Chapter 8:
Forest Vegetation Management

Ed Fredrickson, Thunder Road Resources, Redding, CA

Mark Gray, Sierra Pacific Industries, Anderson, CA

Table of Contents

The Influence of Competing Vegetation in Forestry

The focus of this chapter is primarily on the use of chemicals to control competing vegetation both before and after the conifer seedlings are planted. Mechanical, fire, and managed intensive grazing approaches to controlling competing vegetation can also be used in combination with chemical methods or as a substitute method. These methods are typically more expensive per acre and often do not achieve the same level of control of competing vegetation.

Competition

The success of forest regeneration depends on many things. In California's Mediterranean climate, the most critical factor which influences the success or failure of establishing a new forest is competing vegetation (Powers 1999). Competing vegetation can and will deprive newly established conifer seedlings of valuable light, nutrients and most importantly, water (White & Newton 1989). In California, where summer temperatures can exceed one hundred degrees, relative humidity may be in the single digits and long periods without rainfall are common, competing vegetation in excess of just twenty five percent cover may be enough to influence growth and survival of first year seedlings (Oliver 1984).

Pioneer brush species and hardwoods inherently grow faster than conifer seedlings and can quickly over-top planted trees depriving them of valuable light needed for photosynthesis (McDonald & Abbott 1997). Herbaceous vegetation in the form of grasses and forbs has adapted to capitalize on early available soil moisture for growth, and can quickly deplete available water for seedlings (White, Witherspoon & Newton 1990). It is important to realize that any vegetation other than the planted conifers are utilizing light, nutrients and water that are required for successful establishment of new seedlings.

The impacts of competing vegetation on conifer seedlings have been well documented. Ponderosa pine (*Pinus ponderosa*) survival was dramatically increased by controlling bear clover (*Chamabatia foliolosa*). Tappeiner & Radosevich (1982) demonstrated that in areas where bear clover was not controlled, ponderosa pine survival ranged from six to twelve percent survival compared to eighty to one hundred percent where it was removed. The same study also predicted wood volume losses of 75 percent by age 50 if bear clover was not controlled. Fisk (1984) also estimated volume losses of up to 70 percent in mixed conifer forests where bear clover was not controlled. Oester et al. (1995) showed survival increased from 18 percent to 63 percent and stem volume increased from 39 cubic centimeters to 819 cubic centimeters in ponderosa pine five years after planting from a single application of hexazinone compared to untreated controls in northeastern Oregon. In a study by White & Newton (1989) ponderosa pine growth was substantially reduced by manzanita ground cover as low as 20 to 30 percent. Powers (1999) showed a threefold gain in stem volume averaged over all sites using herbicides compared to the non-treated controls eight years after treatment in the Garden of Eden Study. Ponderosa pine growth was reduced by 80 to 90 percent three years after planting when greenleaf manzanita cover reached 50 percent (Radosevich 1984).

Controlling competing vegetation is most important early in the life of a new forest. McDonald & Fiddler (2001) showed that delaying release treatments until four years after planting and then treating each year for the next three years did not significantly increase growth over the non-treated controls. Small trees that received release treatments during the first three years after planting were statistically larger McDonald & Fiddler (2001).

Fuel Loading and Fire Risk

A secondary reason to manage competing vegetation is to maintain a relatively fire resistant landscape. When woody brush goes unchecked, it can quickly outgrow planted conifers. Usually one or two species will dominate a site and suppress others. Heavy fuel loads accumulate and plant biodiversity is also reduced (DiTomaso et al. 1997). Radosevich (1984) showed that greenleaf manzanita (*Arctostaphylos patula*) biomass on a good site one year after planting was almost 60 times that of ponderosa pine seedlings. One year after planting a site that had been mechanically site prepped, greenleaf manzanita plant density consisted of 123,500 seedlings per acre. During the ten year study, manzanita plant numbers decreased, but foliar cover increased by 21 times while height increased by seven times (McDonald & Fiddler 2001). As the average investment by private landowners to establish new forests is around five hundred dollars per acre, managing the vegetation to reduce fire risk is critical. Fire proofing a stand is impossible, but by managing the density and size of vegetation the intensity of the fire may be lowered to allow survival of the stand.

Environmental Considerations

Herbaceous and woody vegetation do have positive benefits and are an important but minor component of most reforestation projects in California. They provide habitat and food for wildlife, protect water quality, increase soil stability and can provide some aesthetic qualities to the landscape. It is very important as a land manager to realize that effectively treating vegetation to establish a new forest produces a very short-term effect on the landscape. Vegetation rebounds very quickly and by not letting one or two species dominate a site, plant biodiversity and species richness increase in the long-term (DiTomaso et al. 1997). How one manages vegetation depends on the landowners objectives. Goals for wildlife, water quality, soils and aesthetics can be easily integrated into a management plan. The ability to recognize where, when and how special vegetation management considerations need to be addressed is critical to sound and responsible planning. Specific concerns will be addressed later in this text.

The chemical control of competing vegetation is tightly regulated in California and commercial application in limited to licensed professionals who must follow the latest regulations.

Choosing a Method of Vegetation Control

Choosing a method of vegetation control should not be taken lightly. Failure has significant ramifications that are enormous from both a financial and biological perspective. The inherent cost of treatment and the potential cost of failure should provide the incentive to choose wisely and do it right the first time. So what should be considered in choosing a method of vegetation control?

It is imperative that foresters fully understand the treatment objectives before starting. Site preparation treatments for conifer establishment are usually much more intensive than managing vegetation for wildlife or recreation to achieve the primary goal of fast growth of the desired set of newly planted trees. The land management objectives and constraints will dictate what methods are suitable and which are not. Land managers must have a clear understanding of the desired outcome in order to evaluate effectiveness of the components of their work.

The budget is a very important consideration. The greatest savings can be achieved by doing things right the first time. Vegetation treatments are inherently expensive. Some treatments cost much more than others and may be less effective. It is important to consider both present and future treatment costs. Are repeat treatments going to be necessary? Will the treatments be mechanical, chemical or manual?

Another question involves the duration of desired control. Manual and mechanical treatments generally provide short-term control, while certain herbicide prescriptions can provide control over a number of years. There are exceptions to the short term impacts of manual and mechanical treatments. Large whiteleaf manzanita (*Arctostaphylos viscida*) for example, re-sprouts very little when disturbed. If it is too large to treat chemically, mechanically piling or masticating may provide satisfactory control.

One of the most important things to be aware of when deciding on a treatment option is the surroundings. Are there any sensitive areas around that may preclude the forester from using one type of treatment over another? The presence of sensitive water courses or wells, property lines, neighbor issues, or endangered species are all things that may influence the decision on which type of treatment to use. The crop species tolerance to herbicides may be an issue that dictates using another method of control. For example, if a particular conifer species is intolerant to available herbicides, manual or mechanical removal may be a better option.

Worker safety may be an important issue that influences the selection of a method. Slope, rockiness, temperature and access may all be safety issues that favor one type of treatment over another. Newton &

Dost (1984) showed through medical records that the risk of worker injury was magnitudes greater with manual removal treatments when compared to hand applied chemical applications.

