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Economics of redberry juniper control in the Texas Rolling Plains

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Abstract

Redberry juniper (*Juniperus pinchotii* Sudw.) is a common invasive brush species that reduces rangeland productivity over vast acreages in the Rolling Plains and Edwards Plateau regions of Texas. The objectives of this study were to evaluate the economic feasibility of redberry juniper control and determine the optimum treatment cycle for maintenance burning. A response equation was used to estimate the relationship between herbage production and redberry juniper canopy. Data to estimate the relationship was obtained for a site in the Texas Rolling Plains. The analysis used chaining as the initial treatment and periodic prescribed burns as maintenance treatments. Additional livestock production resulting from brush treatments and the costs of treatments were estimated and used to calculate net present values of the investment in brush control over a 30-year time horizon. Net present values indicated that juniper control was economically feasible across a wide range of economic and environmental conditions. Prescribed burn intervals were found to be optimal at 7-year intervals under most conditions.

Key Words: optimal re-treatment interval, prescribed burning, brush management

Resumen

El "Redberry juniper" es una especie arbustiva invasora que reduce la productividad del pastizal en una gran área de las regiones "Rolling Plains" y "Edwards Plateau" de Texas. Los objetivos de este estudio fueron evaluar la factibilidad económica del control del "Redberry juniper" y determinar el ciclo de tratamiento óptimo para el mantenimiento por quema. Se utilizó una ecuación de respuesta para estimar la relación entre la producción de forraje y la copa del "Redberry juniper". Los datos para estimar la relación se obtuvieron de un sitio en la región "Rolling Plains" de Texas. El análisis utilizado encadeno el tratamiento inicial y las quemas prescritas periódicas como tratamientos de mantenimiento. Se estimaron la producción adicional de ganado resultante de los tratamientos de control de arbustos y los costos de los tratamientos; estos datos se utilizaron para calcular los valores netos actuales de inversión en el control de arbustos en un horizonte de tiempo de 30 años. Los valores netos actuales indicaron que el control de "Juniper" fue económicamente factible a lo largo de un amplio rango de condiciones económicas y ambientales. Se encontró que para la mayoría de las condiciones el intervalo óptimo de quemas prescritas es de 7 años.

The infestation of redberry juniper (*Juniperus pinchotii* Sudw.) is a major problem on Texas rangelands, particularly in the Rolling Plains and Edwards Plateau regions of Texas (Ansley et al. 1995). Dense stands of redberry juniper reduce the capacity of these lands to support livestock and wildlife, as well as reducing the amount of water available to recharge underground aquifers (Texas Soil and Water Conservation Board 1991).

Ansley et al. (1995) presented evidence of a substantial increase in the distribution of redberry juniper in a 65-county area in northwest Texas. The area infested by redberry juniper in this region increased 63% (from 15.3 to 25.0 million hectares) from 1948 to 1982. During this period, the percentage of this 65-county area infested by redberry juniper increased from 16% to 26%. The 1987 National Resources Inventory (NRI) indicated that moderate and dense infestations of redberry juniper in the Rolling Plains and Edwards Plateau regions had increased by 16% from 1982 to 1987 (U.S. Department of Agriculture 1990).

Ranchers have used mechanical, fire, and chemical applications to control infestations of redberry juniper. Mechanical control techniques are effective, yet costly. Due to the resprouting nature of redberry juniper and its propensity to reproduce sexually, maintenance control practices are necessary to prolong the effectiveness of control. Prescribed burning has proven to be an effective tool for maintenance treatment of redberry juniper (Rasmussen et al. 1986). The use of fire in combination with a mechanical treatment extends the

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life of expensive mechanical treatments, increases the production of forage plants, and improves the ease of handling livestock (Steuter 1982).

Van Tassell and Conner (1986) used a 15-year dynamic optimization model to evaluate various brush control methods for redberry juniper and other brush species under continuous, deferred, and rotational grazing systems. The control method assumed for redberry juniper was chaining with prescribed burning after 3 years and repeated every 6 years. The results indicated that control of redberry juniper under the assumed conditions was not economically feasible. The response relationships for the brush control practices were compared to a constant level of herbage production on the untreated rangeland, therefore assuming that infestation rates would not increase on the untreated rangelands over the 15-year time frame. Additionally, no benefits were given for reduced labor requirements following brush control treatments.

