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Research article

Economic returns and the perceived obstacles to adopting active management in the forest-grassland transition ecoregion in south-central USA☆

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ABSTRACT

Forest-grassland ecotones are a mosaic of grassland, savanna, and upland forest. As such, landowners may have opportunities to choose to manage their lands for multiple objectives. We estimated the economic returns from managing forest and rangeland in southeastern Oklahoma, USA to produce different combinations of timber, cattle forage, and white-tailed deer (*Odocoileus virginianus* Zimmermann) browse for a 40-year period. We further conducted a survey to understand landowner perceptions of obstacles to adopting active management that involve timber harvest and prescribed fire. The highest net return was obtained from the treatment with harvested timber that was burned every four years (uneven-aged woodland/forest) because it had the greatest gross return from a combination of timber (46%), cattle forage (42%), and deer browse (11%). The return from this treatment was greater than that for managed for timber only (closed-canopy forest) or prioritizing cattle and deer (savanna). Survey results suggested that landowners were aware of the benefits of active management but that the majority (66%) considered cost a major obstacle in the management of their forest or rangeland. In particular, women forestland owners and older landowners considered cost an obstacle. Our findings advocate integrated timber, cattle, and deer management as the best economic strategy within the forest-grassland ecotone and for targeted outreach and landowner education related to the benefits of active management.

1. Introduction

In the United States, forest landowners are a major class of ownership having multiple forest management objectives that range from timber production to recreation (Butler et al., 2016). Therefore, Forest landowners choose among management alternatives such as maximizing the value of specific tree products, reducing tree cover to increase understory productivity to balance tree growth with forage and browse for livestock and wildlife, and minimizing tree cover to optimize herbaceous productivity for livestock or grassland-dependent wildlife species (Bettinger et al., 2010; Nyland, 2016). Management decisions depend on the landowner's expected economic returns, perceived obstacles, experience, and willingness to implement various management strategies (Butler et al., 2016; Joshi and Arano, 2009). Understanding the economic returns from scenarios that vary outputs among trees, cattle, and wildlife is vital for informed management decisions (Bettinger et al., 2010). Landowner opinions on perceived obstacles can further help design appropriate outreach programs to facilitate decision-making.

In the continental United States, there is significant variation in major land uses between regions. For example, while forestland is dominant in Northeast, Appalachia, and southern states, the majority of lands in the southern plains are in grassland/pasture lands (Bigelow and Borchers, 2017). The Central Forest-grassland Transition Ecotone of the south-central USA is a dynamic region consisting of tallgrass prairie, savanna, and upland forest that occurs between the grasslands of the Great Plains and the forests of the eastern USA (Hallgren et al., 2012; Hoff et al., 2018a; Joshi et al., 2019b). The ecoregion is affected by prolonged droughts (Tian et al., 2018), erratic rainfall (Otkin et al.,

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2019), and unpredictable wildfires (Clark et al., 2007; Hallgren et al., 2012) which alter the relative abundance of trees vs herbaceous vegetation. Historically, the transitional nature of the region was maintained by climate and frequent burning that was influenced by topographic features, particularly waterway distribution (Anderson, 1983, 2006; Hoff et al., 2018a). Fire was largely excluded since the mid 20th Century, which increased forest cover, increased the abundance of mesic hardwood tree species, and allowed encroachment of eastern redcedar (*Juniperus virginiana* L.) (Hoff et al., 2018b; Kaur et al., 2019). The changes resulting from fire exclusion have adverse effects on many ecosystem services (Joshi et al., 2019b) including reduced understory productivity (Feltrin et al., 2016), which provides forage and browse for cattle and some wildlife species.

Management using prescribed fire at three years or less return interval can maintain savanna while longer fire intervals or fire exclusion result in uneven-aged or even-aged forests respectively (Adhikari et al., 2021a; Feltrin et al., 2016; Masters et al., 2006). Active management to shift from a closed-canopy forest to woodland or savanna using thinning and prescribed fire benefits a number of ecosystem services. For example, evapotranspiration is greater in forest than in mixed cover and non-forested land (Zhang et al., 2001) such that reducing tree cover increases water yield to streams (Qiao et al., 2017; Zhong et al., 2020). Prescribed fire and thinning improves forest health by reducing fuel load (Starr et al., 2019), improves wildlife habitat (Harper and Johnson, 2008), and increases grass production (e.g., Feltrin et al., 2016) for cattle forage.

Implementation of prescribed fire and thinning is, however, limited by economic and financial burdens and liabilities incurred by landowners (Starr et al., 2019). While portions of the Central Forest-Grassland Transition Ecotone have a viable timber industry, cost becomes a major impediment for adoption of active management, especially on marginal forestlands or areas not near mills and processing facilities (OFS, 2010). Therefore, landowners may prefer integrated enterprises (Hines et al., 2021), especially on lands not suited for row-crop agriculture or plantation silviculture. Landowners in Oklahoma, USA, in the Central Forest-Grasslands Transition Ecotone, have the potential to earn income from timber, cattle, and wildlife. In Oklahoma, the forest sector annually contributes more than 5.5 billion dollars in direct industry output and indirectly generated about 18,500 jobs (Gore et al., 2022). Oklahomans received an estimated $722.4 million in total annual ecosystem services from cattle grazing on approximately 15 million acres of mostly private rangeland (Maher et al., 2020). White-tailed deer (*Odocoileus virginianus* Zimmermann) hunting is an important wildlife management activity (Arnett and Southwick, 2015; Hines et al., 2021), an avenue for social interaction, and holds cultural value in the southern United States (Arnett and Southwick, 2015). Annually, 13.7 million deer hunters contribute $38.3 billion to the USA economy (Arnett and Southwick, 2015).

Our first objective was to determine the economic returns from different management scenarios including timber harvest, thinning, and prescribed fire to create stand conditions ranging from closed-canopy forest to savanna/grassland in southeastern Oklahoma. Specifically, we compared benefits and costs related to management objectives for timber, cattle, and white-tailed deer habitat over a 40-year time horizon. This research is especially important along the forest-grassland ecotone as forest production is typically lower than areas with greater precipitation such that the relative production of trees and herbaceous vegetation shifts according to management regime, weather, and climate. Since our study area spans the forest-grassland ecotone, study results provide direct ecological context for the broad landmass that runs from Texas to Illinois. Indirectly, our study is relevant to integrated forest and agriculture-based production in North America, Asia, and other parts of the world (Kanianska et al., 2014; Liu et al., 2017; Sharma et al., 2014).

While active forest management through intensive silviculture provides several tangible and intangible benefits (Nyland, 2016), it adds substantial costs due to increased use of labor and capital (Callaghan et al., 2019). In particular, the cost comes as a major obstacle to managing millions of acres of marginal forestlands in North America (Kaur et al., 2019; Starr et al., 2019; Stoof et al., 2015). Therefore, an economic analysis does not provide a complete picture without understanding the social issues that may be obstacles for active management. Therefore, the second objective was to understand landowner perceptions of obstacles in adopting active management that involves timber harvest and prescribed fire.

Given the multiple management opportunities, it is imperative to explore how landowner management objectives, socio-economic realities, and landownership characteristics are associated with their perceptions of cost as an obstacle in adopting active management in the forest-grassland transition ecoregion. Economics and perceptions of cost are driving factors to influence landowners' decisions to actively manage their land. Our research, therefore, will provide a basis for decision-making and allow prediction of how potential economic returns and perceptions about costs may affect management choices by landowners.

2. Methods

2.1. Data collection and analyses

2.1.1. Economic value of timber, cattle forage, and deer forage

We utilized the field data collected from the ~53 ha Forest Habitat Research Area located at the Pushmataha Wildlife Management Area to understand the economics of management for different mixes of timber, cattle, and deer habitat. The research site is in the semi-humid region of Oklahoma characterized by hot summers and moderate winters (Thornton et al., 2018). Research plots were established in 1983 using a random experimental design and included Control (no treatment), HT (harvest pine and thin hardwood), HT2, HT3, HT4 (harvest pine, thin hardwood, and burn at 2-year interval, 3-year interval, 4-year interval, respectively). The combination of thinning and prescribed fires describe the intensity of active forest management. Details on the study area are available in previous publications (Adhikari et al., 2021a, 2021b; Masters and Waymire, 2012; Masters et al., 2006). In 2017, the Control treatment was closed-canopy forest of mixed pine *(Pinus echinata* Mill), oak (*Quercus stellata* Wangenh. And *Q. marilandica* Muenchh.) and hickory (*Carya* spp.) approximately 90 years-old, the HT treatment was a closed-canopy, even-aged forest approximately 35-years-old, the HT4 treatment was an uneven-aged woodland, and the HT3 and HT2 treatments were savanna (Adhikari et al., 2021b, 2022).

We utilized the data collected from the three Control stands using 20 variable-radius plots per stand (Basal Area Factor 10 prism) that included tree DBH and height (Feltrin et al., 2016) to represent the condition of stands before treatments were implemented. The basal area factor is the multiplier that converts number of trees counted as 'in' to the basal area, i.e., total cross-sectional area of trees (ft^2 per acre) (Bettinger et al., 2010). The forest vegetation simulator (FVS) was used to simulate the tree growth and yield over 40 years of time horizon. FVS is an individual tree growth and yield model, which projects future growth based on stands as a population units. It has ability to calibrate most forested areas of the United States utilizing localized equations from the National Volume Estimator Library (Dixon, 2022). Our simulations used *the southern variant (locational code 80,906)*. Treatments were simulated using various combinations of harvest (FVS Key: THINBBA), thinning (FVS Key: THINBBA), prescribed burn (FVS Key: SIMFIRE), annual growth (FVS Key: FIXDG), natural regeneration (FVS Key: FIXDG), and mortality modifiers (FIXMORT) in FVS to imitate treatments and vegetation dynamics in the research plots. *Quercus stellata* and *Q. marilandica* mortalities rates were obtained from Masters et al. (2006) to estimate tree mortality. Detailed description of data needed and outputs obtained from FVS are provided in Fig. 1.

The growth and yield simulation for the Control stands did not receive any treatment. The HT, HT2, HT3, and HT4 stands were

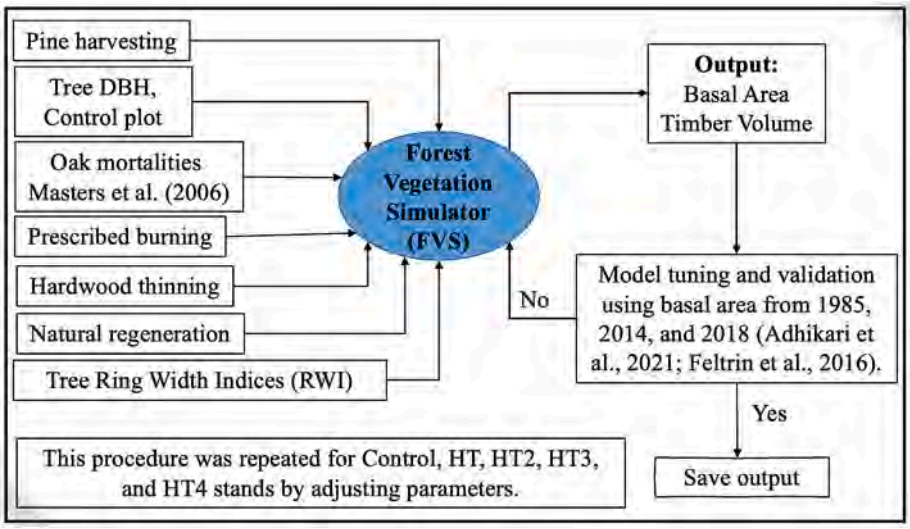

Fig. 1. A flowchart showing data input needed and outputs obtained for growth and yield analysis in the forest vegetation simulator.

simulated with the appropriate combination of thinning and prescribed fire. The growth rate and burn-induced mortality rates within FVS were adjusted such that FVS outputs closely mimicked the measured basal areas reported in Adhikari et al. (2021a) and Feltrin et al. (2016) for the years 1984, 2014, and 2018. These adjustments were necessary because FVS simulations are known to over-predict post-fire mortality (Barker et al., 2019).

Because prices are not publicly available for Oklahoma, average annual stumpage prices of sawlogs and pulpwood for adjacent north-eastern Texas were obtained from Texas A&M Forest Service annual summary reports. *The time value of money was taken into consideration for the financial analysis* as timber revenues are realized through commercial harvesting at the end of rotation. *Since end of the rotation timber values are future sums, timber value was annualized using the sinking* fund *formula, which provides annual payments that become equal in value to accumulate a specific sum over time (Bullard and Straka, 2011). The annual value reports the equivalent of the revenue that can be obtained annually over the life of an investment considering the discount rate applied (5.5%) (Bettinger* et al., *2010*; *Bullard and Straka, 2011).*

$$\text{End of rotation timber value} = \sum_{t=0}^{T} R_t(1+r)^t \tag{1}$$

$$\text{Annual value} = \text{Timber value}\left(\frac{r}{(1+r)^t - 1}\right) \tag{2}$$

In the above equation, R_t *represents the timber value in the current year, r represents the discount rate, and t represents the rotation age.*

The aboveground net primary production (ANPP) of understory vegetation was collected annually from the research plots from 1987 to 2017 (Adhikari et al., *2021b) and used to calculate the average annual forage available during the 40-year simulation.* We assumed that cattle and deer don't compete for forage with low to moderate stocking rates and thus, classified understory woody growth, forbs, (Johnson et al., 1995), and cool season *Panicum* and *Dichanthelium* spp. (Gee et al., 2011) as deer forage, and grass and sedge (Sedivec and Printz, 2014) as cattle forage. *The total forage produced was multiplied by 0.25 (25% of ANPP) to account for grazing and browsing efficiency (Redfearn and Bidwell, 2017). The stocking rate of cattle and deer (Meehan* et al., *2018), i.e., the total number of cattle or deer* supported *by available dry forage on 1 ha of land, was calculated using Eq (3). We assumed a dry matter intake of 10.*89 kg *cattle*$^{-1}$ *day*$^{-1}$ *(Rasby, 2013) and 1.*93 kg *deer*$^{-1}$ *day*$^{-1}$ *(Fulbright and Ortega-S, 2013) for this analysis. The total land required* per *head of cattle or deer was the inverse of the stocking rate.*

$$\text{Stocking Rate} = \frac{(\text{Cattle or deer forage dry mass(kg)/hectare/day}) * 365 * 0.25}{(\text{Dry forage consumed by a cattle or deer/day}) * 365} \tag{3}$$

The market price of cattle for a 226.8–272.2 kg (500–600 pounds) steer was obtained from Oklahoma National Stockyards (Oklahoma National Stockyard, 2022) between 1984 and 2020, whereas prices between 2021 and 2024 were predicted using the FORECAST formula in Excel. Of note, FORECAST uses linear trend relationship to predict future value (Microsoft, 2023). The annual economic value of cattle forage was obtained by multiplying the annual auction price of cattle, producer price index (PPI) ratio, and stocking rate of cattle after adjusting for grazing efficiency (Meehan et al., 2018; Redfearn and Bidwell, 2017; Sedivec and Printz, 2014).

A non-market-based valuation approach was needed to obtain the value of a deer forage because deer is not sold in the market and thus, does not have a market value like livestock or timber. While hunting lease can be used to capture market value of the land (Baen, 1997), tenant access to hunting land does not directly provide value of a deer. Therefore, we relied on a survey instrument administered to landowners in the study region to determine the economic value of a deer. The survey responses and respondent details are discussed in section 2.1.3. In the survey, two questions were designed to obtain necessary information. The first question revealed the landowner's total willingness to pay (WTP) to maintain the current population of deer observed at their regular deer hunting location. The second question asked respondents to report total number of deer observed per visit at their regular hunting site. The reported average WTP was divided by the average number of deer observed per visit to calculate WTP per deer, which we used as the economic value of a deer. We calculated the average WTP to see one additional deer was $12.96. The annual economic value of deer was obtained by multiplying WTP ($) deer^{-1} by the deer stocking rate adjusted for grazing efficiency.

We calculated total economic return by summing the market (cattle forage + timber) and non-market based (deer forage) ecosystem services. This approach is consistent with the common practice of adding provisioning (timber and cattle) with cultural (WTP based on deer habitat management) ecosystem services together (Costanza et al., 1997).

2.1.2. *Prescribed fire costs*

Expenses for prescribed burning were the only active management cost considered for the financial analysis. We reported average annual

prescribed fire costs separately because management costs served as inputs to obtain outputs for timber, cattle forage, and deer forage. The time value of money considerations were deemed to be impractical in annualizing prescribed fire cost calculations as cattle forage is produced and sold on an annual basis whereas timber-sale revenues are realized at the end of the rotation. Since average prescribed fire costs in our experimental plots were 60% more than average costs in eastern Oklahoma (Masters et al., 1993), we believe that average costs from multiple reports provide more realistic estimations. Therefore, prescribed fire costs, available from secondary sources in 1990 (Masters et al., 1993), 1994 (Cleaves et al., 2000), 1996 (Gabbert, 2014), 2016 (Maggard and Barlow, 2018), 2020 (Maggard, 2021), and 2021 (Watts et al., 2022) were converted to 2021 dollars using an inflation adjustment calculator (https://westegg.com/inflation) and were projected for 2024. Therefore, annual values of prescribed fire were obtained by dividing average prescribed fire costs by its frequency. Net returns then were calculated by subtracting annualized prescribed fire costs from the annualized total economic return.

2.1.3. Data on landowner perceptions on cost as an obstacle for active management

A survey instrument was designed to understand the factors that influence landowner perception of impediments for active management in the study area. The survey instrument was designed following Dillman et al. (2014) and mailed to 2500 randomly selected landowners in the forest-grassland transition ecoregion living in the Oklahoma counties east of interstate I-35. The survey constituted several questions asking about landowner perceptions toward active forest management, obstacles to implementing active management, their land management objectives, preferences for deer hunting sites, and socio-demographics. Further, we asked landowners to select the major obstacles to implementing active management in their forest or rangeland. The options included cost, time limitation, fire risk and liability, lack of knowledge, government policy, economically not beneficial, practically not feasible, rented out the property, don't live close to property. Because cost was chosen as an obstacle by the highest percentage of the landowners (66%), our focus was to understand the factors associated with cost as a perceived obstacle in adopting active management in the forest or rangeland.

The dependent variable, cost as a perceived obstacle in adopting active management, was measured as a binary choice (chosen/not chosen). We used a binary probit regression model to understand the factors (independent variables) that had a statistically significant association with cost as an obstacle. Since the dependent variable had a binary choice, the standardized normal cumulative distribution function fits well to establish the regression relationship (Greene, 2008).

Accordingly, if Y^* is the binary dependent variable, the basic probit model can be simplified as:

$$Y_i^* = \beta_0 + \sum_{j=1}^{j} \beta_j X_{ji} + \varepsilon_i \tag{4}$$

In above equation, X_{ji} represents the values of the i observations in all independent variables J. Also, β_0 is the regression intercept and β_j is a vector of regression coefficients. Similarly, ε_i represents standard normal error term (Greene, 2008; Poudyal et al., 2014). Of note, since latent variable cannot be measured, observable binary variable receives the value of 1 if $Y^* > 0$. Finally, the probability of the landowner's decision to consider cost as a perceived obstacle in adopting active management can be explained below.

$$P\left(Y = 1 | X_{ij}\right) = \Phi(\beta_i X_i - \varepsilon_i > 0) \tag{5a}$$

In equation 5, Φ is the cumulative distribution function.

Concerning empirical model for our study, landowner management objectives, awareness about the issue, and the socio-demographic information had significant associations with management behavior (Arano and Munn, 2006; Joshi et al., 2013; Joshi and Mehmood, 2011a; Joshi and Arano, 2009) and were found to be significant in past research. These attributes, thus, were chosen as candidate independent variables in our regression model. The summary statistics of the dependent and independent variables used in probit regression analysis are provided in Table 5. The empirical specification of the binary probit model can be described as:

$$\text{Choice (cost as an obstacle)} = f\ (\text{awareness, interest, management objectives, socio} - \text{demographics}) \tag{5b}$$

3. Results

3.1. Economics of active management

3.1.1. Quantification of timber, cattle, and deer forage

The basal area (BA), merchantable timber volume, and sawlog volume in the non-managed Control stands were the highest among all treatments at the beginning of the simulation in 1984. Among the forest treatments, the increase in BA was smallest (3.1 m^2 ha^{-1}) in Control stands during the 40-year period, largest in the HT treatment stands (34.6 m^{-2} ha^{-1}), and intermediate in the HT4 treatment (19.6 m^{-2} ha^{-1}). The two savanna treatments (HT3 and HT2) increased in BA < 3 m^2 ha^{-1}. The initial BA of the Control stands (26.6 m^2 ha^{-1}) resulted in a stocking of approximately 80% (Rogers, 1983) and remained below 100% even with no thinning due to relatively slow growth and occasional individual tree mortality (stocking based on *P. echinata* which was ~60% of total basal area). The initial reduction in competition due to thinning and harvesting treatments provided growing space for existing and new trees in HT stands such that in 2024, the treatment was an overstocked (110%), even-aged stand undergoing some density-dependent mortality. The HT4 stands developed as more open, uneven-aged stands (70% stocking) as trees would sporadically establish between the four-year period between burns. The HT2 and HT3 treatments were savanna or open woodland with the repeated fires maintaining these conditions (Fig. 2).

While the Control treatment had the greatest merchantable timber at the end of the simulation, much of that was present at the beginning, resulting in net growth of 43.1 tons ha^{-1} (Table 1). In contrast, the other treatments had low initial basal area such that the HT (144.8 tons ha^{-1}) and HT4 (97.3 tons ha^{-1}) treatments grew more. Repeated fire in the HT3 and HT2 treatments limited growth of merchantable timber (<25 tons ha^{-1}). The ratio of merchantable timber in sawlog vs pulpwood size classes in 2024 depended on initial density and tree sizes. Most of the trees reached sawlog size classes (>95% of merchantable timber was sawlogs) due to the lower stand densities in the HT2, HT3, and HT4 treatments. In the Control treatment, most of the new growth was in the sawlog category as sawlog-sized trees grew larger (79% of merchantable timber growth was sawlogs). In contrast, the HT treatment was overstocked, and the majority of the trees remained pulpwood sized and only 32% of merchantable timber growth was sawlogs.

Cattle forage was dominated by warm-season grasses, i.e., 97% grass vs 3% sedge. The average ANPP of sedge was the greatest in HT2 stands (42 kg ha^{-1} yr^{-1}), but still composed only 2% of cattle forage (Table 2).

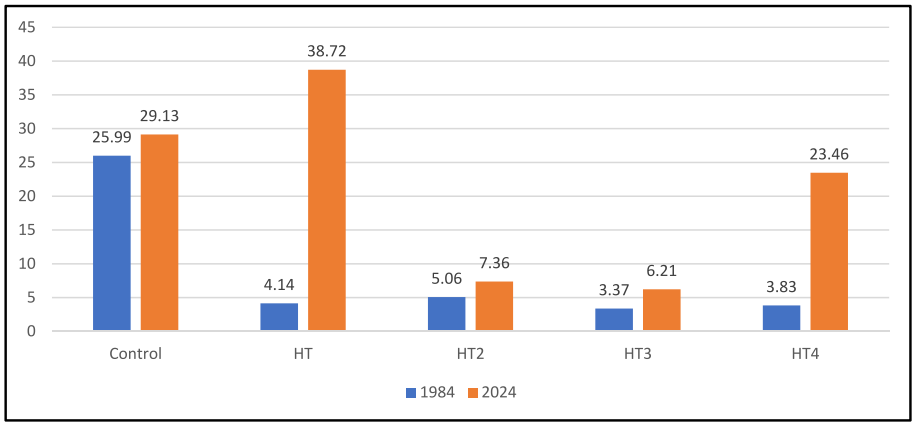

Fig. 2. Change in Basal Area estimated using FVS growth and yield model simulation in southeastern Oklahoma, USA.

Table 1
Timber production estimated using FVS growth and yield model simulation in southeastern Oklahoma, USA.

Treatment	Timber Production (ton ha^{-1})								
	Merchantable			Saw Log			Pulp Wood		
	1984	2024	Change	1984	2024	Change	1984	2024	Change
Control	160.71	203.81	43.09	119.77	153.82	34.05	40.94	49.96	9.02
HT	33.28	178.04	144.75	32.84	79.22	46.38	0.44	98.82	98.37
HT2	40.85	65.73	24.88	40.30	65.36	25.06	0.54	0.37	−0.17
HT3	27.95	50.88	22.93	27.70	50.01	22.31	0.27	0.86	0.59
HT4	31.31	128.64	97.33	31.01	123.38	92.37	0.30	5.26	4.97

Table 2
Annual average dry biomass of understory vegetation (kg ha^{-1} y^{-1}) produced in southeastern Oklahoma, USA. Grass refers to warm-season grasses. Panicums are mainly cool season *Panicum* and *Dichanthelium* spp.

Treatment	Cattle Forage			Deer Forage				
	Sedge	Grass	Total	Legume	Woody	Forbs	Panicum	Total
Control	5	111	116	8	125	10	15	158
HT	5	102	107	5	151	4	15	175
HT2	42	2008	2050	94	732	108	93	1027
HT3	33	2062	2095	64	833	46	58	1001
HT4	41	1450	1491	80	715	47	80	922

Cattle forage was greatest in the HT2 and HT3 treatments that were savanna (>2000 kg ha^{-1} y^{-1}), intermediate in the HT4 treatment (1491 kg ha^{-1} y^{-1}), and minimal in the closed-canopy forests (Control and HT < 120 kg ha^{-1} y^{-1}). Deer forage, i.e., woody browse, legume, forb, and panicum grass (cool season *Panicum* and *Dichanthelium* spp.), was dominated by the woody component (>71%) (Table 2) in all treatments. Legumes, forbs, and panicum grass made up 8%, 6%, and 8% of deer forage respectively. Deer forage was relatively large in the HT2 (1027 kg ha^{-1} y^{-1}), HT3 (1001 kg ha^{-1} y^{-1}) and HT4 (922 kg ha^{-1} y^{-1}) treatments and low in the HT (175 kg ha^{-1} y^{-1}) and Control (158 kg ha^{-1} y^{-1}) treatments. The percentage of the different vegetation categories was similar among treatments except for legumes, which were greater in the burned treatments (8%) compared to the non-burned treatments (4%). *The number of cattle* supported *were 9 to 13 times greater and number of deer were 5 to 6 times greater for the HT2, HT3, and HT4 stands compared to the Control and HT stands (Table 3).*

Table 3
Total number of cattle and deer supported by various treatments in south central transitional ecoregion of USA.

Treatment	Cattle Stocking Rate (Cattle ha^{-1})	Deer Stocking Rate (Deer ha^{-1})
Control	0.01	0.06
HT	0.01	0.06
HT2	0.13	0.36
HT3	0.13	0.36
HT4	0.09	0.33

3.1.2. Economic analysis

The greatest annual gross economic return per hectare from combining timber, cattle forage, and deer forage were in the burned treatments, i.e., HT4 ($38.06) followed by HT2 ($31.64) and HT3 ($31.54), and lowest in the non-burned treatments HT ($16.35) and Control ($8.91) (Table 4). The returns in the highest producing treatment (HT4) were 46% from timber, 42% from cattle forage, and 11% from deer forage. The most heavily forested treatments, Control and HT, had 78% and 88% of returns from timber, while returns for the frequently burned savanna treatments were dominated by cattle forage, HT3 (72%) and HT2 (70%). Returns from deer forage ranged between 5% in the HT treatment to 15% in the HT2 and HT3 treatments. Even though the HT treatment produced the most timber, the HT4 treatment provided the greatest timber revenue ($2411.78 ha^{-1}) over 40 years because of the larger fraction of sawlog vs pulpwood production. The Control, HT3, and HT2 treatments had timber revenues less than $1000 ha^{-1} over the 40-year period because of lower timber productivity.

The costs were proportional to burn frequency. Net returns were lowest in the HT2 treatment ($3.63 per year) when costs of prescribed

Table 4
Gross and net economic return (per hectare) from timber and forage in actively managed ecosystems in south-central transitional ecoregion, USA.

Treatment	[b]End of rotation timber value	Annualized Timber value	Annualized Cattle Forage	Annualized Deer Forage	Annualized Total economic value	[a]Annual prescribed burn costs	Net return
Control	$945.65	$6.92	$1.26	$0.73	$8.91	None	$8.91
HT	$1965.41	$14.39	$1.16	$0.81	$16.35	None	$16.35
HT2	$642.28	$4.70	$22.21	$4.72	$31.64	$29.58	$2.06
HT3	$577.85	$4.23	$22.70	$4.61	$31.54	$19.72	$11.82
HT4	$2411.78	$17.66	$16.16	$4.24	$38.06	$14.79	$23.27

[a] Average prescribed fire cost was $59.16 per hectare.
[b] 40-year forest management regime was assumed to calculate end of the rotation timber value. The timber value does not include cost.

Table 5
The definitions and the summary statistics of the variables used in the regression model highlighting the factors affecting cost as an obstacle for active management in the grassland-forestland ecoregion, Oklahoma, USA.

Variable	Definition	Mean	Std. Dev.
Cost	Binary variable: 1 if respondent perceives cost is an obstacle in implementing active management, 0 otherwise.	0.76	0.43
Aware	Binary variable: 1 if the respondent was aware that active management can enhance fodder, forage, and timber production in forest or rangeland	0.93	0.25
Interest	Binary variable: 1 if respondent was interested in knowing more about active forest and range management	0.54	0.50
Wildlife Mgt	Likert scale (0 = not important, 5 = extremely important) variable capturing the importance of wildlife management in the property	2.96	1.57
Land Invest	Likert scale (0 = not important, 5 = extremely important) variable capturing the importance of land investment as an objective of the property	3.33	1.88
Forest Majority	Binary variable: 1 if the landowner has the majority land as forestland, 0 otherwise	0.13	0.33
Range Majority	Binary variable: 1 if the landowner has the majority land as forestland, 0 otherwise	0.78	0.41
Age	Age of the landowner in a logarithmic scale	4.17	0.20
Gender	Gender of the landowner, 1 if male, 0 otherwise	0.11	0.31
Income	Income of the landowner in a logarithmic scale	11.33	0.57
Education	Education of the landowner, 1 with a graduate degree, 0 otherwise	0.20	0.40

burning were included (Table 4). The HT4 treatment had the greatest net return ($24.05 per year) because it had the greatest gross return and the costs of burning were incurred only once in every four years. In contrast, gross and net returns of the Control and HT treatments were the same (no burning costs), such that the HT treatments had the second largest net return ($16.35 per year). The net return of the savanna treatment with a three-year fire return interval (HT3) was more than three times greater ($12.86 per year) compared to the net return of the savanna treatment burned every two years (HT2).

3.2. Cost as an obstacle in active management

The survey received an adjusted response rate of 20.5%, which is comparable to other social science research conducted in the past decade (Cleary et al., 2021; Joshi and Arano, 2009). The average age of the landowners was 67.4 years, which standard deviation (SD) of 2.4. Among them, more than 66% had at least a college degree. The majority of landowners (mean = 50.42, SD = 0.50) had hunted in Oklahoma in the past five years. On average, landowners had 82.40 ha (SD = 175.66) of agricultural land, 82.40 ha (SD = 177.53) of forestland, and 197.83 ha (SD = 247.65) of rangeland. About 82% of the landowners were Caucasian and 14% were Native American. On the Likert Scale of 0 (not important) to 5 (extremely important), landowners ranked livestock production (mean = 4.53, SD = 1.08), land investment (mean = 3.28, SD = 1.87), and wildlife management (mean = 2.90, SD = 1.56) as the top three reasons for owning their property. These demographics are comparable with the national woodland owner database(Butler et al., 2020). While most landowners (92%) were broadly aware that active management can enhance fodder, forage and timber production in forests or rangeland, the majority (51%) still wanted to know more about active management in the study region.

Further, landowners revealed that forest or rangelands were owned by them or their family for an average of 47.7 years. The majority were still interested in knowing more about active management even though 88% of landowners practiced active management such as removal of unwanted trees, weed control, and prescribed burning. Female landowners had lower income, education, and landholding size, but higher average age than the male landowners.

The definitions of the variables used in the regression analysis are reported in Table 5 and the results based on binary probit regression analysis are presented in Table 6. The overall logistic regression model was statistically significant (wald chi-square = 25.96; P = 0.0038). Six out of ten independent variables were statistically significant at $P < 0.10$. The landowners who were aware that active management could enhance forage and timber production in their forest or rangeland were more likely to consider cost as obstacle in their decision whether to adopt active management. Those interested in learning more about active management of forest and rangeland also seemed concerned about costs. In contrast, landowners with mostly rangeland and those having wildlife management objectives were less likely to consider cost as obstacle compared to others. Females were more likely to consider

Table 6
Variables used in the regression model highlighting the factors affecting cost as an obstacle for active management in the grassland-forestland ecoregion, Oklahoma, USA.

Variable	Coefficient	Standard Error
Aware	0.668**	0.287
Interest	0.251	0.170
Wildlife Mgt	−0.088*	0.053
Land investment	0.006	0.047
Forest Majority	−0.406	0.277
Range Majority	−0.612**	0.247
Age	−0.679*	0.406
Gender	0.585*	0.306
Income	0.041	0.151
Education	−0.391*	0.202
Constant	3.184	2.444

Note: * significant at $P < 0.10$, ** significant at $P < 0.05$.

cost as obstacle, and those having higher education and younger landowners were less likely to consider cost as obstacle. Both of these variables were statistically significant at $P < 0.10$. Interest, land investment, majority forest ownership, and income were not statistically significantly related to cost as an obstacle (Table 6).

4. Discussion

The treatment with the highest net return was the HT4, which had both the greatest gross return of all treatments and the least cost among the burned treatments. For this treatment, returns from timber and cattle forage were approximately equal indicating the benefits of multi-purpose management within forest-grassland ecotones. Cattle forage was calculated as the average ANPP measured between 1987 and 2017. For the HT4 treatment, the herbaceous component was declining as tree canopy cover increased such that ANPP was approximately half the savanna treatments at the end of the period (Adhikari et al., 2021b), which was less than the approximately 70% based on the long-term average. With continued stand development, cattle and deer forage likely will continue to decrease in the HT4 treatment. In contrast, understory productivity was relatively constant over time for the other treatments (Adhikari et al., 2021b).

Timber production was relatively low in our study given it was a naturally regenerated stand of *P. echinata* growing along the drier, western edge of the species' range on soils with a large fraction of surface rock and coarse fragments. However, this area can support commercial *Pinus taeda* (L.) plantations. Adopting plantation management with genetically improved seedlings may increase the timber product growth and the economic returns (Bettinger et al., 2010). However, the longer than average distance to mills, high risk of disturbance from drought and ice storms, and uncertain timber markets, make it difficult for landowners in the study area to justify the investment in plantation management.

The HT2 and HT3 treatments produced cattle forage which was 69% of annually burned grasslands at the same site (Adhikari et al., 2021b). While annual burning would have increased cattle forage, it also increases the cost of management and would result in a negative net return. Given the ecological threshold between burning at a four-year interval (forest) and three-year interval (savanna), burning at a 3-year interval minimizes the costs related to prescribed fire if the objective is to maintain savanna with ample cattle forage. Current cattle leases are approximately \$37 ha^{-1} for native grasslands in eastern Oklahoma (Sahs, 2021), which is greater than the value of the annualized cattle forage we calculated. However, our values were scaled to a grazing efficiency of 25% such that more intensive grazing will increase the number of cattle produced, but likely reduce sustainability and limit the ability to conduct prescribed fire due to reduction of fuels. In addition, our site exhibited fairly low productivity (2000 kg ha^{-1} y^{-1}) of dry forage compared to other grasslands in the region that produced between 2500 and 7000 kg ha^{-1} y^{-1} (Schmidt et al., 2021).

Prescribed fire is necessary to maintain high levels of deer browse. Even the HT4 treatment, which had transitioned to an uneven-aged forest, produced 4.5 times greater woody browse compared to the Control or HT treatments, and woody browse did not decrease over time (Adhikari et al., 2021b). The calculated economic values of deer browse were below deer hunting lease rates of \$5 to \$25 per hectare in Oklahoma (Porter et al., 2017). We calculated the value of deer browse based on landowner willingness to pay for additional deer. In contrast, a lessee is paying for access to suitable areas to hunt. Therefore, contingent valuation based WTP numbers are not directly comparable to hunting leases. To this end, our findings quantified the relative value of deer forage produced within different ecosystems and justifies placing a premium lease rate on savanna and woodland.

For calculating cattle and deer forage we combined several vegetation types. While the sedges composed a minor component of cattle forage, they are often available during the cool season, which can make them important seasonal sources of nutrition. Likewise, panicums in the genus *Dichanthelium* are cool season, which may be available for deer when legumes and forbs are not. In addition, the nutritive quality differs among plant species and time of year (McKinney et al., 2023) which affect the overall quality and timing of forage availability.

The relative abundance of grassland vs forest in the south-central USA can change depending on drought and other changes in weather (Albertson and Weaver, 1945; Rice and Penfound, 1959). Therefore, climate change may alter the optimal management strategies if there are differential responses of timber, cattle forage, and deer browse. Adhikari et al. (2021a, 2021b) determined the effect of climate variability between 1987 and 2017 on the radial growth of *P. echinata* and on understory ANPP and found that a 100 mm decrease in growing season precipitation decreased diameter growth by 5%, a 1 °C increase in summer maximum temperature decreased diameter growth by 7%, and a 1 °C increase in minimum October temperature increased diameter growth by 6%. Except for a correlation between June precipitation and grass ANPP, understory ANPP was less impacted by climate variability and effects were inconsistent among treatments. Therefore, we expect a shift to drier, hotter summers will likely have a greater negative impact on tree growth than cattle forage or deer browse, resulting in a greater economic contribution from of cattle and deer when considering multi-purpose management.

Although most landowners have done some form of active management, sustaining these practices will help landowners achieve management objectives and generate income. In contrast, passive management will lead to forgone revenue from timber harvest, degradation of cattle, and a reduction of deer browse. For our study, we considered active management to include prescribed fire and timber harvest. However, gross returns could have been higher with added inputs and more intensive management, e.g., fertilization, herbicide, mid-rotation thinning, etc.

Results based on the survey suggested that most landowners were aware of the benefits of active management. However, the majority (66%) considered cost as a major obstacle to managing their forest or rangeland. Our economic analysis suggests that any form of active management is financially beneficial over the status quo (Control). These findings contrast with the belief system of landowners and other stakeholders who consider cost as a major impediment to the sustained adoption of active management in this region (Starr et al., 2019). Because landowners represent a diverse group with multiple management objectives, outreach must focus on clientele needs (Joshi and Mehmood, 2011b).

Given that landowners have generally adopted integrated range and forest management, timber or range-only focused outreach may not meet the diverse management needs of landowners in grassland-timberland transition regions. Multi-disciplinary Extension professionals from forestry, wildlife, and range management will need to work together in developing a comprehensive land management plan, which can facilitate experiential learning on the co-management of livestock, timber, and wildlife (Herrero et al., 2009; Hines et al., 2021). Similarly, landowners can benefit from the prescribed fire costs-share program administered through Natural Resources Conservation Service (NRCS) (Wilbur et al., 2021).

Results based on regression analysis suggest female landowners were more likely to consider cost as a challenge to active management. This finding is consistent with a previous study that suggested female landowners own less land and are less likely to conduct active management (Schelhas et al., 2012). Of note, female life expectancy is longer than males such that female landowners often play an important role in family bequest decisions (Butler et al., 2018). Overall, our results suggest that it is important to engage female landowners in outreach efforts that emphasize the importance of active land management practices.

In contrast, landowners owning majority (>50%) land as rangelands and those having higher education and younger age were less likely to consider cost as obstacle in adopting active management. In the study

region, prescribed burn associations (PBA) have been well-established within the rangeland-dominated areas, adding to the awareness of benefits of prescribed fire (Joshi et al., 2019a). In the southern Great Plains, landowners can help offset prescribed fire costs through technical and other assistance from PBAs (Joshi et al., 2019a). Higher level of education and younger age have been found to be positively associated with any form of active management (Joshi and Mehmood, 2011a; Joshi and Arano, 2009).

Our findings have important positive and practical implications for integrated forest and rangeland management. Our study results suggest that the stand with harvested pine, thinned hardwood, and burned every four-years generated ample timber and forage. Such a management regime improves wildlife habitat (Nyland, 2016; Bettinger et al., 2010) and reduces financial risk by diversifying investment return. Likewise, while focus of our study was on economic returns, active management strategies provide other ecosystem services benefits by improving biodiversity and overall health of the natural environment (Starr et al., 2019; Bettinger et al., 2010; Nyland, 2016). In our survey, landowners prioritizing wildlife management were less likely to consider cost as impediments. Many landowners in the United States have wildlife management objectives (Butler et al., 2020), which are achieved through integrated forest and range management.

Although our study was conducted within the grassland-timberland ecoregion, our findings have broader implications since timber production, recreational hunting, and cattle grazing are important land management objectives in many parts of the world (Butler et al., 2020; Ferranto et al., 2012; Suyanto et al., 2002). For instance, the restoration in tropical countries often focuses on tree management that promotes fire suppression and woody encroachment in savannas of Asia, Africa, and South America (Kumar et al., 2020; Vetter, 2020). This narrative, however, overlooks ecosystem benefits of grasslands and savannas and considers them as degraded lands requiring forest restoration (Vetter, 2020). Considering the ecological significance of disturbance-adapted ecosystems, prescribed fire needs to be promoted in these regions. However, the budget for active management can be a concern. To this end, community-based fire management practices in Asia and Africa (Jurvélius, 2004; Makarabhirom et al., 2002; Suyanto et al., 2002), that promote volunteer participation in prescribed fire, can help reduce prescribed fire costs. Additionally, economic valuation of integrated forest and range management is necessary for these regions.

A couple of limitations are worth noting. First, we did not account for structural changes in the timber market in the past 40 years, which might affect the economic return from timber. Second, yearly prescribed fire costs were not available, which is a limitation. Nonetheless, we feel that averages of the prescribed fire costs from multiple studies represent realistic costs for a reasonable landowner in the study area. Finally, deer are often limited by forage nutrient concentration and digestibility. To account for this, we assumed only 25% of forb, legume, woody, and panicum productivity would be available for deer. However, the actual percentage of consumed forage will vary as deer perform nutrient demanding biological processes like lactation (Hewitt, 2011).

5. Conclusion

This research quantified economic return from actively managed forest, savanna, and grassland over 40 years using prescribed fire, harvesting, and thinning in the south-central ecoregion of the USA. In addition, study results provided insights on how management cost serve as obstacle in landowner decision to adopt active management. The non-burned Control and HT closed-canopy forest treatments required larger area to support cattle and deer because of less of cattle and deer forage production compared to burned woodlands and savanna treatments. Findings suggest that the management associated with the HT4 was suitable for integrated timber, cattle, and deer production, whereas the treatments such as HT2 and HT3 primarily support cattle and deer management. When integrating timber, cattle, and deer, the total annual economic return from the HT4 treatment was the greatest. Results based on regression analysis suggest that the majority landowners consider cost as an impediment for adoption of active management in the study region. In particular, female landowners considered cost as a challenge. Therefore, outreach programs identifying information needs of these clientele are recommended.

