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Authors: Symstad, Amy J., and Leis, Sherry A.

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# Woody Encroachment in Northern Great Plains Grasslands: Perceptions, Actions, and Needs

Amy J. Symstad<sup>1,3</sup>

<sup>1</sup>U.S. Geological Survey  
Wind Cave National Park  
26611 US Highway 385  
Hot Springs, SD 57747

Sherry A. Leis<sup>2</sup>

<sup>2</sup>Biology Department  
Missouri State University  
901 S National Avenue  
Springfield, MO 65897

<sup>3</sup> Corresponding author: [asymstad@usgs.gov](mailto:asymstad@usgs.gov); 605-745-1191

**ABSTRACT:** The United States Northern Great Plains (NGP) has a high potential for landscape-scale conservation, but this grassland landscape is threatened by encroachment of woody species. We surveyed NGP land managers to identify patterns in, and illustrate a broad range of, individual managers' perceptions on (1) the threat of woody encroachment to grasslands they manage, and (2) what management practices they use that may influence woody encroachment in this region. In the 34 surveys returned, which came from predominantly public lands in the study area, 79% of responses reported moderate or substantial woody encroachment. Eastern redcedar (*Juniperus virginiana*) and Rocky Mountain juniper (*Juniperus scopulorum*) were the most problematic encroachers. Thirty-one survey respondents said that prescribed fire was used on the lands they manage, and 64% of these responses reported that controlling woody encroachment was a fire management objective. However, only 18% of survey respondents using prescribed fire were achieving their desired fire return interval. Most respondents reported using mechanical and/or chemical methods to control woody species. In contrast to evidence from the central and southern Great Plains, few survey respondents viewed grazing as affecting encroachment. Although the NGP public land managers we surveyed clearly recognize woody encroachment as a problem and are taking steps to address it, many feel that the rate of their management is not keeping pace with the rate of encroachment. Developing strategies for effective woody plant control in a variety of NGP management contexts requires filling ecological science gaps and overcoming societal barriers to using prescribed fire.

*Index terms:* juniper expansion, perceived impact, prescribed fire, survey, woody species control

## INTRODUCTION

The World Wildlife Fund (WWF) identified the Northern Great Plains (NGP) as one of the 238 most biologically significant places on Earth because it harbors exceptional and distinctive biodiversity (Olson and Dinerstein 2002). Furthermore, WWF considers the NGP as one of its 18 priority conservation areas (<http://www.worldwildlife.org/places>) because large expanses of native grassland still remain. Overall, this region has a high potential for landscape-scale conservation, in part because current rangeland management practices support habitat for many grassland specialists, but it is threatened by stressors ranging from sod-busting to energy development and climate change (Forrest et al. 2004).

The encroachment of native woody species (trees and shrubs) into Great Plains grasslands is one critical threat to grassland conservation. Expansion of woody species in areas where they were previously minor components is well documented on the edges of the NGP (Steinauer and Bragg 1987; Eggemeyer et al. 2006; Spencer et al. 2009; Barger et al. 2011), where encroachment rates are some of the greatest in North America (Barger et al. 2011). For example, the area in Nebraska with eastern redcedar (*Juniperus virginiana* L.) as a dominant species increased by 61%—an

addition of 17,000 ha—between 1983 and 1994 (Schmidt and Wardle 1998) and is still increasing (Walker and Hoback 2007). A detailed study of outlier populations of ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson) in southwestern North Dakota found that this species was gradually extending into grasslands, particularly on sandy soils and in wetter periods (Potter and Green 1964).

In these and other semi-arid areas of the world, woody encroachment affects the habitat of grassland specialists. Grassland-nesting birds avoid areas with shrub and tree cover (Cunningham and Johnson 2006, and references therein), as do prairie dogs (Milne-Laux and Sweitzer 2006), which are keystone species of the mixed-grass prairie. Woody encroachment can reach the point where grasslands are wholly converted into shrublands and forests. Following the establishment of eastern redcedar in tallgrass prairie of the Kansas Flint Hills, its cover increased from 2 to 98% over a 40-year period (Hoch et al. 2002). At an ecological level, such conversion exacerbates landscape fragmentation (Coppedge et al. 2002), eliminates habitat for grassland species (Coppedge et al. 2001; Rosenstock and Van Riper 2001; Horncastle et al. 2005; Frost and Powell 2011), reduces plant species richness (Ratajczak et al. 2012), and changes carbon cycling and storage

(Wessman et al. 2004; Barger et al. 2011). Societal effects of grassland conversion include lost forage, lost or fragmented ranches and the economic (livestock production) and recreational (hunting, birding, aesthetic) benefits they provide, as well as increased wildfire danger resulting from increased fuel loading (Burkinshaw and Bork 2009) and human health issues exacerbated by allergenic juniper pollen pulses (Van de Water et al. 2003). Once converted, restoring shrub/tree-invaded areas back to functioning grassland can be costly (Ortmann et al. 1998).