There is a wealth of knowledge available to landowners regarding all types of vegetation control depending on the resource professional. Generally, foresters that work for private industry, consulting foresters, pest control advisors, licensed applicators and university personal work more with chemical vegetation management than state or federal employees. State and Federal employees tend to rely more on non-chemical vegetation control than private and have a vast amount of experience with alternative treatments. County offices of the Department of Agriculture as well as the Department of Pesticide Regulation can also provide valuable information. Consulting with vegetation management professionals will save the landowner valuable time and money as well as ensure a successful application to achieve the desired objective.

Methods of Vegetation Control

There are many different methods for controlling unwanted vegetation, and the selection of the desired method is a keystone in the success of the reforestation project. These various methods are introduced here and may be found in greater detail later in this chapter or within other chapters of this book.

Chemical

Chemical vegetation control involves the use of herbicides, desiccants or growth regulators to control unwanted vegetation. The overwhelming majority of chemical vegetation management is done with herbicides and therefore will be the predominant method discussed in this text. Herbicides are generally the most effective and efficient method of vegetation control. Today's herbicides and application methods also have a very high margin of safety and any specific concerns can be easily mitigated (Newton & Dost 1984).

Mechanical

Mechanical vegetation control is done utilizing some type of equipment to manipulate existing vegetation on a site. Piling, ripping and mulching are common examples. With subsequent weed germination or resprouting, mechanical vegetation control alone does not provide control in the long-term (Fiddler & McDonald 1997). As a result, mechanical vegetation control is usually done in combination with other methods of vegetation control such as chemical. Mechanical treatments may be especially appropriate where large brush or trees that cannot be treated by other methods is present, or where some type of soil amelioration may be desired.

Manual

Manual vegetation control involves cutting, grubbing, pulling or some other method of physically removing vegetation by hand. Vegetation control using these methods is usually of short duration and application costs can be very high (Knowe 1992), and as a result, they are commonly used in combination with another method of vegetation control. Manual control of vegetation is particularly useful in areas that chemical application is not feasible, such as projects in close proximity to residential areas or in areas that may be sensitive to herbicide application due to multiple water courses and associated buffer zones. Other uses might be in very remote areas with limited access by application equipment where grubbing crews can provide a release treatment by hiking into the treatment site. Manual treatments are frequently used by the United States Forest Service (USFS) in their reforestation activities, at least, in part, due to the complex authorization process required prior to use of chemical treatments.

Biological

Biological control is achieved utilizing a naturally occurring organism or substance to control vegetation. Successful examples of biological control include control of tansy ragwort (*Senecio jacobaea*) using the Cinnabar Moth (Fuller 2002) and control of St Johnswort (*Hypericum perforatum*) with the Klamath weed beetle (Holloway 1964). Pathogenic fungi are also under investigation to control certain types of vegetation, but to date the results have not been as successful (Wall 1996, Wall & Shamoun 1990). Biological control methods are usually limited to very specific pests, which does not make them applicable to broad spectrum vegetation control. They are usually also restricted to certain geographic ranges or elevations. In most cases, biological controls are a small part of a larger management program (Newton & Dost 1984).

Cultural

Cultural treatments are management practices that have a direct or indirect effect on vegetation control and can take on many forms. They can be land management activities such as burning or grazing that can affect competing vegetation itself, or seedling development programs such as seedling nutrition or stock type selection to enable seedlings to outcompete the vegetation. There is virtually an endless stream of concepts and ideas that one can incorporate into a management program to try and minimize vegetation management inputs. Like some of the other methods of vegetation control, cultural treatments are only a part of an integrated approach for vegetation management.

Non Chemical Weed Control Methods

Mechanical Weed Control

Mechanical operations in forestry are not always solely for the purpose of weed management. Mechanical treatments may have multiple objectives included mitigating compaction, improving water absorption, facilitating planting, slash removal, thinning or vegetation management. Mechanical treatments are also not usually used alone, but are one part of a larger program (McHenry 1982).

The majority of the discussion of mechanical site preparation treatments as they refer to aspects other than vegetation will be discussed in the site preparation chapter of this manual. We will briefly discuss the benefits associated with vegetation removal here. Mechanical vegetation removal can be an important part of the reforestation program and will usually have a significant impact on future treatments regarding cost, quality and accessibility.

Biomass removal

Removal of unwanted vegetation may start before the logging operations are even completed. When markets allow, one of the most important mechanical treatments foresters can do is biomass removal or chipping. The ability to chip unwanted material in the woods has several advantages. Fuel loading is drastically reduced as unwanted material is chipped and hauled off site. The costs of piling and potentially slashing after logging are drastically reduced or not needed at all. Poor quality sub-merchantable conifers can be easily and efficiently removed. Accessibility for planters, spray crews, and other reforestation efforts is improved. While the chipping treatments won't provide long-term control of the competing vegetation that is removed, it does bring it down to a manageable level. Future entries for chemical, hand or mechanical treatments will be much easier and more cost effective.

Piling

Depending on the slash load and component of large woody brush or sub-merchantable conifers following logging operations, reforestation units may need to be piled to improve access, remove residual vegetation and facilitate planting operations. Weed control by piling is primarily through the removal of large brush. In many cases, large plants such as manzanita can be entirely pulled or pushed from the ground root systems and all. This can control some plants where the entire plant system can be removed. In other cases the brush is too small or flimsy to be entirely removed and control must rely on some other method. If pre-sprayed prior to harvesting, much of the brush is dead by the time piling occurs, and it can be easily crushed or piled. This also reduces the amount of time needed for piles to dry in preparation for burning.

Piling operations can be conducted with several different types of equipment. Bull dozers are the primary method used. All bull dozers utilized for piling should be equipped with brush rakes to minimize the amount of soil disturbance.

Excavator piling is another option that has several additional benefits. Much less of the ground is covered by the tracks of an excavator compared to a bull dozer due to the reach of the boom, and as a result, potential compaction is lessened. Using the grapple of the boom, large brush and woody sprout can be pulled from the ground minimizing movement of topsoil. Furthermore, steeper slopes can also be reached with an excavator, often times up to 40 percent.

Piling costs when using tractors in logging units usually range between $150 and $250 per acre for logging units, but the use of excavators is more expensive and can add another $50 to $100 to the per acre cost. If converting old brushfields, piling costs are usually higher when dense and large old brush is present that must be removed prior to any other activity. It has become less popular to utilize piling for site preparation. Increased opportunities are now available to avoid the cost and disruption of piling. These include chemical pretreatment and planting through resultant slash and creating micro-sites for conifer seedlings with equipment that does not operate over the entire unit's surface area. In addition, poor piling practices can impact site quality through excessive soil disturbance. Finally, the liability when burning piles or windrows created by this method is a risk many landowners are now unwilling to accept.

Sub-soiling

Site preparation treatments with sub-soiling utilize a bulldozer fitted with a brush rake and a series of steal shanks fitted with slightly angled wings on each side of the shank. The shank and wings are designed to rip, lift and drop the soil to mitigate compaction. A secondary result of the treatment is that it disturbs any remaining vegetation it comes in contact with.

