Establishing seed islands for native forb species on rangelands using N-Sulate ground cover fabric

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ABSTRACT

Native forbs are an integral component of native rangelands in Western North America. Reseeding forbs in degraded rangelands can be difficult and costly with varying success. One method for reseeding rangeland vegetation is the creation of "islands." Using this technique, seedings are concentrated in areas with the highest probability for success, creating self-sustaining populations of reproducing individuals. The purpose of our study was to establish islands of native forbs in big sagebrush (*Artemisia tridentata* Nutt. [Asteraceae]) communities in central Utah. We used a lightweight ground cover fabric (N-Sulate) to increase soil moisture and temperature for enhancing seedbed conditions. Fourteen species of native forbs and 1 native grass were planted on 4 sites using a randomized block design with covered (N-Sulate ground cover fabric) and non-covered variations, replicated over 2 y. We collected species density and ground cover data 1 y, 2 y, and 5 y following implementation. Eight species exhibited increased first year seedling density with ground cover fabric; 5 species emerged equally well in both covered and non-covered plots. Overall, ground cover fabric did aid in emergence of some species but did not produce any long-term effects on native forb populations. This fabric increased cheatgrass (*Bromus tectorum* L. [Poaceae]) and annual weeds, especially on drier sites. Regardless of site, species, or ground cover fabric treatment, native forb islands did not establish long-term. Establishment success may be improved with herbicide application to control cheatgrass and annual weeds, and with a more careful species selection that matches ecological conditions of planting sites.

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seeds, islands, reclamation, row cover fabric, insulation fabric, succession

NOMENCLATURE
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Early efforts to restore and reclaim western rangelands have focused on the use of introduced perennial plant species (Ewel and Putz 2004; Pellant and others 2004; Fansler and Mangold 2011). However, recent research and management strategies have emphasized the importance of restoring native plant species in rangeland reclamation projects (Davies and Sheley 2011). While non-native species were often successful in establishing and reclaiming degraded rangelands, in some cases undesirable side effects, such as the creation of monoculture stands, loss of biodiversity, and the reduction of less-competitive plants, affected native floral populations (Chambers and others 1994; Gunnell and others 2010). Although non-native grasses are still frequently used in reclamation, such as post-fire disturbance efforts, forbs are used to combat the spread of invasive annual grasses in highly degraded areas and to provide valuable forage for grazing animals.

Native forbs provide many important functions in ecological restoration and habitat development. They are a valuable resource for both vertebrate and invertebrate wildlife (Drawe 1968; Stevens and Monsen 2004; Walker and Shaw 2005; Dumroese and others 2015) including a critical food source for pollinators (Ollerton and others 2011; Burkle and others 2013). Forbs are an essential component of both Greater Sage-grouse (*Centrocercus urophasianus* Bonaparte [Phasianidae]) and Gunnison Sage-grouse (*C. minimus* Bradbury and Vehrencamp) habitat and diet, especially in nesting and brood-rearing areas (Crawford and others 2004; Dumroese and others 2016). Apart from the benefits to wildlife, many forbs are also useful for stabilizing soil, increasing biodiversity within plant communities, and competing with invasive annual species (Shaw and Monsen 1983; Skousen and Call 1987; Richards and others 1998; Shaw and others 2005a; Shaw and others 2005b; Leger and others 2014).

Ongoing efforts to restore sagebrush communities throughout western North America have faced many challenges. Infrequent and sporadic precipitation coupled with extreme temperatures and nutrient-poor soil can make germination and establishment difficult in low- to mid-elevation environments, even under ideal conditions. Although land managers recognize the importance of native forbs for restoration, managers must be selective when determining when and where to use these plant materials because of their high cost and challenging propagation and growth requirements (Shaw and others 2005). Unlike many grass and shrub species commonly used in restoration projects that have well-established seed production and harvest methods, many native forb species are much more difficult to cultivate and harvest, resulting in higher prices and lower availability (Kimball and others 2015). Furthermore, in cases where native forbs are used for restoration projects, success is often limited because of poor emergence and establishment (Shaw and others 2005). For example, seed placement in the soil profile is important for successful forb establishment. A planting depth of 3.2 to 6.4 mm (0.13–0.25 in) is typically optimal for Great Basin native forbs (Monsen and others 2004), which can be difficult to achieve in many Great Basin environments using common seeding practices. Most standard rangeland seeding equipment is not designed to provide highly precise seed placement. Also, at shallow depths, soils can experience significant desiccation early in the growing season before seedlings have an opportunity to establish. Finally, high forb seed costs will often limit the purchase of quantities required to meet minimum seeding rate recommendations (Monsen and others 2004; Ott and others 2019).

Seed islands (also known as restoration islands, island plantings, shrub islands, seed islands, assisted nucleation) can be used to increase forb establishment (Longland and Bateman 2002; Reever Morghan and others 2005; Corbin and Holl 2012; Boyd and Obradovich 2014; Hulvey and others 2017; Fund and others 2019). The seed island technique focuses on restoring areas within a project that have the highest potential for success, with the expectation that eventually a self-sustaining population of desirable plants will provide a propagule source for natural recruitment. Land managers have successfully employed this technique within tropical forests, salt marshes, and coastal dunes (Castellanos and others 1994; Franks 2003; Holl and others 2011; Zahawi and others 2013), and to a lesser extent in slow-growing arid sagebrush ecosystems (Longland and Bateman 2002; Reever Morghan and others 2005; Boyd and Obradovich 2014). Seed islands are being explored as an alternative to traditional methods of drilling or broadcasting sagebrush seed in low-elevation sagebrush communities (McAdoo and others 2013; Boyd and Obradovich 2014), and it may be useful as a method for establishing native, desirable forbs.

The purpose of this research was to assess the potential for creating seed islands by establishing plants in concentrated areas where establishment potential is greatest. For this study, we concentrated on native forb establishment and propagule production for maximizing emergence, establishment, and persistence of a diversity of forb species. Additionally, we tested the utility of lightweight row-cover fabric (N-Sulate) for establishing seed islands and to examine the effect of this fabric on perennial vegetation and invasive annual weed species.

METHODS

We initiated this study in 2009 at 4 sites in Utah (Table 1, Figure 1). Two of the sites (Hatch Ranch and Lookout Pass) were located in the Great Basin (Ecoregion 13), and the Fountain Green site was located in the Wasatch and Uintah Mountains (Ecoregion 19), all within plant communities dominated by Wyoming big sagebrush (*Artemisia tridentata* Nutt. ssp. *wyomingensis* Beetle & Young [Asteraceae]). The Gordon Creek site was in the Colorado Plateau (Ecoregion 20) in an area dominated by mountain big sagebrush (*A. tridentata* Nutt.

TABLE 1

Experimental site locations and characteristics.