Perhaps because the degree and extent of woody encroachment in the NGP are not yet as great as in other regions (USDA NRCS 2014) and despite its demonstrated negative impacts, the issue has received relatively little scientific attention in the NGP (but see e.g., Grant and Murphy 2005; Springsteen et al. 2010; Pinno and Wilson 2011; Bork et al. 2013). World-wide, woody encroachment into grassland has been explained by a variety of factors, including changes in climate, altered grazing and/or fire regimes, increasing atmospheric CO<sub>2</sub> concentration, or a combination thereof (Archer et al. 1995; Van Auken 2009; Buitenwerf et al. 2012). In the southern and central Great Plains, woody encroachment has been tied to reduced fire frequency, as natural fire regimes have been disrupted directly by fire suppression and indirectly by grazing regime modifications, landscape fragmentation, and human population density growth (Fuhlendorf et al. 1996; Hoch et al. 2002; Ratajczak et al. 2014). The NGP are not immune to these forces. Moreover, ample seed sources are available to facilitate the spread of woody plants in the NGP. Two native juniper tree species (*J. virginiana* and *J. scopulorum* Sarg., Rocky Mountain juniper) occur in the region, there is a cultural preference for trees in areas of human habitation (Dwyer et al. 1992), and programs encourage citizens to plant trees in the name of soil conservation and wildlife habitat (West 1988; Ganguli et al. 2008a). Thus, woody encroachment is a plausible risk in NGP grasslands.

In 2012 we began an ecological modeling project to investigate this risk in a variety of future climate scenarios (King et al.

2015). To ensure that the fire and grazing components of the ecological model were realistic and appropriate, we conducted an informal survey of land managers in the NGP regarding the management practices they use that may influence woody encroachment in this region. As part of this survey, we also asked managers about their perceptions about woody encroachment as a threat to the grasslands they manage. Because the survey was originally intended to construct reasonable management scenarios to explore in the modeling project, our survey methodology did not follow scientifically accepted methods for sociological studies (see Methods below). However, we found the answers to the survey compelling enough that we wished to present them to a broader audience with the goal of stimulating greater awareness of and interest in the conservation issue of woody encroachment in the NGP. We hope that the information we gathered will encourage interdisciplinary research that rigorously addresses the sociological and ecological questions surrounding woody encroachment in the NGP.

## METHODS

### Study Area

For this study, we focused on native grasslands and shrublands and the portions of the NGP where they are the predominant land cover. Therefore, we defined our NGP study area as the Northwestern Glaciated Plains, Northwestern Great Plains, and Nebraska Sandhills Level III ecoregions (Omernik 2007); the portions of the Middle Rockies ecoregion that these completely surround; and the portion of the High Plains ecoregion northeast of the North Platte River (Figure 1). Survey respondents were instructed to answer questions only as they pertain to grasslands and sagebrush steppe within this study area. Such areas have flat to rolling topography and continental climates with hot summers, cold winters, and spring-peak precipitation. Total annual precipitation in the study area ranges from 200–300 mm in the northwest to 600–700 mm in the southeast. Native vegetation is predominantly northern mixed-grass prairie, with sagebrush (*Artemisia* L. spp.) steppe more

