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PRACTICE INSIGHTS

UN Decade on Ecosystem Restoration

Upland prairie adaptive management staged-scale restoration practices for native plant and endangered butterfly reintroduction

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Abstract

1. The present practice insight derives from land manager requests to document current on-site activity and provides a management planning reference for restoration on Violet Prairie. Start-up restoration initiates from trial-and-error adaptive management practices in the Puget Sound region of western Washington, USA. Treatments used focus on the implementation of staged-scale restoration. Preparation intends to meet reintroduction goals of establishing a native plant community that could potentially support the threatened endemic *Castilleja levisecta* (golden paintbrush). Reintroduction of the associated native plant community provides habitat for endangered *Euphydryas editha taylori* (Taylor's checkerspot butterfly).
2. Known conventional agricultural use coupled to fire suppression since the 1800s altered regional prairie lands to an unfavourable state for native plant species. Local native prairie soil types were favoured for growing conventional grasses and exotic forb species common to grazing pastures. Land abandonment and degradation has lengthened the time of disturbance and complicated restoring to a generalized reference point prior to settlement. Persistent exotic species, encroaching housing development, coniferous forest and recent wildfire complicate converting back to native prairie.
3. Threatened and endangered species and their habitat are targeted in a trial-and-error process of staged-scale adaptive management within the goal of whole ecosystem and connectivity restoration. Land managers focus on exotics removal and intensive native reseeding while restoring the use of prescribed burning as a maintenance tool. Embedded monitoring and observation advises where future practices need to be adapted by focusing on treatments and outcomes.
4. Past land use practices replaced native soil seed banks with exotic seed banks that further distort reference proxies. Unknowns interrupt the current implementation additionally to soil conversion issues, while short-term adaptive management methods initiate conversion back to native prairie. Species reintroduction

choices to develop community structure are complicated by the fact that historical reference point species may be missing altogether from existing native communities. An unanswered outcome of the restoration process is determining which set of treatments best prepares soil for the desired native plant community.

KEYWORDS
adaptive management, endangered species, exotic plants, land conversion, native plants, prescribed burn, soil seed bank, staged-scale

1 | INTRODUCTION: SITE CHARACTERISTICS

Violet Prairie is part of the 104-acre (42 ha) Violet Prairie-Scatter Creek Preserve located in Thurston County South Puget Sound Prairie lands in western Washington, USA (46°49′53.7″N, 122°57′47.7″W; see Figure 1). The site was previously used for conventional agriculture since the 1800s and is today an important restoration subject of land use for habitat connectivity. It is deemed ecologically similar to nearby (11 miles/17.7 km distance) extant Rocky Prairie (46°55′12.19″N, 122°51′32.41″W), the only mainland population with high-quality habitat and low exotic species occurrence (Dunwiddie & Martin, 2016). Rocky Prairie is an important natural study and reference site because it supports a genetically diverse native plant population containing both *Castilleja levisecta* (the golden paintbrush, currently federally listed in the United States as a threatened species) and *Castilleja hispida* (the harsh paintbrush; Lawrence & Kaye, 2011), both used as a host plant by endangered *Euphydryas editha taylori* (Taylor's Checkerspot butterfly; Haan et al., 2018).

The main goal on Violet Prairie is to convert the land out of its former agricultural state, restore and maintain a once connected native oak prairie ecosystem for the purpose of native species reintroduction (Freed, 2017). Fragmentation and historical widespread agricultural use confuse local plant species genetic diversity (Lawrence & Kaye, 2011), deters pollinators (Fleckenstein, 2014), impedes survival of native butterfly species (Haan et al., 2018) and blocks native plant species establishment (Dunwiddie et al., 2014) while invading non-native European (and also African and Asian originating) plant species overtake the land (Chappell & Crawford, 1997; see Figure 2). No native plant species were present at the beginning of

