COLORADO PARKS & WILDLIFE

Piceance Basin Restoration for Wildlife

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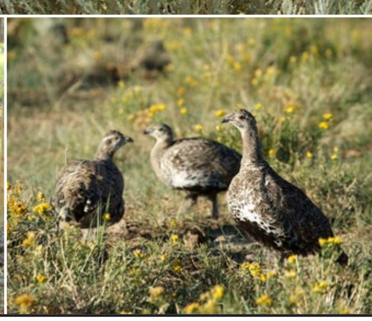

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COVER PHOTOS

Top: Restored pipeline disturbance in the Piceance Basin (credit D. Johnston)

Bottom (left to right): Piceance Basin elk (credit D. Johnston),
Piceance Basin sage-grouse (credit B. Walker),
Herbicide and tillage experiments at Yellow Creek (credit D. Johnston),
Piceance Basin mule deer bucks (credit B. Walker)

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PICEANCE BASIN RESTORATION FOR WILDLIFE

DANIELLE BILYEU JOHNSTON

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CHALLENGES FACING WILDLIFE MANAGERS IN THE PICEANCE BASIN

In the mid-2000s, Colorado Parks and Wildlife (CPW) was faced with a challenge in the Piceance Basin of Northwestern Colorado. Natural gas prices were high, driving rapid development of new natural gas wells in prime wildlife habitat. What was the best way to protect the largest migratory mule deer herd in the continental US, as well as a small, isolated population of greater sage-grouse? With the cooperation of energy developers, CPW embarked on three ambitious research projects targeting mule deer, sage-grouse, and habitat. The habitat research focused on restoration techniques for well pads and pipelines. Could we re-create the plant communities that are most valuable to wildlife?

The Piceance Basin is a geologic structure rich in natural resources. Following the latest pulse in development (2000 - 2015), the Piceance Basin was home to about 4,500 natural gas well pads, each averaging just over an acre in size (Martinez and Preston 2018) and each with about two acres of supporting infrastructure such as facilities, roads, and flowlines (Walker et al. 2020). Although drilling for natural gas has been slow in recent years, development is far from over. The Piceance Basin also contains rich deposits of oil shale. Although extracting the oil from the shale is not economical with current technology, much new research is focused on finding ways to access that resource. An estimated 1.5 trillion barrels of oil are held within Piceance oil shale, approximately five times the known oil reserves of Saudi Arabia (Dittrick 2009).

Our research focused on the northern half of the Piceance Basin, a biologically diverse area with plant communities representative of much of western Colorado and northern Utah (Figure 1). Lower elevations tend to be weedy with non-native annuals, both in the southern Colorado River Valley (~5,000 ft) and the northern Piceance Creek area (~6,000 ft; Figure 1). A gentle north-facing slope extends from Piceance Creek to the top of the Roan Plateau (~8,200 ft), supporting predominantly native shrub communities which vary with elevation. Lower elevations are dominated by pinyon, juniper and Wyoming big sagebrush, moderately wet middle elevations are dominated by a mixture of deciduous mountain shrubs, and mountain big sagebrush dominates at the highest elevations, in areas where soils are too thin to support aspen or spruce. A series of parallel creeks drain the slope, creating a variety of aspects and a mosaic quality to the plant communities. North of Piceance Creek, the south-facing slopes of the Magnolia region support pinyon and juniper, increasingly interspersed with mountain shrubs as elevation increases. As on the Roan, the highest elevations of Magnolia are dominated by mountain big sagebrush.

This region is heavily utilized by wildlife. Greater sage-grouse are year-round residents of the small patches of mountain big sagebrush which grace the tops of the hills and ridges both on the Roan Plateau and Magnolia. The local sage-grouse population is somewhat atypical in that birds nest and winter in areas with taller, denser shrubs and use more rugged terrain than in other parts of the species' range (Walker et al. 2016). Mule deer use the Roan Plateau as summer habitat, where diverse broadleaf plants such as American vetch, northern bedstraw, milkvetch, and hawksbeard allow deer to gain body fat to fortify them for winter. The slopes draining to Piceance Creek provide high-quality transitional range, and deer winter in the Magnolia region, where stands of serviceberry, mountain mahogany, and bitterbrush provide essential nutrition in the late winter months. The Colorado River Valley is also heavily utilized by mule deer in winter.

The complexity of the landscape accommodates wildlife needs, but it also creates challenges for restoration of oil and gas disturbances. A single flowline connecting a well pad to a gathering facility may cross several soil types and plant communities. With thousands of such disturbances to consider, regulatory agencies are hard pressed to gather the knowledge, provide the recommendations, and enforce the requirements to ensure that reclamation meets basic standards (Pilkington and Redente 2006).

For managers striving to maintain or improve native habitats, oil and gas disturbances represent both a threat and an opportunity. As in other places, disturbances in the Piceance Basin must be considered in the context of interacting factors, namely invasive species and climate change. Where habitats are intact, disturbances can hasten the invasion of undesirables like cheatgrass (Bradford and Lauenroth 2006, Speziale et al. 2018). As climate change alters habitat suitability for both invasives and desirable species (Bradley 2009, Renwick et al. 2018), disturbances can endanger plant communities which might otherwise be resistant to invasion (Larson et al. 2017). On the other hand, where habitats are already invaded, disturbances can be an opportunity to bury unwanted seed and get a fresh start (Johnston 2015).

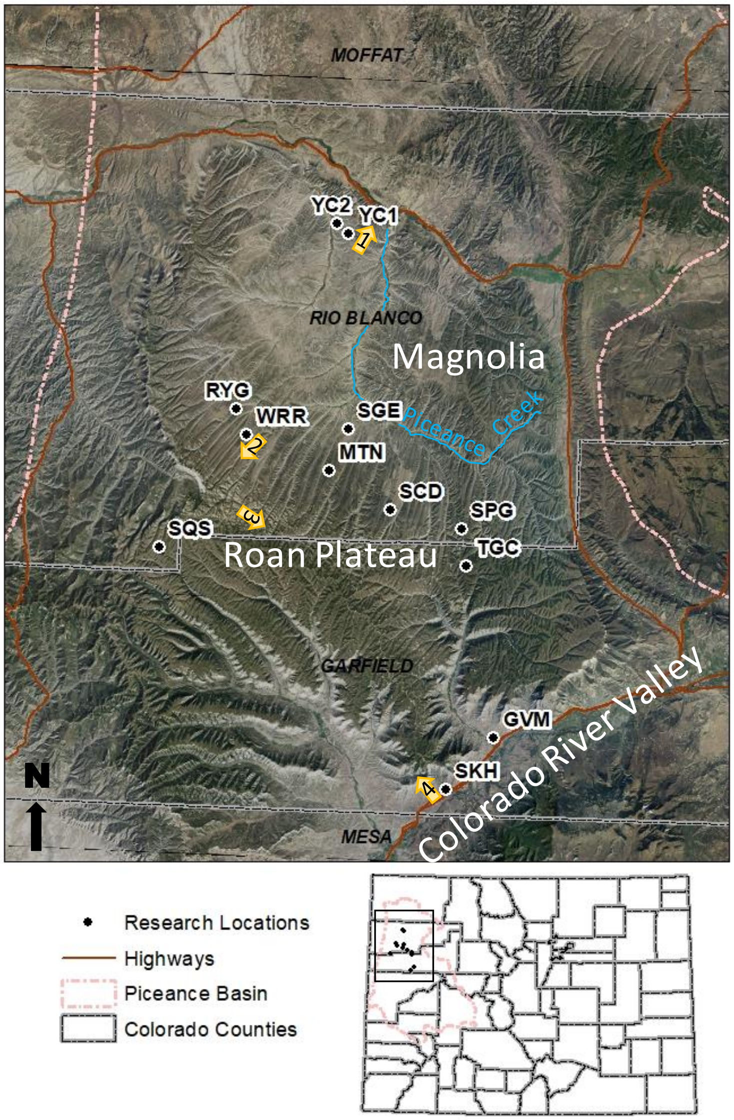

Figure 1. The twelve study sites in Rio Blanco and Garfield Counties, Colorado, in the northern half of the geologic Piceance Basin. Yellow arrows indicate the approximate location and direction of photos, taken 2007-8.

