

ELEMENT STEWARDSHIP ABSTRACT
for

Lepidium latifolium L.

perennial pepperweed
tall whitetop

To the User:

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THE NATURE CONSERVANCY

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SCIENTIFIC NAME:

Lepidium latifolium L.

Synonym: *Cardaria latifolia* (L.) Spach

COMMON NAMES:

This plant is most commonly referred to as perennial pepperweed or tall whitetop. Several other common names are used throughout the U.S. such as giant whiteweed, perennial peppergrass, slender perennial peppergrass, broadleaf or broadleaved pepperweed, and ironweed.

DESCRIPTION & DIAGNOSTIC CHARACTERISTICS:

Unless otherwise cited, all information in this section was obtained from *The Weeds of California* (Healy & DiTomaso, in prep.).

Perennial pepperweed is a herbaceous perennial that produces dense stands with stems reaching up to 1.5 meters in height. These stems originate from large perennial below-ground roots and emerge in early spring/late fall. Shoots will remain in the rosette form for several weeks before stems elongate (bolt). Shoots flower and fruit during late spring and continue throughout much of the summer. Plants senesce by mid to late summer while fruits remain on the stem.

SEEDLINGS: Seedlings are rarely found in the field. Cotyledons are obovate to oblong, 3-8 mm long with a rounded tip and the base tapered to a short petiole 2-3 mm long. The first leaves are developmentally alternate, but appear opposite. These leaves are ovate to oblong, 4-12 mm long, glabrous, with the tip +/- rounded and with +/- wedge-shaped bases. The leaves have entire to slightly wavy margins and a petiole approximately 5 mm long. Subsequent leaves resemble first leaves, but are larger in size.

MATURE PLANT: Typically in field conditions, shoots originate from perennial roots or semi-woody crowns. Foliage can be glabrous and green to gray-green in color. Rosette leaves are approximately 30 cm long and 8 cm wide with serrate margins on long petioles (3-15 cm long). Stem leaves are highly reduced, +/- less sessile, tapered at the base, with margins entire to weakly serrate. These leaves are alternate and lanceolate to elliptic or oblong in shape. As the canopy develops, rosette and basal leaves commonly senesce. Stems typically reach 0.5-1.5 meters in height.

ROOTS: Roots are typically long, thick and minimally branched. 85% of root biomass occurs in the top 60 cm of the soil (Renz et al., 1997), but roots can extend much deeper. Roots of this plant are believed to grow into the water table (phreatophytic) and in deep soils rooting depths greater than 3 meters have been observed (Blank & Young 1997). Preliminary experiments have also shown that these roots perennialize rapidly (by the 8 leaf stage) (Renz & DiTomaso, unpublished data).

FLOWERS: This plant forms dense clusters of flowers in panicles. Flowers have 4 green oval sepals less than 1 mm long, 4 white, spoon-shaped petals approximately 1.5 mm long, 6 stamens (4 long, 2 short), and a single pistil approximately 2 mm long.

FRUITS and SEEDS: Pods (silicles) are 2-chambered, approximately 2 mm long at maturity and slightly flattened producing a fruit round to slightly ovate in shape covered with long, simple hairs. The stigma is sessile, and remains on the fruit. The fruit is borne on a pedicel that is much longer than the pods itself. Fruit contain one seed per chamber that is ellipsoid, slightly flattened, approximately 1 mm long and 0.5 mm wide. These seeds are reddish-brown with a shallow groove on each side. Seeds fall from pods irregularly through winter and some may remain in pods until the following season. Plants frequently abort seeds if the plant is under stress during fruit set.

POST-SENESCENCE CHARACTERISTICS: Aboveground parts typically die in late summer to fall with pale dead stems persisting for several years.

STEWARDSHIP SUMMARY:

Perennial pepperweed is a highly invasive herbaceous perennial. It can invade a wide range of habitats including riparian areas, wetlands, marshes, and floodplains. Once established this plant creates large monospecific stands that displace native plants and animals and can be very difficult to remove. It can currently be found throughout all states west of the Rocky Mountains and has been reported in coastal New England.

With the exception continual flooding, no non-chemical treatments have been found to effectively control this weed. Excellent control can be obtained with several herbicides which fit in various control strategies, but limited recovery of desirable plants is seen in these controlled areas unless the soil surface is disturbed. Perennial roots can also remain dormant in the soil for several years, thus intense monitoring with early detection and removal is the best control measure for perennial pepperweed. Sources of infestations should also be located and eliminated to prevent future infestations.

IMPACTS:

Perennial pepperweed poses a serious threat to many native ecosystems and previously disturbed areas returning to their native conditions by creating large monospecific stands. These dense stands can displace threatened and endangered species, such as the salt marsh harvest mouse (Trumbo 1994) or interfere with the regeneration of important plant species such as willows and cottonwoods (Young et al., 1995). Besides decreasing plant diversity, perennial pepperweed is also believed to reduce nesting frequency of waterfowl in and near wetlands that it invades (Trumbo 1994).

Perennial pepperweed also alters the ecosystem that it grows in. Blank and Young (1997) have shown these plants can act as “salt pumps” which take salt ions from deep in the soil profile, transport them up through their roots and deposit them near the surface. This can favor halophytes and put other species at a disadvantage, thereby shifting plant composition and diversity.

GLOBAL RANGE:

This herbaceous perennial is native to southeastern Europe and southwestern Asia. Infestations have been reported in coastal New England and throughout all of the states

west of the Rocky Mountains. Within these regions perennial pepperweed can be found in many habitats, from intermountain and mountainous areas to coastal wetland and marshes. It can currently be found in all counties of California except for counties composed exclusively of coastal rainforest (Humboldt & Del Norte county) or desert habitats (Imperial & San Bernadino county)(Young et al. 1997). Infestations have also been found in Australia (Kloot 1973) and nearly every landfill in Europe (Kiegel et al., 1988).

HABITAT:

Perennial pepperweed has the ability to invade and establish in a wide range of habitats. It is most frequently found in riparian areas, marshes, estuaries, irrigation channels, wetlands, and floodplains, but is not exclusive to these areas. If introduced, it can proliferate in roadsides, native hay meadows, alfalfa fields, and rangeland habitats.

