



Vegetation Response to Elk Population and Habitat Management in Rocky Mountain National Park

Analysis of Elk and Vegetation Management Plan Monitoring Data, 2008–2023



Bull elk among river birch in the fall.

NPS

Vegetation response to elk population and habitat management in Rocky Mountain National Park: Analysis of elk and vegetation management plan monitoring data, 2008–2023

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Contents

	Page
Figures.....	v
Tables.....	viii
Abstract.....	ix
Executive Summary.....	xi
Acknowledgments.....	xiv
List of Acronyms	xv
Introduction.....	1
Objectives.....	7
Intermediate Reports and Workshops	7
Methods.....	10
Study Area.....	10
Monitoring Design.....	10
Vegetation Data Collection	15
Aspen.....	16
Willow	16
Upland	17
Animal Presence.....	17
Data Analyses.....	18
Winter-Range-Wide Estimates of Aspen and Willow.....	19
Results and Discussion	20
Aspen.....	20
Stand Structure	20
Kawuneeche Valley.....	26
Animal Presence in Aspen Sites.....	29
Progress Toward EVMP Aspen Objectives	32
Willow	34
Willow height	34
Willow cover	38

Contents (continued)

	Page
Range-wide Willow Cover and Height	43
Kawuneeche Valley.....	46
Willow Browse Intensity.....	47
Animal Presence in Willow Sites.....	51
Progress Toward EVMP Willow Goals	54
Upland	56
Shrub cover.....	56
Animal Presence in Uplands	58
Progress Toward EVMP Upland Objectives.....	60
Conclusions.....	61
Literature Cited	65

Figures

	Page
Figure 1. Approximate locations of primary winter range, area of potential distribution change where elk are now wintering in greater numbers, and primary summer range in Rocky Mountain National Park, Colorado (NPS 2007).....	3
Figure 2. Annual population estimates (filled circles) and medians of the marginal posterior distribution of the true, unobserved elk population size (solid line) on winter range, during the winter, in Rocky Mountain National Park during 1969–2023 and forecasts for 2023, 2024, and 2025.	5
Figure 3. Location of Elk and Vegetation Management Plan (EVMP) plots by vegetation type and fencing status used in plot stratification on the Rocky Mountain National Park elk winter range at time of 2023 sampling.....	12
Figure 4. Location of Elk and Vegetation Management Plan (EVMP) plots by vegetation type and fencing status in the Kawuneeche Valley, Rocky Mountain National Park, at time of 2023 sampling.	14
Figure 5. Stand structure of (A) fenced and (B) unfenced aspen trees on the core elk winter range based on diameter at breast height (DBH) size classes.....	21
Figure 6. Stand structure of aspen trees on the noncore elk winter range based on diameter at breast height (DBH) size classes.....	22
Figure 7. Comparison of vegetation composition over time at plot AC35 inside aspen exclosure in HP30 at Little Horseshoe Park.	24
Figure 8. Comparison of vegetation composition over time at unfenced plot AC22 in west Horseshoe Park.	25
Figure 9. Photo series of fenced plot AC64 shows abundant aspen regeneration in 2013 (A) following the 2012 fire, followed by good recruitment of tall aspen saplings in 2018 (B).	26
Figure 10. Stand structure of aspen trees in individual Kawuneeche Valley aspen plots based on diameter at breast height (DBH) size classes.....	27
Figure 11. Box plots of aspen density (stems/acre) for (A) short (≤ 150 cm height) and (B) tall (151–250 cm height) aspen saplings in the Kawuneeche Valley of Rocky Mountain National Park.	28
Figure 12. Photo series of Kawuneeche Valley aspen plot AK1 showing little to no regenerating aspen at 2013 (A), 2018 (B), or 2023 (C).	29
Figure 13. Moose presence detected in Elk and Vegetation Management Plan (EVMP) core and noncore aspen plots from baseline to 2023.	31

Figures (continued)

	Page
Figure 14. Deer presence detected in Elk and Vegetation Management Plan (EVMP) core and noncore aspen plots from 2013 to 2023.	32
Figure 15. Estimated mean willow height (cm) for fenced and unfenced willow over 15 years on the core and noncore elk winter range of Rocky Mountain National Park.	35
Figure 16. Estimated maximum willow height (cm) for fenced and unfenced willow over 15 years on the core and noncore elk winter range of Rocky Mountain National Park.	37
Figure 17. Comparison of vegetation composition over time inside willow exclosure HP50 at plot WC16.	37
Figure 18. Comparison of vegetation composition inside willow exclosure MP50 at plot WC28 over time.	38
Figure 19. Comparison of vegetation composition over time at unfenced plot WC55 in Moraine Park.	39
Figure 20. Estimated mean percent willow canopy cover for fenced and unfenced willow over 15 years on the core and noncore elk winter range of Rocky Mountain National Park.	39
Figure 21. Estimated mean willow height (A), maximum willow height (B), and mean percent willow cover (C), derived from only willow plots that did not burn in 2020 on elk winter range (WR) of Rocky Mountain National Park.	41
Figure 22. Estimated mean willow height (A), maximum willow height (B), and mean percent willow cover (C), derived from data collected using the line intercept method at all monitoring plots on winter range (WR) of Rocky Mountain National Park.	42
Figure 23. Correlation plots for macroplot vs. line intercept measurement methods for willow mean height (A), maximum height (B), and canopy cover (C).	43
Figure 24. Mean height (centimeters) and standard error bars for fenced and unfenced willow species in the Kawuneeche Valley of Rocky Mountain National Park.	46
Figure 25. Mean canopy cover (%) and standard error bars for fenced and unfenced willow species in the Kawuneeche Valley of Rocky Mountain National Park.	47
Figure 26. Linear regression lines showing trend in willow browse intensity on the elk winter range of Rocky Mountain National Park 2010–2023.	48
Figure 27. Willow browse intensity on the elk winter range of Rocky Mountain National Park 2010–2023.	49
Figure 28. Trend in willow browse intensity in the Kawuneeche Valley of Rocky Mountain National Park 2012–2023.	50

Figures (continued)

	Page
Figure 29. Mean willow browse intensity in the Kawuneeche Valley of Rocky Mountain National Park 2012–2023.	51
Figure 30. Moose presence detected in Elk and Vegetation Management Plan (EVMP) core and noncore willow plots in 2018 and 2023.	53
Figure 31. Beaver presence in Elk and Vegetation Management Plan (EVMP) core and noncore willow monitoring plots from baseline to 2023.	54
Figure 32. Estimated mean total shrub cover on upland EVMP monitoring plots in Rocky Mountain National Park, Colorado.	57
Figure 33. Box plots of percent cover of major upland shrub species recorded at EVMP plots in Rocky Mountain National Park baseline through 2023	58
Figure 34. Moose presence in Elk and Vegetation Management Plan (EVMP) core and noncore upland monitoring plots from baseline to 2023.	60

Tables

	Page
Table 1. Vegetation types and their desired future conditions, indicator variables, and thresholds specified in the Elk and Vegetation Management Plan [EVMP] (NPS 2007; Zeigenfuss et al. 2011; Zeigenfuss and Johnson 2015).	xii
Table 2. Count of Elk and Vegetation Management Plan (EVMP) plots by vegetation community type and range type in Rocky Mountain National Park.	13
Table 3. Estimated marginal means of stem density (stems/ha) $\pm$ standard error (se) for short aspen saplings (plants with height ≤ 150 cm) at core and noncore winter range aspen monitoring plots in Rocky Mountain National Park, Colorado, baseline (BL) through 2023.	23
Table 4. Estimated marginal means of stem density (stems/ha) $\pm$ standard error (se) for tall aspen saplings (plants with height > 150 cm) at core and noncore winter range aspen monitoring plots in Rocky Mountain National Park, Colorado, baseline (BL) through 2023.	23
Table 5. Proportion of sampled aspen plots that had observed cervid (elk, moose, deer) or beaver sign from baseline (2006–2009) through 2023.	29
Table 6. Percentage of plots in core unfenced, core fenced, and noncore elk winter range that meet the criteria for desired future condition for regeneration (saplings 151–250 cm height at density of at least 400 per hectare [162/acre]).	33
Table 7. Percentage of elk winter range with plots meeting the desired future condition of at least 75% small diameter (< 10 cm DBH) trees.	34
Table 8. Mean willow heights on suitable willow habitat in the elk winter range of Rocky Mountain National Park from baseline to 2023.	36
Table 9. Mean willow cover on suitable willow habitat in the elk winter range of Rocky Mountain National Park from baseline to 2023.	45
Table 10. Proportion of sampled willow plots that had observed cervid (elk, moose) or beaver sign from baseline (2006–2009) through 2023.	52
Table 11. Proportion of sampled upland plots that had observed cervid (elk, moose, deer) sign from baseline (2006–2009) through 2023.	59
Table 12. Progress toward desired future conditions in relation to thresholds specified in the Elk and Vegetation Management Plan ([EVMP]; NPS 2007; Zeigenfuss and Johnson 2015).	61

Abstract

Fifteen years ago, Rocky Mountain National Park (RMNP) implemented an Elk and Vegetation Management Plan (EVMP) in response to increasing negative impacts of winter elk herbivory on key plant communities. The EVMP is intended to guide the management of elk and vegetation over a 20-year period, reduce the impacts of elk on vegetation, and bring target ecosystems into the natural range of variability for elk and vegetation in aspen, montane riparian willow, and upland herbaceous habitats. Monitoring plots were established at the outset and vegetation data is collected, analyzed, and results are reported every 5 years. These results are used by managers to modify management actions as needed to improve the condition of key habitats on the elk winter range. A small number of aspen and willow sites are also monitored in the Kawuneeche Valley, an elk summer range area that has experienced willow and aspen decline from summer elk herbivory as well as several decades of moose herbivory.

After 15 years of EVMP management, results are mixed. Progress toward improved habitat that was observed through the first 10 years appears to have plateaued in the last 5 years, likely due to several additional factors, namely an increasing moose population and large wildfires which affected EVMP aspen and willow sites. Aspen regeneration and recruitment has steadily increased since baseline and, by 2023, was just short of reaching the 20-year EVMP objective, but most progress has been inside protective fences. Aspen stand structure has improved, but only inside fences and in unfenced, noncore winter range. Willow height increased by 43% relative to baseline conditions and willow cover nearly doubled over the entire winter range, however these increases were mostly limited to fenced areas. Noncore winter range showed only modest willow height and cover gains, while no significant change was observed on unfenced core winter range despite a ~50% reduction in browse intensity. In the Kawuneeche Valley, unfenced willow and aspen have continued to decline. The level of elk grazing on winter range upland herbaceous vegetation has been successfully reduced and no additional grazing-related changes appear to be taking place. Although many EVMP objectives have been met after 15 years, the habitat fences are key to maintaining patches of high-quality habitat and we advise against removing them until other components of the system (beaver communities, restoration of hydrologic regimes, willow recruitment, stable elk and moose populations) are functioning.



Beaver dam inside willow exclosure on the elk winter range of Rocky Mountain National Park, Colorado.
NPS / N. BARTUSH

Executive Summary

Elk have traditionally been the most abundant ungulate species in Rocky Mountain National Park (RMNP), however, the loss of native predators, disruption of traditional migrations, encroachment by human settlement, and habitat change resulted in high concentrations of elk on winter range areas of the Park. In 2008, RMNP implemented an Elk and Vegetation Management Plan (EVMP) in response to increasing negative impacts of winter elk herbivory on willow, aspen, and upland plant communities. The EVMP is intended to guide the management of elk and vegetation over an initial 20-year period to reduce the impacts of elk on vegetation and bring target ecosystems into the natural range of variability for elk and vegetation in aspen, montane riparian willow, and upland communities. A series of vegetation monitoring plots was established in target habitats on the Park's elk winter range and Kawuneeche Valley at the initiation of EVMP. These plots have been monitored since that time and data analysis is conducted every 5 years to assess the status of key habitats. The results of these analyses are reported and used by RMNP managers to assess whether modification of management practices for winter range habitat or the wintering elk herd are necessary to progress toward EVMP objectives. This report presents the progress of the EVMP through year 15 (2023). After 15 years of EVMP management, some habitat areas (mainly those inside fences) have improved and other areas have continued to decline. In some areas, improvement observed over the first 10 years (2008–2018) appeared to have plateaued, with no significant gains or losses in the past 5 years (2018–2023). This plateau in progress is likely due to several additional factors affecting the elk winter range, namely an increasing moose population and large wildfires which have impacted several EVMP aspen and willow sites.

Aspen plots showed mixed success after 15 years of EVMP practices. The percentage of EVMP plots meeting the condition of having desired tall aspen sapling density has steadily increased since baseline and by 2023, is just short of reaching the 20-year objective of 45% across the winter range. Tall sapling density has increased and stand structure has improved, even in unfenced, core winter range plots. While regeneration is on track to meet objectives by 2028, most of this success is confined to inside habitat fences whose purpose is to limit elk and moose herbivory, or to areas burned by wildfires in 2020. Aspen appears to be benefitting from a burst of regeneration in sites that were burned in 2020, but it is too soon to tell whether this increased regeneration will translate into increased recruitment, especially as the fire removed the recruiting cohort of young trees that was becoming established in several stands. We expect, however, the young tree class that is represented by small diameter aspen stems to return within a few additional years if there are no substantial increases in browse intensity.

Overall, willow metrics have now achieved the 20-year objectives identified in the EVMP, namely increased willow height and cover and reduced offtake (i.e. browse intensity), driven mainly by gains inside habitat fences that exclude most elk and moose on the core winter range as well as on the noncore winter range where there are no protective fences. Our analysis indicated that by 2023 willow height had increased by 43% relative to baseline conditions across the winter range. However, these height gains are modest and current mean willow height is only just now moving into

a zone beyond the reach of elk browsing and mean and maximum willow heights are still well within the reach of moose browsing. Progress appears to have slowed for willow between 2018 (10 years after EVMP implementation) and 2023 (15 years). Mean willow height and cover appear to have stalled at roughly 150 cm and about 59% cover in fenced core winter range and noncore winter range sites. Reduction in wintering elk population size and coincident reduction in winter browsing pressure have had virtually no effect on unfenced willows in the core winter range. In the Kawuneeche Valley, willow condition has continued to decline except within fenced areas that remained unburned by the 2020 wildfires. Although the improvement of willow metrics over the first 15 years of the EVMP is encouraging, much more time will be needed to meet the long-term EVMP objectives listed in Table 1.

Table 1. Vegetation types and their desired future conditions, indicator variables, and thresholds specified in the Elk and Vegetation Management Plan [EVMP] (NPS 2007; Zeigenfuss et al. 2011; Zeigenfuss and Johnson 2015). WR=winter range.

Vegetation Type and Desired Future Condition ^A	Indicator	Thresholds/Measures of Progress
Aspen: Higher diversity of age classes, expressed as 1) Distribution of stem diameters reflects many (~75%) small-diameter stems, some (~20%) medium-diameter stems, and few (~5%) large-diameter stems; and 2) at least 45% of aspen plots across the WR regenerating (1–2 regeneration events/decade).	Stem density by height and diameter class	Progressive increase in aspen regeneration above the baseline level of 13% (presence of stems <2 cm diameter at breast height [DBH] reaching 150–250 cm tall). Progressive shift in the distribution of stem sizes toward the desired future condition.
Riparian Montane Willow: Up to 70% willow cover within suitable willow habitat across the WR and mean willow height beyond the reach of elk browsing (2–2.5 m). Within the 20-yr life of EVMP, the goal was a 10% increase over baseline conditions, i.e., mean willow height of at least 1.1 m and mean cover of >31%.	Willow consumption	No net increase in annual willow offtake across the WR above the baseline level of 35%.
	Cover	Progressive increase in willow cover across the WR above the baseline level of 21%.
	Structure	Progressive increase in willow height across the WR above the baseline level of 0.9 m.
Upland Herbaceous: Increased diversity of grazing levels so that not all areas are heavily grazed, but at no point should there be more than 1% of sites consumed at greater than 80% offtake and no more than 15% of sites consumed at 50–80% offtake.	Herbaceous consumption	No net increase in winter upland herbaceous offtake across the WR above baseline levels of 61% ^B , with ≤ 25% of sites with offtake >70% and ≤10% of sites with offtake >85%.

^A Desired future condition of willow not expected to be achieved in the 20-yr timeframe of the EVMP, so an expectation of a lesser desired condition for the life of the EVMP was also identified.

^B Baseline level of offtake in the EVMP Environmental Impact Statement (NPS 2007) was 47%, however, the method for calculating baseline offtake was revised in 2013 resulting in a baseline value of 61% (Zeigenfuss and Johnson 2015).

The level of elk grazing on winter range upland herbaceous vegetation has been successfully reduced and no additional grazing-related changes appear to be taking place based on the very coarse level of sampling currently being done. Given the apparent stability at these sites, unless there appears to be

cause to re-initiate offtake measures or to continue shrub cover measurements, the upland measurements could be discontinued in 2028.

Most habitat improvement in both willow and aspen has occurred within fenced areas. Until other components of the system (beaver communities, restoration of hydrologic regimes, willow recruitment, stable elk and moose populations), are functioning the fences are key to maintaining these patches of high-quality habitat. Passive willow restoration through reduced wintering elk population has resulted in little change to areas of the core winter range outside of fences. We recommend retaining habitat fences, and fencing additional areas in the Kawuneeche Valley, as well as adding fence materials to increase the height of existing winter range fences to reduce moose trespass in these areas of recovering willow and aspen.

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List of Acronyms

BL:	Baseline
CPW:	Colorado Parks and Wildlife
DBH:	Diameter at breast height
EVMP:	Elk and Vegetation Management Plan
GLM:	General linear model
KV:	Kawuneeche Valley
NPS:	National Park Service
RMNP:	Rocky Mountain National Park
ROMN:	Rocky Mountain Inventory and Monitoring Network
SE:	Standard Error
WR:	Winter Range
Yr:	Year

Introduction

Native wild ungulates play an important role in ecosystems worldwide including the diverse habitats of the Rocky Mountains. Large herbivores strongly influence many aspects of forest, shrub, and herbaceous communities in myriad positive and negative ways, both directly and indirectly (Pastor et al. 1988, 1993; Hobbs 1996; Schoenecker et al. 2004). Ungulate browsing can degrade woody vegetation, disrupting functional mechanisms of many riparian and wetland ecosystems (Kauffman et al. 1997). The growth and reproduction of riparian and wetland associated shrub and tree species such as willow (*Salix* spp.), cottonwood (*Populus* spp.), birch (*Betula* spp.), and aspen (*Populus tremuloides*), can be greatly affected by wild ungulates, including elk (*Cervus canadensis*) and moose (*Alces americanus*; Danell et al. 1985; Singer et al. 1994, 1998).

Even though most ecosystems in the western United States have evolved with suites of native ungulates, the effects of ungulate herbivory are not universally positive. Negative effects can range from negligible to moderate to extensive depending on many factors, including: the intensity of browsing; the evolutionary history of the ecosystem; influence of humans on native plants, animals, and habitats; climate conditions; and the seasonal use patterns of ungulates (Hobbs 1996; Bilyeu et al. 2008; Marshall et al. 2013, 2014). When these factors result in degraded natural communities which require restoration, excessive herbivory can be a barrier to the success of restoration actions (Xu et al. 2023).

Rocky Mountain National Park (hereafter RMNP, or “the Park”) encompasses nearly 108,000 hectares (ha) of high-elevation forest, shrublands, meadows, and alpine tundra and rocklands in north-central Colorado. The Park supports numerous species of wildlife, including several large ungulate species. Elk have traditionally been the most abundant ungulate species in RMNP, but wintering elk populations have declined over the past 2 decades and mule deer (*Odocoileus hemionus*) and increasing populations of moose (*Alces americanus shirasi*) also inhabit the Park and use both elk winter and summer ranges. All three species have the ability to strongly shape ecosystem patterns and processes in the habitats they utilize when their overall populations are high or locally concentrated (Hobbs 1996, Connor et al. 2000).

Elk are native to RMNP but were extirpated from the area by the late 1800s. They were reintroduced to RMNP in 1913–1914, and the population steadily increased until it reached an estimated 1,000 animals within the Park boundaries in 1944 (Packard 1947a). Park staff removed animals to maintain a population of 350–800 animals from 1944 until 1968 (Stevens 1980). Starting in 1968, elk populations were no longer controlled within the Park’s boundaries as a result of a change to a U.S. National Park Service management paradigm. This new paradigm, known as natural regulation, allowed the elk population to regulate naturally, through natural predation and forage availability (Stevens 1980). Although hunting was not allowed within the Park, it still occurred outside Park boundaries. The herd increased from approximately 500–600 animals (1969–1975) to a high point ranging from 2,800 to 3,500 (1997–2001). Roughly 1,100 elk wintered primarily inside the Park boundary and the remaining majority wintered in the town of Estes Park (Lubow et al. 2002; National Park Service [NPS] 2007).

The east side RMNP/Estes Valley elk population is part of the St. Vrain elk herd (Colorado Parks and Wildlife [CPW] Data Analysis Unit E-9) which migrates seasonally between high-elevation summer ranges and low-elevation winter-ranges east of the Continental Divide where snow is less deep and forage more available in winter. The primary summer range includes subalpine and alpine areas within the Park, as well as the Kawuneeche Valley (also known as the Colorado River Valley, hereafter KV) on the west side of the Park. Elk use summer range primarily during June, July, and August, migrating up through the winter range in March–May. In September, the majority of the elk herd typically begins to migrate to low-elevation winter range in the Estes Valley on the east side of the Park and adjacent areas outside the Park, as well as areas further east in the foothills at the edge of the Colorado plains (Bear 1989; Larkins 1997; Ben Kraft, Wildlife Biologist, Colorado Parks and Wildlife, oral commun., August 2014 in Zeigenfuss and Johnson 2015). Since 2001, the overwinter distribution of the St. Vrain elk herd has shifted to lower elevations with animals occupying short grass prairie, agricultural, and suburban landcover types outside RMNP between November and March. Increased cow hunter harvest occurring outside of RMNP’s boundary also contributed to lower regional elk population estimates, which may have contributed to a reduction in the number of elk overwintering in RMNP. A portion of the Troublesome elk herd (Colorado Parks and Wildlife Data Analysis Unit E-8) also summers on the west side of the Park, including in the KV, often remaining into the fall hunting season, but wintering at lower elevations >30 km southwest of the Park. Summer elk populations in the park are not counted, however, patterns in CPW’s post-hunt population estimates indicate the two herds combined have fluctuated between 6,000 and 8,000 animals total and have remained relatively stable in size since 2010 (CPW 2005–2023).

Elk winter range (hereafter WR) areas in RMNP are located at lower elevations (~2300–2600 m) on the east side of the Park, and throughout the Estes Valley and surrounding foothills. Large numbers of elk are observed occupying the WR for periods outside the winter season as they migrate between summer and winter ranges, particularly during the spring calving and fall breeding seasons (Bear 1989; Larkins 1997; Lubow et al. 2002). The primary areas used by elk during winter are referenced as either core WR (areas of high elk use) or noncore WR (areas with less intense elk use; Monello et al 2006; NPS 2007; Figure 1).

In 2008, RMNP implemented an Elk and Vegetation Management Plan (EVMP) in response to increasing negative impacts of winter elk herbivory on willow, aspen, and upland plant communities. The EVMP is intended to guide the management of elk and vegetation over an initial 20-year (yr) period to reduce the impacts of elk on vegetation and bring target ecosystems into the natural range of variability for elk and vegetation in aspen, montane riparian willow, and upland communities (NPS 2007). Although the EVMP outlined the first 20 years of progress, it was assumed that many more decades would be required to reach the desired future conditions of willow, aspen, and upland vegetation. Prior to initiation of the EVMP, many studies demonstrated how excessive herbivory was contributing to dramatic changes in the structure of willow communities that dominate wet meadow and riparian areas of the WR (Singer et al. 1998; Singer and Zeigenfuss 2002; Baker et al. 2005). Elk herbivory also suppressed the growth and recruitment of aspen suckers in stands bordering the large open meadows that make up much of the WR, resulting in stands with few small or medium diameter trees (Olmsted 1979; Baker et al. 1997; Binkley 2008; Zeigenfuss et al. 2008). Riparian shrub cover

in Horseshoe and Moraine Parks declined at least 20% between the 1940s and 1996, with the decline in tall willow cover declining roughly 55% over this time period (Peinetti et al. 2002). Willow production was found to be 66% lower in browsed sites, catkin production was 70% lower, and browsed willow had fewer shoots and leaves per stem (Singer and Zeigenfuss 2002). Only 20% of the aspen stands in the Estes Valley contained a cohort of regenerating aspen stems, compared to 45–75% of aspen stands across the larger landscape of the Front Range, and no aspen stands in the Kawuneeche Valley had a regenerating cohort (Suzuki et al. 1999). In the Park, aspen less than 80 years old accounted for 90% of aspen trees and 50% of aspen basal area, and the number of aspen dating to 1975–1995 on the WR fell 80–95% below the level expected from the long-term trend (Binkley 2008).

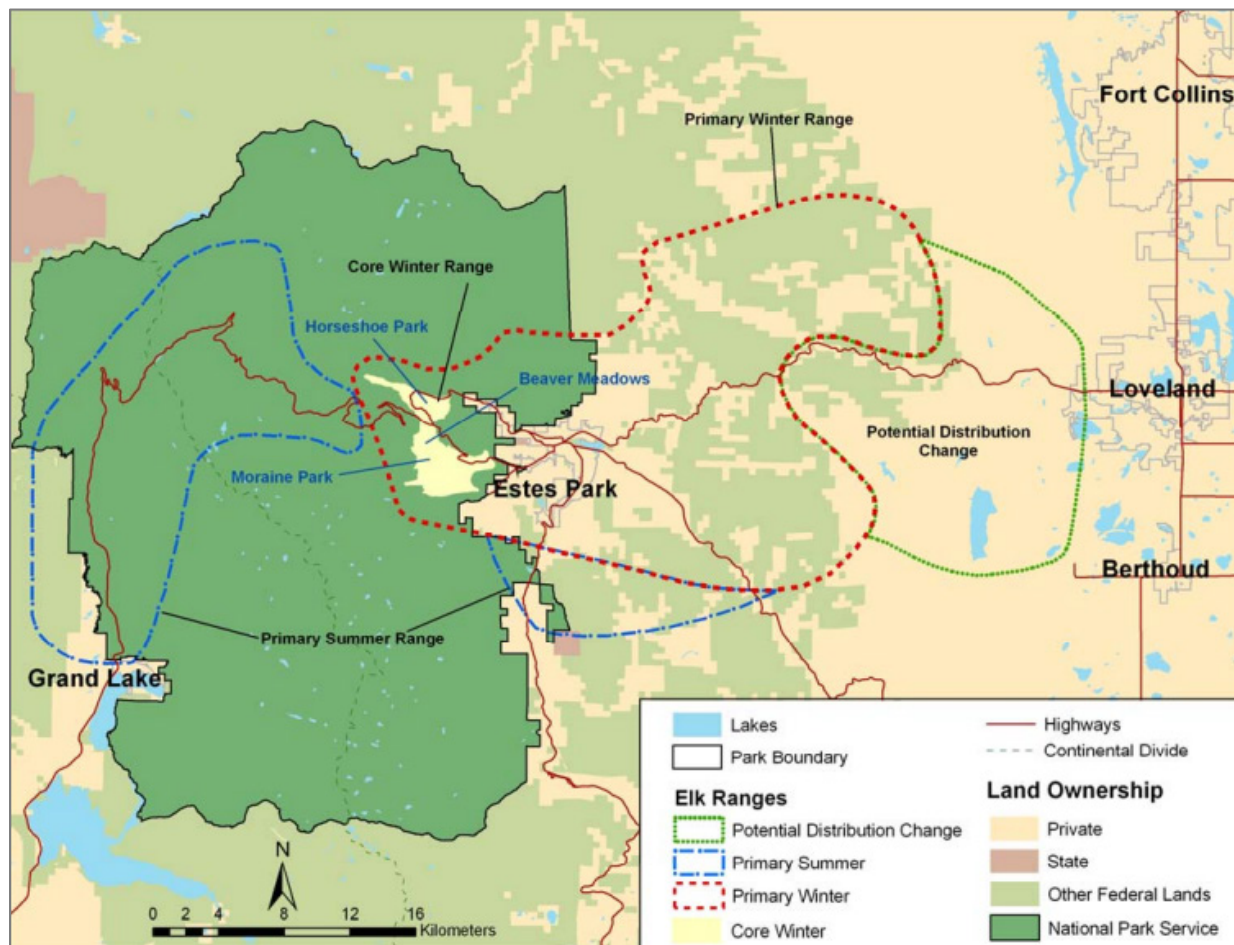


Figure 1. Approximate locations of primary winter range, area of potential distribution change where elk are now wintering in greater numbers, and primary summer range in Rocky Mountain National Park, Colorado (NPS 2007). The elk core winter range sits within the primary elk winter range and was the area with the highest concentration of elk when the Elk and Vegetation Management Plan (EVMP) was written (NPS 2007).

