Available online at www.sciencedirect.com

SCIENCE DIRECT®

Ecological Economics 53 (2005) 247–260

ECOLOGICAL ECONOMICS

www.elsevier.com/locate/ecolecon

ANALYSIS

Texas landowner perceptions regarding ecosystem services and cost-sharing land management programs

Keith L. Olenick[a,1], Urs P. Kreuter[b,*], J. Richard Conner[c]

[a]*Plateau Land and Wildlife Management, P.O. Box 1251 Dripping Springs, TX 78629, USA*
[b]*Department of Rangeland Ecology and Management, Texas A&M University, College Station, TX 77843-2126, USA*
[c]*Department of Agricultural Economics, Texas A&M University, College Station, TX 77843-2124, USA*

Received 9 January 2004; received in revised form 23 August 2004; accepted 1 September 2004
Available online 2 February 2005

Abstract

Publicly funded management programs can enhance important ecological services including watershed functions, wildlife habitat, and carbon sequestration. A mail survey was conducted in 2003 in the Western Edwards Aquifer area of Texas to assess landowner perceptions regarding the supply of ecological services from rangelands and their willingness to participate in various land management programs aimed at enhancing such services, which are receiving increasing public consideration. In general, landowners favorably viewed programs that would reduce woody plant (brush) cover in an effort to increase water yields or to improve wildlife habitat, but they disapproved of programs that would encourage the proliferation of woody plants in an attempt to increase atmospheric carbon sequestration. In addition, whether land management programs were voluntary or mandatory had a much greater influence on the level of landowner willingness to participate in programs than the availability of publicly funded cost-sharing. Three-fourths of respondents indicated they would be willing to enroll in cost-sharing brush management programs, and most viewed short-term (5–10 year) performance contracts as the most acceptable legal instrument for participating. To deal with ecosystem trade-offs resulting from woody plant management, we recommend that publicly funded programs aimed at enhancing ecosystem services through effective woody plant management should be flexible. In addition, we recommend the promotion of ecosystem level planning for such programs and cooperative management strategies for landowners participating in such program in order to maximize the effectiveness of associated public investments.

Keywords: Brush management; Carbon sequestration; Mail survey; Water yield; Wildlife habitat

1. Introduction

Important ecological services provided by rangelands in the Edwards Plateau include watershed functions, wildlife habitat, and carbon sequestration, all of which are being affected by changes in land use

* Corresponding author. Tel.: +1 979 8455583; fax: +1 979 8456430.
E-mail address: urs@tamu.edu (U.P. Kreuter).
[1] When paper was written, main author was a Research Assistant in the Department of Rangeland Ecology and Management at Texas A&M University.

0921-8009/$ - see front matter © 2004 Elsevier B.V. All rights reserved.
doi:10.1016/j.ecolecon.2004.09.016

and land cover. During the last 25 years, changes in the use of rangelands overlying the Edwards Aquifer have been driven mainly by the outward population migration from nearby urban areas. The associated land subdivision and development has led to a decline in the area of farmland and contiguous rangelands. In addition, the encroachment of woody plants into the native grasslands and savannas of the Edwards Plateau has accelerated during the 20th century, mainly due to increased suppression of fire, as well as overgrazing and the dissemination of woody plant seed by livestock (Smeins and Merrill, 1988; Taylor and Smeins, 1994; Archer, 1994; Ansley et al., 1996; Smeins et al., 1997).

The westward expansion of human population in Texas has been especially pronounced along Highway I35 between the State Capital, Austin, and San Antonio, the ninth largest city in the United States (USBC, 2000). For example, the area of urbanized land in Bexar County, in which San Antonio is located, increased 29% between 1976 and 1991 and led to a 4% decline in the estimated annual value of ecosystem services as a result of land conversion (Kreuter et al., 2001). In addition to reducing the amount of rangeland, the rapidly growing population is exerting ever greater pressure on the relatively static supply of water from the Edwards Aquifer, which has been capped at 450,000 acre-feet per year and upon which San Antonio and several surrounding communities rely exclusively (Wagner and Kreuter, 2004). The water supply challenges are being further exacerbated by political pressure to restrict the construction of new surface reservoirs (Griffin and Chowdury, 1993; TWDB, 2001).

Elevated woody plant (brush) cover, especially Ashe juniper (*Juniperus ashei* Buchh.) that dominates much of the Edwards Plateau, can diminish streamflow and aquifer recharge because woody plants with dense canopies tend to increase evapotranspiration because they often intercept more precipitation and use more soil moisture than herbaceous plants (Thurow and Hester, 1997). As a consequence, reduction in brush cover can enhance water yields under certain geohydrologic conditions (Dugas and Mayeux, 1991; Dugas et al., 1998; Wright et al., 1976). In particular, the shallow soils and fractured karst geology of the Edwards Plateau may favorably impact the effect of woody plant removal on water yield (Wilcox, 2002) and be less costly than buying open-market water rights to supplement the existing supply of Edwards Aquifer water (Bach and Conner, 2000; Olenick et al., 2004).

Conversely, indiscriminate woody plant removal can lead to habitat fragmentation and a decline in biodiversity as well as food and cover resources for wildlife (Rollins, 2000). These impacts could be especially harmful to whitetail deer (*Odocoileus virginianus* Boddaert) and associated hunting enterprises that represent a significant source of income for Edwards Plateau landowners (Fulbright, 1997; Rollins et al., 1988). Garriga (1998) and Thurow et al. (2000) reported that the most common response from 119 Edwards Plateau ranchers (some with livestock grazing operations, some with deer hunting enterprises, and some with both) to a mail survey was a preference for landscapes with a brush cover average of 27%. In addition, the shift from grassland to shrubland can detrimentally affect grassland-associated wildlife, especially grassland birds which are declining at a faster rate than any other bird group in North America (Peterjohn and Sauer, 1999). Because the Edwards Plateau provides both breeding and wintering habitat for many grassland bird species, selective brush management programs could enhance habitat for such species as well as species requiring hiding cover (Wilkins et al., 2002).

Public concern over the environmental impact of greenhouse gas emissions has gradually grown due to projections by the Intergovernmental Panel on Climate Change that global temperatures will rise 1.4 to 5.8 °C by the end of the century if current greenhouse gas emissions rates persist (IPCC, 2001), which would lead to significant climate and land use changes. Texas is particularly vulnerable to climate changes because increasing temperatures could cause more severe droughts that could decrease groundwater resources and streamflow by 35% to 75% (Schmandt et al., 1992; North et al., 1995; EPA, 1997; Bernow et al., 2000).

To counteract such environmental impacts, the current U.S. administration has included carbon sequestration through changes in land cover as a key element of its climate change initiative. U.S. farmlands and rangelands could potentially sequester 13% of the country's carbon emissions (Comis et al., 2001). In addition, soils with high organic carbon

levels represent a significant atmospheric carbon sink (Post and Kwon, 2000), and land conservation practices that increase soil carbon (no-till farming, improved rangeland management, and conversion of cropland to native vegetation) could increase carbon sequestration by 50 to 1200 kg ha^{-1} annually (Follett et al., 2001; Lal et al., 1998). More specifically, in South Texas, soil organic carbon was found to be greater in mesquite and mixed brush stands than in native grasslands, suggesting that carbon storage increases as woody plant communities mature and expand into surrounding herbaceous areas (Archer et al., 2000; Boutton et al., 1999). In contrast, research comparing three Texas locations found organic carbon levels in the top meter of soil to be more than four times higher in grasslands than in some shublands or woodlands (Jackson et al., 2002). Given these contradictory findings and the lack of rangeland carbon sequestration studies that are Edwards Plateau specific, no general conclusions can be drawn regarding the impact of brush encroachment on the carbon retention capacity of the Edwards Plateau or about the most effective land management practices for maximizing terrestrial carbon sinks.

