a single-fire regime (fire in year 17) and the average price set is compared to the No Fire Model and presented in Fig. 4.4. This graph shows that in years 18 and 19, the years of exclusion from the BLM allotment, the Fire Model substitutes deeded rangeland, increasing its use to 1700 AUMs, which is the maximum amount available. However, this increase is not sufficient to account for the 1,200 BLM AUMs previously used by the ranch before the fire occurred. Therefore, the model must reduce forage needs by reducing its herd size. Herd size reductions are discussed in the following section.

4.1.3 Herd size reduction

Brood cow stocking decreases on average for the Fire Model when compared to the No Fire Model under both the high and average sales price (Fig. 4.5). Over the forty-year planning horizon, the random fire years appear as variable declines in brood stocking (Fig. 4.6).

This graph demonstrates the difficulty with averaging the stocking rate results for all fire regimes to determine ranch impacts as it is not possible to discern herd size fluctuations following any given fire year. The pattern becomes more apparent when observing the impacts of each of the 100 fire regimes separately. In Fig. 4.7 the fire occurs in year 17 which excludes use of the BLM allotment in the model during years 18 and 19. The results of individual fire regimes show a slow decline in the stocking rate prior to the fire year and a sharp decline immediately following the fire year. The stocking rate reaches a minimum of approximately 184 brood cows in the second year following a fire regardless of the price set or the number of fires in the given fire regime. This is equivalent to a 38% percent reduction compared to the equilibrium stocking rate in the No Fire Model (Fig. 4.8). After this minimum point is reached, the ranch’s brood stock rebounds and, over time, is able to regain its 300 brood cow equilibrium level. If a second fire occurs within the 40 year planning horizon, the herd size drops again to the same minimum of 184 brood cows regardless of the sale price set and then is able to recover to 300 brood cows in the years following (Fig. 4.9).

Both the impact of the two-fire regimes and the single-fire regimes considered independently had downward impacts on the average brood cow stocking rate compared to the No Fire Model as is shown in Fig. 4.10. Comparing Fig. 4.10 to Fig.

4.9 shows that although the immediate impact is the same, two fires did result in a cumulative impact on the average stocking rate.

4.2 Results for research question 2

An infeasible solution indicates bankruptcy for the representative ranch. The probability of infeasibility in the Fire Model depends upon the sale price set, the number of fires and the timing of the fire experienced within each iteration of the model whereas the No Fire Model only depends upon the price set. Each of these independent variables in the Fire Model has a combined and inseparable influence on average ranch returns and costs, which in turn directly influence the probability of an infeasible outcome.

4.2.1 Net present value (NPV)

NPV decreased slightly for both sales prices in the Fire Model when compared to the NPV for the corresponding sales price in the No Fire Model (Fig. 4.11). The high sales price in the Fire Model resulted in a 6% decrease in NPV, whereas the average price set resulted in a 4% decrease. The average of the single-fire regimes resulted in a lower impact on NPV than the average of the two-fire regimes for both sales prices (Figs. 4.12).

The cumulative impact of 4 years of exclusion from grazing on BLM land, as occurred when the model was subject to two-fire regime, was therefore greater than the impact from that of two years of exclusion in the single-fire regime (Fig. 4.12). In the Fire Model, given the high sales price, the average of the single-fire regimes and the average of the two-fire regimes showed a decrease in NPV of 4% and 14%, respectively, from that of the No Fire Model. A 4% decrease also resulted from the average sales price for the average of the single-fire regimes. The percent decrease in the NPV as the result of the two-fire regimes given the average sales price is not able to be determined as all these solutions are infeasible.

4.2.2 Sensitivity analysis (discount rate)

A sensitivity analysis was performed in order to determine the impact of the assumed 7% discount rate on the results of the model. For each model, the 10% discount rate resulted in a lower NPV and the 4% discount rate resulted in a higher NPV. As was true given the 7% discount rate, the low sales price again returned all infeasible solutions for the low sales price set in both models and no infeasible solutions resulted in the No Fire Model given the high or average sales price.

The results of this study are sensitive to the chosen discount rate if, for a given sales price, the percent change between the NPV in the No Fire Model and that of the Fire Model varies depending upon the discount rate. The last column in Table 4.1 shows that for both the high and average sales prices there exists small differences in this percent change in NPV.

Table 4.1. The difference in the ranch's NPV compared by discount rate and sales price.

		NPV (1,000's) ($)			
Sales Price	**Discount Rate**	**No Fire Model** (Y)	**Fire Model (X)**	**% Δ** ((Y-X)/Y)	**Difference from % Δ Given 7% Discount Rate**
High	4%	1294.82	1208.58	6.66%	0.89%
	7%	879.03	828.26	5.78%	0.00%
	10%	651.53	618.69	5.04%	-0.74%
Average	4%	780.52	726.79	6.88%	3.32%
	7%	532.23	513.25	3.57%	0.00%
	10%	400.81	392.43	2.09%	-1.48%

The greatest difference in percent change in NPV occurred given the average sales price and the 4% discount rate. This difference is likely due to the increase in the number of feasible solutions as can be seen in Table 4.2.

Table 4.2. The number of infeasible solutions out of the 100 iterations in the Fire Model compared by discount rate and sales price.

	Sales Price		
Discount Rate	High	Average	Low
4%	11	30	100
7%	11	32	100
10%	11	32	100

4.2.3 Gross and net income

Average gross ranch income declined compared to the No Fire Model under both sales prices. Given the high sales price, this decline increased when the model was subject to additional fires (Fig. 4.13). Again, as in the case of the NPV results, the average gross income for the model when subject to the two-fire regimes and the average sales price cannot be quantified due to 100% infeasibility.

Unlike the gross income, an analysis of net ranch income is not meaningful if averaged over the forty-years of the model because within every fire regime iteration there existed at least one year in which the net income was negative. Summing over these years masks the overall impact of fires on the ranch's net income. The net income is therefore shown averaged for each year within the forty-year time line for all the fire regimes in the Fire Model and compared to the No Fire Model in Fig. 4.14. This shows the net income remained lower in most years in the Fire Model than in the No Fire Model. However, similar to the stocking rate results, averaging all fire regimes for each year in this way makes it difficult to discern net income fluctuations as a the result of temporary losses in permitted AUMs.

For this reason, the results of a single fire regime are presented in Fig. 4.15. For this particular scenario, the fire occurs in year 17 which excludes use of the BLM allotment in years 18 and 19. For both the high and average sales price, net income becomes negative starting in year 18 and remains negative until year 21 with the minimum point occurring in year 20. The high sales price recovers by year 32, although it is near 3% of the equilibrium net income in the Fire Model by year 23 and within 1% by year 24. The low sales price recovers a little more slowly and fully recovers by year 34. At year 23 it is within 8% of the equilibrium level and within 1% by year 25.

The fire in year 17 also impacts the behavior of the ranch previous to the two-year exclusion from the BLM allotment. Under the high sales price, net income increases in year 16, reaching a maximum in year 17 of 23% above that of the No Fire Model high price set in that same year. Similarly, under the average price set, the ranch increases its net income in year 16 and reaches a maximum in year 17. At this maximum, the net income is 24% above that of the No Fire Model.

In the two-fire regime presented in Fig. 4.16, this pattern of recovery is repeated regardless of the fact that the first fire year is in year 4, which is much earlier than the single-fire regime evaluated above. However, the ranch increases its net income by almost 30% prior to the first fire under the high price set, which is about 7% more than in the single-fire regime subject to the same sales price.

Fig. 4.17 gives an example of the various changes in forage costs, total costs, animal costs and accumulated savings which coincide with a drop in net income following a fire year in year 17 when the model is subject to the average sales price. In the No Fire Model all of these costs and net income remained fairly constant over time with the exception of the accumulated savings which increased over time (Fig. 4.18).

Comparing Fig. 4.18 to Fig. 4.17 reveals a number of differences in terms of the pattern of ranch returns. Early in the planning horizon, average forage costs, total costs and animal costs continually decrease by a relatively small amount every year rather than staying relatively constant as is the pattern in the No Fire Model. The timing of this decreasing trend in returns coincides with a decrease in deeded rangeland used (Fig. 4.4).

Costs decrease, and the model obtains the maximum net income and accumulated savings levels during the year of the fire. In year 18, the ranch is unable to use its BLM allotment. Total, forage, and animal costs all reach their minimum point and accumulated savings and net income decrease drastically. In year 19, the second year after the fire, costs begin to climb again with the exception of forage costs which remain at the same level as in the previous year. Net income becomes negative in year 19 and accumulated savings is still decreasing. In year 20, in the same year that brood cow stocking begins to increase, as described above and shown in Fig. 4.7, all costs reach their maximum point except for forage costs which simply increase. Net income is at its minimum point in this year. Finally, in year 21, accumulated savings reaches its minimum point and, compared to the previous year's total, costs decrease, net income rises, and animal and forage costs decrease slightly but remain primarily constant in the following years. After year 22 all costs and net income stay relatively constant but at a slightly higher value than previous to occurrence of the fire.

4.2.4 Probability of bankruptcy

The number of infeasible solutions changes depending on the sale price set, number of fires and the year in which the fire occurs. Fig. 4.19 compares the number of feasible and infeasible solutions according to sales price and the number of fires in the fire regime. Tables 4.3 and 4.4 show the probability of feasibility and infeasibility for the ranch for all 100 fire regimes and broken down into those with one and two fires.

Table 4.3. The number of infeasible solutions in the Fire Model given the high sales price.

Number of Fires in Regime	Count	Number of Feasible Solutions	Number of Infeasible Solutions	Probability of Feasibility	Probability of Infeasibility
1	76	71	5	93%	7%
2	24	18	6	75%	25%
1 and 2	100	89	11	89%	11%

Table 4.4. The number of infeasible solutions in the Fire Model given the average sales price.

Number of Fires in Regime	Count	Number of Feasible Solutions	Number of Infeasible Solutions	Probability of Feasibility	Probability of Infeasibility
1	76	68	8	89%	11%
2	24	0	24	0%	100%
1 and 2	100	68	32	68%	32%

Subject to the average sales price, the number of infeasible solutions in the Fire Model increased by 67% when a second fire occurred. Subject to the high sales price, this increase was 17%. In addition to the number of fires and the sale price set, the timing of the fire(s) also appears to impact the relative probability of infeasibility for a given iteration of the model. Table 4.4 shows, according to sales price, the range of fire years in which the model is able to find a feasible solution.

Table 4.5. The range of years that return feasible model solutions compared by sales price and number of fires.

Sales Price	Single-Fire Regime Year of Fire (t)	Two-Fire Regime Year of 2nd Fire (t)
High	$t \leq 36$	$t \leq 36$
Average	$10 \leq t \leq 36$	$t < 25$

Given the average sales price, the model resulted in a feasible solution if a single fire occurred either in or after the first 10 years or prior to the last 3 years of the forty-year planning horizon. Runs of the model subject to a fire prior to the first 10 years of the planning horizon returned infeasible solutions given the average sales price but returned feasible solutions given the high sales price. However, the model runs that were subject to the fire regimes with fires occurring in the last 3 years of the model remained infeasible regardless of the sales price.

Fig. 4.20 specifies the first and second fire year according to sales price for two-fire regimes that resulted in infeasible model solutions. Subject to the high price, fire years that returned infeasible solutions are organized in ascending order of the first fire year to show that the timing of the first fire year does not seem to affect the ability of the model to find a feasible solution. Similar to the results given a single fire regime, a fire after year 36 appears to be the reason for the model's infeasibility. Given that the model is subject to the average sales price, information in this figure is arranged in ascending order of the second fire year to demonstrate that a second fire in or after year 25 resulted in an infeasible solution.

4.3 Results for research question 3 (Cheatgrass Sensitivity Analysis)

The results presented for the previous two research questions may depend upon the relative amount and the proportion of cheatgrass and native grass AUMs on the ranch's BLM allotment. As cheatgrass and native grasses have different peak growing seasons, each level of cheatgrass invasion entails a different quantity of available AUMs per season and per year.

The difference in NPV between the No Fire Model and the Fire Model should remain fairly constant for all price sets within a given level of invasion if the level of invasion is not a significant indicator of the percent difference in NPV between the two models. Table 4.6 below summarizes these differences in percent change of NPV between the two models. Comparing the results between the No Fire Model and the Fire Model of the NPV subject to the high price set shows a decrease of 7% for the least invaded, 7% for the more invaded and 6% for the most invaded. Therefore, subject to the high sales prices, results of this analysis show that there is very little impact from the chosen proportion of AUMs dedicated to cheatgrass and native grass on the results of this study.

When the model is subject to the average sales price, the percent change between the two models, listed in order from the least invaded to most invaded level is: 12%, 9%, and 4%. In this case, it does appear that the proportion of AUMs does make a difference as to the model results. However, the lowest percent change of 4%

in NPV occurs given the most invaded level of invasion, which implies a downward rather than an upward bias on the percent decline in NPV for this study. The results of this study with regards to the average price set can therefore be thought of as a lower bound estimate of the decrease in NPV as the result of adding fire constraints.

Table 4.6. The difference in the ranch's NPV compared by level of invasion and sales price.

Sales Price	Phase of Invasion	% Δ in NPV from No Fire Model	Difference from % Δ in Most Invaded Phase
High	Least	7%	1%
	More	7%	1%
	Most	6%	0%
Average	Least	12%	8%
	More	9%	5%
	Most	4%	0%

Comparing the NPV results of the most invaded level in the Fire Model to the more invaded and least invaded level shows an increase in NPV as the level of invasion decreases given the high price set, however, the average price set shows the NPV decreasing as the level of invasion decreases (Fig. 4.21). Subject to the high price set, the Fire Model NPV results from the more invaded state and the least invaded state show an increase from that of the most invaded state of 6% and 7%, respectively. On the contrary, this same comparison given the average price results in a 1% and 4% decrease in NPV, respectively.

The No Fire Model shows an increase in NPV as the level of invasion decreases regardless of the sales price (Fig. 4.22). For the more invaded state, NPV increases by 8% given the high price set and by 5% given the average price set. For the least invaded state, NPV increases by 9% given the high price set and by 8% given the average price set.

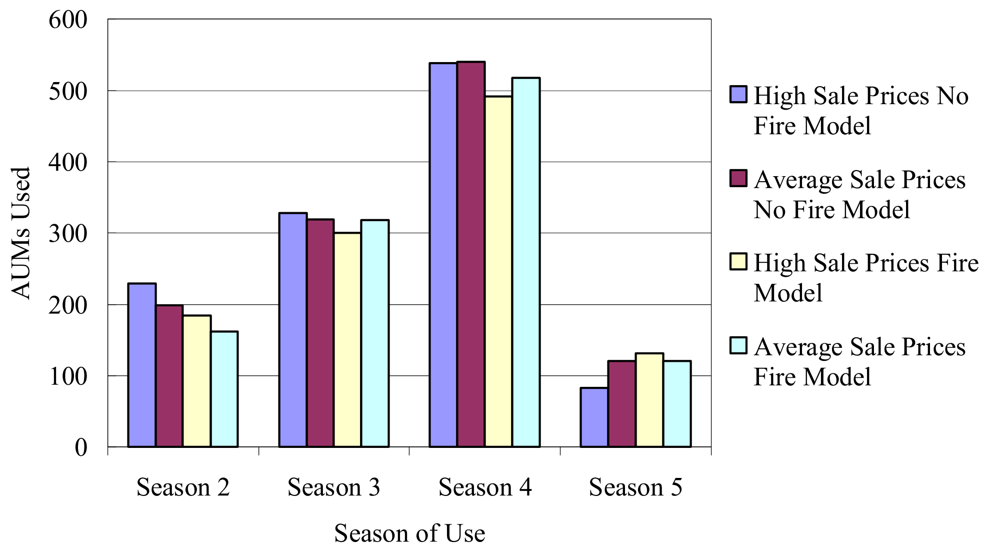


Figure 4.1. The number of BLM AUMs for each ranch model compared by season of use and sales price.

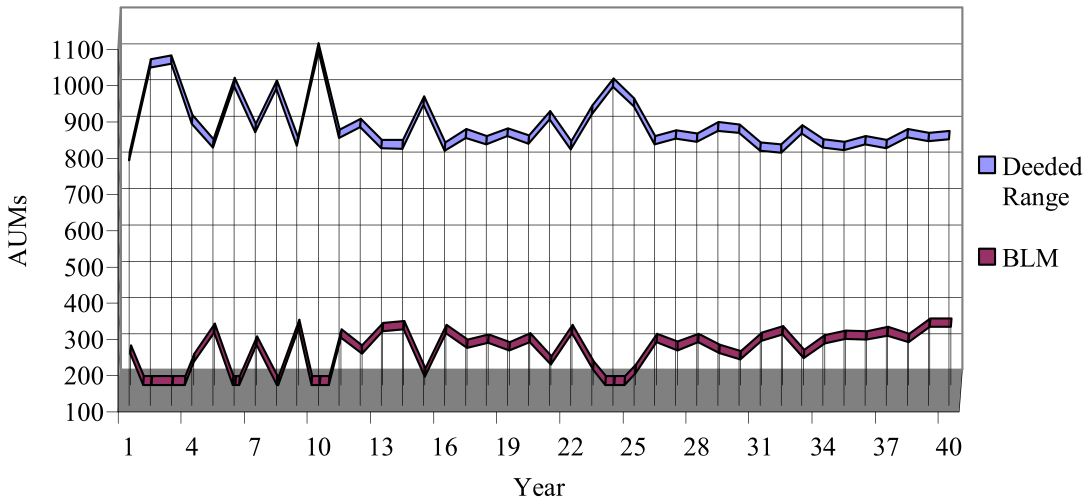


Figure 4.2. The deeded range and BLM AUMs used by the ranch in season 2 of the Fire Model over time (high sales price).

