J. Range Manage.
53:23-31 January 2000

Policy prospects for brush control to increase off-site water yield

T.L. THUROW, A.P. THUROW, AND M.D. GARRIGA

Authors are professor and head, Department of Renewable Resources, University of Wyoming, Laramie, Wyo. 82071, natural resource economics consultant, 1071 Duna Dr., Laramie, Wyo. 82072, and project manager, Phytokinetics, 1770 N. Research Park Way, Logan, Ut. 84341. At the time of the research authors were associate professor, Department of Rangeland Ecology and Management, assistant professor, Department of Agricultural Economics, and graduate research assistant, Texas A&MUniversity, College Station, Tex. 77843.

Abstract

Water yield from rangeland on the Edwards Plateau, Texas is significantly greater if a site is dominated by grass instead of brush. Brush control programs are being considered by policy-makers as a way to relieve water shortages in the region. This research analyzed ranchers' willingness to participate in a publicly-funded brush control cost-sharing program that would be ranch-revenue neutral. A survey instrument was mailed to 226 ranchers, 119 were completed and returned (53%). The cost-sharing program required that brush on enrolled land be cleared and maintained at 3% cover for a 10-year period. Respondents estimated that current brush cover on their land averaged 41%, which contrasted with their preference that brush cover average 27%. This expression of preferred brush cover was similar to an independent estimate by a panel of experts in the region which indicated ranch livestock and deer-hunting lease value would be maximized at 30% brush cover. These estimates indicate that a program designed to increase water yield by reducing brush cover to 3% would likely require a financial incentive to offset the cost of brush control that exceeded the preference of the owner. Sixty-six percent of respondents indicated a willingness to enroll some portion of their land in the cost-sharing program described in the survey instrument. Ranch size, the percentage of ranch income earned from deer-hunting leases and livestock, and whether or not ranchers indicated that expense limited past brush control efforts were the variables measured by the survey instrument which best explained the probability of participation and the amount of land the owner was willing to enroll.

Key Words: watershed management, ranch management, cost-share, Edwards Plateau, Texas

Resumen

La producción de agua en el Edwards Plateau en Texas, es significativamente mayor si el sitio es dominado por pastos en lugar de arbustos. Los programas de control de arbustos están siendo considerados por los formuladores de políticas como una manera de aliviar la escasez de agua en la región. Esta investigación analiza la voluntad de los rancheros en participar en un programa financiado con fondos públicos para el control de arbustos con costos compartidos con beneficios neutros para el rancho. Se envió por correo un instrumento de encuesta a 226 rancheros, de los que 119 fueron completados y devueltos (53%). El programa de costos compartidos requería que los arbustos fuesen cortados y que se mantuvieran a una cobertura arbustiva del 3% por un período de 10 años. Los respondientes estimaron que la cobertura actual en sus tierras era en promedio 41%, lo que contrastaba con su preferencia de un promedio de 27% de cobertura arbustiva. Esta expresión de preferencias de cobertura arbustiva fue similar a la estimada independientemente por un panel de expertos en la región, que indicaron que el valor del ganado del rancho y licencia de caza de ciervos sería maximizado con una cobertura del 30%. Estos estimados indican que un programa designado para aumentar la producción de agua a través de la reducción de la cobertura arbustiva a un 3% probablemente requiriría de un incentivo financiero que compense los costos de control de arbustos que excediesen la preferencia del proprietario. Sesenta y seis porciento de los respondientes estarían de acuerdo en enrolar una porción de sus tierras en el programa de costos compartidos descrito en el instrumento de encuesta. Las variables medidas en la encuesta sobre el tamaño del rancho, el porcentaje de ingresos del rancho derivados de las licencias de caza de ciervos y ganadería, y si los rancherosindicaban o no que los gastos limitaron en el pasado sus esfuerzos en el control de arbustos fueron las que explicaron mejor la probabilidad de participación y la cantidad de tierra que el proprietario tendría voluntad de enrolar en el programa.

Consumptive water use in the western U.S. exceeds recharge by an estimated 2.7 x 10^{13} liters per year (22 million acre-feet per year) (Fredrick 1995). This imbalance of supply and demand has resulted in a significant depletion of aquifers and stream flows throughout much of the region (van der Leeden et al. 1990). Reconciling the regional water budget is a fundamental challenge for public policy and is prompting consideration of non-traditional approaches that can increase supply and/or reduce demand (Reisner and Bates 1990). One option involves increasing the water yield of rangeland through brush management. There are hydrology, ecology, socioeconomic, and policy aspects to consider when analyzing the viability of this option. The fundamental hydrology considerations are whether increased water yield as a result of brush management is technically possible and, if so,

Thanks are given to the following individuals who assisted with developing cost-share criteria that were part of the survey instrument: USDA-NRCS range conservationists J. Franklin, C. Englerth, T. Bolzle, L. Post, B. Griffin, and R. Brand; Texas A&M University scientists T. Welch, M. Kothmann, A. McGinty, C. Taylor, Jr., D. Ueckert, D. Rollins and R. Conner. Thanks to B. Rector and R. Griffin for their review comments.

Manuscript accepted 24 Apr. 1999.

what type of management would be required and how much water yield could be expected. The ecology, socioeconomic, and policy considerations are associated primarily with the costs and benefits of implementing brush control designed to increase water yield.

Hydrology Rationale

The theoretical basis for using brush management to increase water yield is founded on the premise that shifting vegetation composition from species associated with high evapotranspiration potential (trees and shrubs) to species with lower evapotranspiration potential (grass) will increase the likelihood of water yield (runoff and/or deep drainage). Climatic and soil traits influence whether reduction in transpiration and interception loss associated with brush to grass conversion would be offset by increased evaporation from soil. An analysis of climate and evapotranspiration characteristics of vegetation types indicated that tree and shrub communities of the Colorado River Basin need to annually receive over 460 mm precipitation and have a potential evapotranspiration rate of over 380 mm to yield significantly more water if converted to grasslands (Hibbert 1983). Studies in many other forest and rangeland habitats throughout the world corroborate that a water yield increase can occur when the dominant vegetation cover is shifted from brush to grass (Douglass 1983, Jofre and Randal 1993).