BIOLOGY/ECOLOGY:

SEASONAL GROWTH PATTERNS:

Perennial pepperweed stems originate from large perennial below-ground roots that allow rapid growth of shoots. Growth can begin at varying periods depending upon the last frost, but generally shoots emerge in late winter/early spring before those of most native species. In coastal areas where frost is infrequent, rosette leaves will persist through winter months. Observations of perennial pepperweed seedlings have been very rare in the field, but germination appears to occur late winter/early spring.

The shoots remain in rosette form for several weeks before internodes elongate and stems appear. Day length (long days) is believed to be a main factor in the regulation of stem elongation. Flowering develops by mid spring to early summer. As the flowers develop, the shoot apical meristem loses its apical dominance and axillary buds elongate and form a 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 can occur for several months. Stems quickly senesce after fruits mature late in the summer. Rosette leaves frequently emerge from dormant buds below the soil in the late summer/early fall and persist until the initial frost.

SEED BIOLOGY:

Infestations can produce over 16 billion seeds/ha annually (unpublished data, USDA, ARS Reno, NV). These seeds rapidly germinate in laboratory conditions, but few seedlings are observed in the field. Reasons for this are unknown. Germination rates are high in laboratory conditions when seeds are exposed to fluctuating cold/warm temperatures (Miller et al., 1986). However the seeds lack a hard coat and do not seem to be capable of surviving long periods in the soil, thus seed viability may be short. This suggests that reinfestations from the seedbank may not be a problem once control is achieved (Miller et al., 1986).

ROOT BIOLOGY:

Perennial pepperweed allocates about 40% of its biomass to below-ground organs (Renz et al., 1997) These organs consist of annual roots, perennial roots and semi-woody root crowns. Excavation of below-ground organs in a riparian habitat revealed that 19% of the below-ground biomass was present in the top 10 cm of the soil, with 85% in the top 60 cm (Renz et al., 1997). This extensive creeping root system is thought to enhance the below-ground competitiveness of perennial pepperweed for water and nutrients while increasing the carbohydrate reserve important for rapid shoot development in the spring (Renz & DiTomaso, 1999a, 199b; Blank & Young 1997).

Some roots creep horizontally below the soil and others penetrate deep into the soil, but neither type forms dense clusters of roots. The combination of the low root density and perennial roots fragmenting easily allows soil erosion to occur more frequently along riverbanks that they infest. It has been observed that perennial pepperweed root systems will allow an infested bank to erode during flooding events or other high waterflow events. The water will carry the roots (which float) downstream where they can establish new populations (personal communication Susan Donaldson, Jim Young). Perennial pepperweed roots' ability to tolerate dry conditions and resist desiccation help new colonies get established.

CARBOHYDRATE ALLOCATION:

Studies have shown that perennial pepperweed can store large amounts of energy in its perennial roots. When spring growth is initiated, below ground stored energy rapidly decreases and reaches a minimum at the bolting stage before flowerbuds develop (Renz & DiTomaso, 1999, a & b). Perennial pepperweed begins allocating large amounts of photosynthate below ground during the flowerbud stage. The rate of translocation of photosynthates to below-ground structures is greatest from the full flowering to seed filling stages (Renz & DiTomaso, 1999, a & b). Assuming that herbicide movement parallels carbohydrate movement, herbicide applications during these stages would be expected to maximize herbicide movement and accumulation into the perennial roots and thus provide more effective long-term control. Previous research however, has determined the optimal timing for herbicide applications to be the flowerbud stage (Young et al., 1998; Trumbo 1994) (see Chemical control section, Applications to initial shoots for discussion). As stems senesce in the late summer/early fall, a decrease in stored carbohydrates 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 remains constant until early spring growth begins (Renz & DiTomaso, 1999, a & b).

LEAF AREA:

Leaf area of perennial pepperweed fluctuates over the season and appears to be highly dependent upon environmental factors. Total leaf area has been observed to attain its greatest value at the flowerbud stage when it reaches values over 26,528 cm² leaf area/m² (Renz & DiTomaso, unpublished data). As stems flower and fruit, leaf area decreases until plants senesce. Leaf area is not evenly distributed within the canopy. Approximately one half of the leaf area can be found within the top third of the canopy during the flowerbud to fruiting stages (Renz & DiTomaso, unpublished data). This skewed

distribution of leaf area and the presence of many potential sinks (apical meristems, flowerbuds, young leaves) within the top third of the canopy may have dramatic consequences for herbicide movement, preventing transfer to below-ground perennial organs and limiting control (Hill & Weaver 1961).

An early season mowing has been shown to dramatically shift the total leaf area and the location of the leaf area within the plant canopy. Resprouting stems had 21-59% less leaf area than plants not mowed at the flowerbud stage. In mowed areas, 84-86% of the leaf area was found within the lower third of the canopy. If herbicide applications are made to resprouted shoots, more herbicide will be deposited onto the lower third of the canopy. This may in turn lead to the translocation and accumulation of more herbicide to below-ground perennial organs, enhancing control (Hill & Weaver 1961; Stamm Katovich et al., 1996).

LITTER LAYER:

Significant amounts of litter can build up in dense infestations. Old stems take several years to degrade, and can form a layer impenetrable to light. Litter layers can reach upwards of 10 cm in depth (Renz & DiTomaso, 1998a). This deep litter layer prevents the emergence of annual plants in these areas and may reduce competition from other species. Few plants besides perennial pepperweed have enough stored energy to grow through this dense litter layer. Even if perennial pepperweed is controlled, it may be necessary to remove the litter to stimulate germination and growth of desirable plant species.

RECOVERY POTENTIAL OF LAND:

Previously infested land can recover, but costs incurred will vary depending upon location, density, and length of time infested. New infestations that cover a small area will be the cheapest and simplest to remove. As infestations grow, the density of perennial roots and stems increase. Increased stem production can result in dense litter layer that prevents the establishment of desirable plants in subsequent years. This layer must be removed in order to ensure successful restoration. Any creeping perennial roots present in the soil must be killed or removed to prevent reinfestations. This can be very difficult since roots resist desiccation and have been found more than 3 meters deep in the soil profile (personal communication, Jim Young). Perennial pepperweed also has been shown to alter its ecosystem by taking salt ions from deep in the soil profile and depositing them near the soil surface (Blank & Young 1997). If soil salinities are dramatically increased, an intensive soil remediation program may be necessary before desirable native species can reestablish.

