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A comprehensive outlook on drought caused economic losses and landowner perceptions concerning drought and erratic rainfall patterns

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ABSTRACT

Natural disturbances such as drought reduce timber volume growth and increase tree mortality, which can have serious repercussions for the forest-based industries that rely on timber as a raw material. To assess these impacts, we utilized Forest Inventory and Analysis data and estimated weather caused-mortality and loss of total live timber volume for Oklahoma, USA between 2011 and 2015, a period in which this region experienced major drought events. An input-output model was built to understand economic implications for the forest sector given the live timber volume lost during this period. The results showed that the timberland drought could result in more than $20 million in the total losses for the Oklahoma forest sector. We also administered a survey instrument to understand landowner perceptions concerning drought and erratic rainfall patterns in Oklahoma. Our survey results revealed that landowners focused on livestock production, hunting, and active management perceived greater drought impacts. Our findings recommend outreach regarding forest thinning as a potential tool to reduce drought-related losses.

1. Introduction

Concerns regarding drought disturbances in forests are increasing, driven by recent drought events and future projections (Alizadeh et al., 2020; Clark et al., 2016; Martin, 2018). Projections indicate that future droughts will become more frequent and severe in specific regions of the USA by the middle of the 21st century (Peters and Iverson, 2019). In particular, if global warming persists at its current rate, the southern and central United States are expected to experience more frequent severe drought occurrences (Naumann et al., 2018). Additionally, drought durations are projected to significantly lengthen in many parts of the world, creating significant water supply-demand deficits (Naumann et al., 2018). Indeed, the south-central United States endured a severe drought from 2010 to 2015 (Doughty et al., 2018).

In Oklahoma, the forest sector faces various challenges with drought disturbances emerging as a major concern due to both the anticipated volatile nature of future droughts (Zhao et al., 2020) and the current threats posed to forests by drought (Brodribb et al., 2020). The forest sector plays a vital role in the Oklahoma economy. In 2022, the direct, indirect, and induced impacts of Oklahoma's forest sector amounted to $6.9 billion in industry output, providing employment for over 19,280 individuals (Joshi, 2024). Furthermore, for each dollar generated by the forest sector, an additional $0.49 cents contributed to the state economy (Joshi, 2024). In 2018, 17 primary wood processing mills operated in Oklahoma, producing 113,248 cubic feet of timber products (USDA, 2020). Under drought conditions, forests may suffer reduced productivity, including decreased growth and fecundity, as well as increased mortality (McDowell et al., 2020). Consequently, the economic output of the forest sector is hindered by diminished productivity induced by drought, resulting in a range of direct and indirect effects (Prestemon et al., 2016).

Drought is a highly impactful natural disturbance. In recent times, its impacts were realized for various states in the southern US. In Arkansas, it is estimated that 10–15 % of the trees lining Interstate I-30 between Arkadelphia and Texarkana were killed due to drought stress in 2010 and 2011 (Watkins, 2012). Moreover, the forestry plantations and associated timber industries were among the most affected sectors by the drought in 2010 and 2011 in Arkansas (Watkins, 2012). Similarly, Texas and Oklahoma experienced significant economic losses due to drought in the same time (Khand et al., 2017; Ziolkowska, 2016).

The economic ramifications of drought on various industries have been extensively studied. Input-output analysis, pioneered by Wassily

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Leontief in the 20th century (Christ, 1955), stands as a useful method for understanding how market shocks such as drought can affect an economy. The input-output analysis is built on the premise that different sectors of the economy are interconnected. For example, the forest sector is highly interconnected with many facets including forest propagation and management as well as varying wood uses and end-of-life alternatives (Poudyal et al., 2017). One of the most widely used tools for this analysis is the Impact Analysis for Planning (IMPLAN) software, widely adapted by economic practitioners and policy analysts (Joshi et al., 2012).

