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OPTIMUM CONCENTRATION OF ASHE JUNIPER IN THE EDWARDS PLATEAU OF TEXAS

by

KOLADO BOCOUM, B.S., M.S.

A THESIS IN AGRICULTURAL AND APPLIED ECONOMICS

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CHAPTER I

PROBLEM STATEMENT

General problem

Livestock and deer enterprises are important economic activities in Texas. Texas leads the nation in the number of cattle and calves, number of beef cows, number of fed cattle marketed, number of sheep and lambs, number of angora goats, wool production and mohair production (Texas Agricultural Statistics, 1994). In addition, Texas deer population was estimated at 4.2 million in 1986. The Edwards Plateau region, which has the greatest concentration of white-tailed deer in North America, accounts for 48% of the state's deer population (Texas Parks and Wildlife Department, 1995).

The amount of cash receipts indicates the importance of the range livestock industry to the state economy. In 1994, livestock and livestock products accounted for $8.23 billion of cash receipts representing 61.3% of the cash receipts of all agricultural commodities (Texas Agricultural Statistics Service, 1994). Although the value of wildlife cannot be precisely calculated, the contribution of white-tailed deer alone to rural land values in Texas is estimated at approximately $4.2 billion. The 1981 revenues from deer were estimated to be between $100 million to over $350 million, or 3.5% of the total cash receipts from agricultural production in Texas in 1981 (Pope et al., 1984).

The contributions of livestock and deer to the state economy are possible because of the availability of an important rangeland resource consisting of 46 million hectares (ha.), representing 66% of the total acreage of Texas and 72% of all rural lands in Texas

(U.S. Department of Agriculture (USDA), 1990). However, Texas ranchers face a major problem caused by brush infestation. Surveys conducted by the USDA reveal that millions of acres of grazing lands are heavily infested with woody plants, reducing nutritious forage production and making the range unprofitable for livestock grazing. In 1964, 35.8 million ha, representing 82% of Texas grasslands, were infested with one or more brush species (USDA, 1964). The infested area has increased in spite of extensive control measures. In 1982, the Texas Brush Inventory (TBI), conducted by the National Resource Conservation Service (NRCS), indicated that 41 million ha of rangelands were infested with 50 noxious brush species (USDA, 1988), corresponding to a 12% increase when compared to the 1964 survey. The level of infestation ranged from light (1-10% canopy cover) on 11 million ha, to moderate (11-30% canopy cover) on 16 million ha, to dense (31-100% canopy cover) on 14 million ha (USDA, 1988).

Ashe juniper infestations are among the most difficult problems facing Texas ranchers. Table 1 indicates that 3.1 and 2.7 million ha of Ashe juniper infested rangelands existed in Texas in 1982 and 1987, respectively. Ashe juniper has low forage value, with negative effects on palatability and metabolic processes of most animals. It can significantly alter the composition and structure of rangeland plant communities and become a dominant plant in nearly all sites (Smeins et al., 1994). When Ashe juniper cover increases to a critical threshold, there is a corresponding decrease in animal carrying capacity caused by a reduction in both herbaceous forage production and available grazing space. The increase in brush infestations results not only in reduced grass production, but also in higher consumption of soil and water resources to the detriment of grass and other

Table 1. Ashe juniper infestations in 1982 and 1987 (million ha)

Regions	1982	%	1987	%
Edwards Plateau	2.195	71	2.090	77
Central Basin	0.183	6	0.115	4
West Cross Timbers	0.064	2	0.048	2
East Cross Timbers	0.025	1	0.024	1
Grand Prairie	0.613	20	0.446	16
Total	3.080	100	2.723	100

Source: Texas Soil and Water Conservation Board, 1991

range plants. Research in Arizona has shown that mesquite trees use about 1,725 pounds of water to grow one pound of dry matter, whereas sideoats grama, one of Texas most widespread and better forage grasses uses only about 705 pounds of water per pound of dry matter. It is estimated that brush, cacti, and weeds in Texas account for about 40% of the state's total water use (USDA, 1964). Brushy ranges are nearly always in drought conditions. Therefore, little quality forage is produced on these areas. Ranchers are faced with high feed bills, livestock death losses, low weight gains, and declining profitability. Research indicates that with no juniper growing in pastures one animal-unit could be stocked per 7.4 ha, but at 50% canopy cover it would take 12.3 ha to produce forage for that animal unit (Rowan and Conner, 1994).

However, brush density is also associated with wildlife improvement. Canopy cover reduction can negatively impact white-tailed deer (Rollins et al., 1988). Some brush species such as Ashe juniper can be a dependable source of protein, energy and other nutrients during winter for deer and some species of livestock. Ashe juniper can provide animal protection from weather by reducing the effects of wind and rain (Hudson et al., 1994).

The effects of Ashe juniper invasions are particularly important on the Edwards Plateau of Texas. This region, as shown in Figure 1, is located in southwest Texas. The Edwards Plateau accounted for 71% and 77% of Ashe juniper infestations in 1982, and 1987, respectively (Texas Soil and Water Conservation Board, 1991). The Edwards Plateau, which was originally predominantly grassland, has changed to predominantly woodland. By 1964, 51% of the land area was occupied by brush with canopy cover in

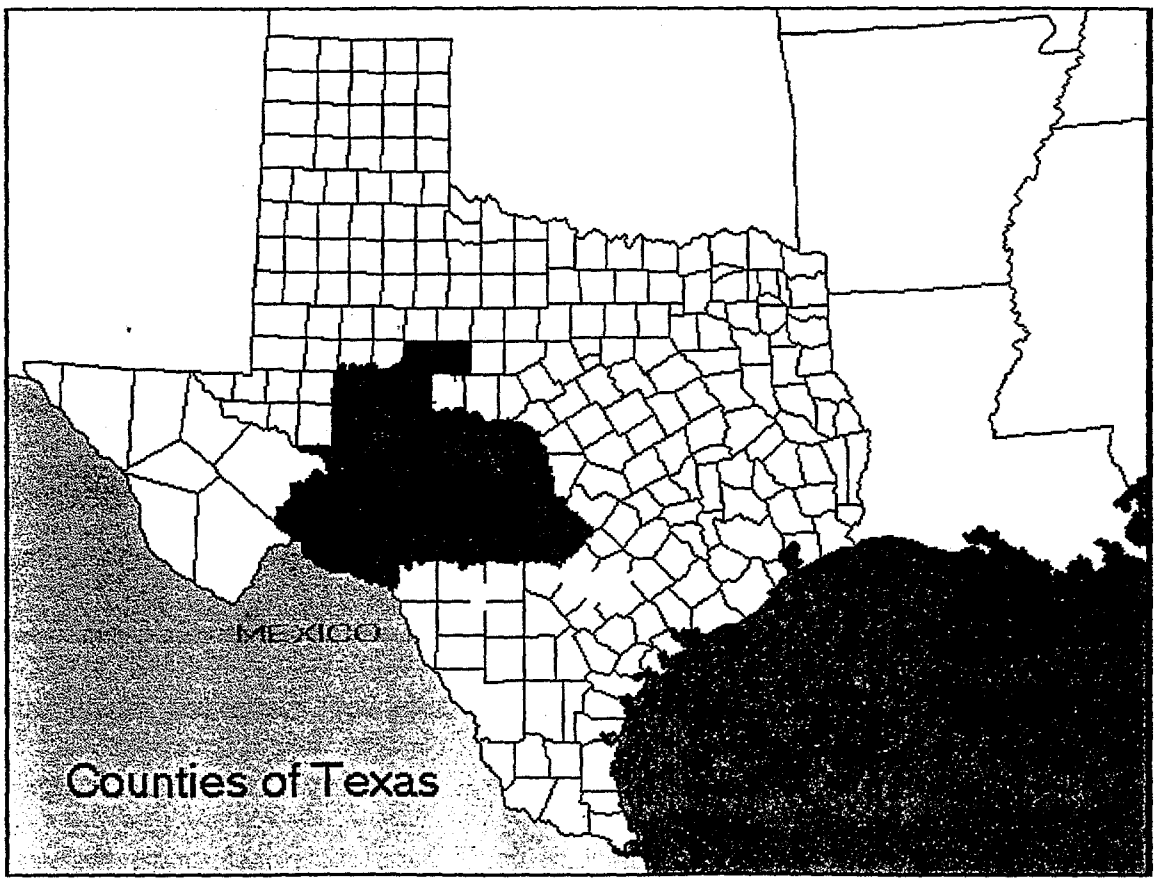

Figure 1. The Edwards Plateau of Texas

excess of 20% (Rollins et al., 1988). Many factors have favored this invasion, including the nature of the land, the stocking rate with domestic animals, and the suppression of fire (Smeins, 1990).

The brush encroachment problem has resulted in the suppression of grass production to the point where little improvement in livestock production can be expected without range restoration and reduction of the brush competition. Many methods are used to control Ashe juniper including mechanical methods (hand-slashing, chaining, tree dozing or grubbing, root plowing), fire control, and herbicidal control. In 1988, 566,000 ha of land were treated with mechanical and chemical control (Welch, 1989). The use of prescribed burning as a method for brush and weed control has averaged 117,000 ha per year over the period 1980 to 1988 (Johnson and Ethridge, 1995). Deciding upon the type of control method is not exclusively an economic question. Biological limitations such as tree size and age are also involved in the selection of brush control method.

Brush control has improved the brush situation in Texas, particularly with regard to moderate and dense infestations, despite a slight increase in the total infested area. In fact, Ashe juniper infested areas decreased by 13% between 1982 and 1987 (Texas Soil and Water Conservation Board, 1991). The distribution of "cedar" (redberry juniper, Ashe juniper, and eastern cedar) between 1964 and 1982 indicates that light infestations increased from 3.97 million ha in 1964 to 5.95 million ha in 1982, while moderate and dense infestations decreased from 4.73 million ha to 2.83 million ha (USDA, 1964, 1988).

Specific problem

The specific problem ranchers face is to optimize the level of brush control, considering the costs involved in removing the initial brush and maintaining high productivity of the range. Clearing operations undertaken in the past were most often aimed at improving herbaceous production for livestock benefits. Several studies have shown that herbaceous production will increase following brush reduction, despite the fact that little is known about the rate of growth of the brush over time. Aro (1971) reported that burned areas produced 300% more herbage than controlled areas following burning of piñon juniper in the South West. Ashe juniper removal by chaining produced an increase in the standing crop of grass to 657 kg/ha compared to 424 kg/ha on untreated areas (Rollins, 1983). These studies found that brush control may be beneficial to livestock production. Ethridge et al. (1985) reported an additional present value of $36.16/ha and an additional cost of $10-12.5/ha following prescribed burning on tobossagrass in the Rolling Plains region of Texas. Carpenter et al. (1991) indicate that control of moderate and heavy infestations of broom snakeweed are generally economically feasible, and that benefits from livestock efficiency gains are generally greater than the value of increased grass production. Thus, the pattern of brush control to improve livestock production considers removing substantial amounts of brush to insure maximum grass and livestock production.

Other studies have found that brush control may be beneficial to wildlife. Ramsey (1965) shows that potential economic returns from deer may be higher than from livestock on the Edwards Plateau of Texas. Glover and Conner (1988) used a linear programming

model to maximize net income in selecting optimal combinations of livestock and deer lease-hunting enterprises on the Edwards Plateau of Texas. The analysis was made using four different deer leasing models: Model I (no deer lease hunting), Model II (no services and facilities lease), Model III (facilities and services), and Model IV (services, facilities, and deer population control). Their results showed that Model IV had the highest net income with a smaller number of deer in the optimal solution. Whitson et al. (1977) indicated that 80% brush treatment and complete brush treatment with aerial sprays of 2,4,5-T and picloram at 1 lb/ac. would be economically feasible, based on returns for lease hunting of white tailed-deer in conjunction with livestock production.