MONITORING REQUIREMENTS AND PROCEDURES:

One must be diligent in monitoring areas where perennial pepperweed is being managed, since roots are difficult to kill. Areas should be monitored in early spring and late summer if possible. In many areas perennial pepperweed is one of the first plants to emerge in the spring and can be identified very early in the growing season. In areas not dominated by perennial pepperweed, care must be taken if monitoring early in the season as other emerging plants can interfere with the detection of pepperweed rosettes. In these

areas, infestations should be monitored either before other species begin growing or as they senesce. Early in the season, perennial pepperweed rosettes and stems are often the only green foliage visible, later in the season as other plants senesce, perennial pepperweed will be the remaining plant alive and green. In larger, monospecific infestations, plants are most visible when they are flowering and producing fruit. Photographic monitoring has been successful in some cases (Kramer et al., 1995), but rosette plants cannot be monitored using this method. Rosettes can form the leading edge of an infestation, which is the most important area to monitor and control (Moody & Mack 1988). The best time to detect these new rosettes is late summer. Monitoring can also be done in fall/winter by looking for senesced stems (gray in color with fruits visible on stems throughout fall), but often rosettes may be missed by this late season evaluation.

Efforts should be made to locate the source of the infestation and if possible the source should be eliminated. 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). Therefore monitoring of all of these potential sources is recommended.

RESEARCH NEEDS:

Currently many gaps in knowledge exist regarding the biology, ecology, and control of perennial pepperweed. Important issues include:

- Seed germination. Seeds are present within the seed bank, but few ever germinate in the field. Why?
- Perennial roots appear to be the major mechanism of spread. More information is needed describing the growth patterns and longevity of these roots and what depths they can emerge from.
- Perennial pepperweed can exist in low, moderate, or highly saline habitats and use water that is brackish or fresh. How does this species cope with varying soil water salinities?
- These plants can invade and be extremely competitive in a wide range of habitats, but infestations are believed to expand via movement of vegetative parts, particularly root fragments. Are several biotypes of perennial pepperweed found throughout the world, and if so how do these biotypes respond to varying conditions? And if biotypes exist can they cross-pollinate?
- Many control strategies use herbicides with one mode of action, thus the potential exists for resistance. Even though these plants appear to mainly spread via asexual organs, is resistance possible within populations of perennial pepperweed? If so how can its spread be minimized?
- Once control is established, future restoration efforts need to be taken to prevent new invasions. Information about which species can best compete with perennial pepperweed and/or prevent new invasions is needed.
- Many sites have dense infestations in one area and no plants invading into nearby locations. This indicates that perennial pepperweed spread is limited by environmental, physical, and/or geographical factors. What factors limit the expansion of perennial pepperweed?

- What impact do infestations have on native plant and animal populations?
- Is absorption and translocation of systemic herbicides altered in resprouting tissue after mowing?
- How do environmental factors such as soil moisture affect translocation and accumulation of systemic herbicides into perennial organs?

MANAGEMENT REQUIREMENTS:

Several control strategies are described below; each of these strategies fit well in specific types of habitats. The most appropriate control strategy should control perennial pepperweed while allowing desirable species to reclaim the area. Two types of infestations are seen: 1) large monospecific stands and 2) spotty, scattered populations. If resources are available to control the entire infestation, including large stands, efforts should be made to do so. If only part of the infestation can be treated, modeling and experience indicate that controlling outlying patches and the leading edge of infestations are most important (Moody & Mack 1988). For smaller scattered populations, an early response can lead to reduced long-term cost of control. Research has also shown these satellite populations (low density) can be controlled with reduced herbicide rates (Dieleman et al., 1999). If possible, early detection and spot treatment of new satellite populations are the most effective way to control this invasive weed.

With all of these control methods it is important to restore desirable vegetation wherever reinvasions might occur. Limited data is available, but it appears some species can compete with perennial pepperweed and may help prevent it from reestablishing (Fredrickson & Murray, 1999; Kramer et al., 1995). More research in this area is necessary.

MANAGEMENT PROGRAMS:

Few management programs have been implemented to control perennial pepperweed. This is likely due to the recent rapid increases in populations throughout the west. Currently several land managers are initiating management programs for perennial pepperweed in the west, unfortunately it is too early to tell whether or not they will be successful.

Refuge managers of the Grizzly Island Wildlife Refuge, a seasonal wetland near Suisun Bay, California, have been implementing a management program for several years. This refuge had large monospecific infestations. Refuge managers used reduced rates of chlorsulfuron applied at 0.1875 to 0.5625 oz/A (0.01325-0.03975 kg/ha)[Telar at 0.25-0.75 oz/A & 0.25% nonionic surfactant]. After 1 year, excellent control was observed. Desirable grasses established within control areas, which helped prevent reestablishment/resprouting of perennial pepperweed to this area for several years. The area later flooded due to a ruptured levee and the following spring large infestations of perennial pepperweed reappeared in this area (Trumbo 1994 and personal communication). It is not known why/how the flooded area was reinfested. It is believed that the loss of control was due to the loss of grass and litter from the flood. These grasses were believed to be suppressing or outcompeting growth of dormant perennial pepperweed roots. Currently refuge managers have increased the rate of chlorsulfuron to

0.75 oz/A (0.053 kg/ha)[Telar at 1.0 oz/A & 0.25% nonionic surfactant] to increase long-term control.

CONTROL METHODS:

Unfortunately, many control methods are ineffective against perennial pepperweed or can only be used in specific areas. The only non-chemical control method effective against large populations is long-term flooding, but it is not known if plants will reestablish if the flooding regime is removed from these areas (Fredrickson & Murray 1999). The most consistent control was found with the use of herbicides applied at the flowerbud to early flowering stage (Young et al., 1998; Trumbo 1994). Chlorsulfuron at 1.5 oz/A (0.052 kg /ha) [Telar[®] at 2 oz/A with 0.1% silicone based or 0.25% nonionic surfactant] provided the best long-term control. Unfortunately, this herbicide is registered only for noncrop areas in most states and cannot be applied near or over water. Metsulfuron-methyl (Escort[®]) and imazapyr (Arsenal[®]) are also effective against perennial pepperweed.

