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Sustainable management of unused eastern redcedar: An integrated spatial and economic analysis approach

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Highlights

- ERC has caused considerable economic and ecological losses in Oklahoma.
- Utilization of ERC biomass would contribute $96 million to Oklahoma's economy.
- A new ERC-based bioproducts industry would generate over 300 jobs in Oklahoma.

Abstract

The changes in native forest and grassland management regimes following European settlement, particularly fire exclusion, have prompted the growth of fire intolerant woody tree species such as eastern redcedar (*Juniperus virginiana*). Eastern redcedar is a native species that has encroached into the prairies and forests of the southern Great Plains of the United States. Over the past few decades, the state of Oklahoma has witnessed considerable ecological and economic losses due to the widespread encroachment of eastern redcedar. This study performed an economic impact analysis in conjunction with a spatial analysis to understand the impacts of the introduction of new eastern redcedar-based bioproducts industries on the economy of Oklahoma. The results suggested that the new eastern redcedar industry manufacturing particleboard, mulch, and oil would contribute an additional USD 96 million per year to the economy of Oklahoma, while generating 319 employment opportunities. In addition, the spatial analysis identified two hotspot clusters suggesting that the existing biomass in the northwest and southeast counties of the state could sustain the bioproducts industry for two to ten decades based on the annual feedstock requirement of different operations.

Previous Next

Keywords

Bioproducts industry; Input-output modeling; Hot spot analysis

1. Introduction

Juniperus virginiana (eastern redcedar; ERC) is a fire susceptible, native species whose occurrence was historically restricted to the areas not experiencing regular fires such as rock outcroppings or canyon bluffs (Rice, 2016). Eastern redcedar has expanded rapidly and widely following the Anglo-European settlement that prompted fire suppression and exclusion in the southern Great Plains (Butler and Leatherberry, 2004; Fowler and Konopik, 2007; Haase, 2010; Wright et al., 1982). Apart from fire exclusion, the accelerated spread of ERC is also attributed to its wide soil and climate adaptability, and its seed dispersal by birds (Cai et al., 2004). Unlike other *Juniperus* spp., the encroachment of ERC is not restricted to semi-arid and open landscapes, but it has encroached upon the native forests in the southern Great Plains as well (Engle et al., 1996; van Els et al., 2010). The encroachment of ERC into the native deciduous forests ((Kaur et al., 2019) is likely facilitated by its evergreen nature that provides a comparative growth advantage during the winter season (Caterina et al., 2014).

Eastern redcedar encroachment into the grassland ecosystems of Oklahoma has facilitated many ecological changes. For example, ERC increases water use (Caterina et al., 2014) and decreases runoff (Zou et al., 2015, 2016). In addition, the closed ERC woodland stands that eventually develop may reduce water yields for streamflow and groundwater recharge by intercepting or transpiring over 95% of the total annual precipitation (Caterina et al., 2014). It also alters plant habitat (Van Auken, 2009), decreases understory herbaceous species richness (Limb et al., 2010), and reduces fine fuel load from the forest floors (Hoff et al., 2018b). Increasing ERC canopy cover also reduces light and rain penetration, causing decline in soil moisture under dense canopy covers (Nunes Biral et al., 2019). As such, the encroachment of ERC has multi-scale impacts threatening the biodiversity of the native prairie and forest ecosystems in the Great Plains (Norris et al., 2001; Pierce and Reich, 2010).

Along with plant habitat alterations, ERC encroachment brings management challenges by altering wildlife habitat as well (Van Auken, 2009). Its expansion into the native prairies and grasslands causes habitat loss of greater prairie chicken (*Tympanuchus cupido*), lesser prairie chicken *(T. pallidicinctus)*, Rio Grande turkey (*Meleagris gallopavo*), and Bobwhite quail (*Colinus virginianus*) among other birds and animals (Engle et al., 1996; Smith, 2011). Of importance, bobwhite quail is a popular game species in Oklahoma, and the decrease in quail population diminishes the opportunities for landowners to lease their land during the hunting season (Smith, 2011). Likewise, the large decline in forage production due to increasing tree density and canopy cover of ERC over the past decades increases concerns for livestock producers (Engle et al., 1996).

Eastern redcedar encroachment poses an even greater threat to the post oak (*Quercus stellata*) dominated Cross Timbers forests of Oklahoma, which represent the ecotone between the eastern deciduous forests and the tallgrass prairies of the southern Great Plains (Hoff et al., 2018b). Where measured in northcentral Oklahoma, encroachment into the Cross Timbers resulted in more than 18% canopy cover of ERC and has increased the existing fuel loads by 38% (Hoff et al., 2018b). Moreover, the encroachment of ERC increases wildfire risk because its foliage and small limbs are highly flammable, and comprise 75% of its biomass (Hoff et al., 2018b).

The uncontrolled ERC encroachment into the forests and rangelands of Oklahoma caused economic losses of $218 million in 2001, and these losses were approximated to double by 2013 (Drake and Todd, 2002). Almost half of the projected losses were attributed to the reduction of forage yield, while catastrophic wildfires and loss of lease hunting each contributed 24% of the losses (Drake and Todd, 2002). The remaining economic losses were due to reduced water yield and encroachment into recreation sites (Drake and Todd, 2002). Similar losses were observed in other states of the Great Plains as well. For example, the succession of ERC in grasslands of Nebraska reduced forage biomass, thereby reducing the livestock carrying capacity causing 80% loss in returns for livestock producers in the Great Plains (Simonsen, 2015). Although these losses have not been verified, recent findings indicate increasing growth and encroachment of ERC in Oklahoma (DeSantis et al., 2011; Hoff et al., 2018a; Wang et al., 2017), thus suggesting an increase in these economic losses.

Although active management practices such as prescribed fire, mechanical control, and the use of herbicide can control ERC encroachment, the cost of management is seen as the major impediment in the adoption of such practices (Barth, 2002; Bidwell et al., 2002; Starr et al., 2019a, 2019b). In addition, prescribed burning is perceived to be risky (Joshi et al., 2019), and demands specific skills with often only a limited window available to burn (Oklahoma Forestry Services, 2015). The lack of markets to support harvesting and management has served as a barrier in controlling ERC in both grasslands and forests of Oklahoma (Elmore et al., 2009; Starr et al., 2019b). Therefore, the expansion of the existing ERC-based operations would help offset landowner costs and would potentially ecological and economic impacts pertaining to its encroachment.

1.1. Utilization opportunities

Given the inherent costs associated with active management (Starr et al., 2019b), it is important to explore the economic potential of unused ERC biomass in bioproducts industries. Previous research has highlighted the environmental (Maggard et al., 2012b) and economic (Gold et al., 2005) benefits of the utilization of unused ERC biomass. However, limited research was focused on the analysis of investment suitability. One effort in this direction is the work done by Ramli et al. (2017), who recently estimated costs of removing ERC from rangelands of Oklahoma. Unfortunately, their efforts were limited to a select group of counties in central Oklahoma and notably do not account for the available ERC biomass in the forested region of Oklahoma.

The traditional forest bioproducts of Oklahoma support an industry of more than $5 billion per year contributing to the state's economy (Starr et al., 2018), and ERC being a largely untapped resource has the potential to make additional contributions. Although ERC often does not provide high quality traditional timber products, the wood can be used for solid wood products or for manufacturing particleboard (Hiziroglu et al., 2002). Likewise, the foliage of the tree has volatile essential oils (Semen and Hiziroglu, 2005) for the bioproduct market, and the tree can additionally serve as mulch for gardening and landscaping (Maggard et al., 2012b). Even the residue from sawmills can be used as boiler fuel for the oil extraction process and as space heating in the winter (Gold et al., 2005). The potential uses of ERC in some industries and its production efficiency are described below.