Site	Elevation (ft)	soil survey unit	precipitation annually (in)	topography	dominant plant species	Imazapic	pendamethilin	rough surface	seed barriers	seed mixes	not seeding	brush mulch	soil amendment	rolling
SKH	5120	Arvada loam	14	valley bottom	cheatgrass, Wyoming big sagebrush, bulbous bluegrass	x	x		x					x
GVM	5451	Potts-Ildefonso (loams)	15	mesa top	Wyoming big sagebrush, Utah juniper, cheatgrass, needle-and-thread grass, western wheatgrass	x		x		x				x
YC2	5999	Glendive fine sandy loam	15	valley bottom	cheatgrass, Wyoming big sagebrush, needle-and-thread grass, scarlet globemallow	x	x		x					x
YC1	6248	Yamac loam	15	valley bottom	Wyoming big sagebrush, Indian ricegrass, cheatgrass, needle-and-thread, prairie junegrass, scarlet globemallow	x	x		x					x
SGE	6573	Piceance sandy loam	16	ridge top	Wyoming big sagebrush, western wheatgrass, needle-and-thread grass, Sandberg bluegrass, prairie junegrass, scarlet globemallow			x		x			x	x
RYG	6835	Glendive fine sandy loam	18	valley bottom	Wyoming and basin big sagebrush, basin wild rye, cheatgrass, western wheatgrass	x	x		x					x
MTN	7160	Piceance sandy loam	17	ridge top	mountain and Wyoming big sagebrush, green rabbitbrush, saskatoon serviceberry, western wheatgrass, needle-and-thread grass, Sandberg bluegrass, prairie junegrass, indian ricegrass	x		x		x				
WRR	7268	Piceance sandy loam	18	ridge top	mountain big sagebrush, Saskatoon serviceberry, western wheatgrass, needle-and-thread grass, Sandberg bluegrass, prairie junegrass, indian ricegrass, hawksbeard, silvery lupine	x		x		x			x	x
SCD	7681	Castner channery loam	18	ridge top	Mountain big sagebrush, roundleaf snowberry, silvery lupine, antelope bitterbrush, green rabbitbrush, pinyon pine, Saskatoon serviceberry, Sandberg bluegrass, sulfur-flower buckwheat			x			x	x		
SPG	8019	Irigul/ Parachute (loams)	19	plateau top	Mountain big sagebrush, roundleaf snowberry, silvery lupine, antelope bitterbrush, Saskatoon serviceberry, Sandbery bluegrass			x			x	x		
TGC	8288	Parachute-Rhone Loams	19	plateau top	Mountain big sagebrush, roundleaf snowberry, silvery lupine, antelope bitterbrush, Sandberg bluegrass, sulfur-flower buckwheat, white locoweed			x			x	x		
QS	8777	Irigul/ Parachute (loams)	25	plateau top	Mountain big sagebrush, roundleaf snowberry, silvery lupine, antelope bitterbrush, Kentucky bluegrass, muttongrass, northern bedstraw, bluebunch wheatgrass			x			x	x		

Table 1. Study site elevations, descriptions, and tested treatments. Soil descriptions are Natural Resource Conservation Service (NRCS) units and precipitation values are 30 year normals for 1981-2010 (PRISM Climate Group). X's indicate which treatments were tested at each site.

A GRADIENT OF RESTORATION EXPERIMENTS

To meet the challenge of understanding best restoration practices in the complex terrain of the Piceance Basin, CPW embarked on a 12-year-long research program comprised of 12 sites and 6 restoration experiments arranged on an elevation gradient from 5,100 ft to 8,800 ft (Figure 1, Table 1). We focused on sagebrush-dominated communities because of their importance to wildlife. In all experiments, establishment of native, perennial plants was emphasized. Perennial plants are critical for wildlife because they provide nutritious forage for a longer portion of the growing season, their overall productivity is higher, and their productivity is less variable from year to year than annual plants (DiTomaso 2000). Treatments in our experiments included herbicides (imazapic and pendamethilin), soil surface roughening, seed dispersal barriers, seed mix types, not seeding, mulching with woody debris, a soil amendment, and rolling (Figure 2).

The experiments conducted at lower elevations emphasize weed control, while the experiments at high or middle elevations emphasize maximizing plant diversity. All of the research sites were fenced to exclude wildlife and livestock. Though this was a sacrifice in realism, it was necessary to eliminate some variability in order to discern how treatments, elevation, soils, and climates would interact to influence restoration.

Simulated pipeline and well pad disturbances were created 2008-9, treatments were implemented 2009-2012, and monitoring has occurred through 2019. As details of the experiments can be found elsewhere (Johnston 2011, Monty et al. 2013, Johnston and Chapman 2014, Johnston 2015, 2019, Johnston and Garbowski 2020), we focus here on the take-home messages from the overall effort.

CHEATGRASS CONTROL

Cheatgrass is an annual, exotic grass which has invaded over 5 million acres in western North America and is expected to continue to expand in range (Bradley and Mustard 2006, Abatzoglou and Kolden 2011). Cheatrgrass presents a serious obstacle to effective reclamation (Knapp 1996, Chambers et al. 2007, Reisner et al. 2013). Cheatgrass is able to germinate at lower temperatures and in drier soils than native perennial grasses, and this allows it to develop its roots throughout the fall, winter, and early spring (Harris 1967, Hardegree et al. 2013). By the time perennial seedlings germinate in the spring, cheatgrass has an established root system and is already depleting soil moisture. Cheatgrass invasion reduces forage for livestock and wildlife (Knapp 1996, Ielmini et al. 2015), changes soil nutrients (Norton et al. 2004), and increases fire frequency (Knapp 1996, Balch et al. 2013).

Controlling cheatgrass propagule pressure

Propagule pressure is the technical term for the number of seeds per area, per unit of time. The propagule pressure of weeds versus desirable plants is incredibly important in determining the outcome of restoration- more important than other factors a manager might try to influence, such as herbivory (Eschtruth and Battles 2009) or abiotic conditions (Von Holle and Simberloff 2005). Controlling weed propagule pressure during the vulnerable period after disturbances is especially important (DiVittorio et al. 2007, Eschtruth and Battles 2009). This was apparent in this study, as all but the highest elevation site proved vulnerable to rapid invasion by cheatgrass after we imposed disturbances.

Cheatgrass is a massive seed producer (Figure 3). A vigorous cheatgrass stand can produce 1,900 seeds per square foot per year (Hempy-Mayer and Pyke 2008). For comparison, a restoration seed mix typically includes 50 to 150 seeds per square foot. Cheatgrass also bounces back incredibly quickly; even if the cheatgrass seed bank is reduced by 98%, the seed density can rebound in as little as two years (Morris et al. 2009). This occurs because the few surviving plants produce seed especially well- solitary cheatgrass plants will produce 40 times more seed than plants within a dense stand (Hulbert 1955). Getting enough cheatgrass control, for long enough to allow perennial plants to establish, is the trick. "Enough" cheatgrass control in heavily invaded areas means better than a 99% reduction in viable seeds, because it takes as few as 4 cheatgrass seeds per square foot to hinder establishment of perennial grasses (Evans 1961) (Figure 3).

