

SPECIES: *Lepidium latifolium*

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INTRODUCTORY

SPECIES: *Lepidium latifolium*

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AUTHORSHIP AND CITATION:

Zouhar, Kris. 2004. *Lepidium latifolium*. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: <http://www.fs.fed.us/database/feis/> [2007, September 24].

FEIS ABBREVIATION:

LEPLAT

SYNONYMS:

Cardaria latifolia (L.) Spach [87]

NRCS PLANT CODE [83]:

LELA2

COMMON NAMES:

perennial pepperweed
broadleaved pepperweed
tall whitetop

TAXONOMY:

The currently accepted name for perennial pepperweed is *Lepidium latifolium* L. (Brassicaceae) [[22](#),[29](#),[31](#),[36](#),[38](#),[41](#),[42](#),[43](#)].

LIFE FORM:

Forb

FEDERAL LEGAL STATUS:

None

OTHER STATUS:

As of this writing (2004), perennial pepperweed is designated a noxious or prohibited weed or weed seed in at least 13 states in the United States and 1 Canadian province [[84](#)]. See the [Invaders](#), [Plants](#), or [APHIS](#) databases for more information.

DISTRIBUTION AND OCCURRENCE

SPECIES: *Lepidium latifolium*

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GENERAL DISTRIBUTION:

Perennial pepperweed is native to western Asia and southeastern Europe and now occurs from North Africa north through Europe to Norway and east to the western Himalayas. It has been introduced to Australia, Mexico, and throughout much of the U.S. Perennial pepperweed was probably introduced into North America several times, possibly as a contaminant of sugar beet (*Beta vulgaris*) seed, imported from eastern Europe ([[39](#),[99](#),[100](#)] and references therein).

In the U.S., perennial pepperweed occurs in a few states along the eastern seaboard, in several midwestern states, and in all far western states. [Plants database](#) provides a state distribution map of perennial pepperweed. It is also found in Quebec, western Canada, and Mexico. Perennial pepperweed has greatly increased in distribution and dominance in western North America during the past 2 decades ([[99](#)] and references therein).

Perennial pepperweed occurs throughout California, except coastal rainforest in the northwest, and low elevation desert in the southeast. Perennial pepperweed is a serious problem in the Modoc Plateau [[81](#)]. Small infestations of perennial pepperweed occur along roadsides in the Sierra Nevada. It is found east of the Sierra Nevada in native hay meadows and managed alkaline wetlands. Its range in southern California is not well documented. According to observations by land managers, perennial pepperweed populations in California have expanded, and it has increased its overall range during the last 15 years [[39](#),[101](#)]. In the Intermountain Area perennial pepperweed occurs along river systems from the lower edge of coniferous forests to saline/alkaline deltas and sinks, and is adapted to string meadows characteristic of the big sagebrush zone. It is not yet a major pest in high mountain meadows in the coniferous forest zone [[101](#)]. Perennial pepperweed is among several nonnative species that pose "critical weed management concerns" in the San Luis Valley in Colorado [[73](#)],

where it is particularly problematic in Monte Vista and Alamosa National Wildlife refuges [12].

The following lists include North American ecosystems, habitats, and forest and range cover types in which perennial pepperweed is known or thought to be invasive, as well as some types that may be invaded by perennial pepperweed following disturbances in which vegetation is killed and/or removed and/or soil disturbed (e.g. cultivation, logging, fire, grazing, herbicide application, flooding). These lists are not necessarily exhaustive, as habitat information for perennial pepperweed in the midwestern and eastern states is not available.

Perennial pepperweed is invasive primarily in riparian areas and wetlands and may invade adjacent areas once established [9,99]. Some ecosystems and plant communities are included in the following lists because wetland and riparian areas within these types may be susceptible to invasion by perennial pepperweed. More information is needed regarding of particular ecosystems and plant communities where perennial pepperweed is invasive.

ECOSYSTEMS [27]:

FRES17 Elm-ash-cottonwood
 FRES19 Aspen-birch
 FRES20 Douglas-fir
 FRES21 Ponderosa pine
 FRES23 Fir-spruce
 FRES28 Western hardwoods
 FRES29 Sagebrush
 FRES30 Desert shrub
 FRES34 Chaparral-mountain shrub
 FRES36 Mountain grasslands
 FRES38 Plains grasslands
 FRES39 Prairie
 FRES41 Wet grasslands
 FRES42 Annual grasslands

STATES/PROVINCES: [\(key to state/province abbreviations\)](#)

UNITED STATES

AZ	CA	CO	CT	ID	IL	IN	KS	MA	MO
MT	NE	NV	NH	NM	NY	OR	TX	UT	WA
WY									

CANADA

AB	BC	PQ
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MEXICO

BLM PHYSIOGRAPHIC REGIONS [5]:

1 Northern Pacific Border
 2 Cascade Mountains
 3 Southern Pacific Border
 4 Sierra Mountains
 5 Columbia Plateau
 6 Upper Basin and Range
 7 Lower Basin and Range
 8 Northern Rocky Mountains

- 9 Middle Rocky Mountains
- 10 Wyoming Basin
- 11 Southern Rocky Mountains
- 12 Colorado Plateau
- 13 Rocky Mountain Piedmont
- 14 Great Plains
- 16 Upper Missouri Basin and Broken Lands

KUCHLER [\[46\]](#) PLANT ASSOCIATIONS:

- K025 Alder-ash forest
- K026 Oregon oakwoods
- K030 California oakwoods
- K035 Coastal sagebrush
- K036 Mosaic of K030 and K035
- K037 Mountain-mahogany-oak scrub
- K038 Great Basin sagebrush
- K040 Saltbush-greasewood
- K048 California steppe
- K049 Tule marshes
- K050 Fescue-wheatgrass
- K051 Wheatgrass-bluegrass
- K055 Sagebrush steppe
- K056 Wheatgrass-needlegrass shrubsteppe
- K063 Foothills prairie
- K064 Grama-needlegrass-wheatgrass
- K069 Bluestem-grama prairie
- K070 Sandsage-bluestem prairie
- K073 Northern cordgrass prairie
- K074 Bluestem prairie
- K076 Blackland prairie
- K098 Northern floodplain forest
- K101 Elm-ash forest

SAF COVER TYPES [\[25\]](#):

- 16 Aspen
- 63 Cottonwood
- 217 Aspen
- 220 Rocky Mountain juniper
- 222 Black cottonwood-willow
- 235 Cottonwood-willow
- 246 California black oak
- 249 Canyon live oak
- 250 Blue oak-foothills pine
- 255 California coast live oak

SRM (RANGELAND) COVER TYPES [\[78\]](#):

- 101 Bluebunch wheatgrass
- 102 Idaho fescue
- 103 Green fescue
- 105 Antelope bitterbrush-Idaho fescue
- 107 Western juniper/big sagebrush/bluebunch wheatgrass
- 201 Blue oak woodland

202 Coast live oak woodland
203 Riparian woodland
210 Bitterbrush
214 Coastal prairie
215 Valley grassland
217 Wetlands
303 Bluebunch wheatgrass-western wheatgrass
304 Idaho fescue-bluebunch wheatgrass
305 Idaho fescue-Richardson needlegrass
306 Idaho fescue-slender wheatgrass
307 Idaho fescue-threadleaf sedge
309 Idaho fescue-western wheatgrass
314 Big sagebrush-bluebunch wheatgrass
401 Basin big sagebrush
402 Mountain big sagebrush
403 Wyoming big sagebrush
404 Threetip sagebrush
406 Low sagebrush
408 Other sagebrush types
409 Tall forb
411 Aspen woodland
413 Gambel oak
414 Salt desert shrub
418 Bigtooth maple
419 Bittercherry
422 Riparian
501 Saltbush-greasewood
601 Bluestem prairie
602 Bluestem-prairie sandreed
604 Bluestem-grama prairie
605 Sandsage prairie
606 Wheatgrass-bluestem-needlegrass
607 Wheatgrass-needlegrass
609 Wheatgrass-grama
611 Blue grama-buffalo grass
615 Wheatgrass-saltgrass-grama
701 Alkali sacaton-tobosagrass
702 Black grama-alkali sacaton
712 Galleta-alkali sacaton
724 Sideoats grama-New Mexico feathergrass-winterfat
725 Vine mesquite-alkali sacaton
802 Missouri prairie
803 Missouri glades
805 Riparian

HABITAT TYPES AND PLANT COMMUNITIES:

Perennial pepperweed seems to be most problematic in riparian areas and wetlands in California, Nevada, and the Intermountain Area. Information on habitat types and plant communities in which perennial pepperweed occurs comes primarily from literature focused on these areas. More information on habitat types and plant communities where perennial pepperweed occurs outside these areas is needed to better understand and predict its invasive potential.

In **California**, perennial pepperweed is most common in coastal areas, beaches, tidal shores, inland marshes, riparian areas, wetlands, grasslands, and roadsides, and has the potential to invade montane wetlands [15,36]. Perennial pepperweed occurs at the Honey Lake Wildlife Refuge in northeastern California, where native vegetation includes black greasewood (*Sarcobatus vermiculatus*), saltgrass (*Distichlis spicata*), basin wildrye (*Leymus cinereus*), and rushes (*Juncus* spp.) [11]. At the Cosumnes River Preserve, small populations of perennial pepperweed establish in grasslands "in areas that have at least some sun" [72]. Perennial pepperweed has invaded pickleweed- (*Salicornia* spp.) dominated marshes in some areas in California, although, in most areas, it typically prefers sites slightly higher in elevation than those dominated by pickleweed [39].

Perennial pepperweed is considered "highly invasive and competitive" in sagebrush (*Artemisia* spp.) ecosystems in the **Intermountain Area**, where it is found in locally dense populations in transitions from meadow to upland [62]. It also commonly infests native hay meadows in this area, where plant communities consist of native and introduced perennial grasses, sedges (*Carex* spp.), and rushes [99].

At Malheur National Wildlife Refuge in **Oregon**, perennial pepperweed occurs in dense stands with trace amounts of beardless wildrye (*L. triticoides*), bottlebrush squirreltail (*Elymus elymoides*), basin wildrye, saltgrass, cheatgrass (*Bromus tectorum*), flixweed tansymustard (*Descurainia sophia*), rushes, and sedges in lower areas [44]. At Diamond Pond in southeastern Oregon, amid plant communities dominated by shadscale (*Atriplex confertifolia*), black greasewood, spiny hopsage (*Grayia spinosa*), basin big sagebrush (*Artemisia tridentata* ssp. *tridentata*), rabbitbrush (*Chrysothamnus* spp.), and horsebrush (*Tetradymia* spp.), perennial pepperweed codominates with stinging nettle (*Urtica dioica*) near the western margin of the pond among stands of native and nonnative weeds [90].