Site name	Latitude	Longitude	Elevation (m)	Mean annual precipitation (mm)
Fountain Green	39.62167	–111.6189	1776	349
Gordon Creek	39.63972	–111.0181	2187	351
Hatch Ranch	40.29139	–112.6286	1525	359
Lookout Pass	40.09167	–112.6572	1613	331

Notes: m × 3.3 = ft; mm × 0.04 = in.

ssp. *vaseyana* (Rydb.) Beetle). All sites receive 33 to 36 cm (13–14 in) of annual precipitation (PRISM Climate Data) with elevation ranging between 1500 m and 2200 m (4920–7200 ft; Table 1). Hatch Ranch and Lookout Pass are located in close proximity to each other and have similar soil and climate characteristics; however, Lookout Pass is more degraded and has higher cheatgrass (*Bromus tectorum* L. [Poaceae]) densities.

The study was implemented using a randomized block design, with 5 blocks at each site. Each block was made up of 6 plots: seed mix 1 covered and non-covered, seed mix 2 covered and non-covered, and unseeded control covered and non-covered. Seeded species were divided between 2 seed mixes to prevent oversaturation of seeded species within study plots and to allow for easier monitoring. Seed mix 1 consisted of 8 commercially available species that were accessible for use in reseeding projects. Seed mix 2 consisted of 7 forb species that were being considered for commercial development (Table 2). We added rice hulls to each seed mix to ensure a consistent rate of flow through the broadcast seeder. Each plot was 1.5 m × 7.6 m (5 ft × 25 ft), with a 1.5 m (5 ft) buffer between plots. Seed was planted at a higher than typical rate (Table 2) to increase the chances of success, and the same rate was used across all sites. Seed was provided and mixed by the Utah Division of Wildlife Resources (UDWR) Great Basin Research Center (GBRC) and Seed Warehouse. Seed was tested for purity and viability prior to being used in this study and met the minimum pure live seed (PLS) requirements of the warehouse.

Prior to implementation, we used a Dixie harrow to remove standing plant material at all plots. Once clear of residual vegetation, we used a hand-crank broadcast seeder to distribute seed evenly across the soil of all plots. We pulled a Brillion imprinter and lightweight chain across plots to incorporate seed into the soil. At Lookout Pass we used a heavier chain with the imprinter to cover the seed, but we determined that the heavier chain was causing too much seed displacement between plots; therefore we used a doubled-over lightweight chain with the imprinter at all other sites.

Seeding took place in November 2009 and was replicated on all 4 sites in October 2010. Following seeding, designated plots were covered with N-Sulate (DeWitt Company, Sikeston, Missouri). This material is a medium weight (51 g/m² [1.5 oz/yd²]), permeable, UV-treated ground cover fabric designed to offer frost protection to plants, lengthened harvest time, and an extended flowering season. We had previously used this product in an agronomic setting, and it appeared to improve emergence and establishment of native forbs in seedbeds (unpublished observations). We included N-Sulate ground cover fabric in an effort to increase moisture retention and raise soil temperatures during cooler periods. Once cover fabric treatment plots were secured, they remained in place throughout the winter

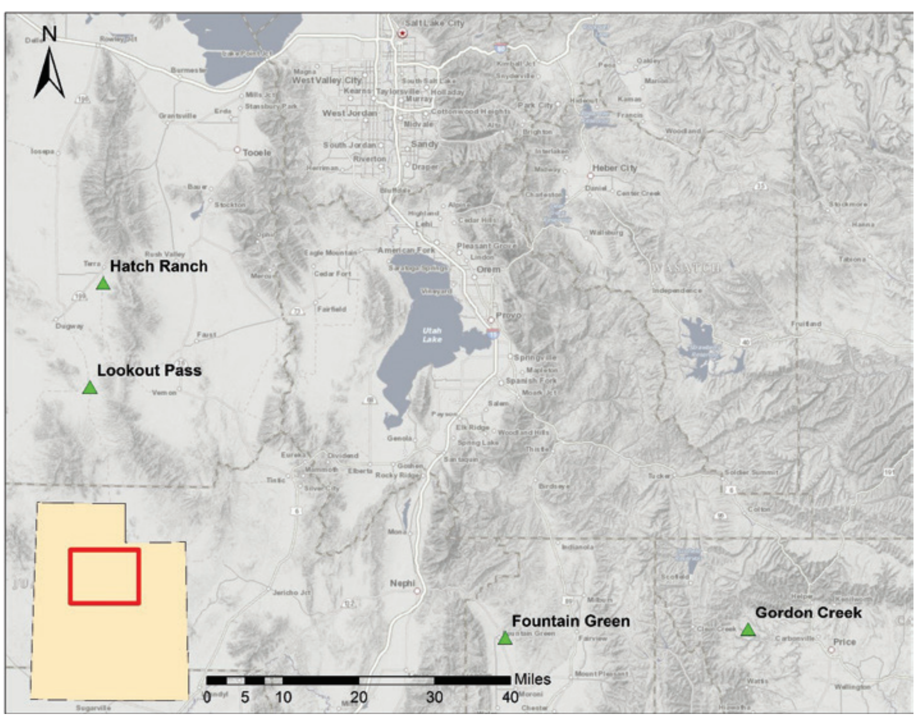

Figure 1. Map of study sites throughout central and south-central Utah.

TABLE 2

Seed mixes and seeding rate, pure live seed per square meter (PLS/m²).

Mix	Species code	Scientific name	Common name	PLS/m²
1	LIPE2	*Linum perenne* (Linaceae)	Blue flax 'Appar'	47.15
1	POFE	*Poa fendleriana* (Poaceae)	Muttongrass	49.51
1	CLSE	*Cleome serrulata* (Capparaceae)	Rocky Mountain beeplant	47.25
1	LUAR3	*Lupinus argenteus* (Fabaceae)	Silvery lupine	33.80
1	SPGR2	*Sphaeralcea grossulariifolia* (Malvaceae)	Gooseberryleaf globemallow	46.18
1	BASA3	*Balsamorhiza sagittata* (Asteraceae)	Arrowleaf balsamroot	41.87
1	HEBO	*Hedysarum boreale* (Fabaceae)	Northern sweetvetch 'Timp'	31.65
1	PEPA6	*Penstemon pachyphyllus* (Scrophulariaceae)	Thickleaf penstemon	42.41
2	AGGR	*Agoseris grandiflora* (Asteraceae)	Bigflower agoseris	31.75
2	AGHE2	*Agoseris heterophylla* (Asteraceae)	Annual agoseris	29.60
2	NIAT	*Nicotiana attenuata* (Solanaceae)	Coyote tobacco	43.06
2	LONU2	*Lomatium nudicaule* (Apiaceae)	Barestem biscuitroot	38.75
2	ARMU	*Argemone munita* (Papaveraceae)	Flatbud pricklepoppy	39.93
2	HEMUN	*Heliomeris multiflora* subsp. *nevadensis* (Asteraceae)	Nevada goldeneye	37.14
2	THMI5	*Thelypodium milleflorum* (Brassicaceae)	Manyflower thelypody	35.95

until we removed them the following spring during the first week of April when sampling began. Data were collected from all plots on 3 occasions: spring following seeding (April 2010 and 2011), the summer of the second year following seeding (June 2011 and 2012), and finally after 5 growing y (June 2014 and 2015). Seedling emergence was recorded in year 1, while data recorded in the second and fifth year allowed us to note survival and persistence of seeded species, as well as to capture residual effects of ground cover treatment on both seeded and extant vegetation.