Reinecke et al. (1997) looked at 6 scenarios for the control of ashe juniper *Juniperus ashei*: Buchholz) using mechanical, herbicide, and fire as control methods over a 12-year period for the Edwards Plateau region of Texas. Ashe juniper densities varied from 3% to 22.5% across the 6 scenarios. Only in situations where densities were highest (18% to 22.5%) did positive internal rates of return to brush control occur over the 12-year period. Returns from livestock production were estimated using grazing lease revenues and an assumed 25% forage grazing-harvest efficiency.

Previous studies have shown mixed results with regard to the economic feasibility of juniper control, thus further evaluation is needed. Comparisons should be made between the increased herbage production following control treatments and the further deterioration of the rangeland as brush canopies increase over time. Additionally, the optimal timing of maintenance burning practices need to be evaluated. Therefore, the objectives of this study were to evaluate the economic feasibility of prescribed burning as a redberry juniper control measure following a mechanical control practice in the Rolling Plains region of Texas and determine the optimum prescribed burning cycle for maintenance control of redberry juniper.

Methods and Procedures

To understand the effects of redberry juniper control on herbage production and income, several relationships are relevant. The brush problem involves both biological and economic phenomena. It is therefore important to understand both the physical and financial relationships associated with the control of redberry juniper.

Control of redberry juniper constitutes an investment in the long-term productivity of rangeland. Costs of control are incurred at the time of initial treatment and periodically thereafter for maintenance of the control level, with benefits being realized throughout the treatment life. The treatment practice of initial control by chaining, followed by prescribed burning 2 years later, and a sequential re-introduction of fire, was the regimen used for this analysis.

Increased revenues from greater herbage production occur each year after the initial redberry juniper control treatment, while added costs are realized only in years when redberry juniper control treatments are applied. For the control practice to be feasible, the present value of added revenues from increased livestock production must exceed the present value of added juniper control and livestock production costs over the period of analysis. A 30-year time frame was used to evaluate the investment in juniper control as a long-term investment. This planning horizon was chosen for 2 reasons: (1) it allowed for a more realistic scenario, considering the life of the investment; and (2) it ensured at least 2 maintenance burns 13 years apart, which is the biological maximum time interval recommended between maintenance burns on flat areas to achieve accentable mortality of juniper seedlings and saplings (Steuter and Britton 1983).

Two time periods are important in the analysis, the time following the initial treatment and the time following the last redberry juniper treatment. Because these 2 time periods occur simultaneously, redberry juniper canopy cover is measured in 2 simultaneous time-frames, "without" (CC_t) and "with" ($CC_{t,tw}$) juniper control applied to the rangeland. The relationship between juniper canopy cover and time may be expressed as:

$$CC_t = CC_{t=0} + r(t) \quad \textbf{(1)}$$

and

$$CC_{t,tw} = CC_{t,tw=0} + r(tw), \quad \textbf{(2)}$$

where CC_t is the percent canopy cover in year *t* without redberry juniper control, $CC_{t=0}$ is the percent canopy cover at time *t*=0, *r(t)* is the percent canopy cover increase per year without redberry juniper control, and *t* is time (yr) following the initial treatment. $CC_{t,tw=0}$ is the percent canopy cover at year *t* from the beginning of the analysis and year *tw* from the last redberry juniper control treatment. $CC_{t,tw=0}$ is the level of canopy cover in years *t* and *tw* = 0, and *r(tw)* is the percent redberry juniper canopy cover increase per year following juniper control.