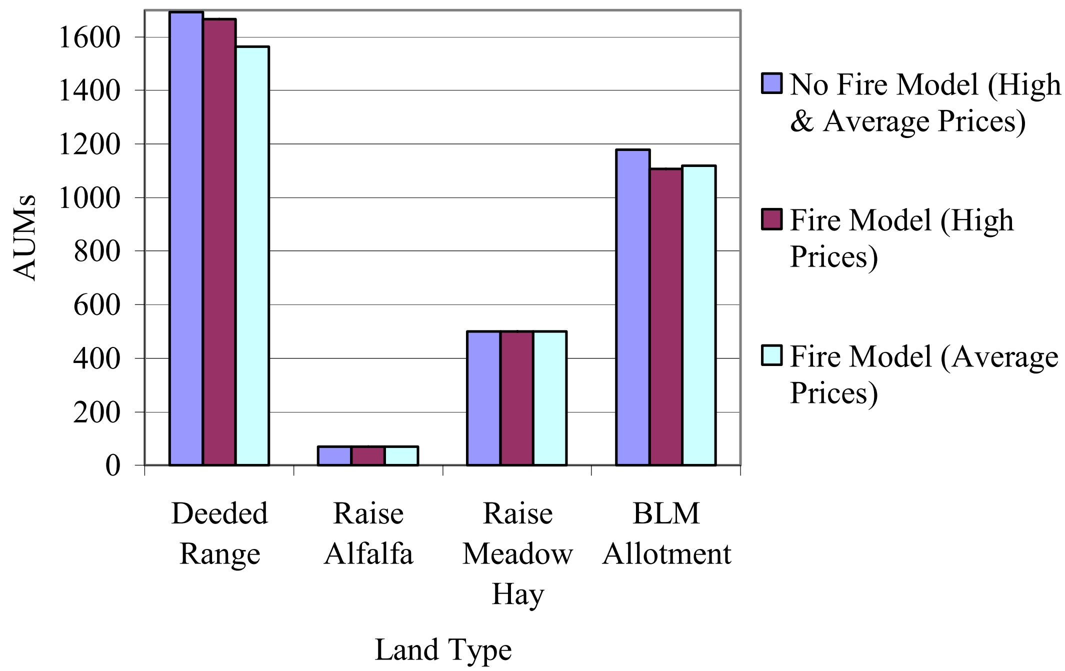


Figure 4.3. The average yearly land used by each model compared by land type and sales price.

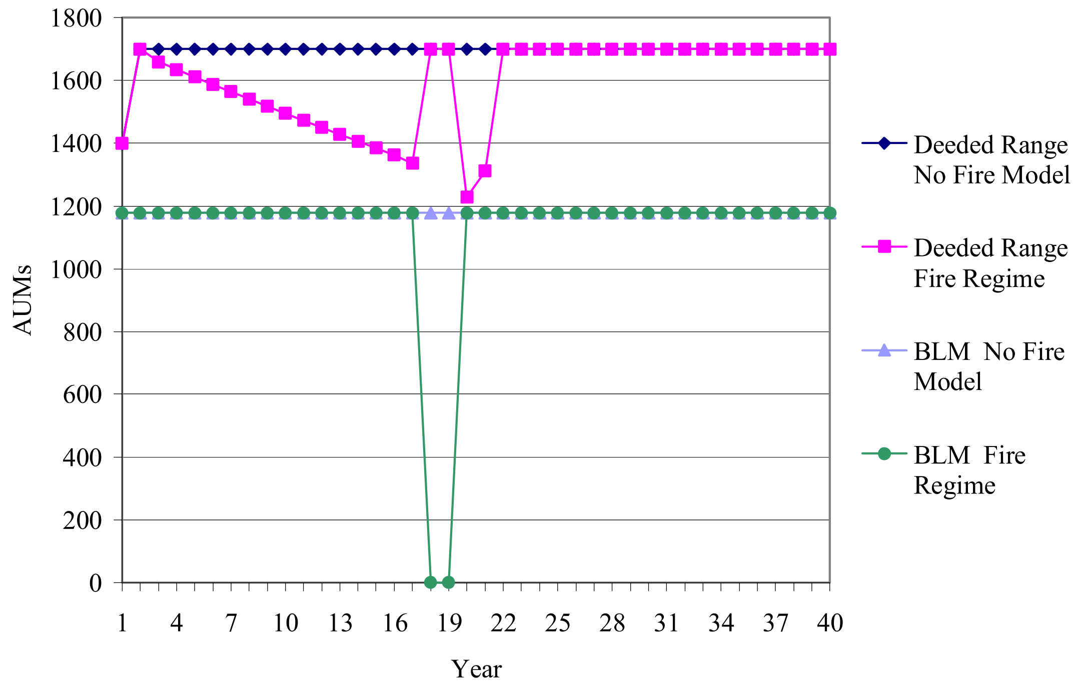


Figure 4.4. The ranch's BLM and deeded range AUMs used over time when subject to a single fire occurring in year 17 and compared to that of the No Fire Model (average sales price).

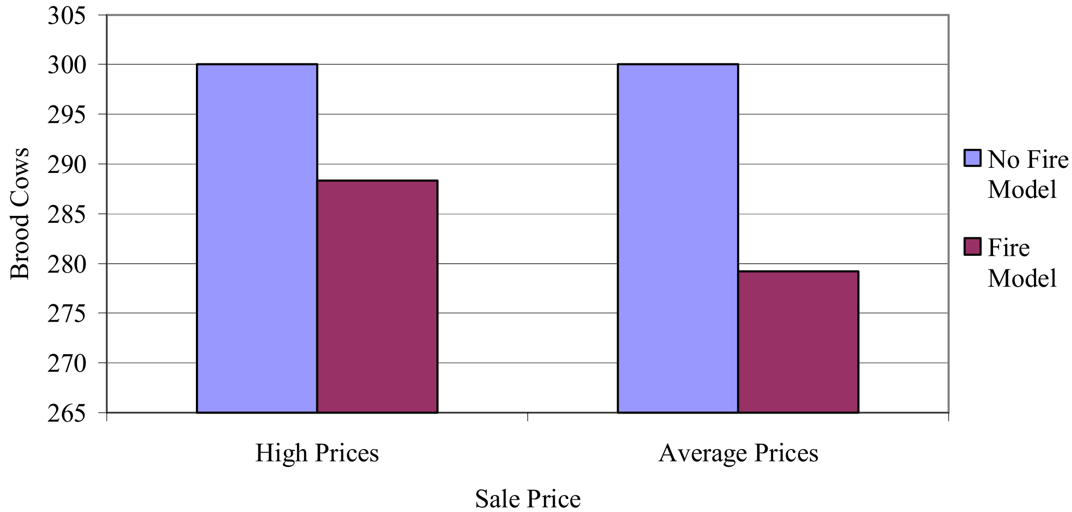


Figure 4.5. The average number of brood cows stocked per year for each ranch model compared by sales price.

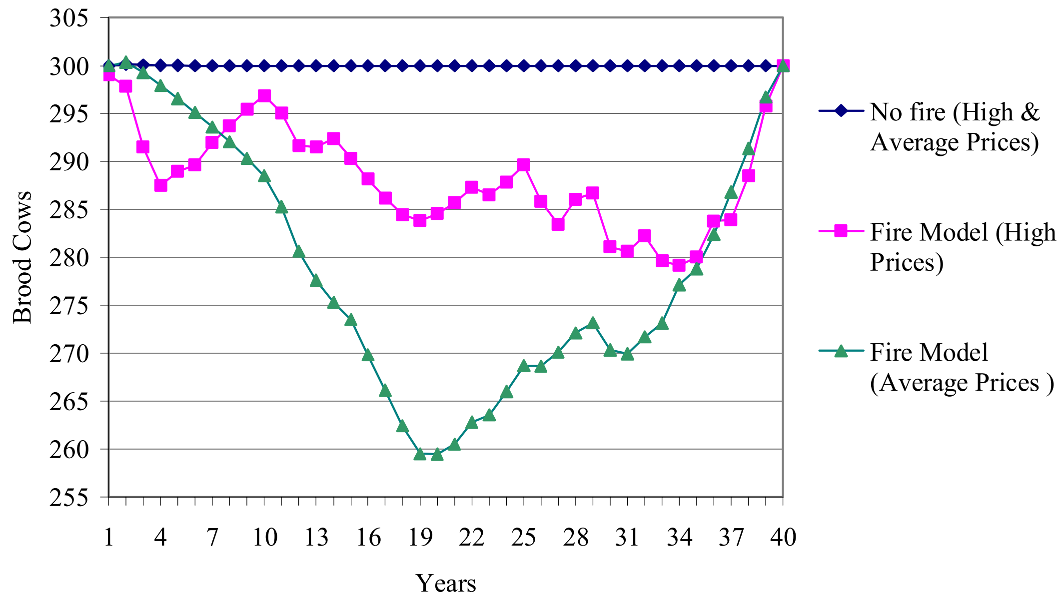


Figure 4.6. The number of brood cows stocked per year for each ranch model compared over time by sales price.

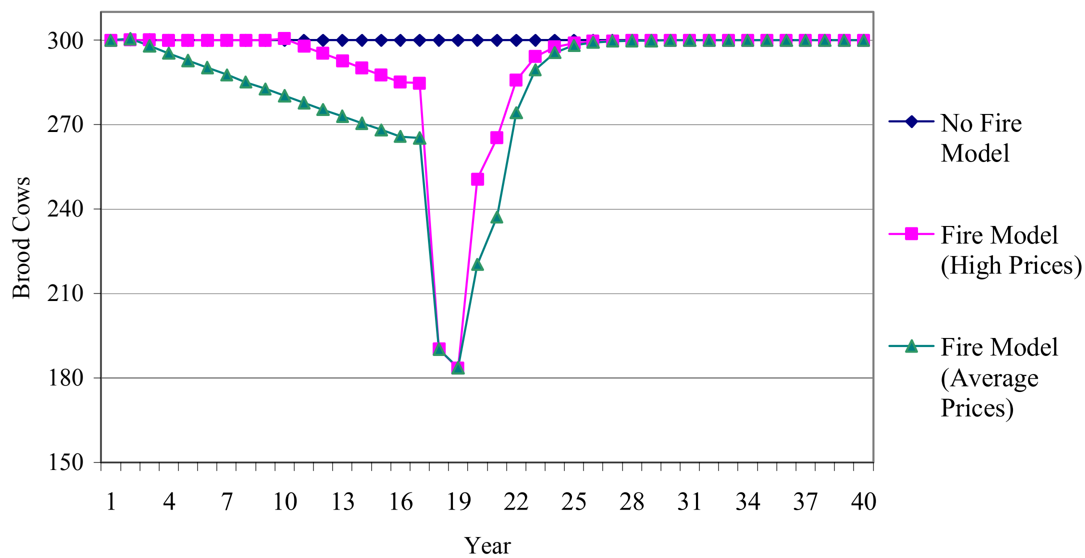


Figure 4.7. The number of brood cows stocked per year over time with a single fire occurring in year 17 compared to No Fire Model (high and average sales prices).

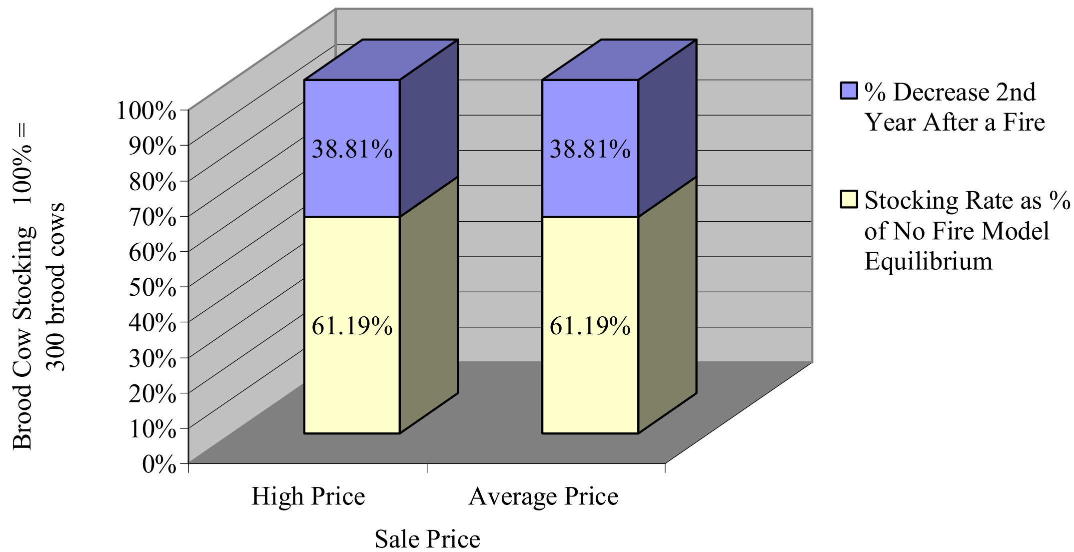


Figure 4.8. The ranch's minimum number of average yearly brood cows with a fire compared to No Fire Model (high and average sales prices). This number is shown as a percentage of the No Fire Model equilibrium stocking rate.

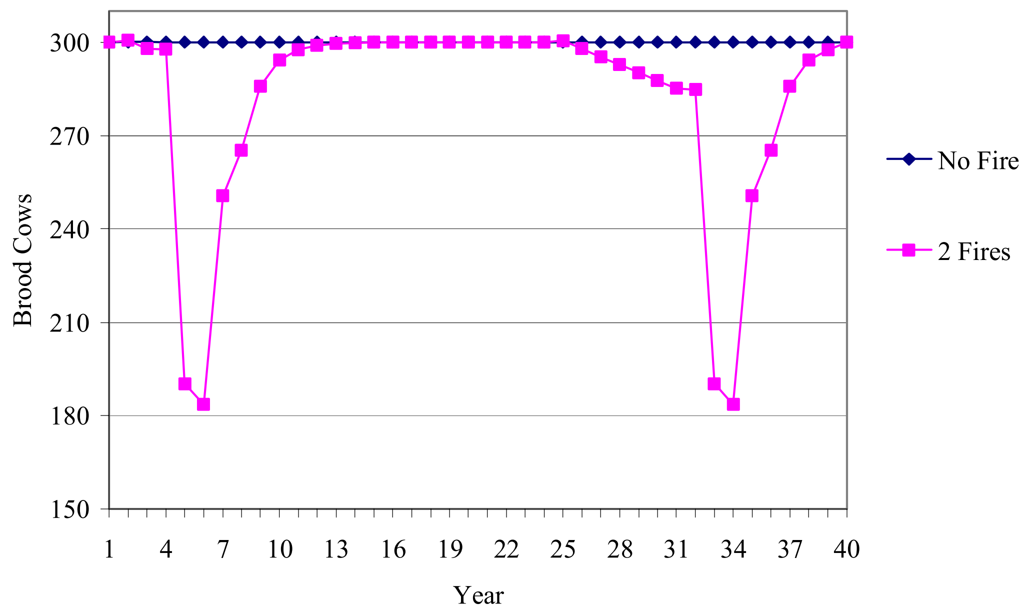


Figure 4.9. The number of brood cows stocked by the ranch per year over yime with two fires compared to No Fire Model (high sales price). Fires occur in years 4 and 32.

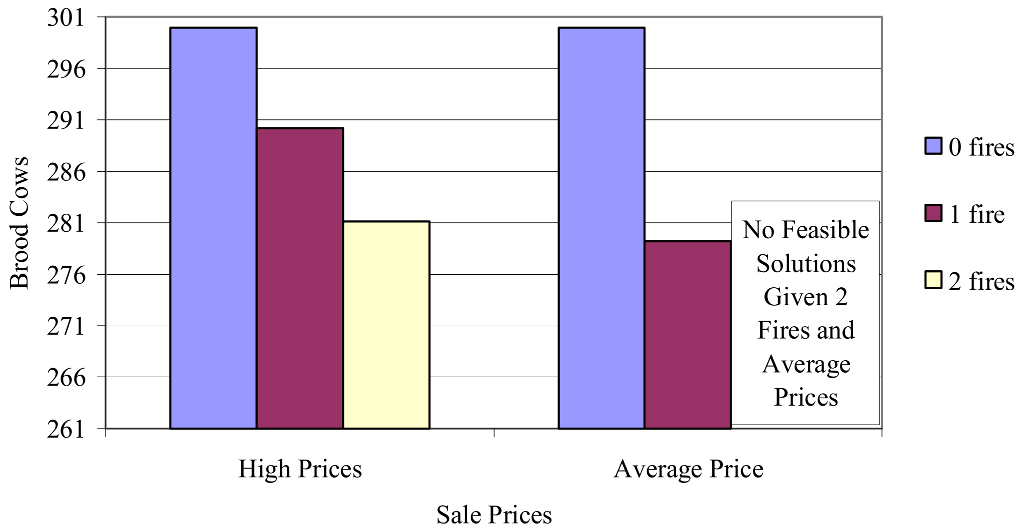


Figure 4.10. The number of brood cows stocked on average per year by the ranch compared by the number of fires and sales price.

