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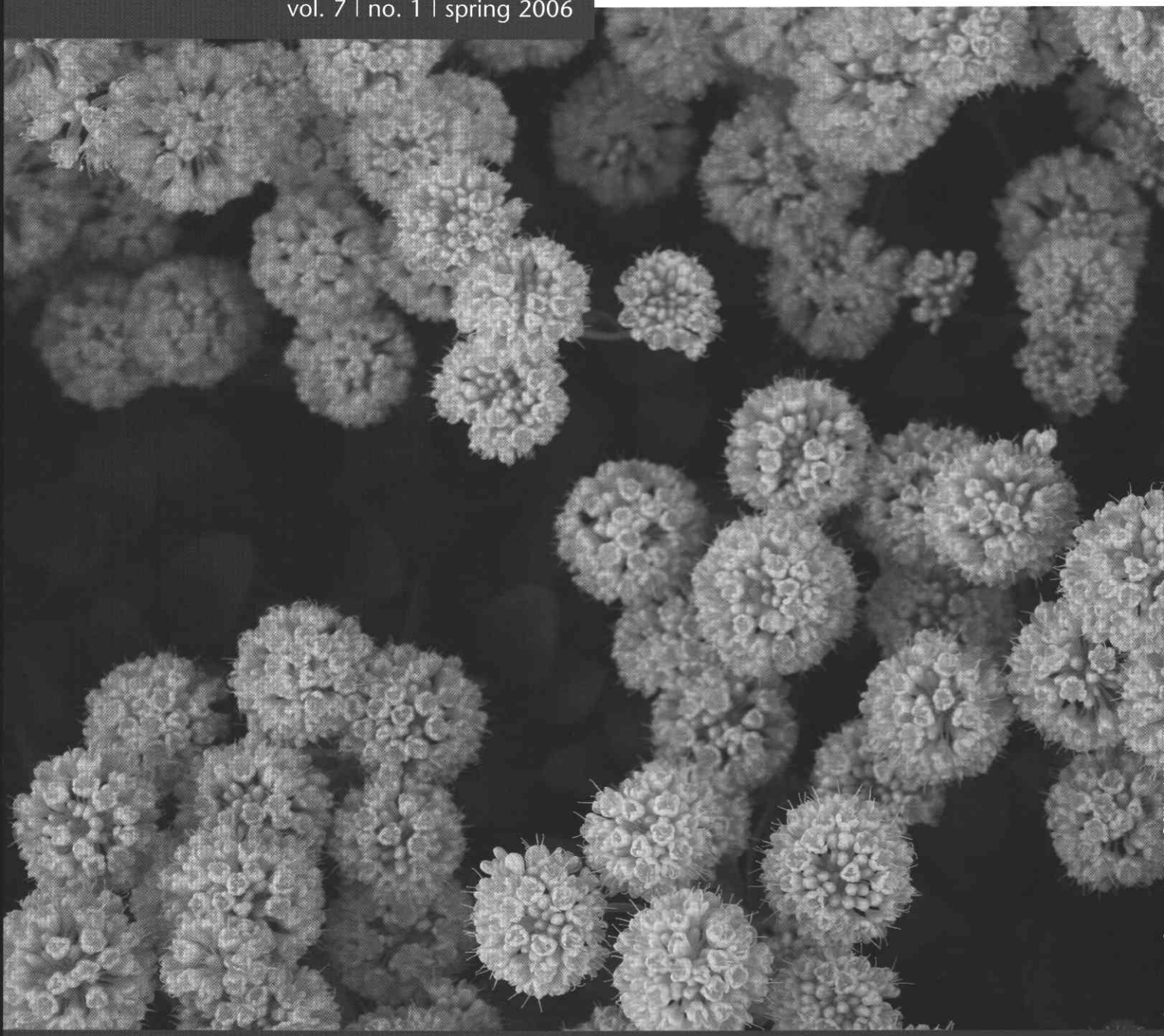

in this issue PACIFIC NORTHWEST NATIVE PLANT CONFERENCE

Photo by Nan Vance

Native grass seeding and forb planting establishment

in a degraded oak savanna plant community in the Coast Range foothills of western Oregon

| Nan Vance, Andrew Neill, and Frank Morton

ABSTRACT

After a dense stand of conifers encroaching on an oak savanna/meadow was removed, exotic forbs and grasses quickly populated the newly disturbed area. Establishing desirable native grasses and forbs that contribute to native plant diversity and compete with exotic species could aid in restoring this oak savanna plant community. Two experiments were conducted over time to test different native plant establishment approaches for increasing native plant diversity and abundance. The first evaluated effect of sown native grass species establishment on graminoid cover and composition. The second evaluated 3 outplanted native perennial forb species to determine their survival. Concurrent with the experimental work, we compared change in the plant community, including species richness and forb and graminoid cover. Graminoid cover changed over time, was significantly higher in sown than unsown plots, and significantly decreased cover of outplanted native forbs but not their survival. Species survival was high the first year after outplanting but declined in subsequent years; nevertheless, outplanted forbs produced flowers and fruits by the third year. Species richness and abundance increased, and composition of native and exotic forbs and grasses changed over the years, influencing establishment of native species. Efforts to improve native plant diversity and abundance within a dense population of native and exotic species may require varied and repeated treatments, as well as more time to assess plant interactions.

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KEY WORDS

restoration, oak savanna, exotic weeds, native grass seed, native forb propagules, *Bromus carinatus, Bromus sitchensis, Danthonia californica, Deschampsia caespitosa, Elymus glaucus, Eriophyllum lanatum, Hordeum brachyantherum, Potentilla gracilis, Sidalcea malviflora* ssp. *virgata*

NOMENCLATURE

USDA NRCS (2002)

Until the early nineteenth century, prairie and open grasslands in the Willamette Valley and adjacent uplands of western Oregon were perpetuated through fires set by local tribes (Thilenius 1968; Boyd 1986). These prairies formed a mosaic of fragmented landscapes with mixed hardwood and coniferous forests that included open woodland and oak savanna. Euro-American settlement converted much of these lands to agriculture so that by the late twentieth century the open prairies and oak savannas had all but disappeared (Johannessen and others 1971; Boyd 1986). In addition, without the repeated fires set by indigenous people, coniferous forests dominated by Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco [Pinaceae]) have encroached on much of the remaining upland oak savannas (Riegel and others 1992).