- **Particleboard:** Eastern redcedar has unique characteristics that are desirable to consumers and can be used in construction and furniture, especially for cedar chests and closet wardrobes. The heartwood of ERC contains secondary metabolites "oils" that resist and/or repel insects and decay (Gold et al., 2005). Since open-grown ERC trees that are encroaching into grassland areas are of poor quality and cannot be used in lumber manufacturing (Hiziroglu et al., 2002), particleboard manufacturing will allow the opportunity to convert low-quality material into value-added products, providing both environmental and economic benefits. Apart from the insect-repellent properties and comparable panel strength, manufacturing of ERC particleboard is economically feasible for landowners as compared to other wood particleboards due to the cost-share funding available for the removal of ERC (Lockwood and Cardamone, 2002; Service, 2008).

- **Cedar-oil:** Another valuable tree product is cedar oil, which can be used in pesticides, pharmaceuticals, and fungicides and can be sold for up to $45 per gallon ($11.9 per liter) (McNutt, 2012). While most of the cedar-oil market exists in the southern Great Plains (Russell, 2006), there are no cedar oil facilities in Oklahoma, which provides a competitive advantage for its introduction to the local economy.

- **Mulch:** Eastern redcedar mulch provides the same benefits as other tree mulches such as cypress mulch, pine mulch, hardwood mulch, eucalyptus mulch, and is a viable product (Maggard et al., 2012a). The benefits of the ERC mulch include increased soil moisture, decreased weed growth and increased growth of planted annuals and trees (Maggard et al., 2012a, 2012b). Due to its slow decomposition, ERC mulch helps in erosion control (Maggard et al., 2012b). Therefore, the unused ERC biomass can serve as an input to the mulch industry.

Even though the uses of ERC have generated interest among stakeholders, a comprehensive assessment highlighting the suitable locations of potential facilities and their contributions to the local economy is yet to be conducted. Since Forest Inventory and Analysis (FIA) data provide the opportunity to conduct ERC resource assessment for the entire state, our objective is to estimate the economic impacts of the introduction of new ERC-based bioproducts industries (i.e. particleboard, mulch and the cedar oil) in Oklahoma through an integrated approach of spatial and economic impact analysis.

2. Methods and study area

We conducted a resource assessment of ERC using the data from USDA Forest Service's Forest Inventory and Analysis (FIA) program for Oklahoma. It is a national forest inventory program that was initiated in 1936 under the management of USDA (McRoberts et al., 2005). The forests in eastern Oklahoma have been measured periodically since 1936 in accordance with FIA's initial objectives to assess productive timberlands (Tinkham et al., 2018). However, the scope of FIA was recently include central and western Oklahoma in 2008 (Dooley, 2017). Since central and western Oklahoma, which contains much of the ERC, was not previously considered productive timberlands (Johnson et al., 2010), recent statewide inventory of the forestland provided us the opportunity to conduct an economic impact and spatial inquiry of ERC in the state. The economic impact analysis provides potential economic opportunities coming from the establishment of ERC-based industries, the management implications of such findings are limited without identification of suitable locations for the establishment of these industries. Therefore, our integrated approach utilizes spatial analysis to identify the suitable locations where ERC industries can be best positioned in Oklahoma. In our integrated framework, the resource assessment from inventory analysis provides total available feedstock, the spatial analysis identifies suitable locations and the economic impact analysis provides an economic outlook (Fig. 1).

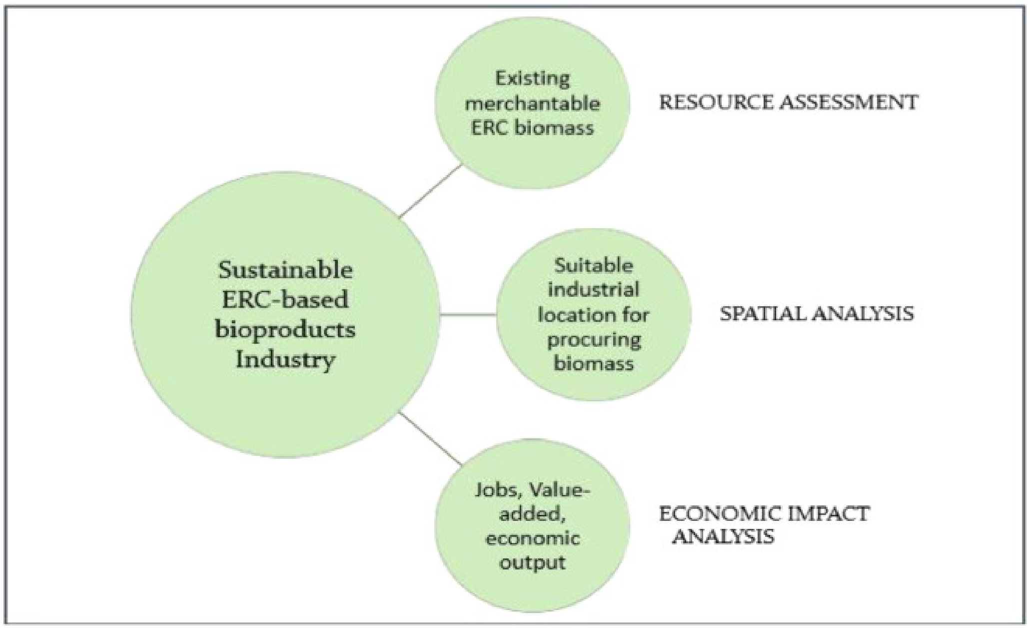

Fig. 1. An integrated framework of economic and spatial analyses that highlights economic outlook of Oklahoma counties with ERC abundance.

Eastern redcedar volume estimates for merchantable biomass, which is ≥5 in diameter outside bark measured at breast height 4.5 ft or 1.37 m (d.b.h.) above the ground or at root collar (d.r.c.), and aboveground live stocking biomass (≥1 in d.b.h./d.r.c.), were obtained using the EVALIDator tool (Miles 2012, Version 1.8.0.00, https://apps.fs.usda.gov/Evalidator/evalidator.jsp) of the FIA program. We performed product differentiation for utilization of this biomass for three different ERC-based bioproduct industries: particleboard, cedar oil, and mulch. Using the information from FIA and local industries, input-output (IO) modeling using Impact Analysis and Planning (IMPLAN) 2016 data was performed to obtain the results of economic impacts generated by the introduction of new ERC-based industries for three different bioproducts in Oklahoma. Of note, IMPLAN is an economic assessment software that has been widely used for estimating the economic impacts of forestry and forest products industry across the nation (Henderson et al., 2017). These applications include the employment provided by the forestry sector in a region, impacts associated with the introduction of a bioproducts industry, and the exit of an existing industry from a region. The employment output estimated by IMPLAN is a sum of full-time, part-time, and seasonal jobs, which is represented as total employment (Steinback, 1999).

The IMPLAN software is built on the framework of the traditional IO model. The IO modeling provides a quantitative approach for the assessment of the economic impacts of the introduction of a new industry to the economy (Miller and Blair, 2009). The IO modeling uses the principle of inverse Leontief matrix to estimate the output changes in industrial sectors of the economy (Miller and Blair, 2009). It has been used for a wide range of research in natural resources, including sustainable use of resources, estimation of spending patterns, pollution and environmental impacts (Chen and Chen, 2011; Miller

The mathematical structure of IO model is set up with *n* linear equations each representing a sector having *n* unknowns. This relationship can be represented as the following matrix:

$$\mathbf{AX} + \mathbf{Y} = \mathbf{X} \tag{1}$$

where,

Y is the final demand, X is the total industry output, and A is the technical coefficient (Miller and Blair, 2009). The total impact for employment, labor income, value added, and output sales is captured by the economic multipliers in IMPLAN. IMPLAN utilizes the framework of total multipliers through Social Accounting Matrix (SAM) to calculate the total impact to the local economy.

The total effects in IMPLAN are a sum of the direct, indirect, and induced effects. The direct effects estimate the number of employment, labor income, output, and value-added that can be supported by a fixed annual industrial sale for the bioproducts establishment (IMPLAN, 2017). The indirect effects measure the inter-industry transactions, as the output of one sector serves as the input in another sector (IMPLAN, 2017). For example, the cedar-oil produced at the bioproducts establishment will be used as an input by the pesticide manufacturing and pharmaceutical sectors. The induced effects capture the local household spending to the retail sector (e.g., restaurants, grocery stores) by the employees working in the industries impacted directly or indirectly (Henderson et al., 2017). The indirect impacts to the related industry as well as the induced impacts to retail sector are the part of output.