Herbicides

To date there is no reasonably successful method to achieve that kind of cheatgrass control in heavily invaded areas without the use of herbicides. In a review of studies spanning 64 years, herbicides and revegetation were the only methods with any success at controlling cheatgrass for more than 2 years (Monaco et al. 2017). With that being said, herbicides can be tricky to apply appropriately, sometimes produce unintended consequences, and may not supply enough cheatgrass control. We had a mixture of successes and failures with

Figure 2. Two herbicides (imazapic and pendamethilin), a rough soil surface, seed dispersal barriers, and woody debris mulch were among the treatments tested in this study.

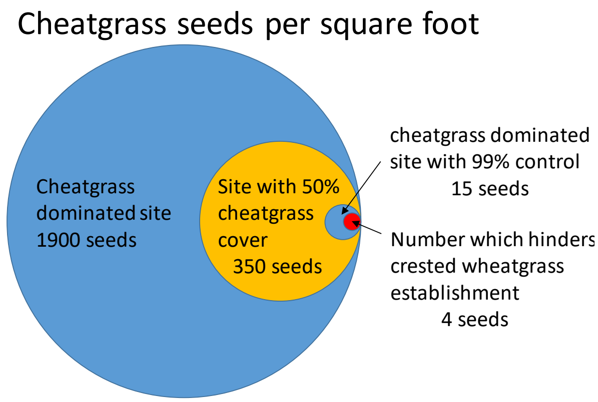

Figure 3. References for seed density: Cheatgrass dominated site (Hempy-Mayer and Pyke 2008); Site with 50% cheatgrass (this project, SKH site); Number hindering crested wheatgrass (Evans 1961).

herbicides. At six of our study sites, ranging from 5120 to 7268 ft in elevation, where cheatgrass had already invaded the area, a 6 oz/ac Plateau™ application (105 g ai ha^{-1} imazapic, BASF Corp.), coupled with a well-timed, seed-burying disturbance, provided enough control to allow big sagebrush to establish (Johnston 2015) (Figure 4). On the other hand, at the MTN site (7160 ft), which was uninvaded prior to disturbance, an 8 oz/ac Plateau application (140 g ai ha^{-1} imazapic) severely limited perennial plant establishment. Five years after treatment, cheatgrass cover was 15 times higher where Plateau had been applied (Figure 4). After the first few years, the herbicide itself is not active; it is the effect of the herbicide on perennial plants which will determine long-term outcome (Whitson and Koch 1998). Therefore, it's essential that the net effect of the herbicide on perennial plant establishment is positive. Another herbicide we tested, pendimethalin (Pendulum® AquaCap, BASF Corp.), provided excellent cheatgrass control, but had a devastating impact on perennial grasses and shrubs (Johnston 2016). This is not a win.

Currently, Plateau is commonly applied at a light rate [4 oz/ac Plateau (70 g ai ha^{-1} imazapic)] to avoid unacceptable injury to desirable plants. Although Plateau is a helpful tool, a single application may not provide enough cheatgrass control for perennial plants to establish (Morris et al. 2009, Elseroad and Rudd 2011, Owen et al. 2011). The search continues for an herbicide with greater selectivity for cheatgrass. Indazilfam (Esplanade®, Bayer) shows promise for areas which have established desirable vegetation (Sebastian et al. 2017). However, it is harmful to many desirable plants at the germination stage, and that effect lasts multiple years (Gunnell et al. 2020). Cheatgrass is sensitive to glyphosate (e.g. RoundupPro®, Monsanto), with good control at some sites at rates as low as 4 oz/ac (280 g ai/ha) (Beck et al. 1995) when applied before the seed heads begin forming (Blackshaw 1991). However, control is inconsistent from site to site, likely because glyphosate is only effective on actively growing plants, so late-germinating cheatgrass plants escape (Whitson and Koch 1998, Kyser et al. 2013). Until a more effective product is developed, restoring perennial plant communities from seed will require coupling an herbicide with another method of reducing cheatgrass propagule pressure. We investigated several such methods, and found that the methods which involved burying cheatgrass seeds and/or hindering their dispersal had the most success.

Cheatgrass seed dispersal

Cheatgrass seeds can be rolled along the ground surface by wind, and they go much further over bare soils than over vegetated surfaces (Johnston 2011, Monty et al. 2013). A dense stand of cheatgrass lining the sides of a pipeline can provide enough seeds to compromise restoration (Johnston 2011). Disturbances can create a perfect storm for cheatgrass invasion, because competition is cleared away at the same time that dispersal is enhanced. This is one reason that fire benefits cheatgrass (Monty et al. 2013). Even if the fire kills most of the seeds, the few survivors will grow well and produce seed copiously. These seeds will then be able to disperse easily so that they also grow well and produce seed copiously (Figure 5a). Within two generations, cheatgrass seed density can be higher than what it was prior to the fire (Humphrey and Schupp 2001).

We found that a rough soil surface with 20 inches of relief between mounds and holes effectively interrupts this process. The rough surface limits wind-driven cheatgrass dispersal so that seeds remain near the parent plant (Johnston 2019). This prevents the second generation of isolated, highly productive cheatgrass plants from occurring (Figure 5b).

Without herbicide, the rough surface controlled cheatgrass at higher elevation sites which were not invaded prior to disturbance (Johnston and Chapman 2014, Johnston 2019). Coupled with Plateau, the rough

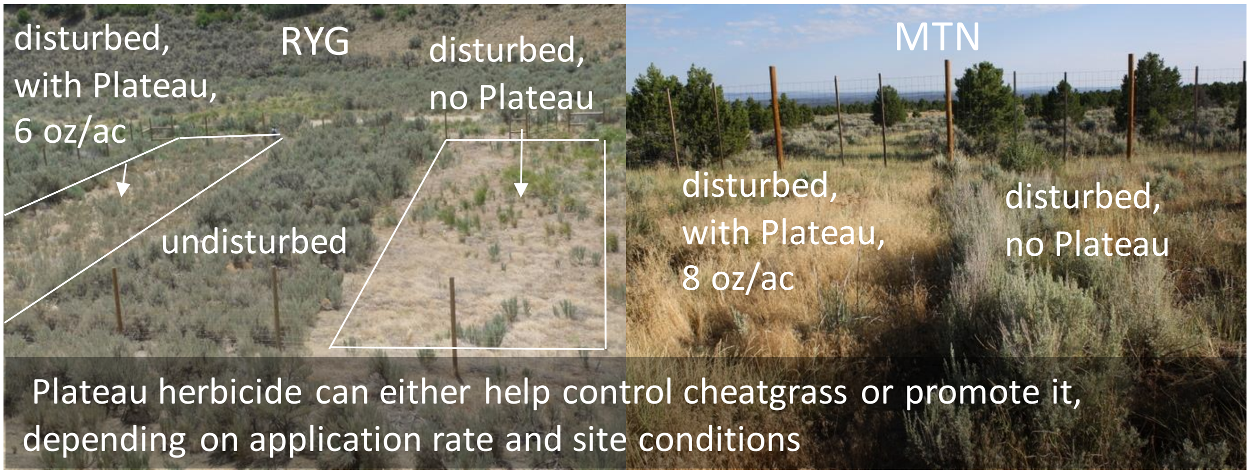

Figure 4. The RYG site (left photo) had heavy cheatgrass cover in undisturbed areas. A 6 oz/ac Plateau application helped control cheatgrass and allow sagebrush to establish. The MTN site (right photo) had no cheatgrass in undisturbed areas. An 8 oz/ac Plateau application hindered grass and shrub establishment, eventually resulting in abundant cheatgrass.

surface provided enough cheatgrass control at low-elevation, heavily invaded sites to establish desirable plant communities (Johnston and Chapman 2014, Johnston 2018) (Figure 6).