Rollins et al. (1988) showed that 50% to 70% would be the most appropriate Ashe juniper removal for maximizing deer production, but the study did not use economic criteria. The study on brush control to improve deer production suggested that the level of brush canopy cover that will yield maximum production should be within a certain range. Contrary to the level of canopy cover required for maximum livestock production, higher deer production results from a level of canopy cover sufficient enough to provide deer with food and cover for protection, yet not too dense to prevent freedom of movement.

Since increased livestock production and maintenance of white-tailed deer populations may be inversely related when brush control exceeds threshold requirements for adequate wildlife habitats, there is a trade-off between livestock and deer production. Most studies in relation to the brush control optimization problem have either focused on livestock benefits or on wildlife benefits. Few have been concerned about brush

optimization from the perspective of both livestock and wildlife benefits. In most cases, the analyses did not concern Ashe juniper control. The estimated production did not take into account many factors affecting livestock and deer production such as the amount of precipitation, the grazing system, and the nature of range sites. In addition, the production relationships did not account for the effects of the evolution of the brush content over time. The studies also did not specifically address the optimum level of brush control when considering the benefits of both livestock and wildlife.

Objectives

General objective

The overall objective of this study is to determine the optimum level of Ashe juniper canopy cover for the production of livestock and deer on the Edwards Plateau region of Texas to maximize both livestock and wildlife returns.

Specific objectives

The specific objectives are to:

1. Estimate grass, livestock, and white-tailed deer response functions to Ashe juniper canopy cover,

2. Determine the optimum level of Ashe juniper canopy cover to maximize livestock and deer returns, and

3. Analyze the effects of changes in livestock and deer prices on the optimum level of Ashe juniper canopy cover.

CHAPTER II

LITERATURE REVIEW

This section presents an overview of prior research related to brush control, focusing particularly on Ashe juniper. To better understand the relevance of this research to this study, the review is divided into three parts. Part 1 addresses research on the effectiveness of brush control methods. Part 2 outlines studies on the physical and biological relationships between Ashe juniper canopy cover and herbaceous production, and between Ashe juniper canopy cover and wildlife development. Part 3 presents economic research on brush control.

Effectiveness of control methods

The reduction of brush competition and range restoration involve controlling the undesirable brush, re-establishing the desirable plants, controlling the sprouts and re-infestation of brush species, and managing the grass to maintain grasslands in a state of high productivity. Several methods are used to control Ashe juniper, including mechanical methods (hand-slashing, chaining, tree dozing or grubbing, root plowing), fire control, and herbicidal control.

Effectiveness of mechanical control

Because of the growth characteristics of Ashe juniper, mechanical control has been the traditional method of controlling this brush species in Texas (Ueckert et al.,

1994). Different types of mechanical treatments are used according to brush density. However, chaining and tree dozing are the most widely used methods. Rollins (1983) conducted a study on the effect of double chaining on Ashe juniper infested rangelands located in northwestern Kerr County in the Edwards Plateau Region of Texas. The results indicate that total brush canopy cover was reduced by 81% compared to untreated sites as a result of restricted root depths and excellent soil moisture conditions, with Ashe juniper reduced by 93%. Trees greater than 2m tall were uprooted by the first pass of the chain, but trees less than 1.5m in height were not uprooted. In addition, the lowest juniper reduction (81%) was observed in rocky pastures. These results suggest that the effectiveness of this type of control depends on soil moisture conditions and size composition of junipers.

Research indicates that mechanical brush control is a costly operation, with increasing levels of canopy cover corresponding to higher control cost. Chaining at 16% canopy cover costs $82/ha, while dozing used at 32% canopy cover costs $122/ha (Rowan and Conner, 1994). This indicates that brush management decisions are influenced by the type of the control method used.

Effectiveness of herbicide control

Chemical treatment has not been commonly used for Ashe juniper control in South Texas until recently, with the advent of herbicides such as picloram. Herbicide control of juniper in Texas is limited to individual plant treatment. Ashe and redberry junipers can both be controlled with high volume foliar sprays containing 0.5% picloram applied at 2-4

ml/90 cm of shrub height beneath the shrub canopy. Ueckert et al. (1994) indicates that in the western Edwards Plateau, 10 ml of picloram per 90 cm of canopy height killed 82% of redberry junipers less than 1.8m tall and 65% of those over 1.8m tall

Effectiveness of fire control

Lack of fire is a commonly accepted cause for the spread of Ashe juniper into grassland areas. Prescribed burning can be useful for controlling the initial invasion of juniper seedlings into grass lands. It can also be effectively used following chaining or tree dozing. This method is rarely used on rangelands supporting high densities of mature junipers because competition from the junipers prevent production of enough grass (fine fuel) to carry a fire of sufficient intensity to kill woody plants (Ueckert et al., 1994). These authors also indicate that the first fire should be 3 to 5 years following mechanical treatment and subsequent repeat burns should be on an 8 to 10 year cycle before the seedlings exceed 1.2m in height. Successful burning requires fine fuel loads of 2,242 kg/ha. Ashe juniper is more easily controlled with fire compared to other species such as redberry juniper because it is a non-sprouting species.

Prescribed burning has given successful results in controlling Ashe juniper in Oklahoma (Dalrymple, 1969). With 560 to 1,120 kg/ha of herbaceous fuel, the mortality was 100% of trees less than 0.6m tall, 77% of trees 0.6 to 1.8m tall, and 68% of trees over 1.8m tall.

Wink and Wright (1975) used prescribed burning to reduce woody debris and suppress newly established Ashe juniper plants. The objective was to enhance results from

mechanical techniques and prolong treatment life. They reported that burns consumed 99% of the brush piles and killed 99.7% of the Ashe juniper plants less than 1.8m tall when at least 1,120 hg/ha of fine fuel was present. When the amount of fine fuel was 2,240 kg/ha, almost all trees were killed.

Research dealing with integration of fire and herbicide technology in controlling redberry junipers near San Angelo, Texas, suggests that there is a synergism between fire and picloram for redberry juniper control. The reason is that picloram sprays alone rarely kill redberry juniper. However, with 1,680 kg/ha of fine fuel when soils were moist, fire intensities killed 10% of the redberry juniper. Sprays of picloram applied at 0.28 kg/ha, 0.56 kg/ha, and 1.12 kg/ha, when growth was 0.05m to 0.1m tall, increased juniper mortality to 30%, 44%, and 45%, respectively. The same intensity of fire applied on a different site when soils were dry killed 40% of the junipers. When previous sprays of picloram at 0.28 kg/ha, 0.56 kg/ha, and 1.12 kg/ha were applied, redberry juniper mortality increased to 64%, 70%, and 95%, respectively. Researchers are evaluating the feasibility of using herbicides such as picloram and paraquat prior to prescribed burning in Ashe juniper communities (Ueckert et al., 1994)

Physical and biological relationships

This section presents prior research describing the effect of brush control on livestock and wildlife production. The purpose is to indicate the contribution of prior research to understanding the relationships between brush reduction as expressed by the level of canopy cover, and herbaceous production for livestock and deer production.

Ashe juniper canopy cover and herbaceous production

Rowan and Conner (1994) studied the influence of Ashe juniper cover on herbaceous production and associated livestock carrying capacity in a typical rangeland in Edwards and Sutton counties in Texas. Four different Ashe juniper stands with 4.3%, 7.7%, 16.5%, and 32.2% levels of canopy cover were cleared using prescribed burning, chaining, grubbing and hand cutting, respectively. Mechanical treatments were followed by burning. Herbaceous production through time, with and without control, were estimated for each stand.

Their study shows that herbaceous production varies inversely with the level of canopy cover. Canopy cover of 4.3%, 7.7%, 16.5%, and 32.2% were associated with herbage production of 2,240 kg/ha, 2,080 kg/ha, 2,020 kg/ha, and 1,740 kg/ha, respectively. In each case brush control resulted in an increase in herbaceous production to near maximum production potential. Without treatment, herbaceous production was 1,795 kg/ha, 1,570 kg/ha, 1,340 kg/ha, 475 kg/ha, respectively. However, there was no indication concerning the level of canopy cover corresponding to changes in herbaceous production through time, either with or without control. Thus, the study does not allow for the estimation of this relationship.

Rasmussen (1986) studied the impact of prescribed fire on Ashe juniper communities. The study area was located on Spring Mesa, 25 km southeast of Baird, Texas, in the Edwards Plateau Region. The objective was to determine the relationship between herbaceous components (grass and forb yield, foliar cover and herbaceous composition), and canopy cover of Ashe juniper and flameleaf sumac on two different soil

sites (shallow and deep), using 1984 and 1985 data. The brush control method consisted of tree dozing followed by prescribed burning.

The results indicate that the effect of Ashe juniper on yield and percent composition of herbaceous foliar cover varied with precipitation received during the growing season and with soil depth. On shallow soils, herbage production declined with increasing canopy cover. During the dry 1984 growing season, total grass yield declined by 51% as canopy cover increased from 0% to 10%. Grass yield was less than 20 kg/ha when Ashe juniper canopy cover was greater than 40%. When precipitation increased to average levels during the1985 growing season, yields of forage and grass declined with canopy cover, but not as quickly as in 1984. Forage yield was not reduced by 50% until canopy cover reached 45%. On deeper soils, forage yield and Ashe juniper relationships also depended on precipitation received. With 1985 average precipitation, forage yield responses were quite different. Increasing Ashe juniper cover resulted in a continual decrease in grass, forb, and total forage yield.

Relationships between Ashe juniper canopy cover and grass production were estimated for shallow and deep soil series for 1984 and 1985.

Shallow soils in 1984: $Y = 184.02 - 41.71 \log (X+1)$ $R^2 = 0.91$

Shallow soils in 1985: $Y = 403.48 - 4.36 X$ $R^2 = 0.86$

Deep soils in 1984: $Y = 108.08 + 1755.76\ 1/X$ $R^2 = 0.70$

Deeep soils in 1985: $Y = 1423.81 - 200.74 \log (X+1)$ $R^2 = 0.63$,

where Y is grass production in kg/ha and X is percent Ashe juniper canopy cover.

The study found that there was an inverse relationship between total herbaceous cover and Ashe juniper canopy cover during both the dry (1984) and average (1985) precipitation growing season. Total herbaceous foliar cover was reduced by Ashe juniper canopy cover regardless of soil and precipitation received. The study indicates that the most probable factor for the impacts of Ashe juniper and flameleaf sumac on herbaceous vegetation is the density of their canopies.

This study was among the few that estimated the relationship between herbaceous production and Ashe juniper canopy cover in the Edward Plateau Region. However, despite the fact that forage yield depends on many factors, including the amount of precipitation and soil types, these equations were estimated using canopy cover as the only independent variable. In addition, the equations did not consider the dynamic aspect of the relationship. The study also did not provide any explanation of the differences in the model specifications besides the goodness of fit as expressed by the respective R^2.

Rollins (1983) studied forage response to Ashe juniper reduction following a chaining operation on the Edwards Plateau of Texas. The Ashe juniper control was aimed at improving habitat for white-tailed deer. The study area had shallow soils, subhumid climate, and an average annual precipitation of 64 cm, which peaks in May and September. The results indicate that forage response showed a 55% increase following overstory removal. The average grass standing crop was 657 kg/ha on chained areas, compared to 424 kg/ha on untreated areas. Most grass species did not significantly increase following overstory removal. However, Texas wintergrass, the major cool season forage species doubled on chained sites. Forb biomass and diversity were variable

because of seasonal variation in precipitation. On chained sites, forb standing crop was higher during both March 1982 and 1983, but the most significant difference occurred from April to December 1982 during drought conditions when forb standing crop was 500% to 600% higher on cleared sites. In response to these improved conditions, most foraging activities of goats and white-tailed deer took place on cleared areas.

