Meadow establishment research plots located on the Aberdeen Research and Extension Center in southeastern Idaho. Photo taken on 17 October 2013.

Managing weeds during wildflower meadow establishment in the arid Intermountain West: efficacy of a grass-first strategy for sites with heavy annual weed pressure

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ABSTRACT

The creation of attractive, sustainable wildflower meadows in private and public green spaces is becoming increasingly popular. Establishment failure rate for new meadow plantings can be very high, primarily because of the initial annual weed pressure. We proposed a 3-step grass-first establishment protocol based on plant augmentative succession principles: 1) spring planting of grass component species; 2) application of standard turf-appropriate weed-control methods; and 3) early fall overseeding or outplanting of forbs into the established grasses. This grass-first meadow establishment protocol was successful, regardless of standard weed-control method employed (mowing; 2,4-D application; or application of a three-way pre-mix containing mecoprop, 2,-4-D, and dicamba [Ortho Weed B Gon]). Among the weed-control treatments, weed density during the establishment year did not affect ultimate meadow establishment success, as long as weeds were controlled sufficiently to allow grass and forb survival. Seeding resulted in a greater density of forbs and, ultimately, an overall more aesthetically pleasing mix of flowering plants and grasses as compared to outplanting. Among the grasses in the species mix, slender wheatgrass (*Elymus trachycaulus* (Link) Gould ex Shinners [Poaceae]) was dominant. Among the forb species, 5 Asteraceae species persisted over the period of the study and contributed good color to the meadow plantings. An augmented succession protocol based on grass-first establishment will be valuable where native meadow plantings are desired for urban habitat development and beautification.

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KEY WORDS
forb, herbicide, plant succession, augmentative restoration, urban habitat

NOMENCLATURE
Native species: USDA NRCS (2015)
Weed species: Whitson and others (2004)

CONVERSIONS
1 sq ft = 0.09 sq m
1 lb = 0.45 kg
1 oz = 28.35 g
Seeds/kg = seeds/lb × 2.20
Seeds/sq m = seeds/sq ft × 10.75
oz/plot = grams/plot × 28.35

Photos by Stephen L Love

Wildflower meadows are becoming increasingly popular as land managers attempt to restore pockets of local habitat and to create more sustainable urban and suburban landscapes. Meadows are employed for roadside beautification, reclamation of disturbed urban public lands, habitat establishment in parks and golf courses, and improvement of minimally managed private property (Weston 1990; Henry and others 1999; Delaney and others 2000; Rothenberger 2002; USDT 2007; Weaner 2012). Potential benefits from a sustainable wildflower meadow planting include soil stabilization, improved aesthetics, pollutant entrapment, habitat improvement, reduced maintenance costs, species conservation, and opportunities for education (Delaney and others 2000; Aldrich 2002).

Recommended procedures for planting wildflower meadows involve selection of an appropriate site, choice of adapted and compatible grass and forb species, site preparation, weed control, and effective planting methods (Delaney and others 2000; Aldrich 2002; Perry 2005; Neal and Papineau 2012). Of these factors, inadequate weed control during establishment is the most common contributor to all-too-frequent failure (Aldrich 2002; Perry 2005; Norcini and Aldrich 2009).

Adherence to proven restoration principles and protocols may improve the chances for successful meadow establishment. Models encompassing plant succession principles are emerging as part of restoration science (McLendon and Redente 1990; Bradshaw 1996; Bard and others 2004; Suding and others 2004; Walker and del Moral 2008). Plant succession is defined as changes in vegetation following natural or human-caused disturbance, eventually resulting in a stable climax plant community (Roundy 2005). Primary succession occurs when vegetation begins to grow on a site where a plant-based ecology previously never existed. Secondary succession occurs where elements of a pre-existing ecology remain intact after a disruptive event. Walker and del Moral (2008) suggested that restoration of abandoned agricultural fields—representative of most disturbed urban sites—is akin to primary succession rather than secondary succession because of an extended period of disruption. Application of succession processes may help ameliorate meadow establishment issues.

Succession in any plant community presumes the presence of seed sources for the climax species (Bomberger and others 1983). In urban and suburban sites, a paucity of climax species in the seedbank means the first successional stage, made up of ruderals and annual weeds, will be repeated in an unending cycle of germination, growth, and seed production. As a result, the residual bank of annual weed seeds is very high, creating unmanageable conditions for noncompetitive native species seedlings. Pre-establishment of native perennial grasses has been shown to be an effective first step in restoration of degraded, arid sites (Blumenthal and others 2003; Porensky and others 2014). Grass-first establishment combines the primary succession concept for old agricultural sites outlined by Walker and del Moral (2008) with the augmentative restoration procedures presented by Bard and others (2004).

Suggestions for enhancing success during meadow establishment include the use of modern postemergence herbicides, outplanting to increase competitiveness of desirable plants, and selection of appropriate native species. Variable species tolerance limits the effectiveness of herbicides for reclamation weed control. Regardless, herbicides are being employed to enhance native plant stands during revegetation projects (Bekedam 2005; Baker and others 2009; Bahm and Barnes 2011; Benson and others 2011; Davies and Sheley 2011; Wiese and others 2011). Postemergence–applied herbicides are more likely to damage or kill seedlings while producing only minor injury on large, established plants (Bahm and Barnes 2011; Davies and Sheley 2011; Morishita and others 2011; Wiese and others 2011).

Outplanting, as opposed to direct-seeding, could be an effective augmentative restoration method for overcoming forb establishment barriers (Sheley and others 2008). Published meadow planting guides make reference to the advantages of outplanting meadow elements, but no research is cited to support the concept (Delaney and others 2000; Aldrich 2002; Perry 2005). Additionally, choice of grass and forb species used as components in a wildflower meadow will determine long-term successional development and ultimate aesthetic value. Research to identify suitable grass and forb components for wildflower meadow plantings in the arid, high-desert regions of the northern Intermountain West is lacking.

Research objectives for this study were fourfold: 1) determine the efficacy of a grass-first strategy for wildflower meadow establishment; 2) compare outplanting and direct seeding as tools to optimize species establishment; 3) test the efficacy of a spring postemergence application of the herbicides imazapic and pendimethalin for reducing second-year weed density; and 4) evaluate short-term persistence and succession of grass and forb species in a wildflower meadow.

