Mulching and Shade Effects on Emergence and Survival of Direct-Seeded Western Redcedar (*Thuja plicata*)

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Abstract

Western redcedar (*Thuja plicata* Donn ex D. Don) is an important forest species valued by foresters for its timber value and by the public for its beauty. Regeneration of this tree species, however, is threatened by difficulties in plantation establishment and by predicted climate change. Western redcedar trees are one of the most shade-tolerant species in northwestern forests, but regeneration requires sufficient light and moisture. Previous attempts at direct seeding the species have been mostly unsuccessful. We modified environmental conditions of direct-seeded western redcedar in two ways: we altered (1) light with wire hardware cloth and (2) soil moisture with two types of mulch or no mulch. The treatment without mulch had significantly higher emergence, but seedlings in all treatments did not survive through the first season. Additional environmental factors and establishment strategies need to be considered for successful direct seeding of western redcedar.

Introduction

Western redcedar (*Thuja plicata* Donn ex D. Don) is an ecologically important and economically versatile species. The species grows in a variety of forest types and provides habitat and browse for animals (Minore 1990). Western redcedar has long been an important timber species (Haig et al. 1941); the wood is workable and durable, making it useful in a wide variety of applications, from roofing shingles to decorative chests (Nystrom et al. 1984, Minore 1990). Western redcedar is also valued for its beauty by the general public (Sharpe 1974). Despite this species' environmental, economical, and aesthetic value, establishing plantations or managing natural stands to increase the number of western redcedar trees can be challenging (Nystrom et al. 1984). In addition, predicted climate changes will shift the region of suitable growing conditions for western redcedar, which will require careful consideration of replanting schemes involving this species (Hebda 2009). These changes will force foresters to plan for a dynamic context and may require assisted migration of some species (Williams and Dumroese 2014).

Western redcedar is found on the Pacific Coast and in the Inland Northwest, with little overlap between the two ranges. In the Inland Northwest, the species grows from lat. 54°30' N. in British Columbia and south into Montana and northern Idaho (Minore 1990). Along the coast, its range extends farther south into California (lat. 40°10' N.) and north into southeast Alaska (lat. 56°30' N.). In the central part of its Pacific range, the species grows inland as far as the western slopes of the Cascades (Minore 1990). Western redcedar is distributed across a range of environmental conditions but grows best on moist, humid sites (Fan et al. 2008), such as in stream bottoms, moist flats, and north-facing slopes (Brand and Schopmeyer 2008). Precipitation within the coastal range for western redcedar ranges from 890 mm to 6,600 mm (35 in to 260 in), mostly as winter rain; the interior range receives 710 to 1,240 mm (28 in to 49 in) annual precipitation, as snow and rain (Minore 1990). Western redcedar is one of the most shade-tolerant species in northwestern forests (Coates and Burton 1999, Ferguson et al. 1986) and can grow on a variety of soils across a range of elevations (Brand and Schopmeyer 2008), although sedimentary bedrock can increase mortality (Moore et al. 2004). Western redcedar does not commonly grow in pure stands but grows readily within mixed stands (Sharpe 1974).

Western redcedar is present in all stages of forest succession (McKenzie and Tinker 2013), but natural regeneration depends on well-disturbed mineral soil and canopy gaps in established stands (Clark 1970, Gray and Spies 1996). Remnant individuals in old-growth stands provide sources of seed for regeneration (Keeton and Franklin 2005). Western redcedar can be a prolific, although erratic, seed producer (Gashwiler 1970, Minore 1990). Survival of seed through its first winter can exceed 90 percent

(Gashwiler 1967). The seed has low survival in storage for 3 months at 2.0 °C (35.6 °F), however, suggesting that naturally dispersed seed will not be viable for more than one season (Terskikh et al. 2008). Western redcedar seed is less susceptible to predation than other, larger conifer seeds (Gashwiler 1970). The seed may be less palatable because of its pungent odor (Gashwiler 1967). Vegetative reproduction can also occur in some stands (Parker 1986).

