EASTERN REDCEDAR (*Juniperus virginiana*) EXPANSION, EFFECTS, AND CONTROL

A LITERATURE REVIEW FROM THE TALLGRASS PRAIRIE REGION OF THE CENTRAL U.S.

Eastern redcedar burning, photo by Dirac Twidwell

A collaborative product from the Great Plains Fire Science Exchange and Tallgrass Prairie and Oak Savanna Fire Science Consortium

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Tallgrass prairie ecosystems in the United States are priorities for conservation of grassland communities. While much of the tallgrass prairie in the Great Plains and upper Midwest has been converted to cropland or other developments, some areas still support native prairie species (Samson and Knopf 1994). Less than 4% of the original tallgrass prairie remains (Samson and Knopf 1994). In addition to the threats of expanding urban development and agriculture, many of these open grasslands are being invaded by woody species (Briggs et al. 2005). One tree species of concern in this change to woody dominance is eastern redcedar (*Juniperus virginiana*; hereafter redcedar) a rapidly expanding evergreen common throughout the eastern United States. In this document, we focus on the expansion of redcedar (Fig. 1) into the tallgrass prairie of the Great Plains and upper Midwest, United States. Our goal is to review the expansion and ecological repercussions of redcedar encroachment and to summarize the best practices for control of redcedar in the tallgrass prairie region. However, this species and other junipers that are encroaching in grasslands are of much concern across the Great Plains.

*Figure 1: Close up of leaves and berries of a redcedar (*J. virginiana*) tree. Wikimedia Commons.*

Key Points

- Changes in wildland fire regime have led to an expansion of eastern redcedar in tallgrass prairie.
- Increased eastern redcedar leads to decreased herbaceous biodiversity, decreased forage production, and increased Wildland Urban Interface concerns.
- Prescribed fire is most effective for controlling small trees, or maintaining sites where eastern cedar is not a problem; mechanical treatments may be necessary for dealing with larger trees.
- Control of eastern redcedar is an ongoing process; there is not a one-time solution to the problem.

LITERATURE SEARCH

The importance of this topic to both the Tallgrass Prairie and Oak Savana Fire Science Consortium and Great Plains Fire Science Exchange led the cooperative development of this literature review. Additionally, a recent workshop at the Society for Range Management annual meeting focused on evaluating the existing science and information needs and can be viewed here (Leis and Blocksome 2014).

The literature search was conducted using the Web of Science and Google Scholar. The works cited for the redcedar page in the Fire Effects Information System (Anderson 2003) was also reviewed for additional sources. Many peer reviewed publications and University Extension documents[1] were provided by the staff of the Great Plains Fire Science Exchange.

[1] Information included in text boxes and list of sources and links at end of document.

We chose to limit the information included in this literature review. We focused on publications from tallgrass prairie sites where redcedar was a study species. Although some additional resources were included, the majority of the content in this review is based on evidence from tallgrass prairie sites in the central United States (Fig. 2). We did include some studies where ashe juniper was the focus because of similarities in the life history traits of redcedar and ashe juniper (*J. ashei*). These sources are noted within the text.

Figure 2. Approximate locations of where data was collected for research highlighted in this document. Note that a single location may represent multiple field studies. Map created by T. Hmielowski using Google Fusion Tables.

REDCEDAR LIFE HISTORY

Redcedar occurs throughout the northern Great Plains and Midwest and east to the Atlantic coast (USDA 2014, Fig. 3). These evergreens are long-lived and can be found as mixed or pure stands (sometimes called 'cedar glades') in the Midwest (Hall 1955, Anderson 2003). The cedar populations interspersed in tallgrass prairie were historically limited on the landscape to rocky outcroppings (Arend 1950, Ferguson et al. 1968), where competition from other plants is low and fire is unlikely to occur. Redcedar is also frequently found on former cropland, sometimes called go-back land or oldfields. The rate of colonization observed in northeast Kansas was similar to rates of colonization of redcedar observed in Illinois and New Jersey (Yao et al. 1999).

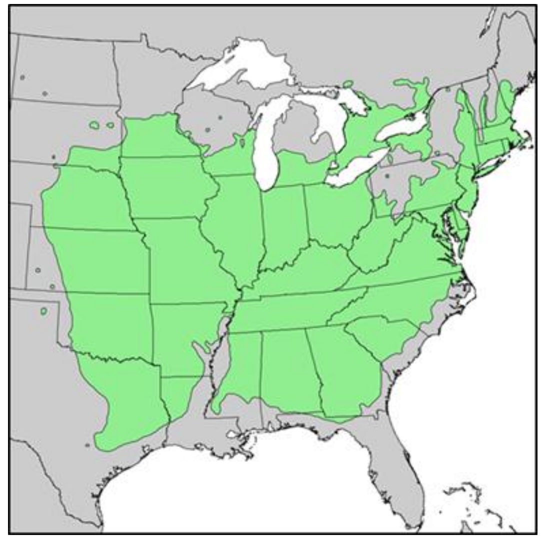

Figure 3: Range of eastern redcedar in United States shown in green. Image from the USDA Plants Database.