METHODS

A meadow establishment experiment was conducted 2013 through 2015 at the University of Idaho Aberdeen Research and Extension Center, Aberdeen, Idaho. The Center is located on the Snake River Plain in the southeastern region of the state.

Site Description

Climate at the study location is semi-arid high desert, with annual precipitation 234 mm (9.2 in), average July high temperature of 30.5 °C (87 °F), average January low temperature of −11 °C (12 °F), and USDA Plant Hardiness Zone equivalent to 4. Soil type in the study field is a Declo silt loam (course-loamy, mixed, superactive, mesic, xeric, haplocalcid) with pH 8.2, 1.02% organic matter, and relatively low fertility levels. The trial was located on the site of an abandoned farmstead. Native grasses and forbs were absent from the site, the soil weed seedbank was high and persistent, and annual weed pressure historically intense. The most common weed species observed included the broadleaf species common purslane (*Portulaca oleracea* L. [Portulacaceae]), kochia (*Kochia scoparia* (L.) Schrad. [Chenopodiaceae]), redroot pigweed (*Amaranthus retroflexus* L. [Amaranthaceae]), common lambsquarter (*Chenopodium album* L. [Chenopodiaceae]), and blue mustard (*Chorispora tenella* (Pall.) DC. [Brassicaceae]). Several other annual grass and broadleaf weed species were present in smaller numbers.

Site Preparation

On 17 June 2013, the entire trial area was sprayed with a 3% solution (acid equivalent) of glyphosate (Roundup, Monsanto Corporation) using a backpack sprayer at a pressure of 2.1 kg/sq cm (30 psi) and a water carrier volume of 140 l/ha (15 gal/ac) to control existing patches of perennial weeds. On 26 June 2013, the plot area was tilled with a rotovator to produce a clean seedbed. On 11 July 2013, the entire plot area was broadcast-fertilized with a generic 30-0-3 product at a rate equivalent to 44.8 kg/ha (40 lb/ac) of nitrogen (N).

Meadow Species Seed Mixes and Outplants

Seeds of 17 native plant species—5 grasses and 12 forbs—were purchased from Western Native Seed (Coaldale, Colorado). Table 1 lists the selected species and their individual seed characteristics. Species choice was based on native presence in the arid Intermountain West and presumed ability to be competitive in a grassland environment. USDA Natural Resources Conservation Service (NRCS) recommendations from the New Mexico Plant Materials Center located at Las Lunas, New Mexico, where climate also is semi-arid, were used as a basis for seeding rates (Dreesen n.d.). Seeds were combined to create 2 separate seed mixes, one for grasses and the other for forbs. Calculations for the mixes were based on target composite seeding rates of 538 pure live seed (PLS)/m^2 (50 PLS/ft^2) for

TABLE 1

Common names, scientific names, seed weights, seeding rates, and pure live seed (PLS) weight planted in each plot for 17 native grass and forb species used as components in a meadow seed mix.

Common name	Scientific binomial/Authors	Seed weight	Seeding rate	PLS g/plot[z]
Grasses (Poaceae)		#/lb	PLS/sq ft	
Idaho fescue	*Festuca idahoensis* Elmer	425,000	10	4.4
Indian ricegrass	*Achnatherum hymenoides* (Roem. & Schult.) Barkworth	141,000	10	13.1
Big bluegrass	*Poa secunda* J. Presl	925,000	10	2.4
Slender wheatgrass	*Elymus trachycaulus* (Link) Gould ex Shinners	159,000	10	13.3
Tufted hairgrass	*Deschampsia caespitosa* (L.) P. Beauv.	1,300,000	10	1.5
Forbs				
Yarrow	*Achillea millefolium* L. (Asteraceae)	2,700,000	4	0.3
Pacific aster	*Symphyotrichum chilense* (Nees) G.L. Neesom (Asteraceae)	800,000	4	1.1
Purple prairie clover	*Dalea purpurea* Vent. (Fabaceae)	293,000	4	2.6
Western larkspur	*Delphinium x occidentale* (S. Watson) S. Watson (Ranunculaceae)	500,000	4	2.2
James' buckwheat	*Eriogonum jamesii* Benth. (Polygonaceae)	400,000	4	6.1
Blanketflower	*Gaillardia aristata* Pursh (Asteraceae)	132,400	4	6.5
Lewis flax	*Linum lewisii* Pursh (Linaceae)	295,000	4	2.6
Rocky Mountain penstemon	*Penstemon strictus* Benth. (Scrophulariaceae)	692,000	4	1.6
Firecracker penstemon	*Penstemon eatonii* A. Gray (Scrophulariaceae)	600,000	4	1.8
Black-eyed Susan	*Rudbeckia hirta* L. (Asteraceae)	1,575,000	4	0.6
Mexican hat	*Ratibida columnifera* (Nutt.) Wooten & Standl. (Asteraceae)	1,200,000	4	0.9
Munro's globemallow	*Sphaeralcea munroana* (Douglas) Spach (Malvaceae)	750,000	4	1.9

Notes: Seed weights (seeds/lb) and seeding rates (pure live seed [PLS]/ft^2) are given in English Standard units for purposes of common usage.

[z]Percent pure live seed in each seedlot calculated using vendor's certification tags.

the grass species mix and 517 PLS/m^2 (48 PLS/ft^2) for the forb species mix.

Multiple transplants of the 12 forb species were produced in a greenhouse at the Aberdeen Research and Extension Center. Seeds of western larkspur and the 2 penstemon species were stratified for 3 wk at 4.4 °C (40 °F) prior to planting. All 12 species were seeded into flats in mid-July. Following emergence, seedlings with 2 to 5 true leaves were selected out of flats, transplanted into 7.6-cm × 12.7-cm (3-in × 5-in) pots (Thermoform, AM Leonard, Piqua, Ohio) in the greenhouse, and allowed to grow until the designated field outplanting date.