Researchers conducted input-output analysis using IMPLAN to examine the effects of the 2011 drought on the agricultural sector in Texas (Ziolkowska, 2016). To account for drought impacts on the Texas agricultural sector, an input-output and social accounting matrix model were applied (Ziolkowska, 2016). The drought caused $16.9 billion in economic losses across the state and decreased employment by 166,895 people (Ziolkowska, 2016). The agricultural sector, in particular, saw 106,000 jobs lost and significant production losses in cotton farming and livestock production (Ziolkowska, 2016). Similarly, IMPLAN was employed to assess the consequences of the 2015 drought on the California economy (Howitt et al., 2014). California suffered losses totaling $2.74 billion and saw a reduction of 21,000 jobs as a direct result of the 2015 drought (Howitt et al., 2014). Given the magnitude of these economic losses, studying the impacts of drought on the Oklahoma forest sector is crucial.

In this study, we quantified the potential volumes of timber loss caused by drought, which was complemented by the input-output analysis to capture the economic losses in the forestry sector of Oklahoma. To accomplish this, we used Forest Inventory and Analysis (FIA) data and estimated the sound bole wood volume mortality caused by drought and subsequently used input-output analysis to determine the economic repercussions of drought on the forest sector. Furthermore, our study provides an estimate of sustained impact of drought on the regional economy between 2010 and 2015, which may be useful for predicting the severity of financial losses on timber stumpage and forest-based enterprises.

A comprehensive assessment of drought impacts is incomplete without considering its influence on the landowner decision-making as they are the primary stewards in Oklahoma's forestland-grassland ecoregion (Mishra et al., 2023). While climate change has begun to affect our way of life, and it is imperative to adopt strategies to mitigate its impact, successful mitigation faces some political and social hurdles. Research suggests that private landowners are less receptive to altering forest management practices to adapt to climate change compared to other land managers (Scheller and Parajuli, 2018). As droughts are likely to become more frequent in the future, understanding whether drought and erratic rainfall patterns have influenced land management decisions—and what factors are likely to shape those decisions— is important for sustainable forest resource management. Accordingly, our study aims to fill this knowledge gap as well.

2. Methods

2.1. Timber volume loss estimation

To determine the economic effects of drought on the Oklahoma forest sector, it was first necessary to estimate the extent of drought impacts on 6.5 million acres of Oklahoma timberland (USFS 2024). Accordingly, data for estimating timber volume lost from drought between 2011 and 2015 in eastern Oklahoma were from Forest Inventory and Analysis (FIA) database. We used EVALIDator software to estimate the total sound bole wood volume of live trees (ft^3) having at least 5 in. dbh as well as average mortality of sound bole wood volumes between 2011 and 2015. The EVALIDator estimates total mortality by summing up the dead sound wood volumes caused by insects, disease, fire, animal, weather, vegetation and other unknown factors. Following Ambrose et al. (2022), we applied the following formula to estimate weather-related mortality relative to total live volume, calculating the percentage of volume lost to weather-related mortality, which then served as an input for the input-output analysis.

$$\text{Weather mortality percent} = \frac{w}{v} * 100 \tag{1}$$

2.2. Economic loss analysis

As a second step, input-output analysis was implemented to determine how the loss of timberland volume would affect the Oklahoma forest sector. Input-output analysis is a predictive mathematical expression for how the quality or quantity of one or more commodities in the economy can alter the output, employment, and income of industries within a region of interest for a period of time (Eisworth et al., 2005; Miller and Blair, 2009; Poudyal et al., 2017). Mathematically, it follows the assumption of linear production function, where each linear equation represent the sector of economy (Miller and Blair, 2009) as below:

$$AX + Y = X \tag{2}$$

In the above equation, the vector of final demand is represented by Y, and X represents the total output. Further simplification of eq. 1 provides Leontief inverse matrix, which serves the foundation for estimating economic impacts in terms of direct, indirect, and induced impacts (Miller and Blair, 2009). Concerning drought impacts, direct impacts may include the reduction of timber or pulpwood as a commodity as drought negatively impacts forest inventories by increasing mortality and decreasing growth of trees (Vose et al., 2016). Subsequently, reduced forest inventories lead to a decline in supply causing increased market price and decreased production (Prestemon et al., 2016). Indirect impacts of drought may include reduced business activity and subsequent job losses in related industries due to a decline in inter-industry trade. For example, diminished forest inventories may force local industries to expand their procurement zones. However, transportation costs may limit a processor's ability to source from other procurement zones (Prestemon et al., 2016). Furthermore, facilities which require water in their operations, such as pulp or paper mills, may face increased operating costs under drought due to water shortages (Prestemon et al., 2016). Finally, induced effects of drought include the ripple effects of changing household spending patterns that are influenced by the direct and indirect impacts (Joshi et al., 2012). For example, drought may affect household spending patterns as a result of job loss at a sawmill due to reduced timber output caused by a decreased forest inventory. Overall, there are various impacts to consider when assessing drought effects on the forest sector. Furthermore, input-output models are static and best utilized to represent changes in a single time period (Ziolkowska, 2016). It can be applied to estimate the impacts of a market shock, such as drought, in one sector on other sectors of the economy (Ziolkowska, 2016).

Impact Analysis for Planning (IMPLAN) software was utilized to conduct input-output analysis given lost timber volume following industry contribution protocols. IMPLAN makes provisions to explain the relationships between direct, indirect, and induced effects (Schmit et al., 2013) using multipliers. Following previous literature (Joshi et al., 2017), 29 sectors related to the Oklahoma forest sectors were utilized for drought analysis. These sectors collectively represent forestry (sector 15, partial 19) operations, logging (sector 16), primary (sectors 132–134, 136) and secondary (sector 135, 137–143, 365–368, 370,371, 373) wood processing industries, and the primary (144–146) and secondary (147–151) paper and paperboard industries (Joshi et al., 2017). As Joshi et al. (2017) pointed out, these sectors have been commonly adopted in forestry and forest products industry contribution analysis. The event years included in this analysis range from 2011 to 2015. All economic results were reported in 2015 dollars.

While drought-related mortality was most severe between 2011 and 2015, it is possible that other weather disturbances, such as wind, tornadoes, snow, and flooding, might have contributed to weather-related mortality during study period. Given the inherent uncertainty, we followed Liu and Piper (2016) and conducted a sensitivity analysis by creating alternative drought mortality scenarios. Sensitivity analysis is a common approach for addressing uncertainty in economic analyses (Bullard and Straka, 2011). Specifically, we considered two hypothetical cases: one where drought accounted for 50 % of total weather-related mortality and another where it accounted for 25 %. In our baseline scenario, we assumed that all weather-related mortality was caused by drought.

2.3. Impact of drought patterns on land management decisions

A survey instrument was designed to understand the impact of drought patterns on land management decisions in Oklahoma. This survey, based on the methodology outlined by (Dillman et al., 2014), was distributed to 2500 randomly chosen landowners residing in the forest-grassland transition zone in Oklahoma, specifically in counties located east of Interstate I-35 (Fig. 1). This is a typical transition region of Oklahoma where landowners generally integrate range, forest, and agricultural land uses.

The questionnaire included various questions addressing landowners' views on active forest management and their land management goals including their preferences for deer hunting locations. In addition, socio-economic information about these landowners was also obtained from the survey. While the survey instrument had multiple components, the primary focus of this study was to assess the extent to which climate impacts, such as drought and erratic rainfall patterns, influenced forest and natural resource management decisions. We also aimed to explore whether and how landowners modified their existing practices in response to these climate challenges, as well as how land management objectives and socio-demographic factors affected their perceptions of the impact of drought on land management decisions.

The dependent variable capturing perceived influence of drought in forest, rangeland and deer habitat management decision was measured on a 6-point Likert Scale (0 = Not influential to 5 = Extremely influential). Therefore, we used the ordinal logit model to understand the factors that had statistically significant role with perceived influence of drought (Greene, 2008). The basic form of ordinal logit model can be written as below.

$$Y_i = X_i\beta_i + \epsilon i, \tag{3}$$

In the above equation, X_i β_i represent vectors of different explanatory variables that affect dependent variables. Similar to other regression model, error term ϵ_i is assumed to present a logistically distributed random component (Greene, 2008). Unlike other regression models, the ordinal logit model is assumed to hold the proportional odds assumption, which posits that the relationships between multiple categories of dependent variable remain the same (Brant, 1990; Greene, 2008). If the empirical data fails to hold this assumption, we need to explore other alternatives as such generalized ordered logit model ((Williams, 2016).