Redcedar is dioecious, having both male and female trees, and reproduces solely by seed (Ferguson et al. 1968). Seeds are produced in berrylike cones which mature in the winter or early spring and cone production may be influenced by tree size, age, and site conditions (Anderson 2003). The seeds of redcedar are dispersed via birds and small mammals. Passage through bird digestive tracts can disperse seeds greater distances from parent trees and may increase germination rates (Holthuijzen et al. 1987). However, seeds may be passed relatively quickly (30 min) limiting the dispersal distance from parent trees (Anderson 2003). In addition to birds, some mammals including opossum, coyotes, and rabbits disperse redcedar seeds (Horncastel et al. 2004). However, rodents are commonly seed predators (Horncastle et al. 2004). Seedling establishment is typically greater in open areas (Ferguson et al. 1968) and where herbaceous competition is reduced (e.g., grazed pasture; Schmidt and Stubbendieck 1993). Growth rates of redcedar vary from west to east across the range because of differences in site quality and competition (Engle and Kulbeth 1992).

Redcedar does not exhibit resprouting when the aboveground portion of the plant is killed as the result of damage from fire or cutting via mechanical methods (Owensby et al. 1973). Low intensity fire can kill most small trees (Owensby et al. 1973), and high intensity fires have been observed to kill larger trees of *Juniperus ashei* (Twidwell et al. 2013a). Cutting trees near the ground will result in death of individuals, but if lower green branches remain individual trees can survive (Engle and Stritzke 1992). Juniper species that occur in the Midwest and Great Plains vary in their response to removal of aboveground tissues, *J. virginiana* and *J. ashei* (ashe juniper) do not resprout, while *J. pinchotii* Sudw. (redberry juniper) is capable of resprouting following death of aboveground structures by fire or mechanical methods (Lyons et al. 1998). Understanding how redcedar and related juniper species spread and respond to fire and mechanical control is important for developing plans to control redcedar invasions into tallgrass prairie.

REDCEDAR EXPANSION

The expansion of redcedar can be documented through historical land survey records and, more recently, remote sensing. In the Missouri Ozarks, land surveys show that redcedar was more common in areas burned less often (10 years vs 5 years) prior to 1820 (Batek et al. 1999). However, a reduction in fire frequency as the result of active fire suppression in the 1940s led to an expansion of redcedar (Nigh et al. 1985). This expansion of redcedar in the Ozarks was also discussed by Beilmann and Brenner (1951) in the mid 1900's. Aerial photographs of rangelands in the Flint Hills of Kansas revealed that sites can transition from prairies without trees to closed canopy redcedar stands in as little as 40 years (Briggs et al. 2002). Although redcedar can tolerate a wide range of climate and soil conditions (Ferguson et al. 1968) this rapid expansion suggests that natural mechanisms for controlling redcedar distribution have been altered since the early 1900s (Ganguli et al. 2008).

How rapidly is redcedar expanding?

University Extension publications estimate the expansion of redcedar in Kansas and Oklahoma at an annual rate close to 5% since the 1950's.

Bidwell, T.G. and M.E. Moseley. 1989.
Fick, Walt. 2013.

The increase in cover by redcedar is often attributed to fire suppression and cattle grazing. Long fire return intervals and fire exclusion enable redcedar trees to grow to sizes that are tolerant of future fire events rather than being topkilled (Engle and Kulbeth 1992, Alemayehu et al. 1998, Twidwell et al. 2013a). The impacts of grazing are less clear. Redcedar has been observed to have an increased likelihood of survival in grazed areas, potentially the result of decreased competition with grasses (Schmidt and Stubbendieck 1993). There are also potential interactions between grazing and fire, and it is suggested that high cattle stocking rates reduce the effects of fire. Intense grazing decreases fuel loads, thereby limiting the spread and intensity of fires (Archer 1989, Briggs et al. 2002a, Briggs et al. 2002b). There is also evidence that increased cattle stocking in the growing season (May-Oct) reduces the occurrence or spread of redcedar on the landscape (Owensby et al. 1973). This decrease in redcedar expansion with grazing may be attributable to reduced mulch creating unfavorable conditions for redcedar germination (Owensby et al. 1973) or cattle trampling young redcedar (Ferguson et al. 1968). However, it is still unclear how grazing (stocking rate and season) and fire (season and frequency) interact to create conditions that either favor or suppress redcedar expansion.

