

Effects of prescribed fire on a drought-stressed Trembling Aspen (*Populus tremuloides*) stand

ELLA HYDOMAKO¹ and ERIC G. LAMB^{1,*}

¹Department of Plant Sciences, University of Saskatchewan, Saskatoon, Saskatchewan S7N 5A8 Canada

*Corresponding author: eric.lamb@usask.ca

Hydomako, E., and E.G. Lamb. 2024. Effects of prescribed fire on a drought-stressed Trembling Aspen (*Populus tremuloides*) stand. Canadian Field-Naturalist 138(4): 285–290. <https://doi.org/10.22621/cfn.v138i4.3397>

Abstract

A small stand of drought-stressed Trembling Aspen (*Populus tremuloides*) near Saskatoon, Saskatchewan, Canada, was surveyed before and after a prescribed fire. A headfire in grass understorey fuel caused near complete mortality of established stems and of all aspen saplings. In the second and third years post-fire, only limited establishment of saplings was observed. Woody encroachment by aspen into grassland is challenging to control in the Aspen Parkland ecoregion; our results indicate that combining prescribed burning with secondary stress from drought conditions can enhance the fire effects.

Key words: Trembling Aspen; *Populus tremuloides*; prescribed fire; woody plant control

Introduction

The encroachment of woody species into grasslands is an issue of significant ecological and economic concern (Van Auken 2000; Soubry and Guo 2022). In the Aspen Parkland on the northern edge of the Great Plains (Coupland 1961), expansion of both low shrub species such as Snowberry (*Symphoricarpos occidentalis* Hooker) and Wolf Willow (*Elaeagnus commutata* Bernhardt ex Rydberg) and trees such as Trembling Aspen (*Populus tremuloides* Michaux) is common (Romo *et al.* 1993; Romo 2003). The consequences of this woody encroachment include reduced cattle grazing capacity, fragmentation of areas of grassland habitat, reduced connectivity between grassland fragments, and reduced grassland biodiversity through habitat loss (Romo 2003; Twidwell *et al.* 2013). The causes of these increases in woody plant abundance are complex and likely include the post-European-settlement reduction in the frequency and intensity of fire, a change in grazing regime from one dominated by migratory bison to one dominated by sedentary cattle, and changing climatic conditions (Chen *et al.* 2017; Soubry and Guo 2022).

Methods, such as mulching and herbicides, can be used for woody plant control (e.g., Waddington and Bittman 1987; Zentner and Bowes 1991; Paragi and Haggstrom 2007), but suffer from poor public acceptance and may not be suitable on lands where conservation is a management objective. Improved methods for controlling woody encroachment that align with

natural disturbance processes are of interest to range-land managers with both conservation and grazing objectives.

Prescribed fire is increasingly being used for grassland management as social acceptance of fire as a management technique becomes more widespread and the organizational capacity to safely conduct fire improves (Twidwell *et al.* 2013; Gross and Lamb 2025). Regionally relevant fire prescriptions are needed for diverse management objectives, including control of aspen and other woody species (Gross 2023). Past studies have found that fire, as an isolated control tactic, will readily kill mature aspen stems, but it is often ineffective for long-term control of aspen encroachment because it stimulates vegetative reproduction (i.e., suckering) and creates soil conditions necessary for seedling establishment (Bartos and Mueggler 1981; Brown and DeByle 1987; Ripley and Archibold 1999; Fraser *et al.* 2004; Paragi and Haggstrom 2007; Guedo and Lamb 2013; Margolis and Farris 2014). After fire, aspen's regeneration response can result in thousands of saplings per hectare (Fraser *et al.* 2004; Kreider and Yocom 2021). Thus, long-term control is typically thought to require repeat fires, high intensity fires, or secondary control methods (Bartos and Mueggler 1981; Guedo and Lamb 2013). However, repeat and high-intensity prescribed fires are difficult to implement because of high costs and such limitations as the availability of personnel and the right weather conditions (Gross and Lamb 2025).

Given these challenges, it is important to explore the combination of fire with secondary control factors. Combined burning and grazing, for example, was highly successful in mitigating post-fire suckering in European Aspen (*Populus tremula* L.) in southern Europe (Ascoli *et al.* 2013), and fire can open dense shrub canopies sufficiently to allow grazing animals to enter shrubby areas (Tarleton and Lamb 2021). Drought may be a relevant secondary factor, because aspen is drought-sensitive and exhibits lower growth rates and increased mortality under dry conditions (Michaelian *et al.* 2011; Worrall *et al.* 2013; Chen *et al.* 2017). Given that stressed plants can be more vulnerable to fire (Nolan *et al.* 2021), greater efficacy of prescribed fire on aspen might be expected under drought conditions.