Because over 95% of land in Texas is privately owned (Conner and James, 1996), any policy instrument aimed at improving water production, wildlife habitat, or carbon sequestration must take into account the interests of private landholders if such instruments are to be widely implemented. Previous studies in the Edwards Plateau found that landowners have substantial interest in cost-sharing programs aimed at manipulating woody plant cover (Garriga, 1998; Thurow et al., 2000, 2001; Narayanan et al., 2002; Kreuter et al., 2004).

The study reported in this manuscript is an expansion of these previous studies. It is also part of a broader study which aims to determine the impact on regional ecological services of land cover and land use changes due to urbanization near San Antonio, and to use this knowledge to evaluate public policies that aim to enhance the future supply of these services. The two specific objectives of our study were (1) to better understand landowner perceptions about the relationship between brush cover and ecological services; and (2) to determine the willingness of landowners within the western portion of the Edwards Aquifer to enroll in land management activities that can enhance an array of specific ecosystem services.

2. Methodology

2.1. Study area

The study area is located in the San Antonio section of the Edwards Aquifer (Fig. 1), which extends westwards from Bexar County in a 160-mile arch and is geologically separated from eastern sections of the aquifer. The Edwards aquifer is one of the world's most prolific artesian aquifers and is the primary water source for about two million inhabitants of south central Texas. The Edwards Aquifer area is divided into three parts: the 11,400 km^2 catchment area on the Edwards Plateau, the recharge zone, and the artesian area, shown in Fig. 1.

The catchment and recharge areas of the western section of the Edwards Aquifer were selected for the study for two reasons: (1) most of the recharge for the aquifer occurs in the western section; and (2) the widespread deleterious effects of rapid land development in this area on the ecosystem services provided by the Edwards Plateau rangelands. Specifically, our study focused on the five counties containing the greatest proportion of the catchment and recharge zones of the western section of the aquifer: Kerr, Real, Bandera, Uvalde, and Medina.

The total area of the five counties included in the survey is 1,409,212 hectares, 84% of which is classified as agricultural land according to 1997 USDA Agricultural Census statistics (LIS, 2003). Of the landowners with agricultural land in 2002, 22% owned less than 20 ha (50 acres), 25% owned 20–73 ha (50–180 acre), 23% owned 73–202 ha (180–500 acres), and 30% owned more than 202 ha (500 acres; LIS, 2003). Landowners with more than 20 ha owned over 99% of all of the agricultural land, while those with more than 202 ha owned 88% of this land.

2.2. Mail survey

A mail survey was sent to landowners in the five selected counties. Mailing lists were obtained from the County Appraiser Office in each county for

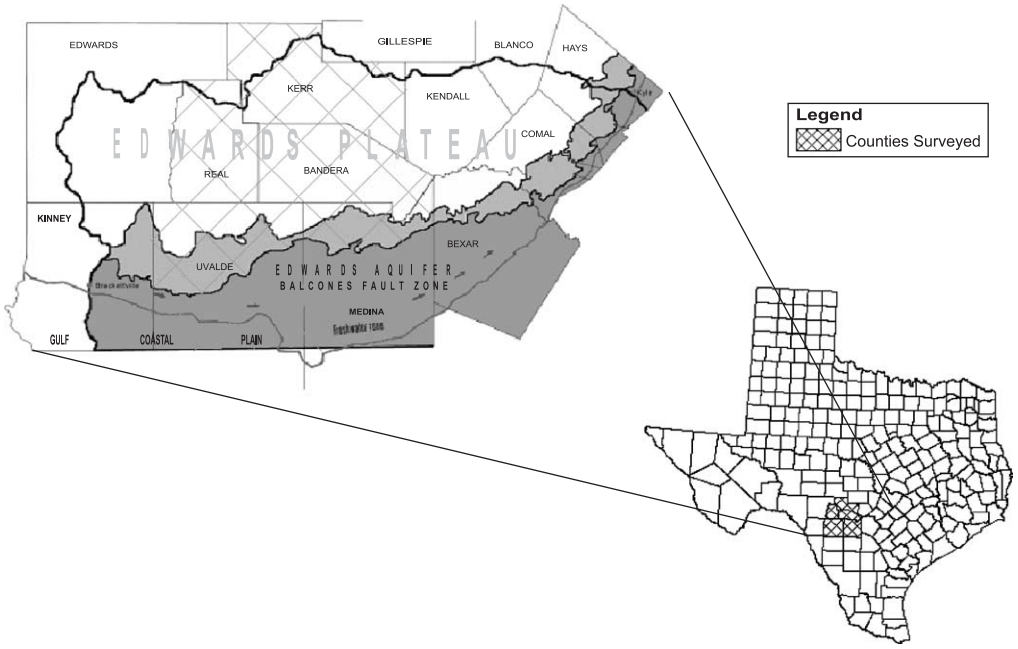

Fig. 1. Location of the Edwards Plateau and Aquifer, and counties surveyed.

landowners with at least 20 ha (50 acres). Landowners with less land were excluded from the survey because of the excessively high per-hectare contract costs they would incur if included in cost-sharing programs. A total of 600 survey participants were randomly selected from the list of landowners with at least 20 ha.

The mail survey was conducted in April and May 2003 using the multiple-contact technique refined by Dillman (2000). The procedure consisted of five mailings: a presurvey letter to provide advance notice to the selected landowners about the survey (day 1), an initial survey questionnaire with cover letter (day 7), a reminder/thank you card (day 21), a second questionnaire with reminder letter to nonrespondents (day 35), and a final card to nonrespondents (day 49).

The nine-page questionnaire consisted of five areas of inquiry: (1) property and land management characteristics, (2) woody plant cover, (3) ecosystem services, (4) cost-sharing programs, and (5) personal information. All questions asking landowners about their level of agreement with or interest in the issue in question used a seven-point Likert scale to measure their level of response (e.g., 1—very unimportant/strongly disagree/very disinterested, 4—neutral, 7—very important/strongly agree/very interested).

Survey data were analyzed using the Statistical Package for the Social Sciences (SPSS). Statistical methods adopted to interpret data included the Pearson correlation coefficient, paired-samples t-test, independent t-test, and Analysis of Variance (ANOVA). In the following section, sample means are presented with their 95% confidence intervals to indicate the level of dispersion. Correlation coefficients (r), paired-samples t-test values (t), and ANOVA F-statistics (F) are all presented with the associated level of probability (p).