Humans have also directly aided the expansion of redcedar across the landscape. Redcedar was planted as a "living fence" (Steavenson et al. 1943), planted to serve as windbreaks across the Midwest (Ferguson et al. 1968, Owensby et al. 1973), and is commonly used in landscaping (Fig. 4, Fig. 5). Redcedar was also planted on oldfields to prevent erosion, although use may have been limited in favor of other species (McClurkin 1968). Currently, redcedar continues to be sold and planted, which increases the seed source available and perpetuates the existing problem of redcedar encroachment into grasslands.

Figure 4. Example of a row of redcedar planted as a fence or windbreak. Wikimedia Commons.

IMPACTS OF REDCEDAR EXPANSION

The expansion of redcedar into grassland ecosystems in the Midwest has ecological, social and economic impacts. Here we highlight some of the effects of redcedar invasion into grasslands. Additionally, we discuss some of the social and economic impacts of redcedar expansion.

Where redcedar trees invade and become dominant there is a reduction in biodiversity, primarily in the herbaceous species. In north central Oklahoma and Nebraska, less herbaceous biomass was observed growing under redcedar canopies than beyond the dripline of individual trees (Engle et al. 1987, Smith and Stubbendieck 1990). As redcedar canopy cover increases the species richness of herbaceous species decreases (Limb et al. 2010). These changes can occur relatively quickly in prairie habitats, where even individual redcedar trees alter the herbaceous communities occurring in their immediate vicinity within 20 years (Gehring and Bragg 1992). Closed canopy eastern redcedar sites in Kansas had a 99% reduction in herbaceous production compared to annual burned tallgrass prairie (Briggs et al. 2002).

Figure 5. Redcedar planted as part of golf course landscaping. Wikimedia Commons.

Increased cover by woody plants can also alter water availability. Woody plants are capable of taking up more water than grasses and shrubs, altering the water table (Wilcox and Thurow

2006). Evergreens invading grasslands commonly intercept rainfall, as seen for *J. ashei* (Wilcox et al. 2006), and reduce soil moisture under tree canopies. Woody plants may also take up more ground water than grasses (either recent precipitation or deeper sources), which can reduce the soil water content near individual trees (Engle et al. 1987) or across larger landscapes as tree density increases (Wu et al. 2001, Huang et al. 2006). Redcedar encroachment in Oklahoma has been shown to reduce groundwater recharge and streamflow when compared to non-encroached tallgrass prairie (Zou et al. 2013). However, woody encroachment into grasslands may not impact water availability in regions where precipitation is retained near the surface and ground water is not accessible to vegetation since dense grasses can take up the same amount of water as trees (Wilcox 2002, Wilcox et al. 2006). The impacts of woody cover on water availability are likely to vary greatly across different ecosystems (Wu et al. 2001). Furthermore, the effects of redcedar encroachment on water resources will vary by soil type, local climate, precipitation, and tree density.

Shifts in dominant plants from grasses to trees also affect nutrient pools and nutrient cycles (Scholes and Archer 1997, Norris et al. 2007). Nutrient pools typically differ between grasslands and woody dominated ecosystems. For example, redcedar stands in Kansas were observed to store 14 times as much nitrogen aboveground than tallgrass prairie (Norris et al. 2001). Redcedar stands also lead to increased nitrogen pools in leaf litter (Norris et al. 2007). Changes to soil nitrogen availability and nitrogen mineralization were not detected when comparing redcedar stands established within 80 years to grazed tallgrass prairie (Norris et al. 2007). However, comparisons across sites with different fire and grazing histories would be necessary to determine long-term effects of redcedar on nutrient cycles. Redcedar stands often occur on more alkaline soil, possibly because redcedar outcompete other species that occur on these soils (Pierce and Reich 2010) or because redcedar litter is high in calcium content and can decrease soil acidity (Arend 1950).

Climate change will potentially affect rates of redcedar encroachment. Worldwide, woody species may gain a competitive advantage over grasses as CO_2 increases and growth rates increase (Bond and Midgley 2000, 2012). Specific predictions of climate change for the Great Plains and upper Midwest include increased temperatures and longer dry periods or drought (EPA 2014). Evidence from Texas has demonstrated that redcedar trees withstand increased temperatures and summer drought better than other woody species (Volder et al. 2012[2]) and are likely to have greater rates of encroachment.