We report a case study of the application of prescribed fire to an aspen stand experiencing drought stress: a small aspen stand that was observed to be dying back during a dry period was subject to a spring-prescribed fire. The objectives of the study were to assess post-fire mortality and recovery in this stand, including how the pre-fire size of individual mature trees influenced mortality rates and rates of sapling re-establishment post-fire.

Methods

Field site and study design

The study was conducted on Kernen Prairie (52°10'N, 106°33'W), a 130-ha relic fescue grassland on the east side of Saskatoon, Saskatchewan, Canada (Pylypec 1986). The site is on the southern edge of the Aspen Parkland ecoregion (Coupland 1961) and is characterized by Plains Rough Fescue (*Festuca hallii* (Vasey) Piper) grassland communities with several small (<0.5 ha) isolated stands of *P. tremuloides* in low and moist areas underlain by Dark Brown Chernozem soils (Saskatchewan Land Resource Unit 2009).

Our study focussed on a 0.45-ha aspen stand in the northeast corner of Kernen Prairie. The stand, which is visible in 1960s aerial photographs, has had a static boundary for at least 20 years and no record of a previous fire. Anecdotal observation of the stand suggested that it was under drought stress, because the area had experienced drought conditions for the previous four years (Agriculture and Agri-Food Canada 2023), and many individual stems died between 2017 and 2020. In spring 2020, one year before the fire, an electric fence was established around the aspen stand to prevent grazing by cattle and to allow for the accumulation of understorey grass litter, primarily Smooth Brome (*Bromus inermis* Leysser) fuel. The fence was removed to avoid fire damage, then replaced post-fire to exclude cattle during the study.

The stand was burned in April 2021 with the objective of reducing woody cover. Blacklines, or burned fireguards, were established by ignition off mowed fireguards in open grassland ~50 m outside the perimeter of the aspen stand. Blacklines width was increased by allowing backfires to creep into the burn unit. Headfires, or fires pushed by the wind, were started from the north and west sides and burned through the stand. Headfire flame lengths (3–5 m) reached into the tree canopy; consumption of grass fuel was complete on the stand margins, but several small patches of unburned understorey fuel remained in the interior. Mop-up, or final extinguishment of the fire, was conducted using hand tools and backpack sprayers; fallen logs were turned over during mop-up but no standing trees were cut or otherwise disturbed.

Field sampling

The stand was surveyed in 2020 (before the fire) and annually post-fire from 2021 to 2023. Before the fire in July and August 2020, the stand was surveyed comprehensively, with all mature stems (≥ 2 m high) mapped and tagged; saplings (<2 m) were surveyed in a 623 m² area in the north half of the stand. All surveyed stems were located using a differential Global Positioning System receiver (Geo7x; Trimble Inc., Westminster, Colorado, USA), measured for diameter at breast height, and classified as live or dead (green leaves present or absent). All stems were marked using a numbered aluminum tag. Post-fire sampling in August or September 2021, 2022, and 2023 included the relocation of each mature stem for a visual measure of injury class (Table 1), adapted from Brown and DeByle (1987). In 2021, each pre-fire sapling location was checked. Because all pre-fire saplings were dead in 2021 (generally completely consumed), we did not resurvey for them in subsequent years. The area of the stand previously surveyed for saplings was resurveyed for new saplings each year.

Statistical analysis

We examined how pre-fire mature tree size affected survival using a generalized linear model (GLM). Specifically, live and dead stem diameters were compared using a model with diameter as the response variable, status (live or dead) as a categorical predictor, and a binomial family. Models were fit using the *glm* function in R version 4.2.1 (R Development Core Team 2022).