The overall conclusion of Rollins (1983) concerning forage response is that chaining could be an effective means of controlling Ashe juniper to benefit both wildlife and livestock. Doubled chaining led to an overstory reduction of 80% one year following treatment, with a 55% increase in forb and grass biomass 22 months following treatment. While prior studies (Heady, 1975; Vallentine, 1980) suggest treating only sites with deep fertile soils to obtain maximum forage yield from brush control, Rollins indicated that grass production was greatest on sites with deeper soils, but forb production was greatest on rocky, shallow sites. Therefore, there should be a trade-off in species between sites and in controlling Ashe juniper some brush should be spared for deer use.

Rollins (1983) is among the few studies directly related to the topic of brush control from the perspective of both livestock and wildlife. However, Rollins (1983) did not provide information concerning variations of forage production associated with changes in the level of canopy cover in its static or dynamic dimension that could be used in estimating the forage response function. In addition, Rollins was not concerned with an economic evaluation of brush control.

The studies reviewed show that canopy cover reduction will increase herbage production and consequently will enhance livestock production. The amount of increase

depends on soil sites, moisture conditions, and size of juniper trees. However, most studies did not concern the Edwards Plateau Region. In addition, most studies evaluated brush control impacts on herbaceous production at a specific control level and did not analyze the changes in herbaceous production as a result of changes in brush content. Rasmussen (1986) was among the few studies that addressed this issue, but the estimated relationships between canopy cover and total herbaceous production did not account for the effects of an important variable such as the amount of precipitation received as suggested by many studies.

Ashe juniper canopy cover and deer production

Brush control impacts on deer are not extensively documented. Darr and Klebenow (1975) are among the few authors that have addressed this issue. Their objective was to identify deer habitat preference and the influence of brush control and grazing practices in the Texas Rolling Plains. The specific research objectives were to obtain data on habitat use by white-tailed deer during all seasons, determine how existing brush control influences deer use of habitats, and evaluate the impact of livestock on habitat use by deer.

The research was conducted on an area with a semiarid climate and was characterized by low rainfall (50 cm per year). Deer habitats included bottomland (13%), mesquite-juniper redland (42%), sand shinnery oak (4%), sandyland ecotone (4%), mimosa-eroneuron upland (18%), and upland savanna (19%). Herbicide, chaining and cabling were used for treatments.

The results show that deer densities were greatest in the bottomland habitat. Chaining bottomland habitat was detrimental to deer, with the larger the area chained, the lower density of deer it contained. Herbicide applications had little detrimental effects on deer population. Grazing by sheep was inversely related to deer densities except in bottomland habitat.

Rollins (1983) studied how deer populations responded to different intensities of brush removal on the Edwards Plateau of Texas. Brush was removed at 30%, 50%, 70% and 80% levels by double chaining. The results show that use of cleared areas by deer equaled or surpassed use of adjoining brushlands. The lower the level of brush removal, the greater the use of cleared areas. The same results on deer population trends were obtained from helicopter counts and cruise counts. White-tailed deer densities tended to increase at 50% and 70% removal, but showed little change at the 80% site throughout the study. Deer counts were highest at the 50% and 70% brush removal levels and lowest at 30% and 80% removal levels.

Deer use of cleared areas relative to brush areas was greatest at the lowest intensities of removal (30% and 50%), suggesting a more convenient combination of brush and cleared areas, but the use of cleared areas was similar at the 70% and 80% brush removal levels. Thus, the study indicates that there should be more than one criterion in evaluating an "optimal" clearing intensity. However, deer densities decreased relative to pre-treatment levels at 80% removal and were stable at the 30% level. In contrast, deer densities increased continually following 50% and 70% brush removal. Consequently, the author indicates that 50% and 70% clearing should be the safer levels of controlling Ashe

juniper in the Edwards Plateau to improve habitat for white tailed deer. These intensities of removal should maintain 0.25 to 0.5 white tailed deer/ha while simultaneously improving forage availability and palatability, facilitating livestock operations, and improving animal visibility to hunters.

Thus, prior research concerning brush control impacts on white-tailed deer suggests that brush control must meet certain requirements in terms of the sites ehere brush should be removed, as well as the level of removal, in order to insure deer population improvement. Research has not estimated the relationship between deer population and brush control level as determined by the percent of canopy cover.

Brush control economic impacts

Studies on the economic impacts of brush control have been conducted, but few have integrated the deer component into the analysis. Ethridge et al. (1984, 1985, 1987) evaluated economic returns from brush control on Texas rangelands. These analyses consisted of comparing the present value of added revenue and cost resulting from the control practice. Ethridge et al. (1985), showed that after burning, tobosagrass ranges yielded an additional present value of $16.64/ac. over a five-year period. Whitson et al. (1977) conducted an economic evaluation of cattle and deer response to aerial spraying of mixed brush in South Texas. The economic effects were based on returns for lease hunting of white-tailed deer and livestock production following partial treatment (80% sprayed) and total treatment with 2,4,5-T and picloram at 1.120kg/ha. The results show that at a 10% discount rate over a 9-year projected treatment life, both approaches were

economically feasible, except when the brush was completely sprayed and cattle prices were $0.496/kg. However, when cattle prices were $1.091/kg, partial treatment was preferred because returns from hunting more than compensated for reduced cattle returns.

Research on the economic impacts of brush control taking into account both livestock and deer enterprises is very limited. Most studies have focused on the impacts of brush control on livestock production. In the few studies that have evaluated economic returns from deer, Ashe juniper control techniques (dozing or chaining, followed by prescribed burning) that were recommended by many studies have not been analyzed. In addition, economic studies have not specifically addressed the question of the extent of brush cover to optimize livestock and deer enterprises.

CHAPTER III

CONCEPTUAL FRAMEWORK

The problem of optimizing brush density for deer and livestock production may be approached using the theory of a firm producing two products. A ranch in controlling Ashe juniper may be considered as a firm making an investment designed to improve the productivity of land in the production of livestock and wildlife. Investment costs consisting of the cost of brush removal are incurred periodically along with related operating costs, with the expectation of increasing annual output and revenue. The question to ask is: Do available technologies, input and output prices, control costs and interest rate make this investment worthwhile?

This section describes how economic theory can be used to analyze the relationships associated with Ashe juniper control with regard to incurring costs and generating revenues from livestock and deer production. Subsection one discusses the biological relationships that take place as a result of the control. Subsection two outlines the economic relationships involved.

Biological relationships

The biological relationships involved in Ashe juniper control include the response functions between grass and canopy cover, grass and livestock, and deer and canopy cover. Each case will be examined to determine the nature of the relationship and the underlying hypotheses that are assumed.

Ashe juniper response

Rangelands may be invaded by several brush species, but it is assumed in this study that Ashe juniper is the major undesirable brush species for which control is needed. The ability of Ashe juniper to grow depends on many factors, including the existing amount of brush, the pattern of control, the method of control used, the available moisture, and the nature of the range site.

The effects of these factors on Ashe juniper growth have not been extensively studied, yet Rowan and Conner (1994) indicated an exponential relationship between canopy cover and time as depicted in Figure 2. This relationship implies that Ashe juniper canopy cover increases at an increasing rate through time and may be expressed as:

$$CC = e^{f(t)}, \qquad (1)$$

where CC is the amount of Ashe juniper canopy cover in %, t is time, and $e^{f(t)}$ is an exponential function.

The level of CC representing brush density is not normally uniform across the ranch. However, in this study, CC represents the weighted average level of canopy cover considering the ranch as a whole and taking into account brushy and cleared areas. The next two subsections examine the effect of Ashe juniper average canopy cover level on grass and deer production.

Grass response

Rollins (1983) and Rasmussen (1986) have indicated that Ashe juniper canopy cover and grass production are inversely related. The hypothetical relationship is indicated

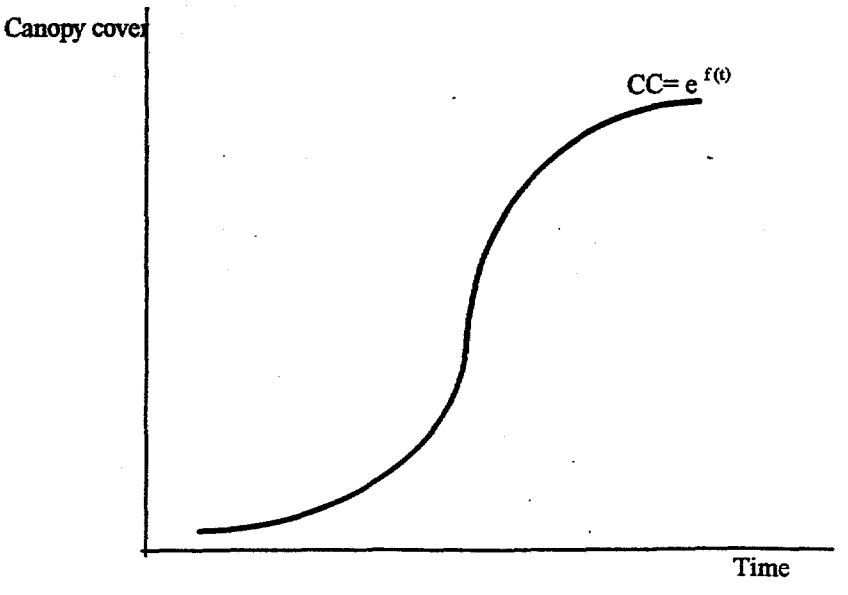

Figure 2. Juniper cover through time

in Figure 3 and shows that as canopy cover increases, grass production decreases at an increasing rate and then decreases at a decreasing rate. However, prior research indicates that this relationship may or may not be linear, Rasmussen (1986). The relationship between grass production and Ashe juniper canopy cover is hypothesized to follow:

$$G = g\,(CC), \tag{2}$$

where G is grass production, and $\partial G/\partial CC < 0$. Assuming that brush control takes place on an ongoing ranch operation, grass would have been produced with or without control. Thus, added grass production is given by:

$$AG = G_w - G_{w/o}, \tag{3}$$

where AG is added grass production, G_w is grass production with brush control treatment, and $G_{w/o}$ is grass production without brush control treatment. Grass production without treatment is expected to be decreasing in the future because of an increase in the level of canopy cover, so that the change in the added grass production will mainly result from the change in the grass production with treatment.