Plot Design

Plots were arranged in a randomized complete block design with 3 replications. Individual main plots were 37.2 m^2 (400 ft^2) with dimensions of 6.1 m × 6.1 m (20 ft × 20 ft). In the spring of 2014, each main plot was randomly divided into 2 subplots, with or without an application of a tank mixture of imazapic (Plateau, BASF, Ludwigshafen, Germany) plus pendimethalin (Prowl H_2O, BASF), resulting in a split-plot statistical design. Lack of response to the spring 2014 imazapic plus pendimethalin tank mix resulted in a decision to retract the split-plot design in 2015.

Experimental Treatments

The study consisted of 8 main-plot treatments (Table 2). Of the 8 treatments, 2 were controls included to provide comparisons with full-spectrum response potential: one control was designed as a common-practice treatment of a mixture of grasses and forbs seeded during spring 2013 with no subsequent weed control, and the other comprised a grass mix seeded during early summer, followed by periodic hand-weeding to provide complete weed control. The forb mixture was then seeded or outplanted in the fall into the weed-free, established grass stand. The other 6 treatments consisted of a factorial arrangement of 3 standard grass establishment weed-control practices: 1) mowing; 2) 2,4-D herbicide (Hi-Yield 2,4-D amine, VPG Fertilome, Bonham, Texas); or 3) a 3-way premix product (Ortho Weed B Gon herbicide [mecoprop-p dimethylamine salt 5.30% + 2,4-D, dimethylamine salt 3.05% + dicamba, dimethylamine salt 1.30%], The Scotts Miracle-Gro Company, Marysville, Ohio) and 2 forb-establishment techniques—seeding or outplanting into established grass stands. A grass species mix was seeded on 28 June for 6 treatments that included standard weed-control practices and the hand-weeded control treatment. Forb components were added to the appropriate plots on 28 August after the grasses were fully established and weed-control treatments complete.

Application details for treatments that included the standard weed-control practices after grass seeding occurred were as follows: mowing, beginning when overall vegetation in the plots was about 10.1 cm (4 in) tall; application of 2,4-D at 2.3 l/ha (2 pints [pt]/ac) product; or application of Ortho Weed B Gon at 9.1 l/ha (7.8 pt/ac) product. Herbicide treatments were

TABLE 2

Experimental main-plot treatments designed to test the efficacy of standard weed-control practices in grass-first meadow plantings and the potential advantage of forb outplantation.

Treatment	Description
Common-practice control	Mixture of grass and forb species spring-seeded on 28 June. No weed-control methods employed other than late fall mowing.
Hand-weeded control	Weekly hand-weeding. Forb species seeded into the established grass stands on 28 August.
Mowed and seeded	Mowed twice weekly at 6.4 cm (2.5 in) height. Forb species seeded into grass/weed stands on 28 August.
Mowed and outplanted	Mowed twice weekly at 6.4 cm (2.5 in) height. Forb species outplanted into grass/weed stands on 28 August.
2,4-D herbicide application and seeded	Application on 26 July when grasses reached 10.1 cm (4 in) height. Forb species seeded into grass/weed stands on 28 August.
2,4-D herbicide application and outplanted	Application on 26 July when grasses reached 10.1 cm (4 in) height. Forb species outplanted into grass/weed stands on 28 August.
Weed B Gon herbicide application and seeded	Application on 26 July when grasses reached 10.1 cm (4 in) height. Forb species seeded into grass/weed stands on 28 August.
Weed B Gon herbicide application and outplanted	Application on 26 July when grasses reached 10.1 cm (4 in) height. Forb species seeded into grass/weed stands on 28 August.

Notes: A third variable, second-spring herbicide (imazapic and pendamethalin) application, was imposed over the 8 treatments, resulting in 16 total split-plot treatments. Grasses were seeded in all treatments into a clean seedbed on 28 June 2013. For the common-practice control treatment, forbs were seeded on the same date.

applied on 26 July 2013 with a backpack sprayer using specifications previously described.

On 17 April 2014, the spring after all grass and forb components were seeded or outplanted, a tank-mix of imazapic at 59 ml/ha (2 oz/ac) and pendimethalin at 2.1 l/ha (1.8 pt/ac) was applied with a backpack sprayer using specifications described previously to a randomly selected half of each main plot while perennial vegetation was dormant or in the early green-up phase.

Planting and Maintenance

Initial seeding of the grass mix and the forb mix for the common-practice control was completed on 28 June 2013 (Figure 1). Seeds were broadcast by hand, and the soil was lightly raked to incorporate seeds to a depth of about 6.4 mm (0.25 in). Plots were then sprinkler-irrigated daily with approximately 0.64 cm (0.25 in) of water for 10 d after planting to maintain a damp soil surface to encourage emergence, after which irrigation was scheduled weekly with water applications of approximately 12.7 mm (0.5 in).

The forb mix was seeded or outplanted into established grass stands (some weeds were present depending upon the efficacy of the applied weed-control practice) for all treatments except the common-practice control on 28 August 2013. Figures 2 and 3 illustrate the status of weed control in the plots at planting time. The forb seed mix prepared for seeded treatments was broadcast by hand and plots raked carefully to limit damage to the established grasses. Greenhouse-grown forbs at outplanting time were between 3 cm (1.2 in) and 10 cm (3.9 in) tall, depending on species. Ten plants each of yarrow, purple prairie clover, Pacific aster, James' buckwheat, blanketflower, Lewis flax, Munro's globemallow, black-eyed Susan, and Mexican hat, plus 5 plants of firecracker penstemon (limited greenhouse germination) were randomly (but regularly) placed and outplanted within each plot. Rocky Mountain penstemon and western larkspur did not emerge when planted in flats in the greenhouse so were not included in the outplant palette. A total of 95 forb plants were outplanted into each plot, considerably fewer than the approximately 39,200 total live forb seeds broadcast across each seeded plot. The number of out-

Figure 1. Site preparation activities on 28 June 2013 prior to seeding grass component species for the meadow establishment study.

Figure 2. Weed-dominated common-practice control plot: grass and forbs spring planted, non-weeded (A) and hand-weeded control plot (B). Photo taken on 22 August 2013, one week prior to forb-seeding in the hand-weeded plot.

