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Climatic impact on woody plant invaders in the Flint Hills region of Kansas

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There is currently an increasing trend of woody plant encroachment into prairie landscapes. Fire regime, grazing patterns, and climatic variability are primary factors that could affect woody plant encroachment into prairies. Among these, climatic variability, including temperature and precipitation, is the most controversial and debated. In this study, I gained an insight into how climate affects woody plants in both cellular development and growth response of woody grassland invaders. This study was conducted on private property near Reading, Kansas. I collected samples from three different kinds of the habitat (prairie area, transitional area, and forest edge area). Specimen information was recorded. For each specimen, I collected three sections of small branches in the width of a 50-mL centrifuge tube for cellular experiment and had one section from the very bottom of the specimen for tree-ring dating analysis. During the laboratory analysis, I collected data on variables obtained from tree-ring dating: tree ring number and whole ring width, and cellular analysis: the averaged lumen area, average lumen diameter, and cell wall thickness in the earlywood and latewood annually, were collected. I compared these variables with climate data (monthly and seasonally precipitation and temperature) retrieved from PRISM Climate Group. I assessed the correlation coefficient of both dendrochronological and cellular parameters with the climatic variables. Also, I evaluated the different intraspecific growth in different habitats. I concluded that woody invaders grow faster in prairie areas and their growth rates are positively facilitated by precipitation; temperature in Kansas exceed the threshold that can prohibit the growth of woody invaders, and thus, does not affect the growth rate.

Keywords: Climatic variables, Lumen area, Woody encroachment, Flint Hills

CLIMATIC IMPACT ON WOODY PLANT INVADERS IN THE FLINT HILLS REGION OF KANSAS

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PREFACE

This thesis consists of two chapters, concerning the impact of climatic variables, precipitation and temperature, on the dendrochronological (Chapter I) and cellular growth (Chapter II) of the prairie woody invaders. These two chapters are in publishable status. At the end of the second chapter, a conclusion for the whole thesis can be found. This is a research conducted to inform land owners and land management agencies of the vital importance of controlling the woody encroachment into prairie; and, the mechanisms of which would respond to the climatic variations.

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CHAPTER I

INTRODUCTION

Tallgrass prairie is a typical native ecosystem in central North America. Historically, bison grazing and natural or artificial fire disturbance were two major ways to regulate woody plant encroachment into prairies (Klinkenborg 2007, Robinson 2018). The historical range of the tallgrass prairie extended throughout the eastern portion of the Great Plains of North America, and even to a small portion of southcentral Canada. Currently, however, the extent of the tallgrass prairie has been reduced enormously, mainly due to conversion to crop land (Klinkenborg 2007, Robinson 2018). Today, the Flint Hills, due to unfavorable farming conditions and shallow soil, has cattle ranching as its main agricultural activity. The failure to plow this area means it has the densest and largest coverage of intact tallgrass prairie in North America.

There is a wide range of woody plants, including shrubs and trees that spread from wooded areas into pastures (Briggs et al. 2005). This study addresses questions about how climatic variability affects the growth rate of woody plant invaders in prairies in the Kansas Flint Hills region as well as how woody invaders would grow in different woody cover conditions. Because of the large number of combinations of possible variability in temperature and precipitation, I do not have a specific hypothesis about which specific climatic conditions facilitate prairie invasion of grassland ecosystem. Rather, I hypothesize that climate factors, including precipitation and temperature, were a factor in woody plant invasion success. I explored the relationship between climatic variability, including seasonal temperature and precipitation, and the growth of woody plants in prairies.

Woody plant encroachment is an increasing threat to pastures and prairies in the Great Plains and around the world (Briggs et al. 2005). The establishment of woody plants can be attributed to several factors including soil type, seed dispersal, temperature, and precipitation (Briggs et al. 2005, Auken 2009). The woody plants' various requirements for climate conditions engender the likelihood that certain conditions would either facilitate or hinder the distribution and invasion of woody plants.

Prairies are dominated by grassy and, to a lesser extent, herbaceous species. However, there is also a diversity of woody plant species found in prairies at lower densities than grasses but highly competitive to resources (Briggs et al. 2005). Within the prairie, plants usually compete for light on relatively equal grounds because most species do not achieve a large size. Woody plants are those that have a woody stem as their structural tissue, and woody plants consume resources which could be used by grasses to grow, which may bring about a significant problem for land managers. Light and water deficiencies around the woody plants increase competition so that the grasses have little chance to live with them; invasive woody plants can cause a barren area around themselves, which can cause a decline of biodiversity (Auken 2009).

Woody species are common in many prairie ecosystems, but they are typically found scattered among the more dominant grasses and herbaceous plants. Most woody species found in the grassland are not capable of overtaking and outcompeting their non-woody neighbors, but some species including *Juniperus virginiana* L. (eastern redcedar), *Cornus drummondii* C.A. Mey. (roughleaf dogwood), and *Rhus glabra* L. (smooth sumac) do have this ability (Weaver and Fitzpatrick 1934, Bryant 1989, Gleason and Cronquist 1991).

Juniperus virginiana L. (eastern redcedar) [Growth Type: Tree] resides in a mixed forest condition commonly with pine trees and oak trees (Wasser 1982). Throughout the Great Plains, it is also commonly used as a windbreak in and around pastures. Eastern redcedar is important to livestock and wildlife: many birds and small animals eat the cones (Beal 1915, Simpson 1988), deer browse the leaves of eastern redcedar when a shortage of food happens (Ferguson et al. 1968, Halls 1977). The domination of eastern redcedar brings about a low species diversity (Bryant 1989). Eastern redcedar is a tree that can not only grow higher and bigger than any grass or forb, but can also reduce the availability of light and water for plants growing under its canopy (Limb et al., 2010). The overall effect of the encroachment of eastern red cedar is a loss or alteration of biodiversity and richness. For example, there is a decrease in diversity of mammals (Horncastle et al. 2005) and plants (Auken 2009) and an alteration in the diversity of avian species under *J. virginiana* (Coppedge et al. 2001). Eastern redcedar may eventually dominate prairie or vegetation if fire is absent or suppressed (Abrell 1990, Anderson and Schwegman 1991). Eastern redcedar seedling and saplings are vulnerable to fire (Ortmann et al. 1998); thus, the control of eastern redcedar by fire is most effective at less than ten years old as well as below 2 m tall. (Alemayehu et al. 1998). It is a major contributor to the transformation of prairies to forests in the Great Plains.

Ulmus americana L. (American elm) [Growth Type: Tree] is a fast-growing tree that is long-lived to about 200 years old (Van and William 1938, Bey 1990). They can reach a height of 24 m commonly in mesic sites but can be shorter (about 15m) in extremely wet or dry conditions (Vines 1960, Bey 1990). Open-grown trees in the prairie can form a 3-m to 6-m as radius arching crown at maturity, becoming a very competitive species in the prairie (Yeager 1935, Guilkey 1957). *Ulmus* *americana* favors wet bottomlands and flats and has optimal growing condition in fertile, well-drained loams (Guilkey 1957; Vander-Kloet 1989, Bey 1990). Fire management specifically for *Ulmus americana* rarely occurs due to its typical moist growing habitat (Daubenmire 1949). However, *Ulmus americana* decreases significantly provided fires occur; and, young trees will sprout from the base of the burned old tree base after fire (Daubenmire 1949, Bey 1990). Thus, fire is usually not a major control in the north, but can be damaging in the southern Plains (Fennell and Hutnik 1970, McMurphy and Anderson 1965).

Fraxinus pennsylvanica Marshall (green ash) [Growth Type: Tree] is also often found in moist areas such as floodplains, swamps, and riparian areas, but can be found in areas with periodic drought as well (Great Plains Flora Association 1986, Stephens 1973, Vines 1960). *Fraxinus pennsylvanica* provides food to livestock (Cox and Franklin 1989, Bjugstad 1986) and wildlife, such as bison (Coppedge and Shaw 1997), deer (Vines 1960), American beaver (Allen 1983) and birds (Nemick 1987, Trammel and Butler 1995, Twedt and Best 2004). *Fraxinus pennsylvanica* is tolerant to changes in climatic conditions. It can grow in a range of precipitation from 380 to 1,520 mm and of a temperature ranging from -18 to 13 °C in winter and 18 to 27°C in summer (Kennedy 1990). With such tolerance, *Fraxinus pennsylvanica* can be a threat to prairie biodiversity. Also, although seedlings and trees can be killed effectively by fire, they can resprout after fire due to its high seed production which is wind dispersed (Williams and Hanks 1976, Severson and Boldt 1977, Severson and Boldt 1978, Kennedy 1990).

Rhus glabra L. (smooth sumac) [Growth Type: Shrub/Tree] is found in prairies, wooded areas, hillsides and canyons (Great Plains Flora Association 1986, Hayes and Garrison 1960, Weaver and Kramer 1932). Dense thickets are often formed when found growing in prairies (Weaver and Fitzpatrick 1934) and favors sun exposures (Stanton 1974). The fruits and leaves of *Rhus glabra* are a food source of birds, insects, and mammals (Robinson and Handel 1993, Strauss 1991, Willson 1993, Balfour 1989). *Rhus glabra* thickets propagate with underground rhizomes (Weaver and Fitzpatrick 1934). The root system is massive and has shallow laterals and the main root can reach 2 m in depth underground (Canadell et al. 1996). All these features contribute to the vigorous expansion of *Rhus glabra* thickets, which outcompete prairie grass species and lead to the decrease of biodiversity in the prairie. Moreover, *Rhus glabra* sprouts rapidly after the fire with the help of underground rhizomes. However, repeated annual fires may be considered effective during late spring (Smith and Owensby 1973).

Morus rubra L. (red mulberry) [Growth Type: Tree] lives well under a wide range of conditions and is often found in prairie and field margins (Lamson 1990). *Morus rubra* is not well documented in the literature as a common prairie invader. I, however, saw many examples of this species in the prairie. It tolerates various soil types and pH conditions (Silker 1961). The fruits are eaten by many birds and small mammals (Lamson 1990), foliage and twigs are browsed by deer, and bark is food for beavers (Hunter 1989). *Morus rubra* can be easily controlled by fire due to its shallow root system and thin bark (Silker 1961).

Cornus drummondii C.A. Mey. (roughleaf dogwood) [Growth Type: Shrub/Tree] is often found in forest margins, open woodlands, along with the roadside, and meadows (Braun 1961, Gleason and Cronquist 1991). It is the primary food source of white-tailed deer in Missouri (Dalke 1941). *Cornus drummondii* can be trees and shrubs, and has ascending branches and stems, forming an impenetrable shaded area underneath its crown (Chapman and Bessette 1990). In the prairie, these characteristics are often lethal to prairie grass species and can easily form a barren area under its crown (Lett and Knapp 2005). The aboveground of *Cornus drummondii* can be killed by fire when they are juvenile (Swan 1970, Tester 1989). It is an important successional species in the progression from prairie to forest.

Ulmus pumila L. (siberian elm) [Growth Type: Tree] is native to central Asia and northern China (Fu et al. 2002). It is a fast-growing and adaptable tree that can grow from dry sites to moist areas; it can also tolerate cold winter times as well as hot summer drought (Vines 1960). As far as *Ulmus pumila* is concerned, literature for fire management is not well documented, but it likely has a similar response to fire as *Ulmus americana* due to their similar morphology.

