Silverleaf phacelia (Phacelia hastata)

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Nomenclature

Silverleaf phacelia (*Phacelia hastata*) Douglas ex Lehm. belongs to the Hydrophyllaceae or waterleaf family (USDA NRCS 2020).

Family

Hydrophyllaceae Ð Waterleaf family

Genus

Phacelia

Species

hastata

NRCS Plant Code

PHHA (USDA NRCS 2020).

Subtaxa

Currently (2021) four silverleaf phacelia varieties are recognized (ITIS 2021; USDA NRCS 2021): Charleston phacelia (*P. h.* var. *charlestonensis* Cronquist), compact phacelia (*P. h.* var. *compacta* [Brand] Cronquist), spearshaped phacelia (*P. h.* var. *dasyphylla* [Greene ex J.F. Macbr.] Kartesz & Gandi), silverleaf phacelia (*P. h.* var. *hastata* Douglas ex Lehm).

Synonyms

Phacelia alpina Rydb., *P. dasyphylla* Greene ex J.F. Macbr., *P. frigida* Greene, *P. f.* subsp. *dasyphylla* (Greene ex J.F. Macbr.) Heckard, *P. h. hastata* var. *alpina* (Rydb.) Cronquist, *P. leucophylla* Torr., *P. h.* var. *leucophylla* (Torr.) Cronquist, *P. l.* var *alpina* (Rydb.) Dundas, *P. l.* var *suksdorfii* J.F. Macbr., *Phacelia oreopola* subsp. *simulans* Heckard (ITIS 2021).

Common Names

Silverleaf phacelia, Charleston phacelia, compact phacelia, lanceleaf phacelia, silverleaf scorpionweed, spearshaped phacelia, whiteleaf phacelia (Lambert 2005; Welsh et al. 2016; Hitchcock and Cronquist 2018; Scherer et al. 2000; ITIS 2021).

Chromosome Number

Chromosome numbers are: 2n = 22, 33, 44 (Constance 1963; Munz and Keck 1973; Gilbert et al. 2005; Walden et al. 2014; Welsh et al. 2016).

Hybridization

No hybridization was reported in the literature.

Distribution

Silverleaf phacelia occurs from British Columbia and Alberta east to the western parts of North Dakota, South Dakota, and Nebraska and south to southern Colorado, Utah, Nevada, and California. It is found in all counties of Utah and Nevada, nearly all counties of Wyoming and Idaho, and all but the coastal areas of Washington, Oregon, and California (USDA NRCS 2021).

Variety *hastata* is most common and widespread, occupying nearly the entire range described for the species, except it occurs only in northern California (USDA NRCS 2021). Variety *charlestonensis* occurs in NevadaÕs three southernmost counties. Variety *compacta* occurs in subalpine to alpine habitats in the Cascade and Sierra mountain ranges in Washington, Oregon, California, and western Nevada (Hitchcock and Cronquist 2018; USDA NRCS 2021). Variety *dasyphylla* is rare and occupies a disjunct range in Oregon and Placer County, California (USDA NRCS 2021).

Habitat And Plant Associations

Grasslands. Silverleaf phacelia grows in grasslands throughout its elevation range. It is common in rocky gullies or outcrops in valley grasslands of MontanaÕs Upper Clark Fork River Basin (LeFebvre 2014). It also occurs in alpine grasslands dominated by western needlegrass (*Achnatherum occidentale* subsp. *occidentale*) with a high percentage of bare soil and active frost heaving in the supalpine fir (*Abies lasiocarpa*) zone of Oregon and Washington (Franklin and Dyrness 1973).

In the northern Blue Mountains of Oregon, silverleaf phacelia is common in bluebunch wheatgrass-Sandberg bluegrass (*Pseudoroegneria spicata*Ð*Poa sandbergii*) grasslands on steep (average 53%), southwest slopes at elevations of 3,200 to 3,870 ft (980Ð1,180 m) and in bluebunch wheatgrass-sulphur-flower buckwheat (*Eriogonum umbellatum*) communities on moderate slopes above 5,000 ft (1,500 m) (Johnson and Swanson 2005). In MontanaÕs upper Blackfoot Valley, frequency of silverleaf phacelia is greatest (43%) on southeastern slopes dominated by sixweeks fescue (*Vulpia octoflora* var. *octoflora*) or woolly plantain (*Plantago patagonica*) in morainal vegetation. Summer soil temperatures on southern exposures fluctuate more and are warmer than those at western or northern exposures where silverleaf phacelia is much less common (Blinn 1966). In montane grasslands on the east side of Rocky Mountain National Park, Colorado, silverleaf phacelia only occurred in plots not invaded by sweetclover (*Melilotus officinalis*). Montane grasslands occupy well-drained soils and are dominated by mountain muhly (*Muhlenbergia montana*), blue grama (*Bouteloua gracilis*), and needle and thread (*Hesperostipa comata* subsp. *comata*) (Wolf et al. 2004). Silverleaf phacelia is abundant in talus and scree communities above tree line (10,249 ft [3,124 m]) on Mt. Washburn in northcentral Yellowstone National Park. Spreading wheatgrass (*Elymus scribneri*) dominates talus and scree communities, where the frost-free season averages 93 days, and precipitation is less than 32 in (800 mm)/year (Aho and Bala 2012).

Figure 1. Silverleaf phacelia in a California grassland. Photo: USDI Bureau of Land Management (BLM) CA320 Seeds of Success (SOS) .

Shrublands. Silverleaf phacelia occurs in many semi-arid shrubland communities. It occurs in big sagebrush (*Artemisia tridentata*)/bluebunch wheatgrass vegetation in Penticton, southern British Columbia (Pitt and Wikeem 1990). In north-central Washington, Youtie et al. (1988) identified an antelope bitterbrush (*Purshia tridentata*)/needle and thread/silverleaf phacelia community in a study area heavily grazed by cattle spring through fall. This is considered an early seral community with a semiarid climate of cold winters, warm dry summers, and 9.5 in (240 mm) of annual precipitation. (Youtie et al. 1988). At Craters of the Moon National Monument, Idaho, silverleaf phacelia occurs in cinder gardens and antelope bitterbrush-dominated vegetation types. Cinder gardens occupy harsh sites with low available soil moisture, high summer soil temperatures, and low total plant cover (<5%) dominated by cushion buckwheat (*Eriogonum ovalifolium*) and silverleaf phacelia. Antelope bitterbrush communities occur on deeper soils and support greater vegetation cover (Day and Wright 1985). In the White Mountains of California, silverleaf phacelia occurs in alpine vegetation on south- and east-facing slopes below 13,000 ft (4,000 m) (Mitchell et al. 1966). Dominant shrubs and subshrubs are wax current (*Ribes cereum*), granite prickly phlox (*Linanthus pungens*), NuttallÕs linanthus (*Leptosiphon nuttallii*), low sagebrush (*A. arbuscula*), and timberline sagebrush (*A. rothrockii*). Climate in the White Mountains is cold and semi-arid with an average annual precipitation of 15.5 in (394 mm) and temperature of 28 ¡F (-2 ¡C) (Mitchell et al. 1966). In Clark and Nye counties of Nevada, silverleaf phacelia is associated with sagebrush/pinyon-juniper, big sagebrush-curl-leaf mountain mahogany (*Cercocarpus ledifolius*), and ponderosa pine (*Pinus ponderosa*) communities occurring at elevations of 6,000 to 8,500 ft (1,800Ð2,600 m) (Beatley 1976).

Figure 2. Silverleaf phacelia in a sagebrush community in Oregon. Photo: BLM OR931 SOS.

Woodlands/Forests. Silverleaf phacelia can be found in a variety of montane woodland and forest types. It grows in western juniper (*J. occidentalis*) woodlands in the Steens Mountain of southeastern Oregon dominated by 80-year-old trees and 24% overstory canopy cover (Bates et al. 2000). In central OregonÕs pumice region, silverleaf phacelia is associated with ponderosa pine forests (Busse et al. 2009). Silverleaf phacelia occasionally occurs in exceptionally well-drained, shrub-free pumice sand flats in Jeffrey pine (*P. jeffreyi*) forests on Glass Mountain, Mono County, California (Horner 2001). In the South Warner Mountains in southeastern California, silverleaf phacelia grows in several forest types found on western and northwestern slopes including white fir/sweetcicely (*Abies concolor*/*Osmorhiza berteroi*), white fir/tailcup lupine (*Lupinus caudatus*), and white fir/whiteveined wintergreen (*Pyrola picta*) forests (Riegel et al. 1990).

Figure 3. Silverleaf phacelia conifer habitat in Oregon. Photo: BLM OR110 SOS.

Elevation

Silverleaf phacelia occupies a broad elevation range from 3,000 to 13,120 ft (900Ð4,000 m).In Utah, the elevation range is 4,400 to 11,500 ft (1,340Ð3,510 m) (Welsh et al. 2016). In California, variety *hastata* occurs at elevations of 3,000 to 7,900 ft (900Ð2,400 m) and variety *compacta* at elevations of 5,900 to 13,120 ft (1,800Ð4,000 m) (Hickman 1993).

Soils

Silverleaf phacelia commonly occurs on a variety of dry, coarse-textured soils (Fig. 4) (Taylor 1992; Link 1993; Lambert 2005; Blackwell 2006; PŽrez 2012). It is also found on disturbed soils from the foothills to above timberline (LeFebvre 2014).

Figure 4. Silverleaf phacelia (variety *compacta*) growing in rocky soils in California. Photo: John Doyen, 2018, CalPhotos.