A summary of lysimeter and catchment research conducted on the Edwards Plateau at the Texas A&M Experiment Station at Sonora concluded that pastures cleared of brush and managed as grassland yielded approximately 940,000 liters ha^{-1} yr^{-1} more runoff and deep drainage than rangeland vegetated with dense brush (60% cover) (Thurow and Hester 1997). Similar estimates of vegetation effects on water yield at the site were independently obtained using the Simulation of Production and Utilization of Rangelands (SPUR-91) model (Redeker 1998). This model has been validated on Texas rangelands (Carlson et al. 1995, Carlson and Thurow 1996).

Both the empirical and modeling investigations conclude that water yield increases exponentially as brush cover declines (i.e., very little change in water yield from dense brush cover to about 15% brush cover and a rapid rise in water yield from 15% brush cover to 0% brush cover). These findings imply that it is necessary to remove most of the brush cover to maximize water yield potential. This conclusion is corroborated by numerous anecdotal observations by ranchers and agency personnel with brush control experience in the region (Kelton 1975, Willard et al. 1993). The exponential pattern of water yield increase relative to a decrease in brush cover has been postulated for the Colorado River Basin as well (Hibbert 1983). The exponential relationship is believed to occur because the intraspecific competition among trees (Ansley et al. 1998) and interspecific competition with herbaceous vegetation results in little increase in water yield until the tree density becomes sparse.

Policy Considerations Regarding Brush Control to Increase Water Yield

Landowners do not receive direct financial benefits from increased off-ranch water yields associated with brush management, therefore water yield considerations are unlikely to influence their current behavior. Decisions of a landowner to control brush are based on the expected benefits from an improved vegetation complex that promotes livestock and wildlife production and various non-financial criteria, such as aesthetic considerations. Maintenance of sustainable ecosystems is an implied assumption of range management, therefore some sites that are susceptible to accelerated erosion (steeplands) or are critical wildlife habitat would not be considered acceptable sites for brush control.

In Texas, ranchers choose the level of brush control since 98% of the rangelands in the state are privately owned. The value of increased forage for livestock associated with controlling brush offsets neither the cost of clearing brush and maintaining grass pastures nor the reduced revenues from deer-hunting leases (Reinecke et al. 1997). Moreover, the expected benefits of brush control accrue over time whereas most of the cost is up-front (Rowan and Conner 1994). Accordingly, without publicly-funded cost-sharing, few ranchers in Texas are likely to engage in the level of brush control needed to improve water yields accruing to off-ranch beneficiaries.

In Central Texas, 2.1 million people depend exclusively on rangeland water recharge to the Edwards Aquifer and to the many streams and rivers that originate on the Edwards Plateau. Over the past century Ashe juniper (*Juniperus ashei* Buchh.), redberry juniper (*Juniperus pin - chotii* Sudw.), and live oak (*Quercus vir - giniana* Mill.) have become dominant on much of the Plateau that was previously characterized as grassland or open savanna (Smeins et al. 1997) resulting in a decrease in water yield (TWDB 1990). A public policy rationale for government support of cost-sharing for brush control is based on the belief that improved water yields from suitable range sites will raise groundwater levels and/or increase stream flow in the region thus benefitting off-site water users.

The objective of this research was to estimate responsiveness to a cost-share offer that would compensate ranchers for the estimated financial outlay and opportunity costs associated with reducing brush cover to 3% (with a corresponding increase in grasses), and then maintaining that level of brush cover for ten years. This is a first step in gauging the extent to which landowners would be willing to participate in a program that could significantly alter the appearance of their land—i.e., there may be hydrology and policy reasons for a program designed to increase water yield but would landowners be willing to participate? A related objective was to develop the capability to predict the participation pattern by analyzing the demographic profile of landowners likely to participate in such a program.

Methods

The survey research protocol of Dillman (1978) was followed in implementing the mail survey. A survey instrument and a postage-paid return envelope were sent in November, 1996 to 226 landowners from 21 counties on the Edwards Plateau, Tex. The sample was developed using mailing lists provided by 6 National Resource Conservation Service (NRCS) range conservationists and the mailing list of ranchers that receive information distributed by the Texas Agricultural Experiment Station at Sonora. The survey instrument was accompanied by a letter on Texas A&M University stationery providing a brief overview of why the survey was being conducted. The name and phone number of the authors, as well as the person who provided the rancher's name, was provided and the recipient was encouraged to call collect if they had any questions. A follow-up post-card was mailed to everyone on the list (the survey instrument maintained the anonymity of the respondents) 2 weeks after the initial mailing to request completion of the survey if they had not already done so. A second copy of the survey instrument was mailed 6 weeks after the original mailing.

The theoretical and methodological foundation for analysis of the value of public goods (in particular, changes in environmental amenities) in the absence of market transactions is contingent valuation (CV) methodology (Mitchell and Carson 1989, Smith 1993). In the context of this study, CV methods were used to estimate the responsiveness to a hypothetical program by prospective participants. Such analysis has been used by policy-makers to fine-tune the design of prospective policy implementation strategies (Purvis et al. 1989, Lohr and Parks 1995, Cooper and Keim 1996).

Survey Instrument

The following description provides a summary of the content and order of information in the 9-page survey instrument. An overview of the rationale for increasing water yield through brush control was provided as an introduction describing why the survey was conducted. This was followed by questions to determine the ranch location (county), ranch size, percent of ranch income from livestock, income from deer-hunting leases, income from wood harvests, and the percent of household income obtained from ranching enterprises.

A set of 6 color photographs of typical Edwards Plateau rangeland with brush cover of 3%, 15%, 30%, 45%, 60% and 75% (everything else being constant), was provided for reference in answering a question requesting an estimate of the portion of the ranch in each brush cover category. Following this, the respondent was asked to indicate how much of each brush cover category was preferred for the ranch. Space was allocated for respondents to comment on the management constraints that prevented current brush cover from matching the preferred brush cover.