Perennial pepperweed occurs in riparian areas east of the Cascades in **Oregon** and **Washington** where plant associates include desert false indigo (*Amorpha fruticosa*), sagebrush, knapweed (*Centaurea* spp.), reed canarygrass (*Phalaris arundinacea*), willow (*Salix* spp.), Fuller's teasel (*Dipsacus fullonum* ssp. *sylvestris*), dock (*Rumex* spp.), cheatgrass, and tumble mustard (*Sisymbrium* spp.) [28].

Cox [19] reported in 1997 that the heaviest infestations of perennial pepperweed in **Idaho** were in the southwestern portion of the state, with small infestations in southern and eastern Idaho. The heavy infestations occurred primarily near rivers, canals, and in other areas with high water tables. It was not considered a problem in cropland, but was considered a potential pest in pastures if not controlled. While the author states that county weed control superintendents indicated perennial pepperweed was not rapidly spreading, it did appear to be getting denser in some areas [19].

In **Nevada**, perennial pepperweed is a problem for ranchers and natural resource managers along the Humboldt and lower Truckee Rivers in the western part of the state [81]. It is also reported on Nature Conservancy preserves such as Ash Meadows, where it occurs along edges (e.g. roads, streams, etc.), and in areas where changes in hydrology (i.e. water release timing) and loss of native cottonwood (*Populus* spp.) recruitment enables perennial pepperweed establishment. Here perennial pepperweed affects cottonwood and willow communities and oxbow meadows [72].

In **Utah**, perennial pepperweed is found in riparian and wetland habitats and, less commonly, in dry barrow pits and roadsides [88]. Along the Green River in Uintah County, perennial pepperweed occurs in areas that would naturally consist of saltgrass, alkali sacaton (*Sporobolus airoides*), and povertyweed (*Iva axillaris*) [65].

On a study site in northwestern **Colorado**, dominated by basin big sagebrush, perennial pepperweed occurs with twisted moss (*Tortula ruralis*) and desert goosefoot (*Chenopodium pratericola*) in valley bottoms near streams, but not away from streams [18].

Perennial pepperweed is less common in the **eastern U.S.** On the Atlantic coast, perennial pepperweed is rare, but occurs on beaches and tidal shores from New York to Massachusetts [24,76], and at widely scattered

locations elsewhere in the northeastern U.S. [29].

BOTANICAL AND ECOLOGICAL CHARACTERISTICS

SPECIES: *Lepidium latifolium*

- [GENERAL BOTANICAL CHARACTERISTICS](#)
- [RAUNKIAER LIFE FORM](#)
- [REGENERATION PROCESSES](#)
- [SITE CHARACTERISTICS](#)
- [SUCCESSIONAL STATUS](#)
- [SEASONAL DEVELOPMENT](#)



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GENERAL BOTANICAL CHARACTERISTICS:

The following description of perennial pepperweed is a compilation of information from several sources [29,36,37,38,39,88] unless otherwise cited. It provides characteristics that may be relevant to fire ecology, and is not meant for identification. Correct identification of nonnative invasive species is critical before control measures are implemented. Keys for identification of perennial pepperweed are available (e.g. [22,29,31,38,43]). According to Young and others [101], none of the *Lepidium* species native to North America is similar in size and growth habit to perennial pepperweed.

Perennial pepperweed is a nonnative, perennial forb with 1 to many aboveground stems, 3 to 8 feet (1-2.5 m) tall. Initially, shoots form a rosette near the soil surface (see [Seasonal Development](#)). Basal leaves are long-petioled, 4 to 12 inches (10-30 cm) long and 1 to 3 inches (2.5-8 cm) wide. Older stems have alternate cauline leaves, 0.4 to 1.5 inches (1-4 cm) wide. Lower leaves are petioled and upper leaves are sessile. Leaf size decreases up the stem. Leaf area of perennial pepperweed is highest at the flowerbud stage when it reaches values over 26,528 cm² leaf area/m². Leaf area is not evenly distributed within the perennial pepperweed canopy, with about one half of the leaf area in the top third of the canopy during the flowerbud to fruiting stages. Total leaf area decreases as perennial pepperweed stems flower and fruit (Renz and DiTomaso, unpublished data, as cited by [67]).

Perennial pepperweed has a panicle inflorescence 5 to 6 inches (25-27.5 cm) wide and composed of many small flowers, about 3 mm wide, in dense clusters at the tops of stems. Fruits are 2-chambered pods (silicles), about 2 mm long at maturity and slightly flattened. Fruits contain 1 seed per chamber, about 1mm long and 0.5 mm wide.

Perennial pepperweed roots are typically highly elongated and thick, with minimal branching. Some roots creep horizontally below the soil and others penetrate deep into the soil, but neither type forms dense clusters of roots. Roots are coarse and widely spaced [8]. Excavation of perennial pepperweed belowground biomass in a riparian

habitat revealed that 19% of perennial pepperweed roots occurred in the top 4 inches (10 cm) of soil, and 85% in the top 24 inches (60 cm) [71]. Some perennial pepperweed roots may extend much deeper. In excavations at Honey Lake National Wildlife Refuge, Blank and Young [11] observed perennial pepperweed rooting depth in excess of 9 feet (3 m). Belowground biomass constitutes about 40% of perennial pepperweed's total biomass [71]. This extensive creeping root system is thought to enhance the belowground competitiveness of perennial pepperweed for water and nutrients while increasing the carbohydrate reserve important for rapid shoot development in the spring [9,67]. Several floras describe rhizomes in perennial pepperweed; however, researchers indicate that it has no rhizomes, and that the underground portion of perennial pepperweed is technically creeping roots [70,95]. Also, no floras describe a woody caudex in perennial pepperweed, but several authors indicate that the base of the stem is woody, and that roots enlarge at the soil surface, forming a semi-woody crown (e.g. [39,67,70,101]).

Perennial pepperweed may occur as spotty, scattered populations, or as large, dense, nearly monospecific stands [67,101]. Dense colonies are most common under moist conditions, as roots creep out from initial plants and form new shoots, eventually merging into closed canopy stands [99]. The aerial portion of perennial pepperweed stems dies back to the ground in fall and winter, leaving a thick thatch of dry, semi-woody stems that may persist for several years [101]. According to Renz [67], large amounts of litter may build up in dense infestations, with litter layers reaching upward of 4 inches (10 cm) in depth. Old stems and deep litter form layers that are impenetrable to light and prevent the emergence of other plant species, as few plants besides perennial pepperweed have enough stored energy to grow through perennial pepperweed's dense litter layer [67].

To date, there is no verifiable evidence of allelopathy in perennial pepperweed (Blank and young, unpublished data, as cited by [100]).

RAUNKIAER [64] LIFE FORM:

[Hemicryptophyte](#)

[Geophyte](#)

REGENERATION PROCESSES:

Perennial pepperweed reproduces from seed, creeping roots, and semi-woody crowns [70,95].

Breeding system: No information is available on this topic.

Pollination: According to DiTomaso and Healy [21], perennial pepperweed is insect pollinated.

Seed production: According to a review by Howald [39], each mature perennial pepperweed plant has the capacity to produce thousands of seeds each year. Seed production is reported as 16 billion seeds per hectare per year from stands with 200 perennial pepperweed stems per m² ([10,67] and references therein).

According to Young and others [100], flowering of perennial pepperweed is profuse in dry years, but seed set and maturity is minimal. In very wet years, infection with the white rust (*Albugo* spp.) appears to largely inhibit seed production [100].

Seed dispersal: According to a review by Howald [39], perennial pepperweed seeds have no special adaptations for long-distance dispersal, although they could be transported by wind, water, and possibly by waterfowl and other animals. Perennial pepperweed seeds may also be transported in agricultural products and by vehicles and machinery.

Perennial pepperweed seeds do not dehisce from the pods at maturity, but fall at irregular intervals during the winter [101], and some seeds may remain in pods until spring [21].

Spread to new areas may occur when seeds are transported in water from upstream sources [65]. According to

Young [94], perennial pepperweed seeds initially sink when immersed in water. Then a layer of mucilage forms on the seed surface making them buoyant.

The role of domestic livestock and waterfowl in dispersing perennial pepperweed seeds is not fully understood [100].

There is concern that perennial pepperweed seeds are transported in high quality alfalfa (*Medicago sativa*) grown in the Intermountain Area. However, perennial pepperweed does not appear to be a contaminant in well-managed alfalfa hay fields, and the cutting and harvesting practices for alfalfa usually preclude seed contamination of hay. Long distance transportation of straw from grain crops may be a source of perennial pepperweed spread. Even if the straw is weed free (as is likely for perennial pepperweed in straw), the storage sites for the straw may provide inoculum, with transportation vehicles serving as the vector [100].

Seed banking:

It is unclear how long perennial pepperweed seeds may persist under field conditions and whether perennial pepperweed seeds in the soil seed bank may establish seedlings following disturbance. Laboratory tests indicate that perennial pepperweed seeds may remain viable for 2 years or more. Research is needed to determine longevity and viability of perennial pepperweed seeds in the field.

Miller and others [53] found germinability of perennial pepperweed seeds tested 1, 6, and 12 months after harvest did not change with time, and concluded that perennial pepperweed seeds can be stored under laboratory conditions for at least a year with no special precautions. More importantly, there seems to be no inherent dormancy system (e.g. a hard seed coat) present in perennial pepperweed seeds. Additionally, the temperature conditions that produce optimum germination for perennial pepperweed seeds do not change within a year after harvest, as would be the case if an afterripening requirement existed. This evidence suggests that buried seeds of perennial pepperweed may not be a prolonged source of reinfestation once a population is controlled. To be certain of this, however, the fate of deeply buried seeds that are not exposed to diurnal temperature fluctuations necessary for germination (see [Germination](#)) must be determined.

According to Young [94], the seed and seedbed ecology of perennial pepperweed is poorly understood. Weekly bioassay of surface soils collected for 2 years from dense perennial pepperweed stands at Reno, Nevada, demonstrated peak emergence of perennial pepperweed seedlings from samples collected in February and March. Emergence from bioassay samples indicates a potential field emergence of 25 to 35 seedlings per square foot. The original bioassay samples were then alternately wet and dried for 4 week periods for 2 years, and continued to produce occasional perennial pepperweed seedlings during that time. In the stands where the seedbed bioassay samples were collected, seedlings were never observed, even in plots where all surface vegetation was removed by hand or rototilling. In 2 to 5 acre (0.8-2 ha) field plots perennial pepperweed seedling establishment is not a serious problem after the established population is suppressed. Numerous, isolated roadside infestations of perennial pepperweed suggest, however, that seedling establishment may play an important role in establishment of new populations.