3. Results

A total of 248 (41%) usable questionnaires were returned, of which 24% were from Bandera County, 24% from Kerr, 23% from Medina, 21% from Uvalde, and 8% from Real. The respondents were divided into three property size groups: small properties being 20–73 ha (50–180 acres), midsize properties being 73–202 ha (180–500 acres), and large properties being more than 202 ha. Of the respondents, 44% owned

small, 24% midsized, and 32% large properties. The total area owned by the respondents was 102,334 hectares which represents 8.5% of all agriculture land in the survey area.

3.1. Property and landowner characteristics

Small properties represented 4%, midsize properties 7%, and large properties 89% of the total area owned by respondents. These proportions are comparable to those of the land area in each of the three property-size categories in the study counties (LIS, 2003), meaning that results can be expected to be representative of actual landholding sizes. The mean area of land owned by the survey respondents was 416±128 ha, while the median area was 90 ha reflecting that the distribution of property sizes in the study area is positively skewed.

The primary nature of the properties owned by the respondents (n=236) was mixed livestock and wildlife operation (33.9%), followed by mainly livestock production (19.5%), and mainly wildlife operation (14.4%). The remaining 32.2% included crop production, various crop/animal production systems, tourism, primarily a place of residence, and investment.

The largest source of land-based income reported by respondents (n=184) was sale of livestock (43.8±6.0% of property-derived income) followed by income from hunting (22.3±4.7%), while income from other sources ranked third (14.2±4.8%). However, respondents derived only 13.2±3.2% of their 2002 household income from land-based activities, and one-half of respondents earned 2% or less of their income from their land. Percent of income derived from the property was positively correlated with property size (n=223, r=0.391, p<0.001), with small-property landowners averaging 4.5±1.7% (n=96), midsize 10.6±5.6% (n=55), and large 25.7±7.9% (n=71). The total 2002 income category most frequently chosen by the respondents (n=225) was "over $100,000" (42.2%), while only 8.9% of respondents reported earning less than $25,000 indicating that landowners in the study area are relatively affluent.

Survey participants were asked to use a scale of seven to rate the importance (1—very unimportant . . . 7—very important) they place on various rangeland components. Respondents valued grass and forb cover most highly (mean=6.57±0.11, n=240), followed by surface water, such as springs, ponds, creeks (6.34±0.15, n=233), habitat for white-tailed deer (6.26±0.08, n=236), and savanna-like landscape (mean of 5.48±0.19, n=232), while dense brush cover (e.g., juniper) was valued least (2.73±0.24, n=233).

3.2. Woody plant cover

Next, we report landowner responses to questions about their perceptions regarding woody plant cover on their land. When asked to quantify the proportion of eight plant cover types on their land, respondents (n=233) indicated that open grassland (mean=26.1±2.9%), mainly juniper (mean=20.2±3.3%), and mixed live oak/juniper (mean=21.5±3.6%) were the most abundant cover types (Fig. 2). Next, when asked to estimate the portion of their property that fell into four generic plant cover types, respondents (n=233) reported heavy cover (>50% woody plant canopy) to be most abundant (mean=36.5±3.6%), followed by moderate cover (26–50% canopy, mean=25.9±3.0%), open grassland (<5% canopy, mean=24.1±3.3%), and light cover (5–25% canopy, 17.9±2.5%). With the exception of open grassland, which was most abundant for small landowners (F=6.36, p=0.002) and mainly live oak which was more abundant for midsize than small landowners (F=3.05, p=0.049), the vegetative patterns were very similar across the three property-size categories. Thus, over 60% of the area owned by the survey respondents consisted of moderate or heavy woody plant cover, much of which was comprised of juniper or oak/juniper mixed woodlands.

Survey participants were also asked to use the four canopy classes (open, light, moderate, and heavy) to indicate what they consider to be the ideal cover for oak, juniper, mesquite, and mixed brush (Table 1). For oak (n=232), respondents preferred light cover (36%) followed by moderate (32%), heavy (23%), and open cover (9%). For juniper and mesquite, more than two-thirds of the respondents (n=213 and 189, respectively) selected the open cover category (juniper—70%; mesquite—67%), while for mixed brush about half of the respondents (n=221) selected light cover. When the open and light cover categories were combined, midsize-property owners showed a preference for higher densities of juniper than small or

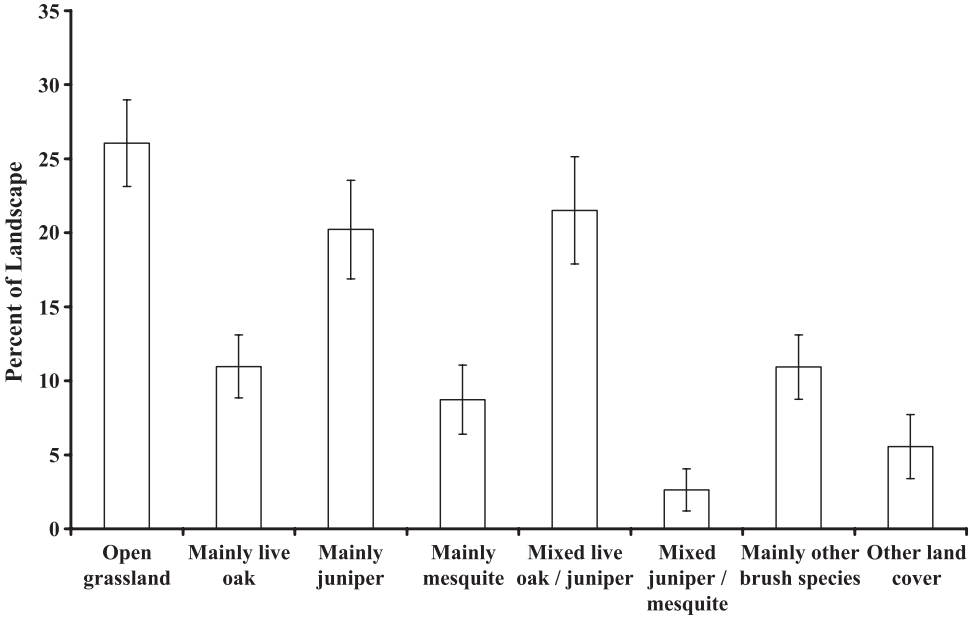

Fig. 2. Plant cover types currently occupying study area (error bars represent 95% confidence limits).

large-property owners (F=5.987, p=0.003). These results suggest that, in general, respondents were tolerant of oak trees because of their aesthetic appeal, but they were intolerant of other woody cover types, especially juniper and mesquite, which they preferred less than occurred on their land.

Table 1
Ideal canopy cover class for of four dominant brush types for small, midsize, and large landholdings

		Canopy cover class			
		Less than 5% (%)	5–25% (%)	26–50% (%)	More than 50% (%)
Oak	Small	10	33	29	28
	Midsize	6	37	42	15
	Large	9	42	29	21
	Average	9	36	32	23
Juniper	Small	71	23	3	3
	Midsize	55	26	14	6
	Large	78	19	1	1
	Average	70	22	5	3
Mesquite	Small	68	27	4	1
	Midsize	54	32	15	0
	Large	73	22	6	0
	Average	67	26	7	1
Mixed brush	Small	39	46	13	2
	Midsize	16	62	16	6
	Large	21	46	27	7
	Average	27	49	19	5

Finally, when asked to rate the importance (1—very unimportant … 7—very important) they place on rangeland components when considering woody plant management, respondents rated increasing grass/forb cover and protecting live oak trees highest (n=231, mean=6.55±0.12; n=230, mean=6.37±0.14, respectively). Other considerations that were also important included reduction of moderate and heavy brush cover (n=225, mean=5.51±0.19), controlling light levels of brush infestation (n=221, mean=5.38±0.20), and creating a mosaic of brush stands separated by open areas (n=220, mean=5.05±0.21). Differences between property-size categories were statistically not significant in each case. Therefore, while maintaining open rangelands and protecting oak trees were most important for respondents, no single plant community consideration appears to dominate their brush management decisions.