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The wintering elk population objective in the EVMP is 600–800 animals to be achieved through increased hunting outside RMNP and lethal culling of elk in RMNP, if necessary. This population objective was based on modeling that determined the “natural range of variation” of the wintering herd inside the park to be 300–800 animals under natural migration and predation (wolves) conditions and no elk hunting by humans. Model scenarios that held the Park winter elk population at 600–800 elk showed gradual improvement in vegetation conditions, and this was thought to be an achievable population goal (Coughenour 2000; Monello et al. 2006; NPS 2007). Since 2001, the wintering population in the Park has been declining and by 2008 numbered roughly 650 animals wintering in RMNP. The wintering elk population has continued to decline, numbering fewer than 100 animals in the Park since 2020 (Figure 2; Ketzer et al. 2016; Hobbs 2023). Consequently, culling operations have not been conducted since 2011.

The EVMP relies on the principles of adaptive management—an approach that builds on learning (common sense, experience, experimenting, and monitoring) and adjusts management practices based on learned knowledge (Holling 1978; Lancia et al. 1996; Walters 1996; Bormann et al. 1999). The EVMP includes management options such as habitat fencing and active vegetation restoration as well as the non-lethal redistribution and lethal culling of elk herds (NPS 2008). The EVMP allows for fencing of up to 65 ha of aspen and 178 ha of suitable willow habitat in high elk-use areas of the primary summer and winter ranges. RMNP constructed habitat fences around patches of ~20 ha of aspen and 67.5 ha of willow habitat in core elk WR to exclude large herbivores, primarily elk, and facilitate the recovery of vegetation beginning in 2008 and continuing through 2014, with the majority of fencing complete by 2011. A 6.7 ha fence was also installed around willow in the KV elk summer range on the west side of the Park in 2011. Additional areas of willow (2.3 ha WR, 0.6 ha KV) and aspen were fenced as part of earlier research and restoration efforts, and fences were also added in 2007 and 2012 to protect willow areas destroyed by the floods and fire (17.5 ha).

As part of the EVMP, RMNP and the U.S. Geological Survey (USGS) developed a vegetation monitoring plan focused on the goals of the EVMP (Zeigenfuss et al. 2011). The plan included measurement protocols and a statistical sampling design and monitoring schedule. Monitoring plots were established in aspen, willow, and upland communities in core and noncore parts of the WR with initial (baseline) data collected from 2006–2009. In addition to these baseline data, subsets of plots have been sampled annually for vegetation offtake by ungulates and extensive sampling of aspen and willow shrub structure and composition across all plots has been conducted on a five-yr basis (baseline [BL] 2006–2009; 5 years, 2013; 10 years, 2018; 15 years, 2023).

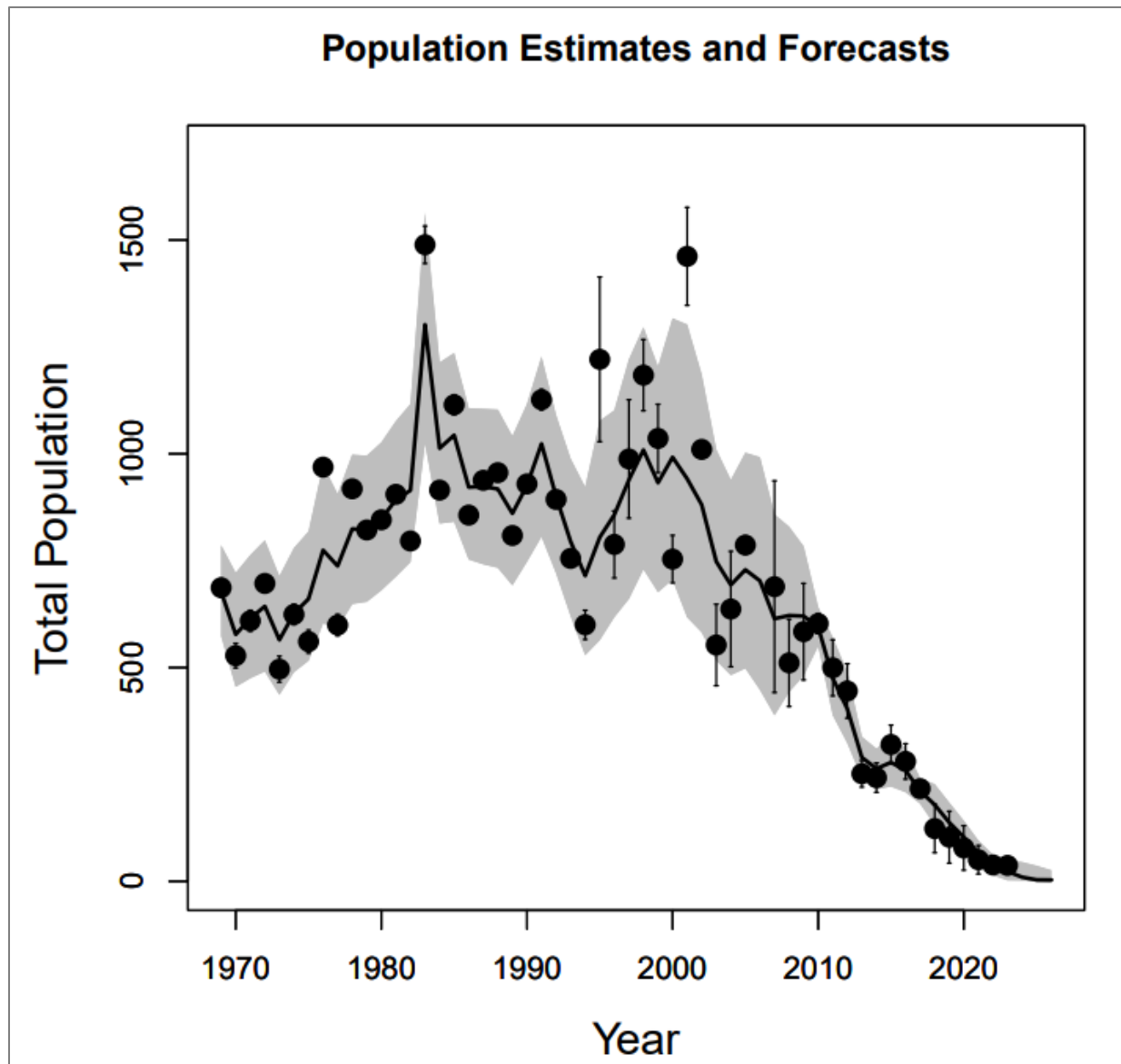


Figure 2. Annual population estimates (filled circles) and medians of the marginal posterior distribution of the true, unobserved elk population size (solid line) on winter range, during the winter, in Rocky Mountain National Park during 1969–2023 and forecasts for 2023, 2024, and 2025. Forecasts assume 0 culling and use 2022–2023 harvest levels for 2023 through 2025. Shaded areas define 95% highest posterior density intervals on the true population size. Vertical lines are approximate 95% confidence envelopes on the mean of the adjusted census estimates (from Hobbs 2023).

TOM HOBBS

The number of elk wintering on the park’s winter range has been on a downward trajectory over the last two decades (Figure 2). An unexplained decline in elk recruitment as reflected by the number of offspring produced per yearling and adult females probably contributed to the declines in elk numbers during 1969–2009 (Hobbs 2023). Recruitment increased during 2009–2017, before leveling off but these changes did not reverse the decline in elk numbers. Redistribution of animals because of movement out of the Estes Valley (Ketz et al. 2018) is likely responsible for most of the reduction in

population size within the WR in winter. The post-hunt population size of the entire St. Vrain herd (as opposed to the population wintering on the Park's WR) has remained relatively stable ($\bar{x}$ = 2,365 from 2016–2019, $\bar{x}$ = 2,234 from 2020–2024; CPW 2005–2023), despite the large areas affected by the Cameron Peak and East Troublesome fires in 2020 (Sadegh et al. 2021; Rodman et al. 2022). Based on empirical data and modeled estimates, a continued decline in the number of elk using the WR is projected (Figure 2).

The Kawuneeche Valley (sometimes referred to as the Colorado River Valley) on the west side of the Park is mainly elk summer range and was not included in the original EVMP monitoring plan. This area supported a higher density of riparian willows than the WR until the early 2000s, when a notable decline in condition of both willow and aspen communities in the area began to be evident. Analysis of historical aerial imagery indicates that willows ≥ 2.0 m tall covered 283 ha of the KV in 1999 and declined by 98% to 7 ha in 2019, while willows < 2.0 m tall increased by 204% from 116 ha to 353 ha (Cooper et al., in review). Willow and aspen decline in the KV were likely influenced by herbivory from an expanding moose population as well as changes in hydrology secondary to declining beaver populations. Hydrologic impacts from the Grand Ditch, increased vulnerability to infection of willows by *Cytospora chrysosperma* (Woods 2000; Kaczynski and Cooper 2013, 2015; Kaczynski et al. 2014), and persistent impacts from historical and extant human use (Schweiger et al. 2016) have also been identified as factors in KV aspen and willow decline.

Historical records indicate that moose, typically bulls, were very infrequently observed in northern Colorado. The lack of moose remains in archeological sites reinforced that moose occasionally wandered in from Wyoming and never established a resident population (Andrews 2011). There is only one recorded historical occurrence of a moose near RMNP when one was reported killed near Estes Park in 1860 (Monello et al. 2006). In 1978, the Colorado Division of Wildlife (now Colorado Parks and Wildlife [CPW]) began introducing moose to the North Park area of the Routt National Forest approximately 25 km NW of the KV (Kufeld and Bowden 1996) and within 2 years, moose were sighted in the KV. CPW also introduced moose to the Laramie River drainage just north of RMNP. By 1988, moose were wintering on the west side of the Park (Dungan and Wright 2005). Dungan (2007) estimated approximately 100 moose inhabited the west side of the Park in the Colorado River drainage during summer 2003. Colorado moose populations have continued to thrive even as many other states experience moose population declines (CPW 2020). Moose inhabit RMNP year-round but are most visible in spring through fall. Previously, moose were most abundant in the KV area (Monello et al. 2006). However, as moose numbers have increased, they have colonized other parts of RMNP and now have been sighted throughout the Park including all drainages that comprise the WR on the east side of the Park (Zeigenfuss and Abouelezz 2018). Recent research on moose population ecology estimated that the moose population in 2019 and 2020 was roughly between 140 and 150 animals (with a density of ~ 0.21 moose/km²), however, the study area covered $\sim 65\%$ of the Park and excluded some areas where high moose densities are expected (i.e. Wild Basin), so estimates for the whole Park would be higher (Abouelezz and Hobbs, in press). As observed elsewhere, RMNP moose highly favor riparian and herbaceous wetland habitats, using them in much greater proportion than their availability on the landscape, particularly during May through September. Moose densities in these favored habitats may be as much as 50–100% greater

than their density on the landscape as a whole. The estimated moose density in more suitable habitats was 0.391 moose/km² in 2019 and 0.281 moose/km² in 2020 (Abouelezz and Hobbs, 2025).

Beaver (*Castor canadensis*) are ecosystem engineers and have historically shaped riparian areas in RMNP (Packard 1947b; Jones et al. 1994; Peinetti et al. 2002; Baker et al. 2005). Beaver populations in RMNP initially declined due to trapping during the 1800s but then rebounded by 1940 (Packard 1947b). More recently, their population decline has been linked to a lack of tall willow needed by beaver for food and dam building (Monello et al. 2006; Schweiger et al. 2019), and this lack of tall willow has been tied both directly and indirectly to elk herbivory (Baker et al. 2005, 2012; Kaczynski 2013). Additionally, loss of beaver in these ecosystems can lead to a downward spiral for willow as habitats created by beaver dams are ideal for willow seedling establishment and growth (Cooper et al. 2006).

Objectives

The EVMP is focused on the influence of elk on vegetation structure and condition for three vegetation communities on the primary elk winter range of RMNP (NPS 2007) and on assessing several community attributes including:

- Aspen stem density and stem size distribution (assessed every 5 years through a full resampling of plots).
- Willow height and cover (resampled every 5 years across all plots).
- Vegetation offtake by herbivores in riparian shrub (with an emphasis on willow, *Salix* spp.) and upland herbaceous communities (both assessed through annual subsampling of plots).

The primary objective of this report is to assess progress toward the EVMP goals over the first 15 years of monitoring. The EVMP outlined the desired future condition for each of the target vegetation types and identified indicator variables associated with these desired conditions which would be monitored over the 20-yr life of the plan (NPS 2007). Thresholds, or more precisely, measures of progress, were identified for each indicator variable in the EVMP to inform adaptive management of landscapes and ungulate populations (Table 1). The EVMP acknowledged that recovery to desired conditions was not likely to be accomplished within the 20-yr timeframe of the plan (particularly for willow), therefore the plan calls for progressive increases toward these goals that are likely to be achieved barring other major changes that might affect vegetation conditions (e.g., fires, floods, novel competing herbivores; Table 1).

Intermediate Reports and Workshops

A report detailing the sample design, sampling protocols, and baseline conditions was produced in 2011 (Zeigenfuss et al. 2011). Detailed analyses were performed after 5 and 10 years of monitoring and these analyses were reported in two separate reports (Zeigenfuss and Johnson 2015; Gage et al. 2023). Two workshops (one addressing elk population objectives and the other vegetation objectives) were convened in 2014 with the purpose of evaluating the findings of the monitoring program thus far and recommending adjustments going forward. A summary of the recommendations of these workshops can be found in Gage and others (2023).

The 5-yr monitoring results (Zeigenfuss and Johnson 2015) found increased small-diameter, tree-sized (stems > 2.5 m height) aspen stems inside habitat protection fences, but in unfenced areas, stand structure was stagnant, with mostly large-diameter older stems and no replacement of small-diameter stems. Aspen saplings (stems $\leq$ 2.5 m height) were recruiting on 29% of sampled plots, an increase from 13% of plots at baseline, mainly due to growth inside fences. After 10 years (Gage et al. 2023), aspen stand structure remained unchanged or declined across sampling periods in unfenced plots across the winter range (WR) and Kawuneeche Valley (KV) with continued patterns of little regeneration and recruitment and steady progression toward stands dominated by large-diameter trees. However, there was a progression towards taller sapling heights and recruitment of small diameter tree-sized stems inside habitat fences. Fenced plots that burned in the 2012 Fern Lake Fire had higher density of aspen saplings than unfenced and unburned plots.

After 5 years, average heights and cover of willow increased within fenced habitat on the core WR and on noncore (all unfenced) WR. Positive trends in willow height and cover continued over 10 years, but were generally restricted to fenced sites, however, modest increases in willow height continued on noncore (all unfenced) WR plots as well. In contrast, willow in unfenced core WR plots had only minor increases in height over the 10 years since the EVMP began. Willow cover increased nearly 5-fold over 10 years within fenced core WR and roughly 1.5-fold in noncore WR but changed little on unfenced core WR. Fencing reduced or eliminated browsing from plots located inside fences, but offtake varied widely among unfenced plots. Patterns of willow browse intensity generally showed a downward trend between 2009 and 2018. Winter herbivory on willows remained steady from over the first 5 years of the EVMP, with no substantial increases or consistent declines in willow offtake. However, by year 5, willow offtake was below the baseline level of 35% and continued below this baseline through year 10.

Upland herbaceous offtake had dropped below baseline levels (61%) across the WR by year 5 and less than 10% of the upland plots had intense herbivory. An expert panel determined that upland vegetation goals had been achieved and recommended discontinuing offtake measures. Herbaceous offtake in upland communities was discontinued after 2013, but continued monitoring of upland shrubs indicated no shift from herbaceous-dominated to shrub-dominated communities that might be indicative of herbivory-induced changes (Milchunas and Lauenroth 1993; Van Auken 2000; Krannitz 2008).

Overall, results indicated that RMNP was making progress toward the vegetation objectives set out in the EVMP, however positive trends were most pronounced in plots protected from ungulate herbivory through fencing. Aspen recruitment, willow height, and willow cover were increasing in fenced WR plots demonstrating that fencing is an effective means of improving condition in aspen and willow habitats in RMNP. Changes outside the fences were slower and less pronounced than inside the fences. Small increases in willow height and cover and aspen regeneration, as well as decreases in upland herbaceous offtake, indicated that the smaller wintering elk population was also contributing to improvement of habitat conditions on the elk WR. In the KV, poor and declining habitat conditions were recorded in unfenced willow and aspen sites. Monitoring results indicated that management actions, such as fencing, planting, and elk redistribution, would continue to be

needed to stop the continued decline of willow and aspen conditions in the KV as well as on some parts of the WR. By 2018, moose presence had increased in WR aspen and willow plots, while beaver presence at our monitoring plots had decreased. The 10-yr report emphasized the need for increased attention to the effects of moose herbivory on WR aspen and willow habitat condition.

Methods

Study Area

The EVMP was developed with a focus on the primary elk winter range (WR) which encompasses three major valleys in the upper montane zone on the east side of RMNP (Marr 1961; NPS 2007). Each of these valleys has a distinct ecological history, influencing current vegetation composition and structure. Geomorphic processes that shaped these areas and their hydrologic regimes vary as does their historical land use and herbivore dynamics. Most of these areas have experienced significant change since Euro-American settlement, particularly as the result of agricultural practices (crop cultivation, domestic livestock grazing) and recreational development (lodges and golf course) prior to their acquisition by RMNP. High levels of elk browsing severely degraded willow communities, and beaver are now mostly absent (Peinetti et al. 2002; Singer and Zeigenfuss 2002). At the outset of the EVMP, willows were commonly in the “short-old” morphotype due to ungulate browsing (Peinetti et al. 2002; Baker et al. 2005), with taller willows limited to the western-most portions of the three valleys, within small research exclosures built to eliminate ungulate herbivory, or outside “core” WR areas.

The EVMP divided the WR into core elk WR, where elk concentrate during winter (Moraine Park, Beaver Meadows, Horseshoe Park), and noncore WR areas that typically have less elk use (Figure 1). Data have also been collected in the Kawuneeche Valley (KV) in the headwaters of the Colorado River, an area supporting extensive wet meadows and areas that were formerly willow-dominated riparian shrublands.

Common species in riparian shrub communities include *Betula occidentalis* (Western river birch), *Alnus incana* subsp. *tenuifolia* (thinleaf alder), and several willows, primarily *Salix monticola* (Bebb), *S. geyeriana* (Andersson), *S. planifolia* (Pursh), *S. bebbiana* (Sargent), *S. drummondiana* (Barratt), and *S. petiolaris*. Wetland meadows are dominated by native and introduced grasses, sedges, and forb species, with additional cover provided by non-willow shrubs. Aspen communities are characterized by a canopy of trembling aspen with aspen suckers, grasses, herbaceous dicots, and shrubs dominant in the understory. Upland grasslands and shrublands make up 43% of the WR (Monello et al. 2006) and contain various grasses (*Agropyron* spp., *Danthonia intermedia*, *Danthonia parryi*, *Hesperostipa comata*, *Bouteloua gracilis*, *Muhlenbergia montana*), sedges (*Carex* spp.), and shrubs including antelope bitterbrush (*Purshia tridentata*), big sagebrush (*Artemisia tridentata*), and rabbitbrush (*Chrysothamnus viscidiflorus*).

In addition to elk, mule deer (*Odocoileus hemionus*) also use areas in the Park year-round, mainly upland shrub communities. Moose are another significant herbivore affecting RMNP aspen and riparian communities. At the beginning of EVMP monitoring, moose sightings on the WR were rare but have increased to the point that moose are regularly observed on the WR.

Monitoring Design

The sample design for EVMP vegetation monitoring was designed to monitor for the response of aspen, willow, and upland habitat metrics to fencing and reduction in elk population size. A stratified

random sampling design was used that stratified each focal vegetation community into elk winter-range zones of fenced core winter-range (aspen and willow only), unfenced core winter-range, and noncore winter-range (Zeigenfuss et al. 2011, Figure 3). Monitoring plots were selected from vegetation communities of interest based on the Park vegetation map (Salas et al. 2005), clipped to the winter-range boundary, and then further subsetted to represent core and noncore winter range (WR) and fenced areas. Random points were generated in each subset and monitoring sites were selected from these points. Details of sample design can be found in the report that presents the monitoring plan and describes baseline data collection (Zeigenfuss et al. 2011).

Initial sample sizes (n=25 upland; n=35 willow; n=20 aspen) for each management subtype (core unfenced/core fenced/noncore) were determined based on data from research studies conducted prior to 2000 for willow and upland. Very little pilot data were available for assessing appropriate sample sizes for aspen plots, so sample sizes were selected based on consultation with experts who had conducted aspen research in the Park. Zeigenfuss and others (2011) used baseline data to perform retrospective power tests for aspen and upland vegetation and determined that the selected initial sample sizes were large enough to detect a 5 percent change in upland herbaceous offtake, willow offtake, and willow cover with a power of 0.90 and a 10 percent change in willow height from our measured baseline condition with power of 0.95 (Zeigenfuss et al. 2011). Baseline plots were established in 2006–2009, with the majority installed by 2008. Therefore, we use 2008 as our baseline year for calculation. Between 2008 and 2013, ~100 ha of habitat fences had been installed on the WR (19 ha aspen, 81 ha willow), and an additional 1 ha of aspen and 4 ha of willow were fenced in 2014. The number of monitoring plots has varied over the 15 years covered in this report, due to the addition of plots to study vegetation response following the 2012 Fern Lake Fire, as well as removal of plots that were destroyed by floods in summer 2013; loss of those plots that were not able to be located in subsequent sample visits; or removal of plots too close to fences or other plots after habitat fences were erected. Excluding plots removed from the data set, there were 245 plots included in this 15-yr analysis—123 willow plots, 74 aspen plots and 48 upland grassland/shrubland plots (Table 2).

Habitat restoration fences, built to exclude elk, are a key element in the EVMP. Comparisons of vegetation characteristics (e.g. height, canopy area) in fenced and unfenced areas is of particular interest (Zeigenfuss et al. 2011; Zeigenfuss and Johnson 2015). Habitat fences were erected with the goal of improving habitat condition inside fenced patches, therefore, only core WR willow and aspen were fenced, and some willow habitat was fenced in the Kawuneeche Valley (KV). No upland habitat, noncore WR aspen or willow habitat, or KV aspen were fenced (Figure 3 and Figure 4).

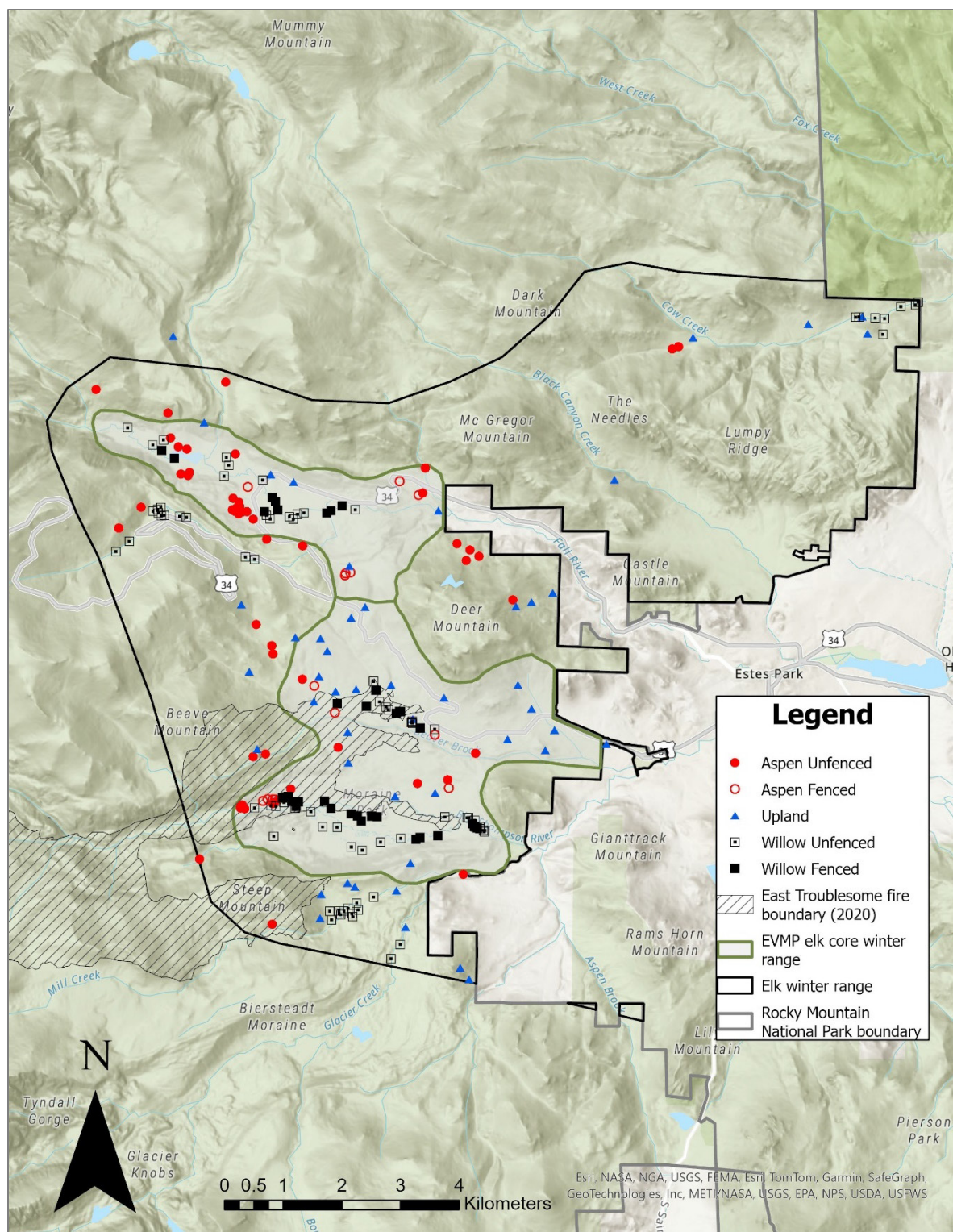


Figure 3. Location of Elk and Vegetation Management Plan (EVM) plots by vegetation type and fencing status used in plot stratification on the Rocky Mountain National Park elk winter range at time of 2023 sampling.

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Table 2. Count of Elk and Vegetation Management Plan (EVMP) plots by vegetation community type and range type in Rocky Mountain National Park. Parentheses denote number of plots that were burned in 2012 and 2020 fires.

Range Type	Total Number of EVMP Sample Plots (and Count of Burned Plots) by Vegetation Type		
	Aspen	Upland	Willow
Core Winter Range, Unfenced	32 (5 ^A , 9 ^B)	25	44 (12 ^A , 9 ^B)
Core Winter Range, Fenced	14 (3 ^A , 6 ^B)	0	36 (16 ^A , 11 ^B)
Noncore Winter Range	20 (1 ^A , 3 ^B)	23	34
Kawuneeche Valley	8 (5 ^B)	0	9 (4 ^B)

^A Total plots burned in 2012 Fern Lake Fire

^B Total plots burned in the 2020 East Troublesome Fire

Wildfires burned through our monitoring areas in Moraine Park in December 2012, and in Moraine Park, Hollowell Park, Beaver Meadows, and the KV in October 2020 affecting 42 willow plots, 23 aspen plots, and 1 upland plot. Plots burned in both fenced and unfenced areas in the 2012 Fern Lake Fire, offering an opportunity to evaluate wildfire effects on aspen and willow communities with and without browsing, so we conducted annual monitoring of a subset of plots for 4 years (2015–2018) to provide information on the short-term effects of fire and ungulate herbivory. Since 2018, these plots were sampled every 5 years to provide information on long-term effects of wildfire and ungulate herbivory. No willow plots and only one aspen plot burned in the noncore WR in 2012 (Table 2), so sampling and inference for fire effects was restricted to the core WR. No additional monitoring was put in place after the 2020 East Troublesome Fire beyond noting whether a plot was burned. All 9 aspen plots that burned in the 2012 fire were burned again in 2020. Ten of the 28 willow plots burned in 2012 reburned in 2020 as well as an additional 14 willow plots, many of which were established in 2014 to replenish the number of unburned willow plots available for analysis following the 2012 Fern Lake fire.