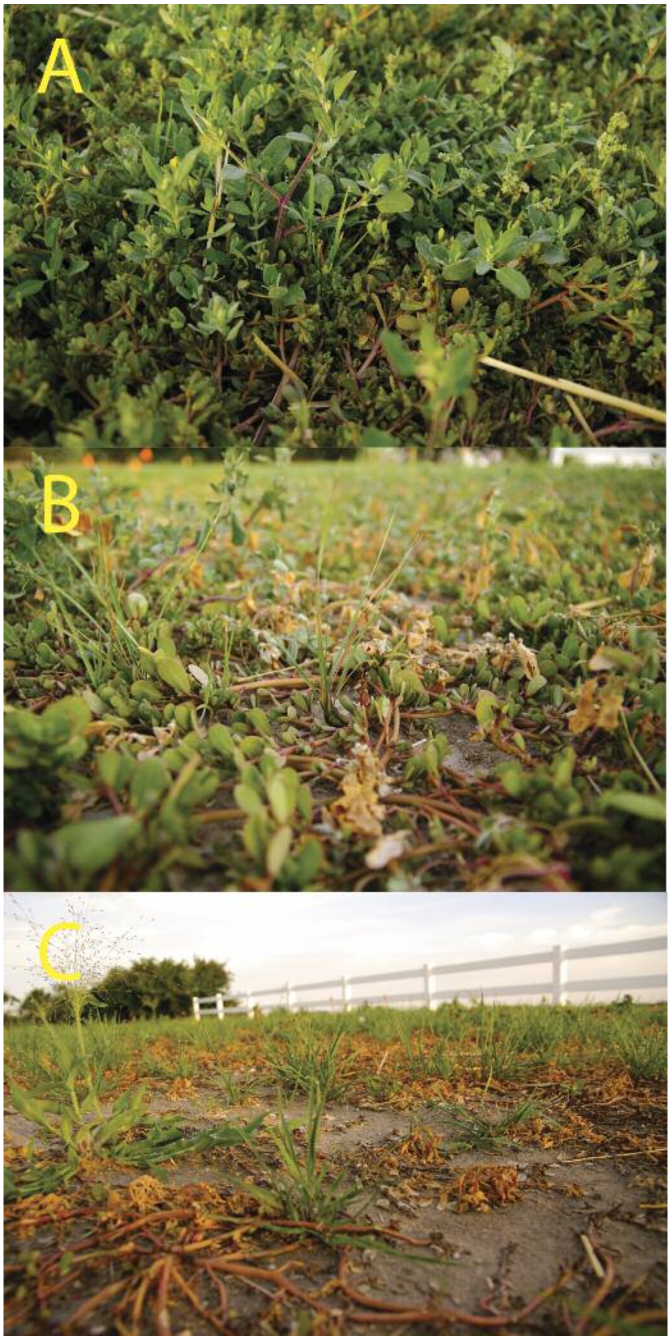

Figure 3. Grass seedlings growing with annual weeds in plots treated to control weeds by mowing (A), a single application of 2,4-D herbicide (B), and a single application of Ortho Weed B Gon herbicide (C). Photo taken on 22 August 2013, one week prior to forb seeding.

plants to employ was determined by our interpretation of cost and workload practicality.

Following forb seeding or outplanting, the entire trial area was irrigated daily for 10 d with approximately 0.64 cm (0.25 in) of water to maintain a damp seeding and root zone. After the initial 10 d, the summer irrigation schedule was resumed until irrigation was terminated mid-October. During the summers of 2014 and 2015, plots were irrigated once every 10 d with 2.5 cm (1 in) of water per application. Each year, during the last week of October, all plots were mowed down and the litter chopped and left on the soil surface.

Data Collection

We recorded visual estimates of ground cover of grasses, forbs, or weeds on a 0 (no cover) to 100% (complete cover) scale on 16 October 2013 before mow-down during late October. In 2014 (24 June) and 2015 (17 July), plant counts within a single randomly positioned meter-square quadrat were used to estimate densities of grasses, forbs, and weeds. In 2015, data collection included a subjective aesthetic value score on a scale of 1 to 10, where 10 = the best, and whole-plot density counts of forbs, by species, on 17 July.

Data Analyses

We analyzed data comprising the factorial arrangement of standard weed-control practices and planting methods using a generalized linear mixed model assuming appropriate distributions for the various responses (Stroup 2012). Percentage ground cover data assumed a beta distribution, while plant count data assumed a Poisson distribution. We assessed aesthetic value scores assuming a normal distribution with constant variance. Statistically significant treatment effects were further evaluated through pair-wise mean comparisons. All statistical computations were carried out using Proc Glimmix, SAS 9.4 (SAS Institute, Cary, North Carolina).

RESULTS

Consistent emergence and survival of species in the meadow grass and forb mixes occurred in all plots at each planting step, both for seeds and outplants, thus providing appropriate conditions for evaluating establishment success. Visual ground cover estimates taken in October of the establishment year (2013), almost 2 mo after planting forbs into the grass-first plots, provided a measure of initial planting success and demonstrated the impact of early weed competition in the plots (Table 3). Cover of grass species among standard weed-control treatments was highest following application of Weed B Gon (38.3%), followed by 2,4-D application (24.0%), and mowing (12.6%). In comparison, grass species cover approached zero for the common-practice control and 45.0% for the hand-weeded control treatment. Planting method, consisting of either fall seeding or fall outplanting, did not influence grass species coverage.

Forb (wildflower) cover overall was low after less than 2 mo of growth, highest in the Weed B Gon-treated plots (3.8%) and somewhat lower in the 2,4-D (2.1%) and mowed (2.0%) treatments (Table 3). In comparison, ground cover of

TABLE 3

Effect of 3 weed-control practices and 2 forb-planting methods on mean percent ground cover of grasses, forbs, and weeds at the end of the establishment year.