Many factors can affect woody plant encroachment into prairies, including increases or decreases in fire frequency, grazing patterns by non-native livestock and climate variability (Fuhlendorf 1997). Of these, the climate variability is the least understood and most debated. There is a strong relationship between precipitation and woody plant growth, especially during years of higher rainfall, which suggests water availability is an essential factor in woody invasion (Lesser and Jackson 2012). Lesser and Jackson (2012) found that four spatially distant stands of ponderosa pine (*Pinus ponderosa*) had increases in population in years with higher rainfall. In fact, these stands also established only during years of higher rainfall. Temperature could also play a vital role during encroachment because it is related to growth as well and because it too varies annually (Bell et al. 1995). Although it is less widely studied, it is necessary to understand how climate variability (precipitation and temperature) affects woody plant establishment and growth in prairies, because as in the mountains, woody growth and establishment are likely linked to climate.

METHODS

The study area was located on private property north of Reading in Lyon County, Kansas (Figure 1, 38°31'24.45"N, 95°57'25.99"W). The study area was a typical tallgrass prairie primarily with some actively-encroaching wooded areas scattered around the prairie, including a mature forest area and a juvenile one. The prairie was dominated by *Schizachyrium scoparium* (Michx.) Nash (little bluestem), *Andropogon gerardii* Vitman (big bluestem), and *Panicum virgatum* L. (switchgrass). The prairie area had an area of approximately 75,967 square meters. The majority species in the mature forest area were *Ulmus americana* L. (American elm), *Fraxinus pennsylvanica* Marshall (green ash), *Celtis occidentalis* L. (common hackberry), and *Quercus macrocarpa* Michx. (bur oak); the mature forest covers 75,328 square meters. A mixture of *Juniperus virginiana* L. (eastern redcedar) and to a lesser extent, *Fraxinus* pennsylvanica, was dominating the transitional area. The total area of the transitional forest area is approximately 7,517 square meters.

The research sites were determined by the size and availability of woody prairie invaders. my species of interest were *Rhus glabra, Juniperus virginiana, Cornus drummondii, Ulmus pumila, Ulmus americana, Fraxinus pennsylvanica,* and *Morus rubra*. It was impossible for us to conduct a random sampling of trees due to the favor of specific establishment habit areas and sparse population of some species. Three kinds of habitats were determined by tree canopy cover in this research area: forest edge, prairie, and transitional forest. A spherical densiometer (Forest Densiometers, Model-C). was used to measure tree canopy cover above each specimen in forest edge and transitional sites. An averaged value of the canopy cover was calculated with four measurements, which were converted following the protocol provided by the densitometer. The prairie site exhibited no tree canopy cover over my specimens. The transitional site had been prairie previously but was actively transforming into a wooded area during sample collection. This was indicated by the abundance of saplings and young trees as compared to the prairie or mature forest areas. The forest edge site was the edge of the mature forest where active encroachment into prairie was occurring. In the mature forest area, it was hard to find prairie invader species of a similar size to those found in the prairie and transitional areas. This illustrates their proclivity to invade open areas and act as pioneer species into prairie margins. This reduced my ability to sample the species of interest in the mature forest; thus, the densely-wooded forest area was disregarded for this study.

During sample collection, I recorded GPS location, took plot photos, the direction of slope on which the tree was growing, elevation, associated species cover type (grass, forb or shrub), tree density and physical characteristics of the tree (stem or basal diameter and height) on each of the woody plants. The associated species cover type and canopy cover were collected between April and June in 2017, and the rest of the data was collected between September and December in 2016.

I cut down the tree at about 10-cm from the ground and collected the 10-cm cross-section using a lunch bag and dried it for dendrochronological analyses. The stem cross-sections were dried in a drier at low temperature to avoid damaging them. After that, these sections were cut into 1-cm thick sections with a hacksaw and glued to individual wood bases, which were 5-cm in length and 2-cm in width. Larger samples had their wood base fitting their length and width. Samples glued on wood were polished using progressively finer grits of sandpaper. The grit of sandpaper started at 100, gradually become finer (150, 220, 320), and end at 400 or 600, depending on the wood texture and level of polish achieved.

I collected data on two dendrochronological characteristics with a Velmex Unislide measuring system and a microscope with a mounted camera: tree ring number and whole ring width of each tree ring. These data were transferred to a desktop computer by the software MeasureJ2X, which communicates between the Velmex measuring system and the desktop computer. The age and annual growth rate of specimens were compared with the climate data (annual temperature and precipitation) retrieved from PRISM Climate Group, a database that has climate data from 1895 to the present for the study area and that divides America into 4 km X 4 km grids, enabling me to gather the climate data especially for that research site.

All the data analyses were performed in SAS (V.9.3). All ANOVA tests were followed by Tukey's test if a significant difference among means occurred. The mean tree density of each species in different sites was calculated by the reciprocal of the square of the mean distance for all sample points in different sites. The graminoid cover in pooled specific data was compared site-wise using ANOVA tests. The growth rate of each species was compared based on site differences with ANOVA. Among the species sampled, four had significant differences among them. Thus, they were chosen for the growth rate comparison. Lastly, the relationship between annual temperature and precipitation from April to September were compared to the annual tree-ring width (mm) using R^2 of linear regression as test statistics.

RESULTS

The tree density has its highest value, thirteen trees, in the transitional area, where the trees were densely populated (Figure 2). The forest edge area comes the next, having five trees, and the prairie area was the least populated area, having a density of two trees per hundred square meters (Figure 2). The cover of graminoid was of particular interest because of my focus on prairie invasion (Table 2); thus, a comparison of the mean cover of all sites showed that there is a significant difference in grass cover in these three sites. my species association results showed a significant decrease in the cover of graminoid from prairie to transition, and finally to forest edge sites (Table 5). The prairie site had a mean cover of 71.48 % and was the highest one among three sites. Also, the cover in prairie site was significantly higher than both the transitional and forest edge sites (Table 5). The second largest grass cover was in the transitional site. The mean of grass cover was 44.91% and was significantly higher than the forest edge site which had a mean of 23.06%.

The comparison of intraspecific growth in different sites showed the growth of these four species: *Juniperus virginiana, Ulmus americana, Fraxinus pennsylvanica,* and *Cornus drummondii,* which varied based on site. In most cases, the growth rate of woody invaders was higher in either prairie site or transitional site than forest edge site. However, for *Juniperus virginiana*, the highest growth rate was found in the transitional site and was significantly higher than both prairie and forest edge sites (Table 5). No significant difference in mean growth was found between prairie and forest edge sites for *Juniperus virginiana* (Table 5). *Ulmus americana* showed a significantly higher growth rate in the prairie site than the transitional site (Table 5). The highest growth rate of *Fraxinus pennsylvanica* was found in the prairie as well and significantly higher than the other two sites (Table 5). Meanwhile, the forest edge site exhibited the lowest growth rate among these three sites and was significantly lower than the transitional site (Table 5). *Cornus drummondii* showed the highest growth rate in the transitional site although it was not significantly higher than the prairie site, which was significantly higher than the forest edge site (Table 5).

Table 3 showed the relationship between annual precipitation from April to September and annual wood growth as well as the sample size for each species in each site. All the relationships were positive. The strongest relationship with the precipitation was found in *Morus rubra* in forest edge site, although the samples size was low. *Juniperus virginiana* showed strong relationships in both prairie and transitional sites, but weak relationship in forest edge site. Both *Ulmus pumila* and *Ulmus americana* showed a strong relationship in transitional site. *Ulmus pumila* showed a weak relationship in forest edge site while *Ulmus americana* showed a weak relationship in prairie site. *Fraxinus pennsylvanica* and *Cornus drummondii* showed a strong relationship in prairie site. *Fraxinus pennsylvanica* showed weak relationships in both forest edge and transitional sites while *Cornus drummondii* showed a weak relationship in transitional site and no relationship in forest edge site. *Rhus glabra* and *Morus rubra* showed no relationship in prairie sites, and *Morus rubra* showed no relationship in transitional site.

Table 4 showed the relationship between an annual temperature from April to September and annual wood growth as well as the sample size for each species in each site. Most of the species in different sites showed no relationship with temperature. *Ulmus americana* showed a strong positive relationship with temperature in the prairie site while *Rhus glabra* showed a weak positive relationship. *Morus rubra* showed a strong positive relationship in forest edge site while *Fraxinus pennsylvanica* exhibited a weak negative relationship. Also, *Morus rubra* showed a weak positive relationship in the transitional area as well.

DISCUSSION

Association Information. The significant decrease in the cover of graminoid from prairie to transition and finally to forest edge sites agrees with other studies that indicate that the encroachment of woody invaders into prairie leads to a decrease of biodiversity as well as a decrease in the cover of graminoid and fabaceous species (Briggs et al 2005, Auken 2009, Ratajczak 2011). As stated previously, all my three sites share different features and were characterized by their tree canopy cover. The tree canopy cover decreased significantly from transitional site to forest edge site. This difference in tree canopy cover is occurring due to the open prairie that the forest edge is actively encroaching, leading to the fact that the woody invaders at the margin of the forest can only be shaded in one direction. In contrast, the woody invaders in transitional site have the ability to grow together, thus bringing about the high tree canopy cover at all directions. The rapid growth and high density of trees exhibited in the transitional area suggests that the trees, and particularly *J. virginiana*, have not yet reached stem exclusion (Oliver and Larson 1996).

Juniperus virginiana. Somewhat surprisingly, *Juniperus virginiana* showed a significantly higher growth rate in the transitional area and was the dominant species in this area. I supposed there could be some underground association with fungus or collaboration with adjacent *Juniperus virginiana* trees such that *Juniperus virginiana* was capable of growing much faster together than growing individually and suppressed by mature trees. No significant difference in growth was found between *Juniperus virginiana* growing in the prairie or forest edge sites, indicating that *Juniperus virginiana* may be able to compete for resources even near mature trees with a more massive and wider root system, showing its excellent ability as an invasive and pioneer species (Bryant 1989, Abrell 1990, Anderson and Schwegman 1991). The possible dispersal vector of *Juniperus virginiana* could be birds and small animals who feed on its cones and carry digested seeds in feces that land on prairie sites (Beal 1915, Simpson 1988). Also, deer may take *Juniperus virginiana* as a food source when lacking more desirable food, thus, can also be a possible carrier of seeds. The most effective control of *Juniperus virginiana* should be done when they are young by fire (Alemayehu et al. 1998). The knowledge that they may grow faster when they are dense can be good information to land managers and land owners:

immediate attention needs to be paid when a dense cluster of *Juniperus virginiana* is noticed. It may very well be that they continue their growth, and even may thrive.

Ulmus americana. Ulmus americana is not a forest edge species (Van and William 1938; Vines,1960), and I failed to collect any samples at my forest edge site. However, I did find it in the open prairie where it grows significantly faster than my transitional site, which agrees with Yeager (1935) and Guilkey (1957). The invasion of *Ulmus americana* into prairie can be lethal to tallgrass prairie species since it is a long-lived and fast-growing tree species which is good at expanding its territory (Van and William 1938, Bey 1990). Fire may not be a major control for these two species. *Ulmus americana* favors moist areas, and thus, it is hard to be burned. However, a significant decrease of *Ulmus americana* was found if fire successfully occurred (Daubenmire 1949, Bey 1990). Thus, if fire can be used easily, it should be a good eliminator for this species, despite its ability to tolerate a range of light conditions.