3.3. Ecosystem services

Next, we report responses to questions about level of agreement with statements about environmental changes and ecosystem services (1—strongly

disagree … 7—strongly agree). This set of questions was prefaced with a description of the role rangelands may play in global climate change (Appendix A). On average, respondents expressed slightly above neutral agreement with the following statements: global warming is an environmental problem (n=242, mean=4.66±0.24), temperatures have become more extreme (n=240, mean=4.62±0.23), droughts have become more prevalent (n=241, mean=4.88±0.23), and floods have become more prevalent (n=240, mean=4.64±0.21). Respondents were more likely to believe that stream flow has decreased (n=238, mean=5.33±0.23), brush has become more prevalent (n=241, mean=5.62±0.18), and forage supply has decreased (n=242, mean=5.04±0.20). Mean response values did not differ significantly between the three property-size categories. These results suggest that respondents were generally more convinced about local ecosystem changes than global changes.

The survey participants were also asked to provide their views on the role of landowners in providing ecosystem services. Potential roles of land managers in maintaining or improving ecosystem services were listed under four scenarios: Scenario 1—*voluntary* implementation of land management practices *without* public compensation; Scenario 2—*voluntary* implementation of land management practices *with* public compensation; Scenario 3—*required* implementation of land management practices *without* public compensation; and Scenario 4—*required* implementation of land management practices *with* public compensation. Most publicly sponsored cost-sharing programs in Texas aimed at enhancing ecosystem services are voluntary (i.e., Scenario 2). By comparing the results of the four scenarios, the influence of regulated participation in a program and the influence of public funding on the potential level of landowner participation in programs aimed at improving the environment can be estimated.

Differences between the mean response values for each of the four scenarios were highly significant for all six of the listed land management programs (F values ranged from=20.4 to 106.3; p<0.000 in all

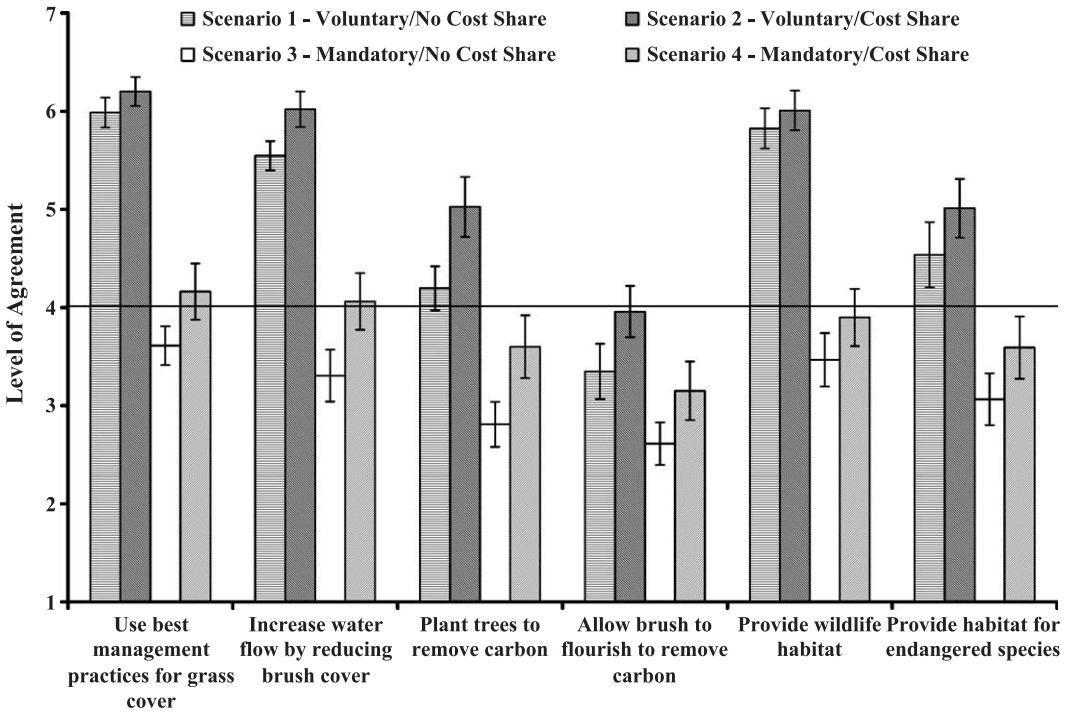

Fig. 3. Landowner agreement in land conservation programs under various scenarios (1—strongly disagree … 7—strongly agree; error bars represent 95% confidence limits).

cases; Fig. 3). In almost all cases, Bonferonni multiple comparison tests showed that potential participation was statistically greatest ($p<0.05$) under Scenario 2 (voluntary with compensation), followed by Scenario 1 (voluntary without compensation), Scenario 4 (mandated with compensation), and Scenario 3 (mandated without compensation). Only for programs aimed at increasing water flow by reducing brush cover and those aimed at providing endangered species habitat were the probabilities greater than 0.05 that the mean response values for Scenarios 1 and 2 were equivalent ($p=0.051$, $p=0.103$, respectively). Based on these analyses, respondents were more receptive to volunteer than mandatory land management programs aimed at enhancing rangeland-related ecosystem services. Although public funding elevated the average response value in every case, this effect was insufficient to offset respondents' aversion to being "required" to adopt certain management practices. In addition, respondents were most favorably inclined towards the idea of using best management practices to improve grass cover, increasing water yields by reducing brush cover, and providing wildlife habitat, and were less interested in the concepts of planting trees or allowing brush to flourish in order to increase carbon sequestration or providing habitat for endangered species.

The final question regarding survey participants perspectives about ecosystem services listed a series of carbon sequestration activities and asked participants to indicate their level of interest in each (1—very disinterested . . . 7—very interested) if a carbon credit program was implemented in which landowners would participate voluntarily and receive "adequate compensation." The level of compensation was not specified in the question, but relative levels of interest in the different programs could be determined from responses. The question was preceded by several statements regarding carbon programs (Appendix B). Survey respondents were most interested in programs aimed at removing brush cover and then seeding grasses ($n=234$, mean=5.51 ± 0.23), minimum or no-till farming practices ($n=175$, mean=5.24 ± 0.26), afforestation ($n=217$, mean=5.07 ± 0.26), and developing buffer strips between grazing lands and riparian areas ($n=191$, mean=4.99 ± 0.26). In contrast, they were neutral in their reaction to methane abatement programs ($n=184$, mean=4.06 ± 0.24) and disapproved of programs aimed at allowing native brush to flourish ($n=215$, mean=3.15 ± 0.27). In addition, the level of respondent interest in voluntary/cost-sharing programs aimed at allowing brush to flourish was negatively correlated, albeit weakly, with the percent of income derived from land ($n=218$, $r=0.179$, $p=0.008$), and proportion of income derived from livestock ($n=178$, $r=0.136$, $p=0.070$), but it was positively correlated with the value respondents placed on dense brush and deer habitat ($n=217$, $r=0.388$, $p=0.000$; $n=229$, $r=0.248$, $p=0.000$, respectively). These perceptions did not differ significantly among property-size categories, except for afforestation to which small-property owners were significantly more amenable than midsize and large-property owners ($F=3.244$, $p=0.041$). The higher level of interest in afforestation than in brush flourishing suggest that landowners may support some programs aimed at increasing woody plant cover to enhance carbon sequestration, but they would probably be selective with respect to species and the location where they would be allowed to flourish, and they would likely resist programs aimed at increasing native brush species, such as juniper, that they perceive to be already overabundant.