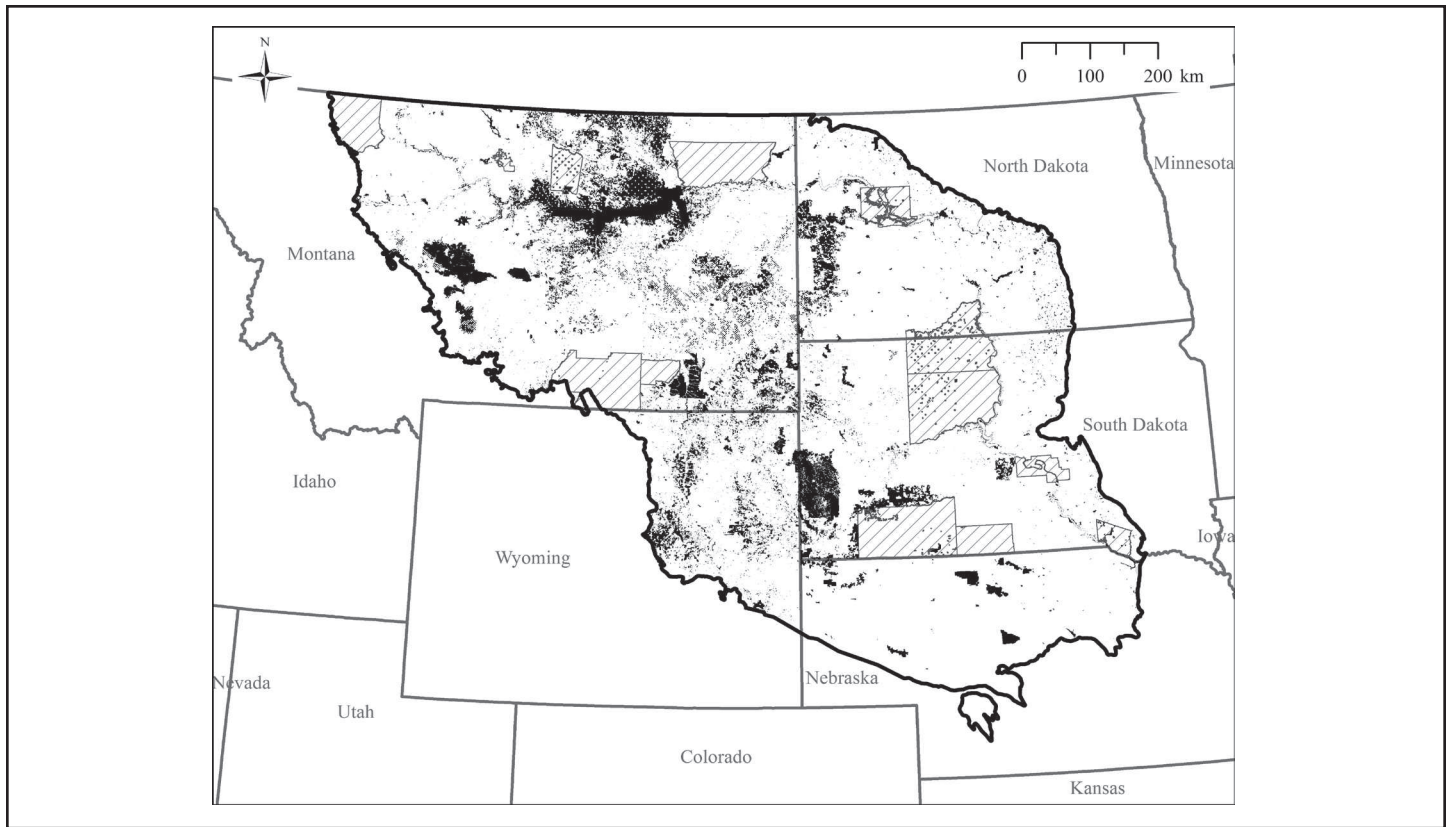
abundant in the western half of the study area. Several large Native American reservations exist in the study area. Outside of these, public land ownership generally increases from east to west (Figure 1).

### Survey

The open-ended (free response) survey requested categorical to semi-quantitative answers and allowed respondents to provide the amount of detail they wished, as well as comments. The 19-question survey (contact primary author for the survey) consisted of four types of questions: location, vegetation, and management type context (3 questions); perceived effects and characteristics of woody encroachment into grasslands and sagebrush steppe the respondent managed (5); fire regimes and goals for the managed area (6); and herbivore effects on grasses and woody encroachers in the managed area (3).

We distributed the survey via email in April 2013 to 57 primary contacts: superintendents or natural resource division chiefs of all National Park Service units in the study area; state (Montana, Nebraska, North Dakota, South Dakota, Wyoming) school trust land managers; field staff of some national grasslands, national forests, and Bureau of Land Management lands in the study area; the US Fish and Wildlife Service Region 6 biologist; Natural Resource Conservation Service field staff in South Dakota and Nebraska; state chapters of the Society for Range Management; and the technical committee of the Plains and Prairie Potholes Landscape Conservation Cooperative (PPP LCC). The PPP LCC geographically encompasses all but the Nebraska portion of the study area and its technical committee has representatives from all federal agencies and states, as well as five non-governmental conservation organizations, with natural resource management concerns in the area. The primary contacts further distributed the survey both to those within their organizations most qualified to answer the questions and to others in positions similar to theirs, as appropriate.

This nonrandom distribution of fixed



**Figure 1.** Public land ownership (black polygons) and Native American Reservations (hatched polygons) within the northern Great Plains study area (thick black line).

questionnaires to an unknown number and composition of ultimate recipients precludes quantitative (statistical) analysis of the responses. As a descriptive study, the goal is to identify patterns in the responses and illustrate a broad range of individual perceptions. We do not assert that the findings can be generalized across the target population (grasslands and shrublands in the study area) (Groves et al 2009). We report responses to each question as tallies by category (i.e., degree of woody encroachment as “none,” “moderate,” or “substantial” following definitions in Table 1).

Some respondents answered questions differently for different land management units under their jurisdiction. Although these responses are not independent, we tallied them as separate responses (for the appropriate questions) to illustrate the full range of responses provided.