Fort Hoskins Historic Park, located 16 km (10 mi) west of Corvallis, is managed by the Benton County Department of Natural Areas and Parks. It is situated in the foothills of the central Willamette Valley–Coast Range interface on the uplands of the Luckiamute River. The park is the site of a fort initially established in 1850 to oversee resettlement of western Oregon tribes on the newly established Coastal Indian Reservation. Open meadows and vistas were maintained to accommodate the fort's activities and to provide its strategic location with an unencumbered view of the river valley. The Fort Hoskins property was sold in the mid-nineteenth century and became privately owned farmland. Some upland areas were used as pasture until the 1990s when they were abandoned to the encroachment of coniferous forest (Ferguson and Miller 2000).

A major goal of Benton County staff has been to return the park, as much as possible, to presettlement forest conditions. Their objectives include preserving and perpetuating the native Oregon white oak (*Quercus garryana* Dougl. ex Hook. [Fagaceae]), restoring open savanna, and enhancing prairie plant communities that once dominated the Willamette Valley and adjacent uplands (Wilson 2001). To restore the native plant community structure that originally characterized the oak savanna complex, a stand of 40- to 50-y-old *P. menziesii* trees, encroaching on an adjacent open meadow, was logged in late 2000 to improve and enlarge the oak savanna and release suppressed *Q. garryana*.

A plant inventory of the Fort Hoskins property in 2000 found that less than 50% of the herbaceous species in the savanna are native (Salix Associates 2000) because of past logging and pasturing of livestock (Salix Associates 2000; Wilson 2001). Efforts to restore savanna/prairies have become more difficult because of the increasing abundance of unwanted species in the valleys and foothills of Oregon (Maret and Wilson 2005). Use of heavy equipment to remove coniferous trees to enlarge savanna results in highly increased light levels in the openings and creation of large areas of bare mineral soil. Such disturbances provide a favorable environment for invasion and spread of opportunistic exotic species (Forcella and Harvey 1983; Maret and Wilson 2005).

Part of the oak restoration strategy is to increase diversity of native grasses and forbs that grow in association with Oregon white oak/upland prairie communities as characterized by Thilenius (1968) and Wilson (1998). Establishing underrepresented native species could enhance the community of native grasses and forbs that have declined in diversity and abundance. A number of approaches commonly used in restoration efforts could be employed to achieve that goal, including different kinds of interseeding, interplanting, shrub or tree removal, and burning or mowing treatments applied singly or in combination (Jacobson and others 1994; Packard and Ross 1997; Abella and others 2001; Brown and Bugg 2001; Maret and Wilson 2005). Clark and Wilson (2000) concluded that sowing seeds in an unmanaged Willamette Valley prairie may be an option, but sowing rates should be high.

The lack of information about the historic plant species composition specific to this upland site and the performance of native grasses and forbs under these conditions increase the challenge of reintroducing native species. In addition, little is known about the optimum number of seeds to sow of each grass species at any particular site, given differences in soil quality, amount and type of vegetative competition, level of disturbance, and other factors that influence the fate of seed once sown (Clark and Wilson 2003). Recently Maret and Wilson (2005) evaluated how different treatments affect seedling establishment in different prairie locations, and noted that establishment may be limited by undesired exotic species that are often stimulated by disturbance. By increasing propagule density in highly disturbed areas, native forbs and graminoids may be able to establish sufficient cover to reduce invasion of exotic species (Tilman 1997; Brown and Bugg 2001); however, establishing native plant species, particularly long-lived perennials, in an area where exotic weeds are established remains problematic.

In order to address the problem, our primary objective was to evaluate establishment of underrepresented native forb and grass species in a disturbance-driven plant community of a degraded oak savanna. We performed 2 experiments introduced one year apart. The first evaluated whether establishment of native grass species from broadcast sown seeds would influence graminoid cover over time. The second evaluated survival of 3 native perennial forb species reared in a nursery and outplanted by comparing survival among species between grass sown and unsown plots over time. We also characterized the changing species composition and cover of the plant community on the plots where the experiments took place.

SITE DESCRIPTION

The study site is located on the Fort Hoskins property (44° 40'40"N, 123°27'36"W) in an upland oak savanna/meadow populated by scattered *Q. garryana* and bordered by encroach-

TABLE 1

Study site at Fort Hoskins showing the range in parameters: slope, aspect, mean soil temperatures from sensors on site (n = 21), mean monthly temperatures and precipitation from climate data taken at Agrimet station, Oregon Climate Service, Corvallis, Oregon.

	Slope (%)	Aspect	Air temperature (°C)		Soil temperature (°C)		Precipitation (cm)	
Low	13	238°WSW	2.2	Jan 2004	3.6	Jan 2004	0.08	Jul 2004
High	22	294°WNW	29.0	Jul 2004	26.8	Jul 2004	29.20	Dec 2003

