Photo by Amanda G Stanley

Regional strategies for restoring invaded prairies

Observations from a multisite, collaborative research project

| Amanda G Stanley, Thomas N Kaye, and Peter W Dunwiddie

ABSTRACT

Invasive plants, especially nonnative perennial grasses, pose one of the most critical threats to protected prairies and oak woodlands in the Pacific Northwest. Our current knowledge regarding the effectiveness of weed control methods, especially in sites that retain a significant component of native vegetation, is largely anecdotal or based on results from a few site-specific studies. The Nature Conservancy jointly with the Institute for Applied Ecology and its partners have initiated a large-scale, long-term, interdisciplinary, and collaborative project to: 1) evaluate and improve strategies for controlling the abundance of invasive nonnative herbaceous weeds while maintaining or enhancing the abundance and diversity of native plant species; and 2) develop an approach to generalize results so they can be applied by land managers engaged in prairie stewardship throughout the region. This project combines simultaneous small-scale replicated experiments with large-scale unreplicated experiments at 11 sites in Washington, Oregon, and British Columbia. Experimental treatments, begun in 2005, include combinations of spring and fall mowing, burning, a grass-specific herbicide (sethoxydim), a broad-spectrum herbicide (glyphosate), and seeding of native species. Our preliminary observations show sethoxydim applications effectively reduce exotic perennial grasses. Combining sethoxydim with other treatments had added benefits: fall burning reduced thatch and moss cover, glyphosate application 1 to 2 wk after burning reduced broadleaf weeds, and seed addition increased native diversity.

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NOMENCLATURE
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Invasive plants, especially nonnative perennial grasses, pose one of the most critical threats to protected prairies in the Willamette Valley–Puget Trough–Georgia Basin Ecoregion (WPG). The remaining prairies, often small and fragmented, are among the most endangered ecosystems in North America and support many imperiled species (Noss and others 1995; Dunn and Ewing 1997; Floberg and others 2004). Invasive species reduce native diversity and alter vegetation structure, fire regimes, soil characteristics, and faunal diversity. Our current knowledge regarding the effectiveness of techniques for controlling many herbaceous invasives, especially in sites that retain a significant component of native vegetation, is largely anecdotal or based on results from only a few site-specific studies.

It is believed that these ecosystems were historically maintained as prairies through deliberate burning by Native Americans (Habeck 1961; Johannessen and others 1971; Norton 1979; Boyd 1986; Kruckeberg 1991; Storm 2004). In the absence of this frequent disturbance, most of these habitats rapidly convert to woodlands or forests (Schultz and Crone 1998; Wilson and Partel 2003). Removal of encroaching woody species such as *Pseudotsuga menziesii* (Mirb.) Franco (Pinaceae) and *Cytisus scoparius* (L.) Link (Fabaceae) has been a primary focus of managers in many areas and has proved to be a relatively tractable problem to remedy (Sinclair and others 2006). These efforts, however, only begin the restoration process. As woody species are removed, other invasive herbaceous species that are already abundant often expand dramatically, creating a formidable challenge to restoring native communities. Perennial grasses, mostly Eurasian pasture grasses such as *Arrhenatherum elatius* (L.) P. Beauv. ex J. Presl & C. Presl (Poaceae) and *Agrostis capillaris* L. (Poaceae), are particularly damaging, as they can quickly become dominant and form dense layers of thatch that limit establishment and growth of native species.

Restoration of these invaded prairies is complicated by the overlap in plant traits (for example, phenology, life history, or tolerance to fire or grazing) between native and exotic species. It is difficult to find strategies that reduce exotic abundance without causing nontarget damage to native species (Smith and Knapp 1999; Sheley and Krueger-Mangold 2003). Many of the invasive grasses are fire tolerant, so that prescribed fire often benefits invaders as much as the native species. Grass-specific herbicides, such as sethoxydim or fluazifop, provide an opportunity to target invasive perennial grasses, but most native grasses are also susceptible. However, *Festuca idahoensis* Elmer ssp. *roemeri* (Pavlick) S. Aiken (Poaceae), one of the most common matrix species in the region, is resistant to both sethoxydim (Dunwiddie and Delvin 2006) and fluazifop (Blakeley-Smith 2006), which makes it possible to retain a dominant native grass cover when invasive grasses are targeted.

