Answering complex questions as we make headway on annual grasses and fire.

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Abstract Annual grasses challenge our ability to meet forage production and plant community conservation objectives. Direct competition, potential mutualism, and shortened fire return interval interplay resulting in complexity of how to meet challenges we face. *Bromus tectorum* presents challenges to sagebrush dominated plant communities with shortened fire return intervals and the advancing invasion of *Ventenata dubia* poses threats to forage production through competitive interactions that may involve mutualism to enhance *V. dubia's* invasion of annual and perennial grass dominated plant communities. Use of fuel breaks can reduce the extent of fires and their proper function hinges on their reduced plant biomass in contrast to surrounding vegetation to improve fire fighting ability. Reducing annual grass biomass within fuel breaks reduces fuel continuity and shortens the duration of dry vegetation. Indaziflam and imazapic are two herbicide active ingredients that allow control of annual grasses within fuel breaks and sagebrush plant communities. Aerial application of these herbicides allows us to match control actions to the scope of the problem. These herbicides can also reduce competition from annual grasses, allowing increased cover and diversity of native plant communities. Removal or reduction of annual grasses has improved plant species diversity and forage production.

Introduction Annual grasses challenge our ability to meet forage production and plant community conservation objectives. One of our invasive annual grasses, *Ventenata dubia*, has impacted forage production resulting economic losses for eastern Washington and northern Idaho of $16 million per year (Jones et al. 2022). Plant species diversity in canyon grasslands and sagebrush grasslands within the Inland Northwest are reduced as *V. dubia* plant cover increases (Jones et al. 2018; Jones et al. 2020). Fire further extends V. dubia impact affecting species richness, evenness and functional diversity (Tortorelli et al. 2020). *Bromus tectorum* shortens fire return intervals with subsequent transition from dominance of perennial to annual plant species (Mahood, A & J. Balch. 2019). Additionally, foraging success by small mammals may be reduced as annual grass litter increases (Bachen et al. 2018).

Fuel breaks are being placed in sagebrush systems, intent on reducing scale and frequency of fire. Prior modeling of reduced fuel beds suggests lower flame lengths and rate of spread (Ellsworth et al. 2022). Maintaining reduced fuel beds includes control of annual grasses that increase continuity of fuels and contribute to higher fuel beds. Herbicides and grazing are considered candidates for maintaining reduced fuel beds. Annual grass removal may allow increased cover of perennial plants and potential recruitment of forb species that may both reduce the season of drier fuels and improve forage for wildlife.

Indaziflam and imazapic control annual grasses, including both *V. dubia* and *B. tectorum* (Wallace and Prather 2016; Courkamp et al. 2022). The scale of invasion by annual grasses suggests control of annual grasses within sagebrush communities and within fuel breaks will benefit by aerial application of these herbicides for annual grass management. *V. dubia* is still at an early stage of invasion into sagebrush steppe and it also has begun to invade fuel breaks so while it was not within the study area, we posit that including *V. dubia* raises awareness of invasive potential and that techniques presented in this paper should apply to *V. dubia* as well. We investigated aerial application of indaziflam and imazapic, then assessed plant community response post application. We hypothesize that coverage of the herbicides will impact efficacy and that release from annual grass competition improves perennial plant cover.

Methods The study was established at Rinker Rock Creek Ranch near Hailey, ID (43º 24.557' N 114º 21.495' W). Indaziflam and imazapic were applied on September 16 and 19, 2019 (Table 1). Airplane and helicopter application of herbicides was done with carrier rates that varied from lower volumes of 23.5 L ha^{-1} and 47 L ha^{-1} to higher volumes of 94 L ha^{-1} and 188 L ha^{-1}. The carrier rates were then converted to % coverage by analyzing coverage of the herbicide treatments on water sensitive paper (Table). The amount of indaziflam and imazapic applied per hectare remained constant at 0.065 kg ai ha^{-1} and 0.078 kg ai ha^{-1}, respectively 0.365 L ha^{-1}. All treatments were applied with a non-ionic surfactant at 0.25% v/v.

Table 1. Herbicide droplet coverage categories.

