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Original Research

Reducing Exotic Annual Grass Competition did not Improve Shrub Restoration Success During a Drought ☆

Kirk W. Davies*, Jon D. Bates, Lauren Svejcar

US Department of Agriculture–Agricultural Research Service, Burns, OR 97720, USA*

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ABSTRACT

Restoration of native shrub species is challenging but direly needed in arid and semiarid rangelands globally as native shrubs provide critical habitat for wildlife and livestock forage. Restoration of antelope bitterbrush (*Purshia tridentata* Pursh DC), a wildlife-important shrub, is often a priority on western US rangelands. One challenge to bitterbrush restoration is competitive exotic annual grasses. Exotic annual grasses can be successfully controlled with pre-emergent herbicides, but the effects of controlling exotic annual grasses with pre-emergent herbicides on bitterbrush survival and growth are unknown. We evaluated the effects of applying a pre-emergent herbicide, imazapic, to control exotic annual grasses on planted bitterbrush seedlings and existing vegetation for 2 yr post treatment at five sites in southeastern Oregon. Imazapic application reduced exotic annual grass cover and density but did not improve bitterbrush establishment. Exotic annual grass control did lead to an increase in native perennial bunchgrass cover. We suspect the lack of treatment effect was caused by high mortality of bitterbrush seedlings from drought in the first year. By the second year, bitterbrush was largely lost across the study sites with only four individuals surviving. The high bitterbrush seedling mortality observed in this study highlights that multiple barriers to restoration success likely exist in arid and semiarid rangelands. For successful restoration, land managers and restoration practitioners need to have a plan and resources for overcoming multiple barriers, which may require several restoration attempts should initial attempts be unsuccessful.

Introduction

Restoration of wildlife-important shrubs is needed around the globe to improve habitat for native species (Wong et al. 2007; Medina-Roldán et al. 2012; Linstadter & Baumann 2013; Li et al. 2013; Davies and Bates 2019). Shrubs are also an important component of many plant communities, suppressing exotic species (Prevéy et al. 2010), facilitating the growth and establishment of other species (van Zonneveld et al. 2012; Torroba-Balmori et al. 2015), and storing soil carbon (Fonseca et al. 2012). Though restoration of shrubs is needed in many arid and semiarid rangelands, success is often less than desired. Shrub establishment may be hindered by environmental conditions and competition from herbaceous vegetation, especially invasive species (Porensky et al. 2014; Rinella et al. 2015, 2016; Davies et al. 2020).

Antelope bitterbrush (*Purshia tridentata* Pursh DC) is a native shrub that is often a restoration priority in western US rangelands. Bitterbrush is an important habitat element in many communities, providing fall and winter browse for ungulates (Kufeld et al. 1973; Vavra & Sneva 1978; Shaw & Monsen 1986), and its seeds are a valuable food source for rodents (Everett et al. 1978; Vander Wall 1994). Bitterbrush has decreased in many rangelands because of wildfires, excessive defoliation, low recruitment, and tree encroachment (Billings 1952; Tueller & Tower 1979; Winward & Alderfer-Findley 1983; Miller et al. 2000). Thus, restoration of bitterbrush is often needed; however, success has been limited in arid and semiarid lands (Hubbard 1964; Kituku et al. 1995; Davies et al. 2017).

Success of bitterbrush restoration efforts may be improved by reducing competition. In general, competition from herbaceous vegetation can negatively affect bitterbrush (Hubbard 1957; Davies et al. 2017) and other shrubs (Porensky et al. 2014; Rinella et al.

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* Correspondence: Kirk W. Davies, US Department of Agriculture–Agricultural Research Service, 67826-A Hwy 205, Burns, OR 97720, USA.
E-mail address: kirk.davies@usda.gov (K.W. Davies).

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2015). Competition from exotic annual grasses and other weeds is especially problematic (Shaw and Monsen 1986; Davies et al. 2017). Competition for soil moisture from exotic annual grasses is likely the most limiting barrier to bitterbrush seedling establishment in many postfire landscapes (Clements and Young 2002). This is because exotic annual grasses are highly competitive with native plants and can shorten the growing season by depleting soil moisture to the detriment of other vegetation (Melgoza et al. 1990; Nasri and Doescher 1995; Humphrey and Schupp 2004). Therefore, control of exotic annual grasses should increase the establishment of bitterbrush.