Soil preference can vary by location. In Jackson County, Oregon, silverleaf phacelia grows with western juniper and arrowleaf balsamroot (*Balsamorhiza sagittata*) in flat open areas with fine gravelly, basaltic soils (Duncan and Chambers 2013). In the White Mountains of eastern California, silverleaf phacelia is restricted to non-carbonate substrates, occurring on basalt and adamellite substrates, and having a slight affinity to sandstone (Marchand 1973). Wright and Mooney (1965) found that silverleaf phacelia occurred on sandstone and granite but not on dolomite soils in the White Mountains. Dolomite soils were 64% sand, 34% silt, 2% clay with 20% available moisture and pH of 8. Sandstone soils were 63% sand, 33% silt, and 4% clay with 25% available moisture and pH of 6.3. Granite soils were 82% sand, 15% silt, 3% clay with 16% available moisture and pH of 5.9 to 6.2 (Wright and Mooney 1965). On Siyeh Pass in Glacier National Park, Montana, silverleaf phacelia occurs on calcareous soils of limestone and diorite overlaying argillic substrate (Bamberg and Major 1968). When vegetation on dolomite and quartzite soils were compared in the Bear River Range of UtahÕs Wasatch Mountains, silverleaf phacelia was characteristic of and almost entirely restricted to dolomite soils. Dolomite soils had significantly higher pH, silt, calcium, and magnesium, and significantly lower sand content than quartzite soils ($P < 0.01$) (Neely and Barkworth 1984). In an evaluation of sweetclover invaded and uninvaded montane grasslands on ColoradoÕs east side of Rocky Mountain National Park, silverleaf phacelia occurred only in uninvaded plots. Uninvaded plots had higher nitrogen availability and mineralization than invaded plots ($P < 0.02$). Organic matter content was the same for invaded and uninvaded plots at 0 to 4 in (10 cm) deep but significantly greater for uninvaded than invaded plots at 4- to 8-in (10Ð20 cm) soil depths

(P < 0.05) (Wolf et al. 2004).

Well-drained, low-moisture soils were described for silverleaf phacelia habitats in Oregon and California. In western juniper woodlands in southeastern OregonÕs Steens Mountain, silverleaf phacelia occurs in rocky, clay loam soils 16 to 20 in (40Ð50 cm) deep (Bates et al. 2000). In OregonÕs northern Blue Mountains, silverleaf phacelia occurs on steep (average 53%), southwestern slopes with basaltic soils high in coarse fragments and very low available water capacity (Johnson and Swanson 2005). On Glass Mountain in Mono County, California, silverleaf phacelia is occasional on gravelly and exceptionally well-drained pumice soils (Horner 2001). In a survey of vegetation and habitat preferences in the Bishop Creek watershed on the east side of CaliforniaÕs Sierra Nevada range, silverleaf phacelia occurred in dry, high-elevation (11,119 ft [3,389 m]) plots. The wetness preference of silverleaf phacelia was 1.6 on a 1 to 4 gradient where 1 represented usually dry, 2 often dry, 3 often wet, and 4 continually wet soil (P < 0.01) (Kimball et al. 2004).

Description

Silverleaf phacelia is a short-lived perennial with a stout taproot. Plants have a multi-branched caudex, numerous prostrate to ascending stems, and rarely reach more than 20 in (50 cm) tall. Stems and leaves are silvery green with fine to stiff, spreading to appressed pubescence, making the hairs almost sticky (Fig. 5) (Munz and Keck 1973; Hickman 1993; Pavek et al. 2012; Welsh et al. 2016; Hitchcock and Cronquist 2018; Luna et al. 2018). Root systems of plants growing on talus slopes in Lassen Volcanic National Park, California, grew upslope from the caudex because soil shifting pushed the aboveground plant material away from the roots. For 10 silverleaf phacelia plants on these slopes, the root/shoot biomass averaged 0.63. Root length averaged 10.8 in (27.5 cm) and depth averaged 8.6 in (21.8 cm) (PŽrez 2012).

Figure 5. Silverleaf phacelia (variety *hastata*) has silvery green foliage. The leaves are lanceolate and petiolate with pointed tips. Photo: Steve Matson, 2006, CalPhotos.

Leaves are arranged alternately, although lower leaves may be opposite. Leaf blades are lanceolate to widely elliptic with pointed tips and prominent veins (Fig. 5). Leaf margins are entire or occasionally have one to two pairs of small lateral lobes near the base (Hickman 1993, Pavek et al. 2012; Welsh et al. 2016; Hitchcock and Cronquist 2018). Lower leaf blades measure 0.8 to 5 in (2Ð12 cm) long, which is less than or equal to the petiole length. Upper leaves are smaller and sessile (Hickman 1993; Pavek et al. 2012). Leaf venation is deeply sunken on the upper surface and useful in distinguishing silverleaf phacelia from some other *Phacelia* species (LBJWC 2014; Luna et al. 2018).

Silverleaf phacelia produces many tight- to open-coiled cyme inflorescences (helicoid cymes) with small white to lavender or purple flowers (Fig. 6) (Blackwell 2006; Pavek et al. 2012; Welsh et al. 2016; Hitchcock and Cronquist 2018). Inflorescences are terminal and simple to branched with flowers along most of the flowering stalk length (Munz and Keck 1973; Blackwell 2006; Luna et al. 2018). Individual flowers are subsessile with urn to bell-shaped, tubular corollas 4 to 7 mm long with five spreading lobes (Munz and Keck 1973; Hickman 1993; Luna et al. 2018). The five stamens extend beyond the spreading corolla lobes by more than 2 mm. Styles are 7 to 10 mm long and deeply divided (Hickman 1993; Welsh et al. 2016; Luna et al. 2018). Silverleaf phacelia produces dry, stiff, ovoid, 2 to 4 mm long capsules with stiff hairs (Hickman 1993; Welsh et al. 2016; Luna et al. 2018). Capsules are two-chambered and typically contain one to three seeds (Hickman 1993; LeFebvre et al. 2017b). Seeds measure 1.5 to 2.6 mm long, and have pits in vertical rows (Hickman 1993; Welsh et al. 2016).

Figure 6. Silverleaf phacelia inflorescence with helicoid cyme of small, crowded, white flowers with long exerted stamens, Oregon State UniversityÕs Malheur Experiment Station (2018). Photo: USFS.

Reproduction

Researchers calculated a fruit/flower percentage average of 65% for 161 silverleaf phacelia plants growing in the Wasatch Mountains near Brighton, Utah (Wiens et al. 1987). Seed/ovule percentages averaged 27% for 21 plants when the preemergent reproductive success (PERS) or the number of viable seeds that enter the ambient environment was evaluated. Average PERS (product of fruit/flower and seed/ovule) for silverleaf phacelia was 18% compared to 22% among all outcrossing species evaluated (Fig. 7) (Wiens et al. 1987).

Figure 7. Bee pollinators visiting silverleaf phacelia flowers at the Plant Materials Center in Bridger, MT (2010). Photo: Joe Scianna, NRCS.

Vegetative regeneration from root fragments has been observed for silverleaf phacelia, although this is not common. On talus slopes in Lassen Volcanic National Park, California, sprouting from root fragments was observed for silverleaf phacelia plants damaged by talus movement (PŽrez 2012).

Breeding System

Research by Cane (2016) in research plots near Logan, Utah, showed that silverleaf phacelia plants are self-fertile, but flowers do not auto pollinate and require pollination for seed production. Seed set was just 1.4% for 937 hand-pollinated flowers from 76 racemes on 19 caged plants. When planted alone or in groups of three to determine seed set from self-pollination and outcrossing, seed set averaged 55% for single plants and 73% for trios, but seed set was highly variable (Cane 2016).

Pollination

Silverleaf phacelia is visited by a variety of pollinators when in flower (Fig. 7) (Cane 2016), which is commonly May to August (Munz and Keck 1973; Ogle et al. 2017). In northern Utah and Nevada, silverleaf phacelia had the highest average bee density (28.5 bees/100 plants) among 16 forb species surveyed (Table 1).

Table 1. Percentages of bee genera comprising the floral guild at silverleaf phacelia from seven sample sites in northern Utah and Nevada (Cane and Love 2016).

Genus	Common Name	Percentage
Agapostemon	sweat bee	1.1
Andrena	mining bee	2.2
Anthidium	carder bee	7.7
Anthophora	mining bee	2.2
Bombus	bumblebee	14.3
Dufourea	shortface bee	17.6
Eucera	long-horn bee	11.0
Halictus	sweat bee	1.1
Hoplitis	mason bee	6.6
Hylaeus	yellow-faced bee	3.3
Lasioglossum	sweat bee	1.1
Megachile	leaf-cutter bee	2.2
Osmia	mason bee	15.4
Pseudomasaris	pollen-collecting wasp	14.3

In bumble bee surveys of plants growing along roadsides or walking trails near Crested Butte, Colorado, researchers counted 381 bumble bees on silverleaf phacelia flowers. Surveys were conducted at various times of the day and lasted 45 minutes or until at least 20 bumble bees were recorded. Most sites were visited once every 8 days from June 22 to September 8, 1974 (Pyke 1982).

Greenhouse and field experiments conducted in Bozeman, Montana, evaluated effects of drought, herbivory, and increased CO2 on silverleaf phacelia flower traits and pollinator attraction (Burkle and Runyon 2016; Glenny et al. 2018). For drought treatments, water was withheld until the first signs of wilting, which was typically 2 days for silverleaf phacelia. Herbivory treatments used cabbage loopers (*Trichoplusia ni*) to feed on leaves, which resulted in low levels of herbivory. Pollinator visitation was assessed in July by observing potted flowering plants in a large meadow, where silverleaf phacelia occurs naturally (Burkle and Runyon 2016). Drought in the greenhouse significantly (*P* < 0.0001) reduced plant area (length × width) by 50%, flower width by 10%, flower depth by 5%, and floral display more than 8 fold. Plants subjected to continuous drought did not flower. Drought increased per flower visitation 10-fold (*P* = 0.0086) but did not affect per plant visitation. Herbivory exacerbated the effects of drought on flower size and pollinator visitation rate for drought + herbivory plants. The same volatile organic compounds (VOCs) were emitted by flowers in all treatments, but drought treatments produced some composition changes (Burkle and Runyon 2016). CO2 fertilization (800 ppm) increased plant size (37% larger, *P* < 0.03), flower production (33% more flowers, *P* < 0.01), as well as VOC emissions and composition, but these changes did not impact pollinator visitation rates (per plant or per flower) (Glenny et al. 2018). Pollinator visitors included bees (Hymenoptera) and flies (*Diptera* spp.). See the Nursery Practice section for details on plant establishment and rearing conditions.