One of the largest environmental studies in the history of the United States is the Long Term Soil Productivity Study (LTSP) which is installed on many sites across the country (Powers & Fiddler 1997), with twelve sites installed in California. The study looked at several factors affecting conifer survival and growth including compaction, vegetation management and soil organic matter. Treatments consisted of light, moderate and heavy compaction, with or without vegetation, and organic matter removed or present. The LTSP study has been in existence since 1989 and occurs over a wide range of conditions and soil types across the country.

Regarding the sub-soiling effect on vegetation, the results vary by site but on the Challenge, California site some interesting results occurred. At the end of the fourth growing season the average ponderosa pine volume increment was greatest in the compacted plots and least in the lightly compacted treatments that were sub-soiled in two directions. This seems counter intuitive, but it is because of the competing vegetation this occurred. Vegetative cover averaged 56 percent in the compacted plots and 91 percent in the sub-soiled plots. Less weed cover translates to increase moisture availability. When the effect of vegetation was removed, the sub-soiled plots were clearly superior to the compacted ones (Powers 1997). Potter (1984) also showed that when units with bear clover present were ripped, rhizomes were broken up and spread across the unit resulting in even more of an infestation. This result seems to heavily rely on the type of vegetation present. Others have shown very positive growth responses on ponderosa pine to sub-soiling (Helms et al. 1986, Froehlich & Robbins 1983).

Mastication

Mastication involves crushing or grinding vegetation on site with some type of specialized head mounted on a piece of heavy equipment. This method of vegetation control is expensive, but negates the need to follow-up piling. Organic mulch that is left on site may also increase the water holding capacity of the soil (Hudson 1994). It is a good method to use when vegetation is large enough to hinder reforestation efforts and can sometimes be used in place of broadcast burning. Masticating the vegetation will not kill re-sprouting species, and as result, it is best used in combination with herbicides for effective control. Recently, dense stands of 60 year old tanoak regrowth in the Sierras have been operationally treated using this method. Trees were severed and laid on the ground with a feller buncher and then masticated. This created a relatively thick layer of shredded organic matter that could be picked through for planting spots, albeit with some difficulty. While this operation was expensive, ranging from $400 to $500 per acre, it created an opportunity for recapturing hardwood-dominated, high site timberland that would otherwise have required heavy equipment clearing and high risk burning, if even possible at all. As mentioned earlier, the resultant fuel loading during the early years of the plantation must be considered, and the presence of re-sprouting species would require the consideration of a site preparation spray as part of the prescription.

One masticating site preparation tool that has been used in the past, but now with relatively limited availability, is the VH Mulcher. This machine utilizes a high-torque spinning head with angled blades that is ground down into the soil. In so doing, it not only masticates vegetation in a circular area about four feet in diameter, but also alleviates surface compaction and creates planting spots for seedlings. It is expensive and can run between $250 and $400 per acre depending on the number of planting spots created, density and size of brush, slope and rockiness. This method generally does not preclude the need for herbicide treatment of the surrounding terrain, as encroachment from the edges can be fairly rapid. Care should be taken in some soil textures as the vigorously disturbed planting spots may initially have a high percentage of macro pores that can impact root growth.

Using masticating heads on a maneuverable boom can reduce residual damage to the conifer plantation. Where large brush is present in established plantations, mastication can be used as an effective release tool by reducing brush competition at the same time as pre-commercially thinning existing conifers to desired levels. Release treatments such as these usually occur in older plantations, where brush has been allowed to dominate and is too large for any type of manual treatment.

Fiddler and McDonald (1997) compared different mechanical release treatments in a 12 year old Ponderosa pine plantation which included a non-treated control, removing vegetation with a Hydro-Ax shear only, and removing vegetation with the shear followed by an application of 2,4-D to the re-sprouting vegetation the year after masticating. After 11 years, the Hydro-Ax plus the use of herbicide had significantly larger crowns, diameter and height than either the Hydro-Ax alone or the non-treated controls. The only difference between the hydro ax only treatment and the untreated controls was in crown volume. A study by Fiddler et al. (2000) showed similar results on a 16 year old ponderosa pine plantation using a Trac-Mac shear instead of a Hydro-Ax. The treatments consisted of a untreated control, Trac-Mac cut-only, and Trac-Mac cut plus a herbicide treatment with 2,4-D two years after cutting. Eleven years after treatment the Trac-Mac only treatments had no significant differences in crown volume, diameter or height compared to the non-treated controls, whereas the Trac-Mac plus 2,4-D treatment had significantly larger crowns than the untreated control or the Trac-Mac only treatment. Somewhat larger diameters and heights resulted from the Trac-Mac plus 2,4-D treatment, and while not significant, the authors did point out that growth rates were diverging over time between treatments.

All mechanical mastication methods are expensive and should be reserved for those situations where other options are limited or specific objectives have been identified, such as reduction of herbicide use or elimination of burning. When needed for release, the costs necessary to reclaim a site using mechanical methods emphasize the importance of adequate vegetative control in the first place.

Manual Weed Control Methods

An advantage of manual weed control is that these methods can be more socially acceptable and have fewer environmental constraints than other methods. Additionally, manual treatments can be highly selective and can even be incorporated into pre-commercial thinning programs. The disadvantages of manual treatments is that they require a large skilled crew, often result in more worker injuries, and are less effective than chemical methods (Newton & Dost 1984). The largest disadvantage is high cost and a very short duration of control (Knowe 1992).

Manual release treatments can include such treatments as hand grubbing, cutting, utilizing mulch mats, shade cards and other non-chemical control methods. Probably the most popular method of manual weed control is hand grubbing. Hand grubbing involves the manual removal of live vegetation through the use of hoes, shovels or other implements. Hand grubbing is usually done after the seedlings have been planted. To maximize effectiveness, treatments should occur after the large majority of vegetation has emerged in the late spring to early summer and should remove all root systems within the grubbed area to be effective.

Several studies have evaluated the results of hand grubbing. McDonald and Fiddler (1990) compared several sizes and intensities of hand grubbing treatments to a single application of Velpar L (hexazinone). Treatments included two and four foot scalps applied at age one, half of which were expanded to four and six foot scalps at age four. Four years after treatment, trees treated with the single application of Velpar L were significantly larger in caliper and height for all treatments except the four foot scalp that was expanded to six feet. No grubbing treatments had significantly larger calipers or heights than the non-treated controls other than the six foot radius scalp. Labor costs were high, however, with the six foot radius scalp treatment costing $578 per acre in 1984 dollars compared to $38 per acre for the single Velpar L treatment. With annually repeated grubbing treatments for the first three years after planting, McDonald and Fiddler (2007) did show increases in caliper and ponderosa pine leaf area compared to non-treated controls, but at a cost of $1890 per acre assuming labor rates of $28 per man hour.

While expensive, hand grubbing can be successful in achieving survival provided the scalps are large enough and the treatments are repeated when competing vegetation returns. In the absence of chemical vegetation control methods, the hand grubbing treatment is better than doing nothing.