Finding ways to limit dispersal is a useful concept for more species than just cheatgrass. Weedy species, almost by definition, produce large numbers of rapidly dispersing seeds to quickly exploit any open or disturbed areas (Sakai et al. 2001). Many types of weeds, even those not commonly thought to be wind dispersed, are influenced by soil surface obstructions (Davies and Sheley 2007). Potholing works well because it treats the whole landscape; no matter where the seeds are coming from, their movement will be restricted. Barriers can also be helpful if the seeds are coming from a particular direction. A 20-ft wide strip of crested wheatgrass will prevent the spread of the invasive annual grass medusahead into a native bunchgrass community (Davies et al. 2010). Barriers may need to be fairly impervious to the target weed species to be effective. The windowscreen barriers we tested worked for Russian thistle, but not for cheatgrass (Johnston 2016). Although we saw many cheatgrass seeds caught by the barriers, we also saw seeds migrating under them and cheatgrass plants growing through them, and there was no impact of the barriers on cheatgrass cover within the plot. Wider barriers of vegetation or potholes may be a better option for cheatgrass. In designing barriers using vegetation, the type of seed you need to control must be considered. For medusahead, an awned grass with a morphology similar to cheatgrass, vegetation at least 12 inches tall is effective (Davies and Sheley 2007). For yellow salsify, a wind-dispersed species similar to a dandelion, vegetation must be at least 24 inches tall. In general, taller vegetation does a better job of limiting the spread of weed seeds than short vegetation (Davies and Sheley 2007).

We designed and built an implement to make the rough surface and seed over it in a single pass, and the implement is now available for use (Figure 7) (Johnston 2018). It features Truax™ Flex II drill boxes to allow grass seeds, small seeds, and fluffy seeds to be metered independently. Seeding rate is controlled by a ground drive wheel. Large notched discs create an alternating pattern of mounds and holes when the implement is dragged. The tool is capable of creating 12-15 inches of relief between mounds and holes, however extremely dry or hardpan soils result in less relief. We are continuing to test the tool and make improvements to it.

Timing

The spring after the pipeline disturbances, cheatgrass was 10 times less dense where we had disturbed the soil (Johnston 2015). Given that cheatgrass disperses readily over bare soils, how could this be? Timing is everything. We simulated our pipelines in September, after cheatgrass was done dispersing for the season (Figure 8). The disturbances buried the seed that was there, and it was too late for any more seed to arrive that year. Cheatgrass seeds tend to die when buried at least 1 inch (Wicks 1997), so this left us with a relatively clean slate. We planted immediately after the

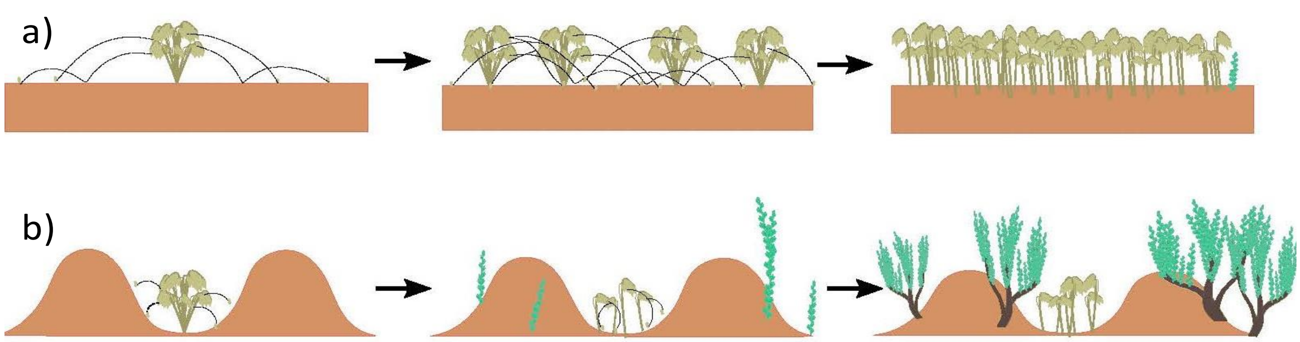

Figure 5. a) Cheatgrass seeds disperse readily over bare, flat soils. Plants are productive when isolated, so the second generation of plants produces many seeds, allowing cheatgrass to quickly dominate a site. b) Dispersal obstructions interrupt this process. Seeds are trapped near the parent plant, which forces the second generation of plants to compete with each other, rendering them less productive.

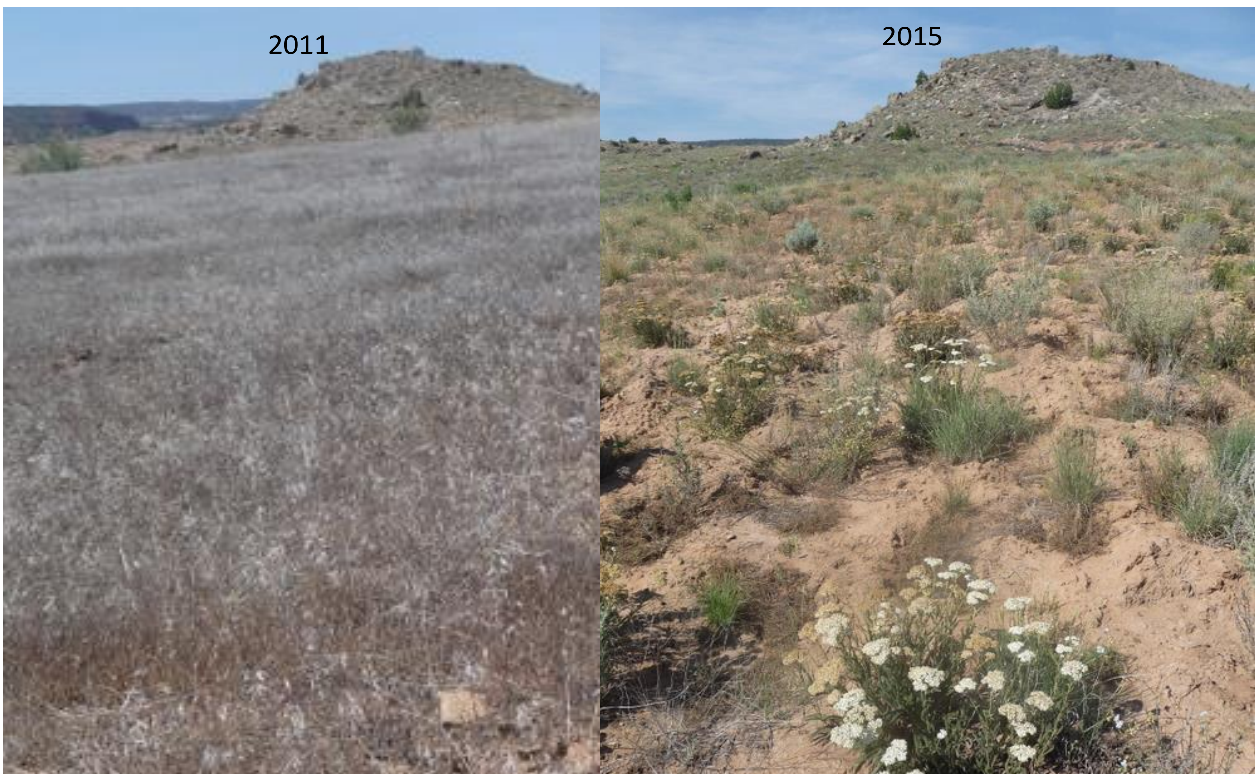

Figure 6. Using techniques learned in this study, we rehabilitated a severely invaded rangeland at Horsetheif State Wildlife Area by a light application of Plateau (4 oz/ac), and then seeding over a roughened surface of mounds and holes.

disturbances, and our seeded species had enough of a head start to become established.

