Monument
Soil & Water
Conservation District

August 28, 2017

Assessment of New Techniques of Herbicide Use for Juniper Management

Introduction

The spread of western juniper (*Juniperus occidentalis*) beyond its historic range has become a major factor threatening the health and function of rangelands across Oregon and other western states. Western juniper is a native species with adaptations that make it very drought tolerant and capable of outcompeting understory vegetation, including desirable grasses, forbs, and shrubs. Because it easily succumbs to fire, western juniper's presence on the landscape had typically been limited to fire safe sites such as rimrock areas or soil types that did not allow much growth of understory fuels. Post-settlement changes in land use and management led to vast expansion and dominance of western juniper across an abundance of sites it was not previously found within. Many of these sites are now dominated by juniper, which has vastly reduced, if not completed eliminated the desirable understory species that were once present.

Often times the only understory vegetation remaining under western juniper stands is a monoculture of invasive annual grasses. While these annual grasses are certainly prone to fire, they typically do not carry fuel loads high enough to result in juniper mortality that fires within the historic bunchgrass or sagebrush communities once caused. As a result, vast acreages are being converted to western juniper woodlands with an invasive annual grass understory. This conversion of once productive rangeland greatly reduces carrying capacity for livestock, diminishes habitat values for wildlife, leads to decreased diversity and cover of desirable plant species, results in accelerated soil erosion and sediment inputs into streams, and negatively impacts the overall hydrologic function by intercepting significant amounts of snow and rain that never make it to the ground. For these reasons, much effort has been put into juniper control. A description of the pros and cons of commonly used methods to control juniper follows below as a background to why the new techniques of herbicide use were assessed with this study.

Traditional methods of western juniper control

There are several methods commonly used to control western juniper, including mechanical treatments and prescribed burning. There are also some traditional herbicide treatments that have been attempted to a lesser extent than mechanical treatments and prescribed burning. Each of these methods involves a set of environmental and human risk factors, plus a range in efficacy, costs, and liability. For example, mechanical treatments have been proven to be quite effective, but tend to have high costs, high risk to the operator, and moderate to high impacts on the environment. Prescribed burning tends to have a low cost per acre, but can have high to low efficacy (depending on site conditions and stage of juniper encroachment) and very high liability due to the risk of an escaped fire. Traditional herbicide treatments have not proven to be a widely effective or accepted method for controlling juniper. It can also have negative environmental impacts, such as mortality of non-target species.

Mechanical methods of juniper control include cut-and-let-lay, cut-and-stack, and removal with heavy equipment. Cut-and-let-lay and cut-and-stack are probably the most commonly used juniper control methods in eastern Oregon. Both of these methods require a chainsaw operator to fell each juniper by cutting the tree off below the lowest live branches, or cutting off any remaining live branches after the tree is felled since western juniper is able to continue growing successfully from any live branch left below a cut. As implied by the name, the cut-and-let-lay method involves leaving each tree where it is felled, whereas the cut-and-stack method involves creating slash piles of the downed trees. This may be done by hand in the case of smaller trees, but often involves the use of equipment such as a bulldozer, excavator, or feller-buncher. Heavy equipment may also be used to remove the trees instead of cutting them with a chainsaw. Bulldozers are effective at pushing over large trees. Excavators with a thumb attachment have been utilized to grab and pull trees directly out of the ground. Feller-bunchers have also been used to grip and pull trees and have the added benefit of being able to cut larger trees that cannot be pulled. They can also be used in areas where pulling trees is not desired due to the excessive ground disturbance it causes. While effective against larger trees, heavy equipment does not work on smaller trees. Hand crews must follow to remove the juniper that are missed by the machinery to ensure no trees are left to reoccupy the site.

Because western juniper often has live branches at or near the ground surface, an operator has to saw much lower than when felling other conifer species to ensure that all live branches have been cut. This usually results in the chainsaw cutting into the dirt and rocks, which then requires frequent chain sharpening and increases potential fire risk due to sparks created when the saw chain hits a rock. Felling the tree, especially on steep terrain, places the operator and others in the area at risk of injury from the falling tree, as well as debris (e.g., rocks or downfall) that be may be dislodged and roll downhill. The use of heavy equipment, whether to remove the trees or just to stack them, can cause significant soil disturbance. This soil disturbance provides an opportunity for noxious weeds to establish, which are frequently transported on the equipment from site to site if care is not taken to clean the machinery. Soil disturbance may also cause erosion problems depending on slope, soil type, and typical precipitation for the area.

A large fallen juniper tree can occupy a significant footprint on the ground surface. As the cut trees dry out, they do eventually drop their needles, usually within a year or two. But during this time, desirable vegetation underneath the felled tree can be smothered due to lack of sunlight. This is especially prevalent in the case of the cut-and-stack method. Felled trees also prevent grazing by livestock and wildlife for several years until the smaller branches decay and fall off. Since slash piles are usually burned following sufficient dry down, the intensity of these fires often results in a patch of sterilized ground that has killed out any desirable grasses or forbs. These fire scars are sites where noxious weeds and annual grasses frequently become established, especially where there is a lack of desirable understory species to begin with. The same results may be witnessed if a fire passes through an area of cut-and-let-lay where most trees are fairly large and closely spaced.

Prescribed burning is usually the most inexpensive treatment on a per acre basis. It has the benefit of mimicking the natural disturbance that once kept western juniper limited to fire safe sites. It causes much less soil disturbance than removal using heavy equipment. However, the use of prescribed burning carries with it a very high liability factor due to the risk of an escaped fire. It can be ineffective on sites were fuel loads are not great enough to carry the fire into the canopy of larger trees. This limits its use to areas being occupied by younger and shorter stands of western juniper. The effectiveness of fire often varies across treated sites due to nonuniform fuel loads. This can result in a good kill of some trees while leaving others unharmed. Since prescribed fire is indiscriminate in what it burns, there is a greater potential to impact non-target species. If the site does not have a desirable understory, there may be the increased likelihood it will be reoccupied by a monoculture of undesirable species such as invasive annual grasses or noxious weeds. Prescribed burning also destroys organic matter on the soil surface and requires specific weather conditions to be conducted.

Traditional herbicide treatments used for juniper control include foliar, basal bark, frill, and hack-and-squirt applications, along with soil applications of granules or pelleted compounds. Foliar sprays usually require complete coverage of the entire tree, which limits ground applications to small trees and may injure desirable vegetation in the understory. Soil applied granules and pellets can be expensive due to the rate required to control large juniper and the labor necessary to apply them. The can also cause injury to non-target species with roots extending into the treatment area. Basal bark applications are difficult to conduct due to the number of branches at the base of juniper trees that can complicate proper herbicide placement. They also carry the risk of becoming active in the soil through rainfall or snow melt, creating the potential to injure non-target plants.

