SUPPORTING DETAILS

Scroll down for direct quotes from the literature that represent the scientific consensus. A full citation to each direct quote can be found at Suggested Readings.

BIRDS

- "Recent studies point to the expansion of eastern redcedar as a primary factor responsible for changes in Great Plains avifauna during the past 30 years." (Engle et al. 2008)
- "We suggest an upper tolerance limit to shrub cover of grasshopper sparrows occurs between 25%-35% woody canopy cover." (Chapman et al. 2004)
- "Greater sage-grouse (*Centrocercus urophasianus* Bonaparte) lek (i.e., breeding site) activity was found to decline as juniper (*Juniperus* sp.) canopy cover increases and the probability of greater sage-grouse lek persistence is near zero at 5% juniper canopy cover (Baruch-Mordo et al., 2013)." (Lautenbach et al. 2017)
- "The grasshopper sparrow was most abundant on our study patches where eastern redcedar cover was <10%." (Chapman et al. 2004)
- "Juniper cover should be kept well below 10% to maintain black-capped vireo habitat (Grzybowski et al. 1994)." (Engle et al. 1996)
- "Grassland birds are the most rapidly declining avian guild in North America (Fuhlendorf et al. 2012) and are rarely observed once juniper exceeds 10% of land cover (Chapman et al. 2004)." (Twidwell et al. 2013)
- "Woody encroachment is also the primary reason for the decline of the lesser prairie chicken (*Tympanuchus pallidicinctus*; Fuhlendorf et al. 2002), which is now being considered for listing under the Endangered Species Act." (Twidwell et al. 2013)
- "An influx of woody vegetation generally increases the resource base for the avian community, but in turn alters composition by attracting avian exotics and habitat generalists and decreasing habitat suitability for endemic and obligate avian species (Blair 1996; Farina 1997; Preiss et al. 1997)." (Coppedge et al. 2001)
- "In general, those birds (grasshopper sparrow and dickcissel) that were negatively correlated with canopy cover of eastern redcedar were grassland specialists and intolerant of eastern redcedar, whereas those species (Carolina chickadee, yellow-billed cuckoo, and Bewick's wren) were positively correlated with canopy cover of eastern redcedar were species associated with woodland habitats." (Chapman et al. 2004)
- "Grassland-obligate avian species, such as lesser prairie-chicken (*Tympanuchus pallidicinctus*), upland sandpipers (Bartramia longicauda), burrowing owls (Athene cunicularia), and western meadowlarks (*Sturnella neglecta*), were either too scarce to model, declined with increasing woody cover (mostly eastern red cedar—Coppedge et al. 2001; Fuhlendorf et al. 2002), or were predicted to decline with the current rate of red cedar expansion (Coppedge et al. 2004). Open-habitat generalists, woodland species, and

successional shrub species of birds increased or were predicted to increase with woody or red cedar expansion (Coppedge et al. 2001, 2004).” (Horncastle et al. 2005)

- “In contrast to our data on woodland mammals, overall avian species richness was enhanced with red cedar invasion by attracting open-habitat generalist and woodland bird species that generally increased with increasing woody plant cover (Chapman et al. 2004a; Coppedge et al. 2001). However, this enhancement of species richness is at the expense of the few endemic species of grassland birds.” (Horncastle et al. 2005)
- “Survey points with high cedar density had low species richness ($\beta = -0.158$, $SE = 0.041$; $p < 0.01$). Species richness appeared to be fairly independent of canopy cover, although mid-level of canopy cover tended to have more species ($p = 0.22$). Cedar density was the single variable that best explained community similarity between points. High-density cedar sites had more ground-nesting successional shrub habitat species, whereas the low-density sites, overall, had more species diversity with an increase in cavity-nesting and woodland species.” (Frost and Powell 2011)
- “Bird species richness was highest in areas with low density of cedar” (Frost and Powell 2011)
- “Several recent studies have demonstrated shifts in avian communities in southern mixed-grass prairies associate with red cedar encroachment (Chapman et al. 2004a; Coppedge et al. 2001, 2004; Fuhlendorf et al. 2002).” (Horncaslte et al. 2005)
- “Three known juniper feeders and seed dispersers, the cedar waxwing (Bombycilla cedrorum), eastern bluebird (*Sialia sialis*), and yellow-rumped warbler (*Dendroica coronata*), had significant positive abundance trends with regional juniper levels, as did the ruby-crowned kinglet (*Regulus calendula*).” (Engle et al. 2008)
- “Two other know juniper feeders (American robin, *Turdus migratorius*; blue jay, C*yanocitta cristata*) exhibited unimodal trends, indicating a preference for regions with moderate juniper levels.” (Engle et al. 2008)
- “Four species, the song sparrow (*Melospiza melodia*), white-crowned sparrow (*Zonotrichia leucophrys*), house sparrow (*Passer domesticus*), and American goldfinch (*Carduelis tristis*), were negatively related to regional juniper encroachment levels.” (Engle et al. 2008)

INSECTS

- “The results of this study indicate that cedars reduce numbers of most silphid species (including the American burying beetle), likely by limiting their ability to forage for carrion, a required resource for feeding and reproduction.” (Walker and Hoback 2007)
- “Significantly more (Mann-Whitney rank test, $P < 0.001$) Silphidae were collected in open sites (66.9 ± 3.5) than from cedar-dominated sites (54.9 ± 3.3).” (Walker and Hoback 2007)
- “Significantly more (Mann-Whitney rank sum test, $P < 0.001$) *N. marginatus* were collected in open sites (40.97 ± 2.379) than in cedar-dominated sites (16.85 ± 1.544).” (Walker and Hoback 2007)