Germination: Germination studies [53] (Robbins et al 1951, as cited by [39]) have shown high germination rates (64%-100%) for perennial pepperweed under a variety of conditions. However perennial pepperweed seedlings are rarely observed in the field (e.g. [21,94]).

Miller and others [53] found that very cold temperatures and constant temperatures between 32 and 104 °F (0-40 °C) failed to support perennial pepperweed germination. The highest germination rates (96% to 100%) for perennial pepperweed seed occurred under alternating temperature regimes with low night temperatures (32, 36, or 41 °F (0, 2, or 5 °C)) and high day temperatures (95 to 104 °F (35-40 °C)). These fluctuating regimes represent realistic temperatures of seedbeds in the Intermountain Area during fall or late spring when diurnal fluctuations are characterized by low night temperatures and high day temperatures. Perennial pepperweed seeds would probably have to be on or near the soil surface to experience temperature fluctuations of this magnitude. Deep burial of perennial pepperweed seeds may greatly reduce emergence because of poor

germination due to more constant and cooler temperature regimes with depth.

No significant ($p < 0.01$) differences in germination of perennial pepperweed seed were attributed to year of production, duration of storage after harvest, or seed source [53].

According to Howald [39], perennial pepperweed seeds typically germinate in spring in wet sand or mud, although the source of this information is not given.

Seedling establishment/growth:

Little is known about perennial pepperweed seedling establishment under field conditions. Some authors indicate that perennial pepperweed seedlings are rarely found in the field [21,94]. This may be because perennial pepperweed seedlings are difficult to recognize in the field as they are easily confused with many other adventitious members of the mustard family [100]. Seedling establishment may, however, play an important role in establishment of new populations [94]. More research is needed in this area.

Once established, it seems that perennial pepperweed plants grow and spread rapidly. Preliminary experiments have shown that perennial pepperweed roots perennialize rapidly (by the 8-leaf stage) (Renz and DiTomaso, unpublished data as cited by [67]). A single established plant can become a small population, several meters in diameter, in 2 seasons. After 5 years, areas infested by perennial pepperweed may be near monocultures, with stem densities approaching 150 per m^2 [7,11].

A conceptual model of perennial pepperweed spread is presented by Blank and Young [10]. Perennial pepperweed seeds are dispersed, plants establish and spread by creeping roots, establishing single-species colonies. A visual estimate of perennial pepperweed coverage at this initial stage of invasion would be about 2%. The colonies expand and eventually merge (see [Successional status](#)) [10].

Blank and Young [10] also provide an example that illustrates the rate of spread of perennial pepperweed colonies. An 80 acre (32 ha) field within the Honey Lake Wildlife Refuge in California had no perennial pepperweed plants in 1993. In 1994 a 431 ft^2 (40 m^2) plot was established to monitor spread of perennial pepperweed, at which time there were 2 colonies in the plot, each less than 11 ft^2 (1 m^2), with stem densities less than 10 stems per m^2 . In 2000, most of the 431 ft^2 (40 m^2) plot had become invaded, with stem densities greater than 100 stems per m^2 in some areas. Perennial pepperweed densities began to decline in 2000 and the decline continued to 2002. The authors suggest that this decline was due to below normal winter precipitation. A graphical summarization of these data can be seen at the [EIWRU](#) website [10,11].

In a study to determine the rate of spread of perennial pepperweed at 3 locations in California, Renz and others [69] found that undisturbed perennial pepperweed infestations spread clonally in a predictable pattern along the leading edge, about 3 to 6 feet (1-2 m) per year. Initial size and area of infestations were found to influence the rate of spread, with infestations of small area and large perimeter expanding at the greatest rate. Rosette and stem density was highest at the center of infestations. Similar rates of expansion were observed at all undisturbed plots at Colusa and Grizzly Island sites, with populations expanding from 44 to 129% from 1999 to 2001. Thus it was concluded that in the absence of disturbance, perennial pepperweed infestations will continue to expand and increase in density over time.

Asexual regeneration:

Rather than expansion from seedlings, it is much more common to see perennial pepperweed populations expand by creeping roots [95,100] (also see [Seedling establishment/growth](#)). Perennial pepperweed also regenerates from roots and semi-woody crowns [70,100] when tops are removed, and from root fragments that produce buds and sprout new plants [92].

Perennial pepperweed has a deep, extensive root system with a high reproductive potential that allows it to

sprout from previously dormant buds near the soil surface following removal of aboveground parts via cutting or mowing [69], grazing [4], or herbicide treatments [100].

New perennial pepperweed plants can also establish from root fragments. Pieces of rootstock less than 0.8 cm in diameter and less than 1 inch (2.5 cm) long can form new perennial pepperweed plants. One-inch-long (2.5 cm) root segments can produce more than 1 shoot sprout. Shoots produced by segments that were planted in the greenhouse in early summer produced flowers and seed in late summer. There was a significant ($p < 0.05$) difference in sprouting between root fragments from plants that had been treated with 2,4-D at flower bud stage during the previous summer, and roots fragments taken from untreated perennial pepperweed plants. Five percent of herbicide-treated roots sprouted, and 50% of the control roots sprouted, indicating that considerable amounts of 2,4-D were translocated to the roots. The authors note that, based on observations of field plots, 5% sprouting is still sufficient to result in complete recolonization of treated plots by the end of the 1st growing season following 1 herbicide treatment [92].

Roots are buoyant and when broken from eroding banks can be transported long distances by water and establish new populations [100]. Perennial pepperweed roots also have the ability to tolerate dry conditions and resist desiccation. Research is needed to understand the growth patterns and longevity of perennial pepperweed roots and what soil depths they can emerge from [67].

SITE CHARACTERISTICS:

In its native range, perennial pepperweed grows in a wide variety of habitats, including fresh, brackish, and saltwater wetlands, in and around agricultural fields, in waste places, and even on stony slopes, from sea level to above 10,000 feet (3,050 m) (May 1995, unpublished report, as cited by [39]).

Perennial pepperweed also tolerates a wide variety of environmental conditions in North America. Many sites have dense infestations in one area and no plants invading into nearby locations, indicating that perennial pepperweed spread may be limited by environmental, physical, and/or geographical factors, although it is unclear what these factors are [67]. In California, for example, perennial pepperweed typically grows in full sun in heavy, moist soils that are often saline or alkaline, but it also grows on drier sites and on other soil types. Its precise tolerance limits for aridity, alkalinity, and salinity are unknown [39].

Perennial pepperweed seems to be most problematic in riparian areas, marshes, estuaries, irrigation channels, wetlands, and floodplains, but is not exclusive to these areas. According to Muldavin and others [56], perennial pepperweed is a facultative plant; i.e. it has about equal probability of occurring in wetland or non-wetland sites.

Perennial pepperweed is tolerant to halomorphic soils and thus is adaptable in coastal areas, interior salt marshes, and sinks such as brackish marshes of San Francisco Bay, and in saline/alkaline sinks in the Carson Desert of western Nevada. Once established in wetlands, infestations often follow irrigation structures into irrigated pastures, native hay meadows, agronomic fields, and urban landscaping [4,9,67,99,100]. Once established, perennial pepperweed can persist in roadsides, native hay meadows, alfalfa fields, and rangeland habitats [67]. According to Trumbo [81] perennial pepperweed is highly invasive in areas of California that were formerly under intensive agriculture and then sold to the State of California for use as wildlife refuges. Perennial pepperweed populations in these areas, unchecked by frequent cultivations and crop competition, then expanded at the expense of recovering native plants.

In the Intermountain Area the major sites of infestation are native hay meadows. These meadows generally have not been leveled or plowed, and they vary considerably in site characteristics and topography. They are irrigated by "wild-flooding" in the spring, with depressions flooded for prolonged periods. The soils of these meadows range from slightly to highly influenced by salts [99]. In the Susan River Valley of northeastern California, perennial pepperweed has invaded beyond native meadows to where it is now a serious pest in more intensive agricultural rotation crops such as cereal grains and alfalfa [100].

Research by Blank and others [8] demonstrates that perennial pepperweed achieves optimal growth within a narrow range of soil water potential. Accumulated biomass was greatest when perennial pepperweed was grown at -0.02 MPa soil matric water potential. At higher potential (saturation) perennial pepperweed grew poorly, but all plants survived. At lower potential (more negative), perennial pepperweed biomass decreased substantially, yet all plants survived. The authors suggest that perennial pepperweed primarily invades wetlands because the high soil water content reduces tortuosity and allows efficient transport of nutrients to this sparsely rooted species. When soil moisture and/or the nutrient supplying capacity of the soil declines, plants with greater root density may out-compete perennial pepperweed (see [Successional status](#)).

According to Young and others [96,100], perennial pepperweed is adapted to but not restricted to salt-affected soils, alkali soils, and soils with sodium hazards. Perennial pepperweed invades brackish to saline or alkaline wetlands throughout California, from the coast to the interior and north and eastward into the Great Basin and Columbia Basin. It is also found in native hay meadows and as a weed in agricultural fields where the soil is slightly alkaline or saline (Young and Turner 1995, as cited by [39]). In Wyoming, perennial pepperweed is found on soils of high alkalinity (pH 9.2), and it appears to tolerate, but not require, saline conditions. Patches of perennial pepperweed occurred right up to the edge of white alkali patches [4]. Roots of perennial pepperweed are not hindered by root-restricting layers or high water tables [10,11]. More research is needed to understand the mechanism(s) that allow perennial pepperweed to cope with varying soil salinities [7,11,67].

At Honey Lake Wildlife Refuge in northeastern California, field infestations of perennial pepperweed occur in almost pure colonies with few other species. Soils in the area are slightly saline and sodic, generally fine-textured, and have compact and hard natric subsoils [11]. Perennial pepperweed invaded areas have thick organic and debris-rich O horizons that are lacking in uninvaded areas (occupied primarily by tall wheatgrass (*Thinopyrum ponticum*)). Researchers also noted that natric horizons in invaded areas were modified both physically and chemically (see [Successional status](#) and Impacts for more details) compared with uninvaded sites [7,9,11]. The authors state that while many of the differences in soil attributes observed between sites are attributable to perennial pepperweed invasion, it is also possible that antecedent soil differences favored invasion by perennial pepperweed in some areas [11].

Disturbance: Perennial pepperweed is often described as occurring on roadsides and in "waste places." Initial establishment of perennial pepperweed in the intermountain Area has often occurred in association with structures for diversion of irrigation water from streams. Construction or repair of such physical facilities usually provides bare soil for colonization by pioneer species. The undercarriage of track-laying heavy construction equipment is an ideal mechanism for transporting vegetative propagules of weeds such as perennial pepperweed from site to site [100].