Understanding the conditions under which western redcedar regenerates requires consideration of both the establishment phase and the growth phase (Ferguson et al. 1986). Natural regeneration can occur on disturbed areas, indicating that western redcedar is exposure tolerant (Wang et al. 1994). Initial seedling survival, however, requires a balance between light and moisture (Carter and Klinka 1992). Mortality of naturally regenerating seed can be high soon after peak emergence, but, after September, additional losses are minimal (Gashwiler 1971). The seedling first grows primary needle leaves before growing secondary, scale-like foliage, which may correspond to decreased mortality later in the growing season (Weber et al. 2003). If seedlings establish in full sunlight, abundant moisture is required for survival (Weber et al. 2003). Conversely, western redcedar seedlings exhibit greater shade tolerance on sites of low water availability (Harrington 2006). High temperatures, drought, and frost-heaving are major causes of seedling mortality (Brand and Schopmeyer 2008, Gashwiler 1971, Soos and Walters 1963).

Some western redcedar seedlings can survive at 10 percent of full sunlight, but seedling mortality tends to be higher at low light levels (Harrington 2006, Soos and Walters 1963). Seedling growth responds positively to increasing light and soil disturbance (Carter and Klinka 1992, Weber et al. 2003), with maximum growth rates occurring at 30 percent to more than 40 percent full sunlight (Harrington 2006, Wang et al. 1994). At high light, however, seedlings are susceptible to sun scorching (Wright et al. 1998). Western redcedar seedlings are particularly vulnerable to drought during the first 2 years (McKeever 1942). Height growth is slow during the seedling's first 5 years and peaks during the sapling's second decade (Nystrom et al. 1984). Ungulates are known to browse western redcedar repeatedly and severely, dramatically decreasing the number of leaved shoots per individual and increasing mortality (Burney and Jacobs 2010, Martin and Baltzinger 2002). Once established, western redcedar stands can have low mortality for several decades (Lutz and Halpern 2006).

Public concern about the decline of western redcedar in the Northwest has existed since the early 1970s (Sharpe 1974). Foresters are keen to promote western redcedar regeneration because of the tree's value. In intact stands, however, intense competition from overstory trees and understory vegetation limits seedlings' access to light, soil water, and nutrients (Harrington 2006). In gaps and larger openings such as clear cuts, natural regeneration requires seed sources that are within 100 m (330 ft), and several seed crops may be needed to fully stock the site; good seed crops can be expected only every few years (Clark 1970). Open environments present other challenges to the seedling, including competition, browsing, and sun scorching. Artificial regeneration using direct seeding or planting may be required to achieve reforestation objectives. Planting seedlings can be a way to avoid the stochastic events surrounding natural seedling establishment (Coates 2000). Seedlings need to be appropriately hardened for field conditions (Major et al. 1994). Direct seeding may be a low-cost option for regenerating western redcedar if successful techniques can be developed.

Successful direct seeding for any species requires proper timing, sufficient seed, predation and competition control, a suitable seedbed, and adequate soil moisture (Farmer 1997). Direct seeding has been used to reforest large areas of land in the American Southeast and has been particularly useful in large, remote, or low-productivity sites (Barnett 2014). Efforts to direct-seed western redcedar have generally proved unsuccessful, with lower germination and survival in western redcedar than Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson), and grand fir (*Abies grandis* [Douglas ex D. Don] Lindl.) (Engstrom 1955, Loewenstein and Pitkin 1966). Direct seeding has been most successful on north-facing sites with some shade and little competition; even under these conditions, however, the results have been only moderately successful (McKeever 1942). Direct seeding in fall may result in higher survival than in spring, although total survival through the first growing season was low in both treatments (Loewenstein and Pitkin 1966).

The objective of this study was to evaluate environmental influences on establishment success of direct-seeded western redcedar. We modified the environment using wire hardware cloth and mulch. Wire hardware cloth limits access by herbivores to the seeds and small seedlings (McKeever 1942) and hardware cloth increases shading on the seed by 15 to 21 percent (Minore 1972, Strothman

1972), which may help reduce mortality caused by high surface temperatures (Fowells and Arnold 1939). Mulch has a lower thermal admittance than bare soil, thereby helping to mitigate soil temperature and moisture stresses to newly germinated seedlings (Campbell and Norman 1998). The mulch retains moisture, which may also reduce water stress in the seedling. We hypothesized that seeds in the mulch and hardware cloth treatments would have higher emergence than the treatment with no environmental modifications.

Materials and Methods

This study was conducted on a relatively level, tilled agricultural field with coarse, loamy soil at the University of Idaho's Pitkin Forest Research Nursery (46°43' N, 116°57' W). The site receives an average of 600 mm (23.6 in) of precipitation annually, and the average summer and winter temperatures are 18 °C and 0 °C (64 °F and 32 °F), respectively (Western Regional Climate Center 2005). No persistent vegetation existed at the site.