In addition to ecological consequences, redcedar expansion can have economic and health impacts for those working and living in the region. The decrease in herbaceous cover under redcedar trees and stands (Engle et al. 1987, Smith and Stubbendieck 1990, Briggs et al. 2002) has economic impacts on landscapes where grazing is used. Landowners in Iowa and Missouri self-reported a concern over the loss of forage and wildlife habitat due to redcedar encroachment (Morton et al. 2010). This was likely because of concerns over potential lost income resulting from redcedar encroachment. However, landowners may not recognize the potential impacts when redcedar encroachment is in early stages (Harr et al. 2014).

In conjunction with economic losses, redcedar encroachment increases health concerns. Pollen from juniper species can travel great distances on the winds resulting in allergy responses for distances from redcedar populations. Allergy symptoms from redcedar pollen can be severe in some people requiring immunity building shots (Van De Water and Levetin 2001). The amount of redcedar pollen in the air as well as health costs has been steadily increasing as

[2] Link to Research Brief in Works Cited

encroachment progresses (Van De Water and Levetin 2001).

Wildland Urban Interface

In populated areas where redcedar has been planted, or rangeland invaded by cedar is sold for development, the tree poses an increased hazard associated with wildfire in the Wildland Urban Interface. The increase in redcedar on the landscape and near homes changes the fire regime from frequent, low intensity fires to infrequent, high intensity fires.

From *"Eastern redcedar as a hazardous fuel. "*

REDCEDAR CONTROL AND RECOVERY

Methods for controlling redcedar in the tallgrass prairie region vary and are dependent upon the size of trees and scale of area to be treated (Ortmann et al. 1998).

Preventing encroachment

Prescribed fire (Fig. 6) is the most effective way of controlling small redcedar (<2m) and maintaining large landscapes (Owensby et al. 1973). Frequent use of prescribed fire (i.e., fire return interval of 1-3 years) is the most efficient method of controlling small trees, when compared to herbicide or mechanical treatments (Ortmann et al. 1998). Given the variability in growth rates across the range of redcedar, fire return intervals may need to be more frequent in the eastern portion of the range than the west (Engle and Kulbeth 1992).

Figure 6. Prescribed fire used to control invading redcedar. Photo by A. Sheshuvov.

Controlling encroached areas

Treating areas where redcedar has encroached will vary based on the area to be treated and size of the trees. The costs associated with controlling invasive woody plants often increase as the size and number of trees increases (Brown and Archer 1999).

At some sites an intial prescribed fire can be used to kill trees in small size classes and a follow up treatment is required to eliminate larger trees. Burning with follow up herbicide treatment can kill larger trees in a way that minimizes costs and soil disturbance (Ortmann et al. 1998). Another method that minimizes soil disturbance is burning individual trees after an intial prescribed fire, which can kill large trees that survive a low-intensity prescribed fire (Engle and Stritzke 1992).

At sites where redcedar trees have grown into size classes that are unlikely to be killed by low intensity fires, or prescribed fire cannot be used, removal may require the use of herbicides or heavy equipment (Owensby et al. 1973, Briggs et al. 2005). When herbicides are used alone, granules are more effective than foliar applications (Owensby et al. 1973). Both soil and foliar-applied herbicides are labeled and recommended for redcedar control (Thompson et al. 2014). Mechanical removal methods include chainsaws, treecutters, bulldozers, and chains dragged between equipment (Fig. 7). Heavy equipment, while effective, can cause soil disturbance while chainsaws and hand tools are not practical to treat large areas.

Figure7. Mechanical removal of redcedar. Photo by C. Blocksome.

There is potential to treat redcedar trees > 2m tall with prescribed fire. Eliminating larger trees with prescribed fire requires the application of high intensity prescribed fires, where fireline intensity exceeds 160 kJ/m/s (Twidwell et al. 2013a[3]), which may not be an option at all sites. Use of prescribed fire (Fig. 8) and mechanical or herbicide treatments to control redcedar will likely depend upon the degree of invasion, surrounding vegetation, and adjacent developments.

Redcedar control on private lands

Use of prescribed fire in the Great Plains by private landowners who recognize the problems associated with redcedar has increased. Burn cooperatives, where multiple private landowners pool time and resources to burn rangelands, can reduce the encroachment of redcedar and keep the cost of prescribed fire down for landowners (Twidwell et al. 2013b[4]).

Figure 8. Dead redcedar trees following a prescribed fire. Photo by D. Whisenhunt.