Credit author statement

Bijesh Mishra: Conceptualization, Methodology, Data curation, Investigation, Resources, Formal analysis, Software, Visualization, Writing - original draft. Omkar Joshi: Funding acquisition, Conceptualization, Validation, Writing - review & editing, Supervision, Project administration. Ron Masters: Conceptualization, Validation, Data curation, Writing - review & editing. Caleb McKinney: Data curation, Writing - review & editing. Arjun Adhikari: Data curation, Writing - review & editing. Chris B. Zou: Funding acquisition, Writing - review & editing. Rodney E. Will: Funding acquisition, Writing - review & editing, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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References

Adhikari, A., Masters, R.E., Adams, H., Mainali, K.P., Zou, C.B., Joshi, O., Will, R.E., 2021a. Effects of climate variability and management on shortleaf pine radial growth across a forest-savanna continuum in a 34-year experiment. For. Ecol. Manag. 491.

Adhikari, A., Masters, R.E., Adams, H.D., Will, R.E., 2022. Radial growth responses of post oak (*Quercus stellata*) to climate variability and management in southeastern Oklahoma, USA. Can. J. For. Res. 52, 209–219.

Adhikari, A., Masters, R.E., Mainali, K.P., Zou, C.B., Joshi, O., Will, R.E., 2021b. Management and climate variability effects on understory productivity of forest and savanna ecosystems in Oklahoma, USA. Ecosphere 12, e03576.

Albertson, F.W., Weaver, J.E., 1945. Injury and death or recovery of trees in prairie climate. Ecol. Monogr. 15, 393–433.

Anderson, R.C., 1983. The eastern prairie-forest transition-an overview. In: Proceedings of the Eighth North American Prairie Conference. Western Michigan University, Kalamazoo, MI, pp. 86–92.

Anderson, R.C., 2006. Evolution and origin of the Central Grassland of North America: climate, fire, and mammalian grazers. J. Torrey Bot. Soc. 133, 626–647.

Arano, K.G., Munn, I.A., 2006. Evaluating forest management intensity: a comparison among major forest landowner types. For. Pol. Econ. 9, 237–248.

Arnett, E.B., Southwick, R., 2015. Economic and social benefits of hunting in North America. Int. J. Environ. Stud. 72, 734–745.

Baen, J., 1997. The growing importance and value implications of recreational hunting leases to agricultural land investors. J. R. Estate Res. 14, 399–414.

Barker, J.S., Fried, J.S., Gray, A.N., 2019. Evaluating model predictions of fire induced tree mortality using wildfire-affected forest inventory measurements. Forests 10, 958.

Bettinger, P., Boston, K., Siry, J.P., Grebner, D.L., 2010. Forest Management and Planning. Academic press.

Bigelow, D., Borchers, A., 2017. Major Uses of Land in the United States, 2012.

Bullard, S.H., Straka, T.J., 2011. Basic Concepts in Forest Valuation and Investment Analysis. Clemson University.

Butler, B., Hewes, J.H., Dickinson, B.J., Andrejczyk, K., Butler, S.M., Markowski-Lindsay, M., 2016. USDA Forest Service National Woodland Owner Survey: national, regional, and state statistics for family forest and woodland ownerships with 10+ acres, 2011-2013. Res. Bull. NRS-99 39 (99), 1–39. Newtown Square, PA: US Department of Agriculture, Forest Service, Northern Research Station.
Butler, S.M., Huff, E.S., Snyder, S.A., Butler, B.J., Tyrrell, M., 2018. The role of gender in management behaviors on family forest lands in the United States. J. For. 116, 32–40.
Butler, B.J., Butler, S.M., Caputo, J., Dias, J., Robillard, A., Sass, E.M., 2020. Family forest ownerships of the United States, 2018: Results from the USDA Forest Service, national woodland owner survey. In: Gen. Tech. Rep. NRS-199. US Department of agriculture, forest service, Northern research station, Madison, WI, p. 52.
Callaghan, D.W., Khanal, P.N., Straka, T.J., 2019. An analysis of costs and cost trends for southern forestry practices. J. For. 117, 21–29.
Clark, S.L., Hallgren, S.W., Engle, D.M., Stahle, D., 2007. The historic fire regime on the edge of the prairie: a case study from the cross timbers of Oklahoma. In: Masters, R. E., Galley, K.E.M. (Eds.), 23rd Tall Timbers Fire Ecology Conference: Fire in Grassland and Shurbland Ecosystems. Tall Timbers Research Station, Tallahassee, Florida, USA, pp. 40–49.
Cleary, M., Joshi, O., Fairbanks, W.S., 2021. Factors that determine human acceptance of black bears. J. Wildl. Manag. 85, 582–592.
Cleaves, D.A., Martinez, J., Haioes, T.K., 2000. Influences on prescribed burning activity and costs in the national forest system. General Technical Report SRS-37. United States Forest service 34.
Costanza, R., D'arge, R., Groot, R.d., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, R., Belt, M.V.D., 1997. The Value of the World's ecosystem services and natural capital. Nature 387, 253–260.
Dillman, D.A., Smyth, J.D., Christian, L.M., 2014. Internet, Phone, Mail, and Mixed-Mode Surveys: the Tailored Design Method, fourth ed. John Wiley & Sons, Hoboken, New Jersey, USA.
Dixon, G.E., 2022. Essential FVS: A User's Guide to the Forest Vegetation Simulator, second ed. U. S. Department of Agriculture, Forest Service, Forest Management Service Center, Fort Collins, CO.
Feltrin, R.P., Will, R.E., Meek, C.R., Masters, R.E., Waymire, J., Wilson, D.S., 2016. Relationship between photosynthetically active radiation and understory productivity across a forest-savanna continuum. For. Ecol. Manag. 374, 51–60.
Ferranto, S., Huntsinger, L., Stewart, W., Getz, C., Nakamura, G., Kelly, M., 2012. Consider the source: the impact of media and authority in outreach to private forest and rangeland owners. J. Environ. Manag. 97, 131–140.
Fulbright, T.E., Ortega-S, J.A., 2013. White-Tailed Deer Habitat: Ecology and Management on Rangeland, second ed. FCI Print Group.
Gabbert, B., 2014. The cost of prescribed fire in Oklahoma. Available online: https://wildfiretoday.com/2014/04/17/the-cost-of-prescribed-fire-in-oklahoma/. .
Gee, K.L., Porther, M.D., Demarais, S., Bryant, F.C., 2011. White Tailed Deer: Their Food and Management in the Cross Timbers, third ed. The Samuel Roberts Noble Foundation, Ardmore, OK.
Gore, M., Mishra, B., Joshi, O., 2022. Economic Contribution of Forest Sector in Oklahoma in 2020. Oklahoma Cooperative Extension Service, p. 2.
Greene, W.H., 2008. Econometric Analysis. Prentice-Hall International Inc., New Jersey, USA.
Hallgren, S.W., DeSantis, R.D., Burton, J.A., 2012. Fire and Vegetation Dynamics in the Cross Timbers Forest of South-Central North america, 4th Fire in Eastern Oak Forests Conference, pp. 52–66.
Harper, R.A., Johnson, T.G., 2008. In: RB (Ed.), SRS-187. Forest Resource of East Oklahoma, 2008.
Herrero, M., Thornton, P.K., Gerber, P., Reid, R.S., 2009. Livestock, livelihoods and the environment: understanding the trade-offs. Curr. Opin. Environ. Sustain. 1, 111–120.
Hewitt, D.G., 2011. Biology and Management of White-Tailed Deer. CRC Press.
Hines, S.L., Fulbright, T.E., Ortega-S, A.J., Webb, S.L., Hewitt, D.G., Boutton, T.W., 2021. Compatibility of dual enterprises for cattle and deer in North America: a quantitative review. Rangel. Ecol. Manag. 74, 21–31.
Hoff, D., Will, R., Zou, C., Lillie, N., 2018a. Encroachment Dynamics of Juniperus Virginiana L. And Mesic Hardwood Species into Cross Timbers. Forests of North-Central Oklahoma, USA. Forests 9.
Hoff, D.L., Will, R.E., Zou, C.B., Weir, J.R., Gregory, M.S., Lillie, N.D., 2018b. Estimating increased fuel loading within the Cross Timbers forest matrix of Oklahoma, USA due to an encroaching conifer, *Juniperus virginiana,* using leaf-off satellite imagery. For. Ecol. Manag. 409, 215–224.
Johnson, A.S., Hale, P.E., Ford, W.M., Wentworth, J., French, J.R., Anserson, O.F., Pullen, G.B., 1995. White-tailed deer foraging in relation to successional stage, overstory type and management of southern appalachian forests. Am. Midl. Nat. 133, 18–35.
Joshi, O., Grebner, D.L., Hussain, A., Grado, S.C., 2013. Landowner knowledge and willingness to supply woody biomass for wood-based bioenergy: sample selection approach. J. For. Econ. 19, 97–109.
Joshi, O., Mehmood, S.R., 2011a. Factors affecting nonindustrial private forest landowners' willingness to supply woody biomass for bioenergy. Biomass Bioenergy 35, 186–192.
Joshi, O., Mehmood, S.R., 2011b. Segmenting southern nonindustrial private forest landonwers on the basis of their managment objectives and motiations for wood-based bioenergy. South. J. Appl. For. 35, 87–92.
Joshi, O., Poudyal, N.C., Weir, J.R., Fuhlendorf, S.D., Ochuodho, T.O., 2019a. Determinants of perceived risk and liability concerns associated with prescribed burning in the United States. J. Environ. Manag. 230, 379–385.
Joshi, O., Will, R.E., Zou, C.B., Kharel, G., 2019b. Sustaining cross-timbers forest resources: current knowledge and future research needs. Sustainability 11.
Joshi, S., Arano, K.G., 2009. Determinants of private forest management decisions: a study on West Virginia NIPF landowners. For. Pol. Econ. 11, 118–125.
Jurvélius, M., 2004. Community-based fire management in southern Africa. Unasylva 55, 12–14.
Kanianska, R., Kizeková, M., Nováček, J., Zeman, M., 2014. Land-use and land-cover changes in rural areas during different political systems: a case study of Slovakia from 1782 to 2006. Land Use Pol. 36, 554–566.
Kaur, R., Joshi, O., Will, R.E., 2019. The ecological and economic determinants of eastern redcedar (Juniperus virginiana) encroachment in grassland and forested ecosystems: a case study from Oklahoma. J. Environ. Manag., 109815
Kumar, D., Pfeiffer, M., Gaillard, C., Langan, L., Martens, C., Scheiter, S., 2020. Misinterpretation of Asian savannas as degraded forest can mislead management and conservation policy under climate change. Biol. Conserv. 241, 108293.
Liu, C., Xu, Y., Sun, P., Huang, A., Zheng, W., 2017. Land use change and its driving forces toward mutual conversion in Zhangjiakou City, a farming-pastoral ecotone in Northern China. Environ. Monit. Assess. 189, 1–20.
Maggard, A., 2021. Costs and Trends of Southern Forestry Practices 2020. https://www.aces.edu/blog/topics/forestry/costs-trends-of-southern-forestry-practices-2020/.
Maggard, A., Barlow, B., 2018. Costs & trends of southern forestry practices. 2016. Alabama Cooperative Extension System (ACES): Auburn, AL, USA.FOR-2051. 5 pages.
Maher, A.T., Maczko, K.A., Taylor, D.T., Tanaka, J.A., 2020. In: Miller, S. (Ed.), National and State Economic Values of Cattle Ranching and Farming-Based Ecosystem Services on Federal and Private Lands in the U.S., Sustainable Rangelands Roundtable Publication. University of Wyoming, Laramie, Wyoming.
Makarabhirom, P., Ganz, D., Onprom, S., 2002. Community involvement in fire management: cases and recommendations for community-based fire management in Thailand. In: Proceedings of the International Conference on Community Involvement in Fire Management, pp. 10–15. Bangkok, Thailand.
Masters, R., Waymire, J., 2012. Developing management strategies from research: Pushmataha forest habitat research area, Oklahoma. In: Sands, J.P., DeMaso, S.J., Schnupp, M.J., Brennan, L.A. (Eds.), Wildlife Science: Connecting Research with Management. CRC Press, Kingsville, Tex, pp. 272–303.
Masters, R.E., Lochmiller, R.L., Engle, D.M., 1993. Effects of timber harvest and prescribed fire on white-tailed deer forage production. Wildl. Soc. Bull. 21, 1973–2006, 401-411.
Masters, R.E., Waymire, J., Bidwell, T.G., Houchin, R., Hitch, K., 2006. Influence of Timber Harvest and Fire Frequency on Plant Community Development and Wildlife. Tall Timbers Research Station, Oklahoma Department of Wildife Conservation, Oklahoma Department of Agriculture, Food and Forestry, Oklahoma State University, Oklahoma State University.
McKinney, C.M., Masters, R.E., Adhikari, A., Mishra, B., Joshi, O., Zou, C.B., Will, R.E., 2023. Forage quantity and protein concentration changes across a forest-savanna gradient with management implications for white-tailed deer. For. Ecol. Manag. 538, 120987.
Meehan, M., Sedlvec, K.K., Printz, J., Brummer, F., 2018. Determining Carrying Capacity and Stocking Rates for Range and Pasture in North Dakota. North Dakota State University, North Dakota.
Microsoft, 2023. FORECAST and FORECAST. LINEAR functions.
Nyland, R.D., 2016. Silviculture: Concepts and Applications. Waveland Press.
OFS, 2010. Oklahoma forest action plan 2010. Oklahoma forestry services. Available online: http://www.forestry.ok.gov/Websites/forestry/Images/Oklahoma%20Forest%20Resource%20Assessment,%20FINAL%20FOR%20WEB.pdf.
Oklahoma National Stockyard, 2022. Oklahoma City Steer and Heifer Price. Oklahoma City Stockyeards, OKlahoma City, OK.
Otkin, J.A., Zhong, Y., Hunt, E.D., Basara, J., Svoboda, M., Anderson, M.C., Hain, C., 2019. Assessing the evolution of soil moisture and vegetation conditions during a flash drought–flash recovery sequence over the south-Central United States. J. Hydrometeorol. 20, 549–562.
Porter, M.D., Ferrell, S.I., Elmore, D., Bidwell, T.G., 2017. Lease Hunting Opportunities for Oklahoma Landowners. Oklahoma State University. Division of Agricultural Sciences and Natural.
Poudyal, N.C., Joshi, O., Hodges, D.G., Hoyt, K., 2014. Factors related with nonindustrial private forest landowners' forest conversion decision in Cumberland Plateau, Tennessee. For. Sci. 60, 988–993.
Qiao, L., Zou, C.B., Stebler, E., Will, R.E., 2017. Woody plant encroachment reduces annual runoff and shifts runoff mechanisms in the tallgrass prairie, USA. Water Resour. Res. 53, 4838–4849.
Rasby, R., 2013. Determining How Much Forage a Beef Cow Consumes Each Day. University of Nebraska, Lincoln, Nebraska.
Redfearn, D.D., Bidwell, T.G., 2017. Stocking Rate: the Key to Successful Livestock Production. Oklahoma State University, Oklahoma.
Rice, E.L., Penfound, W.T., 1959. The upland forests of Oklahoma. Ecology 593–608.
Rogers, R., 1983. Guides for Thinning Shortleaf Pine. USDA Forest Service general technical report SE-United States, Southeastern Forest Experiment, Station (USA).
Sahs, R., 2021. Oklahoma Pasture Rental Rates: 2020-21. Oklahoma Cooperative Extension Service. Oklahoma State University. Page 8.
Schelhas, J., Zhang, Y., Zabawa, R., Zheng, B., 2012. Exploring family forest landowner diversity: place, race, and gender in Alabama, United States. International Journal of Social Forestry 5, 1–21.
Schmidt, K.N., Zou, C.B., Kakani, V.G., Zhong, Y., Will, R.E., 2021. Improved productivity, water yield, and water use efficiency by incorporating switchgrass cultivation and native ecosystems in an integrated biofuel feedstock system. GCB Bioenergy 13, 369–381.

Sedivec, K.K., Printz, J.L., 2014. Ranchers Guide Grassland Management IV. NDSU Extension.
Sharma, L.N., Vetaas, O.R., Chaudhary, R.P., Måren, I.E., 2014. Ecological consequences of land use change: forest structure and regeneration across the forest-grassland ecotone in mountain pastures in Nepal. J. Mt. Sci. 11, 838–849.
Starr, M., Joshi, O., Will, R.E., Zou, C.B., 2019. Perceptions regarding active management of the Cross-timbers forest resources of Oklahoma, Texas, and Kansas: a SWOT-ANP analysis. Land Use Pol. 81, 523–530.
Stoof, C.R., Richards, B.K., Woodbury, P.B., Fabio, E.S., Brumbach, A.R., Cherney, J., Das, S., Geohring, L., Hansen, J., Hornesky, J., 2015. Untapped potential: opportunities and challenges for sustainable bioenergy production from marginal lands in the Northeast USA. BioEnergy Research 8, 482–501.
Suyanto, S., Applegate, G., Tacconi, L., 2002. Community-based fire management, land tenure and conflict: insights from Sumatra, Indonesia. In: Communities in Flames: Proceedings of an International Conference on Community Involvement in Fire Management. FAO Regional Office for Asia and the Pacific, Bangkok, Thailand.
Thornton, M., Thornton, P., Wei, Y., Mayer, B., Cook, R., Vose, R., 2018. Daymet: Annual Climate Summaries on a 1-km Grid for North America. ORNL DAAC, Oak Ridge, Tennessee, USA. Version 3.
Tian, L., Yuan, S., Quiring, S.M., 2018. Evaluation of six indices for monitoring agricultural drought in the south-central United States. Agric. For. Meteorol. 249, 107–119.
Vetter, S., 2020. With power comes responsibility–a rangelands perspective on forest landscape restoration. Front. Sustain. Food Syst. 4, 549483.
Watts, M., Russell, A., Adhikari, S., Weir, J., Joshi, O., 2022. Analysis of the cost and cost components of conducting prescribed fires in the Great plains. Rangel. Ecol. Manag. (under review).
Wilbur, R., Stanley, C., Maczko, K.A., Scasta, J.D., 2021. Perceptions of NRCS assistance with prescribed fires on US private lands: a regionally stratified case study. Fire 4, 47.
Zhang, L., Dawes, W.R., Walker, G.R., 2001. Response of mean annual evapotranspiration to vegetation changes at catchment scale. Water Resour. Res. 37, 701–708.
Zhong, Y., Zou, C.B., Saenz, A., Stebler, E., Kakani, G., Will, R.E., 2020. Conversion of encroached juniper woodland back to native prairie and to switchgrass increases root zone soil moisture and watershed runoff. J. Hydrol. 584, 124640.

EXTENSION

Economic Contribution of Forest Sector in Oklahoma in 2020

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Highlights

- Oklahoma's forest sector directly contributed $3.8 billion in industry output and employed more than 8,900 people with a payroll contribution of $575 million in 2020.
- The state received $1.4 billion directly from the forest sector through payroll, other employee compensation and property taxes.
- Including direct, indirect and induced impacts, the forest sector had a total economic impact of $5.6 billion in industry output and supported more than 18,450 jobs with a payroll of $1.1 billion.
- Every job created in the sector resulted in another 1.07 jobs in the state.
- Every dollar generated in the sector contributed an additional 45 cents to the rest of the state economy.
- In 2020, the forest sector witnessed mixed effects during COVID-19 in Oklahoma. Compared to 2019, industry output and employment were decreased. Averaged over all direct and total impact categories, labor income and value added were slightly increased by 2-4% from 2019 to 2020.

Figure 1. A wood load truck from SE Oklahoma.

Figure 2. A forest located in SE Oklahoma.

Industry Analysis

- Secondary solid wood and primary paper and paperboard products were the top two employers in the Oklahoma forest sector.
- Almost half (49%) of the forest sector workforce - 4,369 workers - were directly employed in secondary industries.
- The primary paper and paperboard industry produced the largest value added, economic output and the labor income.
- Primary paper and paperboard and primary solid wood products were the top two highest-paying forestry industries, based on their labor income to employment ratio.
- The forestry and logging industries together accounted for about 13% of the total employment. However, these were the lowest-paying forestry industries in Oklahoma.
- The loss of economic contribution from other forest sectors were mostly compensated by pulp and paper industries, which witnessed higher demand during the first year of the pandemic.

Table 1. Total economic contribution of forest sector on Oklahoma employment, output and value-added.

	Employment (jobs)	Change from 2019	Labor Income (million $)	Change from 2019	Value Added (million $)	Change from 2019	Industry Output (million $)	Change from 2019
Direct Impact*								
Forestry	394	-11%	15.14	-1%	17.82	2%	22.98	-5%
Logging	735	-10%	17.23	-13%	21.07	-10%	44.13	-12%
Primary solid wood products	1,069	-6%	81.28	-5%	137.16	-3%	399.25	-16%
Secondary solid wood products	3,216	-2%	142.77	-4%	181.72	-4%	562.22	-6%
Primary paper and paperboard products	2,340	3%	234.49	6%	822.21	7%	2,200.33	6%
Secondary paper and paperboard products	1,153	8%	83.75	15%	170.13	5%	608.36	7%
Total	**8,908**	**-1%**	**574.66**	**2%**	**1,350.12**	**4%**	**3,837.26**	**1%**
Total Impact**								
Forestry	469	-11%	18.49	-4%	23.69	-3%	34.07	-9%
Logging	958	-7%	24.66	-12%	33.42	-12%	68.14	-14%
Primary solid wood products	2,096	-13%	137.66	-11%	230.93	-11%	586.36	-19%
Secondary solid wood products	5,042	-4%	235.67	-5%	334.64	-6%	861.56	-8%
Primary paper and paperboard products	7,328	5%	525.58	7%	1,311.05	6%	3,182.43	5%
Secondary paper and paperboard products	2,558	9%	157.54	13%	292.96	6%	850.59	6%
Total	**18,451**	**-1%**	**1,099.61**	**2%**	**2,226.70**	**2%**	**5,583.16**	**-0.5%**
SAM Multiplier								
Forestry	1.19	-1%	1.22	-2%	1.33	-5%	1.48	-5%
Logging	1.30	3%	1.43	1%	1.59	-2%	1.54	-2%
Primary solid wood products	1.96	-7%	1.69	-7%	1.68	-9%	1.47	-3%
Secondary solid wood products	1.57	-2%	1.65	-1%	1.84	-2%	1.53	-2%
Primary paper and paperboard products	3.13	2%	2.24	1%	1.59	-1%	1.45	-1%
Secondary paper and paperboard products	2.22	1%	1.88	-2%	1.72	1%	1.40	0%
Total	**2.07**	**-1%**	**1.91**	**-2%**	**1.65**	**-3%**	**1.45**	**-2%**

* Economic impacts, based on multi-industry contribution analysis, are reported in 2020 dollars.

** Ripple Effects = SAM Multiplier – 1

Key Definitions

- **Industry output** reveals total value of production or service by industry in a snapshot of time.
- **Employment** includes all full-time, part-time and self-employed persons.
- **Labor income** includes wages, salaries, benefits of the employees (including their tax contributions to the government) and income for the self-employed individuals.
- **Value-added** is the difference between total output and the costs of its intermediate outputs.
- **Direct contributions** include forestry sector's own production, value-added, employment and labor incomes.
- **Indirect contributions** include economic activities in other sectors impacted by forestry sector's purchase of goods and services.
- **Induced contributions** are economic activities from consumption of goods and services using incomes generated from direct and indirect contributions.
- **Total economic contributions** include direct, indirect and induced contributions.

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Adoption of Sustainable Agriculture Practices among Farmers in Kentucky, USA

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Abstract

Promoting the sustainable agricultural practices at an individual farm level is essential to ensure agricultural sustainability. This study analyzed whether and how various factors related to farm or farmers' characteristics influence the adoption intensity of sustainable agriculture practices. We used a negative binomial regression model to fit the data collected from a mail survey of farmers in Kentucky, USA. Our results showed that the adoption intensity of sustainable agriculture practices varied significantly among agricultural districts in Kentucky. Farmers who grew row crops, had irrigation facilities, and were in favor of crop diversification were significantly more likely than their respective counterparts to adopt more sustainable agriculture practices. Similarly, having a college education and participating in the Tobacco Buyout Program also positively and significantly affected the intensity of adopting sustainable agriculture practices among Kentucky farmers. In contrast, a lack of adequate knowledge about sustainable farming and an unfamiliarity with technology significantly and negatively related to less adoption of sustainable agriculture practices.

Keywords Adoption intensity · Best management practices · Small farmers · Negative binomial regression · Kentucky

Introduction and Relevant Literature Synthesis

The US Congress (1990) defined sustainable agriculture as an integrated system of animal and plant production practices that satisfy human food and fiber needs, enhance environmental quality by making the most efficient use of non-renewable resources, sustain the economic viability of farm operations, and enhance the quality of life. Sustainability in agriculture is a complex and dynamic concept, including a wide range of environmental, social, economic, and resource use issues that changes with the time, location, society, and priorities. It is intended to minimize external inputs added to maximize agriculture output or production and maintain farm resources, achieving socioeconomic, environmental, and economic welfare, along with quality of life, without harming the environment, public health, communities, or animal welfare (Kornegay et al. 2010; Pretty 2008). Sustainable agriculture entails understanding the benefit of ecological and agronomic management, especially in regard to its manipulation and redesign to shift a farming system toward a natural system without reducing productivity (Pretty 2008).

Ensuring sustainability in agriculture requires the integration of sustainable agriculture practices (SAPs). Sustainable agriculture adopts productive, competitive, and efficient practices while protecting and improving the environment and the global ecosystem as well as the socioeconomic conditions of local communities. SAPs do not exclude external inputs but encourage incorporating them to complement local resources (Zaharia 2010). SAPs

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are not "one-size-fits-all" prescriptions, but are uniquely designed for the best management practices to address the uniqueness of farming systems (Lashgarara 2011).

Pretty (2008) traces the study of SAPs back to 1950s. Rural sociologists (see Ryan and Gross 1943; Ruttan 1996) were the pioneers in technology adoption–diffusion studies during the early 1940s to late 1950s; these studies were continued by economists and other researchers afterward (see Foster and Rosenzweig 2010). Griliches (1957) wrote one of the influential papers on hybrid corn technology adoption and diffusion. Later, the National Research Council also published reports on "Alternative Agriculture" in 1989 and "Towards Sustainable Agricultural Systems in the 21st Century" (Kornegay et al. 2010). Prokopy et al. (2008) summarize 45 studies related to sustainable agriculture practice adoption among US farmers from 1982 to 2007, and in a follow-up study Baumgart-Getz et al. (2012) summarize the variables affecting the adoption of these practices. Other studies (Knowler and Bradshaw 2007; Knowler 2015) have summarized the factors influencing the adoption of conservation agricultural practices. Liu et al. (2017) provide a summary of 16 studies with emphasis on agricultural best management practice adoption and their abilities to improve hydrology and water quality.

The adoption of sustainable agriculture possesses several long and short-term benefits. In the long run, the adoption of SAPs can replace some or all external inputs in agriculture systems (Pretty 2008). SAPs help to maintain the water table, increase carbon sequestration, improve soil fertility, and protect land from erosion reducing sediments load from agriculture lands, as well as bring socioeconomic benefits, such as an increase in net present value, reduction on-farm costs, labor and time saving (Knowler and Bradshaw 2007; Pretty 2008). There are also some negative aspects associated with sustainable practices, like no tillage, which is known to increase herbicide use, require special machinery use, and increase the incidence of fungal diseases. However, the overall benefits of conservation programs for reducing soil erosion and improving water quality have been validated by the Natural Resources Conservation Services of United States Department of Agriculture (NRCS 2014). Design, promotion, and adoption of location-specific SAPs are one of the important tools for protecting the environment, water quality, and agricultural land and reduce overall investment to implement conservation programs (Greiner et al. 2009; Mullendore et al. 2015).

Previous studies have shown that Kentucky farmers have been adopting soil and water conservation-related SAPs. Cropping systems, such as no-tillage practice, spread widely during the 1950s in Kentucky (Coughenour 2003). Recent studies by Da Costa et al. (2012) and Zhong et al. (2016) emphasize the adoption of conservation practices to improve water quality. Despite the widespread benefits and positive impacts of SAPs in farming, the adoption intensity of these practices has not been studied well. A limited amount of research focusing on the adoption of only a few conservation-related practices are found in the context of Kentucky. Thus, we included 31 different SAPs commonly adopted among Kentucky farmers to understand how farmers respond to the adoption of a set of SAPs. These practices were identified through workshops and group discussions with local farmers throughout the state of Kentucky. So, the originality of the paper lies in its identification of the most commonly adopted SAPs throughout Kentucky. It is well understood that not all practices are equally effective toward improving soil and water quality and hence developing sustainable agriculture. Their effect varies based on the physical characteristics of the landscape (Rittenburg et al. 2015). SAPs that are most commonly studied in the context of Kentucky, as well as the SAPs identified as commonly adopted by Kentucky farmers, are provided in Table 1. The overall objective of this research is to investigate factors that influence the adoption intensity of these identified SAPs in Kentucky.

The rest of the paper proceeds as follows. In section 2, we provide the broad literature related to SAPs. We present the conceptual model in section 3. We explain data and model related details in section 4. In section 5, we describe the results and implications. We conclude the paper in section 6.

Factor Influencing SAPs Adoptions

The adoption decision-making process of SAPs is influenced by several factors, such as farmers' knowledge and skills, the existence of and connections to a market for the commodities they produce, agricultural policies, and regulations, available resources, geographic features of the farm, and economic, social, and conservation motivations (Greiner et al. 2009; Kornegay et al. 2010; Lashgarara 2011). Farmers with irrigation facilities are more likely to adopt soil conservation practices like cover crops (Carlisle 2016; Snapp et al. 2005).

Socio-demographic factors such as age and land tenure, and cognitive factors such as knowledge and attitude toward a program, are also believed to influence the adoption of SAPs (Kabii and Horwitz 2006). Older farmers are less likely to adopt new practices that they are not very familiar with (Baumgart-Getz et al. 2012; Kabii and Horwitz 2006). But, farmers are positive and more likely to adopt SAPs with a higher level of formal education (Soule 2001; Upadhyay et al. 2003). Factors such as income, education level, access to information, capital, positive environmental attitudes, environmental awareness, and farm size generally have a positive impact on the adoption rate of SAPs

Table 1 Commonly adopted sustainable agriculture practices among farmers in kentucky, USA

Some commonly adopted and studied SAPs in Kentucky and included in this research:

Animal for land reclamation: small mammals such as mouse help to loosen the mined surface, which favors quick succession (Larkin et al. 2008).

Biological pest control: pest is suppressed by their natural enemies (Filho et al. 1999).

Conservation tillage: tillage and cultivation practice that incorporate crop residue into the field (Coughenour 2003).

Composting: waste recycling technique converting waste into nutrient-rich humus with high soil organic matter using microbes (Filho et al. 1999).

Cover crops and green manuring: use of legumes such as clover, vetch, and non-legumes such as rye, wheat to improve soil fertility and reduce erosion and incorporate into the soil as green manure (Gillespie et al 2007).

Crop rotation: system of rotating legumes and non-legumes crops in the same field to maintain soil fertility (Kornegay et al. 2010).

Improved water management: improve irrigation facility to reduce irrigation water losses (Kornegay et al. 2010).

Increase biodiversity: diversify flora and fauna in the farm (Kornegay et al. 2010).

Integrated pest management: a pest management strategy using biological, chemical and physical, cultural production cost and protect the environment (Kornegay et al. 2010).

Mulching: a shallow layer of grass or crop residues at the soil/air interface to improve soil quality and moisture retention (Filho et al. 1999).

Precision agriculture: observation, measurement, and response based farm management strategy to address inter and intra-field variability in crops and increase farm efficiency, productivity, and economic returns (Kornegay et al. 2010).

Reduced chemical fertilizer use: reduced in the use of chemical fertilizers (Kornegay et al. 2010).

Reduced chemical pesticide use: reduce the use of chemical pesticides (Kornegay et al. 2010).

Other commonly adopted SAPs in Kentucky as identified by this research through the workshops and group discussions:

Alley cropping: planting trees or shrubs with agronomic, horticultural, or forage crops cultivated in the alleys between woody plants (Kornegay et al. 2010)

Controlled grazing: the grazing of animals is controlled by rotating and striping field letting field to recover before a successive round of grazing (Gillespie et al 2007).

Crop and livestock production system integration: an integrated system where crop and livestock enterprise are combined and benefitted from each other (Kornegay et al. 2010).

Cultural pest control: managing the crop, weed, disease, and pest complex by manipulating cultural practices (Kornegay et al. 2010).

Fallow management: the use of the fallow period to conserve rainfall as stored soil water and reduce soil erosion (Kornegay et al. 2010).

Farm machinery adjustment: adjustment in planting, spraying, and harvesting farm machinery operation, calibration, repair, and their safety (Kornegay et al. 2010).

Table 1 (continued)

Forest stewardship: forest conservation and development of forest in own farmland.

Land reforming: forming terrace, reducing slope, and other slope stabilizing technologies to reduce surface runoff of water and topsoil.

Local or native crops: locally available crops or local varieties (Kornegay et al. 2010).

Multi-species grazing: grazing more than one species of livestock such as chicken, duck, goat, and horse in the same land (Kornegay et al. 2010).

Polyculture farming: different and less competitive crops grown together to optimize biomass yield and improve environmental quality (Kornegay et al. 2010).

Reforestation: reestablishing forest in barren land or farmland.

Ridge tillage: scalping and planting on ridges built during cultivation (Kornegay et al. 2010).

Sprayer calibration (and application accuracy): calibrate sprayers to use optimum amount of chemicals as well as other spraying inputs in the farm.

Varietal mixture of single crop: mixing a different variety of same crops. also known as Cultivar Mixtures (Kornegay et al. 2010).

Windbreaks and shelterbelts: create wind barriers and provide shelter to crops by planting tall, dense and strong trees along the edge of farmland (Kornegay et al. 2010).

(Carlisle 2016; Prokopy et al. 2008). Hall et al. (2009) found that among floriculture farmers with a farm size of 1–5 acres, there is a significant and positive relationship to the adoption of SAPs, but not with other land sizes.

Access to quality information and extension training have a positive and significant impact on the adoption of best management practices (Baumgart-Getz et al. 2012). Farmers with better knowledge, education, and access to information are more likely to adopt. In addition, knowledge, education, and access to information help to reduce other perceived barriers regarding sustainable practices (Carlisle 2016). Also, networking and outreach activities among farmers motivate them to adopt and expand the adoption of SAPs. In Kentucky, conservation agriculture was widely spread among farmers as a result of networking and the innovation of the system. The overall impact from conservation practices has been better synergy between the environment and agriculture in Kentucky (Coughenour 2003).

Researchers have found that the relationship between farm size and the adoption of soil health-related practices is complicated. Farmers with sloping or highly erodible land are more likely to adopt soil conservation practices (Carlisle 2016; Soule et al. 2000). A study among Brazilian farmers found that the likelihood of the adoption of environmentally friendly practices decreased with an increase in farm size but increased with an increased awareness about the negative effect of chemicals on health and the environment (Filho et al. 1999). However, the use of erosion control practices had a positive relationship to farm size among

farmers in eastern Uganda (Barungi et al. 2013). Small farmers are more motivated to adopt soil health-related practices and relate their adoption behavior to environmental problems than large farmers. Also, small farmers identify the problem of soil erosion faster than larger farmers but are less likely to adopt technologies to reduce erosion. This may be due to higher investment in technologies required per unit of land (Carlisle 2016).

Awareness, attitudes, available resources, and incentives influence the adoption of environmentally friendly practices among Michigan farmers (Swinton et al. 2015). The study concluded that farmers' hesitation to adopt such practices were attributable to the misperception that SAPs are less profitable or that SAPs require skilled and expensive labor. However, farmers who have already adopted SAPs develop positive attitudes about practices and are motivated to adopt more, in contrast to non-adopters, who are motivated by potential yield benefits. The protection of the environment, land conservation, belonging to the land, motivation to make changes, and off-farm benefits are some of the motivations to adopting SAPs (Carlisle 2016).

Policies can have both positive and negative relationships on the adoption of SAPs. Policies like Farm Bill conservation programs have a positive impact on the adoption of SAPs. Farmers who have already participated in conservation programs are motivated to make long-term investments in adopting SAPs (Coughenour 2003; Carlisle 2016). A conservation reserve program was helpful in increasing the adoption of SAPs to reduce erosion, but the pace of adoption is slow. However, the Risk Management Agency policy prevents the adoption of cover crops, as farmers may lose their insurance after adopting those cover crops (Carlisle 2016).

The adoption of SAPs has been well accepted as one of the tools for achieving environmental improvement in agriculture (Greiner et al. 2009). Kabii and Horwiz (2006) found that conservation easement is affected by socioeconomic factors, farm attributes, geography, behavior, attitude, and knowledge. Similarly, Knowler and Bradshaw (2007) summarize factors influencing the adoption of conservation tillage all around the world. Prokopy et al. (2008) summarize the US-based research focusing on the adoption of SAPs during the last 25 years. Mullendore et al. (2015) found that place attachment and place identity among farmers in the Midwestern U.S. have significant effects on conservation practices adoption. Similarly, among Michigan farmers, the adoption of new, environmentally friendly management practices was influenced by attitudes, available resources, and incentives (Swinton et al. 2015). In aggregate, the existing literature collectively indicates that the adoption of SAPs is affected by various socioeconomic factors, demographics, farm attributes, knowledge, behavior, and attitudes, not only in the USA but throughout the world. Also, factors that affect the adoption of SAPs are not consistent throughout the world in the sense that one variable that appears to be statistically significant in one location with a positive sign may not necessarily be statistically significant and possess the same direction in other locations (Baumgart-Getz et al. 2012). However, research focus on the determinant variables of SAP adoption that are generally significant across different geographical areas can improve the overall adoption rate of SAPs (Prokopy et al. 2008).

A table summarizing the major influencing factors is presented in Table 2.

Research Method

Study Area

The study area of this research is the state of Kentucky, USA (Fig. 1). Western Kentucky contributes significantly to the state's agricultural sector. This region is more mechanized than the other parts of the state. Central Kentucky is more urbanized compared with other regions. It has three big cities and several other small and growing urban centers. However, this area also has the highest number of farmers. This region is known for having large acres of farmland and a large number of farmers. Eastern Kentucky has fewer agricultural enterprises compared with other regions of the state. This region features the Appalachian Mountain range and is also well known for coal mining and reclaimed lands.

According to the Agriculture Census of 2012, Kentucky has ~77,000 farmers and 13 million acres of land used for agriculture. The average size of a farm is 169 acres. The majority of the farmers have < 500 acres. Most of the farm operators in Kentucky are small farmers with an age of over 45 years. Looking at the trend over some decades, the number of farmers is decreasing, the average size of each farm is increasing, and the average age of farmers is also increasing (NASS 2015).

The adoption of SAPs also varies with the agriculture district in Kentucky. Western Kentucky is well known for commercial agriculture production and flat plains. So, the use of precision agriculture, computers, and large farm machinery are some of the most commonly adopted practices in that region. However, Eastern Kentucky is well known for coal mining. So, practices such as the use of animals for land reclamation are more applicable to Eastern Kentucky (Larkin et al. 2008). Some SAPs that have a common application, such as the reduced use of chemicals, cover cropping, and green manuring, the use of manure as fertilizer, and controlled grazing are also some of the most commonly used practiced throughout the state.

Table 2 Relevant literatures and summary of major findings

Reference	SAPs types	Study area	Relevant findings to SAP study
*Baumgart-Getz et al. (2012)	BMPs	USA	Access to and quality of information, financial capacity, connection with extension agents and farmer's network have the largest impact on adoption.
*Carlisle (2016)	Soil health practices	USA	Combining education, research, policy, measure to overcome equipment barriers, and addressing farm and food system context increase the adoption of soil health practices.
Da Costa et al. (2012)	Watershed conservation	Kentucky, USA	Counties with more farms and larger farms are more likely to participate in the conservation program. The adoption depends upon land characteristics of individual plots.
Gillespie et al. (2007)	16 BMPs in cattle industry	Louisiana, USA	Farmers do not adopt technologies because of unfamiliarity, non-applicability, high cost, preference towards technologies. Education and extension activities are important to improve the adoption of BMPs.
Hall et al. (2009)	Sustainable floriculture practices	USA	The concerns about the implementation (e.g., easiness) and the risk associated with the implement are two major important factor affecting adoption of SAPs beside location and farm size.
*Kabii and Horwitz (2006)	Conservation easement programs		Landlords' demographics, land tenure nature, knowledge, and awareness about the program, financial circumstances, and participation risk perception, benefit of programs, incentives, and compensation are important factors that affect the participation of conservation programs.
*Knowler and Bradshaw (2007)	Conservation agriculture		The variable explaining the adoption of conservation practices is also localized alike conservation practices themselves. So, policy development and planning attempts to improve adoption should be localized to address location-specific needs and demands.
Mullendore et al. (2015)	Conservation behavior	Midwest USA	The sense of place or place attachment and the place identity have a significant effect on the specific conservation behavior but not in the overall.
*Prokopy et al. (2008)	Best management practices	United States	Education level, income, farm size, access to information, positive environmental attitudes, environmental awareness, and utilization of networking have more often positive relation with the adoption of best management practices.
Singer et al. (2007)	Cover crop	US Corn Belt: IL, IN, IA, MN	Crop diversification plays an important role in the adoption of cover crops and availability of cost-share program would enhance the use of cover crop among corn belt farmers.
Wilson et al. (2014)	Nutrient management practice	Ohio, USA	The attitude toward the adoption of practice to improve nutrient management is driven by farmer's attitudes, perceived risks, and response toward the negative impact of nutrient losses from a farm in the environment. Younger farmers are already engaged in and have more positive attitudes toward management practices.
Zhong et al. (2016)	BMPs via water quality trading program	Kentucky, USA	Farmers who participate in the conservation program are more likely to adopt BMPs. The attitude of farmers towards BMPs and conservation practices are more important when adopting BMPs among farmers.