Other integrated control strategies consisting of mowing and/or disking followed by herbicide applications to resprouting shoots have shown enhanced control. Unfortunately, resprouting of shoots is highly variable and may be limited during dry conditions. When herbicides are applied to shoots that have resprouted after mowing equivalent or enhanced control is seen at reduced rates. Chlorsulfuron at 0.75 oz a.i/A (0.026 kg /ha) [Telar[®] at 1 oz/A with 0.1% silicone based or 0.25% nonionic surfactant] provided near complete control after 1 year. If infestations are in sensitive areas (e.g. riparian, wetland) glyphosate at 3 lbs. a.e./A(3.33 kg a.e./ha) [¾ gal Rodeo[®] pro/A] following an early season mowing and/or disking has proven effective. If land managers cannot use chlorsulfuron, metsulfuron methyl, or imazapyr, the use of glyphosate integrated with disking and mowing can be substituted and provide equivalent control.

Increased plant diversity in the glyphosate treated areas was observed compared to other treatments. This may be due to glyphosate having no soil activity compared to sulfonylurea and imidazolinone herbicides. Plant diversity is also greatly enhanced if disking is included in any control program for dense infestations. Due to the dormancy of perennial roots, monitoring and spot spraying are necessary over several years to eliminate this weed.

BIOLOGICAL CONTROL:

No biological control agents have been introduced to control perennial pepperweed. To date no biological control agents have been established on any member of the *Brassicaceae* (Birdsall et al., 1997). This is most likely due to several factors such as the important cultivated crops within this family (canola, mustard, cabbage, and kale). ARS employees have searched native areas for potential candidates for perennial pepperweed biocontrols, however, there are several threatened and endangered native species of *Lepidium* in the U.S. In order for an agent to be introduced research will need to be conducted to ensure the agent will not harm these species.

Several general herbivorous insects are present that feed on perennial pepperweed (e.g. *Lygus* spp.). While these insects can damage the plant, the damage is not significant

enough to prevent populations from spreading. Typically these insects feed on the flowerbuds exclusively, which can prevent seed production, but do not prevent the clonal expansion by the creeping root system.

A white rust (*Albugo sp.*) has been found growing on plants in several areas throughout the west. In wet years this rust infects large numbers of flowers and limits seed production (Young et al., 1997). Unfortunately, this rust has never been observed to prevent clonal expansion by the creeping root system.

BURNING:

Several land managers have attempted using prescribed burns to control perennial pepperweed. Stems from previous years may be difficult to ignite and maintain if other fuels are not present (Kilbride et al., 1997). If a fire can be established, it can be efficient in removing existing and past stems. Burning does not, however, appear to harm the below-ground perennial roots (Trumbo 1994). Biomass of resprouting stems may even increase in subsequent years due to the removal of the litter layer (Renz & DiTomaso, 1998 a & b) and the addition of nutrients from the fire.

CHEMICAL:

Applications to initial shoots:

Research has determined the most effective phenological stage to apply systemic herbicides to perennial pepperweed is the flowerbud to early flowering stage (Young et al., 1998). Reduced control has been observed when herbicides are applied at other stages. Control data exist for several herbicides, which will be discussed individually. For each treatment, unless mentioned, assume the stage of herbicide application to be the flowerbud to early flowering stage.

Specific herbicide options are discussed below in detail, but in brief chlorsulfuron at 1.5 oz/A (0.052 kg /ha) [Telar[®] at 2 oz/A with 0.1% silicone based or 0.25% nonionic surfactant] delivers the most consistent long-term control of perennial pepperweed. Metsulfuron methyl (Escort[®]) appears to work as well as chlorsulfuron, but this herbicide has not been studied in as much detail. Both of these herbicides are fairly selective and will not cause significant damage to many grass species. Imazapyr (Arsenal[®]) can also deliver excellent control, but is a fairly nonselective herbicide, thus lower plant diversity and more bare ground will occur in areas following the use of this herbicide. Other herbicides have been highly variable in controlling perennial pepperweed, but are typically poor and these compounds are not recommended for use unless integrated with other control methods.

The table below is a synopsis of varying levels of control 1 year after treatments were applied at the flowerbud to early flowering stages. Data are given as % **control** (100% = no perennial pepperweed plants); % **cover** (0% = no perennial pepperweed plants); % **reduction in biomass** (60% = 60% less biomass of perennial pepperweed compared to control plots); % **reduction in density** (65% = 65% fewer stems of perennial pepperweed compared to control plots).

TREATMENTS MADE AT THE FLOWERBUD STAGE

Active Ingredient & Rate	Product & Rate	% Control or % Cover*	% Reduction in Biomass*	% Reduction in Density*
2,4-D 1.9 lbs. a.e./A (2.13 kg a.e./ha)	Weedar [®] 64 0.5 gal/A Weedone [®] LV4 0.5 gal/A	14-73% control ^{4,5} 63.2% cover	13-70	29-65
Triclopyr 2.25 lbs. a.e./A (2.52 kg a.e./ha)	Garlon 3A 0.75 gal/A Garlon 4A 0.56 gal/A	65.2% cover	35	38
Chlorsulfuron 1.5 oz/A (0.105 kg /ha)	Telar [®] 2.0 oz/A	0.0% cover	100	100
Imazapyr 6 oz a.e./A (0.42 kg a.e./ha)	Arsenal [®] (2 lbs. a.e./gal) 6-24 fl. oz/A	2.5% cover	98	88
Metsulfuron methyl 0.3-0.6 oz/A (21-42 g /ha)	Escort [®] 0.5-1.0 oz/A	76-85% control ^{1,2,3}	-	-
Glyphosate 0.38 lbs. a.e./A and 2,4-D 0.63 lbs. a.e./gal	Landmaster [®] 54 fl. oz/A Campaign [®] 54 fl. oz/A	72% control ¹	-	-
Imazethapyr 1.5 oz/A (0.11 kg /A)	Pursuit [®] 6 fl. oz/A	27% control ⁴	9	10
Glyphosate 3 lbs. a.e./A (3.33 kg a.e. a.e./A)	Roundup [®] 1 gal/A Rodeo [®] 0.75 gal/A	20% control ⁵ 77% cover	32	0-27

¹ Crockett 1997, ² Reid et al., 1999, ³ Beck 1999, ⁴ Renz et al., 1997 CWSS

⁵ Renz & DiTomaso, 1998 a & b

* Data is from unpublished results from Renz & DiTomaso.