Redberry juniper is a re-sprouter, meaning that it exhibits basal sprouting following injury or removal of the above-ground portion of the plant (Steuter 1982). Also, mature redberry plants are usually accompanied by an understory of seedlings and saplings which are "released" and grow rapidly after the mature trees are killed or suppressed by mechanical methods. Therefore, the initial control of redberry juniper must be followed periodically with maintenance treatments using prescribed burning or individual plant chemical or mechanical treatments. Figure 1 illustrates the relationship between redberry juniper canopy cover and time. The line labeled CC_t represents the level of redberry juniper canopy cover through time if control treatments were not applied, while the lines $CC_{t,tw}$ represent the levels of canopy cover through time with juniper control treatments being applied. The level of redberry juniper canopy cover is reduced by the initial treatment and maintained below the level of canopy cover without control, CC_t, by periodic re-treatments using prescribed burning.

A herbage production response model was developed to estimate the relationship between herbaceous production and redberry juniper canopy cover. The functional form chosen followed Jameson (1967) and Ffolliot (1983) who suggested negative exponential functions to explain understory-overstory relationships The functional form of the estimated herbage production equation without redberry juniper control treatment was expressed as:

$$HP_t = e^{BO + B1(CC_t)^2}, \quad (3)$$

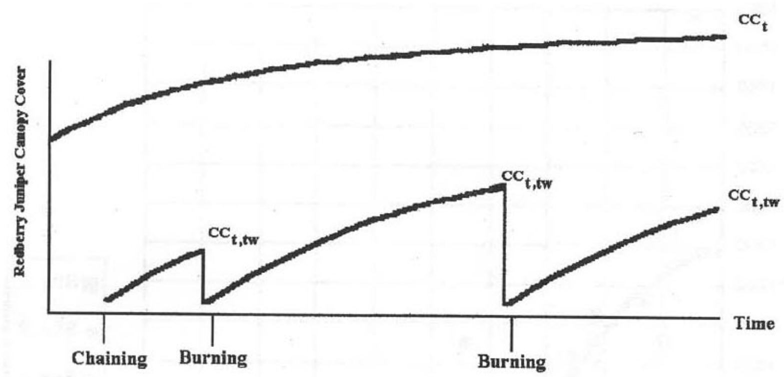

Fig. 1. Redberry juniper canopy cover with and without control treatments.

where HP_t is the production of herbage in kg/ha in year *t, e* is a transcendental number 2.718282, *BO* and *BI* are estimated coefficients, CC_t is percent redberry juniper canopy cover in year *t*, and e^{BO} is the herbage produced in kg/ha when CC_t =0. The functional form of the estimated herbage production equation with juniper control treatment is expressed as:

$$HP_{t,\,tw} = e^{BO\,+\,BI(CC_{t,\,tw})^2}, \quad (4)$$

where HP, CC, and e^{BO} are as previously defined, and *t,tw* represents year *t* from the beginning of the analysis and year *tw* from the last juniper control treatment.

The herbage production relationship shown in Figure 2 represents the estimated herbage production in kg/ha as a function of percent canopy cover of redberry juniper on very shallow range sites in the Texas Rolling Plains near Roscoe, Tex. (Nolan County) (Gerbolini 1996). This relationship was estimated using data collected in 1995 from randomly placed 30-m transects (n=23) along which juniper canopy cover and herbage production were estimated. Herbage production was estimated at each transect's level of canopy cover by clipping 0.25-m^2 quadrants located randomly along the transect. Redberry juniper canopy cover was determined by the line intercept method. Precipitation received during 1995 for the region where the data was collected was near normal. Environmental factors such as rainfall would be expected to influence the level of herbage production. Given that the data used in this analysis was for only 1 year, no rainfall variables were included in the estimated equation.

The equation relating herbage production and canopy cover was estimated as the log-linear equation:

$$\begin{aligned} lnHP = {} & 6.467791 - \underset{(0.000036)}{0.000441}\, CC^2 + \underset{(0.111846)}{0.668824}\, locA + \underset{(0.115501)}{1.180198}\, locB \\ & + \underset{(0.140064)}{1.020753}\, locC + \underset{(0.096812)}{0.670359}\, locD \end{aligned} \quad (5)$$

where lnHP is the natural log of herbage production and CC^2 is the percent canopy cover squared. The variables locA, locB, locC and locD are dummy variables for sampling sites A, B, C, and D, respectively. Site E was the sampling site if the dummy variable values are all zero. The numbers in parentheses are the standard errors of the regression coefficients. All variables were significant at the 1% level. The equation had an adjusted R^2 of 0.9054 and a F-value (5,17) of 43.128.