- “Three *Nicrophorus* species showed apparent preferences for cedar-dominated habitats over open grassland. Only one of these, *N. orbicollis*, was captured significantly more often in cedar-dominated habitats. Many other researchers have found *N. orbicollis* to prefer wooded habitats (Anderson 1982, Shubeck 1983, Peck and Kaulbars 1987, Shubeck 1993, Beninger 1994, Lomolino et al. 1995, Lomolino and Creighton 1996, Trumbo and Bloch 2000, Bishop et al. 2002), so the results of this study were not surprising.” (Walker and Hoback 2007)

SMALL MAMMALS

- “An increase in overstory cover from 0% to 30% red cedar can change a species-rich prairie community to a depauperate community dominated by 1 (small mammal) species, *Peromyscus leucopus*.” (Horncastle et al. 2005)
- “When red cedar colonizes an area, it reduces the herbaceous ground cover under the canopy zone (Engle et al. 1987; Smith and Stubbendieck 1990) on which prairie mammals depend.” (Horncastle et al. 2005)
- “That is, species richness (an average of seven small mammal species) was greatest when woody cover was ≤17%, but this species-rich community decreased to only one species, the white-footed mouse, in closed-canopy deciduous forest sites.” (Matlack et al. 2008)
- “Horncastle et al. (2005) and Matlack et al. (2008) found the small mammal communities of eastern redcedar-dominated habitat in the Great Plains were less diverse than nearby grassland and woodland habitats. In Kansas (Matlack et al., 2008) and in Oklahoma (Horncastle et al., 2005) deer mice (*Peromyscus maniculatus*), hispid cotton rats (*Sigmodon hispidus*), western harvest mice (*Reithrodontomys megalotis*), and fulvous harvest mice (*R. fulvescens*) dominated the grassland small mammal communities whereas white-footed mice (*P. leucopus*) constituted most of the eastern redcedar forest small mammal population.” (Reddin and Krementz 2016)
- “Encroachment of eastern redcedar into grasslands could result in local extirpation of grassland-associated species such as least shrews, fulvous harvest mice, and hispid cotton rats as we only captured these three species in open grass habitats, similar to the findings of Stancampiano and Schnell (2004).” (Reddin and Krementz 2016)

PUBLIC SCHOOOL FUNDING

- “In the last 15 years, the School Land Trust (known formally as the Nebraska Board of Education Lands and Funds) has contributed $573 million to K-12 public schools in Nebraska. The School Land Trust is the largest landowner in the state, receives no State funding, pays county real estate taxes (more than $10,320,000 in 2015), and all of its net revenue goes to K-12 public schools. The Trust owns and manages nearly 1.26 million acres of agricultural land in Nebraska. More than 950,000 acres of Trust land are grasslands that generate income for public schools from grazing leases.” (Lally et al. 2016)

- "The Trust first established programs to control cedar in the 1980s. That campaign has been stepped up in the last ten years. The School Land Trust has increased annual expenditures for cedar control by $250,000 since 2006." (Lally et al. 2016)
- "The future trajectory of risk (corresponding to a 75% reduction in grazing profits) is equivalent to an average budgetary loss of $30 million per year over the last 15 years for public education. While it will take decades to reach those losses statewide, the steadily declining profitability will slowly consume school budgets at the rate of a few million dollars a year in the near term." (Lally et al. 2016)

HERBACEOUS PLANT COMPOSITION

- "Beneath the red cedar canopy, virtually all grassland species were eliminated and richness was very low – often fewer than four species per 10-m2 plot. In contrast, plots adjacent to red cedar stands had as many as 35 herbaceous species." (Briggs et al. 2002)
- "Herbaceous species richness declined from about 27 species per 10 m^{-2} at 0 eastern redcedar trees per ha^{-1} to 5 species per 10 m^{-2} at about 1,500 eastern redcedar trees ha^{-1} (Briggs et al. 2002)." (Limb et al. 2010)
- "Pretreatment species richness declined linearly along the increasing juniper canopy gradient from 36 and 37 species at the two reference sites to 13 and 15 species respectively at the two 76% canopy cover sites, a 62% loss in species richness." (Limb et al. 2014)
- "Species richness declines immediately under the crown of individual Ashe juniper trees (*Juniperus ashei* Buckholz; Fuhlendorf et al. 1997) and eastern redcedar trees (Briggs et al. 2002) compared to grass-dominated interspaces". (Limb et al. 2010)
- "When juniper invades grasslands, plant composition can shift from C4-dominated midgrasses and tall grasses to C3-dominated midgrasses, short grasses, and sedges and abundant shrub species directly under individual trees (Gehring and Bragg 1992; Fuhlendorf et al.1997; Briggs et al. 2002)." (Limb et al. 2014)
- "Dominant grasses in the interstitial zone were *Andropogon gerardii*, *Bouteloua curtipendula*, *Schizachyrium scoparium*, *Dichanthelium [Panicum] oligosanthes var.* scribnerianum*, Carex* eleocharis and *Agropyron smithii [Elymus smithii]* whereas canopy zone grasses included *Bromus japonicus, Poa* pratensis and *C. heliophila*." (Smith and Stubbendieck 1990)
- "Herbaceous species commonly found in the closed-canopy sites included Kentucky bluegrass (*Poa pratensis*), western yarrow (*Achillea millefolium*), and bedstraw (*Galium species*). However, there were no species that were found consistently in the understory of these forests or that were distinct from those species present in the adjacent grasslands." (Briggs et al. 2002)
- "Kaul et al (1983) studied species composition, using relative density, under closed canopy eastern redcedar stands that had previously existed as prairie sites. They found that only one shade tolerant species, littleseed ricegrass (*Oryzopsis micrantha* (Trin. And Rupr.) Thurb.), to regularly occur in the understory." (Smith 1986)