In support of this, Clements and Young (2000) found that bitterbrush seedling survival was greater with grass control with sethoxythim herbicide application but did not specify what grasses were present. Sethoxydim is a contact herbicide, which would not be prudent to use in plant communities with desirable bunchgrasses remaining as this would probably result in their decline. Furthermore, reductions in bunchgrasses would likely facilitate increases in exotic annual grasses as bunchgrasses are a critical plant functional group to limiting exotic annual grasses (Chambers et al. 2007; Davies 2008). Exotic annual grass control is needed, but in plant communities with residual desired vegetation, application of contact herbicides may exacerbate the situation.

In contrast to contact herbicides, pre-emergent herbicides are effective at controlling exotic annual grasses and limiting nontarget damage to residual bunchgrasses (Davies and Sheley 2011). However, restoration seeding is often delayed at least 1 yr after pre-emergent herbicide application to allow herbicide effectiveness to diminish to prevent nontarget herbicide damage to seeded vegetation. At this time, however, exotic annual grasses may reinvade these areas because of diminished herbicide toxicity and, thereby, reduce the success of seeded vegetation. Thus, it would be advantageous to have desired vegetation establish in these communities before experiencing substantial pressure from reinvading exotic annual grasses. Planting bitterbrush seedlings shortly after pre-emergent herbicide application may be a strategy to allow bitterbrush to establish while exotic annual grasses are controlled. However, the response of bitterbrush seedlings to pre-emergent herbicide applications to control exotic annual grasses is unknown.

The purpose of this study was to investigate the effect of pre-emergent herbicide applied to control exotic annual grasses on planted bitterbrush seedlings. To accomplish this, we applied the pre-emergent herbicide imazapic and then planted bitterbrush seedlings in plant communities that had lost the shrub overstory in a wildfire 3 yr earlier and were currently composed of exotic annual grasses and native bunchgrasses. We hypothesized that 1) pre-emergent herbicide application would reduce exotic annual grass cover and density and, subsequently, 2) increase bitterbrush survival and growth.

Methods

Study area

The study occurred in areas burned in the 2014 Buzzard Fire Complex in southeastern Oregon. The 160 153-ha Buzzard Fire Complex was ignited by multiple lightning strikes on July 14, 2014. Before burning, study sites were Wyoming big sagebrush (Artemisia tridentata *Nutt.* ssp. wyomingensis Beetle & Young)–bunchgrass communities with frequent bitterbrush plants. Sagebrush and bitterbrush were eliminated from the study sites by wildfire. Common perennial bunchgrasses included bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] A. Löve), bottlebrush squirreltail (*Elymus elymoides* [Raf.] Swezey), Idaho fescue (*Festuca idahoensis* Elmer), prairie Junegrass (*Koeleria macrantha* [Ledeb.] J.A. Schultes), and Sandberg bluegrass (*Poa secunda* J. Presl).

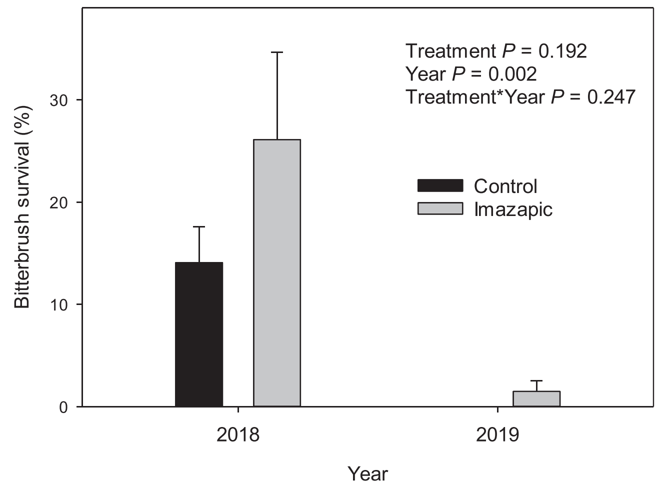

Figure 1. Bitterbrush seedling survival in areas with annual grass control with imazapic (imazapic) compared with an untreated control (control) in 2018 and 2019.