Private landowner participation in these burn cooperatives may be influenced by their need for high quality forage on rangelands rather than a desire to maintain high biodiversity prairie for the sake of conservation (Morton et al. 2010). Although redcedar has some commercial use there is little opportunity for private landowners to profit from redcedar removal. Recognizing that motivation to control redcedar on privately owned land is more likely to be based on economics than biodiversity than conservation, those working to decrease redcedar in the region must examine the sociological aspects of redcedar expansion and control.

Restoring grasslands

Although redcedar invades tallgrass prairie and reduces herbaceous cover, there is potential to restore these sites. Limb et al. (2010, 2014) suggest that redcedar removal at sites with up to 75% canopy cover by redcedar could recover to pre-encroachment species richness and diversity. Similarly, when redcedar trees were removed from bluff prairies in Minnesota, herbaceous species recovered (Pierce and Reich 2010). These studies suggest recovery is possible with minimal cost beyond removal of redcedar trees.

[3] Link to Research Brief in Works Cited
[4] Link to Research Brief in Works Cited

Follow up to redcedar removal

When initiating redcedar removal land managers should plan for post-removal recovery and maintenance. Once redcedar is removed grasses may recover without reseeding, however intensive grazing may cause erosion on some soil types. Recovery plans should carefully consider stocking rates and plans for either future prescribed fire, continued herbicide, or mechanical treatment to remove redcedar seedlings.

Bidwell, T. G. and J.R. Weir. 2002.
Nelle, S. 1997.

CONCLUSION

Redcedar is likely to continue to expand throughout its range as a result of fire exclusion, development, and climate change. Although a single fire or mechanical treatment can kill many individual trees, there is an extensive seed bank throughout the region that will sustain recruitment of new trees regionally. Fire is most effective at killing redcedar when adequate fuel loads are present to carry fire through grasslands. Therefore stocking rate adjustments or grazing deferrals may be necessary to build adequate fuel loads for burning on grazed land. Extension and outreach support for landowners is critical to create awareness of the problem as well as develop solutions to reduce redcedar encroachment in the tallgrass prairie region.

From this literature review, we identified four major topics relating to redcedar expansion, effects, and control that are not fully understood or have contradicting evidence. Despite these research needs, researchers agree that redcedar and other encroaching juniper species are a threat to grassland ecosystems in the central United States. The tallgrass prairie in particular is at risk from redcedar encroachment as the total land area continues to decline. Juniper displaces other species and results in economic and health concerns. However, control methods are available and continued research and information exchange can affect the populations of this species.

Information Needs

1. The effects of cattle grazing on redcedar encroachment are mixed, and interactions with fire not well understood. Understanding how grazing intensity and duration effect redcedar establishment can inform grazing practices.

2. There are few studies that explore the impact of redcedar expansion on water availability in tallgrass prairie. The precipitation differences from west to east may influence the effects of redcedar encroachment or removal on streamflow across the range of tallgrass prairie sites.

3. There is limited research on the recovery of tallgrass prairie following redcedar removal. Although these studies highlighted suggest that tallgrass prairie sites are highly resilient, it is unclear how site history, prescribed fire, and grazing might influence recovery of the tallgrass prairie community.

4. A social science approach to the juniper encroachment issue may help researchers identify solutions and effective science delivery mechanisms (S. Leis, personal communication, Juniper workshop Society for Range Management 2014).

For additional information about ongoing fire science research and events connect with your regional Fire Science Exchange

Tallgrass Prairie and Oak Savanna Fire Science Consortium - www.tpos.firescience.org

Great Plains Fire Science Exchange - https://gpfirescience.org

Joint Fire Science Program – http://www.firescience.gov

Information from University Extension publications

Bidwell, T.G.and M.E. Moseley. 1989. Eastern redcedar: Oklahoma's centennial brush problem. Circ. E. 892. Stillwater, OK: Oklahoma State University, Cooperative Extension Service. 4 p.

Bidwell, T. G. and J.R. Weir. 2002. Eastern Redcedar Control and Management – Best Management Practices to Restore Oklahoma's Ecosystems. Oklahoma Co-operative Extension Service Facts F-2876, Stillwater.

Eastern redcedar as a hazardous fuel. Oklahoma Cooperative Extension. L-381. Available online: www.fireecology.okstate.edu/files/L-318.pdf Last accessed 15 July 2014.

Nelle, S. 1997. A holistic perspective on juniper. Texas A&M University, Juniper Symposium. Available online: http://texnat.tamu.edu/library/symposia/juniper-ecology-and-management/holistic-perspective-on-juniper/ Last accessed 15 July 2014.

WORKS CITED and FIGURE CREDITS

Alemayehu, D., D. M. Engle, R. F. Wittwer, and S. Anderson. 1998. Pattern of growth of sapwood, heartwood, and stem volume of open-grown eastern redcedar in grasslands. Southern Journal of Applied Forestry 22:169-174.