Auxin mimicking herbicides

2,4-D (Weedar[®] 64 or Weedone[®] LV4, both are 3.8 lbs. acid equivalent (a.e.)/gal)

Triclopyr (Garlon 3A, 3 lbs. a.e./gal; Garlon 4A, 4 lbs. a.e./gal)

These herbicides are only active on foliage of broadleaf plants and with surfactant (non ionic at 0.25% or silicone based surfactants at 0.1%) are effective in removing above ground growth without harming grass species. Unfortunately, these compounds provide poor long-term (i.e. longer than 1 year) control of perennial pepperweed. Applications of 2,4-D at 1.9 lbs. a.e./A (2.13 kg a.e./ha) [0.5 gal Weedar[®] 64/A with 0.1% silicone based or 0.25% nonionic surfactant] or triclopyr at 2.25 lbs. a.e./A (2.52 kg a.e./ha) [0.75 gal Garlon 3A/A with 0.1% silicone based or 0.25% nonionic surfactant] provided anywhere from 13-70% reduction in biomass after 1 year (typically 30-50% reduction) compared to

untreated areas (Renz & DiTomaso, 1998 a & b, 1999 a & unpublished data). No differences were observed in the level of control between the amine (Weedar[®] 64) and the ester formulations of 2,4-D (Weedone[®] LV4) (Young et al., 1998). In spray to wet situations Garlon 3A showed similar results as above when applied as a 2% tank mix with surfactant (personal communication, Joel Trumbo).

Successive years of wicking a 100% solution of 2,4-D onto stems growing in riparian areas has suppressed infestations, but if this treatment is stopped it is believed that control will be lost (personal communication, Susan Donaldson).

Formulations of these herbicides are registered for use in/near water in many states and are in many cases the *only selective* herbicide option in these sensitive areas. Control of new infestations within large stands of desirable grasses along riverbanks and in floodplains is currently being attempted with these herbicides. Diligent monitoring and repeated applications for several years will likely be necessary to be successful.

Sulfonylureas

Perennial pepperweed is very sensitive to herbicides in the sulfonylurea family. At extremely low rates (0.5-2 oz/A) these herbicides can control dense stands. In general these herbicides selectively control broadleaf plants, but some of these herbicides within this family can cause damage to grasses (Whitson et al. 1999). These herbicides should also not be used exclusively in any management program because several weed species have become resistant to this herbicide family (Ahrens 1994). Even though these herbicides offer excellent long-term control, perennial roots sometimes remain viable after treatment, and lay dormant for long periods before resprouting. As herbicide concentrations in the soil decrease, shoots may reemerge from these viable roots. Because of this, monitoring is extremely important in these areas.

These herbicides are registered for use in noncrop, roadside, and even rangeland areas in most states. Before using these herbicides contact the appropriate agency within your state as to specific regulations for each herbicide. Also, be cautious when making applications of these herbicides near/under trees or shrubs as they have activity on several shrub and tree species.

Chlorsulfuron (Telar[®], 75% active ingredient (a.i.))

Applications of chlorsulfuron at 1.5 oz/A (0.052 kg /ha) [Telar[®] at 2 oz/A with 0.1% silicone based or 0.25% nonionic surfactant] have been highly effective in controlling perennial pepperweed for 2 years (Young et al., 1998). Chlorsulfuron at lower rates, 0.75 oz/A (0.026 kg /ha)[Telar[®] at 1 ounce/A with 0.25% nonionic surfactant] has been effective in controlling perennial pepperweed in some areas (Beck 1999), but inconsistent control has been observed in other studies (Renz & DiTomaso, unpublished data). Chlorsulfuron has both foliar and soil activity on plants. Its half-life in soils can vary between 4-6 weeks, but this herbicide can be mobile in soils with a high pH (Ahrens 1994).

Metsulfuron methyl (Escort[®], 60% a.i.)

Applications of 0.3-0.6 oz/A of Metsulfuron methyl (21-42 g /ha) [0.5-1.0 oz/A Escort[®] with 0.25% nonionic surfactant] can provide 76-85% control 1 year after applications (Crockett 1997; Reid et al., 1999; Beck 1999). As with chlorsulfuron, high variability is seen in the level of control with lower application rates. One researcher found enhanced control with a fall application (97% control 1 year after applications), but this treatment has not been repeated (Beck 1999). Metsulfuron methyl also has foliar and soil activity. Its half-life in soils can vary from 1-6 weeks, depending on location and it can be mobile in high pH soils (Ahrens1994).

Imidazolinones

Perennial pepperweed is also sensitive to herbicides within this family. The mode of action of herbicides in this family is identical to the sulfonylurea herbicides (it inhibits the biosynthesis of branched chained amino acids). The repeated use of these herbicides or other herbicides with the same mode of action (e.g. sulfonylurea) may promote resistance. Due to this, repeated use of herbicides with the same mode of action is not recommended.

Imazethapyr (Pursuit[®] 2 lbs. a.e./gal)

Imazethapyr is primarily used in alfalfa and soybeans and has foliar and soil activity with a half-life in soils of 60-90 days (Ahrens 1994). Perennial pepperweed infests some high elevation alfalfa fields in Northern California. Research was conducted to test the effectiveness of imazethapyr for perennial pepperweed control in these fields. Imazethapyr was applied at 1.5 oz/A (0.11kg a.e./ha)[6 oz/A of Pursuit[®]] and gave less than 30% control with limited reduction in biomass and stem density (Renz & DiTomaso 1998a). This indicates the limited effectiveness of this herbicide on perennial pepperweed without integrating other control methods.