Livestock response

Grass production is assumed to be utilized in a cow calf operation and may be converted into livestock production, assuming a positive and constant relationship between grass and livestock production. Increased livestock production is given by:

$$L = k^* AG, \tag{4}$$

where L is livestock production, AG is added grass production, and k is a constant conversion factor to convert grass production into livestock production. Prior research

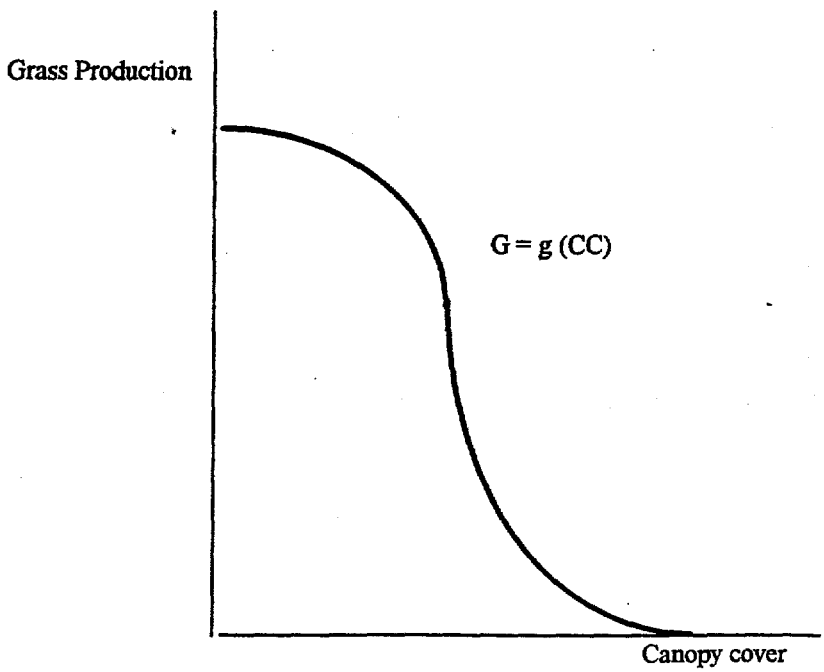

Figure 3. Grass production curve

(Ethridge et al., 1985) indicated that k is positive and less than one. Thus, livestock production is a linear function of grass production and is inversely related to canopy cover.

Deer population

The pattern of brush clearing for purposes of optimizing deer production should be designed to leave sufficient and well distributed cover. The reason for that is that low levels of canopy cover do not provide sufficient cover to retain deer, yet deer may also avoid dense brushlands because of a lack of freedom of movement. Deer move into open areas to feed, but require cover nearby for protection from the weather or for security. This pattern of brush control could be achieved through strip clearing, with cleared strips alternating with strips of brush. Thus, it is assumed as suggested by Rollins (1983) and Darr and Klbenow (1975) that the relationship between deer population and brush content is non linear. This relationship is shown in Figure 4, and implies that deer production will increase with increasing levels of canopy cover up to Dm*, representing maximum deer production, then decline as canopy cover becomes more dense. The relationship can be expressed as:

$$D = d(CC), \tag{5}$$

where D is quantity of deer and $\partial D/\partial CC = d'(CC)$, that is, the slope of the function D= d(CC) is some function of the level of canopy cover. However, when the amount of Ashe juniper canopy cover increases over time as indicated in Figure 2, it is expected that deer production will, at each time period follow the relationship shown in Figure 4.

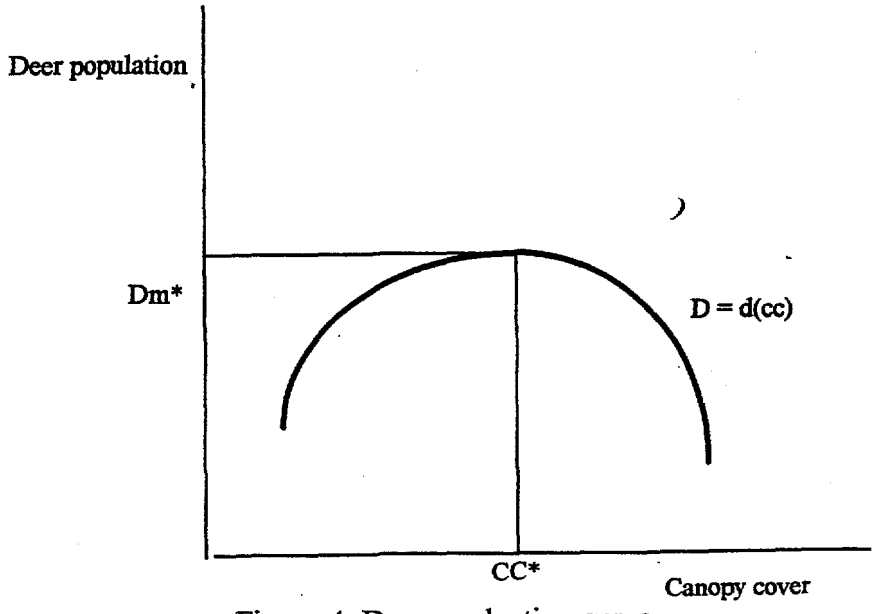

Figure 4. Deer production curve

As canopy cover increases between brush control treatments, total deer density will increase up to a point, then decrease.

Livestock and deer relationship

The relationships described above show that deer and livestock production are both functions of different levels of Ashe juniper canopy cover. A rancher's decision problem is such that increasing the level of canopy cover reduces livestock production, yet increases deer production within a canopy cover range. Therefore, there is a trade off between livestock and deer production. Curves G and D in Figure 5 represent grass and deer production curves, as previously shown in Figures 3 and 4. Livestock production as a linear function of grass is also shown on the same figure. At canopy cover level CC0, grass production Gm is maximum, whereas deer production D0 is equal to zero. The corresponding maximum livestock production is Lm. At CC1 level of canopy cover, deer production is maximum at Dm, grass and livestock production are G1 and L1, respectively. At CC2 level of canopy cover, grass and livestock production, G0 and L0, respectively, are equal to zero. Between CC0 and CC1, as canopy cover increases grass and livestock production decrease while deer production increases. Between CC1 and CC2, as canopy cover increases, both deer, grass, and livestock production decrease. Thus, the relationship between deer and livestock production indicates that the optimum level of canopy cover should be between CC0 and CC1.

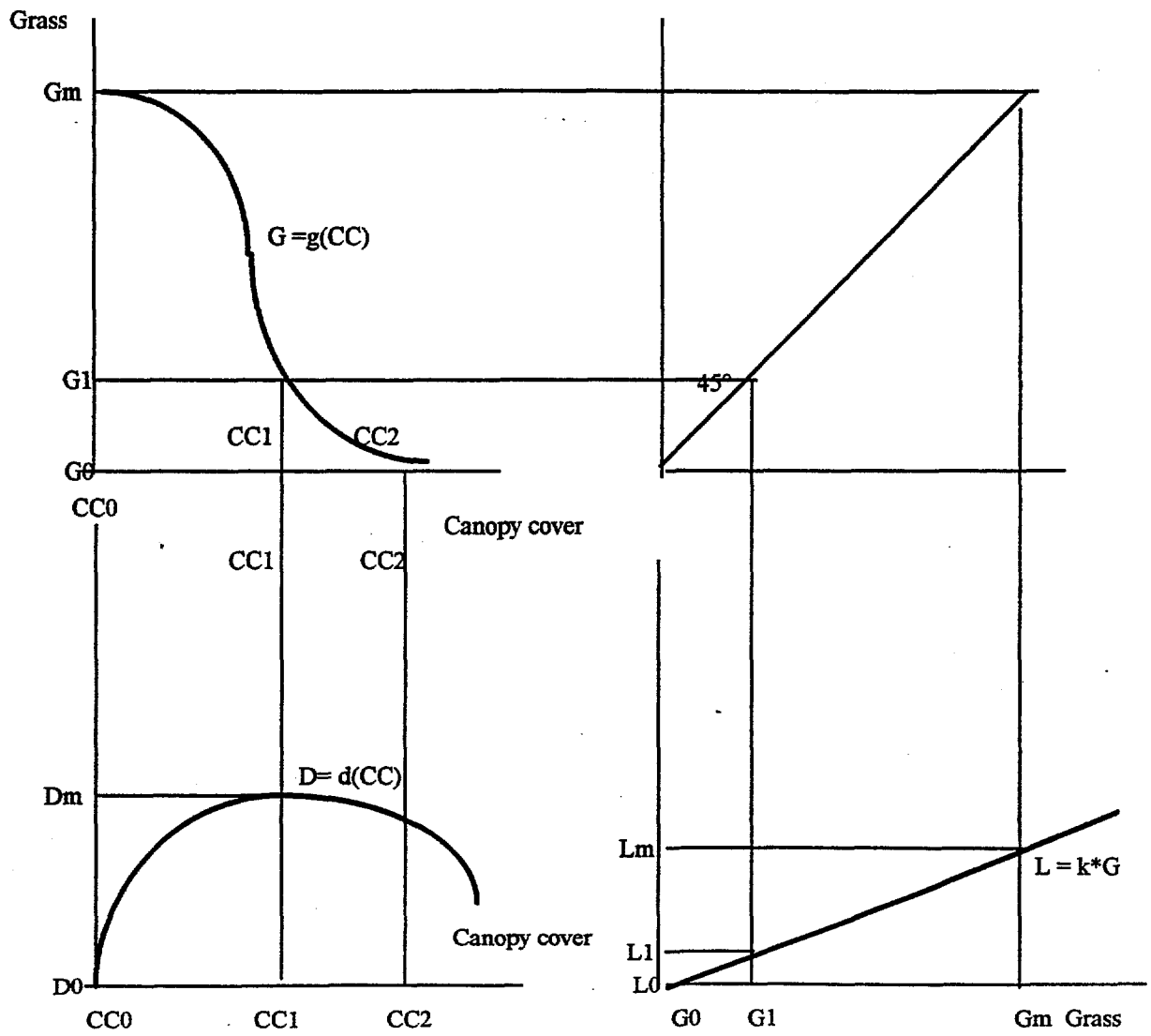

Figure 5. Grass, livestock and deer production functions

Economic relationships

A rancher's decision problem is to obtain the maximum profit from brush control. Different possible combinations of deer and livestock production may be determined by the level of brush control, as indicated by the level of canopy cover. Economic theory suggests that a rancher will choose a level of canopy cover such that the value of the marginal product of canopy cover in livestock production is equal to the value of the marginal product of canopy cover in deer production, with both being equal to the marginal factor cost. The value of the marginal product of canopy cover is defined as the price of the product times the marginal product with regard to canopy cover for each production process, whereas the marginal factor cost is the marginal cost of a unit of output. The condition for deer and livestock optimization is expressed as:

$$P_L * MP_{cc}^{l} = P_D * MP_{cc}^{d} = MFC, \qquad (6)$$

where P_L is price of livestock, MP_{cc}^{l} is marginal product of livestock production with respect to canopy cover, P_D is price of deer, MP_{CC}^{d} is marginal product of deer production with respect to canopy cover, and MFC is marginal factor cost.

Given the shape of the grass production curve as shown in Figure 3, the value of the marginal product of canopy cover in livestock production (VMP_{cc}^{l}), under perfect competition, is expected to be a function of canopy cover as shown in Figure 6. The optimum level of canopy cover in livestock production is graphically represented by point O_L where VMP_{cc}^{l} is equal to MFC. This optimum level corresponds to an optimum level of livestock production. Because grass is produced under a level of canopy cover that varies with time, it is expected that the optimum level of canopy cover to achieve optimum

livestock production will also vary with time. The increase in the level of canopy cover over time will lead to a decrease in the value of the marginal product, corresponding to a movement along this curve.

The hypothesized deer production function as shown in Figure 4 is expected to result in a value of the marginal product of deer under perfect competition that will be negatively sloped as indicated in Figure 7. The optimum canopy cover under deer production is represented by point O_D where VMP_{cc}^{d} is equal to MFC.

Competition between deer and livestock production will be such that, if the value of the marginal product of livestock increases as a result of an increase in livestock price, the marginal product of deer must be increased to optimize the overall production, if deer prices were to remain at the same level, and vice versa. Changes in the slopes of the production functions will also affect the conditions of optimum production from both deer and livestock.