Previous research (e.g. Arano and Munn, 2006; Joshi and Arano, 2009) suggests that management objectives and socio-demographics play an important role in land management decisions of the landowners. Accordingly, those attributes were considered as candidate independent variables in our regression model. Therefore, the empirical ordinal regression model was hypothesized as below:

$$\begin{aligned}\text{Perceived drought influence} = {} & \beta_1 \text{ Livestock production} + \beta_2 \text{ Land investment} + \beta_3 \text{ Timber management} + \beta_4 \text{ Recreational hunting} \\ & + \beta_5 \text{ Active Management} + \beta_6 \text{ Age} + \beta_7 \text{ Education} + \beta_8 \text{ Female} + \beta_9 \text{ Race} + \epsilon_i\end{aligned} \tag{4}$$

3. Results

3.1. Results based on economic loss analysis

The FIA data-based results indicated weather-related mortality of over 22.5 million cubic feet of sound bole wood volume between 2010 and 2015 (Table 1). The highest percentage of weather-related mortality occurred in 2011, followed by 2014. Assuming most of the weather-related mortality was due to drought, Table 1 presents the economic impacts of drought on the timber industry at various levels, showing direct and total impacts on employment, labor income, value added, and industry output for each year. In 2011, the forest sector experienced a direct loss of 39 jobs, nearly \$2.04 million in labor income, and \$13.66 million in industry output due to drought-related mortality. Including indirect and induced effects, the total losses were estimated at 79 jobs, \$3.96 million in labor income, and \$20.38 million in industry output (Table 1). Similarly, in 2015, the forest sector experienced a direct loss of 37 jobs, nearly \$2.01 million in labor income, and \$14.10 million in industry output. The total effects, including indirect and induced impacts, were estimated at 77 jobs lost, \$4.04 million in labor income, and \$20.95 million in industry output (Table 1). In contrast, 2013 witnessed the lowest drought impacts, with a direct loss of 23 jobs, nearly \$1.16 million in labor income, and \$8.41 million in industry output. The total effects, considering indirect and induced impacts, were 46 jobs lost, \$2.29 million in labor income, and \$12.75 million in industry output (Table 2).

As expected, the results from sensitivity analysis show lower economic losses compared to the baseline, where all weather-related mortality was attributed solely to drought. The 'drought related to 50% of total weather-mortality scenario' showed that the forest sector had a direct loss of 20 jobs, nearly \$1.02 million in labor income, and \$6.83 million in industry output. Including indirect and induced effects, the total losses were estimated at 40 jobs, \$1.99 million in labor income, and \$10.19 million in industry output. The 'drought related to 25% of total weather-mortality scenario' showed that the forest sector had direct loss of 10 jobs, nearly \$0.51 million in labor income, and \$3.4 million in industry output. Including indirect and induced effects, the total losses were estimated at 20 jobs, \$0.99 million in labor income, and \$5.10 million in industry output. Similar trends were noted for other years as well.

3.2. Landowner drought perceptions

Out of all the mailed surveys, 20.5 % of the respondents provided complete responses. Our ordinal logistic regression analysis is based on 375 responses due to itemized non-responses. The average age of the respondents was 66 years, and nearly 88 % were male. More than 70 % of the respondents attended at least some colleges. The average forest-land reported by survey respondent was 69.88 acres, the average agricultural land was 80.80 acres and average rangeland reported was 185.43 acres. Among respondents, nearly 80 % reported removing dead trees or branches destroyed by wind, tornadoes, or snow, and 28 % had built barriers to manage flash floods. As an adoption mechanism, 14 % chose to plant tree species that may suit changing weather, while only 5 % irrigated their land following a severe drought. More than 45 % of respondents indicated that drought and erratic rainfall patterns very much or extremely influenced their land management decisions, whereas a rise in temperature influenced only 19 % of the respondents.