RESEARCH APPROACH

Progress toward developing successful restoration strategies has been hampered by several problems. Funding for prairie restoration has been directed primarily toward on-the-ground actions, with little devoted to developing the scientific understanding that underpins successful adaptive management. Most studies have been of relatively short duration and involve only single treatments (although see Kephart 2001). Few have employed combinations of treatments, an approach that is likely to produce more effective, synergistic outcomes, as suggested by results from studies in other systems.

To address this problem The Nature Conservancy jointly with the Institute for Applied Ecology and numerous partners began a long-term, ecoregion-wide study of restoration methods in 2005 that will continue through 2010. Our project is designed to test multiple treatment combinations developed collaboratively by scientists and land managers in a series of workshops. The goal of this collaborative project is to develop and evaluate strategies for restoring invaded prairies that can be applied effectively throughout the ecoregion.

We established identical experimental blocks at 11 sites in prairie habitats in Oregon, Washington, and British Columbia (Figure 1). The experiment includes 5 site management treatments (Table 1) in combination with 2 native seeding treatments (either no seeding or with seed mix shown in Table 2). Treatments were arranged in a split-plot design at each site, with the site management treatments in 5 m x 5 m (16.4 ft x 16.4 ft) whole plots and the seeding treatments in two 2.5 m x 5 m (8.2 ft x 16.4 ft) subplots within each whole plot. Each site management treatment was replicated 4 times, yielding 20 whole plots and 40 subplots at each site. The site management treatments (Table 1) include combinations of sethoxydim, a grass-specific herbicide (2% solution with surfactant), to reduce dominant exotic grasses; spring or fall mowing to reduce thatch, seed production, and stored reserves of exotic grasses; burning, to reduce thatch and moss and prepare seedbeds for germination; and postburn application of glyphosate, a broad-spectrum herbicide (1.5% solution, 2 to 4 wk postburn) to reduce broadleaf weeds that typically resprout

Figure 1. Map of study sites in the Willamette Valley–Puget Trough–Georgia Basin (WPG) Ecoregion. From north to south: Cowichan Garry Oak Preserve, The Nature Conservancy of Canada; AuSable Institute; Triangle Prairie (13th Division) and South Weir Prairie, Fort Lewis Military Reservation, US Army; Morgan Property (Tenalquot Prairie), The Nature Conservancy; Mima Mounds Preserve, Washington Dept. of Natural Resources; Glacial Heritage Preserve, Thurston County Parks/The Nature Conservancy; Scatter Creek Wildlife Area, Washington Dept. of Fish and Wildlife; Fort Hoskins, Benton County Parks Dept; Bellfountain and Pigeon Butte, Finley Wildlife Refuge, US Fish and Wildlife.

TABLE 1

Treatment combinations developed at a collaborative workshop February 2005. Sethoxydim is an herbicide that targets all Poaceae; however, the native grass Festuca idahoensis *ssp.* roemeri *is resistant. Glyphosate is a broad-spectrum herbicide and was applied 2 to 3 wk after burning. Native seeds were added to one half of each plot for all treatment combinations, including controls.*

Treatment code	**2005**		**2006**		**2007**	
	Spring	**Fall**	**Spring**	**Fall**	**Spring**	**Fall**
SBG	sethoxydim		sethoxydim	burn+ glyphosate	sethoxydim	
MBG	mow			burn+ glyphosate		
MM	mow	mow	mow	mow	mow	mow
SM	sethoxydim	mow	sethoxydim	mow	sethoxydim	mow
Control			NO TREATMENT			

quickly after fire. The postburn treatment was developed based on managers' observations that invasive species often resprout more quickly after fire than most native species. Native seeds were broadcast and lightly raked into the subplots in fall 2006 after the other fall treatments.