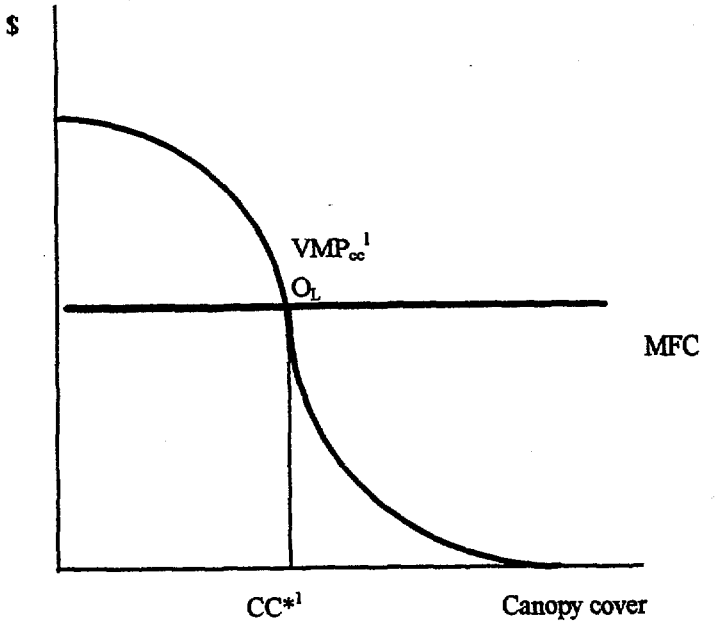

Figure 6. Optimum canopy cover for livestock production

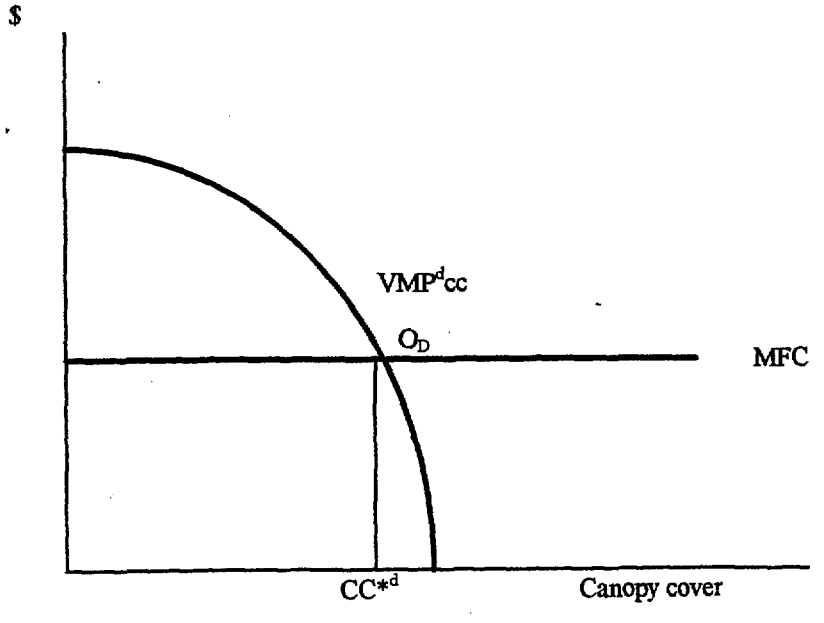

Figure 7. Optimum canopy cover for deer production

CHAPTER IV

METHODS AND PROCEDURES

This section presents the methods and procedures used to determine the optimum level of Ashe juniper canopy cover for livestock and deer enterprises. This process consisted of specifying the livestock and deer optimization model, setting the first order conditions, and solving for canopy cover. This section is divided into three parts: part one deals with model specification, part two presents the procedures used to determine the different components of the model and discusses the problems related to required data, and part three concerns the determination of the optimum level of canopy cover.

Model specification

The main objective of this study was to determine the extent of brush content corresponding to a level of canopy cover within a ranch for which the objective was to optimize brush control for livestock and deer production. This problem was stated as maximizing revenue net of brush control cost from the production of livestock and deer and expressed as:

$$\text{Maximize } R = PL*L + PD*D - TFC, \tag{7}$$

where:

$$L = k*G, \tag{8}$$

$$G = g(CC), \tag{9}$$

$$D = d(CC). \tag{10}$$

R was revenue, L was the quantity of livestock produced and sold, PL was the price of livestock, D was the quantity of deer produced and sold, PD was the price of deer, G was the amount of grass produced, CC was the average level of canopy cover, and TFC was total factor cost. TFC cost represented the total amount of dollars spent on brush control by the rancher, to maintain brush density at optimum level. It did not include direct production costs of livestock and deer related to labor, capital, and management.

Combining equations (8) through (10) into equation (7) gave:

$$R = PL * k * g(CC) + PD * d(CC) - TFC. \quad (11)$$

The first-order condition for profit maximization with respect to canopy cover was expressed as:

$$\partial R/\partial CC = PL * k * \partial g(CC)/\partial CC + PD * \partial d(CC)/\partial CC - \partial TFC/\partial CC = 0. \quad (12)$$

Transferring $\partial TFC/\partial CC$ to the right side of the equation resulted in:

$$PL * k * \partial g(CC)/\partial CC + PD * \partial d(CC)/\partial CC = \partial TFC/\partial CC. \quad (13\ a)$$

The terms $PL * k * \partial g(CC)/\partial CC$, $PD * \partial d(CC)/\partial CC$, and $\partial TFC/\partial CC$ were, respectively, the value of the marginal product of canopy in livestock production ($VMPcc^l$), the value of the marginal product of canopy cover in deer production ($VMPcc^d$), and the marginal factor cost of controlling Ashe juniper (MFC). Therefore, equation (13 a) was written as:

$$VMPcc^l + VMPcc^d = MFC. \quad (13\ b)$$

Given the assumption that both livestock and deer were produced under the same average canopy cover, the condition for revenue maximization expressed in equation (6) was modified by equation (13 b). Equation (6) indicated that the optimum canopy cover level was determined where the value of the marginal product of canopy cover in livestock

production was equal to the value of the marginal product of canopy cover in deer production, and both are equal to the marginal factor cost. Equation (13 b) showed that the optimum average canopy cover level was determined where the marginal factor cost was equal to the sum of the value of the marginal products of livestock and deer. This equation was solved to determine the optimum average canopy cover level for production of both livestock and deer.

Determination of model components

The determination of the optimum level of canopy cover on the basis of equation (13 b) required data on livestock and deer production functions with respect to canopy cover, costs of brush control, and livestock and deer prices. Not all these data were readily available. Each component of the model was examined to evaluate the data, data sources, and indicate the procedures to obtain the required information.

Deer production function

The only available data allowing an estimation of a deer production function with respect to the level of Ashe juniper canopy cover was obtained from Rollins (1983). The method of this study consisted of double chaining four sites, with an initial average level of canopy cover of 40%, to remove the brush from 30%, 50%, 70%, and 80% of the total area, respectively. Deer population trends were monitored at each site compared to untreated sites over a two-year period. The results indicated that when compared to initial levels, deer population increased on the areas with between 50% and 70% clearing,

corresponding to 11.6% and 8.5% weighted average canopy cover, respectively. Whereas, on areas with 30% and 80% clearing, corresponding to a weighted average canopy cover of 19.2% and 7.5%, respectively, deer densities decreased. These results are shown in Figure 8. These data represent observations with an open deer population, meaning that changes in deer counts may be an indication of attraction of deer from adjacent untreated areas. Changes in deer total density for the whole area, as a result of brush control, was not measured in Rollins' study

The functional form of deer population as a function of the average level of canopy cover indicated a cubic relationship represented by the curve ABCDE in Figure 8. The point at 40% weighted average canopy cover, corresponding to the initial level of brush density without control, was an observation not consistent with the other observations obtained by the experiment. When this observation was excluded, the functional form of deer production was best fitted with a quadratic equation represented by the curve ABCD. This relationship was expressed as:

$$D = d_0 + d_1CC + d_2CC^2, \tag{14}$$

where D was deer population density in units/ha, and CC was the level of weighted average canopy cover in %. Maximum deer population density production occurred where:

$$\partial D/\partial CC = d_1 + 2d_2CC = 0. \tag{15}$$

Solving equation (15) for CC resulted in:

$$CC = -d_1/2d_2 \tag{16}$$

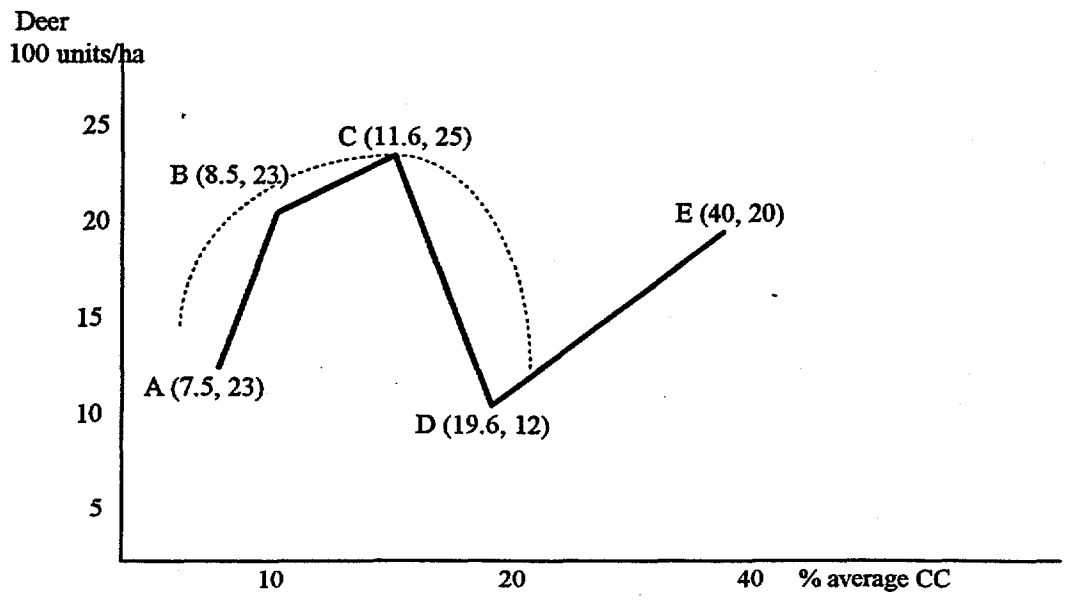

Figure 8. Deer population density curve

Source: Rollins et al., 1986

Livestock production function

Rassmussen (1986) was the only study in which a grass response function to Ashe juniper canopy cover was estimated for the Edwards Plateau of Texas. The author derived production functions for shallow and deep soils for 1984 and 1985 shown. These equations are presented on page on pages 14 and 15. The coefficients of CC in the four equations were negative, indicating an inverse relationship between grass production and percent of canopy cover. The results showed a relatively good fit to the data, with an R^2 ranging from 0.63 to 0.91. The study tested for differences in regression coefficients (intercept and slope) for forage classes (grass and forb), but did not indicate whether the coefficients of production functions for a given forage class, for example grass, were significantly different from zero.

The use of grass production functions estimated by Rasmussen (1986) posed some problems. First, the results did not offer a means to chose among the estimated grass production functions. The functional forms varied from year to year and between soil types without any explanation of the underlying causes. Second, for the purposes of this study, the 1985 grass production function for shallow soil sites was considered more appropriate because deer production was estimated for the same soil type by Rollins (1983), and the 1985 results, obtained when precipitation was average, seemed to be more realistic than the results obtained during the dry 1984 season. However, the 1985 grass production function for the shallow soil site was linear in contrast to the other grass production functions estimated by the author. Third, the Rasmussen (1986) study was not designed to express the relationship between Ashe juniper canopy cover and forage

production on a pasture basis, rather the relationship between a tree canopy cover and the surrounding area. The prospect for the forage production to be utilized for livestock production was not taken into account in.