Further explanation of the rationale and implementation requirements for a brush control cost-sharing program was then provided. The terms of this hypothetical Texas Brush Control Cost-Sharing Program required the prospective participant to identify how much land in each of the brush cover categories was to be enrolled. The agreement required that the landowner would be responsible for clearing and maintaining the brush so that the enrolled area would have no more than 3% brush cover for the 10-year program period. A 3% brush cover was chosen instead of removing all brush cover because it was presumed there would be a desire to use the area for grazing, thus there is a practical animal physiology consideration for maintaining some shelter provided by brush (Bird et al. 1984). It was stated that the enrolled area would be monitored by Texas authorities to ensure management in accord with the hypothetical contract agreement.

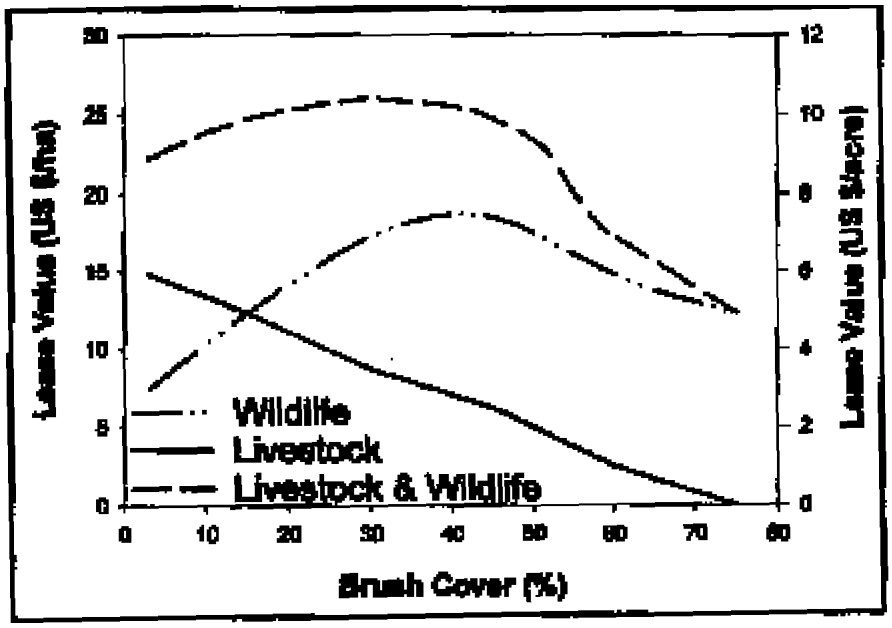

Fig. 1. Lease values for the Edwards Plateau, Texas as influenced by brush cover.

The payment offer for the cost-share agreement was presented in a dichotomous-choice format (i.e., the survey respondent either accepted or rejected a specific cost-share offer). This procedure was preferable to asking the respondent to propose a level of compensation needed to trigger participation because it reduced the potential for them to inflate their required payment above a threshold they would actually be willing to accept (Mitchell and Carson 1989, Hoehn and Randall 1987). A stratified sample posing dichotomous-choice cost-share offers at increasing increments would have enabled the development of a function to describe how participation is likely to increase as cost-share offers increase, following standard contingent valuation techniques (Hanemann 1984). Such an effort requires a significantly larger sample size and was not warranted given the uncertain state of knowledge regarding Texas ranchers' preferences for brush control, their willingness to participate in government programs yielding off-ranch benefits, and other personal values that might influence participation. Rather, this survey was designed to begin the process of understanding factors that influence a decision to reduce brush to a level necessary for significantly enhancing water yield.

The cost-share offer depended on the amount of brush cover on the enrolled land. Participants characterized the brush cover by estimating the amount of land that was in each of the brush cover categories according to the photo key described above. In the first year of the contract, prospective participants would receive a check issued by the State of Texas for their full ten years of participation. Cost-share offers aimed to cover the net present value of the expected cost of the initial brush treatment and its management over ten subsequent years, plus or minus the net expected change in ranch revenues from livestock over 10 years, plus or minus the net expected change in ranch revenues from wildlife over 10 years. A discount rate of 8% was applied to calculate the net present value of the 10-year stream of payments.

Cost-share criteria were developed using expert opinion. Estimates of livestock and deer-hunting lease values (Fig. 1) (i.e., the current market rental rates for land used for grazing and for hunting), were calculated based on a round-table discussion with 7 NRCS range conservationists who have extensive experience on the Edwards Plateau. Input was also obtained from 4 range management specialists, a wildlife ecologist, and a range economist, all with long-term experience gained while employed by the Texas Agricultural Experiment Station and/or the Texas Agricultural Extension Service. Estimated deer-hunting lease rates, which can provide substantial revenues to landowners in Central Texas, were corroborated by county-level data (Texas Comptroller of Public Accounts 1996). Moderate brush cover is

preferable to dense or sparse brush cover in terms of providing wildlife habitat that supports a significant source of prospective ranch income (Rollins et al. 1988). The brush management and maintenance regimes used as the basis for the cost-share calculations were based on regional costs for chaining as the initial treatment and follow-up treatments at 3 year intervals with spot herbicide application. Garriga (1998) provides a detailed discussion of the brush management and maintenance regimes for the 5 types of sites with differing brush densities.

The exact wording of the payment question was as follows: "Enrolling in the Texas Brush Control Cost-sharing Program means converting your acreage to make it look like Site 1 {keyed to the color photograph of 3% brush cover} and maintaining that range condition for 10 years. How many acres of your ranch would you consider enrolling in the Texas Brush Control Cost-sharing Program? (Please write in how many acres you would consider enrolling.)"

Survey respondents indicated how much land they were willing to enroll for a given cost-share payment, expressed in English units (dollars per acres). Five enrollment options were offered: (1) land which now looks like Site 2 {15% cover} would receive a cost-share payment of $146 per ha, (2) land which now looks like Site 3 {30% cover} would receive a cost-share payment of $188 per ha, (3) land which now looks like Site 4 {45% cover} would receive a cost-share payment of $205 per ha, (4) land which now looks like Site 5 {60% cover} would receive a cost-share payment of $173 per ha, and (5) land which now looks like Site 6 {75% cover} would receive a cost-share payment of $188 per ha.