Exotic annual grasses contributed ~50% of the herbaceous vegetation cover across the study areas. Exotic annual grasses included cheatgrass (*Bromus tectorum* L.) and medusahead (*Taeniatherum caput-medusae* [L.] Nevski). Elevation of study sites ranged from 1 310 to 1 460 m above sea level. Slopes were 6° to 14° and aspects were north and east. Long-term (1981–2010) average precipitation was 283 mm and was 314, 193, and 362 mm in 2017, 2018, and 2019, respectively (PRISM 2021). Cattle were excluded from the study sites for the duration of the study. Native ungulates and other wildlife occupied the study areas and had unrestricted access to study sites.

Experimental design and measurements

We use a randomized complete block design with five blocks to investigate the effects of applying imazapic to control exotic annual grasses on planted bitterbrush seedlings. Treatments were 1) an untreated control (control) and 2) preplanting imazapic application to reduce annual grasses (imazapic). Treatment replicates were 16 × 16 m. The imazapic treatment was applied at a rate of 175 g ae·ha^{-1} on September 21, 2017 using a manual pump backpack sprayer (Solo, Newport News, VA) with a tank pressure of 138 kPa. During herbicide application, temperatures were between 4.5°C and 6.1°C, relative humidity ranged from 50% to 70%, and average wind speeds were between 4 km·h^{-1} and 5.3 km·h^{-1}. Bitterbrush seedlings (50 individuals per treatment replicate) were planted into each treatment replicate between October 26 and 31, 2017. Bitterbrush seedlings were planted at a density of one plant per ~4 m^2. Bitterbrush seedlings were grown by seeding four locally collected bitterbrush seeds in cone containers (3.8 × 21 cm) filled with a 50:50 mixture of silt loam soil and potting soil on March 30, 2017. The silt loam soil was collected from a plant community codominated by bitterbrush and sagebrush. Three wk after emergence, seedlings were thinned to one individual per cone container. Seedlings were grown in a grow room for 2½ mo and then exposed to outdoor conditions for increasing periods of time until they were outside for 10 to 14 h·d^{-1} before planting. At the time of planting seedlings averaged 7.2 cm in height and had an average longest canopy diameter of 3.5 cm. Bitterbrush seedlings were planted by digging a 21-cm deep hole, extracting the seedling from the cone container, placing the seedling in the hole, and pressing soil around seedling roots. When planting seedlings, care was taken to ensure that the upper soil layers, which likely had imazapic concentrated in them, did not fall into the planting holes.

