RESEARCH ARTICLE

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forest ecology

Status and Trends of Eastern Redcedar (*Juniperus virginiana*) in the Central United States: Analyses and Observations Based on Forest Inventory and Analysis Data

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Eastern redcedar (*Juniperus virginiana*) (ERC) is a conifer native to North America that has been used for a variety of wood products, and its planting has been encouraged to help stabilize soil, reforest abandoned farmland, and provide cover for wildlife. However, ERC tends to expand rapidly and take over certain areas primarily because it can grow on a wide variety of soils and tolerates salt and harsh climatic conditions. As a result of this invasive behavior, the ERC composition of central United States forestlands has been on the rise over several decades. To evaluate the current status and recent trends of ERC on forestland in eight central states, we analyzed forest resource data collected annually from 2001 to 2012 by the Forest Inventory and Analysis (FIA) program of the USDA Forest Service at county, state, and regional levels. Our results indicate that ERC increased in terms of area, density, and volume across a range of diameter classes. In addition, ERC seedling abundance increased, and we found a statistically significant relationship between decreasing tree species diversity and ERC basal area proportion. We draw several conclusions from these analyses: (1) the geographic distribution of ERC in central US forestlands is widespread, but varies in density, (2) the area of ERC forestland increased most significantly in Nebraska and Missouri during the early 2000s, (3) the density and volume of ERC are on the rise in the region, and (4) the changes in seedling species abundance and the negative association between diversity and ERC presence suggest that the future composition of forests in the region could be altered if the current trends in ERC invasion continue.

Keywords: forest inventory, eastern redcedar, biological invasion, species diversity

Eastern redcedar (*Juniperus virginiana*) (ERC) is a very common and widely distributed coniferous species. Its native range includes at least part of every state in the eastern half of the United States as well as southern Ontario and Quebec (Burns 1983, Lawson 1985), and its plantable range extends across the 48 contiguous states (Gilman and Watson 1993). ERC is known for its hardy nature and ability to grow on a wide variety of soil types and under harsh climatic conditions, such as drought and extreme temperatures (Burns 1983, Lawson 1985). In the Great Plains in particular, it was widely planted as a windbreak species because it is good for protecting soils from desiccation and wind erosion and provides food, nesting sites, and thick cover for wildlife (Burns 1983, Dronen 1984, Lawson 1985).

Historically, ERC has been a valued and economically important species (Jelley 1937). It was recognized throughout the 1800s for its profitable uses, such as split-rail fences, pencils, and wine barrels (Hemmerly 1970). Jelley (1937) referred to it as an important and valuable timber tree, and he encouraged its planting on agricultural lands that were no longer productive and on areas that had been cleared of their timber in Tennessee. Burns (1983) even suggested that converting poor hardwood sites to ERC could be economically and ecologically beneficial. The wood and other products made from ERC continue to be valued for their nice scent and beauty, including cedarwood oil, closet linings and paneling, chests, furniture, fence posts, sachet bag filling, and souvenirs and novelties (Jelley 1937, Hemmerly 1970, Semen and Hiziroglu 2005). ERC has noneconomic value as well. Its ability to protect soil, livestock, and structures from the wind has made it one of the most common and recommended wind-

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break species in the Great Plains (Burns 1983, Dronen 1984). In addition, new ERC forests have gained attention for their role in sequestering carbon, and more recent research suggests that they may provide more potential carbon storage than that of grasslands in the central United States (Norris et al. 2001, McKinley and Blair 2008).

Despite the positive aspects of ERC, it is well known that the rapid and widespread expansion of this tree species remains an issue of ecological and economic concern. Invasion of tallgrass prairies results in the displacement of native grasses and forbs, thus reducing plant diversity and productivity in these areas (Engle et al. 1987, Schmidt and Stubbendieck 1993, Briggs et al. 2002), and less forage for livestock and wildlife (Stritzke and Bidwell 1990, Starks et al. 2011). The increased presence of ERC also affects hydrologic and nutrient cycling (Horncastle et al. 2004, Limb et al. 2010). From an economic perspective, ERC removal at low densities can be labor intensive and requires upkeep by landowners, and converting areas where ERC has formed dense stands back to original grassland communities is very expensive (Bidwell and Weir 2002).

Many studies have addressed the expansion of ERC in different geographic areas, such as Nebraska, Kansas, Missouri, and particularly Oklahoma. For example, a survey conducted in Oklahoma by the Soil Conservation Service found that the ERC and ashe juniper (*Juniperus ashei*) invasion had grown from about 1.5 million acres in 1950 to 3.5 million acres by 1985 (Snook 1985 as cited in Bidwell et al. 2000), and Grumbles (1989) estimated that the invaded acres numbered more than 4 million by 1989. Bidwell et al. (2000) replicated Snook's 1985 survey and reported that the area of rangeland and forestland occupied by these two juniper species exceeded 6 million acres by 1994.

In Nebraska, Schmidt and Kuhns (1990, p. 3) noted that

> The ERC-hardwood forest type accounted for 1.7 percent of all commercial forestland in 1955. However, by 1983 it had increased to 7.8 percent of all commercial forestland. Even greater increases in ERC acreage occurred in Nebraska's other woodland resource types.

Walker and Hoback (2007) reported that ERC had invaded the Loess Canyons region of Lincoln County, Nebraska, and was continuing to expand at an annual rate of 2%.

ERC expansion has been documented in Kansas and Iowa as well. Owensby et al. (1973) wrote about ERC infestations in the Kansas Flint Hills and what might possibly be done to control further expansion. Briggs et al. (2002) examined a time series of aerial photos from northeastern Kansas and found that grasslands there became ERC forest in a matter of 40 years. Similarly, Norris et al. (2001) noted the formation of closed-canopy ERC forests in the same region of Kansas. In Iowa, Blewett (1986) found substantial increases in ERC along the bluffs of the Mississippi River.

On a coarser scale, Schmidt and Leatherberry (1995) conducted an analysis of ERC expansion across a four-state region that included Illinois, Indiana, Iowa, and Missouri. They compared area of forestland with ERC present between consecutive statewide inventories; the earlier inventories occurring in the 1960s–1970s and then again from 1985 to 1990. The increase in forestland with ERC present was nearly 2.4 million acres and the percentage of the total forest area containing ERC more than doubled between inventories; much of the increase in ERC occurred on former pasture land in Missouri.