Immediately following the payment question, the text in the survey instrument explained why the cost-share offers differed for sites with different starting brush cover levels. An explanation was presented for why the cost-share offers were highest for sites with 30% and 45% cover (rather than for the more densely vegetated sites): "Please note: You might expect the payments to be highest for ranchers enrolling acreage which looks like Site 5 and Site 6. In fact, the compensation for the estimated cost per ha of the initial brush treatment and the 10-year maintenance is highest for the most densely-vegetated sites: it's $217 per ha for land resembling Site 6, $170 for land resembling Site 5, $153 for land resembling Site 4, $138 for land resembling Site 3, and $101 for land resembling Site 2. However, for ranchers enrolling acreage which looks like Site 5 and Site 6, there are large gains in forage for livestock which help to offset the cost of brush management. Furthermore, ranchers enrolling acreage which looks like Site 3 and Site 4 are losing relatively more revenues from wildlife, thus payments to these ranchers are slightly higher than payments to those enrolling acreage resembling Site 5 and Site 6." The survey concluded by soliciting written comments to explain non-participation or to express concerns from those willing to participate.

Statistical analysis

The probit model was used to estimate the likelihood of participation (PARTICIPATE) in the Texas Brush Control Cost-sharing Program, fitting the equation

$$Participate = f(size, livestock, deer, expensive) + \varepsilon$$

where PARTICIPATE is the probability of the respondent being willing to accept the offered cost-share payments and enroll in the program for 10 years, SIZE is the land area of the ranch, LIVESTOCK and DEER are the percentage of ranch income earned from livestock enterprises and deer-hunting leases, respectively, EXPENSIVE indicates identifying cost as a constraint to past investments in brush control, and ε is a normally-distributed random variate.

The Cragg model, also known as a double-hurdle model (Cragg 1971, Lin and Schmidt 1984), was used to estimate the joint relationship between a respondent's decision about whether or not to participate and the subsequent choice of how much land to enroll in the program (ENROLL). In this 2-stage estimation process, the level of the censored variable, ENROLL, was estimated, conditional on PARTICIPATE being a non-limit (positive) observation. Fitting this Cragg model involved comparing the fit of a truncated regression model and a tobit model, their estimation being contingent on the probit results estimating the probability of participation. The key advantage of the Cragg model is that the same set of 4 variables were hypothesized to be important in determining both ENROLL and PARTICIPATE, but the model allows that the explanatory variables may have opposing effects on the two dependent variables. For this application, positive relationships between LIVESTOCK, DEER, and SIZE and ENROLL were hypothesized, following the same rationales as for the probit model. However, a negative correlation between EXPENSIVE and ENROLL was hypothesized, on grounds that prospective participants who expressed concern about controlling brush being too expensive were more likely to be conservative in the number of acres they were willing to enroll than were prospective participants who had not named EXPENSIVE as a constraint to such investments. Likelihood-ratio tests were conducted to evaluate the specification and the fit of the Cragg model (Greene 1995, p. 596-597).

Results and Discussion

Of the 226 surveys mailed to ranchers, 119 were completed and returned (53%). The total area managed by the respondents was 178,543 ha (or approximately 2.2% of the land area of the Edwards Plateau). Sixty-six percent of the respondents (78 of 119) indicated a willingness to enroll at least part of their land in the cost-sharing program described in the survey instrument. These 78 respondents manage 129,199 ha and were willing to reduce brush cover to 3% on 65,182 ha. This represents 51% of prospective participants' land and 37% of the overall land area managed by both prospective participants and non-participants.

Brush Cover Preferences

The average brush cover on the ranches was estimated by the respondents to be 41%. There was no difference in the amount of existing (current) brush cover between respondents willing or unwilling to participate in the program. There were, however, differences in preferred brush cover between prospective participants and respondents who were not willing to participate (Fig. 2). As a group, those who indicated a willingness to enroll in the program had a brush cover preference skewed to favoring the 3% and 15% brush cover classes; the mode of the 6 cover classes was 15% brush cover for prospective participants as opposed to 30% for non-participants. Both groups preferred a significant reduction of area in the 60% to 75% brush cover categories. Given the survey constraint of requiring land to be cleared to 3% brush cover, the prospective participants were willing to accept having much more of their land in the 3% brush cover category than they would prefer. Since clearing pastures to 3% brush cover would mean removing most of the oaks along with the juniper, ranchers apparently felt

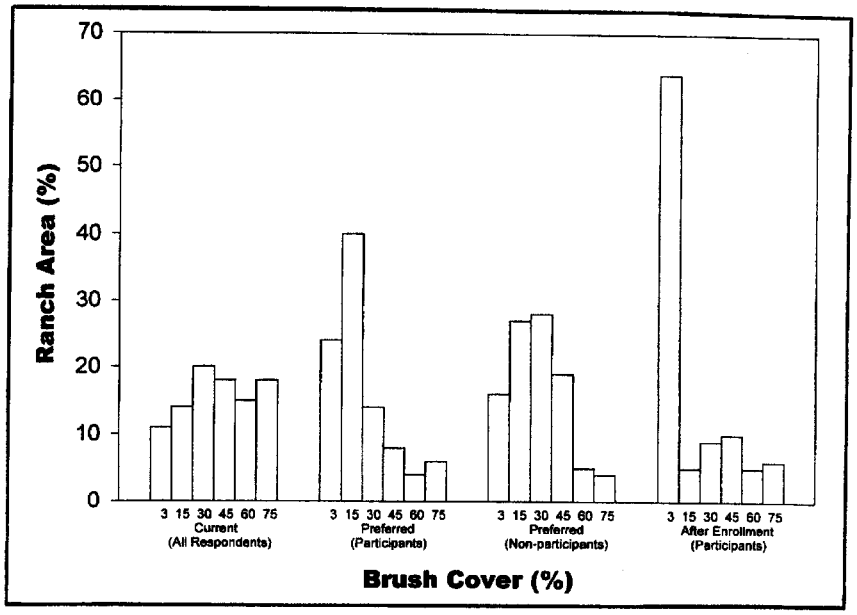

Fig. 2. Current and preferred brush cover as reported by respondents to a survey on willingness to participate in a Texas Brush Control Cost-sharing Program, Edwards Plateau, Texas.

that the loss of oaks which have dietary (browse and acorn) and cover value for both livestock and wildlife was an acceptable tradeoff for more herbaceous forage production and more open spaces making it easier to manage livestock.