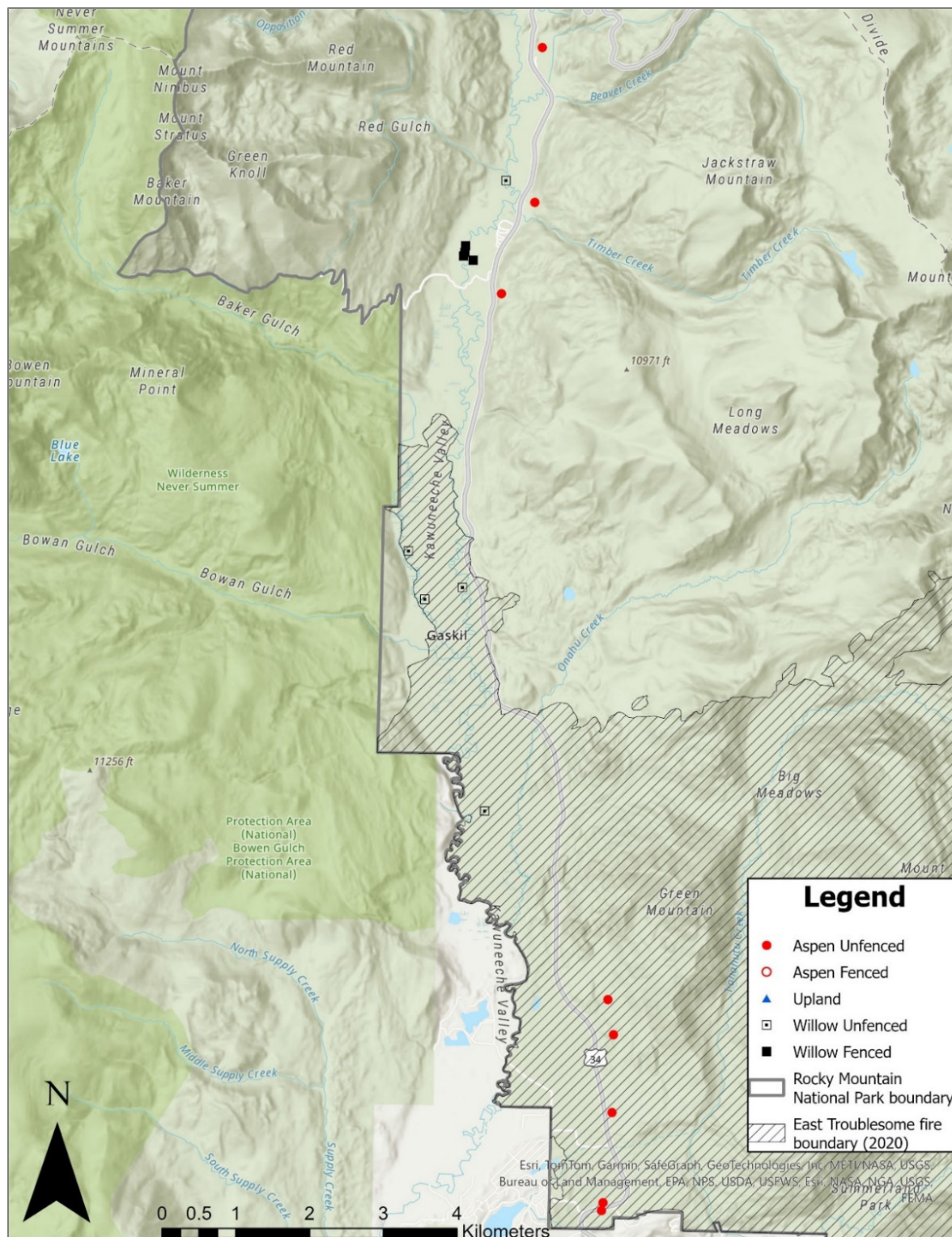


Figure 4. Location of Elk and Vegetation Management Plan (EVMP) plots by vegetation type and fencing status in the Kawuneeche Valley, Rocky Mountain National Park, at time of 2023 sampling. All fenced plots in the Kawuneeche Valley are located in willow habitat. Fire boundary extends to the west beyond the park boundary.

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Even though the KV on the west side of the Park was included in the scope of the EVMP, separate indicators and thresholds for this area were not addressed. Elk use the KV mainly in the summer and the area is used by elk from 2 different herds that winter on opposite sides of the Park (Huerfano 2007; Oldham 2010). Moose browsing was occurring in the KV but not the WR at the time of the Record of Decision (NPS 2007) and had been for over 20 years. Although the KV once supported a robust tall willow community, by 2008, the overall condition of willow and aspen in the KV was much poorer than on the WR. All these factors combined would make it difficult, if not impossible to achieve the EVMP vegetation objectives in the KV within 20 years without more intensive management, so a minimal number of monitoring plots were established in KV aspen in 2008 (Figure 4). In 2011, 8 willow monitoring plots were established in connection with the placement of a large fence around 6.7 ha of willow habitat. However, the single patch of fenced habitat does not constitute the type of large-scale effort needed to restore functional willow communities in the KV, and the Park has now begun a comprehensive restoration effort which will include monitoring many of the elements which are presently part of the EVMP monitoring. Four of the five unfenced EVMP willow monitoring plots in the KV burned in the 2020 East Troublesome Fire, further complicating the limited capabilities for statistical inference from these data. In this report, KV data are presented separately from WR data and do not contribute to the assessments of progress toward EVMP goals. Only minimal descriptive data is included because little statistical analysis can be conducted on this small, non-independent sample.

Baseline sampling occurred from 2006 to 2009 on the WR (2011 through 2014 for KV willow), with revisits occurring through 2023. Because observed changes in willow and upland shrub height and cover can occur slowly, they were measured on a 5-yr rotation. Sampling of all plots was done when plots were established (2006–2009), and in 2013, 2018, and 2023. To capture the effects of weather and ungulate population size on annual consumption rates, offtake was measured annually on a subsample of plots (unfenced only) using a serially-alternating sampling design with a 20-yr monitoring period (2009–2028) divided into five panels (Urquhart and Kincaid 1999; Zeigenfuss et al. 2011).

Vegetation Data Collection

Field data were collected following the protocols of the EVMP monitoring plan (Zeigenfuss et al. 2011). Field methods are very briefly described here; for full details on sampling design and field protocols, see the original monitoring plan (Zeigenfuss et al. 2011), updated protocols stored with RMNP resources staff, and progress reports (Zeigenfuss and Johnson 2015; Gage et al. 2023). The EVMP provides a timetable for sampling as well as specifying field methods for the different variables measured in each community analyzed:

- Aspen
 - Stem density and height/diameter at breast height (DBH) at 5-yr intervals
- Willow
 - Annual browse intensity from 0 to 100% (annual offtake measured through 2023)
 - Willow cover (%) and height at 5-yr intervals

- Upland
 - Annual percent herbaceous offtake from 0 to 100% (discontinued in 2014)
 - Shrub cover from 0 to 100% and height at 5-yr intervals

Aspen

Regeneration and Recruitment

To assess aspen regeneration and recruitment, all live and dead aspen stems were tallied inside 25 m² (5 m × 5 m) square fixed plots with permanently marked corners. Detailed descriptions of field methods can be found in Zeigenfuss and others (2011). Stems were placed into two groups, saplings and trees. Saplings were defined as stems less than 2.5 m in height and were tallied by height class (0–50 cm, 51–100 cm, 101–150 cm, 151–200 cm, 201–250 cm). Saplings are indicative of aspen regeneration at a plot. Trees were defined as stems greater than 2.5 m in height and were tallied in 2 cm width classes from 0–2 cm to DBH > 34 cm. Stem counts were converted to stem density (stems/hectare) by dividing by plot area and scaling up to a hectare.

Willow

All willow plots in core winter range (WR), noncore WR, and Kawuneeche Valley (KV) sites, both fenced and unfenced, were visited during summer (and sometimes early fall) of 2008, 2013, 2018, and 2023 to evaluate willow height and cover. A subsample of unfenced plots was visited annually in spring to evaluate browse intensity. We collected browse intensity data annually to account for the high interannual variability in offtake patterns which can be caused by weather conditions, short-term loss of habitat due to fire and floods, or in response to short-term changes in human use (e.g., road closures or construction). We did not collect separate data on summer browsing intensity.

Height and Cover

Two methods were used for assessing willow cover and height—macroplot and line intercept. For the macroplot method, all willow species within a 16 m² (4 m × 4 m) square plot (the macroplot) were identified to species and measured for cover and height (see Zeigenfuss et al 2011, Zeigenfuss and Johnson 2015, and Gage et al. 2023 for details). Macroplot willow canopy cover was derived by calculating the canopy area of each individual willow that was within or intersected the macroplot—canopy diameter measures were converted to area measures using the elliptical area formula, then multiplying by the proportion of the willow plant that fell within the macroplot. Individual canopy areas were then totaled for the plot and divided by the macroplot area (16 m²) and multiplied by 100 to derive percent willow cover estimate for the plot. For the purposes of this analysis, canopy cover was limited at 100% and cover estimates that were greater than 100% due to plant canopies that overlapped at various heights were set to 100%. Macroplot willow heights were determined by averaging height measures of all willows that fell within the plot. Maximum height for a plot was determined by taking the maximum recorded height from all willow records at a plot each year. For the line intercept method, willow cover and height were measured separately by species along a 5.7 m-long transect bisecting macroplots from east to west. Line intercept willow canopy cover was calculated by totaling the entire length (in meters) of the transect line that was intercepted by willow for the plot and then dividing by 5.7 m (the length of the transect line) and multiplying by 100 to get

a percent cover value. Line intercept mean and maximum heights and average canopy cover for each plot were derived by averaging across all willow on the transect line at a plot. Although, the information gathered using both methods is similar, the macroplot method emphasized in this report is more accurate and intensive than the line intercept method (Zeigenfuss and Johnson 2015). Both methods were built into the protocol to allow flexibility for less intensive data collection, and we analyzed these data to determine if lower intensity line-intercept data might be collected in 2028 (20-yr sample) without losing the ability to accurately determine trends in EVMP metrics.

Browse Measures

Browse intensity (often referred to as percent leader use) was measured annually on a subset of unfenced plots from 2009–2023. This is a measure of the proportion of total browsed shoots on a willow stem and was based on a subsample of twigs and stems selected following documented methods (Bilyeu et al. 2008; Gage et al. 2023) (Equation 1).

$$BI = \left(\frac{b}{b + u} \right)_{(1)}$$

where, b, the number of browsed shoots on the stem; and u, the number of unbrowsed shoots. Browse intensity measurements were gathered throughout the 15 years. These measurements were originally collected for use in the calculation of offtake metrics presented in baseline and 5-yr reports (Zeigenfuss et al. 2011, Zeigenfuss and Johnson 2015). Most measurements of willow browse intensity (BI) were made in mid-April through May, although weather pushed sampling as late as mid-July in some years.

Upland

Shrub Cover and Height

Upland line intercept transect data were collected in core and noncore winter range (WR) areas following established protocols (Zeigenfuss et al. 2011; Zeigenfuss and Johnson 2015; Gage et al. 2023). Shrub species, cover, and height were measured for each shrub whose canopy intercepted a permanently marked 30-m transect line through the plot. Shrub cover was calculated by totaling the entire length (in meters) of the transect line that was intercepted by shrubs for the plot and then dividing by 30 m (the length of the transect line) and multiplying by 100 to get a percent cover value. These measurements were taken from all upland plots at baseline, 2013, 2018 and 2023. Herbaceous offtake was collected during the first sampling period (baseline through 2013) but was discontinued because reduction of elk population and redistribution of herbaceous offtake in line with EVMP objectives were achieved during that time period.

Animal Presence

Due to revisions made to the monitoring protocol over time, sampling consistency for animal presence was variable across years. Elk presence, per se, was not originally recorded because a separate effort surveyed elk winter populations each year and reported elk population size. Prior to 2023, elk presence was mainly recorded at upland and aspen plots, extending back to baseline, but not at willow plots which were generally assumed to have elk presence. However, as wintering elk

numbers declined and moose presence increased at the monitoring sites, we determined that it would be helpful to begin collecting data on elk presence at all monitoring plots and this effort started in 2023. Indicators such as tracks, scat, browse, and elk sightings within the boundary of each plot were considered evidence of presence. Field crews were trained to distinguish scat between cervid species based on the size and shape of the scat, and overall size of scat piles, as well as the preponderance of other evidence in the site (e.g., tracks and browse) when there was a question as to which species were present. In the overwhelming majority of cases, scat alone was not used to determine presence of animal use by a species at a plot.

Moose presence data was not collected in any vegetation plot types during the baseline sampling period and was collected only in aspen plots in 2013. An expert panel that was convened in 2014 to review EVMP results through 2013 identified the apparent increase in moose dispersal from the west side of the Park to the east side as a critical factor potentially influencing vegetation changes on the elk winter range (W)R. Monitoring crews began recording moose presence in all three vegetation types starting in 2018. Indicators such as tracks, scat, browse, and moose sightings within the boundary of each plot were considered evidence of presence.

Beaver presence data was collected in willow plots starting at baseline. Beaver presence data at aspen plots has only been collected in 2013 and 2023. Since beaver do not use upland sites, their presence was not recorded in this type. Indicators such as food caches, cuttings, dams, lodges, tracks, scat, and beaver sightings within the boundary of each plot were considered evidence of presence.

Deer presence was also only recorded throughout the study at the upland plots, but in recent samples, signs of deer presence have been added and now they are specifically noted at all plots.

Data Analyses

Data were transferred from paper datasheets to MS Excel worksheets following baseline and 2013 data collection. In 2018 and 2023, most data were electronically recorded on tablets in the field and then downloaded to Excel. Extensive quality assurance was conducted on the raw data, including checking electronic data against paper data sheets, checking for consistent style and nomenclature between years, updating species name to reflect a single name for each species in cases where scientific nomenclature has varied over time, and conducting exploratory data analysis to identify anomalous data points. Raw data provided by RMNP as MS Excel workbooks were combined and cleaned using R statistical software (R version 4.2.0) to facilitate exploratory data analyses, quality assurance, and statistical modeling. Derived data sets were produced and exported for use in statistical analyses.

We used linear mixed effects models to evaluate whether there was evidence of trends (continuous change in a single direction between years sampled) and differences between management subgroups (unfenced core winter range [WR], fenced core WR, and noncore WR) in variables (aspen sapling density, willow height, willow cover). Management subgroups and time (sample year) and their interaction were treated as fixed effects with individual plots as random effects. All analyses were conducted using R statistical software version 4.4.1 (R Core Team, 2024). Willow height was log

transformed to equalize the variance and modeled using the *glmer* function in package “lme4” (Bates et al. 2014). Aspen stem counts were modeled as general mixed effects models with Poisson distribution using “*glmer*” and zero-inflation where necessary through the package “glmmTMB” (Brooks et al. 2017). Proportion data (cover, browse intensity) were modeled as generalized linear mixed effects models with a beta distribution (Ferrari and Cribari-Neto 2004) which constrains values from 0 to 1, using package “glmmTMB”. Estimated marginal means (i.e., least squares means) and pairwise comparisons between year and management subgroups were estimated using package “emmeans” (Searle et al. 1980; Lenth et al. 2017). Fixed effects were considered significant when the p-value for that effect was <0.05 . Pairwise comparisons that had a p-value of <0.05 were considered significantly different from each other.

We included burned plots in the analyses of aspen and willow variables because the objective of the EVMP monitoring is to assess condition on aspen and willow communities on the entire WR. Removal of the burned plots from this analysis has the potential to inflate willow cover values (as areas where willow burned would no longer be considered representative of the WR) and decrease aspen regeneration and recruitment values (due to the positive effect that fire has on aspen suckering) resulting in an assessment of conditions on only unburned portions of the WR. We recognize, however, that it is important to understand the role of the 2012 and 2020 wildfires on the present conditions measured on the WR and Kawuneeche Valley (KV). Whereas we established several plots in 2013 to examine the comparative differences between burned and unburned plots, we did not undertake a similar effort after the 2020 fire and several plots designated as unburned paired samples in 2013 were subsequently burned in 2020. Therefore, in order to understand the influence of the 2020 East Troublesome Fire on 2023 aspen and willow metrics, we ran analyses again minus those plots burned in 2020 to determine if this resulted in differences to mean values in 2023.

Winter-Range-Wide Estimates of Aspen and Willow

Our estimates of progress toward EVMP objectives for aspen and willow habitat are weighted by the area of existing habitat (as well as potential habitat in the case of willow) in each type of winter range (WR) management group (core fenced, core unfenced, noncore). It is important to include fenced areas in progress toward overall objectives because fenced areas comprise a substantial part of the WR and to entirely omit them from calculations would underestimate overall willow height and cover metrics and aspen recruitment on the WR. If fenced area metrics are included, but not weighted in proportion to the amount of impact they have on the entire WR, then overestimation of progress toward objectives would result. We calculated weighted averages of percent of WR meeting aspen regeneration objectives based on the total amount of aspen area available in the core unfenced, core fenced and noncore WR. The weighted averages used for willow were based on maps of areas with the potential to support willow in Moraine and Horseshoe Parks that were developed by hydrologists and wetland researchers (E. Gage and D. Cooper, Colorado State University, written communication, 2006). In this analysis, rather than try to weight burned areas separately and apply burn-specific value to these areas, we took the more conservative approach that simply uses the area of the 3 major management groups to determine weighting values to apply to range-wide estimates. These estimates are used to evaluate progress toward EVMP goals for each sample year.

Results and Discussion

Aspen

Stand Structure

Trees (Stems > 2.5 m in Height)

By 2023, ~30% of winter range (WR) aspen monitoring plots showed evidence of recruitment of young aspen to the tree canopy and of this 30%, all plots but two had small-diameter trees (< 10 cm DBH) making up over 75% of all tree-sized stems (Figure 5). At baseline, only 13% of WR plots had any small-diameter aspen stems and none of these plots had the high proportions of these smaller trees that would indicate sustainable aspen recruitment (Binkley 2008). However, the shift in stand structure is mainly occurring on monitoring plots inside the habitat fences (Figure 5A), with the remainder in the noncore WR plots (Figure 6). Little change in stand structure has occurred on unfenced core WR aspen with most of these plots containing only large, old, decadent trees or having lost their complement of tree-sized stems entirely (Figure 5B).

Stand structure has gradually changed in 6 of the 20 (33%) noncore WR plots (Figure 6). Small-diameter stems increased in noncore WR over time from 15% of plots having any stems <10 cm DBH at baseline to ~30% of plots by 2023 (Figure 6). However, over half of the noncore plots still had only trees of 20 cm DBH or greater or no tree-sized stems at all by 2018, and by 2023, an additional 2 plots had lost all of their tree-sized stems (Figure 6). One plot had only very small diameter (<2 cm DBH) trees in 2018 and also in 2023. This plot burned in both the 2012 and 2020 fires and this recruitment class was likely a result of growth instigated by burning. This plot also had some small trees (<10 cm) prior to the 2012 burn which may be an indicator that this site had optimal growth conditions, accounting for its rapid recovery from fire. Two plots that burned in 2020 still had no stems that had grown beyond the reach of elk browsing (2.5 m) by 2023.

It may be too soon to determine the effect of the 2020 wildfire on aspen stands outside of habitat fences. At least 3 plots that were showing signs of an increased cohort of small diameter trees by 2018 were burned in the 2020 wildfires. None of these plots had any tree-sized aspen stems as of 2023, however, saplings that began to grow in 2021 may need more time to attain enough height growth to move into the tree-sized category.

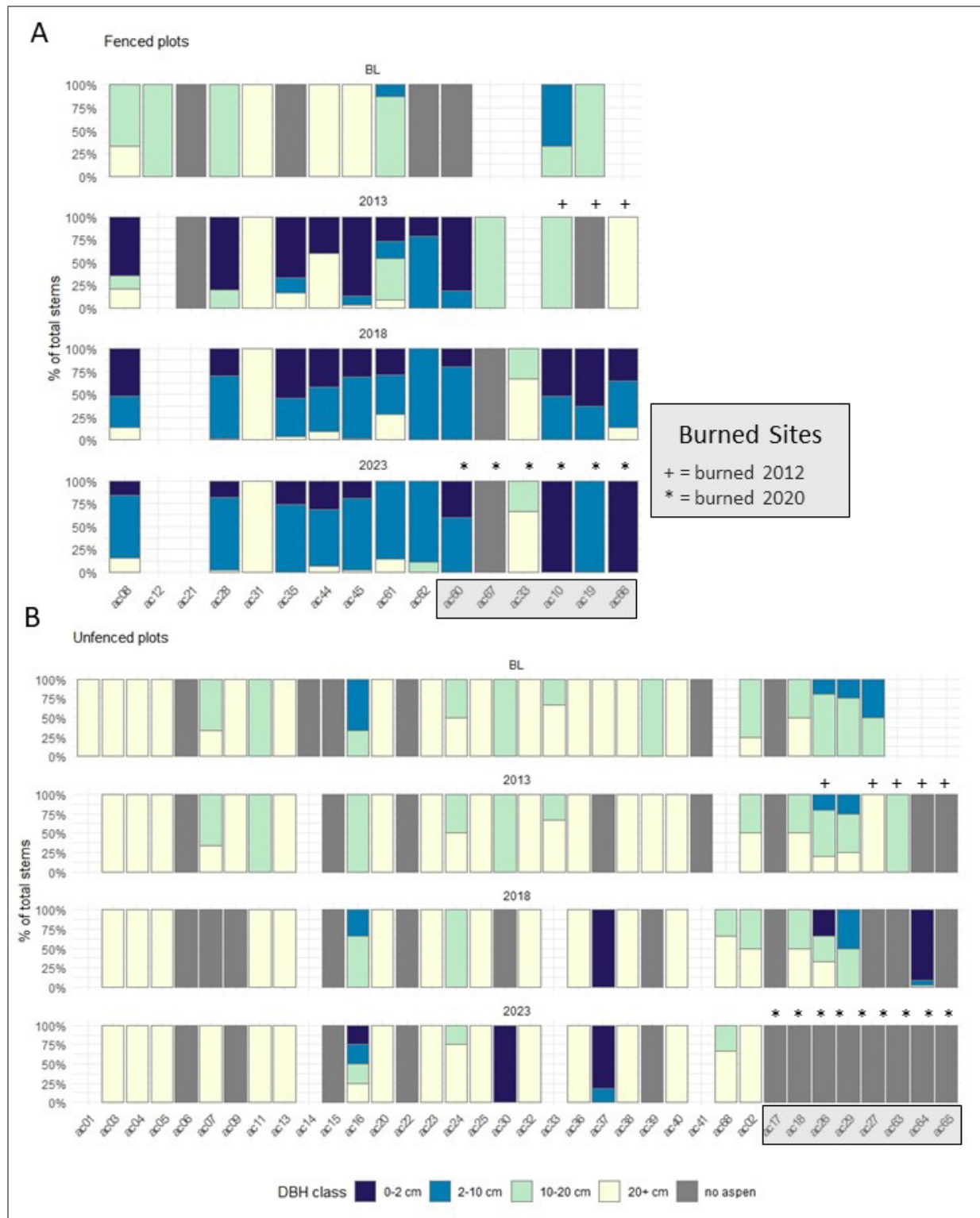


Figure 5. Stand structure of (A) fenced and (B) unfenced aspen trees on the core elk winter range based on diameter at breast height (DBH) size classes. BL= baseline data (collected 2006–2008). Several plots were burned in 2012 and again in 2020.

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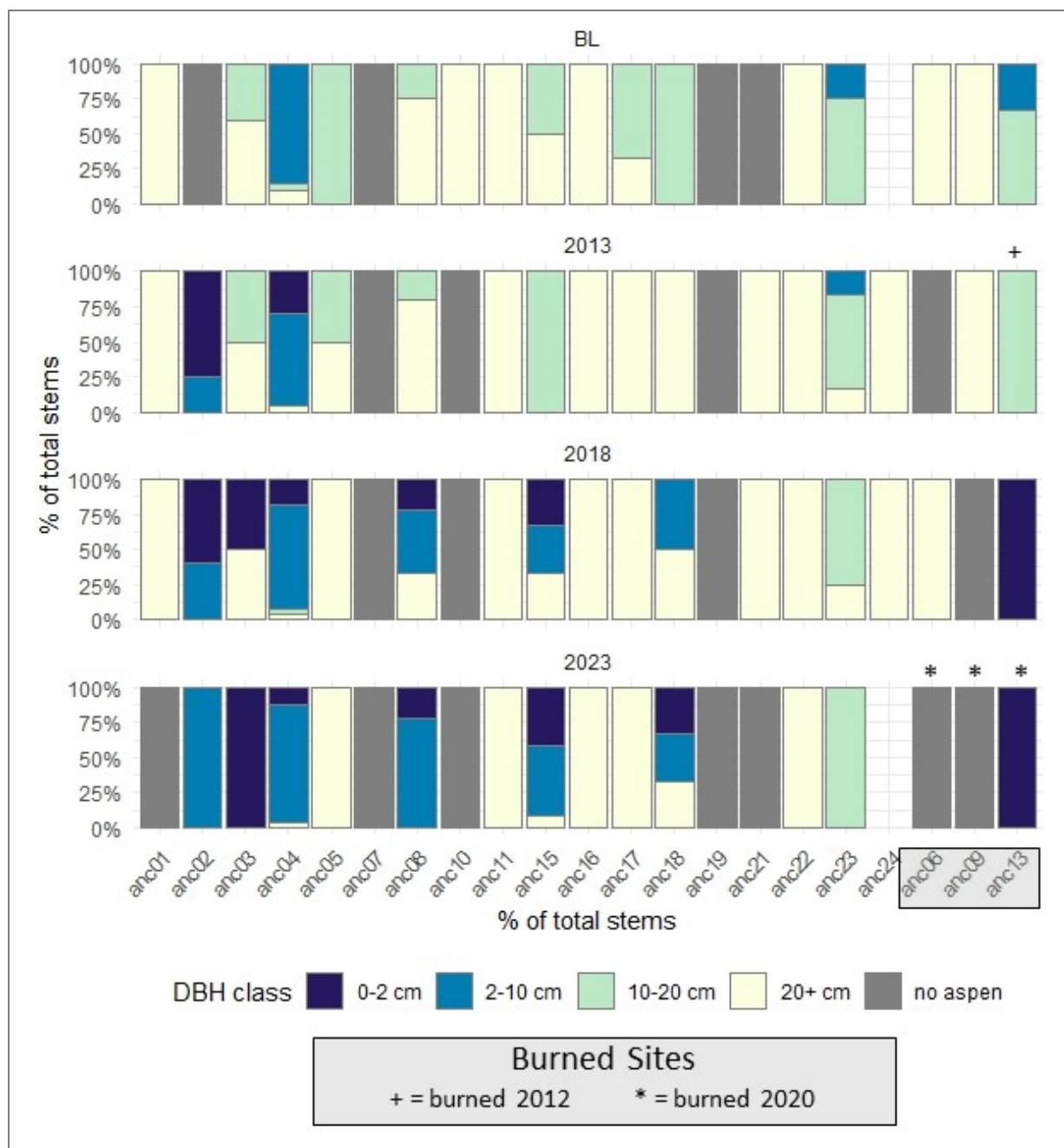


Figure 6. Stand structure of aspen trees on the noncore elk winter range based on diameter at breast height (DBH) size classes. BL= baseline data (collected 2006–2008). All noncore aspen are unfenced. One plot was burned in 2012 and reburned in 2020 along with 2 additional plots.

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Saplings (Stems up to 2.5 m Height)

Total aspen sapling density did not change significantly over the 15 years since baseline, however, the density of saplings falling into the “tall” height category (1.5 to 2.5 m height) had increased significantly by 10 years after EVMP implementation and this increased density was sustained through the 15-yr sample (Tables 3 and 4). Short sapling density was greater at baseline in plots that

were eventually fenced to exclude elk compared to unfenced aspen plots, both in the core winter range (WR) or noncore WR (Table 3, $P \leq 0.05$). This is not surprising as sites selected to be fenced were those expected to have the greatest potential for successful aspen recruitment based on apparent abundant aspen regeneration prior to fencing. This high density of short saplings significantly decreased in fenced plots over the following 15 years, as tall sapling and small tree density increased and crowded out shorter stems (Table 3).

Table 3. Estimated marginal means of stem density (stems/ha) $\pm$ standard error (se) for short aspen saplings (plants with height ≤ 150 cm) at core and noncore winter range aspen monitoring plots in Rocky Mountain National Park, Colorado, baseline (BL) through 2023. Includes plots burned by the Fern Lake Fire in 2012 and East Troublesome Fire in 2020.

Year	Range Type		
	Core Range, Unfenced (mean $\pm$ se)	Core Range, Fenced (mean $\pm$ se)	Noncore Range (mean $\pm$ se)
BL	6136 $\pm$ 796	12056 $\pm$ 2188 ^A	3836 $\pm$ 628
2013	7904 $\pm$ 1004	9396 $\pm$ 1660	4568 $\pm$ 736 ^A
2018	8128 $\pm$ 1052	2904 $\pm$ 540 ^A	6688 $\pm$ 1052
2023	8728 $\pm$ 1112 ^A	5428 $\pm$ 968	5868 $\pm$ 940

^A Means are significantly different between range-type within a given year (also shaded in gray).

Table 4. Estimated marginal means of stem density (stems/ha) $\pm$ standard error (se) for tall aspen saplings (plants with height > 150 cm) at core and noncore winter range aspen monitoring plots in Rocky Mountain National Park, Colorado, baseline (BL) through 2023. Includes plots burned by the Fern Lake Fire in 2012 and East Troublesome Fire in 2020.

Year	Range Type		
	Core Range, Unfenced (mean $\pm$ se)	Core Range, Fenced (mean $\pm$ se)	Noncore Range (mean $\pm$ se)
BL	5 $\pm$ 6	38 $\pm$ 33	27 $\pm$ 19
2013	16 $\pm$ 11	166 $\pm$ 122 ^A	74 $\pm$ 43
2018	33 $\pm$ 20 ^A	430 $\pm$ 257	175 $\pm$ 91
2023	77 $\pm$ 42	362 $\pm$ 219	122 $\pm$ 68

^A Means are significantly different between range-type within a given year (also shaded in gray).