Elevation: Elevation ranges for perennial pepperweed occurrence are reported by area as follows:

State	Elevation range	References
CA	6,200 feet (<1,900 m)	[36]
CO	5,500-8,000 feet (1,700-2,440 m)	[34]
NV	3,900-8,000 feet (1,200-2,440 m)	[43]
NM	5,000-8,000 feet (1,500-2,440 m)	[51]
UT	4,100-7,900 feet (1,250-2,410 m)	[88]

SUCCESSIONAL STATUS:

While there is some anecdotal evidence that disturbance favors establishment of perennial pepperweed (e.g. [81,98]) it is unclear whether perennial pepperweed requires disturbance for initial establishment. Once established, perennial pepperweed may remain as scattered, isolated plants or populations [67,94], or it may form dense colonies which eventually merge into closed-canopy stands that are practically monospecific [99]. The root architecture of perennial pepperweed is such that monoculture stands may be self-limiting as soil

fertility levels decline, but longevity of perennial pepperweed populations is unknown. In some areas, invasion of perennial pepperweed introduces a radically different plant community such that soil physical properties and biogeochemical cycling are altered [8,11]. Invasion of an area by perennial pepperweed may alter soil properties to such an extent that different successional trajectories are triggered, possibly altering subsequent soil evolution [10,11].

Evidence presented by Blank and Young [10] suggests that succession proceeds differently in disturbed compared with undisturbed perennial pepperweed-invaded sites. Where perennial pepperweed invades undisturbed native vegetation, the population expands along a narrow front, with the dominant mode of invasion via creeping roots. In more disturbed areas, the invasion front is wide with small colonies scattered throughout. Perennial pepperweed stem densities increase, and individual colonies expand and eventually merge. When perennial pepperweed stem densities exceed about 20 stems per m², other plant species are excluded.

In established monocultures, large root reserves, shading, and accumulation of plant litter may contribute to the competitiveness of perennial pepperweed [10]. Results presented by Blank and others [8,10] suggest that competitiveness of perennial pepperweed may decline over time. Wetland and riparian environments that perennial pepperweed invades are often occupied by shallow-rooted species such as saltgrass, rushes, and sedges, and many areas are saline and/or alkaline with root-restricting soil layers (natric horizons). In the environments studied, root length density (root length per volume of soil) of perennial pepperweed is typically less than that of the native community. However, perennial pepperweed rooting depth often exceeds 9 feet (3 m) and it is capable of exploring a nutrient niche in these deep soil layers, even below the dense, compact natric horizons, that has been minimally explored by the vegetation it is replacing. Optimal nutrient uptake by sparsely-rooted perennial pepperweed requires efficient transport of nutrients through the soil, which is fostered by a wet soil. Biogeochemical cycling in which natric horizons are altered and nutrients are taken from deep soil layers and deposited on the surface through litter fall, enriches surface soil with nutrients. High nutrient levels in surface soil will be of minimal value to perennial pepperweed because the surface soil dries relatively early in the growing season, thereby limiting mass flow of nutrients [10].

In a greenhouse study, Blank and others [8] investigated the influence of soil nutrient depletion on plant growth and plant competition between perennial pepperweed and cheatgrass. As nutrient supplying capacity of the soil declined through growth cycles, aboveground mass of perennial pepperweed decreased significantly ($p \leq 0.05$) and growth potential of cheatgrass surpassed that of perennial pepperweed. These findings are explained by a combination of differences in root architecture, processes involved with soil nutrient bioavailability, and soil nutrient depletion. It is unclear whether nutrient depletion will eventually lead to a decline of perennial pepperweed in the field. The oldest monocultures of perennial pepperweed observed by Blank and others are about 15 years old, and they had not yet noticed any decline in its vigor and stature.

Invasion by perennial pepperweed has the potential to alter soil properties and processes relative to uninvaded sites to favor its own growth and survival, and possibly alter the trajectory of soil evolution [11]. Observed differences between perennial pepperweed-invaded sites and similar, noninvaded sites include a thick, nitrogen-rich litter layer; greater nitrogen availability and nitrogen-mineralization potentials; increased enzyme activities; increased biogeochemical fluxes of carbon, nitrogen, phosphorus, calcium, magnesium, and sulfur; lower sodium absorption ratios; and less compact, more friable natric horizons in sites occupied by perennial pepperweed as compared to sites dominated by tall wheatgrass [7,10,11]. Amelioration of sodic soils, including those with hard and compact subsoils (natric horizons) could give these soils greater effective rooting depth and more favorable physical properties that would make them likely to support a richer, more productive plant community if perennial pepperweed is controlled. The potential for excessive salt accumulation at the soil surface via litter decomposition cautions that long-term invasion by perennial pepperweed may increase the osmotic potential of the soil surface, thereby reducing seed germination and growth of salt-intolerant species [11].

All differences in soil attributes observed between perennial pepperweed invaded and uninvaded sites are difficult to attribute solely to perennial pepperweed invasion. It is possible that antecedent soil differences favored invasion by perennial pepperweed in particular areas. However, the case can be made that some differences in soils occupied by perennial pepperweed are a direct consequence of plant invasion through a combination of differential biogeochemical cycling and rhizosphere interactions. Where perennial pepperweed has converted diverse plant communities to monocultures, it is reasonable to conjecture that this conversion will promote divergent soil evolution [11].

SEASONAL DEVELOPMENT:

As early as mid-winter in the western Intermountain Area, careful examination of perennial pepperweed root crowns reveals multiple buds that are green and slowly developing. Shoot growth can begin at varying periods, depending on timing of the last frost, but generally shoots emerge in late winter to early spring before those of most native species [21,100]. In coastal areas, where frost is infrequent, rosette leaves persist through winter. Observations of perennial pepperweed seedlings are rare in the field, "but germination appears to occur late winter/early spring" [67].

Perennial pepperweed shoots initially form a rosette near the soil surface and remain in rosette form for several weeks before stems elongate [67]. Rosettes may remain largely hidden by persistent, semi-woody herbage from previous years' growth. Stem elongation is rapid during May, and by the 1st of June stems are 1.6 to 2.6 feet (0.5-0.8 m) tall [100]. Day length is believed to be a main factor in the regulation of stem elongation [67].

Flowering dates are given by area are as follows:

Area	Flowering dates	References
CA	May-August	[39,58]
NV	June-August	[43]
NM	June-August	[51]
Atlantic coast	May-June	[24]
Great Plains	June-August	[31]
Intermountain Area	begins mid-June	[100]
New England	August	[76]
Pacific Northwest	June-September	[37]

Flowering time varies from May to August in different parts of California [39,58], and peak bloom lasts for several weeks [39].

As perennial pepperweed flowers develop, the shoot apical meristem loses its apical dominance and axillary buds elongate and form secondary panicles with many clusters of flowers. This combination creates a dense canopy of stems, flowers, and fruit throughout much of the summer. Flowering and fruit set may occur for several months [67]. At flowering, stalks are 3 to 6 feet (1-2 m) in height. The basal rosette leaves are nearly senescent and stands are usually so thick that virtually no light reaches the soil surface at flowering [100].

Perennial pepperweed seeds mature between June and mid-August [39,100]. Plants mowed in hay fields or injured in control treatments may flower late and have seeds still maturing at 1st frost. Mature seeds do not immediately disperse from the pods, and some seeds may remain on senesced plants until the following season [100]. Aboveground parts typically die in late fall and winter. Dead stems of perennial pepperweed degrade slowly and may persist for more than a year [21]. Rosette leaves often emerge from dormant buds below the soil in the late summer/early fall and persist until the initial frost [67].

Perennial pepperweed can store large amounts of energy in its perennial roots. When spring growth is initiated, total nonstructural carbohydrates (TNC) in the top 16 inches (40 cm) of root material rapidly decrease and reach a minimum at the bolting stage before flowerbuds develop. Perennial pepperweed begins allocating large

amounts of photosynthate below ground during the flowerbud stage. The rate of translocation of photosynthates to belowground structures is greatest from the full flowering to seed filling stages. As stems senesce in the late summer/early fall, a decrease in stored TNC is seen. Researchers believe that a flush of new root growth causes this reduction in stored energy, but further research is necessary. After this decrease, stored carbohydrates in perennial roots remain constant until early spring growth begins [68,69].

Leaf area distribution of perennial pepperweed also fluctuates during the growing season. Perennial pepperweed leaf area is not distributed evenly within the canopy, appears to be dependent on environmental factors, and is altered in plants that sprout after mowing [67]. These factors can have consequences for herbicide movement (see [Physical/mechanical](#) control).

FIRE ECOLOGY

SPECIES: *Lepidium latifolium*

- [FIRE ECOLOGY OR ADAPTATIONS](#)
- [POSTFIRE REGENERATION STRATEGY](#)

FIRE ECOLOGY OR ADAPTATIONS:

Fire adaptations:

There is no information in the literature regarding adaptations of perennial pepperweed to fire. Perennial pepperweed has a deep, extensive root system with a high reproductive potential that allows it to sprout repeatedly following removal of aboveground growth. Physical and mechanical control methods such as mowing and disking, for example, are unlikely to control perennial pepperweed because new plants quickly regenerate from roots and root crowns (see [Regeneration Processes](#)). Perennial pepperweed is likely, therefore, to similarly re-establish after fire. There is no information in the literature regarding the response of perennial pepperweed seed to heat, smoke or fire.

Fire regimes:

Perennial pepperweed is often found in riparian and wetland communities. There is little quantitative information on prehistoric frequency, seasonality, severity and spatial extent of fire in North American riparian ecosystems. Fire frequency probably varied with drought cycles, prevalence of lightning strikes, prevalence of burning by Native Americans, and fires in surrounding uplands. Perennial pepperweed was not widespread in these communities when historic fire regimes were functioning, but has established since habitat alteration and fire exclusion began. It is unclear how historic fire regimes might affect perennial pepperweed populations, and it is unclear how the presence of perennial pepperweed in native ecosystems might affect fire regimes.

In general, in ecosystems where perennial pepperweed replaces plants similar to itself (in terms of fuel characteristics), it may slightly alter fire intensity or slightly modify an existing fire regime. However, if perennial pepperweed is qualitatively unique to the invaded ecosystem, it has the potential to completely alter the fire regime [20]. No examples of fire regimes altered by perennial pepperweed invasion are described in the available literature.

The following table provides fire return intervals for plant communities and ecosystems in which perennial pepperweed may occur. If you are interested in the fire regime of a plant community that is not listed here, please consult the complete [FEIS fire regime table](#).