*Review or meta-analysis paper

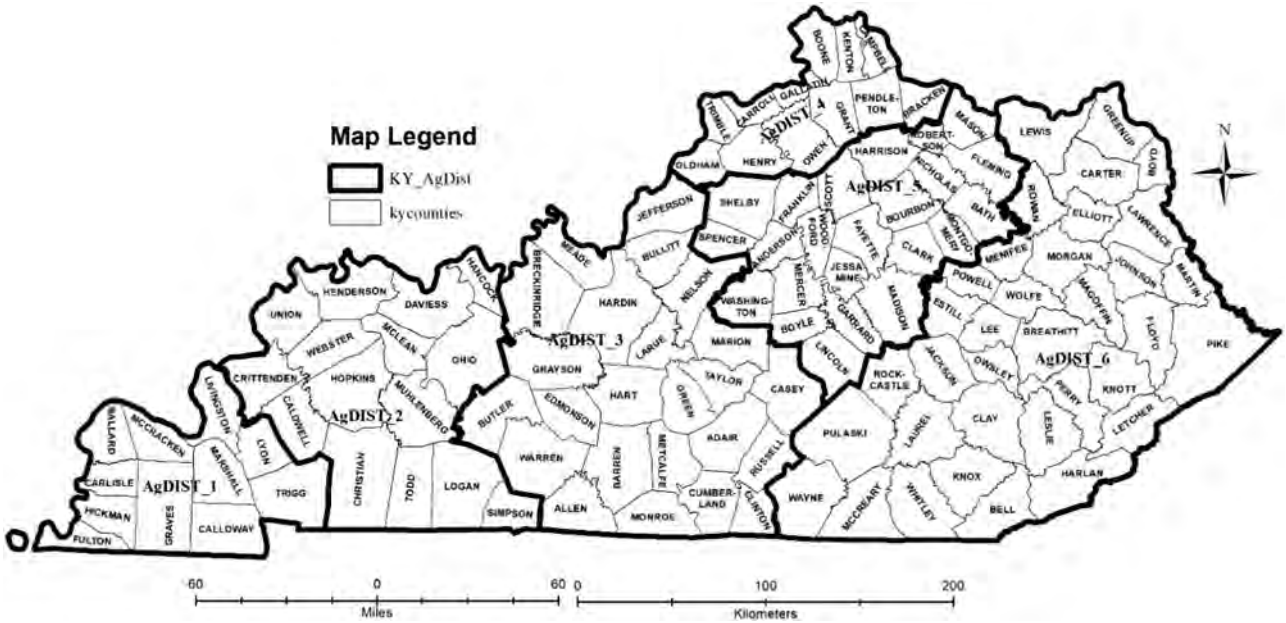

Fig. 1 The state of Kentucky with the six crop growing regions and counties

Sampling Procedure Applied

A survey questionnaire was developed to ask respondents about their farm characteristics, current farming practices, and knowledge and attitudes toward SAPs. The survey questionnaire was tested among small farmers all over the State of Kentucky at the "Third Thursday Thing"—an outreach program on every third Thursday of each month—at the Kentucky State University Research Farm. The final survey questionnaire incorporated suggestions made by the participants. The annual gross sales value of farm outputs and agriculture districts were used for a double-stratified sampling to select samples from all agriculture districts. The annual gross sales value and agricultural districts were taken as reference, with stratification for the proportional representation of farmers with different income levels throughout the state and farmers from different agriculture districts with different agricultural characteristics, respectively.

Data Collection Techniques Used

A mail survey, followed by phone calls, was conducted by The National Agriculture Statistics Service of the United States Department of Agriculture (NASS/USDA) from 10 September 2015, to 13 January 2016. One thousand surveys requesting information for the production year 2014 were mailed to farmers across Kentucky from the North Carolina Print Mail Center. Survey responses were returned and documented at the Regional and Field Office (RFO) of USDA/NASS in Louisville, Kentucky. Surveys were randomly cross-verified by the USDA/NASS staff and demographic and farm attributes summaries were cross-checked with the 2012 United States Census of Agriculture.

Definition of Variables

Dependent Variable

We find that the majority of the farmers are non-adopters of SAPs. Only 34.68% of farmers have adopted SAPs, and 65.32% of farmers have not adopted any type of agricultural practices that were identified as the most commonly adopted SAPs among Kentucky farmers by this research. Among adopters, the majority of farmers have adopted 1–7 different practices. About 22.37% of farmers have adopted 1–7 practices, 9.39% of farmers have adopted 8-14 practices, and only 0.65% of farmers have adopted more than 21 SAPs. At most, a single farmer has adopted up to 28 different types of the most commonly adopted SAPs identified in this research (Table 3).

"Manure distribution as fertilizer" is the most adopted practice by farmers followed by the "reduced use of chemicals." Agriculture practices such as precision agriculture, polyculture farming, reforestation, and mulching are adopted by only a few farmers. The results suggest that the easiness in the adoption process, technical skills requirements, investment, and income play important roles in farmers' decisions of whether and which SAPs to adopt for their farm. Highly adopted practices among Kentucky farmers are less expensive as well as easy to adopt, and the least adopted practices are highly skill based and investment

Table 3 Sustainable agriculture practices adopted by farmers ($N = 230$)

Number of practices	Number of farmers	Percent
0 (not adopted)	150	65.32
1–7	51	22.37
8–14	22	9.39
15–21	5	2.27
22–28	2	0.65

demanding. The most commonly adopted practices and their adoption intensity are shown in Fig. 2.

The dependent variable (SAPs) is the count variable (non-negative whole numbers) that shows the total number of SAPs adopted by Kentucky farmers who responded to the survey. The value of the dependent variable ranged from 0 to 28 (Table 3). The description of variables and their descriptive statistics are given in Table 4.

Independent Variables

Based on the review of influencing factors provided in section 2, the adoption of SAPs is affected by various socioeconomic factors, demographics, farm attributes, knowledge, education, behavior, and attitude. Fourteen explanatory variables related to these factors were used for the analysis: Crops (row crops growers), *Veggies* (vegetable growers), *Livestock* (livestock farmers), *Irrigation* (irrigation facilities in farm), *Diverse* (in favor of farm diversification), *Solo Proprietorship* (single owner of farm), *Off-Farm Work* (working off-farm for income), *Age* (year), *TBP* (participation in Tobacco Buyout Program), *College Degree* (education level of farmers with college degree or above completed), and *Land Operated* (Acres). Three barriers to the adoption of SAPs—*Happy* (happy with current practices reflecting the attitude of farmers toward SAPs), *Implementation Difficulty* (perceived difficulty of implementation), and *Inadequate Knowledge*—were also used as independent variables in the model. These were the top three barriers marked by respondents to the survey. Six dummy variables were created based on the crop growing regions of Kentucky to examine spatial impacts of on the adoption of SAPs. These crop growing areas are shown in Fig. 1.

Econometric/Empirical Model

Condition for SAPs Adoption Consideration

Farmers adopt SAPs for various reasons. Some farmers adopt SAPs because they believe these practices increase yield (and consequently the net returns) associated with farming, whereas others believe that SAPs are good for the environment. Also, there are farmers who adopt SAPs while considering economic and environmental benefits. Whether farmers adopt the technology for a yield or profit reason or for an environmental quality reason, they believe that adopting SAPs gives them higher utility than not adopting the technology. We believe that farmers adopt a higher number of SAPs because they perceive a number of SAPs adoption or more SAPs applied in more acres of land gives them higher utility than otherwise. We can write this as: $U_{\text{SAPs adoption=yes}} > U_{\text{SAPs adoption=no}}$. The probability of adopting SAPs can be shown as:

$$\begin{aligned} P_i &= \text{Prob}\left[U_{\text{adopt}} > U_{\text{not adopt}}\right] \\ &= \text{Prob}[X_i\alpha_1 + e_{1i} > X_i\alpha_0 + e_{0i}] \\ &= \text{Prob}[X_i(\alpha_1 - \alpha_0) > (e_{0i} - e_{1i})] \\ &= \text{Prob}[X_i b > \varepsilon_i] \\ &= \text{F}[X_i b]. \end{aligned}$$

Here, X is a matrix of explanatory variables, b (and α) is the parameter vector, $\in$ (and e) is error term, F is the cumulative distribution function, $i = 1$ when SAPs are adopted, and $i = 0$ when no adoption occurs (Gillespie et al. 2007).

Data Analysis Techniques Applied

Data were analyzed using SPSS 24.0. To address the disproportionate response rate among strata, the post-stratification weight was applied before analyzing the data using the equation:

$$W_{ih} = rP_h/r_h$$

For each sample case in the post-stratum h, where r_h is the number of survey respondents in the post-stratum h, P_h is the population proportion from the US Census 2012, and r is the respondent sample size (Little 1993).

When the variable of interest is a count variable, which is our case with the total number of SAPs adopted by farmers, a count data model such as the Poisson regression model is used. In the Poisson distribution, mean and variance are assumed equal, which generally is not the case. When this mean-variance equality assumption is violated, it is called an over dispersion problem. In such cases, the Poisson regression parameters will be inefficient. We can estimate a negative binomial model that produces coefficients that are robust to distributional misspecification as long as the dispersion parameter is known, and the variance function is correctly specified.

The number of SAPs adopted by farmers is a function of several independent variables identified in Table 2. The

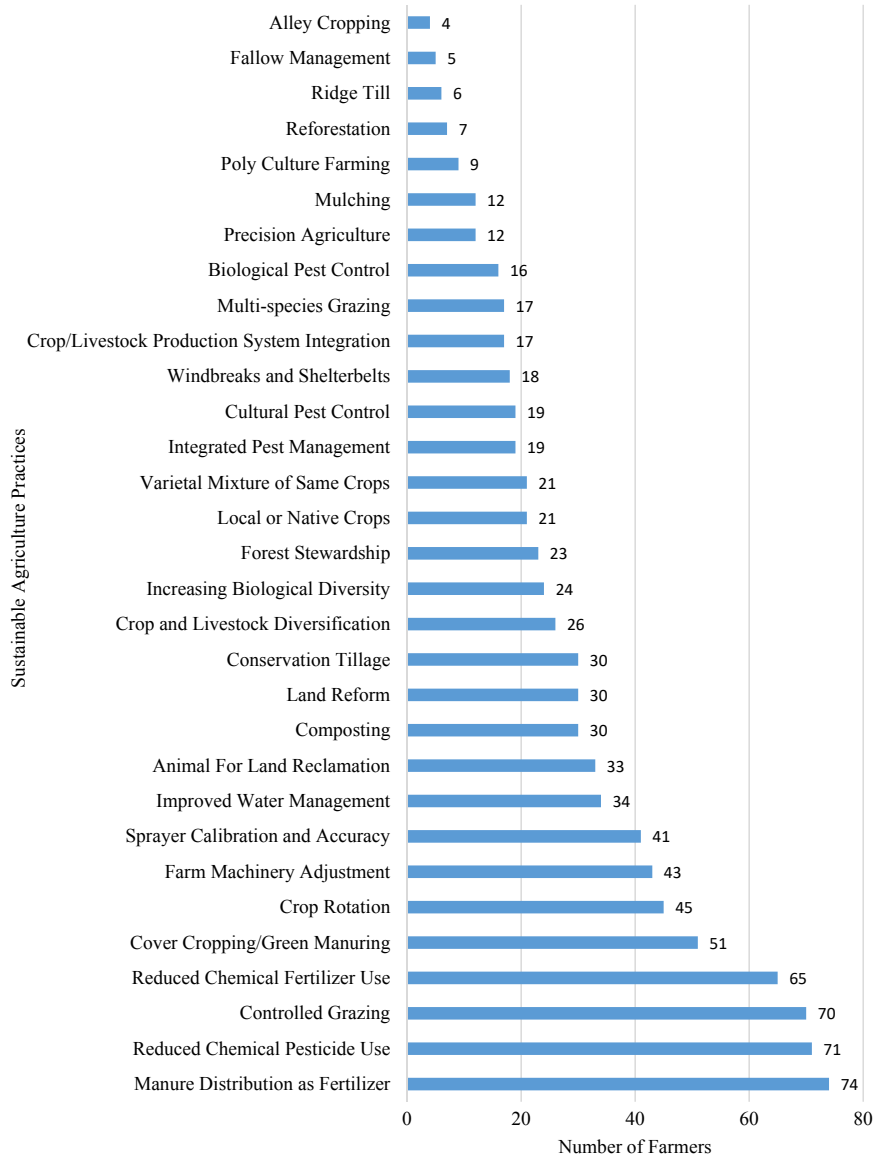

Fig. 2 Most commonly adopted sustainable agriculture practices among Kentucky farmers

model can be written as:

$$S(SAPs_i|X_i) = \lambda_i = \exp(b_o + b_1X_1 + b_2X_2 + \ldots + b_nX_n)$$

where, *SAPs*, is the number of sustainable agricultural practices adopted by farmer i, b_o is the intercept of the regression model, $b_1, b_2, \ldots, b_n$ are coefficients of respective predictors $X_1, X_2, \ldots, X_n$ (Coxe et al. 2009). λ_i is the intensity of rate parameter.

Results and Discussion

We compare the mean and variance of the number of SAPs practiced by farmers and find that those are not equal. In addition, the likelihood ratio χ^2-test is conducted to find if the dispersion parameter alpha is equal to zero. The test statistics indicate that SAPs are overdispersed and are not sufficiently described by the Poisson distribution. Therefore, we estimate a negative binomial regression (NBR) model to understand the role of different influencing factors on the adoption intensity of SAPs by Kentucky farmers. The result of the NBR model Table 5 shows that variables *Crops, Veggies, Irrigation, Diverse*, and *College Degree* were positive statistically significant at a 1% level. Also, variable *TBP* was positive and significant at a 5% level. Variables *Implementation Difficulty* and *Inadequate Knowledge* were statically significant at a 1% level, and *Age* was statistically significant at a 5% level, but all of these variables had negative signs in the model. Regional variables were statistically significant in the model at various significant levels. *AgDist_2* and *AgDist_4* were significant at a 1% level with

Table 4 List of variables and their descriptive statistics

Variables	Variable name	Mean	Variance
Dependent variable			
SAPs	Number of SAPs adopted by farmers	2.52	21.16
Independent variables			
Crops	Row crop farmers; yes = 1; otherwise = 0	0.54	0.15
Veggies	Vegetable growing farmers; yes = 1; otherwise = 0	0.16	0.02
Livestock	Livestock farmers; yes = 1; otherwise = 0	0.81	0.16
Irrigation	Irrigation facility in farm; yes = 1; otherwise = 0	0.04	0.04
Diverse	In favor of diversifying farm; yes = 1; otherwise = 0	0.42	0.24
Sole proprietorship	Farm with sole proprietorship; yes = 1, otherwise = 0	0.75	0.19
Off farm	Working off farm; yes = 1; otherwise = 0	0.49	0.25
Age	Age (years)	62.85	149.81
TBP	Participated; yes = 1; otherwise = 0	0.42	0.38
College degree	Formal education: college degree or above; yes = 1; otherwise = 0	0.20	0.16
Land	Total land operated (acres)	169.60	300804.59
Happy	Happy attitude (a reason for not adopting SAPs); yes = 1; otherwise = 0	0.43	0.25
Implementation difficulty	Perceived difficult of implementation of practices; yes = 1; otherwise = 0	0.05	0.05
Inadequate knowledge	A reason for not adopting SAP; yes = 1; otherwise = 0	0.15	0.13

positive signs, whereas *AgDist_3 and AgDist_5* were significant at a 5% level and both have negative signs.

We interpret the regression results as incident rate ratios by exponentiating the regression coefficients (the last column in Table 3). When interpreting these coefficients, we hold all other variables, except the one we are interested-in in the model, constant. Therefore, all our interpretations of coefficients explained below should be understood that way. The variable *Crops* (farmers growing row crops) and *Veggies* (farmers growing vegetables) are a significant predictor of the adoption of SAPs in Kentucky. The results show that the incident rate for SAP adoption for farmers growing row crops were 2.294 times greater than the incident rate for the farmers without row crops. The incident rate for farmers growing vegetables was 1.511 times the incident rate for the farmers not growing vegetables. Several researchers have identified the importance of cover crops to improve soil health, reduce pest infestation, weed control, and reduce the use of chemicals (Lichtenberg 2004; Singer et al. 2007; Snapp et al. 2005; Teasdale 2013). In addition, the adoption of sustainable agriculture is a common practice among vegetable farmers. The use of approaches that can enhance vegetable production safely has been increasing with the increased interest of consumers in organic and healthy vegetables (Simmons 2008).

The variable called *availability of irrigation facility* had a positive and significant effect on the adoption of SAPs among Kentucky farmers. The incident rate for farmers with irrigation facilities on the farm *(Irrigation)* was 1.876 times the incident rate for farmers without irrigation facilities.

The incident rate for farmers in favor of farm diversification *(Diverse)* was 2.072 times than that of their counterparts. A significant predictor of the adoption of SAPs is whether farmers are in favor of diversifying their farms. Those farmers who were in favor of diversifying were also likely to adopt more SAPs compared with farmers who did not favor diversification. Farmers diversify their farms by adding high-value crops, short season crops, vegetables, or cover crops, which are helpful in weed control, reduce the use of chemicals, improve soil health and fertility, and ensure improved crop production (Lichtenberg 2004; Singer et al. 2007; Snapp et al. 2005; Teasdale 2013).

Also, the incident rate for farmers who participated in the Tobacco Buyout Program *(TBP)* were 1.286 times that of farmers who did not participate in the TBP. The US government has collectively spent billions of dollars in designing policies that shape agriculture and facilitate the conservation programs through different farm bills (Mullendore et al. 2015). These Farm Bill programs also transition farmers from tobacco to different crops that may have provided positive motivations for farmers who participated in the TBP program to adopt SAPs. Litchenberg (2004) found that the adoption of several soils and water conservation practices are responsive to the USDA/NRCS cost-sharing program. The increase in the cost of the practice reduces the adoption of conservation practices among

Maryland farmers. Also, the interaction between different conservation practices may be less costly in reducing the share of the cost. It may increase the adoption of conservation practices. Several other researchers also have found that the adoption of management practices related to soil health was enhanced by the Farm Bill Conservation Program (Carlisle 2016; Coughenour 2003; Soule 2001).

Several studies about SAPs show that policy factors play an important role in the adoption process. A few policy-related studies have been done in relation to SAPs in Kentucky. Cuoghenour (2003) studied the innovation of no-tillage cropping practices. Zhong et al. (2016) studied farmers' participation in cost-share conservation programs in the Kentucky watershed. Also, Da Costa et al. (2012) studied the impact of the Agriculture Water Quality Act in the adoption of SAP and participation in conservation programs in Kentucky. Larkin et al. (2008) studied the use of small mammals in the coal-mining reclamation process in Kentucky.

We have included some policy-related factors, such as farmers' "happy" attitudes, implementation and knowledge barriers, TBP as policy-related variables that are identified as important in the adoption of SAPs through literature review and interaction with farmers.

The incident rate for farmers with formal education above the college degree *(College Degree)* was 2.097 times compared with farmers without a college degree. Kabii and Horwitz (2006) also found that the attitude of farmers plays a role in the adoption of conservation agriculture. Lashgarara (2011) found that the education, knowledge, and attitude of farmers are significantly correlated with the adoption of sustainable agriculture adoption. Baumgart-Getz et al. (2012) mentioned that attitude had a positive and significant influence on the adoption of agricultural best management practices. The chains of practices created following from the previous one (also called a "foot in the door" model) could lead to the complete transformation of farming systems (Wilson et al. 2014).

The percent change in the incident rate of SAPs' adoption is a decrease of 1% for every single year the farmer's age *(Age)* increases. Increasing farmer age had a negative impact on the adoption of SAPs among Kentucky farmers. This is consistent with several other studies. This could be because younger farmers have more positive attitudes toward sustainable practices compared with older farmers, who are relatively hesitant to change farm practices from traditional to SAPs (Baumgart-Getz et al. 2012). The incident for farmers who perceive that the technology is difficult to adopt *(Implementation Difficulty)* were 4.892 times less compared with farmers who do not perceive implementation difficulties associated with SAPs. The incident rate for farmers with an inadequate knowledge of technologies *(Inadequate Knowledge)* was 0.532 times less than farmers who do not perceive that they have an inadequate knowledge to adopt SAPs. These incident rates suggest the need for extension activities, training, and education to improve the adoption of SAPs. Swinton et al. (2015) reported that owing to a perception of lower profitability farmers are unwilling to adopt new technologies.

Hall et al. (2009) identified implementation concerns and perceived risk of failure as two major barriers to the adoption of sustainable agriculture and recognized the importance of education and training to overcome these barriers. These barriers can be overcome through education, extension, and outreach activities (Baumgart-Getz et al. 2012; Kornegay et al. 2010). These findings validate the importance of education to reduce knowledge barriers, as well as the perceived difficulty of implementation among farmers. Carlisle (2016) also suggested that education in combination with other activities such as research and policies are essential to mitigate the adoption barriers related to soil health equipment adoption.

The incident rate of adopting SAPs for farmers living in Agriculture District 2 *(AgDist_2)* and Agriculture District 4 *(AgDist_4)* were 2.352 times and 1.76 times more, respectively, compared with the farmers living in Agriculture District 6 *(AgDist_6)*, the reference group. However, farmers residing in Agriculture Districts 3 *(AgDist_3)* and 5 *(AgDist_5)* possess behavior that is the opposite compared with the above two districts. The incident rate for these farmers in agriculture districts 3 and 5 were 0.676 and 0.669 times, respectively, compared with the reference group *(AgDist_6)*. The result clearly shows that the issue of sustainability in agriculture is highly localized. Thus, the solution also should be location specific. A blanket approach to solving the problems of agriculture sustainability may not be equally valid and equally adaptive in the same state or same country. Sustainable agriculture and SAPs are localized by nature and should be addressed locally. However, the solution should have a more significant impact on solving this global problem.

In contrast to the common trend of farmers moving toward sustainable farming (Kornegay et al. 2010), we found that farmers in agriculture districts 3 and 5 are more profit-oriented than environmentally friendly, whereas farmers from agriculture district 4 are more environmentally friendly. Agriculture districts 3 and 5 have two major cities —Lexington and Louisville—as well as several small and medium sized growing towns. Farmers from these regions might be motivated by the growing commodity market in this region. However, agriculture district 4 lies in between two major cities, Louisville and Cincinnati. As they are not part of major cities but are located in between them, environmental pollution coming from these surrounding cities might be a big concern to farmers in agriculture district 4.

Research conducted among New Zealand dairy farmers to understand the adoption of the best management practices suggests that farmers close to each other make similar choices owing to the potential for frequent interactions (Yang and Sharp 2017). The results of the current research are partially supportive of the previous studies. Specifically, results from agriculture districts 3 and 5 are consistent with the earlier findings, as they are neighboring districts and have a similar result in the model. However, the results from agriculture districts 2 and 4 contradict previous findings. Agriculture district 2 is primarily farmland with some coal mining areas. This region is also well known for large-size farm operations. A positive relationship with the adoption of SAPs in this region can be linked to the awareness among farmers of the negative impact of coal and coal-mining sites on the environment and agricultural commodities. Also, as large enterprise and agriculture have occupied this region and have been major parts of the economy for a long time, farmers in that region might have developed an awareness about the importance and role of SAPs for long-term sustainable agriculture enterprise.

This research included practices that are commonly adopted by Kentucky farmers. Some of them were previously researched and some of them are newly identified through the discussion and workshops. Not all practices included in this research are equally important for environment management (Lashgarara 2011), nor are uniformly adopted by farmers. However, this research identified new practices throughout the state that had not been studied before. In this context, this research played an important role in understanding the role of influencing factors in sustainable agricultural practice adoption intensity in Kentucky.

Conclusions

This study explored factors influencing the intensity of the adoption of SAPs among Kentucky farmers using negative binomial regression. Fourteen variables representing socioeconomics, demographics, farm attributes, attitudes, knowledge, and behavior were used in the analysis. Agriculture districts were also included in the model to account for the regional characteristics of SAPs. The text box summarizes the major findings of the research.

Table (continued)

Adoption intensity of SAPs among Kentucky farmers has a positive and significant relationship with crop and vegetable growers with irrigation facilities, farmers in favor of diversification, farmers participating in the tobacco buyout program, farmers with a formal college degree or above education level, but has a negative and significant relationship with the age of farmers. Lack of knowledge and the perceived difficulty of implementation are two major and significant barriers to the adoption of SAPs. Last but not the least, the adoption of SAPs is localized very specifically: agriculture districts 2 and 4 have a positive and significant relationship with SAP adoption, but agriculture districts 3 and 5 are significant but negative.

This research provided important insights and corroborated some previous findings as well. The research into SAPs in Kentucky was itself limited in several ways: only a little research has been conducted so far in Kentucky to understand the adoption of SAPs; the research was limited to a small locality taking into account only a few practices that were mostly prioritized by governmental and non-governmental policies. The behavior and attitudes about SAP adoption throughout the state were not known. Also, the research surveyed farmers from all over the state and identified SAPs that were commonly adopted throughout the state through discussion and survey. More importantly, this research explored how farmers from different agricultural regions behave toward the adoption of SAPs. This result, on one hand, further verified previous findings that SAPs are localized in nature, and also gave a direction for policymakers to consider design policies when approaching farmers in the different agricultural district based on their interest in the Adoption of SAPs. For instance, it is easier for policymakers and extension workers to expand the SAPs in agriculture districts 2 and 4 compared to agriculture districts 3 and 5, as the former two are positive toward the adoption of SAPs, whereas later two are negative.

Policy-wise, this research has provided some insights for policymakers and extension practitioners. The positive relationship of crop and vegetable growers with irrigation facilities but not significant relationship with livestock farmers shows that crop and vegetable farmers should be approached to expand the adoption of SAPs. This research found that the farm diversification approach could be implemented to reduce the crop risk while introducing and expanding the adoption of SAPs. According to this research, educated and young farmers should be the major focus for expanding adoption. Also, education and extension activities play a vital role in the expansion of the adoption of technologies as knowledge and perception are major barriers among Kentucky farmers. However, the localized nature of adoption behavior and intensity of SAPs and the varied attitude toward the adoption of SAPs according to different agriculture district shows that the extension and education program also should be localized

Table 5 Parameter estimates obtained from a negative binomial regression model of factors affecting adoption of sustainable agriculture practices among kentucky farmers ($N = 205$)

Variables	Estimates (b)	SE	Exp (b)
Constant	0.024	0.423	1.024
Crops	0.830***	0.121	2.294
Veggies	0.413***	0.136	1.511
Livestock	0.228	0.143	1.257
Irrigation	0.629***	0.171	1.876
Diverse	0.728***	0.100	2.072
Sole proprietorship	− 0.084	0.116	0.920
Off farm	0.063	0.120	1.065
Age (years)	− 0.010**	0.005	0.990
TBP	0.251**	0.105	1.286
College degree	0.740***	0.136	2.097
Land	0.000	0.000	1.000
Happy	0.004	0.102	1.004
Implementation difficulty	− 1.588***	0.180	4.892
Inadequate knowledge	− 0.631***	0.158	0.532
AgDist_1	0.225	0.194	1.253
AgDist_2	0.855***	0.163	2.352
AgDist_3	− 0.392**	0.161	0.676
AgDist_4	0.565***	0.159	1.760
AgDist_5	− 0.402**	0.166	0.669

*** & ** = Statistically significant at 1 and 5% levels, respectively. SE is standard error

and should be designed based on the needs and attitudes of farmers.

There are some limitations of this study as well. To find the causal effects of some of the variables in the model, we need a more sophisticated econometric model. Adoptions patterns of some of the major SAPs identified by this study and the impacting factors for those adoptions can be further studied in future. In addition, efforts should be made to collect relevant data on risk, policy variables, cost-share payment, and other important socioeconomic factors to establish more robust conclusions on the causality of these variables in determining the adoption or adoption intensity of SAPs in Kentucky or elsewhere.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Disclaimer Summaries were derived using data collected in the Kentucky State University Economics Survey by the National Agriculture Statistics Service, United States Department of Agriculture (NASS). Any interpretations and conclusion derived from the data do not necessarily represent the views of the NASS.

References

Barungi M, Ng'Ong'Ola DH, Edriss A, Mugisha J, Waithaka M, Tukahirwa J (2013) Factors influencing the adoption of soil erosion control technologies by farmers along the slopes of Mt. Elgon in Eastern Uganda. JSD J Sustain Dev 6:2

Baumgart-Getz A, Prokopy LS, Floress K (2012) Why farmers adopt best management practice in the united states: a meta-analysis of the adoption literature. J Environ Manag 96(1):17–25

Carlisle L (2016) Factors influencing farmer adoption of soil health practices in the united states: a narrative review. Agroecol Sustain Food Syst 40(6):583–613

Coughenour CM (2003) Innovating conservation agriculture: the case of no-till cropping. Rural Sociol 68(2):278–304

Coxe S, West SG, Aiken. LS (2009) The analysis of count data: a gentle introduction to poisson regression and its alternatives. J Personal Assess 91(2):121–136

Da Costa PF, Hu W, Pagoulatos A, Schieffer J (2012) Participation in government cost-share conservation programs in the Kentucky river watershed: a county-level analysis. Environ Econ 3:122–130

Filho HD, Young T, Burton M (1999) Factors influencing the adoption of sustainable agricultural technologies. Technol Forecast Social Change 60(2):97–112

Foster AD, Rosenzweig MR (2010) Microeconomics of technology adoption. Annu Rev Econ 2(1):395–424

Gillespie J, Kim S, Paudel KP (2007) Why don't producers adopt best management practices? An analysis of the beef cattle industry. Agric Econ 36(1):89–201.

Greiner R, Patterson L, Miller O (2009) Motivation, risk perceptions and adoption of conservation practices by farmers. Agric Syst 99 (2–3):86–104

Griliches Z (1957) Hybrid corn: an exploration in the economics of technological change. Econometrica 25(4):501–522

Hall TJ, Dennis JH, Lopez RG, Marshall ML (2009) Factors affecting growers' willingness to adopt sustainable floriculture practices. HortScience 45(2):1346–1351

Kabii T, Horwitz P (2006) A review of landholder motivations and determinants for participation in conservation covenanting programmes. Environ Conserv 33(01):11–20

Knowler D, Bradshaw B (2007) Farmers' adoption of conservation agriculture: a review and synthesis of recent research. Food Policy 32(1):25–48

Knowler D (*2015*) Farmer adoption of conservation agriculture: a review and update. In: Farooq M, Siddique KHM Eds Conservation Agriculture. Springer, Cham, p 621–642

Kornegay JL, Harwood RR, Batie SS, Bucks D, Flora CB, Hanson J, Jackson-Smith D, Jury W, Meyer D, Reganold JP, Schumacher Jr A, Sehmsdorf H, Shennan C, Thrupp LA, Willis P (2010) Towards sustainable agriculture system in the 21st century. National Academics Press, Washington, DC

Larkin JL, Maehr DS, Krupa JJ, Cox JJ, Alexy K, Unger DE, Barton C (2008) Small mammal response to vegetation and spoil condition on a reclaimed surface minein Eastern Kentucky. Southeast Nat 7 (3):401–412

Lashgarara F (2011) Identification of influencing factors on adoption of sustainable agriculture among wheat farmers of Lorestan Province, Iran. Adv Environ Biol 5(5):967–972

Lichtenberg E (2004) Cost-responsiveness of conservation practices adoption: a revealed preference approach. J Agric Resour Econ 29(3):420–435

Little RJ (1993) Post-stratification: a modeler's perspective. J Am Stat Assoc 88(423):1001–1012

Liu Y, Engel BA, Flanagan DC, Gitau MW, McMillan SK, Chaubey I (2017) A review on effectiveness of best management practices in improving hydrology and water quality: Needs and opportunities. Sci Total Environ 601-602:580–593

Mullendore ND, Ulrich-Schad JD, Prokopy LStalker (2015) U.S. farmers' sense of place and its relation to conservation behavior. Landsc Urban Plan 140:67–75

National Agricultural Statistics Service (NASS). (2015). 2012 census publications. Retrieved 16 April 2017, from 2012 Census Publication, Desktop Data Query Tools 2.0 https://www.agcensus.usda.gov/Publications/2012/Online_Resources/Desktop_Application/

NRCS 2014. Regulatory impact analysis (RIA) for the environmental quality incentives orogram (EQIP). Accessed from the web on 8 December 2018 https://nrcs.usda.gov

Pretty J (2008) Agricultures sustainability: concepts, principles and evidence. Philos Trnasactions R Soc B 363:447–465

Prokopy L, Floress K, Klotthor-Weinkauf D, Baumgart-Getz A (2008) Determinants of agricultural best management practice adoption: evidence from the literature. J Soil Water Conserv 63(5):300–311

Rittenburg RA, Squires AL, Boll J, Brooks ES, Easton ZM, Steenhuis TS (2015) Agricultural BMP effectiveness and dominant hydrological flow paths: concepts and a review. J Am Water Resour Assoc 51(2):305–329

Ruttan VW (1996) What happened to technology adoption-diffusion research? Sociol Rural 36(1):51–73

Ryan B, Gross. NC (1943) The diffusion of hybrid seed corn in two iowa communities. Rural Sociol 8(1):15–24

Simmons, L. V. Moving Towards Agroecosystem Sustainability: Safe Vegetable Production in Vietnam. Master's thesis, University of Waterloo, Ontario, Canada, 2008

Singer JW, Nusser SM, Alf CJ (2007) Are cover cops being used in the U.S. Corn-belt? J Soil Water Conserv 62(5):353–358

Snapp SS, Swinton SM, Labarta R, Mutch D, Black JR, Leep R, Nyiraneza J, O'Neil K (2005) Evaluating cover crops for benefits, cost, and performance within cropping system niches. Agron J 97 (1):322–332.

Soule MJ (2001) Soil management and the farm typology: do small family farms manage soil and nutrient resources differently than large family farms? Agric Resour Econ Rev 30(2):179–188

Soule MJ, Tegene A, Wiebe KD (2000) Land tenure and the adoption of conservation practices. Am J Agric Econ 82(4):993–1005

Swinton SM, Rector N, Robertson GP, Jolejole-Foreman CB, Lupi F (2015) Farmers decisions about adopting environmentally beneficial practices. The Ecology of Agricultural Landscapes: Long-Term Research on the Path to Sustainability. Oxford University Press, New York, NY

Teasdale JR (2013) Contributionof cover crops to weed management in sustainable agriculture systems. J Prod Agric 9(4):475–479

Upadhyay B, Young D, Wang H, Wandschneider P (2003) How do farmers who adopt multiple conservation practices differ from their neighbors? Am J Altern Agric 18(1):27–36

US Congress. Food, Agriculture, Conservation, and Trade Act, Public law (1990) Title XVI, Subtitle A, Section 1603. Government Printing Office, Washington DC, p 101–624. https://www.gpo.gov/fdsys/pkg/USCODE-2007-title7/pdf/USCODE-2007-title7-chap64-subchapI.pdf

Wilson RS, Howard G, Burnett EA (2014) Improving nutrient management practices in agriculture: the role of risk-based beliefs in understanding farmers' attitudes toward taking additional action. Water Resour Res 50(8):6735–6746

Yang W, Sharp B (2017) Spatial dependence and determinants of dairy farmers' adoption of best management practices for water protection in New Zealand. Environ Manag 59(4):594–603

Zaharia C (2010) Sustainable agricultural development concepts, principles, eco-efficiency, eco-equity, eco-conditioning. Cercet Agron Mold 143(3):91–100

Zhong H, Qing P, Hu W (2016) Farmers' willingness to participate in best management practices in Kentucky. J Environ Plan Manag 59(6):1015–1039

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URBAN HEAT ISLAND IN KATHMANDU, NEPAL: EVALUATING RELATIONSHIP BETWEEN NDVI AND LST FROM 2000 TO 2018

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Abstract

The term "urban heat island" (UHI) describes increased surface and atmospheric temperatures in an urban core relative to surrounding non-urbanized areas. Although the phenomenon has been studied to a great extent throughout the world, it is less understood for Kathmandu, Nepal. This study used the Moderate Resolution Imaging Spectro-radiometer (MODIS) 8-day product (MOD11A2) to evaluate land surface temperatures (LSTs), the MODIS-derived Normalized Difference Vegetation Index (NDVI) 16-day product (MOD13Q1) to quantify land surface characteristics, and the Landsat-based annual land cover classification product to identify major land cover classes. We evaluated the spatial correlation between significant changes in LSTs and NDVI between 2000–2018. Overall, urban (permanently developed areas) LSTs were consistently greater than non-urban (forests and dynamic agriculture lands) LSTs; however, the rate of increase in temperature was higher outside the central Kathmandu developed urban area. Furthermore, significant changes in NDVI values over time were more widespread and not always spatially coincident with significant changes in LST values, particularly for forested land areas. These results provide insight into systematic planning of open and green areas, construction of new infrastructure in peripheral areas, and highlight the challenges in applying traditional UHI conceptual models to rapidly developing urban areas such as Kathmandu, Nepal.

Keywords: Urban Heat Island, Urbanization, Land Cover Change, Nepal, Kathmandu.

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1. Introduction

Urbanization in Nepal has been observed since 1970 (Rimal et al. 2017; Thapa et al., 2008). In last few decades, Nepal has been among those countries with the highest urbanization rates with an annual increase of 3.0%. This trend is expected to continue until 2050 (Bakrania, 2015; UN DESA, 2015). The areas with the greatest urbanization rates were in the Kathmandu Valley (MoUD, 2015; Thapa et al., 2008), which comprises 24.02% of the total urban area. Kathmandu's metropolitan municipality contains approximately 9.72% of the valley's total urban population (Bakrania, 2015; MoUD, 2015). Kathmandu is a major urban center with a population exceeding three million people (Chitrakar et al., 2016).

The climatic and weather conditions of the Kathmandu Valley have changed tremendously over last few decades because of rapid urbanization and conversion of a valley dominated by agricultural practices into an impervious surface layer. It has become uncomfortable and unhealthy for living as well as susceptible to disease outbreaks (Maharjan and Regmi, 2014). Throughout the year, the temperature and relative humidity are both higher in Kathmandu city (which consists of only the Kathmandu Metropolitan City area) and nearby areas compared to the surrounding valley (which includes Kathmandu, Bhaktapur, and Lalitpur districts) and nearby locations (Maharjan and Regmi, 2014; MoUD, 2015).

Kathmandu Valley's land use and land cover has changed significantly in the last four decades. Rimal et al. (2017) report that Kathmandu Valley had an average annual urban growth rate of 7.34% between 1976 and 1989, 7.70% between 1989 and 2002, and 5.90% between 2002 and 2015. The city has expanded as much as 412%, with the majority of land converted from agricultural land, which has changed the valley's landscape considerably (Ishtiaque et al. 2017).

The urbanization process reduces greenery and increases the number of impervious surfaces. This process causes changes in land use, land cover, and land surface characteristics that subsequently modify the local climate, moisture exchange, and ecosystem services, favoring heat trapping and storage (Cui et al., 2016; Jin et al., 2005; Lavaysse et al., 2018; Li et al., 2009). Heat trapping leads to temperature differences between urban and surrounding rural areas, with temperatures in urban areas higher than in rural areas, a phenomenon known as an "urban heat island" (UHI; Jin et al., 2005; Li et al. 2009). Increasing the population within these urban areas exacerbates UHI effects as well as exposes more people to the potential risks of UHI, such as hyperthermia (Azevedo et al., 2016). Land surface temperature (LST) is an important factor in UHI (Zakšek and Oštir, 2012). Various studies found a correlation between the Normalized Difference Vegetation Index (NDVI) and LST (Grover and Singh, 2015; Liu et al., 2015). This correlation, however, may vary based on differences in topography, demographics, and land cover attributes.

The UHI phenomenon is important to study because it affects many aspects of life, such as infrastructure, health, energy consumption, environmental stress, and discomfort, and leads to additional costs in building infrastructure (Azevedo et al., 2016). Depending on the nature and developmental phase, UHI can have detrimental socio-economic effects (Cui et. al., 2016). Although some studies about changes in temperature have been conducted in the Kathmandu Valley, none of these studies has examined UHIs closely or the relationship of UHIs to other possible factors. Our study focuses on two major research questions: 1) Was there a significant change in LSTs of the Kathmandu Valley from 2000–2018? and 2) Was the LST change associated with a change in NDVI?

2. Material and Method

2.1. Study site

As shown in Fig. 1, Kathmandu Valley is located at a latitude of 27°38'32"-27°45'7" N and longitude of 85°16'5"-85°22'32" E (Thapa et al., 2008). The bowl-shaped valley has an elevation of 1,100–2,700 m (average: 1,350 m) above mean sea level (Chitrakar et al., 2016; Thapa et al., 2008; Thapa and Murayama, 2009). The valley is subdivided into five neighboring urban areas (Kathmandu, Bhaktapur, Lalitpur, Kirtipur, and Madhyapur Thimi) and 97 surrounding peri-urban and rural villages based on administrative units (Ishtiaque et al., 2017; Thapa and Murayama, 2012). The Kathmandu Metropolitan City area is flat with less than 1° slope and the soil is predominantly loamy and boulder in texture (Haack and Khatiwada, 2007; Thapa et al., 2008).

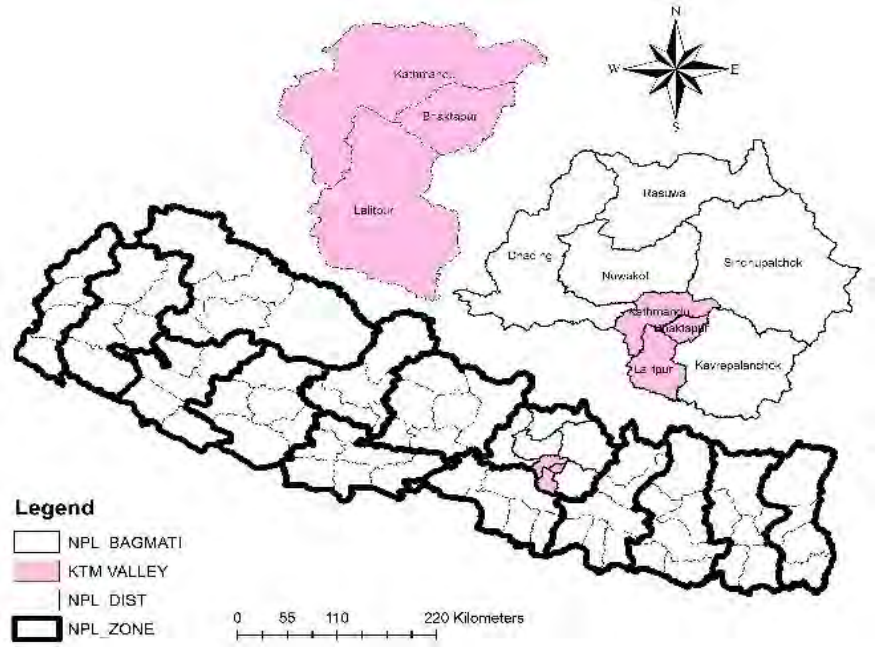

Figure 1: The Kathmandu Valley, Nepal.

2.2. Data Collection

Land cover information that possesses spatially and temporally consistent attributes or that carry the same classification definitions is not widely available for Nepal (Aksha et. al. 2018). Little consensus exists on how to define the particular classes of interests best. In lieu of sampling existing land cover data, simple classification data were developed in ArcGISPro using Landsat 5 Thematic Mapper (TM) and Landsat 8 Over Land Imager (OLI) 30-meter imagery for deriving the NDVI for grouping segmented land areas into 3 broad classes: development, forest, and agriculture. For this region, cloud-free imagery data are more readily available during the months of March and October each year. Imagery data from 2000 and 2018 were used to classify all land pixels into one of three classes according to the persistence of the Landsat-derived NDVI indices over the year according to the following equation:

$$NDVI_{October} - NDVI_{March} = NDVI_{minus} \quad (1)$$

$NDVI_{minus}$ is an indication of how variable the productivity of a particular pixel is over the year. For example, an urban development or a forest has a relatively stable signal while an agricultural site as an erratic signal. This information is combined with the actual estimates of NDVI to enable us to discern the three relevant land cover classes without having to tackle the issue of defining consistent land cover classes. Developed areas were land segments with highly persistent (continuous pixels with spectral homogeneity), but relatively low magnitude NDVI values. Forest areas were land segments highly persistent with relatively high NDVI values. Agricultural areas included any and all land segments where both the persistence and relative magnitude of the NDVI values varied widely, including cropland and open fields. No less than three specific agricultural land cover classes were detected, but for the scope of this study, all were aggregated into a single class. Finally, derived land cover products were spatially resampled to 500 meters using the *majority* method.