The order that seeds arrive at a site is extremely important (Tilman 2004). In a study by Firn and colleagues, a head start of only 3 weeks was enough to help a native grass to outcompete an invader (Firn et al. 2010). Although we may not always have the flexibility to time disturbances when it's best for cheatgrass control, understanding timing can help us set expectations and prioritize control efforts. The key is to recognize whether or not seeded species will be able to germinate before cheatgrass seed arrives at the site. The recommended seeding window in the Piceance Basin is from late summer to early spring (Taliga 2011); for practical purposes, late summer to late fall are possible. Disturbances occurring any time other than late summer to late fall will require more thoughtful cheatgrass control (see Recommendations).

Figure 7. Pothole seeder. When the discs are dragged, the large notches produces a pattern of mounds and holes. The seeder requires a tractor of at least 50 HP with two sets of hydraulic ports.

PROMOTING SAGEBRUSH PLANT COMMUNITIES

Seed mixes and seeding rate

Seeding competitive grasses, even native ones, can prevent big sagebrush from establishing (Hild et al. 2006, Porensky et al. 2014, Johnston 2019). Managers attempting to establish big sagebrush communities face a quandary, since competitive grasses are sometimes needed to prevent erosion and/or keep weeds in check. Restoration seed mixes used in Colorado vary greatly, but often contain 8-12 lbs/ac of pure live grass seed and only a small fraction of broadleaf plants or shrubs (Figure 9). Pure live seed, or PLS, is the weight of live seeds. We found that a mix can contain as little as 1.5 PLS lbs/ac of grass and keep cheatgrass in check as well as a mix with 9 PLS lbs/ac of grass. The low-grass mix also promoted better sagebrush establishment (Johnston and Chapman 2014). Our low-grass mix contained commercially available broadleaf plants as well as broadleaf plants from local sources supplied by the Uncompahgre Partnership Native Plant Program (http://www.westerncolc.org/projects#/native-plants/). Such mixes are certainly more effort to pull together and more expensive, but they can produce results that are more comparable to intact plant communities. This is important because restoration areas can remain dominated by grasses for decades (Newman and Redente 2001), and these grass-dominated areas cause wildlife responses which may be hard to predict. For instance, deer mice are attracted to the seeds available in grass-dominated pipelines, and the mice then eat the eggs of songbirds nesting in the area (Sanders and Chalfoun 2018). Restoring a mixture of grasses, shrubs, and broadleaf plants may help avoid these complications.

The typical advice on seeding rates is to double the rate for broadcast seeding versus drill seeding. We kept seeding rates the same when we compared broadcast seeding (with a rough surface) to drill seeding (on a flat surface) and found that both worked equally well. If the seedbed is prepared, meaning that the soil surface is neither hardpan or fluffy, then doubling the seeding rate for broadcasting is probably a waste of money.

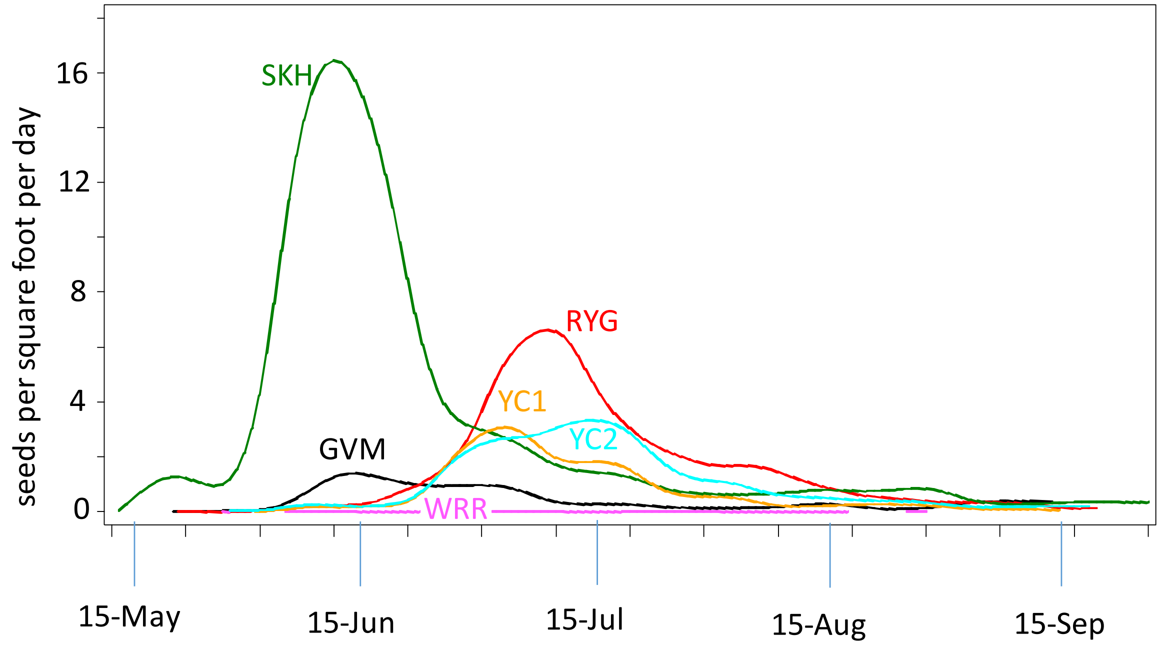

Figure 8. Cheatgrass seeds captured in undisturbed locations near each of six study locations. Seeds were captured in sticky traps and counted weekly. Data are averaged over 3 years.

Furthermore it could lead to a high grass seeding rate which could limit shrub establishment.

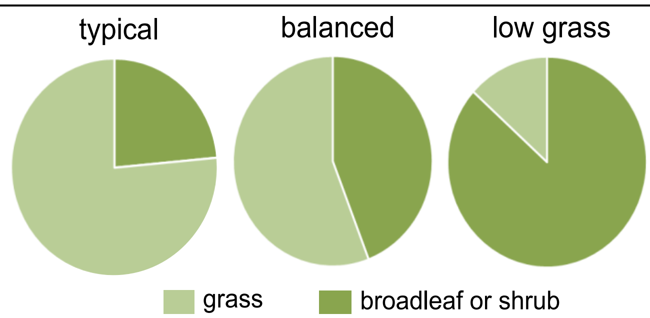

Figure 9. We tested a 'balanced' mix and a 'low grass' mix, both of which had more broadleaf plants and shrubs than typical mixes. The low grass mix performed well, holding out cheatgrass and allowing more rapid recovery of sagebrush.