The IMPLAN model, based on the premises of the input-output model, has defined the US economy into 536 sectors. The IMPLAN data is available for macro and micro-level boundaries such as national, statewide, the county as well as zip code (Joshi et al., 2017). Since 536 sectors are highly aggregated to represent large economies such as the United States, the standard procedure is to select appropriate sectors by searching a bridge between the North American Industry Classification System (NAICS) and IMPLAN sectors (Zhang et al., 2016). Using the same procedure, we identified appropriate IMPLAN sectors for particleboard, mulch, and cedar-oil. The input information for mulch and cedar-oil was obtained from existing industries in Oklahoma and neighboring states, whereas, secondary source (Wilson, 2008) was used for economic impact analysis of the particleboard industry.

Apart from existing ERC-based establishments in Oklahoma, Arkansas, and Texas, existing literature (e.g., Nelson and Iddrisu, Wilson, 2008, McPherson and Kendall, 2014) was used to obtain the data on industrial sales, product price, feedstock, labor requirement, and days of operation. For example, a life cycle assessment by Wilson (2008) provided the feedstock requirement and production capacity data for a medium-sized particleboard facility. The standard dimensions of a particleboard panel were indicated as 8 ft in length and 4 ft in width (2.4 m × 1.2 m). Since 90% of the weight of the panel is wood (Wilson, 2008), we calculated that 0.25 million tons (2.26×10^8 Kg) of ERC biomass is annually required to operate such a facility. After adjusting the market price by 50% of retail markup, the manufacturer sale price of a panel with given dimensions was estimated to be $10. Therefore, annual industrial sales for the facility were calculated and used as an input in IMPLAN for economic impact analysis of the particleboard facility, which is represented under industrial sector 138 (Reconstituted wood products) of IMPLAN.

Cedar-oil can be obtained through several different processes such as steam distillation, continuous partial pressure, solvent extraction, and super critical fluid extraction (Semen and Hiziroglu, 2005). Steam-distillation is the easiest and least expensive method of producing cedar-oil (Nelson and Iddrisu). Additionally, it is a non-laborious process as only three people are needed to run a small-scale facility (Winford Bates, Personal communication). The annual feedstock requirement of an existing small-sized facility is 1080 tons (9.79×10^5 Kg) with an average daily production of 60 lbs. (27.22 Kg) of cedar-oil. To understand the economic impacts pertaining to the cedar-oil facility, IMPLAN industrial sector 187 (Other miscellaneous chemical product manufacturing) was used for the economic impact analysis.

The manufacturing of mulch is classified under sector 134 (Sawmills) of IMPLAN. As per local entrepreneurs, the process of producing cedar mulch is very simple as the particle size required can be achieved easily by two hammer mills (Patrick Clark, Personal communication). The annual production of a small mulch facility is 7000 tons (6.35×10^6 Kg) and the input into output conversion factor for mulch is 77% (McPherson and Kendall, 2014). Therefore, we calculated the feedstock requirement for such a facility to be 9100 tons/year (8.25×10^6 Kg/year). The market price of mulch per cubic yard was obtained from Eastern Red Cedar, LLC, a local mulch establishment (Personal communication). The industrial sales (production units x market price/unit) were calculated for a small-sized mulch facility and used as an input for the IMPLAN model.

2.1. Hot spot analysis

Following the input-output analysis, we constructed a biomass distribution map for the existing merchantable and total biomass of ERC in the counties of Oklahoma using ArcGIS Pro (Esri, Redlands, CA, USA) to analyze the geographic resource availability of ERC. A hot spot (HS) analysis was performed using net ERC biomass in a county as the input field of interest, which was estimated from ERC harvests that occurred from 2012–2016 in the state. The ArcGIS HS analysis tool calculates the significance of input point data using the Getis-Ord Gi* statistic, represented mathematically as (Esri, 2017):

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j}x_j - \overline{X}\sum_{j=1}^{n} w_{i,j}}{S\sqrt{\frac{\left[n\sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j}\right)^2\right]}{n-1}}} \tag{2}$$

where x_j is the attribute value (existing biomass) for feature j (given county), $w_{i,j}$ is the spatial weight between feature i and j, n is equal to the total number of features that is the number of counties in Oklahoma (n=77). The resulting Gi* statistic is a statistically significant z-score at p-values 0.10, 0.05, and 0.01. The z-score is a measure of spatial clustering of features with either high or low values in reference to their neighboring features (Esri, 2017). As such, features with large significant positive score are classified as hot spots and features with significant negative values are identified as cold spots (Esri, 2017). The HS analysis was followed by geographically locating the existing wood products facilities in the state that rely on ERC for feedstock requirement. The existing facilities were located to foresee the potential competition from these facilities for ERC feedstock in the state. Likewise, current harvest level of ERC from Oklahoma counties were also taken into account. These considerations are important to ensure the sustainability of the proposed industries.

3. Results

3.1. Resource assessment

The results of EVALIDator queries showed that there is 6.5 million dry tons (5.89×10^{10} Kg) of merchantable (≥ 5 in d.b.h./d.r.c.) biomass of ERC contained in the forestland of Oklahoma when estimated between 2012 and 2016. The total aboveground green biomass of ERC (>1 in d.b.h./d.r.c.) in the state is approximately 14.6 million tons (1.32×10^{11} Kg). Dewey, Caddo, Major, Payne and Pushmataha Counties contained the greatest amounts, constituting 30% of the total (merchantable and green) biomass of ERC in the state (Fig. 2). A total 18,000 tons (16.33×10^{6} Kg) of ERC was harvested from 2012–2016, mainly in Bryan, Cherokee, Coal, Latimer, Le Flore, McCurtain and Pittsburg counties (Fig. 2).

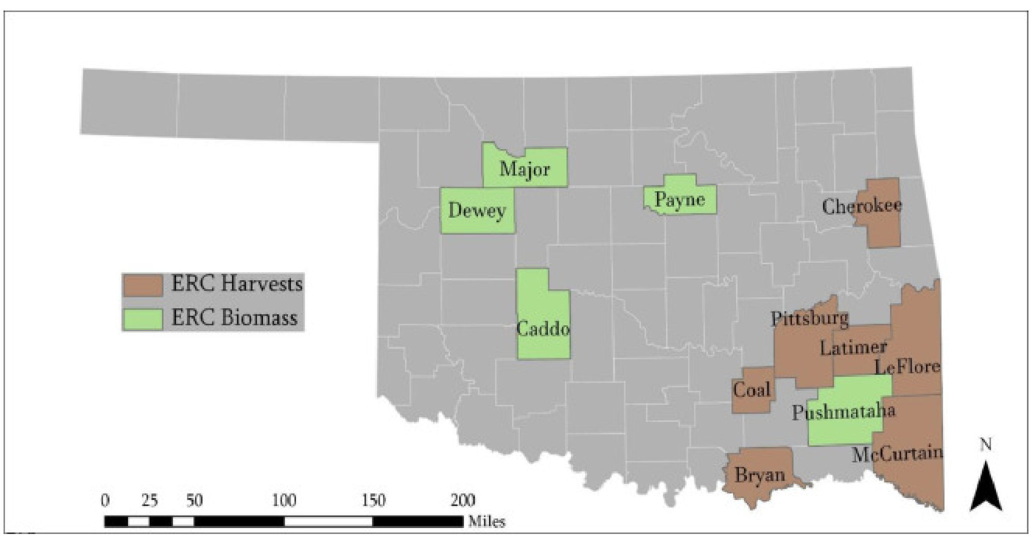

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Fig. 2. Geographic location of the state of Oklahoma w.r.t. to neighboring states. Counties in Oklahoma constituting largest ERC biomass are highlighted in green and counties experiencing ERC harvests in Oklahoma are highlighted in brown. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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3.2. Economic impact analysis

The results of the IO modeling, indicating the economic impacts of the introduction of the new ERC-based bioproducts industries in Oklahoma, are presented in Table 1. The IMPLAN results indicated that a medium-sized particleboard establishment, with an annual production capacity of 5.8 million standard dimension panels, will have an annual industrial sale of USD 58 million and will generate 118 direct employment opportunities. Taking indirect and induced impacts into account, such a facility will generate 300 new employment opportunities with an industrial output of USD 91.17 million. In addition, the results of SAM indicate that every dollar generated by this facility will contribute one dollar to the state's economy and every direct job will create 1.53 additional job opportunities. The sectors benefiting from particleboard included wholesale trade (395), commercial logging (16), full (501) and limited (502) service restaurants and services to buildings (468).