Ecology

Silverleaf phacelia is a short-lived perennial characteristic of early-seral communities and disturbed sites (Link 1993; Majerus 1999; Skinner et al. 2005; Ogle et al. 2014). Plants are fast growing (Ogle et al. 2013) and tolerate partial shade (LBJWC 2014).

Seed And Seedling Ecology

At sites with harsh growing conditions, silverleaf phacelia plays a role in advancing succession. On talus slopes in Lassen Volcanic National Park, California, it provides safe sites for germination of co-occurring species (PŽrez 2012). At Craters of the Moon National Monument, south-central Idaho, silverleaf phacelia was positively associated with cushion buckwheat (*P* < 0.05), and densities of silverleaf phacelia seeds were significantly higher beneath cushion buckwheat and sulphur-flower buckwheat canopies than on bare soil (*P* < 0.05; Table 2; Day and Wright 1989).

Table 2. Density of silverleaf phacelia seeds (seeds/m2) beneath buckwheat canopies and on bare ground in sparsely vegetated cinder gardens at Craters of the Moon National Monument, south-central Idaho (Day and Wright 1989).

Year	Cushion buckwheat canopies	Bare ground
1983	833	183
1984	2,283	383
1986*	1,856	78

*600 seeds were collected beneath sulphur-flower buckwheat canopies in 1986.

Disturbance Ecology

Silverleaf phacelia tolerates fire and some below-ground disturbances but may be sensitive to cattle grazing. It typically survives burning by sprouting from the root crown (caudex) (Lyon and Stickney 1976; Scherer et al. 2000) but is also known to colonize burned sites soon following fire (Roche et al. 2008).

Fire. Following a prescribed fire in a Douglas-fir (*Pseudotsuga menziesii*) forest north of Ketchum, Idaho, silverleaf phacelia frequency was greater in the first (8%) and second (20%) post-fire years than before the fire when it was present but not sampled (Lyon 1966). In WashingtonÕs Cascade Mountains the frequency silverleaf phacelia was 4% prior to treatments and more than double that 2 to 3 years (15%) and 10 to 13 years (10%) following treatments of thinning, burning, or thinning then burning (Rossman et al. 2018). Findings were similar after thinning and burning treatments in mixed-conifer forests in CaliforniaÕs Teakettle Experimental Forest (Wayman and North 2007). The frequency of silverleaf phacelia was 3% before treatments and 30% 1 to 2 years following treatments, which included burned, not thinned; unburned, understory thinned; unburned, overstory thinned; burned, understory thinned; and burned overstory thinned. Silverleaf phacelia abundance was greatest in burned and thinned treatments (Wayman and North 2007). Cover of silverleaf phacelia was greater (although not significantly) on unseeded burned than on seeded burned plots in a dry grand fir (*Abies grandis*) forest in WashingtonÕs Wenatchee National Forest. The fire was a high-intensity crown fire that burned in July. Aerial post-fire seeding included common wheat (*Triticum aestivum*), slender wheatgrass (*Elymus trachycaulus* subsp. *trachycaulus*), and white clover (*Trifolium repens*). Two years after fire and seeding, cover of silverleaf phacelia was 7.4% on unseeded and 4.7% on seeded burned plots (Schoennagel and Waller 1999).

Mechanical disturbances. Frequency of silverleaf phacelia was significantly greater on rototilled sites than on cut, chained, or herbicide-treated sites in Boulder Canyon on UtahÕs Manti-La Sal National Forest (Anderson and Thompson 1993). Treatments were targeting removal of California false hellebore (*Veratrum californicum*) from sheep-grazed sites. Rototilling done once to a depth of 4 to 6 in (10Ð15 cm) in silty clay loams (15Ð30 in [38Ð76 cm] deep) resulted in 13% frequency of silverleaf phacelia. Frequency was half as much on herbicide-treated plots, and silverleaf phacelia was absent from chained plots (Anderson and Thompson 1993).

Grazing. Silverleaf phacelia was present on ungrazed but not grazed plots in northeastern NevadaÕs Ruby Mountains (Rickart et al. 2013). Unprotected plots were grazed on a 3-year cycle. Grazed plots occurred within an almost 5,000-ac (20 km²) allotment supporting 250 cow-calf pairs from July 15 to Aug 26 (42 days) in year 1 and from June 1 to July 15 (45 days) in year 2. In year 3, grazed plots were rested (Rickart et al. 2013).

Successional status. Silverleaf phacelia is an early colonizer of disturbed sites and often found in early-seral communities. It was one of the more prevalent species colonizing silver mine dumps near Park City, Utah (Alvarez et al. 1974), a volunteer on reclaimed coal mine sites in northeastern Wyoming (Schladweiler et al. 2005), and an early colonizer of mine spoils in British Columbia (Smyth 1997). In the near-alpine mine spoil in British Columbia, silverleaf phacelia appeared 4 to 5 years after the spoil was seeded. Silverleaf phacelia was not seeded but did occur along haul roads near the dump 0.6 to 3 mi (1Ð5 km) from the spoil (Smyth 1997).

Following the eruption of Mount St. Helens in Washington, silverleaf phacelia colonized Pumice Plains within 6 years of the blast (Wood and Del Moral 1988). Within 13 years, it occurred on barren, pyroclastic, drainage, and mudflow sites, but its frequency was higher on refugia sites (19%) where belowground plant parts survived compared to denuded sites with no survival (4Ð6%) (del Moral et al. 1995). Silverleaf phacelia was considered a ruderal species at Centennial Sandhills in southwestern Montana (Lesica and Cooper 1999). Cover and frequency of silverleaf phacelia were greatest in early-seral communities with sand movement and low big sagebrush cover (up to 7%). Cover was 3% on lower slopes experiencing sand erosion and on upper slopes experiencing sand deposition. Cover was 0.4% on stabilized upper and lower slopes without sand movement and higher big sagebrush cover (up to 17%) (Lesica and Cooper 1999).

Wildlife And Livestock Use

Although silverleaf phacelia is not considered good livestock forage (Hermann 1966) and use by large mammals was not reported, it is imporant to small mammals (Martin et al. 1951), birds (Luna et al. 2018), and insects (Ley et al. 2007). *Phacelia* species make up to 2% of California ground squirrel (*Otospermophilus beecheyi*) diets and up to 10% of golden-mantled ground squirrel (*Spermophilus lateralis*) diets (Martin et al. 1951). Greater sage-grouse (*Centrocercus urophasianus*) eat silverleaf phacelia flowers and invertebrates that utilize silverleaf phacelia as habitat (Luna et al. 2018). For these reasons, it is considered good greater sage-grouse brood-rearing species (Ogle et al. 2014).

Silverleaf phacelia is important to many insects and pollinators, including bees, butterflies, and moths (Ogle et al. 2013, 2017; LBJWC 2014). Silverleaf phacelia provides habitat for bumble, digger (*Colletes* spp.), small carpenter (*Xylocopa* spp.), leafcutter (*Megachile* spp.), mason, sweat, plasterer (Colletidae), and miner (*Andrenid* spp.) bees. Silverleaf phacelia also functions as a host plant (Ley et al. 2007). Mason bees (*Osmia indeprensa*, *O. lignaria*, and *O. bruneri*) provision their nests with pollen from silverleaf phacelia to provide protein for their offspring (Cripps and Rust 1989; Cane and Love 2016). Bumble bees used *Phacelia* species (*P. heterophylla, hastata,* and *egena*) more than expected based on plant availability on 11- to 12-year-old burned sites in the Eldorado National Forest in eastern California. Twenty percent of all bumble bees (n=455) were collected from the *Phacelia* complex. Bumble bee surveys were conducted from May through August in 2015 and 2016 in vegetation dominated by whitethorn ceanothus (*Ceanothus cordulatus*), deerbrush (*C. integerrimus*), and greenleaf manzanita (*Arctostaphylos patula*) (Loffland et al. 2017).

Silverleaf phacelia is a food source for moths (*Sparganothis senecionana*) (Gilligan and Epstein 2012). LeonaÕs little blue butterfly (*Philotiella leona*) was observed nectaring on silverleaf phacelia once during surveys made for 3 years on the Mazama tree farm and the adjacent Winema National Forest in Klamath County, Oregon (James et al. 2014). Plant bugs (*Chlamydatus schuhi*, *Plagiognathus verticalis*) were collected from silverleaf phacelia in Oregon (Schuh 2001; Schuh and Schwartz 2005).

Ethnobotany

Thompson and Lillooet Interior Salish women used silverleaf phacelia for relief from difficult menstruation (Turner 1988; Turner et al. 1990).

Horticulture

Silverleaf phacelia is listed as a native species for xeriscaping in the northern Great Plains and Rocky Mountains (Majerus et al. n.d.). It produces attractive flowers and has a long blooming period, making it a good choice for planting in native landscaping or public use areas (LeFebvre et al. 2017a). It may also attract pollinators that improve crop production and insects that prey upon or parasitize crop pests (Eldredge et al. 2013; Burkle et al. 2020). In the Gallatin Valley, Montana, silverleaf phacelia was visited by a variety of pollinators when grown near pollinator-dependent crops (e.g., squash, tomatoes, cucumbers) (Burkle et al. 2020).

Revegetation Use

Silverleaf phacelia is recommended for pollinator and wildlife habitat improvement, erosion control, and mine land reclamation at sites with medium- to coarse-textured soils receiving 10 to 18 in (254Ð457 mm) of annual precipitation (Skinner et al. 2005; LeFebvre et al. 2017a; Tilley et al. 2019). It is easily grown from seed and has moderate seedling vigor, moderate longevity, and reliably re-seeds itself (Skinner et al. 2005; Tilley et al. 2013). For all of these reasons, it has been referred to as the Òwork-horseÓ species for roadside revegetation (Landis et al. 2005).