3.4. Willingness to participate

Finally, we report the results of analyses regarding landowner willingness to participate in potential land management programs aimed at enhancing ecosystem services. Those who chose not to participate are referred to as "nonparticipants," while those who indicated at least some willingness to participate are referred to as "potential participants." Of the respondents ($n=231$), 75% indicated they were potentially willing to participate in such programs.

There were no significant differences between potential participants ($n=174$) and nonparticipants ($n=57$) with respect to mean property size, mean years of ranching/farming experience, and distribution of perceived vegetative patterns on their land. Potential participants derived a larger portion of their income from land-based activities ($t=2.609$, $p=0.010$). They also agreed more strongly with statements about global and ecosystem changes than nonparticipants (temperatures have become more extreme: $t=2.790$, $p=0.006$; increasingly frequent droughts: $t=2.327$,

p=0.021; increasing abundance of woody plants: t=2.690, p=0.008; decline in stream flows: t=2.225, p=0.027). The only statement regarding ecosystem services where the two groups agreed equally strongly was that "forage supply has decreased".

In a question about the minimum level of cost-sharing they would require to participate in such programs, survey participants were informed that the federal Environmental Quality Initiative Programs (EQIP) currently provides up to 80% cost-sharing. Responses from potential participants (n=174) were bimodally distributed with 31% indicating a 50% cost-sharing requirement, 7% indicating 60%, 17% indicating 70%, 26% indicating 80%, and 19% indicating more than 90%. This distribution did not vary significantly among the three property-size groups.

When asked to indicate their interest (1—very disinterested … 7—very interested) in voluntarily participating in publicly funded incentive programs specifically aimed at accelerating carbon sequestration, potential participants rated all listed interventions more favorably than nonparticipants ($p \leq 0.05$), except for allowing brush to flourish over the entire property, which was considered an unfavorable strategy by both groups (Fig. 4).

Survey participants were also asked to indicate their interest in performance contracts, lease agreements, and conservation easements that could be incorporated in publicly sponsored land improvement programs. Performance contracts are legal instruments in which landowners are partially/fully compensated for their costs of participating in a land improvement program after meeting predetermined performance criteria; lease agreements are instruments in which landowners give up all/part of their land use right in exchange for an annual payment; and conservation easements are instruments in which the landowners receive a lump sum payment in exchange for the transfer of part of land use rights, specifically development rights. Typically, conservation easements are longer in duration than performance contracts or lease agreements. The level of landowners' interest in eight variants of these three categories of legal instruments is presented in Fig. 5.

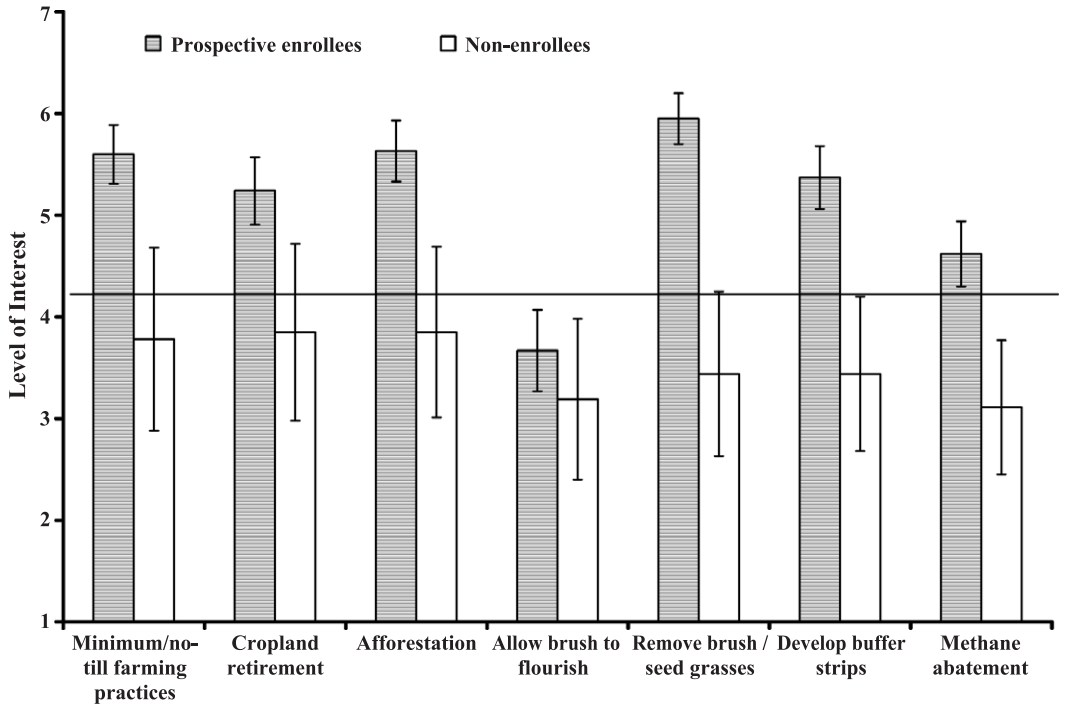

Fig. 4. Level of respondent interest in participating in alternative land management programs aimed at increasing carbon sequestration (1—very disinterested … 7—very interested; error bars represent 95% confidence limits).