Community or Ecosystem	Dominant Species	Fire Return Interval Range (years)
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bluestem prairie	<i>Andropogon gerardii</i> var. <i>gerardii</i> - <i>Schizachyrium scoparium</i>	< 10 [45 , 60]
silver sagebrush steppe	<i>Artemisia cana</i>	5-45 [35 , 63 , 93]
sagebrush steppe	<i>A. tridentata</i> / <i>Pseudoroegneria spicata</i>	20-70 [60]
basin big sagebrush	<i>A. tridentata</i> var. <i>tridentata</i>	12-43 [75]
mountain big sagebrush	<i>A. tridentata</i> var. <i>vaseyana</i>	15-40 [3 , 13 , 54]
Wyoming big sagebrush	<i>A. tridentata</i> var. <i>wyomingensis</i>	10-70 (40**) [85 , 97]
coastal sagebrush	<i>A. californica</i>	< 35 to < 100
saltbush-greasewood	<i>Atriplex confertifolia</i> - <i>Sarcobatus vermiculatus</i>	< 35 to < 100
desert grasslands	<i>Bouteloua eriopoda</i> and/or <i>Pleuraphis mutica</i>	5-100 [60]
plains grasslands	<i>Bouteloua</i> spp.	< 35 [60 , 93]
blue grama-needle-and-thread grass-western wheatgrass	<i>B. gracilis</i> - <i>Hesperostipa comata</i> - <i>Pascopyrum smithii</i>	< 35 [60 , 74 , 93]
blue grama-buffalo grass	<i>B. gracilis</i> - <i>Buchloe dactyloides</i>	< 35 [60 , 93]
grama-galleta steppe	<i>B. gracilis</i> - <i>Pleuraphis jamesii</i>	< 35 to < 100
blue grama-tobosa prairie	<i>B. gracilis</i> - <i>P. mutica</i>	< 35 to < 100 [60]
cheatgrass	<i>Bromus tectorum</i>	< 10 [61 , 89]
northern cordgrass prairie	<i>Distichlis spicata</i> - <i>Spartina</i> spp.	1-3 [60]
California steppe	<i>Festuca</i> - <i>Danthonia</i> spp.	< 35 [60 , 80]
Rocky Mountain juniper	<i>Juniperus scopulorum</i>	< 35 [60]
wheatgrass plains grasslands	<i>Pascopyrum smithii</i>	< 5-47+ [60 , 63 , 93]
galleta-threawn shrubsteppe	<i>Pleuraphis jamesii</i> - <i>Aristida purpurea</i>	< 35 to < 100 [60]
eastern cottonwood	<i>Populus deltoides</i>	< 35 to 200 [60]
aspen-birch	<i>P. tremuloides</i> - <i>Betula papyrifera</i>	35-200 [23 , 86]
quaking aspen (west of the Great Plains)	<i>P. tremuloides</i>	7-120 [2 , 33 , 52]
mountain grasslands	<i>Pseudoroegneria spicata</i>	3-40 (10**) [1 , 2]
California oakwoods	<i>Quercus</i> spp.	< 35 [2]
oak-juniper woodland (Southwest)	<i>Quercus</i> - <i>Juniperus</i> spp.	< 35 to < 200 [60]
coast live oak	<i>Q. agrifolia</i>	2-75 [32]
canyon live oak	<i>Q. chrysolepis</i>	<35 to 200
blue oak-foothills pine	<i>Q. douglasii</i> - <i>P. sabiniana</i>	<35
Oregon white oak	<i>Q. garryana</i>	< 35 [2]
California black oak	<i>Q. kelloggii</i>	5-30 [60]
blackland prairie	<i>Schizachyrium scoparium</i> - <i>Nassella leucotricha</i>	< 10 [86]
little bluestem-grama prairie	<i>S. scoparium</i> - <i>Bouteloua</i> spp.	< 35 [60]
elm-ash-cottonwood	<i>Ulmus</i> - <i>Fraxinus</i> - <i>Populus</i> spp.	< 35 to 200 [23 , 86]

**mean

POSTFIRE REGENERATION STRATEGY [79]:

Caudex/herbaceous root crown, growing points in soil
Geophyte, growing points deep in soil
Ground residual colonizer (on-site, initial community)
Initial off-site colonizer (off-site, initial community)
Secondary colonizer (on-site or off-site seed sources)

FIRE EFFECTS

SPECIES: *Lepidium latifolium*

- [IMMEDIATE FIRE EFFECT ON PLANT](#)
- [DISCUSSION AND QUALIFICATION OF FIRE EFFECT](#)
- [PLANT RESPONSE TO FIRE](#)
- [DISCUSSION AND QUALIFICATION OF PLANT RESPONSE](#)
- [FIRE MANAGEMENT CONSIDERATIONS](#)

IMMEDIATE FIRE EFFECT ON PLANT:

There is little information in the literature regarding the immediate effect of fire on perennial pepperweed plants. Based on a single experiment [44], field observations during another study [69], and other unknown sources, several authors [39,67,69,81] have suggested that perennial pepperweed infestations are difficult to ignite and may not sustain a burn. When perennial pepperweed does burn, one might assume that the aboveground growth would be killed, but that much of the perennial root system would be unharmed by fires of low to moderate severity. It is unclear what kind of damage a high severity fire might have on perennial pepperweed roots. There is no information in the literature regarding the effects of heat or fire on perennial pepperweed seed.

DISCUSSION AND QUALIFICATION OF FIRE EFFECT:

No additional information is available on this topic.

PLANT RESPONSE TO FIRE:

There is no information in the literature regarding perennial pepperweed's response to fire that includes measurements beyond 1 year following fire, and only 1 study in which the effects of fire on perennial pepperweed were among the objectives of the study [44]. This study did not include data on the effects of fire alone on perennial pepperweed. More research is needed to understand the response of perennial pepperweed to fires of varying severity, in various ecosystems over long time periods.

Observations by Renz and others [69] suggest that high severity fire may "temporarily" reduce perennial pepperweed cover and spread, although the site that burned was also flooded in the same and the preceding years, and changes in total area infested were measured for only 1 year following the burn. The effects of fire were not the focus of the study, rather the study was designed to measure the rate of spread of perennial pepperweed at 3 different sites in California, all seasonal wetlands. It is also unclear what the objectives of the prescribed burn were (see [Fire Management Considerations](#)).

DISCUSSION AND QUALIFICATION OF PLANT RESPONSE:

No additional information is available on this topic.

FIRE MANAGEMENT CONSIDERATIONS:

Fire as a control agent: Most anecdotal evidence in the literature suggests that fire is not a viable control agent for perennial pepperweed (e.g. [39,67,69,81]). Conversely, 1 reference suggests that periodic mowing and

spring burning have reduced perennial pepperweed density in Utah (Hansen, K.S. 1988, personal communication as cited by [47]).

Only 1 study was found in which the effects of fire on perennial pepperweed were among the objectives of the study [44]. The study took place at 3 locations in Malheur National Wildlife Refuge, Oregon, and was designed to test the combined effects of herbicides and disking or fire on perennial pepperweed density and basal cover. For both herbicide-fire treatments, herbicides were sprayed in early summer and then vegetation was cut to a height of 10 cm with a brush mower 1 week before burning "to increase fire heat at the soil surface for perennial pepperweed control." For fire only treatments, plots were similarly mowed 1 week before burning. All burns were conducted on October 17 with back fires ignited by drip torches. Fuels consisted of live grass/forb, dead grass/forb, live perennial pepperweed, and dead perennial pepperweed. Fuel moisture content and dry weight were determined in the laboratory. Fuel consumption by fire for each plot was calculated as the difference between the average biomass of all fuel types pre- and postfire. Perennial pepperweed and native vegetation response were measured pretreatment and 1-year posttreatment. Perennial pepperweed density, basal cover of live plant species, bare ground, and residual plant material were determined by sampling along transects within each plot.

A lack of adequate fuels resulted in unsuccessful burns at 2 of these sites. The 2 plots that had a higher proportion of live and dead perennial pepperweed biomass and a lower proportion of live grass/forb biomass, lacked adequate fuels for successful burns [44].

Site	Fuel biomass (g/m ² DW)	Live grass/forb biomass (%)	Live and dead perennial pepperweed (%)	Dead grass forb biomass (%)
Big Sage	69	55	15	30
Oliver Springs	48	8	62	30
Skunk Farm	46	15	56	30

At the site that did burn (Big Sage), fuel consumption ranged from 82% to 94%.

After 1 posttreatment year, herbicides alone and in combination with fire generally reduced cover of forbs and increased cover of grasses (predominantly beardless wildrye). Beardless wildrye on the herbicide-fire treatments was at least twice as tall as that on the herbicide only plots. The authors speculate that vigorous stands of beardless wildrye on herbicide-fire plots likely resulted from release of nutrients and or stimulation of root buds by fire. Although beardless wildrye was prevalent on the burn-only plot, its stand was not as vigorous as those for herbicide-fire treatments and resembled those of herbicide only treatments at that site [44].

In a study of the rate of spread of perennial pepperweed within seasonal wetlands in California, 2 of the study sites were burned under prescription during the study period. At Colusa National Wildlife Refuge, 2 plots were burned in December 1999. At Lower Klamath National Wildlife Refuge all plots were completely burned in October 2000, and all plots were annually flooded from October to May, for 3 years (1999-2001) during the study period. Stem and rosette densities of perennial pepperweed were compared from year to year to calculate rate of spread. In the absence of disturbance, perennial pepperweed infestations continued to expand and invade new areas. Colusa plots that were burned in winter, 1999, had varying results. After 1 year, the perennial pepperweed infested area of burned plots was reduced at Colusa 1 by 6%, and increased at Colusa 2 by 55%. The author speculates that the variability observed may be dependent on other factors such as the intensity of the fire, which was "strong" at Colusa 1 compared to Colusa 2 (data not shown). Two years after the burn, the perennial pepperweed-invaded area at both sites had increased; 7% and 128% at Colusa 1 and 2, respectively. At the Lower Klamath site, infestations declined in all but 1 plot, which had a 6% increase during the 2 years of the experiment. One plot had a reduction in infested area after the 1st year (all plots flooded). All plots had reduction in area infested in the 2nd year (all plots flooded and burned). All but 1 plot had a reduction in

infested area over the period of study. The authors conclude, "while burning may provide temporary reductions in infestation size, unless repeated annually, burning alone is ineffective in long-term management of perennial pepperweed" [69].

Postfire colonization potential:

It is unclear whether fire increases the probability of perennial pepperweed establishment if seeds or roots are present. Establishment of perennial pepperweed by seed under field conditions is poorly understood [67]. When planning a prescribed burn, it is a good idea to survey the surrounding area for perennial pepperweed and control plants that may disperse seed or root material into the burn area.