## RESULTS

### Response Rate and Respondents

Thirty-four surveys were returned from the unknown number of those receiving it. Respondents were from one tribal wildlife department, two Bureau of Land Management units, five national grasslands, two national forests, nine national wildlife refuge and wetland management district complexes, four state wildlife departments, two state land trusts, and two agencies that advise private landowners; three private landowners also responded. Responses included lands managed in 104 of the 152 counties in the study area. Most responses were from South Dakota and Nebraska, and all but six of the responses represented land managed by federal, state, or tribal agencies (Figure 2). Respondents described the dominant native vegetation in their managed areas as predominantly

mixed-grass prairie, but shortgrass prairie, sagebrush steppe, and woody draws were also indicated as important vegetation types.

### Woody Encroachment

Most respondents saw woody encroachment occurring in their jurisdictions: 44% and 35% of responses reported moderate and substantial woody encroachment, respectively. A few responses quantified the rate of encroachment (15% in the last 10 years; 1–2% per year since the 1960s; 40%), and descriptions recognized a variety of impacts.

Respondent #17: “[One area] has an estimated 40% eastern redcedar encroachment on the rangeland. This encroachment is substantial as it reduces forage production by the same amount (40%). ... Wildlife habitat and plant diversity are also negatively

**Table 1. Descriptions of categories for degree of woody encroachment.**

Category	Description
None	Survey response stated that no or very little encroachment had occurred.
Moderate	Survey response indicated either (a) woody species have become more abundant over time, but they are not substantially impacting ecosystem services, or (b) only highly localized areas where woody encroachment has impacted ecosystem services.
Substantial	Survey response either (a) used words similar to “substantial” or “severe,” or (b) described impacted ecosystem services over a broad area.

impacted by the encroachment.”

Respondent #9: “Thirty years ago, encroachment from cedar trees was not considered to be a problem in this state. Today it is the most significant rangeland issue my agency faces.”

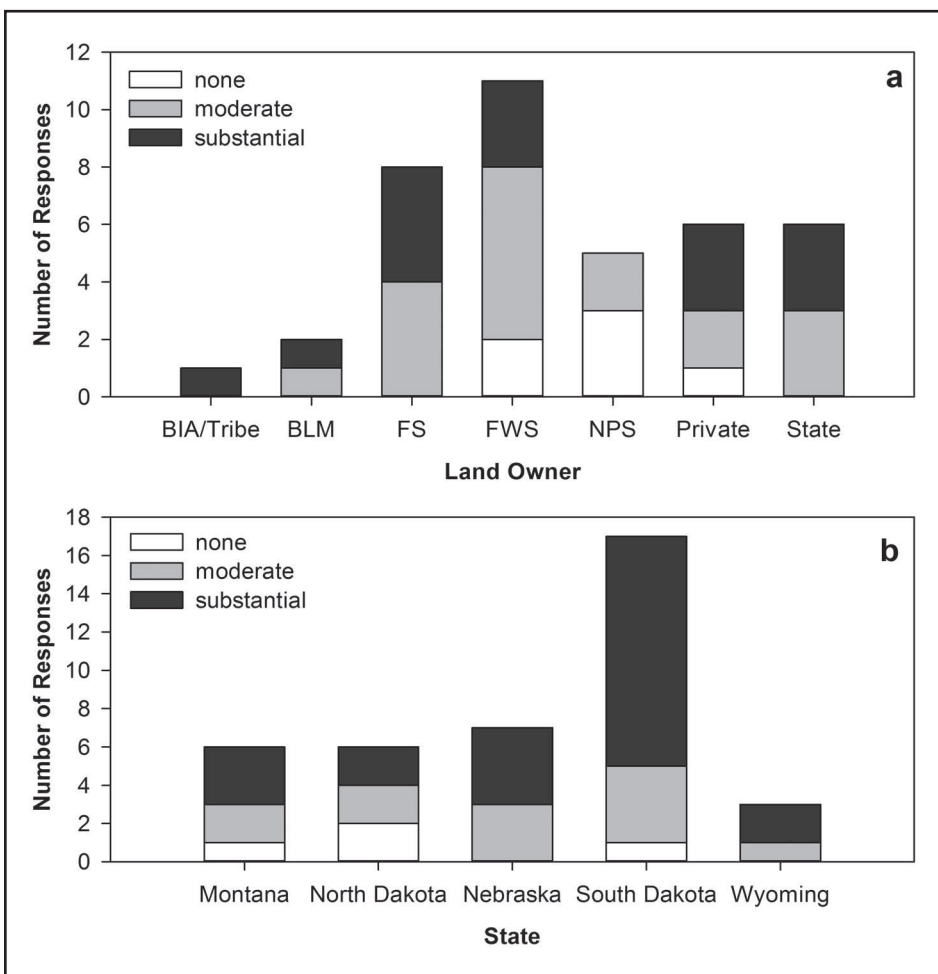
Respondent #2: “Surveys often indicate a Fire Regime Condition Class 3 [high departure from the natural regime of vegetation characteristics].”