The rapid expansion of ERC led to concern over the effect this would have on native grassland communities and prairie forests, particularly those dominated by oak (*Quercus* spp.). Generally, Schmidt and Leatherberry (1995) found that the area of oak forest types in a four-state region in the Lower Midwest declined between the 1960s and 1990, whereas forestland with oaks and ERC doubled during the same time period. The pattern was similar in Oklahoma: DeSantis et al. (2010, 2011) and Van Els et al. (2010) found that the increased density of ERC resulted in the displacement of several dominant oak species and inhibited oak recruitment, thus probably altering the structure and function of future forests. Likewise, Hanberry et al. (2012) also noted reduced dominance of oaks in lieu of other species in the Missouri Ozark Highlands, mainly ERC that had expanded significantly and became much more prevalent.

ERC has been referred to as an invasive species because it spreads quickly and inhibits other prairie species from growing, and its ability to photosynthesize all year long gives it an advantage in deciduous forests (Lawson 1985, Horncastle et al. 2004, Pierce and Reich 2010, DeSantis et al. 2011). ERC is often the first species to infringe on grasslands (e.g., Figure 1), abandoned farm fields and those cleared for pastures, and marginal lands such as those that have been surface mined (Lawson 1985, Blewett 1986). In addition, its prolific natural regeneration from planted trees has greatly expanded its range, primarily in the Great Plains (Lawson 1985). Although all the mechanisms responsible for the rapid expansion of ERC are not known, the key contributing factors are its hardiness, fire suppression, increased seed source due to widespread planting as a preferred windbreak species, changes in farm and grazing practices and policies, and a decline in ungulates (Owensby et al. 1973, Lawson 1985, Schmidt and Stubbendieck 1993, Schmidt and Wardle 1998, Pierce and Reich 2010).

The ecological conditions found throughout the wide expanse of grasslands and prairie forests in the Great Plains region makes these lands susceptible to continued and future invasions by ERC. The purpose of this article is to report the current extent of ERC forest and to quantify how it has expanded in terms of area, vol-

Management and Policy Implications

Eastern redcedar (ERC) can be beneficial but its rapid expansion, especially into grasslands, has become an issue of ecological concern. Management and control efforts require knowing where and to what extent these increases are occurring. The USDA Forest Service Forest Inventory and Analysis (FIA) program measures forested plots on an annual basis in all states. Using repeated field measurements, we are able to detect and assess changes in forest resources, which are important for identifying changes in land use or forest health conditions. In this study, we used data collected throughout the 2000s to determine the current extent of ERC presence on forestlands and its change over the past decade, including examining tree seedling data to gain insight into future forest composition. The results provide information for developing ERC management goals, such as desired area or density levels, or identifying target areas for management actions and opportunities to use the ERC resource that could provide revenue for landowners while mitigating the impacts of the ongoing ERC expansion.

ume, and number of trees. We present analyses at various spatial scales, from the county level to a regional level, for eight states in the central United States. In addition, we identify where most of the expansion occurred and examine tree species diversity in forest stands that contain ERC. To assess potential future forest composition, we analyzed the distribution and estimated the population of the most common tree seedling species in the region.

Methods

Study Area

Our region of interest consists of eight states in the central United States: Illinois, Indiana, Iowa, Missouri, Kansas, Nebraska, North Dakota, and South Dakota (Figure 2). Although our study does not include the entire native range of ERC, it does examine ERC expansion over a large geographic portion of the central United States, which is unique among previous studies. These particular states were selected because field data were collected over a similar period of time, and remeasurement data were available to quantify changes in ERC during that time period. We acknowledge that ERC expansion is problematic in other states as well, particularly Oklahoma, Texas, and Arkansas; however, temporal differences in data collection and availability precluded them from being a part of this study.

Forestland comprises approximately 35 million acres (about 10%) of the total land area in the region, but agriculture is the dominant land use overall. The focus of this assessment is forestland with ERC trees present. The forest inventory data used in this report were collected over various years starting in 2001 through 2012.

Figure 1. An example of eastern redcedar (*Juniperus virginiana*) expansion into grasslands in eastern Nebraska. Photo by Dacia Meneguzzo.

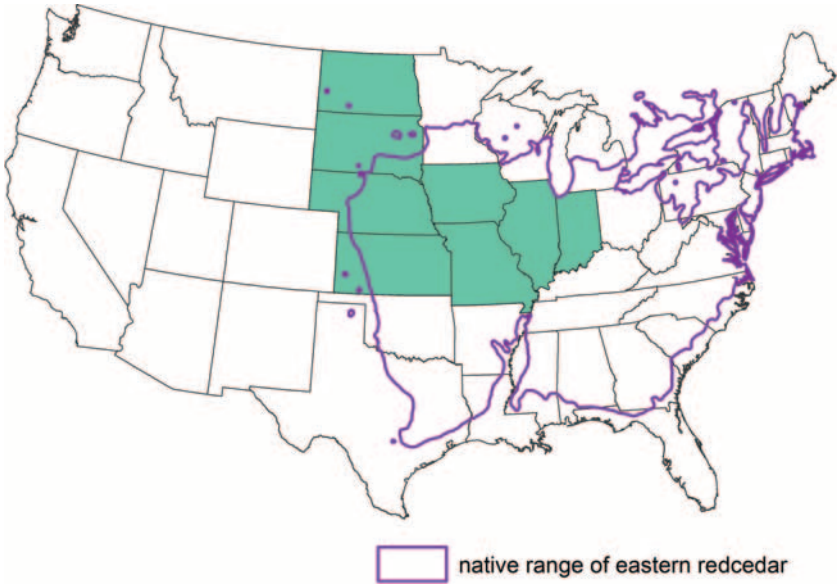

Figure 2. Eight-state study area in the central United States. (The native range is derived from Little 1971.)