Treatment[z]	Grasses	Forbs	Weeds
	% Ground cover[y]		
Weed-control practice			
Mowing	12.6 a (9.0, 17.5)[x]	2.0 a (1.5, 2.7)	69.4 b (62.0, 76.0)
2,4-D	24.0 b (18.8, 30.1)	2.1 a (1.6, 2.8)	20.7 a (15.1, 27.8)
Weed B Gon	38.3 c (32.2, 44.8)	3.8 b (3.0, 4.7)	21.6 a (16.0, 28.6)
Forb-planting method			
Seeding	24.3 a (19.8, 29.5)	1.4 a (1.1, 1.9)	44.5 b (37.8, 51.3)
Outplanting	22.4 a (18.1, 27.4)	4.3 b (3.7, 5.1)	27.2 a (21.4, 34.0)
Control plot means[w]			
Common practice	0.3	0.7	99.3
Hand-weeded	45.0	3.3	14.3

Notes: Study conducted at the University of Idaho Aberdeen R&E Center near Aberdeen, Idaho. Control treatment means are included for comparison.

[z] A factorial analysis was computed based on the 3 weed-control practices (mowing, application of 2,4-D, or Ortho Weed B Gon) and 2 forb-planting methods (seeding or outplanting). There was no interaction between weed-control practice and forb-planting method, both effects were significant, weed-control practice means were pooled across forb-planting method, and forb-planting method means were pooled across weed-control practice.

[y] Percent ground cover was estimated visually on 16 October 2013 at the end of the establishment season on a 0 (no ground cover) to 100 (total ground cover) scale.

[x] Values in parentheses represent approximate 95% confidence intervals. Letter designations indicate significant differences at the 95% level of confidence.

[w] Control plots omitted from statistical analyses to conserve the factorial nature of the data. The common-practice control consisted of seeding a mix of grass and forbs during June 2013 with no subsequent weed control. The hand-weeded control consisted of seeding a grass mix during June 2013 and a forb mix during August 2013, with periodic hand-weeding.

spring-planted forbs in the common-practice control was 0.7% and 3.3% in the fall-seeded, hand-weeded control treatment. Outplanting resulted in higher forb ground cover (4.3%) than did seeding (1.4%), in spite of plant density in the seeded plots being much higher, a result caused by outplants being considerably larger than their seedling counterparts.

Weed ground cover displayed a direct association with grass and forb establishment. October weed cover in the common-practice control was 99.3% with correspondingly low cover of grasses and forbs (Table 3). Weed cover in the hand-weeded control treatment was only 14.3%, while the combination of grasses and forbs covered almost 50% of the soil surface. Weed coverage in the standard weed-control plots was related to efficacy of the treatments, with mowing having the highest percentage of cover (69.4%) and treatment with 2,4-D (20.7%) and Weed B Gon (21.6%) resulting in lower coverage. Outplanting of forbs resulted in lower weed coverage (27.2%) than did seeding (44.5%), likely an artifact of soil disturbance during the planting process.

In the second year (2014) after establishment, weed density in the common-practice control was still extremely high (1,144.7/m^2 [106.3/ft^2]), whereas density in the hand-weeded control was relatively low (11.0/m^2 [1.0/ft^2]) (Table 4). All three standard weed-control treatments produced a reduction in weeds compared to the common-practice control, with the significantly superior treatment being Weed B Gon application (6.8/m^2 [0.6/ft^2]), followed by mowing (25.5/m^2 [2.4/ft^2]) and application of 2,4-D (71.2/m^2 [6.6/ft^2]). Although not significantly higher than the mowing treatment, the high weed density in the 2,4-D treatment was the result of high weed counts in one plot, an outlier from the typical successional response seen in the remaining plots.

Spring 2014 application of the imazapic plus pendamethalin tank-mix did not significantly reduce weed density (20.8/m^2 [1.9/ft^2]) as compared to the untreated (25.5/m^2 [2.4/ft^2]) subplots (Table 4); nor did this herbicide application affect density of meadow-component grasses or forbs. Visual inspection revealed that the weed composition in these herbicide-treated

TABLE 4

Effect of 3 weed-control practices and 2 forb-planting methods applied during the 2013 establishment year and a spring 2014 herbicide treatment on density of grasses, forbs, and weeds on 24 June 2014.

Treatment[z]	Grasses	Forbs	Weeds
	Number of plants/m²		
2013 Standard weed-control practice			
Mowing	14.0 a (9.3, 21.1)[y]	2.5 ab (1.5, 4.1)	25.5 b (9.5, 68.7)
2,4-D	14.2 a (9.4, 21.5)	1.7 a (0.9, 3.1)	71.2 b (26.6, 191.1)
Weed B Gon	20.9 a (14.0, 31.1)	3.6 b (2.3, 5.7)	6.8 a (2.4, 18.9)
2013 Forb-planting method			
Seeding	16.6 a (11.7, 23.5)	3.9 b (2.7, 5.6)	20.7 a (8.5, 50.5)
Outplanting	16.0 a (11.0, 22.1)	1.6 a (1.0, 2.6)	25.8 a (10.4, 63.6)
2014 Herbicide application			
None	15.5 a (11.3, 21.4)	2.6 a (1.7, 3.9)	25.5 a (10.9, 59.5)
Pendamethalin + imazapic	16.6 a (12.1, 22.9)	2.4 a (1.6, 3.7)	20.8 a (8.9, 49.1)
Control plot means[x]			
Common practice	1.3	1.3	1,144.7
Hand-weeded	13.5	3.0	11.0

Notes: Study conducted at the University of Idaho Aberdeen R&E Center near Aberdeen, Idaho.

[z] Factorial analysis based on the 3 weed-control practices (mowing, or application of 2,4-D or Ortho Weed B Gon), 2 forb-planting methods (seeding or outplanting), and 2 spring 2014 herbicide applications (none or imazapic + pendamethalin). There were no interactions between weed-control practice, forb-planting method, and spring 2014 herbicide treatment. All 3 effects were significant. Effect means shown are pooled across the other 2 effects.

[y] Values in parentheses represent approximate 95% confidence intervals. Letter designations indicate significant differences at the 95% level of confidence.

[x] Control plots omitted from statistical analyses to conserve the factorial nature of the data. Common-practice control consisted of seeding a mix of grass and forbs early summer 2013 with no subsequent weed control. Hand-weeded control consisted of grass seeding June 2013 and forb seeding August 2013 with periodic hand-weeding.

split-plots was slightly different, with treatment resulting in a reduction in annual mustard species. But overall weed density and competition was unchanged.