- “In contrast, eastern redcedar, unlike other North American junipers, does not produce fertile and unfertile zones extending beyond the tree; rather, the influence of vegetation is limited to directly under the canopy (Engle et al. 1987; Engle and Kulbeth 1992). Therefore, we saw no compositional shift at the stand level with our study.” (Limb et al. 2010)
- “Early in the encroachment process, young redcedar trees with small stem diameters and heights (Owensby et al. 1973) are likely to have only limited shading effects on herbaceous vegetation, and in turn, on grassland fauna that rely on herbaceous vegetation for food and cover.” (Alford et al. 2012)
- “At lower levels of encroachment, individual trees tend to be isolated within a spatially homogenous matrix of herbaceous plant cover. However, at higher levels of redcedar cover, herbaceous vegetation becomes confined to small patches between clumps of redcedar trees.” (Alford et al. 2012)
- “Reduced species richness and species compositional shifts are a reflection of reduced light penetration immediately under the tree crown (Fuhlendorf et al. 1997).” (Limb et al. 2010)
- “This study indicates that the magnitude of the effect of the eastern red cedar presence on the bluff prairie system is altered by the slope position around the tree through a combination of light availability due to canopy cover and slope aspect, and possibly runoff due to slope steepness or differential root water uptake based on slope position.” (Pierce and Reich 2010)
- “The data indicate that bluestem prairie species composition can be significantly affected by less than 20 yr of shading by invading trees, suggesting that protection from such invasion is essential to the continuation of this ecosystem.” (Gehring and Bragg 1992)
- “The topsoil was covered primarily by eastern redcedar leaf litter under and near the eastern redcedar canopy and by grass beyond the tree canopy.” (Wine et al. 2011)
- “Leaf litter of evergreens has more lignin, making it more difficult for microbes to decompose, relative to leaf litter of grasses (Murphy et al. 1998). Consequently, litter accumulates under eastern redcedar as we observed.” (Wine et al. 2011)

HERBACEOUS PRODUCTION

- “Thus, as compared to tallgrass prairie, herbaceous production in a red cedar forest was decreased by over 99%.” (Briggs et al. 2002)
- “Canopy zone biomass production averaged 83% less than the interstitial zone.” (Smith and Stubbendieck 1990)
- “Estimated herbaceous biomass had a strong negative linear relationship with juniper canopy cover, decreasing approximately 70% at the two 76% juniper canopy sites compared to the reference sites.” (Limb et al. 2014)
- “A weighted average of all life-form, year, and site combinations indicated that forage production was 83% less in the canopy zones that in the interstitial areas.” (Smith 1986)

- “Similarly, Engle and others (1987) and Schmidt and Stubbendieck (1993) measured a reduction in herbaceous productivity of 33%-96% under isolated red cedar trees growing in grasslands.” (Briggs et al. 2002)
- “The influence of eastern redcedar on herbage production surrounding individual trees appears to be primarily restricted to beneath the tree canopy.” (Engle et al. 1987)
- “Reduction of forage production by junipers on western rangelands is proportional to tree canopy size and tree density (Arnold et al. 1964; Jameson 1967). This relationship also applies to tallgrass prairie invaded by eastern redcedar since our data indicate that the primary effect of eastern redcedar on herbage production is beneath the canopy.” (Engle et al. 1987)
- “Reductions in light (averaging 85%) and available soil water (11.5%) are suggested as two possible explanations of reduced canopy zone biomass.” (Smith and Stubbendieck 1990)

LIVESTOCK PRODUCTION

- “The Great Plains accounts for nearly 50% of US beef production (Wishart 2004), a $79 billion industry (USDA ERS 2011), but livestock production has decreased by 75% in areas where grasslands have been converted to juniper woodlands (Fuhlendorf et al. 2008).” (Twidwell et al. 2013)
- “On a range site with the potential to produce 4,000 pounds per acre of forage, a stand of eastern redcedar trees with 200 trees per acre that increases to 470 trees per acre in ten years would produce about 3,700 pounds per acre of forage in the first year, and less than 2,200 pounds per acre of forage in the tenth year (Engle and Stritzke 1992).” (Engle et al. 1996)
- “This has had an adverse effect on livestock production because eastern redcedar reduces total forage production (Engle 1985; Engle et al. 1987; Smith and Stubbendieck 1990), leads to undesirable changes in plant species composition (Gehring and Bragg 1992), and increases livestock handling costs (Stritzke and Rollins 1984).” (Ortmann et al. 1998)

WILDFIRE RISK

- “Guidelines developed by the US Forest Service indicate that fire suppression is unlikely to be successful in the presence of wildland fuels when flame lengths are greater than 3.4 m (Andrews and Rothermel 1982). In areas of long-term juniper encroachment, fires have shifted from frequent, grass-driven surface fires that vary in flame length (range = <0.1 m to well over 3.4 m; Finney et al. 2011) to infrequent, juniper driven crown fires that consistently exhibit extremely long flames (>14 m) and are of increasing societal concern (Twidwell et al. 2012). Such alterations to the fire regime and fire suppression potential are important contributors to the recent rise in housing losses, suppression costs, and human injuries and deaths resulting from wildfires in the Great Plains.” (Twidwell et al. 2013)