Preventing postfire establishment and spread:

The USDA Forest Service's "Guide to Noxious Weed Prevention Practices" [82] provides several fire management considerations for weed prevention in general that apply to perennial pepperweed.

Preventing invasive plants from establishing in weed-free burned areas is the most effective and least costly management method. This can be accomplished through careful monitoring, early detection and eradication, and limiting invasive plant seed dispersal into burned areas by [30,82]:

- re-establishing vegetation on bare ground as soon as possible
- using only certified weed-free seed mixes when revegetation is necessary
- cleaning equipment and vehicles prior to entering burned areas
- regulating or preventing human and livestock entry into burned areas until desirable site vegetation has recovered sufficiently to resist invasion by undesirable vegetation
- detecting weeds early and eradicating before vegetative spread and/or seed dispersal
- eradicating small patches and containing or controlling large infestations within or adjacent to the burned area

In general, early detection is critical for preventing establishment of large populations of invasive plants. Monitoring in spring, summer, and fall is imperative. Managers should eradicate established perennial pepperweed plants and small patches adjacent to burned areas to prevent or limit dispersal into the site [30,82].

The need for revegetation after fire can be based on the degree of desirable vegetation displaced by invasive plants prior to burning and on postfire survival of desirable vegetation. Revegetation necessity can also be related to invasive plant survival as viable seeds, root crowns, or root fragments capable of reproduction. In general, postfire revegetation should be considered when desirable vegetation cover is less than about 30% [30].

When prefire cover of perennial pepperweed is absent to low, and prefire cover of desirable vegetation is high, revegetation is probably not necessary after low- and medium-severity burns. After a high-severity burn on a site in this condition, revegetation may be necessary (depending on postfire survival of desirable species), and intensive monitoring for invasive plant establishment is necessary to detect and eradicate newly established invasives before they spread [30].

When prefire cover of perennial pepperweed is moderate (20-79%) to high (80-100%), revegetation may be necessary after fire of any severity if cover of desired vegetation is less than about 30%. Intensive weed management is also recommended, especially after fires of moderate to high severity [30].

Fall dormant broadcast seeding into ash will cover and retain seeds. If there is insufficient ash, seedbed preparation may be necessary. A seed mix should contain quick-establishing grasses and forbs (exclude forbs if broadleaf herbicides are anticipated) that can effectively occupy available niches. Managers can enhance the

success of revegetation (natural or artificial) by excluding livestock until vegetation is well established (at least 2 growing seasons) [30]. See [Integrated Noxious Weed Management after Wildfires](#) for more information.

When planning a prescribed burn, managers should preinventory the project area and evaluate cover and phenology of any perennial pepperweed and other invasive plants present on or adjacent to the site, and avoid ignition and burning in areas at high risk for perennial pepperweed establishment or spread due to fire effects. Managers should also avoid creating soil conditions that promote weed germination and establishment. Weed status and risks must be discussed in burn rehabilitation plans. Also, wildfire managers might consider including weed prevention education and providing weed identification aids during fire training; avoiding known weed infestations when locating fire lines; monitoring camps, staging areas, helibases, etc., to be sure they are kept weed free; taking care that equipment is weed free; incorporating weed prevention into fire rehabilitation plans; and acquiring restoration funding. Additional guidelines and specific recommendations and requirements are available [82].

MANAGEMENT CONSIDERATIONS

SPECIES: *Lepidium latifolium*

- [IMPORTANCE TO LIVESTOCK AND WILDLIFE](#)
- [OTHER USES](#)
- [IMPACTS AND CONTROL](#)

IMPORTANCE TO LIVESTOCK AND WILDLIFE:

Most domestic livestock generally do not prefer perennial pepperweed as forage; however, domestic sheep and goats are known to graze thick stands of perennial pepperweed in some areas (see [Palatability](#)) [4,98]. Perennial pepperweed is apparently inferior food and cover for wildlife compared to native vegetation that it replaces [39,81], although there are no data to support these observations.

Palatability/nutritional value:

Little information is available on the palatability of perennial pepperweed. Observations of researchers in Nevada suggest that cattle and domestic sheep will graze it when it grows amid other plants, but they do not eat perennial pepperweed growing in pure dense stands [91]. According to Baker [4], in Wyoming, pastures with perennial pepperweed rapidly become useless to cows and horses, but sheep readily eat perennial pepperweed, and even heavily infested pastures appear weed free when grazed by sheep.

Cattle reportedly graze perennial pepperweed rosette leaves in early spring. However, these leaves cannot be reached by livestock unless the accumulation of previous years' stalks is removed. When perennial pepperweed plants occur as occasional plants in saltgrass meadows, flowerstalks may be eaten by grazing cattle. In dense stands of perennial pepperweed in perennial pastures, there was no evidence of utilization by "grazing animals" even when drought had seriously depleted preferred forage species [100]. Domestic goats graze thick stands of perennial pepperweed and seem to prefer the young, tender, more digestible regrowth following grazing and mowing. For example, domestic goats ate about 75% of regrowth, compared to about half of the vegetation in older stands, on which they ignored the semiwoody stems and nibbled only leaves and soft tips (Jim Young, personal communication in [91]).

Cover value: Observations and/or reports of some authors (e.g. [11,39,81,99]) suggest that perennial pepperweed provides inferior cover for many bird species compared with the vegetation that it replaces.

OTHER USES:

Perennial pepperweed has been used extensively in traditional medicine for over 2,000 years as a diuretic, stomachic tonic, and for antilithiasis. Sulphurated essences have been isolated from its roots, seeds, and leaves;

mirosin is also reported as present in its seeds (Front Quer 1973, as cited by [59]). Several sterols and polyphenols have been isolated from its leaves (Navarro et al 1992, as cited by [59]). The leaves are often given as an infusion in the treatment of renal disorders, and several commercial laboratories sell the dried powdered leaves [59].

In a pharmacological screening for diuretic activity in rats using an aqueous extract of perennial pepperweed given orally and intraperitoneally, enhanced urinary excretion was observed as compared to control groups. A slight increase in ion excretion was also observed [59].

IMPACTS AND CONTROL:

Impacts: Perennial pepperweed is listed by the California Invasive Plant Council ([Cal-IPC](#)) on List A-1: a widespread, aggressive invader that displaces natives and disrupts natural habitats. These are the most invasive wildland pest plants in their classification [15]. Little research is available documenting or quantifying impacts of perennial pepperweed. However, several authors indicate observed impacts, especially in wetland and riparian settings. Observed and/or suggested impacts include altered species diversity, structure and function [9,65,81,100], displaced native species [72,81] including rare plant populations (Skinner and Pavlik 1994, as cited by [39]), decreased food and habitat for several wildlife species [39,44,81,99,101], changes in biogeochemical cycles [7,10,11] including emission of mercury from contaminated soils into the atmosphere [48], increased streamside soil erosion (personal communications with Susan Donaldson and Jim Young, as cited by [67]), and economic losses through reduced forage quantity and hay quality [4,39,44,99,100,101].

Observations of researchers and managers (e.g. [9,72,81,100,101]) suggest that perennial pepperweed has altered species diversity, structure, function, and succession in many wetland and riparian areas in the western U.S. Because perennial pepperweed is highly competitive, grows in dense patches that are near monocultures, and results in a buildup of heavy thatch and litter that may be rich in salts (depending on the site), seedling recruitment and productivity of important, native species may be adversely affected [9,100,101]. Few data are available to support these observations. Reports of perennial pepperweed replacing quackgrass (*Elytrigia repens*), another highly competitive, nonnative species, attest to the competitiveness of perennial pepperweed [10,101]. An inventory of rare and endangered plants in California indicates that perennial pepperweed is encroaching on several rare plant populations at Grizzly Island Wildlife Area in Suisun Marsh, including soft bird's-beak (*Cordylanthus mollis* ssp. *mollis*), Suisun thistle (*Cirsium hydrophilum* var. *hydrophilum*), and Suisun Marsh aster (*Symphotrichum lentum*) (Skinner and Pavlik 1994 as cited by [39]).

Changes in vegetation structure caused by perennial pepperweed may interfere with management objectives and reduce habitat for various wildlife species. For example, observations along the Green River in Utah indicate that because of perennial pepperweed's increased canopy height and density as compared to native vegetation, it directly interferes with mosquito control efforts in the area (Steven V. Romney, personal communication as cited by [65]). Perennial pepperweed's tall stature, dense growth pattern, and accumulations of semiwoody stems (see [General Botanical Characteristics](#)) are also purported to negatively impact nesting habitat for wildlife [81,99,101]. Observations by Blank and Young [11] suggest that when perennial pepperweed populations reach a density of 50 stems per m², no waterfowl nesting occurs. According to Howald [39], perennial pepperweed outcompetes grasses that provide food for waterfowl. Perennial pepperweed has invaded pickleweed-dominated marshes in some areas in California, and thus poses a threat to the habitat of the endangered salt marsh harvest mouse, California black rail, and California clapper rail [39,81]. No data are provided to support these observations. At the Malheur National Wildlife Refuge in Oregon, perennial pepperweed has displaced 5 and 10% of the meadow and grass/shrub uplands, respectively, that are critical habitats for nesting aquatic and neotropical birds (US Fish and Wildlife Service, unpublished data, as cited by [44]). Because perennial pepperweed makes hay from infested pastures unmarketable, perennial pepperweed jeopardizes the haying program on the Malheur National Wildlife Refuge, which provides short and medium grasses for sandhill cranes, shorebirds, and waterfowl [44].

Observations at the Honey Lake Wildlife Refuge in northeastern California, indicated "striking differences" in

soil profiles in perennial pepperweed infested areas compared with soils in similar, noninvaded areas of native hayland [9]. These observations led to a series of research projects that indicated many differences in soil physical and chemical properties between perennial pepperweed infested sites and similar noninvaded sites [7,9,10,11] (see [Successional Status](#)).

Perennial pepperweed can take up mercury from contaminated soils and emit about 70% of that taken up during the growing season into the atmosphere (for every one molecule retained in perennial pepperweed foliage, 12 molecules were emitted) [48]. The most critical factors governing mercury flux from plants are mercury concentration in the soil, leaf area index, temperature, and irradiance [49]. See Leonard and others [48,49] for more details.

The combination of low root density and easily-fragmented perennial roots allows soil erosion to occur during flooding events or other high waterflow events along riverbanks infested with perennial pepperweed. The water will also carry root pieces (which float) downstream where they can establish new populations (personal communications with Susan Donaldson and Jim Young as cited by [67]).