In each plot in each block, 12 quadrats (0.25 m [0.8 ft]) alternating along either side of each transect line were used to collect cover data and individual species density data. We used a modified Daubenmire quadrat method to measure cover of annual weeds, cheatgrass, and perennial grasses. We measured the density of each seeded species as well as the density of all non-seeded extant species in each plot by identifying and counting all plants within each quadrat. Density data were subsequently converted to plants/m². Because of difficulty in field identification, we combined the seeded species of *Agoseris grandiflora* (Nutt.) Greene (bigflower agoseris [Asteraceae]) and *Agoseris heterophylla* (Nutt.) Greene (annual agoseris) in the analysis (denoted *Agoseris* spp.).

Statistical Analysis

Using SAS statistical software (version 9.4; SAS Institute Inc, Cary, North Carolina), we used a mixed model analysis of variance to analyze density. Separate analyses for each seeded species and commonly occurring extant perennial species combination were performed. We blocked the analysis by site and implementation year to account for correlations in spatial and temporal variation. We also used a similar mixed model analysis of variance to analyze perennial, annual, and cheatgrass ground cover. The explanatory variables used were year after treatment and treatment type. The interaction of these 2 variables was also included. This factorial design was replicated in 5 plots with 6 subplots each at all of the study sites. The analyses for cover were analyses of variance without blocking so that we could test for differences in species response due to site. These analyses included interactions of year-after-treatment × treatment, year-after-treatment × site, and year-after-treatment × site × treatment. Differences were considered significant at $\alpha = 0.05$. For this analysis, year 1 refers to data collected in the first spring after seeding, and not for the entire year after seeds were planted. During the second year, data were collected to represent the first year of survival. The fifth year of data collection was to characterize more persistent treatment effects.

RESULTS

Seeded Species Density

Seven taxa were significantly influenced by the ground cover fabric treatment during the first year: *Agoseris* spp. (Asteraceae), *Argemone munita* Durand & Hilg. (flatbud pricklypoppy [Papaveraceae]), *Hedysarum boreale* Nutt. (Northern sweetvetch [Fabaceae]), *Lupinus argenteus* Pursh (silvery lupine [Fabaceae]), *Nicotiana attenuata* Torr. ex S. Watson (coyote tobacco [Solanaceae]), *Penstemon pachyphyllus* A. Gray ex Rydb. (thickleaf penstemon [Scrophulariaceae]), and *Poa fendleriana* (Steud.) Vasey (muttongrass [Poaceae]) (Table 3,

TABLE 3

Mean plant density by site, treatment, species, and time since treatment based on data collected in both temporal replications initiated in 2009 and 2010.

		Fountain Green			Gordon Creek			Hatch Ranch			Lookout Pass			All sites (mean)		
Species	**Year**	**C**	**NC**	***P***	**C**	**NC**	***P***	**C**	**NC**	***P***	**C**	**NC**	***P***	**C**	**N**	***P***
Agoseris	1	6.68	1.56	**0.0516***	6.91	3.34	0.1660	14.78	2.37	**>0.0001***	8.47	1.78	**0.0132***	9.21	2.26	**>0.0001***
	2	0.28	0.17	0.9658	4.05	2.94	0.6619	2.40	1.12	0.6133	0.85	1.24	0.8754	1.89	1.37	0.6225
	5	0.00	0.00	1.0000	0.07	0.00	0.9789	0.20	0.27	0.9789	0.00	0.07	0.9789	0.07	0.08	0.9875
ARMU	1	0.00	0.00	1.0000	0.10	0.02	**0.0481***	0.04	0.08	0.2861	0.07	0.01	0.1542	0.05	0.03	0.1963
	2	0.01	0.01	1.0000	0.02	0.11	**0.0352***	0.00	0.02	0.6245	0.00	0.01	0.8063	0.01	0.04	0.1235
	5	0.00	0.03	0.4353	0.00	0.00	1.0000	0.00	0.00	1.0000	0.00	0.00	1.0000	0.00	0.01	0.6687
BASA3	1	2.48	1.46	0.2273	2.28	1.76	0.5300	3.37	0.89	**0.0059***	0.99	0.65	0.6790	2.28	1.19	**0.0419***
	2	0.15	0.12	0.9696	1.01	0.60	0.6250	1.43	0.43	0.2367	0.29	0.25	0.9579	0.72	0.35	0.4608
	5	0.03	0.00	0.9679	0.53	0.43	0.9040	5.80	1.63	**>0.0001***	0.43	0.13	0.7179	1.70	0.55	**0.0333***
CLSE	1	1.36	1.14	0.7487	1.63	2.14	0.4520	0.76	0.47	0.6665	1.37	1.13	0.7186	1.28	1.22	0.5523
	2	0.00	0.02	0.9803	0.16	0.14	0.9754	0.02	0.02	1.0000	0.39	0.69	0.6521	0.14	0.22	0.4594
	5	0.00	0.00	1.0000	0.00	0.00	1.0000	0.00	0.07	0.9214	0.00	0.03	0.9606	0.00	0.03	0.8042
HEBO	1	1.46	1.07	0.3555	2.91	1.27	**0.0006***	4.05	1.12	**>0.0001***	1.98	0.60	**0.0028***	2.60	1.01	**>0.0001***
	2	0.01	0.02	0.9827	0.51	0.43	0.8467	0.14	0.16	0.9525	0.12	0.06	0.8817	0.19	0.17	0.9095
	5	0.00	0.00	1.0000	0.03	0.07	0.9368	0.33	0.07	0.5273	0.00	0.00	1.0000	0.09	0.03	0.8091
HEMUN	1	0.02	0.00	0.9827	0.02	0.01	0.9892	0.50	0.35	0.8449	0.48	0.60	0.8712	0.25	0.24	0.0601
	2	0.00	0.03	0.9740	0.19	0.04	0.8407	0.39	0.10	0.7120	0.10	0.90	0.3008	0.17	0.27	0.4381
	5	0.00	0.00	1.0000	0.60	0.07	0.4887	2.55	1.10	0.0671	0.00	0.00	1.0000	0.79	0.29	1.0000
LIPE2	1	2.44	1.20	0.5131	5.71	2.25	0.0763	10.08	3.04	**0.0010***	5.01	1.03	**0.0442***	5.81	1.88	**0.0001***
	2	1.01	0.43	0.7554	3.27	1.49	0.3493	5.59	2.61	0.1233	2.35	0.42	0.3108	3.06	1.23	**0.0192***
	5	0.60	0.27	0.8600	1.33	0.53	0.6727	4.73	4.03	0.7115	0.67	0.33	0.8600	1.83	1.29	0.4454

(continued)

TABLE 3 *(continued)*

Mean plant density by site, treatment, species, and time since treatment based on data collected in both temporal replications initiated in 2009 and 2010.