Fraxinus pennsylvanica. Fraxinus pennsylvanica was found growing significantly faster in the prairie area in my research, indicating that this species is growing well individually, with high light, but growth is reduced in lower light conditions. For example, the transitional site showed the second fastest growth rate and was significantly higher than the forest edge site, showing that the growth of this species can be suppressed by the dominance of other species: *Juniperus virginiana* in the transitional site and mixed mature trees at forest edge site. However, this species was found as a dominant species in the deep forest area in my research site, demonstrating that it has the potential to become dominant over time at maturity.

Rhus glabra and *Morus rubra.* Neither of young *Rhus glabra* and *Morus rubra* was largely found in the transitional and forest edge sites due to their less competitive ability compared with other species. Also, these two species can be killed by fire easily, and they will resprout rapidly (Silker 1961, Smith and Owensby 1973). Also, no relationship with either temperature or precipitation was found for these two species.

Cornus drummondii. The ANOVA test of the growth rate of *Cornus drummondii* uncovered a significantly higher growth rate in prairie and transitional sites than forest edge sites. Although it is often found in forest margins (Braun, 1961), my results showed that it grew faster without mature trees. The highest growth rate was found in the transitional site as well, implying that it may be fond of group growth when they were young. This is likely because of its tendancy to resprout after fire, which means there is a well developed root system from which stems emerge. *Cornus drummondii* is good at expanding its territory in the prairie and can decrease the biodiversity in the prairie easily (Chapman and Bessette, 1990; Ratajczak et al, 2011). The aboveground part of *Cornus drummondii* can be easily controlled by fire, but it will sprout on the underground part after fire (Swan, 1970; Tester, 1989). Thus, it may be a good idea to dig the underground part out after the burning.

Climate. Precipitation serves as a major factor in the growth of my species while temperature, it seems, does little. Most species of interest showed a strong correlation between annual growth and precipitation in at least one site. In prairie site, *Juniperus virginiana, Fraxinus pennsylvanica, Cornus drummondii* , and *Ulmus americana* showed a strong correlation with the precipitation, suggesting that these species would grow faster providing a wet year is approaching. In forest edge area, this trend seems to be lessened, indicating that competition from other species becomes more important in this area, and that mature trees may be the major impact of the growth of young trees at that area. In the transitional area, however, this trend was amplified. The group growing of trees seem to have the ability of making the full use of precipitation and yield a better growth rate compared to forest edge site, which may also be due to the collaboration underground with fungus that associated with tree growth in that area. Overseen a wet year, land owners and land management agencies may want to treat their lands with fire.

REFERENCES

Abrell, B. 1990. Control of eastern red cedar (*Juniperus virginiana*) by girdling and burning at Leavenworth Barrens Nature Preserve, Indiana. *Natural Areas Journal*. 10(3): 140.

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(3): 169-174. [43384]

Allen, A. W. 1983. *Habitat suitability index models: beaver*. FWS/OBS-82/10.30 (Revised). Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service. 20 p.

Anderson, R. C., and J. E. Schwegman. 1991. Twenty years of vegetational change on a southern Illinois barren. *Natural Areas Journal*. 11(2): 100-107. [16256]

Auken, V. 2009. Causes and consequences of woody plant encroachment into western North American grasslands. *Journal of Environmental Management* 90: 2931-42.

Beal, F. E. L. 1915. *Food of the robins and bluebirds of the United States*. Bulletin No. 171. Washington, DC: U.S. Department of Agriculture. 31 p.

Bryant, W. S. 1989. *Redcedar (Juniperus virginiana L.) communities in the Kentucky River Gorge area of the bluegrass region of Kentucky*. In: Rink, George; Budelsky, Carl A., eds. Proceedings, 7th central hardwood conference; 1989 March 5-8; Carbondale, IL. Gen. Tech. Rep. NC-132. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 254-261.

Balfour, P. M. 1989. *Effects of forest herbicides on some important wildlife forage species*. Victoria, BC: British Columbia Ministry of Forests, Research Branch. 58 p.

Bell, D. T., D. P. Rokich, C. J. McChesney, and J. A. Plummer. 1995. Effects of temperature, light and gibberellic acid on the germination of seeds of 43 species native to Western Australia. *Journal of Vegetation Science* 6: 797-806.

Bey, C. F. 1990. *Ulmus americana L. American elm*. In: Burns, Russell M.; Honkala, Barbara H., tech. coords. Agric. Handb. 654. Silvics of North America. Vol. 2. Hardwoods. Washington, DC: U.S. Department of Agriculture, Forest Service: 801-807.

Bjugstad, A. J. 1986. Wooded draws of the northern high plains: characteristics, value and restoration (North and South Dakota). *Restoration & Management Notes*. 4(2): 74-75.

Braun, E. L. 1961. The woody plants of Ohio. Columbus, OH: *Ohio State University Press*. 362 p.

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

Canadell, J., R. B. Jackson, and J. R. Ehleringer. 1996. Maximum rooting depth of vegetation types at the global scale. *Oecologia* 108(4): 583-595.

Chapman, W. K., and A. E. Bessette. 1990. Trees and shrubs of the Adirondacks. Utica, NY: *North Country Books*, Inc. 131 p.

Coppedge, B. R., D. M. Engle, R. E. Masters, M. S. Lett, and J. K. McCarron. 2001. Avian response to landscape changes in fragmented southern Great Plains grasslands. *Ecological Applications* 11: 47-59.

Coppedge, B. R., J. H. Shaw. 1997. Effects of horning and rubbing behavior by bison (*Bison bison*) on woody vegetation in a tallgrass prairie landscape. *The American Midland Naturalist* 138(1): 189-196.

Cox, M. K., and W. L. Franklin. 1989. Terrestrial vertebrates of Scotts Bluff National Monument, Nebraska. *The Great Basin Naturalist* 49(4): 597-613.

Dalke, P. D. 1941. *The use and availability of the more common winter deer browse plants in the Missouri Ozarks*. Transactions, 6th North American Wildlife Conference. 6: 155-160.

Daubenmire, R. F. 1949. Relation of temperature and daylength to the inception of tree growth in spring. *Botanical Gazette*. 110: 464-475.

Fennell, N. H., and R. J. Hutnik. 1970. *Ecological effects of forest fires*. Unpublished paper on file at: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Fire Sciences Laboratory, Missoula, MT. 84 p.

Fu, L., Y. Xin and A. Whittemore. 2002. *Ulmaceae*, in Wu, Z. & Raven, P. (eds.) Flora of China, Vol. 5 (Ulmaceae through Basellaceae). Science Press, Beijing, and Missouri Botanical Garden Press, St. Louis, USA.

Ferguson, E. R.; E. R. Lawson, W. R. Maple, and C. Mesavage. 1968. *Managing eastern redcedar*. Res. Pap. SO-37. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 14 p.

Gleason, H. A., and Cronquist, A. 1991. Manual of vascular plants of northeastern United States and adjacent Canada. 2nd ed. New York: *New York Botanical Garden*. 910 p.

Great Plains Flora Association. 1986. Flora of the Great Plains. Lawrence, KS. *University Press of Kansas*. 1392 p.

Guilkey, P. C. 1957. *Silvical characteristics of American elm (Ulmus americana)*. Station Paper No. 54. St. Paul, MN: U.S. Department of Agriculture, Forest Service, Lake States Forest Experiment Station. 19 p.

Halls, L. K., ed. 1977. *Southern fruit-producing woody plants used by wildlife*. Gen. Tech. Rep. SO-16. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Region, Southern Forest Experiment Station, Southeastern Area, State and Private Forestry. 235 p.

Hayes, D. W., and G. A. Garrison. 1960. *Key to important woody plants of eastern Oregon and Washington*. Agriculture Handbook. 148. Washington, DC: U.S. Department of Agriculture, Forest Service. 227 p.

Horncastle, V. J., E. C. Hellgren, P. M. Mayer, A. C. Ganguli, D. M. Engle, and D. M. Leslie, Jr. 2005. Implications of invasion by *Juniperus virginiana* on small mammals in the southern Great Plains. *Journal of Mammalogy* 86: 1144-1155.

Hunter, C. G. 1989. Trees, shrubs, and vines of Arkansas. Little Rock, AR: The Ozark Society Foundation. 207 p.

Klinkenborg, V. 2007. Splendor of the Grass: The Prairie's Grip is Unbroken in the Flint Hills of Kansas. *National Geographic*. Retrieved on March 17th 2018.

Kennedy, H. E. Jr. 1990. *Fraxinus pennsylvanica Marsh. green ash*. In: Burns, Russell M.; Honkala, Barbara H., technical coordinators. Silvics of North America. Vol. 2. Hardwoods. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture, Forest Service: 348-354.

Lamson, N. I. 1990. *Morus rubra* L. red mulberry. In: Burns, Russell M.; Honkala, Barbara H., technical coordinators. Silvics of North America. Volume 2. Hardwoods. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture, Forest Service: 470-473.

Lesser, M. R., and Jackson S. T. 2012. Making a stand: five centuries of population growth in colonizing populations of *Pinus ponderosa*. *Ecology* 93: 1071-81.

Lett, M. S., and A. K. Knapp. 2005. Woody plant encroachment and removal in mesic grassland: production and composition responses of herbaceous vegetation. *The American Midland Naturalist* 153:217-231.

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.

McMurphy, W. E., and K. L. Anderson. 1965. Burning Flint Hills range. *Journal of Range Management* 18: 265-269.

Nemick, J. J. 1987. *Sharp-tailed grouse management and ecology in Wyoming*. In: Fisser, Herbert G., ed. Wyoming shrublands: Proceedings, 16th Wyoming shrub ecology workshop; 1987 May 26-27; Sundance, WY. Laramie, WY: University of Wyoming, Department of Range Management, Wyoming Shrub Ecology Workshop: 45-47.

Oliver, C. D., and B. C. Larson. 1996. *Forest stand dynamics: updated edition*. ISBN: 0471138339. Record Number: 19980604521.

Ortmann, J., J. Stubbendieck, and Masters, R. A. et al. 1998. Efficacy and costs of controlling eastern redcedar. *Journal of Range Management*. 51(2): 158-163.

Ratajczak, Z., J. B. Nippert, J. C. Hartman, and T.W. Ocheltree. 2011. Positive feedbacks amplify rates of woody encroachment in mesic tallgrass prairie. *Ecosphere* 2(11):121. doi:10.1890/ES11-00212.1

Robinson, G. R., and S. N. Handel. 1993. Forest restoration on a closed landfill: rapid addition of new species by bird dispersal. *Conservation Biology* 7(2): 271-278.

Robinson, S. 2018. Central forest-grasslands transition. *Terrestrial Ecoregions*. World Wildlife Fund. Retrieved on March 17th 2018.

Severson, K. E., C. E. Boldt. 1977. *Problems associated with management of native woody plants in the western Dakotas*. In: Johnson, Kendall L., editor. Wyoming shrublands: Proceedings, 6th Wyoming shrub ecology workshop; 1977 May 24-25; Buffalo, WY. Laramie, WY: Shrub Ecology Workshop: 51-57. [2759]

Severson, K. E., and C. E. Boldt. 1978. *Cattle, wildlife, and riparian habitats in the western Dakotas*. In: Management and use of Northern Plains rangeland: Regional rangeland symposium: Proceedings; 1978 February 27-28; Bismarck, ND. Dickinson, ND: North Dakota State University: 90-103.