Perennial pepperweed invasion also causes economic losses when it persists in hay meadows, pastures, and/or cropland. Where perennial pepperweed invades native hay meadows (e.g. in the Humboldt River Valley of Nevada and Lassen County, California), it reportedly lowers the quality of hay in terms of protein content and digestibility [100]. Rumors that perennial pepperweed may be poisonous are usually based on horses being fed hay containing perennial pepperweed under confined conditions, but no data are available to confirm its toxicity [101]. In infested pastures that are not mowed annually, the accumulation of perennial pepperweed stems inhibits grazing [4,101]. Fence rows and "waste areas" within fields may become dense, impermeable thickets of perennial pepperweed [99].

Control:

Eradication of perennial pepperweed is no longer an option in western North America, and control and quarantine efforts for perennial pepperweed have been largely unsuccessful. Biological suppression may be a viable goal that is likely to require an integrated management approach, as no single technique is likely to control perennial pepperweed [100]. Perennial pepperweed has a deep, extensive root system with a high reproductive potential that allows it to sprout repeatedly following removal of aboveground growth. Perennial roots must be killed or removed to prevent reinfestation by perennial pepperweed. According to Renz [67], these roots may remain dormant in the soil for several years, resist desiccation, and have been found more than 9 feet (3 m) deep in the soil profile (personal communication from Jim Young as cited by [67]). Strategies to control perennial pepperweed must include removing aboveground growth and perennial roots, preventing seed production, monitoring for perennial pepperweed re-establishment for several years, locating and controlling potential sources of reinfestation (e.g. populations upstream, down the road, next door, etc.), and establishing desirable vegetation. Timing control efforts to coincide with vulnerable stages in perennial pepperweed phenology may increase the probability of success (see [Seasonal development](#)). It is also important to consider how different control techniques may affect perennial pepperweed phenology and distribution of energy stores in perennial pepperweed (see [Physical/mechanical control and Chemical control](#)) [26,67]. More research is needed in these areas, especially long-term research, as many studies report results for only 1 year after treatment.

If resources are available to control an entire infestation of perennial pepperweed, including large stands, efforts should be made to do so. If only part of an infestation can be treated, modeling and experience indicate that controlling outlying patches and the leading edge of infestations are most important [55]. For smaller, scattered populations, an early response strategy can lead to reduced long-term cost of control. If possible, early detection and eradication of small satellite populations is the least expensive and most effective way to control perennial pepperweed [67,72]. Management of perennial pepperweed will likely be more intensive and costly as infestations age. Without management, infestations are expected to increase in density, store energy in belowground tissues, and close the canopy structure. All of these factors increase the difficulty of managing perennial pepperweed [69]. Therefore, intense monitoring, early detection, and rapid removal of perennial

pepperweed increase the probability of successful control.

Diligent monitoring in areas where perennial pepperweed is being managed is important since roots are difficult to kill. Areas should be monitored in early spring and late summer whenever possible. In many places perennial pepperweed is one of the first plants to emerge in the spring and can be identified early in the growing season. Later in the season, as other plants senesce, perennial pepperweed will be one of the last remaining plants alive and green. Rosettes can be difficult to detect, but they may form the leading edge of an infestation and so are important to detect and control [55]. The best time to detect new rosettes is late summer. Monitoring can also be done in fall/winter by looking for senesced stems [67]. Nearby populations should also be located and controlled in an effort to limit off-site propagule sources [67,81].

With all control methods, it is important to restore desirable vegetation [96]. When perennial pepperweed is controlled, it may be necessary to also remove its litter in order to stimulate germination and growth of desirable plants. Previously infested land can recover, but costs incurred will vary depending upon location, density, and length of time infested. If soil salinities are dramatically increased by perennial pepperweed infestation, an intensive soil remediation program may be necessary before desirable native species can re-establish [67]. More research is needed to identify plants that can effectively compete with perennial pepperweed.

Prevention:

The most efficient and effective method of managing invasive species is to prevent their invasion and spread [77]. Preventing the establishment of weeds in natural areas is achieved by avoiding management activities that encourage invasion, maintaining healthy natural communities, and conducting aggressive monitoring several times each year. Monitoring efforts are best concentrated on the most disturbed areas in a site, particularly along roadsides, parking lots, fencelines, and waterways. When a perennial pepperweed infestation is found, the location can be recorded and the surrounding area surveyed to determine the size and extent of the infestation, so these sites can be revisited on follow-up surveys [40]. New infestations should be controlled promptly to prevent further spread [6,101], followed by monitoring and some combination of control methods. Prevention of new invasions is much less costly than postinvasion control [50].

Sources of infestations must be controlled to prevent further spread. Equipment used in perennial pepperweed infested areas must be thoroughly cleaned before transport. Water sources, imported soil, and hay bales used for erosion control should be monitored to ensure they do not contain perennial pepperweed roots or seeds. Many infestations of perennial pepperweed have been initiated by one of these sources (CalEPPC 1999, as cited by [67]). Seed sources of revegetation species should be checked to ensure that there is no perennial pepperweed contamination.

Integrated management:

A combination of complementary control methods may increase effectiveness of control efforts for perennial pepperweed. Integrated management includes not only killing the target plant, but establishing desirable species and discouraging nonnative, invasive species over the long term. Components of any integrated weed management program are sustained effort, constant monitoring and evaluation, and the adoption of improved strategies. An integrated management plan includes efforts to place continual stress on undesirable plants while promoting growth of desirable plants.

Integrated perennial pepperweed control strategies consisting of mowing, disking, or burning combined with herbicide applications before or after treatment, have been studied (see [Physical/mechanical](#) and [Chemical](#) control sections). Kilbride and others [44] examined the potential to restore native vegetation in infested meadows in the Malheur National Wildlife Refuge using integrated management techniques including herbicides, disking, fire, and combinations thereof. Study plots were predominantly perennial pepperweed interspersed with trace amounts of beardless wildrye, squirreltail, basin wildrye, saltgrass, cheatgrass, and forbs (e.g. flixweed tansymustard), as well as rushes and sedges in lower (wet) areas. Percent reduction of perennial pepperweed density 1 year after treatment was reported as follows [44]:

Site	chlorsulfuron	metsulfuron methyl	disk	chlorsulfuron-disk	metsulfuron methyl-disk	fire	chlorsulfuron-fire	metsulfuron methyl-fire
Big Sage	100	90	46	100	99	not reported	100	97
Oliver Springs	100	100	-2	100	99	lack of fuels	lack of fuels	lack of fuels
Skunk Farm	100	not reported	32	100	98	lack of fuels	lack of fuels	lack of fuels

Herbicide treatments alone or in combination with disking or fire resulted in 90% to 100% reduction in perennial pepperweed density 1 year after treatment, with chlorsulfuron providing slightly greater reductions than metsulfuron methyl. All herbicide treatments were more effective than disking alone. It is unclear what effectiveness fire alone had on perennial pepperweed density, as no data are given. For more information on the constraints and effects of fire treatments, see [Fire Management Considerations](#). Disking in combination with herbicide treatments reduced cover of native forbs and grasses and resulted in the establishment of undesirable, nonnative species (cheatgrass and Canada thistle (*Cirsium arvense*)). Combining herbicide treatments with fire or disking did not increase effectiveness over herbicide treatment alone [44]. However, data from only 1 year may be insufficient to judge long-term effectiveness of control measures.

With all control methods, it is important to encourage growth of desirable vegetation. According to Young and others [96] when herbicidal weed control is used on near monocultures of perennial pepperweed in native hay meadows in the Intermountain Area, spontaneous regeneration of meadows is slow and reinvasion of perennial pepperweed likely. This makes seeding of desirable species necessary to maintain suppression of perennial pepperweed [96] (see [Cultural](#) control).

Discussion of other combinations of control methods is included in the following sections when these were encountered in the literature.

Physical/mechanical:

Physical and mechanical control methods such as mowing and disking alone are unlikely to control perennial pepperweed because new plants quickly regenerate from both undisturbed and fragmented roots in the soil (see [Regeneration Processes](#)). Small infestations of perennial pepperweed can be controlled by repeated removal of above- and belowground plant material. Care must be taken to remove as much of the root as possible as small pieces can sprout. If repeated several times this process can be successful, but it is labor intensive [67]. For larger infestations, combining mowing or disking with other control strategies may improve success (e.g. [69]). Neither mowing nor disking is usually appropriate in natural areas, as they are likely to damage desirable plants, expose soil, and increase erosion potential.

While it is generally accepted that mowing will not control perennial pepperweed (e.g. [39,67,81]), Baker [4] notes that haying (i.e. repeated mowing) perennial pepperweed infested fields in Wyoming, seems to prevent it from developing into a monoculture. There are no examples in the literature where repeated mowing was tested as a control method for perennial pepperweed.

Timing manual defoliation or other disturbances of above ground tissues during periods when minimum pools of stored energy are present can deplete stores of energy for future growth and thus enhance long-term control. Research has shown that minimum amounts of stored energy are in belowground tissues of perennial pepperweed at the bolting stage [68] (see [Seasonal Development](#)), indicating this as the optimal time to mow stems. Unfortunately, perennial pepperweed quickly recovers from mowing and produces leaves from previously dormant buds near the soil surface [69]. Sprouting may require less than 14 days (unpublished data as cited by [66]), and total nonstructural carbohydrate (TNC) pools in the top 16 inches (40 cm) of roots in mowed plants were not different than unmowed plants 7 and 19 days after mowing at 2 study sites, respectively. The authors speculate that TNC from roots deeper than 16 inches (40 cm) may have been mobilized, or that

reserves were replaced through photosynthesis by new leaves [68,69].

Mowing changes the architecture of a perennial pepperweed stand. Stem density is reduced (64 stems/m² in mowed plots compared to 142 stems/m² in plots not mowed), as well as stem height (19.4 inches (49.21 cm) in mowed plots compared to 38.0 inches (96.42 cm) in unmowed areas), and leaf area distribution is altered within the stand (see [General Botanical Characteristics](#)) [67]. Unmowed plants have the majority of leaf area in the top 3rd of the canopy, whereas in mowed areas, 84-86% of perennial pepperweed leaf area was found within the lower 3rd of the canopy. Sprouting stems also had 21-59% less total leaf area than plants not mowed at the flowerbud stage. According to Renz and DiTomaso [69], this change may increase effectiveness of herbicide sprays used after mowing by depositing more herbicide on basal leaves where it can preferentially be translocated to roots. Also, perennial pepperweed plants sprouting after mowing are more uniformly synchronized in growth stage, so herbicide application at a time of maximal below ground translocation is consistent throughout the stand [69]. According to Renz [67], a potential drawback of this approach is that perennial pepperweed sprouting is limited in dry sites and/or low precipitation years.