None of the treatment variables, including standard weed-control practice, planting method, or 2014 herbicide application had an influence on grass density (Table 4). Grass density in the 3 standard weed-control treatments was comparable to the hand-weeded control and much higher than the common-practice control, where the presence of grass plants was extremely limited, and those present were weak and noncompetitive.

In 2014, forb density was highest in the Weed B Gon-treated plots (3.6/m² [0.3/ft²]), mowing treatment was intermediate (2.5/m² [0.2/ft²]), and 2,4-D-treated plots the lowest (1.7/m² [0.2/ft²]) (Table 4). Forb density was markedly higher in the seeded plots (3.9/m² [0.4/ft²]) than in the outplanted plots (1.6/m² [0.1/ft²]), not surprising given the much higher seeding rate. In spite of higher numbers of seedling forbs, the outplanted forbs were much more robust and produced consistent bloom the second year after establishment. Seeded forbs were smaller and produced bloom only sporadically in 2014.

In the third growing season after establishment (2015), weed density effects among the 3 standard weed-control treatments and planting methods lacked statistical significance (Table 5). At the same time, the common-practice control exhibited high levels of repeat annual weeds. The hand-weeded control showed weed densities that were in line with the 3 standard weed-control treatments. For any treatment in which some form of weed control was practiced, the grasses and forbs survived in the plots and became competitive with weeds by the third growing season.

By 2015, grass density was consistent across standard weed-control treatments and planting methods (Table 5). At this time, virtually no grass plants remained in the common-practice control plots. Grass density in the hand-weeded control plots was lower than in the standard weed-control treatments, likely the result of damage to and loss of grass plants during the hand-weeding process applied during summer 2013.

TABLE 5

Effect of 3 weed-control practices and 2 forb-planting methods in the 2013 establishment year on density of grasses, forbs, and weeds and a subjective aesthetic value rating on 17 July 2015, the 3rd season after establishment.

Treatment	Grasses	Forbs	Weeds	Aesthetic rating[z]
	Number of plants /m²			
2013 Standard weed-control practice[y]				
Mowing	13.9 a (10.0, 19.4)[x]	3.0 a (1.4, 6.3)	10.0 a (2.3, 43.5)	6.3 a (4.6, 8.1)
2,4-D	13.2 a (9.4, 18.5)	0.9 a (0.2, 4.8)	28.6 a (6.7, 120.5)	5.5 a (3.8, 7.2)
Weed B Gon	14.7 a (10.6, 20.4)	2.0 a (0.8, 4.8)	10.7 a (2.5, 45.8)	6.0 a (4.3, 7.7)
2013 Forb-planting method				
Seeding	14.0 a (10.6, 18.3)	5.0 b (2.8, 8.9)	10.3 a (2.8, 37.5)	7.1 b (5.4, 8.7)
Outplanting	13.9 a (10.5, 18.2)	0.6 a (0.2, 2.2)	20.4 a (5.7, 72.9)	4.8 a (3.2, 6.4)
Control plot means[w]				
Common practice	0.0	1.0	545.0	1.8
Hand-weeded	4.0	8.5	40.3	6.2

Notes: A factorial analysis was completed based on 3 weed-control methods (mowing, 2,4-D, or Ortho Weed B Gon) and 2 forb-planting methods (seeding or outplanting). Aesthetic value was rated using a scale of 1 to 10 with 10 = best. Values in parentheses represent approximate 95% confidence intervals. Letter designations indicate significant differences at the 95% level of confidence.

[z] Aesthetic value was rated using a scale of 1 to 10 with 10 = best.

[y] A factorial analysis was completed based on 3 weed-control methods (mowing, or 2,4-D, or Ortho Weed B Gon) and 2 forb-planting methods (seeding or outplanting).

There was no interaction between weed-control practice and forb-planting method, both effects were significant, weed-control practice means were pooled across forb-planting method, and forb-planting method means were pooled across weed-control practice.

[x] Values in parentheses represent approximate 95% confidence intervals. Letter designations indicate significant differences at the 95% level of confidence.

[w] Control plots omitted from statistical analyses to conserve the factorial nature of the data. Common-practice control consisted of seeding a mix of grass and forbs June 2013 with no subsequent weed control. Hand-weeded control consisted of grass seeding June 2013 and forb seeding August 2013 with periodic hand-weeding.

Achieving high aesthetic value is an important goal of urban and suburban meadow plantings. Because of minimal grass and forb survival, plus high weed density, the common-practice control in this study rated very poorly for aesthetic value (Table 5; Figure 4). Each of the standard weed-control treatments and the hand-weeded control achieved similar and moderately high levels of aesthetics. We noted a distinct difference in aesthetic rating between the seeded and the outplanted plots, with seeding markedly higher. This result can be attributed to a greater number and a more uniform distribution of flowering forbs in the seeded plots.

Of the 5 grass species used in the study, 4 successfully established in the plots: Idaho fescue, big bluegrass, Indian ricegrass, and slender wheatgrass. Slender wheatgrass emerged in relatively high numbers, grew rapidly, was tall and competitive at maturity, and ultimately developed very dense stands. As a result, this single grass species became dominant in most plots. Of the 12 forb species, 5 established well, competed adequately with weeds and other meadow components, and contributed visible color to the plots: yarrow, Pacific aster, blanketflower, black-eyed Susan, and Mexican hat (Table 6). Two additional species, Lewis flax and Munro's globemallow, were present in the plots in low numbers. Purple prairie clover, James' buckwheat, and firecracker penstemon did not successfully establish in the seeded plots. These 3 species were successfully outplanted but disappeared over the 2 y of evaluation, apparently due to lack of competitiveness. As mentioned earlier, Western larkspur and Rocky Mountain penstemon seeds failed to emerge, either in the field or in the greenhouse flats, during transplant production, and these species were entirely absent from the study plots.