Results

The pre-fire stand included 1047 mature trees of which 374 (35.6%) were alive (Figure 1). Live trees were significantly larger in diameter than dead ones (live: 15.1 cm $\pm$ 2.5 SD, dead: 2.6 cm $\pm$ 2.8; $F_{1, 1045} = 208.9$; $P < 0.001$); following the fire in 2021, only 114 of the 374 trees living in 2020 remained alive

TABLE 1. Injury classes of surviving Trembling Aspen (*Populus tremuloides*) and corresponding indicators of fire damage at Kernen Prairie near Saskatoon, Saskatchewan, Canada.*

Injury class	Damage characteristics
1. Dead	Stems charred for full circumference for at least one metre in height; no green foliage
2. Major damage	Majority of fire-damaged stem area charred with some browning; trace amounts of green foliage present
3. Moderate damage	Fire-damaged stem area is equal parts charring and browning; moderate amounts of green foliage present
4. Minor damage	Majority of fire-damaged stem area is browned with some charring; most branches support green foliage
5. Healthy	No apparent fire damage; abundant green foliage

*Adapted from Brown and DeByle (1987).

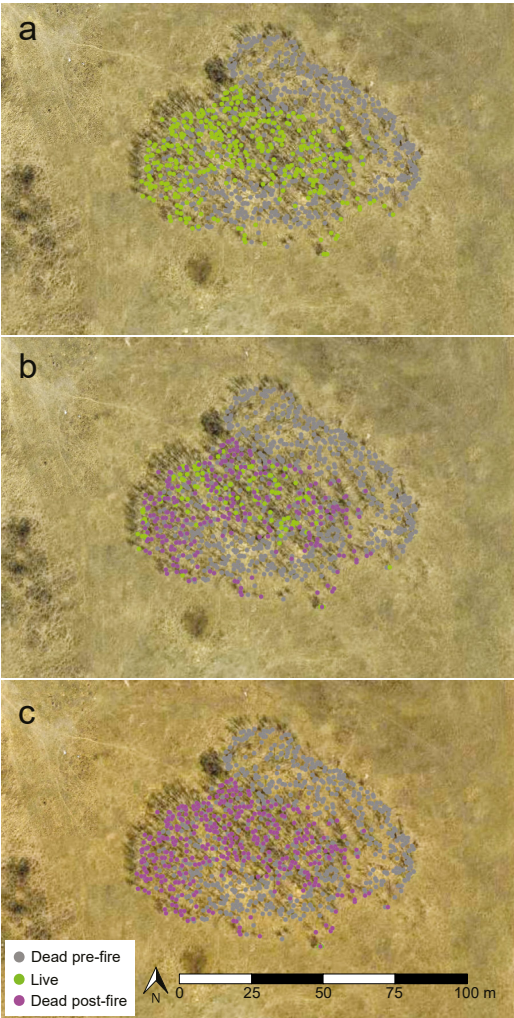


FIGURE 1. Map of mature Trembling Aspen (*Populus tremuloides*) stems at Kernen Prairie near Saskatoon, Saskatchewan, Canada, in the stand pre-fire (a) and one- (b), and two years (c) post-fire. Dead post-fire stems were alive pre-fire.

(Figure 2; Table 2). Of the living trees post-fire in 2021, 64.0% were in injury class 2 (major injury), 35.1% in class 3 (moderate injury), and 0.9% in class 4 (minor injury). No stems were injury free (class 5). Size did not influence survival, because there was no difference in stem diameter between live individuals in 2020 that were dead in 2021 and those that had survived (live: 15.4 cm $\pm$ 2.5, dead: 15.0 cm $\pm$ 2.4; $F_{1,372}$ = 2.3, P = 0.132). Mortality was almost complete in follow-up surveys. In 2022, only two of the 114 live individuals from 2021 remained alive (injury class 2). In 2023, eight live stems were observed; the two live stems observed in 2022 that were classified as injury class 3 and six stems classified as live in 2021 (injury class 1–3) but not considered live in 2022 showed evidence of recovery (healthy bark, budding, and small numbers of leaves). There was no clear spatial pattern to the mortality of mature individuals (Figure 1).

The pre-fire stand included 424 saplings in a 623-m² subset of the stand (6806 saplings/ha or ~3060 saplings in the 0.45-ha stand). Post-fire in 2021, there were no surviving saplings, and no new sapling emergence was documented. In 2022, 11 of the pre-fire saplings were found alive, resprouting from a burned stem base marked with a tag before the fire, and 189 new saplings were documented in the sampling area (3210 saplings/ha). In 2023, four of the 11 pre-fire saplings observed in 2022 were confirmed alive and one dead. Missing tags precluded confirmation of the fate of the remaining six saplings. Thirty-eight of the new 2022 saplings were located and confirmed alive in 2023 and 145 new saplings were identified (3002 saplings/ha).