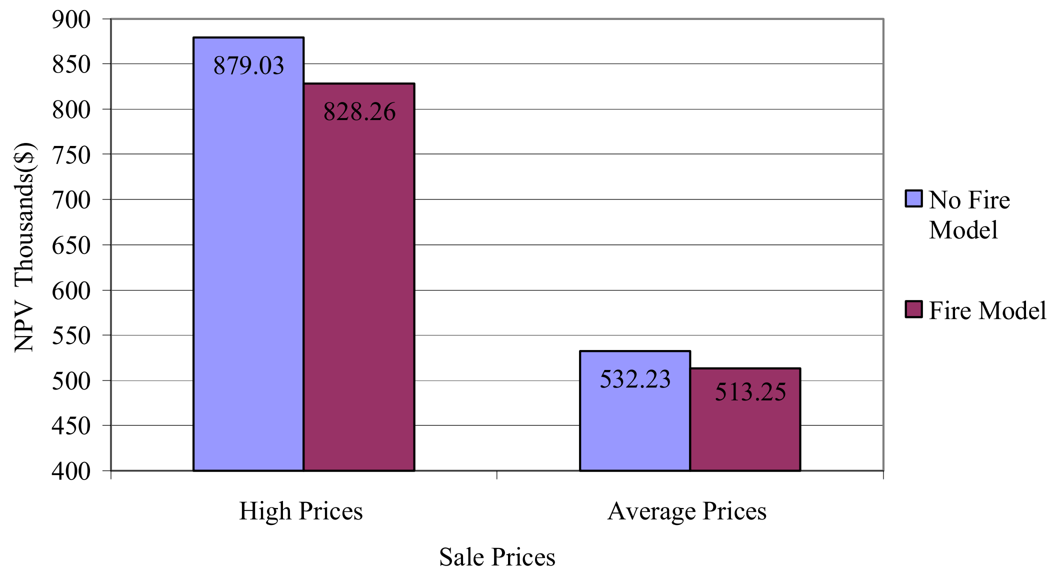


Figure 4.11. The NPV of the No Fire Model compared to that of the Fire Model (7% discount rate).

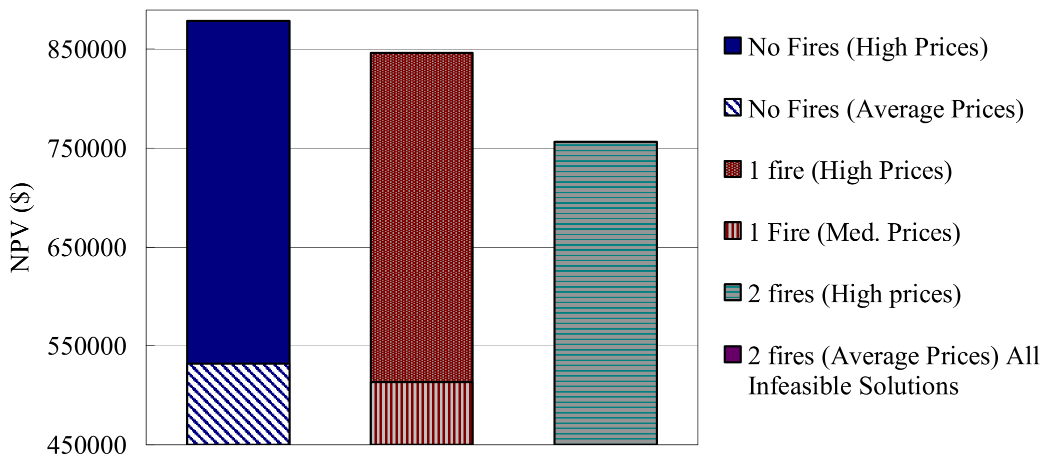


Figure 4.12. The NPV of the ranch compared by the number of fires and the sales price.

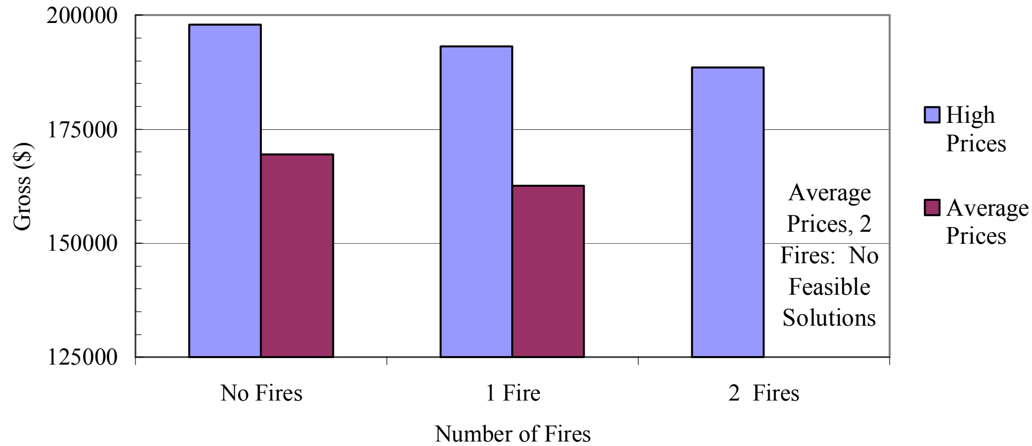


Figure 4.13. The ranch's gross income compared by number of fires and sales price.

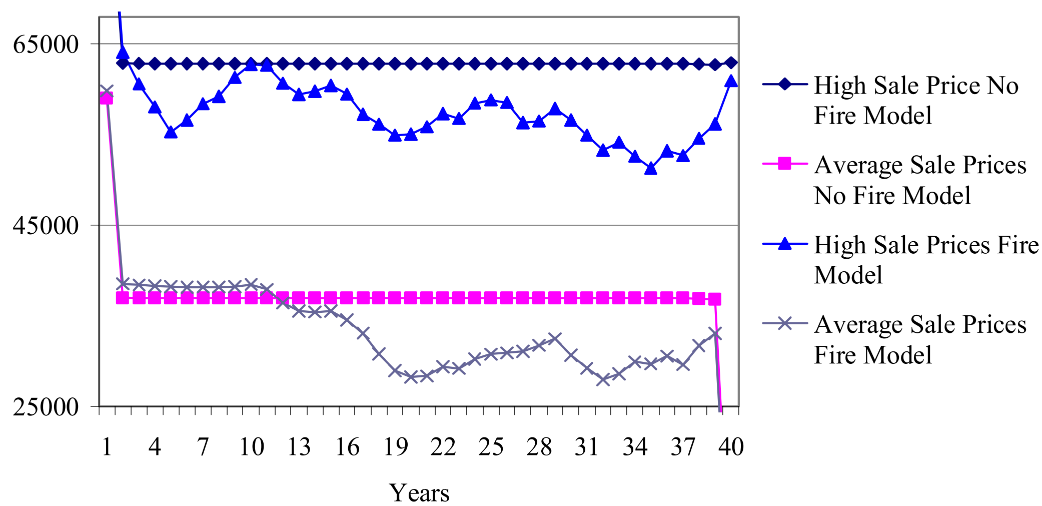


Figure 4.14. The ranch's net income in the Fire Model compared to the No Fire Model over time (high and average sales prices).

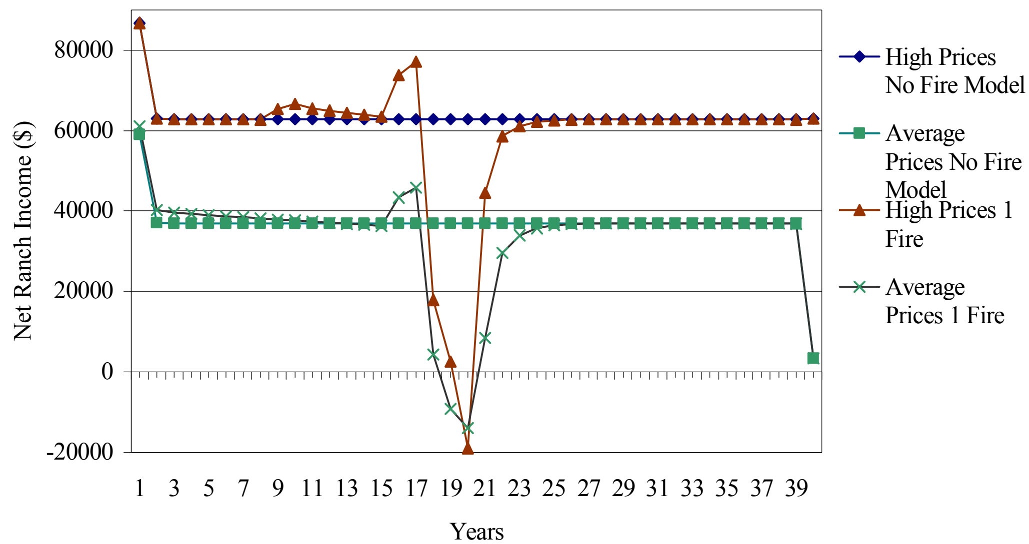


Figure 4.15. The ranch's Net income with a single fire in year 17 compared to the No Fire Model over time (high and average sales prices).

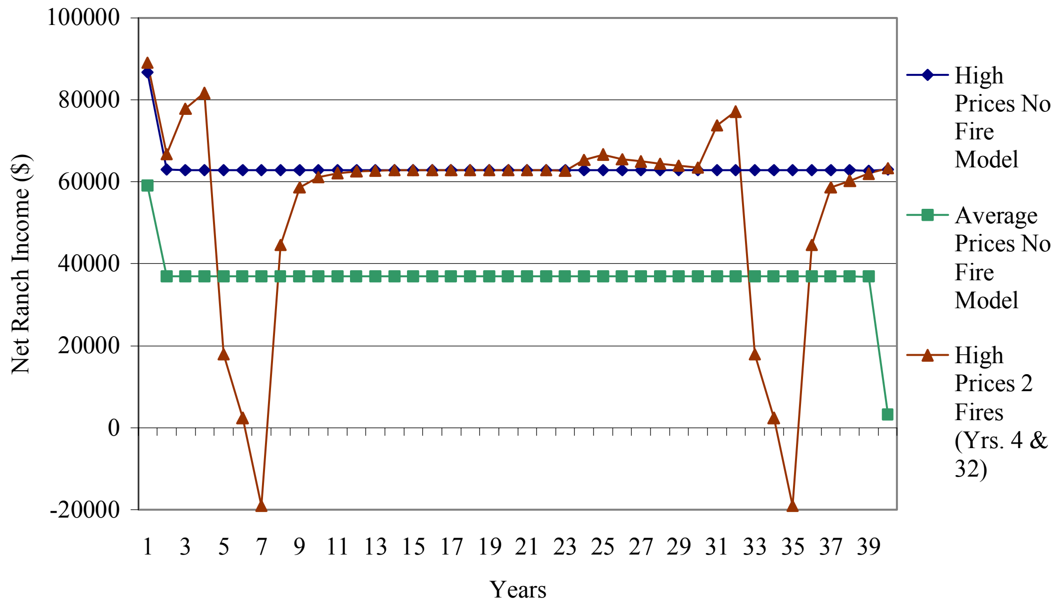


Figure 4.16. The Ranch's Net Income with Two Fires Compared to the No Fire Model Over Time (High and Average Sales Prices).

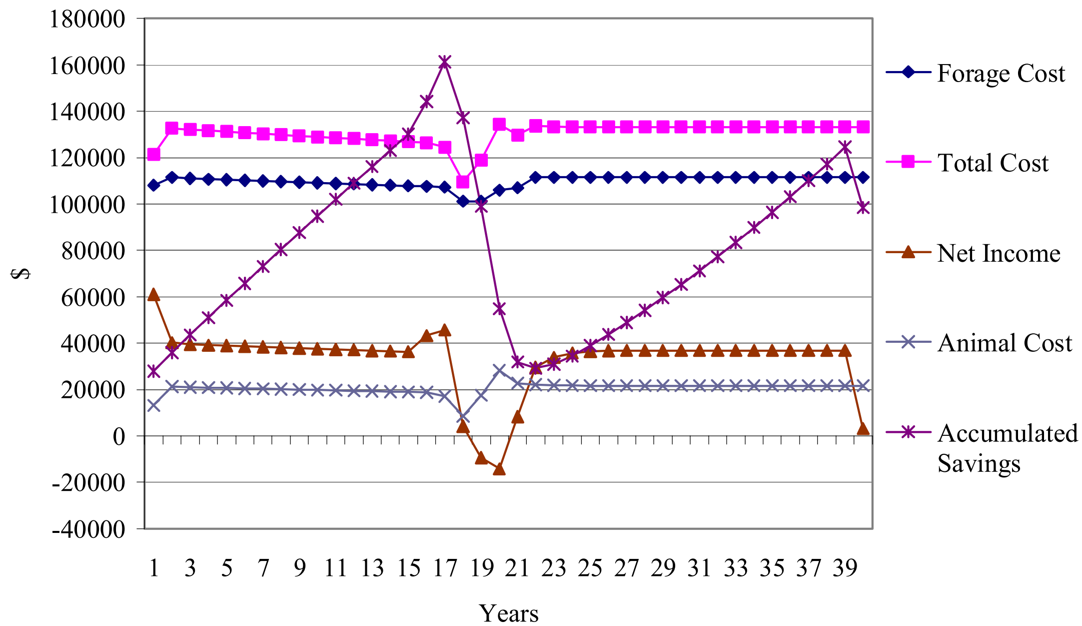


Figure 4.17. The ranch's costs and returns over time with a single fire in year 17 (average sales price).

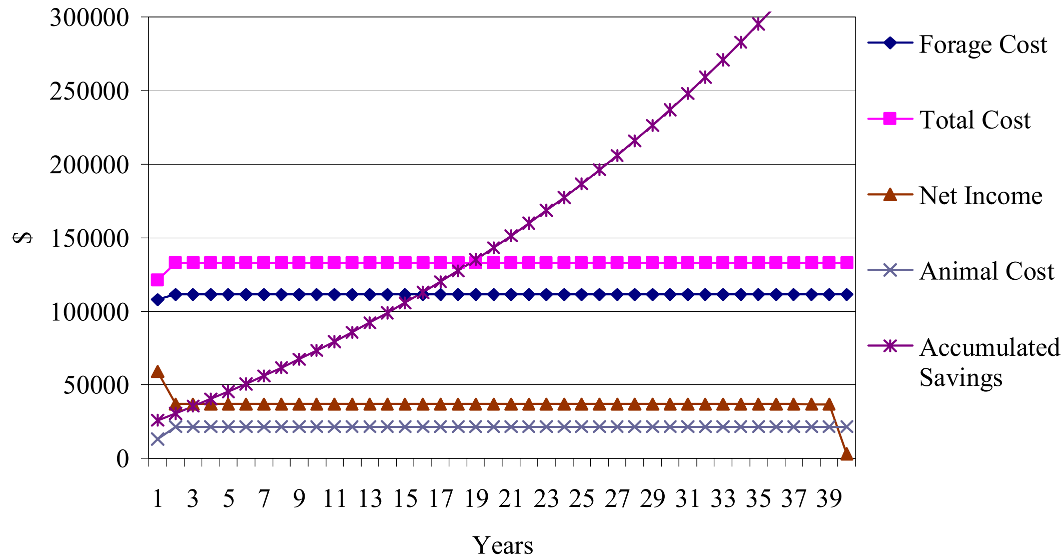


Figure 4.18. The ranch's costs and returns with a single fire in year 17 over time (average sales price).

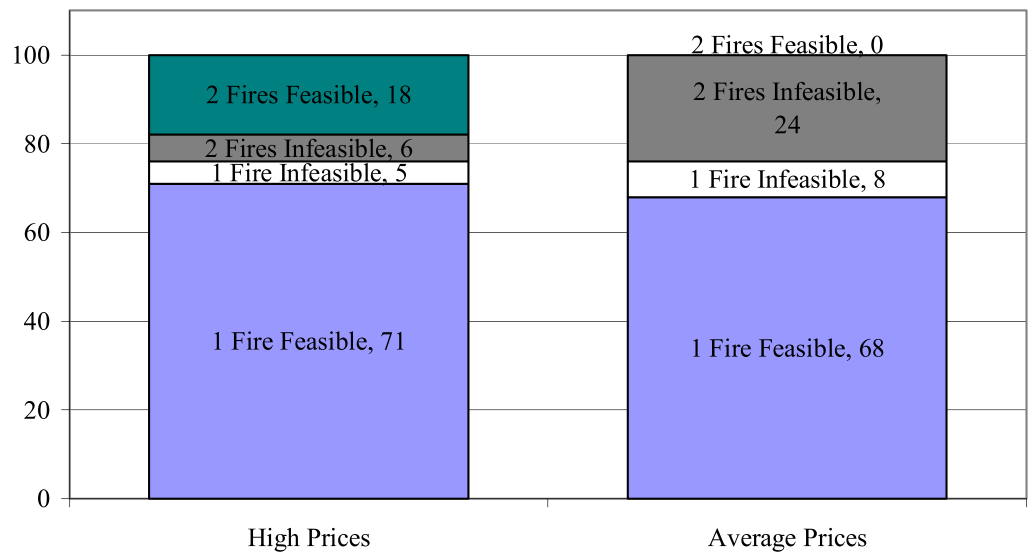


Figure 4.19. The 100 fire regime iterations of the model broken down by the number of feasible and infeasible (bankruptcy) solutions and compared by number of fires and sales price.