Northwest Seed (IFA Nurseries, Canby, OR) supplied the seed on behalf of Potlatch Corporation. The seed was collected at 883 m (2,900 ft). The seed arrived at Pitkin Forest Research Nursery in sealed pouches on October 16, 2013, and was stored dry in a cooler at 0 to 1.5° C (32 °F to 35 °F) for 4 weeks until direct seeding. The seed was not soaked or cold stratified before direct seeding, because stratification does not change germination capacity in western redcedar (Khadduri 2007).

Five frames were constructed from plywood and placed on top of the soil at the research site (figure 1). Each frame was divided into six 15-by-15 cm (5.9-by-5.9 5.9 in) sections. Within each frame, six treatments were randomly assigned to the sections (three mulch treatments by two screening treatments). Mulch treatments consisted of no mulch, pine mulch, or straw mulch. Screening treatments consisted of wire hardware cloth or no wire hardware cloth. The pine mulch was aged pine needles collected from a stand of ponderosa pine adjacent to the field site. The straw mulch was from baled wheat straw. The pine and straw mulch pieces were similar in size with a maximum length of 12.7 cm (5 in) and interspersed smaller pieces. The screened sections were covered with 6.35-mm (0.25-in) hardware cloth, which sat on top of the frame, about 10 cm (3.9 in) above the soil. The unscreened sections were left uncovered.

Figure 1. To assess environmental influences on direct seeding of western redcedar, five wooden frames were constructed, each with six treatment sections. After sowing, seed were subjected to three mulching treatments (pine, straw, or no mulch), with or without wire hardware cloth screening. (Photo by Rebecca Sheridan, 2013)

Before direct seeding, a minimal number of weeds were hand weeded from the site and the ground was lightly scarified with a rake. The seeds were sown on November 15 and 17, 2013. In each section, 100 seeds were surface sown in a 10-by-10 grid, spaced 1.27 cm (0.5 in) apart. In the mulched treatments, the respective mulch was spread across the section approximately 2 cm (0.78 in) deep. No followup treatment was done to ensure seed-soil contact; however, the soil was wet at the time of sowing, and the seed stayed in contact with the soil once sown. The site received no maintenance from the time of seeding until the seed began to germinate. The plots were hand weeded through the spring and summer.

Because, western redcedar germination is epigeal, seedling emergence was defined in this study as the presence of the hypocotyl hook above the soil surface (figure 2). In April and May 2014, the plots were checked weekly for newly emerged and newly dead seedlings. From May to October 2014, the plots were checked monthly. Each newly germinated seedling

Figure 2. Seedlings were counted as emerged when the hypocotyl hook was visible above the soil surface. Emerged seedlings were marked with color-coded pins. (Photo by Rebecca Sheridan, 2014)

Figure 3. Seedling emergence was monitored from March through October 2014. On each monitoring date, different colored pins were used to mark newly emerged seedlings. Dead seedlings were marked with a black pin. By October 2014, all seedlings in the experiment had died. (Photo by Rebecca Sheridan, 2014)

was marked with a colored, ballpoint pin, with a different color used each week. When a seedling died, it was marked with a black pin (figure 3).

In addition to the field study, a germination test was conducted with four replications of 100 seeds each. The seed was soaked in cold, running water for 24 hours and then was cold stratified for 1 month at 0 to 1.5 °C (32 to 35 °F) (December 18, 2013 to January 15, 2014). Seeds were then placed on moist germination paper under a full-spectrum light for approximately 12 hours daily (Karrfalt 2008). The temperature fluctuated several degrees around 21 °C (70 °F). The seed was misted three times per day. Germinated seeds were counted every 7 days for 28 days. Germination was defined as the presence of a 5 mm (0.2 in) radicle (Baskin and Baskin 2014).

Statistical analyses were done in R, version 3.1.1 (R Core Team 2015). The experimental design consisted of a factorial (three mulch treatments by two hardware cloth treatments) completely randomized design with five replications. An analysis of variance was performed to test the treatment effects on the total number of emerged seeds in the field trial. Differences among treatment means were determined using Tukey's range test at the $\alpha \leq 0.05$ level. Diagnostic plots for equal variance and normality were examined and no data transformations were deemed necessary. Overall germination average and standard error were determined on the germination test data using Microsoft Excel statistical tools.

Results

In the germination test, the average germination was 81 percent (n = 4, standard deviation = 6.7 percent). In the field planting, however, average emergence across all treatments was 31 percent (n = 30, standard deviation = 7.5 percent). Emergence was quantified in the field planting rather than germination because the radicle was not visible on seeds in the field.