Silker, T. H. 1961. Prescribed burning to control undesirable hardwoods in southern pine stands. Bulletin No. 51. Kirbyville, TX: *Texas Forest Service*. 44 p.

Simpson, B. J. 1988. *A field guide to Texas trees*. Austin, TX: Texas Monthly Press. 372 p.

Smith, E. F., and C. E. Owensby. 1973. *Effects of fire on true prairie grasslands*. In: Proceedings, annual Tall Timbers Fire Ecology Conference; 1972 June 8-9; Lubbock, TX. No. 12. Tallahassee, FL: Tall Timbers Research Station: 9-22.

Stanton, F. 1974. *Wildlife guidelines for range fire rehabilitation*. Tech. Note 6712. Denver, CO: U.S. Department of the Interior, Bureau of Land Management. 90 p.

Stephens, H. A. 1973. Woody plants of the North Central Plains. Lawrence, KS: *The University Press of Kansas*. 530 p.

Strauss, S. Y. 1991. Direct, indirect, and cumulative effects of three native herbivores on a shared host plant. *Ecology* 72(2): 543-558.

Swan, F. R., Jr. 1970. Post-fire response of four plant communities in south-central New York state. *Ecology* 51(6): 1074-1082.

Tester, J. R. 1989. Effects of fire frequency on oak savanna in east-central Minnesota. *Bulletin of the Torrey Botanical Club* 116(2): 134-144.

Trammel, M. A., and J. L. Butler. 1995. Effects of exotic plants on native ungulate use of habitat. *Journal of Wildlife Management* 59(4): 808-816.

Twedt, D. J., C. Best. 2004. Restoration of floodplain forests for the conservation of migratory landbirds. *Ecological Restoration*. 22(3): 194-203.

Van, D., and R. William. 1938. *Native woody plants of the United States, their erosion-control and wildlife values*. Washington, DC: U.S. Department of Agriculture. 362 p.

Vander-Kloet, S. P. 1989. Typification of some North American Vaccinium species names. *Taxonomy* 38: 129-134.

Vines, R. A. 1960. Trees, shrubs, and woody vines of the Southwest. Austin, TX: *University of Texas Press* 1104 p.

Wasser, C. H. 1982. *Ecology and culture of selected species useful in revegetating disturbed lands in the West*. FWS/OBS-82/56. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service. 347 p.

Weaver, J. E., and J. Kramer. 1932. Root system of Quercus macrocarpa in relation to the invasion of prairie. *Botanical Gazette* 94: 51-85.

Weaver, J. E., and T. J. Fitzpatrick. 1934. The prairie. *Ecological Monographs* 4(2): 111-295.

Williams, R. D., and S. H. Hanks. 1976. *Hardwood nurseryman's guide*. Agric. Handb. 473. Washington, DC: U.S. Department of Agriculture, Forest Service. 78 p.

Willson, M. F. 1993. Mammals as seed-dispersal mutualists in North America. *Oikos*. 67: 159-176.

Yeager, A. F. 1935. Root systems of certain trees and shrubs grown on prairie soils. *Journal of Agricultural Research*. 51(12): 1085-1092.

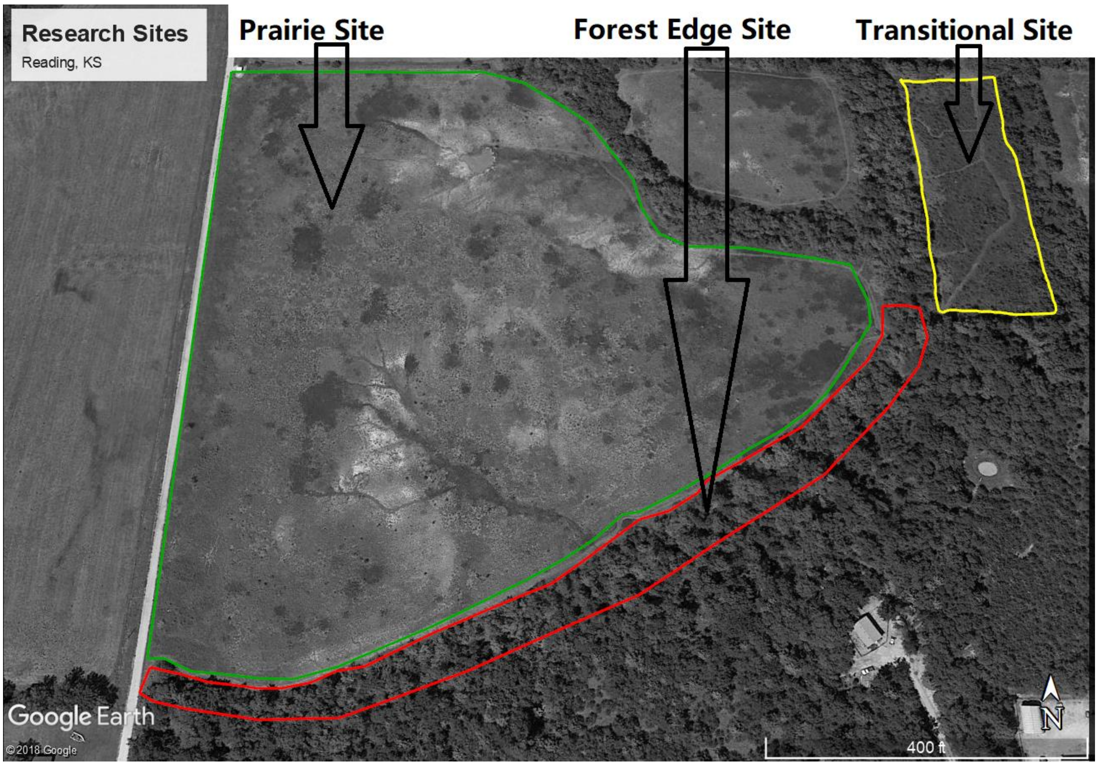

Figure 1. Figure showing the research site in reading, KS obtained from google earth. The scale and direction are shown at bottom right.

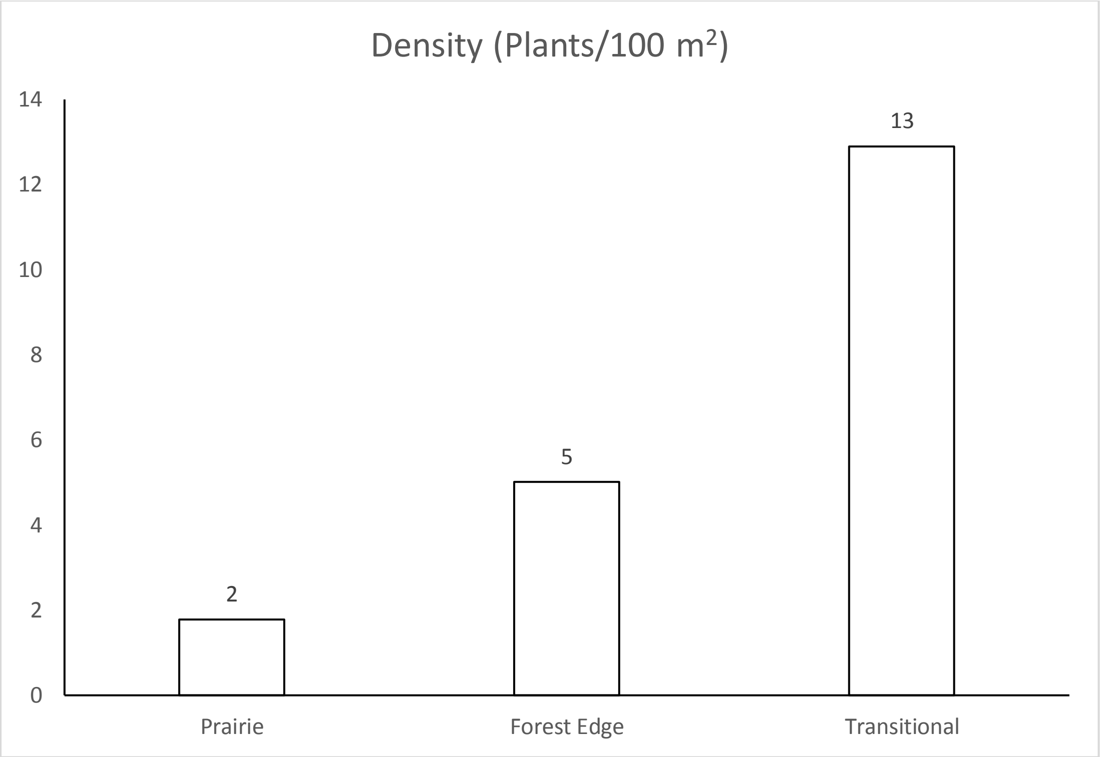

Figure 2. Figure showing the tree density of three different sites per one hundred square meter.

Table 1. Sample size Information using in dendrochronology measurements. J. v. is *Juniperus virginiana* (eastern redcedar). U. p. is *Ulmus pumila* (siberian elm). F. p. is *Fraxinus pennsylvanica* (green ash). R. g. is *Rhus glabra* (smooth sumac). C. d. is *Cornus drummondii* (rRough-leaved dogwood). U. a. is *Ulmus americana* (American elm). M. r. is *Morus rubra* (red mulberry).

	J. v.	U. p.	F. p.	R. g.	C. d.	U. a.	M. r.	Total
Prairie Area	5	4	6	3	5	3	3	29
Forest Edge Area	5	2	5	0	5	0	1	18
Transitional Area	5	3	5	0	6	4	1	24
Total	15	9	16	3	16	7	5	71

Table 2. Associated Species Information. Table listing the collected or calculated associated species information. Values were calculated by using a pooled data in every site. PT means prairie total. TT means transitional total. FT means forest total. All values were rounded up to the closest tenth.

Prairie site

	PTMean	PTSTD	PTCV
Tree Canopy Cover (%)	0.00	0.00	0.00
Ground Cover at drip line-Soil/Gravel (%)	5.86	7.27	1.24
Ground Cover at drip line-Woody Species (%)	5.31	9.55	1.80
Ground Cover at drip line-Litter (%)	6.72	12.86	1.91
Ground Cover at drip line-Graminoid (%)	71.48	25.18	0.35
Ground Cover at drip line-Forbs (%)	19.77	20.21	1.02
Basal diameter (cm) or DBH (cm)	3.31	2.23	0.68
Height (m)	1.75	0.61	0.35
Point-centered quarter (density) (M)	7.99	5.95	0.74

Transitional site

	TTMean	TTSTD	TTCV
Tree Canopy Cover (%)	61.78	27.97	0.45
Ground Cover at drip line-Soil/Gravel (%)	7.22	7.87	1.09
Ground Cover at drip line-Woody Species (%)	15.28	13.26	0.87
Ground Cover at drip line-Litter (%)	8.89	9.04	1.02
Ground Cover at drip line-Graminoid (%)	44.91	27.41	0.61
Ground Cover at drip line- Forbs (%)	25.56	21.69	0.85
Basal diameter (cm) or DBH (cm)	3.43	1.80	0.52
Height (m)	2.38	0.63	0.26
Point-centered quarter (density) (M)	2.78	1.61	0.58

Forest edge site

	FTMean	FTSTD	FTCV
Tree Canopy Cover (%)	30.13	35.32	1.17
Ground Cover at drip line-Soil/Gravel (%)	25.00	12.98	0.52
Ground Cover at drip line-Woody Species (%)	23.89	22.96	0.96
Ground Cover at drip line-Litter (%)	9.44	12.18	1.29
Ground Cover at drip line-Graminoid (%)	23.06	12.83	0.56
Ground Cover at drip line- Forbs (%)	24.72	17.77	0.72
Basal diameter (cm) or DBH (cm)	2.84	1.28	0.45
Height (m)	2.02	0.46	0.23
Point-centered quarter (density) (M)	4.47	2.33	0.52

Table 3. Precipitation vs. wood growth relationship. Table listing the R^2 value and P-value obtained from linear regression analysis. N refers to sample size. N/A refers to no data or not available.