Discussion

As observed in many studies (Brown and DeByle 1987; Ripley and Archibold 1999), prescribed fire was effective in killing mature Trembling Aspen stems with 30% survival one year after fire and only 2% survival three years post-fire. Our survival rates were slightly higher than those of some previous

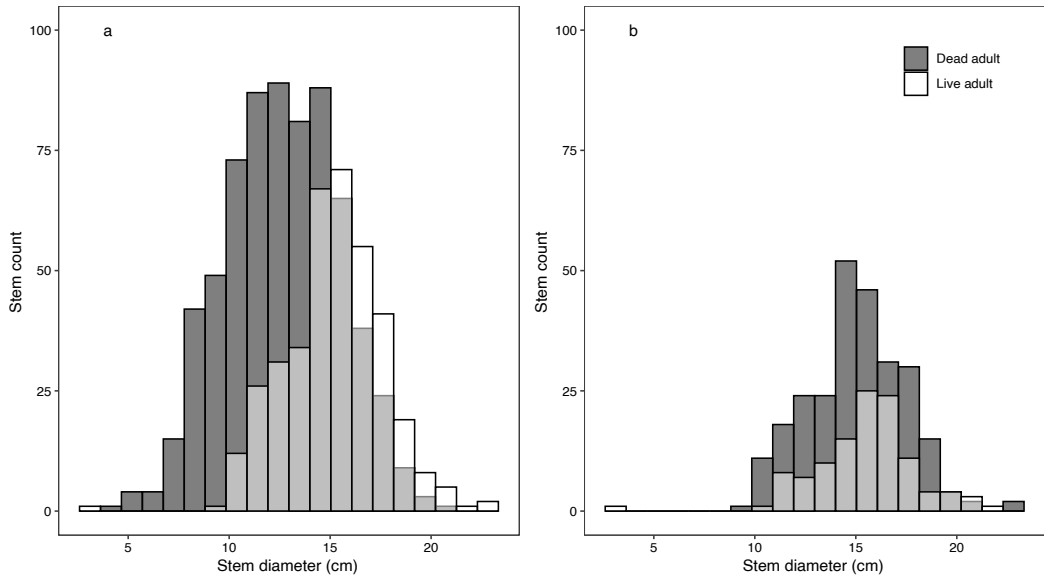


FIGURE 2. Stem diameter distributions of a. living and dead pre-fire (2020) and b. post-fire (2021) mature stems of Trembling Aspen (*Populus tremuloides*) at Kernen Prairie near Saskatoon, Saskatchewan, Canada. Post-fire stems include only those that were alive pre-fire in 2020. Light grey shading indicates overlap between live and dead stem counts.

TABLE 2. Characteristics of surviving mature stems of Trembling Aspen (*Populus tremuloides*) at Kernen Prairie near Saskatoon, Saskatchewan, Canada, including stem counts and basal area (m²/ha) by diameter and injury class one year post-fire (2021).

DBH	Major damage (2)		Moderate damage (3)		Minor damage (4)	
	Count	Basal area	Count	Basal area	Count	Basal area
<10 cm	1	0.002	0	0.000	0	0.000
10–15 cm	25	0.754	16	0.504	0	0.000
15–20 cm	43	2.138	24	1.123	1	0.042
>20 cm	4	0.308	0	0.000	0	0.000
Total	73	3.202	40	1.627	1	0.042

Note: DBH = diameter at breast height.

studies, which found near complete mortality within the first year after the fire. Aspens with larger diameters often have lower fire-related mortality (Brown and DeByle 1987; Alexander and Sando 1989); however, we found no differences in survival based on size in our study. Size effects in our study may be more limited than those in other post-fire studies because of the much smaller maximum size and narrow size range typical in small stands at the southern edge of the Aspen Parkland (Cordes 1965). In our prescribed fire, flames nearing maximum tree height (3–5 m) were achieved with the heavy understory grass fuels, whereas in larger stands with more woody surface fuel, flames well below the upper canopy would be expected.