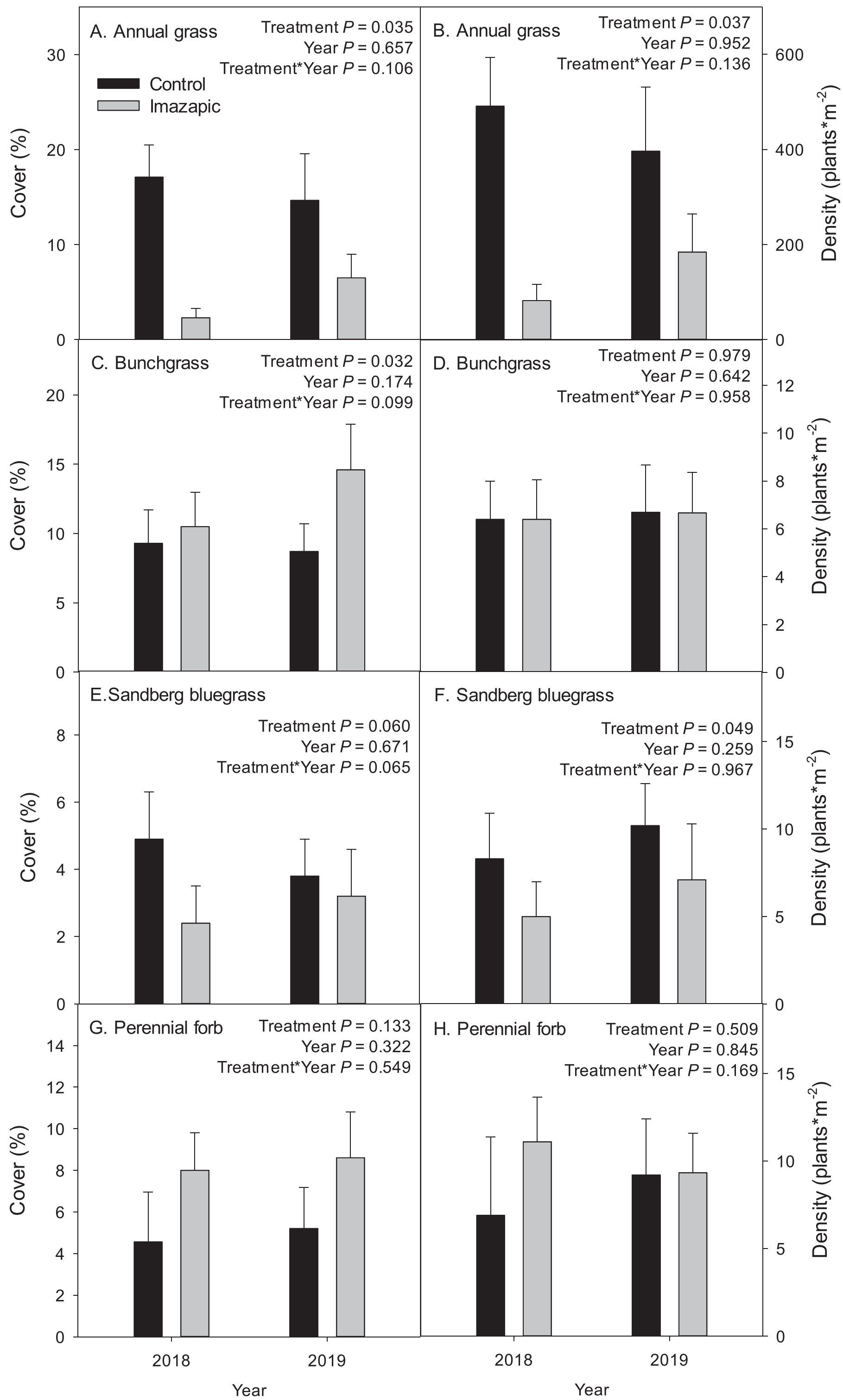

Figure 2. Plant cover and density groups in areas with annual grass control with imazapic (imazapic) compared with an untreated control (control) in 2018 and 2019.

Locations of planted seedlings were marked with a metal stake and recorded with a GPS unit (Trimble GeoExplorer 6000 Series GeoXT, Trimble Inc, Sunnyvale, CA).

Vegetation characteristics were measured in June of 2018 and 2019. Herbaceous vegetation characteristics were measured along three parallel 15-m transects spaced 4 m apart. Herbaceous cover was estimated by species in five 0.2-m^2 quadrats located at 3-m intervals along each 15-m transect. Quadrats had marking along the sides, dividing them into 5%, 10%, 25%, and 50% to aid in visual estimates. Bare ground, litter, and biological soils crust cover were also measured in the 0.2-m^2 quadrats. Herbaceous vegetation density by species was measured by counting all individuals rooted in the 0.2-m^2 quadrats. Bitterbrush survival was determined by locating all 50 planted seedlings in late June in 2018 and 2019. Bitterbrush height and longest canopy diameter were measured on all surviving bitterbrush seedlings.