Very few plots had any tall saplings (150–250 cm height) at baseline sampling, and variability in tall sapling counts was very high (Table 4, Figure 7), resulting in no significant differences in tall aspen sapling density at baseline ($p > 0.05$). By 2013, we observed tall sapling densities inside fences that were greater than densities on their unfenced core WR counterparts. By 2023, both core fenced (Figure 7) and noncore WR plots had greater density of tall, recruiting saplings than unfenced core WR plots (Figure 8). Although the mean densities had dropped compared to the previous sample in 2018, these declines were not statistically significant (Table 4). Despite being unfenced, noncore WR plots did have an increase in tall sapling density that was significantly higher by 2018 than at

baseline (Table 4). Although many fenced core WR aspen plots had abundant regeneration, few stems were able to grow beyond 150 cm in height, and even fewer were able to grow substantially beyond the height of elk browsing (≥ 2.5 m). Some plots had almost no saplings throughout the 15 years (Figure 8).



Figure 7. Comparison of vegetation composition over time at plot AC35 inside aspen enclosure in HP30 at Little Horseshoe Park. Baseline composition at time of fence construction (A, fall 2009); and aspen regeneration after 4 years (B, summer 2013), nine years (C, summer 2018), and 14 years of protection from ungulate browsing (D, summer 2023).

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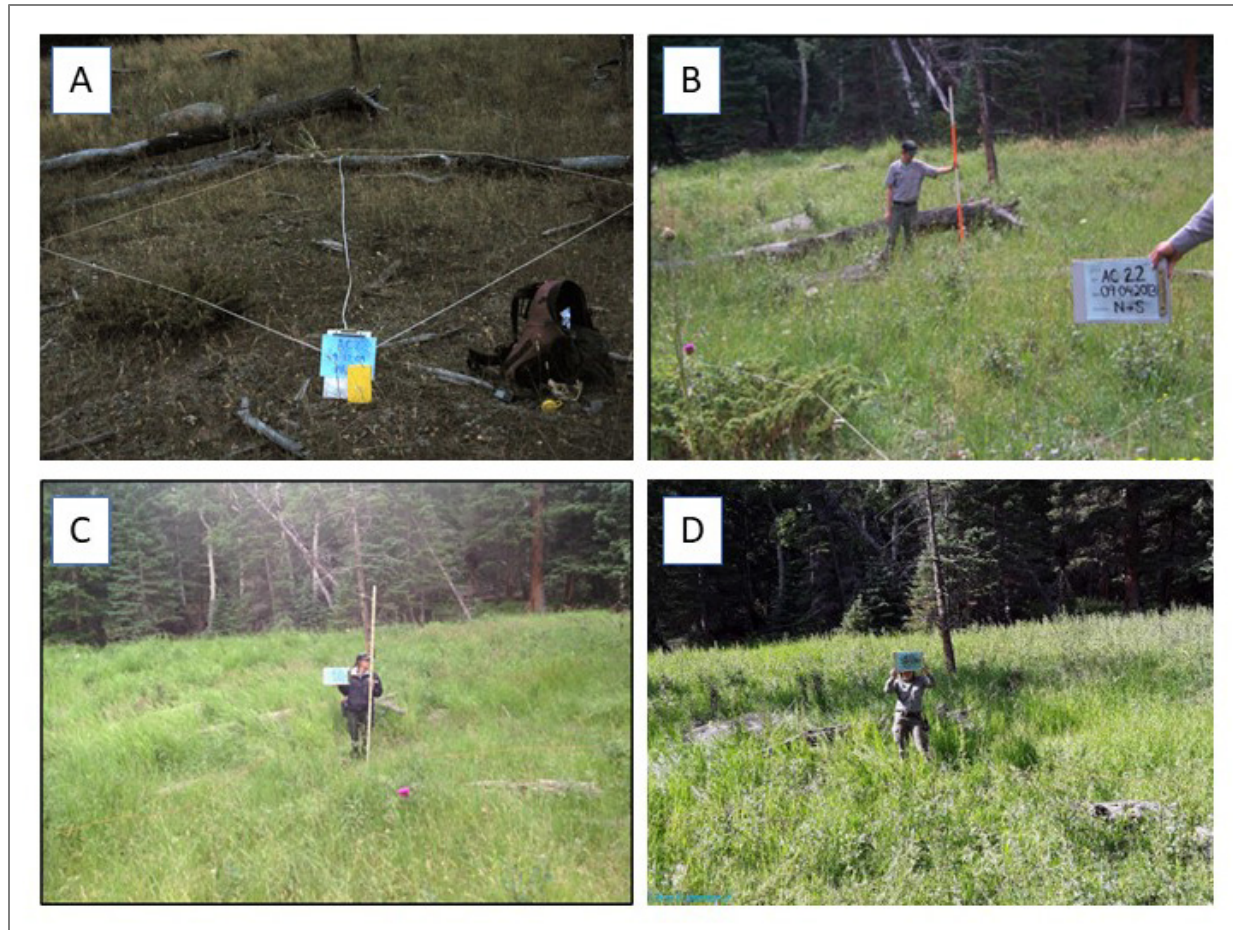


Figure 8. Comparison of vegetation composition over time at unfenced plot AC22 in west Horseshoe Park. Little to no aspen regeneration at baseline (A, fall 2009), five-yr EVMP sample (B, summer 2013), ten-yr EVMP sample (C, summer 2018), and 15-yr EVMP sample (D, summer 2023).

NPS

A total of 17 EVMP plots on the WR were affected by wildfires in 2012 and 2020. Aspen regeneration increased following the 2012 wildfire and this increased regeneration led to increased recruitment of aspen to tree-sized stems by 5 years post-burn in 2018, though much more successfully inside fenced areas (Figures 5, 6, and 9). A recruitment response has not yet been observed for most plots burned in the 2020 fire by 2023, however this may have been too soon to observe recruitment response, particularly as the fire burned very hot. An analysis of just those plots that burned in 2020 had a mean short sapling density of ~22,500 stems/ha and tall sapling density of ~6,600 in 2023. We observed average regeneration at burned plots 3–20 times greater than unburned plots in 2023, however, we caution that these are raw means. This analysis was highly unbalanced as we did not endeavor to create a matched set of comparison unburned plots after the 2020 fire as we did following the 2012 fire.



Figure 9. Photo series of fenced plot AC64 shows abundant aspen regeneration in 2013 (A) following the 2012 fire, followed by good recruitment of tall aspen saplings in 2018 (B). The site reburned in 2020 and by 2023 (C), was again showing high density of regenerating aspen.

NPS

Because fire can stimulate regeneration in aspen, we felt it was important to determine whether differences seen in the 15-yr analysis of aspen regeneration and recruitment were attributable to effects of the 2020 wildfire. We reran the analysis after removing all the plots that burned in 2020 and compared the results for similar patterns. In both 2013 and 2023, estimated mean short sapling density in fenced plots was much lower when the burned plots were removed (more than 1 standard error [SE] lower) than means that included burned plots. For unfenced core plots, only 2013 had mean density values that were more than 1 SE lower than the untrimmed dataset. However, analysis of noncore WR plots yielded similar mean values with and without the burned plots. We concluded that the 2020 wildfire resulted in a burst of regeneration that has contributed to overall increases in aspen saplings less than 150 cm height, primarily inside the habitat fences.

When we removed the plots that burned in 2020 from the analysis of tall sapling density, our results were very different depending upon range/management type. Unfenced core WR plots had lower mean density of tall aspen in all years without the burned plots, but fenced plots had higher mean density in all years. Estimates of tall sapling density in noncore WR plots was within one standard error of means estimated when burned plots were included. We interpret this to mean that the aspen plots that were burned did not substantially affect density of recruiting saplings on the noncore WR plots but did affect density of recruiting saplings on the core WR. The differences also illustrate that fencing appears to facilitate a more rapid transition of regenerating saplings toward a height beyond the reach of ungulates and potentially toward increased aspen recruitment.

Kawuneeche Valley

Aspen sites in the Kawuneeche Valley (KV) have remained stagnant or declined over the 15 years since EVMP implementation (Figure 10). We observed little change to stand structure or aspen regeneration with the notable exception of 5 plots that burned in 2020 (Figures 11 and 12). These plots had increased density of short saplings (stems ≤ 150 cm height) in 2023, but unlike burned aspen on the winter range (WR), only one of these burned plots had any tall saplings (150–250 cm height) by 2023 (Figure 11). This single plot of the 8 KV aspen plots had met the criteria for successful regeneration (≥ 400 stems/ha between 150 and 250 cm height) but still did not have a recruiting cohort (stems > 250 cm height with DBH < 10 cm). It is important to remember that elk

and moose populations in the KV have not experienced the changes observed on the WR, where wintering elk numbers have declined since BL and moose numbers appear to have increased.

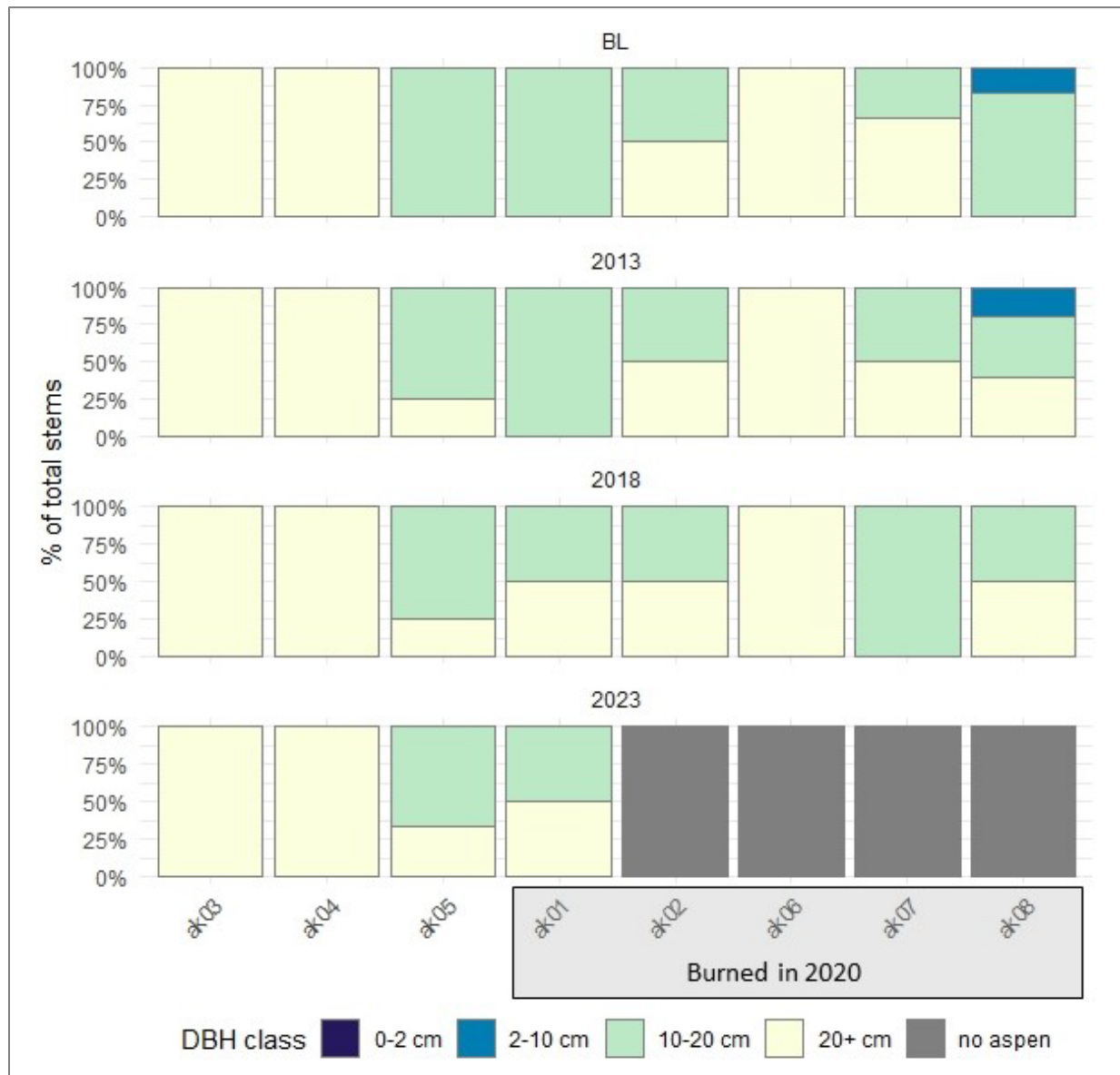


Figure 10. Stand structure of aspen trees in individual Kawuneeche Valley aspen plots based on diameter at breast height (DBH) size classes. All Kawuneeche Valley aspen are unfenced. BL= baseline data (collected 2006–2008).

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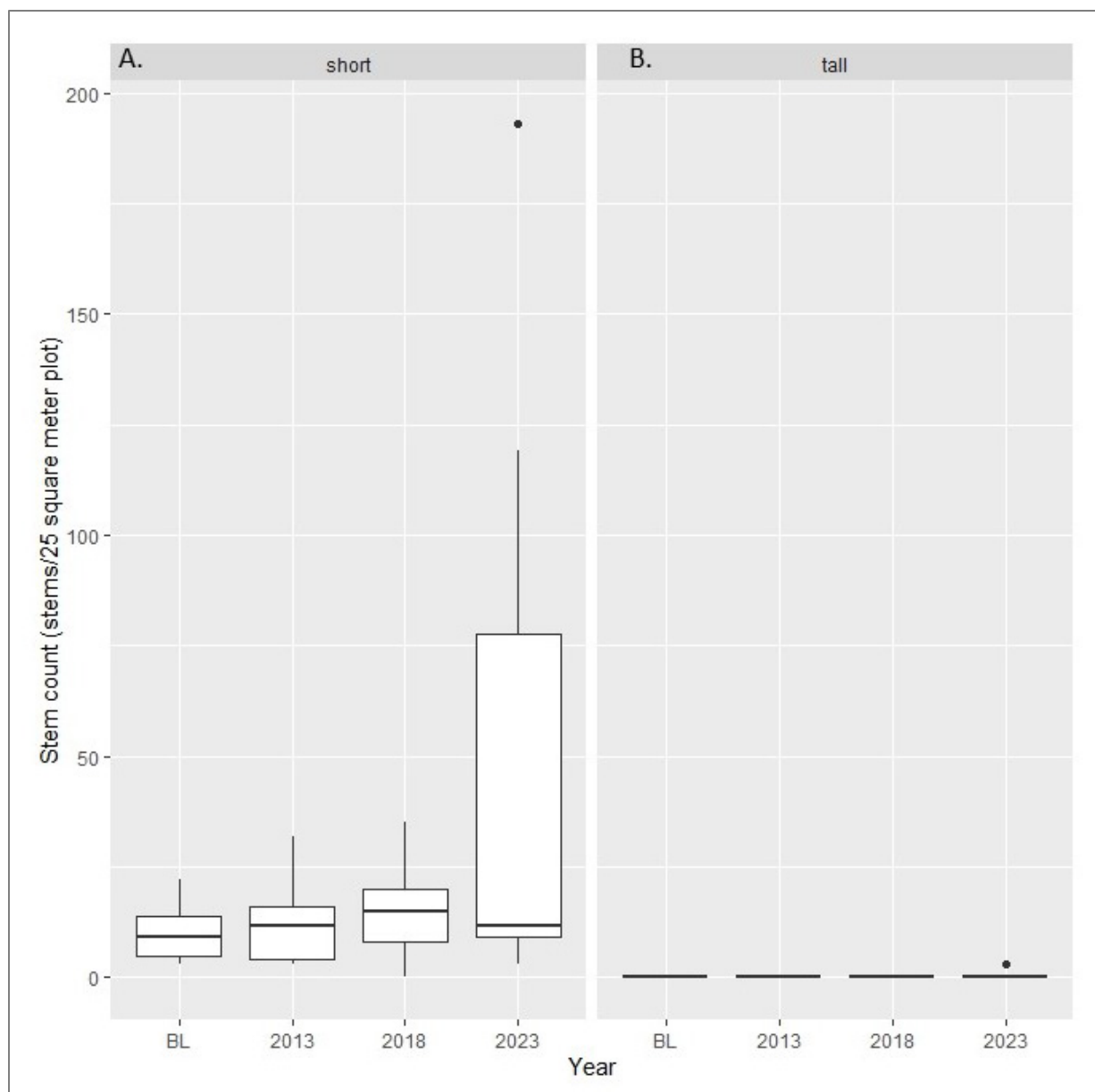


Figure 11. Box plots of aspen density (stems/acre) for (A) short (≤ 150 cm height) and (B) tall (151–250 cm height) aspen saplings in the Kawuneeche Valley of Rocky Mountain National Park. BL= baseline data (collected 2006–2008). A single plot that was burned in 2020 drives the increased range of short sapling density values in 2023.

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Figure 12. Photo series of Kawuneeche Valley aspen plot AK1 showing little to no regenerating aspen at 2013 (A), 2018 (B), or 2023 (C). This plot burned in 2020, but regeneration was very limited with understory dominated by herbaceous plants and no saplings taller than 150 cm.

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Animal Presence in Aspen Sites

Overall, signs of elk presence at EVMP aspen plots were fairly consistent except for the noncore winter range (WR) (Table 5). Whereas only about 2/3 of aspen plots had elk sign in 2013 and 2018, nearly all noncore plots had elk sign in 2023. Moose sign increased throughout the 15 years since EVMP implementation with evidence of moose appearing earlier in noncore WR aspen plots. By 2023, signs of moose presence were recorded in over 60% of WR aspen plots (Figure 13). Deer presence in WR aspen plots also appeared to increase over time (Table 5, Figure 14). Prior to 2023, signs of deer presence were observed on 25% or fewer plots each sample period, but by 2023, deer sign was observed on over 60% of unfenced WR plots, and at half the aspen plots within fencing. The 18-inch gap at the bottom of exclosure fencing was designed to allow passage of mammals including deer. These results are not statistically significant nor rigorous and should be interpreted with caution. However, they may serve as an indicator that factors such as habitat loss due to wildfire or changing population dynamics of moose and elk on the WR *might* be providing an opportunity for deer to start exploiting habitats that they previously avoided, and further investigation of deer use in aspen stands may be warranted. Several studies have found mule deer browsing has similar effects on aspen height and stem density as elk browsing (Kay and Bartos 2000; Rhodes et al. 2018a, b). Both CPW post-hunt deer population for the game management unit that includes the WR and coarse analysis of RMNP deer counts in the Park showed increases in population trend from 2013 to 2023 overall, however, numbers appear to be trending slightly downward since 2019. Beaver presence at EVMP aspen plots has been uniformly low throughout the monitoring period (Table 5).

Table 5. Proportion of sampled aspen plots that had observed cervid (elk, moose, deer) or beaver sign from baseline (2006–2009) through 2023. Total sample size for each year and range type is in parentheses. Blank entry indicates data not collected in that year.

Animal Species	Range Type	Proportion of Plots with Animal Sign (Total Sample Size)			
		Baseline	2013	2018	2023
Elk	Core winter range, Unfenced	–	0.75 (32)	0.69 (32)	0.81 (32)
	Core winter range, Fenced	–	0.21 (14)	0.07 (14)	0.21 (14)

Table 5 (continued). Proportion of sampled aspen plots that had observed cervid (elk, moose, deer) or beaver sign from baseline (2006–2009) through 2023. Total sample size for each year and range type is in parentheses. Blank entry indicates data not collected in that year.

Animal Species	Range Type	Proportion of Plots with Animal Sign (Total Sample Size)			
		Baseline	2013	2018	2023
Elk (continued)	Noncore winter range	–	0.67 (21)	0.71 (21)	0.95 (20)
	Kawuneeche Valley, Unfenced	–	0.62 (8)	1.00 (8)	0.62 (8)
Moose	Core winter range, Unfenced	0.00 (31)	0.00 (32)	0.40 (32)	0.75 (32)
	Core winter range, Fenced	0.00 (11)	0.00 (14)	0.14 (14)	0.14 (14)
	Noncore winter range	0.00 (9)	0.05 (21)	0.48 (21)	0.60 (20)
	Kawuneeche Valley, Unfenced	–	0.75 (8)	0.88 (8)	0.75 (8)
Deer	Core winter range, Unfenced	–	0.25 (32)	0.19 (32)	0.62 (32)
	Core winter range, Fenced	–	0.00 (14)	0.00 (14)	0.50 (14)
	Noncore winter range	–	0.19 (21)	0.14 (21)	0.90 (20)
	Kawuneeche Valley, Unfenced	–	0.25 (8)	0.12 (8)	0.25 (8)
Beaver	Core winter range, Unfenced	0.00 (31)	0.03 (32)	0.00 (32)	0.03 (32)
	Core winter range, Fenced	0.00 (11)	0.00 (14)	0.00 (14)	0.00 (14)
	Noncore winter range	0.00 (9)	0.00 (21)	0.00 (21)	0.05 (20)
	Kawuneeche Valley, Unfenced	0.00 (5)	0.00 (8)	0.00 (8)	0.00 (8)

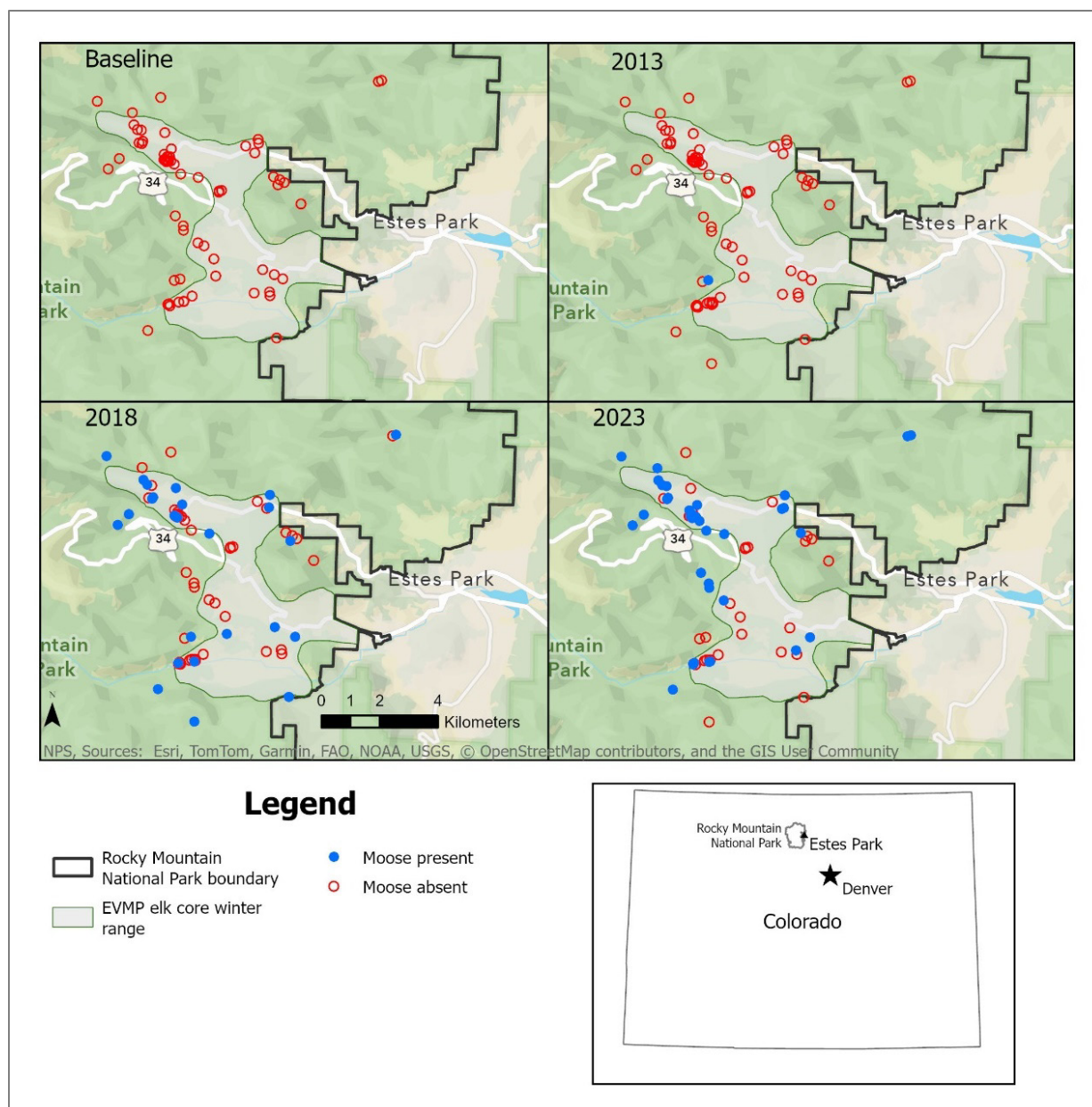


Figure 13. Moose presence detected in Elk and Vegetation Management Plan (EVMP) core and noncore aspen plots from baseline to 2023. Moose presence in aspen plots was added to the protocol in 2013.
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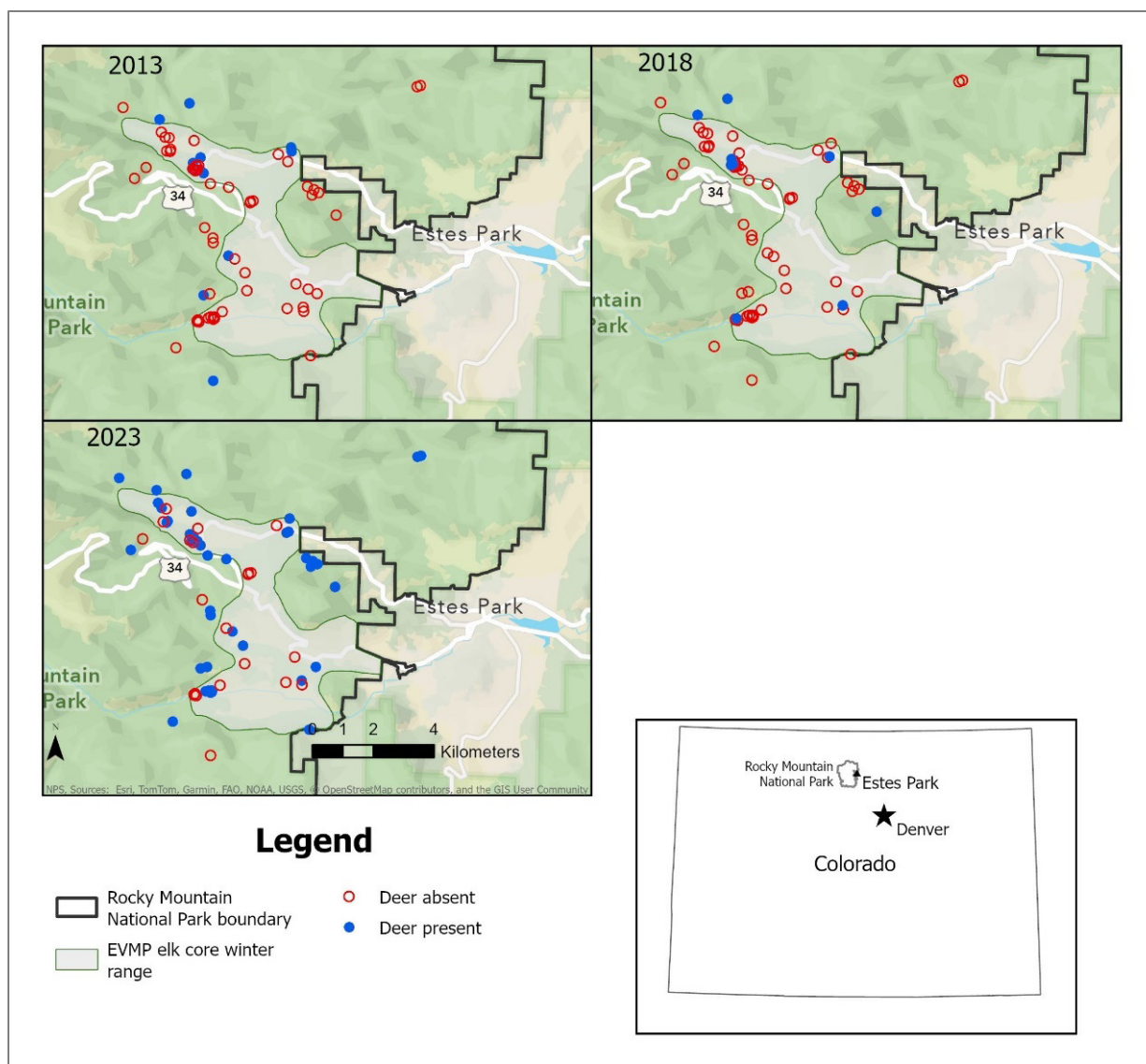


Figure 14. Deer presence detected in Elk and Vegetation Management Plan (EVMP) core and noncore aspen plots from 2013 to 2023.