	Prairie Site			Forest Edge Site			Transitional Site		
	R^2 value	N	P-value	R^2 value	N	P-value	R^2 value	N	P-value
Juniperus virginiana	0.6804	30	0.0000	0.2786	30	0.0027	0.5498	30	0.0000
Ulmus pumila	0.0093	13	0.7540	0.4452	8	0.0706	0.6407	13	0.0010
Ulmus americana	0.3205	9	0.1121	N/A	0	N/A	0.7578	26	0.0000
Fraxinus pennsylvanica	0.5312	26	0.0000	0.4055	28	0.0003	0.1908	30	0.0158
Rhus glabra	0.0029	15	0.8488	N/A	0	N/A	N/A	0	N/A
Cornus drummondii	0.5255	22	0.0001	0.0780	28	0.1500	0.4296	24	0.0005
Morus rubra	0.0982	11	0.3481	0.7908	4	0.1107	0.0034	6	0.9126

Table 4. Temperature vs. wood growth relationship. Table listing the R^2 value and P-value obtained from linear regression analysis. N refers to sample size. N/A refers to no data or not available.

	Prairie Site			Forest Edge Site			Transitional Site		
	R^2 value	N	P-value	R^2 value	N	P-value	R^2 value	N	P-value
Juniperus virginiana	0.0378	30	0.3032	0.0415	30	0.2803	0.0624	30	0.1831
Ulmus pumila	0.0195	13	0.6491	0.0022	8	0.9122	0.0352	13	0.5394
Ulmus americana	0.6587	9	0.0079	N/A	0	N/A	0.0363	26	0.3512
Fraxinus pennsylvanica	0.0000	26	1.0000	0.1970	28	0.0180	0.0968	30	0.0942
Rhus glabra	0.1874	15	0.1070	N/A	0	N/A	N/A	0	N/A
Cornus drummondii	0.0049	22	0.7570	0.0064	28	0.6857	0.0075	24	0.6874
Morus rubra	0.0239	11	0.6499	0.9821	4	0.0090	0.4087	6	0.1717

Table 5. Listing ANOVA results, including degrees of freedom (d.f.), F-value, and P-value. of the grass cover and annual ring width (mm) for each species based on site differences (prairie site, transitional site, and forest edge site). Same lower-case letters indicate groups of mean that are not significantly different from each other (Tukey's Test). The means of group a are significantly higher than group b's, which are significantly higher than group c's.

Variable	d.f.	F-value	P-value	Tukey's Test		
				Prairie Site	Forest Edge Site	Transitional Site
Grass Cover	2, 151	50.29	0.0000	a	c	b
Juniperus virginiana	2, 87	6.11	0.0033	b	b	a
Ulmus americana	1, 33	24.60	0.0000	b		a
Fraxinus pennsylvanica	2, 81	13.25	0.0000	a	c	b
Cornus drummondii	2, 71	12.37	0.0000	a	b	a

CHAPTER II

INTRODUCTION

Tallgrass prairie, a native and typical ecosystem of the eastern Great Plains, is situated in central North America, and two major factors, bison grazing and burning (either natural or anthropogenic), are performed to prohibit the encroachment of woody plants into prairie (Klinkenborg 2007, Robinson 2018). The range of the tallgrass prairie extended through the eastern part of the Great Plains of North America and headed even to south-central Canada. Owing to increasing agricultural needs, the maintenance of tallgrass prairie has been prohibited, and, even worse, greatly reduced (Klinkenborg 2007, Robinson 2018). Due to shallow soil and unfavorable farming conditions, the Flint Hills region of Kansas currently has cattle ranching as its primary agricultural activity, bringing about the failure to fully plow this area. Thus, the Flint Hills region is currently the densest and largest intact tallgrass prairie in North America (Klinkenborg 2007, Robinson 2018).

Woody plant encroachment is a rising threat to prairies in the Great Plains and around the world (Briggs et al. 2005). Several factors, soil type, seed dispersal of woody invaders, and climate, can contribute to the establishment and expansion of woody invaders (Briggs et al. 2005, Auken 2009). The numerous requirements for climatic conditions of woody plants suggest that specific conditions in a certain year would either hinder or facilitate the expansion of woody plants. Graminoid and, to a lesser extent, herbaceous species dominate prairies; however, a wide range of woody species are also found in prairie areas at a lower density but are still highly competitive (Briggs et al. 2005). In the prairie, grass and herbs often compete for light on relatively equal grounds because of their size, but woody plants have more reliable structure, the stem, as their support, enabling them to be highly competitive (Briggs et al. 2005, Auken 2009). Also, they compete and consume resources, light and water, around them, leading to little chance for other species to live with them. This can create a barren area beneath them, and can give rise to a decline in biodiversity, which can become a vital problem for land managers (Auken 2009).

Woody species are commonly found in many prairie ecosystems, which are scattered among prairie species. Most woody species in the prairie are not capable of outcompeting and overtaking their non-woody associates, but, some species, including *Cornus drummondii* C.A. Mey. (roughleaf dogwood) (Gleason and Cronquist 1991), *Juniperus virginiana* L. (eastern redcedar) (Bryant 1989), *Ulmus americana* L. (American elm) (Yeager 1935, Guilkey 1957), *Fraxinus pennsylvanica* Marshall (green ash) (Great Plains Flora Association 1986, Kennedy 1990), *Ulmus pumila* L. (siberian elm), and *Rhus glabra* L. (smooth sumac) (Weaver and Fitzpatrick 1934 , Great Plains Flora Association,1986), do have this ability. However, what does it look like at the cellular level of each of these species? How do they respond to climate variability at a cellular level?

In plants, phloem and xylem are the places where resource transportation occurs; the main function of xylem of woody plants is water and nutrient transportation from the roots and mechanical support (Zimmermann 1983). Plants, in the long-term, alter their physical structure and functional capacity to adapt to the changes of exterior environmental conditions. Plants undertake a long time of evolution as well as various responses and alternations to the outside environment; and, as a result, four kinds of vasculature in wood are formed in extant trees: non-porous wood, diffuse porous wood, ring porous wood, and semi-ring porous wood

(Zimmermann 1983). The differences in porosity also determine the responses that trees will make in response to the exterior environment, especially water conditions. For example, ring porous wood tends to have better conduction and storage rate of water than diffuse porous wood, but it also has a higher risk of embolism, the blockage of the water transportation channel by air (Tyree and Zimmermann 2013). In the short-term, features such as size, quantity, cell wall thickness, and arrangement of cells in water transportation tissue in the xylem responds to the outside environment within the year or after the year of climatic variability. This is known as the lag phenomenon (Wimmer 2002, Giantomasi et al. 2009, Venegas-González et al. 2015). According to the Hagen-Poiseuille Law, the diameter of the cell can directly affect the capability of hydraulic transportation; the increase of the radius of the cell will lead to the fourth power of increase in efficiency of water transportation. Thus, the minor change of the cell diameter would dramatically change the efficiency of water transportation in xylem (Zimmermann 1983). Water stress, as caused by deficiency of precipitation or high temperature, would directly or indirectly bring about the decrease of size or quantity of cells in the xylem (Eilmann et al. 2011, Vaganov et al. 2011), in many ways, including control of cell division, and enlargement and differentiation of cells (Battipaglia et al. 2010, Gruber et al. 2010). In contrast, sufficient water supply can not only form larger cells by increased cell pressure and cell expansion rate (Tyree and Sperry 1989, Vaganov et al. 2011) but also can form more cells by decreasing the concentration of auxin, which decreases the cell differentiation and growth cycle (Kozlowski and Pallardy 1997, Aloni 2001, Vaganov et al. 2011). However, larger cells could also confront implosion, the collapse of conduit caused by water pressure, which can damage the cells in the xylem and may cause permanent damage to the water transportation channel, and cavitation, caused by the vapor phase of water in a closed system, the conduit in xylem, which can decrease the efficiency of conduction in xylem (Tyree and Sperry 1989, Mencuccini 2003, Sperry et al. 2006). Water tends to play an essential role in contributing to the growth of trees in drought conditions, but, overwhelming water amount can also inhibit the growth of trees. For example, pine trees (*Pinus* spp.) in humid conditions form narrower rings and the proportion of latewood is lower (Vaganov et al. 2011). Thereby, the anatomical features can be an important signal in response to the changes of water conditions (Wimmer 2002).

Vessel cells in dicots are the main structure for water transportation in xylem; a close relationship is found between its structure and water transportation (Zimmermann 1983, Fonti and García-González 2008). In normal situations, the arid condition can cause the decrease of size and quantity of vessel cells in the xylem; the humid condition can lead to larger and more vessel cells being formed (Tyree and Sperry 1989, Vaganov et al. 2011). Also, the size and quantity of vessel cells in arid areas are lower than those in humid areas (Rita et al. 2015). The area of vessel cells in *Quercus ilex* was found to be positively related to precipitation, but not temperature, indicating that the vessel cell area is mainly controlled by the precipitation in the growing season (Campelo et al. 2010). Also, plants tend to form smaller and fewer vessel cells when droughts occur, leading to the decrease of water transportation rate, but also, decrease the formation of cavitations and occurrence of implosion (Tyree and Sperry 1989, Mencuccini 2003, Sperry et al. 2006). In short, the focus of vessel formation is put on safety in drought conditions and efficiency in wet conditions (Giantomasi et al. 2009, Venegas-González et al. 2015). Tracheids are a significant component in water transportation in gymnosperms. The characteristics of tracheids have been found closely related to water conditions (Fonti and García-González 2008, Gea-Izquierdo et al. 2012). High precipitation can greatly increase the cell diameter in earlywood while low precipitation can decrease the cell diameter in *Pinus nigra* (Martin-Benito et al. 2013). In drought conditions, the time for cell enlargement and expansion greatly decreased in *Pinus sylvestris* (Gruber et al. 2010), leading to the formation of a narrow ring; in wet condition, however, a larger ring is formed due to the elongation of the time for cell expansion activities (Eilmann et al. 2011). Like vessel cells, tracheids also follow the rule of efficiency and safety.

In this study, I would like to address questions of: 1). How different woody cover conditions would affect the growth of the same species and 2). How climatic variations would affect the cellular response of woody invaders in the prairies in the Kansas Flint Hills region. Due to the wide range of combinations and possibilities in climatic conditions, including temperature and precipitation, I simply hypothesized that different species might favor specific climatic conditions, which were factors that can affect woody invasions. It should also be noted that there is a paucity of information in the literature on the effects of temperature and precipitation on cell development in my species of interest. Thus, in this study, I explored the correlation between climate and the growth of woody plants in prairies.