ing *P. menziesii*. The approximately 4-ha (11-ac) site is on a moderately steep (12% to 25%), west-facing slope, between 200 to 245 m (700 to 800 ft) in elevation on the southeast part of the 57-ha (140-ac) property (Table 1). The climate is representative of OCS Zone 2 (Oregon Climate Service 2004) that includes the Willamette Valley from the Coast Range summit eastward to the foothills of the Cascades with maximum mean temperatures that range from about 30 °C (84 °F) in summer to about 2 °C (35 °F) in winter. The precipitation, primarily in the form of rain, is highest during winter and lowest in July and August (Table 1). The soil is a deep, well-drained, silty clay loam, and rated as productive to very productive moderate Site II, with an effective rooting depth of 51 to 102 cm (20 to 40 in) (Ferguson and Miller 2000). Salix Associates (2000) described the plant communities mapped in the meadow/oak savanna classification (Ferguson and Miller 2000) as a weedy meadow/oak savanna with introduced pasture grasses, scattered *P. menziesii* and *Q. garryana*, and widely scattered hawthorn (*Crataegus* L. spp. [Rosaceae]) and hazelnut (*Corylus cornuta* Marsh. [Betulaceae]), with velvet grass (*Holcus lanatus* L. [Poaceae]), bracken fern (*Pteridium aquilinum* (L.) Kuhn [Dennstaedtiaceae]), trailing blackberry (*Rubus ursinus* Cham. Schlecht. [Rosaceae]), sheep sorrel (*Rumex acetosella* L. [Polygonaceae]), and Kentucky blue grass (*Poa pratensis* L. [Poaceae]) dominant.

METHODS AND MATERIALS

Plot Installation and Site Preparation

In late summer 2000 we installed 14 circular, 3 m (9.8 ft) radius plots (28.3 m^2 [301.7 ft^2]) with an additional 0.6-m (2-ft) buffer forming an outer ring in a wooded area scheduled for mechanical tree removal to increase the size of remnant savanna by removing coniferous trees suppressing *Q. garryana*. The plots, permanently located with GPS, were equally spatially distributed across an approximately 0.8-ha (2-ac) area. For plot relocation following tree removal, numbered metal tags were nailed to the base of large trees, and azimuth and distance from plot center to plot center of all 14 plots in sequence were measured and recorded. In November, a month after tree and slash removal, plots were prepared for grass seeding by removing residual debris and raking tractor-made ruts smooth.

Relative light or canopy openness was measured at each plot before and after tree removal with a LAI-2000 Plant Canopy Analyzer (LI-COR 1990) 1 m (3.3 ft) above ground at 5 points, one at plot center and one at each of 4 cardinal directions 3 m (9.8 ft) from plot center. The measure of relative light or diffuse non-interceptance (DIFN) is derived from the ratio of diffuse light measured on the plot to diffuse light in a nearby area receiving full light.

Grass Seeding

In November 2000, a seed mixture of 5 native grass (Poaceae) species was hand sown in 7 randomly selected plots. The 5 species included blue wild rye (*Elymus glaucus* Bukl.), meadow barley (*Hordeum brachyantherum* Nevski), California brome (*Bromus carinatus* Hook. & Arn.), tufted hairgrass (*Deschampsia caespitosa* (L.) Beauv.), and California oatgrass (*Danthonia californica* Boland.). Seeds were purchased from Pacific Northwest Natives, Albany, Oregon, and donated by the Corvallis, Oregon, Plant Materials Center, USDA Natural Resources Conservation Service. All seeds with the exception of *B. carinatus* were Willamette Valley sources (Table 2).

These species were chosen based on their putative ability to competitively occupy and persist on the site, and collectively represent a range of conditions. *Elymus glaucus*, a tall (culms, 60 to 150 cm [24 to 59 in]) fast growing, self-pollinating, competitive grass, is an early colonizer broadly adapted to a range of light and moisture conditions and favored by disturbance (Johnson 1999). *Hordeum brachyantherum* (culms, 20 to 70 cm [8 to 28 in]), a short-lived, early establishing perennial found in meadows and grassy slopes, is least drought tolerant of the 5 species (Chase 1971). *Bromus carinatus*, an erect annual or biennial (culms, 50 to 100 cm [20 to 39 in]), is highly variable in size and shape of panicle, grows in a range of conditions, and is competitive with forbs and grasses (Chase 1971). (Securing a local seed source of this species is essential; we purchased a low-to-mid Cascade Range seed source of this species in error.) *Deschampsia caespitosa*, a long-lived, densely tufted, and tall (culms, 60 to 120 cm [24 to 47 in]) perennial grass, prefers open, moist meadows, can quickly establish in disturbed areas (Walsh 1995), and was chosen because it was found in other upland locations at Fort Hoskins. *Danthonia californica*, a long-lived perennial bunchgrass (culms, 30 to 100

TABLE 2

Native perennial grass species from Pacific Northwest Natives (PNWN) and USDA Natural Resources Conservation Service, Corvallis, Oregon, Plant Materials Center, seed source and characteristics, calculated application rate, and amount of seed used for 7 hand-seeded, 3-m radius plots in fall 2000.

Name	Oregon source	Purity (%)	TZ (%)	Application rate (kg/ha)	Application rate (lb/ac)	Mixed application rate [z] (kg/ha)	Mixed application rate [z] (lb/ac)	Total used (g)	Total used (lb)
Elymus glaucus	PNWN Mid-Willamette, riverbottom	99.3	95	13.45	12.0	3.59	3.2	95.25	0.21
Danthonia californica	NRCS Baskett Slough, Polk County	NA	79	16.81	15.0	5.38	4.8	158.76	0.35
Bromus carinatus	PNWN Willamette National Forest, mid-zone	99.5	91	16.81	15.0	4.59	4.1	127.01	0.28
Deschampsia caespitosa	NRCS Willamette Valley, Corvallis	NA	56	1.68	1.5	0.56	0.5	18.14	0.04
Hordeum brachyantherum	PNWN Lane County, Eugene	79.7	86	22.42	20.0	8.29	7.4	222.26	0.49

[z] Mixed Application Rate = (Application Rate * Mix Fraction) / (Purity * TZ)

cm [12 to 39 in]) that grows in meadows and open woods, is moderately drought tolerant, variable in its emergence, and may take more than one year to emerge (Chase 1971; Darris 2000).