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Progress Toward EVMP Aspen Objectives

Two metrics are identified in the EVMP as key to determining whether the aspen stands are improving in condition—regeneration and recruitment of young aspen as reflected by 1) aspen sapling density of 400 stems/ha (161 stems/acre) that are between 1.5 and 2.5 meters in height; and 2) a stand structure with 75% small diameter trees, 20% medium diameter trees, and 5% large diameter trees. The percentage of EVMP plots meeting the condition of having desired tall aspen sapling density has steadily increased since baseline and by 2023, is just short of reaching the 45% goal across the winter range (WR). Tall sapling density has increased each year, even in unfenced, core WR plots. The greatest increases still occur inside the habitat fences, however, fenced aspen

account for only about 12.5% of all core WR aspen area (Table 6) so they do not heavily weight the overall totals.

Table 6. Percentage of plots in core unfenced, core fenced, and noncore elk winter range that meet the criteria for desired future condition for regeneration (saplings 151–250 cm height at density of at least 400 per hectare [162/acre]). Entire winter range estimate is weighted to account for the proportion of total winter range aspen area within each range type. Baseline sampling occurred from 2006 to 2008 on the winter range.

Range Type	Sample Year			
	Baseline	2013	2018	2023
Entire Winter Range	7%	21%	32%	43%
Core Winter Range Total	4%	18%	28%	40%
Core Winter Range, Fenced	15%	64%	93%	86%
Core Winter Range, Unfenced	3%	12%	19%	34%
Noncore Winter Range Total	15%	28%	43%	50%

The EVMP identified a progressive increase in aspen stand structure above the baseline level as a management objective for aspen. Not surprisingly, this metric has a slower response since tree diameter growth occurs on a decadal scale and may be particularly affected by climate conditions (less diameter growth occurs in drought years). The percentage of plots in the desired future condition of 75% small diameter (<10 cm) aspen trees rose from 0% in the core WR, increasing to 15% of plots in 2023 (Table 7). Most of this increase was inside the habitat fences where 79% of plots had small diameter aspen trees by 2023 (Table 7), and overall, fenced sites maintained stable recruitment of young trees through 2023, despite several sites being burned by wildfire in 2020 (Figure 9). On the unfenced core WR, there was no change in stand structure from 2018 to 2023, and the 2020 wildfire wiped out potential gains at 3 plots that were seeing increased recruitment in 2018. Several unfenced plots that had an expanding cohort of small diameter trees in 2018 (but less than the 75% threshold for successful recruitment), had not recovered any small diameter trees in the 3 years since they were burned by the East Troublesome Fire in 2020 (Figures 5 and 9). In contrast, noncore WR aspen has shown a steady increase of successful recruitment with an additional 5% of plots joining those plots meeting the desired future condition for this metric every 5 years through 2018 and then doubling between 2018 and 2023. Overall, noncore WR aspen plots had an increase of desirable stand structure from 5% at baseline to 30% after 15 years of EVMP implementation. It must be noted that the stand structure for many stands that have >75% small diameter trees still don't have desirable distribution of medium and large stems. This will take a longer time to achieve as many sites have gaps in their size distribution created by long periods with no aspen recruitment prior to EVMP implementation.

The EVMP does not have set objectives for aspen in the Kawuneeche Valley (KV), but our monitoring indicates that these aspen are in very poor condition. The lack of regeneration following

the 2020 wildfire is concerning. Out of 6 plots that burned, only 2 had regenerating aspen greater than 100 cm in height after 3 years post-burn.

Table 7. Percentage of elk winter range with plots meeting the desired future condition of at least 75% small diameter (<10 cm DBH) trees. It should be noted that only one plot had distribution of medium (10–20 cm DBH) and large (>20 cm DBH) diameter trees similar to the desired condition (20% medium diameter and 5% large diameter) at baseline. Baseline sampling occurred from 2006 to 2009 on the winter range.

Range Type	Sample Year			
	Baseline	2013	2018	2023
Entire Winter Range	1%	5%	14%	19%
Core Winter Range Total	0%	4%	14%	15%
Core Winter Range, Fenced	0%	29%	71%	79%
Core Winter Range, Unfenced	0%	0%	6%	6%
Noncore Winter Range Total	5%	10%	14%	30%

Willow

Willow height

Willow height increased over the entire winter range (WR) during the 15 years since EVMP implementation, with most of the height gain occurring inside the habitat fences (Figure 15, Table 8). However, WR-wide willow height did not change significantly between 2018 and 2023. We observed no change in unfenced core WR willow heights throughout the 15-yr period. In contrast, willow heights increased 150% from 59 cm to 150 cm during that same period in fenced core WR plots. However, this increase occurred in the first 10 years and mean willow height remained unchanged at fenced plots between the 10- and 15-yr samples. After 10 years of habitat protection, the fenced willows were significantly taller than their unfenced counterparts ($p < 0.0001$) on the core WR and they showed no differences from noncore willow heights (Figure 15).

Willow height increased insignificantly in noncore WR willow plots throughout the 15 years (Figure 15). Willows in noncore WR plots were significantly taller than unfenced core WR willows throughout all 15 years (Figure 15), but as previously noted, fenced willow mean heights were approaching noncore willow heights by 2023.

Maximum willow heights followed similar patterns to mean heights (Figure 16) with fenced willows on the core WR reaching maximum heights by 10 years that were no longer significantly different from willows on the noncore WR ($p = 0.49$). Estimated maximum willow heights in fenced plots were approaching the point beyond the reach of elk browsing (2.0–2.5 m height) by 2023 and maximum heights of noncore WR willow were approaching the upper end of this browsing limit by 2013 and currently exceed this height (Figures 16–18). Having a few willows at each plot that exceed the height of browsing is not enough to create sustainable willow communities, but it does indicate the potential to outgrow the reach of tall ungulates like elk and moose still exists on the WR. Current

maximum willow heights in the noncore WR may be able to escape browsing by moose whose longer limbs and neck allow them to browse at heights up to, and often over, 3 meters. However, not all habitat fences in the core WR have maximum heights that could be considered “moose-proof” and the average height of willows in these plots is far from tall enough to withstand both elk and moose browsing.

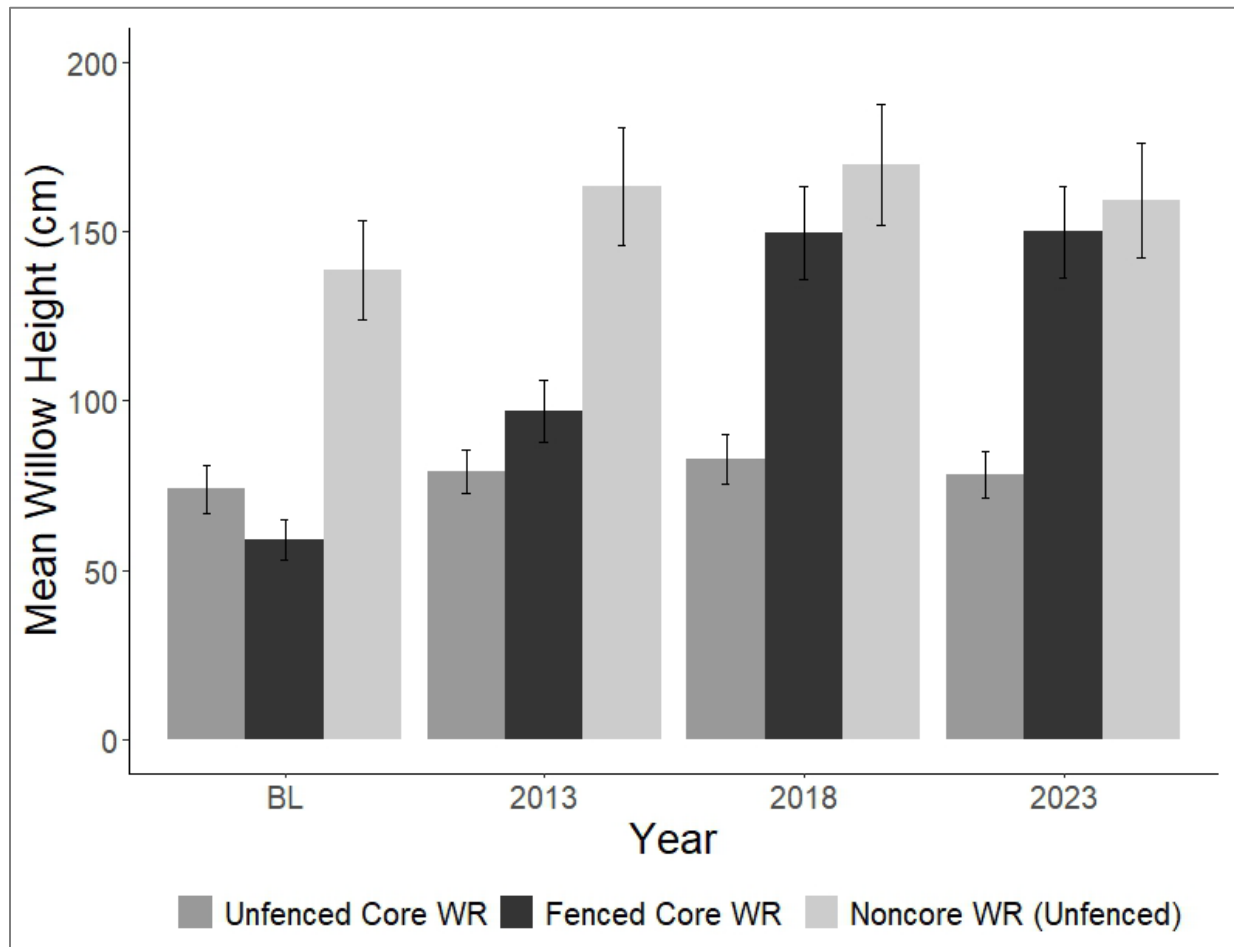


Figure 15. Estimated mean willow height (cm) for fenced and unfenced willow over 15 years on the core and noncore elk winter range of Rocky Mountain National Park. BL = baseline data (collected 2006–2008). Bars denote ± 1 standard error.

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Table 8. Mean willow heights on suitable willow habitat in the elk winter range of Rocky Mountain National Park from baseline to 2023. Entire winter range and core winter range total estimates are weighted means based on the amount of willow area in each of these range types. Baseline sampling occurred from 2006 to 2009 on the winter range.

Range Type or Location	% Willow Area	Willow Height (cm) by Year			
		Baseline ^A	2013	2018	2023
Entire Winter Range	—	90	113	134	129
Core Winter Range Total	—	66	88	116	114
Core Winter Range, Fenced	30	59	97	150	150
Core Winter Range, Unfenced	42	74	79	83	78
Noncore Winter Range Total	28	138	163	170	160
Entire Kawuneeche Valley	—	—	—	—	—
Kawuneeche Valley, Fenced	—	45	—	95	139
Kawuneeche Valley, Unfenced	—	56	—	41	41

^A Baseline year for winter range sites was approximately 2008 and for Kawuneeche Valley was 2012.

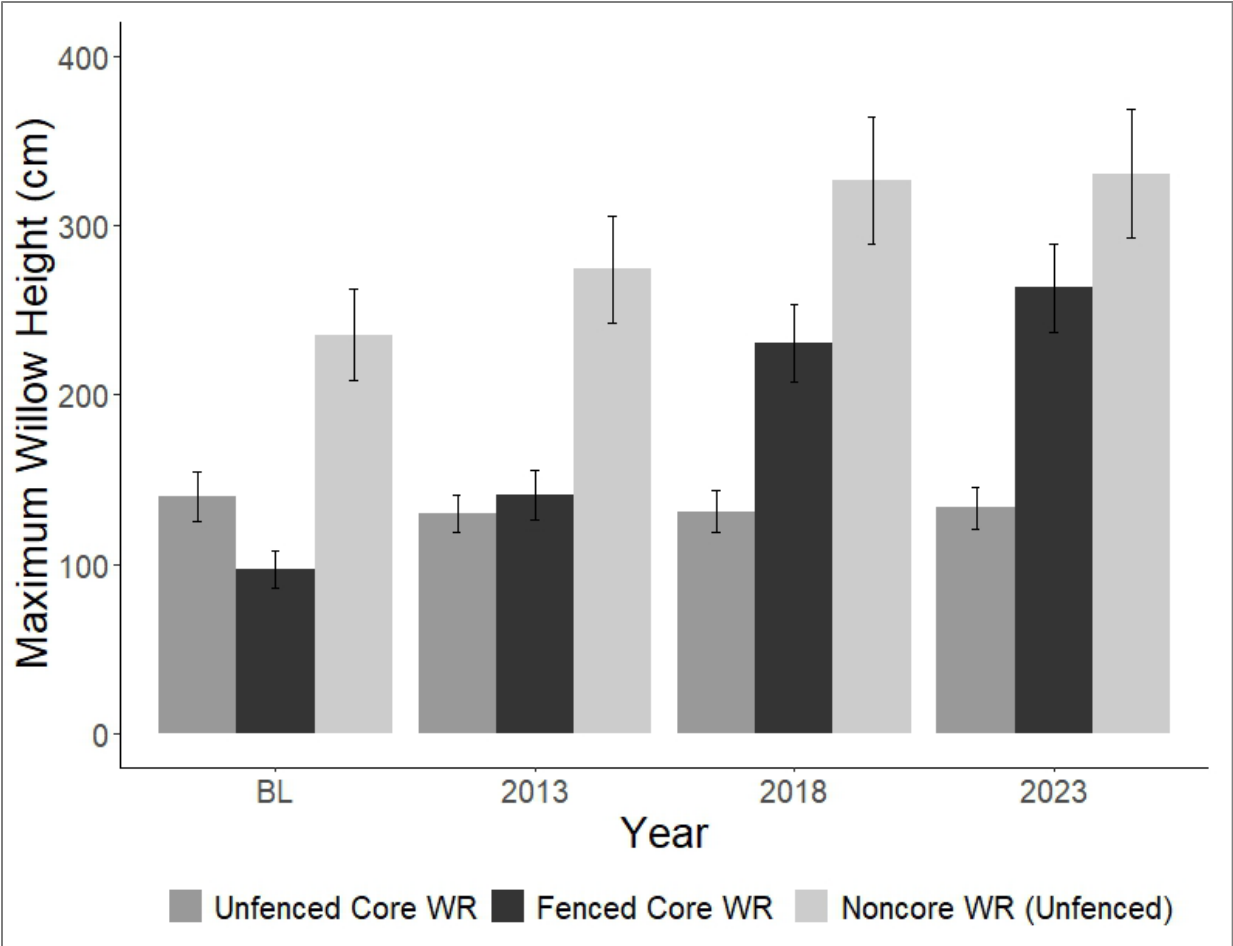


Figure 16. Estimated maximum willow height (cm) for fenced and unfenced willow over 15 years on the core and noncore elk winter range of Rocky Mountain National Park. BL = baseline data (collected 2006–2008). Bars denote ± 1 standard error.
NPS / LINDA ZEIGENFUSS

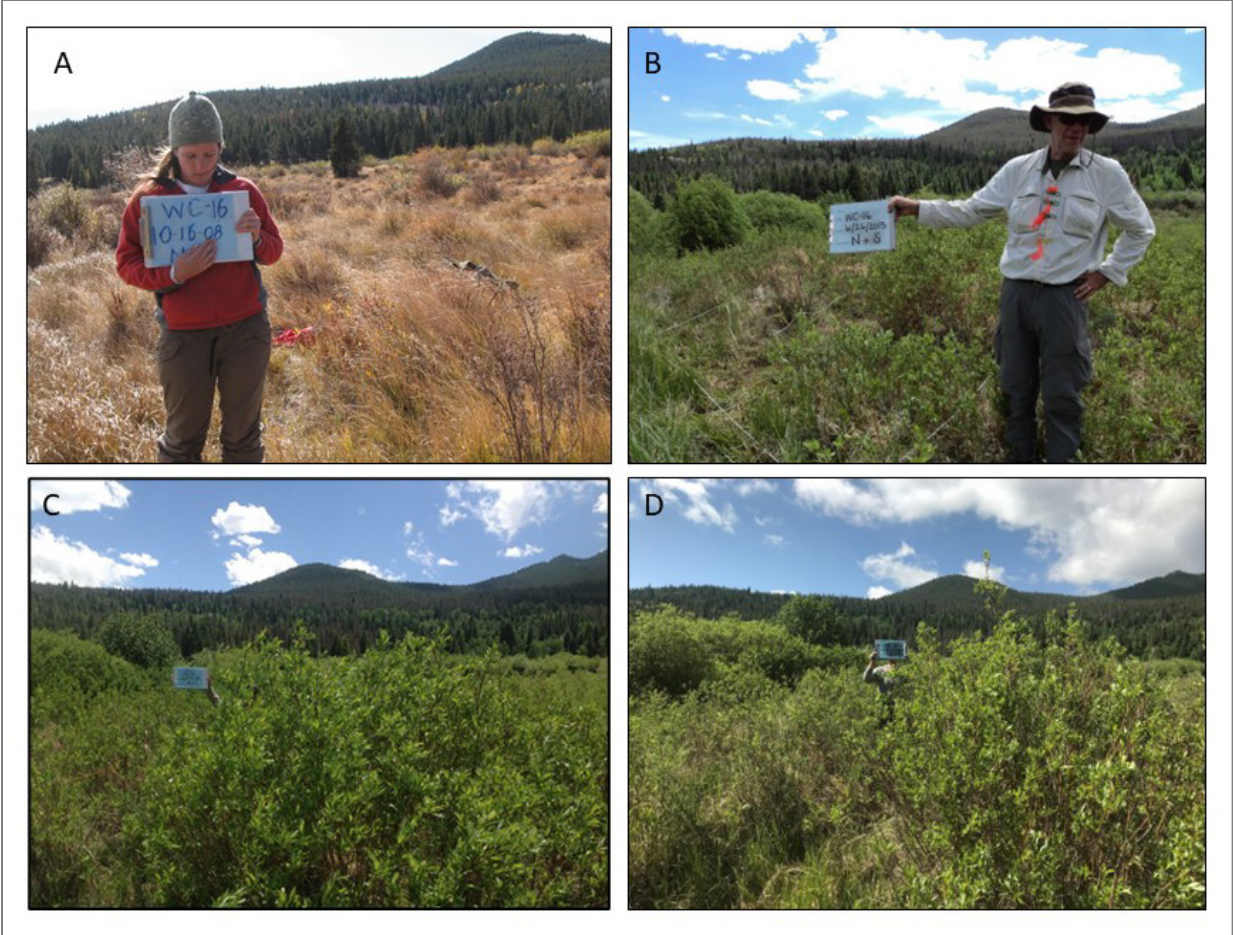


Figure 17. Comparison of vegetation composition over time inside willow enclosure HP50 at plot WC16. Willow composition at baseline (A, fall 2008), five years after fence construction (B, summer 2013), and willow regeneration after ten years (C, summer 2018) and 15 years (D, summer 2023) of protection from ungulate browsing. Baseline photos during summer are not available.
NPS

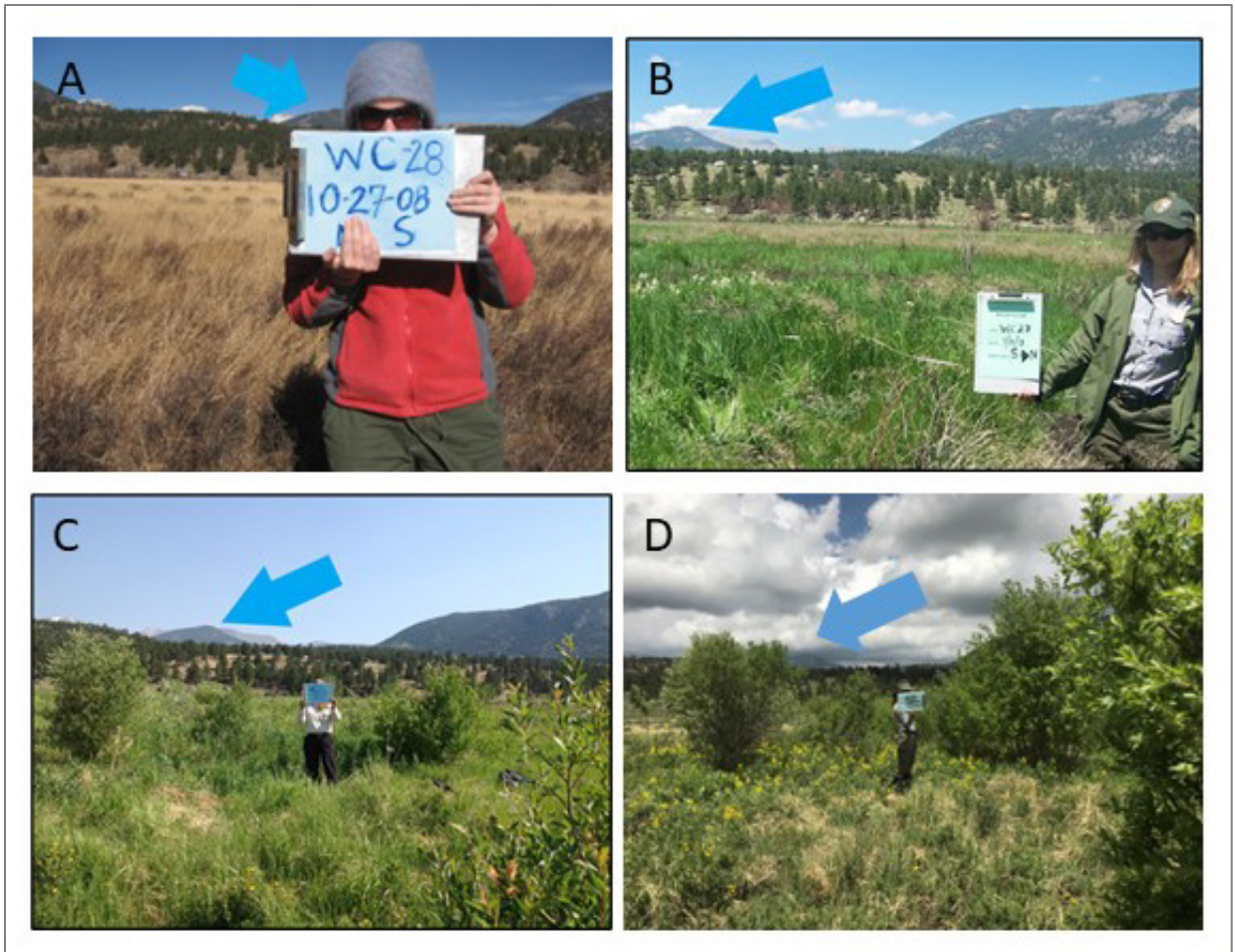


Figure 18. Comparison of vegetation composition inside willow enclosure MP50 at plot WC28 over time. Blue arrow indicates landmark mountain to the north of the plot. Willow composition at baseline (A, fall 2008), five years after fence construction (B, summer 2013), and willow regeneration after 10 years (C, summer 2018) and 15 years (D, summer 2023) of protection from ungulate browsing.

NPS

Willow cover

Willow cover was nearly twice as great on noncore winter range (WR) willow plots than core WR plots at baseline ($p \leq 0.05$), but 5 years after EVMP implementation, willow cover in fenced plots had started to climb, though still not significantly ($p = 0.18$; Figures 17–19). However, by 2018 after 10 years of EVMP, willow cover inside the fences increased significantly ($p < 0.0001$) over baseline and year 5, and willow cover was similar to cover in noncore WR willow plots. This higher level of cover was sustained into 2023, though no significant increase in cover occurred between 2018 and 2023. Noncore WR plots also had a significant increase in willow cover between baseline and year 10, and this higher level of cover was maintained into 2023, but it had neither increased nor decreased significantly between year 10 (2018) and year 15 (2023). Unfenced willow plots in the core WR showed virtually no change in willow cover over time with cover remaining at ~15–19% (Figures 19 and 20).

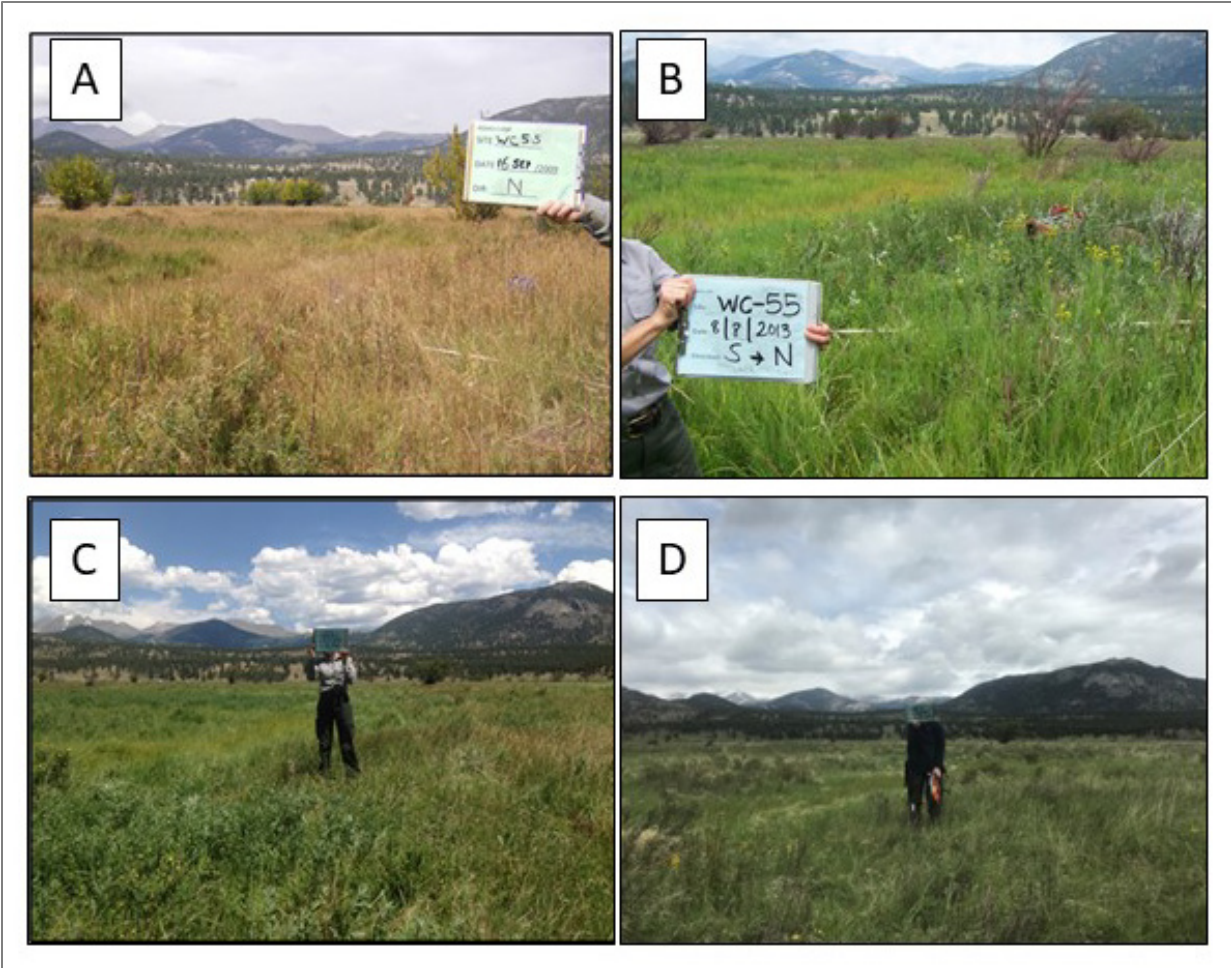


Figure 19. Comparison of vegetation composition over time at unfenced plot WC55 in Moraine Park. Little to no willow regeneration at baseline (A, fall 2009) and at 5-yr EVMP sample (B, summer 2013), 10-yr sample (C, summer 2018), and 15-yr sample (D, 2023). Note that vegetation growth at the bottom left of photo C is not willow. This site burned in 2012.