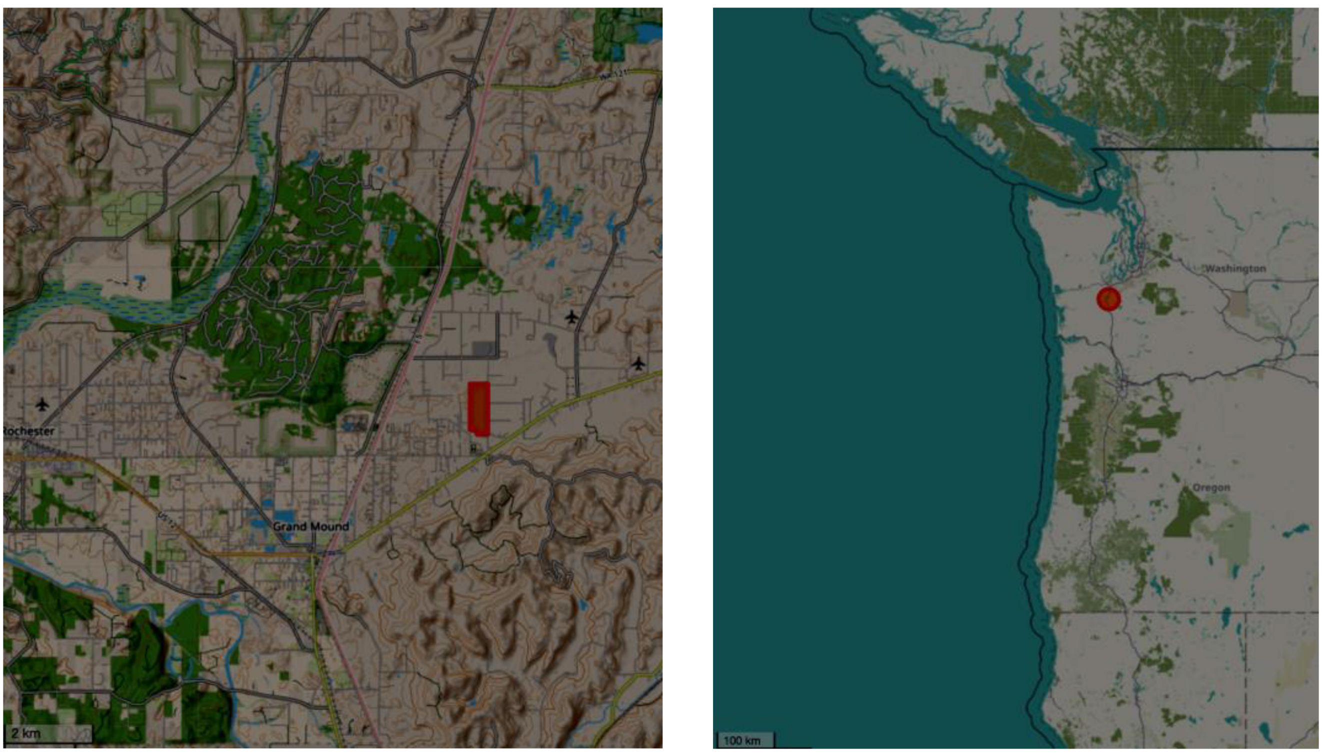

FIGURE 1 Left (a): Violet Prairie restoration (red outlined 104-acres) area situated within surrounding degraded and partially developed lands. Right (b): Local Prairie lands area referred to in this review indicated by the red circle and situated in western Washington along the west coast of the United States. The full 104 acres of Violet Prairie (map (a) left) is located within local prairie lands (red circle, map (b) right).

the restoration effort onset (Dunwiddie et al., 2014) while an undetermined number of exotic forb species survive in the below-ground seed bank (Hamman et al., 2015). Weedy species dominate the site and include *Hedera helix* (English ivy), *Rubus bifrons* (Himalayan blackberry) and *Arctium minus* Bernh. (burdock).

The climate in earlier spring months may be slightly warmer and sunnier than usual. May can be hot while local climate becomes cloudy and cools again in June, then by July through August drought has taken over the flow of precipitation that was typical in humid winter months. From 1895 to 2020, the regional mean precipitation was 188.72 mm in winter and 20.88 mm in summer, and the mean temperatures were 3.23°C in winter and 17.59°C in summer (NOAA, 2021).

Violet Prairie's dominant soil is the dry gravelly somewhat excessively quick draining Nisqually-Spanaway soil type (USDA, 2018), a typical soil for local native plant forbs (Lawrence & Kaye, 2008) found on regional outwash plains and terrace landforms. General details of the three main soil profiles found specifically on Violet Prairie are shown in Table 1.