The seed mixture was formulated based on a combination of factors including seed size, purity, and viability using an application rate for 0.028 ha (0.07 ac) (Table 2). Three parts vermiculite and one part perlite (v:v) were added for ease and uniformity of sowing and to enhance visibility of the sown mix. The seed mixture was broadcast evenly over the plot by hand and very lightly covered with pure straw of *E. glaucus*. The unseeded control plots received no straw covering.

Forb Planting

Propagules of 3 long-lived native perennial forb species common to native plant communities of the Willamette Valley savanna/prairie (Wilson 1998; York 2003) were obtained from Shoulder to Shoulder Farm, Philomath, Oregon. Dry seeds of common woolly sunflower (*Eriophyllum lanatum* (Pursh) Forbes [Asteraceae]) and slender cinquefoil (*Potentilla gracilis* Dougl. ex Hook. [Rosaceae]) were collected in July and August 2000 from wild plants growing in a native prairie on the farm property and cold stored until November. Then, seeds were sown into plug flats (2.5 cm x 5.1 cm [1.0 in x 2.0 in]) containing a 5:4:1 (v:v:v) medium of oak-leaf mold, aged compost, and native top soil, respectively, from the collection area. Flats were kept in an unheated greenhouse until germination in January and February. Plants were not fertilized but were irrigated daily until August. Then irrigation frequency was decreased to simulate natural climate patterns in the Willamette Valley. About 2 wk before outplanting, plants were transplanted to a slightly larger container and irrigated daily to encourage active root growth at time of outplanting.

Because an insufficient number of rose checker-mallow (*Sidalcea malviflora* (DC.) Gray ex Benth. ssp. *virgata* (T.J. Howell) C.L. Hitchc. [Malvaceae]) seedlings was available, we obtained propagules approximately the same size as seedlings of the other 2 species from rooted rhizomes (ramets) of individual plants growing on the farm. In early autumn 2001, mature *S. malviflora* plants were selectively covered with thick oak-leaf mulch, which provided non-soil medium and encouraged rhizomatous growth. By November, frequent rain resulted in the rhizomes rooting and leafing. About 10 to 15 of these propagules, each ranging from 5 to 10 cm (2 to 25 in) in length, were collected from each of about 20 clones. Propagules of each clone were well mixed before outplanting so that each clone would be represented on each plot.

In 2001, one year after the grass seeding, the forbs were outplanted into the plots in a split, split (repeated-measures) plot

design to test grass seeding treatment effect on differences in survival among species over time. Forb outplantings consisted of 16 individuals of each species randomly planted in a grid with equal spacing within each plot (48 forbs/plot).

Because of the presence of Roosevelt elk (*Cervus canadensis roosevelti* [Merrian] Cervidae) and blacktail deer (*Odocoileus hemionus columbianus* [Richardson] Cervidae), we covered outplanted forbs with Vexar® plastic mesh tubes approximately 40 cm (16 in) high and 10 cm (4 in) in diameter supported by a 64-cm (25-in) bamboo stake. We also outplanted excess seedlings near the plot without mesh covering to determine if herbivory by ungulates or other large animals would occur. Based on little evidence of browsing on exposed plants, mesh covers were removed in spring 2002 to avoid interference with plant growth.

Field Measurements

From 2001 through 2004, on each plot we used ocular estimates of vegetative cover by life form in increments of 1% through 5%, then 5% increments to 100%, to determine relative forb and graminoid cover. In 2002 and 2004 only, we estimated the relative cover of dominant graminoid and forb species on each plot. Beginning in 2002, we counted culms for each sown native grass species because an insufficient number had produced culms or flowering stems for a census in 2001. From 2002 through 2004, in late June or early July when grass species developed culms and flowered, density of mature grass in each plot was estimated from a census of all culms of the 5 sown species with one caveat. We also counted culms of Alaska brome (*Bromus sitchensis* Trin. [Poaceae]) even though this species was not sown because it is an important native perennial grass of the oak savanna. Although we continued attempting to count *B. carinatus* culms, it appears the seeds did not germinate and was excluded from analyses. For the forb establishment study, from 2002 through 2004 during flowering of the 3 forb species in late May or early June, we counted surviving individuals and recorded their ontogeny with respect to bolting, flowering, and fruiting. In 2002 we measured stem length (if a plant had multiple stems, the longest stem was selected), and in 2004 we revisited the plots specifically to record fruit production.

In August 2000, before tree removal, and each year from 2001 through 2004, we inventoried the species found on each plot to determine species richness and noted if the species was native or exotic according to the USDA Natural Resources Conservation Service National PLANTS Database (USDA 2002). To characterize the competitive environment into which the native species were being established, we examined forb and graminoid diversity using the reciprocal of Simpson's *D*, a nonparametric index of diversity derived from species occurrence (once in a single plot) and frequency (number of plots in which species occurred) comprising 396.2 m^2 (4224.0 ft^2) total area for 14 plots (Simpson 1949; Barbour and others 1998).

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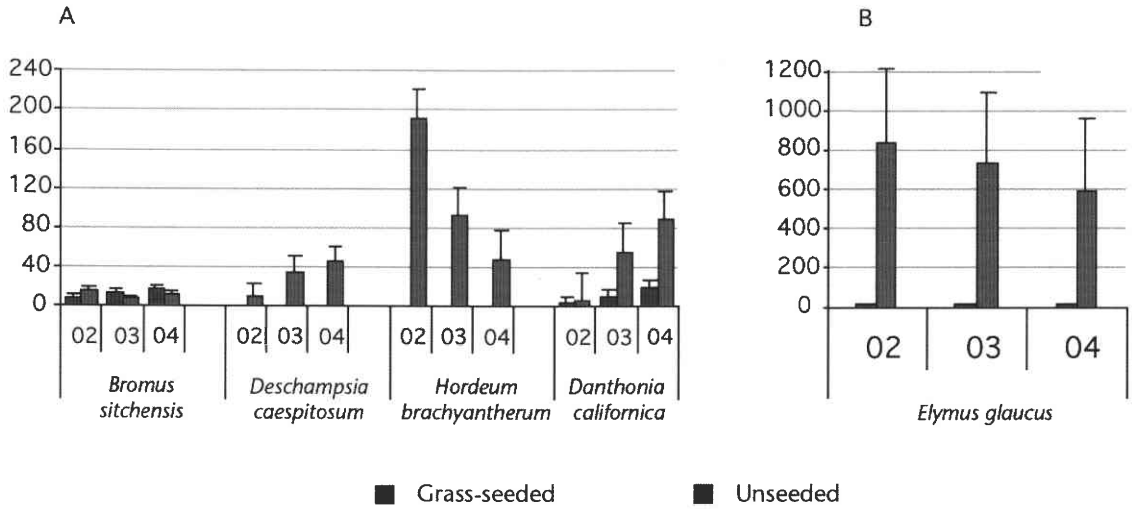