In an expression of early succession, by the middle of the third summer (2015), the weeds common purslane and redroot pigweed had almost completely disappeared from all plots, including the common-practice control plots. Kochia was rare, except along plot borders in plots with well-established and competitive meadow-species components. Kochia continued to dominate the common-practice control plots where meadow species were meager or nonexistent. Blue mustard remained present only where small, open spaces limited competition. In plots where meadow species were competitive, weeds as a whole were relatively sparse, and the species distribution

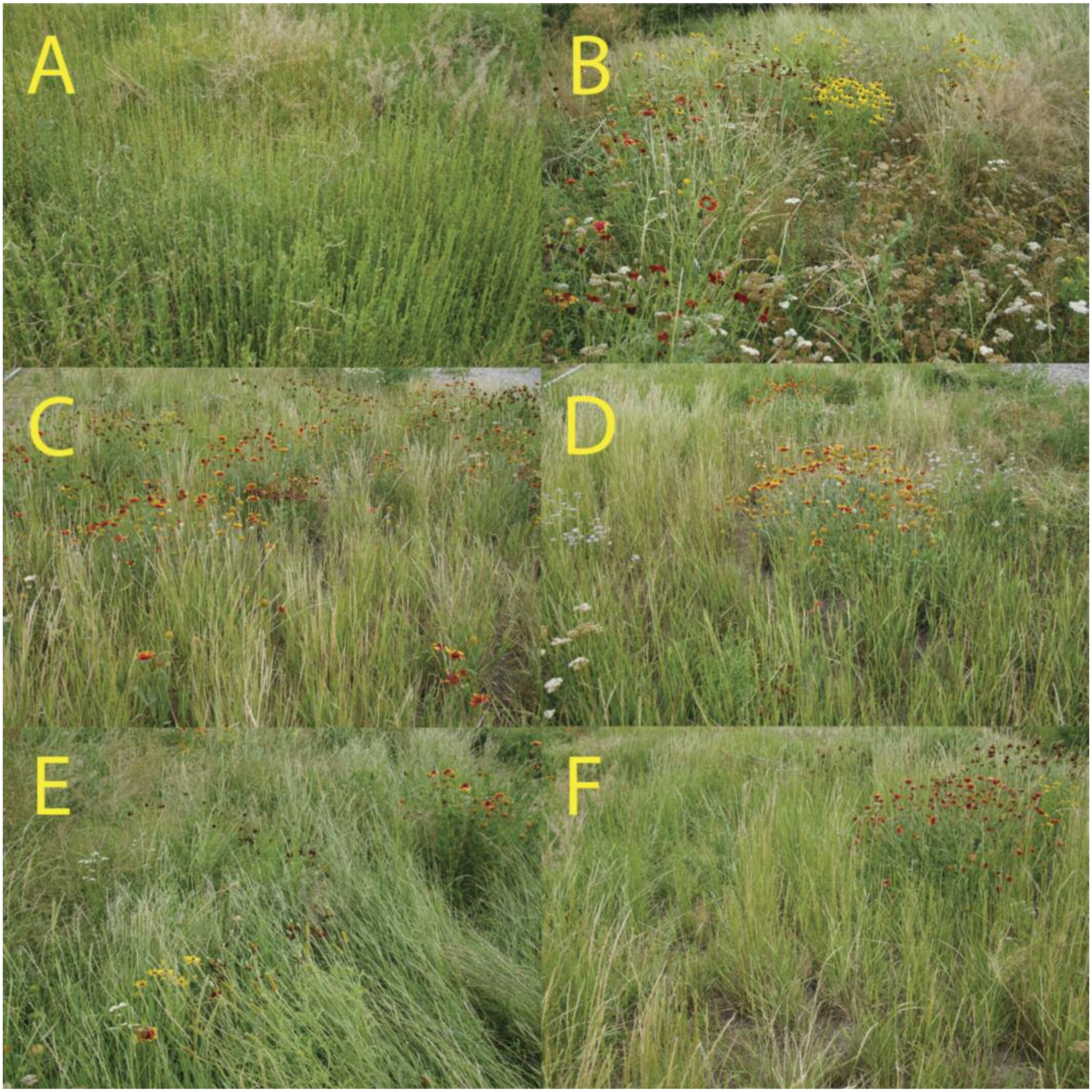

Figure 4. Appearance of meadow plots at the time of final rating on 18 July 2015. Note the high density of annual weeds and complete lack of meadow components in the common-practice control plot (A), the desirable mix of grasses and forbs in the hand-weeded control plot (B) and in the mowed/fall-seeded plot (C), the sparse but robust forbs in the mowed/fall-outplanted plot (D), the dense stand of grasses and forbs in the 2,4-D-treated/fall-seeded plot (E), and the limited number of robust forbs in the Ortho Weed B Gon/fall-outplanted plot (F).

shifted from the most aggressive early colonizers to seemingly less aggressive second-generation successional annuals, such as prickly lettuce (*Lactuca serriola* L. [Asteraceae]), flixweed (*Descurainia sophia* (L.) Webb ex Prantl [Brassicaceae]), western salsify (*Tragopogon dubius* Scop. [Asteraceae]), and tumble mustard (*Sisymbrium altissimum* L. [Brassicaceae]).

DISCUSSION

Cox and Anderson (2004) demonstrated the efficacy of assisted succession in reclaiming arid rangeland dominated by cheatgrass (*Bromus tectorum* L. [Poaceae]). They employed aggressive crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.

TABLE 6

Percentage of total plant stand made up of each of 5 grass component species and 12 forb component species during final evaluation in Oct 2015.

Common name	Scientific binomial	% of total stand	Comments
Grasses			
Idaho fescue	*Festuca idahoensis*	<1	Moderate emergence, outcompeted
Indian ricegrass	*Achnatherum hymenoides*	<1	Poor emergence, moderately competitive
Big bluegrass	*Poa secunda*	3	Moderate emergence, moderately competitive
Slender wheatgrass	*Elymus trachycaulus*	96	Excellent emergence, aggressive and dominant
Tufted hairgrass	*Deschampsia caespitosa*	0	No emergence
Forbs			
Yarrow	*Achillea millefolium*	31	Good emergence, competitive
Pacific aster	*Symphyotrichum chilense*	6	Moderate emergence, competitive
Purple prairie clover	*Dalea purpurea*	0	Poor field emergence; seedlings and outplants outcompeted
Western larkspur	*Delphinium x occidentale*	0	No emergence
James' buckwheat	*Eriogonum jamesii*	0	No field emergence; outplants outcompeted
Blanketflower	*Gaillardia aristata*	27	Good emergence, competitive
Lewis flax	*Linum lewisii*	2	Poor emergence; seedlings and outplants moderately competitive
Rocky Mountain penstemon	*Penstemon strictus*	0	No emergence
Firecracker penstemon	*Penstemon eatonii*	0	No field emergence; outplants outcompeted
Black-eyed Susan	*Rudbeckia hirta*	9	Moderate emergence, competitive
Mexican hat	*Ratibida columnifera*	24	Good emergence, competitive
Munro's globemallow	*Sphaeralcea munroana*	<1	Poor emergence, moderately competitive

Notes: Percentage for grasses and forbs were calculated separately with each category adding to 100%. Grass percentages were based on subjective estimates of stands in each plot. Forb percentages were based on actual plant counts within each plot.