This study made extensive use of the Moderate Resolution Imaging Spectro-radiometer (MODIS) instruments because of the wide systemic geographic coverage, relatively high temporal resolution, and long record length. Utilized products include the 8-day LST 1-km product (MOD11A2) and the 16-day NDVI 250 m product (MOD13Q1). The 500-m MODIS imagery pixel centroids were used as the individual units of observation as well as for sampling LST and NDVI data. The sampling extent was generated by converting the MODIS land cover product raster data into point-based centroids, where each centroid point retains the respective land cover types. Each centroid was sampled against all LST and NDVI layers and spatially resampled to match the 500-meter resolution of the land cover product using the cubic convolution algorithm. The extent was aimed at capturing LST and NDVI variation over time in Kathmandu and adjacent areas within the valley. The points also covered a wide range of geographic conditions and elevation heights.

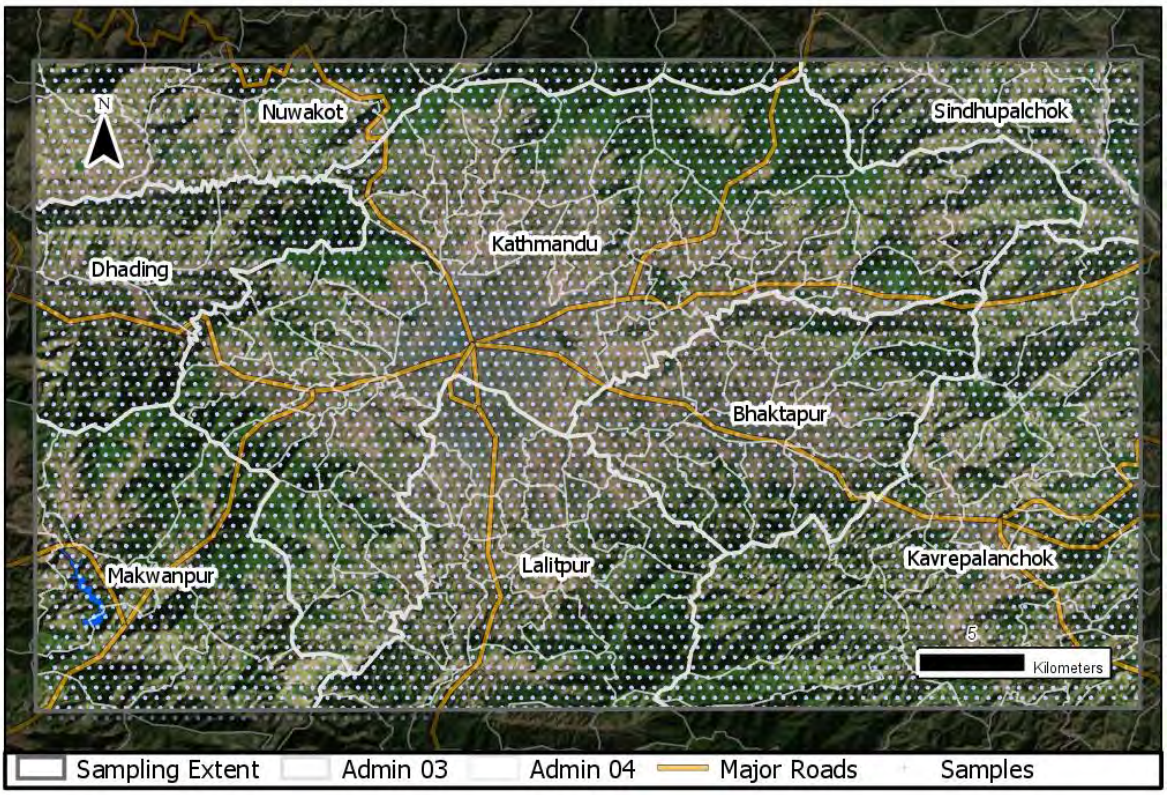

Figure 2: Sampling extent in the study area. MODIS-500-meter centroid observation units (N = 6029)

Sampling was conducted at the pixel level to quantify the distribution of change in LST and NDVI values in a spatially explicit manner not typically captured when aggregating values according to classifications or administrative zones. Pixel-based sampling and calculations on each 8-day LST image layer (N=892) and coincident 16-day NDVI image layer (N=451) were implemented using R and resulted in time series database tables covering the period 2000 to 2018 for each sample location (N=6269). Two simple statistical methods were employed for covering the objectives regarding a) potential change over time and b) the degree to which changes in LST and NDVI are related. For evaluating change over time (magnitude and significance), the simple least-squares-regression model was specified as:

$$Y = C + M\beta m + \varepsilon \qquad (2)$$

where M is the length of time of each location's (m) LST or NDVI value (Y); β is the slope, which equals the increase in Y per time step in M; C is the y-intercept constant; and ε is the error. The generated β coefficients described the approximate mean increase in LST and NDVI over time and any potentially significant change was based on p-values ($p < 0.05$). This analysis was applied to all of the pixels separately for all dates from 2000 to 2018. Each pixel time series was grouped according to the 2018 land cover sampled for that location and by the type of land cover change experienced between 2000 and 2018 to understand how NDVIs and LSTs may be interacting differently across the types. Lastly, the degree of associations between changes in

NDVI and LST was evaluated using the Pearson Correlation (PC) value. All data summaries, figures, and hypotheses were developed using R and a suite of extended packages (R Core Team, 2013).

3. Results and Discussion

3.1. Change in Land Cover Distributions 2000 to 2018

Land cover classification maps developed for the year 2000 and 2018 show a dynamic and changing landscape, including a large overall increase in developed areas of 25%, particularly in the areas adjacent to pre-existing development and largely replacing land previously used for agriculture. Figure 3 highlights the spatial distributions of land cover, including a forestland cover loss of 15% and a small increase (3%) in agricultural land compared to 2000 levels. Table 1 summarizes changes over time by the administrative regions; Kathmandu, Bhaktapur, and Lalitpur had the most substantial increases in overall development at 42%, 123%, and 56%, respectively.

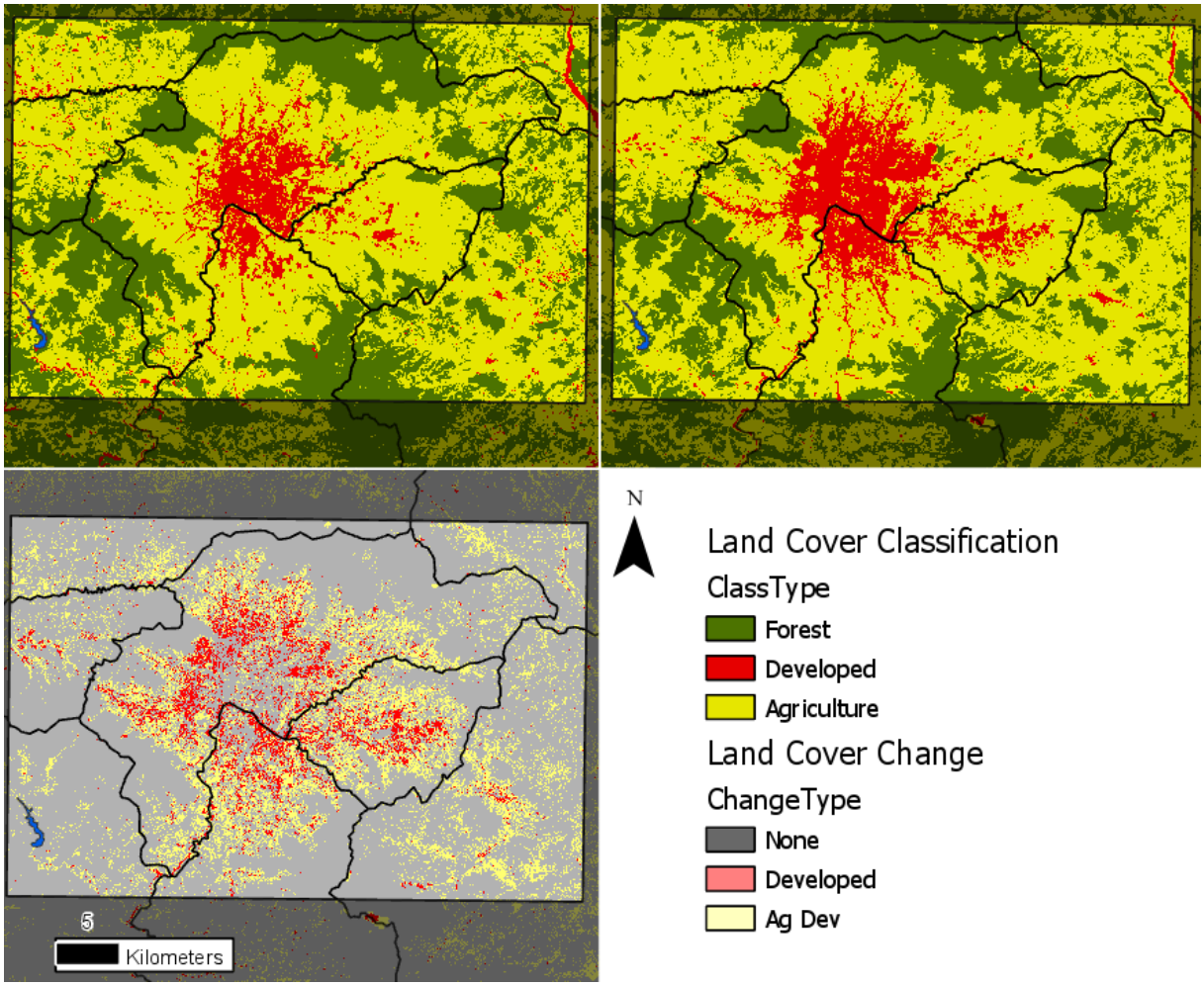

Figure 3: Land cover classifications highlighting the distribution of land cover types for the year 2000 (top left), the year 2018 (top right), and the type of change experienced during that period (bottom left).

Table 1: Land Cover (2000 and 2018) and land Cover Change Over time by Districts.

	2000			2018			Change %			
Name	***Forest***	***Dev***	***Ag***	***Forest***	***Dev***	***Ag***	***Forest***	***Dev***	***Ag***	***Name***
Kathmandu	132.9	57.2	224.0	115.0	81.5	213.5	-13.5	42.4	-4.7	Kathmandu
Lalitpur	44.9	17.1	86.4	34.4	26.5	86.2	-23.4	55.5	-0.2	Lalitpur
Kavrepalanchok	97.2	9.1	147.5	81.4	3.6	167.1	-16.3	-60.6	13.3	Kavrepalanchok
Bhaktapur	23.9	8.7	90.2	18.5	19.4	84.8	-22.3	123.4	-6.0	Bhaktapur
Makwanpur	71.2	5.6	54.6	60.8	1.4	63.6	-14.7	-75.7	16.5	Makwanpur
Nuwakot	40.8	4.9	57.3	37.5	0.9	63.2	-8.1	-80.8	10.3	Nuwakot
Dhading	33.0	4.0	55.1	29.7	2.2	59.8	-9.8	-43.7	8.6	Dhading
Sindhupalchok	24.1	3.0	39.7	20.4	1.9	44.3	-15.5	-38.9	11.7	Sindhupalchok
totals (sq. km)	468	109	755	398	137	783	-15.0	25.5	3.7	***totals (%)***

3.2. Distribution of Land Surface Temperatures of Kathmandu

One of the objectives of the research was to study the distribution of mean LSTs from 2000-2018 in the Kathmandu Valley. These results validated several important findings: A) MODIS MOD11A2 500-m pixel imagery (Figure 4) showed that the daytime mean LSTs in Kathmandu Valley was higher than the surrounding area; B) Kathmandu is the most urbanized part of the valley; therefore, it has more developed areas compared to its surroundings, which may be why the temperature is high; and C) the highest temperature in Kathmandu Valley was in the developed land among the three major types of land covers i.e. forest, agriculture, and developed land. It is clear that LST variation is largely driven by the type of and cover present.

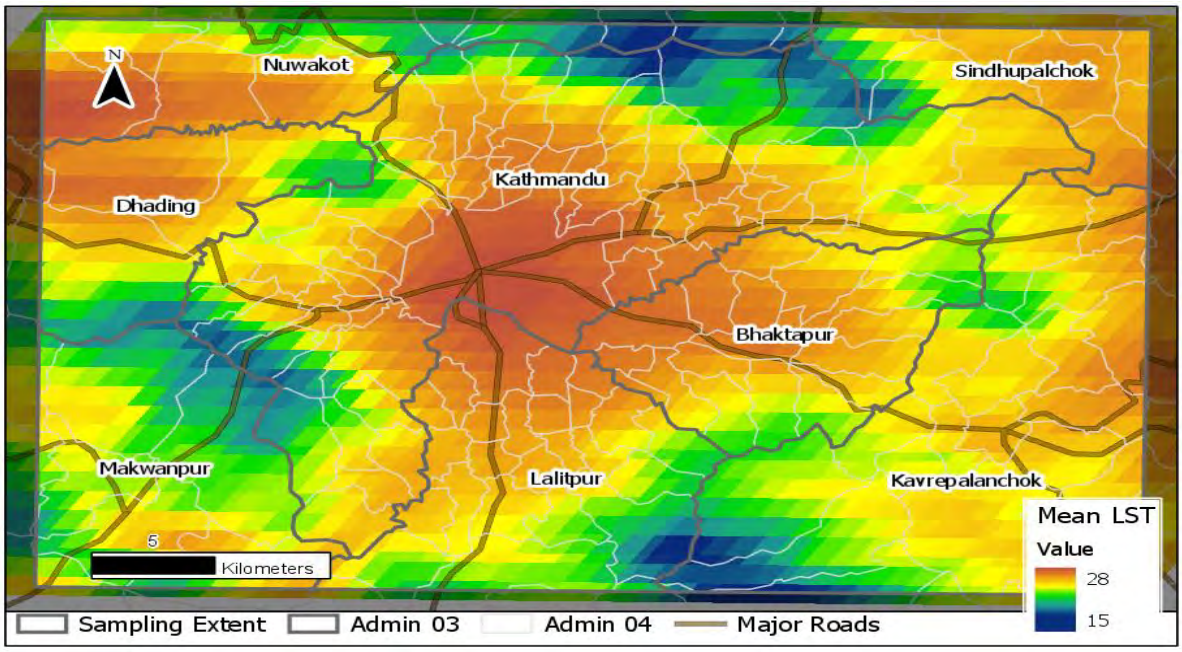

Figure 4: Mean daytime surface temperature distribution for Kathmandu during the period 2000 to 2018, driven largely by land cover such as, the heavily developed areas in central Kathmandu, and elevation.

The variation in LSTs across the various land cover classes is evident as well. Forested land areas, as expected, are the coolest land cover, followed by agricultural lands and developed areas with mean LSTs of 20.5, 23.2, and 25.3, respectively. The difference between the forest LSTs versus those of developed and agricultural lands approximates an UHI potential of 5°C. The newly developed region with the highest temperature is in the west of Kathmandu, where areas of new settlement have been expanding and large areas of forestland are being converted into agricultural land and agricultural land is being converted into urban areas (Ishtiaque et al., 2017; Thapa and Murayama, 2009; Thapa and Murayama, 2012). The center of the Kathmandu Valley is also the most populated region of the valley. However, the population growth is very high in surrounding semi-urban areas (Ishtiaque et. al., 2017). The future trend of the surface temperature is projectable based on the trends of population changes in the Kathmandu Valley. It is more likely that the current temperature of the core city is likely to be reflected in the temperature of the surrounding semi-urban areas of Kathmandu in the future if this trend continues.

3.3. Change in LST and NDVI over time

The LST change over time from 2000–2018 was calculated for each pixel throughout the study area using the simple linear model described in Eq. (1), where the generated β coefficient acts as an estimate for the increase in LST values per each time step from 2000-2018 for the month and highlights each area where LSTs have significantly increased or decreased ($p < 0.05$). In Figure 5, areas colored red represent a relative annual increase of 0°C to 2°C and areas colored blue represents an annual decrease of 0.0°C to 2.5°C. Pixels with statistically significant changes are denoted with black stars as these are the areas with a large magnitude change over time relative to the observed variation in values throughout the record length.

Figure 5 shows that the temperature changed significantly in areas outside the core of Kathmandu City and in those areas where new urban and semi-urban areas are expanding. For example, in the northeast portion of the image, a large clustering of pixels indicates significant changes in temperature; however, these are confined to a small location and not widespread. There are several areas within Kathmandu City that had significant increases in LSTs, although they were relatively small compared to peripheral areas. Overall, the LSTs changed significantly outside the urban Kathmandu Valley.

The NDVI change from 2000-2018 was also calculated for each pixel throughout the study area using the simple linear model described in Eq. (1), where the generated β coefficient acts as an estimate for the increase in NDVI values per each time step. The change in NDVI from 2000-2018 displayed in Figure 6 highlights substantially more areas in which NDVI values increased or decreased significantly, compared to LSTs. Large decreases were evident, especially just north of the administrative areas of the Kathmandu and Bhaktapur districts. In contrast, many peripheral areas experienced significant increases in NDVI values,

especially in the northwest and south central portion of the delineated study area. In each case, these findings were expected based on previous reports (Ishtiaque et al., 2017); much of it was due to increasingly intensive agriculture practices.

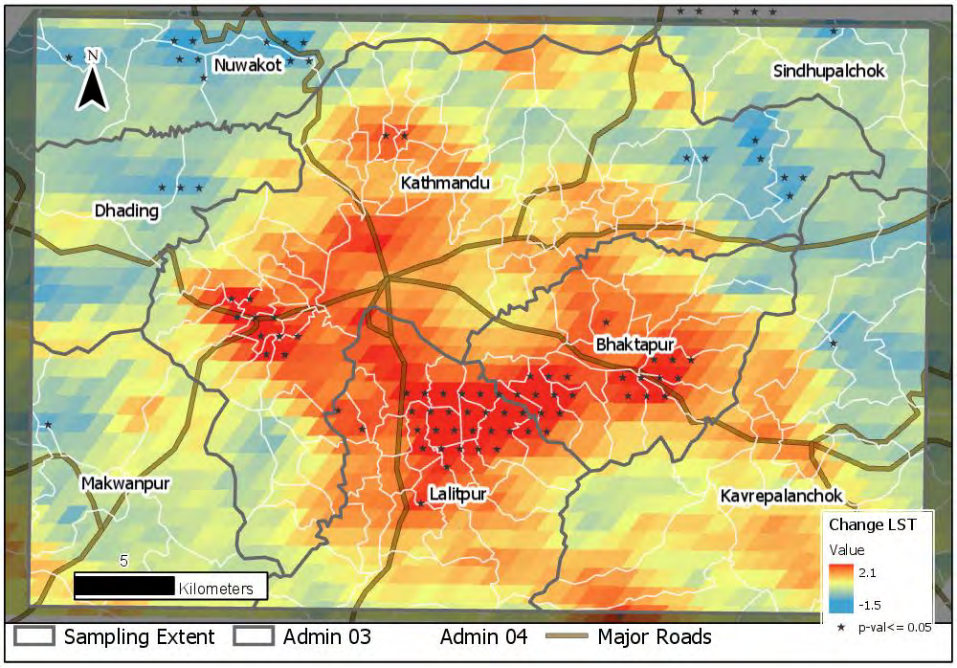

Figure 5: Distribution of estimates of the change in mean daytime land surface temperatures for Kathmandu during the period 2000 to 2018. Statistically significant changes in LST are highlighted with stars (p-value = < 0.05).

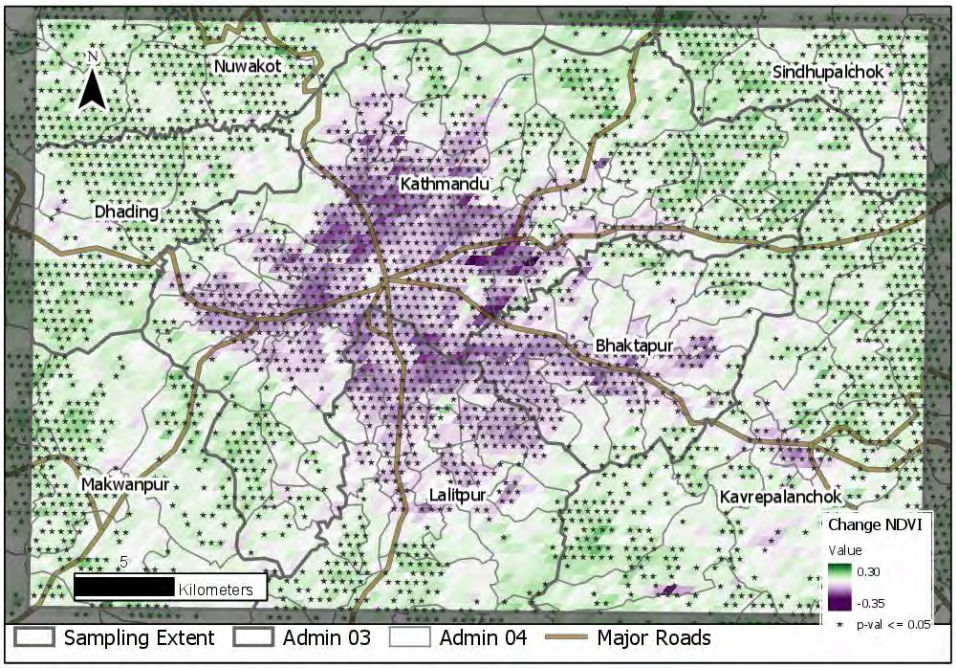

Figure 6: Distribution of estimates of the change in NDVI values for Kathmandu during the period 2000 to 2018. Statistically significant changes in NDVI are highlighted with stars (p-value = < 0.05).

PC coefficients were used to evaluate the linearity of the relationship between NDVI and LST values across all land cover types, resulting in a strong negative association of -0.65 as in Figure 7. In contrast, integration of LST and NDVI change values over time into an ordinary-least-squares (OLS) regression model indicated the predictive power of NDVI only accounted for approximately 45% of the overall variation in LSTs change over time. PC coefficients and OLS models were also applied to the NDVI and LST change values while sub-setting the global data by each land cover type (agriculture, developed, and forests). In the case of agriculture lands, the association between NDVI and LST was more linear (PC = -0.65) and slightly more useful for predictions (~47%). Forested land areas and those with high development levels had a less linear relationship between NDVI and LSTs (-0.3 and -0.22, respectively) and were considerably less useful for predictions (~25%, each).

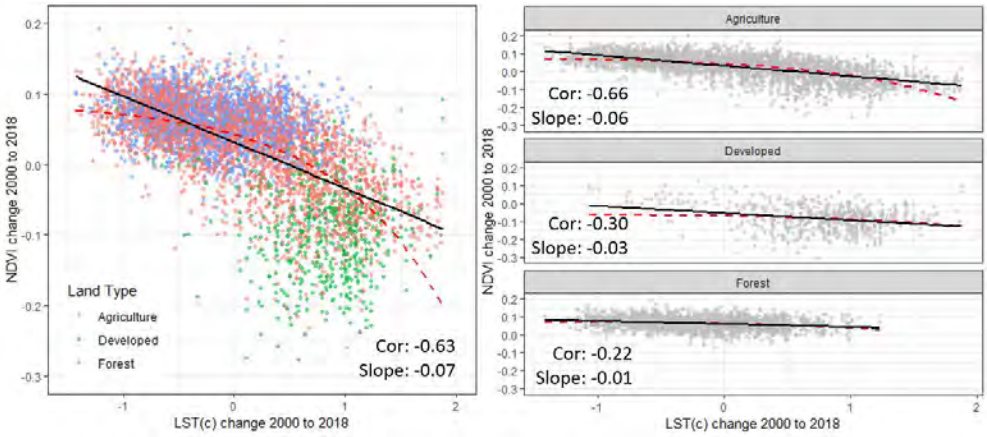

Figure 7: Least-squares-regression models to highlight the relationship between change in land surface temperature (x-axis) and temporally consistent changes in NDVI (y-axis) from 2000 to 2018 globally (left) and specifically for agriculture, developed, and forested land covers (right).

This lack of correlation and predictive power was surprising since NDVI has been highly correlated with LST (Grover and Singh, 2015; Liu et al., 2015) without reporting the decoupling of the relationship for different physical settings. This distribution pattern does not show the expected interrelationship between these parameters; thus, the findings of the current research contrast with previous findings in terms of the coupling between significant change in LSTs and NDVI and the spatial distribution of the LST and NDVI. However, the results support the results of recent research conducted in cities in similar stages of development. Cui et al. (2016) found that UHIs show global heterogeneity for several reasons, including the location's geography and socioeconomic conditions. The research also showed that socioeconomic factors and population dynamics play important roles in determining UHI in developing countries, whereas gross domestic product (GDP) plays a major role in UHI formation and its effects in developed countries. This is because the impact of socioeconomic factors such as population and GDP on the UHI are greater during early stages of the urban

development process has not been linear and is complex to model for the type of analysis presented here. Specifically, general population characteristics are the main impact factor in land cover change and consequent development of increased surface UHI intensity in rapidly developing urban areas, such as in parts of China, whereas nationally aggregated GDP variation was the main impact factor in a developed country like the United States. This difference highlights the need for modelling efforts to incorporate additional information characterizing the spatial dynamics of the population attached to that physical area. These factors should be taken into account when studying UHI and its hazardous effects in developing city such as Kathmandu and its peripheries.

4. Conclusions

This study evaluated drivers of UHIs in Kathmandu using Landsat and MODIS satellite imagery and analyzed the spatial distribution of LST and NDVI in the Kathmandu Valley. The city's core had the highest temperature although the change in temperature was more significant in newly developing urban and semi-urban areas. The development of new urban and semi-urban centers will increase the temperature of the region further and has potential to expand health risks among the urban population and ecosystems of the Kathmandu Valley in the future.

NDVI values also changed significantly in the Kathmandu Valley's central core and outlying areas. The magnitude of change was high in the surrounding areas compared to the valley's core. This suggests that the greenery inside the valley decreased significantly over the past two decades and the removal of vegetation is expanding towards the outer, newly developed semi-urban areas. These newly developing semi-urban areas are likely to become new urban centers that may have many of the same characteristics as the valley's core.

The spatial relation of change in LST and the NDVI was not always spatially coincident, but was statistically significant. Additional research is needed to study drivers of the UHI from other perspectives in addition to land cover and vegetation changes. NDVI data has validated UHI in several big cities (Grover and Singh, 2015; Liu et al., 2015); however, this is not true in the case of Kathmandu. Cui et al. (2016) found that geography and socioeconomic variations play important roles in determining UHI. They also found that population may also have an important role in the UHI phenomenon during the early stages of urbanization. Our findings are consistent with this finding, particularly with respect to Kathmandu in the developing phase. More studies combining NDVI, population, and socioeconomic attributes are needed to understand coupled effects in UHI of Kathmandu Valley.

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References

Aksha S. K, Juran L., Resler L. M. 2018. Spatial and temporal analysis of natural hazard mortality in Nepal. Environmental Hazzards 17(2): 163-179.

Azevedo, J., Chapman, L., and Muller, C., 2016. Quantifying the daytime and night-time urban heat island in Birmingham, UK: A comparison of satellite derived land surface temperature and high resolution air temperature observations, Remote Sens, 8. doi:10.3390/rs8020153.

Bakrania, S., 2015. Urbanization and urban growth in Nepal, GRDC Helpdesk Research Report 1294, Birmingham, UK: GSDRC, University of Birmingham.

Chitrakar, R. M., Baker D. C., and Guaralda, M., 2016. Urban growth and development of contemporary neighborhood public space in Kathmandu Valley, Nepal. Habitat Int., 53, 30-38, doi:10.1016/j.habitatint.2015.11.006.

Cui, Y., Xu, X., Dong, J., and Qin, Y., 2016. Influence of urbanization factors on surface urban heat island intensity: A comparison of countries at different developmental phases. Sustainability, 8. doi:10.3390/su8080706.

Didan, K., 2015. MOD13Q1 MODIS/Terra Vegetation Indices 16 Day L3 Global 250 m SIN Grid V006, NASA EOSDIS Land Processes DAAC. https://doi.org/10.5067/modis/mod13Q1.006.

Grover A., and Singh, R. B., 2015. Analysis of urban heat island (UHI) in relation to normalized difference vegetation index (NDVI): A comparative study of Delhi and Mumbai, Environments, 2 (2), 125-138, doi:10.3390/environments2020125.

Haack, B. N., and Khatiwada, G., 2007. Rice and bricks: Environmental issues and mapping of the unusual crop rotation pattern in the Kathmandu Valley, Nepal, Environ. Manage. 39, 774-782, doi:10.1007/s00267-006-0167-0.

Ishtiaque A, Shrestha M., and Chhetri N., 2017. Rapid urban growth in the Kathmandu Valley Nepal: Monitoring land use land cover dynamics of a Himalayan City with Landsat Imageries, Environments, 4 (72). http://dx.doi.org/10.3390/environments4040072

Jin, M., Dickinson, R. E., and Zhang, D., 2005. The footprint of urban areas on global climate as characterized by MODIS, J Climate, 18, 1551-1565, doi:10.1175/jcli3334.1.

Lavaysse, C., Cammalleri, C., Dosio, A., Schrier, G. V.D., Toreti, A., and Vogt, J., 2018. Towards a monitoring system of temperature extremes in Europe. Nat. Hazards Earth Syst. Sci. 18, 91-104.

Li, J.J.; Wang, X.R.; Wang, X.J.; Ma, W.C.; Zhang, H., 2009. Remote sensing evaluation of urban heat island and its spatial pattern of the Shanghai metropolitan area, China. Ecol. Complex, 6, 413-420. https://doi.org/10.1016/j.ecocom.2009.02.002.

Liu, W., Ji, C. Jiang, X., and Zhong, J., 2015. Relationship between NDVI and the urban heat island effect in Beijing area of China, SIPE Proceedings Vol 5884, Remote Sensing and Modeling of Ecosystem for Sustainability II, Editors: Gao and Shaw.

Maharjan, S., and Regmi, R.P., 2014. Grid based temperature and relative humidity distribution map of the Kathmandu Valley, J Inst Sci Technol, 19, 7-13, doi:10.3126/jist.v19i1.13819.

Ministry of Urban Development (MoUD), 2015. National Urban Development Strategy. Ministry of Urban Development, Government of Nepal, available at: http://moud.gov.np/wp-content/uploads/2016/08/NUDS-2015-final-draft.pdf, last accessed 21 February 2017, 2015.

R Core Team. R, 2013. A language and environment for statistical computing, R Foundation for Statistical Computing, Vienna, Austria, available at: http://www.R-project.org/, last accessed 11 October 2017.

Rimal B., Zhang L., Dongjie O., Kunwar R., Zhai, Y., 2017. Monitoring urban growth and the Nepal earthquake 2015 for sustainability of Kathmandu Valley, Nepal, Land 6 (2) 42; doi:10.3390/land6020042. http://www.mdpi.com/2073-445X/6/2/42/htm.

Thapa, R. B., Murayama, Y., and Ale, S., 2008. City profile Kathmandu. Cities, 25, 45-57. doi:10.1016/j.cities.2007.10.001.

Thapa, R. B., and Murayama, Y., 2009. Examining spatiotemporal urbanization patterns in Kathmandu Valley, Nepal: Remote sensing and spatial metrics approaches, Remote Sens., 1, 534-556. doi:10.3390/rs1030534.

Thapa, R. B., and Murayama Y., 2012. Scenario based urban growth allocation in Kathmandu Valley, Nepal, Landscape Urban Plan, 105, 140-148, doi:10.1016/j.landurbplan.2011.12.007.

United Nations, Department of Economic and Social Affairs (UN DESA), 2015. World Urbanization Prospects: The 2014 Revisions, (ST/ESA/SER.A/366), available at: https://esa.un.org/Unpd/Wup/Publications/Files/WUP2014-Report.pdf, last accessed 20 February 2017.

Zakšek, K., and Oštir, K., 2012. Downscaling land surface temperature for urban heat island diurnal cycle analysis. Remote Sens. Environ, 117, 114-124, doi:10.1016/j.rse.2011.05.02.

Land Use Policy

Deer hunters prioritize quality over the cost for leasing hunting site

--Manuscript Draft--

Manuscript Number:	
Article Type:	Full Length Article
Keywords:	Deer Sanctuary, Food Plots, Canopy Cover, Best Worst Choice, Climate Change
Corresponding Author:	Bijesh Mishra Auburn University AUBURN, AL UNITED STATES
First Author:	Bijesh Mishra
Order of Authors:	Bijesh Mishra
	Omkar Joshi
	Dayton Lambert
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Deer hunters prioritize quality over the cost for leasing hunting site

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Highlights

- Deer hunting can drive sustainable management of degraded ecosystem by offsetting management costs.
- We used best-worst choice to elicit conditional and unconditional demands for deer hunting.
- Hunters prioritize the quality of the hunting site over the cost while leasing land for deer hunting.
- Landowners benefit by diversifying their land management objectives.
- Outreach programs are essential for long-term conservation and ecosystem sustainability.

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Abstract

Fire exclusion and climate change have degraded ecosystem services and increased wildfire risks. Active ecosystem management can restore ecosystem benefits and reduce wildfires risks. However, the cost of management is the main barrier. Deer hunting can generate revenue for landowners to sustainably manage their land, restore ecosystem benefits, and increase resilience against changing climate. We elicited deer hunters preference for the hunting site characteristics in maintaining quality deer habitat on a linear utility scale using the best worst choice model. We further estimated deer hunter's willingness to pay to lease hunting sites with various combinations of deer sanctuaries, food plots, canopy covers, and the number of deer observed per visit. We found that deer hunters prioritized quality hunting experience over the cost when making a hunting site lease decision. Deer hunters were willing to pay $4.69 per acre per year to lease hunting sites that provide the opportunity to observe ten deer per visit. Deer hunters undervalued canopy cover and deer sanctuary despite their crucial role in maintaining high-quality deer habitat. The under-valuation of tree canopy cover characteristics and deer sanctuary by deer hunters might benefit landowners in the short-term. However, it could impede long-term ecosystem conservation efforts.

Keywords: Deer Sanctuary, Food Plots, Canopy Cover, Best Worst Choice, Climate Change

JEL Codes: C35, C83, Q23, Q26, and Q57

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1. Introduction

Fire exclusion over the last century along with climate change such as high temperature, drought, and high-speed wind degraded ecosystems, reduced biodiversity, reduced ecosystem services, and increased wildfires risks (Duff & Penman, 2021; Hallgren et al., 2012; Hoff et al., 2018; Kramer et al., 2019; Santi et al., 2013). Actively managing ecosystem by reintroducing prescribed fire, timber harvesting, and forest thinning can restore the degraded ecosystem and ecosystem services (Adhikari, Masters, Adams, et al., 2021; Adhikari, Masters, Mainali, et al., 2021; Baker & Shinneman, 2004; Hallgren et al., 2012). Prescribed fire with forest thinning and timber harvesting can create diverse ecosystems such as grassland, savanna, woodland, and uneven-aged forests (Fig: 1) (Adhikari, Masters, Mainali, et al., 2021; Dey et al., 2017; Feltrin et al., 2016). Active management further can create ecosystems resilient to changing climate, enhanced biodiversity, and reduce wildfire risks (Duff & Penman, 2021; Hallgren et al., 2012; Kramer et al., 2019; Nitschke & Innes, 2008; Santi et al., 2013; Stephens et al., 2020). However, the financial burden and increased management cost are significant obstacles for landowners to actively and sustainably manage their land actively and sustainably (Mishra, Joshi, Chapagain, et al., 2023; Mishra, Joshi, Masters, et al., 2023; Starr et al., 2019). Additional revenue generation from healthy ecosystems could offset the cost of ecosystem management that motivates landowners to manage their land sustainably and actively (Starr et al., 2019). Revenue from leasing land for deer hunting provides an opportunity for landowners to generate income, thus motivating them to actively and sustainably manage their land actively and sustainably. Deer hunting has economic potential to offset the financial burden incurred from the active management of the ecosystem and provide a recreational activities that has social, cultural, traditional, and historical significance to the local people making an attractive recreational activities in North America (Arnett & Southwick, 2015).

Actively managing the ecosystem to improve and maintain the quality of deer habitat has multiple benefits of attracting more deer (Hallgren et al., 2012), offering better hunting experience, and attracting high-quality avid hunters (Hammitt et al., 1989) which, in turn, provide higher revenue to landowners motivating them to further open land for recreational hunting (Mozumder et al., 2007). The sustainability of ecosystem management depends upon the revenue generated through leasing land for deer hunting. Deer hunter's willingness to pay (WTP) to lease land for deer hunting is an indication of demand for recreational hunting sites, and the WTP is landowners' potential revenue from actively managing lands to improve deer habitat. Thus, we estimated deer hunter's WTP to lease actively managed land by targeting deer sanctuary (Murphy et al., 2021), food plots (McBryde, 1995), forest canopy covers (Lebel et al., 2012), and the number of deer observed per visit (Gruntorad et al., 2020; Hammitt et al., 1989) to improve deer

hunting site quality. We also determined the relative preference of these hunting site attributes among deer hunters on a linear utility scale. These attributes of deer hunting sites are becoming increasingly crucial in quality deer management (QDM) (McBryde, 1995; Murphy et al., 2021) but they have not been studied concerning hunter's demand for actively and sustainably managed ecosystem using prescribed fire, thinning, and harvesting. We aim to fulfill this knowledge gap. We show that deer hunters prioritize hunting site quality over the cost when making hunting site leasing decisions, but they under-valued importance of canopy cover in maintaining quality deer habitat. Our result suggests that landowners may benefit by diversifying their land management objectives beside deer hunting to offset the financial burden incurred by active and sustainable management of their land. We further highlighted need for outreach program among deer hunters to educate them about the importance managing deer habitat using habitat management principles for long-term conservation effort and ecosystem sustainability.

Figure 1: Various types of ecosystems created by thinning and followed by varying fire return interval for about 40 years in Forest Habitat Research Area at Pushmataha Wildlife Management Area in Oklahoma, US. The control (top left) stand is an unmanaged stand with low under-story vegetation density and large amount of leaf litter and dead wood. In the top middle picture, pine was harvested (H), hardwood was thinned (T) in 1984 when this stand was established and burned annually during the spring. The under-story vegetation density is high in this stand, but a very small number of large trees because annual burning killed new saplings and favored the rapid growth of annual grasses, herbs and shrubs. The HNT1 stand (bottom middle) which has a greater number of larger trees received the same treatment as HT except hardwoods were not thinned when the research site was established. HT2 (top right) and HT3 (bottom left) were burned every two and three years. These two stands have mix of annual and perennial grasses, herbs, shrubs, and tall trees. The HT4 (bottom right) was burned every four years allowing the stand to develop into closed woodland with moderate understory. In general, annual fire maintained grasslands, two and three years interval fire maintained savanna and open woodlands, and four year fire interval created multi-story uneven aged forest ecosystems (Adhikari, Masters, Adams, et al., 2021; Adhikari, Masters, Mainali, et al., 2021; Adhikari et al., 2022; McKinney et al., 2023; Mishra, Joshi, Masters, et al., 2023). (Pictures: Bijesh Mishra)

Deer hunting is the most popular recreational hunting activity (Hanberry & Faison, 2023; Hewitt, 2015) which has conservation, economic, cultural, traditional, historical, and social benefits in North America (Arnett & Southwick, 2015; Boehm et al., 2023; Grado et al., 2007; Hanberry & Faison, 2023; U.S. Department of the Interior, 2023) . Deer hunters spend about $38 billion with a total economic impact of $90 billion annually throughout the US. In the southeastern U.S., deer hunting generates about 209 thousands jobs, and $2.1 billion in local, state, and federal taxes (Responsive Management, 2022). Deer management further helps in land conservation, fire fuel reduction, and restoration of open savanna and woodland by controlling trees and shrubs densities (Hanberry & Faison, 2023; Responsive Management, 2022).

Deer observed per visit and habitat quality play a crucial role in providing a high-quality hunting experience. Hunting sites with better habitat quality attract more deer (Fulbright & Ortega-Santos, 2013; Yarrow, 2009) and provide better opportunities to observe and hunt deer. The opportunity to observe more deer per visit provides better opportunities for harvest (Miller & Graefe, 2001) which in turn increases probability of hunter success, satisfaction, and continued participation (Gruntorad et al., 2020; Miller & Graefe, 2001). Deer hunter satisfaction with deer management also depends on the successful hunting experience (Miller & Graefe, 2001) which can be improved be providing quality deer habitat and hunting sites. Managing tree canopy cover, installing food plots, and maintaining deer sanctuary are important management activities to improve habitat, increase deer visitation and improve herd quality (Murphy et al., 2021; Pruitt et al., 2023); these are becoming standard practices in QDM (Green & Stowe Jr., 2008; Murphy et al., 2021; Yarrow, 2009).

The forage quality and availability for deer varies with tree canopy cover. Crude protein concentration of deer forage was up to 45.7% greater in forest and woodland compared to savanna but the above-ground net primary production (ANPP) was much greater in savanna (McKinney et al., 2023). High-quality masts such as acorns are produced in well-matured forests with close canopy. In the absence of acorns, deer (*Odocoileus virginianus*) consume fruits from black gum (*Nyssa sylvatica*), black cherries (*Prunus serotina*), and grapes (*Vitis spp.*) before consuming broad-leaved evergreen shrubs (A. Johnson et al., 1995). Closed canopy forest produces extremely low ANPP but higher shade-tolerant woody plants like green brier, poison ivy, and grapes. Medium canopy uneven aged forest and savanna provide high plant diversity and deer forage during limited-forage seasons (McKinney et al., 2023) which is an essential attribute of quality deer habitat (Fulbright & Ortega-Santos, 2013). Open canopy grassland is dominated by forages with high ANPP (Adhikari, Masters, Adams, et al., 2021; McKinney et al., 2023). The long term use of prescribed fire in 1 to 4 years interval after harvesting pine and thinning hardwood thinning at the early phase of stand development produced and maintained quality deer habitats with closed canopy forest, moderate canopy savanna,

and open canopy grassland (Fig: 1) (Adhikari, Masters, Adams, et al., 2021; Adhikari et al., 2022; Masters et al., 1993; McKinney et al., 2023; Mishra, Joshi, Masters, et al., 2023). The variation in nutrient content based on canopy cover suggests that the deer habitat quality also varies based on canopy cover.