Figure 1. Mean stem density of grasses on seeded (S) and unseeded (U) plots in November 2000. (A) *Bromus sitchensis* (BRSI) which self-seeded, *Hordeum brachyantherum* (HOBR), *Danthonia californica* (DACA), *Deschampsia caespitosum* (DECA); (B) *Elymus glaucus* (ELGL). Grass density was calculated by counting culms each year when grasses were flowering from 2002 through 2004. Vertical bars are 1 SE, N =14.

Data Analysis

The grass seeding experiment, using a repeated-measures completely randomized design, analyzed treatment effect on culm density and graminoid and forb cover separately in a model in which the main effect was the grass seeding treatment and included repeated measures analysis for a temporal effect and interaction. The lack of homoscedasticity among species and number of null values precluded statistical analysis of differences among species. The forb outplanting experiment employed a repeated-measures split plot design and was analyzed for grass seeding effect on native forb survival and among forb species, species response to time, and species by treatment and time interactions. Data were analyzed using SAS (1999) and Statgraphics Plus, statistical software package version 5.1 (Manugistics 2000). Survival differences between forb species were compared with Tukey HSD at $\alpha = 0.05$. Relations between plant performance and relative light levels (mean DIFN) were characterized by regression analysis.

RESULTS AND DISCUSSION

As was expected, the mean culm density (culms/plot) of sown species was significantly higher in the sown (909) than in the unsown plots (21) ($P < 0.0001$). Mean culm density was not significantly different over time ($P = 0.439$). Although we were able to identify each native grass species in the sowing experiment, this data was not part of the experimental design and did not lend itself to analysis. However, based on a census of culm counts of each species each year from 2002 to 2004, we found species differed in rate of establishment and density or abundance of individuals in the plots. In 2002, the mean culm density in unsown plots was 10.4 and on the sown plots, 1044, and in 2004, was 32 and 773 on unsown and sown plots, respectively. The decrease in mean culm density on sown plots was attributable primarily to the decrease in *E. glaucus* and *H. brachyantherum*; however, from 2002 to 2004 the mean density of *D. californica* and *D. caespitosa* culms increased (Figure 1A). Of sown species, *E. glaucus* had the highest density in all years, almost an order of magnitude higher than any of the other species (Figure 1B). Culm density of *E. glaucus* varied widely among plots, however, ranging from 29 to 1866 stems per plot in 2004. In sown plots where *E. glaucus* culm density was high (> 1000 culms/plot) it was the dominant grass species with cover > 30%; however, in plots where *E. glaucus* stem density was relatively low (< 100), exotic grasses *H. lanatus* and *Cynosurus echinatus* L. (Poaceae) were dominant.

Mean culm density of *H. brachyantherum* on sown plots in 2002 was 190, ranging from 39 to 385 culms/plot, but in 2004 was 47, ranging from 15 to 102 culms/plot. Conversely, mean culm density of *D. caespitosa* and *D. californica* between 2002 and 2004 increased from 9 to 45 and 6 to 88, respectively (Figure 1A). *Danthonia californica* and *D. caespitosa* produce seeds that may require cold temperatures and may be relatively slower to germinate than seeds of grass species such as *Bromus* species that rapidly germinate and quickly establish (Walsh 1995). By 2004, *D. californica* was present on 4 unsown plots at a low density ranging from 0 to 69 culms/plot increasing its distribution among the 14 plots (Table 5). Because *D. californica* and *E. glaucus* are scattered across the oak savanna/meadow, they may be seeding in from natural sources also. *Bromus carinatus* did not establish in the plots. This species may have the phenotypic variability and

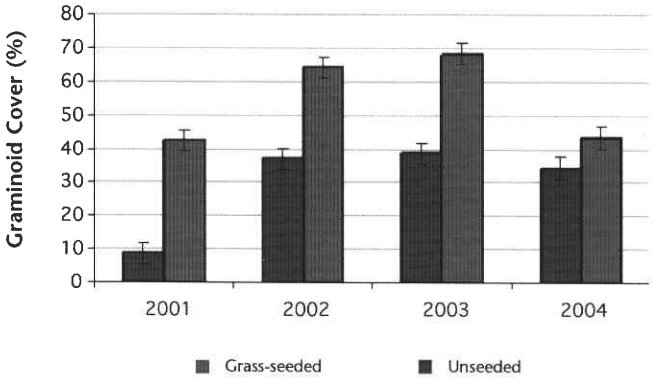

Figure 2. Relative graminoid cover on grass-seeded and unseeded plots from 2001 through 2004. Vertical bars are 1 SE (± 3.19), N = 14.