Grass production functions, expressing an exponential relationship with Ashe juniper canopy were not readily available for the Edwards Plateau region of Texas. But it is reasonable to expect that Ashe juniper canopy cover and redberry juniper canopy cover have the same grass production functions due to their similarity. For this reason, the grass response function to be used in this study was obtained from Gerbolini (1996), where forage production as a function of redberry juniper canopy cover was estimated for a shallow range site in the Texas Rolling Plains. Data were collected using the line-intercept method. First, redberry juniper canopy cover and forage production were measured in 23 randomly selected 30-meter transects. Grass production was estimated by randomly placing 0.25 m^2 quadrats along each transect. The data were used to estimate the following hypothesized forage production function:

$$G = e^{g_0 + g_1 CC^2}, \tag{21}$$

where G was grass production in kg/ha, CC was the level of canopy cover in percent, and e was the base of the natural logarithm. The exponent of e is $(g_0 + g_1 * CC^2)$.

The livestock production function was determined using the relation:

$$L = G * k, \tag{22}$$

where G was grass production in kg/ha as determined by equation (21), and k was a conversion factor. The conversion factor used was 0.02 (Gerbolini, 1996), which

indicates that one kg of grass is converted into 0.02 kg of livestock. Combining equations (21) and (22) gave:

$$L = k * e^{g_0 + g_1 CC^2}. \quad (23)$$

Maximum livestock production (Lm) was obtained where CC = 0. Substituting CC by zero in equation (23) resulted in:

$$Lm = k * e^{g_0}. \quad (24)$$

Costs of brush control

Data on the costs of Ashe juniper control were obtained from Rowan and Conner (1994). This study evaluated the costs of controlling Ashe juniper at various levels of canopy cover using different control methods. The data were used to estimate the cost of control in relation to the level of canopy cover using the OLS method. A linear relationship was hypothesized and expressed as:

$$TFC = c_0 + c_1 CC, \quad (25)$$

where TFC was total factor cost in $/ha and CC was canopy cover in %. It was expected that TFC would be positively sloped because controlling higher brush densities required using heavier and more expensive equipment.

Deer price

Deer price was a weighted average of the prices of a buck and a doe. Weights were based on the share of each type of deer in the harvested quantity. Deer price was given by:

$$PD = h^* (d^* PB + Pdo) /(d+1), \quad (26)$$

where PD was deer price in $/unit, h was deer harvest rate in percent, d was buck\doe quantity ratio, PB was buck price, and Pdo was doe price. Data on buck and doe prices, deer harvest rate, and the bulk/doe ratio, were obtained from an interview with Dr. Fred C. Bryant (1996). The values obtained were buck price of $750, doe price of $150, harvest rate of 10%, and d buck doe quantity ratio of 2.

Livestock price

Livestock price was expressed as the weighted average prices of a heifer, steer, and cow, based on the weight share of each type of animal marketed from a cow producing unit (CPU). This relationship was expressed as:

$$PL = WH^*H\%^* PH/MAU + WS^*S\%^* PS/MAU + WC^*C\%^*PC/MAU, \quad (27)$$

where PL is livestock price, PH, PS, and PC were the respective prices of a heifer, steer, and cow in $/kg; H%, S%, and C% were their respective weight share in percent in a marketable animal unit; WH, WS, and WC were the respective weight of a heifer, steer, and cow in kg; and MAU was the weight of a marketable animal unit in kg. Heifer and steer weaning weights were obtained from Texas A&M University (McGrann, 1995). Cull cow weight was assumed to be 454 kg. Table 2 gives the level of prices and weights.

Table 2. Weights and prices used to calculate livestock price

	Weight (kg)	Price ($/kg)	Percent (%)
Heifer	244.76	1.947	27.135
Steer	262.49	2.134	41.135
Cow	453.60	1.125	14.00

Optimum Ashe juniper canopy cover

The profit function was expressed as:

$$R = PL^* k^* g(CC) + PD^* d(CC) - TFC = 0. \quad (28)$$

Substituting equation (23) for g(CC), equation (18) for d(CC), and equation (25) for TFC resulted in:

$$R = PL^* k^* e^{g_0 + g_1 CC^2} + PD^*(d_0 + d_1 CC + d_2 CC^2) - c_0 - c_1 CC = 0. \quad (29)$$

Taking the first partial of equation (29) with respect to CC resulted in:

$$\partial R/\partial CC = PL^* k^* \partial e^{g_0 + g_1 CC^2} / \partial CC + PD^* \partial (d_0 + d_1 CC + d_2 C)/\partial CC$$

$$-\partial(c_0 + c_1 CC)/\partial CC = 0. \quad (30)$$

Equation (30) was expressed as:

$$2PL^* k^* g_1 CC^* e^{g_0 + g_1 CC^2} + PD^*(d_1 + 2d_2 CC) - c_1 = 0. \quad (31)$$

Equation (31) could not be solved for CC because of the exponential function. Therefore, the optimum level of canopy cover was approximated through a mathematical transformation of the revenue function given by equation (29) using the relationship:

$$R(CC) = R(CCi) + R'(CCi)^* (CC-CCi) + R''(CCi)^* (CC-CCi)^2/2!, \quad (32)$$

where CCi was a given level of canopy cover chosen near optimum level, so that the difference between CC and CCi was small , R' and R''were the first and second partial derivative of R. The terms R(CCi) and R' (CCi) were constants, obtained by replacing

CC by CCi in equations (29) and (31), respectively, and were expressed as:

$$R(CCi) = PL^* k^* e^{g_0 + g_1 CCi^2} * + PD^*(d_0 + d_1 CCi + d_2 CCi^2) - c_0$$

$$-c_1 CCi = m1 \tag{33}$$

Taking the second partial of the profit function with respect to CC and replacing CC by CCi resulted in:

$$R'(CCi) = 2PL^* k^* g_1 CCi * e^{g_0 + g_1 CCi^2} * \ln(e) + PD^*(d_1 + 2d_2 CCi)$$

$$-c_1 = m \tag{34}$$

$$R''(CCi) = 4PL^* k^* g_1^2 CCi^2 * e^{g_0 + g_1 CCi^2} * \ln(e)^2 + 2PL^* k^* g_1 CCi * e^{g_0 + g_1 CCi^2}$$

$$* \ln(e) + 2PD^* d_2 = m3. \tag{35}$$

Combining equations (33), (34), and (35) into equation (32) resulted in the following revenue equation:

$$R(CC) = PL^* k^* e^{g0 + g1 CCi^2} + PD^*(d_0 + d_1 CCi + d_2 CCi^2) - c_0 - c_1 CCi + (2PL^*$$

$$k^* g_1 CCi * e^{g0 + g1 CCi^2} * \ln(e) + PD^*(d_1 + 2d_2 CCi) - c_1)^* (CC - CCi) + (4PL^* k^* g_1^2$$

$$CCi^2 * e^{g0 + g1 CCi^2} * \ln(e)^2 + 2PL^* k^* g_1 CCi * e^{g0 + g1 CCi2} * \ln(e) + 2PD^* d_2)^*$$

$$(CC - CCi)^2/2! \tag{36}$$

Equation (36) was written as a quadratic equation in the form:

$$R(CC) = m1 + m2 * (CC - CCi) + m3 * (CC - CCi)^2/2!$$

$$= m1 + m2*CC - m2*CCi + m3/2*CC^2 - m3*2/2*CC*CCi + m3/2*CCi^2$$

$$= m3/2*CC^2 + (m2 - m3*CCi)*CC + m1 - m2*CCi + m3/2*CCi^2. \quad (37)$$

The first-order condition for revenue maximization was given by the first partial derivative with respect to CC, and was:

$$\partial R(CC)/\partial CC = 2*m3/2*CC + (m2 - m3*CCi) = 0. \quad (38)$$

The optimum level of canopy cover was obtained by

$$CC^* = -(m2 - m3*CCi)/ m3. \quad (39)$$

Optimum level of canopy cover depended on the parameters for livestock and deer production functions and prices. A sensitivity analysis was performed to determine the changes in the optimum level of canopy cover as a result of changes in these parameters.

CHAPTER V

RESULTS

This section presents the results of the study in three parts. The first part concerns the estimation of the deer production function and levels of deer production. The second part deals with the results from the livestock production function estimated by Gerbolini (1996) and is presented along with the implications for livestock production. The third part focuses on the determination of optimum levels of Ashe juniper canopy cover for deer and livestock production and the sensitivity analysis of optimum canopy cover to changes in livestock and deer prices.

Deer population and revenue

Deer population density function

A study by Rollins (1983) was conducted on the Y O Ranch, a 20,000 ha ranch located in Kerr County, Texas, where the vegetation was dominated by Ashe juniper. Brush cover was homogeneous across the selected range sites. White-tailed deer accounted for 64% to 89% of all ungulates, with population densities averaging 1 deer/5ha. The results of deer population census counts following different levels of brush removal are shown in Table 3. On the basis of these data, OLS regression was used to estimate a deer population density function. This function expressed the relationship between observed deer population and canopy cover as hypothesized in equation 14.

Table 3. White-tailed deer densities from census conducted on the Y O Ranch, Kerr County, Texas, 1981-1983.

Sites (% cleared)	Average canopy cover (%)	Deer population (units/ha)
0	40	0.20
30	19.2	0.12
50	11.6	0.25
70	8.5	0.23
80	7.5	0.15

Sources: Rollins (1983) p.41

The OLS estimation produced the following equation:

$$D = -0.297087 + 0.088158\ CC - 0.003463\ CC^2 \qquad (40)$$
$$\quad (-1.2941) \quad (2.2989) \qquad (-2.4635)$$

where D is deer population in units/ha and CC is percent canopy cover. The coefficients of CC and CC^2 were not significantly different from zero at the 5% significance level, as indicated by the t-values shown in parenthesis. However, the R^2 of 0.8932 indicated a good fit to the data. The small size of the standard error of the estimate (0.03530) compared to the mean value of the dependent variable (0.1875) showed that the magnitude of the change between observed and predicted deer production was not significant as indicated in Table 4. Table 4 also shows that for each deer population density level, the model correctly predicted the direction of change. The estimated deer population density function is shown graphically in Figure 8.