Food plots and deer sanctuaries are crucial for successful quality deer management (Fulbright & Ortega-Santos, 2013; Yarrow, 2009) and becoming popular among landowners managing their land for deer hunting (McBryde, 1995; Murphy et al., 2021). Food consumption by deer, their weight, and survival of yearlings increase with the installation of food plots (Keegan et al., 1989; McBryde, 1995; Zaiglin & DeYoung, 1989). Strategic placement of food plots with closed and moderate canopy cover provide food and screening cover for deer (Fulbright & Ortega-Santos, 2013). Food plots can supply forage with balanced and nutritious food which otherwise become deficit in the hunting site (Fulbright & Ortega-Santos, 2013). Sanctuaries are area within a hunting site designed to attract more deer which provide safe hiding places for deer to reduce herd losses. Deer sanctuaries increase management success for landowners (Yarrow, 2009). Despite the huge benefit conferred by sanctuaries in habitat management and maintaining quality deer habitat, deer hunter preferences for hunting sites with deer sanctuaries is poorly understood.

2. Theoretical Foundation

We use Lancaster's consumer theory (Lancaster, 1966) and McFadden's random utility model (RUM) (McFadden, 1974) to model the choice behavior of deer hunters. Lancaster's consumer theory states that a good has multiple characteristics and multiple goods share multiple characteristics. These characteristics generate utility among consumers (Lancaster, 1966; Navrud & Grønvik Bråten, 2007). We designed multiple deer hunting sites using hunting site characteristics and used RUM to model deer hunter's choice behaviors.

Deer hunter willingness to pay (WTP) is the maximum amount of income (m) the hunters, ($i = 1, ..., N$), is willing to relinquish to lease sustainably managed deer hunting site. Let $U_o(x_i, m_i, u_{oi})$ be an initial utility of unmanaged deer hunting site, x_i. The indirect utility of a deer hunter willingness to lease sustainably managed deer hunting site is $U_1(x_i, m_i - t, u_{1i})$, where t is the annual lease fee per acre of sustainably managed deer hunting site. The variables u_{0i} and u_{1i} are random errors in the decision-making process, both, with expected values of zero and constant variances. A hunter is willing to lease the hunting site if the utility of sustainably managed hunting site is greater than the utility of unmanaged hunting site (i.e. $U_0 < U_1$) and unwilling to pay otherwise.

The RUM decomposes the linearly additive indirect utility of an individual i, for selecting site feature j on choice occasion t into systematic and random components.

The utility of unmanaged deer hunting site (U_{0ijt}) is

$$U_{0ijt} = \alpha_{0jt}X_{ijt} + \alpha_{im}m_i + u_{0ijt} \quad (1)$$

where, X_{ijt} includes hunting site characteristics and an alternative specific constant, and β_{0jt} are associated parameters, β_{im} is the marginal utility of income, and u_{ijt} is a stochastic error term.

The indirect utility of deer hunters who are willing to pay to lease sustainably managed deer hunting site is

$$U_{1ijt} = \alpha_{1jt}X_{ijt} + \alpha_{im}(m_i - t_i) + u_{1ijt} \quad (2)$$

The latent change in utility (U^*_{ijt}), WTP for sustainably managed ecosystem, is obtained by subtracting Eq. 1 from Eq. 2 (Train, 2009):

$$U^*_{ijt} = \alpha_{jt}X_{ijt} + \alpha_{im}t_i + u^*_{ijt} \quad (3)$$

where $u^*_{ijt} = u_{1ijt} - u_{0ijt}$ and have an expected value of zero and constant variance.

The WTP is the value that differentiates consumers willing to lease sustainably managed land (Eq. 2) and remain at status quo (Eq. 1). Both consumers are indifferent when the latent utility, U^*_{ijt}, is zero at which t_i is equal to WTP_i (Haab & McConnell, 2002). Equating Eq. 3 to zero, replacing t_i with WTP_i, and solving for WTP_i, we get

$$WTP_i = \frac{\alpha_{jt}X_{ijt}}{\alpha_{im}} \quad (4)$$

The marginal contribution of individual deer hunting site characteristics on WTP can be obtained by partially differentiating Eq. 4 with respect to hunting site characteristics. The marginal WTP of hunting site attributes is

$$\frac{\partial WTP_i}{\partial x_{ijt}} = \frac{\alpha_{jt}}{\alpha_{im}} \quad (5)$$

3. Method

3.1 Best Worst Choice Design

This research used profile case (Case 2) best worst choice (BWC) method which consists of two components: 1) best-worst scaling (BWS), and 2) a discrete choice experiment

(DCE) (Dumbrell et al., 2016; Louviere et al., 2015; Rubino et al., 2018; Soto et al., 2016, 2018). The first BWS part consists of three-column choice set, which asks to select the best and the worst features of the given hunting site. The BWS part of BWC reveals conditional demand of choices conditioned on a given choice profile (Louviere et al., 2015; Potoglou et al., 2011). The second DCE part of BWC consists of deer hunting sites described by a given choice profile and the binary (yes/no) question at the bottom of the choice profile (Louviere et al., 2015). Respondents have the option to reject the profile and choose to remain at status quo by answering "no" to the bottom binary question (Potoglou et al., 2011). The second part facilitate revealing the unconditional demand of respondent which is the same as the traditional DCE with two profiles–hypothetical choice and status quo profiles–at a time (Louviere et al., 2015). We choose the case 2 BWC method to elicit unconditional and conditional demands without additional cost and effort of collecting data (Louviere et al., 2015; Potoglou et al., 2011; Severin et al., 2013) and to reduce cognitive burden by presenting choice profile with one choice set at a time (Flynn et al., 2007; Louviere et al., 2015; Soto et al., 2016). This method provides an additional advantage over traditional DCE by separating attribute impact and level scale values (Flynn et al., 2008; Louviere et al., 2015).

Table 1: Deer habitat characteristics used to design deer hunting sites (choice sets).

Attributes	Descriptions	Levels
Deer Sanctuary and Food Plots (SAFP)	Deer sanctuary is an area within a hunting site designed to attract more deer. This area is secure habitat for deer (Murphy et al., 2021). Food plots are maintained inside deer hunting site to grow forage and attract more deer.	(1) No sanctuary no food plots (NSNFP) (2) Sanctuary without food plots (SNFP) (3) Sanctuary with food plots (SFP)
Canopy Cover (CAN)	How open forest top cover (canopy) is and varies from closed canopy with little understory, moderate, and open canopy with abundant understory and sparse overstory vegetation.	(1) Open (OPEN) (2) Moderate (MOD) (3) Closed (CLS)
Deer (DR)	Total number of deer observed per visit.	(1) 1 Deer (DR1) (2) 6 Deer (DR6) (3) 10 Deer (DR10)
Leasing Fee (LF)	Land leasing fee for hunting deer ($/year/acre)	(1) $ 6 fee (LF6) (2) $10 fee (LF10) (3) $16 fee (LF16)

We selected four attributes and three levels of each attribute (Table 1) to develop choice sets representing individual deer hunting sites (Fig 2). Three attributes–deer

Q: In your opinion, what are the best attribute and the worst attribute of this hunting site?

Best attribute of site (Check only one box)	Hunting site attributes	Worst attribute of site (Check only one box)
☐	Deer sanctuary with food plots	☐
☐	Closed canopy forest	☐
☐	10 deer observed/visit	☐
☐	$16 hunting lease/acre/year	☐

➔ Would you lease this hunting site? ☐ Yes ☐ No

Figure 2: Example choice set presented to respondents in the survey. Respondents were instructed to select a best-worst pair by selecting the best and the worst choices one at a time. Respondents were further instructed to decide whether they would pay given fee to lease the hunting site described by characteristics in the given choice set. Selecting "no" is an indication of respondent's unwilling to lease new hunting site and remain at "status quo" state. In this example, deer sanctuary with food plots and $16 hunting lease/acre/year is selected as the best-worst pair among 12 such possible pairs and chose to lease the hunting site at $16 lease fee/acre/year.

sanctuary and food plots, forest canopy cover, and the number of deer observed per visit–represent hunting site characteristics that are crucial in maintaining quality deer habitat. The fourth attribute, the hunting site lease fee, was used to estimate the monetary value of site characteristics. Three levels of lease fee were decided carefully after reviewing the annual leasing fee for deer hunting sites offered by commercial hunting clubs and private landowners in 2018 in the study region. We used SAS OPTEX procedure (SAS Institute Inc, 2016) to select 18 out of 81 available hunting sites using orthogonal main effect balanced design method and divided into three blocks of survey. Each level appeared twice in a survey.

3.2 Survey Administration

We mailed an eight-page long paper-based survey designed as a booklet with a thick front and back covers, personalized cover letter, and prepaid return envelope. We printed contact and mailing details on the back page of the survey so respondents can return the survey even if a prepaid envelope is lost. We recruited landowners from 50 Oklahoma counties residing roughly east of I-35 (Mishra, Joshi, Chapagain, et al., 2023) who own at least 160 acres (about 65 hectares) of land such that at least one deer hunting site can be managed sustainably. Two rounds of surveys, each, followed by postcards were sent

within two months following Dillman's Tailored survey method (Dillman et al., 2014). A unique numerical code was assigned to each survey to avoid respondent recruitment redundancies. The survey response rate was 20%. We retained landowners who reported they have hunted in the last five years in Oklahoma through the survey. Thus, our respondents are deer hunters and landowners.

Deer hunters from Oklahoma counties east of I-35 were selected because it has a diverse ecosystem composition, structure, and geography. This region includes the Arkansas Valley, cross timbers, central plains, Flint hills, and the Ouachita mountains with post oak (*Quercus stellata*), blackjack oak (*Quercus marilandica*), shortleaf pine (*Pinus echinata*), and hickory (*Carya spp.*) dominant forests (E. Johnson et al., 2010; Joshi et al., 2019). This ecological region is also well known for cross timbers with savannas, woodlands, and forests. The region's diverse ecosystem composition and structure make it easier for hunters to visualize hunting sites presented in the survey. Recruiting experience hunters and familiar choice scenarios eliminate concern of hypothetical bias and provide WTP estimates that reflect the real market value of the activity (Hensher, 2010).

4. Data Analysis

We maintained two separate datasets for BWS and DEC models because they require two different data management processes which are discussed below. We used random parameter logit models with simulated maximum likelihood estimation method using the *mixlogit* module developed by Hole (2007) in Stata 18 for both models. We used Davis-Fletcher-Powell and Newton-Raphson optimization algorithms with 50 burn-in sequences and 1000 Halton draws for the simulation. A Huber-White covariance estimator was used to calculate standard errors (Huber, 1967; StataCorp, 2023).

4.1 Best Worst Scaling of Best Worst Choice

We maintained the BWS dataset assuming deer hunters choose one best-worst pair among all available best-worst pairs which is consistent with the maxdiff paired model of choice decision-making process (Aizaki & Fogarty, 2019; Flynn et al., 2007; Louviere et al., 2015). The selected pair represents the maximum difference in the utility among the utility derived from all available pairs thus, maximizing the total utility from choices available at the time of decision-making (Flynn et al., 2007, 2008; Louviere et al., 2015; Soto et al., 2016, 2018). The distance between attribute levels on the latent scale is proportional to the relative probability of a choosing a given pair (Flynn et al., 2007; Louviere et al., 2015; Marley & Louviere, 2005). There were 4 × (4 - 1) = 12 pairs available in a single choice set (Fig: 2) from which respondent selected a best-worst pair. A binary variable representing the choices is the dependent variable which received 1 for

the selected best-worst pair and 0 otherwise (Aizaki & Fogarty, 2019; Louviere et al., 2015).

We included effect-coded attributes and effect-coded attribute levels as random parameter explanatory variables in the model. In the case of BWS, this can be achieved by creating best and worst dummy variables and subtracting the worst from the respective best dummy variable. Effect coding allows estimation of the effect of all levels in the model; the reference point is internalized in the model, and coefficients are uncorrelated with the intercept (Bech & Gyrd-Hansen, 2005; Lancsar & Savage, 2004). Attributes were coded as 1 or -1 if they appear as best or worst attributes in the best-worst pair and as 0 otherwise. Attribute levels were also coded as 1 or -1 for best and worst levels and 0 otherwise. Following the BWS convention (Aizaki & Fogarty, 2019; Flynn et al., 2007), attribute "deer sanctuary and food plot" was constrained to zero (Lusk & Briggeman, 2009; Soto et al., 2016, 2018). One level from each attribute was eliminated as references in the model. Eliminated levels were "no deer sanctuary no food plots", "open canopy cover", "1 deer observed per visit", and "$6 lease fee per acre". In the case of attribute levels, the coefficient of the omitted level is the negative sum of non-omitted levels within the attribute (Flynn et al., 2007). The coefficients of attributes are called attribute impact and coefficients of levels are called level scale values (Aizaki & Fogarty, 2019; Flynn et al., 2007). The negative sign of an estimated coefficient signifies its relative position in the linear utility scale to the eliminated attribute (Flynn et al., 2007; Soto et al., 2016). The coefficient of effect-coded variables are interpreted as the mean utility of the variable across the population (Flynn et al., 2007; Soto et al., 2018).

The probability of choosing hunting site characters as best level r and worst level r', $r \neq r'$, in the given BWS profile X_{tk} by an individual i was estimated as

$$\begin{aligned} P_{BW}(rr' = 1|\mathbf{X}_{itk}) = \beta_{CAN}CAN_{itk} + \beta_{DR}DR_{itk} + \beta_{LF}LF_{itk} + \\ \lambda_{NSFP}NSFP_{itk} + \lambda_{SFP}SFP_{itk} + \lambda_{MOD}MOD_{itk} + \lambda_{CLS}CLS_{itk} + \\ \lambda_{DR6}DR6_{itk} + \lambda_{DR10}DR10_{itk} + \lambda_{LF10}LF10_{itk} + \lambda_{LF16}LF16_{itk} + \epsilon_{itk} \end{aligned} \quad (6)$$

where the βs are attribute coefficients, λs are coefficients for the attribute levels, and ϵ_i is stochastic error term.

4.2 Discrete Choice Experiment of Best Worst Choice

The binary variable at the bottom of the choice set (Fig: 2) was the dependent variable which was coded as 1 if "yes" was selected and 0 otherwise. "No sanctuary and no food plots", "open canopy cover", and "one deer observed per visit" were selected as reference levels within their respective attributes. All independent variables except "lease fee" were effect coded by subtracting the reference level from the other two levels within

each attributes. Effect coded variables were entered as random parameter explanatory variables in the model. Lease fee (price) was coded as a continuous variable and entered as fixed effect variable in the model. The standard errors for random parameters were estimated using the delta method. An alternative specific constant (ASC), coded as 1 for status quo and 0 otherwise, was included in the model as a fixed effect parameter to capture the hunter's status quo utility (Meyerhoff & Liebe, 2009) of deer hunting site and unobserved heterogeneity of deer hunters. Attribute levels included in the empirical model were coded as 0 for the status quo alternative.

The probability of leasing a hunting site (y_{jt}) given the site profile X_{tj} by an individual i was estimated as

$$P(y_{itj} = 1|X_{itj}) = \gamma_{NSFP}NSFP_{itj} + \gamma_{SFP}SFP_{itj} + \gamma_{MOD}MOD_{itj} + \gamma_{CLS}CLS_{itj} + \gamma_{DR6}DR6_{itj} + \gamma_{DR10}DR10_{itj} + \gamma_{LF}LF_{itj} + \gamma_{ASC}ASC_{itj} + \nu_{itj} \quad (7)$$

where the γs are coefficients of hunting site attributes, and ν_{ijt} is a stochastic error term.

5. Results and Discussion

5.1 Deer Hunter Demographics

Our respondents have hunted in Oklahoma in the last five years. They have hunted for an average of 46.57 years and 50% of them have 50 to 75 years of hunting experience (Table 2). Deer is the primary game for 74% of hunters. The majority of the hunters were White American (81%) or Native American (13%) male (95%) who travel on an average of 11.85 miles one-way to reach their preferred hunting destination. During a hunting trip, they observed an average of 8.31 deer per visit and 50% of the hunters observed 6 deer or less during their visit. In the absence of currently accessible regular deer hunting sites, hunters should travel an average of 33.79 miles–about three times more than their current travel distance–to reach alternative hunting site of similar quality. Twelve percent of deer hunters leased land for deer hunting. The average and median sizes of leased land for hunting were 1733.21 acres and 320 acres.

Table 2: Demographics of Deer Hunters

Demographic Variables	N	Mean	Std. Dev.	Median	Min	Max
Hunting experience (Years)	235	46.57	15.30	50	2	75
Primary game deer (Yes = 1)	233	0.74			0	1
Agricultural Cropland (Acres)	134	196.47	513.36	80	0	5,500
Rangeland (Acres)	224	475.01	529.19	282.50	0	3,000

Forests (Acres)	200	209.56	417.49	100	0	3,500
Land Leased (Yes = 1)[a]	235	0.12		1	0	1
Land Leased (Acres)[b]	38	1,733.21	5,152.33	320	0	30,000
Deer observed per visit	206	8.31	7.83	6	0	50
Travel distance (Miles)[c]	220	11.85	30.43	2	0	300
Alternative site (Miles)[d]	214	33.79	87.33	7.5	0	1,000
Age (Years)	234	63.54	12.07	65	21	92
Race[e]	231	1.49	1.08	1	1	5
White American (1) = 1	231	0.81			0	1
Native American (3) = 1	231	0.13			0	1
Others = 1	231	0.06			0	1
Gender (Female = 1)	227	0.05	0.22	0	0	1
primary job/occupation	228	2.78	2.01	2	1	6
Farmers/ranchers (1) = 1	228	0.48			0	1
Business owners (2) = 1	228	0.10			0	1
Manual labor jobs (3) = 1	228	0.04			0	1
Medical jobs (4) = 1	228	0.04			0	1
Retired (5) = 1	228	0.21			0	1
Other jobs (6) = 1	228	0.13			0	1
Highest education level	233	3.74	1.46		1	6
Less than high school (1) = 1	233	0.01			0	1
High school degree/GED (2) = 1	233	0.25			0	1
Some college education (3) = 1	233	0.21			0	1
Bachelor's degree (4) = 1	233	0.23			0	1
Associate degree (5) = 1	233	0.12			0	1
Graduate degree (6) = 1	233	0.19			0	1
Annual income before tax ($)	228	3.73	2.45	3	0	8
Below $25,000 (1)	228	0.15			0	1
$25,000 to $50,000 (2)	228	0.03			0	1
$50,001 to $75,000 (3)	228	0.13			0	1
$57001 to $100,000 (4)	228	0.21			0	1
$100,001 to $125,000 (5)	228	0.12			0	1
$125,001 to $150,000 (6)	228	0.09			0	1
$150,001 to $200,000 (7)	228	0.10			0	1
Above $200,000 (8)	228	0.07			0	1
Prefer not to answer (0)	228	0.10			0	1

Notes:

a and b = Land leased for hunting.

c = One way travel distance to regular deer hunting site.

d = One way travel distance to alternative hunting site with about the same quality.
e = African American (2), others (4), and more than one races (5) were combined.
(#) = Number (#) assigned to each category in a variable. Eg. Annual income has eight levels as defined by numbers 1 to 8 given to eight income categories.

Their median household income was between $50,001 to $75,000 per year before tax. More than 80% of deer hunters had the highest education below a graduate degree. Deer hunters owned on an average of 209.56 acres of forests, 475.01 acres of rangeland, and 196.47 acres of agricultural croplands. Out of all participating deer hunters, 48% were farmers or ranchers, 10% were business owners, 21% were retired, and 13% held other jobs not stated in the survey. Six percent of the deer hunters were either African American, or others, or more than one races who were collectively categorized as "others" in the Table 2.

5.2 Best Worst Scaling of Best Worst Choice

The likelihood-ratio test for joint significance with the null hypothesis stating all standard deviations are jointly equal to zero (Hole, 2007) was rejected with 99% confidence suggesting a good model fit (Table 3). Based on attribute impact results, "deer observed per visit" was ranked as the best and "lease fee" was ranked as the worst attributes among four deer hunting site characteristics (Fig. 3). Deer hunters preferred to observe more deer at a lower cost. The preference heterogeneity for "number of deer observed per visit" and "lease fee ($) per acres per year" were significant among hunters. The least preferred attribute was the lease fee, which is consistent with previous studies (Mingie et al., 2017b).

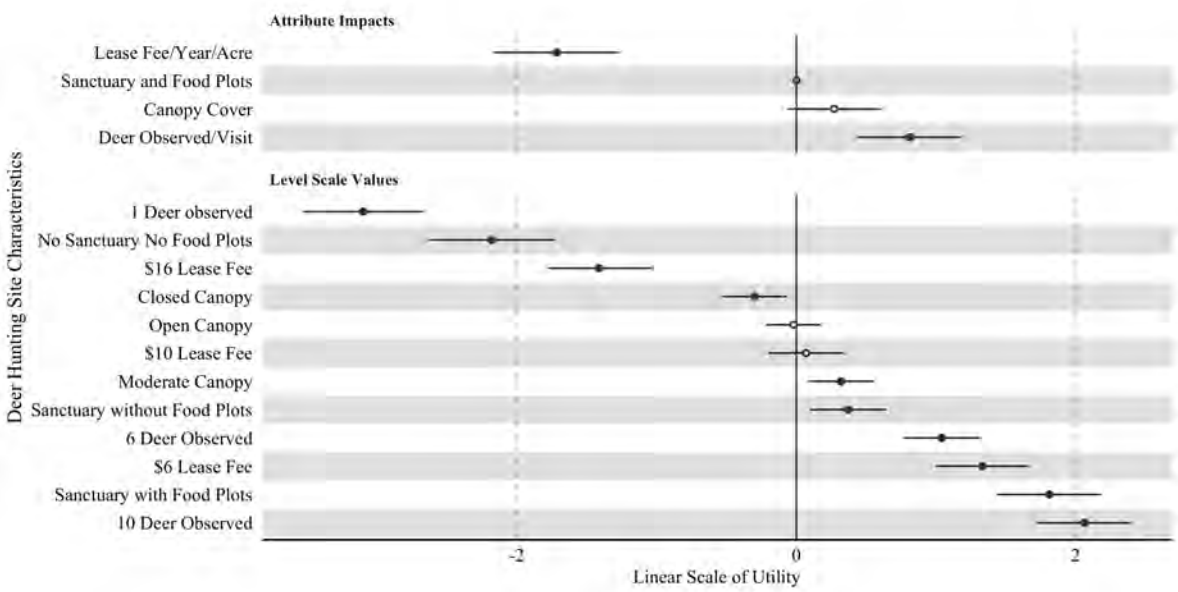

Figure 3: Attribute impacts and level scale values ranking of deer hunting site characteristics based on BWS regression coefficients. This graph shows ascending order of attribute and levels preferences among deer hunters. Statistically significant estimated coefficients for hunting site characteristics at 95% confidence were plotted as solid-filled points and non-significant coefficients were plotted as hollow points.

The higher preference for high-quality low-cost deer hunting sites was further reflected in the deer hunting site characteristics ranking at level scale values results. The hunting site characteristics representing better quality hunting sites such as "10 deer observed per visit" and "deer sanctuary with food plot" were highly ranked compared to "1 deer observed per visit" and "no sanctuary and no food plots". The preference heterogeneity among deer hunters for all attribute levels except for "sanctuary without food plots", three canopy covers, and "$10 lease fee" were statistically significant at 99% level. "Sanctuary without food plots", "moderate canopy", and "closed canopy" were statistically significant at 95% level. Preference heterogeneity among deer hunters for "open canopy" and "$10 lease fee" were statistically non-significant at 90% level.

Comparing relative preferences of twelve attribute levels based on level scale values, "ten deer observed per visit" was the most preferred hunting site characteristic followed by "sanctuary with food plots" and "$6 annual lease fee" (Table 3 and Fig: 3). "One deer observed per visit" was least preferred site characteristic followed by "no deer sanctuary no food plots" and "$16 lease fee". "Sanctuary without food plots", "moderate canopy cover", "$10 lease fee", "open canopy", and "closed canopy" were ranked in the descending order of preferences and fall in the middle of linear utility scale.

Canopy cover related characteristics were ranked as mediocrity preferred site attributes even though they play significant role in maintaining deer habitat quality because security, shelter, and food for deer vary significantly depending upon forest canopy cover (Fulbright & Ortega-Santos, 2013; Masters et al., 1993; McKinney et al., 2023). Previous literature suggested that deer hunters often want to view, pursue, and hunt deer and prefer deer habitats with open and low vegetative cover with high visibility for hunting (Brinkman et al., 2009) which reflect hunter's demand for a high-quality hunting experience (Eliason, 2021; Hammitt et al., 1989). Our findings are consistent with previous literature as deer hunters placed higher preference for moderate and open canopy covers compared to closed canopy cover even though they were statistically non-significant. Our result further suggest that hunting site characteristics such as food plots and sanctuaries that visibly improve the hunting site characteristics were relatively more valuable for deer hunters in the hunting site selection decision making process.

The BWS results show that deer hunters first consider quality of hunting site followed by the cost of leasing the site in their choice decision to lease land for deer hunting. The highest price ($16) to lease deer hunting site was not the least preferred characteristic but site characteristics that have may reduce the quality of their hunting experiences were ranked as two least preferred site characteristics. The hunting site characteristics which

Table 3: Mixed logit model result estimates from BWS of BWC

Site Attributes	Coefficients (Std. Err.)	$p > \|z\|$	95% CI Lower, Upper
Means:			
Attribute Impacts:			
Canopy cover	0.27 (0.17)	0.116	-0.07, 0.61
Deer observed per visit	0.81 (0.19)	0.000	0.43, 1.19
Lease fee	-1.72 (0.23)	0.000	-2.16, -1.27
Deer sanctuary and food plots	0.00 (NA)	NA	NA
Level Scale Values:			
No sanctuary no food plots	-2.18 (0.23)	0.000	-2.62, -1.73
Sanctuary without Food Plots	0.37 (0.14)	0.007	0.10, 0.64
Sanctuary with Food plots	1.81 (0.19)	0.000	1.43, 2.19
Open canopy cover	-0.02 (0.10)	0.844	-0.22, 0.18
Moderate canopy cover	0.32 (0.12)	0.008	0.08, 0.55
Closed canopy cover	-0.30 (0.12)	0.014	-0.53, -0.06
1 deer observed per visit	-3.10 (0.22)	0.000	-3.53, -2.66
6 deer observed per visit	1.04 (0.14)	0.000	0.76, 1.32
10 deer observed per visit	2.06 (0.17)	0.000	1.73, 2.39
$6 lease fee	1.33 (0.17)	0.000	1.00, 1.67
$10 lease fee	0.07 (0.14)	0.600	-0.20, 0.35
$16 lease fee	-1.41 (0.19)	0.000	-1.78, -1.03
Standard Deviations:			
Attribute Impacts:			
Canopy cover	1.49 (0.22)	0.000	1.07, 1.91
Deer observed per visit	2.44 (0.24)	0.000	1.98, 2.90
Lease fee	3.01 (0.40)	0.000	2.23, 3.80
Level Scale Values:			
Sanctuary without food plots	1.31 (0.20)	0.000	0.92, 1.71
Sanctuary with food plots	2.17 (0.21)	0.000	1.76, 2.58
Moderate canopy cover	0.72 (0.18)	0.000	0.37, 1.07
Closed canopy cover	0.82 (0.20)	0.000	0.42, 1.21
6 deer observed per visit	1.01 (0.17)	0.000	0.67, 1.34
10 deer observed per visit	1.68 (0.23)	0.000	1.22, 2.13
$10 lease fee	0.50 (0.26)	0.055	-0.01, 1.02
$16 lease fee	1.84 (0.23)	0.000	1.38, 2.29
Log Likelihood =		-2487.63	
Number of Observations (N) =		16,884	
Wald $\chi^2_{(11)}$ =		356.65	
Prob > χ^2 =		0.000	

Note: Coefficients, Standard error (Std. Err.), and confidence intervals (CIs) for means and standard deviations were rounded to two decimal points.

could provide high quality hunting experiences were chosen as the best two attributes from available choices of hunting site attributes. They further considered costs after the quality in their decision making by ranking "$6 lease fee" as their third best and "$16 lease fee" as third worst hunting site characteristics. Previous literature also reported that the number of deer observed and smaller membership dues have a positive impact on the deer hunting experience (Gruntorad et al., 2020; Hammitt et al., 1989; Mingie et al., 2017a) and hunter's satisfaction (Lebel et al., 2012; Miller & Graefe, 2001).

The results support findings of previous research that hunters carefully select site to increase harvest success (Hammitt et al., 1989). Deer hunters also preferred hunting sites that attract more deer and provide quality hunting experiences. Previous research have recommended hunting site managers to increase deer populations to increase hunting experience quality (Hammitt et al., 1989). Adding hunting site characteristics such as food plots and deer sanctuary which provide food and shelter to deer along with other habitat management interventions to attract more deer can increase probability of observing more deer which further provide better hunting experience (Hammitt et al., 1989; Lebel et al., 2012). Providing high quality hunting experience and better opportunities to observe large number of deer per visit might increase number of avid deer hunters who might be willing to pay high price for quality hunting experience. This will generate higher revenue for landowners while remaining competitive in the market by offering high quality hunting experience at low cost and sustainably manage their land by reinvesting revenue generated through leasing fee.

5.3 Discrete Choice Experiment of Best Worst Choice

The likelihood ratio test of goodness of fit was statistically significant at 99% level suggesting a good model fit and standard deviations were jointly and significantly different than zero (Table 4). The alternative specific constant (ASC) that capture unobserved heterogeneity and status quo alternative were not statistically significant suggesting that the status quo bias effect where respondents disproportionately choose status quo instead of providing alternatives and protest attitude toward new hunting sites were non-existent among the respondents (Meyerhoff & Liebe, 2009; Samuelson & Zeckhauser, 1988). The non-significant status quo suggests that deer hunters derived higher utility from well-managed deer hunting sites that provide better hunting experience compared to that from currently available status quo hunting sites. The utility of price variable (lease) was negative and the preference heterogeneity of price among deer hunters was statistically significant at 99% confidence level. The statistically significant cost suggests that deer hunters considered the cost of leasing deer hunting site while making land leasing decisions. The negative sign of the cost variable (lease fee) was as expected because the utility of leasing hunting sites and their demand decrease with the increase in cost.

Table 4: Mixed logit model result estimates from DCE of BWC

Site Attributes	Coefficients (Std. Err.)	$p > \|z\|$	95% CI Lower, Upper
Means:			
No sanctuary no food plots	-0.13 (0.10)	0.217	-0.32, 0.07
Sanctuary without food plots	-0.09 (0.09)	0.308	-0.27, 0.09
Sanctuary with food plots	0.22 (0.10)	0.033	0.02, 0.42
Open canopy cover	0.06 (0.08)	0.445	-0.09, 0.21
Moderate canopy cover	0.02 (0.08)	0.840	-0.14, 0.17
Closed canopy cover	-0.08 (0.09)	0.405	-0.25, 0.10
1 deer observed per visit	-1.00 (0.28)	0.000	-1.55, -0.44
6 deer observed per visit	0.38 (0.16)	0.013	0.08, 0.69
10 deer observed per visit	0.61 (0.16)	0.000	0.29, 0.93
Lease fee	-0.13 (0.02)	0.000	-0.17, -0.09
ASC	0.08 (0.24)	0.738	-0.39, 0.55
Standard Deviations:			
Sanctuary without food plots	0.02 (0.13)	0.872	-0.20, 0.24
Sanctuary with food plots	0.01 (0.04)	0.836	-0.07, 0.09
Moderate canopy cover	0.03 (0.08)	0.712	-0.12, 0.18
Closed canopy cover	0.05 (0.08)	0.521	-0.10, 0.21
6 deer observed per visit	0.47 (0.28)	0.091	-0.08, 1.02
10 deer observed per visit	0.44 (0.25)	0.076	-0.05, 0.93
Log Likelihood =		-515.38	
Number of Obs. (N) =		2,082	
Wald $\chi^2_{(11)}$ =		71.50	
Prob > χ^2 =		0.000	

Note: Coefficients, Std. Err., and CIs for means and standard deviations were rounded to two decimal points.

Ten deer observed per visit displayed significant preference heterogeneity statistically at 99% confidence level with a positive sign. Six deer observed per visit was also statistically significant at 95% level. One deer observed per visit were significant at 99% level but has negative sign. The result suggest that deer hunters preferred to see larger number of deer during the hunting trip. The magnitude of coefficients also increased with the increase in the number of deer observed per visit. The number of deer observed was also one of the best indicators of quality deer hunting experience (Hammitt et al., 1989). Seeing a game species was considered as the minimum requirement for deer hunters to involve in hunting activities (Gruntorad et al., 2020). The hunting success and the satisfaction with the habitat management were related with number of deer observed during the hunting trips among deer hunters (Knoche & Lupi, 2007; Miller & Graefe,

2001).

The preference heterogeneity of deer hunters for deer habitat with sanctuary and food plots was statistically significant at 95% level and positive. Deer habitat with sanctuary but without food plots and habitat without both were non-significant and negative. The magnitude of the coefficient was stronger but negative when deer sanctuary and food plots were absent. The importance of food plots in maintaining quality deer habitat is well established in the literature (Fulbright & Ortega-Santos, 2013; Yarrow, 2009). Forage produced in food plots often generate greater benefit than food supplements (Pittman, 2019) and was preferred by deer (McQueen, 2020). Food plots were also less expensive to maintain using prescribed fire (Pittman, 2019) and brings additional ecological benefits associated with prescribed burning (Feltrin et al., 2016; Masters et al., 1993; McKinney et al., 2023; Mishra, Joshi, Masters, et al., 2023). Previous research have documented positive effect of food plots in the hunting club dues (Mingie et al., 2017b). Deer sanctuary is relatively a new concept in quality deer management which gaining familiarity among landowners and gradually incorporated in habitat management to improve deer habitat quality (Murphy et al., 2021). Our research made first attempt to quantify the effect of deer sanctuary in deer hunter's decision making for hunting site selection and established its significance in deer hunter's willingness to pay for leasing land for hunting.

The magnitude of coefficients of three forest canopy covers showed that deer hunters prioritized open, moderate, and closed canopy covers in descending order while making hunting site leasing decision. Open canopy has fewer visible obstructions and provides a better opportunity to observe deer (Lebel et al., 2012; Long et al., 2005). The actual shooting to harvest deer happened more often in the sites with good visibility (Lebel et al., 2012) which is provided by open canopy cover compared to moderate and closed canopy covers. Open canopy cover further provides ample space and sunlight for the growth of herbaceous forages (Adhikari, Masters, Mainali, et al., 2021; Long et al., 2005), produce more forbes and browse that are associated with better habitat for deer (Fulbright & Ortega-Santos, 2013). However, the preference heterogeneity for three canopy cover types were non-significant indicting that deer hunters were indifferent of forest canopy cover in their hunting site leasing decision. Even though the chance of harvesting deer is higher in the location with greater forage abundance ($> 50\%$ ground cover), previous research suggest that forage availability was not associated with the harvest success but visibility and accessibility were (Lebel et al., 2012). Deer hunter's familiarity with their preferred hunting site and their hunting experience could play better role in identifying a location with better visibility and accessibility at a familiar site which could explain reason behind non-significance of canopy cover types in hunting site leasing decision.

5.4 Marginal Willingness to Pay from DCE of BWC

Deer hunters were willing to pay a higher lease fee per year per acre for a deer hunting site that has the potential to provide a better quality hunting experience. Deer hunters were willing to pay $4.69 to observe ten deer per visit and $2.95 to observe six deer per visit (Table 5). The WTPs for three levels of deer observed per visit were statistically significant at 99% confidence level. Hunter's marginal WTPs per year per acre was $1.67 for a hunting site with deer sanctuary and food plots, $0.45 for the site with open canopy cover, and $0.12 for the site with moderate canopy cover. Deer sanctuaries with a food plot was statistically significant at a 90% significance level. The WTPs for one deer observed per visit was -$7.64, sanctuaries without food plots was -$0.71, no sanctuary with no food plots was -$0.96, and closed canopy cover was -$0.58 suggesting dis-utility of lower quality hunting site; deer hunters must be compensated by at least the WTP values to motivate them to hunt in sites with given characteristics.

Table 5: Marginal WTPs from DCE of BWC

Site Attributes	Marginal WTP ($) (Std. Err.)	$p > \|z\|$	95% CI Lower, Upper
No sanctuary no food plots	-0.96 (0.81)	0.235	-2.53, 0.62
Sanctuary without food plots	-0.71 (0.71)	0.317	-2.11, 0.69
Sanctuary with food plots	1.67 (0.86)	0.053	-0.02, 3.36
Open canopy cover	0.45 (0.60)	0.453	-0.73, 1.64
Moderate canopy cover	0.12 (0.62)	0.841	-1.09, 1.34
Closed canopy cover	-0.58 (0.72)	0.421	-1.98, 0.83
1 deer observed per visit	-7.64 (2.02)	0.000	-11.59, -3.69
6 deer observed per visit	2.95 (1.12)	0.009	0.75, 5.14
10 deer observed per visit	4.69 (1.17)	0.000	2.41, 6.98

Note: Marginal WTPs, Std. Err., and CIs were rounded to two decimal points.

The WTP values increased with the increase in the perceived quality of deer hunting site. The WTP increased with the increase in the number of deer observed per visit and the dis-utility is very high for one deer observed per visit (Fig: 4). The WTP values were higher for open to moderate canopy covers compared to closed canopy cover. Our findings suggest that landowners benefit by actively managing their land to maintain quality deer habitat in their hunting site by maintaining food plots, deer sanctuary, and increasing deer population so hunters can observe 6 to 10 deer per visit. Landowners can increase their revenue by maintaining food plots and deer sanctuaries to attract more deer which in-turn provides a higher quality hunting experience. Landowners can increase their revenue by introducing other habitat management interventions that increases the number of deer observed per visit in addition to maintaining food plots and deer sanctuaries. The

satisfaction with habitat management among deer hunters and the hunting success is associated with the number of deer observed during the hunting trips (Miller & Graefe, 2001). However, the WTPs for three canopy covers, the site lacking deer sanctuary and/or food plots, and one deer observed per visit were not significantly different than zero. The results also suggest that landowners have the flexibility to maintain diverse canopy covers without compromising deer habitat quality.

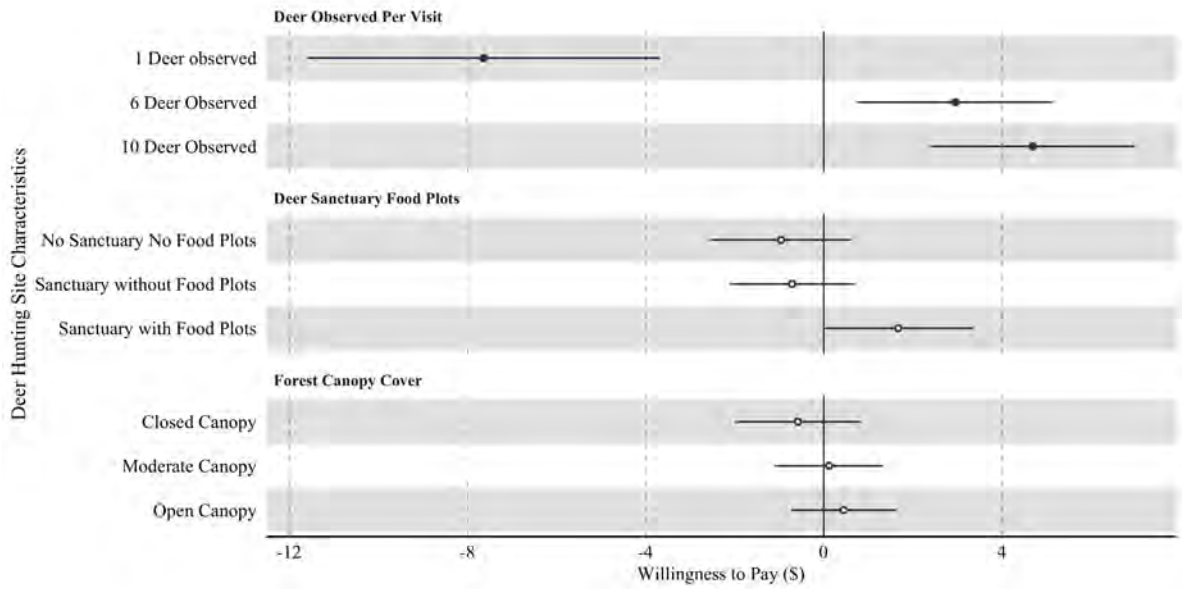

Figure 4: Marginal WTP for deer hunting site characteristics. This chart shows marginal WTP of three levels of all attributes in the increasing order of marginal WTP value. Statistically significant estimated coefficients for hunting site characteristics at 95% confidence were plotted as solid-filled points and non-significant coefficients were plotted as hollow points.

6. Policy Implications

Our findings have a few policy implications. First, deer hunters prioritize quality of deer hunting site over the cost while making leasing decision suggesting that actively managing the land to maintain quality habitat for deer hunting have benefit to landowners. Hunting sites with food plots and deer sanctuary along with other habitat management practices to increase deer population have potential to generate higher revenue which could further motivate landowners to consistently manage their land for a long term ensuring ecosystem sustainability. Actively managing ecosystem for deer hunting, generating continuous revenue stream by leasing hunting site, and reinvesting revenue to actively manage ecosystems could help in building sustainable and resilient ecosystems against changing climate.

Second, deer hunters lack knowledge about the importance of canopy cover in maintaining quality deer habitat because the result suggests that hunters were indifferent to three types of canopy covers. Our respondents were landowners and self-reported deer hunters

implying that landowners lack knowledge about the importance of canopy cover in maintaining quality deer habitat. So, we suggest the need for outreach programs to educate deer hunters and landowners about ecological principles of deer habitat management and importance of incorporating habitat management principles to maintain quality deer habitat. Extension programs are important in fulfilling the knowledge and awareness gaps without which landowners who might be interested in managing their land for deer hunting may ignore maintaining suitable canopy covers. Ignoring canopy cover management in the long run may hamper sustainable land management and conservation effort. For example, the encroachment of invasive species and wildfires may increase additional management cost burden and degrade ecosystem benefits if active management is discontinued after actively managing property for a few years (Joshi et al., 2019; Kaur et al., 2020; Sharma Acharya et al., 2018; Starr et al., 2019).

Third, landowners have flexibility in maintaining canopy cover types they desire based on their land management objectives in the short run because deer hunter's WTP and choice preference for three canopy covers were close to zero and were indifferent to each other. This provides opportunity for landowners to diversify their land management objectives such as cattle, timber, biodiversity, and habitat for multiple wildlife to generate additional revenue throughout the year. Landowners leasing land for hunting have incentives to diversify their land to create a better societal values such as biodiversity conservation, landscape aesthetics, and habitat for endangered species (Lund & Jensen, 2017). Landowners who are interested in managing their land specializing in deer hunting may not have enough incentives to maintain canopy cover that provides excellent quality deer habitat based on deer habitat ecological principles (Fulbright & Ortega-Santos, 2013). While active management is essential for ecosystem sustainability, economic incentive could guide the ecosystem management activities. Thus, balancing economic benefit and ecosystem sustainability might be essential for long term ecosystem conservation and to create resilient ecosystem against changing climate.