Forest Inventory and Analysis (FIA) Data

The data in this report were obtained from the FIA program of the USDA Forest Service. FIA collects field data annually on areas that meet its definition of forestland using a four-subplot plot design, which samples approximately a 1-acre area, and observations may span different conditions rather than being made at only one central point (Figure 3). The FIA field guide defines forestland as land having (or that had) at least 10% live-tree canopy cover, and is 1.0 acre or greater in size and at least 120.0 ft wide. In addition, wooded strips must be 120.0 ft wide for a continuous length of 363.0 ft (O'Connell et al. 2014). For more complete details, see O'Connell et al. (2014).

The FIA annual inventory program is designed in such a manner that forest and tree attribute estimates are updated yearly, allowing users to observe changes and trends on forestland over time. Twenty percent of a state's plot network are visited each year so statewide inventories are completed every 5 years, and then the cycle begins again and plots are revisited. New plots may be added when previous plots cannot be sampled due to issues such as inaccessibility.

Tree and other forest condition data are collected at a ground-sampling intensity of approximately 1 plot per 6,000 acres and each plot represents a specific number of acres when population estimates of forest area, condition, and volume are calculated. Because the actual number of plots sampled each year may vary because of inaccessibility, an area expansion, or adjustment, factor is determined for each set of data, which allows users to acquire population estimates for any grouping of data (Bechtold and Patterson 2005, O'Connell et al. 2014). More than 8,000 field plots with in situ

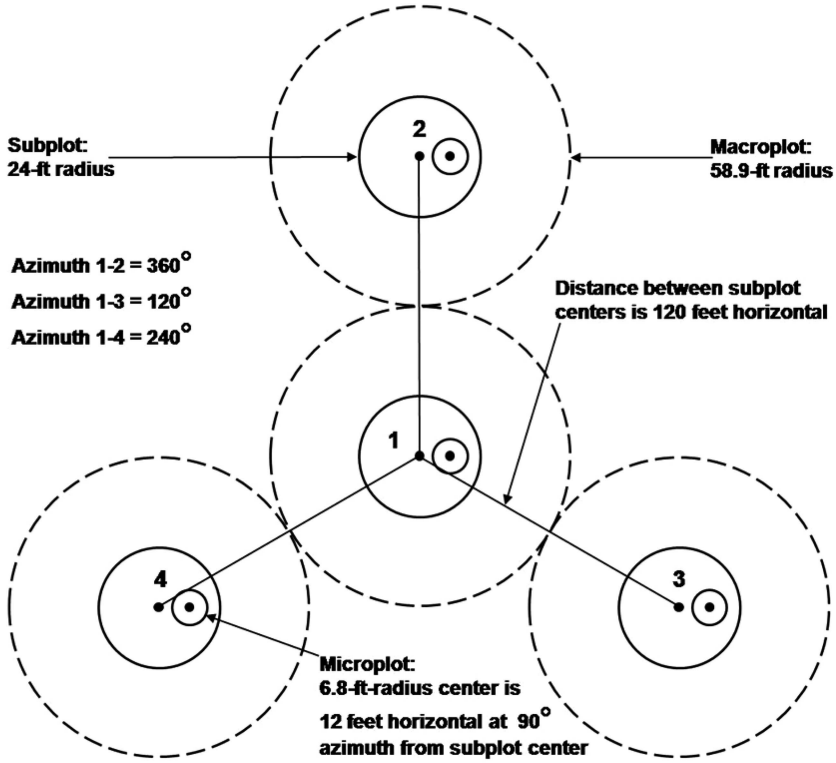

Figure 3. The FIA mapped plot design. Subplot 1 is the center of the cluster with subplots 2, 3, and 4 located 120 ft away at azimuths of 360, 120, and 240, respectively. (From O'Connell et al. 2014, p. 1–7.)

observations of greater than 50,000 individual trees were available for the eight-state study area.

Although there is a large amount of data collected on forestland, FIA does not account for ERC commonly arranged in narrow linear features, such as along fence lines and in windbreaks. These trees often do not meet the area and/or width requirements in the forestland definition described previously and, therefore, are not included in this assessment. This will result in an underestimate of the extent and rate of ERC spread, but data pertaining to such features are severely lacking, especially over large geographic areas. Rather, we analyzed ERC in relation to the FIA definition of forestland using a variety of county-, state-, and regional-level population estimates of its current status and change over time in the study area.

According to the forestland definition used in our analyses, ERC expansion happens via two avenues: ERC becomes so prevalent on existing forestland that the forest type is reclassified to ERC or ERC becomes established on a nonforested area, such as pasture, to the point where there are enough trees present for the area to meet the FIA definition of forestland (e.g., see Schmidt and Leatherberry 1995). The FIA program uses a national forest typing algorithm and tree species information collected on each plot to classify forestland at each location into one of the standard, predefined FIA forest types; this allows consistent classification and reporting of forest conditions (O'Connell et al. 2014). The most prevalent species on the plot determine the forest type, so although there may be other species present on the ERC forest type, ERC is the most abundant and comprises the majority of live trees on the site. All forest types listed in this article are standard, predefined, and labeled by FIA; a complete list of FIA forest types can be found in Appendix D of O'Connell et al. (2014).

The data were grouped into two categories and analyzed separately. The first group included areas of forestland that were classified as the ERC forest type, whereas the second group consisted of areas of forestland with any ERC trees present, regardless of whether or not the area was classified as the ERC forest type. Population estimates for each group were calculated at various spatial scales for two time periods (2005 and 2012), and the differences in the estimates between the two time periods represented change in ERC at the county, state, and regional levels.

In addition to estimating area for a population of plots at each time period, we also examined the net change in the ERC forest type area over time by tracking plots in and out of the ERC forest type between the 2007 and 2012 inventories. Gains in the ERC forest type via the two avenues described above are referred to as "reversions," whereas losses in the ERC forest type through conversion to nonforestland or other forest types are known as "diversions." The net change in the ERC forest type area is determined by subtracting the area of diversions from the area of the reversions. The algorithm used to determine net change is limited to using data from the two most recent inventories, so, at the time of this study, we were calculating the net change in area of the ERC forest type between the 2007 and 2012 inventories.