Anderson, M. D. 2003. Junipersus virginiana. In: Fire Effects Information System [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. Available online: http://www.feis-crs.org/beta/ Last accessed 15 July 2014.

Archer, S. 1989. Have southern Texas savannas been converted to woodlands in recent history? The American Naturalist 134:545-561.

Arend, J. L. 1950. Influence of fire and soil on distribution of eastern redcedar in the Ozarks. Journal of Forestry 48:129-130.

Batek, M. J., A. J. Rebertus, W. A. Schroeder, T. L. Haithcoat, E. Compas, and R. P. Guyette. 1999. Reconstruction of early nineteenth-century vegetation and fire regimes in the Missouri Ozarks. Journal of Biogeography 26:397-412.

Beilmann, A. P., and L. G. Brenner. 1951. The recent intrusion of forest in the Ozarks. Annals of the Missouri Botanical Garden 38:261-282.

Bond, W. J. and G. F. Midgley. 2000. A proposed CO2-controlled mechanism of woody plant invasion in grasslands and savannas. Global Change Biology 6:865-869.57.

Bond, W. J. and G. F. Midgley. 2012. Carbon dioxide and the uneasy interactions of trees and savannah grasses. Philisophical Transactions of the Royal Society B. 367:601-612.

Briggs, J. M., G. A. Hoch, and L. C. Johnson. 2002a. Assessing the rate, mechanisms, and consequences of conversion of tallgrass prairie to *Juniperus virginiana* forest. Ecosystems 5:578-586.

Briggs, J.M., A. K. Knapp, B. L. Brock. 2002b. Expansion of woody plants in tallgrass prairie: a fifteen year study of fire and fire-grazing interactions. The American Midland Naturalist 147:287-294.

Briggs, J. M., A. K. Knapp, J. M. Blair, J. L. Heisler, G. A. Hoch, M. S. Lett, and J. K. McCarran. 2005. An ecosystem in transition: Causes and consequences of the conversion of mesic grassland to shurbland. BioScience 55:243-254.

Brown, J. E., and S. Archer. 1999. Shrub invasion of grassland: Recruitment is continuous and not regulated by herbaceous biomass or density. Ecology 80:2385-2396.

Engle, D. M., and J. D. Kulbeth. 1992. Growth dynamics of crowns of eastern redcedar at 3 locations in Oklahoma. Journal of Range Management 45:301-305.

Engle. D. M., and J. F. Stritzke. 1992. Enhancing control of eastern redcedar through individual plant ignition following prescribed burning. Journal of Range Management 45:493-495.

Engle, D. M., J. F. Stritzke, and P. L. Claypool. 1987. Herbage standing crop around eastern redcedar trees. Journal of Range Management 40:237-239.

EPA. 2014. Environmental Protection Agency Climate Change. Available online: http://www.epa.gov/climatechange/impacts-adaptation/midwest.html Last accessed 15 July 2014.

Ferguson, E. R., E. R. Lawson, W. R. Maple, and C. Mesavage. 1968. Managing eastern redcedar. Page 14 *in* F. S. U.S. Department of Agriculture, editor. Southern Forest Experiment Station.

Ganguli, A. C., D. M. Engle, P. M. Mayer, and S. D. Fuhlendorf. 2008. When are native species inappropriate for conservation plantings? Rangeland 30:27-32.

Gehring, J. L., and T. B. Bragg. 1992. Changes in prairie vegetation under eastern red cedar (*Juniperus virginiana* L.) in an eastern Nebraska bluestem prairie. The American Midland Naturalist 128:209-217.

Hall, M. T. 1955. Comparison of Juniper populations on an Ozark glade and oldfields. Annals of the Missouri Botanical Garden 42:171-194.

Harr, R. N., L.W. Morton. S. R. Rusk, D. M. Engle, J. R. Miller, and D. M. Debinski. 2014. Landowner's perceptions of risk in grassland management: woody plant encroachment and prescribed fire. Ecology and Society 19:41.

Holthuijzen, A.M.A., T.L. Sharik, J.D. Fraser. 1987. Dispersal of eastern red cedar (Juniperus virginiana) into pastures: an overview. Canadian Journal of Botany 65:1092-1095.

Horncastle, V. J., E. C. Hellgren, P. M. Mayer, D. M. Engle, and D. M. Leslie, Jr. 2004. Differential consumption of eastern red cedar (Juniperus virginiana) by avian and mammalian guilds: Implications for tree invasion. American Midland Naturalist: 152:255-267.