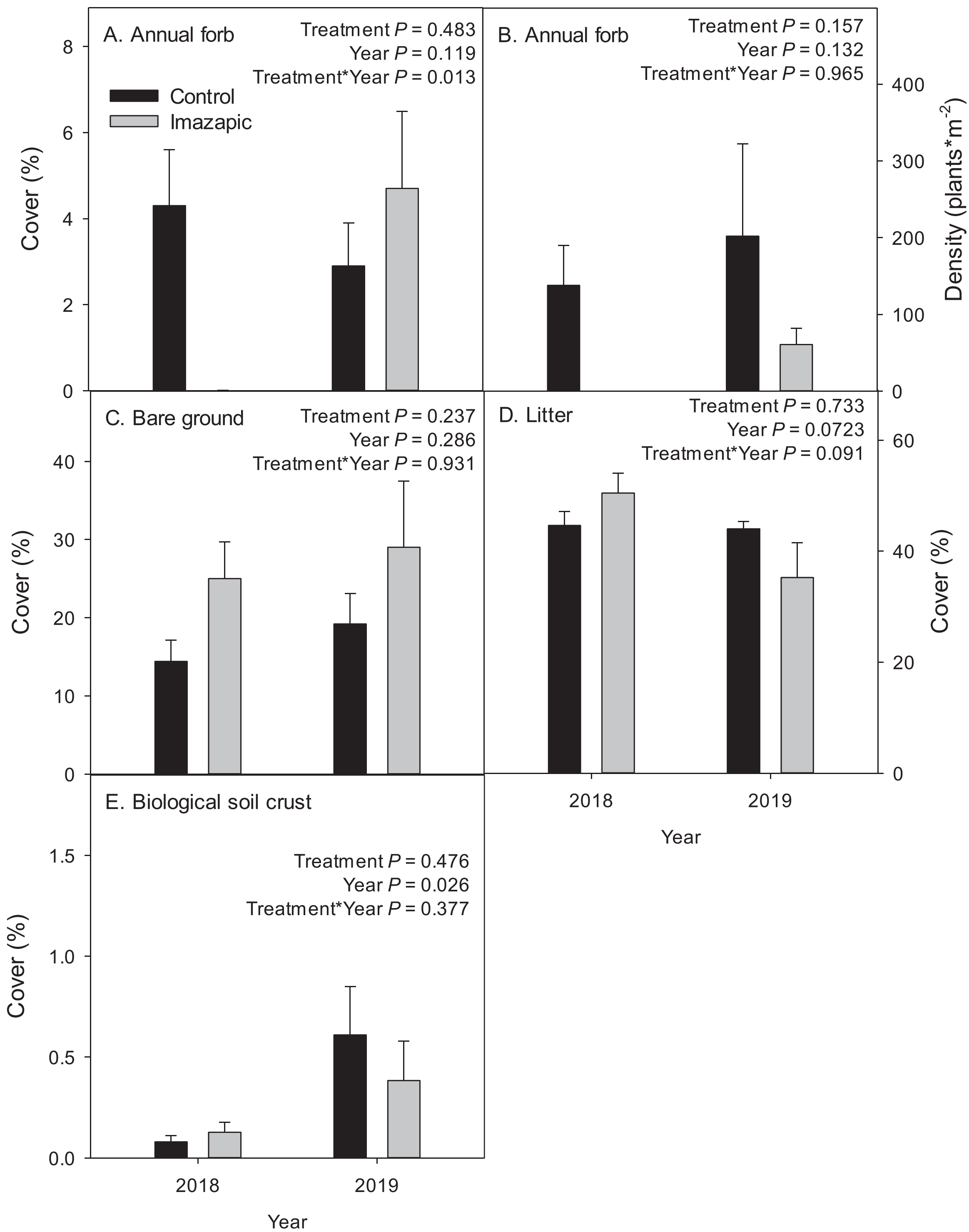

Figure 3. Annual forb cover and density and ground cover groups in areas with annual grass control with imazapic (imazapic) compared with an untreated control (control) in 2018 and 2019.