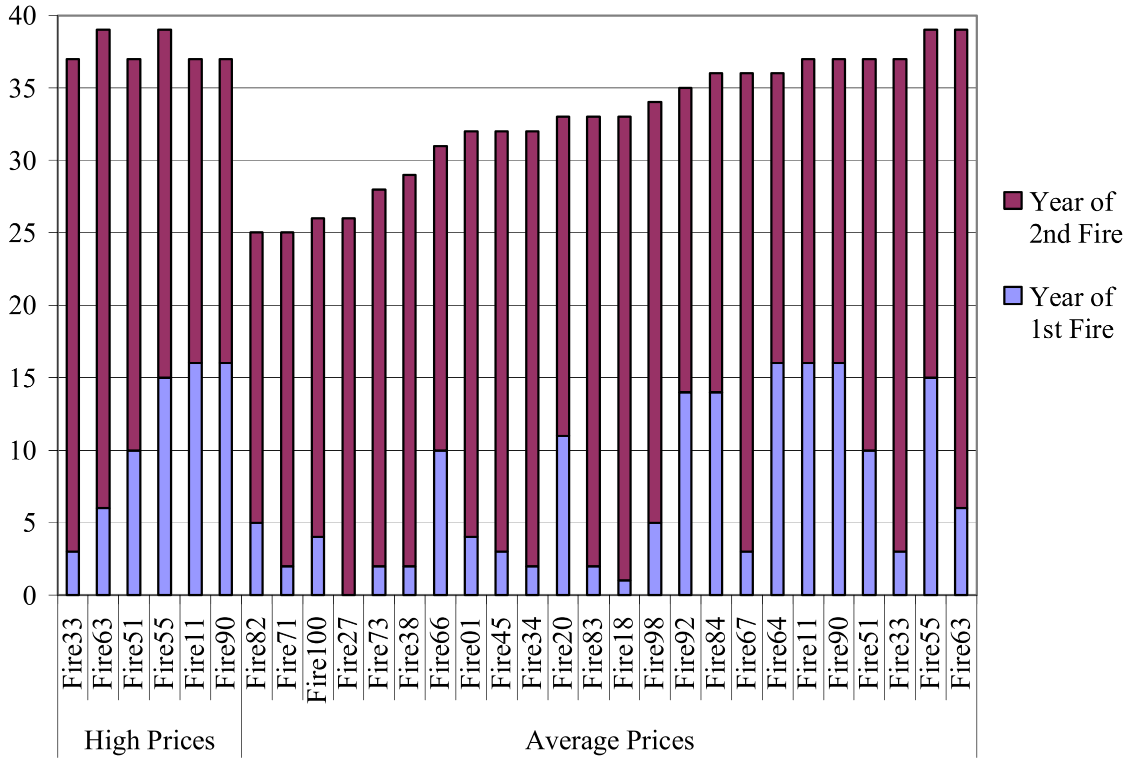


Figure 4.20. The infeasible model solutions with two-fire regimes compared by timing of first and second fire and sales price.

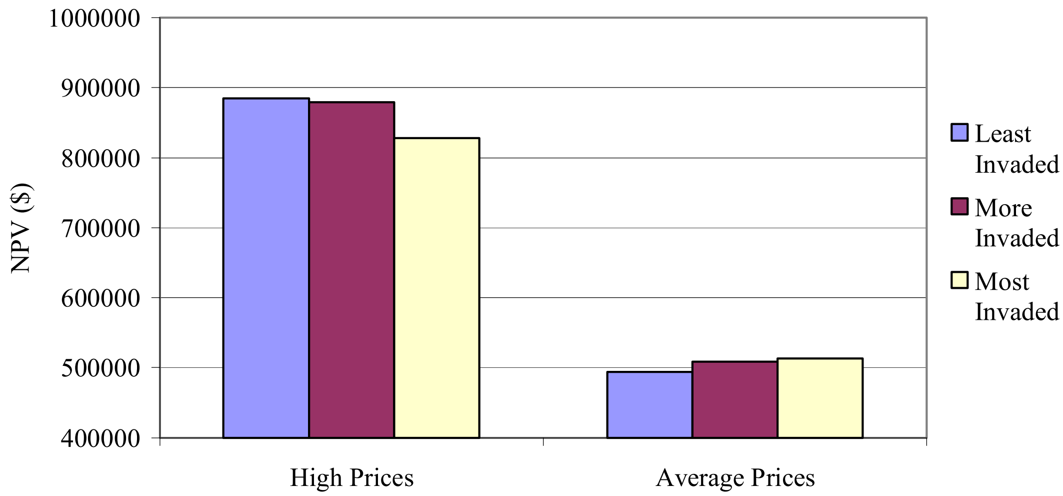


Figure 4.21. The NPV of the ranch compared by level of invasion and sales price in the Fire Model.

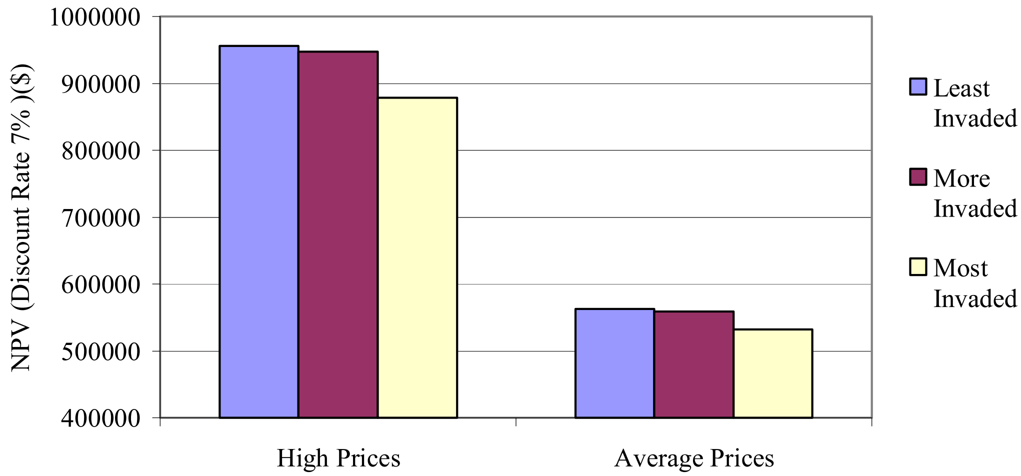


Figure 4.22. The NPV of the ranch compared by level of invasion and sales price in the No Fire Model.

5 Discussion

5.1 Major model assumptions

Results of this study and their implications should be considered within the context of the following model assumptions.

Assumption 1: Ecological state of invasion

As discussed in the introduction, ecological data were chosen that exhibited approximately 15% cheatgrass herbaceous cover. This level of cover was chosen to specifically address study areas that are vulnerable to continued cheatgrass invasion. The results of this study may change if ecological data from a different ecological state was assumed. The Satyal (2006) study compared ranch economic impacts from cheatgrass treatment within a heavily invaded ecological state and without consideration of wildfire impacts. That study found that controlling cheatgrass has a higher economic impact on ranchers than not controlling cheatgrass. Yet, the results presented in this thesis suggest that there are economic impacts associated with the absence of cheatgrass control. The difference in findings may therefore rely on the assumed ecological state.

Assumption 2: Ecological data

The total number of AUMs ac^{-1} are those attributed to the Hart Mountain Study Site. It was assumed that all herbaceous biomass was potentially available as forage. While the number of AUMs may be seem high, both models have the same number of acres and the same number of AUMs ac^{-1}, and therefore for the purposes of this study the total number of AUMs is not as important as the proportion of AUMs assumed to be from cheatgrass and native grasses. Results of the sensitivity analysis showed that the results of this study are not altered given a change in this proportion when the model is subject to the high sales price. Subject to the average price set, the value of the decline in NPV exhibited by the Fire Model is smaller than it would otherwise be given a lesser level of invasion and therefore is not exaggerated by the proportion of cheatgrass and native grass AUMs ac^{-1} assumed on the ranch's BLM allotment.

Assumption 3: Fire return interval

The 20 to 40 year fire return interval is a significant assumption in the model as it is the probability of BLM allotment exclusion. A higher probability would likely result in higher negative economic impacts, while a lower probability would result in lower negative impacts. The employed methodology and results are therefore appropriately considered as an aid in future ranch-level economic studies of cheatgrass invasion on public grazing allotments rather than a precise prediction of monetary losses from cheatgrass associated fires.

Assumption 3: Length of exclusion from BLM allotment

Similar to the assumption of the fire return interval, this assumption is significant to the results of the model as together with the assumed probability of fire, it determines the total number of years of BLM allotment exclusion. It is likely that an increase from the assumed two years of exclusion following a fire would increase negative economic impacts and that a lower number of years would decrease these economic impacts. The number of years depends upon the policy prescribed in the given area.

Assumption 4: Perfectly competitive industry

A perfectly competitive industry is defined by the following four assumptions (Nicholson 1998):

1) A large number of firms produce the same homogenous product.

2) Each firm is a profit maximizer.

3) Each firm is a price taker.

4) Firms have perfect information; prices are known with certainty.

All four of these assumptions hold for this model. Assumption four is particularly important to this study as the ranch model finds feasible solutions based on known prices and timing of each fire. The fact that the ranch model chooses optimal production based on the knowledge of the timing of exclusion from the BLM allotment does influence the results of this study. Although it is reasonable to conclude that these results are a lower bound estimate of ranch-level economic impacts of cheatgrass associated wildfires. A fire that is unknown *a priori* would likely have a greater economic impact on the ranch than that reflected in this study because, in that case, the ranch would be unable to adjust its profit maximizing strategy to account for fire events.

Assumption 5: Planning horizon

The forty-year planning horizon assumed in the model is typical of that used in other similar ranch-level economic studies. This planning horizon was also restricted at the time of this study by the available livestock sales price data, which accounted for no more than forty-years. The first and last five years of the model are usually excluded from analysis regardless of the length of the planning horizon as results are typically impacted by model behavior that is unrelated to the research question at hand. The first five years are excluded in order to eliminate possible impacts due to the model's equilibrium adjustment period. The last five years of the model are excluded due to the model's tendency to sell as much of the herd as possible at the end of the planning horizon. A terminal value is included in the model to reduce this affect.

However, for this study, the first and the last five years of the model were included in this analysis due to the ecological data available which corresponded to a 20 to 40 year fire return interval. The chosen method for including fire in the model means that limiting the analysis to thirty years rather than forty years would increase the probability of fire above that reflected by the assumed fire interval. Failure to exclude the first and last five years of the model may have an unintended effect on the probability of infeasibility (bankruptcy). As can be inferred from Table 4.5, the probability of infeasibility increases given a fire at the beginning or the end of the planning horizon. Results for research question 2 may therefore be affected unintentionally by model behavior. It is possible that the model returns infeasible solutions given fires in the early years of the model, not as the result of model behavior, but rather due to a lower accumulated savings than is required to offset the decline in net income during the two years following the fire.

Assumption 6: Discount rate

The objective function in the model included an assumed 7% discount rate. A sensitivity analysis was performed to address whether or not the model results are significantly altered with a 10% and a 4% discount rate. Results of this analysis showed that the difference between the NPV in the No Fire Model and that of the Fire Model is similar regardless of the discount rate used. It is therefore unlikely that the results of this study are dependent upon the chosen discount rate.

Assumption 7: Available forage substitutes

This model assumes deeded range land, raised alfalfa, and raised meadow hay are the only available forage substitutes for the ranch's BLM allotment. The existence of other comparative cost substitutes would change the results as the ranch could potentially maintain the equilibrium No Fire Model herd size in the years following the fire. However, Rowe and Bartlett (2001) pointed out that if development pressures are a factor and continued to increase, the number of forage substitutes, particularly private leased land and/or hay resources were not likely to increase.

Assumption 8: Monte Carlo simulation: sample size

The Fire Model was subject to a 100 sets of random numbers drawn in a Monte Carlo simulation of the ranch model to determine fire impacts. Due to the fire interval assumed, this resulted in fire regimes with one and two fires. It should be noted that categorizing the 100 random fire iteration results by the number of fires greatly reduces the number of iterations of the model considered. This may lead to a small sample bias. To decrease the impact of this bias for purposes of comparison of the impact of single-fire versus two-fire regimes would require a Monte Carlo approach with a set of 100 random single-fire regimes and a separate simulation with two-fire regimes. However, as this analysis was not performed in this study, the possibility of this small sample bias should be taken into consideration for any results presented that are broken down by the number of fires.

5.2 Results

The following discussion addresses model results by comparing them to the results of similar studies and also, where relevant, addresses the significance of these results in light of the assumptions of the model. In response to the first research question, the results of the Fire Model indicate that the ranch will ameliorate its perceived risk from the impacts of a fire by reducing its herd size prior to the time in which the BLM allotment use is excluded. In the two years immediately following the fire, the model used all of the comparative cost AUMs available (deeded range) in addition to reducing its herd size. After the second year following a fire, the herd size recovers at a rate that depends upon the sales price (Fig. 4.7). The average sales price has a slower herd recovery rate than the high price set due to the fact that a larger percentage of cows must be sold in order fulfill the profit maximizing objective at a lower sales price.

While herd size and forage substitution results can be compared with those results of the Torell et al. (2002) study reviewed in Chapter 2, these results are difficult to compare due to differences in the models' assumptions. The Torell et al. (2002) study considered an Oregon representative ranch subject to a 100% BLM allotment reduction that existed for the extent of the planning horizon, rather than for one or two, two-year period(s). That study showed a 33% reduction in equilibrium herd size compared to the baseline model. In this study herd size begins to decline prior to the fire year and then obtains a minimum point, equivalent to a 38% reduction, during the second year following a fire. Thus, comparing the maximum reduction in herd size of 38% in this study to the 33% reduction in the Torell et al. (2002) study may or may not be meaningful.

Comparing the results of this study with those of Rowe and Bartlett (2001) and Torell et al. (2002) in terms of forage substitution is somewhat difficult also due to differences in model assumptions. Both of those studies considered private leased land as a possible forage substitute, whereas this study does not. However, results are consistent with those of the other studies in the sense that the Fire Model substitutes 100% of the slack deeded range land available during the two post fire years, implying that forage substitution results in lower economic impacts than the strategy of reducing herd size. Also like those studies, results showed that once forage substitution is not an option, reducing herd size becomes the optimal strategy.

It is important to note that the assumption of perfect information is critical to these results. In the absence of this assumption, the years of exclusion would occur as a random shock, and the ranch would not be able to "plan" for a fire event by reducing its herd size prior to the occurrence of a fire. Given a larger herd size in the years immediately following a fire, the difference between the number of AUMs required to meet the herd's forage needs and those available at a comparable cost would be greater than predicted by this study. That is, rather than a slow reduction in herd size in the years prior to the fire, followed by a large reduction immediately after a fire, the entire reduction would likely occur immediately after the fire, which may increase the probability of bankruptcy.

Furthermore, if the model does not reduce herd size prior to the fire year, there would be a lower level of accumulated savings available at the time of the fire. Results of the Fire Model show that the optimal ranch behavior is to increase the rate of accumulated savings just before a fire (Fig. 4.17). After year 15, animal costs decrease, although at a slower rate than the increase in net income. The primary reason behind this sharper increase in net income than is exhibited by the decrease in animal costs is an increase in the rate of gross income that results from selling some of the herd prior to the fire. A lower level of accumulated savings at the time of the fire may also increase the probability of bankruptcy over that seen in the Fire Model.

The second research question necessitates a discussion of NPV, costs and returns, and infeasibility. The Fire Model negatively impacts NPV and gross income when compared to the No Fire Model. The ranch's net income and gross income fluctuate over the course of the planning horizon due to the fire constraint. Net income is at or above the level of the No Fire Model for most of the planning horizon. However, a large drop occurs following a fire that coincides with a large decrease in gross income, herd size and accumulated savings. This decrease in NPV is not at least the direct result of changes in costs as forage costs, animal costs, and total costs (in dollars per head of cattle) as all decrease as the herd size decreases (Figure 4.17). Just as occurs with the brood cow stocking rate, the ranch takes time to recover the level of net income achieved prior to the fire and the rate of recovery is slower given the lower sales price. This is the result of receiving less return per sale than under the high sales price during this period of recovery. Forage costs, animal costs and total costs remain at a lower level compared to the No Fire Model prior to the fire and eventually increase post-fire.

These changes in net income and costs and returns over the course of the planning horizon pose an interesting question: Why does net income and accumulated savings increase prior to the year in which the BLM allotment is excluded? Subject to the average sales price, the model reached its global maximum net income and accumulated savings in the year immediately prior to the years of BLM allotment exclusion. Subject to the high sales price, the model reached a local maximum in this same year. This increase in accumulated savings is due to cattle sales in previous years which increases gross income as well as decreases total animal costs. Selling the herd during these periods may be optimal because it spreads the costs of the fire over a number of years while at the same time boosting the level of accumulated savings.

This ameliorates the large financial impact that occurs following the fire and minimizes the risk of bankruptcy in the years following a fire.

Fig. 4.7 shows that the selling of the cattle herd begins several years earlier in the model when the ranch is subject to the average rather than high sales price. This behavior reflects the lower sale price received for selling the cattle and therefore the need to sell more cattle between the beginning of the model and the fire year in order to attain a feasible solution. In other words, it appears that when the ranch is faced with the financial risk imposed by a fire, this risk is compounded by the lower sales price, which requires a larger total herd reduction over the time periods prior to the fire and therefore increases overall economic impacts (Fig. 4.11).