7. Conclusion

We proposed deer hunting as an economic activity to generate revenue for the sustainable management of degraded ecosystems due to fire suppression and climate change. We studied the relative importance of deer hunting site characteristics such as sanctuary, food plots, canopy covers, number of deer observed per visit, lease fee, and deer hunters WTP to lease a deer hunting site with these characteristics. These characteristics are being actively incorporated in quality deer management (Murphy et al., 2021). We estimated conditional and unconditional demands of these hunting site characteristics. Deer hunters first prioritize quality hunting experience followed by the cost of leasing hunting sites. We found that deer hunters prefer hunting site characteristics such as food

plots, a deer sanctuary, a larger number of deer observed per visit that have the potential to provide a high-quality deer hunting experience at a lower-cost. So, landowners benefit by improving hunting site by actively and sustainably managing their land to attract avid deer hunters who are willing to pay higher leasing fee for better quality hunting experience. Canopy covers were under-valued by deer hunters who may have had a positive effect on landowner's revenue in the short-term as it provides an opportunity to diversity their land management objectives. But it might have a negative impact on the long-term ecosystem management and ecosystem conservation effort because lack of management may result in a degraded ecosystem, increase in fuel load causing wildfire, and encroachment of invasive species. Our result suggests the need for an outreach program to educate landowners about the sustainable management of ecosystem for deer habitat based on ecological principles while addressing the need of diverse deer hunters and landonwers (Lund & Jensen, 2017). Our result further suggests finding a balance between economic benefit and ecosystem sustainability to create resilient ecosystem against changing climate (Browne et al., 2024).

One limitation of this research was combining deer sanctuary and food plot in a single attribute which limited our ability to tease out their independent effects in the hunting site leasing decision choices. However, our results suggest that landowners benefit by maintaining food plot and deer sanctuaries in their hunting site. Impact of food plots in quality deer habitat management is also well known in deer habitat management literature; as an example, the hedonic price had been estimated concerning hunting club dues (Mingie et al., 2017b). Yet, the relative importance of food plots compared to other crucial hunting site attributes in quality deer management and it's WTP was unclear; we fulfill this important knowledge gap. We further studied other hunting sites attributes mentioned above that are becoming increasingly important in QDM in relation to hunter's conditional and unconditional demands for actively and sustainably managed ecosystems. Deer sanctuary is relatively new concept in deer habitat management which was quantified for the first time in our research. Deer sanctuary being new concept, the general unfamiliarity among deer hunters might have contributed to the undervaluation of attribute level "deer sanctuary without food plot" which could be future research question to explore.

References

Adhikari, A., Masters, R. E., Adams, H., Mainali, K. P., Zou, C. B., Joshi, O., & Will, R. E. (2021). Effects of climate variability and management on shortleaf pine radial growth across a forest-savanna continuum in a 34-year experiment. *Forest Ecology and Management*, *491*, 119125. https://doi.org/10.1016/j.foreco.2021.119125

Adhikari, A., Masters, R. E., Adams, H. D., & Will, R. E. (2022). Radial growth responses of post oak (quercus stellata) to climate variability and management in southeastern oklahoma, usa. *Canadian Journal of Forest Research*, *52*(2), 209–219. https://doi.org/10.1139/cjfr-2021-0077

Adhikari, A., Masters, R. E., Mainali, K. P., Zou, C. B., Joshi, O., & Will, R. E. (2021). Managment and climate vaiability effects on understory productivity of forest and savanna ecosystems in oklahoma, usa. *Ecosphere*, *12*(6), Article e03576. https://doi.org/10.1002/ecs2.3576

Aizaki, H., & Fogarty, J. (2019). An r package and tutorial for case 2 best–worst scaling. *Journal of Choice Modelling*, *32*, Article 100171. https://doi.org/10.1016/j.jocm.2019.100171

Arnett, E. B., & Southwick, R. (2015). Economic and social benefits of hunting in north america. *International Journal of Environmental Studies*, *72*(5), 734–745. https://doi.org/10.1080/00207233.2015.1033944

Baker, W. L., & Shinneman, D. J. (2004). Fire and restoration of pinon–juniper woodlands in the western united states: A review. *Forest Ecology and Management*, *189*(1-3), 1–21. https://doi.org/10.1016/j.foreco.2003.09.006

Bech, M., & Gyrd-Hansen, D. (2005). Effects coding in discrete choice experiments. *Health economics*, *14*(10), 1079–1083. https://doi.org/10.1002/hec.984

Boehm, L., Chakraborti, L., Melstrom, R. T., Piccolo, N., & Reeling, C. (2023). Measuring the economic value of deer hunting: Comparing estimates from survey and harvest check-in data. *Human Dimensions of Wildlife*, 1–17. https://doi.org/10.1080/10871209.2023.2283070

Brinkman, T. J., Chapin, T., Kofinas, G., & Person, D. K. (2009). Linking hunter knowledge with forest change to understand changing deer harvest opportunites in intensively logged landscapes. *Ecology and Society*, *14*(1).

Browne, G. R., Hürlimann, A. C., March, A., Bush, J., Warren-Myers, G., & Moosavi, S. (2024). Better policy to support climate change action in the built environment: A framework to analyse and design a policy portfolio. *Land Use Policy*, *145*, 107268. https://doi.org/10.1016/j.landusepol.2024.107268

Dey, D. C., Kabrick, J. M., & Schweitzer, C. J. (2017). Silviculture to restore oak savannas and woodlands. *Journal of Forestry*, *115*(3), 202–211. https://doi.org/10.5849/jof.15-152

Dillman, D. A., Smyth, J. D., & Christian, L. M. (2014). *Internet, phone, mail, and mixed-mode surveys: The tailored design method* (4th ed.). John Wiley & Sons.

Duff, T. J., & Penman, T. D. (2021). Determining the likelihood of asset destruction during wildfires: Modelling house destruction with fire simulator outputs and local-scale landscape properties. *Safety science*, *139*, 105196. https://doi.org/10.1016/j.ssci.2021.105196

Dumbrell, N. P., Kragt, M. E., & Gibson, F. L. (2016). What carbon farming activities are farmers likely to adopt? a best–worst scaling survey. *Land Use Policy*, *54*, 29–37. https://doi.org/10.1016/j.landusepol.2016.02.002

Eliason, S. L. (2021). A place to hunt: Some observations on access to wildlife resources in the western united states. *Human Dimensions of Wildlife*, *26*(5), 461–471. https://doi.org/10.1080/10871209.2020.1839604

Feltrin, R. P., E., W. R., Meek, C. R., Masters, R. E., Waymire, J., & Wilson, D. S. (2016). Relationship between photosynthetically active radiation and understory productivity across a forest-savanna continuum. *Forest Ecology and Management*, *374*, 51–60. https://doi.org/10.1016/j.foreco.2016.04.049

Flynn, T. N., Louviere, J. J., Peters, T. J., & Coast, J. (2007). Best–worst scaling: What it can do for health care research and how to do it. *Journal of Health Economics*, *26*(1), 171–189. https://doi.org/10.1016/j.jhealeco.2006.04.002

Flynn, T. N., Louviere, J. J., Peters, T. J., & Coast, J. (2008). Estimating preferences for a dermatology consultation using best-worst scaling: Comparison of various methods of analysis. *BMC medical research methodology*, *8*, 1–12. https://doi.org/0.1186/1471-2288-8-76

Fulbright, T. E., & Ortega-Santos, J. A. (2013). *White-tailed deer habitat: Ecology and management on rangelands* (2nd ed.). Texas A&M University Press.

Grado, S. C., Hunt, K. M., & Whiteside, M. W. (2007). Economic impacts of white-tailed deer hunting in mississippi. *Proceedings of the Southeastern Association of Fish and Wildlife Agencies*, *61*, 59–67. Retrieved March 31, 2024, from https://www.mdwfp.com/media/3971/economicimpacts.pdf

Green, D., & Stowe Jr., J. P. (2008). Quality deer management: Ethical and social issues. *Human Dimensions of Wildlife*, 62–71. https://doi.org/10.1080/10871200009359195

Gruntorad, M. P., Lusk, J. J., Vrtiska, M. P., & Chizinski, C. J. (2020). Identifying factors influencing hunter satisfaction across hunting activities in nebraska. *Human Dimensions of Wildlife*, *25*(3), 215–231. https://doi.org/10.1080/10871209.2020.1722866

Haab, T. C., & McConnell, K. E. (2002). *Valuing environmental and natural resources: The econometrics of non-market valuation*. Edward Elgar Publishing.

Hallgren, S. W., DeSantis, R. D., & Burton, J. A. (2012). Fire and vegetation dynamics in the cross timbers forests of south-central north america. In D. C. Dey, M. C.

Stambaugh, S. L. Clark, & C. J. Schweitzer (Eds.), *Proceedings of the 4th fire in eastern oak forests conference* (pp. 52–66). U.S. Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, PA, USA. https://www.fs.usda.gov/research/treesearch/42131

Hammitt, W. E., McDonald, C. D., & P., N. (1989). Wildlife management: Managing the hunt versus the hunting experience. *Environmental Management*, *13*(4), 503–507. https://doi.org/10.1007/BF01867684

Hanberry, B. B., & Faison, E. K. (2023). Re-framing deer herbivory as a natural disturbance regime with ecological and socioeconomic outcomes in the eastern united states. *Science of the Total Environment*, *868*, 161669. https://doi.org/10.1016/j.scitotenv.2023.161669

Hensher, D. A. (2010). Hypothetical bias, choice experiments and willingness to pay. *transportation research part B: methodological*, *44*(6), 735–752. https://doi.org/10.1016/j.trb.2009.12.012

Hewitt, D. G. (2015). Hunters and the conservation and management of white-tailed deer (odocoileus virginianus). *International Journal of Environmental Studies*, *72*(5), 839–849. https://doi.org/10.1080/00207233.2015.1073473

Hoff, D. L., Will, R. E., Zou, C. B., Weir, J. R., Gregory, M. S., & Lillie, N. D. (2018). Estimating increased fuel loading within the cross timbers forest matrix of oklahoma, usa due to an encroaching conifer, juniperus virginiana, using leaf-off satellite imagery. *Forest ecology and management*, *409*, 215–224. https://doi.org/https://doi.org/10.1016/j.foreco.2017.11.003

Hole, A. R. (2007). Fitting mixed logit models by using maximum simulated likelihood. *The Stata Journal*, *7*(3), 388–401. https://doi.org/10.1177/1536867X0700700306

Huber, P. J. (1967). The behavior of maximum likelihood estimates under nonstandard conditions. In L. M. Le Cam & J. Neyman (Eds.), *Proceedings of the fifth berkeley symposium on mathematical statistics and probability* (pp. 221–233, Vol. 1). University of California Press.

Johnson, A., Hale, P. E., Ford, W. M., Wentworth, J. M., French, J. R., Anderson, O. F., & Pullen, G. B. (1995). White-tailed deer foraging in relation to successional stage, overstory type and management of southern appalachian forests. *American Midland Naturalist*, *133*, 18–35. https://doi.org/10.2307/2426344

Johnson, E., Geissler, G., & Murray, D. (2010). *Oklahoma forest resource assessment, 2010: A comprehensive analysis of forest-related conditions, trends, threats and opportunities*. U.S. Department of Agriculture, Forest Service. Retrieved March 24, 2024, from https://ag.ok.gov/wp-content/uploads/2022/05/oklahoma_forest_resource_assessment_final_for_web-compressed.pdf

Joshi, O., Will, R. E., Zou, C. B., & Kharel, G. (2019). Sustaining cross-timbers forest resources: Current knowledge and future research needs. *Sustainability*, *11*(17), 4703. https://doi.org/10.3390/su11174703

Kaur, R., Joshi, O., & Will, R. E. (2020). The ecological and economic determinants of eastern redcedar (juniperus virginiana) encroachment in grassland and forested ecosystems: A case study from oklahoma. *Journal of environmental management*, *254*, 109815. https://doi.org/10.1016/j.jenvman.2019.109815

Keegan, T. W., Johnson, M. K., & Nelson, B. D. (1989). American jointvetch improves summer range for white-tailed deer. *Rangeland Ecology & Management/Journal of Range Management Archives*, *42*(2), 128–134.

Knoche, S., & Lupi, F. (2007). Valuing deer hunting ecosystem services from farm landscapes. *Ecological economics*, *64*(2), 313–320. https://doi.org/10.1016/j.ecolecon.2007.07.023

Kramer, H. A., Mockrin, M. H., Alexandre, P. M., & Radeloff, V. C. (2019). High wildfire damage in interface communities in california. *International journal of wildland fire*, *28*(9), 641–650. https://doi.org/10.1071/WF18108

Lancaster, K. J. (1966). A new approach to consumer theory. *Journal of Political Economy*, *117*(5), 132–157.

Lancsar, E., & Savage, E. (2004). Deriving welfare measures from discrete choice experiments: Inconsistency between current methods and random utility and welfare theory. *Health economics*, *13*(9), 901–907. https://doi.org/10.1002/hec.870

Lebel, F., Dussault, C., Massé, A., & Côté, S. D. (2012). Influence of habitat features and hunter behavior on white-tailed deer harvest. *The Journal of wildlife management*, *76*(7), 1431–1440. https://doi.org/10.1002/jwmg.377

Long, E., Diefenbach, D., Rosenberry, C., Wallingford, B., & Grund, M. (2005). Forest cover influences dispersal distance of white-tailed deer. *Journal of Mannalogy*, *86*(3), 623–629. https://doi.org/10.2111/1551-5028(2005)58<128:LGAWDC>2.0.CO;2

Louviere, J. J., Flynn, T. N., & Marley, A. A. J. (2015). *Best-worst scaling: Theory, methods and applications* (1st ed.). Cambride University Press. https://doi.org/10.1017/CBO9781107337855

Lund, J. F., & Jensen, F. S. (2017). Is recreational hunting important for landscape multi-functionality? evidence from denmark. *Land Use Policy*, *61*, 389–397. https://doi.org/10.1016/j.landusepol.2016.10.048

Lusk, J. L., & Briggeman, B. C. (2009). Food values. *American Journal of Agricultural Economics*, *91*(1), 184–196. https://doi.org/10.1111/j.1467-8276.2008.01175.x

Marley, A. A. J., & Louviere, J. J. (2005). Some probabilistic models of best, worst, and best–worst choices. *Journal of Mathematical Psychology*, *49*, 464–480. https://doi.org/j.jmp.2005.05.003

Masters, R. E., Lochmiller, R. L., & Engle, D. M. (1993). Effect of timber harvest and prescribed fire on white-tailed deer forage production. *Wildlife Society Bulletin (1973-2006)*, *21*(4), 401–411. Retrieved January 20, 2023, from https://www.jstor.org/stable/3783411

McBryde, G. L. (1995). Economics of supplemental feeding and food plots for white-tailed deer. *Wildlife Society Bulletin*, 497–501. Retrieved March 10, 2024, from https://www.jstor.org/stable/3782960

McFadden, D. (1974). Conditional logit analysis of qualititave choice behavior. In P. Zarembka (Ed.), *Frontiers in econometrics.* (pp. 105–142). Academic Press.

McKinney, C. M., Masters, R. E., Adhikari, A., Mishra, B., Joshi, O., Zou, C. B., & Will, R. E. (2023). Forage quantity and protein concentration changes across a forest-savanna gradient with management implications for white-tailed deer. *Forest Ecology and Management*, *538*, 120987. https://doi.org/10.1016/j.foreco.2023.120987

McQueen, R. W. (2020). *Comparing natural vegetation and food plot preference in captive white-tailed deer* [Doctoral dissertation, Sam Houston State University]. Retrieved March 10, 2024, from https://hdl.handle.net/20.500.11875/2753

Meyerhoff, J., & Liebe, U. (2009). Status quo effect in choice experiments: Empirical evidence on attitudes and choice task complexity. *Land economics*, *85*(3), 515–528.

Miller, C. A., & Graefe, A. R. (2001). Effect of harvest success on hunter attitudes toward white-tailed deer management in pennsylvania. *Human Dimensions of Wildlife*, *6*(3), 189–203. https://doi.org/10.1080/108712001753461284

Mingie, J. C., Poudyal, N. C., Bowker, J., Mengak, M. T., & Siry, J. P. (2017a). Big game hunter preferences for hunting club attributes: A choice experiment. *Forest policy and economics*, *78*, 98–106. https://doi.org/10.1016/j.forpol.2017.01.013

Mingie, J. C., Poudyal, N. C., Bowker, J., Mengak, M. T., & Siry, J. P. (2017b). A hedonic analysis of big game hunting club dues in georgia, usa. *Human dimensions of wildlife*, *22*(2), 110–125. https://doi.org/10.1080/10871209.2017.1263767

Mishra, B., Joshi, O., Chapagain, B. P., Lambert, L. H., & Will, R. E. (2023). Intentions of landowners towards active management of ecosystem for deer habitat. *Environmental Management*, *72*(3), 529–539. https://doi.org/10.1007/s00267-023-01810-3

Mishra, B., Joshi, O., Masters, R. E., McKinney, C., Adhikari, A., Zou, C. B., & Will, R. E. (2023). Economic returns and the perceived obstacles to adopting active management in the forest-grassland transition ecoregion in south-central usa. *Journal of Environmental Management*, *343*, 118225. https://doi.org/j.jenvman.2023.118225

Mozumder, P., Meghan Starbuck, C., Berrens, R. P., & Alexander, S. (2007). Lease and fee hunting on private lands in the us: A review of the economic and legal

issues. *Human Dimensions of Wildlife*, *12*(1), 1–14. https://doi.org/10.1080/10871200601107817

Murphy, B., Stewart, D., Demarais, S., & Bales, D. (2021). *Developing successful quality deer management cooperatives* (Report). National Deer Association. GA, USA. Retrieved March 10, 2024, from https://deerassociation.com/wp-content/uploads/2018/09/QDM-Cooperatives-Brochure.pdf

Navrud, S., & Grønvik Bråten, K. (2007). Consumers' preferences for green and brown electricity: A choice modelling approach. *Revue d'économie politique*, *117*(5), 795–811.

Nitschke, C. R., & Innes, J. L. (2008). Integrating climate change into forest management in south-central british columbia: An assessment of landscape vulnerability and development of a climate-smart framework. *Forest Ecology and Management*, *256*(3), 313–327. https://doi.org/10.1016/j.foreco.2008.04.026

Pittman, H. T. (2019). Cost and forage production of food plots, prescribed fire, and roller chopping for northern bobwhite at babcock-webb wildlife management area, florida. *Journal of the Southeastern Association of Fish and Wildlife Agencies*, *6*, 117–122. Retrieved March 10, 2024, from https://seafwa.org/journal/2019/cost-and-forage-production-food-plots-prescribed-fire-and-roller-chopping-northern

Potoglou, D., Burge, P., Flynn, T., Netten, A., Malley, J., Forder, J., & Brazier, J. E. (2011). Best–worst scaling vs. discrete choice experiments: An empirical comparison using social care data. *Social science & medicine*, *72*(10), 1717–1727. https://doi.org/http://dx.doi.org/10.1016/j.socscimed.2011.03.027

Pruitt, H. P., Boley, B. B., D'Angelo, G. J., & McConnell, M. D. (2023). Impact of deer management cooperative implementation on white-tailed deer harvest behaviors. *Wildlife Society Bulletin*, *47*(1), e1409. https://doi.org/10.1002/wsb.1409

Responsive Management. (2022). *Economic, social, and conservation benefits of deer hunting in the southern united states* (Report). Responsive Management and Southeast Deer Partnership. Harrisonburg, VA. Retrieved April 1, 2024, from https://deerassociation.com/wp-content/uploads/2022/09/SDP-Research-Report-2022-04-19.pdf

Rubino, E. C., Pienaar, E. F., & Soto, J. R. (2018). Structuring legal trade in rhino horn to incentivize the participation of south african private landowners. *Ecological Economics*, *154*, 306–316. https://doi.org/10.1016/j.ecolecon.2018.08.012

Samuelson, W., & Zeckhauser, R. (1988). Status quo bias in decision making. *Journal of Risk and Uncertainty*, *1*, 7–59. https://doi.org/10.1016/j.eap.2015.01.003

Santi, P. M., Cannon, S., DeGraff, J., & Shroder, J. (2013). Wildfire and landscape change. *Treatise on Geomorphology*, *13*, 262–287. https://doi.org/10.1016/B978-0-12-818234-5.00017-1

SAS Institute Inc. (2016). *Sas/qc 14.2 user guide*. SAS Institute Inc. Cary, NC, USA. Retrieved March 10, 2024, from https://documentation.sas.com/doc/en/qccdc/14.2/qcug/titlepage.htm

Severin, F., Schmidtke, J., Mühlbacher, A., & Rogowski, W. H. (2013). Eliciting preferences for priority setting in genetic testing: A pilot study comparing best-worst scaling and discrete-choice experiments. *European Journal of Human Genetics*, *21*(11), 1202–1208. https://doi.org/10.1038/ejhg.2013.36

Sharma Acharya, B., Kharel, G., Zou, C. B., Wilcox, B. P., & Halihan, T. (2018). Woody plant encroachment impacts on groundwater recharge: A review. *Water*, *10*(10), Article 1466. https://doi.org/10.3390/w10101466

Soto, J. R., Adams, D. C., & Escobedo, F. J. (2016). Landowner attitudes and willingness to accept compensation from forest carbon offsets: Application of best–worst choice modeling in florida usa. *Forest Policy and Economics*, *63*, 35–42. https://doi.org/10.1016/j.forpol.2015.12.004

Soto, J. R., Escobedo, F. J., Khachatryan, H., & Adams, D. C. (2018). Consumer demand for urban forest ecosystem services and disservices: Examining trade-offs using choice experiments and best-worst scaling. *Ecosystem services*, *29*, 31–39. https://doi.org/10.1016/j.ecoser.2017.11.009

Starr, M., Joshi, O., Will, R. E., & Zou, C. B. (2019). Perceptions regarding active management of the cross-timbers forest resources of oklahoma, texas, and kansas: A swot-anp analysis. *Land Use Policy*, *81*, 523–530. https://doi.org/10.1016/j.landusepol.2018.11.004

StataCorp. (2023). *Stata 18 user's guide*. StataCorp LLC. College Station, TX, Stata Press. Retrieved March 10, 2024, from https://www.stata.com/manuals/u.pdf

Stephens, S. L., Westerling, A. L., Hurteau, M. D., Peery, M. Z., Schultz, C. A., & Thompson, S. (2020). Fire and climate change: Conserving seasonally dry forests is still possible. *Frontiers in Ecology and the Environment*, *18*(6), 354–360. https://doi.org/doi:10.1002/fee.2218

Train, K. (2009). *Discrete choice methods with simulation* (2nd ed.). Cambridge University Press.

U.S. Department of the Interior. (2023). *2022 national survey of fishing, hunting, and wildlife-associated recreation*. US Department of the Interior, Fish; Wildlfe Service. Retrieved March 29, 2024, from https://www.fws.gov/sites/default/files/documents/Final_2022-National-Survey_101223-accessible-single-page.pdf

Yarrow, G. (2009). *White-tailed deer biology and management* (Extension Report). Clemson University. SC, USA, Clemson Extension Service. Retrieved March 10, 2023, from https://deeradvisor.dnr.cornell.edu/sites/default/files/resources/White-tailed%20Deer%20Biology%20%26%20Management.pdf

Zaiglin, R. E., & DeYoung, C. A. (1989). Supplemental feeding of free-ranging deer in south texas. *Texas Journal of Agriculture and Natural Resources*, *3*, 39–41.

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Intentions of Landowners towards Active Management of Ecosystem for Deer Habitat

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Abstract

Active management such as prescribed fire and thinning can restore savanna and prairie ecosystem to maintain a full suite of ecosystem services and create suitable habitat for wildlife species such as white-tailed deer (*Odocoileus virginianus*). Active management comes with the cost of management and acceptance of management tools. The south-central transitional ecoregion of the USA, which otherwise was a mixture of forest, savanna, and tallgrass prairie, is increasing in woody plant dominance due to the exclusion of fire and other anthropogenic factors. Deer hunting is a vital source of revenue generation to offset the landowner's management cost in the region. We studied Oklahoma landowners' perceptions regarding active and sustainable management of forest and rangeland for deer habitat using two established theories of reasoned action and planned behavior as well as expanded theories adding moral norms. We analyzed mailed survey data using structural equation modeling. We found that subjective norms and perceived behavior control significantly affected deer hunting intention when moral norms were introduced into the model. Attitudes independently significantly affected intentions of deer hunting but have negative relations with the intentions. The study suggested that landowners have positive social pressure and were interested in active management but associated financial burden and risk could be shaping negative attitudes.

Keywords Theory of planned behavior · Theory of reasoned action · Moral norms · Prescribed fire · White-tailed deer (*Odocoileus virginianus*)

Introduction

Active management using prescribed fire and thinning are important tools used to sustainably manage forest ecosystems by building resiliency against changing climate (Clark et al. 2007; Joshi et al. 2019a; Starr et al. 2019a). Management costs and potential liabilities from using fire have restricted its application as an active management tool (Starr et al. 2019a). Previous research suggested that well managed, healthy, and resilient forests provide an opportunity to increase revenue to landowners, which in turn increases active management (Joshi et al. 2019b; Starr et al. 2019a). Wildlife management activities, such as deer hunting, provide important economic benefits at the local and regional level in the southern USA (Poudyal et al. 2020) and serve as a vital wildlife management tool (Byrd et al. 2017; Peterson 2004). Deer hunting can be an important motivation for landowners to actively manage ecosystems due to its large economic benefit at the local and state level (Poudyal et al. 2020) in the south-central USA.

Historically, fire was used as a tool to manage ecosystems in the south-central USA. The south-central ecoregion was a dynamic area consisting of upland forests, savanna, and tallgrass prairie lying between eastern forests and western grassland (Hallgren et al. 2012; Joshi et al. 2019b). Fire was mostly excluded after European-American settlement leading to an increase in forest cover with a greater abundance of mesophotic, fire-sensitive hardwoods species and the fire-sensitive eastern redcedar (henceforth, redcedar) (*Juniperus virginiana*) (Joshi et al. 2019b; Starr et al.

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2019a). This transitional nature of the ecoregion coupled with drought and erratic rainfall (Clark et al. 2007; Hallgren et al. 2012) makes it vulnerable to climate change (Füssel 2007). The increase in redcedar has the potential to increase wildfire risk (Hoff et al. 2018b) which further worsens the negative consequences of climate change.

Landowners are supportive of using prescribed fire to actively manage their land (Elmore et al. 2010) yet prescribed fire is not frequently used in south-central USA. Beliefs, past experiences, and social pressure play important roles in shaping attitudes and intentions (Ajzen 2020; Madden et al. 1992) of landowners. The intention of landowners towards active management is not yet well understood in this region. Thus, this paper addresses the question of how landowners' beliefs, attitudes, norms, and intentions for the active management of forests and rangeland for deer habitat management are interrelated. Deer hunting is an important cultural tradition often transferred from generation to generation (Byrd et al. 2017; Demarais 1992; Lovell et al. 2004; Mann 2002) in the US South. In addition to harvesting deer for meat (Byrd et al. 2017; Hrubes et al. 2001) deer hunting also provides psychological (Hrubes et al. 2001), social (Byrd et al. 2017; Hrubes et al. 2001), emotional, mental, and physical (Hrubes et al. 2001) benefits to the hunters.

The behavioral intentions of landowners towards active management were studied using the theory of reasoned action (TRA) and the theory of planned behavior (TPB). Both theories describe how human intentions were shaped based on their belief, norms, and past actions (Ajzen 2020). These two theories are widely used in the study of deer hunting (Daigle et al. 2010), willingness to pay (Lopez-Mosquera et al. 2014), and several other subjects summarized by (Ajzen 1991, 2011). No previous studies to the best of our knowledge used TRA and TPB to study landowners' intentions towards active management of forest and rangeland for deer habitat management and expanded these theories by including moral norms.

This research contributes to existing knowledge in three ways. First, this research studied landowners' intentions of adopting active deer habitat management tools that potentially result in increased revenue from hunting. Second, this is the first scholarly effort that used TRA and TPB to analyze inter-relationships between values, norms, attitudes, and behavioral intentions in the grassland-forestland tension zone—a distinct ecoregion having a cultural significance in the United States. Third, following previous work (Lopez-Mosquera et al. 2014), we further the scope of TRA and TPB by adding moral norms into both theories as suggested by Ajzen (1991). This paper, thus, tested four models—two theories with and two without moral norms— to study intentions towards active management of forest and rangeland for deer habitat management. Past researchers highlighted the importance of improvement, refinement, and modifications (Lopez-Mosquera et al. 2014; Miller 2017) of these theories by adding new predictors, testing concepts and models, and merging theories with additional attributes (Miller 2017). Moral norms affect subjective norms and the perceived behavior control of an individual (Heidari et al. 2018; Lopez-Mosquera et al. 2014).

Methods

Theoretical framework: theory of reasoned action (TRA) and theory of planned behavior (TPB)

The TRA proposes that human intention is an immediate precursor to action. The action originates from a belief that performing an activity leads to the intended outcome (Madden et al. 1992), assuming the action is under the volitional control of an individual. The theory, however, does not account for an action that the individual intends to perform but is not under their actual control (i.e., volitional control) (Ajzen 2002). This limitation involving volitional control is addressed in TPB by adding perceived behavioral control as one of the factors affecting the behavioral intention of an individual (Fishbein and Ajzen 1975; Madden et al. 1992; Rossi and Armstrong 1999). TPB, thus, can be understood as the addition of perceived behavioral control to TRA. TPB reduces to TRA when the behavior is under volitional control (Ajzen 2020). The theoretical models (Fig. 1) for this paper were adopted from Ajzen (1991) and Madden et al. (1992).

The TPB assumes that a belief towards an action shapes a person's attitude and norms. Attitude and norms further shape intentions toward the action. Positive beliefs, attitudes, norms, and intentions toward an action motivate an individual to perform given action (Ajzen 1991, 2002, 2011). The beliefs can be categorized into behavioral beliefs, normative beliefs, and control beliefs. Behavioral beliefs originate from the experience of an individual while performing an action which shapes a person's attitude towards action. Normative beliefs originate from social standards, values, norms, and pressure which shape the subjective norms of an individual. The control beliefs shape perceived behavioral control which is a perception of an individual that action is under the volitional control of the individual (Ajzen 2002). This research was designed assuming that landowners used their beliefs to form attitudes, subjective norms, perceived behavior, and intentions while responding to respective survey questions.

Survey Design and Administration

The mailed survey was conducted following the tailored design method suggested by Dillman et al. (2014). The study area represented the portion of the forest-grassland

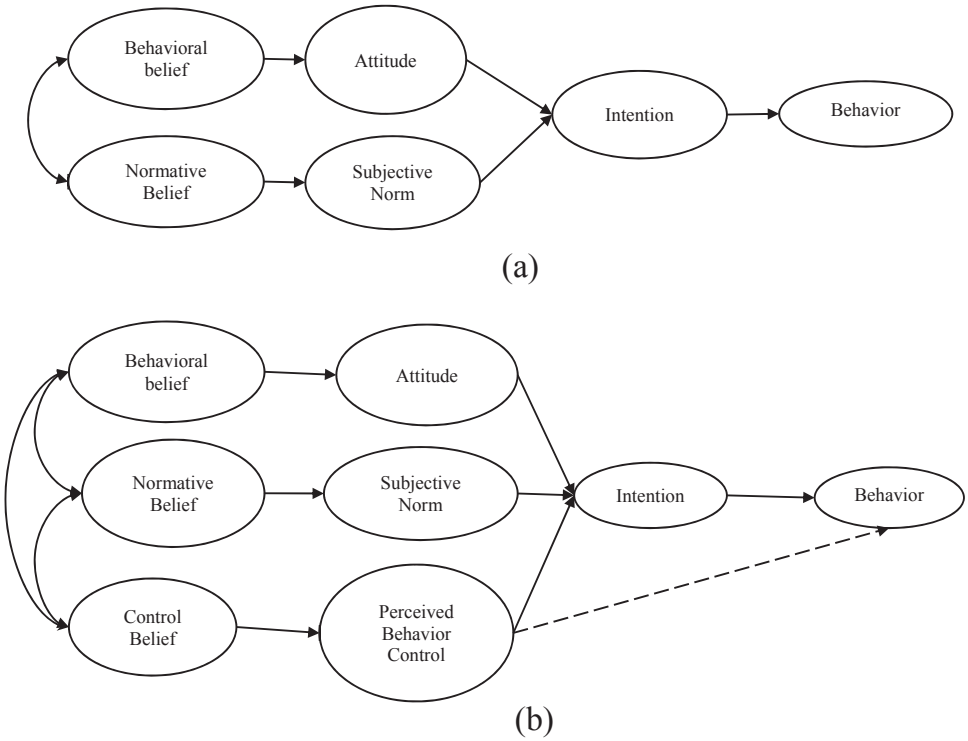

Fig. 1 **a** Theory of reasoned action and **b** theory of planned behavior

transition ecoregion of the south-central USA in Oklahoma (Fig. 2). A mailing list of landowners in Oklahoma owning 160 acres (~65 ha) or more land with forest and rangeland was obtained from a commercial vendor, Dynata (https://www.dynata.com/). The survey was then bulk mailed to 2500 randomly selected Oklahoma landowners out of which, 16 were unable to participate because of missing address, deceased, refused to participate, and no longer managing land reducing total sample to 2484. The survey package included a personalized cover letter, questionnaire, and prepaid return envelope.

With some modifications on Dillman's Total Design Method (TDM) procedures, randomly selected landowners were each sent two rounds of surveys with a gap of about two months, each followed by reminder postcards after about a month of survey mailing (Dillman et al. 2014). The second round of surveys and postcards were mailed to landowners who did not respond during the first round of survey mailing. Total 508 responses, response rate 20.45%, were obtained after the second round of the survey. The demographics of the landowners were compared with National Woodland Owner's Survey (NWOS) results (Butler et al. 2020). Early and late response biases were conducted using chi-square tests on age, gender, income, education, and race among landowners' responses received after the first and second lots of survey and postcards.

The questions were asked on a 5-point Likert scale (1 as strongly disagree to 5 as strongly agree) for all variables except those representing intentions. Intentions were asked as landowners' willingness to pay (USD), travel distance (miles) to alternate hunting sites with similar quality, and interest (yes/no) in active management of their land. Outliers in travel distance (>100 miles) to alternative hunting sites were excluded from the analysis. Because of the difference in measurement scale, the observed variables loaded as intentions in the model were normalized by dividing the difference between the mean and observed value for each observation by the standard deviation of the variable. Mean and standard deviation before standardization were reported for all standardized and non-standardized variables. Cronbach alpha values were obtained after standardization for standardized variables because these were used in structural equation models (SEM). Model Fit indices, factor loadings, standard error of factor loadings, Cronbach alpha, mean and standard deviations of observed variables, and statistics from SEM models were reported after removing missing observations and outliers on a list-wise basis using a total of 165 observations.

Hypothesis

The following hypotheses related to the TRA, TPB, and moral norms regarding active management of forest and rangeland for deer habitat were tested:

Hypothesis 1 (H_1): Positive subjective norms shape positive intentions.

Hypothesis 2 (H_2): Positive attitude shapes positive intentions.

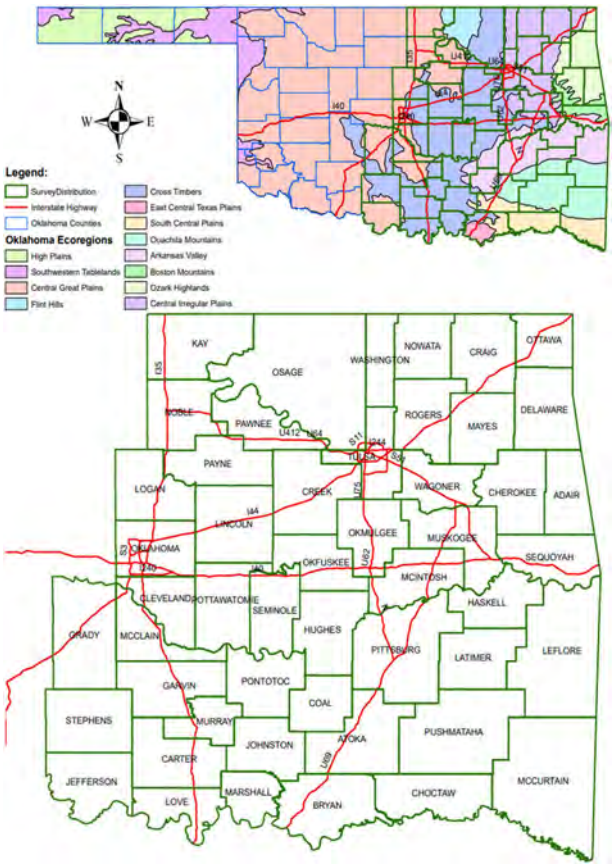

Fig. 2 Study region: map of Oklahoma representing various ecoregions (top) and counties receiving surveys (bottom)

Hypothesis 3 (H_3): Positive attitudes shape positive moral norms.

Hypothesis 4 (H_4): Positive perceived behavior control shapes positive intentions.

Hypothesis 5 (H_5): Positive subjective norms shape positive moral norms.

Hypothesis 6 (H_6): Positive perceived behavior control shapes positive moral norms.

Hypothesis 7 (H_7): Positive moral norms shape positive intentions.

Structural Equation Model (SEM)

Model fit indices and internal validity

The internal validity of measurement variables was determined using Cronbach alpha. A Cronbach alpha value above 0.60 (Coon et al. 2020; Cronbach 1951) was used as an indicator of internal consistency of variable loading in the latent constructs. The model fit indicators were determined by using several models fit indicators such as the root mean squared error or approximation (RMSEA, <0.05) (Schreiber 2017; StataCorp 2017), standardized root mean squared residual (SRMR, ≤0.08) (StataCorp 2017), Comparative fit index (CFI, ≥0.95) (Schreiber 2017; StataCorp 2017), Tucker Lewis Index (TLI), and coefficient of determination (CD, ≥0.95) (StataCorp 2017). Akaike Information Criterion (AIC), the smaller the better, was used for model comparison (StataCorp 2017). RMSEA estimates population errors, CFI and TLI make baseline comparisons with the null model, and SRMR and CD compare the size of residuals. CD is analogous to R^2 for the model (StataCorp 2017).

Path analysis

A structural equation model (SEM) was used for the study. Four different models—TRA and TRA with moral norms (henceforth, TRA-moral) and TPB and TPB with moral norms (henceforth, TPB-moral) were fitted using SEM. To develop TRA-moral, TRA was extended by adding a path from subjective norms to intentions through moral norms. Similarly, TPB-moral was developed by adding two additional paths from subjective norms and perceived behavior control intentions through moral norms. Structural equation models were fit using the "*sem*" command in STATA 15.1 provides estimation under the assumption of joint normality and fits linear SEMs using the maximum likelihood estimation method (StataCorp 2017). The command *sem* provides Maximum likelihood estimators that have asymptotic, unbiased, consistent, and efficient properties under the normality assumption of observed variables (Anderson et al. 1988). The standard error was robust Satorra-Bentler scaled standard error (Satorra and Bentler 1994).

Structural equation models were fit following the procedure suggested by Anderson et al. (1988) after obtaining acceptable ranges of internal consistency and factor loadings in each latent variable for all four models. Observed variables were dropped if an acceptable range of internal consistency and factor loading were not obtained. The same set of observed variables was used in all four models. The command *sem* assumes that observed endogenous, observed exogenous variables, latent endogenous, and latent exogenous variables were jointly distributed normally with a mean ($\boldsymbol{\mu}$) and variance-covariance matrix ($\boldsymbol{\Sigma}$) (StataCorp 2017). The coefficients reported are standardized coefficients which can be interpreted as the change in one variable given a change in another, both measured in standard deviation units (StataCorp 2017).

Results

Demographics of Respondents

Landowners included in this study were 95% male and 5% female. The race composition was 82% white American, 14% Native American, and 4% identified as more than one race. About half of the respondents (48%) reported their

primary job as farmers/rancher, 23% as retired, 11% as business, 5% as working class (physical work), and 3% as medical-related. The remaining 10% of the responders held jobs unidentified in the survey. The average age of respondents was 63 (SD = 12) years. The percentage of respondents with a General Educational Development (GED)/high school degree or below was 28%, some college experience was 20%, associate or technical degree was 12%, bachelor's degree was 22%, and graduate degree was 18%. Of note, NWOS data suggest that average age of landowners having 10+ acres of forestland in Oklahoma was 66 years and that about 53% had college degree and 24% were minorities (USFS 2021). Finally, the early and late response bias was not significant among responders from the first and second lots of survey and postcards mailing. These results suggest that non-response bias in not a major concern among our respondents.

Measurement and Structural Variables, and their Factor Loadings

Cronbach alpha, factor loadings, and their standard deviation of observed variables in their respective latent construct, mean, and standard deviation of variables are presented in Table 1. Subjective norms consisted of observed variables *e1value, e1diverse, e1support*, and *e1livable* variables. Attitudes consisted of variables *e3manage*, *e3effort*, *e3wilder*, and *e3overall*. Moral norms were represented by variables *e2respect, e2maintain*, and *e2invest*. Cronbach's alpha value of subjective norms, attitudes, and moral norms was above the value suggested by Cronbach (1951) for internal consistency. Perceived behavior control consisted of variables *e1resource* and *e1improve*. Lastly, intentions consisted of *a7wtp, a9altdist*, and *c6interst*. Cronbach alpha values of perceived behavior and intentions were slightly below the suggested value for internal consistency.

Among our respondents, the majority of landowners agreed or strongly agreed (henceforth, agree) that sustainable ecosystem management for deer habitat is important for the people they value most (*e1value*). Similarly, the majority of landowners agreed that their family and friends think that forest, rangeland, and deer habitat management could enhance biodiversity (*e1diverse*). Sixty-eight percent of respondents agreed that they feel supported by their friends and families for the active management (*e1support*). Fifty-six percent of landowners agreed, 21% disagreed, and 23% remained neutral that they have resources and opportunities to actively manage their land (*e1resource*). Seventy-four percent of landowners strongly agreed that they can improve their forest, rangeland, and deer habitat by actively managing their land (*e1improve*).

Eighty-seven percent of landowners agreed and 10% of landowners remained neutral on the statement that they give respect and courtesy to people involved in the forest, rangeland, and deer habitat management (*e2respect*). Sixty-eight percent of landowners agreed that they should actively manage their land to maintain deer and wildlife habitats (*e2maintain*). However, only 52% of landowners felt honored in investing their money, time, and resources in managing their forest and rangeland (*e2invest*); 47% of landowners either remained neutral or disagreed with the statement that they feel honored to invest money, time, and resources to manage their land.