Study goal and objective

The goal of this study was to develop and evaluate a new method of western juniper control that is effective, low in cost, and reduces the risks involved with traditional control methods. The method selected for evaluation consists of applying a concentrated amount of herbicide or mixture of herbicides to stem wounds made on individual juniper trees. The concept is that a two-person team comprised of a chainsaw operator and an herbicide applicator would be able to treat individual trees in a manner that meets these criteria of being effective (i.e., kills the tree), lower in cost than traditional felling methods, and reduces the risks to the environment and operator. The expectation was that this treatment would result in each juniper tree dying in place, standing upright without causing any detrimental effects to off target species. The objective of the study was to determine which combination of stem cutting/wounding technique, herbicide mixture, and timing of treatment was most effective at killing western juniper without harming desirable vegetation. A total of three stem wounding methods, nine herbicide solutions, and two different application periods were evaluated.

Expected benefits over traditional methods

There were multiple, anticipate benefits to the treatment method evaluated in this study over the traditional treatment methods described above. In comparison to mechanical treatments, this method reduces risk to the operator, damage to desirable non-target vegetation, and virtually eliminates the ground disturbance associated with traditional control methods. It has the benefit of being able to selectively treat individual juniper trees in mixed stands or sites with sensitive understory species. While this new method may prove to be more expensive on a per acre basis than prescribed fire, it has a greatly reduced level of liability associated with it. It will also add organic matter to the soil that may be destroyed by burning.

Since trees are not felled, operators are not at risk of physical injury associated with cutting operations. The only cutting required is to create the wound in the bark for placement of the herbicide. Therefore, it can be done at a height that keeps the saw chain out of dirt and rocks. Where an operator may have to stop and sharpen their saw multiple times a day during a traditional falling treatment, a chainsaw operator can go all day without needing to sharpen the saw using this new method. The risk of starting a fire due to sparks from hitting a rock are also eliminated. Since the operator is only creating stem wounds rather than cutting through the entire trunk of the tree, the time it takes to make these cuts is greatly reduced.

Treated juniper will die in place and remain standing for approximately 5-10 years. Since trees will remain upright instead of lying on the ground, the possibility of smothering or crushing desirable understory vegetation is removed. Needle sluff will occur over time, and may be more spread out due to wind dispersal. If a fire does pass through a treated stand before the needles have been shed, the heat will be carried up the carcass of the tree rather than being concentrated on the soil surface, eliminating the risk of detrimental effects on the soil organic matter and the possibility of leaving a fire scar prone to invasion by annual grasses or noxious weeds. The remaining juniper snags can provide habitat for wildlife. Dead standing trees are easier to harvest for firewood than those in slash piles. Since all of the herbicide products used in this study are destroyed by moderate heat, any minimal, residual herbicide that may be present in the wood is safely destroyed by the heat of a fireplace or woodstove. When the treated juniper trees eventually fall over, their coarse skeleton of branches can actually create a protected site for desirable grasses and forbs to establish by limiting grazing and allowing the plants to grow to maturity and reproduce, enhancing their abundance.

Disclaimer
The mention of specific brand names of products used throughout this study do not constitute an endorsement by the Monument Soil and Water Conservation District (SWCD) or any of its project sponsors or partners. The Monument SWCD and its partners reminds anyone using herbicides that they must be properly licensed and follow all instructions on herbicide labels. It is also strongly suggested that anyone considering using the method of juniper control evaluated in this study check with appropriate local, state, and federal agencies to ensure they are complaint with any applicable regulations or rules.

While the study reported in this paper was not intended to be a scientific, peer reviewed project, care was taken to ensure that the results witness showed a clear relationship to the testing methods used.

Methods
A combination of three stem wounding methods, nine herbicide solutions, and two seasons of treatment (i.e., fall vs spring application) were evaluated across five test sites. A total of six test sites were initially selected on private property within 15 miles of Monument, Oregon.

However, Site #2 was taken off of the study list because a suitable test plot could not be located on the property. Site selection criteria included willing landowner participation, elevation, western juniper size and density, and the presence of non-target woody species in close proximity to the test trees. Of the five test areas ultimately included in the study, three areas contained both a fall test plot and a spring test plot receiving herbicide treatments, while one area contained only a fall test plot and one area contained only a spring test plot. Additional details are provided in Table 1 on the following page.

Figure 1. Juniper test plots. Test plots #3, #5, and #6 from left to right, showing a range of site conditions.

A total of 1,999 western juniper trees were examined across the five sites. The location of each tree was recorded with a handheld Garmin® GPSmap 62stc unit. Each test tree was then marked with an aluminum number tag and measured for diameter prior to application of any herbicide treatment. Any unusual characteristics about the test tree were noted, such as having a dead top or mistletoe growing in it. Trees ranged in size from ¾-inches to 32-inches diameter at breast height (DBH). Trees were placed into one of three different size classifications based on DBH. Trees that had a DBH less than 6-inches were identified as "Class 1", trees with a DBH between 6-inches and 12-inches were classified as "Class 2", and trees with DBH greater than 12-inches were classified as "Class 3".

Table 1. Test Areas and Western Juniper Size Distributions

		Treatment Period		**Juniper Tree Diameter Class Distribution**			
Site*	**Elevation**	**Spring**	**Fall**	**Class 1 <6" DBH**	**Class 2 >6"-12" DBH**	**Class 3 >12" DBH**	**Total**
#1	3,500 ft	1.08 ac	1.43 ac	161 trees	108 trees	34 trees	303
#3	2,260 ft	2.82 ac	---	546 trees	41 trees	7 trees	594
#4	3,140 ft	2.65 ac	2.89 ac	206 trees	67 trees	34 trees	307
#5	2,750 ft	---	2.57 ac	153 trees	192 trees	60 trees	405
#6	3,700 ft	2.95 ac	1.18 ac	124 trees	142 trees	124 trees	390
	Total	**9.50 ac**	**8.07 ac**	**1,190 trees**	**550 trees**	**259 trees**	**1,999**

*Site #2 is not included since a suitable test plot could not be located on the property

Any woody plant growing within 8 feet of the base of the test tree was noted as to species, condition, and distance from the test tree. Woody species that were observed included sagebrush (*Artemisia tridentata*), antelope bitterbrush (*Purshia tridentata*), currant (*Ribes spp.*), curlleaf mountain mahogany (*Cercocarpus ledifolius*), ponderosa pine (*Pinus ponderosa*), and Douglas- fir (*Pseudotsuga menziesii*). Nearby woody species were observed to see if the herbicide treatments were negatively affecting them. A total of 1,104 woody plants growing near the western juniper test trees were identified and monitored during the study.