The fire achieved complete sapling kill; no sap-

lings were observed one year after the fire, when abundant suckering would normally be expected (Brown and DeByle 1987; Ripley and Archibold 1999; Fraser *et al.* 2004; Paragi and Haggstrom 2007; Guedo and Lamb 2013; Margolis and Farris 2014). The lack of saplings we observed contrasts with the rapid establishment of aspen saplings observed following a spring 1995 prescribed fire in a similar aspen stand at the same site (Ripley and Archibold 1999). The 1995 fire was conducted during a relatively moist period (Bonsal and Regier 2007), in contrast to the prevailing drought conditions of our study beginning in 2016 and continuing post-fire until 2023 (Agriculture and Agri-Food Canada 2023). Together, our observations are consistent with the hypothesis that drought-stressed plants are

more vulnerable to fire (Nolan *et al.* 2021) and that prescribed fire under dry conditions can increase its efficacy for aspen control.

Some longer-term recovery was evident, with densities of ~3000 saplings/ha observed two and three years after the fire. These sapling densities are small relative to the tens of thousands per hectare commonly observed post-fire (Ripley and Archibold 1999; Fraser *et al.* 2004; Kreider and Yocom 2021). Overall, although the aspen stand was not eliminated by the single fire, substantial control was achieved, with post-fire sapling densities ~43% of pre-fire densities. Most saplings were likely vegetative suckers rather than seedlings; seedling establishment is likely extremely rare at the site, as intensive surveys of the site over many years have not identified aspen saplings in any location except in the vicinity of established stands (Attanayake 2020; Bell *et al.* 2020). The emergence of saplings two to three years after fire indicates that the stand will likely recover in the long-term; additional management will be required to revert the site completely to grassland.

Cattle grazing was excluded during the recovery period in our study, so we cannot evaluate how post-fire grazing might impact the sapling densities. Cattle preferentially rest in the shade of trees or tall shrubs at this site (E.G.L. pers. obs.); they would also likely be attracted by improved forage quality post-fire (Winter *et al.* 2014; Gross 2023; Vera-Velez *et al.* 2023). Intensive grazer activity could have positive (e.g., reduced competition from grasses) and negative (e.g., trampling and browsing of saplings) effects (Margolis and Farris 2014; Tarleton and Lamb 2021). A controlled grazing exclusion study would be required to evaluate the role of grazing.

In summary, the available evidence suggests that the prevailing dry conditions and moisture stress induced by the drought were responsible for the limited recovery of the stand. These results suggest that prescribed fire under drought conditions is likely more effective than fire under wet or normal conditions to achieve long-term aspen control in the Aspen Parkland ecoregion. Prescribed fire planning for aspen control should prioritize fires in woody areas over open grassland during drought periods. Excluding grazing from target aspen stands starting in mid-summer will allow grass understorey fuel buildup for sufficiently intense spring fires during the leaf bud period. Allowing grazer access immediately post-fire will maximize the potential for browsing and trampling to impact any aspen saplings that do emerge.

Author Contributions

Writing – Original Draft: E.H. and E.G.L.; Writing – Review & Editing: E.H. and E.G.L.; Conceptu-

alization: E.G.L.; Investigation: E.H.; Formal Analysis: E.H. and E.G.L.; Funding Acquisition: E.G.L.

Acknowledgements

Member agencies of the Canadian Prairies Prescribed Fire Exchange assisted with the prescribed burn. Laura MacMillan assisted in the field. Funding was provided by a Natural Sciences and Engineering Research Council of Canada Discovery grant to E.G.L. Comments from two anonymous reviewers greatly improved this manuscript.