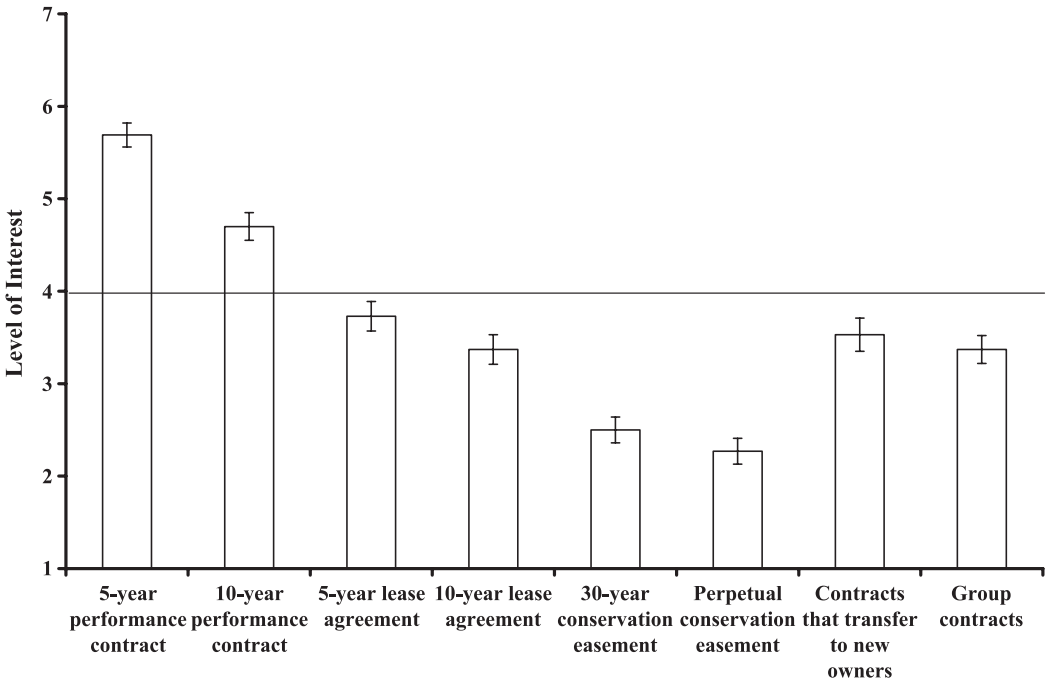

Fig. 5. Level of respondent interest in nine types of potential legal instruments for publicly funded projects (1—very interested . . . 7—very uninterested; error bars represent 95% confidence limits).

On average, performance contracts were the only type of legal instrument in which the potential participants expressed positive interest (F=59.32, p=0.000) with the 5-year term for contracts being more popular than the 10-year term. (t=8.277, p=0.000). This preference for shorter-term contracts was consistent for programs aimed at increasing water yield, improving riparian areas, increasing wildlife habitat, and increasing carbon sequestration. Preference for shorter-term commitments was also reflected in responses for lease agreements and conservation easements. Legal contracts that transfer to new owners when land is sold and group contracts that include multiple landowners also received low interest ratings that did not vary significantly among property-size categories (F=1.46, p=0.234; F=0.52; p=0.597, respectively).

4. Discussion

The management of ground cover on rangelands overlying the Edwards Aquifer and in its 11,400 km^2 catchment is drawing increasing public attention because over two million people rely almost exclusively on the aquifer for their water supply (Wagner and Kreuter, 2004), and this demand is likely to grow significantly with the projected 20–40% population growth by 2040 in Bexar County, in which San Antonio is located. However, water supply is not the only important ecosystem service delivered by the privately owned rangelands on the Edwards Plateau; the supply of forage, wildlife habitat, and atmospheric carbon sinks are three others that are affected by prevailing vegetative patterns.

Increase in brush cover during the last 100 years has been exacerbated by suppression of fire and overgrazing by livestock, which has affected forage and water supplies, as well as habitat for economically important wildlife, such as white-tailed deer and grassland birds (Wilkins et al., 2002). In contrast, the effect of woody plant proliferation on long-term carbon sequestration remains inconclusive (compare Archer et al., 2000; Asner et al., 2003; Boutton et al., 1999; Jackson et al., 2002). However, even if proliferation of woody plants was to increase carbon

sequestration, policy aimed at encouraging such proliferation could further compromise the supply of other ecosystem services and could result in landscape level changes that are impossible to reverse without massive land management interventions.

In regions where land is predominantly privately owned, the maintenance and enhancement of ecosystem services depends on the capacity and incentive of landowners to implement appropriate land management practices. However, analyses using 10-year investment horizons (and that assumed forage productivity to decline if woody plants remain untreated) show that costs of reversing woody plant proliferation are seldom offset by the landowner's benefits of management interventions (Bach and Conner, 2000; Olenick et al., 2004). To ensure the future supply of ecosystem services that benefit society, it is therefore necessary to create positive landowner incentives to implement practices that enhance such services. Public recognition of the positive environmental externalities to society that accrue when private landowners maintain healthy ecosystems has led to growing interest among state and federal agencies to create economic incentive programs that contribute to the cost of maintaining ecosystem services.

In Texas, such programs have included the provision of State funds to clear woody plants aimed at increasing water supply, while at the national level the Conservation Reserve Program, the Environmental Quality Initiative Program, and the Grazing Land Conservation initiative have provided public funds to private landowners for improving ecosystem services. To ensure that such resources are allocated effectively, it is necessary to understand landowner interests and concerns regarding various environmental issues and the implications of participating in such programs. This is especially important when management interventions, such as woody plant reduction, result in trade-offs with respect to the supply of ecosystem services.

Our survey and previous studies indicate that landowners on the Edwards Plateau are very interested in brush management programs aimed at reducing woody plant cover to restore open grasslands, and improve water yields or wildlife habitat (Kreuter et al., 2004; Narayanan et al., 2002; Thurow et al., 2000). However, because of the high cost of removing woody plants, landowner enthusiasm for voluntary implementation of woody plant control measures does not equate with actual implementation of such practices unless the cost of implementing them is offset by public investments. Our survey also found that respondents were generally opposed to allowing brush to flourish beyond moderate levels, but they appear to be favorably inclined towards programs aimed at encouraging the use of best management practices for maintaining grass cover, increasing water supplies, and enhancing wildlife habitat on rangelands.

It is unclear what level of financial incentives would be necessary to overcome landowner resistance to programs aimed at increasing carbon sequestration through brush proliferation. Incentive payments needed for brush proliferation may be greater than those required to increase woody plant reduction efforts by landowners due to the low interest level in allowing brush to flourish. However, these payments could potentially be less than suggested by landowner resistance to woody plant proliferation, because many landowners are economically powerless to treat brush unless they are subsidized. Regardless of the potential public cost of encouraging brush proliferation, programs to increase brush densities over wide areas should be avoided because this could result in potentially irreversible ecosystem shifts that diminish the supply of other ecosystem services, such as clean water supply and grassland bird habitat. Furthermore, allowing woody plants to proliferate may be neither feasible nor acceptable because landowners are less confident about the effect of woody plant cover on global climate changes than about the inverse relationship between brush cover and stream flow.

Our study suggests that landowners will not participate in programs that require long-term agreements. Short-term (5- to 10-year) performance contracts were the most preferred contractual mechanisms. Although, conservation easements still face opposition because many landowners perceive that they curtail landowners' use rights in perpetuity, they are gaining increasing acceptance by some landowners who do not depend on their land for income and who wish to protect their land against subdivision.

The preceding findings and observations suggest that public investments in programs for enhancing ecosystem services through the provision of landowner incentives need to be flexible in order to cope

with land management tradeoffs. This may be especially important for woody plant management given the uncertainties about the effects of alternative land cover types on certain ecosystem services, such as carbon sequestration. Programs that support selective brush management would likely be more effective for enhancing a diverse set of ecosystem services than programs that require uniform brush treatments. Flexible programs allow for a range of brush management treatments depending on the suitability of specific locations for the delivery of alternative ecosystem services.