The trunk of each juniper test tree was cut/wounded by one of three methods, depending on tree diameter, to create an application site for the herbicide treatment. A Stihl® MS362 chainsaw was used to create the cuts/wounds and expose the cambium layer just underneath the bark. Smaller trees that were less than 4-inches DBH (Class 1) were cut off at a convenient height above the ground, usually 6- to15-inches above the soil surface. The herbicide solution was then applied to the cut stump, with the spray directed at the outer circumference where the cambium layer is located. These smaller diameter trees are usually not very tall (less than 4-feet), and therefore the removed top does not create a hindrance to grazing animals. This is also little risk of the cut top smothering desirable vegetation due to its small size.

Figure 2. Example of a non-target, woody species (Douglas fir) growing next to a juniper test tree.

Trees with a DBH between 4-inches and 12-inches (Class 1 – Class 2) were cut/wounded by making a vertical blaze cut (see Figure 3 below) on either one, two, or three sides of the tree. Smaller trees received a single blaze cut, while larger trees received two or three blaze cuts. These blaze cuts were made deep enough to cut through the bark and expose the cambium layer. This type of cut usually produced an oval-shaped wound with the cambium at the outer perimeter of the cut (see Figure 3). Herbicide solutions were then applied to each wound, concentrating the spray to the perimeter of the cut.

Test trees that were larger than 12-inches in DBH (Class 3) received diagonal cuts through the bark to expose the cambium layer. These cuts were made by angling the chainsaw blade downward at a 10-20° angle, canting the saw blade slightly upward, and cutting deep enough to create an inward and downward sloping groove into which the herbicide solution was applied. The chemical applicator could then place the sprayer tip at the top of the groove so that the herbicide solution applied within the cut would then flow down the groove coating the cambium layer. The chainsaw operator tried not to cut any deeper than was necessary to reach the cambium layer because a deeper groove allowed the herbicide solution to flow into the sapwood, past the cambium layer where uptake occurs. The number of diagonal cuts and the length of each cut depended on the total diameter of the tree. The intent was to cut through at least 80% of the tree's circumference without completely "ringing" or girdling the tree. The goal was to leave sections of intact cambium around the circumference of the tree that were no more than 6-inches wide.

Figure 3. Example of cut stem, blaze cut, diagonal cut wounding methods.

Five percent (5%) of the trees (i.e., 80 trees) that received either blaze or diagonal cuts were not treated with herbicides and left as “Control” trees to show that the wounds alone did not affect these trees. Other herbicide application methods initially considered for evaluation included basal bark applications, foliar sprays, and soil drip method, however, the desire to target individual juniper trees without injuring any adjacent vegetation made these other application methods unacceptable.

The herbicides used in this study were selected after many hours of discussion with staff within the Oregon Department of Agriculture (ODA), Pesticide Program and several chemical manufacturers and supplier representatives from around the Pacific Northwest.

Factors considered in the selection of herbicides used in this study included:
1) ability to translocate within the plant,
2) labeled for use in range and pasture sites,
3) labeled for the cut stem application method,
4) active ingredient approved for use on most federal and state-owned lands,
5) prior indications of efficacy on juniper control.

The active ingredients selected for use in this study were glyphosate, picloram, triclopyr, aminopyralid, and 2,4-D amine. The specific herbicide products that were used were Glystar Plus® (Albaugh), Tordon 22K® (Dow AgroSciences), Garlon 3A® (Dow AgroSciences), Milestone® (Dow AgroSciences), Capstone® – a preformulated mixture of the active ingredients in Milestone® and Garlon 3A® (Dow AgroSciences), and Weedestroy AM40 Amine® (Nufarm). Surfactants used in the solutions were either Alligare 90® or Alligare 7®. Alligare Super Marking Dye® was used to aid in herbicide placement and mark which wounds had been treated. The six initial herbicide solutions used in the study are listed below in Table 2. Two separate factors described in additional detail below led to a modification of three of these mixtures during the study. Table 3 lists all of the herbicide solutions that were used in the entire duration of this study.

Herbicide solution applications were made using a Solo® diaphragm backpack sprayer with a Spraying Systems Co. 30 GunJet® spray gun equipped with a 23600 MeterJet® attachment. The MeterJet® gun delivers a pre-measured amount of solution with each pull of the trigger. Prior to each herbicide solution application, the MeterJet® gun was calibrated to deliver 2-ml of solution with each trigger. The MeterJet® gun was re-calibrated with each herbicide solution change due to differing viscosities among the test solutions. A 4001E TeeJet® stainless steel flat fan spray tip was used in the MeterJet® gun to deliver a narrow, flat spray pattern that could be aimed at the cambium layer of each wound.

During the trials, the applications of each herbicide solution were conducted within 2 minutes of creating the cut surface wound. This prevented sap from covering the exposed cambium layer before the herbicide was applied. Each wound received 4-ml (i.e., two trigger pulls) of herbicide solution, unless the wound was very small. Trees that were 1-inch or less in diameter received only 2-ml of herbicide solution (i.e., a single trigger pull). Single stem Class 2 trees received between 4- to 8-ml of herbicide solution, equating to 2 to 4 wounds per tree, each treated with 2- ml of herbicide solution per wound. Single stem Class 3 trees received between 4- to 10-ml of herbicide solution, equating to 2 to 5 wounds per tree, each treated with 2-ml of herbicide solution per wound. Multiple stemmed Class 2 and Class 3 trees received the largest amounts of herbicide, as each stem received wounding and herbicide application. The largest herbicide application within this study was to a 4-stemmed tree with individual stems ranging between 6- to 19-inches DBH. This tree received a total of 44-ml of herbicide solution into 11 wounds.

Table 2. Initial Herbicide Solutions

Solution	Herbicide & (Active Ingredients)*	Dilution	Surfactant	Additives
#1	Tordon 22K® (picloram)	50%	Alligare 7® @ 5%	Water @ 45%
#2	Tordon 22K® (picloram) Glystar Plus® (glyphosate)	50% 45%	Alligare 7® @ 5%	---
#3	Tordon 22K® (picloram) Garlon 3A® (triclopyr)	50% 45%	Alligare 90® @ 5%	---
#4	Tordon 22K® (picloram) Milestone® (aminopyralid)	50% 10%	Alligare 7® @ 5%	Water @ 35%
#5	Capstone® (aminopyralid & triclopyr)	95%	Alligare 90® @ 5%	---
#6	Milestone® (aminopyralid) Glystar Plus® (glyphosate)	10% 85%	Alligare 7® @ 5%	---

*Note: Tordon 22K® is a Restricted Use Pesticide requiring an applicators license to purchase and use.