Silverleaf phacelia is recommended for use on severely impacted sites with low pH and high concentrations of heavy metals (LeFebvre et al. 2017a), and it has colonized abandoned mine sites in several locations (see Successional Status in Ecology section). In guidance for mine reclamation, silverleaf phacelia establishment was rated as moderate, and its cover, longevity, and drought tolerance were rated high (LeFebvre and Jacobs 2014). When planted near Anaconda, Montana, where soils had a pH of 4.5 and highly phytotoxic concentrations of arsenic and copper, silverleaf phacelia Stucky Ridge Germplasm (see Releases section) growth, vigor, and seed production were good after the first post-seeding year (LeFebvre 2014).

Developing A Seed Supply

For restoration to be successful, the right seed needs to be planted in the right place at the right time. Coordinated planning and cooperation is required among partners to first select appropriate species and seed sources and then properly collect, grow, certify, clean, store, and distribute seed for restoration (PCA 2015).

Developing a seed supply begins with seed collection from native stands. Collection sites are determined by current or projected revegetation requirements and goals. Production of nursery stock requires less seed than large-scale seeding operations, which may require establishment of agricultural seed production fields. Regardless of the size and complexity of any revegetation effort, seed certification is essential for tracking seed origin from collection through use (UCIA 2015).

Seed Sourcing

Because empirical seed zones are not currently available for silverleaf phacelia, generalized provisional seed zones developed by Bower et al. (2014) may be used to select and deploy seed sources. These provisional seed zones identify areas of climatic similarity with comparable winter minimum temperature and aridity (annual heat:moisture index). In Figure 8, Omernik Level III Ecoregions (Omernik 1987) overlay the provisional seeds zones to identify climatically similar but ecologically different areas. For site-specific disturbance regimes and restoration objectives, seed collection locations within a seed zone and ecoregion may be further limited by elevation, soil type, or other factors.

The Western Wildland Environmental Threat Assessment CenterÕs (USFS WWETAC 2017) Threat and Resource Mapping (TRM) Seed Zone application provides links to interactive mapping features useful for seed collection and deployment planning. The Climate Smart Restoration Tool (Richardson et al. 2019) can also guide revegetation planning, seed collection, and seed deployment, particularly when addressing climate change considerations.

Map

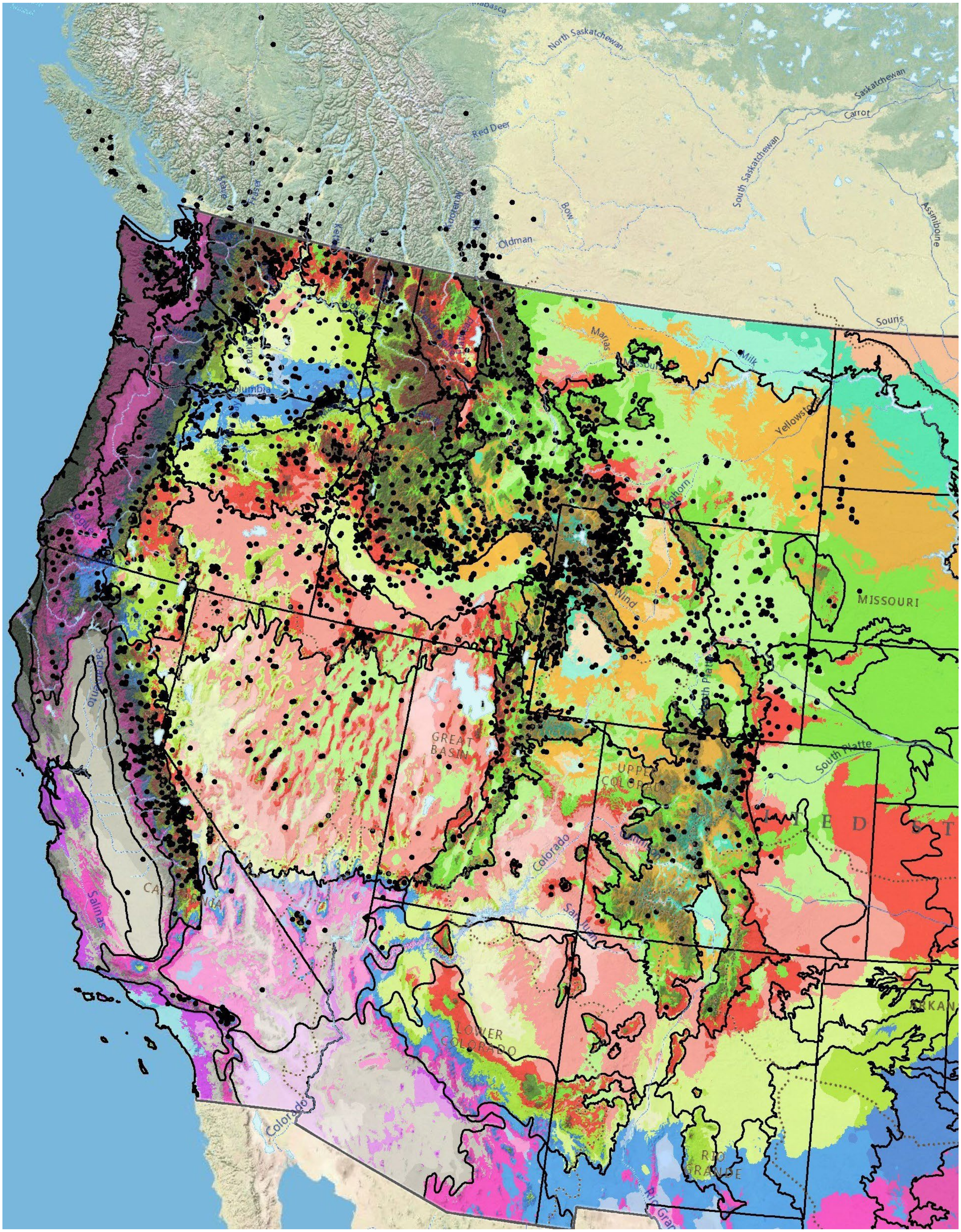

Figure 8. Distribution of silverleaf phacelia (black circles) based on geo-referenced herbarium specimens and observational data from 1881Ð2016 (CPNWH 2020; SEINet 2020; USDI USGS 2020). Generalized provisional seed zones (colored regions) (Bower et al. 2014) are overlain by Omernik Level III Ecoregions (black outlines) (Omernik 1987; USDI EPA 2018). Interactive maps, legends, and a mobile app are available (USFS WWETAC 2017; www.fs.fed.us/wwetac/threat-map/TRMSeedZoneMapper2.php?). Map prepared by M. Fisk, USDI USGS.

Releases

Stucky Ridge Germplasm is a selected class release of silverleaf phacelia for low pH and heavy metal contaminated soils in the intermountain foothills and mountains of central Montana and Wyoming. This release comes from seed collected within the Anaconda Smelter Superfund site in Deer Lodge County, Montana. It is recommended for use on severely impacted sites but also grows well on non-impacted sites. It is adapted to dry open sites, loam to sandy soils, elevations of 2,000 to 8,000 ft (600Ð2,500 m), average annual precipitation of 10 to 14 in (250Ð350 mm), and average frost-free periods of at least 90 days. Stucky Ridge did not survive in Idaho or Utah when planted in annual precipitation zones below 10 in (250 mm) (LeFebvre et al. 2017a).

Wildland Seed Collection

Silverleaf phacelia seeds are mature when capsules are dry, and seeds are hard and dark in color. Because flowering is indeterminate (Fig. 9), both mature capsules and flowers or buds may be present at the time of harvest (LeFebvre et al. 2017b). Bristly hairs on the coiled seed head make hand harvesting uncomfortable (Fig. 10) (Winslow 2002).

Figure 9. Silverleaf phacelia inflorescence exhibiting indeterminate flowering and seed maturation. Photo: BLM ID931 SOS.

Wildland Seed Certification

Verification of species and tracking of geographic source is necessary whether wildland seed is collected for immediate project use or as stock seed for cultivated increase. This official Source Identification process can be accomplished by following procedures established by the Association of Official Seed Certifying Agencies (AOSCA) Pre-Variety Germplasm Program (Young et al. 2020; UCIA 2015). Wildland seed collectors should become acquainted with state certification agency procedures, regulations, and deadlines in the states where they collect.

If wildland-collected seed is to be sold for direct use in ecological restoration projects, collectors must apply for Source-Identified certification prior to making collections. Pre-collection applications, site inspections, and species and seed amount verification are handled by the AOSCA member state agency where seed collections will be made (see listings at AOSCA.org).

If wildland seed collected by a grower or private collector is to be used as stock seed for planting cultivated seed fields or for nursery propagation (See Agricultural Seed Field Certification section), detailed information regarding collection site and collecting procedures must be provided when applying for certification. Photos and herbarium specimens may be required. Germplasm accessions acquired within established protocols of recognized public agencies, however, are normally eligible to enter the certification process as stock seed without routine certification agency site inspections. For contract grow-outs, however, this collection site information must be provided to the grower to enable certification.

Figure 10. Silverleaf phacelia seed heads covered with bristly hairs. Photo: BLM OR030 SOS.

Collection Timing

Seeds are ready for harvest when flower petals are tan, the calyx is papery, and the capsule is stiff and split open at the top (Fig. 11). Mature seeds are dark brown and hard (Winslow 2002; Luna et al. 2008).

The Bureau of Land ManagementÕs Seeds of Success collection crews made 28 collections of silverleaf phacelia seed over 7 years from 2002 to 2015. Most collections (64%) were made in July, but the earliest collection was made on June 28, 2012 in Malheur County, Oregon, at 2,355 ft (718 m) elevation, and the latest collection on September 22, 2015, from Gilpin County, Colorado, at 9,140 ft (2,786 m) elevation. In the single year with the most collections (8 in

2011), the earliest was made on July 1 from elevations of 3,615 to 4,407 ft (1,102Ð1,343 m) in Harney County, Oregon, and the latest was made on August 25 at 3,698 ft (1,127 m) in Boise County, Idaho (USDI SOS 2017). Seed was collected from late July to late September in Montana sites (Winslow 2002; Luna et al. 2008).