METHODS

Research sites were located on private property just north of Reading, Kansas in Lyon County (38°31'24.45"N, 95°57'25.99"W). My research site contained a tallgrass prairie with several areas of active woody plant invasion, as well as a mature forest area and a younger stand of trees. The prairie area is a typical tallgrass prairie dominated by *Andropogon gerardii* Vitman (big bluestem), *Schizachyrium scoparium* (Michx.) Nash (little bluestem), and *Panicum virgatum* L. (switchgrass). It covers approximately 75,967 square meters. The wooded forest area is mostly populated by *Fraxinus pennsylvanica* Marshall (green ash), *Quercus macrocarpa* Michx. (bur oak), *Ulmus americana* L. (American elm), and *Celtis occidentalis* L. (common hackberry) and covers 75,328 square meters. The transitional area is dominated by *Juniperus virginiana* L. (eastern redcedar) and to a lesser extent, *F.* pennsylvanica, and covers approximately 7,517 square meters.

Plot locations were determined by the availability and size of woody invader species of interest. My focal species were *Juniperus virginiana, Ulmus pumila, Ulmus americana, Fraxinus pennsylvanica, Rhus glabra, Cornus drummondii,* and *Morus rubra*. A randomized sampling design was not possible because the species of interest were sparsely populated in some habitat types. The three kinds of habitats identified in this property (prairie area, transitional area, and forest edge area) were differentiated by tree canopy cover. The tree canopy cover was measured using a spherical densitometer (Forest Densitometers, Model-C). For each woody specimen in the transitional and forest edge area, four measurements of canopy cover were recorded and averaged following the protocol on the densitometer. The prairie area contained no tree canopy cover over my specimens. The transitional area used to be a prairie but at the time of the study was becoming a heavily wooded area. The forest edge area was the edge of the active encroachment of the mature forest into the prairie. Most common prairie woody invaders were not found inside the densely-wooded areas in the forest, indicating their ability as both pioneer and invasive species into prairies. It also limited my ability to sample those species in the forest and thus, the dense, mature forest area was ignored for this study.

Information about each specimen was collected in the field. This included GPS location, plot photos, the direction of slope on which the tree was growing, elevation, associated species cover type (grass, forb or shrub), tree density and physical characteristics of the tree (stem or basal diameter and height) on each of the woody plants. All the specimen information was collected between September and December of 2016 except for the associated species cover and tree canopy cover, which was collected between April and June of 2017. Woody specimen collection dates ensured the trees had stopped growing for the year of 2016.

Two or three tree specimens that were narrower than 3-cm in diameter were cut from branches or the main stem and were stored in a 50-ml centrifuge tube. Each of these samples was cut from actively growing stems and were used for cellular-level analyses. I placed these small samples into 50% ethanol and stored them in a cooler with ice. Upon returning these specimens to the lab, I stored them in the refrigerator at 5 degrees Celsius to avoid tissue deterioration before cell analyses (Anfodillo et al. 2012). Specimen general information was recorded and arranged in Microsoft Excel.

Samples were dehydrated using a graded ethanol series (50%, 70%, 85%, 95%, 100%, 100%, and 100%). Each step of series took one hour. Samples were then transferred to Histoclear II (Fisher) (Ziaco et al. 2014) for another one hour and then transferred to pure paraffin overnight at 65 degrees Celsius. Then, they were embedded in paraffin (Lecia EG1150H Embedding set) and cooled on the microtome cooler (Lecia EG1150C Cooler) so that I could easily get them out of the mold without cracks in the paraffin block. After dislodging the specimens from the mold, samples in the paraffin block were cut with a microtome at 10 micrometers (Leica RM 2125 RTS Microtome), and the thin paraffin slices were transferred to a tray with water at 40° C for flattening. Slides were stored in 95% ethanol to wash off the wax coating. Slides were taken out of the container and placed on a warm plate at 40 degrees Celsius. Haupt's medium was spread on the slides for adhesion. Samples were caught by the slides and dried on the warm plate. After that, a few drops of 3% Formalin was added to the samples for further flattening and adhesion. Samples were taken off the plate when dried and put in a slide rack for staining.

Samples were deparaffinized by soaking in Histoclear II for fifteen minutes, twice. After that, samples were immersed in 100% ethanol for fifteen minutes, twice, and then stained in aqueous Safranin O for fifteen minutes. Slides were then washed with distilled water, 30%, 50%, 75%, 95%, 100% ethanol for a few seconds each. After drying, samples were mounted with Permount Mounting Medium (Fisher) for permanent mounting. Small weights (about 500g) were put on the coverslips overnight to remove bubbles. Slides were photographed under a microscope (OLYMPUS BX51) with a mounted camera (DIAGNOSTIC instruments 25.1 2 Mp Monochrome w/IR) at either 200X or 400X magnification.

The average number of tree rings was 6, so the time span 2011-2016 was selected for comparison. Measurement area was three lines of cells within each annual ring (Deslauriers et al. 2003). Wood anatomical parameters measured were averaged lumen area, cell diameter, and cell wall thickness for both earlywood and latewood areas annually. The latewood was defined as the part of the ring in which cells had a radial lumen diameter less than two times of the size of the cell wall (Denne, 1988). All parameters were measured in ImageJ, an image processing program with custom plug-ins and macros that enabled us to customize to my specific use. Once it has been taught, the software can analyze the cell section slides on its own, and the only thing I need to do is determine the area where I would like to analyze. The lumen area for all species measured was determined by all cell types, including vessel cell, tracheids and other possible cell water transportation channel. The cell diameter and cell wall thickness were measured by drawing a line from the starting point of the growth to the end of the growth; and, the stained part would be determined as cell wall width if divided by two and the rest of the width would become the cell diameter. Then, the total length of both parameters was divided by the cell count to calculate the averaged cell wall thickness and diameter. All the acronyms used in this chapter can be found in Table 6.

All the data analyses were performed using SAS (version 9.3). Intraspecific data were analyzed site-wise, comparing trees of the same species growing at different sites. Annual data of averaged lumen area, cell wall thickness, and cell diameter were collected and computed respectively for earlywood and latewood. A correlation coefficient was conducted for earlywood and latewood anatomic features to relate to each other as well as climatic variables. Analysis of variance (ANOVA) was performed on the cell parameters of earlywood and latewood for differences based on sites. Tukey’s test was used if any significant differences were identified. The relationship among climatic parameters, mean temperature and precipitation for spring (April to June) and summer (July to September), and anatomical variables, lumen area, cell diameter and cell wall thickness, of both earlywood and latewood, were tested using linear regression.

RESULTS

Intraspecific comparison. The ANOVA results of the intraspecific comparison, in general, showed little difference based on sites. There were, however, some differences found. The lumen area and cell diameter in latewood in the forest edge site of *Juniperus virginiana* were found to be significantly smaller than both transitional and prairie sites (Table 10). A significantly higher thickness of cell wall was found in the transitional site than forest edge site for *Juniperus virginiana* in latewood (Table 10). For *Ulmus americana*, a significantly thicker cell wall was found in transitional area than prairie area (Table 10). Many significant differences were found in *Ulmus pumila*. In forest edge site, the lumen area in earlywood is significantly smaller than prairie and transitional sites (Table 10); the lumen area in latewood, however, is significantly smaller in the transitional site than prairie and forest edge sites (Table 10). The cell wall in earlywood in the transitional site is significantly thinner than forest edge and prairie areas (Table 10). Earlywood lumen area was the only significant difference found in *Fraxinus pennsylvanica*: the prairie site had a significantly larger lumen area than the forest edge site (Table 10). For *Cornus drummondii*, a significantly smaller earlywood lumen area was found in forest edge site than transitional and prairie sites (Table 10). Also, a significantly thicker cell wall was found in latewood in forest edge site than the prairie site (Table 10).

Prairie site. Strong positive relationships were found in all five species in earlywood lumen area with precipitation while weak positive relationships were found in all species in latewood lumen area except for *Juniperus virginiana* (Table 7). Earlywood cell diameter of *Ulmus americana*, *Fraxinus pennsylvanica*, and *Cornus drummondii* were strongly and positively correlated with precipitation; *Juniperus virginiana* showed a weak positive relationship and *Ulmus pumila* showed no relationship with precipitation (Table 7). All species showed weak positive relationships with precipitation in latewood cell diameter except for *Cornus drummondii*, which showed a strong relationship (Table 7). All species showed either weak or no relationship with precipitation in cell wall thickness in both earlywood and latewood except for *Ulmus pumila*, which showed a strong positive relationship with precipitation in earlywood cell wall thickness (Table 7). Temperature showed no effect on all cell parameters except for a weak positive relationship in latewood cell wall thickness in *Ulmus americana* (Table 7).

Forest edge site. Strong positive relationships were found in *Fraxinus pennsylvanica* and *Cornus drummondii* in earlywood lumen area with precipitation while weak ones were found in *Juniperus virginiana* and *Ulmus pumila*; in latewood, all species showed weak positive relationships between lumen area and precipitation (Table 8). All species showed strong positive relationships with precipitation in earlywood cell diameter and weak ones in latewood except for *Cornus drummondii,* which showed a strong relationship in latewood cell diameter (Table 8). Cell wall thickness had little relationship with precipitation for all species in both earlywood and latewood (Table 8). Temperature, like in prairie site, showed little or no effect on all parameters except for *Ulmus pumila,* showed a weak positive relationship with latewood cell wall thickness (Table 8).

Transitional site. Strong positive relationships were found in all species in earlywood lumen area with precipitation; in latewood, weak positive relationships were found for lumen area in *Ulmus americana, Fraxinus pennsylvanica,* and *Cornus drummondii* while no relationship was found in *Juniperus virginiana* and *Ulmus pumila* with precipitation (Table 9). For cell diameter in earlywood, strong positive relationships were found in *Ulmus pumila, Ulmus americana,* and *Cornus drummondii* with precipitation while weak positive relationships were found in *Juniperus virginiana* and *Fraxinus pennsylvanica*; in latewood, all species showed weak relationships with precipitation (Table 9). *Ulmus americana* showed a weak positive relationship between earlywood cell wall thickness and precipitation while the rest of the species showed no relationship; in latewood, *Ulmus americana* and

Cornus drummondii showed weak positive relationships with precipitation and others showed no relationship (Table 9). Temperature, again, had nothing to do with the cellular parameters excluding *Juniperus virginiana*, which showed a weak relationship in latewood cell wall thickness (Table 9).

DISCUSSION

Intraspecific comparison. Few studies have been done for my species of interest, especially in the prairie region. My comparison on intraspecific differences reveals that, in general, cellular responses rarely occur when it comes to differences in wood canopy cover. Most differences observed agree with the response to water deficiency. A decreasing of lumen area and cell diameter in forest edge area reveals that young woody invaders in that region face water stress, probably due to the large number of mature trees. Similar trends are found in conifer species in mesic (Martin-Benito et al. 2013) and arid (DeSoto et al.2011) sites of Spain. However *Pinus sylvestris* had an opposite trend in that the enlargement of lumen area was found to deal with severe drought in the Alps (Eilmann et al. 2009) and in the Iberian peninsula (Martín et al. 2010). Smaller lumen area is considered as a safe way for water transportation; it is more tolerant to cavitation and has a higher efficiency of hydraulic conductivity in the conduits in xylem under water deficiency, due to their higher resistance to negative pressure in the xylem (Sperry et al. 2006).