The initial strength of the solutions containing Tordon 22K® (picloram) was based off of an estimate of the number of trees to be treated on a per acre, the number of wounds that would be created, and the amount of herbicide to be applied. Tordon 22K® (picloram) has a maximum label application rate of 64 fluid ounces per acre, and this was the basis for starting with a 50% solution. The Milestone® (aminopyralid) label has a maximum concentration rate of 10%. Therefore, a 10% solution was used on all solutions containing Milestone® (aminopyralid). All other herbicides could be used undiluted while remaining within the maximum labeled application rate.

Herbicide treatments were applied during two time periods, a fall treatment period (September – November 2013) and a spring treatment period (April – June 2014). Since most herbicides move within a plant with the flow of sugars, the study tried to evaluate whether the upward movement of the sugars that occur in the spring or the downward sugar movement that occurs in fall would be more effective in causing juniper mortality. Some herbicides such as picloram, can move within the plant in both sugars and water, and therefore may be less affected by the timing of the application. It was thought that the two application timings would allow some determination of whether mortality was caused by the herbicides being moved downward within the tree and killing the root system or by the herbicides being moved upward resulting in death of the foliage.

There were a few changes to the herbicide solutions as the applications proceeded. Solution #2 showed some form of incompatibility between products indicated by a precipitate that formed in the container, ultimately causing the sprayer tip to become plugged. After remixing this solution several different times with the same results, the Glystar Plus® (glyphosate) was removed and replaced with Weedestroy AM40® (2,4-D amine) at the same percentage. This new herbicide mixture was designated as Solution #2A. Eventually it was determined that the marking dye sitting within the concentrated herbicide formulations in Solution #2 was causing the incompatibility problem and not the actual herbicides.

Following the Fall 2013 herbicide applications, treatment areas were measured and the amount of herbicide actually applied was calculated on a per acre basis. This information indicated that Tordon 22K® (picloram) could be used undiluted and still remain within the maximum labeled application rate of 64 fluid ounces per acre. Therefore, the concentrations of Tordon 22K® (picloram) within the herbicide solutions used in the Spring 2014 treatments were increased by removing the water additive and replacing it with additional Tordon 22K® (picloram).

Table 3. Final Herbicide Solutions

Solution	Herbicide & (Active Ingredients)	Dilution	Surfactant	Additives	Timing
#1	Tordon 22K® (picloram)	50%	Alligare 7® @ 5%	Water @ 45%	Fall 2013
#1A	Tordon 22K® (picloram)	99%	Alligare 7® @ 1%	---	Spring 2014
#2	Tordon 22K® (picloram) Glystar Plus® (glyphosate)	50% 45%	Alligare 7® @ 5%	---	Fall 2013
#2A	Tordon 22K® (picloram) WEEDestroy AM40® (2,4-D amine)	50% 50%	---	---	Fall 2013 Spring 2014
#3	Tordon 22K® (picloram) Garlon 3A® (triclopyr)	50% 45%	Alligare 90® @ 5%	---	Fall 2013 Spring 2014
#4	Tordon 22K® (picloram) Milestone® (aminopyralid)	50% 10%	Alligare 7® @ 5%	Water @ 35%	Fall 2013
#4A	Tordon 22K® (picloram) Milestone® (aminopyralid)	89% 10%	Alligare 7® @ 1%	---	Spring 2014
#5	Capstone® (aminopyralid & triclopyr)	95%	Alligare 90® @ 5%	---	Fall 2013 Spring 2014
#6	Milestone® (aminopyralid) Glystar Plus® (glyphosate)	10% 85%	Alligare 7® @ 5%	---	Fall 2013 Spring 2014

*Note: Tordon 22K® is a Restricted Use Pesticide requiring an applicators license to purchase and use.

Treated western juniper trees were evaluated approximately every three months for two years following the herbicide application. Observation intervals were sometimes affected by the inability to access the test sites. Weather and road conditions, along with landowner requests not to access certain sites during hunting seasons were the main reasons for observation delays. The percentage of foliage affected by the herbicide treatment was visually estimated and recorded. The condition of any non-target woody species within eight feet of the treated tree was also noted. For consistency, the same person made the observations and estimations of tree mortality over the duration of this study, thereby eliminating the possibility of biases between different observers.

Specific weather conditions were also required to make good observations of the treated trees. Sunny skies were best for judging foliage color when looking at the tops of the trees. Cloudy or overcast skies made it difficult to differentiate between green foliage (live), grey foliage (dying), and brown foliage (dead). Observations also needed to be made during the middle of the day when the sun was high in the sky and shining brightly on the trees to make the foliage color more evident. During the final visit to evaluate each site, the width of the widest section of intact cambium layer was measured on each treated juniper tree that was not estimated to be completely killed from the herbicide application. Notes were also made on any other reason why some parts of the tree may not have been killed by the treatments.