2 | STAGED-SCALE ADAPTIVE MANAGEMENT

Untreated acreage sits in a disturbed state (see Figure 3) occupied by dominant exotic grasses (see Table 2 for commonly found species) and is hayed to remove nutrients and plant material. Restoration begins with single two-acre increments. Treatments are adapted in smaller stages (Bakker et al., 2018) throughout the site, then applied to additional sets of acres, two to four at a time, up to a full 10 acres, with additional treatment areas added in 10-acre (4.04 hectare) blocks (Freed, 2017). Over each 1-year period, approximately 10 acres are converted in the initial nutrient removal process (Freed, 2017) by adding smaller acreage into larger acreage in a process termed scaling (Bakker et al., 2018). Within the staged-scale process, stages can include direct practices such as addressing issues of hybridization and indirect practices such as managing unknown treatment outcomes. In general, treatments involve mowing, prescribed burning, seeding and (post-fire and spot) herbicide spraying (Schultz et al., 2011).

FIGURE 2 An untreated patch of the Oak Savannah grassland ecosystem at Violet Prairie-Scatter Creek Preserve with *Arrhenatherum* species (oatgrass) dominant in the foreground. Photo credit: author.

TABLE 1 Violet Prairie Nisqually-Spanaway soil type profile.

Soil type	Soil profile depth (cm)	Slope (%)	Elevation (m)	Parent material	Water storage (mm)
Spanaway (100%)	H1 gravelly sandy loam 0–38.1 H2 very gravelly sandy loam 38.1–50.8 H3 extremely gravelly sandy loam 50.8–152.4	0 to 3 and 3 to 15	100.58 to 399.28	Volcanic ash over gravelly outwash	~96.52
Spanaway-Nisqually complex (60% Spanaway, 30% Nisqually)	H1 0–38.1 gravelly sandy loam H2 very gravelly sandy loam 38.1–50.8 H3 50.8–152.4 extremely gravelly sandy loam	2 to 10	100.58 to 249.93	Volcanic ash over gravelly outwash	~96.52
Nisqually (85% Nisqually)	H1 loamy fine sand 0–12.7 H2 loamy fine sand 12.7–78.74 H3 loamy sand 78.74	3 to 15	48.76 to 399.28	Sandy glacial outwash	~124.46

Data source: USDA (2018) map unit descriptions reports.

In the start-up stage, prescribed burns are a first step priority to prepare the site (Freed, 2017) by removing undesirable non-native grasses. Before settlement (see Table 3 for land use overview) Native American tribes used fire intervals to abate forest encroachment as a select management tool targeting prairie ecosystems (Dunwiddie et al., 2014). Occasional fires sustained native plants such as *Rubus specticalis* (salmonberry), *Perideridia gairdneri* (wild carrot), *Lomatium triternatum* (wild celery parsnip), *Lilium columbianum* (tiger lily) and *Fragaria virginiana* (wild strawberry; Storm & Shebitz, 2006). Prescribed burning intervals can prolong the time of early successional stages while preventing shrub growth (Ellsworth et al., 2020). Fire is now reintroduced and used on a 1- to 5-year interval to prevent coniferous forest encroachment and to increase native species yield (Krock et al., 2016). Tribes managed burns by setting small and large backing, head and wider landscape fires on swaths of prairie in carefully timed intervals to manage vegetation seasonally (Storm & Shebitz, 2006). Presently, fire treatments are applied during late summer and early autumn (Stanley et al., 2011). Managers adaptively determine the appropriate timing of prescribed fire tools and whether the fire used is a backing fire (i.e. a fuel-propelled higher intensity (localized) fire with a long residence time, low spread rate and shorter flames), a head fire (e.g. rapid spread among tops of grasses that quickly shape a larger landscape area) or a combination of fire prescriptions (Martin & Hamman, 2016).

The method of fire, the type of burn, the duration and intensity of the burn, and its frequency will dictate the type of plant community. Native forbs may be associated with 'head' fires while 'backing' fires may favour both exotic and native forb resurgence. Depending on the site history and fire severity, the type of fire can alter composition by decreasing the occurrence of a particular species (Martin & Hamman, 2016). For example, excessive burns inflict both damage and recurrence of native prairie plant species by producing a slower rate of recurring early successional native forbs and annual grasses (Tveten, 1998) while reducing perennials. Species whose seeds tolerate fire intervals against those that do not may require head fires that can reduce exotics and burn at a higher intensity (Martin & Hamman, 2016). Bulb, tuber and corm species are preserved while the same fire can break seed dormancy for species that may have laid seeds in a previous season (Krock et al., 2016). Therefore, planning scheduled fire return intervals annually takes preparation to assist establishment of natives adjusted to fire regimes (Tveten, 1998). To control plant survival, head fires are typically used as these heat the top layer surface soil by 1–3 cm and help preserve dormant species (Martin & Hamman, 2016) just beneath the surface.