What happens if you do not seed at all? We asked this question at four high elevation sites of 7681 to 8777 ft. Big sagebrush recovered well, reaching 26% cover after only 5 years. However, cheatgrass established at two of the four sites (Johnston 2019). This was unexpected given the higher precipitation and elevations of these sites. Over the past 20-40 years, specialist strains of cheatgrass have become adapted for montane as well as warm desert habitats (Merrill et al. 2012). As cheatgrass continues to adapt, we can expect it to become a better competitor in a wider range of environments. We recommend seeding higher elevation sites, but keeping the grass seeding rate light to allow big sagebrush to recover, as well as other shrubs and broadleaf plants which may be present in the surrounding area.

Seeding sagebrush

We were able to establish sagebrush from seed at every one of our 12 research sites (Figure 10). We used sagebrush seed that was collected adjacent to each site, and spread it almost immediately.

Sagebrush seeds are tiny- about 10 to 20 times smaller than common rangeland grass seeds. With only a speck of resources to draw upon, sagebrush seeds must germinate at exactly the right time or else they will dry out before their roots are established (Meyer and Monsen 1992). The optimal timing for germination varies with latitude, elevation, aspect, and soils, so sagebrush plants are adapted to site conditions at a very

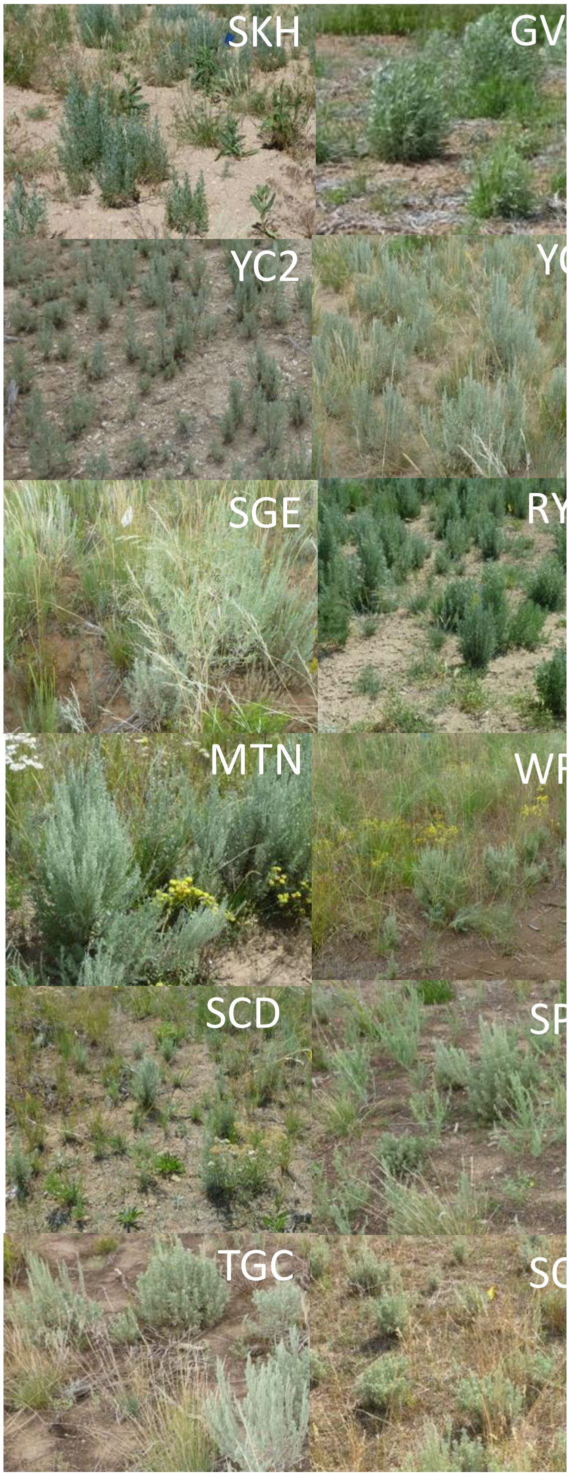

Figure 10. Sagebrush established from seed at each of the 12 sites, 2 or 3 years post-seeding. Light application of imazapic, limited grass in the seed mix, and sagebrush woody debris promoted sage establishment. We collected sagebrush seed locally for each site.

fine scale. In one study, sagebrush seedlings which grew from seed harvested on-site grew better than those which grew from seed harvested only 1000 feet away (Wang et al. 1997). While commercially available varieties certainly have their usefulness for many species, a local seed source is best for sagebrush (Meyer and Monsen 1992, Brabec et al. 2015).

Sagebrush seeding rate recommendations vary widely- from 0.08 PLS lbs/ac (Meyer and Warren 2015) to 3.6 PLS lbs/ac (Vicklund et al. 2011). The correct seeding rate is probably related to how well the seed is adapted to the site, as whatever portion of seed germinates at the wrong time will simply be wasted (Figure 11). The 0.6 PLS lbs/ac rate we targeted produced dense stands, and for well-adapted seed, 0.3 -0.6 PLS lbs/ac is probably sufficient. Higher seeding rates, up to 5 PLS lbs/ac, produce more sagebrush (Landeen et al. 2019). A higher seeding rate may help compensate for poor adaptation if commercial seed must be used. Collecting sagebrush seed takes some time but can be done with cheap equipment and little skill. More information on how to collect sagebrush seed can be found in Appendix A.

Using woody debris

In oil and gas disturbances, vegetation is scraped and piled up before the topsoil is scraped and piled up. When the vegetation was desirable, there are real benefits to respreading the scraped vegetation, as well as the scraped topsoil, over the disturbed area. We found that respreading the woody debris of sagebrush and other shrubs hastened shrub recovery by about 20% at four high elevation sites. The woody debris can provide shady microhabitats which enhance germination (Brown and Naeth 2014, Goldin and Hutchinson 2015), it can entrap dispersing seeds (Reichman 1984), and it may also provide a source of locally-adapted seed. Whatever the mechanism, we found consistent, positive effects of woody debris at improving cover of shrubs, perennial grasses, and perennial forbs.

SOME THINGS THAT DIDN'T WORK

Super-absorbent polymer

Perennial plants compete better when soil moisture is more stable, and this can help reduce cheatgrass (Harris 1967, Bradford and Lauenroth 2006, Chambers et al. 2007). We tried adding granulated super-absorbent polymer (SAP) to drill seeded rows at two middle elevation sites, SGE and WRR. SAP absorbs water when soils are moist and then gradually releases it, and is commonly used in horticulture and gardening to reduce

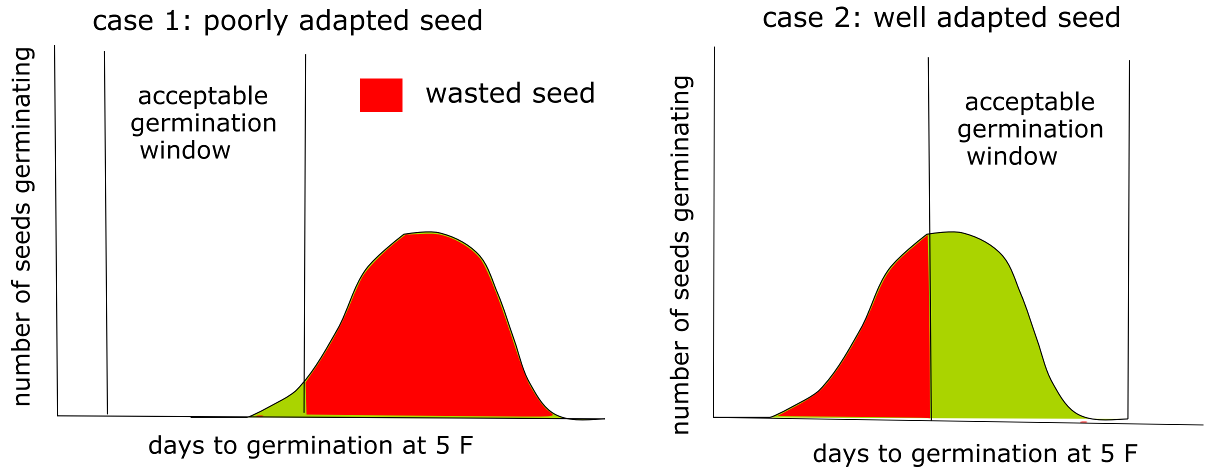

Figure 11. Sagebrush seeds from colder locations are programmed to wait longer at 5° F than seeds from warmer locations (Meyer and Monsen 1991). Planting ill-adapted seed will result in much of the seed germinating at the wrong time.