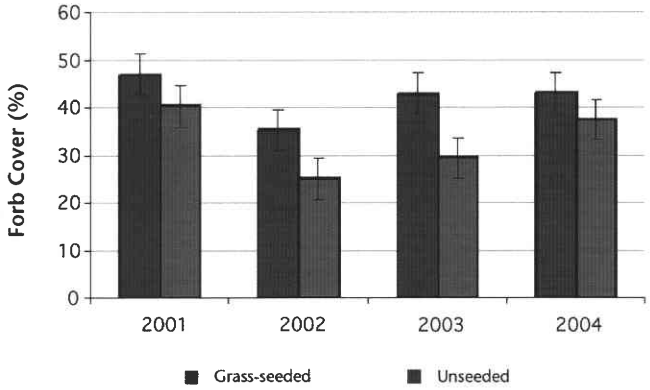

Figure 3. Relative forb cover on grass-seeded and unseeded plots from 2001 through 2004. Vertical bars are 1 SE (± 4.23), N = 14.

ecotypic differentiation that were found in *E. glaucus* (Erickson and others 2004). Therefore, the higher elevation and inland seed source may have been the cause of seed germination failure (Edminster 2004). Future seed procurements must verify seed source and use seed from local sources, unless research demonstrates otherwise.

In 2002, *B. sitchensis* rather than *B. carinatus* was identified in the plots. *Bromus sitchensis* is a tall, stout (culms, 120 to 180 cm [47.2 to 70.9 in]) perennial grass that grows on moist to dry slopes in meadows or woods west of the Cascades (Chase 1971). This species is scattered throughout the property and seeded naturally into the plots. Although not part of the treatment, it provided opportunity to monitor unaided establishment of a native grass species. Culm density in plots was low, ranging from 1 to 29 culms/plot in 2004, but frequency of plot occurrence was high (Figure 1A, Table 5).

Graminoid cover was significantly different between the sown and unsown plots ($P < 0.01$) and linear response over time was also significantly different ($P < 0.01$). Graminoid cover increased between 2001 and 2002 following removal of overstory trees (Figure 2). The increase was greater, however, in sown plots, as mean cover was higher (65%) than in unsown (38%) plots. Mean graminoid cover changed little from 2002 to 2003 on sown and unsown plots; however, from 2003 to 2004, mean cover decreased more on sown than unsown plots (65% to 44% as compared with 38% to 34%, respectively). Thus, in 2004, 4 y after seeding, graminoid cover was similar in sown and unsown plots (Figure 2).

Cover and density are related measures of abundance. Native grass density was significantly higher on sown than unsown plots suggesting that increase in graminoid cover is related to the additional density of sown native grasses. Because of the inferred relation of sown grass density to graminoid cover, we questioned whether the decrease in graminoid cover on sown plots in 2004 was due to decrease in sown grass, exotic grass species, or both. In 2002, 4 of the 7 sown plots were dominated by exotic grass *H. lanatus* and in 2004 by *H. lanatus* or *C. echinatus*, and the other 3 plots, by the sown native grass *E. glaucus*. The 3 plots in which *E. glaucus* was dominant were also plots with highest culm density. Between 2002 and 2004, cover of the dominant exotic grasses decreased 40%, whereas cover of *E. glaucus* decreased 7%, suggesting that decrease in graminoid cover may also be attributable to decrease in exotic grass cover. Notable is that *E. glaucus* retained dominance on 3 of 7 plots over the 3-y period. Reasons for the 2004 decrease in cover and dominance of *H. lanatus*, which was dominant in 11 plots in 2002 and dominant in 6 plots in 2004, are not understood although decline in cover of the dominant *H. lanatus* corresponding with an increase in other species has been reported elsewhere (Bakker and others 1980).

Mean forb cover was significantly lower on the grass sown than unsown plots ($P < 0.01$) but no significant difference was noted in their linear response to time ($\alpha = 0.05$) (Figure 3). In 2002 and 2003, when mean graminoid cover was highest (64% and 68%, respectively) on sown plots, mean forb cover was lowest (25% and 29%, respectively), and in 2004, when mean graminoid cover decreased to 44%, mean forb cover increased to 38% suggesting a negative relation between forbs and graminoids in competition for space.

In 2002, the first growing season following forb outplanting, the overall survival of the 3 forb species was high. Mean relative survival was 89% but declined to 76% in 2003 and 63% in 2004 (Figure 5). The difference in survival among the 3 species was significant as well as the negative linear response of survival over time ($P < 0.01$). Although difference in survival of outplanted forbs between the sown and unsown plots was not significant ($\alpha = 0.05$), mean survival of each of the 3 forb species was higher in sown than in unsown plots over all 3 y. Unsown plots were dominated by exotic grasses *H. lanatus*, *C. echinatus*, and orchard grass (*Dactylis glomerata* L. [Poaceae]), all associated with loss of species diversity (Remison and Snay-

Photo by Nan Vance

Figure 4. Eriophyllum lanatum competing with bull thistle *(Cirsium vulgare).*

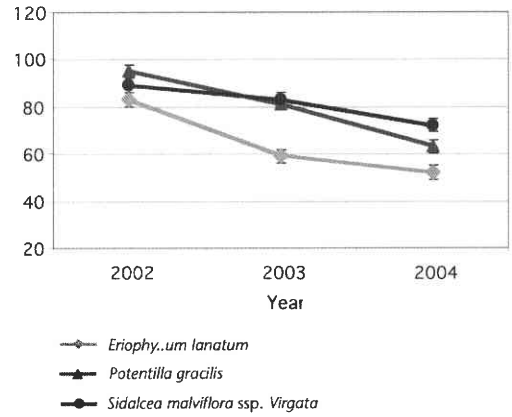

Figure 5. Relative survival of 3 perennial forb species, *Eriophyllum lanatum, Potentilla gracilis,* and *Sidalcea malviflora* ssp. *virgata* over time. Mean survival from 2002 to 2004 calculated for 16 individuals of each species per plot planted in 2001. Vertical bars are 1 SE (± 2.875), N = 14.

don 1980; Riegel and others 1992). Sown plots had higher graminoid cover and a higher abundance of native grasses than unsown plots, which may have negatively influenced total forb cover in 2002 and 2003; however, sown plots did not appear to negatively influence outplanting survival of forbs. These results agree with Brown and Bugg (2001) who found that planted forbs were not adversely affected by established perennial grasses although seeded forbs were (Figure 4).