NPS

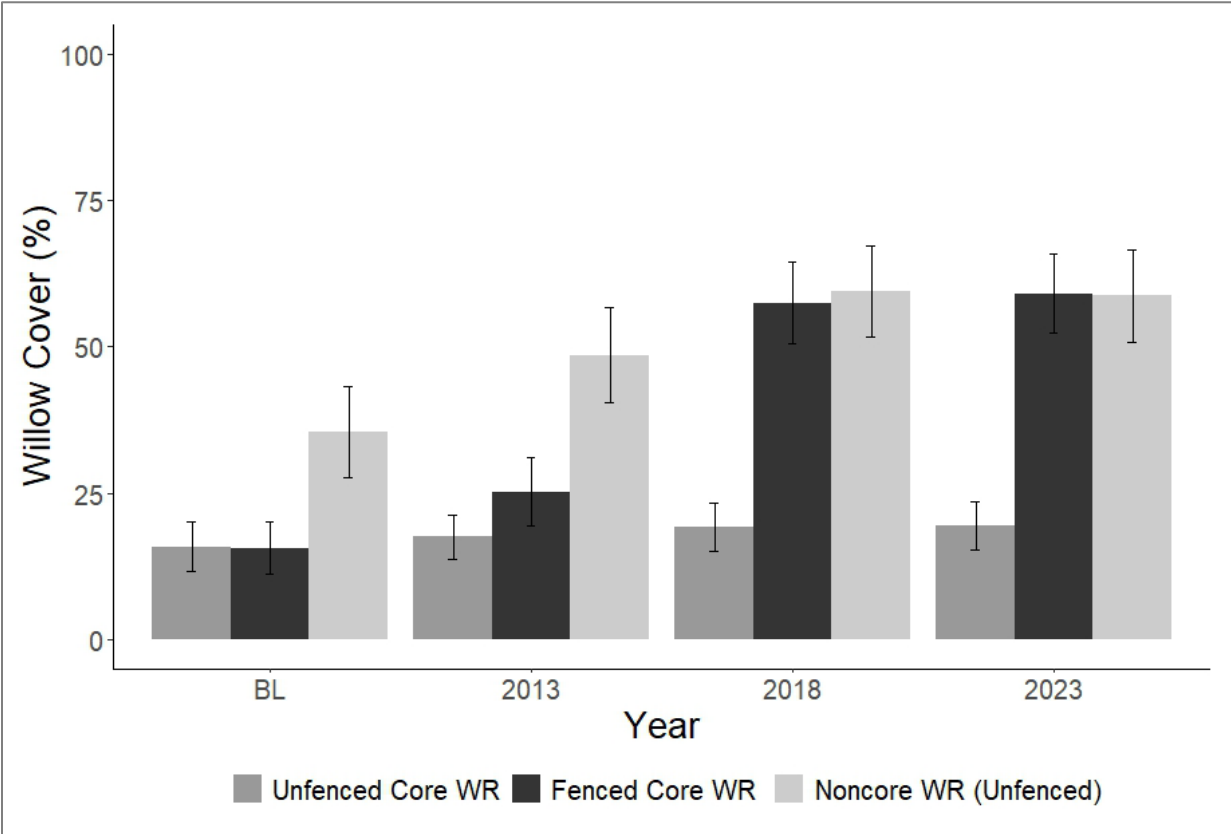


Figure 20. Estimated mean percent willow canopy cover for fenced and unfenced willow over 15 years on the core and noncore elk winter range of Rocky Mountain National Park. BL = baseline data (collected 2006–2008). Bars denote ± 1 standard error.

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As with WR aspen, the 2020 wildfire affected a large number of EVMP willow plots. We wanted to determine the extent to which loss of willow to fire may have contributed to the plateauing of willow height and cover growth, so we reran the analysis with the plots that burned in the 2020 fire removed from the data. Overall, mean height and cover values increased in all years when using only plots that did not burn in 2020 (Figure 21). Upon consideration, this is not surprising. All burned plots were in Beaver Meadows and Moraine Park. These areas had shorter willows and lower willow cover at baseline (Zeigenfuss et al 2002, Peinetti et al. 2002) and removing many of these plots would skew the remaining data set toward plots with taller plants and higher cover. What is surprising is that the patterns in willow height and cover over time are generally the same as when burned plots are included (Figure 21). We conclude that the lack of continued increase in willow height and cover cannot be attributed simply to loss of willow to wildfire.

We found similar patterns in height and cover when we used line intercept methods to calculate these variables compared to macroplot methods (Figure 22). Mean willow height estimates were taller when we used line intercept data, but maximum height estimates were shorter (Figures 15–16 and 22A, B). Line intercept methods resulted in cover estimates that were within 1 standard error of means estimated using macroplot methods (Figure 22C). Estimates of height and cover were highly correlated between sampling methods (Figure 23; $R \geq 0.78$, $p < 0.0001$). We found more significant pairwise comparisons were identified when we used macroplot data than line intercept data. Using line intercept data, no differences were observed between core and noncore willow cover at baseline, whereas macroplot methods found that noncore and unfenced core WR plots were slightly different ($p = 0.046$). However, all other comparisons between types were similarly significant to macroplot data for all other sample years.

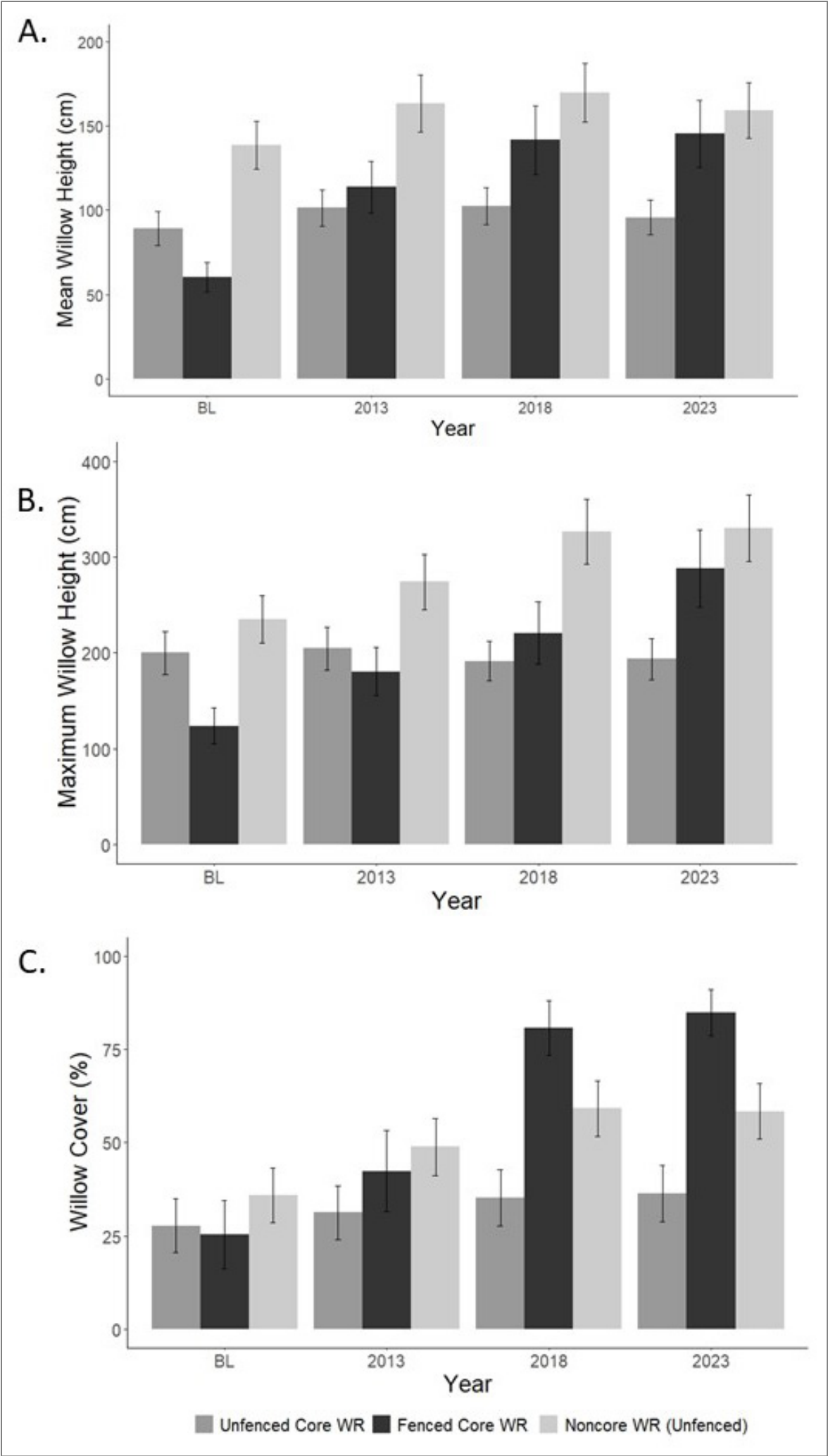


Figure 21. Estimated mean willow height (A), maximum willow height (B), and mean percent willow cover (C), derived from only willow plots that did not burn in 2020 on elk winter range (WR) of Rocky Mountain National Park. BL= baseline data (collected 2006–2009).

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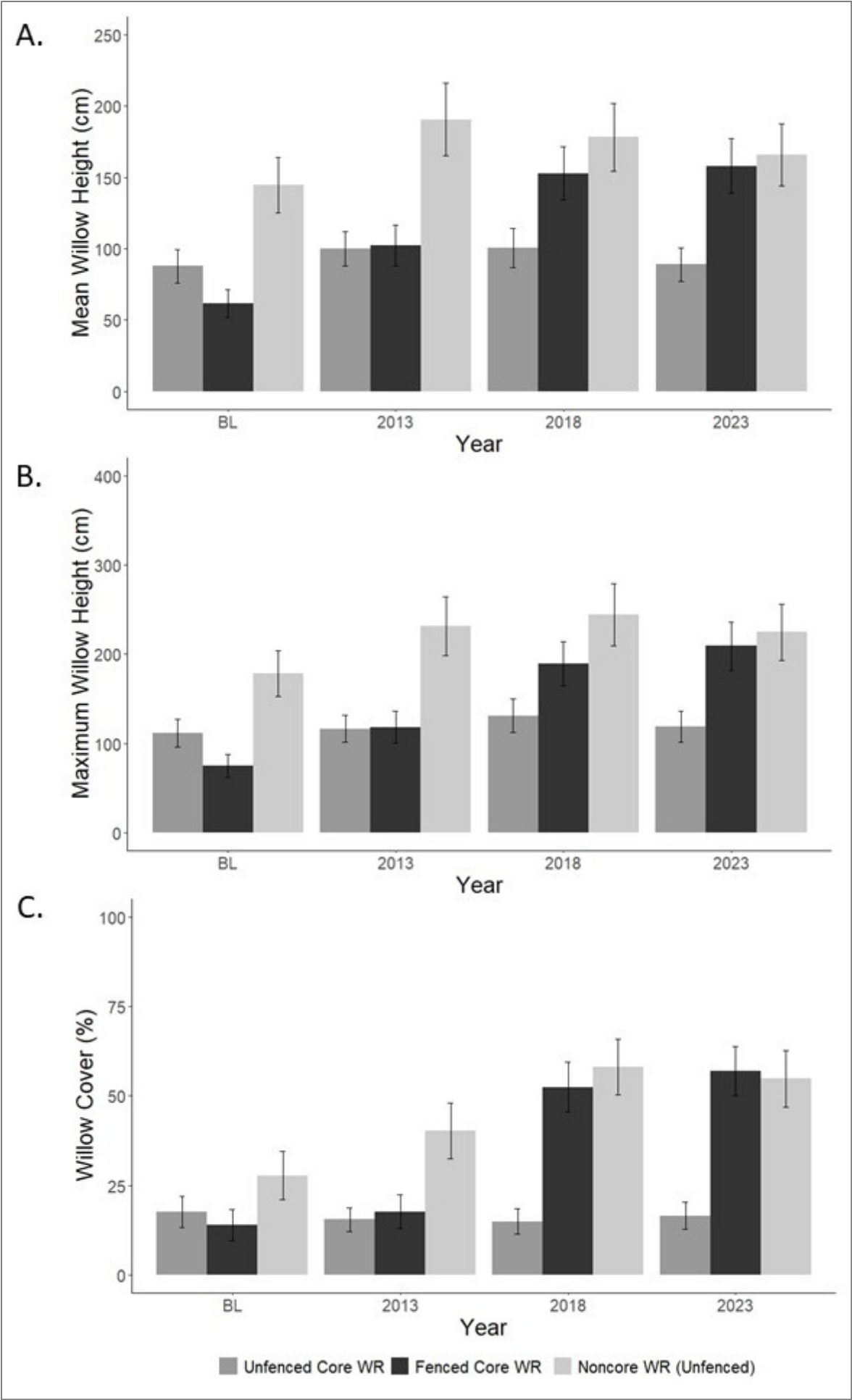


Figure 22. Estimated mean willow height (A), maximum willow height (B), and mean percent willow cover (C), derived from data collected using the line intercept method at all monitoring plots on winter range (WR) of Rocky Mountain National Park. BL= baseline data (collected 2006–2009).

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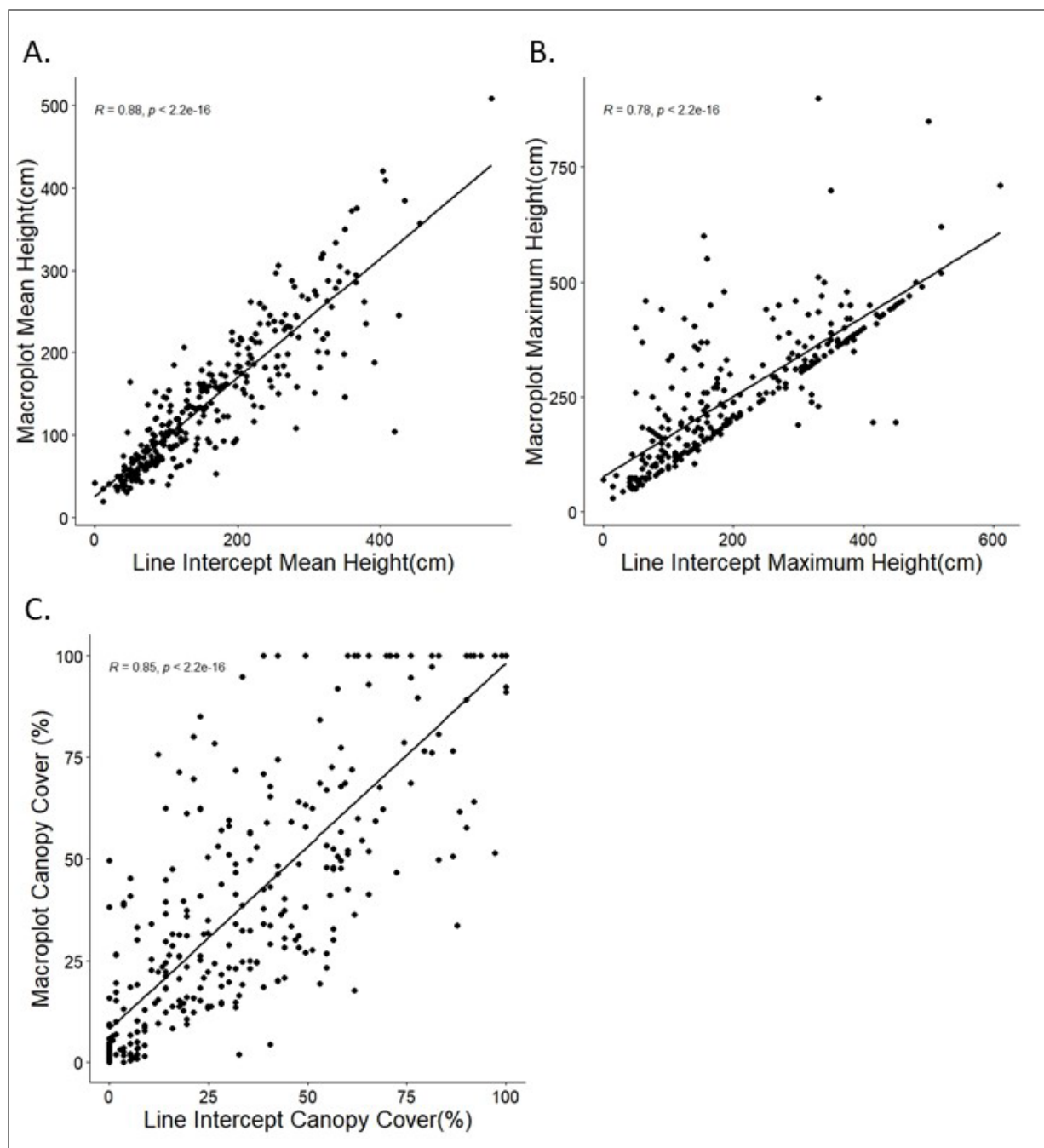


Figure 23. Correlation plots for macroplot vs. line intercept measurement methods for willow mean height (A), maximum height (B), and canopy cover (C).

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Range-wide Willow Cover and Height

We weighted mean willow cover and height for each year sampled based on the proportion of the winter range (WR) that fell into each category of range-type and fencing (Tables 8 and 9). These proportions changed over time as areas were fenced. Weighted mean willow height on the WR increased from 90 cm to 129 cm over 15 years, but this increase was driven largely by growth inside

the fences. While this meets the criteria for a 20% increase over the timeframe of the EVMP, the 60% of the core WR that is unfenced has shown no change in willow height in concert with EVMP management. Mean cover over the entire WR increased steadily from baseline and by 2018 WR willow cover had increased to 45% in areas deemed suitable for willow. Willow cover on the WR remained stable between 2018 and 2023 but didn't increase (Table 9). Fire affected much more of the core WR than noncore WR, with nearly 20% of core WR suitable willow habitat (17% of unfenced and 25% of fenced) being burned compared to only 4% of noncore WR, which may account for the lack of increased cover between 2018 and 2023. None of the noncore WR willow plots burned in 2020, so lack of increases in mean height or cover in noncore WR willow was not due to direct fire losses. However, indirect effects of wildfire, in the form of decreased habitat elsewhere leading to greater ungulate use of noncore willow habitat, may have contributed to the lack of height increases in the noncore between 2018 and 2023, but this is not evident in our measurements of willow browsing (see following sections for discussion of willow browse intensity).

Table 9. Mean willow cover on suitable willow habitat in the elk winter range of Rocky Mountain National Park from baseline to 2023. Entire winter range and core winter range total estimates are weighted means based on the amount of willow area in each of these range types. Baseline sampling occurred from 2006 to 2009 on the winter range.

Range Type or Location	% Willow Area	Willow Cover by Year			
		Baseline ^A	2013	2018	2023
Entire Winter Range	—	21%	30%	45%	45%
Core Winter Range Total	—	15%	21%	38%	38%
Core Winter Range, Fenced	30	15%	24%	56%	58%
Core Winter Range, Unfenced	42	15%	17%	19%	19%
Noncore Winter Range Total	28	35%	49%	59%	59%
Entire Kawuneeche Valley	—	—	—	—	—
Kawuneeche Valley, Fenced	—	14%	—	46%	83%
Kawuneeche Valley, Unfenced	—	21%	—	26%	6%

^A Baseline year for winter range sites was approximately 2008 and for Kawuneeche Valley was 2011.

Kawuneeche Valley

On average, Kawuneeche Valley (KV) willows were very short (45 ± 5 cm, fenced; 56 ± 6 cm, unfenced) at the outset of monitoring—much shorter than willow in the core winter range (WR) (59 ± 6 cm, fenced; 74 ± 7 cm, unfenced) at its baseline (Table 8; Figure 24). By 2018, six years after establishment of these plots and construction of the KV ungulate exclosure, mean height of fenced willows was nearly twice that of unfenced willows and by 2023, they were nearly 3 times as tall as at baseline. Unfenced willow showed no variation in height from 2012 to 2023. Four of the five unfenced willow plots in the KV burned in 2020. By 2023, two of the four still had no willow present. In the remaining two burned plots, willow heights were virtually unchanged from previous years.

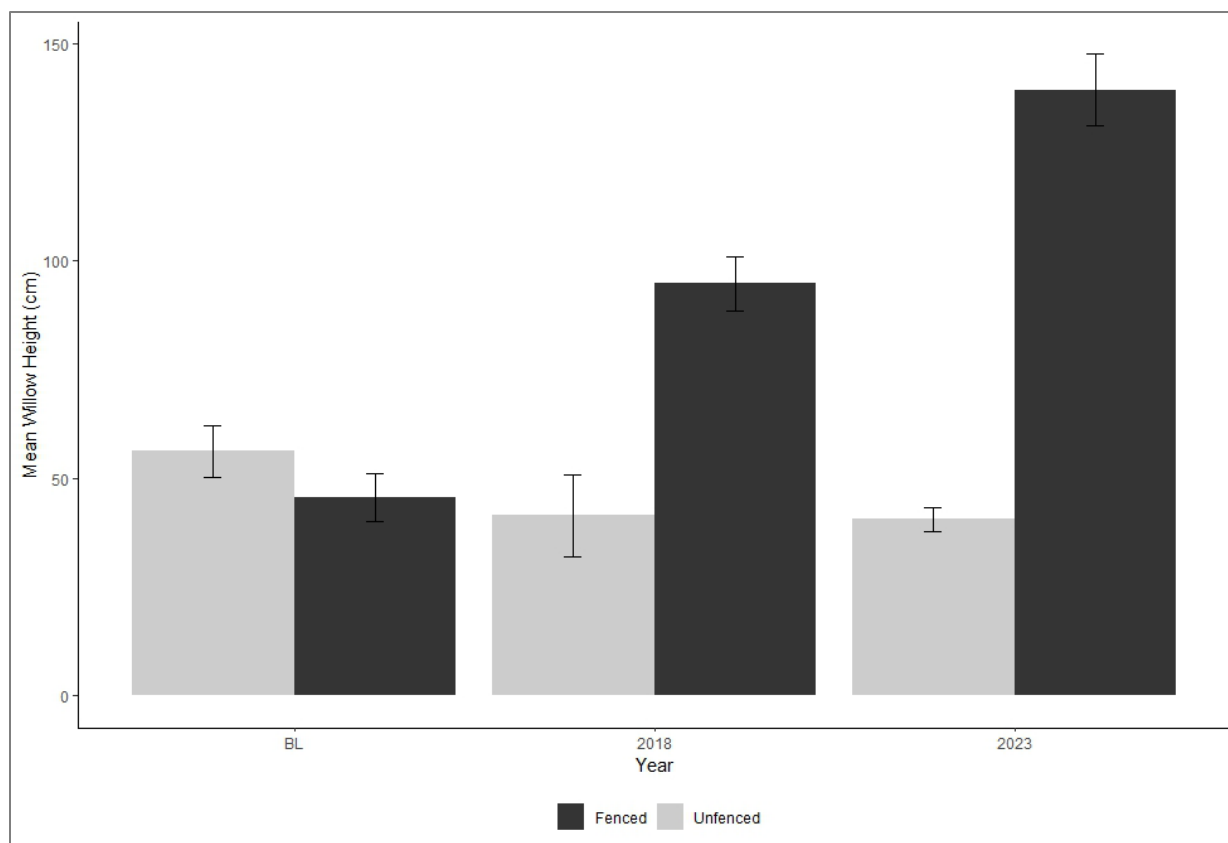


Figure 24. Mean height (centimeters) and standard error bars for fenced and unfenced willow species in the Kawuneeche Valley of Rocky Mountain National Park. BL = baseline data (collected 2011).

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Willow cover in the KV was low ($13.7\% \pm 5.4\%$, fenced; $21.1\% \pm 9.7\%$, unfenced), but similar to cover values at baseline for the WR ($15.6\% \pm 4.4\%$, fenced; $15.8\% \pm 4.1\%$, unfenced) (Table 9; Figure 25). Unfenced willow cover did not change through 2018, but the 2020 wildfire reduced willow cover in unfenced plots to less than 10% overall, with several plots losing all their willow. Inside the fences, willow cover increased dramatically, particularly between 2018 and 2023. Mean willow cover inside the fence was nearly 80%. However, we caution against extrapolating these

results to the entire KV. All EVMP plots are inside a single fenced patch that encompasses 6.7 ha of tall willow—a mere 2% of the former acreage of tall willow in the KV. Both the fenced and unfenced willow samples are extremely small compared to the size of the entire area of the KV that is suitable for willow. Inference cannot be made from our limited sample to the entire KV. Recent restoration activities in the KV will be able to collect a much larger and more widespread sample from which robust statistical inference can be made.

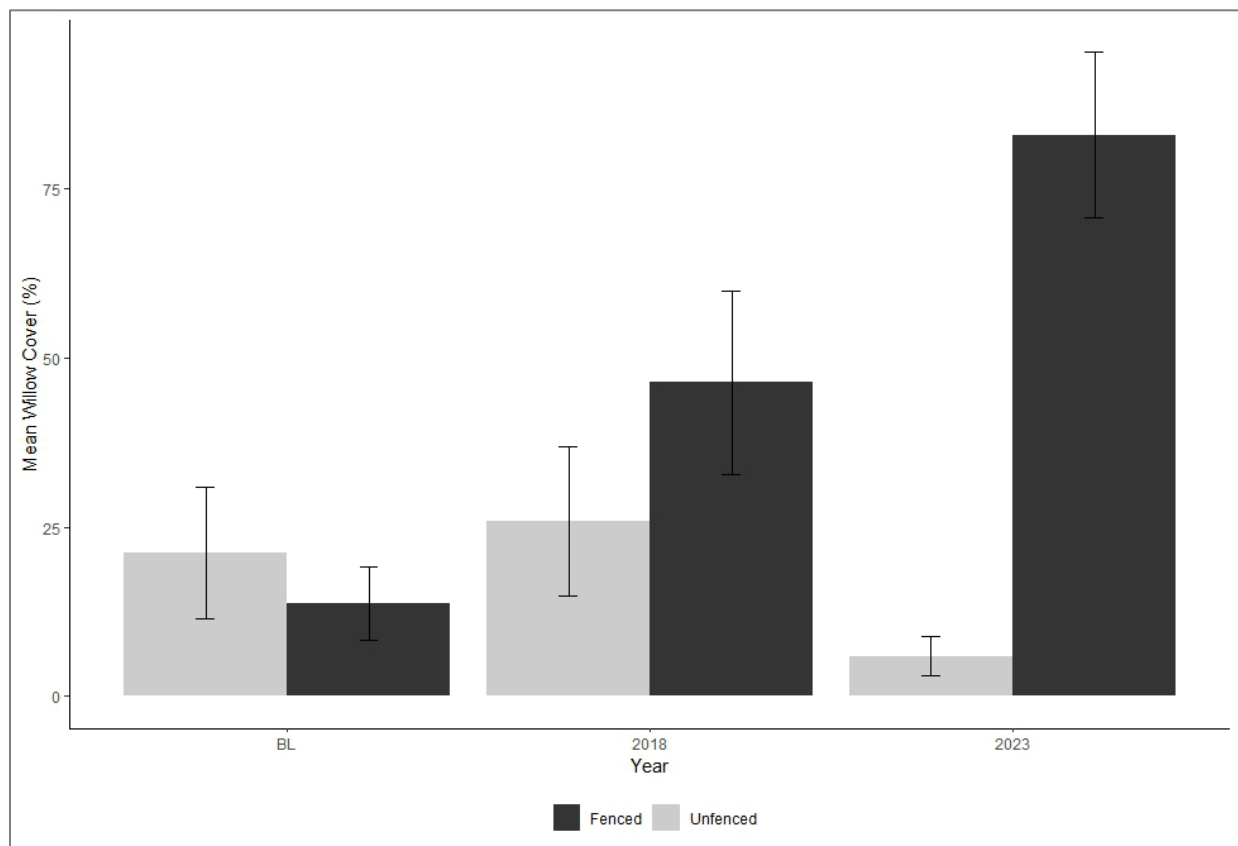


Figure 25. Mean canopy cover (%) and standard error bars for fenced and unfenced willow species in the Kawuneeche Valley of Rocky Mountain National Park. BL = baseline data (collected 2011).

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Willow Browse Intensity

Browse intensity on willow decreased significantly on the entire winter range (WR) over the 15 years since EVMP implementation ($P < 0.0001$). The rate of decrease was nearly identical for both the core and noncore WR as evidenced by similar slopes for each group (coreWR = -0.0272, noncoreWR = -0.0264) and lack of an interaction effect between time and WR type. However, browse intensity was higher on the core WR than the noncore WR throughout the 15 years of monitoring (Figures 26 and 27). Mean browse index (proportion of shoots/stem that were browsed) dropped from a high of 0.80 in core WR at baseline (spring 2009) to 0.38 in spring 2023. Browse intensity in the noncore WR dropped from 0.49 at baseline to 0.12 in 2023, and the range of browse intensity values across sites has narrowed over time (Figure 26). Browsing on willow has been lower overall on the WR since

2017 with overall less than 40% of shoots being browsed. The elk population data (Figure 1) indicates a drop in the overwintering elk population in the WR around this time. And elk use of the WR in winter has continued to be low since 2017. There was an uptick in browsing on the core WR in 2019, but all other years from 2017–2023 have had similar browse intensity values (Figure 27).