Renz and DiTomaso [69] tested the effects of mowing and herbicide treatments, alone and in combination, in 3 contrasting sites (high desert, roadside, and floodplain) in California. Dense, monospecific stands with >85% perennial pepperweed cover were mowed to a height of 1 to 2 inches (2-5 cm) when flowerbuds were present on the main shoot and shoots from axillary buds. Shoots quickly sprouted after mowing, resulting in a dense stand of rosette plants. The majority of these remained as rosettes throughout the season. Herbicide treatments (glyphosate, 2,4-D, and chlorsulfuron) were applied to mowed plants when bolting shoots reached the flowerbud stage. Perennial pepperweed biomass and density were measured 1 year after treatments. Mowing alone did not significantly ($p < 0.1$) reduce perennial pepperweed biomass or density 1 year after treatment. Chlorsulfuron was equally effective (97-100% biomass reduction) with or without mowing on the floodplain site, and mowing improved effectiveness on the high desert and roadside sites. Glyphosate was equally effective with or without mowing (83.5-87.4% biomass reduction) on the high desert site, while mowing enhanced effectiveness on the roadside and floodplain sites. Effectiveness of 2,4-D was not significantly ($p < 0.10$) enhanced by mowing, and was the least effective of the herbicides tested, with or without mowing.

A similar experiment compared the effects of combined mowing and herbicide treatments on dense and sparse perennial pepperweed infestations [69]. Mowing enhanced the effectiveness of herbicides in reducing perennial pepperweed biomass 1 year after treatments in the dense infestation, but not in the sparse infestation. Following control measures, response of resident plants was limited in the dense infestation, but extensive in the site with the sparse infestation. Nonnative annual grass cover increased at both sites. The authors conclude that dense perennial pepperweed populations may require an integrated approach, while less dense or establishing populations may be controllable with chemicals alone. Additionally, recovery of resident plant populations increases when management programs are initiated before perennial pepperweed infestations become dense, monospecific stands [69]. Renz [67] presents data on various herbicides used in this manner. See the [perennial pepperweed ESA](#) for more information.

Disking alone is also not thought to be an effective control method for perennial pepperweed because new plants sprout from root fragments [92]. However, incorporating tillage with other management approaches may improve control [67]. For example, tillage after herbicide application may be an effective way of bringing the treated roots to the soil surface where they will desiccate [94].

Disking perennial pepperweed may increase the density of an infestation (Renz and DiTomaso unpublished data, as cited by [67]). Periodic disking during the growing season over a 2-year period resulted in no permanent reduction in perennial pepperweed cover in native hay meadows in Nevada [99]. Disking perennial pepperweed at Grizzly Island Wildlife Area resulted in a serious increase in its distribution (Feliz, personal communication as cited by [39]).

Control following spring herbicide applications at the flowerbud stage was slightly improved in disked areas

relative to areas not disked. When previously disked areas are mowed the following spring at the flowerbud stage and herbicides are applied to sprouting plants in the flowerbud stage, greatly enhanced control by herbicides is observed. The incorporation of disking into a control strategy had been shown to enhance plant diversity the following year (Renz and DiTomaso, unpublished data), perhaps by stimulating seeds in the seed bank [67]. Renz [67] presents data on various herbicides used in this manner. See the [perennial pepperweed ESA](#) for more information.

Inundation: Case studies described by Howald [39] and Renz [67] suggest that perennial pepperweed may be intolerant of prolonged inundation.

Research presented by Chen and others [16,17] suggests that perennial pepperweed may tolerate and survive saturated conditions, but does not grow well under these conditions. This may be an adaptation to arid or semiarid riparian habitats where spring flooding and summer drought are characteristic. After 7 days of flooding, total biomass ($p < 0.001$) and root/shoot ratio ($p = 0.002$) of flooded plants were significantly less than those of unflooded controls (maintained at -20 kPa soil matric water potential) [17]. Further study of anaerobic metabolism in roots of perennial pepperweed seedlings indicates that perennial pepperweed roots have metabolically adaptive strategies to anoxia, but there is evidence of oxidative stress under anoxia and of postanoxic injury from free radicals upon re-exposure to air. Results suggest that perennial pepperweed exhibits a mixture of characteristics typical of hydrophytic, facultative, and anoxia intolerant species [16].

Fire: See the [Fire Management Considerations](#) section of this summary.

Biological:

Development of a biological control program for perennial pepperweed seems unlikely because of risks to many important crop plants that are members of the mustard family [6]. Additionally, several native pepperweed species from the western U.S. are either listed as endangered or are considered for listing [6,39]. Based on molecular phylogeny, perennial pepperweed is more closely related to Californian species than are other members of the genus [57]. Acknowledging these difficulties, Birdsall and others [6] point out the limitations of other control methods for perennial pepperweed, and suggest that both classical and augmentative biological control approaches warrant further examination, especially the potential for use in conjunction with other available techniques.

According to Young and others [94,96] perennial pepperweed can be suppressed by grazing, and there are examples in both Colorado and Nevada where grazing management suppressed perennial pepperweed. They provide no data or specific examples, nor do they mention which grazing animals are effective. According to Wood [91], in a preliminary test, 13 goats ate perennial pepperweed with no ill effects, and domestic cattle and sheep graze perennial pepperweed growing amid other plants, but they do not eat pure, dense stands of perennial pepperweed. According to Baker [4], domestic sheep readily eat perennial pepperweed in Wyoming, and even heavily infested pastures appear weed free. Once the sheep are removed, however, perennial pepperweed comes back (see [Palatability/nutritional value](#)). Grazing management is most effective in long term suppression of perennial pepperweed when initiated before all perennial grasses are lost from the community [94]. More research is needed on the use of livestock for perennial pepperweed suppression.

Chemical:

Before using herbicides for control of invasive plants, managers must consider the effectiveness of the herbicide on the target plant, appropriate timing and rates of application, the potential impacts on nontarget organisms, and residual activity and toxicity of the herbicide. If chemical control is used it must be incorporated into long-term management plans that include replacement of weeds with desirable species, careful land use management, and prevention of new infestations [14]. Use of herbicides may be restricted in some areas. See the [Weed Control Methods Handbook](#) for considerations on the use of herbicides in natural areas and detailed information on specific chemicals.

According to Howald [39], attempts have been made to control perennial pepperweed with chemical herbicides in California, Oregon, Wyoming, Idaho, and Utah. The shoot portion of perennial pepperweed is susceptible to several herbicides. However, even with 98% initial control, sprouting perennial pepperweed plants may result in total stand dominance by the end of the next growing season [100]. The most effective herbicides appear to be chlorsulfuron, metsulfuron methyl, and imazapyr [4,19,65,69,99]. Glyphosate is effective when applied after mowing to sprouting stems at the flowerbud stage [69]. At Malheur National Wildlife Refuge in Oregon, chlorsulfuron and metsulfuron methyl were tested alone and in combination with either fire or disking, with chlorsulfuron reducing perennial pepperweed densities by 100% in all 3 sites tested, and metsulfuron methyl resulting in density reductions of 90 to 100% [44] (also see [Integrated management](#) and [Fire management considerations](#)).

Chlorsulfuron delivers the most consistent long-term control of perennial pepperweed. Metsulfuron methyl appears to work well but is less studied. Imazapyr controls perennial pepperweed but is a fairly nonselective herbicide and is therefore more likely to damage desirable plants. Chlorsulfuron is not registered for use in many areas where perennial pepperweed occurs, particularly areas adjacent to water [67]. Other problems with chlorsulfuron include its adverse effects on valuable woody species [100], and difficulty in establishing perennial grass seedlings following control of perennial pepperweed [96] (see [Cultural](#) control).

Based on perennial pepperweed's seasonal carbon allocation pattern (see [Seasonal Development](#)), one might expect the optimal stage for herbicide application to be full-flowering to fruiting stages. However, control seems to be maximized when herbicide is applied at the flowerbud stage [99]. Application in late summer, after the haying operation has removed much of the top growth, may also be effective. "Excellent control" was also obtained with early spring or late fall applications in native hay meadows in Nevada [98]. However, fall applications of 9 herbicide treatments had minimal effects on perennial pepperweed in Utah [65].

Longer term studies are needed to better evaluate control potential of herbicides for perennial pepperweed [65]. The potential for perennial pepperweed to develop a resistance to particular herbicides/families also needs to be investigated [67]. For a more detailed synopsis of chemical control and more detail on particular herbicides, rates, timing, and other considerations see the [ESA on perennial pepperweed](#).

Cultural:

Any lasting biological suppression of perennial pepperweed requires establishment and persistence of desirable plants that are capable of competing successfully with perennial pepperweed in managed ecosystems.

Competitive ecotypes of native species are suggested. An example might be the use of saltgrass in halomorphic wetland areas [100]. Perennial pepperweed is, however, highly competitive, as evidenced by its ability to establish and spread in vigorous, well-managed alfalfa or tall wheatgrass stands, and its reputed ability to displace quackgrass [94].

In order to give perennial grass plants a chance to biologically suppress perennial pepperweed, repeated applications of selective herbicides may be necessary to help grasses establish. The choice of perennial species for revegetation of seasonally dry meadows with salt affected soils in the Intermountain Area is limited, and tall wheatgrass is the most widely used species [96]. Young and others [96] compared seedling establishment of tall wheatgrass on sites where perennial pepperweed was controlled with 2,4-D or chlorsulfuron. Perennial pepperweed was controlled with applications of 2,4-D, and tall wheatgrass seedlings established on some of these 2,4-D-treated plots. Plots treated with chlorsulfuron remained virtually free of perennial pepperweed, but no seedling establishment of tall wheatgrass occurred. Even when these plots were seeded for 4 consecutive years after herbicide application, tall wheatgrass seedlings never established. The plots remained weed free except for occasional perennial pepperweed plants until the 4th year, when Russian-thistle (*Salsola kali*), lambsquarters (*Chenopodium album*) and summer-cypress (*Kochia scoparia*) plants established in the treated area. The authors speculate that the apparent persistence of chlorsulfuron residues may be heightened by the high pH of the salt affected soils.

Where perennial pepperweed was initially controlled with applications of 2,4-D a few seedlings of tall

wheatgrass were initially present, but no tall wheatgrass plants were present the 2nd year after seeding. Where perennial pepperweed was initially controlled with 2,4-D and followed with a lower rate of 2,4-D over tall wheatgrass seedlings the spring after the seeds were planted, good stands of tall wheatgrass established.

Results from competition tests performed with perennial pepperweed and cheatgrass presented by Blank and others [8] (see [Successional Status](#)) suggest that a similarly aggressive, densely rooted native grass may successfully compete with perennial pepperweed. Information about which species can best compete with perennial pepperweed and/or prevent new invasions is needed [67].

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