Statistical analyses

We used repeated measures analysis of variance using the mixed model procedure (Proc Mixed) in SAS v. 9.4 (SAS Institute Inc., Cary, NC) with year as the repeated variable. Block and block-by-treatment interactions were treated as random effects in the models. Appropriate covariance structure was selected using the Akaike's Information Criterion (Littell et al. 1996). Data that violated analysis of variance assumptions were log or square root transformed before analyses. Data are presented in their original (nontransformed) dimensions in figures and text. Herbaceous vegetation was separated into five groups for analyses: perennial bunchgrasses, Sandberg bluegrass, exotic annual grasses, perennial forbs, and annual forbs. Sandberg bluegrass was separated from the other bunchgrasses because it is smaller in stature, develops earlier phenologically, and responds differently to management and disturbances (McLean and Tisdale 1972; Davies et al. 2021). Significance level for all tests was set at $P \leq 0.05$, and response variable means are reported with standard errors.

Results

Bitterbrush survival did not differ between treatments (Fig. 1; $P=0.192$) but was less in the second yr than the first yr ($P=0.002$). By the second yr only four bitterbrush seedlings were still alive out of the 500 planted. Bitterbrush height and canopy diameter data were not analyzed because survival was too low for a robust test. Exotic annual grass cover and density were reduced with imazapic application (Fig. 2A and 2B; $P=0.035$ and 0.037, respectively). Exotic annual grass cover and density were twofold to sevenfold greater in the untreated control compared with the imazapic treatment. Exotic annual grass cover and density did not differ between years ($P=0.657$ and 0.952, respectively). Perennial bunchgrass cover was greater in the imazapic treatment compared with the control (Fig. 2C; $P=0.032$) but did not differ between years ($P=0.174$). By the second yr, perennial bunchgrass cover was 1.7-fold greater in the imazapic treatment compared with the control treatment. Perennial bunchgrass density did not differ between treatments or years (Fig. 2C; $P=0.979$ and 0.642, respectively). Sandberg bluegrass cover did not differ between treatments or years (Fig. 2E; $P=0.060$ and 0.671, respectively). Sandberg bluegrass density was greater in the control than the imazapic treatment (Fig. 2F; $P=0.049$) but did not differ between years ($P=0.259$). Perennial forb cover and density did not differ between treatments (Fig. 2G, 2H; $P=0.133$ and 0.509, respectively) or years ($P=0.322$ and 0.845, respectively). Annual forb cover was influenced by the interaction between treatment and year (Fig. 3A; $P=0.013$). Annual forb cover was less in the imazapic treatment compared with the control in 2018 but was greater in the imazapic treatment compared with the control in 2019. Annual forb density did not differ between treatments or years (Fig. 3B; $P=0.157$ and 0.132, respectively). Bare ground and litter cover did not differ between treatments (Fig. 3C and 3D; $P=0.237$ and 0.733, respectively) or years ($P=0.286$ and 0.072, respectively). Biological soil crust cover was low and did not differ between treatments (Fig. 3E; $P=0.476$) but was greater in 2019 than 2018 ($P=0.026$).

Discussion

Counter to our hypothesis, bitterbrush survival was not positively influenced by imazapic control of exotic annual grasses. We suspect that this was largely an outcome of limited survival of bitterbrush seedlings caused by drought in the first postplanting yr (2018). In fact, only four bitterbrush seedlings out of 500 were still alive at the second-yr sampling date. Similarly, other studies in this region have found that most shrub seedlings are lost between the first and second growing season as they were not developed enough to survive the dry summer season (Davies et al. 2017, 2020). The drought in the first yr likely prevented planted bitterbrush seedlings from growing large enough to survive the dry season.

Increases in perennial bunchgrass cover in imazapic treated areas may have also negatively impacted bitterbrush survival. Herbaceous competition can limit establishment of bitterbrush and other shrubs (Hubbard 1957; Porensky et al. 2014; Rinella et al. 2015; Davies et al. 2017). However, increases in perennial vegetation cover in the first yr were relatively small compared with the decrease in annual vegetation cover with imazapic application (Fig. 4). This suggests that resources made available by the control of exotic annual grasses were unlikely fully used by perennial bunchgrasses. Thus, we do not suspect that increases in perennial