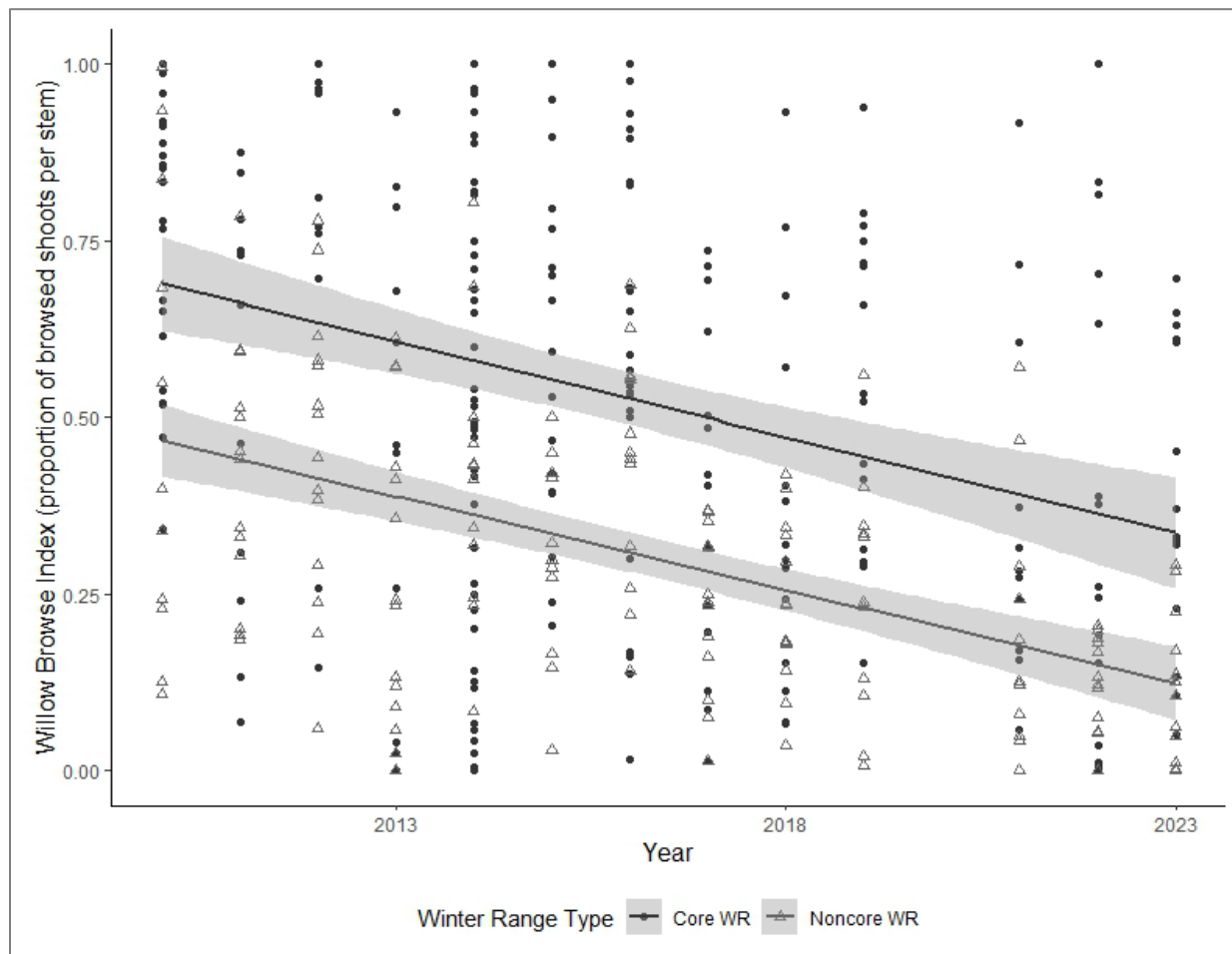


Figure 26. Linear regression lines showing trend in willow browse intensity on the elk winter range of Rocky Mountain National Park 2010–2023. Data from 2009 were not included as browse intensity could not be comparably estimated. Data was not collected in 2020 due to restrictions related to the Covid-19 pandemic.

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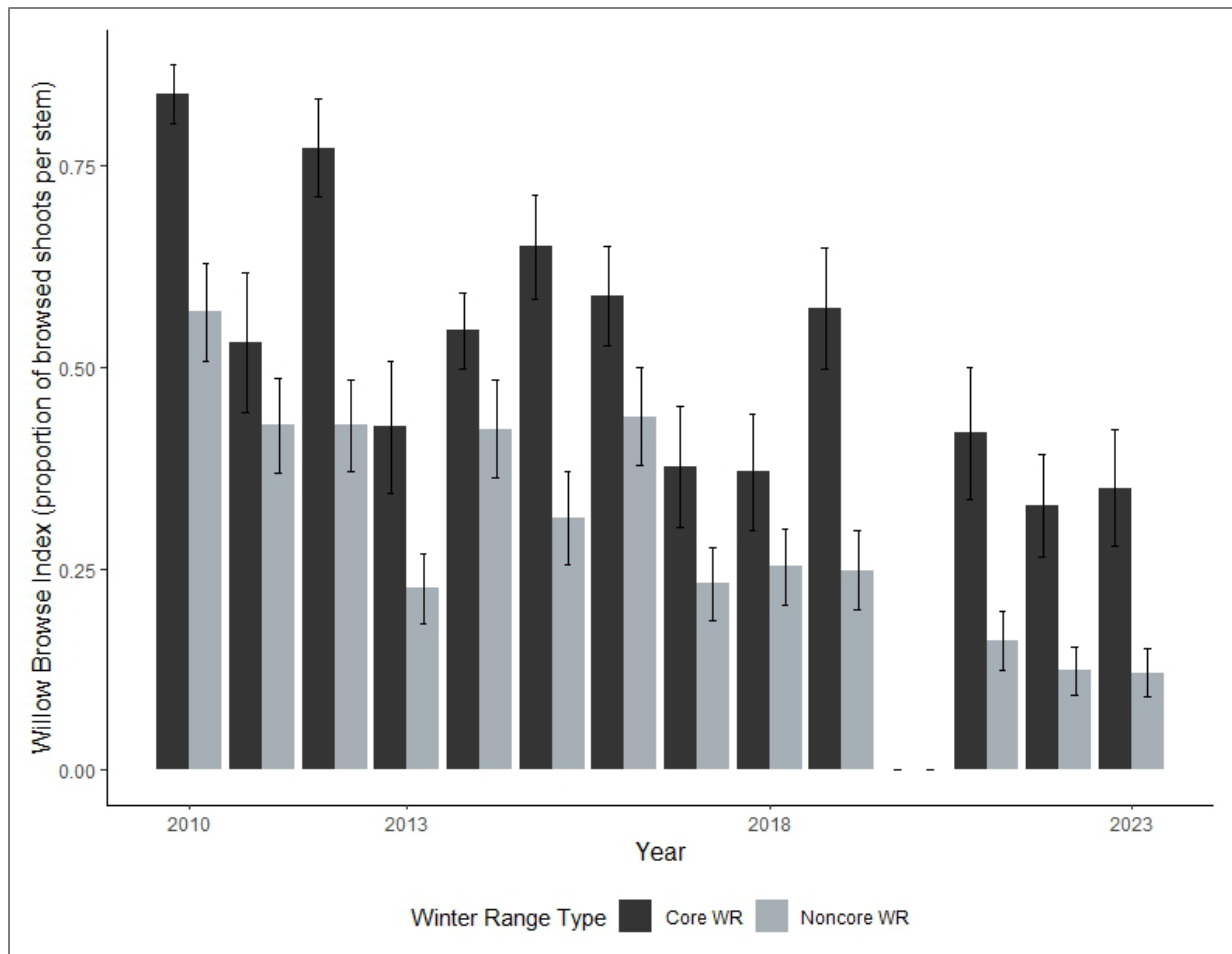


Figure 27. Willow browse intensity on the elk winter range of Rocky Mountain National Park 2010–2023. Data from 2009 were not included as browse intensity could not be comparably estimated. Data were not collected in 2020 due to restrictions related to the Covid-19 pandemic.

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Kawuneeche Valley

Browse intensity declined slightly, though not significantly ($p = 0.066$), in the Kawuneeche Valley (KV) from 2011 to 2023 (Figure 28). Estimated browse index at baseline was 0.61 which declined to 0.37 by 2023 (Figure 28). An apparent uptick in browsing in 2021 is likely the result of the 2020 wildfire removing willow and in turn leading to increased browse pressure on the remaining willows. Only one KV willow plot had measurable willow in 2021 because the East Troublesome Fire consumed all willow in the others. Either the lack of variability caused by a single sample, or an increase in browsing in this site because so little willow was available following the fire, likely accounts for this single year increase (Figure 29). By 2022, willow had returned to 3 of the 4 burned unfenced KV plots, however, in 2023, only 2 of the 4 plots had willow. KV browse indices were similar to the core winter range (WR) by year 15, but browsing was more intense in the core WR at the time of the first KV sample in year 4 (2012).

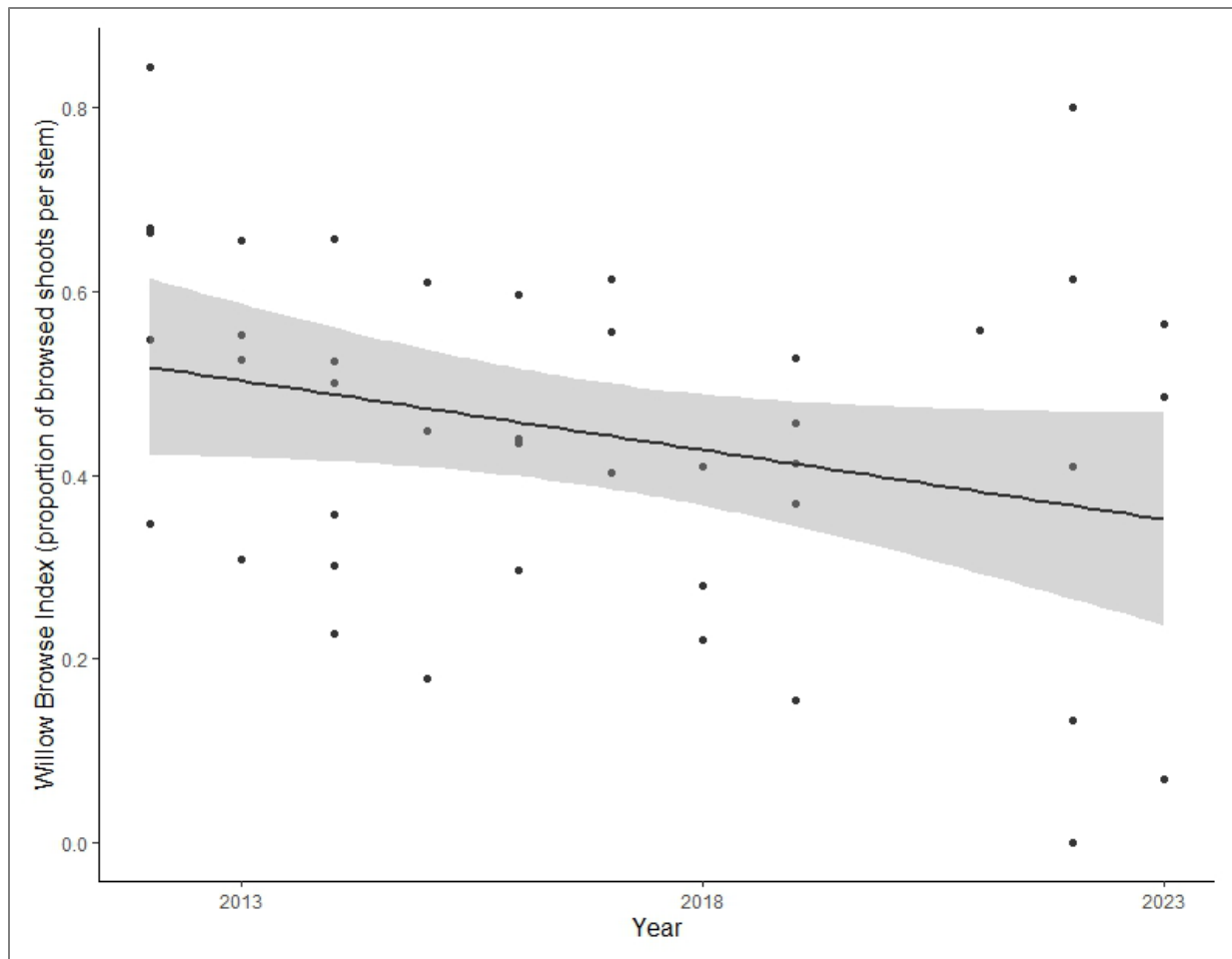


Figure 28. Trend in willow browse intensity in the Kawuneeche Valley of Rocky Mountain National Park 2012–2023. Data were not collected in 2020 due to restrictions related to the Covid-19 pandemic.

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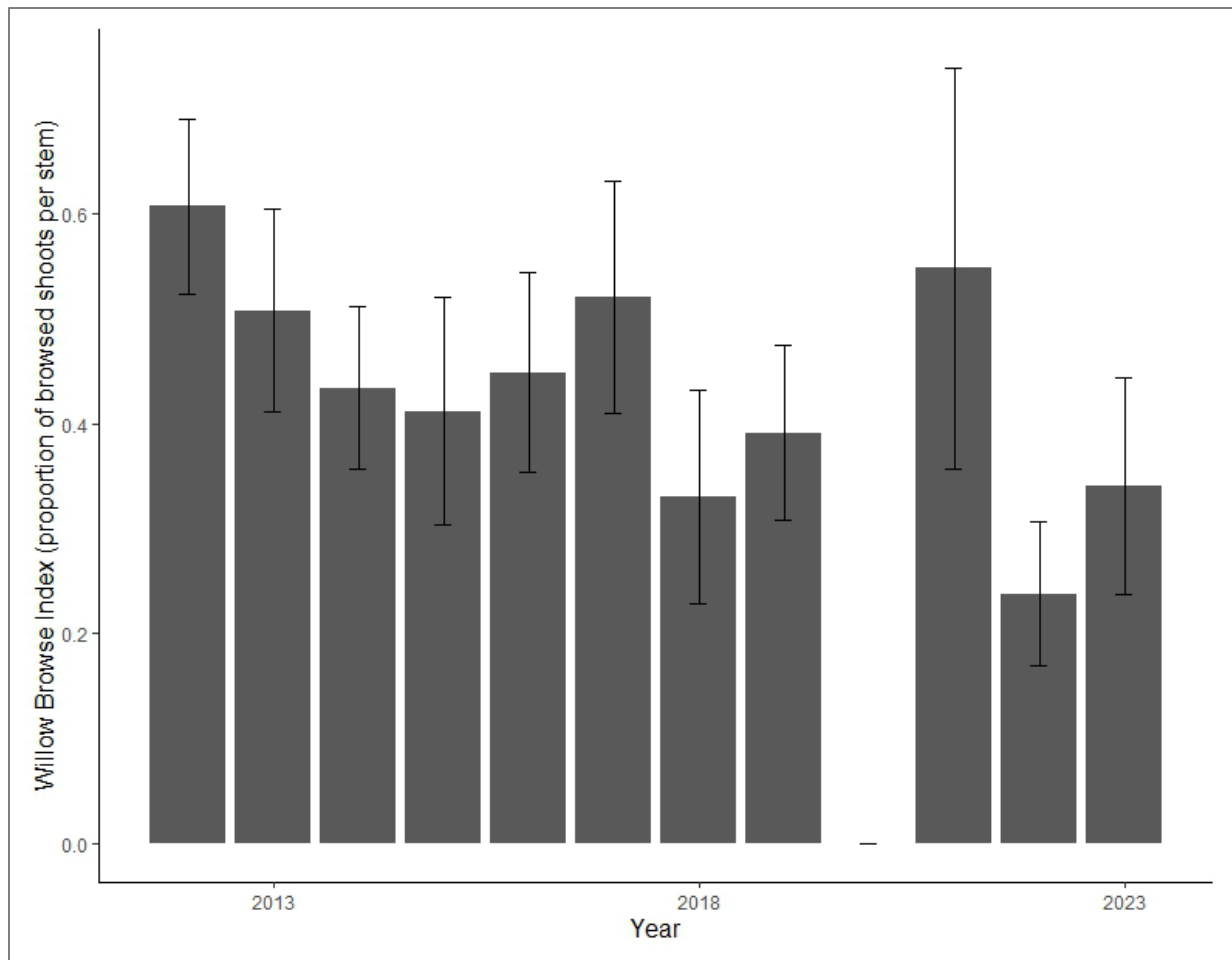


Figure 29. Mean willow browse intensity in the Kawuneeche Valley of Rocky Mountain National Park 2012–2023. Data were not collected in 2020 due to restrictions related to the Covid-19 pandemic.

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Animal Presence in Willow Sites

Observations of elk and moose presence were not consistently gathered throughout the monitoring period. In the case of elk, this was an omission because it was assumed at baseline that all winter range (WR) willow sites were being used by elk. In the case of moose, it was a lack of foresight. Moose had not moved into the elk WR of the Park at baseline either because the moose population had not grown to the point that dispersal into habitats on the east side of the Park was necessary or due to the competition from a large overwintering elk population. However, by 2018, moose were being observed regularly in EVMP willow plots on the WR, and documentation of moose sign was added to the protocol. Addition of elk sign documentation was added in 2023. Based on these observations, it is apparent that by 2023 moose were using most willow areas on both core and noncore WR (Table 10, Figure 30). Moose sign was noted on more willow plots on the noncore WR than elk presence, though this is likely due to seasonal differences in use between the species and timing of willow sampling. EVMP willow plots were sampled in summer when most of the elk

population has moved to higher elevations and when moose are present over much of the WR. Equally concerning is the high number of fenced plots that had elk and moose sign (Table 10).

Table 10. Proportion of sampled willow plots that had observed cervid (elk, moose) or beaver sign from baseline (2006–2009) through 2023. Blank entry indicates data not collected in that year.

Animal Species	Range Type	Proportion of Plots with Animal Sign (Total Number of Sampled Plots)			
		Baseline	2013	2018	2023
Elk	Core Winter Range, Unfenced	–	–	–	0.93 (44)
	Core Winter Range, Fenced	–	–	–	0.64 (36)
	Noncore Winter Range	–	–	–	0.41 (34)
	Kawuneeche Valley, Unfenced	–	–	–	0.60 (5)
	Kawuneeche Valley, Fenced	–	–	–	0.00 (4)
Moose	Core Winter Range, Unfenced	–	–	0.78 (45)	0.70 (44)
	Core Winter Range, Fenced	–	–	0.14 (35)	0.42 (36)
	Noncore Winter Range	–	–	0.94 (34)	0.88 (34)
	Kawuneeche Valley, Unfenced	–	–	1.00 (5)	0.60 (5)
	Kawuneeche Valley, Fenced	–	–	1.00 (4)	0.25 (4)
Beaver	Core Winter Range, Unfenced	0.26 (31)	0.02 (53)	0.02 (45)	0.04 (44)
	Core Winter Range, Fenced	0.27 (26)	0.03 (32)	0.09 (35)	0.06 (36)
	Noncore Winter Range	0.47 (34)	0.26 (34)	0.03 (34)	0.06 (34)
	Kawuneeche Valley, Unfenced	0.00 (4)	0.00 (4)	0.00 (5)	0.00 (5)
	Kawuneeche Valley, Fenced	0.00 (4)	0.00 (3)	0.00 (4)	0.00 (4)

The winter range (WR) habitat fences were designed with elk exclusion as their purpose, so most fences on the WR are only 2–2.2 m (6–7 ft) in height. This height is not sufficient to prevent moose trespass, and apparently elk are increasingly finding ways to breach the fences as well. While our methods for distinguishing elk sign from moose sign are not always accurate, excessive use by either species inside the fences is a cause for concern given the contribution of fenced willows to improvement in willow habitat of the WR as a whole. Even a few animals spending several days browsing within a habitat fence could contribute to decreases in overall willow height. It is possible that elk and moose trespass inside the fences may be responsible for some of the leveling off of height and cover between 2018 and 2023 at fenced plots.

While field crews have occasionally observed deer in willow plots, deer presence was not recorded nor has anecdotal evidence of deer use revealed any overwhelming use in willow plots as has been observed for elk and moose. Although deer are better able to access the fenced areas through openings that were designed to allow animals smaller than elk to enter, they do not appear to be using this access in willow sites to browse willows to any noticeable extent.

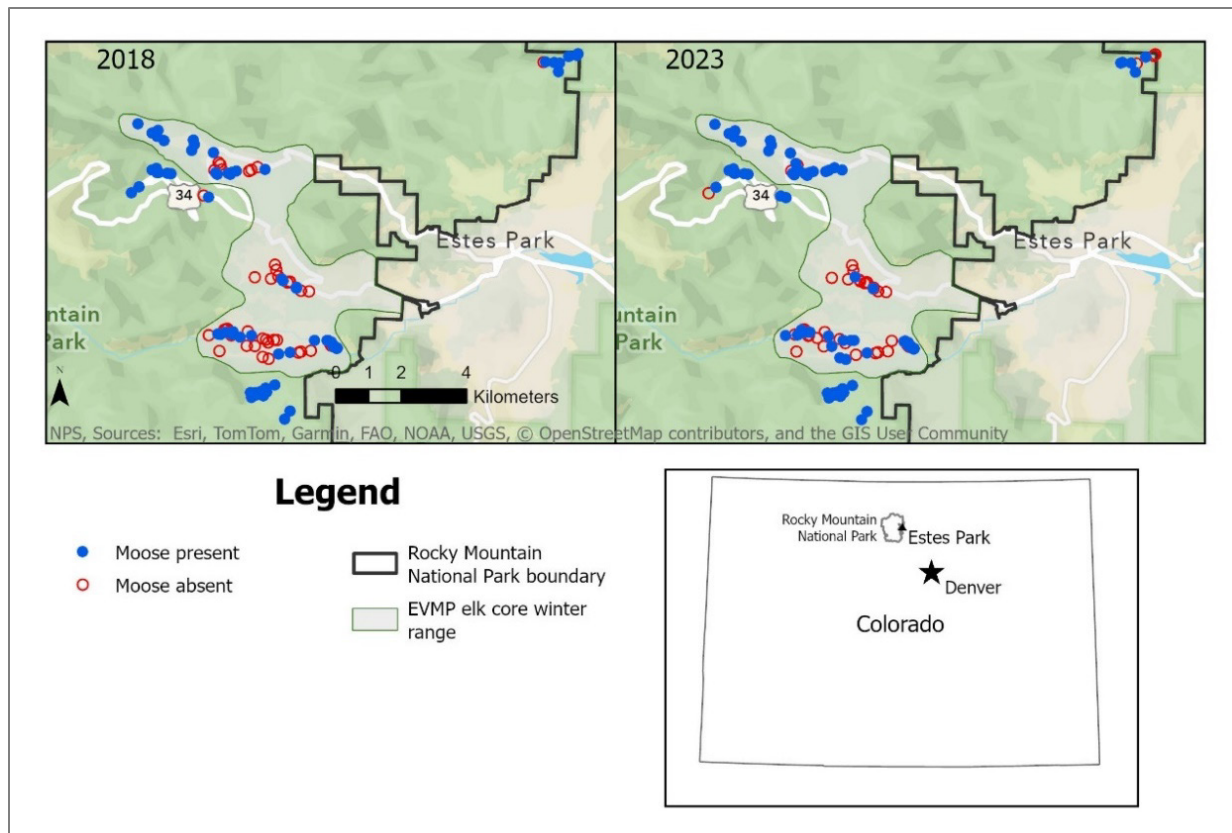


Figure 30. Moose presence detected in Elk and Vegetation Management Plan (EVMP) core and noncore willow plots in 2018 and 2023. Moose sign was not specifically surveyed at willow plots prior to 2018, though notes indicated moose sign at two plots in 2013.

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Beaver presence at EVMP willow plots has steadily declined over the past 15 years. Roughly a quarter of core WR and half of noncore willow plots had signs of beaver activity at baseline, but by 2023, that had been reduced to 5% of plots in both core and noncore WR (Table 10, Figure 31). One potential cause was the September 2013 flood which blew out many of the dams in the park. In the Kawuneeche Valley (KV), beaver sign was not observed in our limited sample of willow during any year since 2012 (baseline date in the KV). Even though data gathered during EVMP monitoring has failed to detect an increase in beaver activity within EVMP plots, Park staff has noted increased beaver activity in and around fenced habitat over the past 5 years, most notably throughout the northern sections of the core WR in Horseshoe Park and Endovalley where beaver have established and maintained multi-dam complexes for the past several years. Beavers have also begun establishing dams in eastern and southern Moraine Park close to many EVMP plots (Figure 31), and inside the habitat fence in KV since 2021 (I. de Silva Shewell, RMNP, personal communication, 2024).

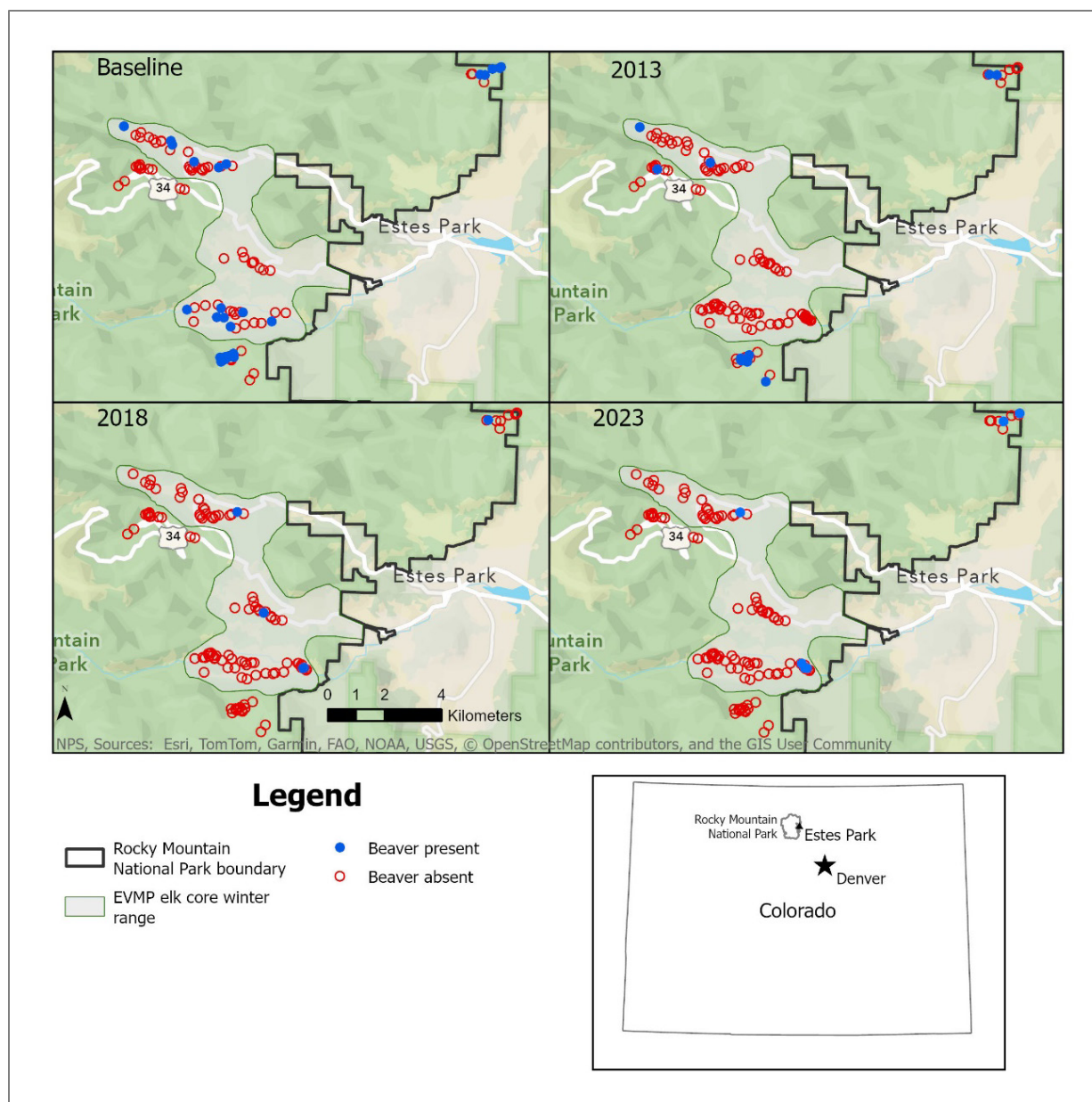


Figure 31. Beaver presence in Elk and Vegetation Management Plan (EVMP) core and noncore willow monitoring plots from baseline to 2023.

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Progress Toward EVMP Willow Goals

A key EVMP management objective is a progressive increase in mean willow height toward a mean height beyond the reach of elk browsing and with an expected 20% increase in this metric relative to baseline conditions over the 20-yr timeframe of the EVMP. Our analysis indicates that by 2023 willow height had increased by 43% relative to baseline conditions across the winter range (WR). However, these height gains are modest and current mean willow height is only just now moving into a zone beyond the reach of elk browsing and mean and maximum willow heights are still well within the reach of moose browsing. Willow height is an especially important variable because it strongly

influences habitat suitability for beaver since taller plants produce more biomass needed for winter food caches and are more suitable than short-statured plants for dam building (Allen 1983; Baker et al. 2005; Wolf et al. 2007). In a drying climate where large, intense wildfires are increasingly common, riparian areas with beaver dams can significantly reduce burn severity when wildfires do occur, providing valuable secondary benefits in postfire ecosystem health, water quality, and biodiversity (Fairfax and Whittle 2020; Fairfax and Westbrook 2024; Fairfax et al. 2024).

The EVMP also identified a desired future condition of up to 70% willow cover within suitable habitat and called for progress toward this desired future condition of >10% increase in willow cover over baseline conditions. Currently, the WR in its entirety is over halfway to the desired future condition with roughly 45% willow cover in areas that are considered willow habitat. This marks a roughly 25% increase in cover compared to baseline thus achieving the desired increase for the 20-yr timeframe of the EVMP. The minimum desired condition of achieving 31% willow cover within this timeframe has also been achieved. However, we advise caution along with celebration of this achievement as most gains are occurring inside the fences on core WR and on the noncore WR and no further improvement in condition has occurred since 2018.