The first seedlings emerged by April 12, 2014, which was defined as week 1. Seedling emergence occurred earlier in the bare soil plots than the plots with mulch (figure 4). Seedlings began dying by the second week of observation, well before emergence was complete (figure 5). More than one-half of the seedlings were dead by week 8 (May 27, 2014). Some seedlings survived into September (figure 6) but, by week 27 (October 20, 2014), all seedlings in all treatments died and monitoring ceased. Dead seedlings were most often found intact and standing upright, with no sign that the cause of death was a pathogen or herbivore.

The highest total emergence occurred in the nonmulched with wire screening treatment (38.6 percent) and the lowest total emergence occurred in the straw mulch with no wire screening treatment (24.4 percent) (table 1). Seed in the nonmulched treatments had significantly higher total emergence than seed in the needle mulch or straw mulch treatments ($p < 0.01$). Emergence did not differ significantly between the two mulch types. No significant interactions occurred between the screening and mulching treatments nor was a significant difference observed between total emergence in screened and nonscreened treatments.

Table 1. Average total seedling emergence percent and standard deviation by treatment (n = 5). Seed in the nonmulched treatments had significantly higher total emergence than those in the mulched treatments ($p < 0.01$). Emergence did not differ significantly between the two mulch types or between screened and nonscreened treatments. No significant interactions occurred between the screening and mulching treatments.

Variable	No mulch		Pine mulch		Straw mulch	
	Without screening	With screening	Without screening	With screening	Without screening	With screening
Percent emergence	36.40	38.60	31.00	28.60	24.40	29.00
Standard deviation	1.95	9.02	4.95	8.56	1.95	6.44

Discussion

This experiment modified the seedbed environment to reduce light (screening treatment) and increase available soil moisture (mulch treatment). These modifications, however, were not sufficient to ensure western redcedar seedling survival past the establishment phase. More than one-half of the seedlings died before July and August, the hottest months of the year, at the field site (Western Regional Climate Center 2005). Soil temperature, soil moisture, and shade levels were not directly measured, but the seedlings likely died from high temperatures and low soil moisture. In a similar way, natural regeneration of western redcedar has been unsuccessful on high fire-severity sites, with high temperatures and low moisture conditions (Larson and Franklin 2005).

The wire hardware cloth was intended to provide some shade and also to limit access by herbivores to the seeds and seedlings. In southern pine forests, seed predation by rodents and birds is a major challenge to successful direct seeding (Barnett 2014). No significant effect of the wire hardware cloth was observed, however, suggesting seed herbivory did not occur in this experiment. Some seedlings were observed with damage from invertebrates, but no evidence suggested damage by vertebrate herbivore. If the seedlings had survived, however, herbivory would be a matter of concern for larger western redcedar seedlings (Stroh et al. 2008). In such cases, fertilization may aid in recovery from browse (Burney and Jacobs 2010).

Mulch can also help reduce the number of weeds on a site. In this experiment, the site was routinely weeded, so the ability of the mulch to suppress weeds was not quantified. If weeds had been present, they would have competed with seedlings for soil moisture. Removal of competing vegetation can lead to greater height growth of western redcedar than only removal of light competition, suggesting competition for water is more important than competition for light (Adams and Mahoney 1991). Weedy vegetation can also compete for soil nutrients, but western redcedar have deep-rooted, fine roots, which can reduce competition for nutrients (Messier 1993).

Both seedling emergence and mortality were observed earlier and at higher levels in the bare soil plots compared with the mulched plots (figures 4 and 5). It is important to note, however, that the absence of mulch in the bare soil plots made it easier to observe emerging seedlings. For eastern white-cedar (*Thuja occidentalis* L.), seed that falls on forest floor litter has a lower chance of survival than seed that falls on nurse logs or mineral soil (Simard et al. 2003). In this experiment, the seed was in direct contact with mineral soil and then was covered in mulch. Although great care was taken to count seedlings within the mulch, additional seeds may have emerged below the mulch and died before they were observed. The bare soil alternatively may have warmed earlier in the spring, allowing for earlier germination and emergence.

The seed was not stratified before planting but was subjected to cold, moist temperatures through the winter months. The need for cold stratification in western redcedar is debated, with some authors suggesting no stratification is needed (Brand and Schopmeyer 2008). Kolotelo (1996) observed no effect of a 3-week stratification period. We do not believe the lack of artificial cold stratification affected the experimental results.