Maximum deer population density

The level of canopy cover at maximum deer population density was calculated using equation (16) and the coefficients from equation (40). The resulting weighted average canopy cover level of 12.7%, and deer population density of 0.264 deer/ha are shown in Table 5. This level of canopy cover and the corresponding deer population were slightly outside the range of Rollins' results. Rollins showed that maximum deer population density occurred between 8.5% and 11.6% canopy cover, with density ranging from 0.23 deer/ha to 0.25 deer/ha. To obtain maximum deer population density, a rancher

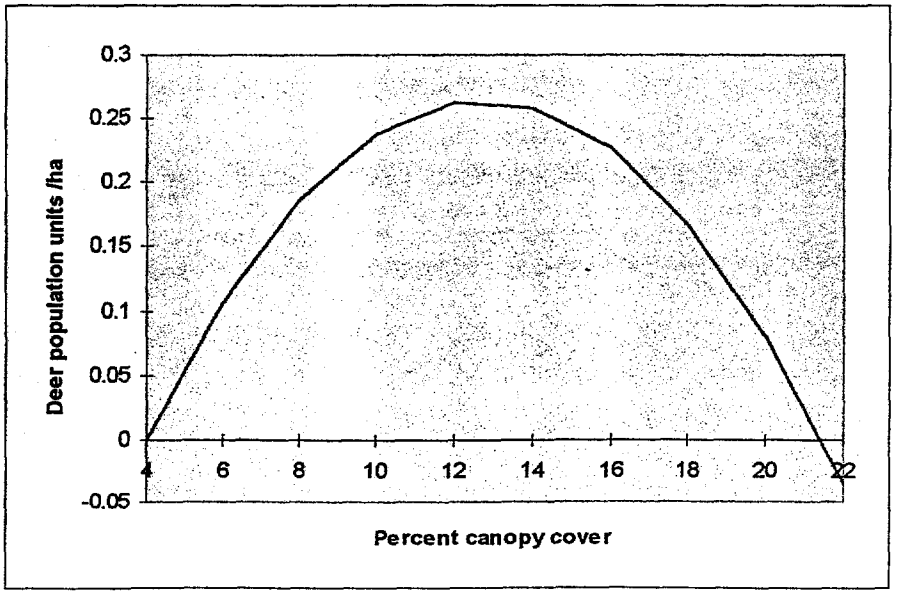

Figure 9. Deer population density curve

Table 4. Predicted and observed values of deer production (units/ha) from various levels of canopy cover (%)

Canopy cover	Observed values	Predicted values	Direct. Change	Residual
19.2	0.120000	0.119026		0.000974
11.6	0.250000	0.259592	correct	-0.009592
8.5	0.230000	0.202068	correct	0.027932
7.5	0.150000	0.169314	correct	-0.019314

Table 5. Summary of results at canopy cover level for maximum deer production

Deer price ($/unit)	750
Harvest rate (%)	10
Livestock price ($/kg)	1.81
Weighted average canopy cover at maximum deer production (%)	12.73
Area cleared (%)	68
Area in brush (%)	32
Deer maximum (units/ha)	0.26
Maximum deer revenue ($/ha)	14.52
Grass production (kg/ha)	1201.29
Livestock production (kg/ha)	24.03
Livestock revenue ($/ha)	43.55
Total revenue ($/ha)	58.07

will have to clear 68% of the land, assuming an initial brush content of 40% canopy cover. In Rollins' study, maximum deer population density was obtained when 50% to 70% of the land was cleared, given 40% initial level of canopy cover.

Deer revenue

Revenue generated from deer depends on the deer population density function, the deer harvest rate, and the deer price. Deer herd composition and harvest rate vary according to the objective of the rancher. If the objective is a sustained harvest of old age bucks, the rancher will increase the percentage of animals in older age classes by allowing young bucks to mature. However, it is assumed in this study that the objective is to maintain a buck/doe ratio of one buck for two does, and to harvest mostly young bucks in the 1.5 to 2.5 year age range corresponding to 10% of the total deer population. Buck and doe prices were assumed to be $750 and $150 per unit, respectively; resulting in an average deer price of $550 per unit. Maximum deer revenue was $14.52/ha, which was obtained when maximum deer production was 0.26 units/ha.

Livestockand revenue production

Grass production function

The grass production function used in this study was estimated by Gerbolini (1996) for a shallow range site where brush canopy cover was comprised of 66% redberry juniper, 2% mesquite, 21% catclaw, 9% combinations of redberry juniper and mesquite, and 2% other species. The model included independent variables pertaining to differences

in location and brush species. Several trial models were developed and evaluated based on goodness of fit using adjusted R^2 and significance of the coefficients. The estimated model that best explained the variation in forage production in relation to redberry juniper canopy cover on shallow range sites was expressed as :

$$\ln G = 7.1626024 - 0.000441 * CC^2, \qquad (41)$$

where ln G is the natural log of grass production at the average location, and CC is the percent canopy cover constituted by redberry juniper, catclaw, mesquite, and the combination of redberry juniper and mesquite. Adjusted R^2 was 0.90 with an F-statistic of 43.12. All coefficients were significantly different from zero at the 5% significance level. Equation 41 may be re-written as:

$$G = e^{7.1626024 - 0.000441 * CC^2}, \qquad (42)$$

where G is grass production in kg/ha, and CC is as defined above. Graphical representation of this function is shown in Figure 9.

Maximum grass and livestock production

The marginal product of grass production (MP_g) is represented by the slope of equation (42):

$$\partial G/\partial CC = MP_g = 0.000882 * e^{(7.1626024 - 0.000441 * CC^2)} * CC. \qquad (43)$$

Grass production reaches its maximum level where MPg is equal to zero. Setting equation (43) equal to zero and solving for CC results in CC equal to zero, which gives a maximum grass production of 1,290 kg/ha as indicated in Table 6. The inflection point, where MP_g

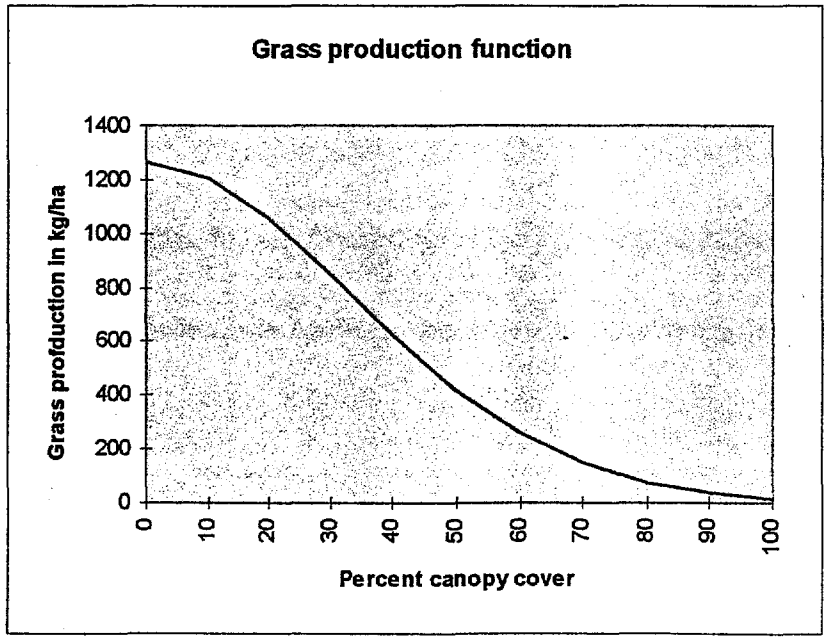

Figure 10. Grass production curve

Source: Gerbolini (1996)

Table 6. Summary of results at canopy cover level for maximum livestock production

Weighted average canopy cover at maximum livestock production (%)	0.00
Area cleared (%)	100.00
Area in brush (%)	0.00
Maximum grass production (kg/ha)	1290.2
	6
Maximum livestock production (kg/ha)	25.80
Maximum livestock revenue ($/ha)	46.71
Deer production (units/ha)	0.00
Dee revenue ($/ha)	0.00
Total revenue ($/ha)	46.71

is maximum occurred at 33.6% canopy cover. At maximum grass production of 1,290 kg/ha, when the weighted average level of canopy cover is zero, forage production decreases as the level of CC increases. Forage production at 60% canopy cover, where full Ashe juniper canopy cover is assumed, is 264 kg/ha. Maximum livestock production was 25.81 kg/ha, which is equal to the maximum grass production times the conversion factor of 0.02 (Gerbolini 1996). The minimum livestock production is 5.28 kg/ha which is obtained at full canopy cover.

Livestock revenue

Livestock revenue was derived for a cow-calf operation in which a cow producing unit (CPU) consisted of a 454 kg cow, 262.49 kg steer and 244.76 kg heifer, weaning percentage of 82.27 %, and a 14% heifer replacement rate. A CPU produced 237.89 kg of marketable animal composed of 14% of a cow, 41.13% of a steer, and 27.13% of a heifer. Prices for cows, steers, and heifers were assumed to be $1.125/kg, $2.134/kg, and $1.947/kg, respectively . The weighted average price of livestock was calculated as $1.81/kg using equation (27). Maximum livestock revenue was $46.71/ha, which is the product of weighted average livestock price and maximum livestock production.

Costs of Ashe juniper control

Cost function

The cost function for Ahse juniper control was estimated using data from Rowan and Conner (1994). The authors evaluated the costs associated with various juniper stands and control methods. Cost items include brush control and deferred grazing costs. Brush densities were measured in terms of size composition of juniper trees and in percent of canopy cover. Table 7 summarizes the brush control costs from the Rowan and Conner study. The relationship between the cost of Ashe juniper control and the percent canopy cover was estimated applying OLS regression. The following cost equation was estimated:

$$\underset{}{TFC} = \underset{(2.8466)}{3.840912} + \underset{(3.3433)}{0.108116}\, CC \qquad (44)$$

where TFC is total factor cost in $ per ha, and CC is percent canopy cover. This estimation was significant as indicated by the t values in parenthesis and the F value (1,5) = 11.178. Adjusted R^2 of 0.6291 also indicated a good fit to the data.

TFC increases with increasing levels of weighted average canopy cover. Given an initial level of 40% canopy cover, TFC at canopy cover percentage corresponding to maximum livestock and maximum deer production was $8.17/ha/year and $5.22/ha/year, respectively. The marginal factor cost (MFC) obtained by taking the first derivative of equation (44) with respect to CC was equal to $0.11/ha/year. This value indicates how much a rancher will spend to remove brush for each percent increase in the level of average canopy cover.

Table 7. Costs of juniper control at various levels of canopy cover

Control methods	Cost ($/ha/year)	Canopy cover (%)
Fire	1.47	4.3
Chaining and fire	5.46	7.7
Grubbing and fire	7.27	16.5
Cutting and fire	8.95	32.2
Dozing and fire	10.30	60
Dozing and first and second fire	10.806	60
Cutting and fire	8.04	60

Source: Rowan and Conner (1994) p 73

Optimum canopy cover

The previous sections concerned the determination of the average level of canopy cover when maximizing the production of either livestock or deer. This section deals with the level of canopy cover when optimizing the production of both enterprises. The results shown in Table 8 indicate that the optimum level of weighted average canopy cover was 11.30%. This level of canopy cover would be obtained by clearing 72% of the initial brush area compared to clearing100% and 68% of the initial brush area when the objective was maximizing livestock production or maximizing deer production, respectively. The results confirmed that the optimum average canopy cover was within the relevant range of maximum livestock production and maximum deer production as hypothesized in this study and defined as 0% < CC< 12.73%.

However, optimum average canopy cover was very close to average canopy cover at maximum deer production. Table 8 also shows that optimum grass production was 1,219.61 kg/ha, which represents a 5.5% decrease from maximum grass production. Optimum livestock production was 24.39 kg/ha and optimum deer production was 0.257 units/ha. Revenue at optimum livestock and deer production was $53.28/ha. This level of revenue is net of costs of brush control. The revenues were $52.85/ha and $42.93/ha at maximum deer production and maximum livestock production, respectively The optimum revenue level was the highest the rancher could obtain from any of the two other alternatives. Because the optimum level of average canopy cover was close to the level of average canopy cover at maximum deer production, the revenue level at maximum deer production was not very different from the optimum profit level.

Table 8. Summary of results at canopy cover level for optimum livestock and deer production

Optimum canopy cover (%)	11.30
Optimum grass production (kg/ha)	1219.61
Optimum livestock production (kg/ha)	24.39
Optimum deer production (units/ha)	0.257
Optimum livestock revenue ($/ha)	44.21
Optimum deer revenue ($/ha)	14.13
Optimum total revenue ($/ha)	58.34
Total brush control cost ($/ha)/year	5.06
Optimum revenue net of brush control costs ($/ha)	53.28
Revenue at maximum deer production ($/ha)	52.85
Revenue at maximum livestock production ($/ha)	42.93

Livestock returns were three time higher than deer returns at the optimum level of canopy cover. At this level of canopy cover, if all variables remain constant, average deer price must be increased from $550/unit to $1,720/unit for deer production to yield the same revenue as livestock production. This means that the price of a buck must be raised from $750 to $2,500. Deer prices vary widely among ranches in Texas, but the average price of a young buck is not expected to reach this upper bound. Therefore, the results seemed not to confirm previous studies (Ramsey, 1965), which indicate that potential economic returns from deer production are higher than livestock production.