Habitat fences were generally established in areas deemed likely to support desired communities based on historical conditions and factors like hydrology (Zeigenfuss et al. 2002; NPS 2007; Zeigenfuss and Johnson 2015), thus increasing the likelihood of successful willow recovery in these areas. The increased structural diversity in fenced stands, encompassing taller willows and greater cover, has now produced benefits in terms of suitable beaver habitat. In both Moraine Park and Horseshoe Park, beaver are constructing dams and establishing colonies inside fenced willow habitat. In Moraine Park, beaver have also connected areas between exclosures with dams and ponds (Chris Clatterbuck, personal communication, August 2024). In Horseshoe Park, beaver dams are flooding large areas both in and outside of fences that had been dry for many years in the absence of beaver driven disturbance regimes that once supported riparian shrub communities. A recent study found that alleviating browsing pressure and providing willow with perennial access to groundwater led to a 3-fold increase in willow growth over control conditions and led to significantly greater effects than either treatment alone (Hobbs et al. 2024). Ongoing restoration efforts in the Kawuneeche Valley (KV) are implementing these findings by constructing new moose-excluding (2.8 m tall) exclosures and installing various forms of instream structures within the fences to mimic the effects of beavers on the landscape.

Willow browse intensity has decreased by roughly 20–40% since baseline measurements (Figure 26). Overwinter elk population size has declined steadily on the core and noncore WR since baseline (Figure 2; Hobbs 2023), but elk still use WR areas extensively into late spring and early summer and then again in the early fall as they migrate between higher elevation alpine and subalpine summer range inside the Park and low elevation WR outside the Park. In addition, moose populations have been steadily increasing in the Park and moose now inhabit the elk WR throughout the year. Moving forward, it will be important to quantify all offtake that is occurring on WR willows, not just winter browsing. Current methods which focus on winter browsing may no longer be sufficient to determine elk browsing impacts that occur in the spring and fall and they are highly inadequate for determining

additional summer use from moose. It may not be possible to accurately apportion browsing among ungulate species, but it will be important to know the amount of browsing occurring seasonally and connecting that to seasonal ungulate use to appropriately manage ungulates into the future. The Park has begun collecting some summer browse intensity data in summer 2024 and these measurements should provide some information on degree of summer browsing occurring on the WR.

Although KV willows are not included in the EVMP objectives, our monitoring indicates that improvement in willow conditions can be achieved through fencing, provided willow still exist at the site and hydrologic conditions are sufficient to support willow plants through annual dry seasons as well as during droughts. Research on KV willows has demonstrated that changes in climate and hydrologic regime, can compound the negative effects of insects and pathogens (Kaczynski 2013; Kaczynski and Cooper 2013; Kaczynski et al. 2014) on browsed willows, further contributing to willow dieback. Additionally, age class dynamics are another important component to consider in the context of willow recovery and hydrological conditions. Mature willows, despite being heavily browsed aboveground, can maintain adequate living root tissue for many years that allow them to continue to access groundwater, even in the face of water table declines (de Silva et al., in preparation). Conversely, young willows that do not have an extensive root system require perennially wet substrate, making them more susceptible to altered hydrology. Thus, recovering mature willows while they are still alive and managing for suitable habitat necessary for willow recruitment (e.g., former beaver ponds, abandoned channels, and point bars) is imperative for achieving recovery on a sustained, landscape level.

The size of the KV, its 40-yr history of moose browsing coupled with summer elk browsing, agricultural history, and extensive manipulation of Colorado River hydrology present both challenges and opportunities to restoration of willow communities in the KV. Our analysis points to the importance of including fencing as one of the many tools necessary to successfully improve willow condition and restore willow habitats to the KV, and we encourage their use in locations where existing small willow indicate that hydrologic conditions may be adequate to recover willow through fencing alone.

Upland

Shrub cover

Upland EVMP monitoring has been minimal since herbaceous offtake goals were achieved in 2013. At that time, an expert panel determined that these grasslands on the winter range (WR) appeared healthy and recommended discontinuing the time-consuming annual task of collecting herbaceous offtake data. Since 2014, only measurements of shrub cover, species, and height were collected on a 5-yr basis. Mean upland shrub cover has remained stable throughout the 15 years since EVMP implementation (Figure 32) with no major increases or decreases over time ($p = 0.77$). Shrub cover was greater on the noncore WR throughout the study and was generally less than 20% (Figure 32). These results indicate that no apparent grazing-induced increases in overall shrub cover are occurring on the WR. Shrub cover was dominated by a few species (Figure 33), including bitterbrush (*Purshia tridentata*), sagebrush (*Artemisia tridentata*), chokecherry (*Prunus virginiana*), buckbrush (*Ceanothus fendleri*), and rabbitbrush (*Chrysothamnus viscidiflorus* and *Ericameria nauseosum*).

Height and cover of each of these species remained stable throughout the 15-yr monitoring period. Patterns reflected those seen for total shrub cover, with more shrub cover in the noncore WR for most species. Sagebrush had the most variability in percent cover, with a range from 0% to nearly 80% cover.

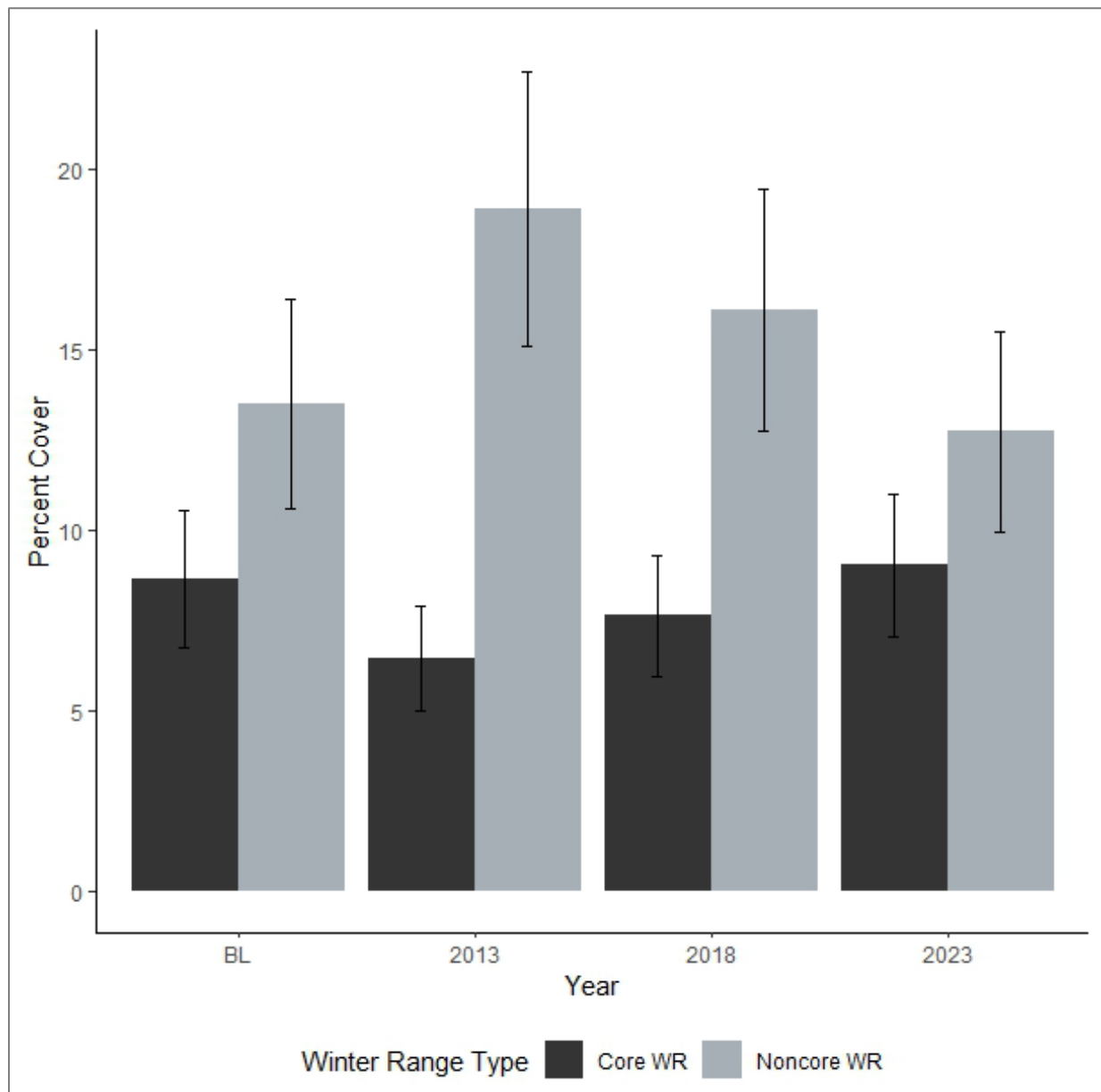


Figure 32. Estimated mean total shrub cover on upland EVMP monitoring plots in Rocky Mountain National Park, Colorado. Error bars denote ± 1 standard error. BL=baseline data collection conducted at plot establishment (2006–2008).

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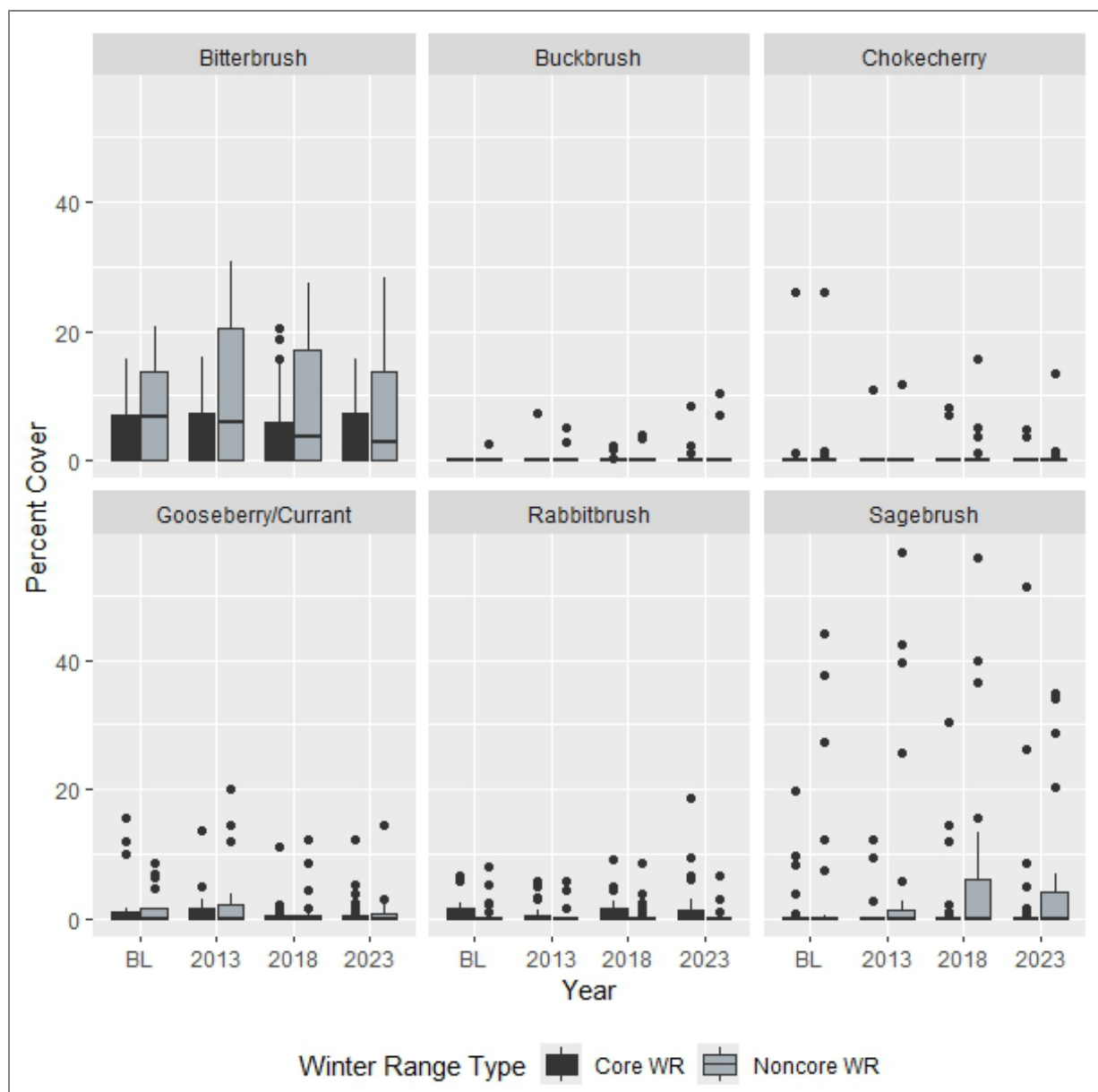


Figure 33. Box plots of percent cover of major upland shrub species recorded at EVMP plots in Rocky Mountain National Park baseline through 2023. BL=baseline data collection conducted at plot establishment (2006–2008).

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Animal Presence in Uplands

Signs of animal presence at upland plots were recorded for deer, elk, and moose throughout the 15-yr monitoring period. The proportion of upland plots that had signs of elk was generally high, but sign was recorded in fewer noncore plots in 2018 and 2023 than in the first 5 years of monitoring (Table 11). Signs of moose were not observed at upland plots prior to 2018, and moose sign was recorded on a larger proportion of noncore winter range (WR) plots than core WR plots (Table 11, Figure 34).

Table 11. Proportion of sampled upland plots that had observed cervid (elk, moose, deer) sign from baseline (2006–2009) through 2023. Blank entry indicates data not collected in that year.

Animal Species	Range Type	Proportion of Plots with Animal Sign (Total Number of Sampled Plots)			
		Baseline	2013	2018	2023
Elk	Core winter range, Unfenced	1.0 (19)	0.91 (22)	0.88 (25)	1.0 (25)
	Noncore winter range	1.0 (12)	0.93 (14)	0.70 (23)	0.74 (23)
Moose	Core winter range, Unfenced	0 (19)	0 (22)	0.08 (25)	0.04 (25)
	Noncore winter range	0 (12)	0 (14)	0.35 (23)	0.23 (23)
Deer	Core winter range, Unfenced	0.84 (19)	0.73 (22)	0.60 (25)	0.60 (25)
	Noncore winter range	0.83 (12)	0.79 (14)	0.65 (23)	0.96 (23)

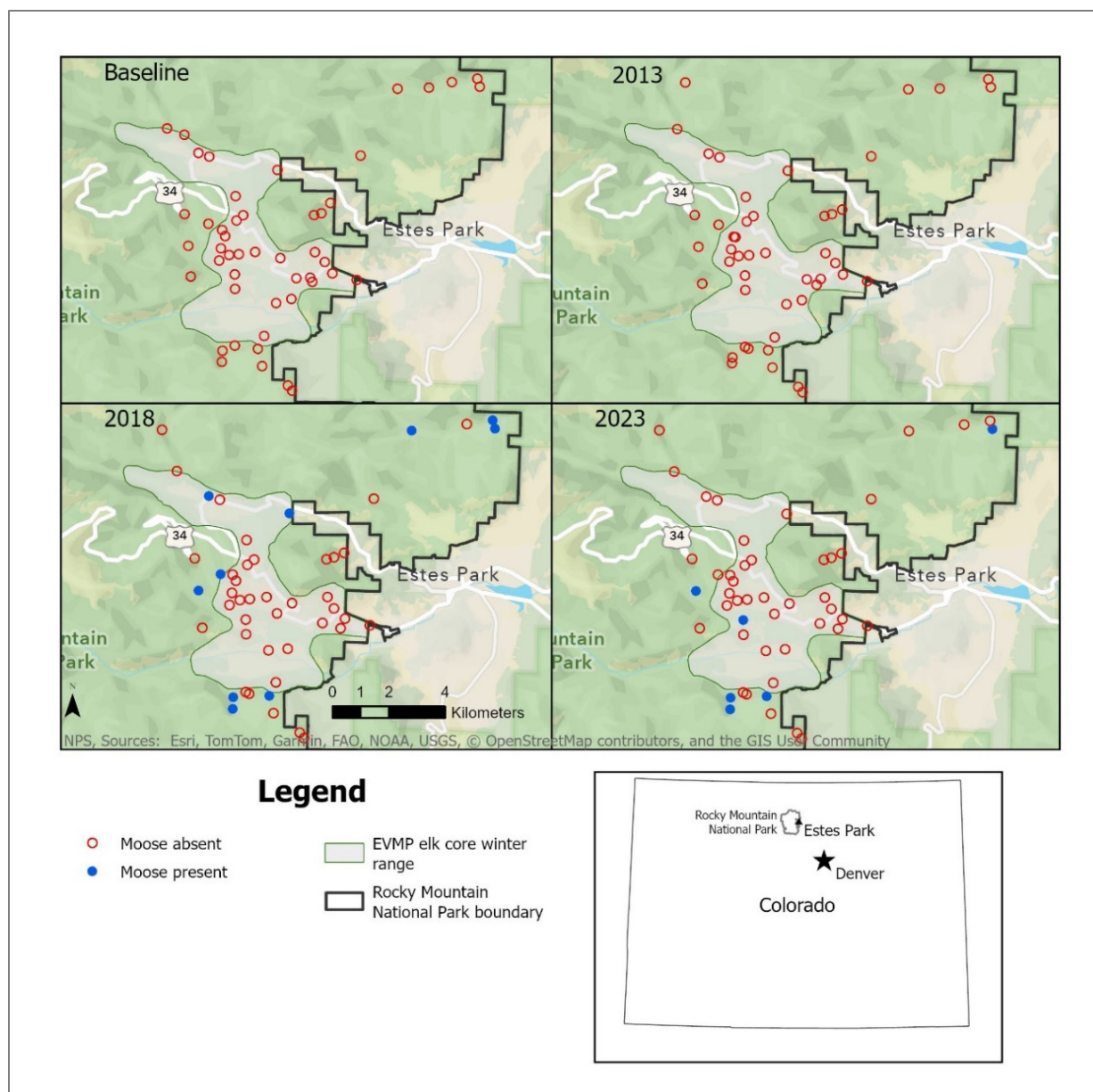


Figure 34. Moose presence in Elk and Vegetation Management Plan (EVMP) core and noncore upland monitoring plots from baseline to 2023. Moose presence in upland plots was added to the protocol in 2018.

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Progress Toward EVMP Upland Objectives

At this time, upland vegetation objectives have been achieved and the data collected over the past 15 years indicate relative stability in shrub cover and species composition. We believe that it is not unreasonable to suggest discontinuing measurements in upland plots unless anecdotal evidence or data from other studies or surveys indicate decreasing habitat condition and increasing ungulate use of upland grasslands of the winter range (WR).

Conclusions

The Elk Vegetation Management Plan was implemented 15 years ago with an overarching objective of reducing elk herbivory and improving habitat condition at aspen, willow, and upland sites on the core elk winter range (WR) of Rocky Mountain National Park. Progress toward these goals has been mixed, but overall improvement in WR habitat conditions is slowly being achieved (Table 12). Several factors have presented challenges and opportunities to the anticipated progression toward improved WR condition, including wildfires, floods, changes in elk migratory patterns, and arrival of a new large ungulate species.

Table 12. Progress toward desired future conditions in relation to thresholds specified in the Elk and Vegetation Management Plan ([EVMP]; NPS 2007; Zeigenfuss and Johnson 2015).

Category	Desired Future Condition ^A	Thresholds/Measures of Progress	Current Status (as of 2023)
Aspen	At least 45% of aspen stands across the winter range regenerating.	Progressive increase in aspen regeneration above the baseline level of 13% (presence of stems < 2 cm DBH reaching 150–250 cm tall).	Regeneration occurring on 43% of winter range stands.
	Distribution of stem DBH reflects many (~75%) small-diameter stems, some (~20%) medium-diameter stems, and few (~5%) large-diameter stems.	Progressive shift in the distribution of stem sizes toward the desired future condition.	Percent of stands with >75% of small diameter stems has increased from 1% to 19% since baseline.
Riparian Montane Willow	At least 31% willow cover within suitable willow habitat across the winter range.	Progressive increase in willow cover across the winter range above the baseline level of 21%.	Willow cover across the winter range is 45%.
	Average willow height of at least 1.1 m.	Progressive increase in willow height across the winter range above the baseline level of 0.9 m.	Average height of willow across the winter range is 129 cm (1.29 m)—largely driven by increases inside habitat fences that exclude elk.
	Levels of browsing within the natural range of variation.	No net increase in annual willow offtake across the winter range above the baseline level of 35%.	Detailed offtake measures discontinued 2013. Current measures indicate browse intensity has decreased roughly 35–40% since baseline.

^A Desired future condition of willow are specific to the 20-yr timeframe of the EVMP.

^B Baseline level of offtake in the EVMP Environmental Impact Statement (NPS 2007) for upland herbaceous was 47%, however, the method for calculating baseline offtake was revised in 2013 resulting in a baseline value of 61% (Zeigenfuss and Johnson 2015).

Table 12 (continued). Progress toward desired future conditions in relation to thresholds specified in the Elk and Vegetation Management Plan ([EVMP]; NPS 2007; Zeigenfuss and Johnson 2015).

Category	Desired Future Condition ^A	Thresholds/Measures of Progress	Current Status (as of 2023)
Upland Herbaceous	Reduction of the level of elk grazing on herbaceous vegetation and maintenance of a diversity of grazing levels across the landscape.	No net increase in winter upland herbaceous offtake across the winter range above baseline levels of 61% ^B , with ≤ 25% of sites with offtake > 70% and ≤ 10% of sites with offtake > 85%.	Achieved as of 2013.

^A Desired future condition of willow are specific to the 20-yr timeframe of the EVMP.

^B Baseline level of offtake in the EVMP Environmental Impact Statement (NPS 2007) for upland herbaceous was 47%, however, the method for calculating baseline offtake was revised in 2013 resulting in a baseline value of 61% (Zeigenfuss and Johnson 2015).

Aspen stands on the WR are having mixed success after 15 years of EVMP practices. While regeneration is on track to meet objectives by 2028, most of this success is confined to inside the fences or areas burned by the 2020 fires (Table 12). Aspen appears to be benefitting from a burst of regeneration in sites that were burned in 2020, but it is too soon to tell whether this increased regeneration will translate into increased recruitment, especially as the fire removed the recruiting cohort of young trees that was becoming established in several stands. Stand structure is on a slow upward trajectory, again driven by fencing and on the noncore WR. Very few stands in unfenced core WR have been successful at adding a recruiting cohort of small diameter trees, and several sites that had been successful saw those gains removed by wildfire. We expect, however, that the young tree class that is represented by the small diameter aspen stems to return within a few additional years if there are no substantial increases in browse intensity. Although prolific aspen resprouting can occur in stands that had live aspen prior to fire, preferential browsing of postfire aspen resprouts will slow the rate of canopy recovery (Andrus et al. 2021). In many studies of post-fire aspen regeneration and ungulate browsing, where there are high concentrations of browsing ungulates, herbivory tends to overwhelm the resprouting response of aspen, resulting in lack of aspen recruitment following wildfire (White et al. 1998; Smith et al. 2016).

Both regeneration and recruitment are important to sustaining aspen stands over time. Aspen regeneration is usually identified as aspen suckers/saplings ≤ 2 m height, whereas aspen recruitment has been described as stems with height > 2 m (a minimum height to escape elk browsing) with diameter at breast height ≤ 10 cm (Baker et al. 1997, Barnett and Stohlgren 2001). Guidelines developed for aspen restoration in Utah National Forests (O'Brien et al. 2010), state that stands with >2500 stems/ha are likely to be self-replacing. By these standards, overall mean aspen regeneration on the WR is productive enough to have self-replacing stands. Over 75% of all EVMP plots have had the regeneration (aspen suckers/saplings ≤ 2 m height) potential to be self-replacing, at least marginally, since the outset of EVMP and continue to have high levels of regeneration. However, these authors identify the need for recruiting stem densities (stems with height > 2 m with DBH ≤ 10 cm) of greater than 1250 stems/ha to be sustainable and self-replacing (O'Brien et al. 2010). Only

about a quarter of EVMP aspen plots met these stricter recruitment criteria for self-replacing stands in 2023. This may indicate that continued maintenance of aspen fences, additional fencing, or more intensive ungulate management may be needed to achieve sustainable aspen stand structure.

Overall, willow metrics have now achieved the thresholds identified in the EVMP (Table 12), namely increased willow height and cover and reduced offtake (i.e. browse intensity), driven mainly by gains inside habitat fences on the core WR as well as on the noncore WR. Passive willow restoration through a reduced wintering elk population has resulted in little change to areas of the core WR outside of fences. Progress appears to have slowed for willow between 2018 (10 years after EVMP implementation) and 2023 (15 years). Mean willow height and cover appear to have stalled at roughly 150 cm and about 59% cover in fenced core WR and noncore WR plots. Reduction in wintering elk population size and coincident reduction in winter browsing pressure have had virtually no effect on unfenced willows in the core WR. This plateau in progress is likely due to several additional factors affecting the elk WR, namely an increasing moose population and large wildfires which have impacted several EVMP aspen and willow sites. Given that the “plateauing” effect seems to be present even when burned plots are removed from the willow analyses, we feel that the effect of the East Troublesome Fire is not driving the slowing of willow height and cover increases. Although overwinter browsing has decreased, we believe it is highly likely that much of what was previously defined as “winter browsing” was actually fall-winter-spring browsing. The migrating elk herds still spend time on the winter range in the spring and fall. Browse pressure by moose on the WR, particularly in summer, also appears to be increasing. We cannot ascertain seasonal browse levels from the data we currently collect. Some spring and fall browsing are captured in our overwinter browse measures, but much of it may be masked by plant compensatory growth that occurs after our sampling season.

EVMP objectives related to upland plots have been well addressed in the previous two reports (Zeigenfuss and Johnson 2015, Gage et al. 2023). The level of elk grazing on upland herbaceous vegetation has been successfully reduced and no additional grazing-related changes appear to be taking place based on the very coarse level of sampling currently being done. Given the apparent stability at these sites, unless there appears to be cause to re-initiate offtake measures or to continue shrub cover measurements, the upland measurements could be discontinued in 2028.

The next 5-yr sample of EVMP vegetation monitoring plots is scheduled for 2028. Based on the 15-yr analyses, we recommend discontinuation of upland monitoring barring any anecdotal information or other studies that indicate ungulate herbivory-induced changes to the condition of these habitats on the WR. At this point, we do not recommend discontinuing the macroplot willow data collection in favor of solely using the less intensive line intercept method, unless budgetary constraints make it absolutely necessary. While the patterns identified by line intercept method were similar to those observed using macroplots, this method appears to overestimate willow height, likely due to sampling fewer plants per plot. However, the method will be adequate to identify trends and differences between management type, if used. Also, because many projects compete for limited staff time and EVMP sampling is intensive, it might be wise to try to “rebalance” the samples for willow and aspen. Following the 2012 wildfire, additional sampling plots were created to compare

vegetative response in burned and unburned plots, resulting in more plots than originally planned and an abundance of plots concentrated in certain areas. Many of these plots reburned in 2020. At this point, re-stratifying the sampling design and removing some sampling plots may be warranted. Finally, it seems of paramount importance to collect more data on summer willow browsing between now and 2028. This information would help inform future management and may help explain patterns in the vegetation data collected in year 20 of the EVMP program.

A final word about objectives that have been achieved thus far. It is tempting to consider removal of ungulate exclusion fences since several EVMP objectives have been met. However, we strongly caution against removing fences at this point. The majority of habitat improvement has occurred within these fences and until other components of the system are functioning (beaver communities, restoration of hydrologic regimes, willow recruitment, stable elk and moose populations), the fences are key to maintaining these patches of high-quality habitat. Additionally, catkin production is vital to willow recruitment and expansion beyond existing willow areas. However, because catkins are produced only on stems produced in the most recent growing season, heavy browsing by ungulates significantly reduces seed production (Kay and Chadde 1992; Brookshire et al. 2002). If a test fence removal is needed, then we suggest that a new plot be fenced to offset the removal and allow restoration in another portion of the WR. Ideally, to maximize the likelihood of successful beaver colony establishment in and around fenced habitat, we recommend new fenced areas should be no less than 5.5 ha in area and optimally, at least 8 ha (preferably larger), contain existing willow, and have an active channel. We've observed establishment of beaver dams inside exclosures meeting these criteria on both the WR and the Kawuneeche Valley (KV). Ideally, new fenced habitat that is close to existing exclosures have potential to provide habitat for a larger network of beaver dams and ponds. In Moraine Park, beaver established in a 5 ha exclosure and then expanded to an 8 ha exclosure roughly 600 m channel length upstream. Additionally, when possible, we advise adding fencing to increase the height of existing WR fences to reduce trespass use by moose and elk and sustain the improved habitat condition on the WR that has been gained over the last 15 years.

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Young aspen trees inside fenced ungulate exclosure in Hondius Park in Rocky Mountain National Park.
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A magpie sits atop the head of an elk calf in winter in Rocky Mountain National Park.
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