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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., 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

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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 simulated with the appropriate combination of thinning and prescribed fire.

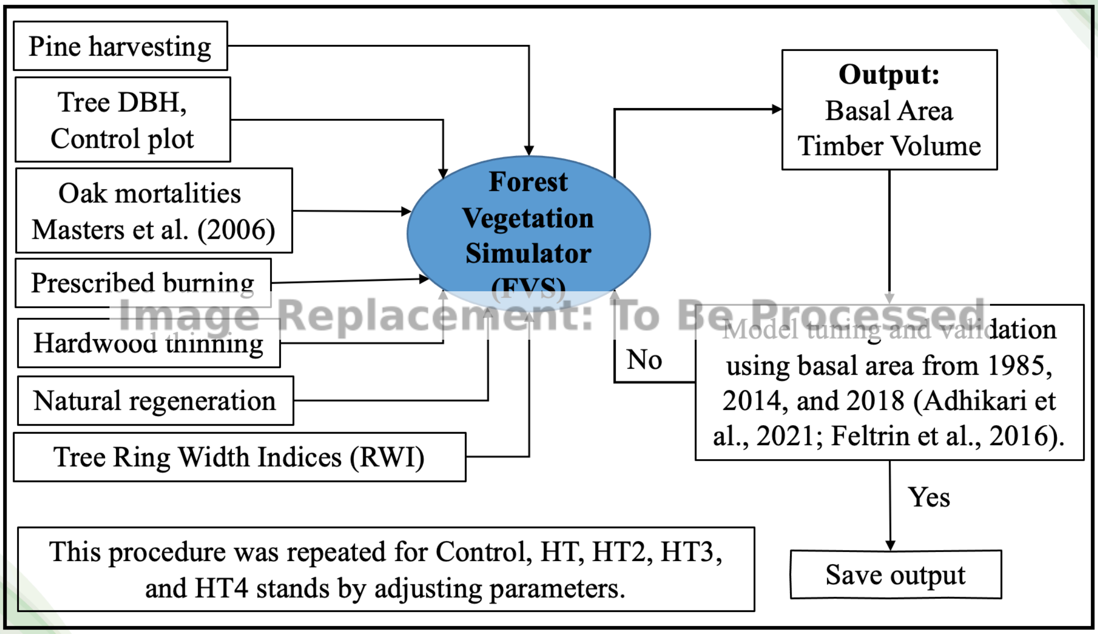

Fig. 1. A flowchart showing data input needed and outputs obtained for growth and yield analysis in the forest vegetation simulator.

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 northeastern 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:

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

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.

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

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:

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

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 grow-

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

ing 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). 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).*

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 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

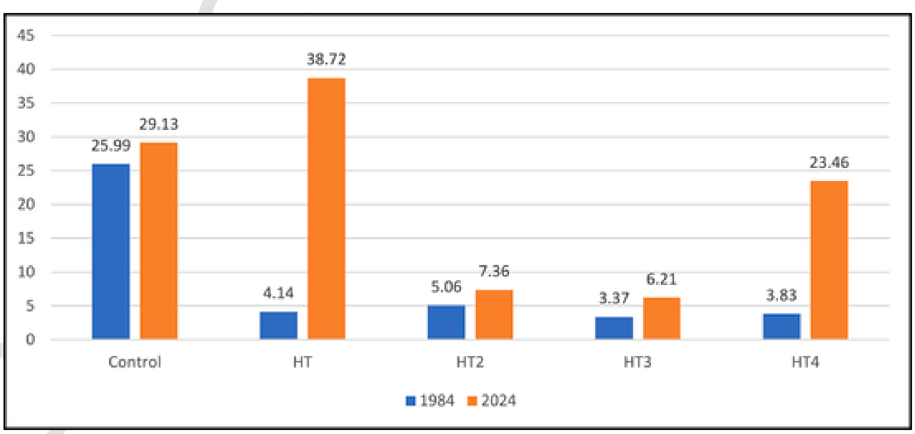

Fig. 2. Change in Basal Area estimated using FVS growth and yield model simulation in southeastern Oklahoma, USA.

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.

	Cattle Forage			Deer Forage				
Treatment	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

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

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 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 multipurpose 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 in-

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 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 $P < 0.05$.

terval (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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