Respondent #6: “There is less use in these [encroached] sagebrush stands by sagebrush obligate species including sage grouse. Where the conifer species encroach into draws and drainages, ... [the drainages] no longer hold water, which is important habitat to many species of wildlife.”

Respondent #19: “Many grasslands that were once clear of any woody species 10–20 years ago are now covered with trees. Encroachment has limited grazing opportunities for livestock and impaired habitat for grassland dependent species.”

Respondent #28: “In some areas, stocking rates for livestock grazing has been reduced. Nutritional condition of elk appears to have declined with increasing cedar encroachment. Elk antler size has diminished over the last 20 years.”

Respondent #34: “We believe that it has changed the composition of the migratory bird communities that use these areas. Birds that favor more grass and less shrubs and trees seem less abundant.”



**Figure 2. Total number of responses (full bar) and perceived degree of woody encroachment (shading; definitions in Table 1) by (a) land ownership and (b) state of survey respondents. In (a), BIA/Tribe = combination of Bureau of Indian Affairs and tribal government agencies; BLM = Bureau of Land Management; FS = USDA Forest Service; FWS = US Fish and Wildlife Service; NPS = National Park Service; Private/NRCS = individual private landowner or USDA Natural Resources Conservation Service (NRCS) agents who work with private landowners; State = state agency.**

Survey respondents listed 15 woody tree/shrub species as having already encroached into the grasslands or steppe that they manage (Table 2). *Juniperus* tree species (Rocky Mountain juniper or eastern redcedar) were the most commonly listed encroaching species in the study area and were the most problematic encroacher in 82% of the responses in which they were listed. However, juniper was listed as an encroacher in only three of the eight responses from Montana and Wyoming. Ponderosa pine, Russian olive (*Elaeagnus angustifolia* L.), and Siberian elm (*Ulmus pumila* L.) were other commonly listed encroaching species.

Locations that respondents noted as having the most prominent woody encroachment included near shelterbelts, in draws, and

on north-facing slopes (Table 3). Many respondents mentioned tree plantings intended for “conservation” or shelter as sources of encroachment. One respondent specifically mentioned areas where prescribed fires were challenging, such as near property boundaries, as problem areas for encroachment.

## Management Goals and Realities

### Goals

The areas managed by most survey respondents were directed by a woody vegetation management goal, though seven respondents reported that no goals had been set (Table 4). The most common type of goal was to achieve, then maintain, a certain per-

cent of the managed area (including none of it) in a wooded state. Woody management goals varied within agencies, indicating that management goals were unique to land areas. One respondent acknowledged that the goal to support popular game species on the areas he managed likely resulted in higher woody cover than historical levels. Two respondents mentioned the decline of native hardwood species—including bur oak (*Quercus macrocarpa* Michx.), American elm (*U. americana* L.), and green ash (*Fraxinus pennsylvanica* Marshall), which are typically associated with draws, and some upland shrubs (winterfat, *Krascheninnikovia lanata* (Pursh) A. Meeuse & Smit, and saltbush, *Atriplex* L. spp.) in sagebrush steppe—due to heavy wildlife or domestic animal use. In these cases, woody vegetation goals were to increase particular species. Several woody vegetation management goals involved fire, such as achieving a certain mortality rate of encroaching species with prescribed fire, achieving a pre-European settlement fire return interval, or simply reducing catastrophic wildfire danger (Table 4).

### Actual Fire Practices

Eighteen responses mentioned wildfire (lightning or accidental human ignition) as occurring in their managed lands. One respondent mentioned that “devastating wildfire” provided temporary relief from woody encroachment (though the implication was this was not his preferred method). Of the 34 surveys returned, only three reported no prescribed fire being used on the lands they managed. Nine respondents qualified their answers by stating that prescribed fire use was very limited. In 20 of the survey responses reporting the use of prescribed fire, controlling woody encroachment was one purpose of this fire. Controlling herbaceous invasive species and stimulating grass growth or shrub sprouting were equally frequent prescribed fire purposes.

Although most survey respondents reported using prescribed fire, only 18% of those were achieving their desired fire return interval (FRI), which was mostly <15 years (Figure 3). One respondent provided a detailed quantification of FRI for each of the

**Table 2. Woody species survey respondents listed as having already encroached into lands they manage, and the number of times the species was listed. Numbers sum to more than the number of surveys returned because respondents could list more than one species.**

Species <sup>a</sup>	Number of responses
<i>Juniperus</i> trees	27
<i>Elaeagnus angustifolia</i>	13
<i>Pinus ponderosa</i>	12
<i>Ulmus pumila</i> <sup>b</sup>	9
<i>Tamarix</i> spp.	3
<i>Caragana arborescens</i>	2
<i>Gleditsia triacanthos</i>	2
<i>Populus deltoides</i>	2
<i>Robinia pseudoacacia</i>	2
<i>Salix</i> spp.	2
<i>Symphoricarpos</i> spp.	2
<i>Artemisia filifolia</i>	1
<i>Artemisia tridentata</i>	1
<i>Juniperus</i> shrubs	1
<i>Populus tremuloides</i>	1

<sup>a</sup>Nomenclature follows USDA Plants (<http://plants.usda.gov/>, accessed 4 December 2014).