The location variables locA, locB, locC and locD can be used as weighting factors to adjust the intercept, based on the number of transects laid at each location. The proportion of transects used in the estimation were 17.4%, 21.7%, 8.7%, 34.8%, and 17.4% for locations A, B, C, D and E, respectively. When these proportions are used in equation (5) to define locA, locB, locC and locD, equation (5) may be simplified to:

$$HP_t = e^{7.1626024\,-\,0.000441 * CC_t^2}, \quad (6)$$

where HP_t is the production of herbage in kg/ha at time t, and $e^{7.162024}$ (1290 kg/ha) is the amount of herbage produced at zero canopy cover, and CC_t is the percent canopy cover. Redberry juniper canopy cover and herbage production are inversely related. Increasing redberry juniper canopy cover reduced herbage production at an increasing rate up to 34% canopy cover. Beyond this point herbage production continued to decrease at a decreasing rate as redberry juniper canopy cover increased. The expected level of herbage production at a zero level of juniper canopy cover was 1,290 kg/ha (oven-dry basis). Herbage production decreased to 16 kg/ha at 100% canopy cover.

The added herbage production associated with redberry juniper control is the additional herbage produced with treatment compared to that on untreated rangeland. Additional herbage produced was calculated as the difference between the production of herbage on treated rangeland and untreated rangeland and is expressed as:

$$AHP_t = HP_{t,tw} - HP_t, \quad (7)$$

where AHP_t, is the added herbage production in kg/ha in year *t* from redberry juniper control, and HP_t and $HP_{t,tw}$ are as described in equations 3 and 4, respectively. Herbage production was converted to livestock production using the following relationship:

$$ALP_t = K * AHP_t, \quad (8)$$

where ALP_t, is the additional livestock production in kg/ha in year *t*, K is the kg of marketable livestock produced per kg of herbage, and AHP_t is as defined in equation 7. The conversion factor K (0.020054) was estimated for the Texas Rolling Plains region assuming 11,863 kg of total herbage are required annually to sustain one cow producing unit, a consumption factor of 40% of standing herbage, and 237 kg of marketable livestock per cow producing unit (Ethridge et al. 1984).

The profitability of the investment in redberry juniper control was evaluated using the net present value capital budgeting technique. The net present value of the investment is the discounted cash flows at the ranch's discount rate. The net present value (NPV) of the investment in brush treatment is expressed as:

$$NPV = \sum_{t=0}^{n} \frac{AR_t}{(1 + i)^t} - \sum_{t=0}^{n} \frac{AC_t}{(1 + i)^t}, \qquad (9)$$

where t is as previously defined, AR is the added revenue from the redberry juniper treatment, AC is the added cost of the juniper treatment, n is the treatment life, and i is the discount rate. If the net present value is greater than zero, then the redberry juniper control treatment regime is financially feasible.

The added revenue (AR_t) in \$/ha from livestock production in year t was calculated as follows:

$$AR_t = ALP_t(PL\text{-}AVC) + LS, \qquad \textbf{(10)}$$

where PL is the weighted average price of livestock in \$/kg, AVC is the added variable cost in \$/kg associated with producing additional marketable livestock (\$0.42/kg), the term $(PL - AVC)$ represents the net price for additional livestock production after variable costs have been subtracted, LS is labor savings in \$/ha that are realized from the redberry juniper control, and ALP_t is as defined in equation 8. Livestock price was estimated using the price of heifers, steers, and cull cows weighted according to the percent contribution of each to a marketable animal unit. Labor savings of \$0.62/ha in gathering and working cattle may be realized due to brush control (Ethridge et al. 1991).