Among our responders 65% of landowners stated that they are satisfied with the overall characteristics of the forest and rangeland they managed (*e3manage*). Sixty-three percent of landowners agreed, 24% of landowners remained neutral, and 13% disagreed that they were satisfied with the number of deer and wildlife observed based on their management effort (*e3wilder*). Sixty percent of landowners agreed, 25% remained neutral, and 15% disagreed that they are satisfied with the overall benefit they are getting from their forest and rangeland.

Model Results

The model fit statistics exhibited a good fit for the four models representing TRA, TRA-moral, TPB, and TPB-moral (Table 2). SEM model results testing TRA, TRA-moral, TPB, TPB-moral are presented in Figs. 3a, 3b, 4a, and 4b respectively. Models were presented in the figures using structural variables only; measurement variables were excluded in the figures to simplify the presentation.

Model summary for all four models are given in Table 3. In the TRA model (Fig. 3a), the subjective norm significantly affected intentions for active management of forest, rangeland, and habitat for deer hunting (henceforth, intentions) supporting H_1. However, attitude significantly affected intentions but showed a negative sign in the TRA model thus partially supporting H_2. In the TRA-moral model (Fig. 3b), subjective norms did not significantly or directly affect intentions, rejecting H_1, but indirectly affected intentions through moral norms. Subjective norms significantly affected moral norms, and moral norms significantly affected intentions positively, thus supporting H_5 and H_7 respectively. Attitude significantly but negatively affected intentions, thus, partially supporting H_2. Attitude did not significantly affect moral norms, thus rejecting H_3.

In the TPB model (Fig. 4a), subjective norms and perceived behavior control did not affect intentions, thus not supporting H_1 and H_4. Like previous models, attitude significantly affected intentions and had a negative sign, thus, partially supporting H_2. In TPB-moral (Fig. 4b), the subjective norm did not directly affect intentions, again failing to support H_1. Subjective norms indirectly affected intentions through moral norms, like the TRA-moral model.

Table 1 Validity of structural variables, descriptions, and descriptive statistics of measurement variables

Measurement variables in SEM models	Factor loading (Std. Err.)	Mean (St. Dev.)
Subjective norms (*SN*): Cronbach alpha (α) = 0.89		
e1value: Sustainable management of forest, rangeland and deer habitat is important to the people I value most.	0.76 (0.05)	3.82 (1.08)
e1diverse: My family and friends think that forest, rangeland, and deer habitat management could enhance plant and animal diversity.	0.82 (0.04)	3.60 (1.14)
e1support: My family and friends are supportive of forest, rangeland, and deer habitat management activities.	0.90 (0.02)	3.82 (1.04)
e1livable: My family and friends think that forest, rangeland, and deer habitat management would make our environment more livable.	0.81 (0.05)	3.57 (1.12)
Perceived behavior controls (*PBC*): Cronbach alpha (α) = 0.48		
e1resource: I have resource and opportunities to manage my land for forest, rangeland, and deer habitat management.	0.48 (0.09)	3.49 (1.16)
e1improve: I think that I can improve forest, rangeland, and deer habitat on my property by actively managing them.	0.68 (0.10)	3.95 (0.98)
Moral norms (*MRL*): Cronbach alpha (α) = 0.82		
e2respect: I give respect and courtesy to people who are involved in forest, rangeland, and deer habitat management.	0.71 (0.05)	4.24 (0.86)
e2maintain: I feel that I should actively manage forest, rangeland, and deer habitat on my property to maintain deer habitat for deer and wildlife.	0.90 (0.03)	3.95 (1.00)
e2invest: I feel honored to invest money, time, and resources to manage forest, rangeland and deer habitat for deer and wildlife habitat.	0.77 (0.04)	3.58 (1.18)
Attitudes (*ATT*): Cronbach Alpha (α) = 0.87		
e3manage: I am satisfied with the overall characteristics of forest, rangeland, and deer habitat that I maintain.	0.67 (0.06)	3.65 (0.96)
e3effort: I am satisfied with the number of deer and wildlife that I observed with the management effort that I put in my property.	0.83 (0.04)	3.72 (1.06)
e3wilder: I am satisfied with the wilderness of forest, rangeland, and deer habitat that I maintain.	0.88 (0.03)	3.66 (1.00)
e3overall: I am satisfied with the overall benefits I am getting from forest, rangeland, and deer habitat that I manage.	0.77 (0.05)	3.58 (1.04)
Intentions (*INT*): Cronbach Alpha (α) = 0.44		
a7wtp: Assume that you do not observe any deer in your regular hunting site. How many dollars/acres are you willing to spend to maintain the deer population you generally observe in that site to receive desired hunting experience? (USD)	0.66 (0.08)	61.51 (106.37)
a9altdist: If you could not go to the site that you regularly hunt deer, how far would you drive one way to go to another deer hunting site of about the same quality? (miles)	0.54 (0.09)	20.25 (27.90)
c6interest: Are you interested in knowing more about active forest or rangeland management in Oklahoma?	0.37 (0.07)	0.60 (0.49)

Table 2 SEM Model fit statistics for all four models along with the sample size used in each model

Fit statistics\models	TRA	TRA-moral	TPB	TPB-moral
Model vs. saturated (MS) Likelihood ratio test: (χ^2):	43.89	85.87	72.44	121.72
Baseline vs. saturated (BS) Likelihood ratio test: (χ^2):	823.04***	1212.59***	937.14***	1333.33***
Satorra-Bentler scaled test (MS) (χ^2):	30.361	63.76	52.00	91.88
Satorra-Bentler scaled test (BS) (χ^2):	612.77***	932.48***	709.53***	1034.54***
Root mean squared error of approximation (RMSEA):	0.02	0.04	0.04	0.04
RMSEA lower bound:	0.00	0.00	0.00	0.01
RMSEA upper bound:	0.06	0.06	0.06	0.06
P-close (probability RMSEA ≤ 0.05):	0.88	0.81	0.76	0.74
Satorra Bentler RMSEA (SB RMSEA):	0.00	0.00	0.00	0.00
Comparative Fit Index (CFI):	1.00	0.99	0.98	0.98
Satorra Bentler CFI (SB CFI):	1.00	1.00	1.00	1.00
Tucker Lewis Index (TLI):	1.00	0.98	0.98	0.97
Satorra Bentler Tucker Lewis index (SB TLI):	1.03	1.01	1.02	1.00
Standardized root mean squared residuals (SRMR):	0.04	0.41	0.05	0.05
Coefficient of determination (CD):	0.99	0.99	0.99	0.99
Akaike's information criterion (AIC):	4187.33	5280.93	5108.11	6177.32
Sample Size (N)	165	165	165	165

***$p < 0.001$

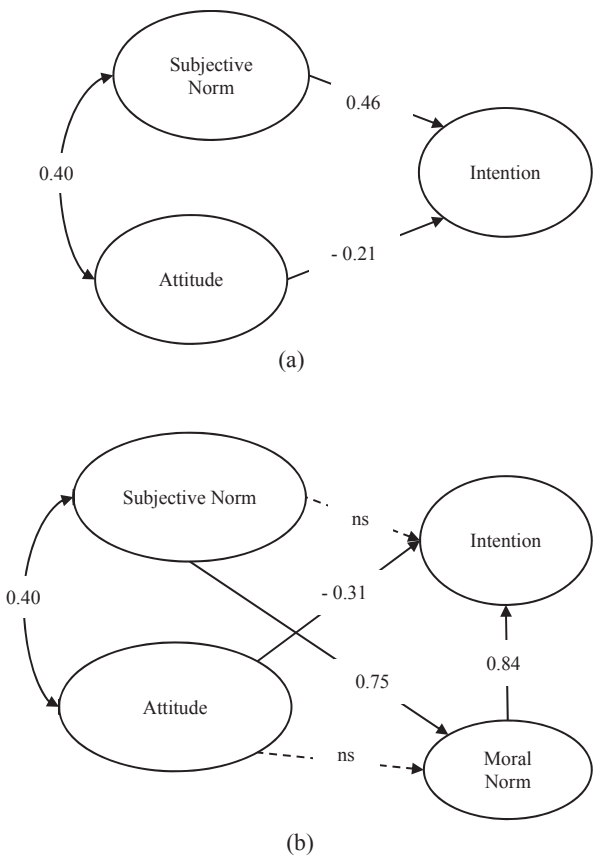

Fig. 3 **a** Theory of reasoned action (TRA) and **b** Theory of reasoned action with moral norms (TRA-moral). Values on the arrow and "ns" indicate coefficients and "non-significant" relationships, respectively

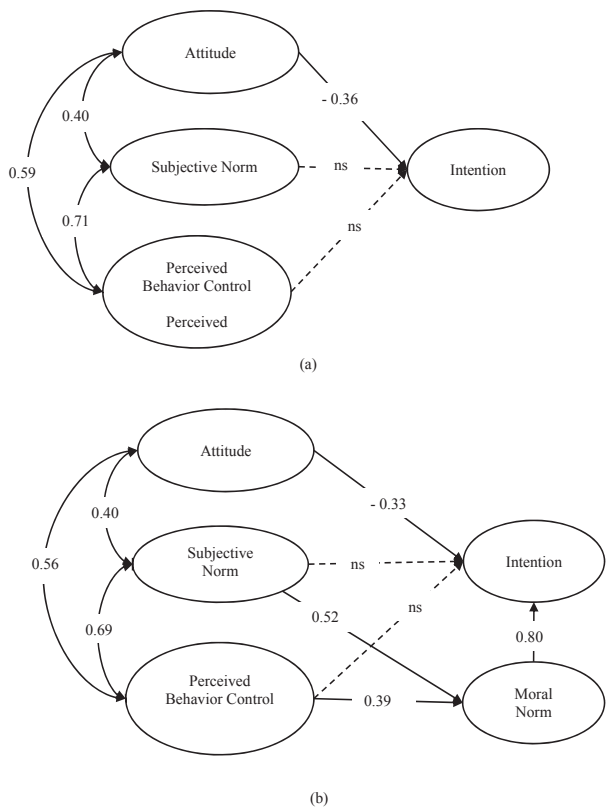

Fig. 4 **a** Theory of planned behavior (TPB) and **b** Theory of planned behavior with moral norms (TPB-moral). Values on the arrow and "ns" indicate coefficients and "non-significant" respectively

Table 3 Standardized Setorra–Bentler coefficients of four SEM models (TRA, TRA-moral, TPB, and TPB-moral)

Structural variables	TRA Coeff. (Std. Err.)	TRA-moral Coef. (Std. Err.)	TPB Coef. (Std. Err.)	TPB-moral Coef. (Std. Err.)
SN → INT	0.46 *** (0.097)	−0.16 (0.21)	0.23 (0.20)	−0.17 (0.20)
ATT → INT	−0.21* (0.12)	−0.31** (0.11)	−0.36** (0.16)	−0.33*** (0.12)
MRL → INT	–	0.84*** (0.26)	–	0.80 *** (0.30)
PBC → INT	–	–	0.42 (0.28)	0.07 (0.22)
SN → MRL	–	0.75*** (0.05)	–	0.52*** (0.14)
ATT → MRL	–	0.12 (0.08)	–	–
PBC → MRL	–	–	–	0.39** (0.16)

Coef. = Standardized correlation coefficients (StataCorp 2017), Std. Err. = Satorra-Bentler robust standard error of coefficients. *SN → INT*: subjective norms (*SN*) impact Intentions (*INT*) and so on. All arrows in the table are in accordance with arrows in respective models. Dashes (–) indicate irrelevant variable in the model

***$p < 0.001$; **$p < 0.05$; *$p < 0.10$

Table 4 Standardized correlation coefficients of latent variables in four SEM models (TRA, TRA-moral, TPB, and TPB-moral)

Components of theories	TRA Coef. (Std. Er.)	TRA-moral Coef. (Std. Er.)	TPB Coef. (Std. Er.)	TPB-moral Coef. (Std. Er.)
*SN*ATT*	0.40*** (0.09)	0.40*** (0.09)	0.40*** (0.09)	0.40*** (0.09)
*SN*PBC*	–	–	0.71*** (0.11)	0.69*** (0.10)
*PBC*ATT*	–	–	0.59*** (0.10)	0.56*** (0.09)

SN*ATT: Standardized correlation coefficient (StataCorp 2017) between subjective norms (SN) and attitudes (ATT). Dashes (–) indicate irrelevant relationship in the model

***$p < 0.001$; **$p < 0.05$; *$p < 0.10$

Subjective norms significantly affected moral norms and moral norms significantly affected intentions with a positive sign, again supporting H_5 and H_7 respectively. Attitude again directly affected intentions and retained a negative sign, but did not affect moral norms; thus, H_2 was partially supported and H_3 was not supported.

Unlike the stated hypotheses, attitude consistently showed a negative sign in all four models. Also, subjective norms had negative signs when moral norms were added to the model; regardless, subjective norms were not significant in either model that included moral norms. However, the pairwise correlation coefficients among subjective norms and attitudes were positive and significant in all four models (Table 4). Also, subjective norms and perceived behavior control, and subjective norms and attitudes were positive and significant in TPB and TPB-moral models.

Discussion

Previous research indicated that Oklahoma landowners were supportive of active management using prescribed burning (Elmore et al. 2010) but were concerned about addressing associated risk, liability issues (Elmore et al. 2010; Kaur et al. 2020; Starr et al. 2019a), and financial burden (Kaur et al. 2020; Starr et al. 2019a). Fire suppression and exclusion since the mid-1900s have reduced grasslands, savannas, and open woodlands and increased closed-canopy forests (Hoff et al. 2018a; Joshi et al. 2019b). Thus, active management is needed to restore the full suite of ecosystem services along the south-central forest-grassland transition zone. Within this context, our research determined how landowners' attitudes, perceived behavior control, moral norms, and subjective norms influence active management of forest and rangeland to improve deer habitat or deer hunting revenue.

Our results showed that landowners had positive social pressure (subjective norms). Three statements representing subjective norms in our models also showed that landowners feel supported by family and friends for the management of the ecosystem for deer habitat management. Landowners felt positive social pressure from friends and family and further agreed that managing land is important for the people they value most which displays two-way motivations for landowners to actively manage their land. Landowners in this region had further realized the need for active management, which can help meet the integrated forest and range management needs in this region.

The research further found that landowners had a positive perception of their ability to actively manage their land (perceived behavioral control). The positive peer pressure coupled with positive perceived behavioral control were important in driving the active management of the ecosystem of in south-central transitional ecoregion. However, we found that many landowners believe that they lacked resources and opportunities to manage their land. Access to

resources could create opportunities and motivate landowners to actively manage their land to improve the quality of forests, rangeland, and deer habitat. Landowners in this region cited the uncertainty of the timber market, lack of interest from manufacturers, and low-quality resources as a hindrance to the market (Starr et al. 2019b) which could be a further indication of a lack of resources and opportunities.

This research further found that landowners expressed strong positive moral support to people involved in the active management of forest, rangeland, and deer habitat. Most of the landowners showed positive moral support towards personnel involved in active management and agreed that they should be involved in active management. However, slightly over half landowners only felt proud to invest their time, money, and resource in actively managing land in this region which can be better understood by relating to landowners' satisfaction with their forest and grassland. Still, more than one-third of landowners were not satisfied with the characteristics of their forest and rangeland, the number of deer and wildlife observed, and the overall benefit they are receiving from their property. This means even though landowners are generally positive about actively managing their land, the overall benefit and the characteristics of their forest and rangeland could not fully meet their expectations, which might be hindering the active management. The dissatisfaction of landowners resulting from the poor performance of their land might be a reason behind the negative attitude observed in our SEM models. Attitude is the reflection of the behavioral belief that originated from an individual's experience of acting (Ajzen 2002). Previous research had further suggested that financial burden (Kaur et al. 2020; Starr et al. 2019a) and fire liabilities (Elmore et al. 2010; Joshi et al. 2019a; Starr et al. 2019a) as major demotivating factors for landowners to actively manage their land.

The pairwise correlations among subjective norms, perceived behavior control, and attitude were positively correlated signifying that the landowners with positive subjective norms and perceived behavior control tend to have a positive attitude towards active management (Table 4). The positive correlation is an indication that the landowners were mostly positive about actively managing their land which suggested a strong need for active management to increase overall satisfaction and increase revenue from forest and rangelands in the south-central transitional ecoregion. Addressing associated risk and liabilities issues and financial burdens could change the attitude of landowners and thus positively affect the intentions of positively towards actively managing their land. The associated risk and liabilities issues can be addressed through extension and outreach programs (Elmore et al. 2010; Joshi et al. 2019a). The financial burden can be offset by helping landowners to realize the potential source of revenue by actively managing their land (Starr et al. 2019a) for activities such as deer hunting.

Among four different models developed and discussed, TRA was best supported by our data, as reflected by AIC value, to explain the intentions for active management of forest, rangeland, and deer habitat for deer hunting. The behavior, management of land for deer hunting, is under the volitional control of our study population because they own at least 160 acres of land. This is likely why the behavior is best explained by TRA (Madden et al. 1992).

Perceived behavior control and intentions in SEM models have lower Cronbach alpha values. Low Cronbach alpha values are not uncommon in SEM models. Lopez-Mosquera and Sanchez (2012) also reported a lower than suggested Cronbach alpha value for perceived behavior control and intentions. Further, intentions had a wide range of factor loading, from 0.37 to 0.66. This could be because intentions, unlike other variables, are not measured on the Likert scale. Latent constructs often have lower Cronbach alpha coefficients because of random error, even with meticulously planned variables (Ajzen 2011).

This paper studied landowners' attitudes, perceptions, and social and peer pressure related to active management of ecosystem using SEM which broadened the scope of wildlife management research through the inclusion of moral norms in TRA and TPB models. From an applied standpoint, our results suggest that forest landowners in the grassland-forestland ecotone have several motivations to adopt active forest management, which can be revealed from positive peer and family pressure, positive moral norms, positive feelings about active management, and positively perceived ability to manage. However, as the attitude statements reveal, many landowners are satisfied with the *status quo*, which could be the major reason behind the negative relationship between 'attitude' and 'intention' to know or invest more in active management activities. Perhaps these landowners feel that while active forest management involving thinning, prescribed fire, and herbicide applications are needed for timber-oriented forest management, it may not be necessary to improve wildlife habitat. This disconnect between landowner perceptions and the science of forest management needs to be addressed through field demonstration and other forms of extension.

A couple limitations of this study is worth nothing. The sociodemographic of our survey respondents are similar to average family forest landowners in Oklahoma, although the numbers are not directly comparable as we limited our sample pool to those having 160 acres. Likewise, there was no statistical difference in socio-demographics between early and late respondents, which is commonly used method for non-response bias analysis (Joshi et al. 2019a, 2019b). Nonetheless, our response rate is less than desirable, causing some concern for non-response bias. Also, in one of the statements defining attitude, we asked respondent to reveal whether they are satisfied with the wilderness of forest, rangeland, and deer habitat. Although very high value of Cronbach's alpha (0. 87)

suggests that the landowner responses to this statement were mostly consistent with other statements, landowners may not characterize medium-sized, managed private land as wilderness. Despite these caveats withstanding, this paper introduced new ways to expand these two well-established theories. We believe TRA, TPB, and moral norms can and should be expanded in the human dimension and wildlife management research. Furthermore, the use of TPB and TRA for other species, and the expansion of these theories using moral norms in the hunting research are yet to be understood fully. Also, TPB is criticized for ignoring human emotions, identity, and moral values (Miller 2017) which are addressed by this paper by expanding theories by adding moral norms as suggested (Ajzen 1991). The recent development of TPB is more suggestive of mediating the role of perceived behavior control between attitude-intention and subjective norms-attitude and inclusion of sociodemographic variables into the model (Ajzen 2020; Sok et al. 2020). Since our study is primarily focused on exploring the role of moral norms in traditional realm of TBP and TRA, future research highlighting mediating role of socio-demogrpahic variables will likely provide additional insights.

Conclusion and Management Implications

This research provided a holistic and broader picture of landowners' intentions towards actively managing their land for deer habitat management which can be crucial in designing Extension and outreach programs. The realization of increased revenue by maintaining healthy and resilient forests can drive active management in this region (Starr et al. 2019a). The findings of this research provide an assurance of positive peer pressure, moral support, feeling of self-sufficiency, and intentions towards active management. Our findings are consistent with the previous research indicating high support for prescribed fire but some degree of hesitancy when it comes to adoption (Elmore et al. 2010). As previous research indicates, fire and related liability issues (Elmore et al. 2010; Starr et al. 2019a) and financial burdens (Starr et al. 2019a) remain obstacles for active management, which can be overcome through Extension and outreach programs (Elmore et al. 2010; Starr et al. 2019a). Outreach and Extension programs can help landowners realize increased revenue due to active management as well as reduce liabilities. The perceived risk and liabilities of fire decrease with the increase in knowledge and experience associated with prescribed burning (Joshi et al. 2019a).

Landowners show respect to those involved in the active management of ecosystems. Landowners are further supportive of actively managing their land for deer hunting by maintaining a good deer habitat and having positive social pressure from friends and family. Landowners, however, are not satisfied with the management outcomes. The positive sentiment of landowners towards active management but below expected outcome can be turned into an opportunity to motivate landowners to actively manage their land for deer hunting and increase revenue as well as revitalize deer hunting activities.

In summary, landowners are generally appreciative of active management, which is further supported by their family and peers. However, landowners seemed to be content with the existing conditions of wildlife habitats and do not see a need for additional investments. Although, the management cost associated with active management can be in part offset through hunting leases; improved deer habitat through active management could motivate deer hunters to pay more money per acre as a lease fee. Based on our research we suggest extension specialists and policymakers focus on educating landowners to make them aware of the cost and benefits associated with active management. This could enhance the confidence of landowners in adopting active management tools and realizing financial benefits. The realization of reduced risk and added financial benefits could motivate landowners to adopt management tools in their forests and rangeland.

Stakeholders from government, non-profit organizations, and industry believe that an increase in investment and financial assistance programs could enhance the active management of the ecosystem in this region (Starr et al. 2019a). These types of programs could drive active management and help landowners to increase their revenue in the short run. Whereas, in the long run, it could help landowners to understand the importance of active management using prescribed fire to maintain quality wildlife habitat and reduce the encroachment of invasive species in this region (Joshi et al. 2019b).

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Compliance with Ethical Standards

Conflict of Interest The authors declare no competing interests.

References

Ajzen I (1991) The theory of planned behavior. Organ Behav Hum Decis Process 50:179–211

Ajzen I (2002) Perceived behavioral control, self-efficacy, locus of control and the theory of planned behavior. J Appl Soc Psychol 32:665–683

Ajzen I (2011) The theory of planned behavior: reactions and reflections. Psychol Health 26:1113–1127

Ajzen I (2020) The theory of planned behavior: frequently asked questions. Hum Behav Emerg Technol 2:314–324

Anderson JC, David W, Grebing (1988) Structural Equation modeling in practice: a review and recommended two-step approach. Psychol Bull 103:411–423

Butler BJ, Butler SM, Caputo J, Dias J, Robillard A, Sass EM (2020) Family forest ownerships of the United States, 2018: Results from the USDA Forest Service, national woodland owner survey. Gen. Tech. Rep. NRS-199. US Department of agriculture, forest service, Northern research station, Madison, WI, p 52

Byrd E, Lee J.G, Widmar NJO (2017) Perceptions of hunting and hunters by U.S. respondents. Animals 7:1–15

Clark SL, Hallgren SW, Engle DM, Stahle D (2007) The historic fire regime on the edge of the prairie: a case study from the cross timbers of Oklahoma. In: Masters RE, Galley KEM (eds) 23rd Tall Timbers Fire Ecology Conference: fire in grassland and shurbland ecosystems. Tall Timbers Research Station, Tallahassee, Florida, USA, p 40–49

Coon JJ, van Riper CJ, Morton LW, Miller JR (2020) What drives private landowner decisions? Exploring non-native grass management in the eastern Great Plains. J Environ Manag 276:111355

Cronbach LJ (1951) Coefficient alpha and the internal structure of tests. Psychometrika 16:297–334

Daigle JJ, Hrubes D, Ajzen I (2010) A comparative study of beliefs, attitudes, and values among hunters, wildlife viewers, and other outdoor recreationists. Hum Dimens Wildl 7:1–19

Demarais S (1992) The pristine myth: the llandscape of the Americas in 1492. Ann Assoc Am Geogr 82:369–385

Dillman DA, Smyth JD, Christian LM (2014) Internet, phone, mail, and mixed-mode surveys: the tailored design method. John Wiley & Sons, Inc, Hoboken, New Jersey

Elmore RD, Bidwell TG, Weir JR (2010) Perceptions of oklahoma residents to prescribed fire. In: Robertson KM, Galley KEM, Masters RE (eds) 24th Tall Timbers Fire Ecology Conference: the future of prescribed fire: public awareness, health, and safety. Tall Timbers Research Station, Tallahassee, Florida, USA, p 55–66

Fishbein M, Ajzen I (1975) Belief, attitude, intention and behavior: an introduction to theory and research. Addison-Wesley Publishing Company, Philippines

Füssel H-M (2007) Vulnerability: a generally applicable conceptual framework for climate change research. Glob Environ Change 17:155–167

Hallgren SW, DeSantis RD, Burton JA (2012) Fire and vegetation dynamics in the cross timbers forest of South-central North America, U.S. Department of Agriculture, Forest Service, Northern Research Station, 4th Fire in Eastern Oak Forests Conference, Newtown Square, PA, p 52–66

Heidari A, Kolahi M, Behravesh N, Ghorbanyon M, Ehsanmansh F, Hashemolhosini N, Zanganeh F (2018) Youth and sustainable waste management: a SEM approach and extended theory of planned behavior. J Mater Cycles Waste Manag 20:2041–2053

Hoff D, Will R, Zou C, Lillie N (2018a) Encroachment Dynamics of *Juniperus virginiana* L. and Mesic Hardwood Species into Cross Timbers Forests of North-Central Oklahoma, USA. Forests 9:1–17

Hoff DL, Will RE, Zou CB, Weir JR, Gregory MS, Lillie ND (2018b) Estimating increased fuel loading within the Cross Timbers forest matrix of Oklahoma, USA due to an encroaching conifer, *Juniperus virginiana*, using leaf-off satellite imagery. For Ecol Manag 409:215–224

Hrubes D, Ajzen I, Daigle J (2001) Predicting hunting intentions and behavior: an application of the theory of planned behavior. Leis Sci 23:165–178

Joshi O, Poudyal NC, Weir JR, Fuhlendorf SD, Ochuodho TO (2019a) Determinants of perceived risk and liability concerns associated with prescribed burning in the United States. J Environ Manag 230:379–385

Joshi O, Will RE, Zou CB, Kharel G (2019b) Sustaining cross-timbers forest resources: current knowledge and future research needs. Sustainability 11:1–12

Kaur R, Joshi O, Will RE (2020) The ecological and economic determinants of eastern redcedar (*Juniperus virginiana*) encroachment in grassland and forested ecosystems: a case study from Oklahoma. J Environ Manag 254:109815

Lopez-Mosquera N, Garcia T, Barrena R (2014) An extension of the Theory of planned behavior to predict willingness to pay for the conservation of an urban park. J Environ Manag 135:91–99

Lopez-Mosquera N, Sanchez M (2012) Theory of planned behavior and the value belief norm theory explaining willingness to pay for a suburban park. J Environ Manag 113:251–262

Lovell WG, Dobyns HF, Denevan WM, Woods WI, Mann CC (2004) 1491: In search of native america. J Southwest 46:441–461

Madden TJ, Ellen PS, Ajzen I (1992) A comparison of the theory of planned behavior and the theory of reasoned action. Personal Soc Psychol Bull 18:3–9

Mann CC (2002) 1491, The Atlantic. The Atlantic Monthly Group, Boston

Miller ZD (2017) The enduring use of the theory of planned behavior. Hum Dimens Wildl 22:583–590

Peterson MN (2004) An approach for demonstrating the social legitimacy of hunting. Wildl Soc Bull 32:310–321

Poudyal NC, Watkins C, Joshi O (2020) Economic contribution of wildlife management areas to local and state economies. Hum Dimens Wildl 25:291–295

Rossi AN, Armstrong JB (1999) Theory of reasoned action vs. theory of planned behavior: Testing the suitability and sufficiency of a popular behavior model using hunting intentions. Hum Dimens Wildl 4:40–56

Satorra A, Bentler PM (1994) Corrections to test statistics and standard errors in covariance structure analysis. Sage, Thousand Oaks

Schreiber JB (2017) Update to core reporting practices in structural equation modeling. Res Soc Adm Pharm 13:634–643

Sok J, Borges JR, Schmidt P, Ajzen I (2020) Farmer behaviour as reasoned action: a critical review of research with the theory of planned behaviour. J Agric Econ 72:388–412

Starr M, Joshi O, Will RE, Zou CB (2019a) Perceptions regarding active management of the Cross-timbers forest resources of Oklahoma, Texas, and Kansas: A SWOT-ANP analysis. Land Use Policy 81:523–530

Starr M, Joshi O, Will RE, Zou CB, Parajuli R (2019b) Understanding market opportunities utilizing the forest resources of the cross-timbers ecoregion. J For 117:234–243

StataCorp (2017) Stata user's guide: release 15. StataCorp LLC, College Station, TX

USFS (2021) Family forest (10+ acres) ownership characteristics, 2018. Department of Agriculture, Forest Service, Northern Research Station, Madison, WI

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Exploring Opinions for Using Prescribed Fire to Control Eastern Redcedar *(Juniperus virginiana)* Encroachment in the Southern Great Plains, United States ☆

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ABSTRACT

Eastern redcedar *(Juniperus virginiana)* is rapidly encroaching on grasslands in the southern Great Plains. This has several adverse effects on the landscape including increased wildfire risk, decreased water runoff, and reduced forage available for cattle production. Several best management practices have been identified to reduce the spread of eastern redcedar, including the use of prescribed fire. However, numerous barriers exist against the use of prescribed fire such as societal acceptance or liability concerns. The purpose of this study was to determine how stakeholders from government agencies, nongovernmental organizations, and landowners perceive the use of prescribed fire to control eastern redcedar encroachment. The strengths, weaknesses, opportunities, and threats–analytical hierarchical process method was used for data analysis. The study showed that governmental and landowner stakeholders viewed that the negatives associated with prescribed fire outweigh the potential benefits. Nongovernmental organization stakeholders had differing opinions, and they were largely supportive of using prescribed fire. The results suggest that there is a need for tailored outreach to alleviate the concerns associated with risks and liabilities, as escaped prescribed fires are highly uncommon.

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Introduction

Eastern redcedar *(Juniperus virginiana)* is a conifer native to the Cross-Timbers ecoregion of the southern Great Plains. This tree has encroached into prairies of this region due to passive land management and fire suppression (Kaur et al. 2019). In particular, fire suppression became the dominant paradigm after European American settlement of the area and is attributable to various factors including logging, railroad industries, cotton plantations, higher industrial demand for timber products, and protection of built structures (Fowler and Konopik 2007; McGranahan and Wonkka 2020). Native Americans are often attributed to using fire for various purposes including ecosystem management, promotion of valued species, and agriculture (Wyckoff 1984; Joshi et al. 2019). Following the displacement and disruption of indigenous land practices, fire diminished from the landscape (Wilcox et al. 2018).

Eastern redcedar is an extremely fire-intolerant species, and as fire became less commonly applied on the landscape, more land became habitable for this species (Bidwell et al. 2002). This encroachment has led to several environmental problems including greater wildfire risk, reduced water yield, unfavorable wildlife habitat, changes in nutrient cycling and carbon sequestration, and reduced forage (Norris et al. 2001; Van Els et al. 2010; Kaur et al. 2019). In particular, eastern redcedar negatively impacts Northern bobwhite quail habitat *(Colinus virginianus),* which is one of the most important game animals in the southern Great Plains (Kaur et al. 2019).

Societal views regarding eastern redcedar have evolved over time. In the early 19th century, eastern redcedar was considered an important windbreak tree species, as well as a useful component for railway fences, pencils, paneling, chests, and furniture. Additionally, eastern redcedar was known for its aesthetic appeal (Meneguzzo and Liknes 2015). Unfortunately, with its rapid expansion into grassland prairies, eastern redcedar altered grassland ecology in the Great Plains of the United States, causing fragmentation and displacement of native grasses and forbs. Forest inventory and analysis (FIA) data suggest that there were > 200 000

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acres of eastern redcedar growth in the central United States between 2007 and 2012 (Meneguzzo and Liknes 2015). These results also showed that Nebraska witnessed an almost twofold increase in eastern redcedar encroachment in the past decade. In Oklahoma alone the economic losses of leaving eastern redcedar untreated are estimated to be over $477 million (Drake and Todd 2002). In Kansas, FIA data in 2010 suggested that eastern redcedar volume has increased by a factor of 15 over a 45-yr period (Galgamuwa et al. 2020). According to recent FIA data (FIA 2022), most eastern redcedar encroachment (> 90%) in the southern Great Plains states like Oklahoma, Nebraska, and Kansas is in privately owned areas. Likewise, the majority of redcedars are located in transition zones between productive timberland and nonforested lands (FIA 2022).

Aggressive encroachment has negatively impacted forage production, which has reduced livestock stocking capacity. Accordingly, cultural views have changed and it is now considered as a primary challenge for sustainable range management in the central United States (Morton et al. 2010). Even so, a 2001 survey of state nurseries found that eastern redcedar seedlings were part of agency-sponsored tree planting programs in 22 states (Ganguli et al. 2008).

Commonly adopted practices to control eastern redcedar include prescribed fire, mechanical brush control, and herbicide use (Ortmann et al. 1998). Mechanical brush control involves selectively harvesting redcedar trees and is the most effective practice to remove larger specimens. Likewise, killing eastern redcedar trees through chemical application is another commonly adopted best management practice. Despite their effectiveness, both of these methods are expensive and bring significant financial burden to rangeland owners (Smith 2011). Therefore, prescribed fire is one of the most appropriate methods for controlling eastern redcedar as it is a management alternative that may be more economical and effective at a landscape scale (Bidwell et al. 2002).

In the southern Great Plains, several efforts have been made to explore landowner perceptions about the use of prescribed fire to control eastern redcedar encroachment. For example, Harr et al. (2014) conducted concept mapping and qualitative interviews to explore landowners' views on risks associated with eastern redcedar management in Iowa and Missouri. The authors found that while landowners generally acknowledged the positive role of prescribed fire in grassland management, they perceived it as a risky tool and were found to be less confident in adoption. Similarly, Morton et al. (2010) explored landowners' perceptions concerning the adoption of best practices for eastern redcedar management in tallgrass prairies. While most (84%) landowners were found to take some action to control eastern redcedar, mechanical and chemical methods were more preferred than prescribed fire. Elmore et al. (2010) found that a solid majority of landowners and agricultural producers in Oklahoma were supportive of controlling eastern redcedar through prescribed burning. In addition, several other social science–focused studies (Twidwell et al. 2013; Symstad and Leis 2017; Kreuter et al. 2019; Stroman, Kreuter et al. 2020) have highlighted landowner perceptions concerning the role of prescribed fire for woody encroachment control in the southern Great Plains.

It is worth noting that although natural resource management agencies have pledged to use prescribed fire as a land management tool, many have not made significant advancements in its application and have become increasingly risk averse in public land management (Maguire and Albright 2005). Although woody vegetation is commonly sought as a windbreak and eastern redcedar can be beneficial for erosion control (Ganguli et al. 2008), the promotion of woody plant expansion in the southern Great Plains contradicts the broader conservation goal of grass-dominated prairie ecosystems.

Current wildfire dynamics highlight the need for reducing hazardous wildfire risks, and research has shown that eastern redcedar is very flammable under dry conditions with low live fuel moisture (Weir and Scasta 2014; Dudek 2020). Previous research provides useful information on how landowners perceive the use of prescribed fire in controlling eastern redcedar; however, literature is limited to determine how other natural resource stakeholders align on the use of prescribed fire as a management tool to control eastern redcedar encroachment. This reveals a significant knowledge gap in one important area of social science inquiry that has implications for effective communication and broader social acceptance of prescribed fire in the southern Great Plains. Therefore, it is necessary to understand the perceived benefits and challenges associated with the use of prescribed fire among key natural resource management stakeholders in the region. Further, such assessment will help determine whether other stakeholders align with the management goals of landowners involving rangeland productivity and woody encroachment control.

While previous research (Twidwell et al. 2013; Symstad and Leis 2017; Kreuter et al. 2019; Stroman et al. 2020) is useful to understand landowner perceptions of prescribed fire, our study is unique in its aims to gauge the degree of similarity or difference between landowners and other stakeholders regarding their views of prescribed fire as a management tool to control eastern redcedar in the southern Great Plains. Accordingly, this study aims to understand stakeholders' opinions regarding prescribed fire and the benefits and challenges associated with its use on encroached landscapes.

Methods

In the southern Great Plains of the United States, prescribed burn associations have played an important role in promoting shared knowledge, resources, tools, and techniques concerning prescribed burns among their members, which involve landowners, public land managers, extension professionals, and government employees (Weir et al. 2016). Therefore, we have posited this stakeholder perception analysis following the underpinnings of collective action theory. According to this theory, successful collective action is possible through the shared governance of the commons (Ostrom 1990). However, the actions must build on common interests, mutual respect, and reciprocity among stakeholders (Ostrom 1990; Kahan 2003).

Collective action principles have been adopted to understand the complex natural resource problems involving invasive species (Epanchin-Niell et al. 2010), water resources, rangeland, and forest management (Knox and Meinzen-Dick 2001). Like other natural resource management issues, eastern redcedar management in the southern Great Plains requires collective actions from resource managers, landowners, and other stakeholders (Weir et al. 2016; Kaur et al. 2019; Weir et al. 2019). Therefore, we evaluated stakeholder perception using the Strength, Weakness, Opportunity, and Threat (SWOT)–Analytical Hierarchy Process (AHP) platform, which is commonly used in the natural resource discipline to gauge similarities or differences of opinions among multiple stakeholders (Joshi et al. 2018). SWOT-AHP combines two distinct tools. The SWOT technique is a commonly used strategic planning tool in which strategies and the alignments likely to impact business are divided into internal and external factors (Namugenyi et al. 2019). The internal factors, which can be positive or negative factors of business establishment, are represented by strengths and weaknesses, respectively (Namugenyi et al. 2019). The external factors, which are listed as opportunities and threats, represent the attributes that indirectly favor or hinder the business environment (Namugenyi et al. 2019).

While SWOT factors provide useful information that can help with the success of a plan, program, or strategy (Kurttila et al. 2000), these factors cannot be quantified to discern their relative

Table 1
Four Strength, Weakness, Opportunity, and Threat factors chosen to compare stakeholders' perceptions of prescribed fire that can help prevent future eastern redcedar encroachment in the southern Great Plains.

Strengths	Weaknesses
S1: Cost-effective	W1: Ineffective for large trees
S2: Pollen reduction	W2: Weather dependent
S3: Easily accessible to landowners	W3: Specialized training required
S4: Help reduce fuel load	W4: Smoke management
Opportunities	Threats
O1: Provide wildlife habitat	T1: Liability issues/uncontrolled fire
O2: Improve cattle/pastureland production	T2: Cultural stigma against fire
O3: Pest control (ticks and horn flies)	T3: Inconsistent policies among agencies
O4: Enhance public acceptance of fire	T4: Inability to burn in urban interface

importance (Joshi et al. 2018; Namugenyi et al. 2019). This brings significant limitations in critical issue identification, resource prioritization, and program reevaluation (Joshi et al. 2018). The inadequacy in SWOT analysis can be overcome by the addition of AHP, which is the multicriteria decision-making tool that can rank these attributes on the basis of a structured scale (Kurttila et al. 2000). The process involves a pairwise comparison between attributes by a select number of experts knowledgeable on the matter or issue (Saaty 1980). Therefore, in SWOT-AHP, the SWOT factors are evaluated against each other using a Likert scale, which provides qualitative comparisons between the different SWOT factors (Joshi et al. 2018).

The data collection process was initiated with the SWOT attribute design, followed by survey design and then data collection in two stages. For attribute design, a focus group meeting was convened among knowledgeable professionals to identify major strengths, weaknesses, opportunities, and threats associated with prescribed fire, which has been recommended to control eastern redcedar in the southern Great Plains. These individuals represented university researchers and other professionals who were affiliated with natural resources management organizations within the region. The process began with a discussion of the brainstormed list of potential strengths, weaknesses, opportunities, and threats. After deliberate discussion within the group and further review of literature, we reduced the list to four factors for each SWOT category. The first survey was designed to solicit ranking on all the factors identified in the focus meeting. The survey participants for this research included prescribed burn professionals primarily knowledgeable on eastern redcedar encroachment. The Institutional Review Board at Oklahoma State University reviewed and approved the survey before administration. A description of the identified SWOT factors is given in Table 1.

The data analysis from the first survey reveals top ranked attributes in each category. Those top-ranked attributes are then used in the second survey to rank attributes across the categories (strength to weakness, opportunity, and threats). The top factor of each SWOT category found in the first survey can theoretically differ between stakeholders; therefore, multiple versions of the second survey were designed to solicit ranking across the categorical factors (Joshi et al. 2018). Following this protocol, the second survey took the top SWOT factors identified in the first survey and then asked responders to compare those in a similarly designed pairwise comparison table. These surveys were originally designed in *Microsoft Word* and replicated in the Qualtrics platform for online distribution. The surveys were administered to landowners, governmental professionals, and nongovernmental organization (NGO) professionals (Table 2).

For the first survey, 47 responses from government employees, 34 responses from landowners, and 16 responses from NGO employees provided SWOT ratings. For the second survey, 38 responses were from government employees, 42 responses were from landowners, and 18 responses were from NGO employees. While most respondents chose only one stakeholder group, 15 respondents in each round represented multiple stakeholder groups, so their responses were counted for each group. The number of responses used for our data analyses were comparatively higher than many SWOT-AHP–designed natural resource stakeholder analysis studies (Shrestha et al. 2004; Dwivedi and Alavalapati 2009; Starr et al. 2019).

Responders completed a pairwise comparisons table as shown in Table 2. This table uses a Likert scale established by Saaty (1977), which includes odd numbers from 1 to 9. The even numbers were designed to serve as transitional values between the successive judgments (Saaty 1977). A selection of 1 meant the factors were equally important, and a selection of 9 meant that the chosen factor has absolute importance over the alternative factor.

Although stakeholders represented prescribed burn professionals and were expected to be familiar with the issue, participants were still provided with some background information on the role of prescribed fire as a land management tool to control eastern redcedar in the southern Great Plains. The data collected from these surveys were then analyzed using the procedures recommended in literature (Saaty 1977; Kurttila et al. 2000). In the first step, a geometric mean of aggregate responses was found for each comparison to account for variance among survey responses. Next, the data were placed into a pairwise comparison matrix as shown in Equation 1 (Saaty 1977) and its reciprocal was then mirrored as depicted. The super matrix for this can be explained in the following equation:

$$B = \begin{bmatrix} 1 & t_1/t_2 & \dots & t_1/t_n \\ t_2/t_1 & 1 & \dots & t_2/t_n \\ \vdots & \vdots & 1 & \vdots \\ t_n/t_1 & t_n/t_2 & \dots & 1 \end{bmatrix} \quad (1)$$

In Equation 1, t represents relative weight for each pairwise comparison. After this step, each column was normalized to 1 and the maximum eigenvalue, λ_{max}, was calculated following the process suggested in the AHP literature (Saaty 1977). Lastly, the maximum eigenvalue was multiplied by the factor weight to produce a consistency ratio (CR) for each set of comparisons (Saaty 1977; Catron et al. 2013). The CR determination is the most important indicator in AHP analysis as it allows insight into the validity of the model and whether the responders generally agree with their rankings of the SWOT attributes (Starr et al. 2019).