Sensitivity analysis

The objective of this part of the analysis was to determine how sensitive the optimum level of canopy cover and the profitability of livestock and deer production enterprises were to changes in livestock and deer prices.

Livestock price changes

Tables 9 and 10 show the effects of changes in livestock prices. Changes in livestock prices from $0.91/kg to $2.72/kg result in a decrease in the level of optimum weighted average canopy cover from 11.85% to 10.79%. This increase in livestock prices caused livestock revenue to increase from $21.98/ha to $66.65/ha. Deer revenue fell slightly from $14.37/ha to $13.80/ha. Total profitability varied from $31.23/ha to $75.44/ha.

Table 9. Optimum canopy cover and livestock and deer revenue response to livestock price changes

Factors	Units	Livestock price ($/kg)						
		0.91	1.45	1.63	1.81	1.99	2.17	2.72
Canopy cover	%	11.85	11.50	11.40	11.30	11.18	11.09	10.79
Brush	%	29.63	28.74	28.49	28.25	27.95	27.71	26.97
Clear	%	70.38	71.26	71.51	71.75	72.05	72.29	73.07
Livestock revenue	$/ha	21.98	35.30	39.75	44.21	48.69	53.16	66.65
Deer revenue	$/ha	14.37	14.23	14.18	14.13	14.06	14.00	13.80
Total revenue	$/ha	36.35	49.53	53.93	58.34	62.75	67.16	80.45
Total cost	$/ha	5.12	5.08	5.07	5.06	5.05	5.04	5.01
Revenue net of brush control cost ($/ha)		31.23	44.45	48.86	53.28	57.70	62.12	75.44

Table 10 Percent change in optimum canopy cover and livestock and deer revenue from changes in livestock prices

	Livestock price					
Factors	-50	-20	-10	10	20	50
Canopy cover	4.87	1.77	0.88	-1.06	-1.86	-4.51
Brush area	2.97	1.04	0.52	-0.64	-1.16	-2.66
Livestock revenue	-50.28	-20.15	-10.09	10.13	20.18	50.76
Deer revenue	1.70	0.71	0.35	-0.50	-0.92	-2.34
Revenue net of brush control cost	-41.38	-16.57	-8.30	8.30	16.59	41.59

The effects of livestock price are also presented in Table 10 which shows the percentage changes in certain factors resulting from various percentage changes in livestock prices. Increases in livestock prices by 10%, 20%, and 50% caused the average level of canopy cover to decrease by 1.06%, 1.86% and 4.51%, respectively. Decreases in livestock prices by the same proportions led to an increase in average canopy cover by 0.88%, 1.77% and 4.87%, respectively. Percentage changes in livestock revenue were almost identical to changes in livestock prices, but percent changes in revenue were inferior to the percent change in livestock prices.

The results indicate that changes in livestock prices have little effect on the optimum level of canopy cover. However, the results confirm the direction of the effect of livestock price changes as hypothesized in this study. That is, an increase in livestock prices will lead to a decrease in the optimum level of canopy cover over the relevant range and vice versa. Therefore, ranchers will clear more brush area when livestock prices increase as indicated by the decrease in brush content shown in Table 10.

Deer price changes

Canopy cover response to changes in deer price are presented in Tables 11 and 12. The effects reflected only variation in buck price. The analysis considered young buck prices ranging from $375/unit to $1,125/unit. As buck price changes within this range, the level of average canopy cover varied from 10.26% to 11.71%. The size of cleared areas decreased with increasing levels of buck price. Deer revenue increased continuously because deer production is increasing throughout as the level of optimum canopy cover

Table 11 Optimum canopy cover and livestock and deer revenue response to buck price changes

		Buck price ($/unit)						
Factors	Units	375	600	675	750	825	900	1125
Canopy cover	%	10.26	10.68	10.75	11.30	11.41	11.51	11.71
Brush	%	25.66	26.70	26.86	28.25	28.53	28.77	29.27
Clear	%	74.34	73.30	73.14	71.75	71.47	71.23	70.73
Livestock revenue	$/ha	44.65	44.48	44.45	44.21	44.16	44.12	44.03
Deer revenue	$/ha	7.29	11.22	12.52	14.13	15.48	16.82	20.83
Total revenue	$/ha	51.94	55.70	56.97	58.34	59.64	60.94	64.86
Total cost	$/ha)	4.95	4.99	5.00	5.06	5.07	5.09	5.11
Revenue net of brush control cost	$/ha	46.99	50.69	51.96	53.28	54.56	55.86	59.75

Table 12 Percent change in optimum canopy cover and livestock and deer revenues from changes in buck prices

	Buck price					
Factors	-50	-20	-10	10	20	50
Canopy cover	-9.20	-5.49	-4.87	0.97	1.85	3.63
Brush area	-5.56	-3.33	-2.98	0.60	1.12	2.19
Deer revenue	-48.40	-20.59	-11.39	9.55	19.03	47.42
Livestock revenue	0.99	0.61	0.54	-0.11	-0.20	-0.41
Revenue net of brush control cost	-11.8	-4.86	-2.48	2.40	4.80	12.12

has not reached the level of maximum deer production. Deer revenue increased from$7.29/ha to $20.83/ha. Deer price changes had little effect on livestock revenue which decreased only from $44.65/ha to $44.03/ha.

Table 12 shows the percent change in canopy cover and revenues associated with percent changes in buck prices. An increase in buck price by 10%, 20%, and 50% led to an increase in the level of average canopy cover by 0.97%, 1.85%, and 3.63%, respectively. A decrease in buck price by 10%, 20%, and 50% led to a decrease in the level of average canopy cover by 4.87%, 5.49%, and 9.20%, respectively. Deer revenues changed by the same proportion as buck prices. The effects of deer price on overall profit were less important than on deer revenue. The analysis indicates that the effect of deer price on optimum canopy cover was relatively insignificant, but as in the case of livestock price, the results confirmed the hypothesis that an increase in deer price will lead to an increase in the optimum level of canopy cover and vice versa. Consequently, when deer price increases the rancher will increase brushy areas within the relevant range, until these areas account for 30% of the total area.

Comparison between deer and livestock price effects

The preceding analysis has shown that both deer and livestock prices have little effect on the optimum level of canopy cover. However, Table 13 shows that deer price effects on optimum canopy cover are slightly higher than livestock price effects. The ratios of percent change in optimum canopy cover due to changes in deer prices and

Table 13 Comparison of livestock and deer price effect on optimum Ashe juniper canopy cover

Factors	Percentage changes in prices					
	-50	-20	-10	10	20	50
	Percentage					
(1) Livestock price effect on CC	4.87	1.77	0.88	-1.06	-1.86	-4.51
(2) Deer price effect on CC	-9.20	-5.49	-0.97	0.50	1.85	3.69
(2)/(1)	-1.8	-3.1	-5.5	-0.92	-0.99	-0.81
(3) Livestock price effect on π	-41.38	-16.57	-8.30	8.30	11.59	41.59
(4) Deer price effect on π	-11.80	-4.86	-2.48	2.40	4.80	12.12
(4)/(3)	0.29	0.29	0.30	0.30	0.29	0.29

percent change in optimum canopy cover due to changes in livestock price are greater than one The negative signs of the ratios confirm that livestock and deer price changes have an inverse effect on optimum canopy cover. Results of price changes on profit showed that the effects of livestock price changes were more significant than deer price effects. The ratios of percent change in profit from deer price change and percent change in profit due to changes in livestock price are less than one, as shown in Table 13. The positive signs of the ratios indicate that both deer and livestock prices have the same type of effects on profit. Increasing price levels increases profit, and decreasing price levels decreases profit over the relevant range.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Summary

Brush management depends on many factors, including the methods of brush control used, the pattern of brush removal, and the amount of brush removed. All these factors are interrelated. The methods of brush control influence the decisions on patterns of brush removal, and therefore, affect deer food and cover, and plant communities. Patterns of brush control must be designed according to the control method.

Several studies have shown profitability of brush control for either livestock production or deer production. Most studies did not address brush management for both livestock and deer production. The objective of this study was to determine the optimum amount of brush to maximize revenue net of brush control cost from both livestock and deer production. The results are summarized in Table 14.

The results showed that the optimum level of Ashe juniper canopy cover to maximize revenue net of brush control cost from the production of both livestock and deer was 11.30%, which is close to the level of Ashe juniper canopy cover prevailing at maximum deer production (12.7%). Given an initial brush density of 40% canopy cover, the optimum level of canopy cover determined in this study requires the removal of brush from 72% of the total area. The analysis of the results showed that the optimum level of

Table 14. Optimum canopy cover and revenue net of brush control cost

	Maximum livestock production	Maximum deer production	Optimum livestock and deer production
Canopy cover (%)	0	12.73	11.30
Revenue ($/ha)	42.93	52.85	53.28

canopy cover was not significantly sensitive to changes in livestock and deer prices, but was moving in the direction hypothesized in this study. That is, increases in livestock prices will decrease the optimum level of canopy cover and vice versa. Increases in deer prices will increase the optimum level of canopy cover and vice versa.

The results of this study show that the optimum revenue net of brush control cost was $53.28/ha. It is the highest level of revenue a rancher could obtain from the two other alternatives: maximizing only livestock revenue, or maximizing only deer revenue.

Conclusions

The results of this study imply that removing 100% of the brush while considering only benefits for livestock, or leaving more than sufficient brush to preserve wildlife production was not the optimum solution for controlling the brush and maximizing revenue. The study shows the relevance of determining the amount of brush to be removed to achieve the rancher's objective, and provides an explanation of the growing importance of wildlife in a rancher's decision problem. The importance of wildlife is supported by the fact that the optimum level of canopy cover was close to the level indicated for maximum deer production, and was relatively more sensitive to deer price changes than to livestock price changes. The benefits of wildlife are expected to be much more important than indicated by this study when potential economic returns from other wildlife species are integrated into the analysis.

Thus, the study implies that with good management, brush control has a positive effect on overall ranch production and revenues. The difficulties ranchers face in

increasing the profitability of Ashe juniper infested rangelands was due to the fact that most brush control practices have been oriented toward increasing livestock production. Consequently, the use of areas of a ranch suitable for wildlife production was not optimized. Considerable and sustainable revenues can be derived from brush control if the level of removal is such that ranchers can provide habitat which meets the dietary needs of deer, use a controlled grazing system, proper livestock stocking rates, and manage deer populations.

Limitations

The specific results obtained have some limitations owing to data problems. The data used to estimate the deer production function has certain limitations. Rollins'study did not measure changes in a closed deer population from brush control, but rather changes in on open that may have resulted in deer movement from one stand to another. Therefore, the change in the total deer population is not known from Rollins'study. Yet, the results of this study were based on the best available data on the responsiveness of deer population to Ashe juniper control. The study also relied on a grass production function estimated for redberry juniper by Gerbolini (1996) because of a lack of appropriate data. For Ashe juniper control these limitations may have significant effects on the results of this study.

Recommendations for further research

The approach used in this study could be applicable to different situations reflecting the production of other types of agricultural products and wildlife in different ecosystems. Further research is needed to better determine the relationship of deer populations to brush quantity and density, particularly in a closed deer population. Additionally, the relationship of forage production to Ashe juniper infestations needs to be evaluated.

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