The Brant test, which was conducted to check for proportional odds

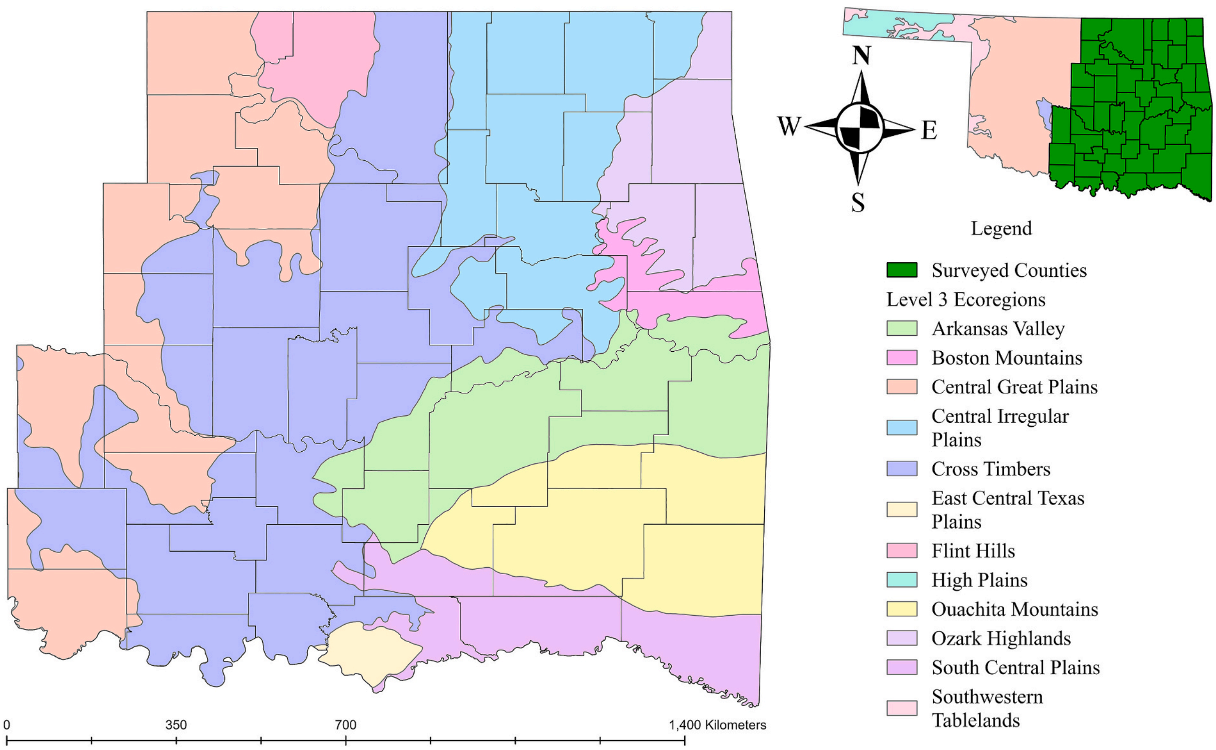

Fig. 1. The ecoregion map of Oklahoma showing the counties where survey was conducted.

assumption, failed to reject the null hypothesis ($Chi^2 = 26.59$, $p > Chi^2 = 0.874$), suggesting that relationship between dependent variable may likely be equal. Accordingly, we analyzed the empirical data with an ordinal logit model. The ordinal logit regression examining the factors that determined the perceived influence of drought on land management decisions was statistically significant overall (Wald chi-square = 39.25. $P < 0.001$). Five out of nine variables were statistically significant at least 10 % level or lower.

The summary statistics of the chosen independent variables are reported in Table 3. Similarly, results based on ordinal logistic regression analysis are reported in Table 4. Among land management objectives, those having livestock production, recreational hunting, and land investment objectives revealed that drought and erratic rainfall patterns influenced their land management decisions. Those involved in active management involving the removal of unwanted trees, weed control, and prescribed burning also revealed similar influences. Finally, while other socio-demographic attributes were not statistically significant, land management decisions non-Caucasian respondents were found to be more influenced by the drought and erratic rainfall patterns (Table 4).