Fire can increase the occurrence of native plant species through nutrient cycling to build soil integrity and further the goal of ecological resilience (Dunwiddie & Martin, 2016) when properly managed. The height/depth of vegetation (native and exotic) can be knee high at the time of burning, with burns to remove exotics and burns to promote seed germination and maintenance (Martin & Hamman, 2016). In the short term, burning can alter soil cations by volatizing N, P and S and directly after a burn, improve nutrient content depending on soil type, horizons and existing organic matter, but not necessarily alter pH

FIGURE 3 Grassland prairie edge showing embedded former agricultural lands, development, coniferous forest in the background, a dirt road in the foreground, and new electricity. Photo credit: author.

(DeBano, 1991). In the long term, the burning process (Dunwiddie & Martin, 2016) helps to build organic soil material by adding biomass as compost to the A horizon surface soil layer (Chappell & Caplow, 2004) creating an additional centimetre of depth, altering surface nutrients (Freed, 2017) and contributing to water-holding capacity. Soil phosphate generally increases, ammonium decreases and nitrogen is unchanged post-burn (Clark et al., 2004). Soil nutrients can deplete in the long term after a burn and require a burn again the following 1–2 years with amendments needed between burn treatments.

Post-burn seeding is a priority method to establish native plant cover on site and reduce the emergency of persistent proliferation and spread of dense exotics. After a burn to clear exotic grasses, the bare ground is exposed and *Festuca roemeri* (Roemer's fescue), *Eriophyllum lanatum* (Oregon sunshine) and *Potentilla gracilis* (chinquefoil) are selected to build endangered butterfly habitat (Applestein et al., 2018). Community structure may be supported by root or germination type after a burn; therefore, a variety of root types is advised to support species diversity (Applestein et al., 2018).

When a treatment outcome is unknown (Bakker et al., 2018), microsites can be used as smaller sites and smaller spaces within the staged-scale where management can 'try out' treatments (Dunwiddie & Martin, 2016; e.g. diversifying a seed mixture) and the potential success of seeding (Bakker et al., 2018). Diverse native plug and seed plantings can be used simultaneously (Dunwiddie & Martin, 2016) as part of the process to occupy bare soil and prevent exotics takeover in areas testing specific diverse introductions.

Seeding takes place using one of the three methods tested in study plots prior to increasing the scale of seeding. The seeding techniques tested are seed drill (Kasco no till seed drill), broadcasting (Truax broadcast seeder) and high rate (4.53+ kg) hydro seeder adjusted for lower seeding rate (Hamman et al., 2015). The seeding that occurred in January used a 0.75:1 mix of *F. roemeri* and *E. lanatum* and in October a 3:1:1 mix of *F. roemeri*, *E. lanatum* and *P. gracilis* (Applestein et al., 2018). About 900 kg per acre of hay layer mulch is applied evenly at the treatment site to deter predation of native seeds (Hamman et al., 2015).

TABLE 2 Common local exotic grasses and forbs.