Climate. In prairie area, strong correlations were discovered between spring precipitation and lumen area and cell diameter in most species, indicating that the cell enlargement and expansion occur greatly during spring for woody invaders in the prairie, and, based on their high correlations, I can interpret that a big consumption of water from precipitation happened in the prairie area for woody invaders. The cell wall of the spring growing season shows little or no correlation for most species, indicating that woody invaders are not concerned about the safety of water transportation, thanks to the abundant precipitation, which does not affect the cell wall thickness. In summertime, woody invaders also have a good response to precipitation for most species. The lumen area and cell diameter show weak correlation with precipitation, illustrating that even during latewood period, woody invaders do a really good job on consuming water in their territory since precipitation is the only major water source of this area. Cell wall, again, in latewood shows little or no correlation with precipitation in summer. Surprisingly, temperature seems to play an unimportant role in this region. Almost all of my cell parameters do not respond to temperature in both spring and summer time. A reasonable explanation would be that the temperature in the Flint Hills region in Kansas meets woody invaders' favorable growing conditions, and thus, does not serve as a good signal for cellular adaptations. Similar correlations were found in the transitional area for precipitation. The strong correlations found in the spring for lumen area and cell diameter uncover the fact that young trees, even grouped, can take up water within their territory during the spring easily, indicating that young trees may have the intention to collaborate rather than to compete for resources. Similar but weaker correlations were found in forest edge area as well, showing that, even surrounded by mature trees, young woody invaders tend to focus on efficiency of water transportation and rapid growth during the spring instead of safety. Cell wall thickness, again, for both sites, show little or no correlations with spring precipitation. In summertime, lumen area and cell diameter could still be used as a good indicator of precipitation; the positive but weak or no correlations in both forest edge and transitional areas may be a indicator of young trees focus less on the water transportation efficiency due to either competition with other trees or a general water deficiency. In short, young woody invaders tend to focus more on efficiency of hydraulic conductivity during the springtime when water supply is abundant and to put more effort on safety during the summer when they group either together with peers or mature individuals, which agrees with *Prosopis flexuosa* and some tropical species (Giantomasi et al. 2009, Venegas-González et al. 2015). Temperature in both transitional and forest edge sites show no correlation in most cases, which agrees with the prairie site that temperature is not impacting the cellular structural adaptation in this region. Although my study does not show a strong correlation between cellular structure and temperature, many studies have shown that temperature can have an effect on features of cellular features. The vessel cells in *Quercus robur* in earlywood had a significant correlation with spring temperature and a weak correlation with temperature in December of last year in Latvija (Matisons et al 2012). Moreover, temperature can directly affect cell division and differentiation in earlywood in the xylem, controlling the size and quantity of vessel cells (Venegas-González et al. 2015, Fonti and García-González 2004); Pérez-De-Lis et al. (2016) also found that high temperature in spring leads to a bigger vessel cell in *Quercus robur* and *Quercus pyrenaica.* In conifer trees, temperature play an essential role in the control of the length of growing in growing season. For *Pinus thunbergii*, the rise of one degree Celsius can lead to an elongation of eight to eleven days of the growing time (Rossi et al. 2011). Also, high temperature can lead to a larger growth rate of latewood during the summer (Vaganov *et al*. 2006). For conifers, the threshold for growth lies between five and fourteen degrees Celsius. Upon exceeding this threshold, temperature tends to not affect the growth of conifers, which may explain what I have in my study (Denne 1971, Vaganov 1996, Vaganov et al. 2011, Liang et al. 2015). *Juniperus virginiana* can be a comparable species as conifers, and, the temperature in Kansas during growing season is around twenty degrees Celsius, which exceeds the upper limit of the threshold; other species in this research may also have this kind of threshold. And, due to the high temperature in Kansas, woody invaders in the prairie do not have good cellular responses to temperature during both spring and summer.

REFERENCES

Aloni, R. 2001. Foliar and axial aspects of vascular differentiation: Hypotheses and evidence. *Journal of Plant Growth Regulation* 20: 22–34.

Anfodillo, T., A. Deslauriers, R. Menardi, L. Tedoldi, G. Petit, and S. Rossi. 2012. Widening of xylem conduits in a conifer tree depends on the longer time of cell expansion downwards along the stem. *Journal of experimental botany* 63: 837-45.

Auken, V. 2009. Causes and consequences of woody plant encroachment into western North American grasslands. *Journal of Environmental Management* 90: 2931-42.

Battipaglia, G., V. De-Micco, W. A. Brand, P. Linke, G. Aronne, M. Saurer, and P. Cherubini. 2010. Variations of vessel diameter and δ13C in false rings of *Arbutus unedo* L. reflect different environmental conditions. *New Phytologist,* 188: 1099–1112.

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

Bryant, W. S. 1989. Redcedar (*Juniperus virginiana* L.) communities in the Kentucky River Gorge area of the bluegrass region of Kentucky. In: Rink, George; Budelsky, Carl A., eds. Proceedings, 7th central hardwood conference; 1989 March 5-8; Carbondale, IL. Gen. Tech. Rep. NC-132. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 254-261.

Campelo F., C. Nabais, E. Gutiérrez, H. Freitas, and I. García-González. 2010. Vessel features of *Quercus ilex* L. growing under Mediterranean climate have a better climatic signal than tree-ring width. *Trees* 24: 463–470.

Denne, M. 1971. Temperature and tracheid development in *Pinus sylvestris* seedlings. *Journal of Experimental Botany* 22: 362–370.

Denne, M. P. 1988 . Definition of latewood according to Mork (1928). *IAWA Bulletin* n.s. 10: 59 – 62 .

Deslauriers, A., H. Morin, and Y. Bégin. 2003. Cellular phenology of annual ring formation of Abies balsamea in the Quebec boreal forest (Canada). *Canadian Journal of Forest Research* 33 : 190 – 200.

Desoto, L., M. D. Cruz, and P. Fonti. 2011. Intra-annual patterns of tracheid size in the Mediterranean tree *Juniperus thurifera* as an indicator of seasonal water stress. *Canadian Journal of Forest Research* 41: 1280 – 1294.

Eilmann, B., R. Zweifel, N. Buchmann, P. Fonti, and A. Rigling. 2009. Drought-induced adaptation of the xylem in Scots pine and pubescent oak. *Tree Physiology* 29: 1011 – 1020.

Eilmann, B., R. Zweifel, N. Buchmann, E. G. Pannatier, and A. Rigling. 2011. Drought alters timing, quantity, and quality of wood formation in Scots pine. *Journal of Experimental Botany* 62: 2763–2771.

Fonti, P., and I. García-González. 2004. Suitability of chestnut earlywood vessel chronologies for ecological studies. *New Phytologist* 163: 77–86.

Fonti, P., and I. García-González. 2008. Earlywood vessel size of oak as potential proxy for spring precipitation in mesic sites. *Journal of Biogeography* 35:2249–2257.

Gea-Izquierdo, G., P. Fonti, P. Cherubini, D. Martín-Benito, H. Chaar, and I. Cañellas. 2012. Xylem hydraulic adjustment and growth response of *Quercus canariensis* Willd. to climatic variability. *Tree Physiology* 32: 401–423.

Giantomasi, M. A., F. A. R. Junent, P.E. Villagra, and A. M. Srur. 2009. Annual variation and influence of climate on the ring width and wood hydrosystem of *Prosopis flexuosa* DC. trees using image analysis. *Trees* 23: 117–126.

Gleason, H. A., and A. Cronquist,. 1991. Manual of vascular plants of northeastern United States and adjacent Canada. 2nd ed. New York: New York Botanical Garden. 910 p.

Great Plains Flora Association. 1986. Flora of the Great Plains. Lawrence, KS: University Press of Kansas. 1392 p.

Gruber, A., S. Strobl, B. Veit, and W. Oberhuber. 2010. Impact of drought on the temporal dynamics of wood formation in *Pinus sylvestris*. *Tree Physiology* 30: 490–501.

Guilkey, P. C. 1957. Silvical characteristics of American elm *(Ulmus americana).* Station Paper No. 54. St. Paul, MN: U.S. Department of Agriculture, Forest Service, Lake States Forest Experiment Station. 19 p.

Klinkenborg, V. 2007. Splendor of the Grass: The Prairie's Grip is Unbroken in the Flint Hills of Kansas. *National Geographic*. Retrieved on March 17th 2018.

Kozlowski, T. T., and S. G. Pallardy. 1997. *Growth Control in Woody Plants*. Academic Press, New York.

Liang, W., I. Heinrich, S. Simard, G. Helle, I. D. Liñán, and T. Heinken. 2015. Climate signals derived from cell anatomy of Scots pine in NE Germany. *Tree Physiology* 33: 833-844.

Martin-Benito, D., H. Beeckman, and I. Canellas. 2013. Influence of drought on tree rings and tracheid features of *Pinus nigra* and *Pinus sylvestris* in a mesic Mediterranean forest. *European Journal of Forest Research* 132: 33–45.

Martín, J. A., L. G. Esteban, P. D. Palacios, and F. G. Fernández. 2010.Variation in wood anatomical traits of *Pinus sylvestris* L. between Spanish regions of provenance. *Trees—Structure and Function* 24: 1017 – 1028.

Mencuccini, M. 2003. The ecological significance of long-distance water transport: Short-term regulation, long-term acclimation and the hydraulic costs of stature across plant life forms. *Plant, Cell & Environment* 26: 163–182.

Pérez-De-Lis, G., S. Rossi, R. A. Vázquez-Ruiz, V. Rozas, and I. García- González. 2016. Do changes in spring phenology affect earlywood vessels? Perspective from the xylogenesis monitoring of two sympatric ring-porous oaks. *New Phytologist* 209: 521–530.

Rita A., P. Cherubini, S. Leonardi, L. Todaro, and M. Borghetti. 2015. Functional adjustments of xylem anatomy to climatic variability: Insights from long-term *Ilex aquifolium* tree-ring series. *Tree Physiology* 35, 817–828.

Robinson, S. 2018. Central forest-grasslands transition. *Terrestrial Ecoregions*. World Wildlife Fund. Retrieved on March 17th 2018.

Rossi, S., H. Morin, A. Deslauriers, and P. Y. Plourde. 2011. Predicting xylem phenology in black spruce under climate warming. *Global Change Biology* 17: 614–625.

Sperry, J. S., U. G. Hacke, and J. Pittermann. 2006. Size and function in conifer tracheids and angiosperm vessels. *American Journal of Botany* 93: 1490–1500.

Tyree, M. T., and J. S. Sperry. 1989. Vulnerability of xylem to cavitation and embolism. *Annual Review of Plant Biology* 40, 19–36.

Tyree, M. T., and M. H. Zimmermann. 2013. *Xylem Structure and the Ascent of Sap*. Springer, Berlin.

Vaganov, E. A. 1996. *Recording of Warming in Current Century by Tracheids of the Annual Tree Rings*. Doklady Akademii Nauk, Moscow, Russia.

Vaganov, E.A., K. J. Anchukaitis, and M. N. Evans. 2011. How well understood are the processes that create dendroclimatic records? A mechanistic model of the climatic control on conifer tree-ring growth dynamics. *Dendroclimatology* 11: 37–75.