<sup>b</sup>Some respondents referred to “Chinese elm” (*U. parviflora*), which is not documented in NGP states (USDA Plants); it is a common misnomer for *U. pumila*, which is widespread in the NGP. Thus, we counted “Chinese elm” as *U. pumila*.

**Table 3. Areas that survey respondents described as having the most prominent woody encroachment, and the number of times the category was listed. Numbers sum to more than the number of surveys returned because respondents could list more than one problem area.**

<b>Problem area category</b>	<b>Number of responses</b>
Near areas planted with woody species (e.g., shelterbelts)	13
Low and/or rugged but not necessarily wet areas (e.g., draws)	11
North-facing slopes	11
Edges of lakes and streams, wet meadows	8
Adjacent to natural woody vegetation	5
Old homesteads	3
Ridgetops and/or shallow soils	1

wild herbivores had little or no impact on pine or juniper encroachment (21 out of 28 responses), though four respondents thought grazing may have encouraged their increase and one respondent stated that, “Bison do a great job of controlling eastern redcedar infestations.” Slightly more respondents (6) thought herbivory negatively impacted encroachment by hardwood species, and only one of 22 thought that grazing encouraged hardwoods.

#### *Encroachment Control Practices*

All but three of the 31 relevant responses reported measures other than prescribed fire being used to control woody encroachment. Mechanical only, mechanical followed by chemical (stump or sprout treatment), and chemical methods were used, with some reporting good results and others acknowledging that these methods were expensive and/or the results short-lived.

## **DISCUSSION**

The NGP land managers surveyed perceive woody encroachment as already occurring in grasslands and sagebrush shrublands and that this encroachment has negative impacts. Harr et al. (2014) found a disconnect between actual encroachment and private

five large management units the response represented (Figure 3). Although variability within these areas was acknowledged, the unit-wide analysis produced results the respondent found “kind of jaw-dropping” (e.g., one with a current FRI of 1600 years).

Survey respondents reported spring as the most common time for actually completing prescribed fire (22 responses), followed by fall (12 responses), dormant season (6), and summer (3). *Desired* timing for prescribed fires was also dominated by spring (23 responses), but dormant-season fires were preferred over fall fires (15 vs. 8), and few responses desired summer burns (5).

Summer was the most reported season for wildfire (all 18 wildfire responses). Fall (6 responses) and spring (1) wildfires were much less common.

#### *Grazing Practices and Herbivory Effects*

Survey respondents characterized grass consumption by any combination of species in their managed areas as predominantly low (25–40% consumption, 10 responses) or moderate (40–60% consumption, 14 responses). Very low (<25% consumption) and heavy (>60%) grazing were less common (6 and 4 responses, respectively). Most respondents thought domestic and

**Table 4. Woody vegetation management goals of survey respondents.**

<b>Woody management goal</b>	<b>Number of responses</b>
No woody management goal	7
Target percent of area wooded or in a specific seral stage (including zero woody vegetation except prairie shrubs)	11
Reduce encroached area	4
Pre-settlement fire-return interval or vegetation structure	3
Maintain current extent and/or density	2
Target percent mortality in fire	2
Maintain some in draws for wildlife	1
Maintain current grass production	1
Reduce fire danger	1
Restore composition	1
Varies, but driven by popular game species	1