Equations 2 and 3 show how the CR was calculated.

$$CI = (\lambda_{max} - n)/(n - 1) \quad (2)$$

$$CR = \left(\frac{CI}{RI(n)}\right) * 100 \quad (3)$$

Table 2
Illustration showing how pairwise comparisons were done between attributes. The direction of arrow shows respondent preference.

Factors	9	7	5	3	1	3	5	7	9	Factors
Cost-effective										Pollen reduction
Cost-effective										Easily accessible to landowners
Cost-effective										Help reduce fuel load
Pollen reduction										Easily accessible to landowners
Pollen reduction										Help reduce fuel load
Easily accessible to landowners										Help reduce fuel load

1 = Equally important; 3 = Moderately more important; 5 = More important; 7 = Very important; 9 = Extremely important.

Table 3
The Strength, Weakness, Opportunity, and Threat (SWOT) factor and global priorities of prescribed fire for eastern redcedar for each stakeholder group,

SWOT attribute	Factor priority Government	Landowner	NGO	Global priority Government	Landowner	NGO
Strengths				***0.25***	***0.21***	***0.31***
S1: Cost-effective	0.31	0.34	*0.34	0.08	0.07	0.11
S2: Pollen reduction	0.10	0.09	0.09	0.02	0.02	0.03
S3: Easily accessible to landowners	0.25	0.20	0.25	0.06	0.04	0.08
S4: Help reduce fuel load	*0.35	*0.37	0.32	0.09	0.08	0.10
Weaknesses				***0.21***	***0.22***	***0.17***
W1: Ineffective for large trees	0.14	0.17	0.19	0.04	0.04	0.06
W2: Weather dependent	*0.35	*0.33	0.29	0.09	0.07	0.09
W3: Specialized training required	0.30	0.32	*0.37	0.08	0.07	0.12
W4: Smoke management	0.21	0.17	0.14	0.05	0.04	0.04
Opportunities				***0.21***	***0.23***	***0.38***
O1: Provide wildlife habitat	0.29	0.26	0.33	0.07	0.06	0.10
O2: Improve cattle/pastureland production	*0.32	*0.38	*0.39	0.08	0.08	0.12
O3: Pest control (ticks and horn flies)	0.12	0.15	0.09	0.03	0.03	0.03
O4: Enhance public acceptance of fire	0.26	0.21	0.18	0.07	0.04	0.06
Threats				***0.33***	***0.34***	***0.14***
T1: Liability issues/uncontrolled fire	*0.33	*0.38	0.27	0.08	0.08	0.08
T2: Cultural stigma against fire	0.25	0.20	*0.33	0.06	0.04	0.10
T3: Inconsistent policies among agencies	0.22	0.17	0.19	0.05	0.04	0.06
T4: Inability to burn in urban interface	0.20	0.24	0.21	0.05	0.05	0.07

N GO indicates nongovernmental organization; *, highest-ranked attribute during factor priority calculation; italicized and bold values, multipliers used to estimate overall priority scores.

Equation 2 shows how the consistency index is related with the maximum eigenvalue (λ_{max}) and the size of the matrix (n), which was 4 in our case. As shown in Equation 3, the final step is the CR calculation, which requires a random index. The random index does not change for given matrix order, and the value is 0.9 for a 4×4 matrix (Saaty 1980). A CR value of $< 10\%$ indicates consistency among opinions of stakeholders and of the model (Starr et al. 2019).

Results

Every SWOT attribute had consistency ratios of $< 10\%$, which indicates consistency among the opinions of the stakeholders and validity of the results. Most (95%) respondents were familiar with eastern redcedar as a management challenge in the southern Great Plains. Among our respondents, most (88%) were male and white (91%) with the average age of 54 years. The results provided an important perspective on stakeholder priorities regarding SWOT attributes related to prescribed burning. Using AHP analysis, priority scores (p) were calculated for each of the 16 factors from the first survey (factor priority) and 4 categories from the second survey (global priority). Table 3 displays the primary results of the research and is organized by category of SWOT attribute and differentiates between the stakeholder groups. Figure 1 provides a further visual aid for examination of the similarities and differences between the stakeholder groups.

Regarding the individual factor priorities, the greatest strengths identified by all stakeholder groups were cost-effectiveness (S1) and hazardous wildfire fuel reduction (S4). For NGO stakeholders, S1 was the highest prioritized strength ($P = 0.34$) while landowners and government stakeholders highlighted its ability to help reduce fuel loads ($P = 0.37$ and 0.35, respectively). The greatest weaknesses emphasized were weather dependency (W2) and the requirement of specialized training (W3). Government and landowner stakeholders prioritized weather dependency ($P = 0.35$ and 0.33, respectively) while NGOs selected specialized training (0.37).

Factor priorities for the opportunities category were similar across all three stakeholder groups with production improvement to cattle and pastureland (O_2) given the highest priority. Government stakeholders provided a relatively similar priority score to cattle and pastureland production and wildlife habitat ($P = 0.32$ and 0.29, respectively), while landowners and NGO members provided greater relative emphasis for the former ($P = 0.38$ and 0.39, respectively). Government and landowner stakeholders found liability issues (T1) to be the greatest threat ($P = 0.33$ and 0.38, respectively). For NGOs, cultural stigma against fire (T2) was the greatest threat ($P = 0.33$).

Turning to the global priorities gathered during the second survey, both government and landowner stakeholders indicated that threats are the most significant of the SWOT categories ($P = 0.33$ and 0.34, respectively). Otherwise, both groups prioritized strengths, weaknesses, and opportunities similarly. NGO stakeholders gave opportunities the highest ranking ($P = 0.38$), followed somewhat closely by strengths ($P = 0.31$). The lowest scored category for NGOs was threats ($P = 0.14$).

Discussion

Overall, our results suggest that two primary stakeholders of prescribed fire, private landowners and state or federal agency pro-

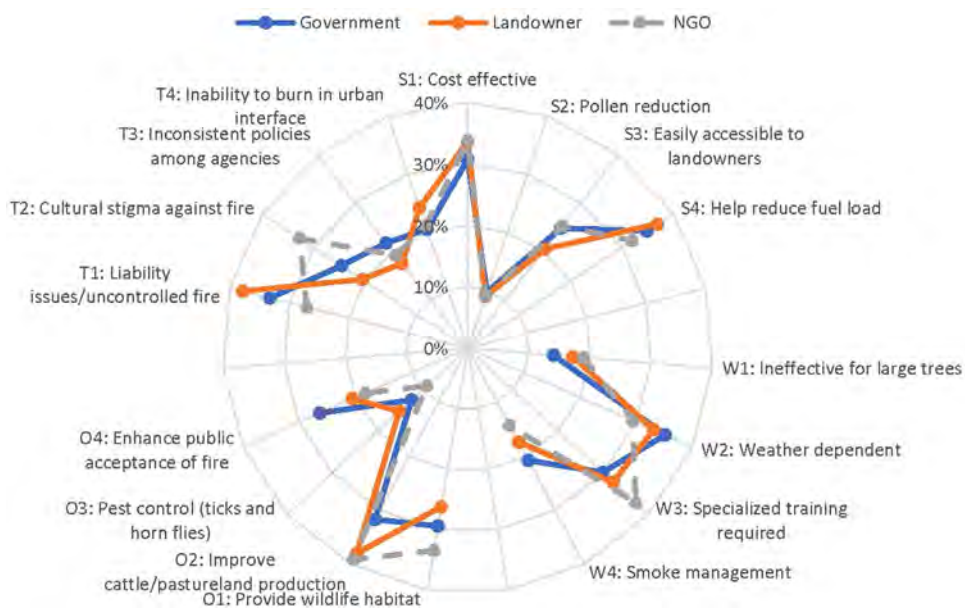

Figure 1. The diagram describes how different stakeholder groups placed importance on Strength, Weakness, Opportunity, and Threat attributes regarding eastern redcedar spread.

fessionals, have several concerns that have collectively outweighed the positive aspects of prescribed fire. These concerns included negative cultural stigma, liability concerns, weather dependency, and a need for specialized training, among others. These concerns created challenges for prescribed burn adoption in the southern Great Plains as several government agencies were mandated to provide technical assistance on prescribed fire to private landowners or other needy constituents (Wilbur et al. 2021). Nonetheless, perceived risks associated with liabilities from fire escape have been consistently identified as obstacles for prescribed fire success in the Great Plains (Elmore et al., 2010; Joshi et al. 2019), and our results also corroborated those findings. Interestingly, there was not universal consensus and the stakeholders representing NGOs perceived these concerns less severely. While NGOs partner with government agencies to establish a culture of shared responsibility and comanagement to alleviate prescribed fire constraints (Marks-Block and Tripp 2021), their involvement may serve in a more supportive role in the other two groups who possessed more legal liability. Previous research also suggests varied risk perceptions among prescribed burn professionals (Parajuli et al. 2019). In particular, landowners and elderly respondents using a burn plan in 14 states in the midwestern, western, and southern regions of the United States were more likely to acquire prescribed burn insurance than others (Parajuli et al. 2019). The contrasting degree of involvement in prescribed fire practice may explain these differences. Likewise, wind speed and moisture conditions play significant roles in ensuring prescribed burn success (Joshi et al. 2019; Yurkonis et al. 2019). Therefore, results suggesting weather dependency as a weakness of prescribed fire make intuitive sense.

Our results also highlighted some positive perspectives, which may help promote broader social acceptance of prescribed fire as a management tool to control eastern redcedar in the southern Great Plains. The use of prescribed fire is among the most cost-effective best management practices and is substantially cheaper than other alternatives such as mechanical brush control and herbicide use (Bidwell et al. 2002; Maggard and Barlow 2018). Our stakeholders broadly acknowledged this fact. In the southern Great Plains, range management for livestock production is a primary objective and research suggests net present value for livestock production is highest when prescribed fire is used in the early stages of eastern redcedar invasion (Coffey 2013). Stakeholder recognition of this was evident in our results as the role of prescribed fire as an opportunity to improve rangeland and forage production was also rated highly.

While prescribed fire use in the southern Great Plains is the focus of the present research, its importance for reducing wildfire risk in other landscapes is well noted across the United States (Kolden 2019). However, it should be noted that prescribed fire adoption and implementation must be anchored by an adherence and acknowledgement of local context. For example, smoke tolerance is notably higher in the southern United States than in other regions (Engebretson et al. 2016). More recently, extremely large fires resulting from escaped prescribed burns in New Mexico during the 2022 burn season resulted in the US Forest Services pausing all prescribed burn activities pending agency review (USFS 2022). In future research, it would be interesting to analyze SWOT attributes, which might vary regionally.

The SWOT-AHP methodology used in this research benefits from fast and cost-effective deployment. We feel that additional research in this vein might be instrumental in creating greater depth and understanding within and across other regions and localities. This is particularly prescient as fire management efforts at various levels across the country continue to strive for greater success in mitigation of wildfire and restoration of fire-dependent ecosystems. This approach would likely be helpful in allowing researchers and managers to respond quickly to changing policies and increasing natural disturbances such as extreme wildfires.

Some limitations of this study are noteworthy. Although most stakeholders were knowledgeable about prescribed fire and its role in controlling eastern redcedar encroachment, some found the Likert scale comparisons difficult to understand or use. Likewise, these stakeholders were not 100% mutually exclusive as a few respondents revealed representing more than one stakeholder group. Though these discussions could be best achieved through in-person meetings, such planning was not possible due to the ongoing COVID-19 pandemic. In the future, in person data collection may help minimize these challenges.

Implication

Our study results have important management implications. For example, despite higher perceived risks associated with escaped prescribed fire (Harr et al. 2014; Joshi et al. 2019; Weir et al. 2019), the actual number of incidents remains very low (approximately 1.5% from 1995 to 2012) (Weir et al. 2015) and the dread factor is mostly attributed to the cultural stigma (Twidwell et al. 2015). Frequent wildfires in the wildland-urban interface and the associated media coverage often enhance fears (Twidwell et al. 2015) that can negatively influence stakeholder perception. Therefore, more tailored outreach on burn plans, smoke management, burn insurance, and other risk minimizing factors may help alleviate this situation. In particular, landowners and government stakeholders may gain a sense of reassurance through burn insurance acquisition and other best practices.

In the southern Great Plains, as well as in much of the southern United States, there is a higher level of cultural familiarity with prescribed fire and its effects. This familiarity appears to positively influence acceptance of this practice (Winter et al. 2006). Additionally, private, government, and NGO actors showed similar responses to the SWOT attributes except for those differences noted in our results. Such relative alignment may positively influence management policies and actions needed to reduce potential wildfire risk. Our results further align this research topic within the realm of social exchange theory and its relationship to collective action and social capital (Ostrom 1990; Cropanzano and Mitchell 2005).

Although prescribed fire requires specialized training, opportunities can be made less intimidating, particularly with peer learning events that are available through many cooperatives, such as prescribed burn associations (PBAs). Fortunately, the citizenry empowered through the PBAs continues to grow in the southern Great Plains (Twidwell et al. 2013) and their success will likely bring stakeholders together to learn from each other. PBAs are often affiliated with the extension offices of state universities, as well as various NGOs including the Nature Conservancy and Wild Turkey Federation. In the southern Great Plains, the Natural Resources Conservation Service, Coalition of Prescribed Fire Councils, and Southern Fire Exchange also represent valuable repositories of expertise. The expansion of educational and youth-outreach efforts in fire safety and land stewardship should be considered a key stepping stone to strengthen the institutional and operational knowledge base of future generations of land stewards.

For researchers and practitioners alike, it will be important to remain vigilant for opportunities to look for, recognize, and include those who may be underrepresented in programs that strive to address ecological issues in the southern Great Plains. Efforts to mitigate such inequities are desirable as has been observed with Black farmers affected by eastern redcedar encroachment in Oklahoma (Fagundes et al. 2020). Additionally, care must be taken to consider how structures associated with those norms and practices espoused in PBAs may also create barriers for the implementation of cultural or traditional burn practices (Adlam et al. 2021). Collaboration and understanding of shared values and differences are needed to define successful future stewardship practices.

Conclusion

This study uses the SWOT-AHP platform to understand how natural resource management stakeholders perceive prescribed fire as a BMP to control eastern redcedar encroachment. Our results suggested that stakeholders representing NGOs favor the positive factors associated with prescribed fire. However, landowners and government stakeholders are particularly concerned about potential fire threats. The primary challenges to promote prescribed fire include cultural stigma, liability, weather dependency, and the need for specialized manpower, which may collectively outweigh the positive aspects of prescribed fire in a given location. Interestingly, stakeholders representing NGOs have somewhat contrasting opinions toward prescribed fire as a land management tool. These findings also suggest broad agreement among stakeholders that prescribed fire is a cost-effective practice that can help reduce fuel loads and improve pastureland. Since landowners and government agencies are two primary stakeholders in the promotion of prescribed fire, their consternations suggest the need for tailored outreach including opportunities to get hands-on experience and increase ease of access to resources and information. We suggest supporting locally attuned fire learning and knowledge exchanges through PBAs and other fire learning networks, as well as university and state extension offices.

Declaration of Competing Interest

Authors do not have any conflict of interest in study design, analysis, and publication.

References

Adlam, C., Almendariz, D., Goode, R.W., Martinez, D.J., Middleton, B.R., 2021. Keepers of the flame: supporting the revitalization of indigenous cultural burning. Society & Natural Resources 1–16.

Bidwell, T.G., Weir, J.R., Engle, D.M., 2002. Eastern redcedar control and management-best management practices to restore Oklahoma's ecosystems. Oklahoma Cooperative Extension Service. NREM-2876, Stillwater, OK, USA.

Catron, J., Stainback, G.A., Dwivedi, P., Lhotka, J.M., 2013. Bioenergy development in Kentucky: a SWOT-ANP analysis. Forest Policy and Economics 28, 38–43.

Coffey, A.J., 2013. Private benefits of eastern redcedar management and the impact of changing stocker value of gain. Oklahoma State University, Stillwater, OK, USA.

Cropanzano, R., Mitchell, M.S., 2005. Social exchange theory: an interdisciplinary review. Journal of Management 31 (6), 874–900.

Drake, B., Todd, P, 2002. A strategy for control and utilization of invasive juniper species in Oklahoma. Redcedar Task Force. Oklahoma Dept. of Agriculture, Food and Forestry 1-75, Oklahoma City, OK, USA.

Dudek, J., 2020. A burning question: how much drought causes increased flammability in eastern redcedar?. Oklahoma State University, Stillwater, OK, USA, 52 pages.

Dwivedi, P., Alavalapati, J.R., 2009. Stakeholders' perceptions on forest biomass-based bioenergy development in the southern US. Energy Policy 37 (5), 1999–2007.

Elmore, R.D., Bidwell, T.G., Weir, J.R., 2010. Prescribed fire public perception and education perceptions of Oklahoma residents to prescribed fire. In: Robertson, K.M., Galley, K.E., Masters, R.E. (Eds.), Proceedings of the 24th Tall Timbers Fire Ecology Conference: The Future of Prescribed Fire: Public Awareness, Health, and Safety. Tall Timbers Research Station, Tallahassee, FL, USA, pp. 50–61.

Engebretson, J.M., Hall, T.E., Blades, J.J., Olsen, C.S., Toman, E., Frederick, S.S., 2016. Characterizing public tolerance of smoke from wildland fires in communities across the United States. Journal of Forestry 114 (6), 601–609.

Epanchin-Niell, R.S., Hufford, M.B., Aslan, C.E., Sexton, J.P., Port, J.D., Waring, T.M, 2010. Controlling invasive species in complex social landscapes. Frontiers in Ecology and the Environment 8 (4), 210–216.

Fagundes, C., Picciano, L., Tillman, W., Mleczko, J., Schwier, S., Graddy-Lovelace, G., Hall, F., Watson, T., 2020. Ecological costs of discrimination: racism, red cedar and resilience in farm bill conservation policy in Oklahoma. Renewable Agriculture and Food Systems 35 (4), 420–434.

Fowler, C., Konopik, E., 2007. The history of fire in the southern United States. Human Ecology Review 165–176.

Galgamuwa, G., Wang, J., Barden, C.J., 2020. Expansion of eastern redcedar (*Juniperus virginiana* L.) into the deciduous woodlands within the forest–prairie ecotone of Kansas. Forests 11 (2), 154.

Ganguli, A.C., Engle, D.M., Mayer, P.M., Fuhlendorf, S.D., 2008. When are native species inappropriate for conservation plantings? Rangelands 30 (6), 27–32.

Harr, R.N., Morton, L.W., Rusk, S.R., Engle, D.M., Miller, J.R., Debinski, D., 2014. Landowners' perceptions of risk in grassland management: woody plant encroachment and prescribed fire. Ecology and Society 19 (2).

Joshi, O., Parajuli, R., Kharel, G., Poudyal, N.C., Taylor, E., 2018. Stakeholder opinions on scientific forest management policy implementation in Nepal. PloS One 13 (9), e0203106.

Joshi, O., Poudyal, N.C., Weir, J.R., Fuhlendorf, S.D., Ochuodho, T.O., 2019. Determinants of perceived risk and liability concerns associated with prescribed burning in the United States. Journal of Environmental Management 230, 379–385.

Joshi, O., Will, R.E., Zou, C.B., Kharel, G., 2019. Sustaining Cross-Timbers forest resources: current knowledge and future research needs. Sustainability 11 (17), 4703.

Kahan, D.M., 2003. The logic of reciprocity: trust, collective action, and law. Michigan Law Review 102 (1), 71–103.
Kaur, R., Joshi, O., Will, R.E., 2019. The ecological and economic determinants of eastern redcedar *(Juniperus virginiana)* encroachment in grassland and forested ecosystems: a case study from Oklahoma. Journal of Environmental Management, 109815.
Knox, A., Meinzin-Dick, R., 2001. Collective action, property rights and devolution of natural resource management: exchange of knowledge and implications for policy. Technical Report CAPRi, Working Paper, No. 11, International Food Policy Research Institute, Washington, DC, page 71.
Kolden, C.A., 2019. We're not doing enough prescribed fire in the Western United States to mitigate wildfire risk. Fire 2 (2), 30.
Kreuter, U.P., Stroman, D.A., Wonkka, C.L., Weir, J., Abney, A.A., Hoffman, J.K., 2019. Landowner perceptions of legal liability for using prescribed fire in the Southern Plains, United States. Rangeland Ecology & Management 72 (6), 959–967.
Kurttila, M., Pesonen, M., Kangas, J., Kajanus, M., 2000. Utilizing the analytic hierarchy process (AHP) in SWOT analysis—a hybrid method and its application to a forest-certification case. Forest Policy and Economics 1 (1), 41–52.
Maggard, A., Barlow, B., 2018. Costs & trends of southern forestry practices, 2016. Alabama Cooperative Extension System (ACES), Auburn, AL, USA, 5 pages.
Maguire, L.A., Albright, E.A., 2005. Can behavioral decision theory explain risk-averse fire management decisions? Forest Ecology and Management 211 (1-2), 47–58.
Marks-Block, T., Tripp, W., 2021. Facilitating prescribed fire in northern California through indigenous governance and interagency partnerships. Fire 4 (3), 37.
McGranahan, D.A., Wonkka, C.L., 2020. Ecology of fire-dependent ecosystems: wildland fire science, policy, and management. CRC Press, Boca Raton, FL, USA, 266 pages.
Meneguzzo, D.M., Liknes, G.C., 2015. Status and trends of eastern redcedar *(Juniperus virginiana)* in the central United States: analyses and observations based on forest inventory and analysis data. Journal of Forestry 113 (3), 325–334.
Morton, L.W., Regen, E., Engle, D.M., Miller, J.R., Harr, R.N., 2010. Perceptions of landowners concerning conservation, grazing, fire, and eastern redcedar management in tallgrass prairie. Rangeland Ecology & Management 63 (6), 645–654.
Namugenyi, C., Nimmagadda, S.L., Reiners, T., 2019. Design of a SWOT analysis model and its evaluation in diverse digital business ecosystem contexts. Procedia Computer Science 159, 1145–1154.
Norris, M.D., Blair, J.M., Johnson, L.C., McKane, R.B., 2001. Assessing changes in biomass, productivity, and C and N stores following *Juniperus virginiana* forest expansion into tallgrass prairie. Canadian Journal of Forest Research 31 (11), 1940–1946.
Ortmann, J., Stubbendieck, J., Masters, R.A., Pfeiffer, G.H., Bragg, T.B., 1998. Efficacy and costs of controlling eastern redcedar. Journal of Range Management 158–163.
Ostrom, E., 1990. Governing the commons: the evolution of institutions for collective action. Cambridge University Press, Cambridge, England, 298 pages.
Parajuli, R., Joshi, O., Poudyal, N.C., Kreuter, U.P., 2019. To insure or not to insure? Factors affecting acquisition of prescribed burning insurance coverage. Rangeland Ecology & Management 72 (6), 968–975.
Saaty, T.L., 1977. A scaling method for priorities in hierarchical structures. Journal of Mathematical Psychology 15 (3), 234–281.
Saaty, T.L., 1980. The analytic hierarchy process. McGraw-Hill, New York, NY, USA, 287 pages.
Shrestha, R.K., Alavalapati, J.R., Kalmbacher, R.S., 2004. Exploring the potential for silvopasture adoption in south-central Florida: an application of SWOT–AHP method. Agricultural Systems 81 (3), 185–199.
Smith, S., 2011. Eastern red-cedar: positives, negatives and management. Samuel Roberts Noble Foundation, Ardmore, OK, USA, 8 pages.
Starr, M., Joshi, O., Will, R.E., Zou, C.B., 2019. Perceptions regarding active management of the Cross-timbers forest resources of Oklahoma, Texas, and Kansas: a SWOT-ANP analysis. Land Use Policy 81, 523–530.
Stroman, D.A., Kreuter, U.P., Wonkka, C.L., 2020. Landowner perceptions of woody plants and prescribed fire in the Southern Plains, USA. PloS One 15 (9), e0238688.
Symstad, A.J., Leis, S.A., 2017. Woody encroachment in northern Great Plains grasslands: perceptions, actions, and needs. Natural Areas Journal 37 (1), 118–127.
Twidwell, D., Rogers, W.E., Fuhlendorf, S.D., Wonkka, C.L., Engle, D.M., Weir, J.R., Kreuter, U.P., Taylor Jr., C.A., 2013. The rising Great Plains fire campaign: citizens' response to woody plant encroachment. Frontiers in Ecology and the Environment 11 (s1), e64–e71.
Twidwell, D., Wonkka, C.L., Sindelar, M.T., Weir, J.R., 2015. First approximations of prescribed fire risks relative to other management techniques used on private lands. PLoS One 10 (10), e0140410.
Van Els, P., Will, R.E., Palmer, M.W., Hickman, K.R., 2010. Changes in forest understory associated with Juniperus encroachment in Oklahoma, USA. Applied Vegetation Science 13 (3), 356–368.
Weir, J.R., Kreuter, U.P., Wonkka, C.L., Twidwell, D., Stroman, D.A., Russell, M., Taylor, C.A., 2019. Liability and prescribed fire: perception and reality. Rangeland Ecology & Management 72 (3), 533–538.
Weir, J.R., Scasta, J.D., 2014. Ignition and fire behaviour of *Juniperus virginiana* in response to live fuel moisture and fire temperature in the southern Great Plains. International Journal of Wildland Fire 23 (6), 839–844.
Weir, J.R., Twidwell, D., Wonkka, C.L., 2016. From grassroots to national alliance: the emerging trajectory for landowner prescribed burn associations. Rangelands 38 (3), 113–119.
Wilbur, R., Stanley, C., Maczko, K.A., Scasta, J.D., 2021. Perceptions of NRCS assistance with prescribed fires on US private lands: a regionally stratified case study. Fire 4 (3), 47.
Wilcox, B.P., Birt, A., Archer, S.R., Fuhlendorf, S.D., Kreuter, U.P., Sorice, M.G., van Leeuwen, W.J., Zou, C.B., 2018. Viewing woody-plant encroachment through a social–ecological lens. BioScience 68 (9), 691–705.
Winter, G., Vogt, C., McCaffrey, S., 2006. Residents warming up to fuels management: homeowners? Acceptance of wildfire and fuels management in the wildland-urban interface. In: McCaffrey, S.M. (Ed.), The public and wildland fire management: social science findings for managers. Gen. Tech. Rep. NRS-1. US Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, PA, USA, pp. 19–32.
Wycoff, D.G., 1984. The Cross Timbers: And Ecotone in Historical Perspective. In page 1–20 Patricia, L., Kawecki, Wycoff, Don G. (Eds.). Contributions to Cross Timbers Prehistory, Studies in Oklahoma's Past, No. 12, Oklahoma Archaeological Survey and Cross Timbers Heritage Association No. 3. Oklahoma Archaeological Survey. University of Oklahoma, Norman, page 1–20.
Yurkonis, K.A., Dillon, J., McGranahan, D.A., Toledo, D., Goodwin, B.J., 2019. Seasonality of prescribed fire weather windows and predicted fire behavior in the northern Great Plains, USA. Fire Ecology 15 (1), 1–15.

7th

NATIONAL SMALL FARM CONFERENCE

SEPTEMBER 20-22, 2016
VIRGINIA BEACH, VA

Proceedings of the 7th National Small Farm Conference

---Creating and Sustaining Small Farmers and Ranchers---

VIRGINIA BEACH CONVENTION CENTER•VIRGINIA BEACH, VA

September 20-22, 2016

PROCEEDINGS OF THE 7TH NATIONAL SMALL FARM CONFERENCE

Theme: *Creating and Sustaining Small Farmers and Ranchers*

Venue: *Virginia Beach Convention Center, Virginia Beach, VA*

Date: *September 20-22, 2016*

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Proceedings of the 7th National Small Farm Conference

The 7th National Small Farm Conference, "*Creating and Sustaining Small Farmers and Ranchers*", was hosted by Virginia State University, in partnership with Virginia Tech and various agencies from the U.S. Department of Agriculture. During the conference, presenters shared successes in small farm and rancher activities, as well as innovative ideas in research, extension and outreach to strengthen collaboration and partnerships among state specialists who work to ensure that small farmers and ranchers continue to have a place in a rapidly changing socio-economic environment. The conference also served as a forum to discuss the results of research geared towards addressing challenges facing small farmers and ranchers. Strengthening and expanding partnerships created at the six previous National Small Farm Conferences was a priority for the Virginia Beach meeting. The 7th National Conference consisted of short courses, oral and poster presentations, exhibits, success stories, and educational tours within the environs of the City of Virginia Beach, and the Eastern Shore of Virginia.

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Welcome to the 7th National Small Farm Conference

Dear Conference Participants:

On behalf of the conference planning committees, our conference host Virginia State University in partnership with Virginia Tech, conference sponsors, land grant colleges and universities, community-based organizations, USDA Agencies, small farmers and ranchers, foundations, State Small Farm Program Coordinators, other public and private sector organizations, other stakeholders and customers, welcome to the 7th National Small Farm Conference. The conference's theme, "***Creating and Sustaining Small Farmers and Ranchers,***" provides a forum to discuss programs and services that have been created as well share strategies to sustain more farmers and ranchers. For discussion at this conference are issues raised by stakeholders from land grant colleges and universities, community-based organizations, farm communities and others working with small farmers and ranchers. Sustaining programs is of essence if we are to promote and encourage innovative ideas that can be replicated in order to enhance economic opportunities and improve the quality of life for small farmers and ranchers nationwide. This conference builds upon the successes of previous conferences held in Nashville, Tennessee in 1996; St. Louis, Missouri in 1999; Albuquerque, New Mexico in 2002; Greensboro, North Carolina in 2005; Springfield, Illinois in 2009; and Memphis, Tennessee in 2012. This is a train-the-trainer conference consisting of several preconference short courses and program efforts focusing on critical areas such as marketing opportunities, traditional and alternative enterprises, food production and safety, risk management, urban agriculture, outreach, training and research and extension priorities.

Tuesday's opening plenary begins with greetings and remarks to set the tone and direction of the conference while providing opportunities for networking. On Wednesday, the highlights include a keynote followed by farmers' panel on small farm opportunities and challenges, and closing out the afternoon with educational tours. Thursday highlights presentations from series of tracks, networking lunch followed by a closing session, entertainment and drawings.

Many thanks to the faculty and staff at Virginia State University for hosting this event in partnership with Virginia Tech and USDA agencies, conference sponsors, the local Planning Committee, the Conference Planning Committee, and others for their hard work over the past two years in planning for the 7th National Small Farm Conference.

Sincerely,

Denis Ebodaghe

Denis Ebodaghe, Ph.D.
Conference Chair &
National Program Leader for Small Farms

William Crutchfield
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Director, Small Farm Outreach Program
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Small Farms: Alternatives to Meet New Challenges from Changing Climate Conditions

Cynthia Rice, Buddhi Gyawali, Marion Simon, Louie Rivers Jr., Bijesh Mishra (Kentucky State University)

Abstract

Exploration of alternative methods of farm production is necessary if small, socially disadvantaged producers are to compete with larger conventional farms. Ideas such as organic, sustainable, bio-intensive, silvopasture, inter-cropping and other methods such as no-till and low till are new concepts which are not necessarily something a large farm can implement but that a small farm could adopt and use as a selling point or for financial growth. Development of apps to educate, train, and connect with others (farmers, wholesalers, value added resellers, retailers, etc.) allow farmers to explore options which may increase their brand and marketability. This presentation is based on years of reading, researching and practical applications as new techniques and information became available and evidence supporting climate change was documented. No one site or person molded the thought processes behind this paper but hundreds of talks, webinars, seminars, classes, papers and images influenced the writing of this paper over the decades. Heartfelt thanks to the many pioneers and their work in sustainability.

Introduction

Climate change and its effects are an increasing source of concern for nations. Addressing climate change issues that face farmers, and alternatives for regaining productivity and profit are the focus of this paper. In the past several years, workshops and training have dealt with financial management, know-how or practical farm management and education in new practices or new areas of growth in farm production. There was a typical pattern which was followed in an annual cycle dealing with animal and plant production and harvest with occasional new technology or practices. Times change and so do needs – today's farmers need to adapt in order to remain viable in the face of climate change. Training and workshops must similarly change to keep up with the new REALITIES of hotter and drier weather as well as changing rainfall patterns.

Factors Affecting the Changing Face of Farming

Farmers are traditionalists in many areas of their work such as always planting in the spring and harvesting in the fall. Unfortunately, things don't remain the same, especially with accelerating climate change. The long term effects of climate change will be manifested in changing vegetation patterns and variations in species composition as both invasive and native species recede from the south and advance to the north. What this means is that species such as apples which require a certain amount of chilling time, will become less productive where they

currently are and will become more productive in areas north of current orchards, how far north only time will tell.

Small farms are uniquely suitable to adapt to climate change. Many small areas/plots allow for many different growth patterns. Different markets and niches including wholesale, restaurants, retailers and ethnic/cultural markets are available to absorb seasonal produce. Small farmers are naturally positioned to be leaders in new techniques as different methods are tried at small scale. They are also leaders in crop introductions as alternative crops are tried and market bases are developed. Due to their involvement in growing specialty or alternative crops, they are able to develop relationships with local restaurants as new crops are provided for signature dishes.

Farmers are caught in unplanned and unexpected situations. By the very nature of farming, weather is one of the driving factors of agricultural production. Issues such as drought and flooding, cooler and hotter temperatures and possible wet and dry monsoon planting seasons are becoming important factors of farm decision making. These situations are causing farmers to suffer reduced yields or crop loss. These weather occurrences can be devastating to planting and harvesting schedules and the frequency with which they occur may lead to farmers losing their farms due to continued economic loss. Small farmers can adjust easier to unplanned and unexpected situations. They can plan short and long term solutions such as developing micro-climates and planting different crops with different needs at different times. By planting smaller plots/area, farmers do not place all their revenue resources in one or two major crops. Continued cropping at a manageable scale requires fewer workers who work throughout the year meaning less need for training/retraining. With production able to occur almost year round, especially with season extender devices such as greenhouses, loss of one crop does not lead to loss of all revenue due to several revenue streams.

Footprint/Carbon Sequestration

A bio-diverse environment will include a cycling of nitrogen and carbon into and out of the ground (hopefully more in than out) as well as organic matter which will add to the fertility year after year. When farmers interact locally, less fuel and better tasting food which is allowed to ripen individually combined with other factors helps to reduce their carbon footprint. Small farms have a small carbon footprint with lower transportation costs, also. They are more involved in their local community in areas such as local fertilizers/animal waste, local storage, local sales, local customer base with less competition and local value added products.

Alternative Maintenance

In terms of alternative maintenance, allowing crop residue to stay in place as organic matter will lower labor costs, lower chemical costs, lower irrigation/water costs, lower fertilization costs, increase bio-diversity, and contribute to a healthier environment. Other alternative maintenance

practices such as weeds left as shade, support and trap crops (bio-control) with taller growth helps to provide a living mulch which retains moisture at ground level. With more organic matter there is more fertile land and less of commercially produced fertilizers can be used in effect conserving dwindling resources. Small farms are more likely to be bio-diverse allowing a healthier environment with more micro-organisms in variety and quantity and generally tend to use environment friendly practices.

Polyculture

For small farms, the capability of moving from a monoculture to a polyculture practice allows the work to be divided into segments to deal with different crops types. Harvests and planting can be done at different times or continually in small segments, which is well suited to a small farm. Farmers can have a continuing source of revenue which can allow them to budget better and borrow less. They can also, plant earlier and later in the season even through the winter months by use of crop extenders which allows them to produce more than previously possible. Small farmers can use innovative approaches such as hydroponics, aquaponics, high and low tunnels, as well as greenhouses, hoop houses, and row covers (different seasons and different crops). Using these crop extenders at different times enables small farmers to achieve continuous or near continuous cropping. Polyculture allows for more types in smaller quantities which could be spread out over a longer period to adapt to climate change issues such as reduced and increased (monsoon type) rainfall levels. With polyculture, fertilizer is used in smaller quantities on crops needing it (no/less nitrogen loading into waterways). Planting and harvesting can be spread over multiple microclimates for better production. The loss of a crop does not mean the loss of all income and farmers are better able to absorb and deal with smaller losses. Polyculture can result in multiple schedules with better labor management and continued employment.

Dry Farming vs Irrigation

A major consequence of climate change will be drier and hotter weather and less rainfall. Traditional crops may not survive or may produce less without additional water or water retention methods. Alternative crops requiring hotter temperatures or less water may be the new cash crop. Small farms can apply spot irrigation where it is needed based on crops currently growing in a specific location. Small plots can prevent or limit erosion because of the different water requirements and irrigation timing. Crops can be placed where they can do best, based on microclimate and nutrient need. Raised beds can be developed for intensive gardening, special needs such as acid or alkaline soil and to drain and/or retain excessive water/moisture allowing faster planting in rainy seasons. In-ground (below ground level) planting where water can be trapped for plant use, and prescriptive mulching are all possible on small farms.

Low Till/No Till

Less disturbance of soil leads to less work and more results. Fertility will increase due to crop residue being composted back into the soil and less time is spent on plowing, disking, and other practices associated with conventional tillage. More organic matter is retained cutting down on the amount of imported organic fertilizer that may harbor disease pathogens or invasive plant seeds. This will also give native plants a chance to multiply improving biodiversity within and above the soil. Less erosion and more moisture retention can occur because the soil is able to retain the structure which contributes to less drainage away from the soil and more drainage down into the soil. Small farms can allow micro-organisms' habitat to expand enriching the soil because smaller plots may be less subject to tillage. Due to differing planting cycles, the farmer can allow soil structure to regulate through thaw and freeze cycles creating air pockets letting gas exchange with the atmosphere. In such small farms, the soil is also able to store up water within the different layers of soil and nutrients increase due to organic matter accumulation.

Natural Fertilizers, Pollinators, Alternative Crops and Crop Rotation

Due to small spaces, synthetic fertilizers can offset the balance of the soil leading to only one crop being suitable for an area. Depletion of specific nutrients due to crop needs can be offset by crop succession. Chemical persistency is not generally a problem as naturally occurring fertilizers break down easily. Pollinators thrive in a no/low chemical environment, which is a high priority in the face of bee decline through colony collapse and destruction of butterfly habitats. Small farms also may be more organically inclined. They tend to have limited use of additional fertilizers as they strive for sufficient organic (as in non-synthetic, not as in US organic standard) production. Natural compostable organic matter is often used with no additives and are not generally hazardous in amounts used. Natural components provide nutrients with usually no residue and GAP (good agricultural practices) is often used. With fertilizer being naturally produced there are often no additional costs and the absorption of waste into the soil releases nutrients back into the soil quicker without bringing in additional salts from commercial fertilizers. This in turn helps with the natural pH balance.

Pesticides/Herbicides/Fungicides/Insecticides vs Biocontrol

With current commercially produced pesticides/herbicides/fungicides/insecticides containing synthetic and often persistent chemicals, many small farms are looking at bio-control as a viable replacement especially since these commercial products, while not harming the current crop, may adversely affect future crops, thus limiting crop rotation possibilities. With the commercially produced products, long term effects may not be known as evidenced by even popular items being pulled off the shelves. If they must be used then a localized, non-drift specialized and not broad spectrum product is recommended but on a small farm drift can affect other crops, animals or even people. Synthetic or lab produced may be shelf stable causing

chemical persistence in soil and water and may be linked to pollinator decline which decreases some crops' yields. So, generally small farms have little or no pesticides/herbicides/fungicides /insecticides use and look to bio-controls which are less damaging to the environment. With no commercial treatments, a proper growing environment where bio-controls are dominant allows plants to develop resistance to micro-organisms or be protected by trap crops, predatory insects, birds and other organisms.

Animal or Plant, or Animal and Plant

Animals may need different housing requirements such as taking advantage of coolness from earth (regulating with cool pipes or partially sheltered by earth to insulate from heat or cold). Positioning structures and watering areas to create cool spots are possible in small farms in relation to small plot usage. Small farms can take advantage of micro-climates through strategic building and vegetation placement (trees, shrubs, and water/irrigation ditches). Work animals and plants as a holistic approach (chicken tractors, movable paddocks) to enhance the production capabilities of small farms. Small farms can work animals into landscape or plants into microclimates which exist (orchard, forest, north slopes) or are created reducing controlled housing or man-made housing with their requirements. Free roaming or paddock roaming allows waste to be spread over land fertilizing ground, and preventing methane buildup while lowering contributions to greenhouse gases. Lower feed requirements due to pasturing animals letting them forage crops and natural food which builds muscle not fat. Using animals to help maintain the health of the land is a natural cycle which usually is environment friendly. Nutrient balance in food with little or no run off into water sources or escape into the atmosphere is a positive aspect of holistic farming which again is a practice well suited to small farms.

Invasives vs. Natives

Invasives such as kudzu, honeysuckle, and many weeds which thrive in the southern states may start to appear in Kentucky as natives migrate northward. If invasives establish themselves then small farms can find uses for them as non-cultivated food or forage. As soils dry out and barren patches appear invasives will enter unless farmers are prepared with heat tolerant alternatives. Small farms being bio-intensive leave little or no ground bare so there is less room for invasives. Little or no herbicides use will help the ground from becoming bare and keep native plants in place. Natives usually provide an ecological service such as deep root penetration to aerate soil. Natives thrive in soils which provide the nutrients/substances they need. The natural cycle of succession plants as planting area moves from bare ground to perennial increasing fertility (annual, biennial or perennial) so small farms can plan and use multistory plantings as natural succession takes place.

Historical/Traditional and New Norm

Traditional farming practices still are very much a presence. It will continue to be used for many years, but to feed the growing population there will be less imports as markets get more competitive. By adding small farms to the mix, they add to food security, help to keep prices low in comparison to other countries. With the climate changes occurring, traditional big farms may well become unfeasible to operate and having small farms already in place will ease the transition. Hoop house, high tunnel, row covers can mediate unusually high or low temperatures. Raised beds for new drainage problems can help mitigate changing rain patterns by better drainage and less disturbed earth can hold more moisture reducing irrigation needs. Smaller areas are easier to spot check to catch the onset of diseases due to too much or too little rain. Small farms are able to mulch easier or set berms or wells around plants to keep water in a set area. Based on size of areas small farmers may hand pollinate or attract pollinators with plants.

Conclusion

Farmers must become more resilient and seek ways to cope with the coming change while continuing to make a decent living. Plans put in place now will be refined and be able to provide food and income as climate change accelerates. Small farmers will become leaders on the forefront of food security for our communities and the nation. Climate change is real and farmers have to become more aware and react to the problems facing them (severe weather including drought and flooding and unusual high and low temperatures). Small farmers are more resilient to the effects of climate change and their experiences and skills to cope with the adverse effects of climate change can be useful for making larger farms resilient and sustainable.