Exotic species	Perennial (P)/ annual (A)/ biennial (B)
Grasses	
Agrostis capillaris	P
Aira caryophyllea	A
Aira praecox	A
Alopecurus pratensis	P
Anthoxanthum aristatum	A
Anthoxanthum odoratum	P
Arrhenatherum elatius	P
Bromus commutatus	A
Bromus hordeaceus	A
Bromus racemosus	A
Bromus sterilis	A
Bromus tectorum	A
Dactylis glomerata	P
Elymus repens	P
Festuca rubra	P
Holcus lanatus	P
Panicum miliaceum	A
Phleum pratense	P
Poa compressa	P
Poa pratensis	P
Vulpia bromoidies	A
Vulpia myuros	A
Forbs	
Arabidopsis thaliana	A
Anthriscus caucalis	A
Cardamine hirsuta	A
Cerastium glomeratum	A
Centaurea diffusa	P/B
Centaurium erythraea	A
Chenopodium album	A
Cirsium arvense	P
Cirsium vulgare	B
Crepis capillaris	A
Daphne laureola	P
Daucus carota	A/B
Dianthus armeria	A
Erodium cicutarium	A
Galium parisiense	A
Geranium columbinum	A
Geranium dissectum	A
Geranium molle	A
Hypericum perforatum	P
Hypochaeris radicata	P
Lactuca serriola	A/B
Lamium purpureum	A
Lepidium campestre	A
Leucanthemum vulgare	P
Logfia arvensis	A
Moenchia erecta	A
Mycelis muralis	A
Myosotis discolour	A
Nepeta cataria	P
Parentucellia viscosa	A
Plantago lanceolata	P
Potentilla recta	P
Rumex acetosella	P
Rumex crispus	P
Senecio jacobaea	P
Senecio sylvaticus	A
Senecio vulgaris	A
Sherardia arvensis	A
Solanum dulcamara	P
Stellaria graminea	A
Stellaria media	A
Taraxacum officinale	P
Tragopogon dubius	A
Trifolium arvense	A
Trifolium campestre	A
Trifolium dubium	A
Trifolium hybridum	A
Trifolium praetense	P
Trifolium repens	P
Teesdalia nudicaulis	A
Urtica dioica	P
Valerianella locusta	A
Verbascum thapsus	B
Veronica arvensis	A
Veronica chamaedrys	P
Vicia hirsuta	A
Vicia sativa	A
Viola arvensis	A

Data source: Adapted from Dunwiddie and Martin (2016).

Native species require manual reseeding because natural reseeding is slow (Dunwiddie et al., 2014) or unsuccessful. Denser seeding (Hamman et al., 2015) and over seeding assist native species competition against exotic species on site (Freed, 2017). As treatment cycles progress, monitoring for the appearance of exotics, changes or alterations to community composition after seeding, flowering and

TABLE 3 Land use overview.

User groups	Land use type	Occurrence
Tribal	Oak savannah grassland prairie ecosystem	~3800 years before 1800s
Explorer arrivals	Small colonies established	~1775–1790s
European settlement	Parcel block distribution	1800s (mid-century peak)
Land owners	Conventional agriculture; farming and grazing	1800s to present (declining)
Restoration	Oak savannah grassland prairie ecosystem	2000 to present

Note: Land acquisition began in the late 1700s, then the Land Use Act of 1800 updated again in 1804 spurred increased settlement west by mid-century (Findlay, 2020). By 1851–1854, the last known existence of some native plant species were recorded in historical records (Dunwiddie et al., 2014).

overall survival may not detect species that failed due to soil nutrient changes (Stanley et al., 2011). For example, *Sisirynchium idahoense* (Idaho blue-eyed grass) and *Trifolium wildenovii* (tomcat clover) did not emerge at all in any treatment plot, while in all fields *Collinsia sp.*, *E. lanatum* and *F. roemeri* emerged, and in other treatments only one or two species emerged (Freed, 2017). Broadcast seeding produced consistently reliable results across all study plots with the least expense and least needed expertise (Hamman et al., 2015) and is the main seeding method used in Violet Prairie. Trial seeding rates to advise adaptive management followed the two-acre increment regime at 0, 350, 700, 1050 and 1400 seeds per m^2 with seed mass per acre of 0, 0.90, 1.81, 2.72 and 3.63 kg (Hamman et al., 2015), respectively. The seeded grasses and forbs are shown in Table 4.

Previously seeded *F. roemeri* slowly returns after a burn and provides ground cover to support native forbs (see Figure 4). While soils are generally acidic (~5.5), containing high sand, iron and magnesium, low calcium, copper, phosphorus, clay and soluble salts (Chappell & Caplow, 2004), the soil properties of each site will vary and produce varying results even for the same species (Stanley et al., 2011).

Multiple stages are in the conversion process simultaneously, with exotics benefiting from the same mowing and burning treatments as native plant species (Stanley et al., 2011). Fire as a tool to remove exotic grasses can increase exotic forbs (Martin & Hamman, 2016). *Hypochaeris radicata* (false dandelion) and *Teesdalia nudicaulis* (shepherd's cress) can appear sporadically (Dunwiddie & Martin, 2016) despite treatment applications. Scatter Creek preserve contains two common exotic grasses *Poa pratensis* (Kentucky bluegrass) and *Arrhenatherum elatius* (tall oatgrass), which can be initially removed by burning and managed with targeted grass-specific herbicide treatments (e.g. Fusilade; Stanley et al., 2011). Preparation treatment with glyphosate herbicide is applied post-burn if the plot is thoroughly burnt. Exotic grasses and forbs are pulled manually or spot treated if necessary during seeding to reduce herbicide use and can continue throughout the year as needed (Freed, 2016).