Results

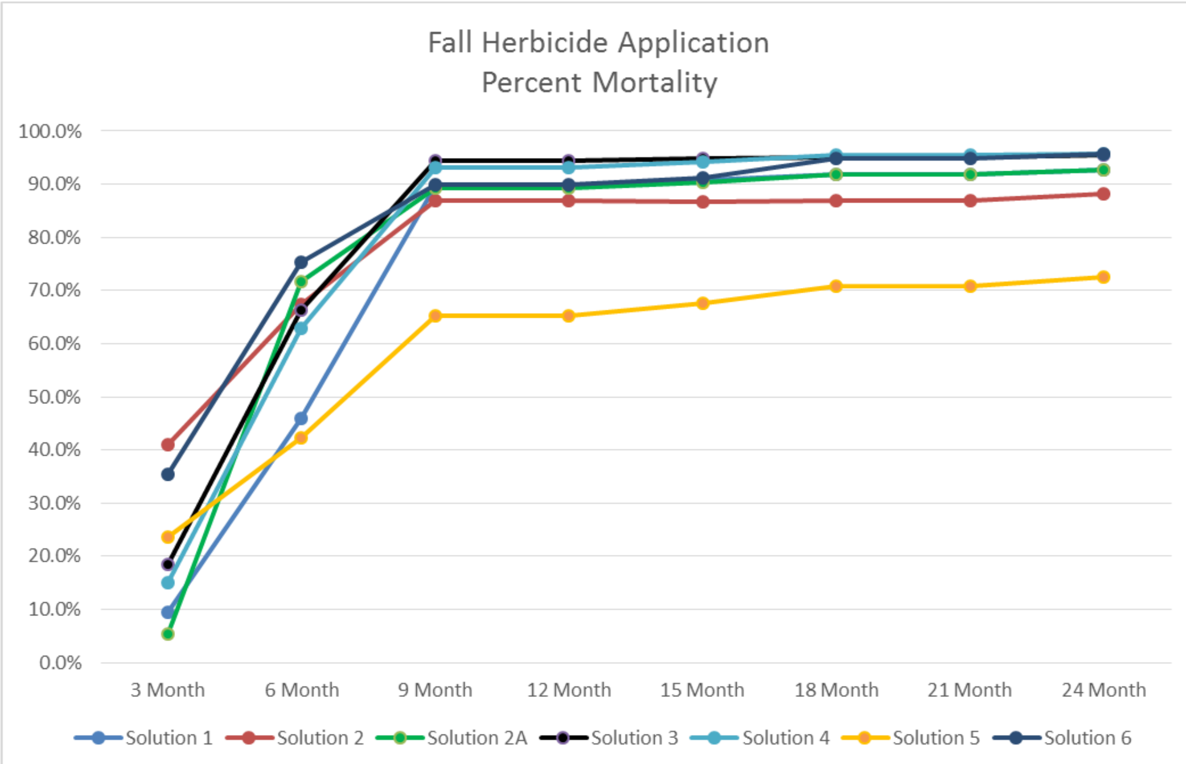
Timing of treatments

Spring 2014 herbicide applications showed much quicker, visible effects on the foliage of treated trees than the applications made in Fall 2013. The slower observed action of the fall treatments was particularly true of applications made later during the fall treatment period. Many of the trees treated in November 2013 did not show any visible effects of the herbicide treatments until the following May of 2014, whereas trees treated in April 2014 showed very evident, visible effects on foliage in less than 14 days. Since some of the herbicide solutions were modified after the Fall 2013 treatments and prior to the Spring 2014 treatments (see Table 3 above), a direct comparison of effects based on seasonality is difficult to make. However, the effects of timing of treatments was consistent across all western juniper size classes, wounding methods, and herbicide solutions evaluated, as shown in Figure 4 below.

Herbicide solution efficacy

Most of the herbicide solutions were successful in killing all size classes of juniper regardless of the wounding method used (see Figure 4 and Tables 4 and 5 below). The one exception was Solution #5 (Capstone®) containing a commercially premixed formulation of the active ingredients aminopyralid and triclopyr. Solution #5 consistently underperformed the other herbicide mixtures regardless of all other factors that were evaluated.

Due to a compatibility issue with the concentrated herbicides and the marking dye, only 50 trees were treated early in Fall 2013 with Solution #2 containing Tordon 22K® (picloram) and GlyStar Plus® (glyphosate) before the switching to Solution #2A containing Tordon 22K® (picloram) and WEEDestroy AM40® (2,4-D amine) at the same respective concentrations (see Table 3 above). Therefore, a true comparison of the efficacy of Solution #2 to the other herbicide solutions is not practical. Solution #1A containing Tordon 22K® (picloram) and Solution #4A containing Tordon 22K® (picloram) and Milestone® (aminopyralid) were only used in Spring 2014 treatments and had increased percentages of Tordon 22K® (picloram) as compared to Solution #1 and Solution #4 used in the Fall 2013 treatments.



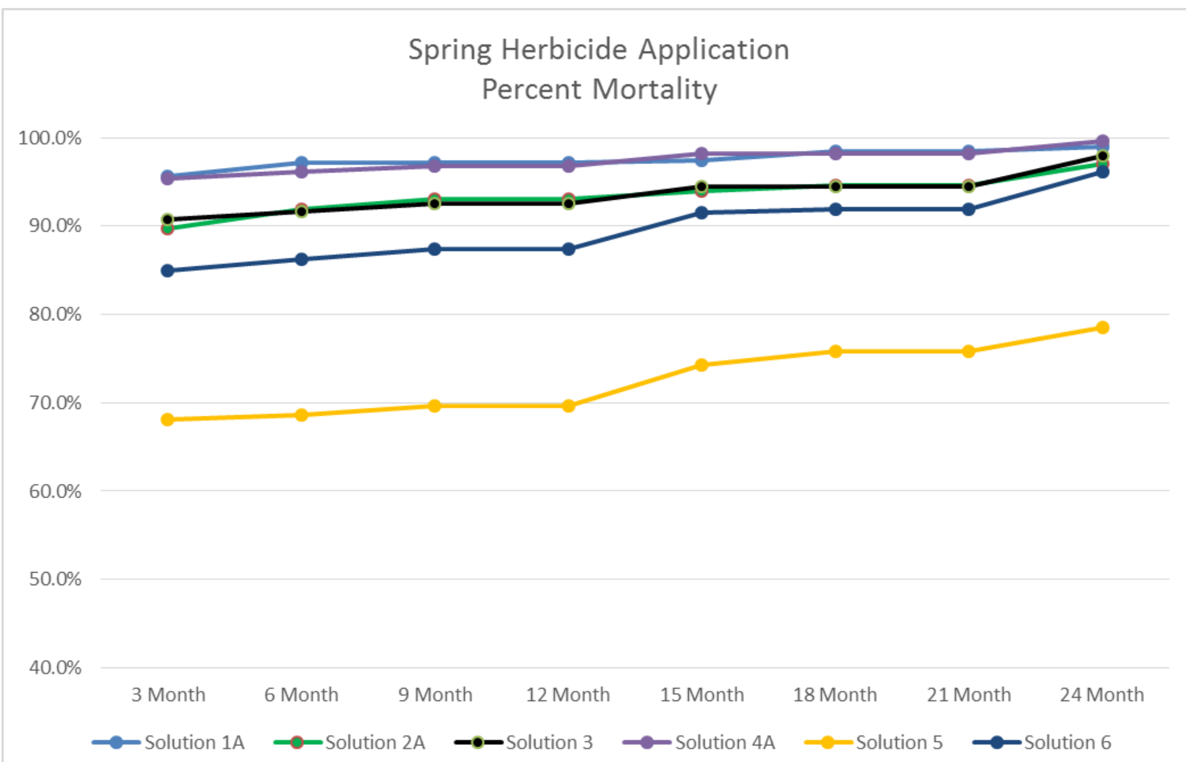


Figure 4. Charts showing the percent of foliar mortality on western juniper trees caused by different herbicide solutions across all tree size classes and wounding techniques evaluated for the Fall 2013 treatment period (top chart) and Spring 2014 treatment period (bottom chart).

Table 4. Percentage of trees by wound type completely killed by cut surface herbicide applications.

	Cut Stem Wounding		Blaze Cut Wounding		Diagonal Cut Wounding	
Solution	**Spring**	**Fall**	**Spring**	**Fall**	**Spring**	**Fall**
#1	n/a	97.4%	n/a	73.6%	n/a	65.6%
#1A	100%	n/a	98.5%	n/a	75.6%	n/a
#2	n/a	100%	n/a	35.3%	n/a	33.3%
#2A	100%	87.5%	98.1%	77.4%	43.4%	45.7%
#3	100%	100%	93.6%	82.3%	64.4%	74.6%
#4	n/a	100%	n/a	84.6%	n/a	85.2%
#4A	100%	n/a	98.2%	n/a	94.6%	n/a
#5	100%	83.3%	54.4%	42.9%	17.9%	22.7%
#6	100%	100%	91.8%	79.2%	58.7%	79.6%

Table 5. Percentage of trees by wound type with a minimum 95% mortality from cut surface herbicide applications.