A three-part woody plant management strategy could be used to simultaneously improve water yield, wildlife habitat, and carbon sequestration. First, woody plants could be intensively removed in upland areas overlying fractured substrata through which surface water can percolate into underlying aquifers and which are suitable for grassland birds. Because of the dominance of this land-type in the Edwards Plateau and the feasibility of controlling juniper via popular mechanical means in these type of areas, trade-offs between water production and carbon sequestration may be particularly strong in these areas (assuming that higher woody plant cover sequester more carbon). Despite the recommendation for intensive removal of woody plants in this land-type, the existence of oaks (*Quercus* spp.) in many areas and the landowner preference for retaining oaks should ensure a reasonable amount of woody plant cover for wildlife.

Second, in riparian zones and adjacent areas frequented by white-tailed deer and many songbirds that require interspersed open areas and closed canopy stands for forage and cover, woody plants could be selectively removed to create heterogeneous vegetative patterns. Based on landowner preferences, target species would include mesquite and juniper, high densities of which are generally unattractive to wildlife (Rollins and Armstrong, 1997) and which may have negative hydrologic effects (Thurow and Hester, 1997).

Third, increased carbon sequestration through woody plant proliferation could be promoted in areas that are too steep for the safe use of mechanical equipment, have high erosion risks, or where soils are too shallow to support vigorous herbaceous ground cover. In the Edwards Plateau, the steeper slopes are generally more fire resistant and support more mature woody plant thickets with closed canopies that are utilized by the federally-listed endangered golden cheeked warbler (*Dendroica chrysoparia* Sclater and Salvin; Armstrong, 2000). Tall mature juniper trees preferred by golden-cheeked warbler are usually associated with drainages, steeper slopes, and canyon areas, and golden-cheeked warblers tend to nest on sloped areas (Wilkins et al., 2002). Thus, brush treatments limited to areas less than 15% in slope are unlikely to impact warbler habitat, while the provision of economic incentives to protect steeper areas from woody plant removal could play a dual role of maintaining a carbon sink and protecting endangered species habitat. Due to the wildfire potential under certain climactic conditions and associated losses of habitat and carbon sequestration, fire prevention measures, such as fire lanes, may be needed in some areas to reduce the risk of disturbance induced habitat losses.

To be effective, the application of such integrated woody plant management programs would require ecosystem level planning and implementation. In turn this requires cooperation among adjacent landowners in the implementation of woody plant treatments. Although obtaining cooperation among landowners at the landscape level is challenging, cooperative management programs have been implemented for the management of deer and the use of prescribed fire, especially in the Edwards Plateau (Wagner and Kreuter, 2004). The provision of public funds to offset the costs incurred by landowners in managing woody plants could be contractually tied to participation in a cooperative management program. While our respondents indicated little interest in group contracts, incentives for participating in cooperative land management programs have been created elsewhere through the establishment of peer monitoring programs for landowners (e.g., LANDCARE program of Australia; Curtis, 1998).

Provided landowner concerns and interests about preferred levels of brush cover and contractual instruments are taken into consideration, such an approach could increase the adoption of ecosystem-scale management strategies that enhance ecosystem services. An additional potential advantage of integrated participatory approaches to land management across landscapes is that they could also strengthen local community stability through increased land-

owner interaction. However, the implementation of such approaches need to be treated carefully so as not to alienate landowners who are concerned that participation in cooperative land management initiatives will compromise their private property rights. Future research should address the extent to which landowners can be encouraged to participate in more integrative ecosystem-level land management programs aimed at enhancing ecosystem services.

Acknowledgements

The research reported in this publication was funded by NASA Land Cover Land Use Management Program Project # NAGS-11144. The authors thank the landowners who voluntarily participated in the mail survey.

Appendix A

In recent years there has been growing awareness of the increase in greenhouse gases. Some scientists estimate that average global temperatures will increase 2–10 degrees (F) in the next century if greenhouse gases, especially carbon dioxide, continue to increase at present rates. Such large increases in temperature could seriously affect ecological services upon which people depend. Because rangelands are widespread and plants absorb carbon dioxide, rangelands could have great potential for absorbing atmospheric carbon. In this section, we seek your opinions about global warming, carbon sequestration (removal by plants) through rangeland management, and the role of landowners in providing ecosystem services. It is possible that in the future, landowners may be compensated for supplying ecosystem services, such as carbon sequestration. In asking these questions, we have no preconceived notions about what is a correct response.

Appendix B

In recent months, the U.S. began implementing methods to aid in reducing greenhouse gases. One method, included in President Bush's Global Climate Change Policy Book, is for companies to pay landowners to remove atmospheric carbon through, for example, cropland conversion to grasslands or by brush cover. The following question seeks information about your potential interest in various land management practices aimed at increasing carbon sequestration if a carbon credit program becomes nationwide and landowners are paid to help remove atmospheric carbon.

References

Ansley, R.J., Cadenhead, J.F., Kramp, B.A., 1996. Mesquite savanna—a brush management problem. Cattleman 82, 10–12.

Archer, S., 1994. Woody plant encroachment into southwestern grasslands and savannas: rates, patterns and proximate causes. In: Vavra, M., Laycock, W.A., Pieper, R.D. (Eds.), Ecological Implications of Livestock Herbivory in the West. Soc. Range Manage., Denver, CO, pp. 13–68.

Archer, S., Boutton, T.W., Hibbard, K.A., 2000. Trees in grasslands: biogeochemical consequences of woody plant expansion. In: Schulze, E.-D., Harrison, S.P., Heimann, M., Holland, E.A., Lloyd, J., Prentice, I.C., Schimel, D. (Eds.), Global Biochemical Cycles in the Climate System. Academic Press, San Diego, CA.

Armstrong, W.E., 2000. Results of "Ecosystem Management" on the Kerr wildlife management area. In: Cearley, J., Rollins, D. (Eds.), Proc. of the Conf. on Brush, Water, and Wildlife: a Compendium of our Knowledge. Res. and Ext. Center, San Angelo, TX, pp. 51–53.

Asner, G.P., Archer, S., Hughes, R.F., Ansley, R.J., Wessman, C.A., 2003. Net changes in regional woody vegetation cover and carbon storage in Texas drylands, 1937–1999. Glob. Chang. Biol. 9, 9316–9335.

Bach, J.P., Conner, J.R., 2000. Edwards Aquifer recharge zone watershed—economic analysis. Brush Management/Water Yield Feasibility Studies for Eight Watersheds in Texas. Tex. Water Res. Ins., College Station, TX, pp. 6:1–6:16.

Bernow, S., Dougherty, W., Dunbar, J., 2000. Texas' Global Warming Solutions. Prepared for The World Wildlife Fund.

Boutton, T.W., Archer, S.R., Midwood, A.J., 1999. Stable isotopes in ecosystem science: structure, function and dynamics of subtropical savanna. Rapid Commun. Mass Spectrom. 13, 1263–1277.

Comis, D., Becker, H., Stelljes, K.B., 2001. Depositing carbon in the bank. Agric. Res. 49 (2), 4–7.

Conner, J.R., James, L., 1996. Environment and natural resources: trends and implications. Texas Agriculture and Natural Resources Summit on Environmental and Natural Resource Policy for the 21st Century. Texas A&M Univ., College Station, TX.

Curtis, A., 1998. Agency-community partnership in landcare: lessons for state-sponsored citizen resource management. Environ. Manage. 22 (4), 563–574.