Cutting brush or hardwoods with a chainsaw or hand saw is another manual method to release conifer seedlings. However, doing so without chemical follow up is a very short-term treatment. McDonald et al. (1989), showed that tanoak cut with a chainsaw was over-topping Douglas-fir seedlings four years after treatment. By nine years after treatment, Douglas-fir height was not significantly different from the non-treated controls, and only small gains in Douglas-fir diameter were achieved. D'Anjou (1990) found that when woody brush and hardwoods were cut, they reached 50 percent of their pre-treatment height by the end of the first growing season. The study also showed no brush mortality occurred as a result of cutting and timing of treatment had little effect. When compared to herbicide treatments, cutting provided significantly poorer control than glyphosate. Similar results were found by Simard and Heineman (1996), who showed that cutting had no effect on Douglas-fir caliper or height nine years after treatment, but treatments with glyphosate significantly increased diameter. The same study on a different site showed significantly larger diameters on lodgepole pine for the cutting and glyphosate treatment compared to non-treated controls nine years after treatment. Whitehead and Harper (1998), compared four types of vegetation control for release of Engelmann spruce including treatments with glyphosate, 2,4-D, manual cutting and a non-treated control. Ten years after treatment, the glyphosate treatments were the most effective in reducing brush cover and height and significantly reduced the height to diameter ratio and competition index. All other treatments failed to meet Canada's minimum stocking standards at the completion of the study. Mixed results on conifer growth have been found by others. Pendl and D'Anjou (1990) found no growth response from grand fir but height growth in Douglas-fir was significantly increased five years after cutting.

If cutting is to be done, some of the literature suggests it is better to cut woody brush and hardwoods later in the season when carbohydrate reserves are low (Pendl & D'Anjou 1990). Increasing the frequency of cutting and cutting to the lowest stump heights possible may also reduce the amount of re-sprouting (Harrington & Tesch 1992), and cutting is much more effective when followed up with herbicides to reduce sprouting (Wagner & Rogozynski 1994). McDonald & Tucker (1989) concluded that cutting treatments are very expensive for a short-term reduction in cover.

Another manual method that has been used over the years is the use of mulch mats. Mulch mats can be made out of paper, plastic, polyester, asphalt or other durable material and range in size up to ten feet in diameter. The purpose of placing mulch mats around tree seedlings is to deprive competing vegetation of light, heat the soil enough to prevent germination and retain valuable soil moisture for tree seedlings (Haywood 1999). Mulch mats can be an effective method of control in certain instances but they are expensive, difficult to install, require maintenance to maintain their position around seedlings, are problematic with sprouting species and often don't degrade in a reasonable amount of time (McDonald & Fiddler 1992).

Early polyester mulch mats reduced the amount of vegetation around tree seedlings, but didn't significantly increase Douglas-fir diameter or height over the controls (McDonald & Fiddler 1992). It found that the mats didn't allow water to penetrate, creating desert like conditions for seedlings. As a result, the type of material used is extremely important, and subsequent studies found that Pac-Weave was the best available material that didn't constrict tree growth, reduce water penetration, degrade too fast and was easy to install (McDonald & Fiddler 1992, Craig & McHenry 1987).

Conifer growth responses from the use of mulch mats are mixed. McDonald et al. (1994), compared polyester and paper mulch mats to hand grubbing treatments annually repeated for five years. Five years after treatment on Ponderosa pine seedlings, the polyester mats and the hand grubbing treatments yielded significantly larger diameter and heights compared to non-treated controls. However, the cost of the mulch mats was $2072 per acre. Harper et al. (2005) found that mulch mats reduced the amount of herbaceous vegetation in the first three years, but they failed to significantly increase survival, diameter or height for Douglas-fir seedlings compared to non-treated controls. That is the opposite of treatments with either glyphosate or hexazinone in that study. Haywood (2000), found that both mulch and hexazinone treatments resulted intaller loblolly pine seedlings and caused them to grow out of the grass stage faster than the non-treated controls. Other studies by Haywood (1999) had mixed results regarding growth of loblolly pine.

Mulch mats may have some potential, but are expensive and require considerable labor to install. McDonald and Fiddler (1992) reported the cost of large mulch mats can be as high as $9.90 per seedling, severely limiting the number of seedlings that can be treated effectively. Land managers that choose to use mulch mats may just want to focus on treating only a certain number of crop trees to keep the costs down.

Manual vegetation control treatments will always have some fit in forest management. However, when used alone, results will be extremely short-term and are best used in combination with chemical treatments for lasting control. If chemical methods are not available, it is important to realize that repeated manual treatments will be necessary and costs will be high.

Biological Control Methods

Biological control of vegetation can be attempted by several different methods. Insects, pathogenic fungi and the use of allelopathic organisms are all methods of biological control. Very little is known about the latter two methods, but some gains have been achieved with the use of insects on species such as Klamath weed (St Johnswort), tansy ragwort and to a much lesser degree Mediterranean sage. (Fuller 2002, Isaacson & Brookes 1999). Currently, new biological agents are being tested for control of alligator weed, Cape ivy, Dalmation toadflax, gorse, musk thistle, Russian knapweed, Russian thistle, Scotch broom, tamarisk and yellow star thistle. Of these, the hairy weevil which was introduced to California to control yellow star thistle is showing the most promise, but yellow star thistle populations remain high.

The problem associated with biological control agents is that they are usually very host specific. From a forester's standpoint, controlling one weed out of a thousand does little to reduce competition. Getting populations of insects established is another concern. In many cases predators reduce populations of beneficial insects to insignificant levels. Some insects only produce one generation per year making establishment difficult (Pitcairn 1999). Using biological control agents is usually out of the forester's control as these programs are usually designed and implemented by the state. There is definitely some potential benefit from biological control, but using insects should be one small part of a larger vegetation management program (Newton & Dost 1984).

Cultural Weed Control Methods

Cultural methods of weed control are indirect management techniques that increase a conifer seedlings ability to out-compete the vegetation. Many types of activities could be considered cultural treatments and more often than not foresters may not even realize they are practicing cultural vegetation management. Regarding this text, we will try and focus on a few of the more relevant concepts.

The Seedling

One of the more obvious cultural treatments a forester can manage is that of producing the conifer seedling itself. Any variable that the forester can manipulate in the nursery to give the conifer seedling a competitive advantage over the vegetation in the field is a cultural treatment. Stock size is the first factor that comes to mind, but different stock sizes behave differently depending on the geography. In wetter high site climates, several authors have shown larger stock sizes for Douglas-fir to increase growth and survival (Ketchum & Rose 2000, Newton et al. 1993). Other authors have shown the stock size effect to be an additive effect when combined with vegetation management and fertilization (South et al. 2001). In drier Mediterranean climates however, Fredrickson (2005) showed that growth differences due to initial stock size were short lived and varied by species. All initial differences in size had disappeared by year 5.

One of the most important seedling variables to manage in the nursery for drier climates, is the shoot to root ratio. Seedlings will compete better with vegetation in the field if they have a balanced shoot to root ratio. Large tops and small root systems cause the seedling to transpire faster than the root system can acquire water for the seedling, resulting in growth loss or death. The nursery manager can manage seedling heights and the shoot to root ratio by regulating photoperiods, thereby tricking the tree into thinking the day length is getting short. This causes the tree to set bud and harden off earlier.