	Cut Stem Wounding		Blaze Cut Wounding		Diagonal Cut Wounding	
Solution	**Spring**	**Fall**	**Spring**	**Fall**	**Spring**	**Fall**
#1	n/a	97.4%	n/a	82.8%	n/a	78.7%
#1A	100%	n/a	100%	n/a	90.2%	n/a
#2	n/a	100%	n/a	41.1%	n/a	50.0%
#2A	100%	100%	100%	87.1%	69.8%	68.6%
#3	100%	100%	98.4%	83.9%	79.7%	84.7%
#4	n/a	100%	n/a	86.2%	n/a	88.9%
#4A	100%	n/a	100%	n/a	98.6%	n/a
#5	100%	83.3%	57.4%	50.0%	22.4%	27.3%
#6	100%	100%	96.7%	83.2%	74.7%	87.0%

An unexpected effect was observed on plots treated in Spring 2014, likely attributed to the increased percentages of the active ingredient picloram found in Tordon 22K®. There was frequent injury or death of untreated juniper trees growing in close proximity to treated trees. It appears that the higher concentrations of Tordon 22K® in the spring treatments resulted in some of the picloram either being exuded from the roots of treated trees or shared by means of root grafting between treated and untreated trees at a strong enough concentration so that nearby, untreated individuals were affected. The exact method of herbicide transfer is unknown, but this effect on untreated trees was limited to western juniper growing immediately adjacent to treated trees. There were no observed, non-target effects for any herbaceous or other woody species growing within or nearby these test plots.

Tree size classes and wound type

Smaller trees were consistently much easier to kill than larger trees regardless of other factors. This might be due to a higher percentage of the tree's cambium layer around its circumference coming in contact with the herbicide than that of much larger trees. Almost every juniper tree less than 3-inches DBH that was cut off and treated was killed, regardless of application season or solution used.

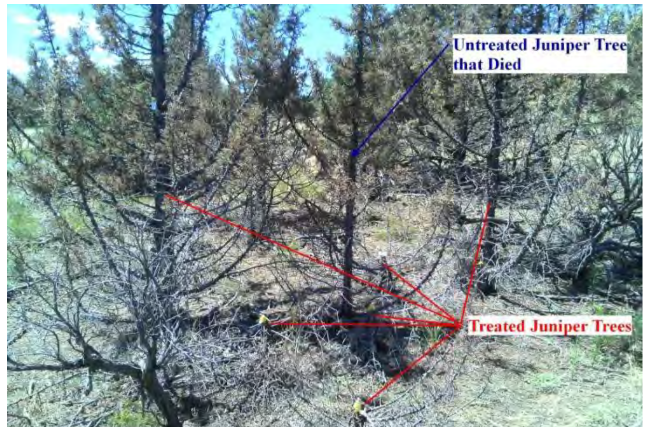


Figure 5. Photo showing an unexpected result only observed on Spring 2014 treatment sites. Multiple untreated western juniper trees growing adjacent to treated trees showed apparent effects from the herbicide treatments, either from soil uptake of chemical exuded from the roots of treated trees or through root grafting with treated western juniper trees.

The larger size classes of juniper proved more difficult to consistently kill. Two main factors that tended to be present for trees not completely killed by the herbicide treatments were sections of intact cambium greater than 6-inches wide around the circumference of the tree and large branches below the wound sites. Often, Class 3 test trees that were greater than 20-inches DBH had large lower branches that were too close to the ground for the wounds to be placed below them. These larger lower branches were often 4- to10-inches in diameter themselves. The herbicides seemed to have difficulty moving down from the wound site and out into these large branches. Frequently, the remainder of the tree was completely dead except for a few of these very large, lower branches.

Larger juniper trees that had split stems or multiple trunks were also difficult to kill with the cut surface herbicide treatments. The split trunks, depending on the height of the split above ground, created an area that was difficult to stem wound. The cambium layers of the two trunks need to be wounded within the fork of the tree to create the herbicide application site. If the trunk split is too high, the chainsaw operator cannot easily reach high enough to inflict an effective wound. These trunk splits sometimes occur close to ground level, making a wound below the split impossible to create. These trunk splits will often result in a large (>6 inches), intact section of cambium which can allow portions of the tree to survive the cut surface herbicide application.

Non-target species

There was a total of 1,104 woody plants inventoried and monitored growing within 8-feet of treated western juniper trees. These nontarget woody species included ponderosa pine, Douglas fir, sagebrush, antelope bitterbrush, curlleaf mountain mahogany, and currant. There were only two observed injuries attributed to the herbicide applications on any of these non-target species. One was a currant bush that was growing directly beside a juniper tree that received a small amount of overspray as the test tree wound was being treated. This currant recovered from the initial injury the following growing season and appeared normal at all of the following observations. The other occurrence was a small ponderosa pine, approximately 4-feet tall