Table 1. Economic impacts of ERC-based bioproducts industries in Oklahoma based on impact analysis for planning (IMPLAN) 2016 database.

Bioproducts facility	Direct	Indirect	Induced	Total	Ripple effects
Particleboard					
Employment	118	110	72	300	1.53
Labor Income (M USD)	5.84	6.63	2.97	15.44	1.65
Total Value Added (M USD)	16.27	10.97	5.32	32.56	1.0
Output (M USD)	58.42	23.12	9.65	91.17	0.56
Cedar Oil					
Employment	3	3	3	9	1.96
Labor Income (M USD)	0.23	0.22	0.11	0.57	1.44
Total Value Added (M USD)	0.43	0.36	0.19	0.99	1.30
Output (M USD)	1.77	0.71	0.35	2.83	0.60
Mulch					
Employment	3	5	2	10	2.11
Labor Income (M USD)	0.24	0.17	0.97	5.02	1.09
Total Value Added (M USD)	0.35	0.26	0.17	0.78	1.26
Output (M USD)	1.0	0.54	0.31	1.85	0.85

We calculated that a small cedar-oil facility could produce 9390 lbs. (4259.23 Kg) of oil per year. Such a facility will generate three direct and nine total job opportunities and an annual sale of USD 1.77 million (Table 1). The SAM multiplier for this sector shows that every direct job created in the facility will generate two additional job opportunities in the state. Whereas, every dollar earned will contribute an additional one dollar and 30 cents to the state's economy. The benefits for the cedar oil facility were shared among management of companies and enterprise (461), wholesale trade (395), full (501) and limited (502) service restaurants, and real estate (440).

A small-sized mulch facility producing 30,777 cubic yards (23,530.7 m^3) or 5390 dry tons (4.88×10^6 Kg) of mulch will have an industrial sale of USD one million (Table 1). The mulch facility will generate three direct jobs and 10 total jobs in the state. Interestingly, the ripple effects of the small-sized mulch facility were greater than the medium-sized particleboard facility. These results show that every direct job at the mulch facility will create 2.1 additional job opportunities and eve[FEEDBACK] generated by the facility will contribute additional one dollar and 26 cents to the state's economy. The industries benefiting most from the introduction of a mulch facility included commercial logging (16), wholesale trade (395), truck transportation (411) and limited (502) and full service (501) restaurants. Of note, we did not estimate the economic impacts associated with the construction of these facilities as those impacts are likely to diminish within a year or two after the establishment.

3.3. Hot spot and sensitivity analysis

Based on merchantable ERC biomass, the results of the HS analysis identified two clusters containing 13 counties, six grouped in the northwest and seven in the southeast parts of the state as the potential hot spots for the establishment of the new particleboard and cedar-oil facilities (Fig. 3). These include the counties of Blaine, Custer, Dewey, Kingfisher, Major, and Woods in the northwest, and Atoka, Coal, Latimer, Le Flore, McCurtain, Pittsburg and Pushmataha in the southeast. Out of these Atoka, Blaine, Custer and Le Flore were considered the major hot spots with 99% significance level, meaning they had the highest suitability as compared to other counties in sustaining the new industries (Fig. 3). In addition, the counties of Beckham, Craig, Delaware, Greer, Harmon, Jackson, Mayes, Nowata, Rogers, Tulsa, and Wagoner were identified as the cold spots (Fig. 3), which were the counties highly unsuitable for the introduction of particleboard and cedar-oil facilities. Of note, all hotspots for merchantable biomass except Kingfisher and Major were also identified as the hotspots for a mulch facility based on the distribution of aboveground green biomass (Fig. 4). Likewise, counties of Beckham, Delaware, Greer, Harmon, Jackson, Mayes, Rogers, Tulsa, and Wagoner were identified as the cold spots (Fig. 4) for the establishment of a new mulch facility.

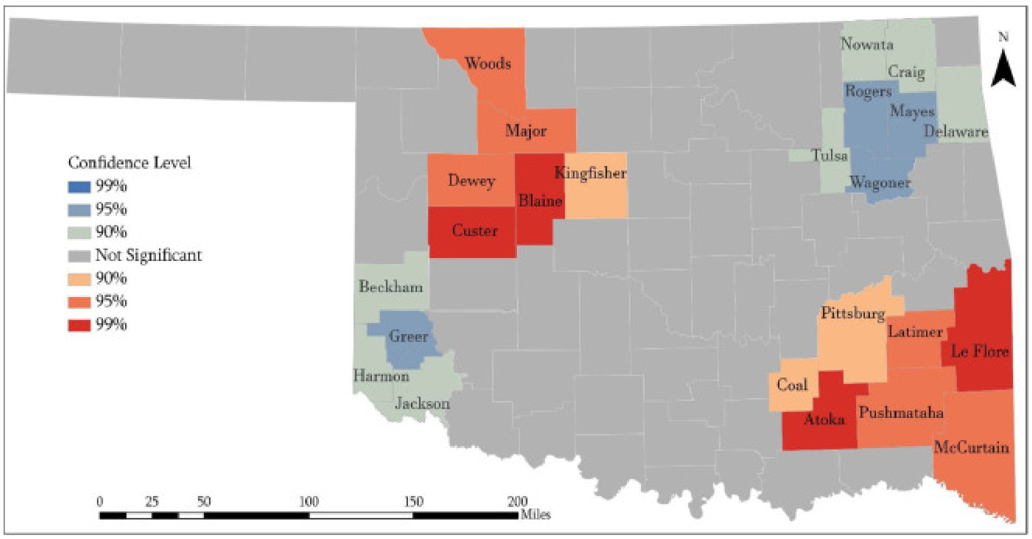

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Fig. 3. Counties identified as potential hot (red color gradient) and cold (blue color gradient) spots based on availability of existing merchantable (≥ 5 inches d.b.h./d.r.c.) ERC biomass. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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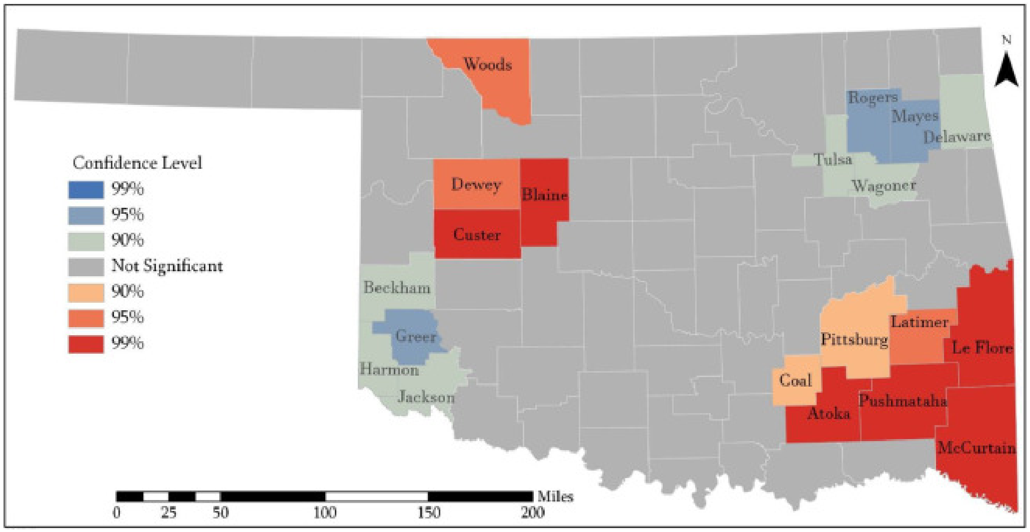

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Fig. 4. Counties identified as potential hot (red color gradient) and cold (blue color gradient) spots based on existing aboveground green (≥ 1 inch d.b.h./d.r.c) ERC biomass. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

The second part of the spatial analysis was to locate the existing ERC-based facilities in Oklahoma to understand the competitive advantage for the new facilities (Fig. 5). There are currently 21 ERC-based facilities in Oklahoma (Services, 2013) and five are located in the perimeter of the counties indicated as hot spots (Fig. 5). Nonetheless, the existing facilities are classified as small permanent mills, and the unused biomass in these counties is sufficient to support the incoming ERC facilities.