Imazapyr (Arsenal[®] 2 lbs. a.e./gal)

Imazapyr applied at 4-6 oz a.e./A (0.28-0.42 kg a.e./ha) [16-24 oz/A of Arsenal[®] with 0.1% silicone surfactant] gave 95-98% biomass reduction and 88-89% reduction in stem density 1 year after applications. However, resulting areas have little to no vegetation reestablishing 1 year after applications (Renz & DiTomaso, unpublished data). Perennial pepperweed reestablished from existing seedbank when 2 oz of imazapyr a.e./A (0.14 kg a.e./ha)[8 oz Arsenal[®] /A with 0.1% silicone surfactant]. While this rate reduced stem density 1 year after applications, biomass was not significantly reduced (Renz & DiTomaso, unpublished data). Imazapyr is a fairly nonselective herbicide, which has foliar and soil activity on many plants, including grasses. Its half-life in soils varies between 3-21 weeks, but does not appear to be mobile in the soil (Ahrens 1994). Imazapyr is registered for use in non-cropland areas such as railroad, rights-of-way and fence rows.

Other herbicides

Glyphosate (Roundup[®] Pro 3 lbs. a.e./gal; Rodeo[®] 4 lbs. a.e./gal)

This herbicide has been successful in controlling many perennial plants, but it is ineffective in controlling perennial pepperweed without integrating other control methods. Glyphosate is a nonselective herbicide with foliar activity exclusively. The

Roundup[®] Pro formulation contains a surfactant that is toxic to fish, but Rodeo[®] has no surfactant and, thus is not toxic to fish. Rodeo[®] is registered for use in aquatic areas or next to water and applications with this product should be mixed with an appropriate surfactant. Rates of glyphosate up to 3 lbs. a.e./A (3.33 kg a.e./ha) [1 gal Roundup[®] pro/A] will only reduce biomass by 30% 1 year after application (Renz & DiTomaso, unpublished data).

Glyphosate and 2,4-D

(Landmaster[®]; 0.9 lbs. a.e. glyphosate/gal and 1.5 lbs. a.e. 2,4-D/gal)

(Campaign[®]; 0.9 lbs. a.e. glyphosate/gal and 1.5 lbs. a.e. 2,4-D/gal)

Two herbicide formulations that combine glyphosate and 2,4-D are available. Both have foliar activity on plants, but are nonselective. Landmaster[®] at 54 oz/A or Campaign[®] at 54oz/A offers up to 72% control 1 year after applications (Crockett 1997). Further research is currently quantifying the consistency of long-term control with these herbicides. Campaign[®] is registered for use in roadsides and other noncrop areas, while Landmaster[®] is registered for use in fallow or reduced tillage systems.

Factors involved in optimizing timing of herbicidal applications:

Based upon the carbon allocation pattern it is surprising to see herbicide control maximized at the flowerbud stage. One would expect the optimal stage to be the full flowering to fruiting stages (stages with greatest movement of carbon to below-ground organs). It is currently believed the flowerbud to early flowering stage gives the best control because the herbicide is deposited in locations that allow the most herbicide to be absorbed, translocated, and accumulate in below-ground organs. During the flowering to seed filling stages plants continue to produce many flowers, stems, and fruits. These organs reduce the interception of herbicide by leaf tissue. Up to 55% of the herbicide recovered from the plant at this stage can remain on the flowers and fruits (Renz & DiTomaso, unpublished data). Since these organs are typically strong sinks, they likely prevent the movement of herbicides to perennial roots, limiting control. Leaf abscission during flowering also reduces leaf area. Although translocation rates are not highest in the flowerbud stage, location of herbicide deposition and absorption may allow greater accumulation of the herbicide into roots and crowns at this time.

Applications to plants resprouting after mowing:

By integrating an early season mowing with systemic herbicide applications to resprouting shoots, dramatic improvement in control of perennial pepperweed has been demonstrated (Renz & DiTomaso, 1998 a & b). This strategy involves mowing stems at the flowerbud stage, followed by a herbicide application to resprouting stems when translocation patterns favor accumulation below ground. Data indicate mowing plants at the flowerbud stage increased the effectiveness of nearly all herbicides 1 year after treatment compared to plots that were not mowed (Renz & DiTomaso, 1998 a & b; unpublished data). Mechanisms responsible for enhanced control are currently being examined and are discussed below.

No differences were found in seasonal photosynthate translocation patterns into below-ground organs if plants were mowed or remained intact (Renz & DiTomaso, 1999 a & b).

Thus seasonal translocation rates do not appear to be responsible for increased control with this strategy. However, stem and leaf morphology and architecture differ dramatically between previously mowed and intact stems at the time of application. Leaves of plants that were not mowed are small and often perpendicular to the ground while leaves from plants previously mowed are much larger and parallel to the ground. Mowing can reduce stem density (64 stems/m² in mowed plots compared to 142 stems/m² in plots not mowed) and stem height (49.21 cm in mowed plots compared to 96.42 cm in areas not mowed) at the time of application (Renz & DiTomaso, 1999 a). While the altered canopy system does not alter the amount of herbicide deposited to resprouting tissue compared to intact plants, it does alter the location of herbicide deposition. The majority of herbicide applied to shoots not mowed remains in the top third of the canopy (61-69% of herbicide recovered). In mowed areas, the majority of the herbicide is deposited on the lower third of the canopy of resprouting plants (67-83% of herbicide recovered), (Renz & DiTomaso, in press). These lower leaves may absorb more herbicide allowing more to move into perennial roots and this may partially explain the enhanced control. It is important to note that in mowed areas herbicide applications are delayed to allow for shoots to resprout. Subsequently, applications to mowed areas are made during periods of the greatest translocation of photosynthate (and herbicide) into below-ground organs. This could also be responsible for an increase in herbicide accumulation in roots and crowns thereby enhancing control. It is currently believed that altering the distribution of the herbicide to the lower third of the canopy results in an increase in absorption and translocation of herbicide to perennial roots. These applications are also synchronized with maximal below-ground translocation rates, which results in increased accumulation in roots and crowns therefore enhancing control.

Several of the herbicides evaluated yielded variable control when used after mowing. Reasons for this are unknown, but likely involve soil moisture and other related site-specific factors. Soil moisture is an important factor because resprouting is limited in dry sites, or low precipitation years. New tissue growth from perennial roots is essential to provide ample surface for herbicide deposition and subsequent translocation into perennial roots.