The additional cost from control of redberry juniper was estimated by considering the cash outflows incurred from the juniper treatment practices and the cost of deferment of rangeland to build up fuel for the prescribed bums. Added cost of the brush control investment per ha (AC_t) in year t was estimated as:

$$AC_t = TC_{b,t} + DC_t, \qquad (11)$$

where, $TC_{b,t}$ is the cost of treatment b in \$/ha in year t, b is the type of redberry juniper control treatment used, and DC_t is the deferment cost of the land in \$/ha in year t. The type of juniper control treatment used was either chaining (initial treatment) or prescribed burning (maintenance treatment). Deferment costs were calculated as the costs associated with accommodating livestock from the treated rangeland on leased pastures during the deferment period, 6 months prior and 6 months following a prescribed burn. The deferment cost for the first maintenance burn under the baseline scenario was \$7.63/ha.

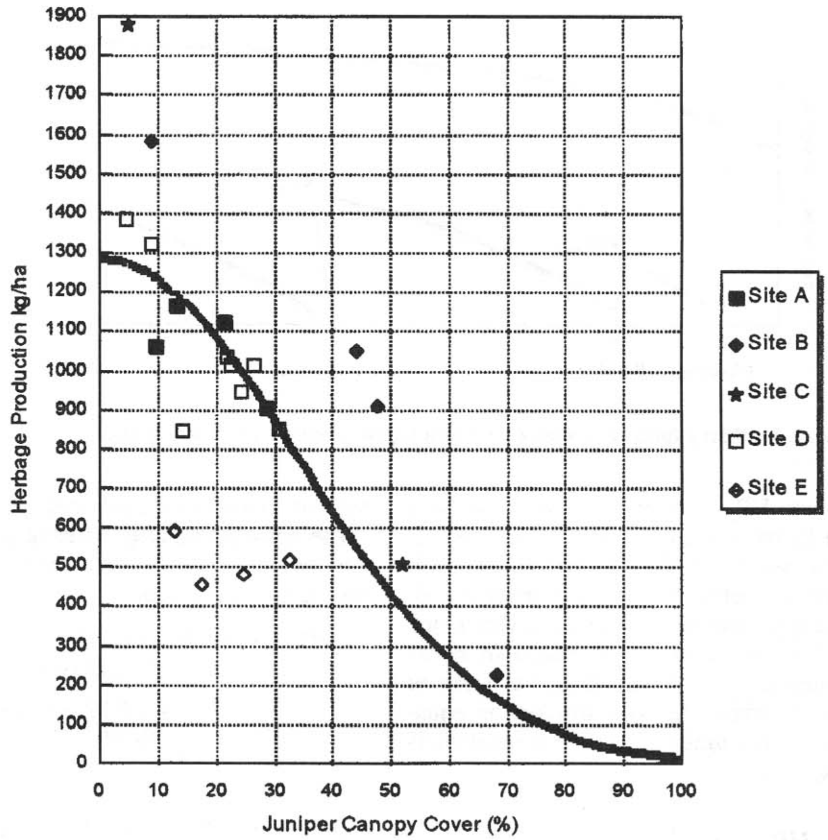

Fig. 2. Herbage production on very shallow ranges as a function of redberry juniper canopy cover. Data collected in 1995 from very shallow range sites (n=23) with various redberry juniper canopy cover percentages in Nolan County, Texas.

The burning cycle was the time (years) between prescribed burns on the treated rangeland. Thirteen years represents the estimated maximum number of years between burns that fire can be used and achieve acceptable control of redberry juniper on flat land (Steuter and Britton 1983). Therefore, burning cycles were evaluated between 2 and 13 years. The optimum burning cycle was that which resulted in the highest NPV for the investment over the 30-year time horizon.

Sensitivity analyses were performed to determine how the economic feasibility of redberry juniper control responded to changes in certain biological and economic variables. Net present value was calculated at the optimum burning cycle for the biological and economic variables at baseline conditions and variations from baseline conditions. Biological variables that were changed included the percent redberry juniper canopy cover increase per year (r) and the initial percent redberry juniper canopy cover ($CC_{t=0}$) on the rangeland. Altered economic variables were price of livestock (PL), real discount rate (i), and treatment cost (TC_t).