Reported differences between actual and preferred brush cover indicate that ranchers have encountered obstacles to controlling brush on their ranches. The reasons offered by respondents to explain why current brush cover differed from preferred brush cover included concerns about: expense (73%), the difficulty of achieving effective brush control (30%), degrading wildlife habitat (6%), liability regarding U.S. Endangered Species Act protection of critical habitat for the Golden-cheeked Warbler (*Dendroica chrysoparia*) and Black-capped Vireo (*Vireo atricapilla*) (5%), and killing desirable woody species (2%).

Ranch Enterprise Considerations

The percent of ranch income currently derived from livestock and deer-hunting leases was markedly different from the prospective livestock and deer-hunting leases that would maximize income from the current brush cover (Table 1). The prevailing market lease rates for livestock grazing and for deer-hunting in the Edwards Plateau (Fig. 1) were used as a proxy for the value-in-use of land, whether actually rented or owned. Given these lease values, survey respondents' descriptions of the current and preferred brush density on their ranches, and their prospective enrollment rates, the value-in-use of land was imputed for prospective participants (the top three rows) and for respondents unwilling to enroll land in the program (the bottom 2 rows). The first row of Table 1 describes the value-in-use of prospective participants' land with brush densities as they were when the survey was conducted. The second row of Table 1 describes the value-in-use of prospective participants' land if they converted it to the level of brush density which they would most prefer. The third row of Table 1 describes the value-in-use of prospective participants' land if they were to enroll in a Texas Brush Control Cost-sharing Program as indicated by their survey response.

A comparison of the imputed lease values in Table 1 implies that ranchers derive a greater percentage of ranch income from livestock and a smaller percentage from deer-hunting leases than is warranted by the brush cover resources they are working with. This corroborates the conclusion by Baen (1997) that the market for deer-hunting leases in Texas is promising, but informal and, therefore, often inefficient. Liability concerns and confusion about the

Table 1. Reported and prospective optimal livestock and deer-hunting lease revenues associated with current and preferred brush cover, as reported by respondents to a survey on willingness to enroll in a Texas Brush Control Cost-sharing Program, Edwards Plateau, Texas.

	Imputed Actual, Optimal, and Prospective Post-Enrollment Lease Values			Mean Proportion of Ranch Income From Livestock Leases		Mean Proportion of Ranch Income From Deer-hunting Leases	
Respondents willing to enroll in a Texas Brush Control Cost-sharing Program**	Livestock	Deer-hunting ($/ha)*	Total	Reported	Optimal	Reported	Optimal
				(%)		(%)	
Lease value associated with current brush cover, pre-enrollment	6.47	14.30	20.77	78	31	22	69
Lease value associated with preferred brush cover, pre-enrollment	10.40	12.15	22.55	–	46	–	54
Lease value associated with brush cover, post-enrollment	11.66	10.32	21.98	–	53	–	47
Respondents unwilling to enroll in a Texas Brush Control Cost-sharing Program**							
Lease value associated with current brush cover	6.57	14.87	21.44	69	31	31	69
Lease value associated with preferred brush cover	9.14	14.30	23.44	–	39	–	61

*Prospective optimal lease values are calculated based on expert opinion estimates (Fig. 1).

**Calculations based on average current and preferred brush cover for prospective enrollees (as a group) and for those unwilling to enroll (as a group).

Table 2. Relationship between ranch size category, participation, and variables used to characterize enrollment. P = Participation, NP = Non-Participation.

	Ranch Size Category							
	< 203 ha		203-810 ha		811-4,049 ha		>4,049 ha	
	P	NP	P	NP	P	NP	P	NP
Number of Respondents	13	13	23	14	29	11	13	3
Respondents Willing to Enroll Divided by the Total Portion of Respondents Within the Ranch Size Category (%)	50		62		73		81	
Ranch Area Enrollment (%)	37		43		46		52	
Median Net Annual Ranch Income From Livestock Enterprises (%)	100	0	75	60	60	80	85	55
Median Net Annual Ranch Income From Deer-hunting Enterprises (%)	0	0	25	30	35	15	15	10
Median Net Annual Household Income From Livestock and Deer-hunting Enterprises (%)	4	0	25	35	55	65	60	35
Portion of Respondents Who Stated that Cost Restricted Their Brush Control Efforts (%)	67	46	79	74	80	94	92	66

potential market prices for deer-hunting leases are cited as key reasons that ranchers fail to realize the potential value associated with their hunting enterprises (Baen 1997). Another reason is that maximizing profit from the ranch is not a primary objective for many small-scale landowners (Rowan and White 1994); the people-management requirements associated with maximizing the value of deer-hunting leases are often not consistent with their expressed primary goals of country lifestyle and managing livestock (Rowan 1994, Rowan and Conner 1995).

Tradeoffs of decreased deer-hunting lease value and reduced total lease value associated with brush control (Fig. 1) did not dissuade individuals who indicated a willingness to participate in the brush control program. A willingness to forego some of the deer-hunting lease value corroborates research indicating that forage and livestock considerations are consistently ranked higher than wildlife considerations when making decisions regarding stocking rate and grazing program benefits (Rowan et al. 1994).

Ranch Size Considerations

Most of the ranches in the survey that were less than 810 ha (2,000 acres) in size were located in the counties adjacent to 1 of 2 large cities of the region: San Antonio (population 1,410,400) or Austin (population 465,622). The configuration of counties around these cities was such that a 1 county radius from the city limit was consistently about 125 km. Regardless of distance from 1 of these cities, participation in the outlined brush control program increased as the ranch size category increased (Table 2).

The percent of median net annual household income from livestock and deer-hunting enterprises tended to increase with ranch size (Table 2). The likelihood of participation and the degree of enrollment increased as the dependence on these enterprises for generating household income increased. Landowners with a ranch size less than 203 ha (500 acres) were not dependent on the ranch for their household income. Landowners in this category who did not derive at least some income from livestock were not willing to enroll in the program.