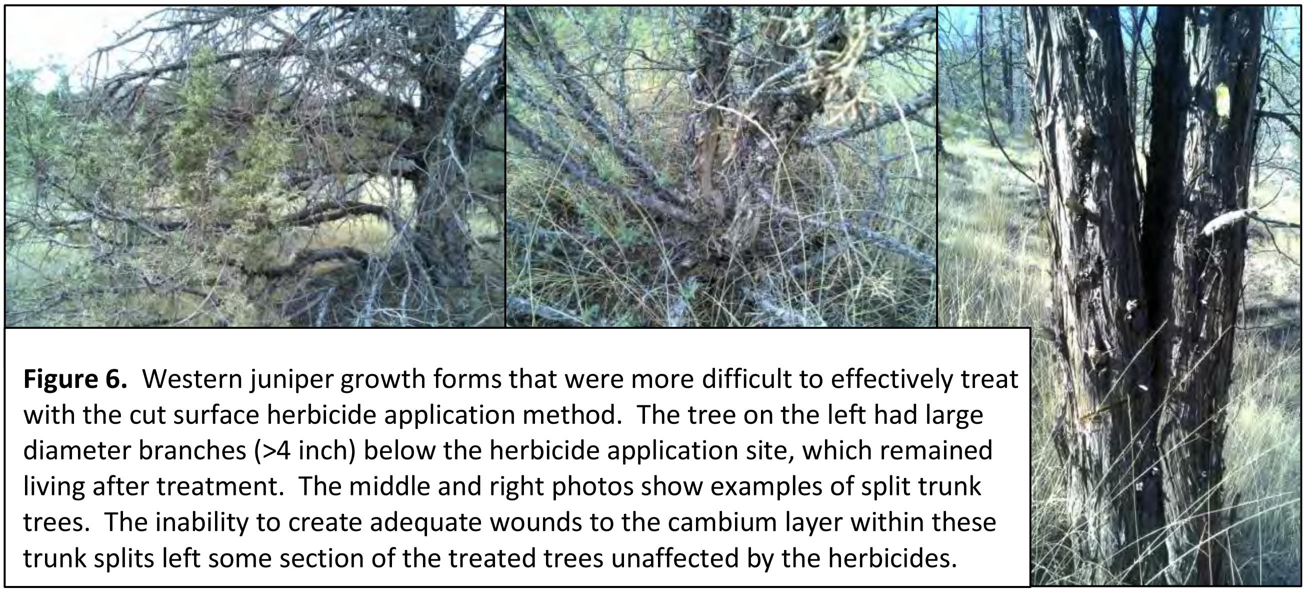


Figure 6. Western juniper growth forms that were more difficult to effectively treat with the cut surface herbicide application method. The tree on the left had large diameter branches (>4 inch) below the herbicide application site, which remained living after treatment. The middle and right photos show examples of split trunk trees. The inability to create adequate wounds to the cambium layer within these trunk splits left some section of the treated trees unaffected by the herbicides.

growing among 12- to16-inch DBH western juniper test trees. The first growing season following the herbicide application some of the needles on the pine tree began to turn red. The injury continued to worsen until the small tree died. It is unknown whether the herbicide applications to the nearby juniper trees caused the injury to the pine or if these effects were the result of some other unknown factor. All of the other 1,102 woody plants showed no apparent signs of injury during the study.

Control trees

Out of the 80 control trees that were wounded with the chainsaw but had no herbicide applied, only 13 showed any signs of foliar damage at any point during the study. Five trees had foliar damage of less than 10% and completely recovered (i.e., no visible foliar damage) by the end of the study. Of the remaining 8 trees, one was 80% dead by the end of the study, one was 95% dead by the end of the study, and 6 showed signs of 100% mortality by the end of the study. Four of these trees were on Site #6, three were on Site #3, and one was from Site #4. All had a DBH of 13-inches or less with half have receiving blaze cuts and half receiving diagonal cuts. There was an average of 3 wounds per tree regardless of the wounding method. All but one of these eight trees were wounded during the spring treatment period.

While it was not tested, it is hypothesized that the close proximity of these 8 control trees to treated trees, particularly those treated in spring with increased levels of picloram, may have resulted in some herbicide solution uptake by the control trees either from root grafting with treated trees or herbicide exuded into the soil by roots of adjacent treated trees. Otherwise, 67 control trees never showed any signs of negative effects during any point of the study. When considering the 5 trees that recovered from minor damage in the months immediately following wounding, 72 control trees (i.e, 90%) were not affected by the stem wounding.

Figure 7. Tree from Site #3 showing effects of Spring 2014 applied herbicide Solution #4A at 3, 6, 12, and 15 months following treatment. The treatment ultimately resulted in 100% mortality of this tree.

Figure 8. Tree from Site #5 showing effects of Fall 2013 applied herbicide Solution #6 at 3, 9, 12, and 15 months following treatment. The treatment ultimately resulted in 100% mortality of this test tree.

Discussion

The most effective cut stem herbicide treatment from this study was a spring application of Solution #4A containing a mixture of Tordon 22K® (picloram) at 89%, Milestone® (aminopyralid) at 10%, and the surfactant Alligare 7® at 1%. This herbicide solution had a 100% mortality rate on juniper trees smaller than 4-inches in diameter, 98.2% mortality on juniper trees ranging from 4- to 12-inches in diameter, and a 94.6% mortality rate on juniper trees larger than 12-inches in diameter. The Tordon 22K® / Milestone® mixture was also the most effective herbicide solution in the fall treatment period. However, the switch from 50% Tordon 22K® (Solution #4) in the fall applied mixture to 89% in spring applied mixture (Solution #4A) is likely the reason that the spring treatments with the Tordon 22K® / Milestone® solution were more effective than the fall treatments.

It took a very small amount of herbicide to kill juniper trees using these methods. In most instances, trees less than 4-inches in diameter only required 2-ml (0.07 fluid ounces) of herbicide solution to cause mortality. Juniper in the 4- to 12-inch diameter range were killed with approximately 4- to 8-mls (0.14 to 0.27 fluid ounces) and larger trees would require up to 22-mls (0.74 fluid ounces) of herbicide solution. Therefore, a 4-gallon capacity backpack sprayer would be able to treat 1,000-2,000 juniper trees. Based on estimates produced in 2015, a two-person crew (i.e., chainsaw operator and chemical applicator) could treat approximately 3 acres an hour with this method at a cost of $35 to $40 per acre. This assumes use of the Tordon 22K® / Milestone® herbicide mixture, which was the costliest of the treatment solutions tested. Average costs for juniper hand felling treatments ranged from $80 to $100 per acre with an additional expense of $60 per acre to stack the downed trees. Estimates of removal with heavy equipment were $160 to $200 per acre.

The study results tend to support the benefit of spring applied treatments over fall applied treatments given their quicker response time and greater efficiency in killing western juniper trees. Across all herbicide solutions tested, the ability of the spring applied herbicide solutions to more quickly affect the foliage was evident (Figure 4). However, the increased percentages of picloram (Tordon 22K®) from the Fall 2013 to Spring 2014 treatments complicates this comparison since the effects of timing versus increased herbicide strength cannot be separated. Herbicide solutions #3, #5, and #6 were the only mixtures that had consistent strengths throughout the entire duration of the study (i.e., no changes were made from fall to spring). If timing comparisons are made just between these three herbicide solutions, the benefit of spring treatments versus fall treatments does seem to be apparent for smaller diameter trees (i.e., those wounded with cut stem or blaze cuts) but not necessarily for larger trees (i.e., those wounded with diagonal cuts) – see Tables 4 and 5. Therefore, the benefit of spring applications versus fall applications cannot be definitively made for the largest tree sizes tested.

All three stem wounding methods proved to be adequate at providing an application site for a low volume, high concentration herbicide treatments for western juniper control. However, there was variation in efficacy between the three methods (see Tables 4 and 5) across all herbicide solutions tested. It is also important that the wounds are placed around the tree in a manner that leaves less than a 4-inch wide section of intact cambium at any point around the circumference of the tree. This is especially important on juniper trees that have live limbs near the height of the wound location or below the sound site. Wide sections of intact cambium after wounding increases the likelihood that a portion of the tree will not be killed.