	Herbicide droplet percent cover		
Category	Minimum value	Maximum value	Plots (n)
None (untreated)	-	-	12
Low (L)	2.2	5.5	38
Medium (M)	7.3	10.3	12
High (H)	12.2	16.0	18

Permanent assessment plots 3 sq m were arranged within treatment areas in locations that were representative of the surrounding plant community assemblages. Pre-treatment plant cover was recorded on October 3, 2019, and post-treatment plant cover was recorded on June 10, 2020, May 26, 2021, and June 1, 2022. Within each plot, plant foliar cover was recorded using cover classes; data were analyzed using the midpoint of cover classes averaged among treatment groups. Cover was measured by plant species and then placed into functional groups. Percentage control was summarized by summing midpoint cover of both *B. tectorum* and *Bromus japonicus* and dividing by the midpoint cover for each species in untreated plots. The dominant shrub was *Artemisia tridentata* ssp *vaseyana* indicating the study location was at a higher precipitation range than *Artemisia tridentata* ssp *wyomingensis*. Percentage cover was summed for functional groups with perennial grasses including *Poa secunda*, *Pseudoroegnaria spicatum*, *Achnatherum thurberianum*, and *Achnatherum nelsonii*. Forb species were diverse, more commonly encountered species included *Phlox longifolia*, *Lomatium nudicale*, *Astragalus sp*., *Lupinus sp*., *Iva axillaris*, and *Agoseris glauca*. Mean separation was calculated using Fisher's Protected LSD.

Results and Discussion

The annual grass cover prior to treatment ranged from 52% to 67%. The airplane and helicopter performed similarly with respect to control (data not shown). Initially, the indaziflam treatment did not control the annual grasses as well as indaziflam + imazapic with control at 48% and 93%, respectively (Table 2). The imazapic must have moved horizontally, more quickly than indaziflam. By 20 months after treatment, control was similar between the two treatments. Even 32 months after treatment, control of annual grasses was still about 85% (Table 2). The carrier rate, translated to coverage of the herbicide, had high variability of annual grass control, 9 months after treatment, at the lowest coverage of 2.5% (Figure 1).

Native annual forb cover was low across all plots and did not change with herbicide treatment (data not shown). Perennial grass cover 30 months after treatment increased with either herbicide treatment as droplet coverage increased, and droplet coverage had a greater affect for indaziflam alone (Figure 2). The percentage cover of all native species increased at 30 months after treatment with annual grass control and with increased droplet coverage of both herbicides (Figure 3). Finally, species richness slightly increased with indaziflam alone treatment as droplet coverage increased (Figure 4). However, species richness slightly decreased with indaziflam and imazapic treatment as droplet coverage increased.

Table 2. Control of winter annual grasses from herbicides applied with different vehicles and at various herbicide coverage categories. Pre-treatment values are % cover of annual grasses prior to treatment. Percentage control was calculated as (% cover of treated plots)/(% cover of untreated plots)x100. Numbers with different letters in the same column are significantly different at $p = 0.05$.

		Months after Treatment		
Treatment	Pre-treatment	9	20	32
		------------------% Control-----------------		
Untreated check	67			
Indaziflam	55	48a	96a	84a
Indaziflam + imazapic	52	93b	99a	86a

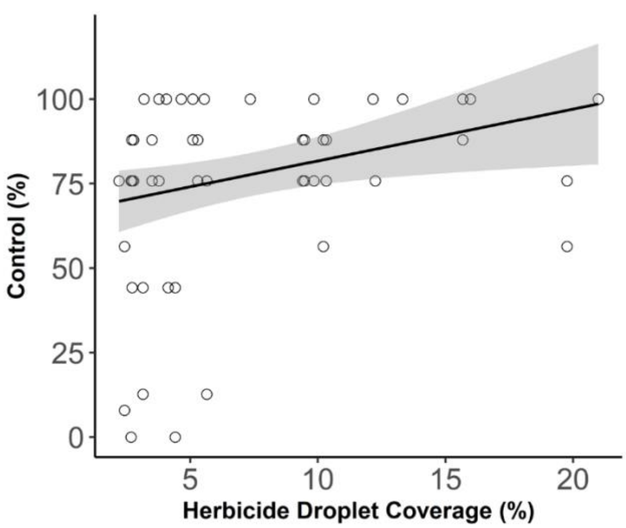

Figure 1. Control of annual grasses at 9 months after treatment within individual sample plots was variable at low droplet coverage with similar variability when droplet coverage was above 5%. Shaded area is the 95% confidence interval.