		Fountain Green			Gordon Creek			Hatch Ranch			Lookout Pass			All sites (mean)		
Species	**Year**	**C**	**NC**	***P***	**C**	**NC**	***P***	**C**	**NC**	***P***	**C**	**NC**	***P***	**C**	**N**	***P***
LONU2	1	8.40	9.60	0.6247	10.06	9.50	0.8210	9.63	5.26	0.0839	4.87	1.62	0.1922	8.24	6.50	0.0657
	2	2.06	2.86	0.7440	6.07	6.33	0.9166	6.14	3.16	0.2308	0.63	0.40	0.9254	3.72	3.19	0.5479
	5	0.30	0.20	0.9674	2.37	1.43	0.7033	9.20	3.80	**0.0353***	0.17	0.00	0.9457	3.01	1.36	0.0796
LUAR3	1	7.66	6.28	0.0954	5.39	4.35	0.2064	6.33	1.09	**>0.0001***	2.38	0.52	**0.0282***	5.44	3.06	**0.0001***
	2	0.12	0.08	0.9533	0.22	0.29	0.9320	0.03	0.06	0.9690	0.04	0.08	0.9659	0.10	0.12	0.9592
	5	0.00	0.00	1.0000	0.00	0.00	1.0000	0.03	0.03	1.0000	0.00	0.00	1.0000	0.01	0.01	1.0000
NIAT	1	0.16	0.03	0.2556	0.02	0.02	0.9749	0.78	0.12	**>0.0001***	0.46	0.13	**0.0051***	0.36	0.08	**0.0008***
	2	0.00	0.00	1.0000	0.04	0.04	1.0000	0.00	0.00	1.0000	0.07	0.03	0.7013	0.03	0.02	0.8755
	5	0.00	0.00	1.0000	0.00	0.00	1.0000	0.00	0.00	1.0000	0.00	0.00	1.0000	0.00	0.00	1.0000
PEPA6	1	0.25	0.11	0.6736	0.99	0.32	**0.0566***	0.66	0.05	0.0785	0.17	0.09	0.8137	0.52	0.14	**0.0050***
	2	0.01	0.00	0.9802	0.39	0.31	0.8233	0.07	0.12	0.8865	0.01	0.01	0.9950	0.12	0.11	0.9347
	5	0.00	0.00	1.0000	0.03	0.00	0.9209	0.03	0.00	0.9209	0.00	0.00	1.0000	0.02	0.00	0.8842
POFE	1	0.39	0.35	0.8791	0.08	0.00	0.7611	0.75	0.02	**0.0123***	0.13	0.12	0.9636	0.34	0.12	**0.0560***
	2	0.00	0.00	1.0000	0.16	0.08	0.7902	0.01	0.00	0.9697	0.00	0.00	1.0000	0.04	0.02	0.8448
	5	0.03	0.00	0.9031	0.00	0.00	1.0000	0.00	0.00	1.0000	0.00	0.00	1.0000	0.01	0.00	0.9376
SPGR2	1	0.00	0.00	1.0000	0.21	0.11	0.7847	0.25	0.01	0.5328	0.39	0.03	0.3450	0.21	0.04	**0.0380***
	2	0.01	0.01	0.9984	0.04	0.03	0.9735	0.12	0.10	0.9646	0.15	0.19	0.9205	0.08	0.08	0.9766
	5	0.13	0.03	0.7904	0.13	0.27	0.7231	0.23	0.38	0.6903	1.17	1.37	0.5958	0.42	0.51	0.2279
THMI5	1	0.02	0.00	0.7965	0.00	0.01	0.8719	0.06	0.08	0.7718	0.05	0.04	0.8974	0.03	0.03	0.9625
	2	0.00	0.00	1.0000	0.06	0.09	0.6293	0.10	0.06	0.5207	0.00	0.00	1.0000	0.04	0.04	0.9065
	5	0.00	0.00	1.0000	0.00	0.00	1.0000	0.10	0.00	0.1308	0.00	0.00	1.0000	0.03	0.00	0.2699

Notes: P values derived from mixed model analysis of variance indicate significance of difference between treatment types. See Table 2 for abbreviation's species name. C = covered treatment, NC = no cover treatment, year = post-treatment sampling year, boldface and * = significant.

Figure 2). These taxa exhibited higher seedling emergence on at least 1 site when seedbeds were covered; however, these differences in treatment failed to persist beyond the first year. For *Agoseris* spp., emergence was 4.0 times higher in covered than non-covered plots across all sites combined ($P < 0.001$) and 6.0 times higher at Hatch Ranch ($P < 0.001$). It was the only taxa that benefited from the covered treatment at Fountain Green where establishment was 4.0 times higher in covered than non-covered plots ($P = 0.05$). Although *Agoseris* spp. persisted through the second year on all sites, density in covered plots dropped significantly ($P < 0.001$) and by the second year was similar to non-covered plots (Table 3, Figure 2A, 2B). Establishment of *Argemone munita* in covered plots was higher at Gordon Creek ($P = 0.0481$); however, in the second year density in non-covered plots was greater than density in covered plots ($P = 0.0352$; Table 3). *Hedysarum boreale* emerged at all sites, but density was only higher in covered plots at Gordon Creek ($P < 0.001$), Hatch Ranch ($P < 0.001$), and Lookout Pass ($P = 0.002$; Table 3). It persisted in small quantities (<0.5 plants/m^2 [0.05 plants/ft^2]) in both covered and non-covered plots at all 3 sites during the second year and appeared in control plots in the second and fifth year at Gordon Creek, suggesting that this species may be naturally occurring at this site. *Lupinus argenteus* seedling emergence was high in both covered plots (5.44 plants/m^2 [0.51 plants/ft^2]) and non-covered plots (3.06 plants/m^2 [0.28 plants/ft^2]) during the first year; however, by the second year density had dropped to 0.12 and 0.1 plants/m^2 (0.011 and 0.009 plants/ft^2) in covered and non-covered plots, respectively, with no apparent differences between treatments ($P = 0.9592$; Table 3, Figure 2).

Nicotiana atenuata, *Penstemon pachyphyllus,* and *Poa fendleriana* had relatively low establishment (<0.5 plants/m^2 [0.05 plants/ft^2]), regardless of treatment or site effect. However, emergence of these species was improved in some cases when covered (Table 3, Figure 2A). *Nicotiana atenuata* emergence was 6.5 and 3.5 times higher when covered at Hatch Ranch and Lookout Pass, respectively. Plant density was 3.7 and 2.8 times higher in covered plots for *Penstemon pachyphyllus* and *Poa fendleriana*, respectively. *Poa fendleriana* density was 37.5 times higher at Hatch Ranch (0.75 compared to 0.02 plants/m^2 [0.07 compared to 0.002 plants/ft^2] in covered and non-covered plots, respectively; Table 3).