Huang, Y., B. P. Wilcox, L. Stern, and H. Perotto-Baldivieso. 2006. Springs on rangelands: Runoff dynamics and influence of woody plant cover. Hydrological Processes 20:3277-3288.

Leis, S. A. and C. Blocksome. 2014 Understanding the problem with Junipers in the Great Plains. Society for Range Management 67th Annual International Meeting, Orlando, Florida February 8-13, 2014. Presentaotns available: http://www.youtube.com/playlist?list=PLkVJry3C6s2c0abnYRxciwkDZSx4yBFDz

Limb, R. F., D. M. Engle, A. L. Alford, and E. C. Hellgren. 2010. Tallgrass prairie plant community dynamics along a canopy cover gradient of Eastern Redcedar (*Juniperus virginiana* L.). Rangeland Ecology and Management 63:638-644.

Limb, R. F., D. M. Engle, A. L. Alford, and E. C. Hellgren. 2014. Plant community response following removal of *Juniperus virginiana* from tallgrass prairie: Testing for restoration limitations. Rangeland Ecology and Management 67:397-405.

Lyons, R. K., M. K. Owens, and R. V. Machen. 1998. Juniper biology and management in Texas. Texas Agricultural and Extension Service. Bulliten-6074. 12 p.

McClurkin, D. C. 1968. Site rehabilitation under planted redcedar and pine. Pages 339-345 *in* North American Forest Soils Conference, North Carolina State University at Raleigh.

Morton, L. W., E. Regen, D. M. Engle, J. R. Miller, and R. N. Harr. 2010. Perceptions of landowners concerning conservation, grazing, fire, and eastern redcedar managmenet in tallgrass prairie. Rangeland Ecology and Management 63:645-654.

Nigh, T.A., S.G. Pallardy, and H.E. Garrett. 1985. Sugar maple-environmental relationships in the River Hills and Central Ozark Mountains of Missouri. American Midland Naturalist 114:235-251.

Norris, M. D., J. M. Blair, and L. C. Johnson. 2007. Altered ecosystem nitrogen dynamics as a consequence of land cover change in tallgrass prairie. American Midland Naturalist 158:432-445.

Norris, M. D., J. M. Blair, L. C. Johnson, and R. B. McKane. 2001. Assessing changes in biomass, productivity, and C and N stores following *Juniperus virginiana* forest expansion into tallgrass prairie. Canadian Journal of Forest Research 31:1940-1946.

Ortmann, J., J. Stubbenkieck, R. A. Masters, G. H. Pfeiffer, and T. B. Bragg. 1998. Efficacy and costs of controlling eastern redcedar. Journal of Range Management 51:158-163.

Owensby, C. E., K. R. Blan, B. J. Eaton, and O. G. Russ. 1973. Evaluation of Eastern Redcedar infestations in the Northern Kansas Flint Hills. Journal of Range Management 26:256-260.

Pierce, A. M., and P. B. Reich. 2010. The effects of eastern red cedar (*Juniperus virginiana*) invasion and removal on a dry bluff prairie ecosystem. Biological Invasions 12:241-252.

Samson, F., and F. Knopf. 1994. Prairie conservation in North America. BioScience 44:418-421.