Native seeds were collected on-site, collected from nearby sites, or purchased from local growers. Seven species that were widespread throughout the ecoregion were chosen to sow at each site, with 2 congeneric substitutions made based on locally abundant species (Table 2). The plants were chosen to represent a range of growth forms and life histories typically found in these prairies, including 2 perennial grasses (*Festuca* and *Danthonia*), an annual forb (*Plectritis*), 2 perennial composites (*Achillea* and *Eriophyllum*), a tap-rooted perennial (*Lomatium*), and a fibrous-rooted perennial (*Ranunculus*) (see Table 2 for complete names). Although we tried to standardize the quantities of seeds sown at all sites, some variations occurred as the desired amounts could not be obtained in certain areas due to difficulties with seed collection (see Table 2 for seed sowing rates).

At each site we measured the percentage cover of all vascular plant species, as well as litter, moss, and bare soil, in four 1 m x 1 m (3.3 ft x 3.3 ft) sampling quadrats per plot (2 in the seeded and 2 in the non-seeded subplots). Percentage cover was assessed visually to the nearest 1% in each sampling quadrat before spring treatments.

TABLE 2

Amount of native seeds (g[z]) added to each subplot (2.5 m x 5 m). Native seeds were obtained from local growers or hand collected from local sources.

Species	Number of sites seeded	Amount seeded
Achillea millefolium L. (Asteraceae)	10	0.36
Danthonia californica Bol. (Poaceae)	8	4.9–8.7[y]
Danthonia spicata (L.) P. Beauv ex Roem. & Schult. (Poaceae)	2	6.8
Eriophyllum lanatum (Pursh) Forbes (Asteraceae)	10	0.47–0.8[y]
Festuca idahoensis Elmer ssp. *roemeri* (Pavlick) S. Aiken (Poaceae)	10	2.93
Lomatium nudicaule (Pursh) J.M. Coult. & Rose (Apiaceae)	1	16.1
Lomatium utriculatum (Nutt. ex Torr. & A. Gray) J.M. Coult. & Rose (Apiaceae)	9	1.83
Plectritis congesta (Lindl.) DC. (Valerianaceae)	10	0.5
Ranunculus occidentalis Nutt. (Ranunculaceae)	10	2.1–2.75[y]

[z] Conversion: grams x 0.003 = ounces.
[y] Some sites received less than the target amount due to constraints on seed availability.

OBSERVATIONS

Although the study still has several years to run, the results after 2 y of treatments show some promising trends. The treatment combination of sethoxydim, burning, postburn glyphosate (SBG), and native seeding showed a decrease in weedy grasses and forbs and an increase in native diversity and abundance at most of our sites (Figure 2).

Sethoxydim proved very effective at reducing exotic grasses at all sites (Figure 3), while not causing an overall decline in native graminoids (grasses and grasslike plants) (Figure 3, Table 3). While susceptible natives such as *Danthonia* spp. (Table 3) declined, native *Festuca*, *Carex* spp., and *Luzula* remained stable. At 2 sites, Scatter and Triangle, native graminoid cover declined from 2006 to 2007, attributable to a drop in cover of *Festuca idahoensis* ssp. *roemeri*. This decline is likely attributable, however, to the burning or postburn glyphosate rather than sethoxydim, as these species initially increased in 2006 (after 1 y of sethoxydim treatment) and only declined after treatments in fall 2006. Other studies showed short-term declines in *F. idahoensis* ssp. *roemeri* following fire (Dunwiddie 2002).

Many sites saw an increase in weedy forbs following 1 y of sethoxydim treatment (Figure 3). The postburn glyphosate treatment in fall 2006 was very effective at reducing weedy forbs (Figure 3), even those that are often problematic after fire such as *Hypochaeris radicata* L. (Asteraceae). At

Glacial Heritage Preserve, cover of *H. radicata* declined from 19% to < 1%. Other problem weeds such as *Leucanthemum vulgare* Lam. (Asteraceae) had similar declines. Overall, native forbs increased, perhaps due to release from competition with invasive species. This increase was most notable at sites like Pigeon and Cowichan that had a high initial cover of native forbs. The postburn glyphosate spray did not appear to damage most native forbs probably because of their delayed emergence after fire and spot-spraying at the 2 sites (Cowichan and Triangle) with highest native diversity.