Three species had higher density in covered plots beyond the first year: *Linum perenne* L. (blue flax [Linaceae]) persisted through the second year after treatment, and *Balsamorhiza sagittata* (Pursh) Nutt. (arrowleaf balsamroot [Asteraceae]) and *Lomatium nudicaule* (Pursh) J.M. Coult. & Rose (barestem biscuitroot [Apiaceae]) had higher density through the fifth year following treatment (Table 3, Figure 2). *Linum perenne* had higher emergence in covered than non-covered plots on every site; however, emergence was only significantly higher in covered plots at Hatch Ranch ($P < 0.001$) and Lookout Pass

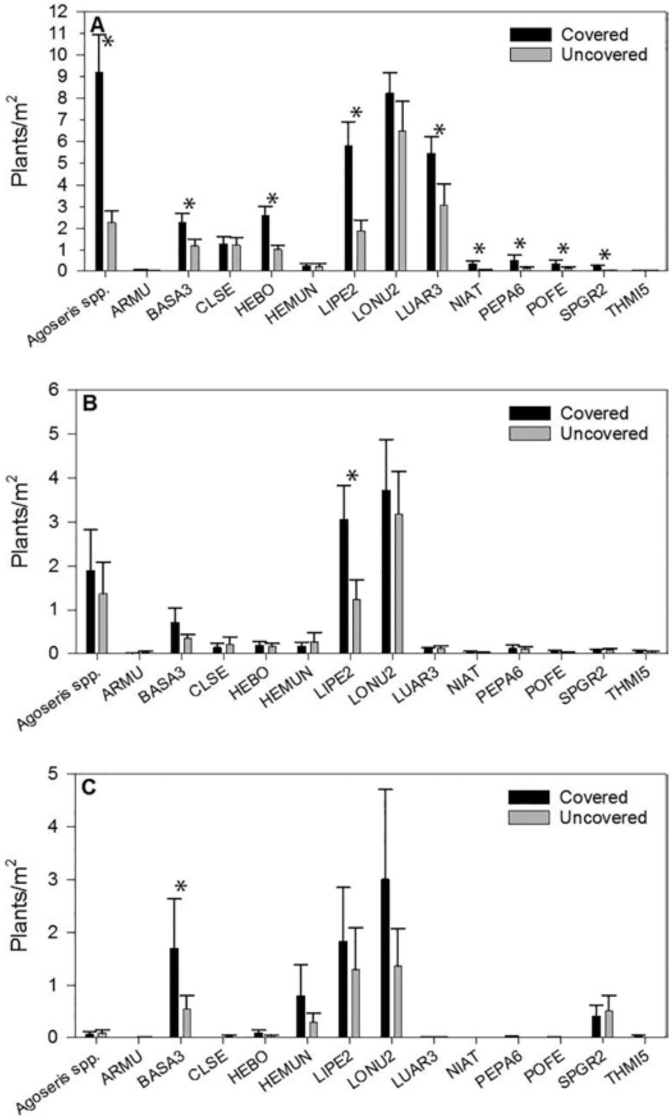

Figure 2. Mean density of seeded species across all sites including both temporal replication. Year 1 post-treatment showing emergence of seeded species (A); year 2 post-treatment showing first-year survival (B); year 5 post-treatment showing seeded species persistence (C). Solid bars represent covered treatments and hashed bars represent non-covered treatments. Asterisks represent statistical significance. ARMU = *Argemone munita*, BASA = *Balsamorhiza sagittata*, CLSE = *Cleome serrulata*, HEBO = *Hedysarum boreale*, HEMUN = *Heliomeris multiflora* subsp. *nevadensis*, LIPE = *Linum perenne*, LONU = *Lomatium nudicaule*, LUAR = *Lupinus argenteus*, NIAT = *Nicotiana attenuata*, PEPA = *Penstemon pachyphyllus*, POFE = *Poa fendleriana*, SPGR = *Sphaeralcea grossulariifolia*, THMI = *Thelypodium milleflorum*.

($P = 0.04$). Although *L. nudicaule* density was slightly higher in covered plots than in non-covered plots on some sites, it did not exhibit any significant differences between treatment types until the fifth year after treatment (Table 3, Figure 2C), and the effect was apparent on only 1 site (Hatch Ranch). At that site, *L. nudicaule* persisted better in covered treatment plots (9.20 plants/m^2 [0.85 plants/ft^2]) than in non-covered plots (3.80 plants/m^2 [0.35 plants/ft^2]). Overall, this species performed equally well in both treatment types in all years. The difference between treatment types became significant ($P = 0.03$; Table 3) only because of a slight density increase in covered plots and a slight density decrease in non-covered plots in the fifth year. This species also persisted in small quantities on the other 3 sites. *Balsamorhiza sagittata* emerged better in covered plots than in non-covered plots across all sites (Table 3, Figure 2A). This finding was particularly apparent at Hatch Ranch, where emergence was significantly higher ($P = 0.005$) with ground cover fabric treatment. Although the differences in treatment were diminished in the second year on all sites, by the fifth year after treatment *B. sagittata* had increase in both covered and non-covered plots and was significantly ($P < 0.001$) more abundant in covered plots (Table 3, Figure 2). This was 1 of only 3 species to show any apparent increase in density over time.

Overall, 9 seeded species (*Agoseris* spp., *A. munita*, *B. sagittata*, *H. boreale*, *L. perenne*, *L. argenteus*, *N. atenuata*, *P. pachyphyllus*, and *P. fendleriana*) showed improved emergence with ground cover fabric treatment on at least 1 site (Table 3, Figure 2A). Mean vegetative emergence in cover treatment plots was 1.68 plants/m^2 (0.16 plants/ft^2), and 0.90 plants/m^2 (0.08 plants/ft^2) in plots without ground cover fabric. At the conclusion of the study, however, only 2 species (*B. sagittata* and *L. nudicaule*) still exhibited any notable effects of ground cover fabric treatment (Table 3, Figure 2C).

Fountain Green showed the lowest response to treatment, with only 1 taxa (*Agoseris* spp.) emerging significantly better in covered plots ($P = 0.0516$; Table 3, Figure 3A). Hatch Ranch showed the strongest response to treatment, with 6 species or taxa (*Agoseris* spp., *B. sagittata*, *H. boreale*, *L. perenne*, *L. argenteus*, *N. atenuata*, and *P. fendleriana*) emerging significantly better in covered plots in the first year (Figure 2A). Also at Hatch Ranch, 2 species (*B. sagittata* and *L. nudicaule*) maintained a significantly higher density in covered plots than in non-covered plots in the fifth year ($P < 0.0001$ and P 0.353, respectively; Table 3, Figure 2C). This site was the only one to show significant difference between covered and non-covered plots in the fifth year of monitoring.