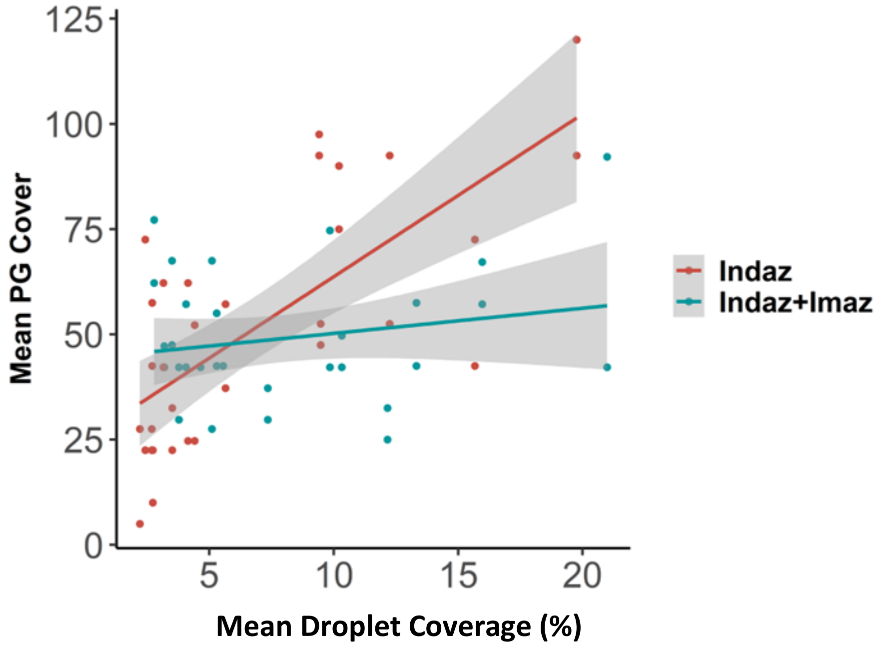

Figure 2. Perennial grass (PG) cover, 30 months after treatment increased as droplet coverage increased with a larger response with the indaziflam (Indaz) alone treatment contrasted with indaziflam plus imazapic (Indaz+Imaz). Shaded areas are 95% confidence intervals.

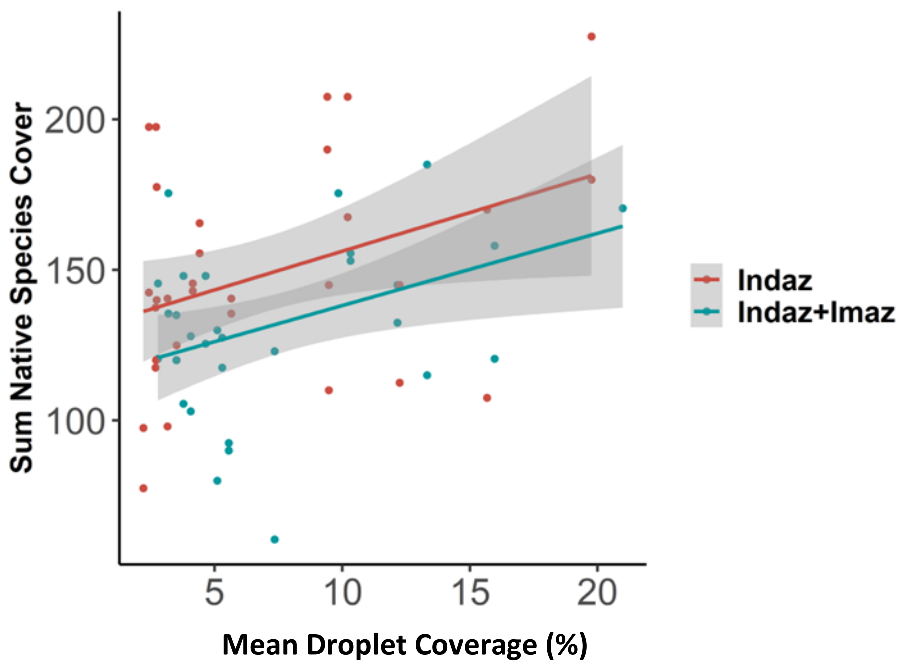

Figure 3. Native plant species cover increased for indaziflam alone (Indaz) or indaziflam plus imazapic (Indaz+Imaz) treatments as droplet coverage increased, 30 months after treatment. Shaded areas are 95% confidence intervals.