Seedling Nutrition

Seedling nutrition is another critical factor that can give seedlings an initial advantage over the competing vegetation. Timmer (1997) has shown that exponential nutrient loading of seedlings in the nursery can induce a steady state buildup of nutrient reserves in seedlings for out-planting. He has consistently shown greater growth and increased nutrient uptake after out-planting compared to conventionally fertilized seedlings of the same stock size. Powers (1999), has shown the benefit of nutritional amendments in the field to ponderosa pine growth, but only in combination with weed control. If weeds were not controlled, any nutrients added to the site were taken up by the competing vegetation and any potential gains to conifers were lost. Powers also noted that fertilization success in the field also depended on moisture availability and water holding capacity. Others have shown water to be a limiting factor regarding fertilization response in the field (Rose & Ketchum, 2002).

The idea of incorporating slow release fertilizer in with the soil media in the nursery initially showed increased growth responses in the field with ponderosa pine (Fan et al. 2002). However, when operational testing and planting was conducted in California, severe root mortality occurred from salinity build up in the plug media, especially during storage. These problems are exacerbated in hot and dry climates where flushing of the root system from spring rains is sparse. This method of fertilization is not recommended for dry California climates.

Grazing

Grazing is a cultural treatment that has been practiced for centuries. Grazing practices in forestry have been done primarily with ungulates such as cattle, sheep and goats. They are usually effective in reducing the amount of herbaceous and woody brush cover depending on the species present (Sharrow 1992, Fullmer 1986, Krueger & Vavra 1984, Thomas 1983). Reductions in vegetative cover however, are short-term and eventually recover (McDonald & Fiddler 1993). Grazing has also released non-palatable vegetation that has actually increased in percent cover after grazing (Fullmer 1986).

The reduction in vegetative cover does not necessarily mean an increase in conifer growth or survival. Results are mixed in the literature as to the benefits regarding seedling growth and survival. In many cases, no beneficial effect of grazing was seen (Milliman 1999, McDonald & Fiddler 1993), while others have documented increases (Barolome 1989, Krueger & Vavra 1984).

Timing and grazing intensity play a significant part in damage to crop trees. Milliman (1999) reported that browse damage on conifer seedlings was the greatest with the highest intensity of grazing pressure and in June when the early season forage was maturing but before the late season forage had begun to grow. Fullmer (1986), also reported that sheep had browsed 49 percent of ponderosa pine and sugar pine buds at one site when browsing occurred prior to conifer bud set in the summer. Grazing was delayed on a second site until after bud set and browsing conifer buds was reduced to 10 percent.

To manage grazing effectively it is somewhat labor intensive. Fences need to be constructed, maintained and moved as needed. Herds need to be rotated to insure over grazing does not occur. Water can also be an issue if not present on site.

Fire

One of the most common cultural treatments historically used to manage vegetation in forestry is fire. Today with increasing constraints and regulations regarding air quality and smoke management along with general liability concerns, this practice is used much less frequently. Historical uses of fire revolved around reducing post-logging slash and residual vegetation on site. The largest advantage of fire is on steep slopes where heavy equipment cannot be used. The use of fire subsequently reduces difficulty for hand crews when planting, spraying and thinning, thereby, reducing costs (Newton & Dost 1984). Substantial gains in vegetation control have also been shown when burning is used in combination with herbicides (Powell 1992). Burning without the use of herbicides can actually release some fire adapted species such as deerbrush, snowbrush, blue blossum (*Ceanothus thyrsiflorus)* and knobcone pine (*Pinus attenuata*) (Weatherspoon 1987, Newton & Dost 1984).

Fire has been shown to increase conifer survival and growth, especially in combination with herbicides (Taylor et al. (1991). The authors looked at piling, broadcast burning and spraying, burning alone, and all treatments with and without disking. Two years after treatment, the spray plus burning treatment had greater consumption of fuel compared to burning alone, and better vegetation control and seedling growth than either burning alone or the piling treatment.

Under burning is also a valuable tool to clear away under story slash, vegetation and smaller unwanted sub-merchantable conifers. Arno et al. (1996) and Newton & Dost (1984)) noted the importance of thinning in combination with fire, along with utilizing other vegetation management options including herbicides to maximize effectiveness. Burning should not be looked upon for fuels reduction as the sole option. Reducing fuels or creating fuel breaks without maintaining them is a waste of time and money. Vegetation will come back rapidly after fire and needs to be managed to prevent an even greater buildup of fuels (Newton & Dost 1984).

There are several disadvantages to using fire for vegetation management. The liability associated with burning is significant as there is always the risk of escape and associated suppression costs. The importance of developing and following a detailed prescription for any planned fire is essential. The forester must also have the experience and ability to call off a potentially high risk burn when conditions are not right. Cutting, clearing and walking fire-lines on steep slopes can also be dangerous, although, Kauffman (1992) demonstrated that the incidence of worker injury and workers compensation claims during post burning activities such as planting, backpack spraying and thinning was less on units that had been broadcast burned compared to units with heavy slash and brush loads.

Chemical Weed Control

As noted in Forests and Right-of-Way Pest Control (Dreistadt 2013) published by UC Agriculture and Natural Resources, herbicides are the most used pesticides in forests because of their effectiveness in controlling competing vegetation. In the most recent edition of the Pacific Northwest Weed Management Handbook, it was noted that reforestation success depends heavily on weed control and that “In the past 20 years, research has made clear that virtually no other practice will produce as much gain in plantation performance as reducing competing cover, and that careful application of the appropriate chemicals exceeds other methods in safety, cost and habitat protection for most operations." (Kelpas and Landgren 2018). The use of chemicals for weed control in California forestry settings are highly regulated by both the US Environmental Protection Agency and the California Department of Pesticide Regulation. Table 8.1 summarizes the herbicides used in forestry by their active ingredient, type of activity and uses.

Table 8.1 Properties and uses of herbicides registered for forestry use in California. Herbicides noted for directed release means there is no over the top conifer tolerance.

Active Ingredient	Type of Activity	Uses
2,4-D ester	foliar	site prep/directed release
aminopyralid	foliar and soil	site prep/directed release
atrazine	soil	site prep/release
clopyralid	foliar and soil	site prep/release
fluroxypyr	foliar	site prep/directed release
glyphosate	foliar	site prep/release
hexazinone	soil	site prep/release
imazapyr	foliar and soil	site prep
oxyfluorfen	soil	site prep/release
penoxsulam	soil	site prep/release
sulfometuron-methyl	soil	site prep/release - coast only
triclopyr ester	foliar	site prep/directed release

The following sections descried the types of herbicide used in reforestation, resource and applicator protection measures, and logistical issues of application.

Types of Herbicides in Forestry

There are several types of herbicides that are currently used in forestry including growth regulators, ALS inhibitors, photosynthesis inhibitors, protoporhyrinogen oxidase inhibitors (PPO inhibitors) and the newest mode of action, cellulose biosynthase inhibitors. Each controls plants in its own way.