Last, we examined tree species diversity where ERC is present from low to high densities. Species accumulation curves are commonly used to quantify species richness and are useful for comparing sites or populations (Ugland et al. 2003). We created species accumulation curves using FIA field plots from the eight-state study area with the vegan package version 2.0-10 in the R statistical environment (Oksanen et al. 2012), choosing the random accumulator method with 1,000 permutations. Separate curves were created for two groups: one consisted of plots on which ERC trees were present and the other comprised of plots that had no ERC trees. Because the ERC group is comparatively small, we drew a random sample of an equivalent number of plots from the non-ERC group on each of the 1,000 permutations when constructing the species accumulation curve for the non-ERC group.

To further examine tree species diversity, we calculated the Gini-Simpson index (Jost 2006; Table 1) as

$$1 - \Sigma p_i^2 \qquad (1)$$

where p_i is the proportion of trees on a plot represented by the ith species. The resulting values range between 0 and 1, where lower values indicate lower diversity. The diversity index was examined for all plots with a minimum of one ERC tree in relation to the proportion of basal area represented by ERC trees on each plot. A nonlinear regression model was fit to the data using the nls2 package version 0.2 in R (Grothendieck 2013), and the model was examined to determine the nature and significance of the relationship between tree species diversity and ERC basal area proportion.

Results and Discussion

ERC Forest Type Area

In 2012, there was an estimated total of 35 million acres of forestland in the region. The ERC forest type was recorded as part of the inventory in all states except North Dakota and was most prevalent in Missouri, Nebraska, and Kansas (Figure 4). The area of the ERC forest type was divided by the total county land area to account for counties of varying size. This process of standardization is a more robust method for comparing the ERC forest type area by county.

The 2005 regional estimate of the ERC forest type grew by almost 287,000 acres to a total of nearly 894,000 acres by 2012; this was the largest gain among the most common forest types in the region (Figure 5). This trend of increasing area of ERC is similar to that found by Schmidt and Leatherberry (1995) who noted that ERC was a "major contributor" to the increase in forestland over an approximately 30-year period in Illinois, Indiana, Iowa, and Missouri.

A few forest types showed slight declines in area between 2005 and 2012: post oak/blackjack oak (*Quercus stellata/Quercus marilandica*), ponderosa pine (*Pinus ponderosa*), and white oak/red oak/hickory (*Quercus alba/Quercus rubra/Carya* spp.). An examination of plot records revealed that post oak/blackjack oak and white oak/red oak/hickory were among the most common types that changed to the ERC forest type by 2012. Again, this finding agrees with observations by Schmidt and Leatherberry (1995) and Hanberry et al. (2012), who noted declines in oaks with simultaneous increases in ERC using FIA data. It is also consistent with DeSantis et al. (2010, 2011) who reported that in the absence of fire, ERC could potentially replace several oak species that were considered the historically dominant species in many forests of the central United States.

Overall, 250 plots in the region remained as or shifted to the ERC forest type; only 75 changed from ERC to another forest type, and nearly one-third of those plots went to the ERC/hardwood forest type. More than half of the plots that changed to the ERC type had previously belonged to the oak/hickory forest type group. Geographically, most plot-level changes to the ERC forest type (n = 119) occurred in Missouri (n = 72; 61%), followed by Nebraska (n = 16; 13%) and Kansas (n = 13;

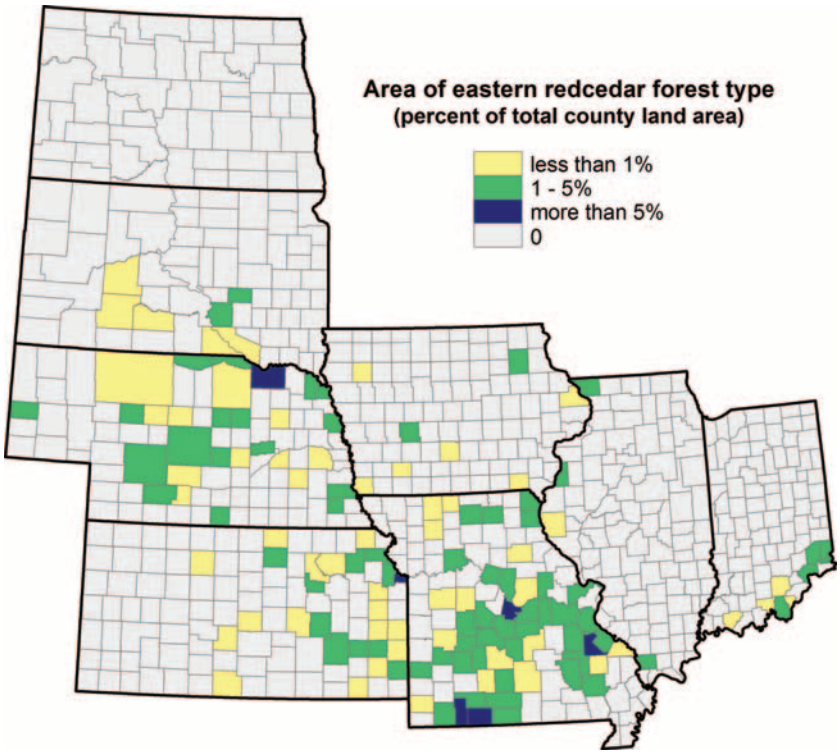

Figure 4. Area of the ERC forest type as a percentage of total county land area in Illinois, Indiana, Iowa, Kansas, Missouri, Nebraska, North Dakota, and South Dakota, 2012.