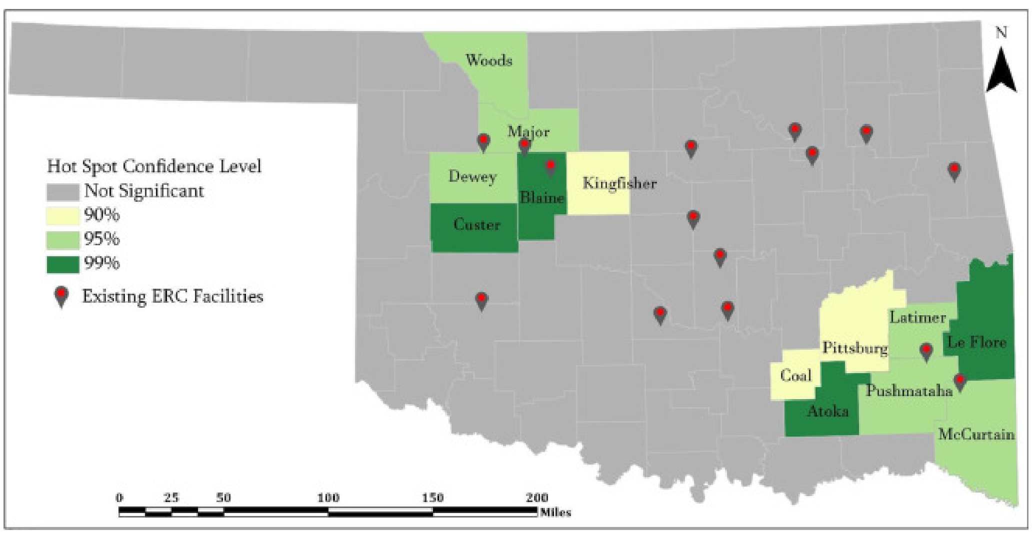

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Fig. 5. Geographical location of small sized ERC-based facilities currently in operation in the state.

While the total merchantable ERC biomass in the entire state of Oklahoma could support a medium-sized particleboard facility for 26 years, the counties identified as hotspots only constitute 40% of the total merchantable biomass in the state. Therefore, the biomass within the hotspots could support one medium-sized particleboard facility for only a decade. In co[FEEDBACK] oil facilities can be supported for almost 200 years based on the total merchantable biomass. However, the biomass in hotspot counties could support 30 such facilities for 80 years due to the relatively small feedstock requirement. Unlike the other two products, trees of all form and shape can be used for mulch. Therefore, we considered the assessment of the existing green biomass in the state for the sustainability of this industry. The assessment showed that the total aboveground green biomass could support 25 small mulch facilities for 64 years, whereas, the biomass at hotspots (32%) could support 25 such facilities for only 20 years.

Given a small feedstock sustainability for a particleboard facility, the economic contributions of the coexistence of small mulch and cedar-oil operations to the Gross Regional Product (GRP) of Oklahoma were estimated (Table 2). These estimates were simulated based on the sustainability of operations for an average economic lifetime of 20 years. Given that the mulch and cedar-oil operations will compete for the same source of ERC biomass, the total economic impacts in Oklahoma economy would depend upon the biomass proportion available for the individual facility type. For example, availability of 100% existing biomass for mulch facilities would generate 802 full- and part-time jobs with $148 million of economic output. Likewise, 40% distribution of biomass in cedar-oil and the remaining 82% used in mulch facilities would generate 1742 full- and part time jobs with $462 million economic output (Table 2). These results indicate that the combined mulch and cedar-oil operations will contribute 0.5% to the state's GRP given the existing ERC biomass is utilized in the bioproducts industry.

Table 2. Simulated economic impacts of introduction of small-sized cedar-oil and mulch facilities for different feedstock availability scenarios, sustainable for 20 years.

Biomass use distribution (%)		*No. of potential facilities*		*Total employment*		*Total output (MUSD)*		*Contribution to GRP (%)*	
Cedar-Oil	**Mulch**	**Cedar-Oil**	**Mulch**	**Cedar-Oil**	**Mulch**	**Cedar-Oil**	**Mulch**	**Employment**	**Output**
100	55	301	44	2708	445	851.62	82.33	0.14	0.50
80	64	241	52	2167	516	681.3	95.55	0.12	0.42
60	73	181	59	1625	588	510.97	108.76	0.10	0.33
40	82	120	66	1083	659	340.65	121.98	0.08	0.25
20	91	60	73	542	731	170.32	135.19	0.06	0.16
0	100	0	80	0	802	0	148.40	0.04	0.08

4. Discussion and management implications

These results provide the prospects for ERC-based bioproducts industries in Oklahoma. The results can be extended to states throughout the southern Great Plains because most of the existing ERC-based facilities in nearby states, e.g., Texas and Arkansas, are small and medium-sized operations (Bureau, 2016). In addition, economic and employment-related multipliers revealing the industrial ripple effects can be used to quantify the economic potential of these facilities in other states having similar geography and the economic realities.

The relatively small economic impacts of the cedar-oil and mulch operations can be attributed to the small size of their production facilities. However, the value-added effects of both cedar-oil and mulch are much higher than for particleboard, which means these small businesses are more profitable to the state's economy. In addition to profitability, feedstock availability for a particleboard facility, assuming no additional growth of ERC in the state, is a concern as the identified hotspots could support this operation for 10 years only, which is less than the average economic lifetime of a wood products facility (Craige et al., 2016; Standards, 2009). In contrast, small feedstock requirements, lower investment needs, and readily available markets make cedar-oil and mulch more appealing than particleboard (Heller, 2012; Nelson and Iddrisu).

Our biomass-based spatial analysis provided important insights. For example, Kingfisher County, which does not have any existing ERC biomass was identified among the hotspots in the northwest region. The identification of this cou industrial location, seemingly unreasonable, was attributed to its closer spatial clustering with the neighboring counties having high ERC biomass.

Additionally, hauling distance and ease of access to the location play an important role in a supplier's margin, landowner profitability, and stumpage price (Ramli et al., 2017). Therefore, the geographic location of a facility is critically important to ensure sustainable feedstock supply. As such, it is likely that economic feasibility of long distance haul is questionable given the low market value of ERC biomass (Han et al., 2004). Therefore, a conservative fiber shed with a 50 miles radius was considered for this analysis. For example, the cost of hauling 10.9 dry tons ERC from the field was calculated to be $2.25 per mile, which includes fixed costs, fuel, and labor costs (Ramli et al., 2017). The clustered hotspots would help reducing the hauling distance, thereby decreasing the cost of feedstock hauling for the producers and landowners. However, due to large feedstock requirements the expected sustainability of a particleboard facility was only 25 years even if the feedstock haul was expanded to counties outside the 50 miles fiber shed. Furthermore, the future ERC growth to drain ratios were not taken into consideration due to lack of harvest data.