The table below illustrates the ranges of control observed with different treatments. All data from the table was taken 1 year after applications were made. For details for each treatment please refer to the table. Several treatments were successful in controlling perennial pepperweed. Chlorsulfuron at 0.75 oz A.i/A (0.026 kg /ha) [Telar[®] at 1 oz/A with 0.1% silicone based or 0.25% nonionic surfactant] provided near complete control. This was one half the rate needed for this level of control in areas not mowed. Imazapyr and imazethapyr also had a high level of control (Renz & DiTomaso, unpublished data). In all of these plots few plants established in areas previously infested with perennial pepperweed. Disturbance of the soil appears necessary to stimulate seed germination (see Resprouting after disking). The above mentioned herbicides are not registered for use near water, but fortunately glyphosate which is registered for use in/near water (Rodeo[®]) showed a high level of control in some areas. Increased plant diversity was seen in the glyphosate treated areas compared to other treatments. This may be due to glyphosate having no soil activity compared to chlorsulfuron, imazapyr, and imazethapyr.

**MOWED AT THE FLOWERBUD STAGE
TREATMENTS MADE WHEN STEMS
RECOVERED TO THE FLOWERBUD STAGE**

Active Ingredient & Rate	Product & Rate	% Reduction in Biomass*	% Reduction in Density*
2,4-D 1.9 lbs. a.e./A (2.13 kg a.e./ha)	Weedar [®] 64 0.5 gal/A Weedone [®] LV4 0.5 gal/A	19-48 ¹	16-57 ¹
Triclopyr 2.25 lbs. a.e./A (2.52 kg a.e./ha)	Garlon 3A 0.75 gal/A Garlon 4A 0.56 gal/A	34	44
Chlorsulfuron 0.75-1.5 oz/A (0.053-0.105 kg /ha)	Telar [®] 1.0-2.0 oz/A	99-100	95-100
Imazapyr 1.5-6 oz a.e./A (0.11-0.42 kg a.e./ha)	Arsenal [®] (2 lbs. a.e./gal) 6-24 fl. oz/A	89-100	89-100
Imazethapyr 1.5 oz/A (0.11 kg /A)	Pursuit [®] 6 fl. oz/A	96 ¹	88 ¹
Glyphosate 3 lbs. a.e./A (3.33 kg a.e./A)	Roundup [®] 1 gal/A Rodeo [®] 0.75 gal/A	73-99 ¹	61-93 ¹

* Data is from unpublished results from Renz & DiTomaso.

¹ Renz & DiTomaso, 1998 a & b

Applications to plants resprouting after disking:

A fall disking of perennial pepperweed infestations followed by spring mowing and applications of herbicides to resprouting stems also enhanced control of perennial pepperweed. Disking minimizes the amount of stored energy each plant has to grow by breaking roots into small fragments. Control following spring herbicide applications at the flowerbud stage was slightly improved in disked areas relative to areas not disked. However, if previously disked areas are mowed the following spring at the flowerbud stage and herbicides are applied to resprouting plants in the flowerbud stage, greatly enhanced control of herbicides is observed. In particular, excellent 1 year control (more than 95% reduction in biomass) with glyphosate was observed. Chlorsulfuron and imazapyr also provided excellent control at lower rates than those needed in sites not disked. Mowing previously disked areas is believed to reduce canopy cover and synchronize systemic herbicide applications with maximum movement into below-ground perennial organs. The incorporation of disking into a control strategy has been shown to enhance plant diversity the following year (Renz & DiTomaso, unpublished data). Disking appears to stimulate germination of seeds from the seedbank (Renz & DiTomaso, unpublished data).

For information on specific treatments see table below. Control data was taken 1 year after applications and improved control was observed when incorporating disking with mowing and herbicide applications. Chlorsulfuron and imazapyr both delivered near complete control at all rates evaluated and may be effective at rates lower than tested (Renz & DiTomaso, unpublished results). Glyphosate was also highly effective, reducing biomass by 95% (Renz & DiTomaso, unpublished data). Control after several years may be reduced without follow-up spot treatments as several plants survived (78% reduction in density) (Renz & DiTomaso, unpublished data). If land managers cannot use chlorsulfuron or imazapyr, glyphosate can be substituted and provide near equivalent control.

**DISKED PREVIOUS FALL, MOWED SPRING AT THE FLOWERBUD STAGE
TREATMENTS MADE WHEN STEMS
RECOVERED TO THE FLOWERBUD STAGE**

Active Ingredient & Rate	Product & Rate	% Reduction in Biomass*	% Reduction in Density*
2,4-D 1.9 lbs. a.e./A (2.13 kg a.e./ha)	Weedar [®] 64 0.5 gal/A Weedone [®] LV4 0.5 gal/A	76	67
Triclopyr 1.5-2.25 lbs. a.e./A (1.68-2.52 kg a.e./ha)	Garlon 3A 0.5-0.75 gal/A Garlon 4A 0.38-0.56 gal/A	55	65-66
Chlorsulfuron 0.75-1.5 oz/A (0.053-0.105 kg /ha)	Telar [®] 1.0-2.0 oz/A	98-100	99-100
Imazapyr 1.5-6 oz a.e./A (0.11-0.42 kg a.e./ha)	Arsenal [®] (2 lbs. a.e./gal) 6-24 fl. oz/A	97-100	100
Glyphosate 3 lbs. a.e./A (3.33 kg a.e./A)	Roundup [®] 1 gal/A Rodeo [®] 0.75 gal/A	95	78

* Data is from unpublished results from Renz & DiTomaso.

Applications to plants resprouting after previous chemical treatments:

Many areas (fence lines, marshes, wetlands, riverbanks) cannot be mowed and/or disked. In these situations, research has shown that the use of a “chemical mow” or an early season application of a herbicide to remove aboveground tissue followed by herbicidal applications to resprouting tissue, can be effective in controlling perennial pepperweed (Renz & DiTomaso, 1998 a & b). This control strategy was developed for use in/near aquatic areas, thus research focused on 3 compounds legal for use near water: 2,4-D at 1.9 lbs. a.e./A (2.13 kg a.e./ha)[Weedar[®] 64 0.5 gal/A], triclopyr at 2.25 lbs. a.e./A (2.52 kg a.e./ha)[Garlon 3A 0.75 gal/A] and glyphosate at 3 lbs. a.e./A (3.33 kg a.e./ha)[0.75 gal Rodeo/A]. Chemical mow herbicides were applied at the flowerbud stage and herbicides in the table below were applied to resprouting tissue in late summer (most were rosettes).