In regards to infeasibility in the Fire Model, when subject to the high sales price, it appears that the number of fires did not have any affect on infeasibility. Rather it is the timing of the fire that determined whether or not the model returned an infeasible solution. Thus, while the probability of infeasibility increased by 17% given a second fire under the high sales price, this is the result of an increase in the probability of having a fire in the last 3 years of the model's planning horizon, rather than due to the combined economic impact of a second fire.

Given the average sales price however, the number of fires does appear to have an affect on infeasibility. Subject to this sales price, there are a number of combinations of first and second fire years that result in infeasible solutions. A pattern emerges in that a second fire that occurs in year 25 with 15 years remaining until the end of the planning horizon appears to have insufficient time for the enterprise to recover. Subject to the same sales price and given a single-fire regime, however, the ranch requires less than four years prior to the end of the planning horizon to recover. Furthermore, the same timing of a single-fire regime that results in a feasible solution can results in an infeasible solution given a two-fire regime. For example, Fire Regime Number 66, the timing of which is shown in Fig. 4.20, is infeasible with the first fire occurring in year 10 and the second fire occurring in year 31. A fire in year 10 or a fire in year 31 for a single-fire regime is however feasible under this average price set. This implies that a combined impact of the two fires may be the reason behind the infeasible model solution for this two-fire regime.

With respect to the third research question, the purpose of the cheatgrass sensitivity analysis was to determine the relative influence of the assumed proportion of AUMs ac^{-1} dedicated to cheatgrass and native grasses on the model results. While the analysis shows that the level of invasion is not vital to the results of this thesis in terms of the difference in NPV in the two models, results did imply that the level of invasion may impact NPV within the individual results of the Fire Model and the No Fire Model. According to this analysis, when the No Fire Model is subject to either the high sales price or the average sales price, the NPV of the ranch income increases as the level of invasion decreases. This result is the same in the Fire Model when the model is subject to the high sales price, while the opposite result is obtained for the average price set. The inconsistency of these results makes it difficult to conclude whether or not the NPV for the ranch increases as the level of invasion decreases.

One reason for this inconsistency may be due to the employed method of averaging the NPV results. All NPV results in the Fire Model were positive for the high sales price, but this was not the case for the average sales price. One negative NPV value was returned given the more invaded state and two negative NPV values were returned given the least invaded state. Averaging over negative and positive values lowers the average NPV for the average price set in the Fire Model. This may explain why the average sales price results in a decrease in NPV as the level of invasion decreases.

6 Conclusion

The goal of this study was to model and evaluate the ranch-level economic impact of fire on an Oregon representative ranch's public grazing allotment to aid future studies of the economic impact of continued cheatgrass invasion on BLM grazing allotments. In doing so, this study explored an additional source of risk on the ranching enterprise that had not previously been explored. Results indicate that, given the assumption of perfect information, ranch impacts from fire go far beyond the time-line of the two years of exclusion from the BLM allotment. The ranch prepares for a fire year by slowly decreasing its herd size over the several years prior and then requires a few years after the fire to recover to its original equilibrium level. The maximum reduction in herd size is 38% which occurs in the second year following the fire. This is higher than that found by Torell et al. (2002) who found the primary ranch response strategy was to reduce livestock production by 33% when faced with a 100% BLM allotment reduction.

During the years of exclusion from the BLM allotment, 100% of the deeded range is used by the Fire Model. This is also consistent with the results of the studies by Rowe and Bartlett (2001) and Torell et al. (2002), which both concluded that substituting forage for lost public grazing land resulted in lower economic impacts than the strategy of reducing herd size. However, like these studies, once forage substitution is not an option, reducing herd size becomes the optimal strategy.

The results of the Fire Model showed a decrease in average BLM AUMs used over the time period of the model of 5% for the average price set, which is not surprising as 2 years of 100% reduction in BLM AUMs over 40 years for a single fire regime should be equivalent to a 5% reduction. However, the number of deeded range AUMs decreased by 7.7%, which is slightly more than the reduction in BLM AUMs used. Again, this result demonstrates that the economic impact from the loss of the public forage allotment goes beyond that of the BLM AUMs lost in the two years of exclusion.

A reduction in Net Present Value (NPV) was also experienced by the representative ranch under the assumed 20 to 40 year fire return interval. NPV averaged over the planning horizon of the model showed a 6% or $51,000 decrease for the high price set and a 4% decrease or a difference of $19,000 for the average price set. The NPV also decreased as the number of fires increased with the high price. This may also be the case for the average price set, but all two-fire regimes returned infeasible solutions. The probability of infeasibility increased when subject to the lower sales price as well with an increase in the number of fires. Gross revenue also declines on average for both price sets compared to the No Fire Model, and this decline increases as the number of fires increases

Perhaps the most vital result of this study is that the model chooses to plan for the random fire event to ameliorate ranch impacts. Planning for the fire by reducing the herd size appears to be the optimal behavior given the knowledge of the fire, but it is not possible to say from this study what the optimal response would be in the absence of this knowledge. This study indicates that there are ranch impacts associated with fires on BLM lands. Furthermore, the results presented are likely conservative estimates of these impacts due to the assumption of perfect information. Therefore, regardless of whether or not the ranch plans for a fire, it is apparent that the ranch impact of fires on BLM lands should be considered in future policy analysis.

6.1 Policy implications

Interpreting the costs and benefits of public policies and land management practices surrounding cheatgrass requires knowledge of its costs and benefits as a forage source. Including information regarding both cheatgrass and native forage production as well as cheatgrass associated wildfires in future ranch-level economic models is necessary to provide a complete understanding of the impact of restoration policies on the ranching community.

As cheatgrass continues to invade the Great Basin sagebrush steppe, the results of this study indicate that there exists a cost associated with fires on public lands in terms of the economic viability of a ranch. Failing to include ranch impacts of fire on public land will underestimate the costs of invasion. Avoiding these costs through restoration efforts may therefore provide a significant financial benefit to a ranching enterprise which may outweigh the benefit of cheatgrass as a spring-time forage source. Comparing the impacts on NPV between one and two fires implies that the economic impact on the ranch will likely increase as the length of the fire interval on public lands decrease. The idea that a ranching enterprise will decrease in value given an increase in the number of fires experienced over its lifetime provides valuable information for managers prioritizing restoration efforts on public lands. Given limited resources, concentrating efforts on those areas that are at the highest risk of experiencing an increase in fire frequency (an area's vulnerability to crossing an ecological threshold into an increased state of invasion) may provide greater benefit to the rancher than spreading resources thinly over all areas affected by cheatgrass invasion.

One policy implication to consider, although not evaluated specifically in this study, is that of a sales tax on livestock. The ranch may have a disincentive to sell the quantity of livestock indicated by these results if the cost associated with these sales is sufficiently high. Furthermore, this extra cost may additionally impact the ability of the ranch to stay in business. Providing a sales tax break for ranches that experience a fire on their BLM allotment may be one way to avoid financial hardship additional to that experienced by the representative ranch in this study.

6.2 Implications for the ranch

Ranchers may be forced to reduce their herd size to stay in business if their BLM allotment experiences or is vulnerable to cheatgrass associated wildfires. Hence this study brings light to an additional source of risk for the enterprise. While the results of the cheatgrass sensitivity analysis were inclusive, they do not negate the possibility that NPV of the ranch may decrease as the level of cheatgrass invasion increases regardless of whether or not a fire occurs, as is shown in the results of this analysis on the No Fire Model.

Ranchers that wish to evaluate the trade-offs of cheatgrass now have additional information to keep in mind not only when operating on their public land allotments but when managing their deeded rangelands as well. As forage substitutes become increasingly few due to development pressures and increased fire risk, low fire risk and/or healthy deeded rangelands may become a vital business management strategy even for those ranchers who are not necessarily profit maximizers.

6.3 Further research needs

The Satyal (2006) study concluded that "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 (p.93)." However, that study only compared economic impacts from treatment on ranch profits within a heavily invaded cheatgrass ecological state. Comparisons made in this study within either model but across levels of invasion provide somewhat inconclusive results, but do present an interesting question. Is it necessarily true that ranchers benefit from cheatgrass as a spring-time forage source, or is this the result of considering a highly invaded ecological state? Was there a cost associated with shifting out of the previous less invaded ecological state that was not taken into consideration in that study?

With these questions in mind, this study was designed to aid future ranch-level economic studies regarding cheatgrass imposed ecological transitions on a rancher's public grazing allotments. It demonstrates the importance of including wildfire impacts in such studies and provides a baseline model that can be used to explore the costs and benefits associated with changes in ecological states of invasion. In addition, this model can work as a baseline to explore the ranch-level economic impacts of various cheatgrass treatment methods and allows for modeling the impact of these methods on increasing or decreasing the probability of fire.

This model could be improved upon by eliminating some or all of the required assumptions for this study. For example, considering a longer planning horizon may be preferable in the future to avoid potential complications with including the results from the first and the last five years of the model. However, doing so would require a price data set that extends beyond forty years. In addition, although much of the randomness considered in other ranch models, such as random prices and random precipitation, was not considered in this model for the purposes of isolating random wildfire impacts, including randomness is the next step necessary to improve the model's realism and in turn its predictability. As a final example, creating a method to incorporate the wildfire constraint in the model as a random shock rather than as a planned event, thus requiring the assumption of perfect information, may provide additional insight into potential ranch-level economic impacts beyond those provided in this study.

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Appendices

Appendix A

GAMS code for Fire Model and No Fire Model (baseline model)*

*No Fire Model is iteration Fire101 in GAMS include file (Appendix C)

```
********************************************************************************
*                       Fire Model and No Fire Model (Base Model)               *
*                                                                               *
********************************************************************************
$Title Oregon Mountain - Northeast Oregon, Oregon 300 head Max Net Income
$ONTEXT
SIZE = Large
Debt = None
Grazing Fee = Current
Available Public AUMs = Current
Season of Use = Current
$OFFTEXT
*$OFFSYMLIST OFFSYMXREF
$onsymxref
file returns /c:\Cheatgrass\JFS\output\Base_returns.txt/;
returns.pc=5;
* Returns is a file that summarizes costs and returns by year
file foragsum /c:\Cheatgrass\JFS\output\Base_land.txt/;              foragsum.pc=5;
* Foragsum is a file that summarizes forage use by year
file raisesum /c:\Cheatgrass\JFS\output\Base_raise.txt/;             raisesum.pc=5;
* Raisesum is a file that summarizes the number of raised animals by year
file risum /c:\Cheatgrass\JFS\output\Base_objfn.txt/;
risum.pc=5;
* Filesum is a file that summarizes the Obective Function (ranch income) by year
file lndsum /c:\Cheatgrass\JFS\output\Base_landuse.txt/;
lndsum.pc=5;
* Lndsum is a file that summarizes seasonal land use by year
file feedsum /c:\Cheatgrass\JFS\output\Base_feeduse.txt/;             feedsum.pc=5;
```

```
* Feedsum is a file that summarizes seasonal feed use by year
file haysum /c:\Cheatgrass\JFS\output\Base_haysale.txt/;
haysum.pc=5;

* haysum is a file that summarizes hay sales use by year
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                /12168/
*Off ranch income set at $12,168 (2005$) for a full-time rancher, $57,191 for part-time
(2005$)
         Family          family living allowance         /24000/
*Family living allowance set at $24,000 for all ranchers
         Fixed           Fixed ranch expenses            /21229/
*Fixed include machinery and equipment insurance and taxes, property tax, depreciation
and interest
         Iwealth         Initial cash position           /0/
         Endval          Last year return per AUY        /3/
         Stloanr         Short term borrowing rate       /0.04/
         Savrate         Interest return on Savings acct /.03/
```

```
         AcBLM           Acres of BLM land  /2310/

*ALL BLM IS represented by the scaler "AcBLM"
         Blmcost         Forage cost per AUM on BLM land         /8.77/
         seas2con        Season 3 conversion in season 3 >= season 2 restriction.  Season
2 is is 2.5 times longer than season 3 /2.5/
         seas4con        Season 4 converson in season 4>= season 3 restriction.  Season 4
is 1.5 times longer than season 3 /1.5/;
*Change years to match price data set, also need to change years in Bounds section near
bottom
Set T Time periods /year01*year40/
     TLAST(T)  Last Period
     TFIRST(T) First Period
*If you have different seasons, there are changes throughout the model that must be made
Set Fireyr Years since last fire /Fire01*Fire101/
*added set "Fireyr to incorporate impact of fire on availability of blm land.
Set seasonON grazing season start date /seas1*seas8/
Set iter iteration /iter001*iter003/
Set season(seasonON) grazing season /seas1*seas7/
*If you have different land or crop types, there are changes throughout the model that
must be made
Set land types of land available /state, trtable, usfs, privleas, deedrang, rmeadow,
gmeadow, raisealf, purchalf, pmeadhay/
Set Crop(land) /rmeadow, raisealf, purchalf, pmeadhay/
Set Graze(land) /state, usfs, privleas, deedrang, rmeadow, gmeadow, raisealf, purchalf,
pmeadhay/
Set BLMT(land) /trtable/
Set landitem /number, aumac, cropyld, conver, usefac, forcost1/
```

```
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 /forcost1, 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   71.63
     raisealf 110.41/;
*both above numbers are in 2005 prices.
parameter buypric(T,livclass);
parameter salepric(T,livclass);
parameter Econ(iter,fireyr,T,costsum)          Economic Variables;
Parameter Landsum(iter,fireyr,Land,T,out1)     Land Use Summary;
Parameter Landseas(iter,fireyr,Land,T,season)  Seasonal land use summary;
Parameter Feedseas(iter,fireyr,Crop,T,season)  Seasonal Crop use summary;
Parameter haysale(iter,fireyr,Crop,T)          crop sales summary;
Parameter anim(iter,fireyr,T,Livclass)         raised animals summary;
parameter AUY(iter,fireyr,T)                   AUY on the ranch;
parameter ri(iter,fireyr)                      Ranch Income Summary;
parameter MS(iter,fireyr)                      Model status by iter;
```

```
parameter Fireint(T,Fireyr)               fire interval;
parameter fireprod(T)                     production in year T if fire occurs;
parameter trtcost(treatmnt) Treatment costs dollars per acre
     /nochng  0
      herb    50
      grazing 10
      fire    25
      integ   100/;

*The following Include statments must be changed for location and name of your price file
*$Include "C:\Cheatgrass\Include Files\IDjordan100.txt"
$Include "C:\Cheatgrass\JFS\Include Files\3AveragePrices.txt"
* The external file that reads in the series of cattle prices for each iteration

$Include "C:\Cheatgrass\JFS\Include Files\Hart_Mt_aums_phse_3.txt"
*$Include "C:\Cheatgrass\JFS\Include Files\Hart_Mt_aums_phse_1.txt"
*$Include "C:\Cheatgrass\JFS\Include Files\Hart_Mt_aums_phse_2.txt"
*$Include "C:\Cheatgrass\JFS\Include Files\TreatORAUM2.txt"
* File containing forage production values by ecological phase

*$Include "C:\Cheatgrass\JFS\Include Files\NoFire.txt"
*File containing column of ones for No Fire Model (baseline)
$Include "C:\Cheatgrass\JFS\Include Files\FireInt100.txt"
*File containing random years of fire and no grazing
*100 iterations of random years of fire 20 to 40 year intervals.
*Fires followed by two years of no blm grazing availability

*  $Include "C:\Cheatgrass\Include Files\IDbuyp.prn"
```

```
* buyp.prn is the external file that reads in the series of yearling buy prices for each
iteration

* compute the number of days in each grazing season and assure total
* is 365 or 366. Uses date functions from GAMs Model library calendar.gms.
* Season 7 must close out the year in the following year.

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
;
```

```
* "Serial" is number of days past Jan. 1, 1900
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"));

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

* put a one (1) in the seasons when grazed forages are to be available
table avail(graze, season) seasonal forage availability

                 seas1    seas2    seas3    seas4    seas5    seas6   seas7
state
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       1
                                                                        ;

* put a one (1) in the seasons when hay can be fed.
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
                                                                         ;

* Enter aumac=1 when units are AUMs
* Add $20/ton to market prices for purchased hays as a delivery cost

* Units of forage types
*     ACRES: State, deedrang, rmeadow, gmeadow, raisealf
*     AUM: blm, USFS, Privleas
*     TON: purchalf, pmeadhay
* cropyld is tons per acre
* conver = conversion factor Tons to AUMs
* usefac = percentage of amount available that can be used in this run - used for policy
analysis
* forcost1 is in units of landtype.  For hays, it is times the cropyld.
```

```
table forage(graze,landitem) forage sources

              number     aumac   cropyld  conver    usefac    forcost1
state           0.       1.0                         1.0       4.80
usfs            0.       1.0                         1.0       9.46
privleas        0.       1.0                         1.0      13.00
deedrang     1700.       1.0                         1.0      11.55
rmeadow       500.       2.04      1.5      2.22     1.0     107.00
gmeadow       500.       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     130.00
pmeadhay     1000.       0.0       1.0      2.22     1.0       92.0

;
*display forage;

table forcrop(crop,landitem) forage sources

              number     aumac   cropyld  conver    usefac    forcost1
rmeadow       500.       2.04      1.5      2.22     1.0       107.
raisealf       70.       0.0       4.5      2.22     1.0      400.0
purchalf     1000.       0.0       1.0      2.22     1.0       130.
pmeadhay     1000.       0.0       1.0      2.22     1.0       92.
;
```

```
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 ;

*animcost = use gross margin divided by brood cows, cull cows, and replacement yearlings
* enter same animal cost for all 3 classes.

* hayuse is the percentage that alfalfa hay must be used to feed that class.

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

              buywt     salewt   deathlss     animcost    hayuse
broodcow                          0.01          32.00
cullcow                 11.00     0.01          32.00
bull                     5.00     0.01           0.0
* assumptions for bull 2000 lb but kept 4 years so (20.00/4) = 5.0
```

```
scalf                    5.75      0.04          0.0        1
hcalf                    5.25      0.04          0.0        1
*syear normally not raised on ranch
syear                       0      0.06          0.0        1
hyear                    8.00      0.06          0.0        1
* owned yearling death loss should include both calf and yearling losses
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         32.00       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)));
*display DF;
     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
*      SUPPUSE(T)          If supplementation - 2 months in seas5 to 1 month seas6
       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
      BLMAval2(BLMT,T)    Total BLM AUMs potententially available
      TREATBLM(T)         Cost of treating BLM acres
      BLMTT(T)            Total BLM treatable acres
      BLMrestrct(BLMT,season,T) Restriction on BLM use to reflect cattle grazing blm
season 2 will also graze season 3
      BLMrstrct2(BLMT,season,T) Restriction on BLM use to reflect cattle grazing blm
season 3 will also graze season 4;

*Forage demand and supply equations

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

```
*if using a treatment, the "nochng" needs to be changed to a treatment code for the
BLMTRTA equation.
*It also occurs in the Treatment Cost equation with the economic equations

BLMTT(T)..                   BLMAcTrt("year01") + BLMAcNT("year01") =e= AcBLM;
BLMNot(t)..                  BLMAcNT("year01") =e= 0;
*the above equations is setting the variable BLMAcTrt equal to the total amount of
treatable land.  Which for this model is all blm land.