CARBON

- "Changes in carbon allocation patterns following redcedar encroachment into grasslands are so profound that the bulk of the ecosystem C storage shifts from belowground in grasslands (~96%) to aboveground (~52%) in Eastern redcedar stands (Norris et al. 2001a; McKinley 2006)." (McKinley et al. 2008)
- "The substantial increase in annual aboveground productivity associated with conversion of prairie to redcedar-dominated stands could lead to a significant increase in regional C storage, especially in consideration of the extensive amount of tallgrass prairie recently encroached upon by redcedar stands." (Norris et al. 2001a)
- "In redcedar, there is almost a fourfold difference in total ecosystem C storage relative to grasslands (including root estimates), which amounts to more than 100 Mg C ha-1 of additional C (Norris et al. 2001b; McKinley 2006). (McKinley et al. 2008)
- "At our paired woodland-grassland sites, aboveground productivity in closed-canopy juniper woodland is double to triple that of tallgrass prairie, and aboveground biomass C stock are from 10- to 20-fold that of tallgrass prairie (Norris et al. 2001a)." (Smith and Johnson 2004)
- "Also, given that the bulk of new C and N allocation is aboveground, these pools are very vulnerable to significant and rapid losses, primarily through fire (Klopatek et al. 1990). (McKinley et al. 2008)
- "Juniper encroachment increases aboveground C stocks and belowground soil organic C (Knapp et al. 2008; McKinley and Blair 2008). However, aboveground biomass comprises approximately 90% of C storage gains in juniper woodlands (Barger et al. 2011) and given the susceptibility of theses woodlands to rapid losses of aboveground C following wildfires, drought, disease, and insect outbreaks, gains in C storage are potentially short-lived (Breshears and Allen 2002). This is particularly true when such disturbance events cause unanticipated feedbacks to soil C storage that further facilitate C loss (e.g. loss of soil C from erosion; Johansen et al. 2001; Breshears and Allen 2002)." (Twidwell et al. 2013)
- "Carbon accumulation in aboveground plant biomass increased by a factor of 37, from a mean seasonal maximum of 163 g C m-2 in grasslands to 6,065 g C m-2 in J. virginiana stands." (McKinley and Blair 2008)
- "Differences in the rate of change in aboveground biomass C and N in J. virginiana forests, relative to grasslands, resulted in a shift in mean C:N ratios in aboveground biomass from approximately 54 in grasslands to approximately 126 in J. virginiana forests." (McKinley and Blair 2008)

SOIL MOISTURE

- "Juniper canopies intercept 35-37% total rainfall (Owens et al. 2006; Caterina 2012), which is 10-15% higher than the value reported for grasses under similar climate condition (Thurow et al. 1987)." (Zou et al. 2014)

- “Our findings suggest that red cedar canopies can intercept ≈33% of annual precipitation in central Oklahoma, and as much as ≈39% in the western (and drier) part of the state.” (Starks et al. 2014)
- “Caterina et al. (2014) indicated that in years with normal rainfall, closed Eastern redcedar canopies are capable of transpiring >99% of all precipitation that reaches the soil surface.” (Starks and Moriasi 2017)
- “Soil water repellency was prevalent both under the canopy and in the intercanopy area. Of sites under eastern redcedar, 94% exhibited water repellency; in contrast, 65% of intercanopy sites exhibited some degree of water repellency. (Wine et al. 2011)
- “The average reduction in the canopy zone soil water content for both sites and years was 11.5%.” (Smith 1986)
- “Duesterhaus (2008) measured canopy intercept in a dense stand of redcedar of about 45 years in age in the Kansas Flint Hills (sub-humid climate) and found it varied from 17 to 77% of total storm precipitation, depending upon storm size and intensity. Annual average canopy intercept was about 52%.” (Starks et al. 2014)
- “In Nebraska, Smith and Stubbendieck (1990) found lower soil water content under eastern redcedar canopies than in the adjacent intercanopy zone, consistent with results in Figure 2C.” (Wine et al. 2011)
- “A corresponding increase in soil water repellency and decreases in sorptivity and unsaturated hydraulic conductivity were observed under Eastern redcedar.” (Wine et al. 2011)
- “Similarly, in Kansas, lower soil water content was observed during the non-growing season under eastern redcedars relative to grassland (Smith and Johnson 2004).” (Wine et al. 2011)
- “Precipitation intercepted by the canopy can run down the stem of the tree, run off the branches of the tree, or evaporate from the branches and foliage into the air (Rowe and Hendrix 1951).” (Van Els 2009) “Contrary to prior research, the current study indicates higher soil moisture under eastern red cedar trees. This increase in soil moisture is likely caused by the runoff from the upper portion of the slope that allows moisture to reach the soil surface under the eastern red cedar trees. The resulting soil moisture may be retained longer under the eastern red cedar due to reduced evaporation associated with the lower light availability and/or due to differences in ‘‘forest’’ floor roughness, infiltration, and structure resulting from cedar litter, root and shed branch characteristics. This suggests that conclusions about cedar effects based on studies in flat landscapes may not always be useful in hilly terrain.” (Pierce and Reich 2010)

STREAMFLOW

- “Our results showed that the encroachment of juniper into mesic grasslands altered catchment hydrological processes.” (Zou et al. 2014)
- “Detailed experiments at the small watershed scale indicate that conversion of grassland to juniper woodlands will result in much lower streamflows, owing to a combination of

higher interception, increases in evapotranspiration, and increases in soil infiltration (Caterina et al. 2014; Zou et al. 2014; Qiao et al. 2015).” (Zou et al. 2015)