The values of the variables at baseline conditions and variations from baseline conditions are given in Table 1. The 9 scenarios evaluated, representing various combinations of the biological and economic variables are shown in Table 2. PL was estimated as the average over the period 1981–1996 (Texas Agricultural Statistics Service 1981–1996). The baseline value of i represents the average intermediate-term interest rate for agricultural loans over the period 1990–1995 adjusted for inflation using the index of producer prices (Federal Reserve Bank of Dallas 1991–1995). The baseline costs of 2-way chaining and prescribed burning treatments were obtained from the Natural Resource Conservation Service (Caudle 1995). The assigned values of r

Table 1. Values of biological and economic variables at low, baseline, and high values.

Variables	Description	High	Baseline	Low
r (%)	Redberry juniper re-infestation rate	5.0	2.5	1.6
$CC_{t=0}$ (%)	Redberry juniper canopy cover at the beginning of the investment	30	20	10
PL ($/kg)	Price of livestock	1.674	1.437	1.200
i(%)	Real discount rate	—	7.50	4.93
TC_{chain} ($/ha)	Treatment cost for chaining	45.097	37.580	—
TC_{burn} ($/ha)	Treatment cost for burning	10.471	8.730	—

and $CC_{t=0}$ represent a typical scenario for the region. The assumed level of redberry juniper canopy cover following brush control treatments was 5%.

High and low values of r were estimated considering canopy increase from 5% to 30% in 5 and 15 years, respectively. High (30%) and low (10%) values of $CC_{t=0}$ were used to reflect extreme conditions with respect to initial canopy cover. Low (10%) represents a mid-point between no infestation and the baseline value.

The high and low PL used were the values 1 standard deviation above and below the baseline value. The low i used was the average of secondary market treasury bills (Board of Governors of the Federal System 1994, 1995). High cost of treatment was estimated by increasing the baseline cost by 20% to adjust for terrain and juniper density differences.

Results

Estimated net present values of an investment in redberry juniper control on very shallow range sites in the Texas Rolling Plains are summarized in Table 3. Under baseline conditions NPVs were positive for all burning cycles. Net present value (NPV) under baseline conditions was highest with a 7- year burning cycle, which represents the optimal burning cycle. The effect of variations in the biological and economic variables on the optimal burning cycle were small. Prescribed burns at intervals slightly shorter or longer than the optimum did not decrease the NPV by a great amount. The present value payback period at baseline conditions was 8 years, which is the period required to recover the investment in the brush control treatments of chaining and burning.

The sensitivity of NPV to changes in the biological and economic variables may be evaluated by the information shown in Table 3. Net present values were calculated for each length of burning cycle while holding variable values at baseline conditions and varying one of the variables to its high or low value. For instance, the NPV with a 7-year burning cycle with all variables at baseline conditions except $CC_{t=0}$ being at a high value of 30% is $140.31/ha. The corresponding NPV with $CC_{t=0}$ being at a low value of 10% is $48.43/ha. The NPV increases as livestock price (PL) increases, while the optimal burning cycle was 7 years at baseline PL and high PL conditions and 9 years at low PL conditions. The level of discount rate had no effect on the optimal length of burning cycle, with the burning cycle being 7 years under both levels of discount rate.

Two important variables regarding the economic feasibility of redberry juniper control are the initial canopy cover ($CC_{t=0}$) and the rate of re-infestation of the brush over time (r). The levels for r influenced the optimal burning cycle and the level of NPV of the treatments while the levels of $CC_{t=0}$ influenced the level of NPV only. As the level of $CC_{t=0}$ increased, the NPV increased because higher levels of initial canopy cover result in greater herbage response after treatment and greater advantage in income with the removal of the redberry juniper. Yet, the optimal burning cycle remained at 7 years for all levels of $CC_{t=0}$ The rate of re-infestation (i.e. canopy cover increase) had an effect on the length of optimal burning cycle. As the re-infestation rate increased the length of burning cycle decreased. These results were as expected, with the lower rate of re-infestation resulting in a longer period between maintenance burns.