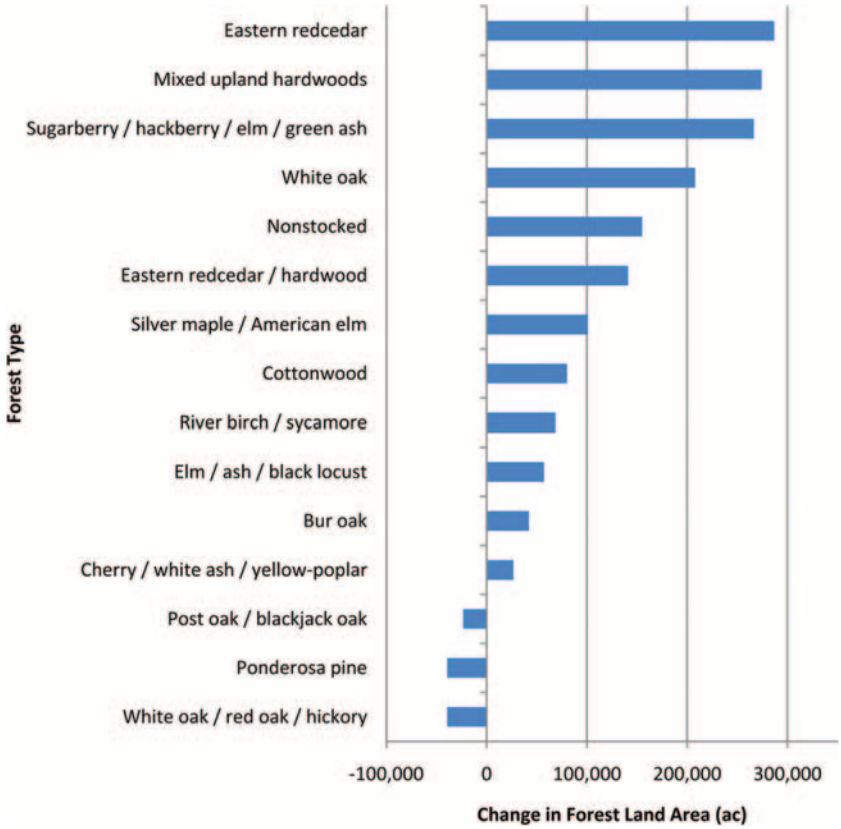

Figure 5. Difference in forestland area by forest type for an eight-state region (Illinois, Indiana, Iowa, Kansas, Missouri, Nebraska, North Dakota, and South Dakota) based on forest inventory estimates from 2005 and 2012 for the top 15 most prevalent forest types for both time periods.

Table 1. Total area of reversions and diversions of the ERC forest type for an eight-state region in the central United States, 2007–2012.

State	Reversion of nonforest land to the ERC forest type	Reversion of other forest types to the ERC forest type	Diversion from ERC forest type to non-forestland	Diversion of ERC forest type to nonstocked or other forest types	Net change in the area of the ERC forest type (reversions − diversions)
	(acres)				
Illinois	7,700	3,400	0	2,600	8,500
Indiana	1,700	5,000	0	6,400	300
Iowa	4,400	16,400	10,300	0	10,500
Kansas	41,800	27,300	5,500	11,800	51,800
Missouri	30,400	107,800	37,400	66,600	34,200
Nebraska	101,500	53,000	6,200	0	148,300
North Dakota	0	0	0	0	0
South Dakota	17,600	0	2,100	21,400	−5,900
Eight-state region	205,100	212,900	61,500	108,800	247,700

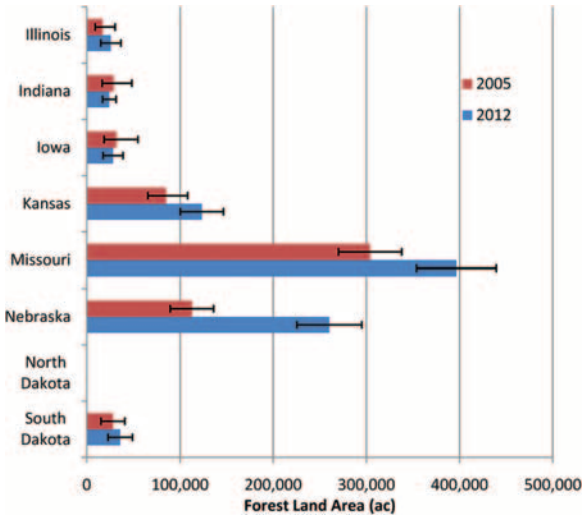

Figure 6. Area of the ERC forest type on forestland in Illinois, Indiana, Iowa, Kansas, Missouri, Nebraska, North Dakota, and South Dakota, 2005 and 2012. Error bars represent a 68% confidence interval around the estimate. Note: North Dakota had no acres of ERC forest type in either inventory.

11%). It is also interesting to note the types of landforms where these changes occurred. Most of the changes (n = 98; 82%) occurred on dry, rocky slopes with a lot of sun and wind exposure or on rolling uplands associated with small streams, indicating the ability of ERC to do well on sites with or without adequate moisture or in areas where it is difficult for fire to decrease ERC because it is rocky or wet.

Diversions and Reversions of the ERC Forest Type

Plots measured during the 2007 inventory and again during the 2012 inventory were used to provide estimates of the net change in the ERC forest type over a 5-year period. Forest types other than ERC and lands previously not forested that reverted to the ERC forest type resulted in a net increase of nearly 248,000 acres of ERC forests (Table 1). The reversion of nonforestland to the ERC forest type is particularly of interest because it describes the area of nonforestland that converted to, or was probably invaded by, ERC. Therefore, on an annual basis, about 41,000 acres of nonforestland changes to the ERC forest type throughout the eight-state region. This rate is highest in Nebraska, where approximately 20,000 acres are converted annually.

A state-by-state analysis revealed that the largest increases in the ERC forest type area occurred in Kansas, Missouri, and Nebraska (Figure 6). The largest statewide gain occurred in Nebraska: in 2005, the ERC forest type made up 9% of the total forestland area, jumping to nearly 17% by 2012. Iowa and Indiana were the only states that had any decreases in the ERC forest type, whereas North Dakota had no reported ERC forest type area in either the 2005 or 2012 inventories. In the four-state ERC expansion study by Schmidt and Leatherberry (1995), they projected the area of forestland with ERC present forward to 1993 for each state using inventory results from the 1980s. They predicted Missouri would have the largest increase followed by much smaller increases in Illinois, Indiana, and Iowa, respectively. The results found in this study follow a similar pattern.