- “Our model suggested that a J. virginiana woodland with a closed canopy is capable of transpiring almost all precipitation reaching the soil in years with normal precipitation, indicating the potential for encroachment to reduce water yield for streamflow and groundwater recharge.” (Caterina et al. 2014)
- “The magnitude of streamflow reduction varies along the precipitation gradient.” (Zou et al. 2015)
- “Juniper has decreased streamflow and groundwater recharge in many cases (Huxman et al. 2005; Wine et al. 2011), and juniper trees have extensive root systems that appear to reduce water storage in soils important to aquifer recharge (Schwinning 2008). However, increases in water infiltration and recharge have also been documented in juniper-dominated systems (Wilcox et al. 2008). Differential hydrological responses to juniper encroachment should therefore be expected (Huxman et al. 2005; Wilcox et al. 2005), with positive and negative species responses dependent on the interrelationships of juniper trees with temp, precipitation, physiography, geology, and runoff and infiltration mechanisms (Jackson et al. 2008; Huxman et al. 2005; Wilcox et al. 2005; Schwinning et al. 2008).” (Twidwell et al. 2013)
- “Infiltration capacity was significantly greater both under unsaturated and saturated soil water conditions for the encroached catchment than for grassland catchment.” (Zou et al. 2014)
- “Soil water held in entire soil matrix was, in general, lower under encroached catchment, especially in spring and early summer immediately preceding the peak rainfall period for this region.” (Zou et al. 2014)
- “The annual streamflow for the encroached catchment averaged about 2% of the precipitation compared with about 10% for the grassland catchment.” (Zou et al. 2014)
- “Annual streamflow duration in the encroached catchment was less than 1/3 annual streamflow duration in the grassland catchment.” (Zou et al. 2014)
- “Our model simulations suggest that encroachment of redcedar into grasslands could have a detrimental effect on stream discharge, which could impact water availability on populations further downstream.” (Starks and Moriasi 2017)
- “A more realistic conversion of 20% of grassland to cedar would, according to our simulations, reduce stream discharge by an amount of water equivalent to ≈27% of the current water demand, or ≈21% of the projected 2060 demand.” (Starks and Moriasi 2017)
- “In this region, changes in the water budget are fundamentally driven by the doubling or tripling in standing biomass that comes about when grasslands are converted to woodlands (Briggs et al. 2005).” (Zou et al. 2015)
- “When eastern redcedar cover passes 60%, most of the watersheds in arid portion of the Cimmarron River basin may completely run out of streamflow.” (Zou et al. 2015)

- “Our results indicate that Eastern redcedar encroachment would lead to reduced streamflow throughout the year, with the largest reduction in April and May, due to mainly to much smaller surface run-off.” (Zou et al. 2015)
- “Juniper encroachment degrades watershed quality be increasing the amount of bare soil and increasing the potential for erosion (Thurow and Carlson 1994).” (Engle et al. 1996)

SOIL pH

- “The high calcium content of its foliage (over 2 percent) tends to change soils from acid to alkaline in a comparatively short time, perhaps less than 15 years (Broadfoot, 1951a; Broadfoot, 1951b).” (Ferguson et al. 1968)
- “The transfer of Ca and other base cations from eastern red cedar litter to soil shown in previous studies is the best explanation for the increase in soil base-cations and pH in the soils surrounding eastern red cedar (Broadfoot and Pierre 1939; Spurr 1940; Bard 1952). However, the results of the current study showed no significant change in Ca and no change in pH under eastern red cedar likely due to the initial high levels of base cations in this.” (Pierce and Reich 2010)
- “Eastern redcedar contains a large amount of cations in its leaves and therefore has a buffering effect on soil acidity, raising pH of acidic soils (Luts and Chandler 1946; Coile 1933; Spurr 1940; Read and Walker 1950; McBain 1983).” (Van Els 2009)
- “The high calcium content of the Eastern redcedar litter agrees with results reported for this species elsewhere.” (Broadfoot 1951b)
- “On soils with naturally high pH, such as calcareous prairie soils, redcedar litter does not raise pH levels.” (Van Els 2009)
- “New juniper C, though prevalent at the soil surface, did not cause significant changes in pH, cation exchange capacity, or concentrations of cations in the top 10 cm of mineral soil.” (Smith and Johnson 2003)

HISTORICAL ABUNDANCE

- “The Spanish explorer Coronado wrote in 1541 as he traveled through the region, “There is not any kind of wood in all these plains, away from the gullies and river, which are very few” (Bragg and Hulbert 1976).” (Bryant 2017)
- “Circa 1840, surveyors noted Eastern redcedar on sites with long fire intervals but made no mention of Eastern redcedar on sites with a short fire interval (Batek et al. 1999).” (Guyette et al. 2002)
- “Most historical accounts of the 1800’s indicate that Eastern redcedar was not a common tree, but it could be found along river bluffs, slopes, and bottoms.” (Blewett 1986)
- “Literature from the early 1900’s note an absence of Eastern redcedar throughout much of the prairie, its range being confined to only canyons and stream channels (Kellogg 1950; Harper 1912). (Smith 1986)

- “Historical records indicate that Eastern redcedar was rare in NE prior to the arrival of European man (Miller 1902; Kellogg 1905; Harper 1912).” (Smith 1986)
- “Historically, fire prevented Eastern redcedar encroachment into tallgrass prairies and forest meadows of the central US (Ared 1950).” (Engle et al. 1987)
- “Burkhardt and Tisdale (1976) found that juniper stands in Idaho were originally confined to poorer soils and rocky ridges by wildfires.” (Schmidt and Stubbendieck 1993)
- “Eastern redcedar has thus been historically restricted across much of its range to rocky uplands. It does not prefer these poorer sites. However, they lack a heavy, continuous, understory fuel, preventing fires from entering (Walker 1967).” (Smith 1986)