Schmidt, T. L., and J. Stubbendieck. 1993. Factors influencing eastern redcedar

seedling survival on rangeland. Journal of Range Management 46:448-451.
Scholes, R. J., and S. R. Archer. 1997. Tree-grass interactions in savannas. Annual Review of Ecology and Systematics 28:517-544.
Smith, S. D., and J. Stubbendieck. 1990. Production of Tall-grass prairie herbs below Eastern Redcedar. Prairie Naturalist 22:13-18.
Steavenson, H. A., H. E. Gearhart, and R. L. Curtis. 1943. Living fences and supplies of fence posts. Journal of Wildlife Mangement 7:257-261.
Thompson, C.R., D.E. Peterson, W.H. Fick, P.W. Stahlman, and J.W. Slocombe. 2014. Chemical Weed Control for Field Crops, Pastures, Rangeland, and Noncropland. Kansas State University Agr. Exp. Sta. and Cooperative Ext. Service. Report of Progress 1099. Manhattan. 136 p.
Twidwell, D., S. D. Fuhlendorf, C. A. Taylor, Jr., and W. E. Rogers. 2013a. Refining thresholds in coupled fire-vegetation models to improve mangment of encroaching woody plants in grasslands. Journal of Applied Ecology 50:603-613. Research brief
Twidwell, D., W. E. Rogers, S. D. Fuhlendorf, C. L. Wonkka, D. M. Engle, J. R. Weir, U. P. Kreuter, and C. A. Taylor, Jr. 2013b. The rising Great Plains fire campaign: Citizens' response to woody plant encroachment. Frontiers in Ecology and the Environment. 11 (Online Issue 1): e64–e71, doi:10.1890/130015. Research brief
USDA. 2014. US Department of Agriculture Plants Database. Available online at http://plants.usda.gov Last accessed 15 July 2014.
Van De Water, P. K., and E. Levetin. 2001. Contribution of upwind pollen sources to the characterization of Juniperus ashei phenology. Grana 40:133-141.
Volder, A., D. D. Briske, and M. G. Tjoelker. 2012. Climate warming and precipitation redistribution modify tree-grass interactions and tree species establishment in a warm-temperate savanna. Global Change Biology. Research brief
Wilcox, B. P. 2002. Shrub control and streamflow on rangelands: A process based viewpoint. Journal of Range Management 55:318-326.
Wilcox, B. P., M. K. Owens, W. A. Dugas, D. N. Ueckert, and C. R. Hart. 2006. Shrubs, streamflow, and the paradox of scale. Hydrological Processes 20:3245-3259.
Wilcox, B. P., and T. L. Thurow. 2006. Emerging issues in rangeland ecohydrology: Vegetation change and the water cycle. Rangeland Ecology and Management 59:220-224.
Wu, X. B., E. J. Redeker, and T. L. Thurow. 2001. Vegetation and water yield dynamics in an Edwards Plateau watershed. Journal of Range Management 54:98-105.
Yao, J., R. D. Holt, P. M. Rich, and W. S. Marshall. 1999. Woody plant colonization in an experimentally fragmented landscape. Ecography 22:715-728.
Zou, C.B., D.J. Turton, R.E. Will, D.M. Engle, and S.D. Fuhlendorf. 2013. Alteration of hydrological processes and streamflow with juniper (Juniperus virginiana) encroachment in a mesic grassland catchment. Hydrological Processes DOI: 10.1002/hyp10102.

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Figure 1. “Juniperus virginiana Maine" by Keith Kanoti, Maine Forest Service, USA - This image is Image Number 5350012 at Forestry Images, a source for forest health, natural resources and silviculture images operated by The Bugwood Network at the University of Georgia and the USDA Forest Service.. Licensed under Creative Commons Attribution 3.0-us via Wikimedia Commons - http://commons.wikimedia.org/wiki/File:Juniperus_virginiana_Maine.jpg#mediaviewer/File:Juniperus_virginiana_Maine.jpg

Figure 3. "Juniperus virginiana var virginiana range map 3" by Elbert L. Little, Jr., of the U.S.

Department of Agriculture, Forest Service - USGS Geosciences and Environmental Change Science Center: Digital Representations of Tree Species Range Maps from: Elbert L. Little, Jr. (1971), Atlas of United States trees, Vol. 1, conifers and important hardwoods: U.S. Department of Agriculture Miscellaneous Publication 1146, 9 p., 200 maps.. Licensed under Public domain via Wikimedia Commons - http://commons.wikimedia.org/wiki/File:Juniperus_virginiana_var_virginiana_range_map_3.png#mediaviewer/File:Juniperus_virginiana_var_virginiana_range_map_3.png

Figure 4. "Juniperus virginiana habitat" by USDA-NRCS PLANTS Database / Herman, D.E. et al. 1996. North Dakota tree handbook. USDA NRCS ND State Soil Conservation Committee; NDSU Extension and Western Area Power Admin., Bismarck, ND. - [1]. Licensed under Public domain via Wikimedia Commons - http://commons.wikimedia.org/wiki/File:Juniperus_virginiana_habitat.jpg#mediaviewer/File:Juniperus_virginiana_habitat.jpg

Figure 5. "2014-05-13 08 32 55 Eastern Red Cedar at South Riding Golf Club in South Riding, Virginia" by Famartin - Own work. Licensed under Creative Commons Attribution-Share Alike 3.0 via Wikimedia Commons - http://commons.wikimedia.org/wiki/File:2014-05-13_08_32_55_Eastern_Red_Cedar_at_South_Riding_Golf_Club_in_South_Riding,_Virginia.JPG#mediaviewer/File:2014-05-13_08_32_55_Eastern_Red_Cedar_at_South_Riding_Golf_Club_in_South_Riding,_Virginia.JPG

Figure 6. Photo by Aleksey Sheshuvov taken in Shawnee Co. Kansas.

Figure 7. Photo by Carol Blocksome, taken in Jewell Co. Kansas.

Figure 8. Photo by Dough Whisenhunt, taken in Nebraska.