A comparative analysis of employment ripple effects, with other economic indicators, suggest that the small-sized cedar-oil and mulch facilities are likely to have a higher number of part-time jobs compared to full-time opportunities. While we cannot segregate full and part-time jobs in IMPLAN (Joshi et al., 2012), we have noticed a larger gap between the employment multiplier (Table 1. 1.96 for cedar-oil and 2.11 for mulch) and the labor income multiplier (1.44 for cedar-oil and 1.09 for mulch) for the small-sized operations. In contrast, the medium-sized particleboard operation has relatively similar multipliers (1.53 and 1.65). Seasonal variation in production is common in small-sized facilities (Joshi et al., 2015) and our results suggest that these operations might prompt more part-time or seasonal job opportunities. While IMPLAN takes into account the seasonality of jobs, it does not adjust for number of hours worked per day (Cheney, 2017). Therefore, the dominance of part-time jobs in these sectors could be attributed to the working hours associated with the seasonality of these operations, thereby, resulting in larger ripple effects relative to the size of these operations.

The study results have several practical management implications. First, while the small-scale cedar-oil and mulch operations contribute only 0.5% to the state's economy (Table 2), it is significant for loggers and small sawmill operators. The focus of this study on enterprise assessment was purposefully geared towards small businesses. It is worth noting that sustainable feedstock supply plays an important role in a financial investment decision (Joshi et al., 2014) and entrepreneurs' are well-positioned to establish small-sized bioproduct facilities (e.g. cedar-oil and mulch,) without being concerned about the sustainability of the feedstock supply.

We hope that while economic potentials of ERC would help incentivize landowners towards active management to include removal of encroached ERC. Due to its relatively slow growth rate and negative effects it has on other more valuable ecosystem services, we are confident that development of new ERC-based bioproducts industries will not cause ERC to become a timber commodity managed by landowners in Oklahoma. We also observed that not all of the 21 facilities reported as ERC-based primary wood product producers in Oklahoma were operational. Therefore, there is a need for an updated state list of the primary wood-product producers to accurately assess the harvest volumes for market analysis. To this end, proper outreach and extension on losses of ecosystem services pertaining to ERC and landowner incentives are suggested.

Second, despite the prospects of these bioproducts industries, new facilities need to overcome some challenges. For example, the eastern part of the state has a comparatively well-developed forest industry (Johnson et al., 2010), therefore, has the inherent capacity in terms of infrastructure (e.g. trucking industry, loggers etc.) to set up a new facility. However, the northwest region that has been identified with six hotspots is underdeveloped (Johnson et al., 2010) and might experience challenges in the industrial development process. Additionally, previous research has highlighted that landowners need incentives to maintain the health and resilience of the Cross Timbers forests (Starr et al., 2019a). Given that ERC encroachment into the Oklahoma's Cross Timbers has resulted into degradation of important ecosystem services, such as diminished water quality and quantity (Zou et al., 2018), economic incentives in terms of tax benefits or other subsidies might help offset management costs and promote active management in the region.

Third, while small scale production of mulch and cedar-oil industry is likely to be consumed in Oklahoma and neighboring states, there is an opportunity to ship these bioproducts to overseas through Tulsa Port of Catoosa (Catoosa, 2018). In addition, there are some promises from federal government as the recent presidential orders of 2018 emphasized the use of forest resources in bioproducts as a forest management tool and to promote rural development nationwide (Voegele, 2 of this economic impact analysis clearly demonstrate that market investment in ERC bioproducts can have significant economic impacts to Oklahoma's economy. Finally, while this study was conducted using IMPLAN data for Oklahoma, these results are applicable to other states having similar forest resource base and the regional economy in the mid-western and the southern United States.

A few caveats of this study are worth noting. First, dedicated investment is contingent upon availability of markets, road networks, social acceptability, and favorable policies among others. Second, we did not account for future projections on ERC growth and harvest volumes while estimating the sustainability of the bioproducts facilities in the state due to the lack of data on annual harvest trends in Oklahoma. Therefore, future research in this direction will facilitate sustainable utilization of unused ERC biomass in Oklahoma.

5. Conclusion

These results show that the existing ERC biomass in Oklahoma can support the incoming facilities alongside the existing facilities in operation. Although there is a clear trade-off between the size of the facility and its sustainability, these variations are not surprising. The particleboard facility exhibited the largest economic impacts among the three proposed facilities, whereas, the mulch and the cedar-oil facilities seem to be a promising option. In addition, the utilization of ERC for bioproducts manufacturing will provide opportunities for the adoption of other active management practices important for restoration of valuable native ecosystems. The increase in harvest of ERC biomass will consequently reduce the existing ERC forest fuel loads thus reducing the risks of wildfires associated with prescribed burning in the native grassland and forest ecosystems. The study results have the potential for directing new management policies to incentivize active management and avoiding future economic and ecological losses owing to the encroachment of ERC.

Declaration of Competing Interest

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

CRediT authorship contribution statement

Ravneet Kaur: 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. **Rodney E. Will:** Funding acquisition, Conceptualization, Validation, Writing - review & editing. **Bryan D. Murray:** Software, Validation, Writing - review & editing.

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References

Barth, 2002 Z. Barth
Invasion of the eastern redcedar
Rangelands, 24 (4) (2002), pp. 23-25
View Record in Scopus Google Scholar

Bidwell et al., 2002 T.G. Bidwell, J.R. Weir, D.M. Engle
Eastern Redcedar Control and Management: Best Management Practices to Restore Oklahoma's Ecosystems
Division of Agricultural Sciences and Natural Resources, Oklahoma State University (2002)
Google Scholar

Bureau, U.C., 2016

Census Bureau, U.S. 2016. Annual Survey of Manufacturers (ASM). https://www.census.gov/data/tables/2016/econ/asm/2016-asm.html.
Google Scholar

Butler and Leatherberry, 2004 B.J. Butler, E.C. Leatherberry
America's family forest owners
J. For., 102 (7) (2004), pp. 4-14
View Record in Scopus Google Scholar

Cai et al., 2004 Z. Cai, Q. Wu, J.N. Lee, S. Hiziroglu
Influence of board density, mat construction, and chip type on performance of particleboard made from eastern redcedar
For. Prod. J., 54 (12) (2004), p. 226
View Record in Scopus Google Scholar

Caterina et al., 2014 G.L. Caterina, R.E. Will, D.J. Turton, D.S. Wilson, C.B. Zou
Water use of Juniperus virginiana trees encroached into mesic prairies in Oklahoma, USA
Ecohydrology, 7 (4) (2014), pp. 1124-1134
View Record in Scopus Google Scholar

Chen and Chen, 2011 G. Chen, Z. Chen
Greenhouse gas emissions and natural resources use by the world economy: ecological input–output modeling
Ecol. Modell., 222 (14) (2011), pp. 2362-2376
Article Download PDF View Record in Scopus Google Scholar

Cheney, 2017 Cheney, P., 2017. Employment faq. https://implanhelp.zendesk.com/hc/en-us/articles/115009510967-Employment-FAQ. 2018).
Google Scholar

Craige et al., 2016 C. Craige, M. Buser, R. Frazier, S. Hiziroglu, R. Holcomb, R. Huhnke
Conceptual design of a biofeedstock supply chain model for eastern redcedar
Comput. Electron. Agric., 121 (2016), pp. 12-24
Article Download PDF View Record in Scopus Google Scholar

DeSantis et al., 2011 R.D. DeSantis, S.W. Hallgren, D.W. Stahle
Drought and fire suppression lead to rapid forest composition change in a forest-prairie ecotone
For. Ecol. Manage., 261 (11) (2011), pp. 1833-1840
Article Download PDF View Record in Scopus Google Scholar

Dooley, 2017 K. Dooley
Forests of Oklahoma, 2015. Resource Update FS–126, 4, US Department of Agriculture Forest Service, Southern Research Station, Asheville, NC (2017), p. 126
1-4
View Record in Scopus

Drake and Todd, 2002 Drake, B., Todd, P., 2002. A strategy for control and utilization of invasive juniper species in Oklahoma.
Google Scholar