Literature Cited

- Agriculture and Agri-Food Canada.** 2023. Canadian drought monitor. Agriculture and Agri-Food Canada, Ottawa, Ontario, Canada. Accessed 17 January 2024. <https://agriculture.canada.ca/en/agricultural-production/weather/canadian-drought-monitor>.
- Alexander, M., and R. Sando.** 1989. Fire behavior and effects in aspen-northern hardwood stands. Pages 17–21 in *Proceedings of the 10th Conference on Fire and Forest Meteorology*. Edited by D.C. MacIver, H. Auld, and R. Whitewood. Canadian Forest Service and Environment Canada, Ottawa, Ontario, Canada.
- Ascoli, D., M. Lonati, R. Marzano, G. Bovio, A. Cavallero, and G. Lombardi.** 2013. Prescribed burning and browsing to control tree encroachment in southern European heathlands. *Forest Ecology and Management* 289: 69–77. <https://doi.org/10.1016/j.foreco.2012.09.041>
- Attanayake, A.U.** 2020. Incorporating plant community structure in species distribution modelling: a species co-occurrence based composite approach. Ph.D. thesis, University of Saskatchewan, Saskatoon, Saskatchewan, Canada. Accessed 18 April 2025. <http://hdl.handle.net/10388/12579>.
- Bartos, D.L., and W.F. Mueggler.** 1981. Early succession in aspen communities following fire in western Wyoming. *Journal of Range Management* 34: 315–318. <https://doi.org/10.2307/3897859>
- Bell, J.K., S.D. Siciliano, and E.G. Lamb.** 2020. A survey of invasive plants on grassland soil microbial communities and ecosystem services. *Scientific Data* 7: 86. <https://doi.org/10.1038/s41597-020-0422-x>
- Bonsal, B., and M. Regier.** 2007. Historical comparison of the 2001/2002 drought in the Canadian Prairies. *Climate Research* 33: 229–242. <https://doi.org/10.3354/cr033229>
- Brown, J.K., and N.V. DeByle.** 1987. Fire damage, mortality, and suckering in aspen. *Canadian Journal of Forest Research* 17: 1100–1109. <https://doi.org/10.1139/x87-168>
- Chen, L., J.G. Huang, S.A. Alam, L. Zhai, A. Dawson, K.J. Stadt, and P.G. Comeau.** 2017. Drought causes reduced growth of Trembling Aspen in western Canada. *Global Change Biology* 23: 2887–2902. <https://doi.org/10.1111/gcb.13595>
- Cordes, L.D.** 1965. An ecological study of isolated *Populus tremuloides* stands. M.Sc. thesis, University of North Dakota, Grand Forks, North Dakota, USA. Accessed 18 April 2025. <https://commons.und.edu/theses/3868>.
- Coupland, R.T.** 1961. A reconsideration of grassland clas-