Predictions of program participation

Concern about whether the cost-share offer would cover the costs of enrollment was the most common issue cited by respondents as an obstacle to participation (Table 3). This concern tended to rise as dependence on livestock and deer-hunting enterprises for household income rose. Nonparticipants expressed concerns regarding wildlife, land value, and aesthetics more frequently than willing participants.

According to the probit model results (Table 4), the most important variables that influenced prospective participation were the percentage of ranch income derived from livestock and deer-hunting enterprises, and whether or not the respondent indicated that expense was a major constraint to their past range management activities. The fitted probit equation predicted that 71% of the respondents would participate in a Texas Brush Control Cost-sharing Program; indeed, 66% were willing to participate. These probit results

Table 3. Write-in comments from survey respondents willing to enroll in a Texas Brush Control Cost-sharing Program, Edwards Plateau, Texas.

Comments	Concerns of Respondents Unwilling to Participate (n=41) (%)	Concerns of Respondents Willing to Participate (n=78) (%)
The cost-share offer would not cover costs of initial treatment and brush management in subsequent years	41	29
The cost-share offer would not offset the negative impact on wildlife values	27	8
The cost-share offer would not offset the negative impact on prospective real estate values	24	3
Brush control negatively impacts aesthetic values	15	3
Respondent does not understand the cost-share offer	15	3
Respondent has a mistrust of government programs	12	9
Benefits of increased forage production would not offset collective negative impacts of brush control	10	3
Brush cover is satisfactory as is	10	0
Respondent too old to fully implement the 10-year cost-share agreement	10	4
Respondent uncertain about how Endangered Species Act habitat preservation restrictions would apply to their land	2	4

Table 4. Probit results, analyzing willingness to participate in a Texas Brush Control Cost-sharing Program

Variable	Coefficient	Standard Error	Z-statistic	Mean	Elasticity
SIZE	0.24 x 10-4	0.37 x 10-4	0.67	3715.00	0.89 x 10-5
LIVESTOCK	0.77 x 10-2	0.42 x 10-2	1.83*	60.52	0.27 x 10-2
WILDLIFE	0.14 x 10-1	0.64 x 10-2	2.09**	23.86	0.49 x 10-2
EXPENSIVE	0.99	0.30	3.24**	0.73	0.36
Intercept	-1.16	0.38	-3.04		-0.42
n	119				
Log-likelihood	-62.16				

Notes: The dependent variable is PARTICIPATE. Elasticities were calculated at the mean. **Indicates significance at the 95% confidence interval and *indicates significance at the 90% confidence interval.

indicated that at the sample mean, if the percentage of ranch income earned from livestock enterprises (LIVESTOCK) were to increase by 1%, then the likelihood of an average respondent (who earns 61% of ranch income from livestock enterprises) enrolling in the program would go up by 0.3%. At the sample mean, if the percentage of ranch income earned from deer-hunting enterprises (DEER) were to increase by 1%, then the likelihood of an average respondent's participation (who earns 24% of ranch income from deer-hunting leases) would go up by 0.5%. An average respondent who offered the explanation that past brush control efforts were constrained by expense (EXPENSIVE) was 36% more likely to enroll in the program than those who did not offer this as an explanation for the discrepancy between the current and preferred brush densities on their ranch.

Results of the Cragg estimation (Table 5) indicate that ranch size, and the percentage of ranch income earned from livestock and deer-hunting leases were statistically significant at the 95% confidence interval in explaining the number of acres the prospective participant was willing to enroll (ENROLL). This equation indicates that at the sample mean, a 1% increase in the portion of ranch income earned from livestock enterprises (LIVESTOCK) increases the amount of land the average prospective participant (who earns 64% of ranch income from livestock enterprises) would enroll in the program by 4.5 ha. At the sample mean, a 1% increase in the proportion of ranch income earned from deer-hunting enterprise (DEER) increased the estimated amount of land which the average prospective participant (who earns 28% of ranch income from deer-hunting leases) would enroll in the program by 6.1 ha. At the sample mean, raising the size of the ranch (SIZE) by 1% would increase the expected amount of land enrolled in the program by the average prospective participant (whose average ranch size is 1,660 ha) by 0.1 ha.

Using the probit and Cragg equations, enrollment in a Texas Brush Control Cost-sharing Program was estimated for five brush density categories among those respondents who were willing to participate (Table 6). Prospective participants had the most eligible land area in the 45% brush density category, in absolute terms, and relatively more densely vegetated land (60% and 75% brush density) than more open land (15% and 30% brush density) was eligible. They were most likely to enroll their most densely vegetated land (45% brush density). The enrolled lands which generate the greatest water yield relative to the cost-share payment are 60% brush density (the most) and 75% brush density (the second most). If response to an actual program were similar to survey respondents' willingness to enroll in this hypothetical program, therefore, the land categories with the highest water yield payoffs would be among those which respondents would be most likely to enroll.

Table 5. Cragg model results, analyzing the number of acres enrolled in a Texas Brush Control Cost-sharing Program.

Variable	Coefficient	Standard Error	Z-statistic	Mean	Elasticity
SIZE	1.45	0.26	5.54**	4099.00	0.28
LIVESTOCK	56.34	26.77	2.11**	64.37	10.77
WILDLIFE	80.20	31.99	2.51**	28.40	15.33
EXPENSIVE	-1023.20	1542.80	-0.66	0.87	-195.55
Intercept	-13806	2957.00	-4.67		-2638.40
n	119				
Log-likelihood	-637.76				

Notes: The dependent variable is ENROLL. Elasticities were calculated at the mean. **Indicates significance at the 95% confidence interval.

Estimated costs of increasing water yield

Increases in water yield from enrollment in a Texas Brush Control Cost-sharing Program depend on the starting level of brush cover on the sites enrolled. Based on analysis of the relationship between brush control and water yield using the SPUR-91 model (Redeker 1998), the estimated increases in water yield associated with clearing brush to 3% density are presented in Table 6. If the program were offered and those who responded to this survey were those who enrolled, an estimated increase of 454 million m^3 (1234 m^3 = 1 acre-foot) water yield from central Texas over the 10 year program would be obtained for a cost of $12.3 million to the taxpayers. Clearing the most densely vegetated sites (i.e., 75% brush cover) generates the greatest total increases in water yield per unit of land area enrolled. However, for the cost-share offers presented to survey respondents evaluating prospective enrollment in a hypothetical Texas Brush Control Cost-sharing Program, the most cost-effective policy option (i.e., the most significant increase in water yield per cost-share dollar) is from enrollment of sites with initial brush cover of 60%.