Vaganov, E. A., M. K. Hughes, and A. V. Shashkin. 2006. *Growth Dynamics of Conifer Tree Rings*. Springer, Berlin.

Venegas-González, A., G. Von-Arx, M. P. Chagas, and M. Tomazello-Filho. 2015. Plasticity in xylem anatomical traits of two tropical species in response to intra-seasonal climate variability.*Trees* 29: 423–435.

Weaver, J. E., and T. J. Fitzpatrick. 1934. The prairie. Ecological Monographs. 4(2): 111-295.

Wimmer, R. 2002. Wood anatomical features in tree-rings as indicators of environmental change. *Dendrochronologia* 20: 21–36.

Yeager, A. F. 1935. Root systems of certain trees and shrubs grown on prairie soils. Journal of Agricultural Research. 51(12): 1085-1092.

Ziaco, E., B. Franco, R. Sergio, and D. Annie. 2014. Climatic influences on wood anatomy and tree-ring features of great basin conifers at a new mountain observatory. *Applications in Plant Sciences* 2: 1400054

Zimmermann M. 1983. *Xylem Structure and the Ascent of Sap*. Springer, Berlin, Germany.

CONCLUSION

At dendrochronological level, some woody invaders grow faster and better individually while others grow faster when they are growing together. The encroachment of woody invaders seems to be driven mainly by precipitation. The intraspecific comparison showed that *Juniperus virginiana* and *Cornus drummondii* may favor group growing while *Ulmus pumila, Ulmus americana, Fraxinus pennsylvanica* and may favor growing individually. Fire can be the major treatment to be used to eliminate woody invaders when they are young and should be done as soon as possible to control and prohibit the invasion of woody species into the prairie. At cellular level, this preliminary research on cellular response to climatic variables for woody invaders in the Flint Hills region of Kansas uncovers a close relationship with precipitation, but not temperature. Despite the preliminary nature of my results limits my general understanding of climate and growth relationships at cellular level, precipitation seems to play a significant role in the growth of woody invaders in the prairie area, which informs the landowners and land management agencies that actions, such as prescribed burning, need to be done if a wet year is approaching, especially a wet and warm spring, to prohibit the growth of woody invaders.

Table 6. Table listing acronyms used in figures and tables in results part.

Acronyms	Full Name
ELA	Earlywood Lumen Area
ECD	Earlywood Cell Diameter
ECW	Earlywood Cell Wall Thickness
LLA	Latewood Lumen Area
LCD	Latewood Cell Diameter
LCW	Latewood Cell Wall Thickness

Table 7. Precipitation and temperature vs. cell parameters in prairie site. Table listing the R^2 values and P-values obtained from linear regression analyses. The sample size for all cell parameters is 25.

	Prairie Site Cell Parameters vs. Precipitation											
Species	ELA R^2	P-value	ECD R^2	P-value	ECW R^2	P-value	LLA R^2	P-value	LCD R^2	P-value	LCW R^2	P-value
Juniperus virginiana	0.7583	0.0000	0.4778	0.0001	0.1003	0.1230	0.0555	0.2570	0.2441	0.0121	0.0411	0.3310
Ulmus pumila	0.5832	0.0000	0.0044	0.7579	0.7663	0.0000	0.4799	0.0001	0.3853	0.0009	0.0390	0.3437
Ulmus americana	0.7896	0.0000	0.5731	0.0000	0.1305	0.0760	0.3479	0.0019	0.3339	0.0025	0.0102	0.6304
Fraxinus pennsylvanica	0.7486	0.0000	0.6229	0.0000	0.0593	0.2409	0.4681	0.0002	0.3474	0.0019	0.1023	0.1191
Cornus drummondii	0.6387	0.0000	0.7643	0.0000	0.0538	0.2648	0.4867	0.0000	0.6413	0.0000	0.1024	0.1188

	Prairie Site Cell Parameters vs. Temperature											
Species	ELA R^2	P-value	ECD R^2	P-value	ECW R^2	P-value	LLA R^2	P-value	LCD R^2	P-value	LCW R^2	P-value
Juniperus virginiana	0.0067	0.6975	0.0274	0.4293	0.0373	0.3549	0.0638	0.2231	0.0145	0.5658	0.0143	0.5685
Ulmus pumila	0.0002	0.9461	0.0400	0.3490	0.0585	0.2547	0.0029	0.7966	0.0008	0.8915	0.0000	0.9875
Ulmus americana	0.0005	0.9165	0.0088	0.6554	0.0009	0.8868	0.0002	0.9497	0.0291	0.4148	0.2184	0.0185
Fraxinus pennsylvanica	0.0146	0.5653	0.0115	0.6093	0.0033	0.7837	0.0021	0.8292	0.0025	0.8119	0.0014	0.8591
Cornus drummondii	0.0132	0.5848	0.0002	0.9442	0.0013	0.8649	0.0215	0.4843	0.0003	0.9343	0.0004	0.9265

Table 8. Precipitation and temperature vs. cell parameters in forest edge site. Table listing the R^2 values and P-values obtained from linear regression analyses. The sample size for all cell parameters is 25.

	Forest Edge Site Cell Parameters vs. Precipitation											
Species	ELA R^2	P-value	ECD R^2	P-value	ECW R^2	P-value	LLA R^2	P-value	LCD R^2	P-value	LCW R^2	P-value
Juniperus virginiana	0.3788	0.0011	0.6609	0.0000	0.0251	0.4497	0.2730	0.0074	0.3122	0.0037	0.0650	0.2188
Ulmus pumila	0.4620	0.0002	0.7428	0.0000	0.1379	0.0676	0.4627	0.0002	0.2656	0.0084	0.0105	0.6256
Fraxinus pennsylvanica	0.6493	0.0000	0.5517	0.0000	0.1138	0.0991	0.4221	0.0004	0.3116	0.0037	0.0989	0.1258
Cornus drummondii	0.6276	0.0000	0.7182	0.0000	0.0361	0.3631	0.3419	0.0021	0.5488	0.0000	0.1033	0.1172
	Forest Edge Site Cell Parameters vs. Temperature											
Species	ELA R^2	P-value	ECD R^2	P-value	ECW R^2	P-value	LLA R^2	P-value	LCD R^2	P-value	LCW R^2	P-value
Juniperus virginiana	0.0005	0.9168	0.0168	0.5369	0.0605	0.2358	0.0000	0.9774	0.0002	0.9413	0.0519	0.2736
Ulmus pumila	0.0018	0.8408	0.0070	0.6916	0.0247	0.4534	0.0180	0.5225	0.0116	0.6086	0.2356	0.0139
Fraxinus pennsylvanica	0.0341	0.3767	0.0097	0.6393	0.0018	0.8403	0.0051	0.7350	0.0616	0.2317	0.0001	0.9582
Cornus drummondii	0.0028	0.8020	0.0028	0.8005	0.0051	0.7342	0.0294	0.4121	0.0067	0.6971	0.0000	0.9807

Table 9. Precipitation and temperature vs. cell parameters in transitional site. Table listing the R^2 values and P-values obtained from linear regression analyses. The sample size for all cell parameters is 25.

	Transitional Site Cell Parameters vs. Precipitation											
Species	ELA R^2	P-value	ECD R^2	P-value	ECW R^2	P-value	LLA R^2	P-value	LCD R^2	P-value	LCW R^2	P-value
Juniperus virginiana	0.6963	0.0000	0.4557	0.0002	0.0786	0.1748	0.0266	0.4360	0.4176	0.0005	0.0044	0.7515
Ulmus pumila	0.7096	0.0000	0.6765	0.0000	0.0624	0.2285	0.0180	0.5221	0.4223	0.0004	0.0737	0.1894
Ulmus americana	0.6286	0.0000	0.6613	0.0000	0.3576	0.0016	0.3875	0.0009	0.2485	0.0112	0.1028	0.1181
Fraxinus pennsylvanica	0.6963	0.0000	0.4557	0.0002	0.0786	0.1748	0.4612	0.0002	0.1574	0.0496	0.0990	0.1255
Cornus drummondii	0.6861	0.0000	0.7429	0.0000	0.0542	0.2627	0.4362	0.0003	0.5418	0.0000	0.1038	0.1163

	Transitional Site Cell Parameters vs. Temperature											
Species	ELA R^2	P-value	ECD R^2	P-value	ECW R^2	P-value	LLA R^2	P-value	LCD R^2	P-value	LCW R^2	P-value
Juniperus virginiana	0.0228	0.4713	0.0000	0.9977	0.0014	0.8612	0.0897	0.1459	0.0877	0.1505	0.1631	0.0453
Ulmus pumila	0.0078	0.6745	0.0031	0.7909	0.0115	0.6103	0.0016	0.8484	0.0045	0.7494	0.0686	0.2060
Ulmus americana	0.0198	0.5028	0.0000	0.9822	0.0739	0.1888	0.0000	0.9854	0.0192	0.5088	0.0225	0.4739
Fraxinus pennsylvanica	0.0228	0.4713	0.0000	0.9977	0.0014	0.8612	0.0014	0.8580	0.0499	0.2830	0.0022	0.8239
Cornus drummondii	0.0000	0.9814	0.0015	0.8558	0.0033	0.7859	0.0216	0.4831	0.0001	0.9696	0.0014	0.8585

Table 10. Listing ANOVA results, including degrees of freedom (d.f.), F-value, and P-value of all six cell parameters for each species based on site differences (prairie site, transitional site, and forest edge site). Same lower-case letters indicate groups of mean that are not significantly different from each other (Tukey's Test). The means of group a are significantly higher than group b's.

Species	Variable	d.f.	F-value	P-value	Tukey's Test		
					Prairie Site	Forest Edge Site	Transitional Site
Juniperus virginiana	ELA	2, 72	2.23	0.1147			
	LLA	2, 72	8.62	0.0004	a	b	a
	ECD	2, 72	0.12	0.8843			
	LCD	2, 72	14.2	0.0001	a	b	a
	ECW	2, 72	1.12	0.3333			
	LCW	2, 72	3.87	0.0252	a	b	a,b
Ulmus americana	ELA	1,48	0.27	0.6048			
	LLA	1,48	1.38	0.2465			
	ECD	1,48	0.13	0.7209			
	LCD	1,48	1.32	0.2558			
	ECW	1,48	0.41	0.5233			
	LCW	1,48	13.85	0.0005	a		b
Ulmus pumila	ELA	2, 72	18.86	0.0001	a	b	a
	LLA	2, 72	7.91	0.0008	a	a,b	b
	ECD	2, 72	1.44	0.2437			
	LCD	2, 72	0.65	0.5242			
	ECW	2, 72	31.17	0.0001	a	a	b
	LCW	2, 72	1.81	0.1711			
Fraxinus pennsylvanica	ELA	2, 72	3.63	0.0316	a	b	a,b
	LLA	2, 72	0.71	0.4932			
	ECD	2, 72	0.79	0.4599			
	LCD	2, 72	0.16	0.8557			
	ECW	2, 72	2.29	0.1090			
	LCW	2, 72	1.01	0.3690			
Cornus drummondii	ELA	2, 72	5.03	0.0090	a	b	a
	LLA	2, 72	2.81	0.0671			
	ECD	2, 72	0.62	0.5394			
	LCD	2, 72	2.87	0.0635			
	ECW	2, 72	2.73	0.0721			
	LCW	2, 72	3.42	0.0381	b	a	a,b

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