the required watering interval. At WRR we had success: higher perennial grass cover and less cheatgrass where SAP was added, but at SGE, we had more cheatgrass where SAP was applied (Johnston and Garbowski 2020). Because the SGE site had lower cheatgrass cover overall, it is possible that cheatgrass was nutrient limited at SGE, and SAP relieved this limitation (Johnston and Garbowski 2020). However, this mechanism remains a guess and we don't yet understand why the product worked so differently at the two sites, which were similar in most respects. Since the product is expensive and can have unintended consequences, we do not recommend it for management purposes without further study.

Surface soil compaction

Cheatgrass is unable to germinate through even slightly compacted soil (Thill et al. 1979, Beckstead and Augspurger 2004). We tried using a static drum roller to slightly compact soil at eight low to middle elevation sites, and we tried it in combination with a soil binding agent (DirtGlue™) at SGE and WRR. In all cases rolling was ineffective (Johnston 2015, Johnston and Garbowski 2020). Cheatgrass plants would find the inevitable cracks in the soil surface and grow there just fine. The soil binding agent itself had mixed, slight effects on cheatgrass, but did not hinder perennial plant establishment, so it could be helpful for areas where erosion and/or dust control is needed (Johnston and Garbowski 2020).

RECOMMENDATIONS

Making use of a higher proportion of forbs and shrubs in seed mixes, avoiding contaminated seed, using locally collected sagebrush seed, and seeding over a rough surface are recommended at all elevations (Figure 12). Other considerations are given by elevation zone below.

Cheatgrass-invaded sites with few desirable plants, elevations less than ~6500 ft

Consider the timing of the disturbance when designing a restoration plan. It's best for disturbances to occur in late summer or early fall. Apply 4 oz./acre Plateau (70 g ai/ha imazapic) immediately after the disturbance. If any cheatgrass has already emerged at the time of herbicide application, also apply 4 oz/ac RoundupPro (or similar product; 280 g ai/ha glyphosate) with 2% v/v surfactant such as methylated seed oil (MSO). If needed, retreat with glyphosate and MSO to control any cheatgrass which emerges prior to planting (up until a week before planting time). Do not reapply Plateau. Seed in the late fall or early winter with a drill seeder or pothole seeder.

This timing is ideal because much of the cheatgrass of the disturbance year will get buried, the herbicides will help control the remainder of the cheatgrass seed, and there will be a couple of months between Plateau application and seeding to avoid injury to newly seeded species. Also, seeded species will have a chance to germinate the next spring before the cheatgrass of the following year arrives.

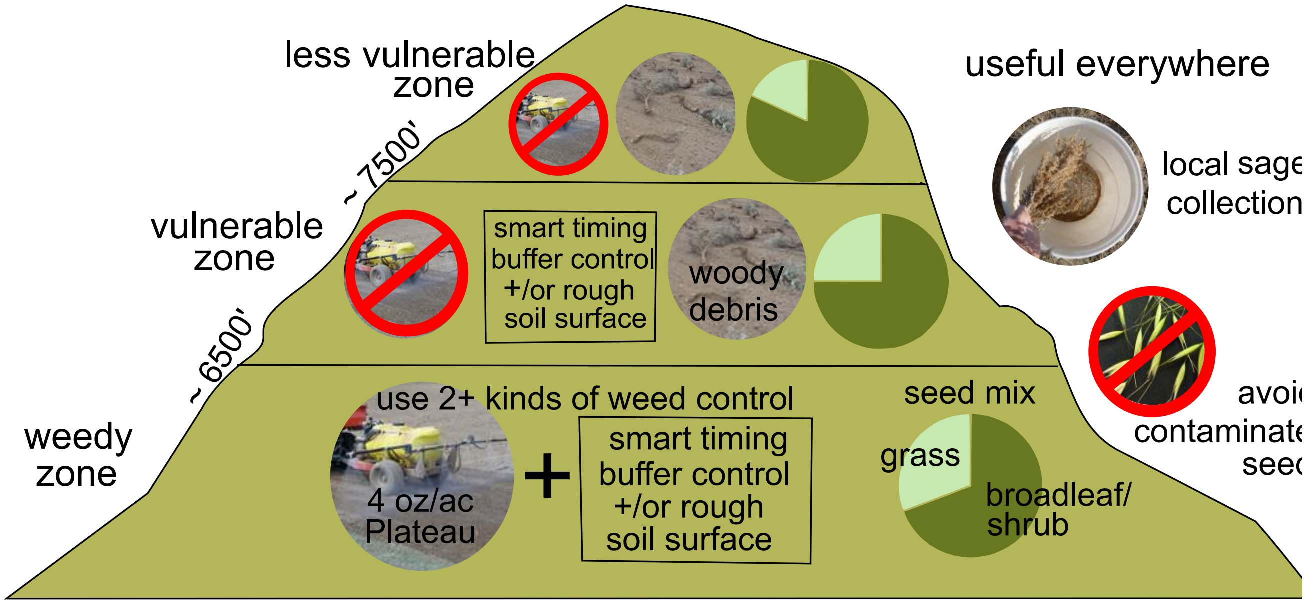

Figure 12. Recommendations for restoration of disturbed areas by elevation zone in the Piceance Basin.

For disturbances at other times of year, treat with 4 oz./acre Plateau (70 g ai/ha imazapic) in the early fall **prior** to the disturbance in the area to be disturbed as well as a 20-ft buffer around it. This way, when the disturbance occurs there will be fewer cheatgrass seeds nearby to disperse onto the bare soils. After the disturbance, control emerging cheatgrass plants with glyphosate and MSO as described above, up to a week before planting. Plant in the fall, and use potholing concurrent with seeding to help bury some of the remainder of the cheatgrass seeds and to limit seed dispersal. If a pothole seeder is not available, drill seed.

In both cases, limit grass in seed mix to 4 PLS lbs/ac or less, use broadleaf plants copiously, and use locally collected sagebrush seed at 0.3 – 0.6 PLS lbs/ac. If using commercial sagebrush seed is the only option, increase the sagebrush seeding rate to 4 PLS lbs/ac.

Sites that are uninvaded but vulnerable to cheatgrass, elevations ~6500-7500 ft

Limit or omit herbicides, as they are not necessary and can have unintended consequences. Instead, employ an alternative way of controlling weed outbreaks, such as pothole seeding, buffer strips of protective vegetation, and/or smart timing of disturbances. That said, if cheatgrass emerges prior to seeding, it should be controlled with glyphosate and MSO as described above.