The cut stem method was the quickest wound type to make and resulted in particularly high mortality rates regardless of the herbicide solution used. This may be the result of higher concentrations of the herbicide mixtures applied in relation to the overall tree size wounded with this method. A dose of 2-ml of herbicide to a tree 4-inches or less in diameter is arguably higher than an 8- to 10-ml herbicide dose to a tree 12- to 30-inches DBH, which may be 20-feet or greater in height. The cut stem wounding method was also the only technique in which 100% of the cambium layer of a tree was treated with a herbicide solution. Additionally, it was the only method that consistently killed all the foliage below the wound site, whereas larger branches below either a blaze cut or diagonal cut wounded tree proved especially hard to kill. With the cut stem method, all herbicide movement is downward to foliage or roots, unlike the other two wounding methods where movement of the herbicide solution can be in both directions within tree.

The blaze-cut wounding method worked well on smaller trees, but took additional time and required more wounds in order to be effective, especially as tree diameters increased. The blaze wounding method also tended to leave wider sections of intact cambium around the perimeter of the tree unless time was taken to create additional wounds. This occurred frequently on trees in the 8- to 12-inch DBH range. It would probably be more effective to use the diagonal cut wounding method on trees of this size, as the diagonal cut wounding method tends to expose a greater percentage of cambium around the circumference of the tree and is easier and faster to create versus the blaze cut method.

The diagonal cut wounding method was refined as the study progressed. It was important that the chainsaw operator perform the cut in a way that help facilitate the herbicide application with the goal of creating a downward sloping groove that allows the herbicide to flow down it without running down the bark of the tree. The cut needs to be made with the blade of the saw canted so that the cut creates a pocket to hold the herbicide solution. It was determined that making the cut at a downward angle of approximately 30°, rather than the initial 10°-20° angle, was best to at accomplishing this objective. Cutting at a steeper angle often resulted in the herbicide solution flowing out of the bottom of the wound. The wound needs to only be deep enough to cut through the bark of the tree and into the cambium layer. If the cut is made too deep, the herbicide will flow down the bottom of the wound channel, past the cambium layer, and mainly come in contact with the sapwood of the tree. If the wound is created properly, the herbicide applicator can place the tip of their sprayer in the upper end of the wound channel to easily apply the solution to the entire wound.

A low sprayer application pressure works best regardless of the wounding technique. This helps ensure that the solution will flow down the wound and contact the cambium, where it is readily absorbed by the tree. A low spray pressure also helps the applicator place the correct amount of herbicide to coat the wound. Any herbicide solution that flows onto the bark or down the tree trunk has the potential to become active in the soil and could cause injury to non-target plants that have roots near the treated tree. Both aminopyralid (Milestone®) and picloram (Tordon 22K®) are highly active and persistent in the soil. Since some non-target species, such as ponderosa pine, are very susceptible to injury from soil active herbicides, it is important to limit the possibility of herbicide runoff from treated trees.

All of the herbicide applications made during this study were applied within a few minutes of the wound being created. This prevented the juniper from having time to exude sap and seal the wound site, which would reduce the herbicide uptake and efficacy. It is unknown how much time can be allowed between the wounding and the herbicide application without decreasing efficacy. If the chainsaw operator works too far in advance of the herbicide applicator, it may be difficult for the herbicide applicator to find and treat all of the trees and wounds that the chainsaw operator has made. It is suggested that the herbicide applicator follows immediately, but safely behind the chainsaw operator so they are able to locate and treat each wounded tree. In most instances, the wounding operation will take longer than the herbicide application allowing the herbicide applicator to keep up with the chainsaw operator on most, if not all sites.

While not measured, during evaluation site visits it appeared that the needles of trees treated with a herbicide solution containing picloram (Tordon 22K®) turned a reddish brown, whereas the needles of trees treated with aminopyralid (Milestone®) remained a grayish green as if they had retained much of their original coloration. On the Milestone® treated trees, it was often difficult to determine if this grayish green foliage was alive or dead. The observer would frequently need to touch the foliage to see if it was still pliable and alive or if it was dry and crumbled.

In consultation with representatives from the ODA Pesticide Division at the initiation of this study, they determined that the cut surface application methods used in this study were not included within the rangeland/wildland/non-crop use sites on the product labels for Tordon 22K® (picloram) and Capstone® (aminopyralid and triclopyr). The use of either of these products under the proposed cut surface method on any site other than those considered under the Forestry section of the label would thereby constitute an off-label, non-legal use. Therefore, an Experimental Use Permit was obtained from ODA, and all applications were conducted by an applicator with a Research and Demonstration certification on their Oregon Applicator's license.

Following the completion of this study, Dow AgroSciences released a 2(ee) label recommendation under the Federal Insecticide Fungicide and Rodenticide Act for Tordon 22K® (picloram) on November 2, 2016 that allows for cut surface treatments of juniper and other unwanted trees. It is very important to point out that the 2(ee) label for Tordon 22K® only allows for 10% solution of herbicide in water compared to the 50% and 99% solutions used in this study. Therefore, applications of Tordon 22K® at the strengths used in this study cannot be made to treat western juniper at a practical level. It is also important to note that most picloram containing products, such as Tordon 22K®, are Restricted Use Pesticides, requiring appropriate licensing to purchase and apply.

The Monument SWCD plans to conduct future studies that test the use of picloram (Tordon 22K®) at the approved 10% dilution rate to control cut stem wounded juniper. The general use herbicides included in this study (i.e., glyphosate, 2,4-D amine, aminopyralid, triclopyr) will also be included as stand alone, single-herbicide solutions at their clearly defined label rates for cut stem applications. This will allow for a more direct, casual comparison between individual herbicides and the timing of treatments on the ability to control juniper with cut stem application methods. Use of each herbicide at clearly defined label rates will prevent the need for an Experimental Use Permit and make the results more applicable for landscape level juniper treatments. Inclusion of general use herbicides (i.e., those that can be purchased without special licensing) as standalone treatments is desired so that a broader group of land managers can make use of this method, provided a general use herbicide is found to be an effective treatment. Overall, any additional, practical, cost-effective method that can be developed for controlling western juniper is desirable in aiding rangeland restoration efforts across Oregon and other western states.

Acknowledgements

This study was made possible by funding provided by the Oregon Watershed Enhancement Board (OWEB) and the John Day Basin Office of the Confederated Tribes of the Warm Spring Reservation of Oregon (CTWS). Special thanks are extended to the landowners who allowed the study to be conducted on their properties. Consultation was provided by the Oregon Department of Forestry, Oregon Department of Agriculture–Pesticides Division (ODA), Dow AgroSciences, and other chemical manufacturers and suppliers operating within the Pacific Northwest. In particular, we would like to recognize the individual efforts of Laurie Gordon with ODA and Bob Stewart with Dow Agrosciences. Over the course of this study, several agencies participated in site tours of the treatment areas including individuals with OWEB, CTWS, Oregon Department of Fish and Wildlife, and the USDA Natural Resources Conservation Service.