A county-level analysis of FIA data provides a more detailed look at where the ERC forest type area increases are occurring in the region (Figure 7). Fifteen percent of the counties saw an increase in the area of ERC. Not surprisingly, most increases were found in Kansas, Nebraska, and Missouri. Any increases in the ERC forest type in Iowa were probably offset by larger decreases in ERC forests, resulting in little change or even a slight decline in the statewide total of the ERC forest type area from 2005 to 2012.

Forestland with ERC Trees Present

Looking at the presence of ERC trees in general (i.e., regardless of whether the area is classified as the ERC forest type) on forestland provides further insight into the extent of how it is expanding. Figure 8 shows the acres of forestland with ERC present for 2005 and 2012. So, even though there does not appear to be a significant change in area of the ERC forest type in Iowa, the forestland area where ERC trees are present is increasing. If this increase continues, it is likely that the ERC forest type area will show an increase in future inventories. In the region overall, the area of forestland with ERC trees present increased by 1.2 million acres, a 17% increase from the 2005 inventory. Ne-

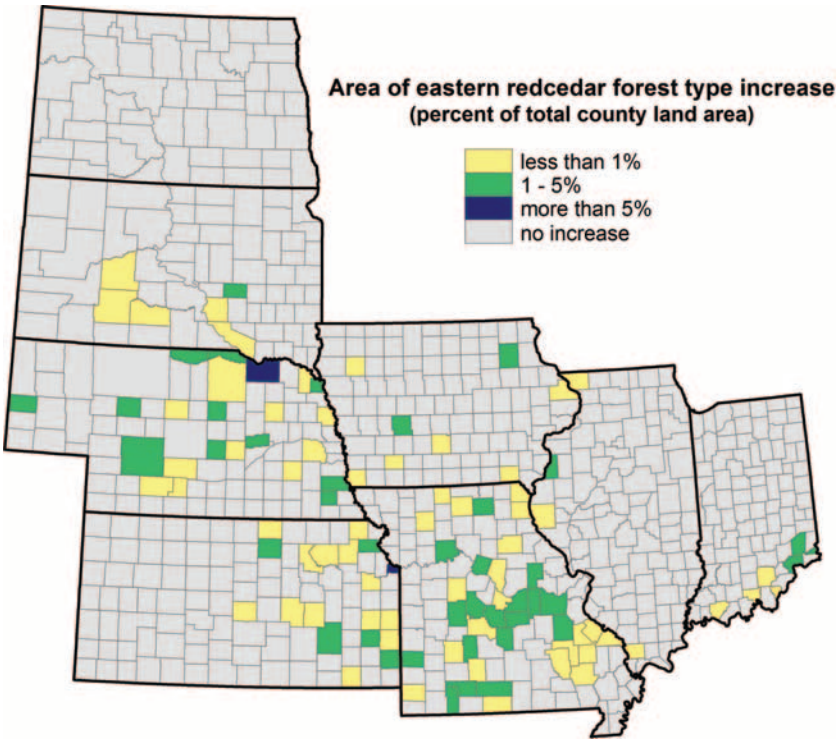

Figure 7. Increase in the ERC forest type as a percentage of total county land area in Illinois, Indiana, Iowa, Kansas, Missouri, Nebraska, North Dakota, and South Dakota between 2005 and 2012.

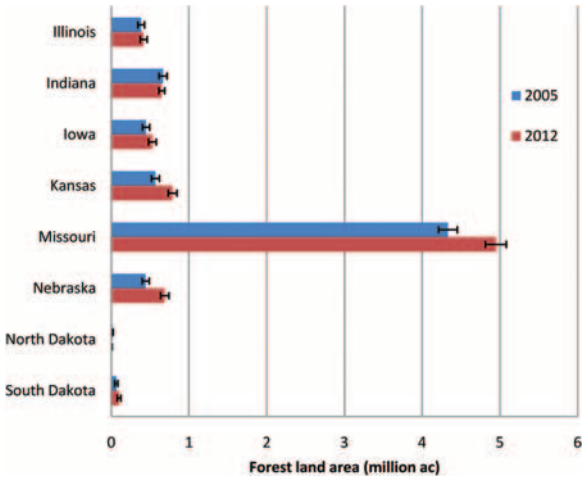

Figure 8. Area of forestland with ERC present in Illinois, Indiana, Iowa, Kansas, Missouri, Nebraska, North Dakota, and South Dakota, 2005 and 2012. Error bars represent a 68% confidence interval around the estimate. Note: North Dakota had 15,000 acres of forestland with ERC present in 2005 and 4,000 acres in 2012.

braska had the highest percent change of all the states at 56%, whereas Missouri had the largest increase in actual acreage.

Density

Conversion to the ERC forest type is often preceded by increases in the number of ERC trees in a stand; thus, we can get an indication of potential future ERC forest by examining this attribute. Regionally, the number of ERC trees per acre of forestland that are at least 1-in. in diameter increased from 30 to 33 between 2005 and 2012 (Figure 9). ERC densities in Nebraska and Missouri are higher than the regional average. Again, the largest gain occurred in Nebraska where the average number of ERC trees per acre of forestland rose from 81 in 2005 to 98 by 2012. ERC density decreased in Indiana and Illinois.

Interestingly, ERC density increased in Iowa where the area of the ERC forest type actually showed a slight decrease, which indicates that ERC trees are increasing in forested areas but are not yet prevalent enough to be classified as the ERC forest type. This finding is further supported by the information in Figure 7. In addition, whereas North Dakota had no reported ERC forest type area, there were an estimated 99,000 ERC trees in the state in 2012. However, this estimate is still less than one tree per acre of forestland on average and is much smaller than the 2005 estimate of nearly 230,000 ERC trees.

Volume

The total volume of live ERC trees that were ≥5 in. in diameter increased from 981 million cubic feet in 2005 to 1.3 billion cubic feet by 2012. In terms of ERC volume per acre of forestland, this was an increase of 6 cubic ft. The smaller diameter classes comprise most of the volume, but almost every diameter class had an increase in volume from 2005 to 2012 (Figure 10). This finding is indicative of smaller trees becoming more numerous and provides further evidence of the rapid expansion of ERC.