4. Discussion

In this study, we examined the impact of drought-induced tree mortality of live timber volumes and the subsequent economic effects in state economy between 2010 and 2015. During this period, Oklahoma and other neighboring states suffered a severe drought (Doughty et al., 2018). Given the detrimental impacts of drought on forests and the projected increase of future droughts (Peters and Iverson, 2019), the forest industry in Oklahoma and other southern states could face significant economic losses. Our results showed that drought effects on Oklahoma timberland can cause losses to the forest industry including consumers and forest industry employees. Varying levels of drought may inflict fluctuating impacts on forests or timberland resulting in different economic consequences. Our results also showed the impacts of different levels of drought on the forest industry. The total economic effects of forest sector in Oklahoma has exceeded more than $6 billion now (Joshi, 2024). It is important to note that apart from direct mortality, drought delays diameter and height growth, thereby reducing the overall timber volume inventory. Therefore, drought-driven losses in timberland have the potential to pose negative impacts for an integral part of the Oklahoma economy.

Drought and erratic rainfall impacts are likely to impact land management decisions. Landowners whose primary objective is livestock production perceived that drought and erratic rainfall had a greater impact on their land management decisions, whereas those focused on timber management did not share the same perception. This difference in perception is intuitive, as trees are generally more resilient to drought than agricultural crops, e.g., only 2 % mortality of living tree volume even during extreme drought in Oklahoma. However, while the immediate effects of drought on trees may not be as visible as they are on crops, it is crucial to educate landowners about the impacts of drought on tree growth, which significantly reduces both diameter and height growth (Klos et al., 2009; Shephard et al., 2021). Slower timber growth would ultimately decrease timber yield and reduce financial returns over time. Additionally, prescribed fire is an active management tool that is cost-effectiveness compared to thinning or herbicide applications (Mishra et al., 2023; Watts et al., 2024). However, since drought is likely to shorten the burn window, landowners who adopt prescribed fire may perceive greater impacts of drought and erratic rainfall patterns on their land management decisions.

A wide range of forest management techniques are available for landowners to mitigate drought stress. Landowners engaged in recreational hunting or those who have adopted active management practices perceived a greater impact of drought and erratic rainfall on their land management decisions. For these landowners, periodic thinning can become an important tool for enhancing drought resilience, complementing wildlife habitat management. Thinning is a widely used practice in which selected trees are removed to promote the growth of remaining trees, increasing stand resistance to drought, insects, disease, and wildfire (Clark et al., 2016). By reducing crown competition (Gyenge et al., 2011), thinning allows the remaining trees' roots to expand and access more soil moisture (Dawson, 1996). This practice has been shown to reduce drought effects within loblolly pine plantations in the southeastern US (Shephard et al., 2021). Finally, most of the sociodemographic factors were statistically insignificant in revealing differences in landowner perceptions of the impacts of drought and erratic rainfall on land management decisions.

Our research is novel because while previous studies used input-output analysis to capture the economic losses (Harron et al., 2020; Kaur et al., 2020; Liu and Piper, 2016), they have typically relied on data from one year to simulate multi-year economic losses. For instance, Liu and Piper (2016) used 2013 data to estimate economic losses caused by the invasive red streak leafhopper over a five-year period in Louisiana. Similarly, Harron et al. (2020) used 2016 data to project economic losses caused by Kudzu in the Oklahoma forestlands. However, as both studies acknowledged, using an input-output model for multi-year projections violates the static assumptions of the methodology. To this end, our research based on multi-year data has provided an important framework for practitioners, ensuring a more appropriate application on input-output model.