Management Implications

The complex hydrogeology of the fractured limestone structures which compose the Edwards Aquifer does not allow analysis of where or when downstream benefits from extra water yield associated with brush control would be realized. This limits the ability to conduct a cost/benefit analysis of individual investments in brush control or public investments in a cost-sharing program to support brush control. Given increased pressure on scarce water resources in central Texas, and the legally-mandated concern for maintenance of aquatic habitat of 9 endangered species dependent on seeps and springs from the Edwards Aquifer, however, it is a maintained assumption of this research that a policy to increase water availability would be valuable. If the program were implemented with the primary policy objective

Table 6. Cost share offers in the survey instrument associated with brush cover categories, the estimated water yield associated with the brush control program, and the annualized (over the 10-year program) estimated water yield cost of the water.

Change in Brush Cover	Cost-share Offer	Estimated Land Area Eligible	Estimated Land Area Enrolled	Estimated Percentage of Enrollment Among Eligible Land	Annual Water Yield	Estimated Water Yield Cost
(%)	(dollars/ha)[a]	(ha)[b]	(ha)[b]		(liters/ha/yr)[c]	(liters/dollar)
15 → 3	145.73	16,796	1,554	9%	360,555	24,741
30 → 3	187.72	28,424	11,424	40%	578,915	30,839
45 → 3	205.01	24,548	19,810	81%	680,474	33,192
60 → 3	172.90	18,088	12,503	69%	728,720	42,147
75 → 3	187.72	27,132	19,891	73%	738,874	39,360
Total		129,199	65,182	/[d]		

[a]English units (dollars per acre) were used in the survey instrument.
[b]Eligible land area and enrollment of survey respondents who indicated a willingness to participate in a Texas Brush Control Cost-sharing Program, estimated using the probit and Cragg equations.
[c] Source: Redeker, 1998.
[d]Percentages do not sum to one; calculated as column 4 divided by column 3.
Note: These SPUR-91 model estimates of water yield (Redeker 1998) were not presented in the survey instrument, but are included here to illustrate the annualized estimated cost for expected water yield.

of protecting threatened and endangered species, then federal funding would be appropriate. If, on the other hand, the driving policy impetus for a brush control cost-sharing program were to relax water constraints on central Texas' growing cities, then the program should rely on state and municipal financial support.

Some policy inferences about the estimated costs of a cost-sharing program can be drawn from the results of this survey research. Based on the estimates of water yield increases associated with enrolling land with different starting brush densities, as presented in Table 6, Texas policy makers could develop a protocol for targeting participation by landowners whose enrollment would generate the greatest expected downstream increases in water yield. For example, if alternative sources of water supply were available at a cost of 38,000 liters per dollar, then policy makers might elect to recruit only sites with starting brush cover of 60% or above. If, however, the cost of alternative sources of water supply were greater than 24,000 liters per dollar, then they might elect to open the program to any site with more than 15% brush density and concentrate recruitment efforts on those with sites with the most dense starting brush cover. Another effective policy lever would be to raise the cost-share offers, thus recruiting greater participation among sites with the desired brush density. The cost-share offers presented here were set at the opportunity cost of participation; raising these offers would raise the expected level of participation. An enrollment elasticity of participation cannot be estimated based on these survey data but could be estimated from a follow-up study using a format demonstrated by Purvis et al.(1989).

This sampling frame was comprised of individuals who had a past record of contact with the NRCS range conservationists or were part of the mailing list used by the Texas A&M Agricultural Research Station at Sonora. This sample population is likely to be better informed about brush management and about government-funded cost-share programs than would be a random sample of ranchers from the Edwards Plateau. Currently, if an actual policy were implemented, then the network of ranchers in contact with NRCS range conservationists (those represented in this sampling frame) would be among the most likely to be recruited to enroll in a program like the Texas Brush Control Cost-sharing Program described here. A recent and growing population of ranchers with smaller land holdings and higher off-ranch incomes are under-represented in the sampling frame for this study.

These survey research results offer preliminary support for the development of publicly-funded cost-sharing programs to promote private investment in brush control likely to yield off-site benefits. The survey results suggest that a brush control cost-sharing program, patterned after the 10-year program discussed here, would be most appealing to large landowners who derive a large percentage of their ranch income from livestock and deer-lease revenues. Since clearing land to 3% brush cover would increase livestock income at the expense of deer-lease income, there is an implication that ranchers are willing to sacrifice deer-lease income potential in favor of obtaining brush control funds that would benefit their livestock income potential. Since respondents to this survey generally did not maximize their deer-lease income potential, there appears to be some reluctance and/or lack of knowledge regarding pursuit of this income source. If the under performance of deer-lease income is a knowledge constraint, as asserted by Baen (1997), then the desire to invest in brush control, with or without cost-sharing, would be likely to decrease as knowledge regarding this income option increased.

Landowners with less than 203 ha derived little to no income from the ranch. None of the 26 respondents in this group obtained revenue from deer-hunting leases, probably because of the ranch size limitations and their land management goals. The landowners with less than 203 ha who earned income from livestock derived only 4% of median household income from this source. As a group, landowners in this ranch size class were least likely to participate in the cost-sharing program and, if they did participate, enrolled a relatively small portion of their land. U.S. census results from the past several decades reflect a marked increase in this small ranch category and an overall trend of declining mean ranch size in the 21 counties that compose the Edwards Plateau. The results of this study indicate that there is lower likelihood of participation in the type of brush control program specified by the survey instrument as ranch size and dependence on ranch-derived income decreases. The regional trend toward smaller ranch size and less dependence on ranch-derived income implies that it will likely be more difficult to persuade landowners to participate in a brush control designed to increase water yield.