Figure 11. Silverleaf phacelia seeds and a dry capsule containing a seed. Photo: BLM OR030 SOS.

Collection Methods

Seed can be collected by hand stripping or by clipping filled seed heads (Fig. 12) (Luna et al. 2008; Bujak and Dougher 2017). Hands should be protected when collecting silverleaf phacelia seed (Winslow 2002). Bristly hairs on the seed heads contain an irritating oil that can cause rashes and itching that lasts several days (LeFebvre et al. 2017b).

Figure 12. Clipped silverleaf phacelia seed head. Photo: BLM OR110 SOS.

Several collection guidelines and methods should be followed to maximize the genetic diversity of wildland collections: 1) collect seed from a minimum of 50 randomly selected plants; 2) collect from widely separated individuals throughout a population without favoring the most robust or avoiding small stature plants; and 3) collect from all microsites including habitat edges (Basey et al. 2015). General collecting recommendations and guidelines are provided in online manuals (e.g., ENSCONET 2009; USDI BLM SOS 2021).

It is critical that wildland seed collection does not impact the sustainability of native plant populations. Collectors should take no more than 20% of the viable seed available at the time of harvest (USDI BLM SOS 2021). Additionally, care must be taken to avoid the inadvertent collection of weedy species, particularly those that produce seeds similar in shape and size to those of silverleaf phacelia.

Collection Rates

Between 0.1 and 11 ounces (4Ð300 g) of clean silverleaf phacelia seed was collected per hour per person based on 25 wildland seed collections made in Yellowstone National Park for an average collection rate of 1.6 oz (46 g)/hour/person (Majerus 1999). Wildland collections made by personnel at USDA Natural Resource Conservation ServiceÕs Plant Material Center in Bridger, Montana (Bridger PMC), yielded an average of 1.2 oz (33 g) of clean seed per hour/person, but rates varied by year, stand density, and collector expertise (Winslow 2002).

Post-Collection Management

At the Bridger PMC, seed collections are spread out on a tarp in a dry, sheltered, rodent-free environment (Winslow 2002). Seed is turned every 3 to 5 days until no moisture or warmth is detected. Dry seed is then put in breathable cloth or plastic seed sacks and stored in a cool, dry environment until it is cleaned (Winslow 2002; Luna et al. 2008).

Seed Cleaning

Small seed size, easily detached flower capsules, and fair seed flow, makes silverleaf phacelia moderately easy to clean (Winslow 2002). Seed is typically cleaned (Fig. 13) by processing it through a hammermill and then a fanning mill (Link 1993; Luna et al. 2008), but more detailed procedures are provided below.

Figure 13. Clean silverleaf phacelia seed. Photo: USFS Bend Seed Extractory.

At the Bridger PMC, seed harvested by clipping filled seed heads was cleaned by first processing through a hammermill and a series of different sized screens. Seed was cleaned of remaining chaff using a seed blower (SD Seed Blower, Seedburo Equipment, Des Plaines, IL) (Bujak and Dougher 2017). Bend Seed Extractory cleaned a small seed lot (0.24 lb [0.11 kg]) by first using a Westrup Model LA-H laboratory brush machine (Hoffman Manufacturing, Corvallis, OR), with a #14 mantel and medium speed. Seed was then air-screened using an office clipper with a 1/18 round top screen and 1/25 round bottom screen, medium speed, and medium air (Barner 2008).

Seed Storage

Silverleaf phacelia seed is orthodox and retained 90% viability when stored for 144 days at -4 ¡F (-20 ¡C) (RBG Kew 2021). Researchers estimate that seed viability can be retained through 5 to 10 years of storage at 37 to 41 ¡F (3Ð5 ¡C) in sealed containers (Link 1993; Winslow 2002; Luna et al. 2008).

Seed Testing

The Association of Official Seed Analysts (AOSA 2000) provides the following tetrazolium chloride (TZ) viability procedure for estimating seed viability of *Phacelia* species. Seed is imbibed on moist blotters, filter paper, or paper towels overnight at 68 to 77 ¡F (20Ð25 ¡C). Seed is cut longitudinally, a thin edge of the embryo is removed, and the remaining seed is exposed to a 0.1% TZ solution overnight at 86 to 95 ¡F (30Ð35 ¡C). Seeds with the entire embryo evenly stained are viable. Seed is nonviable when any part of embryo is unstained, there are black colored areas anywhere on the embryo, or the radical tip is black or discolored (AOSA 2000).

Viability Testing

Quick estimates of silverleaf phacelia seed fill can be made using the Ôpop testÕ, which uses heat to convert moisture in seeds to a gas that breaks the seed coat and produces a pop. Although silverleaf phacelia seed popped using this method, there were no germination or viability tests done on seeds that popped (Tilley et al. 2011).

Germination Biology

Silverleaf phacelia seed exhibits morphophysiological or deep physiological dormancy and germinates best with mechanical scarification (Luna et al. 2008; LeFebvre et al. 2015; Bujak and Dougher 2017; Kildisheva et al. 2019). Many studies show that germination is only marginally improved with stratification (Luna et al. 2008; NRCS 2015a; Barga et al. 2017; Kildisheva et al. 2019).

Several studies show that high germination rates of silverleaf phacelia can be achieved when after-ripened seed is scarified and then stratified. In trials conducted by the Bridger PMC, germination was highest (65%) after 6 minutes of scarification and 30 days of stratification. Half of all seed tested was mechanically scarified using a Seedburo Electric Seed Scarifier (Des Plaines, IL) with 40-grit sandpaper, then scarified and non-scarified seeds were put in cones filled with peat-based potting mix. Cones were treated to 0, 30, or 60 days of cold treatments (37 ¡F [3 ¡C]) and then put in a greenhouse (75Ð80 ¡F [24Ð27 ¡C] for 16 hrs of light and 65Ð70 ¡F [18Ð24 ¡C] for 8 hrs of dark) (Table 3; LeFebvre et al. 2015).

Table 3. Germination of TZ-viable silverleaf phacelia seed following scarification and stratification treatments (LeFebvre et al. 2015).

Scarification duration (s)	Chill period (days)	Germination (%)*
360	30	65a
360	60	47b
0	60	26c
0	30	15cd
0	0	13cd
360	0	1d

*Means in columns followed by different letters are significantly different ($P < 0.05$). Seed viability was 86%.

Findings were similar when Bujak (2015) compared cold-moist stratification, warm-moist stratification, gibberellic acid treatments, and scarification of seed collected from the Anaconda Superfund Site, Montana, and grown at the Bridger PMC. Seed was after-ripened in paper envelopes for 4 months at 70 ¡F (21 ¡C) then 12 months at 41 ¡F (5 ¡C) prior to the treatments. Seed was scarified in a Seedburo Electric Seed Scarifier (Des Plaines, IL) with 40-grit sandpaper. Increasing the duration of scarification over 90 seconds did not result in significant germination increases, but new sandpaper resulted in better germination than worn sandpaper. Germination was 87% within 4 days following 90 seconds of mechanical scarification, which was significantly greater ($P < 0.0001$) than controls (15%). Germination was low (2Ð11%) when unscarified seed was cold-moist (34 ¡F [1 ¡C]) or warm-moist (93 ¡F [34 ¡C]) stratified for 8 days. Increasing concentrations of gibberellic acid (GA3) significantly increased germination over controls ($P < 0.0001$). A high germination of 45% was achieved with 1000 mg/L GA3 treatments, much better than germination of controls (Bujak 2015). In supplemental studies, Bujak and Dougher (2017) examined after-ripened silverleaf phacelia seeds and found that the embryos were not underdeveloped or undifferentiated, embryos imbibed water, and excised embryos had a final germination of 100% within 6 days (Bujak and Dougher 2017).

In controlled experiments, silverleaf phacelia showed no germination response to smoke exposure when seeds were soaked for 20 hours in distilled water or 1:10, 1:100, or 1:1000 smoke water concentrations (Cox 2016).

Wildland Seed Yield And Quality

Post-cleaning seed yield and quality of seed lots collected in the Intermountain region are provided in Table 4 (USFS BSE 2017). Results indicate that silverleaf phacelia can generally be cleaned to high levels of purity, but the fill and viability of fresh seed is variable. Seeds/lb values for silverleaf phacelia reported elsewhere (153,000Ð450,000 seeds/lb [171,500Ð504,400 seeds/kg]) in the literature fell within the range reported in Table 4 (Link 1993; Winslow 2002; Luna et al. 2008; Wiese et al. 2012; Tilley et al. 2013; LeFebvre et al. 2017b; Ogle et al. 2017). Royal Botanic Gardens, Kew (2021) reported 517,218 seeds/lb (579,722 seeds/kg) for variety *compacta* and 704,348 seeds/lb (789,465 seeds/kg) for the species (RBG Kew 2021).

Table 4. Seed yield and quality of silverleaf phacelia seed lots collected in the Intermountain region, cleaned by the Bend Seed Extractory, and tested by the Oregon State Seed Laboratory or the USFS National Seed Laboratory (USFS BSE 2017).

Seed lot characteristic	Mean	Range	Samples (no.)
Bulk weight (lbs)	1.80	0.02Ð29	49
Clean weight (lbs)	0.12	0.001Ð0.72	49
Clean-out ratio	0.11	0.008Ð0.85	49
Purity (%)	97	87Ð99	48
Fill (%)[1]	95	47Ð99	49
Viability (%)[2]	95	79Ð98	34
Seeds/lb	486,584	103,231Ð750,993	48
Pure live seeds/lb	446,870	293,260Ð596,547	34

[1]100 seed X-ray test
[2]Tetrazolium chloride test

Marketing Standards

Acceptable seed purity, viability, and germination specifications vary with revegetation plans. Purity needs are highest for precision seeding equipment used in nurseries, while some rangeland seeding equipment handles less clean seed quite well.