The sensitivity analysis revealed that under all conditions specified, the NPV of an investment in redberry juniper control was positive. As would be expected, the lowest NPVs were found at short burning cycles at the low rate of re-infestation, low initial juniper canopy cover, and low price of livestock. The investment was most attractive when the discount rate was low and least attractive when the initial juniper canopy cover was low.

An optimum burning cycle of 7 years was found under most conditions. The optimum burning cycle was most sensitive to the re-infestation rate, decreasing to 5 years with a high re-infestation rate and increasing to 9 years with a low re-infestation rate. The present value payback period was 7 years when the rate of re-infestation was at the high value of 5% per year and 5 years when the initial redberry juniper canopy cover was at the high value of 30%. The payback period increased to 20 years when the initial canopy cover was at the low value of 10%.

Conclusions

Control of redberry juniper, using 2-way chaining initially and prescribed fire

Table 2. Values of biological and economic variables for various scenarios

	r	$CC_{t=0}$	PL	i	TC_{Chain}	TC_{Burn}
Baseline	2.5	20	1.44	7.50	37.58	8.73
r low	1.6	20	1.44	7.50	37.58	8.73
r high	5.0	20	1.44	7.50	37.58	8.73
$CC_{t=0}$ low	2.5	10	1.44	7.50	37.58	8.73
$CC_{t=0}$ high	2.5	30	1.44	7.50	37.58	8.73
PL low	2.5	20	1.20	7.50	37.58	8.73
PL high	2.5	20	1.67	7.50	37.58	8.73
i low	2.5	20	1.44	4.93	37.58	8.73
TC high	2.5	20	1.44	7.50	45.10	8.73

Table 3. Net present value of redberry juniper control ($/ha) for very shallow range sites with biological and economic variables at various values and burning cycles from 2 to 13 years.[1]

	Biological and Economic Variables								
Burning Cycles	Baseline	r low	r high	$CC_{t=0}$ low	$CCV_{t=0}$ high	PL low	PL high	i low	TC high
Years	($/ha)								
2	47.20	11.64	98.30	0.50	92.38	7.58	85.17	86.83	39.68
3	74.29	39.59	122.22	27.59	119.47	35.17	111.79	124.42	66.77
4	85.50	51.80	129.56	38.79	130.67	46.92	122.47	139.38	77.97
5	90.61	58.10	**130.15**	43.90	135.78	52.64	126.99	145.85	83.08
6	93.59	62.40	128.28	46.88	138.76	56.28	129.34	150.03	86.07
7	**95.13**	65.47	124.41	**48.43**	**140.31**	58.17	**130.17**	**152.40**	**87.61**
8	94.11	65.87	118.76	47.40	139.29	58.26	128.47	150.35	86.59
9	93.72	**67.44**	112.25	47.01	138.89	58.80	127.17	149.93	86.20
10	92.42	67.27	107.99	45.71	137.60	58.07	125.34	148.14	84.90
11	90.16	66.54	102.10	43.45	135.34	56.57	122.35	144.58	82.64
12	87.18	65.37	95.04	40.48	132.36	54.50	118.50	139.60	79.66
13	83.71	63.88	87.38	37.01	128.89	52.03	114.08	133.58	76.19

[1]Values shown in boxes are maximums for the column and indicate the optimum burning cycle.

for maintenance control, appears feasible on very shallow range sites in the Texas Rolling Plains under the conditions considered, with the investment in juniper control increasing range productivity and net revenues over the 30-year time horizon assumed for the study. The NPV was positive across a wide range of economic and environmental conditions which would be observed in this region. Range sites with high levels of initial juniper canopy cover or high rates of re-infestation benefit the most from control measures. Yet, positive net present values were obtained at the low levels of initial juniper canopy cover and low re-infestation rates, thus indicating that the initiation of control measures is economically feasible before brush levels reach severe infestation levels.