Literature Cited

Ansley, R.J., B.A. Trevino, and P.W. Jacoby. 1998. Intraspecific competition in honey mesquite: leaf and whole plant responses. J. Range Manage. 51:345–352.

Baen, J.S. 1997. The growing importance and value implications of recreational hunting leases to agricultural land investors in America. Draft Research Paper. Coll. of Business. Univ. of North Texas.

Bird, P.R., J.J. Lynch, and J.M. Obst. 1984. Effects of shelter on plant and animal production. Proc. Australian Soc. of Anim. Prod. 15:270–273.

Carlson, D.H. and T.L. Thurow. 1996. Comprehensive evaluation of the improved SPUR model (SPUR-91). Ecol. Modeling 85:229–240.

Carlson, D.H., T.L. Thurow, and J.R. Wight. 1995. SPUR-91: Simulation of production and utilization of rangelands. p. 1021–1068. In: V.P. Singh (ed.), Computer models of watershed hydrology. Water Resources Publications, Highlands Ranch, Colo.

Cooper, J.C. and R.W. Keim. 1996. Incentive payments to encourage farmer adoption of water quality protection practices. Amer. J. Agr. Econ. 78:54–64.

Cragg, J.G. 1971. Some statistical models for limited dependent variables with application to the demand for durable goods. Econometrica. 39: 829–844.

Dillman, D.A. 1978. Mail and telephone surveys: The total design method. John Wiley & Sons, N.Y.

Douglass, J.E. 1983. The potential for water yield augmentation from forest management in the Eastern United States. Water Resour. Bull. 19:351-358.

Fredrick, K.D. 1995. America's water supply: Status and prospects for the future. Consequences 1:14-23.

Garriga, M.D. 1998. Tradeoffs associated with increasing water yield from the Edwards Plateau, Texas: balancing private costs and public benefits. M.S. Thesis. Texas A&M Univ., College Station, Tex.

Greene, W.H. 1995. LIMDEP version 7 users manual. Econometric Software, Inc. New York, N.Y.

Hanemann, W.M. 1984. Welfare evaluations in contingent valuation experiments with discrete responses. Amer. J. Agr. Econ. 66:332-341.

Hibbert, A.R. 1983. Water yield improvement by vegetation management on western rangelands. Water Resour. Bull. 19:375–381.

Hoehn, J.P. and A. Randall. 1987. A satisfactory benefit cost indicator from contingent valuation. J. Environ. Econ. and Manage. 14:226–247.

Jofre, R. and S. Randal. 1993. How tree cover influences the water balance of Mediterranean rangelands. Ecol. 74:570–582.

Kelton, E. 1975. The story of Rocky Creek. The Practicing Nutritionist. 9:1–5.

Lin, T.F. and P. Schmidt. 1984. A test of the tobit specification against an alternative suggested by Cragg. Review of Economics and Statistics. 66:174–177.

Lohr, L. and T. A. Parks. 1995. Utility-consistent discrete-continuous choices in soil conservation. Land Econ. 71:23–45.

Mitchell R.C. and R.T. Carson. 1989. Using surveys to value public goods: The contingent valuation method. Resources for the Future. Wash. D.C.

Purvis, A., J.P. Hoehn, V.L. Sorenson, and F.J. Pierce. 1989. Farmers' response to a filter strip program: results from a contingent valuation survey. J. Soil and Water Conserv. 44:501–505.

Redeker, E.J. 1998. The effects of vegetation on the water balance of an Edwards Plateau watershed: a GIS modeling approach. M.S. Thesis. Texas A&M Univ., College Station, Tex.

Reinecke, R., R. Conner, and A.P. Thurow. 1997. Economic considerations in Ashe juniper control. pp. 6:3-10. In: Juniper Symposium 1997, Texas A&M University Research Station At Sonora. TR 97-1.

Reisner, M. and S. Bates. 1990. Overtapped oasis: reform or revolution for western water. Island Press, Wash. D.C.

Rollins, D., F.C. Bryant D.D. Waid, and L.C. Bradley. 1988. Deer response to different intensities of brush removal in central Texas. Wildl. Soc. Bull. 16:277–284.

Rowan, R.C. 1994. Are small-acreage livestock producers real ranchers? Rangelands 16:161-166.

Rowan, R.C. and J.R. Conner. 1994. Economic considerations in the control of Ashe juniper, pp. 69-78. *In:* Taylor, C.A. (ed.), Juniper Symposium 1994. Texas A&M Univ. Agr. Res. Sta., Sonora, Texas. TR 94-2, College Station, Tex.

Rowan, R.C. and J.R. Conner. 1995. Small-acreage livestock operators and resource management. Rangelands 17:167–171.

Rowan, R.C. and L.D. White. 1994. Regional differences among Texas rangeland operators. J. Range Manage. 47:338–343.

Rowan, R.C., H.W. Ladewig, and L.D. White. 1994. Perceptions vs. recommendations: A rangeland decision-making dilemma. J. Range Manage. 47:344–348.

Smeins, F., S. Fuhlendorf, and C. Taylor. 1997. Environmental and land use changes: A long-term perspective, pp. 1:3–21. *In:* Juniper Symposium 1997, Texas A&M Univ. Res. Sta. At Sonora. TR 97-1.

Smith, V.K. 1993. Nonmarket valuation of environmental resources: An interpretative appraisal. Land Econ. 69:1–26.

Texas Comptroller of Public Accounts. 1996. Texas farm and ranch hunting survey. Property Tax Division, Texas Comptroller of Public Accounts. Austin, Tex.

Texas Water Development Board. 1990. Water for Texas: Today and tomorrow. Doc. No. GP-5-1. Austin, Tex.

Thurow, T.L. and J.W. Hester. 1997. How an increase or reduction in juniper cover alters rangeland hydrology, pp. 4:9–22. *In:* Juniper Symposium 1997, Texas A&M Univ. Res. Sta. At Sonora. TR 97-1.

van der Leeden, F., F.L. Troise, and D.K. Todd. 1990. The water encyclopedia. Lewis Publishers, Chelsea, Mich.

Willard, E., J. Franklin, and J. Turrentine. 1993. Brush management: A possible solution to our water problems? USDA-SCS. Temple, Tex. Video.