Dillman, D.A., 2000. Mail and Internet Surveys: The Tailored Design Method. John Wiley and Sons, New York, NY.

Dugas, W.A., Mayeux, H.S., 1991. Evaporation from rangeland with and without honey mesquite. J. Range Manag., 36.

Dugas, W.A., Hicks, R.A., Wright, P., 1998. Effect of removal of *Juniperus Ashei* on evapotranspiration and runoff in the Seco Creek watershed. Water Resour. J. 34, 1499–1506.

EPA (Environmental Protection Agency), 1997. Climate Change and Texas. 230-F-97-008. 4 p.

Follett, R.F., Kimble, J.M., Lal, R., 2001. The Potential of U.S. Grazing Lands to Sequester Carbon and Mitigate the Greenhouse Effect. Lewis Publishers, Boca Raton, FL.

Fulbright, T.E., 1997. Designing shrubland landscapes to optimize habitat for white-tailed deer. In: Rollins, D., Ueckert, D.N., Brown, G. (Eds.), Brush Sculptors: Innovations for Tailoring Brush Rangelands to Enhance Wildlife Habitat and Recreational Value. Tex. Ag. Ext. Serv., San Angelo, TX, pp. 61–67.

Garriga, M.D., 1998. Tradeoffs Associated with Increasing Water Yield from the Edwards Plateau, Texas: Balancing Private Costs and Public Benefits. MS thesis. Texas A&M Univ., College Station, Texas.

Griffin, R.C., Chowdury, M.E., 1993. Evaluating a locally financed reservoir: the case of Applewhite. J. Water Resour. Plan. Manage. 119 (6), 628–644.

IPCC, 2001. Climate Change 2000: The Science of Climate Change. Summary for Policymakers and Technical Summary of Working Group One. Cambridge University Press. 98 p.

Jackson, R.B., Banner, J.L., Jobbagy, E.G., Pockman, W.T., Wall, D.H., 2002. Ecosystem carbon loss with woody plant invasion of grasslands. Nature 418, 623–626.

Kreuter, U.P., Harris, H.G., Matlack, M.D., Lacey, R.E., 2001. Change in ecosystem service values in the San Antonio area, Texas. Ecol. Econ. 39, 333–346.

Kreuter, U.P., Tays, M.R., Conner, J.R., 2004. Landowner willingness to participate in a Texas brush reduction program. J. Range Manag. 57, 230–237.

Lal, R., Kimble, J.M., Follett, R.F., Cole, C.V., 1998. The Potential for U.S. Cropland to Sequester Carbon and Mitigate the Greenhouse Effect. Sleeping Bear Press, Chelsea, MI.

LIS (Land Information Systems), 2003. Texas Cooperative Extension. Texas A&M University. http://landinfo.tamu.edu/, Accessed 12/2003.

Narayanan, C.R., Kreuter, U.P., Conner, J.R., 2002. Tradeoffs in brush management for water yield and habitat management in Texas: Twin Buttes Drainage area and Edwards Aquifer recharge zone. Tex. Water Res. Inst. Technical Report. TR-195. College Station, TX.

North, G.R., Schmandt, J., Clarkson, J. (Eds.), 1995. The Impact of Global Warming on Texas: A Report on the Task Force on Climate Change in Texas. University of Texas Press, Austin, TX.

Olenick, K.L., Conner, J.R., Wilkins, R.N., Kreuter, U.P., Hamilton, W.T., 2004. Economic implications of brush treatments to improve water yield in two Texas watersheds. J. Range. Manag. (in press).

Peterjohn, B.G., Sauer, J.R., 1999. Population status of North American species of grassland birds from the North American breeding bird survey, 1966–1996. Stud. Avian Biol. 19, 27–44.

Post, W.M., Kwon, K.C., 2000. Soil carbon sequestration and land-use changes: processes and potential. Glob. Chang. Biol. 6, 317327.

Rollins, D., 2000. Integrating wildlife concerns into brush management designed for watershed enhancement. In: Cearley, J., Rollins, D. (Eds.), Proc. of the Conf. on Brush, Water, and Wildlife: a Compendium of our Knowledge. Texas Agr. Res. and Ext. Center, San Angelo, TX, pp. 38–46.

Rollins, D., Armstrong, B., 1997. Cedar through the eyes of wildlife. Juniper Symp. Tech. Report 97-1. Tex. Agr. Exp. Stn., San Angelo, TX.

Rollins, D., Bryant, F.C., Waid, D.D., Bradley, L.C., 1988. Deer response to brush management in Central Texas. Wildl. Soc. Bull. 16, 277–284.

Schmandt, J., Hadden, S., Ward, G., 1992. Texas and Global Warming: Emissions, Surface Water Supplies and Sea Level Rise. The Lyndon Baines Johnson School of Public Affairs, University of Texas, Austin, TX.

Smeins, F.E., Merrill, L.B., 1988. Longterm change in a semi-arid grassland. In: Amos, B.B., Gelbach, F.R. (Eds.), Edwards Plateau Vegetation: Plant Ecological Studies in Central Texas. Baylor University Press, Waco, TX, pp. 101–114.

Smeins, F.E., Fuhlendorf, S.D., Taylor, C.A., 1997. Environmental and land use changes: a long-term perspective. Juniper Symp. Tech. Rep. 97-1. Tex. Agr. Exp. Stn., San Angelo, TX, pp. 1–21.

Taylor, C.A., Smeins, F.E., 1994. A history of the land use of the Edwards Plateau and it's effects on the native vegetation. Symp. Juniper, pp. 1–8.

TWDB (Texas Water Development Board), 2001. State Water Plan: Water for Texas-2002. Dec.

Thurow, T.L., Hester, J.W., 1997. How an increase or a reduction in juniper cover alters rangeland hydrology. Juniper Symp. Tech. Report 97-1. Tex. Agr. Exp. Stn., San Angelo, TX.

Thurow, T.L., Thurow, A.P., Garriga, M.D., 2000. Policy prospects for brush control to increase off-site water yield. J. Range Manag. 53, 23–31.

Thurow, A.P., Conner, J.R., Thurow, T.L., Garriga, M.D., 2001. A preliminary analyis of Texas ranchers' willingness to participate in a brush control cost-sharing program to improve off-site water yields. Ecol. Econ. 37, 139–152.

USBC, 2000. Census of Population, 2000. U.S. Bureau of Census, Washington, D.C.

Wagner, M.W., Kreuter, U.P., 2004. Groundwater supply in Texas: private land considerations in a rule-of-capture State. Soc. Nat. Resour. 17, 349–357.

Wilcox, B.P., 2002. Shrub control and streamflow on rangelands: a process based viewpoint. J. Range Manag. 55, 318–326.

Wilkins, R.N., Hejl, S.J., Magness, D.R., Bedford, T.L., 2002. Wildlife response to brush management. Ecosystem and Wildlife Implications of Brush Management Systems Designed to Improve Water Yield. Tech. Report-201. Tex. Agr. Exp. Stan. and Tex. Water Res. Inst., College Station, TX.

Wright, H.A., Churchhill, F.M., Stevens, W.C., 1976. Effect of prescribed burning on sediment, water yield, and water quality from dozed juniper lands in central Texas. J. Range Manag. 29, 294–298.