Four species were not affected by the ground cover fabric treatment in any significant way: *Cleome serrulata* Pursh (Rocky Mountain beeplant [Capparaceae]), *Heliomeris multiflora* Nutt. subsp. *nevadensis* (A. Nelson) Yates (Nevada goldeneye [Asteraceae]), *Sphaeralcea grossulariifolia* (Hook. & Arn.) Rydb. (gooseberryleaf globemallow [Malvaceae]), and *Thelypodium milleflorum* A. Nelson (manyflower thelypody [Brassicaceae]) (Table 3, Figure 2). *Cleome serrulata* emerged relatively well in all seeded plots regardless of treatment, whereas *T. milleflorum* did not emerge well in either covered or non-covered plots. At Lookout Pass, *S. grossulariifolia* appeared in every plot (both seeded and unseeded) and showed an increase in density in both covered and non-covered plots each year it was monitored (Table 3). At Hatch Ranch, the density of *H. m. nevadensis* also increased in both covered and non-covered plots from the second year to the fifth year, though density was slightly higher in the covered plots (Table 3).

Weed Cover

While cover was measured in both seeded and unseeded plots, we chose to analyze cover in the unseeded control plots to eliminate confounding variables of seeded species. Cover from annual weeds was generally slightly higher in covered plots than in non-covered plots, though there was no significant difference (Table 4, Figure 4). Gordon Creek consistently had the lowest cover of annual weeds, with all other sites showing similar annual weed cover percentages. In the first year after treatment, annual weed cover ranged from 2% (Gordon Creek) to 31% (Lookout Pass) in covered plots, and 1% (Gordon Creek) to 28% (Lookout Pass) in non-covered plots. In the second year, annual weed cover decreased slightly on nearly all sites, with annual weed cover ranging from 4% (Gordon Creek) to 21% (Hatch Ranch) in covered plots, and 2% (Lookout Pass) to 26% (Fountain Green) in non-covered plots. In the fifth year

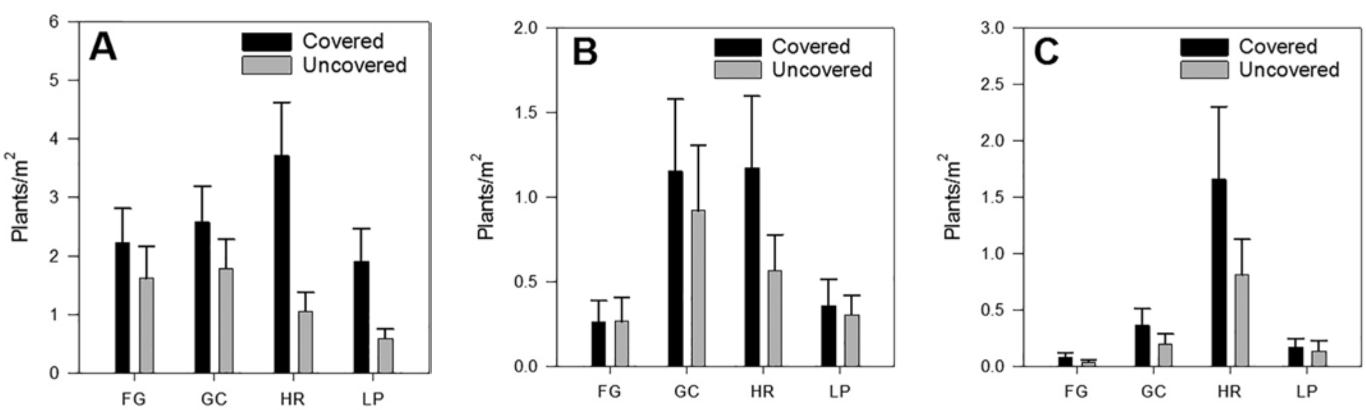

Figure 3. Mean density of seeded species by site including both temporal replications for 1-y post-treatment (A), 2-y post-treatment (B), 5-y post-treatment (C). FG = Fountain Green, GC = Gordon Creek, HR = Hatch Ranch, LP = Lookout Pass.

TABLE 4

Mean cover percentages in unseeded control plots by site, treatment, cover type, and time since treatment, including data from both temporal replications (initiated in 2009 and 2010).

Cover type	Year	Fountain Green			Gordon Creek			Hatch Ranch			Lookout Pass			All (mean)		
		C	NC	*P*	C	NC	*P*	C	NC	*P*	C	NC	*P*	C	NC	*P*
Annual weeds	1	18.29	7.78	0.1704	2.49	0.72	0.8483	21.78	18.40	0.6771	30.79	27.54	0.7040	18.53	14.05	0.1475
	2	19.10	26.14	0.2179	4.38	3.17	0.8315	21.18	12.56	0.1319	7.45	2.49	0.3993	13.03	11.33	0.4721
	5	7.23	7.59	0.9478	2.04	1.59	0.9331	6.00	2.38	0.5035	11.47	12.02	0.9196	6.69	5.89	0.7256
Cheatgrass (*B. tectorum*)	1	39.61	21.48	**0.0076***	0.10	0.27	0.9816	1.61	1.64	0.9959	25.04	6.99	**0.0116***	16.80	8.18	**0.0041***
	2	48.73	47.47	0.8597	0.72	0.12	0.9319	18.10	15.77	0.7434	65.86	37.74	**0.0002***	33.35	24.92	**0.0085***
	5	24.35	30.30	0.3770	0.08	0.08	0.9995	2.08	3.61	0.8209	34.44	41.35	0.3050	15.24	18.84	0.2450
Perennial grass	1	1.26	0.69	0.8951	10.65	8.14	0.4479	1.93	2.54	0.8446	8.47	8.82	0.9114	5.99	5.51	0.7857
	2	2.71	0.59	0.5092	20.72	19.33	0.6637	6.05	3.41	0.4097	11.40	15.06	0.2692	10.22	9.44	0.6965
	5	1.14	0.20	0.7578	30.96	34.02	0.3149	0.48	1.53	0.7308	2.93	1.97	0.7526	8.88	9.43	0.7119

Notes: P values derived from mixed model analysis of variance indicate significance of difference between treatment types. C = covered treatment, NC = no cover treatment, year = post-treatment sampling year, boldface and * = significant.