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"))*fireprod(T
);

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))*fireprod(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))*fireprod(T);

BLMSeas5(BLMT,"seas5",T)..  BLMuse(BLMT,"seas5",T) =L=
(SUM(source,treat(T,"nochng",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))*fireprod(T);
*These 4 equations allocate the BLM AUMs on the treatable acres across the 4 seasons
using the growth curves for native species.
*note, in above, blmuse in aums per acre times the number of acres gives you aums.


BLMrestrct(BLMT,season,T)..  (BLMuse(BLMT,"seas2",T))/(seas2con)-
BLMuse(BLMT,"seas3",T)=L=0;
BLMrstrct2(BLMT,season,T)..  BLMuse(BLMT,"seas3",T)-
(BLMuse(BLMT,"seas4",T))/(seas4con)=L=0;
*These equations restrict the model to avoid alternating use and non-use of blm land in
consecutive seasons within a given year


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)*availblm(BLMT,season)) +
slackblm(BLMT,T) =E=   SUM(source,treat(T,"nochng",source))*BLMAcTrt("year01") +
treat(T,"nochng","cheat")*BLMAcNT("year01");
BLMAval2(BLMT,T)..  SUM(season,blmuse(BLMT,season,T)*availblm(BLMT,season)) =L= AcBLM *
SUM(source,treat(T,"nochng",source));

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))*fireprod(T)) +
SUM(crop,feedcrop(crop,season,T)*forcrop(crop,"conver")* cropaval(crop,season));
*note: availblm multiplies by 1 for each season in the availblm table.

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 6)..  SUM(livclass,
raise(livclass,T)*
*     aue1(livclass,season)*animal(livclass,"hayuse"))* cropaval("purchalf",season)*
onday(season,"months")
*     + SUM(livclass, raise(livclass,T-1)*aue2(livclass, season)*
animal(livclass,"hayuse"))
*     *cropaval("purchalf",season)*onday(season,"months")
*     =L= feedcrop("purchalf",season,T)*forage("purchalf","conver")
```

```
*     +feedcrop("raisealf",season,T)*forage("raisealf","conver");

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");
*Cattle transfer equations

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)$(ORD(T) GT 1).. raise("rephcalf",T-1)*(1- animal("rephcalf","deathlss"))
    =E= raise("rephyear",T);
BULLRAT(T)..  raise("broodcow",T)+ raise("cullcow",T) + raise("rephyear",T)
    =E= cowbull*raise("bull",T);
CULLRATC(T)..  raise("cullcow",T) =e= minrepl*(raise("broodcow",T) +
raise("rephyear",T));
*Jordan Valley model would prefer to raise yearlings, so try sign on next equation as =G=
on most other models
*MINHYRC(T)..  Raise("hyear",T) =G= minhyear*raise("broodcow",T);
MINHYRC(T)..  Raise("hyear",T) =G= minhyear*raise("rephyear",T);
MINREPLC(T)$(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)) ;

*Livestock sales and costs
SALES(livecl,T).. selllive(livecl,T) =L= (1-Animal(livecl,"deathlss"))*
                       Animal(livecl,"salewt")* raise(livecl,T);

COSTFORC(T)..     FORCOST(T) =E= SUM(season,SUM(graze,landuse(graze,Season,T)*
forage(graze,"forcost1")))
                       +
(SUM(season,SUM(blmt,blmuse(blmt,season,T)*blmcost))*fireprod(T));

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");

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);

*This is the objective function
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);

*Terminal Value - need to calculate the gross margin/head.  Divide total gross margin
*by expected number of brood cows, cull cows, replacement heifer calves, and
*replacement heifer yearlings.
TERMVAL(TLAST)..  TERM =E= ((raise("BROODCOW",TLAST)+raise("CULLCOW",TLAST)
     +raise("rephyear",TLAST)+raise("rephcalf",TLAST))*Endval)/RHO*(1-1/((1+RHO)**
CARD(T)));
```

```
*************** Set bounds for selected variables *********************

* accumsav is the minimum accumulated savings
* need to ensure that stborrow year matches your price set
* the year01 numbers set an initial endowment of animals
* the year40 numbers limit the number of replacements for the terminal value

accumsav.lo(T)= 1.;
*stborrow.up(T)= 100000;
stborrow.up(T)$(ORD(T) EQ CARD(T)) = 0;
slacklnd.up("State",T)=0;
raise.up("sellbcow",T)$(ORD(T) EQ 1) = 0;
*raise.up("buybcow",T)=1000;
*raise.lo("broodcow",T) = 0;
raise.up("broodcow",T)$(ORD(T) EQ 1) = 300;
raise.up("rephyear",T)$(ORD(T) EQ 1) = 58;
raise.lo("broodcow",T)$(ORD(T) EQ 40) = 300;
raise.lo("rephyear",T)$(ORD(T) eq 40) = 58;
raise.lo("rephcalf",T)$(ORD(T) eq 40) = 60;
*raise.up("rephyear",T)$(ORD(T) EQ CARD(T)) = 86;
*raise.up("rephcalf",T)$(ORD(T) EQ CARD(T)) = 91;
raise.lo("horse",T)=10;
*landuse.up("blm","seas1",T)=212;
ranchinc.up=5000000;
```

```
****************************************************************************
* You can change the name of the model to match your area.  Need to change the
* name in the solve equation as well.

model Sagebase base level model / all /;
*option lp=gamschk;

option lp=minos5;
option limrow = 000;
option limcol = 00;
option SOLPRINT=off;

****************** Start Loop***********Start Loop*********************
loop(iter,loop(fireyr,

salepric(T,"cullcow")  = salep(iter,T,"cullcow");
salepric(T,"bull")     = salep(iter,T,"bull");
salepric(T,"scalf")    = salep(iter,T,"scalf");
salepric(T,"hcalf")    = salep(iter,T,"hcalf");
salepric(T,"purscalf") = salep(iter,T,"purscalf");
salepric(T,"purhcalf")    = salep(iter,T,"purhcalf");

*assumes %commission of (Commiss), daily yardage fee of YARDAGE, Feed of
* $SALEFEED/cwt
salepric(T,"sellbcow") = salep(iter,T,"cullcow")*Animal("sellbcow","salewt");
*(1-Commiss)- Yardage - salefeed*Animal("sellbcow","salewt")  ;
*buypric(T,"purscalf")= buyp(iter,T,"purscalf");
*buypric(T,"purhcalf")= buyp(iter,T,"purhcalf");
```

```
buypric(T,"buybcow") = salep(iter,T,"buybcow");
buypric(T,"buybull") = 154.09 + 2.0549*buypric(T,"buybcow");


Fireprod(T) = Fireint(T,Fireyr);


display buypric;
display salepric;

* Make sure the second word matches your model name specified above in the MODEL
statement.
SOLVE Sagebase USING LP MAXIMIZING ranchinc;

display ranchinc.l;
display
     landuse.l
     raise.l
     feedcrop.l
*     raise.up
     selllive.l
     sellcrop.l
     BLMAcTrt.l
     BLMAcNT.l
     BLMuse.l
;
```

```
Econ(iter,fireyr,T,'forcost1')  = forcost.L(T);
Econ(iter,fireyr,T,'animcost') = animcost.L(T);
Econ(iter,fireyr,T,'loancst')  = loancst.L(T);
Econ(iter,fireyr,T,'treatcst')  = treatcst.L(T);
Econ(iter,fireyr,T,'totcost')  = forcost.L(T) + animcost.L(T) + loancst.L(T);
Econ(iter,fireyr,T,'gross')    = gross.L(T);
Econ(iter,fireyr,T,'repgross') = raise.L ("rephcalf",T)* salepric(T,"hcalf")*
    animal("hcalf","salewt")+ raise.L ("rephyear",T)* salepric(T,"hyear")*
    animal("hyear","salewt");
Econ(iter,fireyr,T,'Net')      = Net.L(T);
Econ(iter,fireyr,T,'netdisc')  = Netdis.L(T);
Econ(iter,fireyr,T,'cashtr')   = cashtr.L(T);
Econ(iter,fireyr,T,'accumsav') = accumsav.L(T);
Econ(iter,fireyr,T,'stborrow') = stborrow.L(T);
Econ(iter,fireyr,T,'repayst')  = repayst.L(T);

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

Landsum(iter,fireyr,graze,T,'used')   = sum(season,landuse.L(graze,season,T));
Landsum(iter,fireyr,graze,T,'Slack')  = slacklnd.L(graze,T);
Landsum(iter,fireyr,graze,T,'Total')  = sum(season,landuse.L(graze,season,T)) +
slacklnd.L(graze,T);
Landsum(iter,fireyr,graze,T,'Shadow') = slacklnd.m(graze,T);
Landsum(iter,fireyr,graze,T,'value')  =
sum(season,landuse.L(graze,season,T))*forage(graze,"forcost1");
```

```
Landsum(iter,fireyr,BLMT,T,'used')   = sum(season,blmuse.L(BLMT,season,T));
Landsum(iter,fireyr,BLMT,T,'Slack')  = slackblm.L(BLMT,T);
Landsum(iter,fireyr,BLMT,T,'Total')  = sum(season,blmuse.L(BLMT,season,T)) +
slackblm.L(BLMT,T);
Landsum(iter,fireyr,BLMT,T,'Shadow') = slackblm.m(BLMT,T);
Landsum(iter,fireyr,BLMT,T,'value')  = sum(season,blmuse.L(BLMT,season,T))*blmcost;

Landseas(iter,fireyr,graze,T,'seas1') = landuse.L(graze,'seas1',T);
Landseas(iter,fireyr,graze,T,'seas2') = landuse.L(graze,'seas2',T);
Landseas(iter,fireyr,graze,T,'seas3') = landuse.L(graze,'seas3',T);
Landseas(iter,fireyr,graze,T,'seas4') = landuse.L(graze,'seas4',T);
Landseas(iter,fireyr,graze,T,'seas5') = landuse.L(graze,'seas5',T);
Landseas(iter,fireyr,graze,T,'seas6') = landuse.L(graze,'seas6',T);
Landseas(iter,fireyr,graze,T,'seas7') = landuse.L(graze,'seas7',T);

Landseas(iter,fireyr,BLMT,T,'seas1') = blmuse.L(BLMT,'seas1',T);
Landseas(iter,fireyr,BLMT,T,'seas2') = blmuse.L(BLMT,'seas2',T);
Landseas(iter,fireyr,BLMT,T,'seas3') = blmuse.L(BLMT,'seas3',T);
Landseas(iter,fireyr,BLMT,T,'seas4') = blmuse.L(BLMT,'seas4',T);
Landseas(iter,fireyr,BLMT,T,'seas5') = blmuse.L(BLMT,'seas5',T);
Landseas(iter,fireyr,BLMT,T,'seas6') = blmuse.L(BLMT,'seas6',T);
Landseas(iter,fireyr,BLMT,T,'seas7') = blmuse.L(BLMT,'seas7',T);

Feedseas(iter,fireyr,Crop,T,'seas1') = Feedcrop.L(crop,'seas1',T);
Feedseas(iter,fireyr,Crop,T,'seas2') = Feedcrop.L(crop,'seas2',T);
Feedseas(iter,fireyr,Crop,T,'seas3') = Feedcrop.L(crop,'seas3',T);
Feedseas(iter,fireyr,Crop,T,'seas4') = Feedcrop.L(crop,'seas4',T);
Feedseas(iter,fireyr,Crop,T,'seas5') = Feedcrop.L(crop,'seas5',T);
```

```
Feedseas(iter,fireyr,Crop,T,'seas6') = Feedcrop.L(crop,'seas6',T);
Feedseas(iter,fireyr,Crop,T,'seas7') = Feedcrop.L(crop,'seas7',T);

Haysale(iter,fireyr,Crop,T) = sellcrop.L(crop,T);

anim(iter,fireyr,T,"broodcow") = raise.L("broodcow",T);
anim(iter,fireyr,T,"cullcow")  = raise.L("cullcow",T);
anim(iter,fireyr,T,"bull")     = raise.L("bull",T);
anim(iter,fireyr,T,"horse")    = raise.L("horse",T);
anim(iter,fireyr,T,"scalf")    = raise.L("scalf",T);
anim(iter,fireyr,T,"hcalf")    = raise.L("hcalf",T);
anim(iter,fireyr,T,"syear")    = raise.L("syear",T);
anim(iter,fireyr,T,"hyear")    = raise.L("hyear",T);
anim(iter,fireyr,T,"purscalf") = raise.L("purscalf",T);
anim(iter,fireyr,T,"purhcalf") = raise.L("purhcalf",T);
anim(iter,fireyr,T,"rephcalf") = raise.L("rephcalf",T);
anim(iter,fireyr,T,"rephyear") = raise.L("rephyear",T);
anim(iter,fireyr,T,"buybcow")  = raise.L("buybcow",T);
anim(iter,fireyr,T,"sellbcow") = raise.L("sellbcow",T);
anim(iter,fireyr,T,"buybull")  = raise.L("buybull",T);

AUY(iter,fireyr,T) = sum(season, sum(livclass,
raise.L(livclass,T)*aue1(livclass,season))*
onday(season,"months")+ SUM(livclass, raise.L(livclass,T-1)* aue2(livclass, season))*
onday(season,"months"))/12;
*Options display AUY;

ri(iter,fireyr)=ranchinc.L;
```

```
MS(iter,fireyr)=Sagebase.modelstat;
));
* END iter loop

options decimals=1; display feedseas;
options decimals=1; display Econ;
options decimals=1; display Landsum;
options decimals=1; display anim;


put returns 'run' 'year' 'iter' 'fireyr' 'Model Status';
loop(costsum, put costsum.tl);
loop(iter, loop(fireyr,
loop(T,
 put / 'Base' T.te(T);
 put iter.te(iter), fireyr.te(fireyr), MS(iter,fireyr);
 loop (Costsum, put Econ(iter, fireyr, T,costsum)))));

put foragsum 'Run' 'Landtype' 'year' 'iter' 'fireyr' 'Model Status';
loop(out1, put out1.tl);
loop(iter,
loop(fireyr,
 loop(land, loop(T,
    put /'Base'  Land.te(Land), T.te(T), iter.te(iter), fireyr.te(fireyr),

MS(iter,fireyr);
 loop(out1, put landsum(iter, fireyr,Land,T,out1))))));
```

```
put lndsum 'Run' 'landtype' 'year' 'iter' 'fireyr' 'Model Status';
 loop(season, put season.tl);
 loop(iter,
 loop(fireyr,
 loop(land, loop(T,
 put / 'Base' Land.te(Land), T.te(T);
 put iter.te(iter), fireyr.te(fireyr), MS(iter,fireyr);
 loop (season, put Landseas(iter, fireyr,Land,T,season))))));

put feedsum 'Run' 'Hay' 'crop' 'year' 'iter' 'fireyr' 'Model Status';
 loop(season, put season.tl);
 loop(iter,
 loop(fireyr,
 loop(Crop, loop(T,
 put /"Base" "hay" Crop.te(Crop), T.te(T);
 put iter.te(iter), fireyr.te(fireyr), MS(iter,fireyr);
 loop (season, put Feedseas(iter, fireyr,Crop,T,season))))));

put haysum 'Run' 'Crop' 'year' 'iter' 'fireyr' 'Model Status' 'Tonsold';
loop(iter,
loop(fireyr,
 loop(crop, loop(T,
    put /"Base" Crop.te(Crop), T.te(T), iter.te(iter), fireyr.te(fireyr),
MS(iter,fireyr);
    put haysale(iter, fireyr,crop,T)))));

put raisesum 'Run' 'Year' 'iter' 'fireyr' 'Model Status' 'AUY';
loop(livclass, put livclass.tl);
```