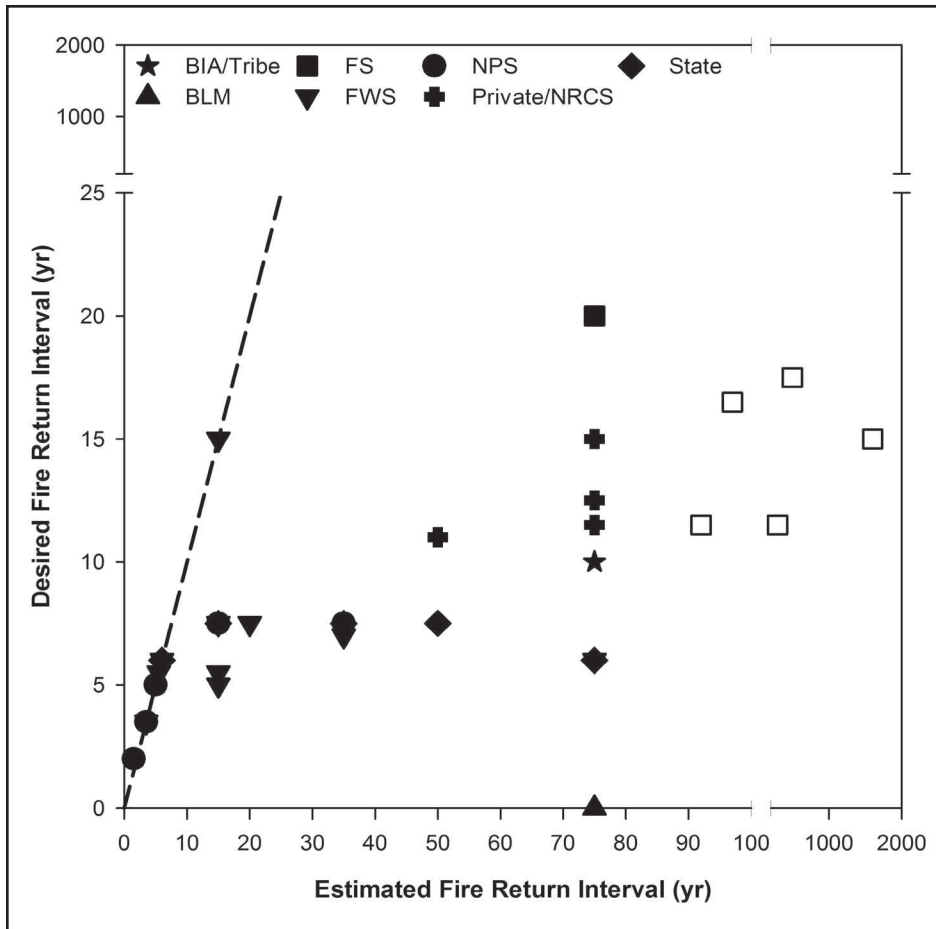


Figure 3. Survey respondents' desired fire return interval vs. achieved fire return interval. Achieved fire return interval was either estimated by the respondent (solid symbols) or, for one respondent covering five management units (open symbols), calculated using management records. Return intervals represent the midpoint of ranges provided by survey respondents; an interval of 75 years was used when a response indicated a fire return interval of greater than 50 years and an interval of 0 indicates no fire is desired. The dashed line indicates where desired and estimated fire return intervals are equal. Abbreviations as in Figure 2.

landowners' perceptions of its impact, but they suggest that this disconnect may be less in land managers who focus on native grassland wildlife and/or sustainable grassland health or who have access to information about encroachment's impacts through professional networks.

The actual degree and spatial distribution of total woody encroachment across the whole study area is not documented. In our survey, all Nebraska respondents perceived at least moderate encroachment in their areas, and some respondents from other states perceived that encroachment was more evident in areas along the Missouri River. An assessment of *Juniperus* cover on private and tribal rangelands in the entire western United States (National Re-

sources Inventory 2014) corroborates these perceptions in that *Juniper* encroachment is greater in the southern portion of the NGP and along major rivers, but a similar assessment has not been done for public rangelands or for other species, such as the hardwood species of concern on the northern edge of the NGP (Grant and Murphy 2005; Springsteen et al. 2010). Regional and local quantitative assessments would improve NGP managers' ability to prioritize areas on which to focus encroachment prevention and control efforts.

The survey respondents' perceived threat of encroachment and undesired impacts on the lands they manage also show in the steps that these managers are taking to prevent new encroachment or reduce it

where it has already occurred. Although we did not ask respondents what they believed caused woody encroachment, answers to other survey questions strongly implied that most managers attributed it to two factors. The first of these is woody species plantings used for windbreaks and promoted as improving wildlife habitat by various government agencies. One survey respondent reported little to no encroachment because all historic shelterbelts had been removed from the managed area. The seed rain from these plantings has been cited by others as a driver of woody encroachment (Briggs et al. 2005; Ganguli et al. 2008b; Bauman 2014), but the perception that spread of woody species from wildlife plantings into grasslands is beneficial to wildlife is still common among private landowners, especially those who do not derive most of their income from ranching (P. Bauman, pers. comm., March 2015).