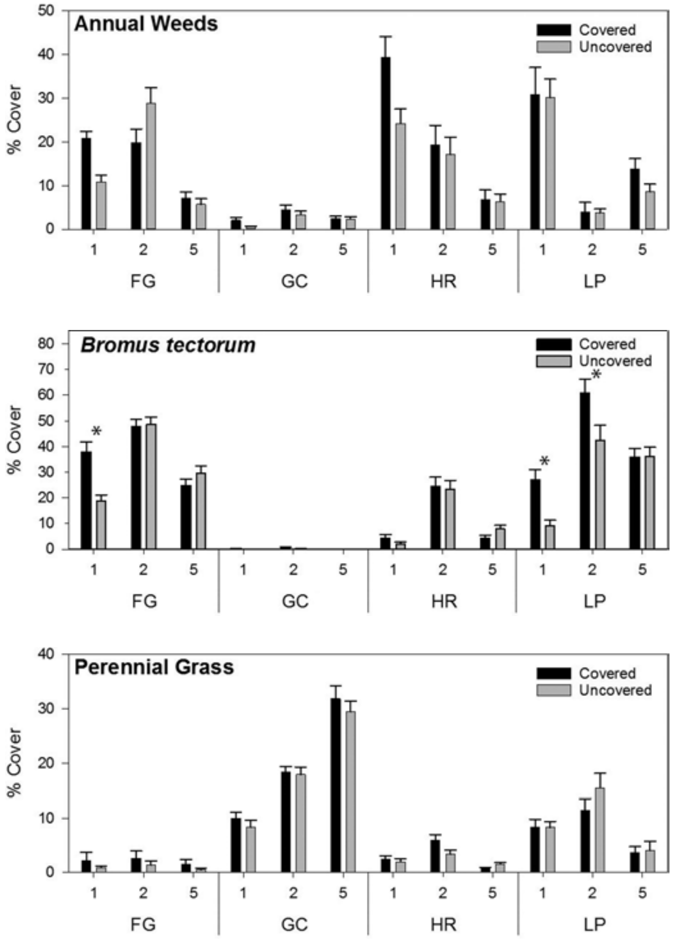

Figure 4. Mean cover of perennial grass, annual weeds, and cheatgrass (*Bromus tectorum*) at each site including both temporal replications over time. FG = Fountain Green, GC = Gordon Creek, HR = Hatch Ranch, LP = Lookout Pass. Asterisks represent statistical significance.

after treatment, annual weed cover continued to decrease, and ranged from 2% (Gordon Creek) to 11% (Lookout Pass) in covered plots, and 2% (Gordon Creek) to 12% (Lookout Pass) in non-covered plots.

Bromus tectorum cover was highest at Lookout Pass and Fountain Green and was present only in trace amounts at Gordon Creek (Table 4, Figure 4). In the first year after treatment, it ranged from 0.1% (Gordon Creek) to 40% (Fountain Green) in covered plots, and 0.27% (Gordon Creek) to 21% (Fountain Green) in non-covered plots. It increased on all sites in the second year after treatment, ranging from 0.7% (Gordon Creek) to 65% (Lookout Pass) in covered plots, and 0.12% (Gordon Creek) to 47% (Fountain Green) in non-covered plots. By the fifth year, *B. tectorum* density had decreased on all sites and ranged from 0.08% (Gordon Creek) to 34% (Lookout Pass) in covered plots, and 0.08% (Gordon Creek) to 41% (Lookout Pass) in non-covered plots. Treatment significantly affected *B. tectorum* density at Fountain Green (P = 0.007) and Lookout Pass (P = 0.01) in the first year after treatment. At Fountain Green, there was nearly twice as much *B. tectorum* in covered plots, and at Lookout Pass *B. tectorum* was 3.5 times higher in covered plots. However, any differences in *B. tectorum* cover between treatment types became insignificant at Fountain Green by the second year after treatment and at Lookout Pass by the fifth year after treatment. There was no significant difference in *B. tectorum* between covered treatment types at Gordon Creek and Hatch Ranch in any year (Table 4, Figure 4).

Perennial grass cover was not significantly affected by ground cover fabric treatment on any site in any year (Table 4, Figure 4). Gordon Creek had consistently higher perennial grass cover than any other site. In the first year, perennial grass cover ranged from 1% (Fountain Green) to 11% (Gordon Creek) in covered plots, and 0.69% (Fountain Green) to 9% (Lookout Pass) in non-covered plots. The second year after treatment showed a slight increase in perennial grass on most sites. It ranged from 3% (Fountain Green) to 21% (Gordon Creek) in covered plots, and 0.59% (Fountain Green) to 19% (Gordon Creek) in non-covered plots. In the fifth year after treatment, perennial grass cover ranged from 0.48% (Hatch Ranch) to 31% (Gordon Creek) in covered plots, and 0.2% (Fountain Green) to 34% (Gordon Creek) in non-covered plots.

Non-Seeded Perennial Species

In addition to the seeded species, we identified and monitored the density of 34 extant perennial species across all sites combined. These perennials included 25 forb species and 9 shrub/tree species. Gordon Creek had the highest species diversity, with 23 non-seeded species recorded in addition to the 14 seeded species. Fountain Green had 16 species, Lookout Pass had 10 species, and Hatch Ranch had 7 species. Three species—*A. tridentata*, *Chrysothamnus viscidiflorus* (Hook.) Nutt. (yellow rabbitbrush [Asteraceae]), and *Gutierrezia sarothrae* (Pursh) Britton & Rusby (broom snakeweed [Asteraceae])—were found across all 4 sites.

Overall, ground cover fabric treatment had no significant effect on non-seeded perennial vegetation in unseeded control plots. A significant response to cover treatment was observed in 4 species (*A. tridentata*, *Astragalus* L. [milkvetch; Fabaceae], *G. sarothrae,* and *C. viscidiflorus*), but only on certain sites and in certain years (Figure 5). Several other species showed statistically significant responses to cover treatment, both positive and negative; however, these responses were not biologically significant as they involved only a single plant per species (Figure 5).

Ground cover fabric treatment more than tripled the emergence of *A. tridentata* at Fountain Green in the 2009 replication year of the study, with an average of 9.4 plants/m^2 (0.87 plants/ft^2) in covered control plots and 2.83 plants/m^2 (0.26 plants/ft^2) in non-covered control plots. However, any advantage gained from ground cover fabric treatment in the first year was lost by the second year with *A. tridentata* density dropping to

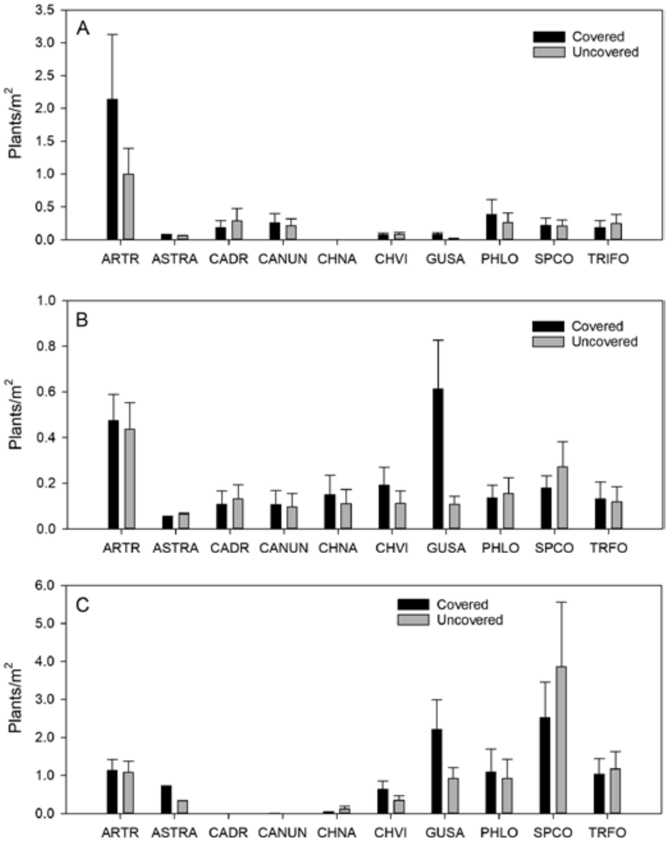

Figure 5. Mean density of most abundant non-seeded perennial taxa across all sites including both temporal replications. Year 1 post-treatment (A), year 2 post-treatment (B), year 5 post-treatment (C). Solid bars represent covered treatments and hashed bars represent non-covered treatments. ARTR = *Artemisia tridentata*, ASTR = *Astragalus* spp., CADR = *Cardaria draba*, CANUN = *Carduus nutans* ssp. *nutans*, CHNA = *Chrysothamnus nauseosus*, CHVI = *Chrysothamnus viscidiflorus*, GUSA = *Gutierrezia sarothrae*, PHLO = *Phlox longifolia*, SPCO = *Sphaeralcea coccinea*, TRIFO = *Trifolium* spp.