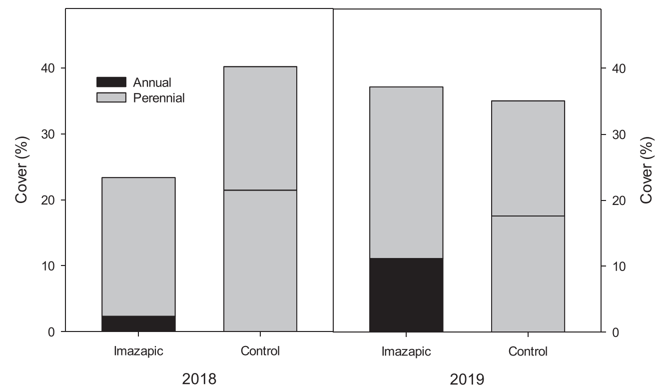

Figure 4. Annual and perennial herbaceous vegetation cover in the imazapic and untreated control treatments in 2018 and 2019.

bunchgrass cover with annual grass control were a substantial factor in the limited establishment of bitterbrush in imazapic treated areas. However, the experiment was not designed to answer this question.

Another possible explanation for not seeing a significant positive effect of annual grass control on bitterbrush establishment is that imazapic can cause nontarget damage to shrubs. In the Kaibab Plateau of Arizona, imazapic application reduced shrub germination by 50−80%, but older shrub seedlings were more tolerant (Owen et al. 2011). Our planted seedlings should have been tolerant of imazapic, especially since it was not applied to their foliage and their roots extended below the upper soil layers, where imazapic would likely be concentrated. However, it is possible that advantages to bitterbrush seedlings from reduced exotic annual competition was offset by nontarget herbicide damage to seedlings. The overall lack of establishment across both treatments suggests that inadequate precipitation was probably the primary factor limiting bitterbrush restoration. Regardless, controlling exotic annual grasses with imazapic did not improve bitterbrush restoration success during a drought.

Controlling exotic annual grasses with pre-emergent herbicides in plant communities with substantial residual perennial herbaceous vegetation may shift community dominance to perennial vegetation. In our current study, imazapic application successfully reduced exotic annual grass cover and density for 2 yr post treatment. One- or 2-yr reductions in exotic annual grasses with imazapic and other pre-emergent herbicide applications have been widely reported (Kyser et al. 2007; Sheley et al. 2007; Davies 2010; Sebastian et al. 2016). The decrease in annual grasses in our study subsequently led to an increase in perennial bunchgrass cover (Fig. 4). Similarly, residual native perennial bunchgrasses increased with imazapic control of medusahead in Oregon (Davies and Sheley 2011). Increases in perennial vegetation are important because this often limits exotic annual grasses' ability to redominate these communities (Davies and Johnson 2017). Imazapic application in our study is likely facilitating the transition of the plant community from exotic annual grass/perennial bunchgrass codominated toward perennial bunchgrass dominated.

Management Implications

Mediating one ecological barrier to restoration may not improve success if another barrier limits establishment. In our current study, we hypothesized that overcoming competition from exotic annual grasses would improve bitterbrush restoration success. However, drought was likely a major barrier to bitterbrush establishment in the planting year, overwhelming the benefits of controlling annual grasses. Multiple barriers often need to be overcome for successful establishment of native species from seed in arid and semiarid rangelands (Copeland et al. 2021). Though Copeland et al. (2021) was specifically referring to establishing native species from seed, it is clearly applicable to restoration efforts in general.

Identifying barriers to restoration success and planning management to mediate multiple barriers would likely improve restoration success. For example, if we had planted bitterbrush seedlings again in the second yr, restoration success may have been much greater since annual precipitation was 128% of average. Seeding sagebrush in 2 different yr greatly increased the probability of restoration success across a large elevation gradient in the northern Great Basin (Davies et al. 2018). To this end, land managers need to be prepared to apply additional restoration actions in the event that initial restoration attempts fail. This requires having resources available and a plan for additional treatments if initial efforts are unsuccessful and could greatly increase the probability of achieving restoration objectives.

Declaration of Competing Interest

We do not have any conflict of interest to declare.

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