Be as careful as possible to avoid weed contamination in the seed that you order. At the MTN site in this study, the cheatgrass which emerged was likely from seed contamination, as there were no nearby patches of cheatgrass, and cheatgrass distribution within plots was even. A small percentage of cheatgrass seed and other weed seed is allowable in commercial seed. However, you can request seed that has 0% weed seed. This is always worth doing, but for sites which are uninvaded but vulnerable, it is especially important.

Keep the grass in the seed mix to 3 PLS lbs/ac or less and use forbs copiously. Plant locally collected sagebrush as described above, or a much greater amount of commercial sagebrush seed. Respread scraped woody debris back over the site.

Less vulnerable sites, elevations greater than 7500 ft

Do not use herbicides. Keep grass in the seed mix to 2 lbs/ac PLS or less, use forbs copiously, and plant locally collected sagebrush as described above, or a much greater amount of commercial sagebrush seed. Drill seed or pothole seed. Respread scraped woody debris back over the site.

The recommendations given here are based on the climate of the study period, 2008 - 2018. If the climate becomes warmer and/or drier, these recommendations will need to be adapted. In particular, the elevations delineating the 'weedy zone' from the 'vulnerable zone' and the 'vulnerable zone from the 'less vulnerable zone' in Figure Recommendations may need to be increased.

CONCLUSION

Restoring oil and gas disturbances to fully functional, diverse plant communities for wildlife habitat in northwestern Colorado is possible. In weedy, lower elevation areas, the goal post-restoration should be to create habitat which is better than what existed prior to disturbance. At higher elevations, the goal should be to maintain habitats with no loss of plant diversity, nutritional value, or function. Although the Piceance Basin is a complex landscape, appropriate restoration plans for individual well pads and pipelines are possible. The landscape receives enough moisture and has enough remaining intact vegetation to allow for excellent recovery after disturbances.

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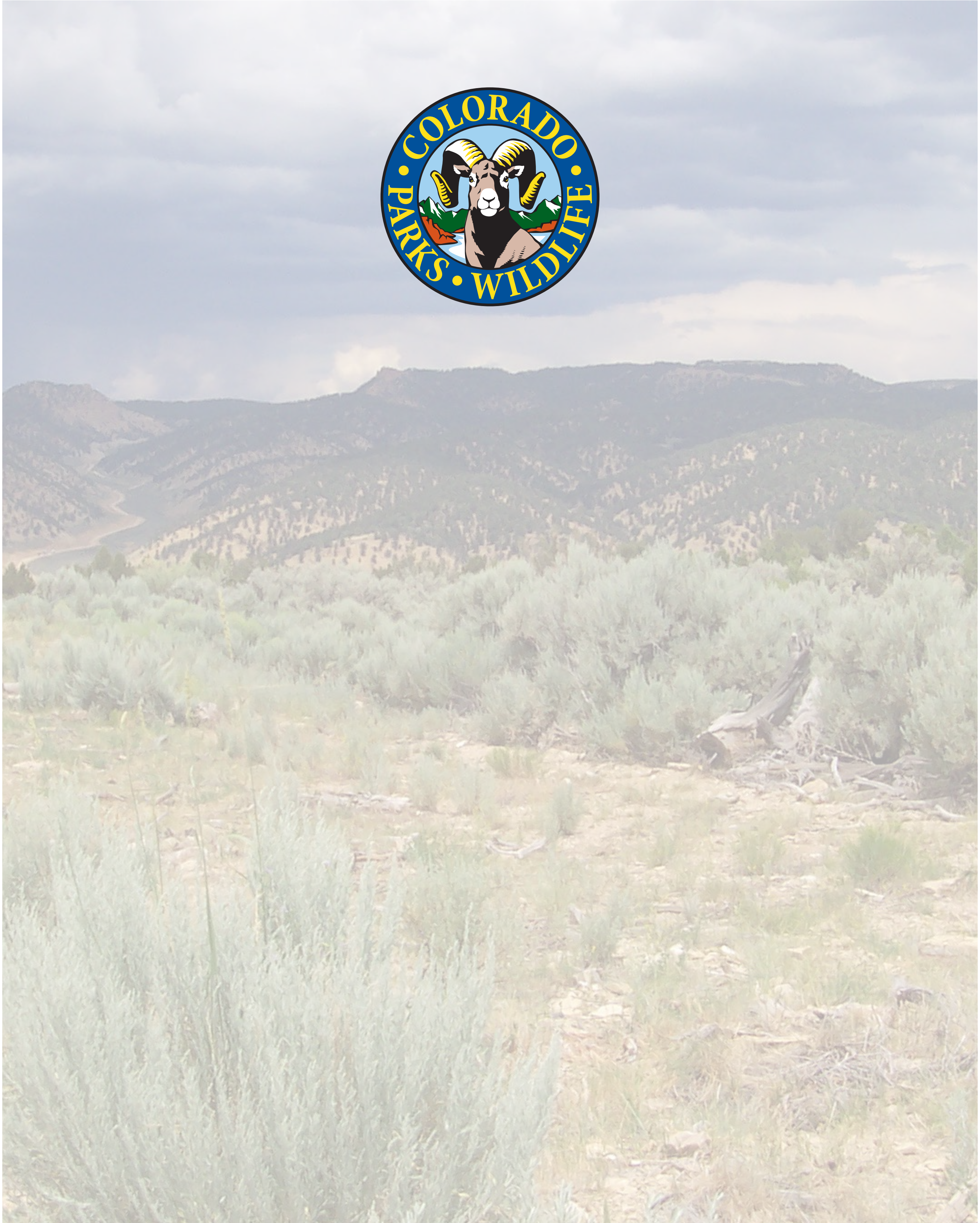
APPENDIX A. Sagebrush Seed Collection and Planting

To collect sagebrush seed, collect seed from as close to the site as possible. Sagebrush seed ripens in November. By beating sage stalks against the inside of a 5-gallon bucket, one person can collect about a pound of bulk material per hour (Figure A1). Avoid collecting near drainages. It will be tempting, because the basin big sage which grows in drainages produces seed heavily. However, this subspecies has low palatability for wildlife, and will not be adapted to your site unless it has a seasonally high water table. You will need about 3 lbs/ac of bulk material to hit a seeding rate of 0.3 PLS lbs/ac, because the bulk material will have low purity.

Figure A1. Collecting sagebrush seed takes time, but is easily accomplished with low-tech tools.

If you'd like a more precise idea of what seeding rate you hit, save a sample to send in for seed testing. To get a good sample, mix all of the seed to be used at a given site. Gather about 5 teaspoon-sized subsamples from the top, middle, bottom, and sides of the container. Mix these together and make sure you have at least 3 oz. Seed testing is available through many land-grant universities, including Colorado State University. Contact the seed lab for current pricing and mailing instructions. You will need a purity test and a 'germ' test, which tells you how much of the seed will actually germinate. Since sagebrush has little dormancy, the germ is equivalent to how much of the seed is alive. Guidance on calculating your seeding rate can be found from the Natural Resources Conservation Service (Houck 2009).

If possible, broadcast the seed immediately, the same year as collection, because sagebrush seed does not store well. If it is impossible to use the seed right away, Colorado Parks and Wildlife has a storage facility in Delta, CO which can store the seed at 3°C and 38% humidity, conditions under which the seed will remain viable for about 18 months. Although seeding over persistent snow is commonly recommended, recent research has shown that broadcast seeding just prior to persistent snow results in best sagebrush establishment (Ott et al. 2017, Landeen et al. 2019).



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