<1 plant/m² (0.09 plant/ft²) in all plots at Fountain Green, regardless of treatment (Figures 5A, 5B). This strong response was not observed in the 2010 replication, nor was it observed at any other site.

In the second year after treatment, *G. sarothrae* was significantly more abundant ($P = 0.0002$) in treated plots than in untreated plots at Hatch Ranch (Figure 5B). By the fifth year after treatment, *G. sarothrae* had more than tripled in both treated and untreated plots at Hatch Ranch and continued to be significantly more abundant ($P < 0.0001$) in treated plots, with an average of 10.3 plants/m² (0.96 plants/ft²) (Figure 5C). This response was not observed at any other sites.

Astragalus (unknown species) and *C. viscidiflorus* were both significantly ($P \leq 0.001$) more abundant in covered plots than in non-covered plots at Gordon Creek in the fifth year after treatment (Figure 5C). In both cases, there was no difference between treatment types in the first or second years of the study, but in the fifth year, density in treated plots began to be higher than in untreated plots. Although these species were present on other sites, this response was not observed at any other site.

DISCUSSION

Regardless of study site, replication year, or species, seed islands did not establish in arid sagebrush communities, even with assistance of ground cover fabric. While a few seeded forb species did manage to survive for multiple years on some sites, we never observed a stable or expanding population of any notable size, or even any mature reproductive individual plants. Fabric cover improved emergence rates in some cases; but rather than increasing in density over time, most species decreased in density or disappeared entirely by the fifth year after treatment (see Table 3, Figure 2C).

Several factors may have contributed to the observed decreased density over time. One factor is competition with weedy species. Studies indicate that competition with weedy species, in particular annual grasses and forbs, reduces plant establishment and persistence (Young and Longland 1996; Di'Tomaso 2000). The added moisture retention and sheltered growing conditions of ground cover fabric created an ideal environment not only for desirable species to grow but also for unwanted weedy species to establish and compete. This finding was apparent in the success rates at Fountain Green and Lookout Pass, which were highly invaded with *B. tectorum*, compared to Hatch Ranch and Gordon Creek, which had considerably less *B. tectorum* (see Figure 3, Figure 4). Competition with annual weeds may also have inhibited seedling establishment, although annual weeds appear to establish and grow equally well in both covered and non-covered plots (Ott and others 2019). We observed greater density of weeds at 2 sites where fabric was used, potentially increasing competition and inhibiting establishment success. It is worth noting that Gordon Creek was free of *B. tectorum* and relatively free of annual weeds throughout the study, but most seeded species still failed to establish and declined over time (see Figure 3, Figure 4). Gordon Creek, however, is located at a higher elevation in a different type of sagebrush community, and therefore the lack of establishment could be attributed to inappropriate species or seedlot. Higher competition with established perennial grasses could also be a factor in the low plant establishment at Gordon Creek.

Species and seedlots selected for this project may not have been compatible with study site locations, resulting in lower seeded species success. Although the concept of using locally adapted seed is not new, when we designed and implemented this study in 2009 the importance of seed transfer zones was only beginning to be recognized (Wilson and others 2008). Seed used for this project came from either commercially available seedlots or wild-collected populations, but with minimal consideration for adaptation to the study sites' potential. If seed had been better matched to site potential, there may have been a better chance of success (Petersen and others 2004). Yet, since several species were able to successfully establish on one or more sites, incompatible seed transfer zone would not entirely account for the failure of seed islands to establish. In some cases, such as *S. grossulariifolia* at Lookout Pass, the species we selected for the study appear to be naturally occurring species on one or more sites. At Lookout Pass, *S. grossulariifolia* emerged well and persisted through the fifth year in both coved and non-covered plots (see Table 3, Figure 2). It is unclear whether emerging seedlings in seeded plots grew from naturally occurring populations in the soil seedbank or from sown seed; nevertheless, *S. grossulariifolia* performed equally well in both covered and non-covered seeded plots but did not occur in a large enough population to be considered a viable seed source, even with aid of ground cover fabric.

Only 1 site (Hatch Ranch) had any substantial seeded species persistence, and only 3 of the 14 species (*B. sagittata*, *L. perenne*, and *L. nudicaule*) persisted through the fifth year (see Table 3, Figure 2). Although *B. sagittata* and *L. nudicaule* were technically present in both covered and non-covered plots in the fifth sampling year, the plants remained immature without any noted flower development in any sample year.

A pattern that we detected across all sites—regardless of implementation year—was a distinct drop in plant density between first and second growing years (see Table 3, Figure 2). This was especially apparent for species with high emergence in covered treatment plots, such as *Agoseris* spp., *B. sagittata* (Fountain Green and Hatch Ranch), *H. boreale, L. perenne, L. argenteus* (Fountain Green and Gordon Creek), *N. attenuata* (Hatch Ranch and Lookout Pass), *P. pachyphyllus*, and *P. fendleriana* (Hatch Ranch; see Table 3, Figure 2). In most cases, any advantage from ground cover fabric in the first year was ephemeral and generally did not lead to increased establishment or persistence. By the second year, species in covered plots experienced losses of 23% to 100%, leaving surviving populations roughly equal to densities in non-covered plots. This outcome suggests that providing favorable conditions for establishment does not necessarily provide a long-term advantage for seeded species when typical site conditions are not similarly favorable. Additionally, below-average precipitation in the spring to summer months could have contributed to lower plant establishment success (NOAA 2019). This finding suggests that establishing plant communities is complex and requires a combination of adapted seeding materials, effective management strategies, and suitable site conditions for successful reclamation (Boyd and Svejcar 2009).

MANAGEMENT IMPLICATIONS

Use of N-Sulate fabric in wildland settings has potential to increase initial emergence of native forb species, but it has limited impact on long-term persistence of most species tested in this study. Caution should be used on sites with weedy species, and especially *B. tectorum*, as the method may also increase undesirable species that compete with desired species. This effect could possibly be mitigated through use of herbicide to control adverse species either pre- or post-emergence, although further investigation into the effects of N-Sulate fabric on areas treated by herbicide may be recommended. If a seedbank could be depleted of weeds prior to native seeds being sown, increased emergence resulting from ground cover fabric may have a more lasting effect.

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