Agricultural Seed Production

Silverleaf phacelia seed production plots were evaluated at the Bridger PMC for 4 years (Winslow 2002) and for 8 years at Oregon State University Malheur Experiment Station (OSU MES) in Ontario, Oregon (Fig. 14; Shock et al. 2018). At the Bridger PMC, annual seed production averaged 54 lbs/ac (61 kg/ha) and varied with weather and stand age (Winslow 2002). At OSU MES, seed yield averages ranged from 34.3 to 153 lbs/ac (38.4Ð171 kg/ha) and increased with irrigation in most years (Shock et al. 2018).

Figure 14. Silverleaf phacelia seed production plots growing at Oregon State UniversityÕs Malheur Experiment Station in Ontario, OR. Photo: USFS.

Agricultural Seed Certification

In order to minimize genetic changes in specific accessions of native species when increased in cultivated fields, it is essential to track the geographic source and prevent inadvertent hybridization or selection pressure. This is accomplished by following third party seed certification protocols for Pre-Variety Germplasm (PVG) as established by the Association of Official Seed Certification Agencies (AOSCA). AOSCA members in the U.S., Canada, and other countries administer PVG requirements and standards that track the source and generation of planting stock. Field and cleaning facility inspections then monitor stand establishment, proper isolation distances, control of prohibited weeds, seed harvesting, cleaning, sampling, testing, and labeling for commercial sales (Young et al. 2020; UCIA 2015).

Seed growers apply for certification of their production fields prior to planting and plant only certified stock seed of an allowed generation (usually less than four). The systematic and sequential tracking through the certification process requires preplanning, knowing state regulations and deadlines, and is most smoothly navigated by working closely with state certification agency personnel. See the Wildland Seed Certification section for more information on stock seed sourcing.

Site Preparation

At the Bridger PMC, silverleaf phacelia was planted in firm, weed-free seed beds with good soil moisture to 4-in (10 cm) depths (Winslow 2002).

Seed Pretreatments

In an evaluation of seed pretreatments and various seed coverings (sawdust, sand, mulch) at OSU MES, stand establishment was best for seed that was fungicide-treated, planted on the soil surface, covered with sand and sawdust, and protected with row cover (Table 5). The various planting and protection treatments were tested in November 2015 and November 2016, and percent stand emergence was evaluated in the following spring (early May) (Table 5). In winter 2015Ð16, plots were snow covered for 44 days, and in winter 2016Ð17, plots were snow covered for 89 days, which may explain the lack an effect of row cover on emergence in 2016Ð17 (Shock et al. 2018).

Weed Management

At the Bridger PMC, silverleaf phacelia seed production plots were planted with widely spaced rows (30 in [76 cm]) to allow for mechanical between-row cultivation, hand weeding, and spot herbicide treatments (LeFebvre et al. 2017). Irrigation trial plots were hand weeded at OSU MES (Shock et al. 2020).

Although there are no herbicides are registered for use in native forb seed production, several preemergent and post-emergent herbicides were tested on silverleaf phacelia at the Bridger PMC and OSU MES. Reference to products in this review does not endorse or recommend that product to the exclusion of others. Nor should any information be considered as recommendations for the application of herbicides.

Preemergent herbicides. All treated plots had lower emergence than untreated plots when preemergent herbicides with or without preceding charcoal treatments were evaluated on silverleaf phacelia seeded in fall 2012 at OSU MES (Shock et al. 2014). Emergence was evaluated on April 24, 2013 (Table 6), but weed pressure was too poor and variable to evaluate the effectiveness of weed control.

Table 5. Stand emergence of silverleaf phacelia (%) based on seed pretreatments, coverings, and protection. Percent stand was corrected to percent of viable seed planted based on TZ testing (Shock et al. 2018).Within a row, values followed by different letters are significantly different (*P* < 0.05). These treatments had no significant impact on emergence for seeding in 2013 where stand emergence ranged from 3.9 to 15% in mid-April 2014 (Shock et al. 2015).

Year	Row cover, fungicide, sawdust	Row cover, fungicide	Row cover, sawdust	Row cover, fungicide, sawdust, sand	Fungicide, sawdust	Mulch, fungicide	Untreated	Mean
2016	23.2b	28.3ab	21.8b	31.7a	11.1c	3.6c	8.5c	18.3
2017	9.5a	13.7a	12.3a	15.2a	11.8a	11.8a	12.7a	12.4

Table 6. Percent emergence of silverleaf phacelia following fall applications of preemergent herbicides at Oregon State UniversityÕs Malheur Experiment Station in Ontario, OR (Shock et al. 2014).

Preemergent herbicide	None	Pendimethalin	Dimethenamid	EPTC	Metolachlor	Trifluralin	Benefin	Bensulide
Application rate (lbs ai/ac)	NA	0.95	0.84	2.60	0.95	0.38	1.20	5.00
Silverleaf phacelia emergence (%) -C*	30.0	10.5	5.8	25.0	0.3	7.5	6.8	14.5
Silverleaf phacelia emergence (%) +C	Ñ	18.3	9.3	8.5	15.3	Ñ	Ñ	Ñ

*Charcoal applied on Nov 28, 2012 at rate of 189 lbs/ac prior to preemergent herbicide treatments(Shock et al. 2014).

Tests of preemergent herbicides in field studies in Montana (Bridger and Bozeman) showed that plots treated with linuron produced more than twice the density and cover of silverleaf phacelia than hand-weeded control plots, but abundance differences were not significant. Seed yield was about four times greater with linuron preemergent treatments and about three times greater with pendimethalin preemergent treatments than for hand-weeded controls. Treatments of imazapic reduced the density, cover, and seed yield of silverleaf phacelia from hand-weeded controls (Wiese 2009).

Post-emergent herbicides. Most of the post-emergent herbicide treatments tested on silverleaf phacelia in greenhouse or field trials resulted in plant damage or stand loss. In the greenhouse, plants sprayed with linuron (0.5 lb of active ingredient (ai)/ac [0.6 kg ai/ha]) or pendimethalin (1.7 lb ai/ac [1.9 kg ai/ha]) had similar biomass as controls, but plants sprayed with imazapic (0.13 lb ai/ac [0.14 kg ai/ha]) or halosulfuron (0.04 lb ai/ac [0.05 kg ai/ha]) had significantly lower biomass than controls ($P < 0.025$) (Wiese 2009; Wiese et al. 2011).

In the first round of post-emergent herbicide trials conducted at OSU MES, only field plots treated with Dimethenamid-P (0.85 lb ai/ac [0.95 kg ai/ha]) had no stand loss. Percent stand loss was less than 15% for plots treated with oxyfluorfen (0.06 lb ai/ac [0.07 kg ai/ha]), clethodim (0.05 lb ai/ac [0.6 kg ai/ha]), flumioxazin (0.05 lb ai/ac [0.6 kg ai/ha]), or imazamox (0.03 lb ai/ac [0.03 kg ai/ha]) and greater than 20% for plots treated with bromoxynil (0.12 lb ai/ac [0.13 kg ai/ha]), pendimethalin (0.95 lb ai/ac [1.1 kg ai/ha]), or carfentrazone (0.02 lb ai/ac [0.02 kg ai/ha]). Herbicides were applied in the spring (April 26, 2013) on plots seeded in the fall using a CO2 sprayer at 30 PSI applying 20 gal/ac. Stands were evaluated on May 14 (Shock et al. 2014).

In the second round of post-emergent herbicide field trials conducted at OSU MES, all silverleaf phacelia plants were injured by herbicide treatments. Injury was about 15% for treatments of bentazon (1.1 lb ai/ac [1.3 kg ai/ha]) + pendimethalin (0.95 lb ai/ac [1.1 kg ai/ha]) and linuron (1 lb ai/ac [1.1 kg ai/ha) + pendimethalin (0.95 lb ai/ac [1.1 kg ai/ha]). Injury was 35% or greater for treatments of: bromoxynil (0.125 lb ai/ac [0.14 kg ai/ha]) + pendimethalin (0.95 lb ai/ac [1.1 kg ai/ha]); oxyfluorfen (0.25 lb ai/ac [0.28 kg ai/ha]) + pendimethalin (0.95 lb ai/ac [1.1 kg ai/ha]); bromoxynil (0.125 lb ai/ac [0.14 kg ai/ha])) + pendimethalin (0.95 lb ai/ac [1.1 kg ai/ha]) + oxyfluorfen (0.25 lb ai/ac [0.28 kg ai/ha]); flumioxazin (0.128 lb ai/ac [0.14 kg ai/ha]) + pendimethalin (0.95 lb ai/ac [1.1 kg ai/ha]); and imazamox (0.0156 lb ai/ac [0.017 kg ai/ha]) + bentazon (1.125 lb ai/ac [1.3 kg ai/ha]) + pendimethalin (0.95 lb ai/ac [1.1 kg ai/ha]). Herbicides were sprayed in spring 2014 (April or May) on silverleaf phacelia plots seeded in fall 2013. Herbicides were delivered using a CO2 sprayer at 30 psi applying 20 gal/ac. Plant injury was evaluated in June 2014 (Felix et al. 2015).

Seeding

Dormant fall seeding is recommended for silverleaf phacelia (LeFebvre et al. 2017c), although plots were established with early spring planting at the Bridger PMC (Link 1993; Winslow 2002). At OSU MES, silverleaf phacelia was seeded on 5-ft (1.5 m) beds in 450-ft-long (137 m) rows in Nyssa silt loam soils (pH 8.3, 1.1% organic matter). Seeding occurred on October 30, 2012 and was done using a custom small-plot grain drill with disc openers in rows spaced 15 in (38 cm) apart. Seeds were placed on the soil surface (20Ð30 PLS/ft [66Ð98/m] of row) and covered with sawdust (558 lbs/ac [0.26 oz/ft of row]). Beds were protected by row cover (N-sulate, DeWitt Co, Sikeston, MO) until early May when row cover was replaced with bird netting. Bird netting was applied and removed annually (Shock et al. 2020).