In 2003, the mean relative survival of the 3 species declined but at different rates among species (Figure 5). From 2002 through 2004, the linear survival response of *E. lanatum* and *P. gracilis* to time was significantly different than that of *S. malviflora* ($P \leq 0.01$); however, the quadratic response to time was significantly different between *E. lanatum* and *S. malviflora* ($P \leq 0.05$) but not between *P. gracilis* and *S. malviflora* (Figure 5).

The lower survival of *E. lanatum* may be explained in part by its morphological adaptation to dry and open habitats (Ross and Chambers 1988; Pojar and others 1994) suggesting it may be less shade tolerant than *S. malviflora.* In April, following overstory removal, mean DIFN increased from 0.02 to 0.60 on all plots combined and ranged from approximately 0.25 to 0.85. Differences among plots in mean DIFN appeared to be related to proximity to plots of released oak trees. Because plots varied in light, we analyzed survival of the 3 planted forb species in relation to light indexed by DIFN. Survival rate of *E. lanatum* in 2004 was linearly related to DIFN (adjusted $R^2 = 0.50$, $P = 0.002$), whereas *P. gracilis* and *S. malviflora* did not exhibit this positive relation. Removing overstory increased light on plots, but linear regression analysis of relative light (DIFN) on mean stem lengths of forbs measured in 2002 resulted in a negative relation that was significant for all 3 species ($P \leq 0.01$). The adjusted R^2 for *E. lanatum, P. gracilis,* and *S. malviflora* was 0.66, 0.53, and 0.63, respectively. Although longer stem length may indicate a larger plant, stem elongation negatively related to light suggests a morphologic response of a heliophytic plant adapting to increasing shade (Daubenmire 1974). Nevertheless, Clark and Wilson (2000) reported that *P. gracilis* seedling establishment rate was not improved by fire or mowing on an upland prairie in the Willamette Valley, and in fact, exhibited a positive relation to litter and spring vegetation.

After the first year on site, only 5 of 672 outplanted individuals flowered, 4 of which were *E. lanatum.* In 2003, *E. lanatum* and *S. malviflora* reached flowering stage but rate of flowering was low for all species (6%). In 2004, average flowering rate of *E. lanatum* and *S. malviflora* increased to 30% and 42%, respectively (Table 3). Although mean flowering rate of *P. gracilis* also increased, it continued to be relatively low (5%) but rate of fruit development was high (Table 3).

We observed more insect-damaged seed heads, herbivory of inflorescences, and aborted flowers on *S. malviflora* than on either *P. gracilis* or *E. lanatum.* Insect predation of fruits and seeds of *Sidalcea* species in Oregon is not uncommon (Gisler and Meinke 1997; Marshall and Ganders 2001). Poor seed yield was one reason we vegetatively propagated *S. malviflora.* Whether individual propagules originate from rhizomes or seeds, 2 full growing seasons after outplanting elapsed before any of the 3 species flowered. Intense competition of forbs and grasses may have limited resources and impeded growth, vigor, and reproduction. Nevertheless, among survivors, the trend in reproduction is positive.

Overstory removal changed species richness and abundance (Figure 6). Among the 14 plots established before *P. menziesii* trees were logged, mean vegetative cover (herbaceous and shrub layer in the understory) was 28% (data not shown) and the total number of species present (species richness) on all 14 plots was 38. The year following overstory removal species richness more than doubled; by 2004, mean cover per plot was

TABLE 3

Relative survival, flowering, and fruit/seed head production in 2004 of native forb species, Eriophyllum lanatum, Potentilla gracilis, *and* Sidalcea malviflora *ssp.* virgata; *16 individuals were planted in each plot in 2001. Shown are the mean number of survivors and relative survival (%), mean number of flowering plants and percentage of plants that flowered, mean number of flowers, mean number of fruit/seed heads, and percentage of flowers that produced fruit/seed heads (N = 14).*

	Surviving plants		Flowering plants		Flowers	Seed heads	
	number	(%)	number	(%)	number	number	(%)
Eriophyllum lanatum	8.4	52	2.9	30	19.6	8.4	34
Potentilla gracilis	10.1	63	0.6	5	14.3	12.9	82
Sidalcea malviflora	11.8	74	5.2	42	56.6	13.1	31

83% and species richness was 109. In 2000, more than 90% of the species were native but by 2002, native species constituted less than 50% of total species richness. By 2004, the proportion of native species increased to 59% of the total due to an increase in native species as well as decrease in exotic species (Figure 6) indicating successional processes in this changing exotic–native grass-forb community.

The greatest contribution to species richness and diversity are forbs and graminoids. Species varied in constancy but dominant exotic species tended to be most constant as well. Simpson's *D* of native forbs and graminoids calculated in 2000 from species richness data was 3.6 times greater in 2004, whereas, *D* partitioned for exotic graminoids and forbs was about 12.7 times greater in 2004 (Table 4). Exotic and native forbs and graminoids found with frequency ≥ 79% changed in constancy on the 14 plots over the years (Table 5). The new appearance of exotic species with high plot frequency the year after overstory removal (2001) indicates that, even in a limited area of disturbance, aggressive exotic species quickly invade and colonize new openings when high levels of light become available (Wozniak 2001). Invasive species also appear to spread readily in a deep-soiled site that can support a diverse and robust herbaceous plant community. Nonnative species with high constancy beginning in 2001 included *Cirsium vulgare* ((Savi) Ten. [Asteraceae]), *R. acetosella, C. echinatus,* and *H. lanatus* (Table 5). Nonnative forbs, such as the introduced annual garden vetch (*Vicia sativa* L. [Fabaceae]) and the biennial *C. vulgare,* quickly established across the study site as constancy increased to 13 in 2002 and remained high (Table 5). A greater variety of forb than graminoid species was dominant on the plots. Dominance also changed among forb species between 2002 and 2004. Bull thistle *C. vulgare* and *R. acetosella*, exotic forbs that were frequently dominant in 2002 were no longer dominant on plots in 2004; instead 2 widely distributed exotic *Vicia* species were dominant on almost half the plots in 2004. Bedstraw (*Galium aparine* L. [Rubiaceae]) and small nemophila (*Nemophila parviflora* Dougl. ex Benth [Hydrophyllaceae]) were the only dominant native species on any of the plots (one plot each) in 2004 (Table 5).