Elmore et al., 2009 R. Elmore, T. Bidwell, J. Weir
Perceptions of Oklahoma residents to prescribed fire
Proceedings of the 24th Tall Timbers Fire Ecology Conference: The Future of Prescribed Fire: Public Awareness, Health, and Safety, Tallahassee, Florida, USA, Tall Timbers Research Station (2009)
Google Scholar

Engle et al., 1996 D.M. Engle, T.G. Bidwell, M.E. Moseley
Invasion of Oklahoma Rangelands and Forests By Eastern Redcedar and Ashe Juniper

Oklahoma Cooperative Extension Service, Division of Agricultural Sciences and Natural Resources, Oklahoma State University (1996)
Google Scholar

Esri 2017 Esri, 2017. How hot spot analysis (Getis-Ord gi*) works. http://pro.arcgis.com/en/pro-app/tool-reference/spatial-statistics/h-how-hot-spot-analysis-getis-ord-gi-spatial-stati.htm. (Accessed April 20 2018,).
Google Scholar

Fowler and Konopik, 2007 C. Fowler, E. Konopik
The history of fire in the southern united states
Hum. Ecol. Rev. (2007), pp. 165-176
View Record in Scopus Google Scholar

Gold et al., 2005 M.A. Gold, L.D. Godsey, M.M. Cernusca
Competitive market analysis of eastern redcedar
For. Prod. J., 55 (12) (2005), p. 58
View Record in Scopus Google Scholar

Haase, 2010 S. Haase
Assessment of Biomass Pelletization Options for Greensburg, Kansas
National Renewable Energy Lab.(NREL), Golden, CO (United States) (2010)
Google Scholar

Han et al., 2004 H.-S. Han, H.W. Lee, L.R. Johnson
Economic feasibility of an integrated harvesting system for small-diameter trees in southwest Idaho
For. Prod. J., 54 (2) (2004)
Google Scholar

Heller, 2012 P.J. Heller
Study shows: invasive red cedar makes a good mulch product
Soil Mulch Prod. News, 6 (4) (2012), pp. 1-24
View Record in Scopus Google Scholar

Henderson et al., 2017 J.E. Henderson, O. Joshi, R. Parajuli, W.G. Hubbard
A regional assessment of wood resource sustainability and potential economic impact of the wood pellet market in the U.S.
South. Biomass Bioenergy, 105 (2017), pp. 421-427
Article Download PDF View Record in Scopus Google Scholar

Hiziroglu et al., 2002 S. Hiziroglu, R.B. Holcomb, Q. Wu
Manufacturing particleboard from eastern redcedar
For. Prod. J., 52 (7/8) (2002), p. 72
View Record in Scopus Google Scholar

Hoff et al., 2018a D.L. Hoff, R.E. Will, C.B. Zou, N.D. Lillie
Encroachment dynamics of juniperus virginiana L. and mesic hardwood species into cross timbers forests of north-central Oklahoma, USA
Forests, 9 (2) (2018), p. 75
CrossRef View Record in Scopus Google Scholar

Hoff et al., 2018b D.L. Hoff, R.E. Will, C.B. Zou, J.R. Weir, M.S. Gregory, N.D. Lillie
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. Manage., 409 (2018), pp. 215-224
Article Download PDF View Record in Scopus Google Scholar

IMPLAN 2017 IMPLAN, 2017. General information about multipliers-implan group.
Google Scholar

Johnson et al., 2010 E.K. Johnson, G. Geissler, D. Murray
Oklahoma Forest Resource Assessment
Oklahoma Forestry Services (2015)
Google Scholar

http://www.forestry.ok.gov/Websites/forestry/images/Forest_Action_Plan_/2015_Oklahoma_Forest_Resource_Assessment_MERGED,_FINAL_FOR_PRINTING_-_Copy.pdf (accessed 22 July 2019).

Joshi et al., 2012 O. Joshi, D.L. Grebner, J.E. Henderson, S.C. Grado, I.A. Munn
Input–output modeling of wood-based bioenergy industries in Mississippi
For. Prod. J., 62 (7) (2012), pp. 528-537
CrossRef View Record in Scopus Google Scholar

Joshi et al., 2015 O. Joshi, D.L. Grebner, P.N. Khanal
Status of urban wood-waste and their potential use for sustainable bioenergy in Mississippi
Resour. Conserv. Recycl., 102 (2015), pp. 20-26
Article Download PDF View Record in Scopus Google Scholar

Joshi et al., 2014 O. Joshi, D.L. Grebner, I.A. Munn, S.C. Grado, R.K. Grala, A. Hussain
Factors influencing utilization of woody biomass from wood processing facilities in Mississippi
For. Prod. J., 64 (1) (2014), pp. 64-71
CrossRef View Record in Scopus Google Scholar

Joshi et al., 2017 O. Joshi, J.E. Henderson, S.M. Tanger, L.A. Boby, M.H. Pelkki, E.L. Taylor
A synopsis of methodological variations in economic contribution analyses for forestry and forest-related industries in the US South
J. For., 115 (2) (2017), pp. 80-85
Article Download PDF CrossRef View Record in Scopus Google Scholar

Joshi et al., 2019 O. Joshi, N.C. Poudyal, J.R. Weir, S.D. Fuhlendorf, T.O. Ochuodho
Determinants of perceived risk and liability concerns associated with prescribed burning in the United States
J. Environ. Manage., 230 (2019), pp. 379-385
Article Download PDF View Record in Scopus Google Scholar

Kaur et al., 2019 R. Kaur, O. Joshi, R.E. Will
The ecological and economic determinants of eastern redcedar (Juniperus virginiana) encroachment in grassland and forested ecosystems: a case study from Oklahoma
J. Environ. Manage. (2019), Article 109815
Google Scholar

Limb et al., 2010 R.F. Limb, D.M. Engle, A.L. Alford, E.C. Hellgren
Tallgrass prairie plant community dynamics along a canopy cover gradient of eastern redcedar (Juniperus virginiana L.)
Rangeland Ecol. Manage., 63 (6) (2010), pp. 638-644
Article Download PDF CrossRef View Record in Scopus Google Scholar

Lockwood and Cardamone, 2002 G. Lockwood, M. Cardamone
Manufacturing particleboard from eastern redcedar
For. Ind., 36 (3) (2002), p. 7
View Record in Scopus Google Scholar

Maggard et al., 2012a A.O. Maggard, R.E. Will, T.C. Hennessey, J.C. Cole
Tree-Based mulches and their leachate suppress weed seed emergence
J. Environ. Hortic., 30 (3) (2012), pp. 146-149

CrossRef View Record in Scopus Google Scholar

Maggard et al., 2012b A.O. Maggard, R.E. Will, T.C. Hennessey, C.R. McKinley, J.C. Cole
Tree-based mulches influence soil properties and plant growth
Horttechnology, 22 (3) (2012), pp. 353-361
View Record in Scopus Google Scholar

McNutt, 2012 M. McNutt
Oklahoma Looks At Ways to Curb Spread of Red Cedar Trees
The Oklahoman (2012)
Google Scholar

McPherson and Kendall, 2014 E.G. McPherson, A. Kendall
A life cycle carbon dioxide inventory of the million trees Los Angeles program
Int. J. Life Cycle Assess., 19 (9) (2014), pp. 1653-1665
CrossRef View Record in Scopus Google Scholar

McRoberts et al., 2005 R.E. McRoberts, W.A. Bechtold, P.L. Patterson, C.T. Scott, G.A. Reams
The enhanced forest inventory and analysis program of the USDA forest service: historical perspective and announcement of statistical documentation
J. For., 103 (6) (2005), pp. 304-308
View Record in Scopus Google Scholar

Miller and Blair, 2009 R.E. Miller, P.D. Blair
Input-output analysis: Foundations and Extensions
Cambridge University Press (2009)
Google Scholar