SEED PRODUCTION

- “Natural reproduction in Eastern redcedar is dependent upon seed production, since sprouting or suckering is not known to occur (Fowells 1965).” (Blewett 1986)
- “Much of the reproduction occurs from seed falling to the ground, but several bird species including cedar waxwings, robins, starlings and mockingbirds have been observed removing cones form the trees as well as from snow-covered ground (Parker 1951). Others have reported small mammals, quail, grouse, pheasant and turkey consuming the seed and, presumably, aiding in seed dispersal (Fowells 1965).” (Blewett 1986)
- “Although Eastern redcedar is a prolific seed producers in the eastern US, seeds did not accumulate in the soil seed bank (Holthuijzen and Sharik 1984).” (Tunnell et al. 2004)
- “Eastern redcedar seeds did not appear to accumulate in the soil outside the canopy, and seeds did not remain highly viable in the seed bank for an extended time. These results are similar to Eastern redcedar seed dynamics in the eastern US (Holthuijzen and Sharik 1984; Holthuijzen and Sharik 1985).” (Tunnell et al. 2004)
- “Our data indicate that most seedling recruitment depends on seeds from the current year’s seed crop.” (Tunnell et al. 2004)
- “Seed production begins at about 10 years and continues up to 175 years, with optimum production between 25-75 years.” (Van Haverbeke and Read 1976)
- “Trees 6-7 years old produced seeds. Secondary invasions from existing trees could occur 6-7 years after tree establishment.” (Owensby et al. 1973)
- “Eastern redcedar bears seeds between the age of 10 and 100 plus years, although maximum seed production occurs between the age of 25-75 years (Ferguson et al. 1968).” (Smith 1986)
- “Good seed crops occur every 2-3 years, with light crops intervening.” (Van Haverbeke and Read 1976)
- “The number of berries per kg averages about 43,000, but it can vary between 36,500-55,000 (Stoeckler and Slabaugh 1965).” (Smith 1986)

- “Each cone contains 1-3 (occasionally up to 6) free seeds which mature in one season (Hall 1952a; 1961).” (Van Haverbeke and Read 1976)

SEED DISPERSAL

- “At least 71 species forage on Eastern redcedar (Van Dersal 1938) and seed dispersal apparently depends heavily upon birds and small mammals (Phillips 1910; Livingston 1972).” (Horncastle et al. 2004)
- “Seed distribution beyond the canopy relies primarily on avian dispersal in the eastern US (Holthuijzen et al. 1987; Joy and Young 2002).” (Tunnell et al. 2004)
- “Single consistent feeders, such as the yellow-rumped warbler, accounted for slow, sustained removal of red cedar cones, whereas flock feeders, such as the cedar waxwing, European starling, and American robin, were responsible for rapid removal of entire cone crops.” (Holthuijzen and Sharik 1985)
- “Conelets of the genus Juniperus, which resemble berries because of their fleshiness, are a good source of food for many animal species. Mammals such as Raccoons (Procyon lotor) and Gray Fox (Urocyon cinereoargentus) readily eat redcedar conelets.” (Van Els 2009)
- “However, in the case of redcedar, which does produce a protective conelet around the seed, seeds pass the digestive tract unharmed (Phillips, 1910).” (Van Els 2009)
- “Redcedar is often found growing along fence lines (Phillips 1910, McAtee 1947, Holthuijzen and Sharik 1984) because birds that consume redcedar conelets leave droppings when the perch on the fence. The species is also frequently found under tall trees, due to the preference of birds to roost in tall trees.” (Van Els 2009)
- “Eastern redcedar cones and seeds have been found in feces of raccoons, foxes, bobcats, and small mammals (Phillips 1919).” (Horncastle et al. 2004)
- “Eastern redcedar seeds and seedlings are distributed randomly across the landscape except for increased abundance near perch sites of frugivorous birds (Holthuijzen and Sharik 1984).” (Limb et al. 2010)
- “Dispersed seeds of Eastern redcedar also are more concentrated along powerlines and fencerows where birds perch (Holthuijzen et al. 1986).” (Horncastle et al. 2004)
- “Because birds have high mobility and a digestion time (18-20 min) that exceeds their feeding time (3-4 m) on trees, they tend to have a high dispersal efficiency (Holthuijzen and Sharik 1985). (Horncastle et al. 2004)
- “Holthuijzena and Sharik (1985) also found that, on average, birds dispersed cones more than 12 m from the parent tree.” (Horncastle et al. 2004)
- “The amount of bird-disseminated seeds dropped into fields is positively associated with the amount of structural complexity in the field (McDonnell and Stiles 1983).” (Horncastle et al. 2004)

- “Eastern redcedar seeds pass unharmed through the digestive tract of avian dispersers, generally within 0.5 hr after ingestion (Holthuijzen 1983).” (Holthuijzen and Sharik 1985)
- “The Eastern redcedar seed shadow was up to 300 m from seed source.” (Holthuijzen and Sharik 1985)
- “The maximum dispersal distance from the Eastern redcedar fruit source was 515 m.” (Holthuizjen and Sharik 1985)
- “Medium sized mammals, such as carnivores and lagomorphs, may spread Eastern redcedar seeds at scales approaching that of birds because longer gut retention times and movements exceeding 1 km (Chavez-Ramirez and Slack 1993; Chambers et al. 1999). For example, a coyote consuming Eastern redcedar cones and moving within the next 12-14 h could disperse seeds several km from the source tree.” (Horncastle et al. 2004)