Conclusions

It is important to understand the whole-plant response of seedlings to environmental factors such as light levels, water stress, and competition to choose the best method, species, and site combinations for successful regeneration projects (Coates and Burton 1999). These factors interact with one another in the field, impacting seedling development in complicated ways (Harrington 2010). In this experiment, germinated seedlings did not survive in spite of modifications to the microenvironment. If direct seeding is

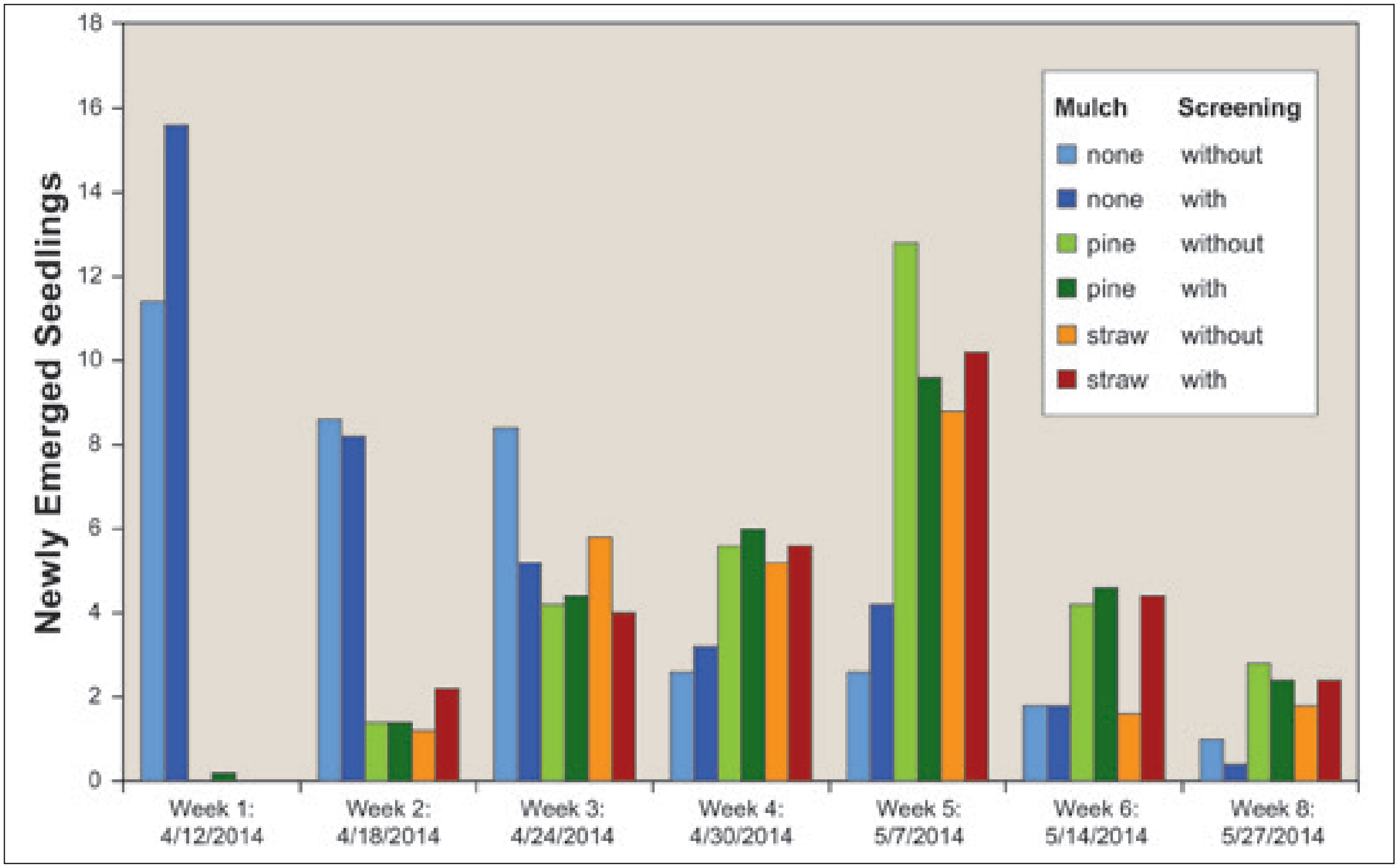

Figure 4. Number of newly emerged seedlings from April through May 2014, as affected by mulching and screening treatments. Seedlings were marked with a pin to ensure they were not recounted.