ERC Presence and Tree Species Diversity

Plots with at least one ERC tree present had lower species richness than plots with no ERC trees (Figure 11). Eighty-seven unique tree species were found in the ERC group, whereas an average of 96 species were in the non-ERC samples. The difference in richness between the ERC and non-ERC groups is significant after approximately 350 plots are observed.

With respect to tree species diversity in the region, we found a generic decay function of the form

$$y = N \cdot (1 - x^{a})^{b \cdot x} \qquad (2)$$

where y is the Gini-Simpson index of diversity, N is an initial value, x is ERC basal area proportion, and a and b are constants, provided a reasonable fit to the data (Figure 12). All model coefficients are significant ($P < 0.001$), and positive values for both a and b indicate that higher ERC basal area proportion is related to lower diversity index (Table 2).

These analyses of richness and evenness do not conclusively point to a cause and effect relationship between ERC expansion and a regionwide reduction of diversity. Because of the establishment of ERC forest on

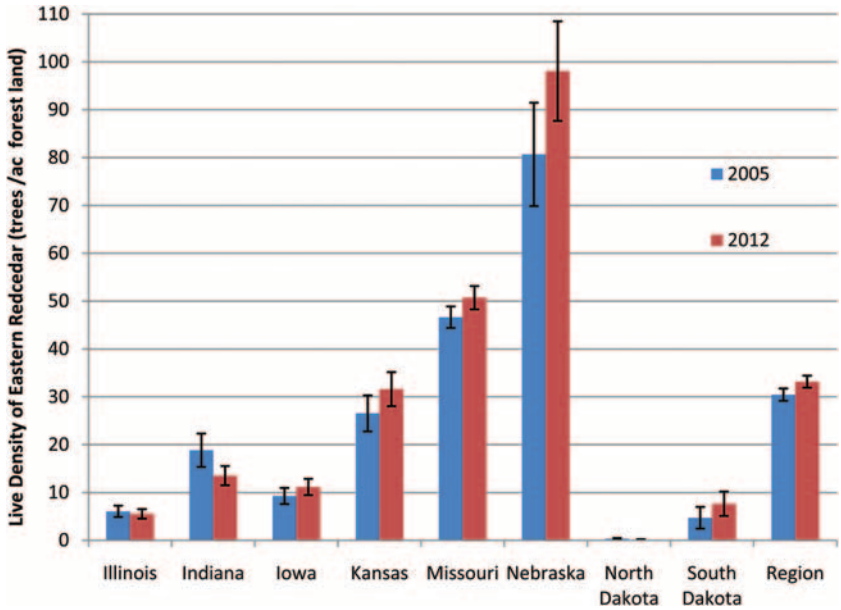

Figure 9. Average number of ERC trees per acre of forestland in Illinois, Indiana, Iowa, Kansas, Missouri, Nebraska, North Dakota, South Dakota, and the region, 2005 and 2012. Error bars represent a 68% confidence interval around the estimate. Note: North Dakota had estimates of less than one ERC tree per acre of forestland for both time periods.

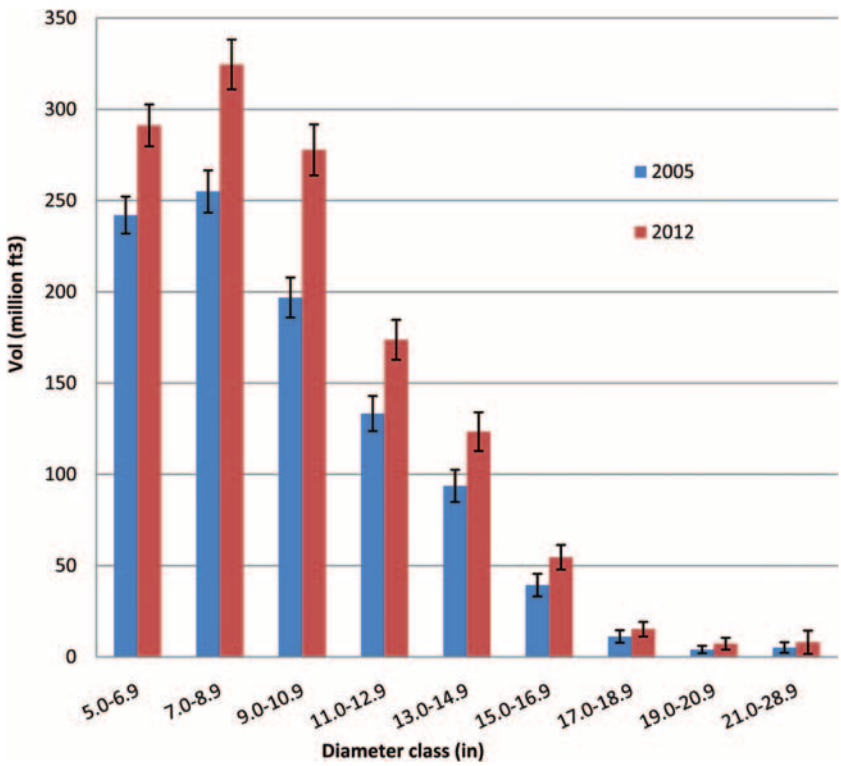

Figure 10. Net volume of live ERC trees (≥5 in. in diameter) on forestland by diameter class in Illinois, Indiana, Iowa, Kansas, Missouri, Nebraska, North Dakota, and South Dakota, 2005 and 2012. Error bars represent a 68% confidence interval around the estimate.

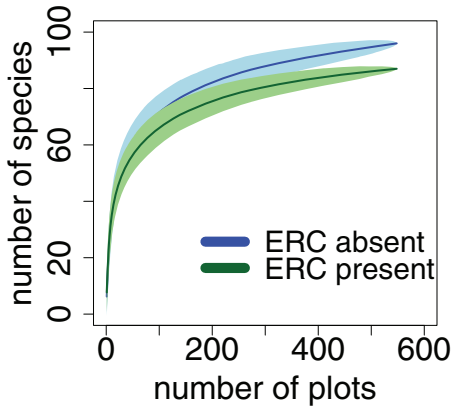

Figure 11. Species accumulation curves based on tree species data collected on field plots in Illinois, Indiana, Iowa, Kansas, Missouri, Nebraska, North Dakota, and South Dakota. Curves were created separately using plots that had at least one ERC tree present and plots for which no ERC trees were observed. The 95% confidence intervals are indicated by the bands surrounding each line.