TABLE 4

Change in diversity of the native (n) and exotic (e) forbs (FB) and graminoids (GR) between 2000 and 2004 using Simpson's diversity index D. Eveness of distribution (E) is weighted by frequency of plots (14) in which species is present.

	D ($1/\Sigma pi^2$)		E ($1/\Sigma pi^2 \cdot 1/S$)	
	2000	2004	2000	2004
FB&GR	8.570	54.054	0.4761	0.6032
FB_e&GR_e	2.286	29.097	0.1270	0.3464
FB_n&GR_n	6.987	25.252	0.3882	0.2940

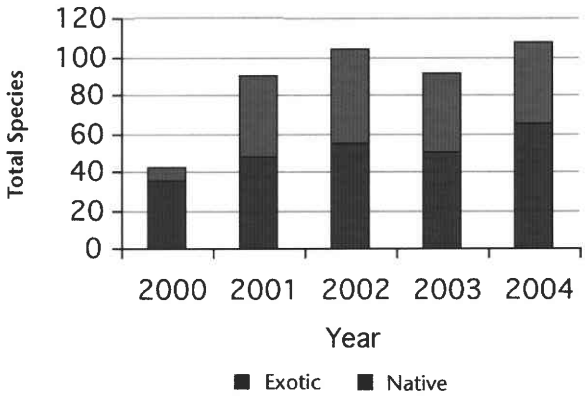

Figure 6. Change in total species richness from 2000 through 2004 on 14 plots representing an area 396.2 m^2 (4224 ft^2). Data partitioned by origin; native, exotic.

TABLE 5

Forb and grass species that occurred in ≥ 11 plots (N = 14) including year 2000 before the coniferous tree removal and the 4 y following.

	2000	2001	2002	2003	2004
Native					
FERNS					
	Polystichum munitum	*Pteridium aquilinum*	*Pteridium aquilinum*	*Pteridium aquilinum*	*Pteridium aquilinum*
FORBS					
	Osmorhiza chilensis	*Cardamine oligosperma* *Claytonia sibirica* *Epilobium ciliatum* *Galium aparine* *Nemophila parviflora* *Osmorhiza chilensis* *Vicia americana*	*Fragaria* spp.	*Fragaria* spp. *Galium aparine* *Osmorhiza chilensis*	*Fragaria* spp. *Galium aparine* *Nemophila parviflora*
GRAMINOIDS		*Bromus sitchensis* *Elymus glaucus*	*Bromus sitchensis* *Elymus glaucus* *Luzula comosa*	*Bromus sitchensis* *Elymus glaucus* *Luzula comosa*	*Bromus sitchensis* *Danthonia californica* *Elymus glaucus* *Poa pratensis* *Luzula comosa*
Exotic					
FORBS		*Cirsium vulgare* *Erechtites minima* *Rumex acetosella* *Senecio sylvaticus* *Senecio vulgaris*	*Cerastium viscosum* *Cirsium vulgare* *Crepis capillaris* *Dactylis glomerata* *Daucus carota* *Digitalis purpurea* *Erechtites minima* *Geranium dissectum* *Hypericum perforatum* *Leucanthemum vulgare* *Myosotis discolor* *Rumex acetosella* *Sherardia arvensis* *Torilis arvensis* *Vicia sativa*	*Cirsium vulgare* *Digitalis purpurea* *Hypericum perforatum* *Leucanthemum vulgare* *Rumex acetosella* *Vicia sativa*	*Cirsium vulgare* *Digitalis purpurea* *Geranium dissectum* *Leucanthemum vulgare* *Rumex acetosella* *Vicia hirsuta* *Vicia sativa*
GRAMINOIDS					
		Cynosurus echinatus *Holcus lanatus* *Hypochaeris radicata*	*Cynosurus echinatus* *Holcus lanatus* *Hypochaeris radicata*	*Cynosurus echinatus* *Holcus lanatus* *Hypochaeris radicata*	*Cynosurus echinatus* *Holcus lanatus* *Hypochaeris radicata*

CONCLUSIONS

The Fort Hoskins site, with deep soil and plentiful moisture, despite a history of disturbance, readily grows a variety of plant species. Those that can successfully establish from propagules available on-site have an advantage. Although mechanical tree removal disturbed the soil, species abundance increased rapidly with exotic grass and forb species a major contributor. Nevertheless, individuals of most species we attempted to establish have survived to reach full maturity. Each native grass species differed in its germination, maturity, and establishment rate. Despite high frequency and abundance of exotic grasses, a native grass became the dominant species on 3 sown plots. Two other sown native perennial grass species were also increasingly populating plots as the competitive dynamics of the site changed over time. Native forb species were outplanted, increasing diversity in plots. Although survival of outplanted native forbs declined over 3 y, survivors have developed fruits or set seeds. Graminoid cover increased on sown plots corresponding with reduced forb cover for 2 y of the study. However, in 2004, sowing effect on graminoid cover was no longer significant suggesting that over time abundance of forbs and grasses may acquire a new equilibrium. Nevertheless, at the species or plot level, cover and composition had changed and native plant diversity as of 2004 appeared to have increased.

Characterizing change in plant composition and cover over several years provided context for interpreting results of this study, yet more time is needed to judge long-term effects of manipulating plant community structure by seeding and planting (Grime and Hillier 2000). Four years after our studies were initiated may be too soon to predict whether outplanting forbs and seeding grasses without additional treatments can meet the objectives of increasing native species diversity in this oak savanna restoration site, but our results suggest that active employment of techniques to establish native grasses and forbs should be considered.

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