The results of this study provide valuable management insights for landowners, outreach professionals, and other stakeholders. First, many landowners manage both forest and rangeland (Mishra et al., 2023). Therefore, while landowners having livestock management expressed higher perceived influence of drought, any possible land-use decisions are likely to impact timberland as well, with long-term effects on the timber industry. Second, although we estimated weather-induced tree mortality and the associated economic losses, these estimates are conservative as they do not account for the lost revenues caused by slower tree growth. Additionally, drought during this period weakened tree physiologically, increasing their susceptibility to disease such as hypoxylon canker (Klockow et al., 2018).

Similarly, FIA data were limited to eastern Oklahoma until recently (Kaur et al., 2020), and the drought mortality between 2010 and 2015 cannot be estimated for timberlands in central Oklahoma. Therefore, overall economic losses caused by drought are more than our estimates.

Finally, as an adaptation tool, periodic thinning may become necessary to mitigate timber losses. Moreover, periodic thinning has been shown to provide the highest net economic returns for integrated forest and range management, particularly for landowners with wildlife management goals (Mishra et al., 2023). It is therefore crucial to provide outreach to landowners on the importance of thinning as a potential tool to reduce drought-related losses on their lands. Thinning creates open-canopy forests that enhance wildlife habitat (Nyland, 2016). A recent study from southern Great Plain (Rodrigo 2024) suggests a higher willingness among forest landowners to adopt this practice. Since commercial thinning is often a source of revenue ((Bullard and Straka, 2011), landowners having timber management objectives may find it appealing (Joshi and Arano, 2009). However, challenges remain, including the social acceptance by landowners of drought mitigation methods and the lack of effective outreach strategies to promote active management in this region.

Drought has significantly impacted natural resources, including forests, in the southern Great Plains and we see a need for better engagement between research and natural resource stakeholders. As Wilmer and Fernández-Giménez (2015) noted, landowner decision-making regarding drought adaption is complex. For example, some Colorado rangeland owners were engaged in long-running adaptation planning, viewing drought as new normal, whereas others were focused on building efficiencies in production through social networks and experiential learning. Similarly, Nielsen-Gammon et al. (2020) suggested need of customized drought communication for long-term water planning in Texas. Consistent with these findings, we recommend tailored drought communication among natural resource stakeholders, as integrated management of wildlife, forests and grassland is found to be the best approach in forestland-grassland ecoregion of Oklahoma (Mishra et al., 2023). Since most landholdings in our study region are owned by private landowners, market-based instruments such as tax credits or technical assistance (Cubbage et al., 2016) may serve as the most effective approach to motivate landowners in adopting best management practices for drought mitigation.

We would like to acknowledge a couple of limitations of our study. While input-output models are routinely used to estimate economy-wide impacts caused of natural calamities or anthropogenic activities (e.g. Liu and Piper, 2016; Harron et al., 2020), inherent static model assumptions with these techniques do not account for market dynamics and price fluctuations (Henderson et al., 2017; Miller and Blair, 2009). Given the significant price fluctuations in the timber market in south-central United States (Parajuli et al., 2016), these assumptions may not fully capture economywide impacts (Agyeman and Ochuodho, 2023). Therefore, future research using dynamic equilibrium models, such as computable general equilibrium, can capture these market realities. Second, while weather-related mortality during the study period was primarily attributed to drought, tornedoes or ice storm may have caused tree damage. However, we could not parse out weather-related mortalities into these specific categories using FIA Evalidator. Therefore, we recommend future research integrating remote sensing techniques with FIA data (Tai et al., 2023) for precise predictions regarding drought-induced tree mortality.

5. Conclusion

The results of this study indicate that Oklahoma timberland experienced economic losses due to drought from 2010 to 2015. With the projected increase in the frequency and intensity of future droughts, timberland and forests may face even greater losses. Reduced timber productivity, caused by a diminished timber supply, could negatively impact both the forest sector and other dependent industries. These economic repercussions may lead to workforce layoffs and shifts in consumer spending. As a result, forest managers may need to adopt management strategies to mitigate drought impacts on timberland and forests. Additionally, the study shows that landowners focused on livestock production, hunting, and active management perceived greater drought impacts. Outreach focusing on drought adaptation mechanisms including the effectiveness of thinning is recommended.