Once a plot is deemed ready, then seeded, it is removed from herbicide treatment (Freed, 2017). Immediate seeding can occur in seasonal processes with or without fire each spring, summer or autumn depending on the treatment cycle and the availability of the timing. Seeding can be delayed if burning did not occur or spraying must increase due to an inability to burn the site (Stanley et al., 2011). Events such as state-wide wildfire-associated burn bans can necessitate adjustment of seeding timing from late spring to late autumn.

Select plant species are seeded adaptively depending on which native forb species are successful (Stanley et al., 2011) in previous stages and as seed bank supply and species types become available (Bakker et al., 2018). Monitoring site results of burning, glyphosate treatment and initial fescue and trial forb seeding inform future considerations of how to prepare for reintroduction of select native plant species (e.g. *C. levisecta* or *C. hispida*). The results can advise managers on seed diversity selection, with successful treatments reapplied and repeated in the next stage (Bakker et al., 2018; see Table 5) before decisions are made to seed a diversity of species at a larger scale.

Soil evaluation, depth and texture were not directly measured, but are compared observationally to existing sites where endangered species are still found. Observations from existing sites can influence seeding decisions for the introduction of native species and direct treatments that promote a more desirable soil on degraded sites (Dunwiddie & Martin, 2016). Adaptive trials and changes in practices may resolve seed failure or point to problems with seed viability or seed production in general (Bakker et al., 2018) relative to site characteristics and selected management practices (Stanley et al., 2011). Regardless of treatment applications, combination seeding and reseeding is ongoing as treatments progress over time and remains key to improving native plant richness (Stanley et al., 2011).

A temporary loan of three cattle from the adjacent ranch (Freed, 2017) is used under careful planning and timing to test whether grazers remove exotics as a method of intermittent control. It is undecided whether borrowing grazers from the ranch again may be used in the future (SH personal communication) to reduce (agricultural) fertility for conversion back to prairie soils (Freed, 2017). Grazing may be used to assist in soil preparation when prescribed burning has not been carried out in a timely manner that is compatible with the reintroduction of native plant species (Stanley et al., 2011). Grazing is mainly used to remove nutrient in the initial preparation stages and is currently not a main means of initial conversion to remove exotics or amend soils.

Known results of grazing were that some invasive plants on the upland prairie were reduced and livestock will consume native plant species along with non-native plants (SH personal communication). Therefore, grazers are currently undesirable as a management tool despite any known or unknown benefits to the soil. Managers will continuously adaptively assess if and when grazing techniques are needed (Freed, 2017) as an option. If used, the scale of grazing will

TABLE 4 Violet Prairie seeded species.