At several sites, however, particularly our 3 sites in the Willamette Valley (Figure 1), we found an explosion of exotic annuals after the burn treatment (Figure 3). The postburn glyphosate treatment did not damage weedy annuals, as these species germinated in winter or spring, long after the glyphosate treatment. All sites with this problem had a high initial diversity of weedy species, and 5 to 10% cover of exotic annuals at the start of the study.

Native seed addition increased diversity of native plants at all sites, in both the control and SBG treatments. By seeding just 7 common native species, some of which were already present at our study sites, we increased species richness on average by 3.4 ± 0.42 species per plot. While there was no influence of the SBG treatment on the number of species established, we did see some effects of the treatment on the abundance of seeded species. The burn increased percentage cover of bare soil, which appeared to aid germination and growth of seeded species. *Plectritis congesta* (Figure 4), which was not found at any of our research sites prior to seeding, had a higher cover (1.13% ± 0.4) than in controls (0.24% ± 0.07). We also noted that *P. congesta* plants found in control plots were smaller and had fewer flowers than in the SBG treatment.

Figure 2. Control (top) versus SBG + seeding in 2007 at the Triangle Prairie site (Fort Lewis Military Base, US Army). Control plots had a thick layer of thatch formed by exotic grasses (at this site, particularly *Poa pratensis* L. [Poaceae]); some native species can be seen struggling through the thatch, including *Cerastium arvense* L. (Caryophyllaceae). In the SBG treated and seeded subplots, the exotic grasses and thatch are gone. Native species, such as *Festuca idahoensis* ssp. *roemeri*, *Lomatium triternatum* (Pursh) J.M. Coult. & Rose (Apiaceae), *Camassia quamash* (Pursh) Greene (Liliaceae, *Ranunculus occidentalis* Nutt. (Ranunculaceae), and the seeded annual *Plectritis congesta* are doing well. Photos by Amanda G Stanley

DISCUSSION

The combination of grass-specific herbicide, fire, broad-spectrum herbicide, and seeding with natives appears to be very successful at many of our sites, at least in the short term. Sethoxydim was very effective at reducing the abundance of the dominant exotic grasses, which released other species from competition. Sethoxydim alone was not sufficient for restoration as exotic forbs as well as native species increased in the second year of the study at many sites (Figure 3). The burning and postburn glyphosate application worked well for reducing weedy forbs, preventing this group from becoming the next dominant cohort. Germination and establishment of sown seeds were successful across treatments, and *Plectritis congesta* in particular did very well in the

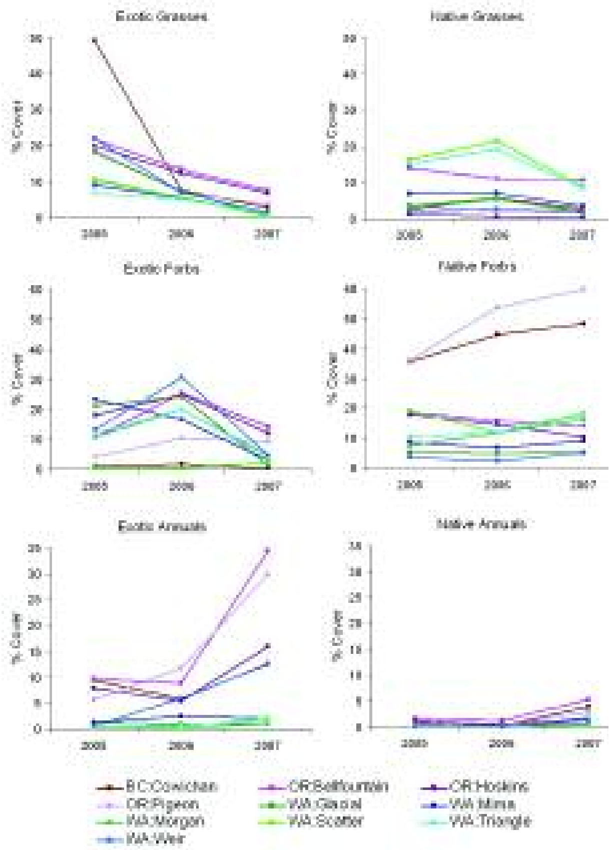

Figure 3. Average percentage cover of different functional groups in the SBG treatment at each site. Standard error bars left off for clarity.