PLANTING

- “The species is extensively used in shelterbelt and windbreak plantings throughout the Great Plains (Read 1964), and as wildlife food and cover (Read 1948; Van Dersal 1938a).” (Van Haverbeke and Read 1976)
- “It ranked high in the Great Plains shelterbelt plantings because of its ability to withstand extremes of drought, heat, and cold (Fowells 1965).” (Lawson and Law 1983)
- “The US government promoted tree planting through programs such as the Timber Culture Act of 1873, which granted homesteaders 160 acres provided trees were planted to 40 of those acres (9).” (Ganguli et al. 2008b)
- “In an effort to cope with the decline of soil and wildlife resources associated with unsustainable farming practices and drought of the 1930’s and 1950’s, tree planting was promoted by federal agencies (e.g. the Soil Conservation Service), which culminated in modern state and federal tree planting programs for conservation.” (Ganguli et al. 2008b)
- “Eastern redcedar is planted in some states specifically to support nonindigenous game species such as ring-necked pheasants (Phasianus colchicus), despite negative effects of eastern redcedar on sensitive sympatric native species such as the lesser prairie-chicken (Tympanuchus pallidicinctus) (13).” (Ganguli et al. 2008b)
- “Nebraska, with a distribution program dating from 1926, distributed more than 1.2 million Eastern redcedar and 350,000 RMJ seedlings from the 1980-early 1990’s.” (Ganguli et al. 2008b)
- “The most common conservation uses for the seedlings were windbreaks and wildlife habitat plantings. Seedlings were used to a lesser extent for soil stabilization, living snow fences, shelterbelts, Conservation Reserve Program (CRP) plantings, and mine reclamation.” (Ganguli et al. 2008b)
- “Duration of the Eastern redcedar seedling distribution programs ranged from 5-76 yr, with older programs located in the prairie biogeographic province.” (Ganguli et al. 2008b)

- "Further exacerbation of forest expansion is caused by direct activities of landowners who plant Eastern redcedar trees for landscaping, as windbreaks, or for wildlife habitat." (Briggs et al. 2002)
- "In addition, the species range has been considerably extended, especially in the Great Plains, by the many thousands of planted trees which provide seed sources for local dissemination by birds." (Van Haverbeke and Read 1976)
- "Many authorities feel this recent spread is due to a reduction in wildfires and/or a more widespread seed availability from many farm shelterbelt plantings (Beilmann and Brenner 1951; Bragg and Julbert 1976; Van Haverbeke and Read 1976)." (Smith 1986)
- "Eastern redcedar is also commonly planted as an ornamental or shade tree (Wright and Bretz 1949)." (Smith 1986)

INVASIVE PROPERTIES

- "It is a versatile tree, well-adapted for growth in a wide range of climate, edaphic, and topographic situations." (Van Haverbeke & Read 1976)
- "Eastern redcedar is adapted to an extremely wide variety of environments: annual precipitations between 41 and 152 cm, temperature extremes ranging from -40° to +46°, elevations from 0 to 1525 m, and growing seasons between 120 and 250 d/yr (Van Haverbeke and Read 1976)." (Lassoi et al. 1983)
- "The more rapid expansion of red cedar forest may be related to its evergreen habitat, the rapid growth rate of the tree, its high reproductive output, and its capability for widespread dispersal (Holthuizjen and Sharik 1985c)." (Briggs et al. 2002)
- "Because red cedar forests can grow on thin, rocky soils, the combination of deciduous and evergreen forest expansion on virtually all soil types represents a significant threat to the remaining tracts of tallgrass prairie." (Briggs et al. 2002)
- "Hence, this species is a vigorous pioneer and is found frequently in pastures, abandoned fields, fence rows, and on calcareous rocky outcrops (Beilmann and Brenner 1951, Ferguson et al. 1968). (Lassoi et al. 1983)
- "Juniperus virginiana is drought tolerant and therefore well adapted to water-limited prairie in this region (Caterina et al. 2014). In fact, *J. virginiana* is more drought tolerant than the tallgrass prairie-dominant *A. gerardii* (Axmann and Knapp 1993), five species of oaks (Quercus spp.) and *Acer saccharum* Marsh. (Bahari et al. 1985) and *Pinus ponderosa* Lawson & *C. Lawson* (Bihmidine et al. 2010)." (Ganguli et al. 2016)
- "…and *J. virginiana* trees possess inherently high water use efficiency and an ability to maintain stomatal opening at low water potentials and are, therefore, well-adapted to drought conditions (Eggemeyer et al. 2006; Willson et al. 2008). (Bihmidine et al. 2010)
- "It is indigenous in every State east of the 100th meridian and the southern parts of Quebec and Ontario (Williamson 1965)." (Van Haverbeke & Read 1976)
- "Over its habitat, annual snowfall averages extend from 0-100 or more inches (2540 mm)." (Lawson and Law 1983).