Service, N.R.C. 2008 Natural Resources Conservation Service. 2008. Fact sheet about eastern Red Cedar.
https://www.nrcs.usda.gov/wps/portal/nrcs/detail/ok/newsroom/?cid=nrcs142p2_000690.
Google Scholar

Nelson and Iddrisu Nelson, R., Iddrisu, M.N., Developing redcedar essential oil market in minnesota: economic opportunity for rural development?
Google Scholar

Norris et al., 2001 M.D. Norris, J.M. Blair, L.C. Johnson, R.B. McKane
Assessing changes in biomass, productivity, and C and N stores following Juniperus virginiana forest expansion into tallgrass prairie
Canad. J. Forest Res.-Rev. Canad. Rec. For., 31 (11) (2001), pp. 1940-1946
View Record in Scopus Google Scholar

Nunes Biral et al., 2019 V.C. Nunes Biral, R.E. Will, C.B. Zou
Establishment of quercus marilandica muenchh. and juniperus virginiana L. in the tallgrass prairie of Oklahoma, USA increases litter inputs and soil organic carbon
Forests, 10 (4) (2019), p. 329
CrossRef Google Scholar

Services, O.F. 2013 Oklahoma Forestry Services, O.F.
A.a.F. (Ed.), Oklahoma Primary Wood Product Poducers Directory, Department of Food (2013)
Google Scholar

http://www.forestry.ok.gov/Websites/forestry/images/Oklahoma_Primary_Wood_Product_Producers_Directory1.pdf.

Pierce and Reich, 2010 A.M. Pierce, P.B. Reich
The effects of eastern red cedar (Juniperus virginiana) invasion and removal on a dry bluff prairie ecosyst

FEEDBACK

Biol. Invasions, 12 (1) (2010), pp. 241-252
CrossRef View Record in Scopus Google Scholar

Ramli et al., 2017 N.N. Ramli, F.M. Epplin, T.A. Boyer
Cost of removing and assembling biomass from rangeland encroaching eastern redcedar trees for industrial use
Rangelands, 39 (6) (2017), pp. 187-197
Article Download PDF View Record in Scopus Google Scholar

Rice 2016 Rice, 2016. Eastern Redcedar-Know your Enemy, in: USDA, F.S., Kansas (Ed.).
Google Scholar

Russell, 2006 G.R. Russell
A Report on: West Central Minnesota's Red Cedar Resource 2004 thru 2006
DNR Forestry (2006), p. 7
View Record in Scopus Google Scholar

Semen and Hiziroglu, 2005 E. Semen, S. Hiziroglu
Production, yield and derivatives of volatile oils from eastern redcedar
Am. J. Environ. Sci., 1 (2) (2005), p. 6
Google Scholar

Services, O.F. 2015 Services, O.F.
O.F. Services (Ed.), Oklahoma Forest Action Plan (2015), p. 254
Google Scholar

Simonsen, 2015 V.L. Simonsen
Act Now Or Pay Later: Evaluating the Cost of Reactive Versus Proactive Eastern Redcedar Management
University of Nebraska–Lincoln Extension (2015)
Google Scholar

Smith, 2011 S. Smith
Eastern Red-Cedar: Positives, Negatives And Management
Samuel Roberts Noble Foundation (2011)
Google Scholar

Standards, D.o.A., 2009 Standards, D.o.A., 2009. Personal Property Manual in: Department of Taxation, S.o.N. (Ed.).
Google Scholar

Starr et al., 2018 M. Starr, P. Harron, O. Joshi
Forestry- Important to Oklahoma's Economy [Fact Sheet]
Oklahoma Cooperative Extension Service (2018), p. 2
View Record in Scopus Google Scholar

Starr et al., 2019a M. Starr, O. Joshi, R.E. Will, C.B. Zou
Perceptions regarding active management of the cross-timbers forest resources of Oklahoma, Texas, and Kansas: a SWOT-ANP analysis
Land Use Policy, 81 (2019), pp. 523-530
Article Download PDF View Record in Scopus Google Scholar

Starr et al., 2019b M. Starr, O. Joshi, R.E. Will, C.B. Zou, R. Parajuli
Understanding market opportunities utilizing the forest resources of the cross-timbers ecoregion
J. For., 117 (2019), pp. 234-243
CrossRef View Record in Scopus Google Scholar

Steinback, 1999 S.R. Steinback

Regional economic impact assessments of recreational fisheries: an application of the IMPLAN modeling system to marine party and charter boat fishing in Maine
North Am. J. Fish. Manage., 19 (3) (1999), pp. 724-736
View Record in Scopus Google Scholar

Tinkham et al., 2018 W.T. Tinkham, P.R. Mahoney, A.T. Hudak, G.M. Domke, M.J. Falkowski, C.W. Woodall, A.M. Smith
Applications of the United States Forest Inventory and analysis dataset: a review and future directions
Can. J. For. Res., 48 (11) (2018), pp. 1251-1268
CrossRef View Record in Scopus Google Scholar

Tulsa Port of Catoosa, 2018 Tulsa Port of Catoosa. 2018. Tulsa Port of Catoosa Ships Record Amount of Soybeans. https://www.tulsaport.com/tulsa-port-of-catoosa-ships-record-amount-of-soybeans/ (accessed 28 May 2019).
Google Scholar

Van Auken, 2009 O.W. Van Auken
Causes and consequences of woody plant encroachment into western North American grasslands
J. Environ. Manage., 90 (10) (2009), pp. 2931-2942
Article Download PDF View Record in Scopus Google Scholar

van Els et al., 2010 P. van Els, R.E. Will, M.W. Palmer, K.R. Hickman
Changes in forest understory associated with Juniperus encroachment in Oklahoma, USA
Appl. Veg. Sci., 13 (3) (2010), pp. 356-368
View Record in Scopus Google Scholar

Voegele, 2018 E. Voegele
Trump Issues Executive Order On Forest Management
Biomass Magazine. BBI International (2018)
Google Scholar

Wang et al., 2017 J. Wang, X. Xiao, Y. Qin, J. Dong, G. Geissler, G. Zhang, N. Cejda, B. Alikhani, R.B. Doughty
Mapping the dynamics of eastern redcedar encroachment into grasslands during 1984–2010 through PALSAR and time series landsat images
Remote Sens. Environ., 190 (2017), pp. 233-246
Article Download PDF View Record in Scopus Google Scholar

Wilson, 2008 J.B. Wilson
Particleboard: a life-cycle inventory of manufacturing panels from resource through product. Phase II final report
Consortium for Research on Renewable Industrial Materials, Seattle, WA, May CORRIM, Inc. University of Washington (2008), p. 58
CrossRef View Record in Scopus Google Scholar

Wright et al., 1982 H.A. Wright, H.A. Wright, A.W. Bailey
Fire Ecology: United States and Southern Canada
John Wiley & Sons (1982)
Google Scholar

Zhang et al., 2016 Y. Zhang, M. Goldberg, E. Tan, P.A. Meyer
Estimation of economic impacts of cellulosic biofuel production: a comparative analysis of three biofuel pathways
Biofuels Bioprod. Biorefin., 10 (3) (2016), pp. 281-298
CrossRef View Record in Scopus Google Scholar

Zou et al., 2018 C. Zou, D. Twidwell, C. Bielski, D. Fogarty, A. Mittelstet, P. Starks, R. Will, Y. Zhong, B. Acharya
Impact of eastern redcedar proliferation on water resources in the great plains USA—Current state of knowledge
Water (Basel), 10 (12) (2018), p. 1768
CrossRef View Record in Scopus Google Scholar

Zou et al., 2015 C.B. Zou, G.L. Caterina, R.E. Will, E. Stebler, D. Turton
Canopy interception for a tallgrass prairie under juniper encroachment
PLoS ONE, 10 (11) (2015)
Google Scholar

Zou et al., 2016 C.B. Zou, L. Qiao, B.P. Wilcox
Woodland expansion in central Oklahoma will significantly reduce streamflows - a modelling analysis
Ecohydrology, 9 (5) (2016), pp. 807-816
Google Scholar

View Abstract