The optimal burning cycle for maintenance burns was approximately 7 years under most conditions. The optimal burning cycle was most sensitive to the rate of redberry juniper re-infestation, with a higher re-infestation rate dictating the use of fire more frequently. The sensitivity of NPV to the length of burning cycle was low. The recommended reintroduction of fire at 5 years for the high level of re-infestation may be delayed 2 years to make the burning schedule ecologically sustainable without resulting in a substantial decrease in NPV.

Redberry juniper control by 2-way chaining is a long-term investment that requires periodic follow-up practices to maintain the benefits over an extended period of time. Evaluation of the investment using a 30-year time horizon was intended to recognize the need to evaluate this type of investment over several maintenance control cycles. The data indicated that the investment was feasible over this time period. The payback periods for the investment under the scenarios examined varied from 5 to 20 years.

Literature Cited

Ansley, R. J., W. E. Pinchak, and D. N. Ueckert. 1995. Changes in redberry juniper distribution in northwest Texas. Rangelands. 17:49–53.

Board of Governors of the Federal Reserve System. 1994. Federal Reserve Bull. 80:1–78.

Board of Governors of the Federal Reserve System. 1995. Federal Reserve Bull. 81:817–916.

Caudle, D. 1995. 1994–95 cost estimates and costs for chaining and prescribed burning of redberry juniper in the Rolling Plains of Texas. Unpublished.

Ethridge, D.E., B.E. Dahl, and R.E. Sosebee. 1984. Economic evaluation of chemical mesquite control using 2,4,5-T. J. Range Manage. 37:152–156.

Ethridge, D.E., K.W. Bowman, and H.A. Wright. 1991. Labor savings from controlling brush in the Texas Rolling Plains. Rangelands. 13:9–12.

Federal Reserve Bank of Dallas. 1991 and 1995. Quarterly survey of agricultural credit conditions in the eleventh federal reserve district. Federal Reserve Bank, Dallas, Tex.

Ffolliot, P.F. 1983. Overstory-understory relationships: southwestern ponderosa pine forests. p. 13–17. *In:* E.T. Barlett and D.R. Betters (ed.). Overstory-understory relationships in western forests. Colorado State Agr. Exp. Sta. West. Reg. Res. Pub. 1. Fort Collins, Colo.

Gerbolini, A. J. 1996. Economic evaluation of redberry juniper control in the Texas Rolling Plains. M.S. Thesis, Dept. of Agr. Econ., Texas Tech Univ., Lubbock, Tex.

Jameson, D.A. 1967. The relationship of tree overstory and herbaceous understory vegetation. J. Range Mange. 20:247–249.

Rasmussen, G. A., G. R. McPherson, and H. A. Wright. 1986. Prescribed burning juniper communities in Texas. Management Note 10. Dept. of Range and Wildl. Manage., Texas Tech Univ., Lubbock, Tex.

Reinecke, R., R. Conner, and A. Thurow. 1997. Economic considerations in ashe juniper control. Tech. Rep. 97-1, 1997 Juniper Symposium, January 9–10, 1997, San Angelo, Tex. Texas Agricultural Experiment Station.

Steuter, A.A. 1982. Ecological role and potential use of fire in redberry juniper-mixed grass habitats. Unpublished Ph.D. Diss., Dept. of Range and Wildlife Manage., Texas Tech Univ., Lubbock, Tex.

Steuter, A. A., and C. M. Britton. 1983. Fire-induced mortality of redberry juniper (*Juniperus pinchotii*). J. Range Mange. 36:343–345.

Texas Soil and Water Conservation Board. 1991. A comprehensive study of Texas watersheds and their impacts on water quality and water quantity. Texas Soil and Water Conserv. Board. Temple, Tex.

Texas Agricultural Statistics Service. 1981–1996. Texas livestock statistics. Austin, Tex.

U. S. Department of Agriculture. 1990. National resource inventory database 1982–1987. Soil Conservation Service. Temple, Tex.

Van Tassell, L. W., and J. R. Conner. 1986. An economic analysis of brush control practices and grazing systems in the Rolling Plains of Texas. MP-1619 December 1986. Texas Agr. Exp. Sta.. College Station, Tex.