- “It also grows on many soil types, from deep, moist, alluvial sites to rough, stony outcrops (Walker 1967).” (Smith 1986)

FACTORS FACILITATING INVASION

- “The elimination of fire in tallgrass prairie is the primary reason closed-canopy Eastern redcedar forests have increased in the Great Plains grasslands (Briggs and Gibson 1992; Engle and Kulbeth 1992).” (Briggs et al. 2002)
- “The primary reason for Eastern redcedar increase is thought to be the suppression of wildfire (Bragg and Hulbert 1976; 2and Gibson 1992).” (Ortmann et al. 1998)
- “However, control of wildfires, genetic adaptability, expanded seed sources, and soil disturbance are primary factors responsible for expansion.” (Schmidt and Stubbendieck 1993)
- “In addition, the species range has been considerably extended, especially in the Great Plains, by the many thousands of planted trees which provide seed sources for local dissemination by birds.” (Van Haverbeke and Read 1976)
- “Expansion has primarily occurred in rangelands and pastures due to the control of wildfires, the physiological adaptability of Eastern redcedar, and expanded seed source availability.” (Schmidt and Wardle 2002)
- “However, the biome shift from grassland to woodland is primarily associated with the encroachment of two non-resprouting, fire-sensitive trees, Ashe juniper and Eastern redcedar (Briggs et al. 2005; Van Auken 2009). Increases in these two juniper species are the result of changes in the human and biophysical feedbacks that have reduced the incidence, intensity, and spatial extent of fires, thereby increasing the competitive advantage of these two species in Great Plains grasslands.” (Twidwell et al. 2013)
- “The elimination of anthropogenic fire and the removal of the herbaceous layer needed to sustain grassland fire spread (as a result of overgrazing by domestic livestock) have led to widespread fire exclusion and juniper encroachment (Briggs et al. 2002, 2005; Fuhlendorf et al. 208; Allred et al. 2012; Taylor et al. 2012).” (Twidwell et al. 2013)
- “Fire historically limited the spread of eastern red cedar, a fire-intolerant species that reproduces solely by seed. In contrast, most native woody plants of the Great Plains reproduce vegetatively and can resprout after fire (Briggs et al. 2002). In the absence of fire, eastern red cedar spreads rapidly across the landscape (Bragg and Hulbert 1976), mostly from animal-driven dispersal of the ripened, fruitlike cones (Holthuijzen and Sharik 1985; Horncastle et al. 2004).” (Horncastle et al. 2005)
- “For example, Owensby et al. (1973) noted that, only when fire is excluded in tallgrass prairie, can Eastern redcedar compete with native grasses and develop dense, nearly monospecific, closed-canopy stands.” (Norris et al. 2001)
- “Present indications are that control of wildfires has allowed Eastern redcedar to occupy many sites within its natural range where it did not previously exist (Beilmann and Brenner 1951a; Hall 1955).” (Van Haverbeke and Read 1976)

- “Because the regional landscape today is a fragmented matrix of grazed lands and developed areas, there is an abundant Eastern redcedar seed source near virtually all remaining grasslands, increasing their vulnerability to Eastern redcedar establishment even when they are burned frequently. Thus, land-use practices that minimized Eastern redcedar expansion in the past may no longer be effective today.” (Briggs et al. 2002)
- “In the absence of fire, a few rapidly growing Eastern redcedar individuals within a plant community might serve as the catalyst for accelerated encroachment and eventual irreversible plant community shift to Eastern redcedar woodland (Hoch et al. 2002).” (Ganguli et al. 2008a)

RATE OF INVASION

- “Eastern redcedar is the most rapidly expanding woody species on rangeland in the Great Plains and is increasing in terms of tree size, acreage occupied, and number of locations (Wilson and Schmidt 1990).” (Schmidt and Stubbendieck 1993)
- “Analysis of aerial photos from five forests in the Flint Kills of eastern Kansas indicated that Eastern redcedar can expand and convert a tallgrass prairie to a closed-canopy forest in as little as 40 years.” (Briggs et al. 2002)
- “The max expansion rate was 5.7% per year between 1969 and 1978.” (Briggs et al. 2002)
- “Norris, Blair, and Johnson (2008) state that Eastern redcedar has encroached upon about 7 million hectares of grasslands in the eastern portion of the Great Plains.” (Starks et al. 2014)
- “In the same area (northern Flint Hills of KS), close-canopy Eastern redcedar forest has increased by 120% in 15 years (Hoch 2000).” Briggs et al. 2002)
- “Eastern redcedar is invading grasslands and forests of the central US at an exponential rate (Snook 1985).” (Engle and Stritzke 1992)
- “Currently, closed-canopy Eastern redcedar forest occupy as much as 1.4% of NE KS counties (Hoch and Briggs 1999) with the areal extent of these closed-canopy stands increasing by 120% from 1983-1997.” (Norris et al. 2001)
- “At a growth rate of 762 acres per day in Oklahoma (Bidwell et al. 1996; Philips 2005).” (Zhang and Hiziroglu 2010)
- “Snook (1985) estimated 600,000 ha of OK’s native grassland had been encroached upon by Eastern redcedar as early as 1950. Recent estimates indicate as much as 3.2 million ha of grassland have been encroached by Eastern redcedar in the state (Drake and Todd 2002), and suggest an average rate of land encroachment of approximately 121,400 ha per year.” (Starks et al. 2014)
- “Walker and Hoback 2007 reported that Eastern redcedar had invaded the Loess Canyons region of Lincoln County, NE, and was continuing to expand at an annual rate of 2%.” (Meneguzzo and Liknes 2015)

- “In the region overall (Illinois, Indiana, Iowa, KS, MI, NE, ND, SD), the area of forestland with Eastern redcedar trees present increased by 1.2 million acres, a 17% increase from the 2005 inventory (to 2012).” (Meneguzzo and Liknes 2015)
- “Eastern redcedar expanded in NE from about 21,900 ha in 1955 to over 76,100 ha in 1983 (Schmidt and Kuhns 1990).” (Schmidt and Stubbendieck 1993)
- “Schmidt and Leatherberry (1995) found that between the North Central Forest Inventory and Analysis (NCFIA) periods of 1962 and 1990 forest land cover increased by one million hectares in Illinois, Indiana, Iowa, and Missouri.” (Pierce and Reich 2010)