Much variability in control has been observed with this strategy. This is likely due to environmental/physical factors such as soil moisture and resprouting of shoots. No differences were seen in the use of 2,4-D or triclopyr as “chemical mowing” herbicides. Pilot studies using glyphosate as a chemical mow indicated improved control over 2,4-D or triclopyr, but further testing is necessary to evaluate this. Any of several herbicides applied to resprouting stems can offer excellent control given adequate emergence of new foliar tissue from roots. If areas are not near water year-round, applications of chlorsulfuron or imazapyr will work well in controlling plants as long as ample time is available to allow the herbicide to degrade in the soil before water returns. If water is near these areas year-round, applications of glyphosate to resprouting plants gives fair to excellent control (62-97% reduction in biomass, 54-88% reduction in density) (Renz & DiTomaso, unpublished data). See the table below for detailed information.

**CHEMICALLY MOWED AT THE FLOWERBUD STAGE
TREATMENTS MADE WHEN STEMS RESPROUTED IN LATE SUMMER**

RESPROUT APPLICATION Active Ingredient & Rate	Product & Rate	% Reduction in Biomass*	% Reduction in Density*
2,4-D 1.9 lbs. a.e./A (2.13 kg a.e./ha)	Weedar® 64 0.5 gal/A Weedone® LV4 0.5 gal/A	2,4-D#: 49-78 ¹ Triclopyr#: 60	2,4-D#: 51-84 ¹ Triclopyr#: 78
Triclopyr 0.75-2.25 lbs. a.e./A (0.84-2.52 kg a.e./ha)	Garlon 3A 0.5-0.75 gal/A Garlon 4A 0.38-0.56 gal/A	2,4-D#: 37-73 Triclopyr#: 35-70	2,4-D#: 52-70 Triclopyr#: 58-62
Chlorsulfuron 0.75-1.5 oz/A (0.053-0.105 kg /ha)	Telar® 1.0-2.0 oz/A	2,4-D#: 93-100 ¹ Triclopyr#: 100	2,4-D#: 86-100 ¹ Triclopyr#: 100
Imazapyr 1.5-6 oz a.e./A (0.11-0.42 kg a.e./ha)	Arsenal® (2 lbs. a.e./gal) 6-24 fl. oz/A	2,4-D#: 92-100 ¹ Triclopyr#: 91-100	2,4-D#: 85-100 ¹ Triclopyr#: 95-100
Glyphosate 3 lbs. a.e./A (3.33 kg a.e./A)	Roundup® 1 gal/A Rodeo® 0.75 gal/A	2,4-D#: 62-80 ¹ Triclopyr#: 82 Glyphosate#: 97	2,4-D#: 76-86 ¹ Triclopyr#: 81 Glyphosate#: 54

* Data is from unpublished results from Renz & DiTomaso.

Chemically mowed with these herbicides at the flowerbud stage at rates mentioned above in the text.

¹ Renz & DiTomaso, 1998 a & b

GRAZING, DREDGING, DRAINING:

Cattle, sheep, and goats will graze perennial pepperweed, although when stands are dense it becomes very difficult for these animals (except goats) to use it as a forage. Cattle will graze the rosette leaves early in the spring, but have difficulty if previous year’s stems are not removed. There are several reports of this foliage being poisonous. These reports are currently being evaluated at the USDA Poisonous Plant Research Laboratory (Young et

al., 1997). Sheep permanently maintained in a pasture suppressed the growth of perennial pepperweed. However, once sheep are removed, plants quickly resprout, thus grazing alone is not an effective control method.

Dredging or removing topsoil from infested areas can reduce infestations, but large amounts of soil must be removed (roots can grow over 3 meters deep). The removed soil must be disposed of in a way that will not contaminate other areas. Typically, perennial pepperweed will resprout and form dense monospecific stands after dredging due to the lack of competition from other plant species.

Since perennial pepperweed thrives in wetland and floodplain areas, draining an infested area would be an advantage to perennial pepperweed plants (see Manipulation of water level and salinity).

MANIPULATION of WATER LEVEL and SALINITY:

Researchers have had success controlling perennial pepperweed by flooding. Areas flooded throughout the growing season for 2 consecutive years had no perennial pepperweed stems present (Fredrickson & Murray 1999). However, it is not known if perennial pepperweed will resprout after flooding is stopped, or how long perennial roots can survive flooded conditions. Manmade dikes were removed from marshes, restoring natural tidal fluxes and reducing the coverage of perennial pepperweed by 34% (Kramer et al., 1995). In both of these situations, highly competitive plants that are adapted to flooded conditions were present and may be an important factor in suppressing perennial pepperweed (Fredrickson & Murray 1999; Kramer et al., 1995)

Salinity does not appear to affect perennial pepperweed and it can grow in highly saline environments. However, salt spray solutions have been utilized at the flowering stage to limit seed production (personal communication Peter Baye).

MOWING and CUTTING:

Research has shown that minimum amounts of stored energy are in below-ground tissues at the bolting stage. This indicates this stage is the optimal time to mow stems. Unfortunately, perennial pepperweed quickly recovers from mowing and produce leaves from previously dormant buds near the soil surface. These leaves quickly expand and reestablish a positive carbon budget for the plant. Mowed plants quickly recovered and had no significant difference in stored energy compared to areas not mowed in less than 14 days (Renz & DiTomaso, 1999 a & b). This explains why mowing or cutting alone is not an effective control strategy.

Mowing can actually increase biomass production (Renz & DiTomaso, 1999 a & b). In one study mowing reduced litter level from 10 cm to 5 cm the following year (Renz & DiTomaso, 1998 a). This litter layer can limit biomass production and removing it can allow for greater production of perennial pepperweed.

DISKING:

Disking fragments perennial roots, which increase the density of infestations (Renz & DiTomaso, unpublished data). Root fragments 2.5 cm long and 0.5-0.75 cm in diameter can produce a shoot within 3 weeks (Wotring et al., 1995). Thus disking is not an effective control method by itself, but incorporating disking into other management can improve control (See Chemical control, Plants resprouting after disking).

PULLING:

Small infestations can be removed by repeated removal of above and below ground organs. Care must be taken to remove as much of the root as possible as small pieces resprout. If this process is repeated several times it can be successful, but it is very labor intensive.

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