Growth Regulators

Growth regulators used in forestry include triclopyr, 2,4-D, aminopyralid, clopyralid and fluroxypyr. Growth regulators control plants by causing rapid cell wall expansion and collapse. Typical symptoms of growth regulator herbicides include twisting and curling of foliage, stems and roots. Growth regulators come in both ester and amine formulations. Typically it's the oil soluble ester formulations that are used in forestry due to superior weed control and better penetration into leaf surfaces over the water soluble amine formulations. However, use of esters is typically limited to the spring and fall due to volatility issues during the hot summer temperatures. The amine formulations are non-volatile, and fluroxypyr ester is much less volatile than 2,4-D or triclopyr ester.

Growth regulators are primarily used to control woody brush and herbaceous broadleaves (triclopyr, fluroxypyr and 2,4-D). Aminopyralid and clopyralid only have activity on herbaceous broadleaves and some annual grasses, but have both foliar and soil activity. Conifer tolerance with triclopyr and 2,4-D is high when applied as a pre-plant application since there is no soil activity. Neither can be used over the top of conifers in California. Aminopyralid also can not be applied over the top of conifers, but has some conifer tolerance when applied as a pre-plant. Clopyralid has excellent conifer tolerance applied pre or post plant over the top of seedlings. Trees can occasionally be injured from soil uptake as a pre-plant treatment, but if damage occurs at all the trees usually recover in a short amount of time.

Aceto-Lactase-Synthase (ALS) Inhibitors

ALS inhibitors inhibit formation of the enzyme aceto-lactase-synthase in plants that is necessary for the formation of essential aromatic or aliphatic amino acids in plants. These amino acids are only found in plants. These herbicides tend to be highly systemic and travel readily through plant tissues. Examples of ALS inhibitors in forestry include glyphosate, imazapyr and sulfometuron methyl. ALS inhibitors mainly occur as water soluble amines. Ester formulations do not exist and volatility is not an issue.

ALS inhibitors can have foliar and soil activity. Glyphosate is strictly foliar active, imazapyr has both strong foliar and soil activity and sulfometuron methyl is strictly soil active. The three have a mixed range of conifer tolerance as well. Glyphosate may be applied over the top of seedlings that have been established for one year after bud set in the late summer or as a pre-plant application. Applications made over the top of seedlings during the active growing season will cause significant damage or mortality. Release applications with imazapyr in California with a few exceptions are not possible due to very low conifer tolerance both from foliar and soil uptake. Even pre-plant site preparation treatments the year prior to planting may see significant conifer injury from soil uptake. Imazapyr has mainly found a fit in forestry applications in California as a pre-harvest treatment prior to logging that will be discussed further in this text. Sulfometuron methyl may be applied as a pre or post plant application on the Coast over redwood seedlings in California, but in the interior parts of the state with a drier climate, significant root suppression, top stunting, or even mortality occurs in conifers. This is mainly due to the inhibition of root growth and as a result, seedlings are not able to capture available soil moisture.

Photosynthesis Inhibitors

The triazine herbicides which include hexazinone and atrazine control plants by inhibiting the Hill reaction which in turn inhibits photosynthesis. Both hexazinone and atrazine are soil active herbicides which are absorbed by plant roots and require rainfall to activate. Atrazine is primarily a pre-emergent herbicide. Once grass and herbaceous broadleaves grow to over three or four inches tall, efficacy is reduced. Hexazinone is a more powerful herbicide and can be applied as a pre or post emergent herbicide, and has some activity on woody brush, which atrazine does not. Conifer tolerance with atrazine is excellent. Applications can be made pre or post plant to any of the conifers native to california. Hexazinone on the other hand has very good tolerance on ponderosa pine, but moderate to no tolerance on other conifers native to California.

Protoporphyrinogen Oxidase Inhibitors (PPO) Inhibitors

PPO inhibition is a new mode of action to California forestry. PPO inhibitors prevent plants from making the enzyme protoporphyrinogen oxidase which results in the destruction of cell membranes. They kill through lipid peroxidation, which is the process in which free radicals take electrons from the lipids in cell membranes causing the destruction of the membrane. The only PPO inhibitor currently registered in California is a component of Dow Agrosciences' product Cleantraxx. Cleantraxx is a combination of two different active ingredients and two different modes of action. The product contains the active ingredients oxyfluorfen, a PPO inhibitor, and penoxsulam which is an ALS inhibitor. ALS inhibitors have already been explained.

The two active ingredients work well together. Oxyfluorfen and penoxsulam have both soil and foliar activity. Oxyfluorfen controls herbaceous broadleaves and annual grasses only. Penoxsulam is a relatively new active ingredient and the list of plants controlled is still being determined, but it appears to have some activity on herbaceous broad leaved plants and weaker activity on woody brush. It does however, inhibit the germination of several woody brush species from seed. The product works best as a pre-emergent application, but does have some selective knockdown of existing vegetation as a post-emergent application. Conifer tolerance is excellent as a pre or post emergent application on all conifers tested in the northwest.

Cellulose Biosynthase Inhibitors (CBI's)

A recently new mode of action is about to enter into the forestry market as the active ingredient indaziflam. Indaziflam is a cellulose biosynthase inhibitor. It controls plants by inhibiting cellulose synthesis, inhibiting germination and root development. Indaziflam is primarily soil active, but does have minor foliar activity. The best fit with indaziflam is with pre-emergent applications. If vegetation is already existing on site, another product must be added to achieve knock down.

It mainly controls annual grasses and herbaceous broad leaved plants. It does not have any activity on woody brush at all. Conifer tolerance is very high, even on western larch, sugar pine and redwood seedlings which are the most herbicide intolerant conifers in the western United States. Conifer safety is maximized with pre-plant applications. No products with indaziflam are currently registered for forestry use in California.

Differences Between Soil and Foliar Active Herbicides

There are several differences foresters should be aware of regarding the mechanism of uptake that a herbicide has. Soil active products are taken up by the roots and require rain to activate. Foliar active products are taken up through the leaves and in some cases stem tissue. Products with soil activity tend to have longer residual control because they are more persistent and have longer half lives in the environment than foliar active products. Some soil active herbicides like hexazinone tend to be very mobile in the soil whereas, others such as atrazine and oxyfluorfen are much less so. Foliar active herbicides are generally not mobile in the soil. It is possible for a herbicide to have both foliar and soil activity, such as imazapyr which has very strong activity for both.

Soil active herbicides are heavily influenced by soil type, texture and percent organic matter. Those that have a high affinity to adsorb to soil particles are less available for plants to uptake and can negatively affect control. Adsorption to soil particles is measured by the soil adsorption coefficient, or Koc. The higher the Koc, the more that soil adsorbs to soil particles and the less mobile it may be in the environment. This measurement in combination with the solubility (S) of the herbicide can give some indication of the potential mobility of a herbicide in the environment. Highly soluble herbicides are generally more mobile. However, mobility in the environment is heavily influenced by the forest soil. Herbicides in clays or clay loams are generally less mobile than in loamy sands or sands (Dreistadt 2013), as they are in high organic matter soils. Several of the soil active herbicides such as hexazinone strongly adsorb to organic matter hindering plant uptake (Neary, Bush & Douglas 1983). Just because a herbicide has a high Koc or solubility doesn't necessarily mean that it is going to be mobile on any given soil. Results are highly variable in the field. In addition, slope also can have a major influence on mobility.