The second, and most common, factor that survey respondents implied as the cause of woody encroachment is the lack of fire on the landscape. Fire's effect on woody encroachment is widely supported in the scientific literature for the central and southern Great Plains (Fuhlendorf et al. 1996; Hoch et al. 2002; Heisler et al. 2003; Briggs et al. 2005; Fuhlendorf et al. 2008; Twidwell et al. 2013a; Ratajczak et al. 2014). The amount of area that burns in the NGP each year is not tracked, but there are many indicators that current fire frequencies are generally below that of pre-Euro-American settlement times (Higgins 1984, 1986). These indicators include the existence of active fire suppression programs for private and public land, the lack of prescribed fire associations in all NGP states but Nebraska (Twidwell et al. 2013b), our survey respondents' assessment of fire return intervals on agency lands (Figure 3), and direct evidence from fire history studies in the region (e.g., Brown and Sieg 1999; Reid and Fuhlendorf 2011). Many of the NGP public lands our respondents manage do have prescribed fire programs with the recognition that it is "the only long term cost effective method to control wood[y] species," but many of the managers in our survey lack the resources to achieve the 5–20-year fire return intervals they believe are necessary to control encroachment



(Figure 3). Moreover, the predominantly spring and fall fires these managers use and desire may not reach the intensities needed to achieve high mortality rates in areas of higher or older encroachment (Bock and Bock 1984; Fuhlendorf et al. 1996; Twidwell et al. 2013a). The frequency, timing, and intensity of fire actually needed to prevent or reduce encroachment in the NGP has not been investigated experimentally, but a recent modeling study suggests that a 10-year fire interval may be insufficient to prevent future encroachment when seed sources are widely available (King et al. 2015). Work from the central and southern Great Plains suggests that effective fire prescriptions could come in various forms, such as low-frequency but high-intensity prescribed fires (Fuhlendorf et al. 1996). However, this work also suggests that, in some cases, fire alone will not be sufficient to restore areas with a high degree of encroachment (Fuhlendorf et al. 1996; Briggs et al. 2005).

Work from the rest of the Great Plains also highlights the interactive effects of fire and grazing on woody encroachment into Great Plains grasslands. In the central and southern Great Plains, grazing has been shown to promote eastern redcedar or juniper encroachment by reducing fine-fuel loads, and therefore fire frequency, fire intensity, and subsequently, tree mortality during fire (Hoch et al. 2002; Heisler et al. 2003; Fuhlendorf et al. 2008). However, only one of our survey responses mentioned this fuel reduction effect. In fact, more survey respondents attributed reduced hardwood species encroachment (or even survival) to herbivory than attributed increased pine or juniper encroachment to grazing. Domestic livestock production is either not at all or only one of many land management goals for the majority of the survey respondents in our study. This, combined with the low incidence of fire in the NGP, suggests that evidence of fire–grazing–encroachment feedbacks may be muted for our survey respondents. Better understanding of the ecological aspects of fire–herbivore–woody encroachment interactions in the NGP is necessary to provide land managers prescriptions for managing woody encroachment in a variety of contexts.

Such prescriptions are not sufficient, however. One survey respondent stated that, in his area, “Prescribed burns are not generally supported by the public.” In both public and private lands, public opposition to prescribed fires may stem from a variety of sources, including fears of reduced or less-flexible grazing allotments to accommodate fuels management needed for effective prescribed fire; perceptions that prescribed fire reduces forage production, increases erosion, or harms wildlife (Reid and Fuhlendorf 2011); and perceived risks of and liability for escaped fires and air-quality impacts (Yoder et al. 2004; Morton et al. 2010; Twidwell et al. 2013b; Harr et al. 2014). These and other barriers impact public land managers’ flexibility in timing or size of burns and ultimately, the amount of funding dedicated to prescribed fire. On private lands, an additional barrier is the lack of equipment and expertise to conduct prescribed fires (Twidwell et al. 2013b). Only when the social barriers to increasing the use of prescribed fire, on both public and private lands, are understood and overcome will management prescriptions have a chance for success (Leis et al. in prep.).

## CONCLUSION

The results of our survey strongly suggest that, although NGP rangelands have received less scientific attention to woody encroachment than their counterparts to the south, they are experiencing encroachment, land managers in the region are aware of it, and prescribed fire, mechanical removal, and chemical treatments are being used to address the problem. Many managers realize, however, that the rate of management is not keeping pace with the rate of encroachment. Our survey puts a spotlight on a diverse management community’s need for accelerated strategies for woody plant control in the NGP. Developing these strategies requires two types of science; ecological and social. Ecological science needs to identify areas or conditions most impacted or threatened by encroachment, as well as to determine effective management strategies for a variety of contexts including a changing climate and increasing CO<sub>2</sub> concentrations (Polley et al. 2013; King

et al. 2015). Equally important, social science needs to identify societal barriers to implementing management strategies and the means to overcome these barriers. Finally, interdisciplinary science needs to provide effective means for prioritizing areas for management and restoration. Filling these knowledge gaps will help public and private managers set priorities, develop strategies, and influence policies required for successful grassland conservation in this region.

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*Amy Symstad is a Research Ecologist with the USGS, Northern Prairie Wildlife Research Center. Her research focuses on native vegetation conservation and management issues in the northern Great Plains.*

*At the time of this work, Sherry Leis was the Fire Science Program Leader of the Great Plains Fire Science Exchange and fire Ecologist for the National Park Service Heartland Network. She is now Plant Ecologist for the National Park Service Heartland Network*

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