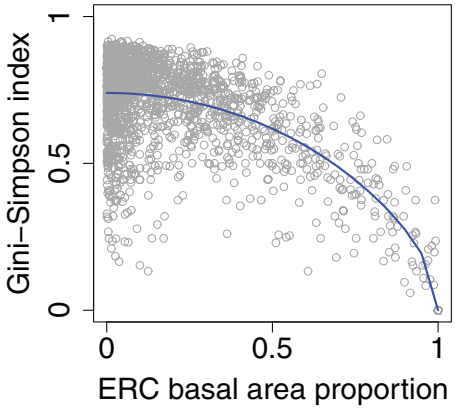

Figure 12. Gini-Simpson index of diversity versus ERC basal area proportion. Data are from the FIA program on a network of field plots in Illinois, Indiana, Iowa, Kansas, Missouri, Nebraska, North Dakota, and South Dakota. A nonlinear model fit is indicated by the blue line.

Table 2. Nonlinear regression model parameters for a model relating tree species diversity to ERC basal area proportion.

Coefficient	Value	SE	*P* value
N	0.74	0.004	<0.001
a	0.86	0.164	<0.001
b	0.45	0.054	<0.001

Data are from the FIA program on a network of field plots in Illinois, Indiana, Iowa, Kansas, Missouri, Nebraska, North Dakota, and South Dakota.

idle farmland and the tendency of ERC to form pure stands, lower diversity should be expected on plots with abundant ERC. However, we present indicators of tree species diversity based on in situ observations to document the nature of the relationship. The decrease in diversity generally accelerates (i.e., has an increasingly negative slope) throughout the range of ERC basal area proportion rather than showing a constant decrease (i.e., a negative linear relationship). In the context of a progressing invasion with increasing ERC density, the analyses could hint at future forests in the central United States with reduced diversity. Furthermore,

Table 3. Rank and percent change in seedling abundance in Illinois, Indiana, Iowa, Kansas, Missouri, Nebraska, North Dakota, and South Dakota, 2005 and 2012.

Seedling species	Rank in abundance 2005	Rank in abundance 2012	Percentage change in number of seedlings
Hackberry	5	1	50
Chokecherry	14	4	46
Eastern redcedar	12	7	15
White ash	3	2	15
Slippery elm	9	9	−8
Eastern hophornbeam	15	14	−12
Green ash	8	8	−12
White oak	7	6	−17
American elm	2	3	−21
Sassafras	4	5	−21
Red maple	13	12	−22
Black cherry	10	13	−29
Black oak	11	15	−32
Sugar maple	6	11	−43
Flowering dogwood	1	10	−54

the data suggest that changes could proceed in a nonlinear manner with more rapid changes occurring as ERC becomes more prevalent in the region's forests. We note that this is probably an oversimplification that does not account for all dynamic effects, such as the tendency for encroachments of ERC on poor sites to be short-lived or cyclical (Murray et al. 2013). The FIA program also collects data on seedling abundance that can provide information for projections of the future composition of forests.

Regeneration: What Does the Future Hold?

Seedling data were analyzed to gain an understanding of how forest composition may be changing. Of the most abundant seedling species in the region, only hackberry (*Celtis occidentalis*) and chokecherry (*Prunus virginiana*) had larger percent increases in the estimated total number of seedlings than ERC (Table 3). In addition, ERC was ranked 12th in terms of seedling abundance in 2005 but moved up to 7th by 2012. Aside from hackberry and chokecherry, this was the largest gain in abundance along with white ash (*Fraxinus americana*). In fact, all of the other common species in the region decreased in seedling abundance.

Conclusions

Although ERC is valued as a windbreak species and for its wood products, its ability to invade and thrive on grasslands has many negative effects, including altered water and nutrient cycling, reduced forage production and species diversity, loss of wildlife habitat for nongeneralist species, and high removal costs. Many studies have addressed ERC expansion but often at the substate level, except for Schmidt and Leatherberry (1995) whose study area consisted of four states in the Lower Midwest. We used FIA data to assess the current extent and recent change in the ERC resources across an eight-state region in the central United States and also examined tree species diversity where ERC was present in low to high densities. Furthermore, we analyzed FIA data at various spatial scales, from county to regional levels, to gain insight about which areas are experiencing higher rates of invasion and how they compare to the regional trends overall.

FIA data clearly show that ERC continues to expand in terms of area and density, particularly in Missouri, Nebraska, and Kansas. There was a gain of nearly 205,000 acres of new ERC forestland that had been previously classified as nonforestland in the eight-state region between the 2007 and 2012 inventories. In addition, the change in seedling abundance and composition on forestland indicates that ERC will continue to be a significant component of forests. Placed in the context of the changes to ERC density and seedling abundance, an analysis of the tree species diversity on plots in the region indicates that future forests in the central United States have the potential to be altered and perhaps become more homogeneous. Overall, it is evident from the data presented that the conversion of forest types, particularly those in the oak/hickory group, to the ERC type and the expansion of ERC into neighboring grasslands will continue.

The results of this study support other ERC research that documents its expansion and the resulting negative effects on forest composition and structure, particularly the displacement of oak species and the potential reduction of species diversity of future forests. A major strength of this study is the large geographic extent that it examines. Whereas much research regarding ERC has taken place in certain areas, such as Oklahoma and the Kansas Flint Hills, other areas have received less attention. Our study includes data from the northern and western fringes of the native range of ERC as well as from a wide variety of landscapes and forest types throughout the central United States, thus providing a comprehensive assessment of ERC expansion that broadens the geographic scope of previous studies and provides more up-to-date information for research and management efforts. This allows managers to target high-risk areas, such as oak forest types in counties that showed dramatic increases in ERC. As more data become available, the study can be extended to gain even more insight about the status and change in ERC. Quantifying and identifying where the most expansion is occurring can assist management, utilization, and control efforts.

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