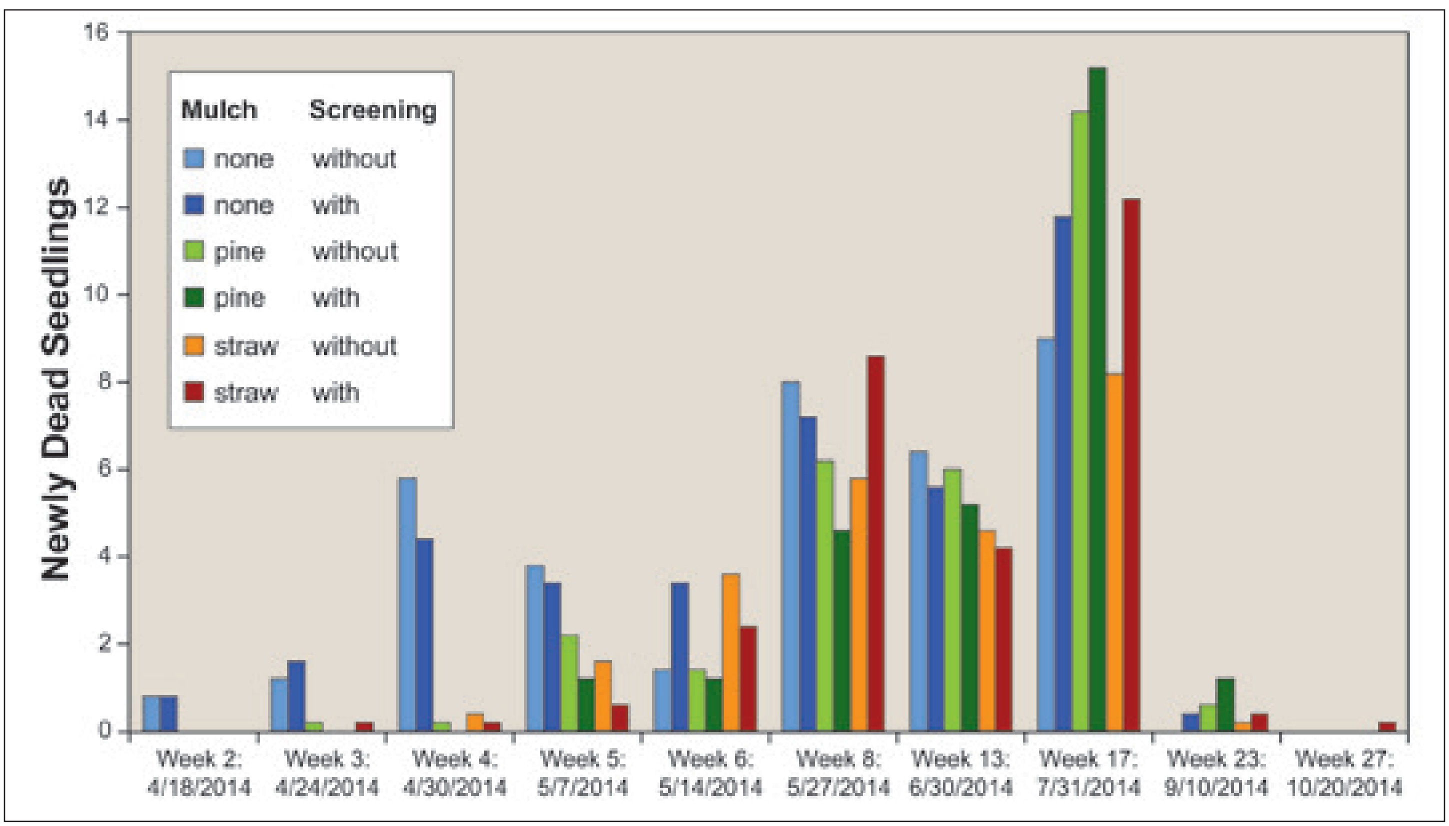

Figure 5. Number of seedlings that died, by week, starting on April 18, 2014. Dead seedlings were marked with a black pin to ensure they were not recounted.

to be successful with western redcedar, it can be considered only on carefully selected sites, and, even then, success is not guaranteed. Based on current approaches, planting seedlings is still the most successful method to ensure western redcedar establishment. Further investigation to develop strategies for direct seeding of this species, such as the use of pelletized seed (Khadduri 2007), is needed if direct seeding continues to be a desirable approach.

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