```
loop(iter,
loop(fireyr,
  loop(T, put /"Base" T.te(T);
put iter.te(iter), fireyr.te(fireyr), MS(iter,fireyr);
put AUY(ITER, fireyr, T);
    loop(livclass, put anim(iter, fireyr,T,Livclass)))));


put risum 'Run' 'iter' 'fireyr' 'ObjFun'  'Model Status';
loop(iter,
loop(fireyr,
put /"Base" iter.te(iter), fireyr.te(fireyr), ri(iter,fireyr), MS(iter,fireyr)));
```

Appendix B

GAMS include files for native grass and cheatgrass annual AUMs Ac-1 at Hart Mountain study site

Appendix B1. Include file for native grass and cheatgrass annual AUMs Ac^{-1} on Hart Mountain study site (most invaded level).

Appendix B1.

Table treat (T, treatmnt, source) Forage production by treatment year.

	nochng.native	nochng.cheat	
Year01	0.37	0.28	
Year02	0.37	0.28	
Year03	0.37	0.28	
Year04	0.37	0.28	
Year05	0.37	0.28	
Year06	0.37	0.28	
Year07	0.37	0.28	
Year08	0.37	0.28	
Year09	0.37	0.28	
Year10	0.37	0.28	
Year11	0.37	0.28	
Year12	0.37	0.28	
Year13	0.37	0.28	
Year14	0.37	0.28	
Year15	0.37	0.28	
Year16	0.37	0.28	
Year17	0.37	0.28	
Year18	0.37	0.28	
Year19	0.37	0.28	
Year20	0.37	0.28	
Year21	0.37	0.28	
Year22	0.37	0.28	
Year23	0.37	0.28	
Year24	0.37	0.28	
Year25	0.37	0.28	
Year26	0.37	0.28	
Year27	0.37	0.28	
Year28	0.37	0.28	
Year29	0.37	0.28	
Year30	0.37	0.28	
Year31	0.37	0.28	
Year32	0.37	0.28	
Year33	0.37	0.28	
Year34	0.37	0.28	
Year35	0.37	0.28	
Year36	0.37	0.28	
Year37	0.37	0.28	
Year38	0.37	0.28	
Year39	0.37	0.28	
Year40	0.37	0.28	

;

Appendix B2. Include file for native grass and cheatgrass annual AUMs Ac^{-1} on Hart Mountain study site (more invaded level).

Appendix B2.			
Table treat (T, treatmnt, source) Forage production by treatment year.			
	nochng.native	nochng.cheat	
Year01	0.61	0.33	
Year02	0.61	0.33	
Year03	0.61	0.33	
Year04	0.61	0.33	
Year05	0.61	0.33	
Year06	0.61	0.33	
Year07	0.61	0.33	
Year08	0.61	0.33	
Year09	0.61	0.33	
Year10	0.61	0.33	
Year11	0.61	0.33	
Year12	0.61	0.33	
Year13	0.61	0.33	
Year14	0.61	0.33	
Year15	0.61	0.33	
Year16	0.61	0.33	
Year17	0.61	0.33	
Year18	0.61	0.33	
Year19	0.61	0.33	
Year20	0.61	0.33	
Year21	0.61	0.33	
Year22	0.61	0.33	
Year23	0.61	0.33	
Year24	0.61	0.33	
Year25	0.61	0.33	
Year26	0.61	0.33	
Year27	0.61	0.33	
Year28	0.61	0.33	
Year29	0.61	0.33	
Year30	0.61	0.33	
Year31	0.61	0.33	
Year32	0.61	0.33	
Year33	0.61	0.33	
Year34	0.61	0.33	
Year35	0.61	0.33	
Year36	0.61	0.33	
Year37	0.61	0.33	
Year38	0.61	0.33	
Year39	0.61	0.33	
Year40	0.61	0.33	

;

Appendix B3. Include file for native grass and cheatgrass annual AUMs Ac^{-1} on Hart Mountain study site (least invaded level).

Appendix B3.			
Table treat (T, treatmnt, source) Forage production by treatment year.			
	nochng.native	nochng.cheat	
Year01	0.71	0.23	
Year02	0.71	0.23	
Year03	0.71	0.23	
Year04	0.71	0.23	
Year05	0.71	0.23	
Year06	0.71	0.23	
Year07	0.71	0.23	
Year08	0.71	0.23	
Year09	0.71	0.23	
Year10	0.71	0.23	
Year11	0.71	0.23	
Year12	0.71	0.23	
Year13	0.71	0.23	
Year14	0.71	0.23	
Year15	0.71	0.23	
Year16	0.71	0.23	
Year17	0.71	0.23	
Year18	0.71	0.23	
Year19	0.71	0.23	
Year20	0.71	0.23	
Year21	0.71	0.23	
Year22	0.71	0.23	
Year23	0.71	0.23	
Year24	0.71	0.23	
Year25	0.71	0.23	
Year26	0.71	0.23	
Year27	0.71	0.23	
Year28	0.71	0.23	
Year29	0.71	0.23	
Year30	0.71	0.23	
Year31	0.71	0.23	
Year32	0.71	0.23	
Year33	0.71	0.23	
Year34	0.71	0.23	
Year35	0.71	0.23	
Year36	0.71	0.23	
Year37	0.71	0.23	
Year38	0.71	0.23	
Year39	0.71	0.23	
Year40	0.71	0.23	

;

Appendix C

GAMS include file for fire regimes
Fire01 to Fire100 (Fire Model)
Fire101 (No Fire Model)

Table fireint(T, fireyr)	Index of production following a fire.					
	Fire01	Fire02	Fire03	Fire04	Fire05	Fire06	Fire07
Year01	1	1	1	1	1	1	1
Year02	1	1	1	1	1	1	1
Year03	1	1	1	1	1	1	1
Year04	1	0	1	1	1	1	1
Year05	0	0	1	1	1	1	1
Year06	0	1	1	1	1	1	1
Year07	1	1	1	1	1	1	1
Year08	1	1	1	1	1	1	1
Year09	1	1	1	1	1	1	1
Year10	1	1	1	1	1	1	1
Year11	1	1	1	1	1	1	1
Year12	1	1	1	1	1	1	1
Year13	1	1	1	1	1	1	1
Year14	1	1	1	1	1	1	1
Year15	1	1	1	1	1	1	1
Year16	1	1	1	1	1	1	1
Year17	1	1	1	1	1	1	1
Year18	1	1	0	1	1	1	1
Year19	1	1	0	1	1	1	1
Year20	1	1	1	1	1	1	1
Year21	1	1	1	1	1	1	1
Year22	1	1	1	1	1	1	1
Year23	1	1	1	1	1	1	1
Year24	1	1	1	1	1	1	1
Year25	1	1	1	1	1	1	1
Year26	1	1	1	1	1	1	1
Year27	1	1	1	1	1	1	1
Year28	1	1	1	1	1	1	0
Year29	1	1	1	1	1	1	0
Year30	1	1	1	1	1	1	1
Year31	1	1	1	1	1	1	1
Year32	1	1	1	1	0	1	1
Year33	0	1	1	1	0	0	1
Year34	0	1	1	1	1	0	1
Year35	1	1	1	1	1	1	1
Year36	1	1	1	1	1	1	1
Year37	1	1	1	1	1	1	1
Year38	1	1	1	1	1	1	1
Year39	1	1	1	0	1	1	1
Year40	1	1	1	0	1	1	1

Table fireint(T, fireyr) (Continued)							
	Fire08	Fire09	Fire10	Fire11	Fire12	Fire13	Fire14
Year01	1	1	1	1	1	1	1
Year02	1	1	1	1	1	1	1
Year03	1	1	1	1	1	1	1
Year04	1	1	1	1	1	1	1
Year05	1	1	1	1	1	1	1
Year06	1	1	1	1	1	1	1
Year07	1	1	1	1	1	1	1
Year08	1	1	1	1	1	1	1
Year09	1	1	1	1	1	1	1
Year10	1	1	1	1	1	1	1
Year11	1	1	1	1	1	1	1
Year12	1	1	1	1	1	1	1
Year13	1	1	1	1	1	1	1
Year14	0	1	1	1	1	1	1
Year15	0	1	1	1	1	1	1
Year16	1	1	1	1	1	1	1
Year17	1	1	1	0	1	1	1
Year18	1	1	1	0	1	1	1
Year19	1	1	0	1	1	1	1
Year20	1	0	0	1	1	0	1
Year21	1	0	1	1	1	0	1
Year22	1	1	1	1	1	1	1
Year23	1	1	1	1	1	1	1
Year24	1	1	1	1	1	1	1
Year25	1	1	1	1	1	1	1
Year26	1	1	1	1	1	1	1
Year27	1	1	1	1	1	1	1
Year28	1	1	1	1	1	1	1
Year29	1	1	1	1	1	1	1
Year30	1	1	1	1	1	1	1
Year31	1	1	1	1	1	1	1
Year32	1	1	1	1	1	1	1
Year33	1	1	1	1	1	1	1
Year34	1	1	1	1	1	1	0
Year35	1	1	1	1	0	1	0
Year36	1	1	1	1	0	1	1
Year37	1	1	1	1	1	1	1
Year38	1	1	1	0	1	1	1
Year39	1	1	1	0	1	1	1
Year40	1	1	1	1	1	1	1

Table fireint(T, fireyr) (Continued)							
	Fire15	Fire16	Fire17	Fire18	Fire19	Fire20	Fire21
Year01	1	1	1	1	1	1	1
Year02	1	1	1	0	1	1	1
Year03	1	1	1	0	1	1	1
Year04	1	1	1	1	1	1	1
Year05	1	1	1	1	1	1	1
Year06	1	1	1	1	1	1	1
Year07	1	1	1	1	1	1	1
Year08	1	1	1	1	1	1	1
Year09	1	1	1	1	1	1	1
Year10	1	1	1	1	1	1	1
Year11	1	1	1	1	1	1	1
Year12	1	1	1	1	1	0	1
Year13	1	1	1	1	1	0	1
Year14	1	1	1	1	1	1	1
Year15	1	1	1	1	1	1	1
Year16	1	1	1	1	1	1	1
Year17	1	1	1	1	1	1	0
Year18	1	1	1	1	1	1	0
Year19	1	1	1	1	1	1	1
Year20	1	1	1	1	1	1	1
Year21	1	1	1	1	1	1	1
Year22	1	1	1	1	1	1	1
Year23	1	1	1	1	1	1	1
Year24	1	1	1	1	0	1	1
Year25	0	1	1	1	0	1	1
Year26	0	1	1	1	1	1	1
Year27	1	1	1	1	1	1	1
Year28	1	1	1	1	1	1	1
Year29	1	0	1	1	1	1	1
Year30	1	0	1	1	1	1	1
Year31	1	1	1	1	1	1	1
Year32	1	1	1	1	1	1	1
Year33	1	1	1	1	1	1	1
Year34	1	1	0	0	1	0	1
Year35	1	1	0	0	1	0	1
Year36	1	1	1	1	1	1	1
Year37	1	1	1	1	1	1	1
Year38	1	1	1	1	1	1	1
Year39	1	1	1	1	1	1	1
Year40	1	1	1	1	1	1	1

Table fireint(T, fireyr) (Continued)							
	Fire22	Fire23	Fire24	Fire25	Fire26	Fire27	Fire28
Year01	1	1	1	1	1	0	1
Year02	1	1	1	1	1	0	1
Year03	1	1	1	1	1	1	1
Year04	1	1	1	1	1	1	1
Year05	1	1	1	1	1	1	1
Year06	1	1	1	1	1	1	1
Year07	1	1	1	1	1	1	1
Year08	1	1	1	1	1	1	1
Year09	1	1	1	1	1	1	1
Year10	1	1	1	1	1	1	1
Year11	1	1	1	1	1	1	1
Year12	1	1	1	0	1	1	1
Year13	1	1	1	0	1	1	1
Year14	1	1	1	1	1	1	1
Year15	1	1	1	1	1	1	1
Year16	1	1	0	1	1	1	1
Year17	1	1	0	1	1	1	1
Year18	1	0	1	1	1	1	1
Year19	1	0	1	1	1	1	1
Year20	1	1	1	1	1	1	1
Year21	1	1	1	1	1	1	1
Year22	1	1	1	1	1	1	1
Year23	1	1	1	1	1	1	1
Year24	1	1	1	1	1	1	1
Year25	1	1	1	1	1	1	1
Year26	1	1	1	1	1	1	1
Year27	1	1	1	1	1	0	1
Year28	1	1	1	1	1	0	1
Year29	1	1	1	1	1	1	1
Year30	0	1	1	1	1	1	1
Year31	0	1	1	1	1	1	1
Year32	1	1	1	1	1	1	0
Year33	1	1	1	1	1	1	0
Year34	1	1	1	1	1	1	1
Year35	1	1	1	1	1	1	1
Year36	1	1	1	1	1	1	1
Year37	1	1	1	1	0	1	1
Year38	1	1	1	1	0	1	1
Year39	1	1	1	1	1	1	1
Year40	1	1	1	1	1	1	1

Table fireint(T, fireyr) (Continued)							
	Fire29	Fire30	Fire31	Fire32	Fire33	Fire34	Fire35
Year01	1	1	1	1	1	1	1
Year02	1	1	1	1	1	1	1
Year03	1	1	1	1	1	0	1
Year04	1	1	1	1	0	0	1
Year05	1	1	1	1	0	1	1
Year06	1	1	1	1	1	1	1
Year07	1	1	1	1	1	1	1
Year08	1	1	1	1	1	1	1
Year09	1	1	1	1	1	1	1
Year10	1	1	1	1	1	1	1
Year11	1	1	1	1	1	1	1
Year12	1	1	1	1	1	1	1
Year13	1	1	1	1	1	1	1
Year14	1	1	1	1	1	1	1
Year15	1	1	1	1	1	1	1
Year16	1	1	1	1	1	1	1
Year17	1	1	0	1	1	1	1
Year18	1	1	0	1	1	1	1
Year19	1	1	1	1	1	1	1
Year20	1	1	1	1	1	1	1
Year21	0	1	1	1	1	1	1
Year22	0	1	1	1	1	1	1
Year23	1	1	1	1	1	1	1
Year24	1	1	1	1	1	1	1
Year25	1	1	1	1	1	1	1
Year26	1	1	1	1	1	1	1
Year27	1	1	1	0	1	1	1
Year28	1	1	1	0	1	1	1
Year29	1	1	1	1	1	1	1
Year30	1	1	1	1	1	1	1
Year31	1	1	1	1	1	1	1
Year32	1	1	1	1	1	1	1
Year33	1	1	1	1	1	0	1
Year34	1	1	1	1	1	0	1
Year35	1	1	1	1	1	1	1
Year36	1	1	1	1	1	1	1
Year37	1	1	1	1	1	1	1
Year38	1	0	1	1	0	1	1
Year39	1	0	1	1	0	1	0
Year40	1	1	1	1	1	1	0

Table fireint(T, fireyr) (Continued)							
	Fire36	Fire37	Fire38	Fire39	Fire40	Fire41	Fire42
Year01	1	1	1	1	1	1	1
Year02	1	1	1	1	1	1	1
Year03	1	1	0	1	1	1	1
Year04	1	1	0	1	1	1	1
Year05	1	1	1	1	1	1	1
Year06	1	1	1	1	1	1	1
Year07	1	1	1	1	1	1	1
Year08	1	1	1	1	1	1	1
Year09	1	1	1	1	1	1	1
Year10	1	1	1	1	1	1	1
Year11	1	1	1	1	1	1	1
Year12	1	0	1	1	1	1	1
Year13	1	0	1	1	1	1	1
Year14	1	1	1	1	1	1	1
Year15	1	1	1	1	1	1	1
Year16	1	1	1	1	1	1	1
Year17	1	1	1	1	1	1	1
Year18	1	1	1	1	1	1	1
Year19	1	1	1	0	1	1	1
Year20	1	1	1	0	1	1	1
Year21	1	1	1	1	1	1	1
Year22	1	1	1	1	1	1	1
Year23	1	1	1	1	1	1	1
Year24	1	1	1	1	1	1	1
Year25	1	1	1	1	1	1	1
Year26	1	1	1	1	1	0	1
Year27	1	1	1	1	1	0	1
Year28	1	1	1	1	1	1	1
Year29	1	1	1	1	1	1	1
Year30	1	1	0	1	1	1	1
Year31	1	1	0	1	1	1	1
Year32	1	1	1	1	1	1	1
Year33	1	1	1	1	1	1	1
Year34	1	1	1	1	1	1	1
Year35	1	1	1	1	0	1	1
Year36	0	1	1	1	0	1	1
Year37	0	1	1	1	1	1	1
Year38	1	1	1	1	1	1	0
Year39	1	1	1	1	1	1	0
Year40	1	1	1	1	1	1	1

Table fireint(T, fireyr) (Continued)							
	Fire43	Fire44	Fire45	Fire46	Fire47	Fire48	Fire49
Year01	1	1	1	1	1	1	1
Year02	1	1	1	1	1	1	1
Year03	1	1	1	1	1	1	1
Year04	1	1	0	1	1	1	1
Year05	1	1	0	1	1	1	1
Year06	1	1	1	1	1	1	1
Year07	1	1	1	1	1	1	1
Year08	1	1	1	1	1	1	1
Year09	1	1	1	1	1	1	1
Year10	1	1	1	1	1	1	1
Year11	1	1	1	1	1	1	1
Year12	1	1	1	1	1	1	1
Year13	1	1	1	1	1	1	0
Year14	1	1	1	1	1	1	0
Year15	1	1	1	1	1	1	1
Year16	1	1	1	1	1	1	1
Year17	1	1	1	1	1	1	1
Year18	1	1	1	1	0	1	1
Year19	1	1	1	1	0	0	1
Year20	1	1	1	1	1	0	1
Year21	0	1	1	1	1	1	1
Year22	0	1	1	1	1	1	1
Year23	1	1	1	1	1	1	1
Year24	1	1	1	1	1	1	1
Year25	1	1	1	1	1	1	1
Year26	1	1	1	1	1	1	1
Year27	1	1	1	1	1	1	1
Year28	1	1	1	1	1	1	1
Year29	1	0	1	1	1	1	1
Year30	1	0	1	0	1	1	1
Year31	1	1	1	0	1	1	1
Year32	1	1	1	1	1	1	1
Year33	1	1	0	1	1	1	1
Year34	1	1	0	1	1	1	1
Year35	1	1	1	1	1	1	1
Year36	1	1	1	1	1	1	1
Year37	1	1	1	1	1	1	1
Year38	1	1	1	1	1	1	1
Year39	1	1	1	1	1	1	1
Year40	1	1	1	1	1	1	1

Table fireint(T, fireyr) (Continued)							
	Fire50	Fire51	Fire52	Fire53	Fire54	Fire55	Fire56
Year01	1	1	1	1	1	1	1
Year02	1	1	1	1	1	1	1
Year03	1	1	1	1	1	1	1
Year04	1	1	1	1	1	1	1
Year05	1	1	1	1	1	1	1
Year06	1	1	1	1	1	1	1
Year07	1	1	1	1	1	1	1
Year08	1	1	1	1	1	1	1
Year09	1	1	1	1	1	1	1
Year10	1	1	1	1	1	1	1
Year11	1	0	1	1	1	1	1
Year12	1	0	1	1	1	1	1
Year13	1	1	1	1	1	1	1
Year14	1	1	1	1	1	1	1
Year15	1	1	1	1	1	1	1
Year16	1	1	1	1	1	0	1
Year17	1	1	1	1	1	0	1
Year18	1	1	1	1	1	1	1
Year19	1	1	1	1	1	1	1
Year20	1	1	1	1	1	1	1
Year21	1	1	1	1	1	1	1
Year22	1	1	0	1	1	1	1
Year23	1	1	0	1	1	1	1
Year24	1	1	1	1	1	1	1
Year25	1	1	1	1	1	1	1
Year26	1	1	1	1	1	1	1
Year27	1	1	1	1	1	1	1
Year28	1	1	1	1	1	1	1
Year29	1	1	1	1	1	1	1
Year30	0	1	1	1	1	1	1
Year31	0	1	1	1	0	1	1
Year32	1	1	1	1	0	1	1
Year33	1	1	1	0	1	1	0
Year34	1	1	1	0	1	1	0
Year35	1	1	1	1	1	1	1
Year36	1	1	1	1	1	1	1
Year37	1	1	1	1	1	1	1
Year38	1	0	1	1	1	1	1
Year39	1	0	1	1	1	1	1
Year40	1	1	1	1	1	0	1

Table fireint(T, fireyr) (Continued)							
	Fire57	Fire58	Fire59	Fire60	Fire61	Fire62	Fire63
Year01	1	1	1	1	1	1	1
Year02	1	1	1	1	1	1	1
Year03	1	1	1	1	1	1	1
Year04	1	1	1	1	1	1	1
Year05	1	1	1	1	1	1	1
Year06	1	1	1	1	1	1	1
Year07	1	1	1	1	1	1	0
Year08	1	1	1	1	1	1	0
Year09	1	1	1	1	1	1	1
Year10	1	1	1	1	1	1	1
Year11	1	1	1	1	1	1	1
Year12	1	1	1	1	1	1	1
Year13	1	1	1	1	1	1	1
Year14	1	1	1	1	1	1	1
Year15	1	1	1	1	1	1	1
Year16	1	1	1	1	1	1	1
Year17	1	0	1	1	1	1	1
Year18	1	0	1	1	1	1	1
Year19	1	1	1	1	1	1	1
Year20	1	1	1	1	1	1	1
Year21	1	1	1	1	1	1	1
Year22	1	1	1	1	1	1	1
Year23	1	1	1	1	1	1	1
Year24	1	1	1	1	1	1	1
Year25	0	1	1	1	1	1	1
Year26	0	1	1	0	1	0	1
Year27	1	1	1	0	0	0	1
Year28	1	1	1	1	0	1	1
Year29	1	1	1	1	1	1	1
Year30	1	1	1	1	1	1	1
Year31	1	1	1	1	1	1	1
Year32	1	1	1	1	1	1	1
Year33	1	1	1	1	1	1	1
Year34	1	1	1	1	1	1	1
Year35	1	1	0	1	1	1	1
Year36	1	1	0	1	1	1	1
Year37	1	1	1	1	1	1	1
Year38	1	1	1	1	1	1	1
Year39	1	1	1	1	1	1	1
Year40	1	1	1	1	1	1	0

Table fireint(T, fireyr) (Continued)							
	Fire64	Fire65	Fire66	Fire67	Fire68	Fire69	Fire70
Year01	1	1	1	1	1	1	1
Year02	1	1	1	1	1	1	1
Year03	1	1	1	1	1	1	1
Year04	1	1	1	0	1	1	1
Year05	1	1	1	0	1	1	1
Year06	1	1	1	1	1	1	1
Year07	1	1	1	1	1	1	1
Year08	1	1	1	1	1	1	1
Year09	1	1	1	1	1	1	1
Year10	1	1	1	1	1	1	1
Year11	1	1	0	1	1	1	1
Year12	1	1	0	1	1	1	1
Year13	1	1	1	1	1	1	1
Year14	1	1	1	1	1	1	1
Year15	1	1	1	1	1	1	1
Year16	1	1	1	1	1	1	0
Year17	0	1	1	1	1	1	0
Year18	0	1	1	1	0	1	1