[Poaceae]) to outcompete cheatgrass and reclaim a degraded site. Subsequently, niche-opening soil disturbances were created in the crested wheatgrass stand and competitive native grasses and forbs were successfully planted. Similarly, we demonstrated the efficacy of augmentative restoration, the step-wise addition of essential resources, for establishing a wildflower meadow within a site suffering from prolonged disturbance. Through addition of competitive native grasses and imposed turf-proven annual weed-control practices, the site was reclaimed. Within 3 y, an abandoned homestead site with a large seedbank of annual weeds was transformed to mimic a stable climax meadow habitat.

Application of augmented succession principles allowed for meadow establishment without elimination of the annual weed seedbank. Realistically, the seedbank in historically disturbed sites is uncontrollable due to seed abundance and dormancy-regulated longevity (Burnside and others 1996; Conn and others 2006). As an alternative to controlling competitive weeds by depleting the seedbank, our study demonstrates the efficacy of employing ecologically sound methodology to enhance succession and rapidly advance a habitat beyond its initial ruderal stages.

Inclusion of a common-practice control demonstrated the weakness of a one-step meadow establishment protocol. Over the 3 y of this study, the common-practice control plots remained as weedy patches, fixed in a static, repetitive cycle of annual weed growth. Over time, we observed some evidence of succession among weed species in the common-practice control plots, but no progression toward a stable meadow habitat because of low initial seedling survival of perennial climax species.

Key insights emerged from this study relative to functional meadow establishment. First, based on grass and forb response to weed species and densities in our study, we concluded that complete weed control is unnecessary for successful establishment of meadow species, as long as grasses and forbs were not terminally outcompeted for light, water, and other resources. Regardless of the weed-control method employed and the density of weeds at forb-planting time, meadow establishment was successful. Ultimate establishment success depended on the presence and vigor of the perennial meadow component species, especially the grass species, which is a finding that conforms to the conclusions of Blumenthal and others (2003).

Second, pre-study expectations were that outplanting would prove to be a superior establishment tool as compared to seeding. During the 2013 establishment season, outplanted forbs did appear to outperform their seedling counterparts in many respects. They expressed very high rates of initial survival, seemed to be more competitive with the grasses and weeds, often bloomed the first year, and produced seed earlier (seed that could potentially contribute to recruitment); but expectations did not bear out over the study period because recruitment did not appear to be important in the early stages of meadow establishment, nor in advancing succession during these first 3 y. Forb densities in the third summer (2015) and the related aesthetic value ratings were higher in the seeded treatments than in the outplanted treatments, which is not surprising given the much higher seeding rate and good seed establishment conditions. At higher outplant density, or under less optimal conditions for seeding, outplanting may prove to be more efficacious.

Third, application of an herbicide the spring after planting was not effective in reducing ultimate weed densities and improving subsequent meadow appearance. Initial establishment success of meadow grasses and forbs was much more important for ongoing weed control than was continued use of the applied herbicidal products.

Fourth, competitiveness and establishment success varied widely among the 17 species included in this study. Pywell and others (2003) listed the most important species performance traits in restoration communities in the UK to be broad adaptation, resistance to stresses, competitiveness (vigor, height, and so forth), high levels of seed production, and seedbank persistence. In our study, slender wheatgrass exhibited these traits, along with several forbs, including yarrow, Pacific aster, blanketflower, black-eyed Susan, and Mexican hat. All of the competitive forb species are large-statured prairie or steppe plants within the family Asteraceae.

Relative competitiveness among meadow species may be more important than absolute competitiveness of individual species. Evaluation of meadow component species is a rich area of future research that could refine meadow establishment protocols for the Intermountain West region. Potential low- to moderate-statured clump-forming grasses (Poaceae) with meadow potential, beyond those utilized in our study, include blue grama (*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths), Canada wildrye (*Elymus canadensis* L.), blue wildrye (*Elymus glaucus* Buckley), Snake River wheatgrass (*Elymus wawawaiensis* J. Carlson & Barkworth), rough fescue (*Festuca campestris* Rydb.), prairie Junegrass (*Koeleria macrantha* (Ledeb.) Schult.), alpine timothy (*Phleum alpinum* L.), bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) Á. Löve), and alkali sacaton (*Sporobolus airoides* (Torr.) Torr.). Numerous forb species have potential as meadow components, including species from the genera *Echinacea, Coreopsis, Liatris, Lupinus, Hedysarum, Machaeranthera, Symphyotrichum, Oenothera, Verbena,* and *Penstemon.*

CONCLUSIONS AND APPLICATION

We accomplished successful establishment of a wildflower meadow through the use of a grass-first, augmentative restoration protocol. The strategy employed a 3-step process: 1) spring planting of grass species; 2) reduction in weed competitiveness through mowing or application of turf-appropriate herbicides; and 3) fall overplanting of forb wildflower species into the established grasses. This approach mimicked accelerated succession under initial site conditions made up of native species absence and very high annual weed pressure.

The grass-first protocol should be a valuable tool for meadow establishment in urban and suburban sites where native plantings are desired for habitat development and beautification. The procedure was vetted under modestly controlled conditions in which water and fertilizers were applied to optimize plant establishment and to enhance nutrient cycling. Consequently, these study results are directly applicable for urban beautification where such inputs are practical. Less clear is whether a grass-first strategy will provide the same efficacy under drier, minimally managed conditions.

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