CRediT authorship contribution statement

Galen Hanby: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Lu Zhai:** Writing – review & editing, Supervision, Project administration, Investigation, Funding acquisition, Data curation, Conceptualization. **Bijesh Mishra:** Software, Methodology, Data curation. **Omkar Joshi:** Writing – review & editing, Validation, Supervision, Software, Methodology, Investigation, Formal analysis, Data curation.

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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Appendix A. Appendix

Table 1
Average annual weather-related mortality of sound bole wood volume of trees (timber species at least 5 in. dbh) in timberland (cubic ft).

Inventory year	Sound bole wood volume of live trees	Total mortality	Weather-related mortality	Total mortality relative to live volume	Weather mortality relative to live
2015	1,030,585,246	19,120,275	4,366,226	2 %	0.42 %
2014	1,168,370,208	19,604,824	5,049,046	2 %	0.43 %
2013	1,011,390,313	14,033,586	2,869,671	1 %	0.28 %
2012	1,152,547,260	17,196,388	4,980,319	1 %	0.43 %
2011	1,010,133,372	15,758,151	5,267,262	2 %	0.52 %
Total	5,373,026,398	85,713,223	22,532,524	2 %	0.42 %

Table 2
Direct and total economic losses in contributions caused by weather-related mortality of sound bole wood volume of trees (cubic feet).

Years	Employment	Labor Income	Value Added	Output
2011 impact				
Direct	39	$2,038,945	$4,082,622	$13,659,391
Total	79	$3,968,988	$7,437,294	$20,376,823
2012 impact				
Direct	34	$1,749,889	$3,863,299	$12,467,374
Total	69	$3,485,082	$6,899,816	$18,482,354
2013 impact				
Direct	23	$1,155,933	$2,833,818	$8,413,992
Total	46	$2,287,950	$4,780,191	$12,292,973
2014 impact				
Direct	36	$1,836,961	$4,448,061	$13,328,226
Total	71	$3,595,113	$7,435,808	$19,281,274
2015 impact				
Direct	37	$2,002,908	$4,600,799	$14,103,763
Total	77	$4,042,707	$8,106,340	$20,952,145

Table 3
Description and the summary statistics of the variables that were used to reveal the influence of drought and erratic rainfall patterns in land management decisions of the landowners.

Variables	Descriptions	Mean	Std. Dev.
Livestock production	Likert scale (0 = Not important, 5 = Extremely important) variable revealing livestock production as an objective of the property	4.54	1.08
Land investment	Likert scale (0 = Not important, 5 = Extremely important) variable revealing land investment as an objective of the property	3.30	1.88
Timber management	Likert scale (0 = Not important, 5 = Extremely important) variable revealing timber management as an objective of the property	0.96	1.45
Recreational hunting	Likert scale (0 = Not important, 5 = Extremely important) variable revealing recreational hunting as an objective of the property	2.33	1.71
Active management	Binary scale(1 = Yes, 0 = No) variable revealing whether landowner conducted active management of land involving the removal of unwanted trees, weed control, and prescribed burning	0.89	0.31
Education	Binary scale (1 = Yes, 0 = No) variable coded as 1 if graduate degree is the highest level of landowner education	0.19	0.40
Age	Landowner age in logarithmic scale	4.18	0.20
Female	Binary scale variable coded as 1 if landowner is female, 0 otherwise	0.12	0.32
Race	Binary scale variable coded as 1 if landowner is White, 0 otherwise	0.84	0.37

Table 4
Results from ordinal logit model that explored the influence of drought and erratic rainfall pattern in land management decisions of the landowners.

Variables	Coefficient	Robust Std. Error	*P*-Value
Livestock production	0.29	0.09	0.00
Land investment	0.12	0.06	0.04
Timber management	−0.05	0.08	0.52
Recreational hunting	0.11	0.06	0.09
Active Management	0.76	0.30	0.01
Education	0.19	0.23	0.43
Female	0.35	0.31	0.26
Race	−0.60	0.27	0.03
Age	−0.47	0.48	0.33

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