Year19	1	1	1	1	0	1	1
Year20	1	1	1	1	1	1	1
Year21	1	1	1	1	1	1	1
Year22	1	1	1	1	1	1	1
Year23	1	1	1	1	1	1	1
Year24	1	1	1	1	1	1	1
Year25	1	1	1	1	1	1	1
Year26	1	1	1	1	1	1	1
Year27	1	1	1	1	1	1	1
Year28	1	1	1	1	1	1	1
Year29	1	1	1	1	1	1	1
Year30	1	1	1	1	1	0	1
Year31	1	0	1	1	1	0	1
Year32	1	0	0	1	1	1	1
Year33	1	1	0	1	1	1	1
Year34	1	1	1	1	1	1	1
Year35	1	1	1	1	1	1	1
Year36	1	1	1	1	1	1	1
Year37	0	1	1	0	1	1	1
Year38	0	1	1	0	1	1	1
Year39	1	1	1	1	1	1	1
Year40	1	1	1	1	1	1	1

Table fireint(T, fireyr) (Continued)							
	Fire71	Fire72	Fire73	Fire74	Fire75	Fire76	Fire77
Year01	1	1	1	1	1	1	1
Year02	1	1	1	1	1	1	1
Year03	0	1	0	1	1	1	1
Year04	0	1	0	1	1	1	1
Year05	1	1	1	1	1	1	1
Year06	1	1	1	1	1	1	1
Year07	1	1	1	1	1	1	1
Year08	1	1	1	1	1	1	1
Year09	1	1	1	1	1	1	1
Year10	1	1	1	1	1	1	1
Year11	1	1	1	1	1	0	1
Year12	1	1	1	1	1	0	1
Year13	1	1	1	1	1	1	1
Year14	1	1	1	1	1	1	1
Year15	1	1	1	1	1	1	1
Year16	1	1	1	1	1	1	1
Year17	1	1	1	1	1	1	1
Year18	1	1	1	1	1	1	1
Year19	1	1	1	1	1	1	1
Year20	1	1	1	1	1	1	1
Year21	1	1	1	1	1	1	1
Year22	1	1	1	1	1	1	1
Year23	1	1	1	0	1	1	1
Year24	1	1	1	0	1	1	1
Year25	1	1	1	1	1	1	1
Year26	0	1	1	1	1	1	1
Year27	0	1	1	1	1	1	1
Year28	1	1	1	1	1	1	1
Year29	1	1	0	1	1	1	1
Year30	1	1	0	1	1	1	0
Year31	1	0	1	1	1	1	0
Year32	1	0	1	1	1	1	1
Year33	1	1	1	1	1	1	1
Year34	1	1	1	1	1	1	1
Year35	1	1	1	1	1	1	1
Year36	1	1	1	1	1	1	1
Year37	1	1	1	1	0	1	1
Year38	1	1	1	1	0	1	1
Year39	1	1	1	1	1	1	1
Year40	1	1	1	1	1	1	1

Table fireint(T, fireyr) (Continued)							
	Fire78	Fire79	Fire80	Fire81	Fire82	Fire83	Fire84
Year01	1	1	1	1	1	1	1
Year02	1	1	1	1	1	1	1
Year03	1	1	1	1	1	0	1
Year04	1	1	1	1	1	0	1
Year05	1	1	1	1	1	1	1
Year06	1	1	1	1	0	1	1
Year07	0	1	1	1	0	1	1
Year08	0	1	1	1	1	1	1
Year09	1	1	1	1	1	1	1
Year10	1	1	1	1	1	1	1
Year11	1	1	1	1	1	1	1
Year12	1	1	1	1	1	1	1
Year13	1	1	1	1	1	1	1
Year14	1	1	1	1	1	1	1
Year15	1	0	1	1	1	1	0
Year16	1	0	1	1	1	1	0
Year17	1	1	1	1	1	1	1
Year18	1	1	1	1	1	1	1
Year19	1	1	1	1	1	1	1
Year20	1	1	1	0	1	1	1
Year21	1	1	1	0	1	1	1
Year22	1	1	1	1	1	1	1
Year23	1	1	1	1	1	1	1
Year24	1	1	1	1	1	1	1
Year25	1	1	1	1	1	1	1
Year26	1	1	1	1	0	1	1
Year27	1	1	1	1	0	1	1
Year28	1	1	1	1	1	1	1
Year29	1	1	1	1	1	1	1
Year30	1	1	1	1	1	1	1
Year31	1	1	1	1	1	1	1
Year32	1	1	1	1	1	1	1
Year33	1	1	1	1	1	1	1
Year34	1	1	1	1	1	0	1
Year35	1	1	1	1	1	0	1
Year36	1	1	1	1	1	1	1
Year37	1	1	0	1	1	1	0
Year38	1	1	0	1	1	1	0
Year39	1	1	1	1	1	1	1
Year40	1	1	1	1	1	1	1

Table fireint(T, fireyr) (Continued)							
	Fire85	Fire86	Fire87	Fire88	Fire89	Fire90	Fire91
Year01	1	1	1	1	1	1	1
Year02	1	1	1	1	1	1	1
Year03	1	1	1	1	1	1	1
Year04	1	1	1	1	1	1	1
Year05	1	1	1	1	1	1	1
Year06	1	1	1	1	1	1	1
Year07	1	1	1	1	1	1	1
Year08	1	1	1	1	1	1	1
Year09	1	1	1	1	1	1	1
Year10	1	1	1	1	1	1	1
Year11	1	1	1	1	1	1	1
Year12	1	1	1	1	1	1	1
Year13	1	1	1	1	1	1	1
Year14	1	1	1	1	1	1	1
Year15	1	1	1	1	1	1	1
Year16	1	1	1	1	0	1	1
Year17	1	1	1	1	0	0	1
Year18	1	1	1	1	1	0	1
Year19	1	1	1	1	1	1	1
Year20	1	1	1	1	1	1	1
Year21	1	1	1	1	1	1	0
Year22	0	1	1	1	1	1	0
Year23	0	1	1	0	1	1	1
Year24	1	1	1	0	1	1	1
Year25	1	1	1	1	1	1	1
Year26	1	1	1	1	1	1	1
Year27	1	1	1	1	1	1	1
Year28	1	1	1	1	1	1	1
Year29	1	1	1	1	1	1	1
Year30	1	1	1	1	1	1	1
Year31	1	1	1	1	1	1	1
Year32	1	0	1	1	1	1	1
Year33	1	0	1	1	1	1	1
Year34	1	1	1	1	1	1	1
Year35	1	1	1	1	1	1	1
Year36	1	1	1	1	1	1	1
Year37	1	1	1	1	1	1	1
Year38	1	1	0	1	1	0	1
Year39	1	1	0	1	1	0	1
Year40	1	1	1	1	1	1	1

Table fireint(T, fireyr) (Continued)							
	Fire92	Fire93	Fire94	Fire95	Fire96	Fire97	Fire98
Year01	1	1	1	1	1	1	1
Year02	1	1	1	1	1	1	1
Year03	1	1	1	1	1	1	1
Year04	1	1	1	1	1	1	1
Year05	1	1	1	1	1	1	1
Year06	1	1	1	1	1	1	0
Year07	1	1	1	1	1	1	0
Year08	1	1	1	1	1	1	1
Year09	1	1	1	1	1	1	1
Year10	1	1	1	1	1	1	1
Year11	1	1	1	1	1	1	1
Year12	1	1	1	1	1	1	1
Year13	1	1	1	1	1	1	1
Year14	1	1	1	1	1	1	1
Year15	0	1	1	1	1	1	1
Year16	0	1	1	1	1	1	1
Year17	1	1	1	1	1	1	1
Year18	1	1	1	1	1	1	1
Year19	1	1	0	1	1	1	1
Year20	1	1	0	1	1	1	1
Year21	1	1	1	1	1	1	1
Year22	1	1	1	1	1	1	1
Year23	1	1	1	0	1	0	1
Year24	1	1	1	0	1	0	1
Year25	1	1	1	1	1	1	1
Year26	1	1	1	1	1	1	1
Year27	1	1	1	1	1	1	1
Year28	1	1	1	1	1	1	1
Year29	1	1	1	1	1	1	1
Year30	1	0	1	1	1	1	1
Year31	1	0	1	1	1	1	1
Year32	1	1	1	1	1	1	1
Year33	1	1	1	1	1	1	1
Year34	1	1	1	1	1	1	1
Year35	1	1	1	1	0	1	0
Year36	0	1	1	1	0	1	0
Year37	0	1	1	1	1	1	1
Year38	1	1	1	1	1	1	1
Year39	1	1	1	1	1	1	1
Year40	1	1	1	1	1	1	1

Table fireint(T, fireyr) (Continued)						
	Fire99	Fire100	Fire101			
Year01	1	1	1			
Year02	1	1	1			
Year03	1	1	1			
Year04	1	1	1			
Year05	1	0	1			
Year06	1	0	1			
Year07	1	1	1			
Year08	0	1	1			
Year09	0	1	1			
Year10	1	1	1			
Year11	1	1	1			
Year12	1	1	1			
Year13	1	1	1			
Year14	1	1	1			
Year15	1	1	1			
Year16	1	1	1			
Year17	1	1	1			
Year18	1	1	1			
Year19	1	1	1			
Year20	1	1	1			
Year21	1	1	1			
Year22	1	1	1			
Year23	1	1	1			
Year24	1	1	1			
Year25	1	1	1			
Year26	1	1	1			
Year27	1	0	1			
Year28	1	0	1			
Year29	1	1	1			
Year30	1	1	1			
Year31	1	1	1			
Year32	1	1	1			
Year33	1	1	1			
Year34	1	1	1			
Year35	1	1	1			
Year36	1	1	1			
Year37	1	1	1			
Year38	1	1	1			
Year39	1	1	1			
Year40	1	1	1			

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Appendix D

GAMS include file for sales prices

high (Iter001), average (Iter002), and low (Iter003) table salep(iter, T, livclass) Sale prices of sale animals at Year T

		bull	Scalf	Hcalf	Hyear	buybcow	cullcow
ITER001.	Year01	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year02	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year03	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year04	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year05	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year06	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year07	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year08	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year09	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year10	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year11	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year12	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year13	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year14	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year15	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year16	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year17	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year18	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year19	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year20	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year21	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year22	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year23	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year24	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year25	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year26	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year27	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year28	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year29	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year30	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year31	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year32	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year33	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year34	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year35	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year36	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year37	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year38	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year39	63.96	113.41	111.85	87.68	863.41	50.65
ITER001.	Year40	63.96	113.41	111.85	87.68	863.41	50.65

table salep(iter, T, livclass) (Continued)

ITER002.	Year01	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year02	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year03	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year04	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year05	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year06	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year07	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year08	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year09	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year10	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year11	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year12	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year13	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year14	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year15	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year16	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year17	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year18	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year19	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year20	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year21	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year22	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year23	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year24	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year25	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year26	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year27	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year28	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year29	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year30	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year31	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year32	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year33	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year34	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year35	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year36	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year37	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year38	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year39	54.50	96.40	92.60	75.82	704.23	42.98
ITER002.	Year40	54.50	96.40	92.60	75.82	704.23	42.98
ITER003.	Year01	45.03	79.39	73.34	63.96	545.04	35.30

table salep(iter, T, livclass) (Continued)

ITER003.	Year02	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year03	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year04	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year05	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year06	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year07	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year08	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year09	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year10	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year11	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year12	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year13	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year14	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year15	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year16	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year17	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year18	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year19	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year20	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year21	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year22	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year23	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year24	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year25	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year26	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year27	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year28	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year29	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year30	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year31	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year32	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year33	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year34	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year35	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year36	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year37	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year38	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year39	45.03	79.39	73.34	63.96	545.04	35.30
ITER003.	Year40	45.03	79.39	73.34	63.96	545.04	35.30