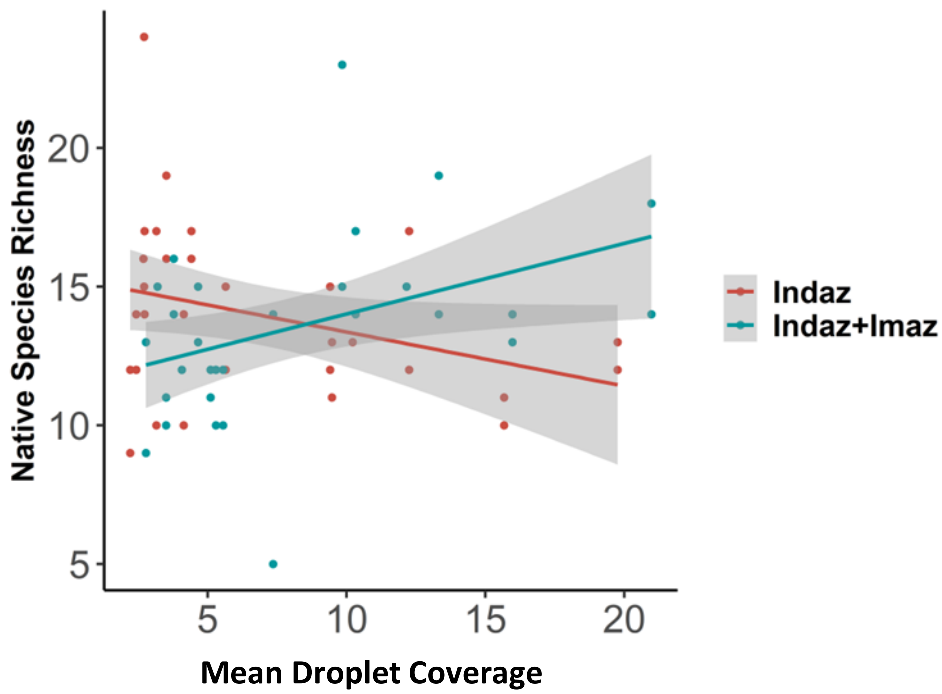

Figure 4. Native plant species richness increased for the indaziflam plus imazapic (Indaz+Imaz) treatment but decreased for the indaziflam alone (Indaz) treatment as droplet coverage increased, 30 months after treatment.

Implications Aerial application of indaziflam and imazapic control annual grasses and that control can extend at least 30 months after treatment. Control of annual grasses for 30 months would have significant implications for fuel break management because removing those annual fuels reduces fire risk earlier in the season as annual grasses dry before native grasses and native forbs. Management of fuel breaks after they are established is important so that lower fuel beds are maintained for the fuel breaks to reduce fire return intervals. Perennial plant cover did increase after annual grass removal, yet that vegetation does not dry out as soon as annual grasses. Other maintenance operations would be important to also reduce fuel beds produced by native plant species and those maintenance operation selection and performance were beyond the parameters of this study.

Release from annual grasses did result in increases to native plant community cover for both grasses and forbs. Native plant species richness changed slightly yet did not result in concern of suppression of native plant species with application of either of these herbicides. Initial droplet coverage had a significant effect on plant communities and approaching aerial application using droplet distribution to configure spray equipment and select a water carrier rate is important. We found droplet coverage above 5% consistently controlled annual grasses and positively affected native grass and native forb cover.

Sagebrush grasslands that are intact but contain annual grasses may have increased risk of burning. Protecting those grasslands by reducing annual grasses could act as a conservation method by protecting those intact sagebrush communities. Conservation through removal of annual grasses did not negatively impact perennial plant cover and had only a slight decrease to native plant species richness. Annual grass impacts to sagebrush plant communities are complex and creating solutions that address the large scale of the problem is challenging. A large-scale solution likely includes conservation of intact sagebrush communities and utilization of fuel breaks to reduce frequency and scale of fires. Both conservation and fuel breaks should benefit from annual grass control and this study shows that long-term control is possible provided proper coverage of the herbicide when applied aerially.

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