Species	Perennial (P)/ annual (A)/ biennial (B)	(2014) stage field 1 (g)	(2015) stage field 2 (g)	(2015) stage field 3 (g)	(2016) stage field 4 (g)	(2016) stage 5 fields 1–3 (over-seeding) (g)	Frequency (monitoring results) 2014/2015/2016 (counts)
Grasses							
Danthonia californica	P	242.8	–	–	–	–	6/0/0
Festuca roemeri	P	5938.9	3624	6161	13078.8	7265.6	81/88/88
Koeleria macrantha	P	11.6	516.8	1265.4	–	28.9	0/0/0
Forbs							
Achillea millefolium	P	–	43.8	107.3	372.7	7.4	–
Aquilegia formosa	P	–	24.4	59.7	–	–	–
Camassia quamash	P	127.0	220.1	538.7	–	–	0/0/0
Campanula rotundifolia	P	–	21.1	51.6	–	6.5	–
Castilleja hispida	P	224.2	70.4	1724	–	–	–
Cerastium arvense	P	7.3	3.6	8.9	444.7	–	0/0/0
Clarkia amoena	A	–	72.3	176.9	–	–	–
Collinsia grandiflora	A	459.4	–	–	–	581.8	[a]81/75/44
Collinsia parviflora	A	505.4	348.9	854.3	1136.4	374.8	[a]
Collomia grandiflora	A	–	–	–	904.1	–	–
Delphinium nuttallii	P	–	–	–	–	46.3	–
Erigeron speciosus	P	26.2	–	–	–	–	6/0/0
Eriophyllum lanatum	P	89.5	310.6	760.6	210.4	126.2	94/94/100
Hieracium cynoglossoides	P	–	–	–	–	8.7	–
Leptosiphon bicolor	A	–	–	–	–	94.9	–
Lomatium utriculatum	P	97.4	–	–	61.2	61.2	0/0/0
Lupinus albicaulis	P	166.6	104.3	255.3	866.6	671.6	25/56/6
Lupinus bicolor	A/P	514.4	–	–	–	107.4	0/6/13
Lupinus lepidus	P	–	–	–	175	70.3	–
Micranthes integrifolia	P	–	1.1	2.8	–	–	–
Microseris laciniata	P	252.6	–	–	947.4	234.6	56/0/0
Microsteris gracilis	A	556.2	–	–	–	315.2	94/13/0
Perideridia gairdneri	P	–	7.9	19.5	–	–	–
Plectritis congesta	A/P	2899.8	60	146.8	–	411.4	50/0/0
Potentilla gracilis	P	57.6	–	–	557	112.6	25/0/0
Ranunculus Occidentalis	P	128.2	260	636.6	–	–	6/0/0
Sisyrinchium idahoense	P	85.6	57.9	141.7	–	250.6	0/0/13
Solidago missourieniss	P	–	73.8	180.6	220.4	34.4	0/25/69
Solidago simplex	P	18.2	–	–	148.6	–	–
Trifolium willdenovii	A	252.0	–	–	–	85.3	0/0/0
Turritis glabra	A/B	–	–	–	–	30.2	–
Viola adunca	P	–	12.9	31.6	–	–	–

Note: The above represents quantity in grams (g) of seeded species by field stages (start-up years). Data source: Adapted from Freed (2017).
[a]*Collinsia* species are counted as one due to unidentifiable distinction between the two at the time of monitoring.

FIGURE 4 The upland prairie after a burning, seeding, and hay mulch cycle shown here in early autumn (2018) with *Festuca roemeri* (Roemer's fescue) visible in the field. Photo credit: author.

TABLE 5 Generalized adaptive staged scale treatment timeline.

Year 1 begins 2014 (8 acres)	Year 2 begins 2015 (2–4 acres)	Year 3 begins 2015–2016 (2–4 acres)	2015–2016 (2 acres)	2016 (8 acres)
Experimental seeding	Burn ➔ glyphosate/herbicides	Fescue seeding ➔ forbs seeding		
Fescue seeding ➔	Herbicides ➔ forbs			
Herbicide ➔	Herbicide	Fescue seeding ➔ forbs		
	Fescue seeding	Winter flood ➔ fescue death	Glyphosate	Fescue re-seeding
	Fescue seeding ➔ forbs		Fescue seeding ➔ forbs	
				Burn ➔ herbicides

Note: Table 5 shows overlapping treatments in start-up years at Violet Prairie. Data source: Freed (2017).

decrease over time as the restoration of native prairie plants increases on site (Freed, 2016).

3 | CONCLUSION

Although staged-scale adaptive management is used as a learning tool in the restoration process in Violet Prairie, scientific studies could be performed to better determine the relationship between soil conditions, plant resilience, and treatments to advise a practical reference point and future planning. Trial microsites could be spaces for soil sampling and designed experimentation to inform soil chemistry and plant physiological relationships under given treatments. Over time, soil health favourable to endemic plants improves through treatment processes (Heneghan et al., 2008), such as prescribed burning, but can change soil chemistry and may not replicate past conditions and species success. In short, there are unknowns. Although adaptive trial-and-error management assists conversion despite unknowns, referencing matching ecological characteristics found at Rocky Prairie acts as a conflicting reference point substitute. Soils there are deeper with mounded topography, whereas Violet Prairie is relatively flat with shallower soils. Despite a soil classification similar to Rocky Prairie, Violet Prairie was a former agricultural site, with suspect changes to soil chemistry through high proliferation of exotic plants over a century, where Rocky Prairie is an intact naturally occurring site with limited exotics takeover. Although endemic plants appear adapted to favour shallow and quick draining soils (Dunwiddie et al., 2014), sampling, analysis, testing and in situ experimentation to determine changes to chemistry under given treatments may lead to better restoration outcomes for the reintroduction of target species.

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PEER REVIEW

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The present paper does not include any data.

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