- sification in the Northern Great Plains of North America. *Journal of Ecology* 49: 135–167. <https://doi.org/10.2307/2257431>
- Fraser, E., S. Landhäusser, and V. Lieffers. 2004. The effect of fire severity and salvage logging traffic on regeneration and early growth of aspen suckers in north-central Alberta. *Forestry Chronicle* 80: 251–256. <https://doi.org/10.5558/tfc80251-2>
- Gross, D.V. 2023. Applications of and barriers to prescribed fire for grassland management in Saskatchewan. Ph.D. thesis, University of Saskatchewan, Saskatoon, Saskatchewan, Canada. Accessed 18 April 2025. <https://hdl.handle.net/10388/15210>
- Gross, D.V., and E.G. Lamb. 2025. Strategies to reintroduce prescribed fire as a grassland management process on the Canadian prairies. *Ecological Solutions and Evidence* 6: e70035. <https://doi.org/10.1002/2688-8319.70035>
- Guedo, D.D., and E.G. Lamb. 2013. Prescribed burning has limited long-term effectiveness in controlling Trembling Aspen (*Populus tremuloides*) encroachment into fescue grassland in Prince Albert National Park. *Canadian Field-Naturalist* 127: 50–56. <https://doi.org/10.22621/cfn.v127i1.1407>
- Kreider, M.R., and L.L. Yocom. 2021. Low-density aspen seedling establishment is widespread following recent wildfires in the western United States. *Ecology* 102: e03436. <https://doi.org/10.1002/ecy.3436>
- Margolis, E.Q., and C.A. Farris. 2014. Quaking Aspen regeneration following prescribed fire in Lassen Volcanic National Park, California, USA. *Fire Ecology* 10: 14–26. <https://doi.org/10.4996/fireecology.1003014>
- Michaelian, M., E.H. Hogg, R.J. Hall, and E. Arsenault. 2011. Massive mortality of aspen following severe drought along the southern edge of the Canadian boreal forest. *Global Change Biology* 17: 2084–2094. <https://doi.org/10.1111/j.1365-2486.2010.02357.x>
- Nolan, R.H., L. Collins, A. Leigh, M.K.J. Ooi, T.J. Curran, T.A. Fairman, V. Resco de Dios, and R. Bradstock. 2021. Limits to post-fire vegetation recovery under climate change. *Plant, Cell & Environment* 44: 3471–3489. <https://doi.org/10.1111/pce.14176>
- Paragi, T.F., and D.A. Haggstrom. 2007. Short-term responses of aspen to fire and mechanical treatments in interior Alaska. *Northern Journal of Applied Forestry* 24: 153–157. <https://doi.org/10.1093/njaf/24.2.153>
- Pylypec, B. 1986. The Kernen prairie—a relict fescue grassland near Saskatoon, Saskatchewan. *Blue Jay* 44: 222–231. Accessed 21 May 2025. <https://bluejayjournal.ca/in dex.php/bluejay/article/view/4733/4722>
- R Development Core Team. 2022. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.
- Ripley, E.A., and O.W. Archibold. 1999. Effects of burning on prairie aspen grove microclimate. *Agriculture, Ecosystems & Environment* 72: 227–237. [https://doi.org/10.1016/s0167-8809\(98\)00182-0](https://doi.org/10.1016/s0167-8809(98)00182-0)
- Romo, J.T. 2003. Reintroducing fire for conservation of fescue prairie association remnants in the northern Great Plains. *Canadian Field-Naturalist* 117: 89–99. <https://doi.org/10.5962/p.353866>
- Romo, J.T., P.L. Grilz, R.E. Redmann, and E.A. Driver. 1993. Standing crop, biomass allocation patterns and soil-plant water relations in *Symphoricarpos occidentalis* Hook. following autumn or spring burning. *American Midland Naturalist* 130: 106–115. <https://doi.org/10.2307/2426279>
- Saskatchewan Land Resource Unit. 2009. SKSIDv4, Digital Soil Resource Information for Agricultural Saskatchewan, 1:100,000 scale. Agriculture and Agri-Food Canada, Saskatoon, Saskatchewan, Canada. Accessed 17 January 2024 via Saskatchewan Soil Information System (SKSIS Working Group 2024). <http://sksis.ca>
- Soubry, I., and X. Guo. 2022. Quantifying woody plant encroachment in grasslands: a review on remote sensing approaches. *Canadian Journal of Remote Sensing* 48: 337–378. <https://doi.org/10.1080/07038992.2022.2039060>
- Tarleton, P., and E.G. Lamb. 2021. Modification of plant communities by bison in Riding Mountain National Park. *Ecoscience* 28: 67–80. <https://doi.org/10.1080/11956860.2020.1850622>
- Twidwell, D., W.E. Rogers, S.D. Fuhlendorf, C.L. Wonka, D.M. Engle, J.R. Weir, U.P. Kreuter, and C.A. Taylor, Jr. 2013. The rising Great Plains fire campaign: citizens' response to woody plant encroachment. *Frontiers in Ecology and the Environment* 11: e64–e71. <https://doi.org/10.1890/130015>
- Van Auken, O.W. 2000. Shrub invasions of North American semiarid grasslands. *Annual Review of Ecology, Evolution, and Systematics* 31: 197–215. <https://doi.org/10.1146/annurev.ecolsys.31.1.197>
- Vera-Velez, R., S.A. Grover, B.K. Bischoff, C.N. Carlyle, and E.G. Lamb. 2023. Wildfire-grazing impact on forage quality assessed with near-infrared spectroscopy and generalized partial least squares regression. *Rangeland Ecology & Management* 87: 132–140. <https://doi.org/10.1016/j.rama.2023.01.003>
- Waddington, J., and S. Bittman. 1987. Control of brush regrowth in northeastern Saskatchewan by several concentrations of herbicides applied with a roller. *Canadian Journal of Plant Science* 67: 467–475. <https://doi.org/10.4141/cjps87-066>
- Winter, S.L., S.D. Fuhlendorf, and M. Goes. 2014. Patch-burn grazing effects on cattle performance: research conducted in a working landscape. *Rangelands* 36: 2–7. <https://doi.org/10.2111/rangelands-d-13-00079.1>
- Worrall, J.J., G.E. Rehfeldt, A. Hamann, E.H. Hogg, S.B. Marchetti, M. Michaelian, and L.K. Gray. 2013. Recent declines of *Populus tremuloides* in North America linked to climate. *Forest Ecology and Management* 299: 35–51. <https://doi.org/10.1016/j.foreco.2012.12.033>
- Zentner, R.P., and G.G. Bowes. 1991. Economics of chemical brush control in pastures of east-central Saskatchewan. *Canadian Journal of Plant Science* 71: 1133–1141. <https://doi.org/10.4141/cjps91-155>

Received 26 June 2024

Accepted 26 March 2025

Associate Editor: J.M. Saarela