At the Bridger PMC, silverleaf phacelia was seeded at a rate of 25 to 30 PLS/ft (66Ð98 PLS/m) of row using a two-row double-disk planter with depth bands. Seeds were planted 0.25 in (0.6 cm) deep (Winslow 2002). Seed production was good with seeding rates of 2.8 to 4.5 PLS lbs/ac (3.1Ð5 PLS kg/ha) in rows spaced 30 in (76 cm) apart (LeFebvre 2017).

Establishment And Growth

Seed production plots growing at OSU MES typically flowered from May to July and produced harvestable seed crops in late June or July (Table 7; Shock et al. 2020). Accumulated growing degree hours were higher than average in most years of the study and could not reliably be related to harvest dates (Tables 7 and 8; Shock et al. 2020).

Table 7. Flowering and harvest dates of non-irrigated and irrigated silverleaf phacelia seed production plots growing at Oregon State UniversityÕs Malheur Experiment Station in Ontario, OR (Shock et al. 2020).

Year*	Flowering			Irrigation		Harvest**
	Start	Peak	End	Start	End	
2013	5/17		7/30	5/22	7/3	Several
2014	5/5		7/10	4/29	6/10	7/14
2015 (1-yr-old stand)	4/28	5/26	8/7	5/20	6/30	8/6
2015 (3-yr-old stand)	4/28	5/26	8/7	4/29	6/10	Several
2016	4/28		6/17	4/27	6/7	6/23
2017	5/8	6/7		5/2	6/20	7/25
2018	5/6		6/20	5/16	6/27	6/27
2019	5/8	6/3	6/30	5/3	6/13	6/27

*See Irrigation section below for an explanation of the 1- and 3-year-old stands. All years following 2015 are averages of two different-aged stands.
**Seed was hand harvested multiple times because of uneven seed ripening by irrigation treatments (2013: 7/30 for 0 in, 8/7 for 4 in, and 8/19 for 8 in; 2015: 7/7 for 0 in and 7/21 for 4 and 8 in) (Shock et al. 2020).

Irrigation

Seed yield can be improved with irrigation (LeFebvre et al. 2017b; Shock et al. 2020). Researchers at the Bridger PMC recommend supplemental irrigation during dry periods of the growing season at sites receiving less than 16 in (406 mm) of annual precipitation. Irrigation and fertilization improved seed production at the Bridger PMC (LeFebvre et al. 2017b).

Irrigation responses for silverleaf phacelia at OSU MES were evaluated for two sets of plots: a 6-year-old stand planted in 2012 and a stand originating in 2015 from volunteer seed (Shock et al. 2020). Irrigation trials delivered 0, 4, or 8 in (100 or 200 mm) of water in the spring to plots seeded on October 30, 2012. Irrigation treatments were delivered four times at about 2-week intervals beginning at the time of bud formation and flowering (Table 7). Irrigation was delivered through drip tape buried 12 in (30 cm) deep, so as not to affect flowering and to limit germination of weed seed (Shock et al. 2020).

Stands seeded in 2012 had the highest seed yields with 4 in (100 mm) or 8 in (200 mm) of irrigation in 2013, 2014, and 2018 ($P < 0.05$; Table 9). It produced very little seed in 2016, and seed was not harvested. This stand regenerated from natural re-seeding in 2017 but did not produce seed until 2018. Stands from volunteer seed establishing in 2014 produced more seed with irrigation in 2015, 2016, and 2018 but not in 2017. Overall, yields were increased most in 2014 and 2018, which were years with below-average precipitation. Stands did not respond to irrigation in 2017 or 2019, both years of above-average precipitation (Tables 8 and 9). Very low seed yields in 2019 may have been caused by unusually high May precipitation after silverleaf phacelia had started flowering. Silverleaf phacelia showed a pattern of increased seed yields in the second year, a decline in the third, and increases again in the fourth or sixth years depending on year of establishment (Shock et al. 2020).

Table 8. Growing conditions for 7 years of silverleaf phacelia irrigation trials at Oregon State UniversityÕs Malheur Experiment Station, Ontario, OR (Shock et al. 2020).

Year	Precipitation (in)			Growing degree (50Ð86 ¡F) hour differences from the 25-yr average
	Spring	Winter + Spring	Fall + winter + spring	

2013	0.9	2.4	5.3	+147
2014	1.7	5.1	8.1	+195
2015	3.2	5.9	10.4	+410
2016	2.2	5.0	10.1	+221
2017	4.0	9.7	12.7	+45
2018	1.9	4.9	5.8	+158
2019	4.7	10.2	12.9	-5
7-yr mean	2.4	5.6	9.3	1,917 hrs (26-yr mean)

Table 9. Silverleaf phacelia seed yields with 0, 4, or 8 in of irrigation for 7 years of varied precipitation and growing conditions (Table 8) at Oregon State UniversityÕs Malheur Experiment Station, Ontario, OR (Shock et al. 2020).

Calendar year	Establishment year	Added irrigation		
		0 in	4 in	8 in
		Yield (lbs/ac)*		
2013	2012	35.3a	102.7b	91.2b
2014	2012	87.7a	305.7b	366.4b
2015	2012	78.8a	79.3a	65.0a
2018	2012	32.8a	108.6b	89.6ab
Mean		58.6a	149.1b	153.0b
2015	2014	0.0a	21.4b	50.4c
2016	2014	82.5a	125.2b	83.1a
2017	2014	20.3a	23.2a	23.2a
2018	2014	57.1a	128.5b	140.2b
2019	2014	11.6a	14.8a	16.0a
Mean		34.3a	65.4b	62.2b

*Yields within the same row followed by different letters are significantly different (*P*<0.05).

Pollinator Management

Silverleaf phacelia requires pollination for good seed production and attracts a variety of native bees (See Pollination section). Any practice to support and protect native bee populations would be beneficial to seed production.

Pest Management

The following fungi were collected from silverleaf phacelia plants growing in the West: *Erysiphe cichoracearum*, *Peronospora hydrophylli*, *Puccinia recondita*, *Ramularia phaceliae* (Farr and Rossman 2017). There are, however, no known pests or problems associated with growing silverleaf phacelia in northern Rocky Mountains or Intermountain West (LeFebvre et al. 2017b). Silverleaf phacelia samples collected from seed production plots at OSU MES were not infected with powdery mildew (Mohan and Shock 2014).

Seed Harvesting

Seed can be hand-harvested or directly combined if maturity across the field is uniform. Seed was often harvested in late June or July at OSU MES (Table 6) and in late July or early August at the Bridger PMC (LeFebvre et al. 2017b). Irrigation and fertilization improved seed production and increased seed head height for improved combine harvests at the Bridger PMC (LeFebvre et al. 2017b). At OSU MES, seed was harvested with a small-plot combine in 2014 and 2015 and manually in 2016 and 2017 when plant heights were low (Fig. 15; Shock et al. 2020).

Figure 15. Silverleaf phacelia nearly ready for harvest at Oregon State UniversityÕs Malheur Experiment Station in Ontario, OR. Photo: USFS.

Seed Yields And Stand Life

Silverleaf phacelia produces seed in its first or second year and stands are harvestable for up to 5 years (LeFebvre et al. 2017b; Shock et al. 2020). At the Bridger PMC, plants flowered from May to September in growing seasons following the seeding year. Average seed production of Stucky Ridge Germplasm (see Releases section) averaged 56 to 65 lbs of clean seed/ac (63Ð73 kg/ha). Stands were productive for 3 to 5 years, and seed was harvested when seed pods began to shatter, usually in mid-July to early August (LeFebvre et al. 2017b). At OSU MES seed was harvested in the first year. Stands produced crops for 5 years. Seed yields increased in the second year, declined in the third, and increased again in the fourth year (Shock et al. 2020). Seed yields of up to 90 lbs/ac (101 kg/ha) were possible without irrigation but average seed yields for non-irrigated stands were much lower (34 or 59 lbs/ac [38Ð66 kg/ha]) (Shock et al. 2020).

Plant growth regulators (PGRs) were evaluated to improve mechanical harvest of silverleaf phacelia seed (Keating 2014). On any given day from July through August at the Bridger PMC, a single silverleaf phacelia plant may have flower buds, flowers, mature seed, and shed seed, so researchers tested the effects of PGRs (gibberellin, paclobutrazol, ethephon, and a hormone compound containing gibberellic acid, cytokinin, and indolebutyric acid) on seed yield, seed quality, and plant growth. Only paclobutrazol, which limits longitudinal shoot growth and plant size showed promise. Two foliar applications of paclobutrazol at 30 ppm at the 1-month rosette stage and again 3 weeks later doubled seed yields from controls without decreased seed germination or viability. Seed yield was increased even more with paclobutrazol in thinned plots (10 plants/24 × 6-ft plots). Seed yield was determined by hand-harvesting plots when at least 40% of seed samples appeared ripe. None of the PGRs resulted in consistent plant heights of 4 in (10 cm) or more, which was considered the minimum for mechanical harvests (Keating 2014).

Nursery Practice

Several protocols have been used to successfully grow silverleaf phacelia in the nursery. At the Bridger PMC, germination of silverleaf phacelia was good for fall-sown seed in containers kept where they experienced winter stratification and fluctuating spring temperatures (LeFebvre et al. 2017b). Seed dormancy has also been broken by sowing seed 0.13 to 0.25 in (0.3Ð0.6 cm) deep in 4 to 7 in^3 (66Ð115 cm^3) containers filled with a commercial peat and sand propagation media. Containers are watered, left overnight, and then kept in a high humidity cooler (33Ð37 ¡F [0.5Ð2.8 ¡C]) for up to 150 days (LeFebvre et al. 2017b).