Non-Synthetic Herbicides

A brief mention will be given to what is referred to as non-synthetic herbicides. These are naturally occurring materials occasionally used for weed control, mostly in organic agricultural programs. They include such compounds as acetic acid (vinegar), citric acid, clove oil, cinnamon oil and corn gluten meal. These compounds are desiccants that accelerate the drying of plant tissue. The herbicidal symptoms they produce are limited to desiccating above ground plant tissue. They do not control the root systems of plants or translocate as true herbicides do.

These material have in some cases controlled very small, freshly germinated herbaceous seedlings. They will not control brush or mature herbaceous vegetation adequately. Plants not killed by these treatments recover rapidly after initial symptoms appear (Chandran 2009, Evans & Bellinder 2009, Moran & Greenberg 2006, Chase et al. 2004, Brevis et al. 2004, Corran et al. 2005, Owen 2002). These types of treatments are completely inadequate for forestry use. It should also be noted that in California, these materials are considered herbicides and need to be registered for use as such by the California Department of Pesticide Regulation. Acetic acid is not on the 25b exempt list of California or the U.S. EPA. However, the other active ingredients such as citric acid, clove and cinnamon oil and corn gluten meal are exempt and do not require registration (unless exceeding concentrations of 8.5% in California). They are considered pesticides in that a licensed pest control business is required to apply them in California but are exempt from reporting and from registration.

Herbicide Behavior in the Environment

Herbicide behavior in the environment is dependent on many things. Degradation rates, solubility, soil sorption capacity, climate, soil type, organic matter, etc, can all play a role in how a herbicide behaves. Potential negative effects of herbicides are easily mitigated. Today's herbicides have very high margins of safety regarding toxicity as well. Knowing how herbicides behave and understanding their toxicology will significantly add to your skill set.

Degradation

Herbicides are broken down in the environment in several ways. The main method of breakdown is microbial (Dreistadt 2013). Microorganisms in the soil rapidly break down most herbicides and in some cases soil arthropods actually utilize them as a food source (Busse, Rapaport & Powers 2000). The second method of breakdown is photolysis, breakdown from light. Not all herbicides photo-degrade. Herbicide breakdown in water is mainly through photolysis and in most cases is fairly rapid (Rhodes 1980).

The length of times it takes a herbicide to break down is denoted by the half-life, the time it takes for 50 percent of the active ingredient to break down in the environment (Dreistadt 2013). Half-lives can range anywhere from a couple of days to six months or more depending on the product, the environment and microbial population. Typically soil active herbicides have the longest half-lives as they are designed to last longer to provide lasting residual control.

Mobility

How mobile herbicides are in forest soils depends on the inherent properties of the herbicide and the environment. Mobility in the soil is influenced by solubility, degradation rate, ability to adsorb to soil particles, soil texture and type, pH, organic matter, slope and precipitation (Beaudry 1990, Neary, Bush &

Douglas 1983). Sandy well drained soils are the most prone to herbicide leaching, and clays are the least. Foliar active products pose little risk from leaching due to very rapid degradation rates. Soil active herbicides are more prone to movement depending on the product. It is important to realize that mobility is strongly influenced by site and that all sites are different. Looking at one or two lab derived indicators of mobility may not give an accurate depiction of what may occur under field conditions.

Toxicity

Herbicides have to pass through over 150 tests to even be considered for federal registration. California has its own testing requirements in addition to the federal ones. Every herbicide's toxicity is carefully evaluated for being a potential harm to human, animal, insect and aquatic life. Toxicity is evaluated for both acute (short-term exposure) and chronic (long-term exposure) hazards. Toxicity information can be found on each product's safety data sheet (SDS). Some of the data collected includes testing for carcinogenicity, teratogenicity, mutagenicity, reproductive effects, endocrine disruption, eye and skin hazards, etc.

Measures of toxicity are usually expressed in milligrams of active ingredient per kilogram of body weight. LC-50 and LD-50 are two frequently used terms that define the toxicity of an active ingredient. LC-50 is the lethal concentration in water required to kill 50 percent of a certain aquatic population of organism, and LD-50 is the lethal concentration required to kill 50 percent of a terrestrial organism (Table 8.2). Another useful term to know is the NOEL. This is the "no observable effect level", defined as the highest concentration of pesticide that did not produce any negative health effects. When used at labeled rates, today's herbicides pose little threat to the environment.

Table 8.2 Relative toxicities of forestry herbicides compared to several common chemicals.

Active Ingredient	LD-50 mg/kg Oral Rat	Source
2,4-D ester	1380	Weedone LV-6 MSDS
aminopyralid	>5000	Milestone MSDS
aspirin	200	aspirin MSDS
atrazine	>2000	Atrazine 4L MSDS
caffeine	192	caffeine MSDS
clopyralid	>5000	Transline MSDS
fluroxypyr	>5000	Vista XRT MSDS
glyphosate	>5000	Accord XRT II MSDS
hexazinone	1310	Velpar DF MSDS
imazapyr	>5000	Polaris AC MSDS
nicotine	50	nicotine MSDS
oxyfluorfen	>5000	GoalTender MSDS
penoxsulam	>5000	Sapphire MSDS
salt	3000	salt MSDS
sulfometuron-methyl	>5000	Oust XP MSDS
triclopyr ester	2966	Forestry Garlon XRT MSDS
vitamin D	42	vitamin D MSDS

Source: MSDS – Material Safety Data Sheets with the official chemical hazard information

Resource Protection Measures for Chemical Methods

There are many resources and sensitive areas that as a land-manager you may wish to remain pesticide free. Protection of these areas is a relatively simple task, and there are a variety of methods that can be used to protect resources, wildlife and property. One of the most valuable documents you should have in your management plan is a list of your company's mitigation measures regarding pesticide applications. Documenting what you do in practice is a necessity, both from a best management practice (BMP) and liability standpoint.

Buffers

Buffers are a designated distance or area of land designed to protect resources, people or property from contact with pesticides. It does not necessarily mean a pesticide free zone. The goal of buffers is to protect an area of concern. A 100 foot buffer, for example, may be used to protect a stream course. The applicator may stop spraying at 100 feet allowing some residue to drift into the buffer zone, but the stream course would still remain pesticide free. There is a major difference between a buffer and a pesticide free zone.

Buffers are the simplest way to protect areas of concern (Figure 8.1).

Figure 8.1 Aerial buffer along a streamcourse. Photo courtesy of John Mateski, Western Helicopter.

In general, aerial buffers tend to be larger than buffers for ground applications, and buffer size can differ between foliar and soil active chemicals. Soil active herbicides generally have larger buffers than foliar active products because soil active herbicides can move in the soil profile but foliar active products cannot. For soil active herbicides, buffer size tends to range between 50 and 150 feet for aerial applications and 50 to 100 feet for ground applications. Foliar active buffers can range from 25 to 100 feet for aerials applications and as close as ten feet or less for ground applications. These distance examples are just to give an idea of what has been used as part of industry BMP's in the past. Buffer size may be more or less depending on the land owner's practices unless it is specified on the product label.