grass-specific herbicide, fire, broad-spectrum herbicide, and seeding with natives treatment. We expect that native species will continue to establish and spread now that they have been released from competition by most exotic grasses and forbs.

Plectritis congesta is an important nectar species for many rare butterflies, but it is not commonly found in prairie remnants. Its overwhelmingly positive response to burning suggests that the lack of regular disturbance and competition from perennial vegetation may explain why native annuals seem to be disappearing from prairie remnants (Dunwiddie and others 2006). Our observations suggest disturbance combined with seeding can bring native annual species back to prairies in the ecoregion.

This observation is, sadly, confirmed by the expansion of nonnative annuals at several sites following burning. We hypothesize that native annuals may have largely disappeared from prairie sites during the last 150 y in the absence of burning. Since then, various invasive nonnative annuals have moved into these sites and are poised to expand into these unoccupied niches when suitable conditions occur, such as following a burn. At similar sites, extra steps may need to be taken not only to reduce the abundance of nonnative annuals but also to reintroduce native annuals that may have been extirpated, such as *Plectritis congesta*. Where a regular burning regime has been reintroduced into these prairies, we have observed a balance between annuals and perennials that shifts over time, with annuals particularly prominent for 2 to 3 y following burning but declining dramatically as the perennials expand (Dunwiddie 2002).

Although most restoration studies are conducted at single sites for a limited duration, we are fortunate to be able to examine outcomes of prairie restoration techniques over the long term and throughout an ecoregion. Our study also greatly benefits from close partnerships between scientists and land managers. The participating managers have a wealth of experience, providing key insights into how research can best inform restoration practice, treatment combinations with the best chance of success, and valuable local knowledge. Managers rarely have the time or resources, however, to devote to replicated experiments or continued monitoring. By working in partnership, we hope to provide well-tested management recommendations and insight into ecological restoration of prairies and woodlands throughout the ecoregion.

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TABLE 3

Direction of change in percentage cover of major native and exotic grass species from 2005 to 2007 for the SBG treatment.

Species	Family	Nativity	Direction of change
Anthoxanthum odoratum L.	Poaceae	Exotic	decline
Arrhenatherum elatius (L.) P. Beauv. ex J. Presl & C. Presl	Poaceae	Exotic	decline
Bromus carinatus Hook. & Arn.	Poaceae	Native	decline
Carex inops L.H. Bailey, *C. tumulicola* Mack.	Cyperaceae	Native	neutral/positive
Danthonia californica, D. spicata	Poaceae	Native	decline
Elymus glaucus Buckley	Poaceae	Native	decline
Festuca idahoensis ssp. *roemeri*	Poaceae	Native	neutral
Holcus lanatus L.	Poaceae	Exotic	decline
Luzula campestris (L.) DC.	Juncaceae	Native	neutral/decline
Poa pratensis L.	Poaceae	Exotic	decline

Annette Rosewich collected seeds for the Cowichan Preserve. We also thank Deborah Clark, Mark Wilson, Jock Beall, Al Kitzman, Rod Gilbert, Eric Delvin, Carri Marschner, Birdie Davenport, Dave Hays, David Wilderman, Lynda Boyer, Tim Ennis, Irvin Banman, Andrew MacDougall, Robert Pelant, and the broader group of collaborators who have provided input and assistance on many stages of this project.

PROJECT INFORMATION

More information on the project can be found at URL: http://www.appliedeco.org/conservation-research/prairie-restoration-research.

Figure 4. Plectritis congesta in an SBG plot at Mima Mounds Preserve. Photo by Amanda G Stanley

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