Burkle and Runyon (2016) used the following procedure to produce silverleaf phacelia plants that flowered in their first season. Seed collected from Mount Ellis, Bozeman, Montana, was sown in cone-tainers (2.6 in [6.5 cm] wide, 9.8 in [25 cm] tall) filled with Sunshine Mix #1 (Sun Gro Horticulture, Agawam, MA) with 1 tsp. Osmocote fertilizer (Scotts Company, Marysville, OH). Seeds were planted in October and kept in a greenhouse (79 ¡F [26 ¡C] day/59 ¡F[15 ¡C] night, 16 hr photoperiod) for 6 weeks before being vernalized in a climate-controlled chamber (39 ¡F [4 ¡C], 12 hr photoperiod) for 100 to 130 days. Plants began flowering within 4 to 6 weeks of returning to the greenhouse (Burkle and Runyon 2016).

Researchers found that with low application rates of nitrogen (N) flowering silverleaf phacelia plants can be produced rapidly (Bujak 2015; Bujak and Dougher 2020). Experiments were initiated in June 2014 and continued for 71 days, at which time plants were flowering and marketable. Plants were grown from seed collected from fields growing at the Bridger PMC. Seed was germinated in germination boxes. After radicle extension of at least 0.4 in (1 cm), seeds were transplanted into 150-cell plug trays filled with Sunshine mix #1, where they were grown to the cotyledon stage (28 days after sowing). Seedlings were then transplanted to 4-in (10 cm) square pots or 5.6 oz (164 mL) cone-tainers and fertilized weekly with 0, 50, 100, 200, or 400 mg of N/l using water soluble 20:10:20 NPK with micronutrients. Plants were kept in a greenhouse (86 ¡F [30 ¡C] day/70 ¡F [21 ¡C] night) without supplemental lighting. In both container types, plant height and spread doubled with 50 mg/l of N. Flowering incidence increased with higher N rates, with most flowering occurring with 400 mg/l of N in both container types. Root dry weight increased with increasing levels of N but was double in square plots compared to cone-shaped containers. However, root-to-shoot ratio decreased when more than 50 mg/l of N was applied. The 10-cm square pot was superior to the cone-tainer, allowing for greater plant height and spread (Bujak 2015; Bujak and Dougher 2020).

Luna et al. (2008) produced plugs from seed for use in Glacier National Park, Montana. Seed collected from Siyeh Bend was cold stratified for 60 days, then placed in containers filled with 70% peat, perlite, vermiculite mix (6:1:1) and 30% coarse sand with a controlled release fertilizer (13:13:13 NPK) and micronutrient fertilizer. Seeds were lightly covered with the same medium, hand watered, and kept in a greenhouse (70Ð77 ¡F [21Ð25 ¡C] day/61Ð64 ¡F [16Ð18 ¡C] night) until mid-May when containers were moved to an outdoor nursery. Germination was non-uniform. True leaves appeared 2 weeks following germination followed by rapid root and shoot development. Careful irrigation is needed to prevent root crown rot of the prostrate seedlings. Plants were fertilized with NPK 20-20-20 at 8 weeks at 100 ppm and at 12 weeks at 200 ppm. Twelve weeks after germination (August, September), seedlings were root tight with 6 to 10 true leaves. Irrigation was gradually reduced in September and October. Plants were hardened for 4 weeks and overwintered outdoors under protective foam and snow (Luna et al. 2008).

Wildland Seeding And Planting

Research conducted by the Bridger PMC suggests that silverleaf phacelia should be seeded in a firm weed-free seed bed, 0.25 in (0.6 cm) deep in rows spaced 12 to 14 in (30Ð36 cm) apart. Fall seeding is recommended when soil temperatures are below 40 ¡F (4 ¡C) to prevent late-season germination. Full stand seeding rates are 7 PLS lbs/ac (8 kg/ha) for drill seeding, 14 PLS lbs/ac (16 kg/ha) for broadcast seeding, and 28 PLS lbs/ac (31 kg/ha) for broadcast seeding in critical areas. These full stand rates would be adjusted as a percentage of a multi-species seeding mixture in wildland restoration. Newly seeded or planted areas should be protected from grazing for at least two growing seasons (LeFebvre et al. 2017b).

Silverleaf phacelia established successfully at several western sites, but in some cases, persistence appeared short-lived although post-seeding monitoring was limited. At Curlew National Grassland near American Falls, Idaho, the seeding site was burned in 2006, plowed and packed in fall 2009, and glyphosate treated in June and July 2010. Silverleaf phacelia was drill seeded on November 17, 2010 at a rate of 40 to 50 pure live seed (PLS)/ft² (431Ð538/m²). Density of silverleaf phacelia was 0.3 plants/ft² (3.3/m²) on July 11, 2011; 0.006 plants/ft² (0.7/m²) on June 14, 2012; 0.009 plants/ft² (0.1/m²) on June 20, 2013; and 0 plants in 2014. The source of silverleaf phacelia seed used in this study was not reported (Tilley 2014).

Silverleaf phacelia was present in 2 out of 3 post-seeding years on drill seeded plots and in one of three post-seeding years on broadcast seeded plots on a reclaimed well pad about 31 mi (50 km) from Pinedale, Wyoming (Winslow et al. 2009). Topsoil (6 in [15 cm]) was taken from the site before drilling and stored for 37 months. In reclamation, the topsoil was reapplied, and the soil was ripped, smoothed, and firmed. This process resulted in a fluffy seedbed not ideal for seed placement. Silverleaf phacelia seed (Stucky Ridge Germplasm obtained from the Bridger PMC, see Releases section) comprised 5.1% of a mixture seeded using a Truax drill at a rate of 2 seeds/ft² (22/m²) and an ATV-mounted broadcast seeder at a rate of 7 seeds/ft² (44/m²) (Winslow et al. 2009).

Despite low initial establishment, silverleaf phacelia plants (Stucky Ridge Germplasm, see Releases section) exhibited good vigor, cover, and seed production the third growing season following seeding a Superfund site near Anaconda, Montana. Soils were acidic (pH 5.7) gravelly loams with high copper and moderate arsenic and other metal levels concentrated in the upper 2 in (5 cm) of soil. The site had an annual precipitation of 10 to 13 in (254Ð330 mm) and averaged 90 to 105 frost-free days/year. Soil was plowed to 6 in (15 cm) and lime and fertilizer were added before a variety of grasses, forbs, and subshrubs were seeded in May 2003. Establishment of silverleaf phacelia was less than 0.5 seedlings/ft² (5 seedlings/m²), but by the third post-seeding growing season, surviving plants exhibited good vigor, cover, and seed production (NRCS 2015b).

Silverleaf phacelia (Stucky Ridge Germplasm, see Releases section) was one of the top performing forbs in field trials conducted at the Bridger PMC to identify pollinator-friendly forbs for commercial production (Majerus et al. 2018; Pokorny and Jacobs 2018). Silverleaf phacelia and Maximilian sunflower (*Helianthus maximiliani*), and narrow purple coneflower (*Echinacea angustifolia*) were rated highest for flower development, pollinator friendliness, and soil stability in field studies evaluating establishment and growth in single species, Indian ricegrass (*Achnatherum hymenoides*)-forb mix, and alternate row forb-Indian ricegrass planting arrangements. The mix of forbs included silverleaf phacelia, Maximilian sunflower, Rocky Mountain beeplant (*Cleome serrulata*), narrow purple coneflower, dotted blazing star (*Liatris punctata*), and fuzzytongue penstemon (*Penstemon eriantherus*). Seeding occurred in late November 2012 using a 4-row cone planter (Kincaid Equipment Manufacturing, Haven, KS) equipped with double-disk furrow openers, depth bands, and double packer wheels. Rows were spaced 14 in (36 cm) apart, and seeds were planted 0.25 in (0.6 cm) deep. Individual species were seeded at 25 seeds/ft² (269/m²) in four plots with 20-ft-long (6 m) rows. Forb-Indian ricegrass mixed plots were seeded at 30 seeds/ft² (323/m²) (80% forb, 20% grass) in four 60-ft-long (18 m) rows. In alternate row plots, Indian ricegrass was seeded at 20 seeds/ft² (215/m²), and forbs were seeded at 30 seeds/ft² (323/m²) both in two 60-ft (18 m) rows. At the Bridger PMC soils are moderately alkaline, Haverson, silty, clay loams, and annual precipitation averages 10 in (254 mm). Experimental fields were glyphosate treated (64 oz/ac [4.7 l/ha]) before seeding, and following seeding were maintained under dryland conditions, not fertilized, and hand weeded. Plants were allowed to mature, shatter seed each fall and were mowed each spring before green-up. Across all seeding arrangements, silverleaf phacelia plant height averaged 4 in (10 cm) in 2013, 12 in (30 cm) in 2014, and 8 in (20 cm) in 2015 and 2016. Silverleaf phacelia, Maximilian sunflower, and narrow purple coneflower had the best flower development, pollinator friendliness, and soil stability in individual, mixed, and alternate plots (Table 10; Majerus et al. 2018; Pokorny and Jacobs 2018).

Table 10. Mature plant and seedling density of silverleaf phacelia (Stucky Ridge Germplasm) following seeding on November 29, 2012, at the NRCS Plant Materials Center in Bridger, Montana (Majerus et al. 2018; Pokorny and Jacobs 2018).

Plots	Seeding rate (PLS/ft²)	Year	Mature plants/ft²	Seedlings/ft²
Individual	25	2015	1.8	6.2
		2016	1.1	0.7
Mixed	4	2015	0.8	2.3
		2016	0.3	0.4
Alternate row	5	2015	0.6	1.5
		2016	0.2	0.1

In a native garden established adjacent to the Governor Tom McCall Preserve between the Hood River and The Dalles, Oregon, the majority of silverleaf phacelia transplants survived to the 2-year monitoring period (Youtie 1992). Seed collected near the Preserve was stored in the refrigerator for several months then grown in a greenhouse from November 1990 to February 1991. Seedlings were moved to a cold frame for a few weeks before being planted in early March. Transplants were watered once/week for 6 weeks (Youtie 1992).

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