Drift Mitigation

Drift is one of the main areas of concern regarding pesticide applications. There are many ways to mitigate drift and this is where it helps to first have your mitigation measures identified in a written plan. This plan will not only help foresters in the field but can also serve as a living document in legal matters.

Drop size has a major effect on drift. Volume median diameter (VMD) is the drop size where 50 percent of the spray volume is in droplet sizes less than the VMD and 50 percent of the spray volume is in droplet sizes larger than the VMD. As VMD decreases, the percentage of small spray droplets increases. Drop sizes less than 154µm are most prone drift (Yates, Cowden & Akesson 1985, Barry 1984). By minimizing this part of the droplet spectrum, drift can be substantially reduced.

There are many different ways to minimize the number of fine drops. As discussed earlier, nozzle size, nozzle angle, air or ground speed, pressure, boom length and humidity can all affect drop size. Nozzle orifice size is the most obvious way to manipulate drop size. The larger the nozzle orifice, the larger the VMD, and hence fewer small drops prone to drift. It is very important to know what nozzle systems your spray applicators are using and what drop size range they produce. Nozzle angle has a major effect on drop size. Nozzles angled straight back (zero degrees) on an aerial spray boom produced a VMD roughly double that of nozzles angled back at 45 degrees in wind tunnel tests which were used to simulate conditions under aerial applications (Yates, Cowden & Akesson 1985).

Increasing air or ground speed increases the number of fine drops due to increased shear of the spray solution at the nozzle. Increases in pressure will have a similar effect. As pressure is increased, fracturing of the spray solution increases, producing more fine drops. Boom lengths limited to three quarters of the rotor length for helicopter applications will also reduce the number of fine drops by reducing rotor wash at the ends of the spray swath. Making applications in higher humidity ranges that reduce the amount of droplet evaporation during flight, will also reduce the amount of smaller drops (Barry 1984).

One of the most important features on modern helicopter boom systems is the advent of the split boom (Figure 8.2). Split boom applications allow for half the boom to be shut off during application. The result is the part of the swath directly under the body of the helicopter in the center of the boom is free from rotor wash. The result is a spray pattern that falls virtually straight down (Figure 8.3). Buffer strips can be flown with the working half of the boom on the opposite side of the area of concern so that any rotor wash is concentrated on the side of the helicopter furthest away from the protected area.

Figure 8.2 Example of a split boom application. Photo courtesy of John Mateski, Western Helicopter.

Figure 8.3 An example of the precision that is achievable with aerial applications. Photo courtesy of John Mateski, Western Helicopter.

Drift control agents can also be added to the spray solution to reduce drift by increasing the formulation VMD's. Drift control agents reduce the number of fine droplets primarily by increasing the surface tension of the spray solution (Sparks et al. 1988). Spray additives are usually cost effective and cheap to reduce drift, however, conifer tolerance can also be affected (Fredrickson 1994).

Weather Guidelines

To insure safe and effective pesticide applications, it is critical to have a clearly defined set of weather guidelines. Limits on wind speed, temperature, humidity, precipitation and avoidance of inversions should be clearly addressed. Field foresters managing spray projects should also have forms in the field to document the actual conditions that were occurring at the time of application. Portable hand held weather gauges should also be available to accurately document the weather conditions on site. It should also be noted that weather can also be used to mitigate potential concerns. Spraying when light winds are blowing away from areas of concern is one example.

Project Layout and Planning

Too much emphasis can not be placed on the importance of proper project layout and planning to mitigate any potential issues. After the spray plans have been developed for any given area, detailed reconnaissance of the spray areas need to be completed on the ground. Foresters should be looking for any areas of concern such as water courses, springs, wells, property lines, ditches, residences, or other issues that may require protection.

All heliports, water sources and batching areas should be identified and mapped ahead of time. All roads should be driven and checked for hazards prior to the start of the project. Detailed contract maps need to be made that include the spray units along with all water courses, lakes, ponds, heliports, roads, batching areas, property lines, heliports and anything else relevant to the project. The contract needs to have strict guidelines regarding weather and spraying conditions, chemical handling and storage, production rates, safety and record keeping responsibilities. Detailed unit prescriptions regarding pesticide products and rates to be used need to be provided in writing. One of the most important safety mitigation measures is to have a written spill plan and spill kit in case of emergency that clearly defines procedures, personal protective equipment and contact information needed in the event of a spill.

Developing a field packet for both the forester on the ground and the spray applicator insures that everyone has all of the pertinent information they will need to complete the project safely and effectively. Field packets should include a copy of the contract, unit maps, spray recommendations and prescriptions, restricted materials permits and site identification numbers, pesticide labels and material safety data sheets, a copy of the spill plan, any necessary permits and weather and application summary forms.

Weather and application records with all pertinent pesticide use data and conditions should be kept daily. Foresters also need to be sure to read and follow all label directions for any pesticide products they are using.

The final and perhaps most important mitigation measure is to physically show the applicator or pilot the units to be sprayed and any areas within that need protection. Do not rely on word of mouth or pictures on a map to convey the message. The liability is too great to not take the time make sure the applicator is fully aware of all sensitive areas and unit boundaries that need to be avoided. Having radio communication with the pilot will also help answer any questions during the application. Portable radios should be supplied to the forester, pilot and batch truck driver to further reduce any potential risks.

On board global positioning systems (GPS) are commonly used to refine targeted aerial application of herbicides so that sensitive areas and areas with desirable vegetation can be avoided. Aerial applicators that use GPS technology should be supplied with geographic information system (GIS) shape files that show the application area, all buffer zones and the heliports that are to be used for the job. Shape files help in the application process as they show on the map where the helicopter has applied material as the application occurs. This allows the pilot and the forester to review the application and correct skips before leaving the application site.

Chemical Site Preparation (Pre-planting) vs. Release Applications (Post-planting)

The type of application and chemical choices foresters will make is largely based on whether the needed treatments are pre-plant (site preparation) or post-plant (release). Once conifers are established on a site, chemical choices and application methods are much more limited due to conifer tolerance issues (Table 8.3).

Table 8.3 Conifer tolerance to forestry herbicides by activity type and season. * conifer tolerance to glyphosate is low until trees have set bud and hardened off in the late summer to fall. ** Hexazinone tolerance varies by conifer species. See Table 8.4

Active Ingredient	Soil Active Conifer Tolerance	Foliar Active Conifer Tolerance	Timing of Highest Tolerance
2,4-D ester	n/a	low	dormant season
aminopyralid	moderate	low	spring/fall
atrazine	high	high	spring/fall
clopyralid	high	high	spring/fall
fluroxypyr	n/a	low/mod	dormant season
glyphosate	n/a	* low/high	post bud set in the fall
hexazinone	** moderate	moderate	spring/fall
imazapyr	low	very low	pre-harvest
oxyfluorfen	high	high	spring/fall
penoxsulam	high	high	spring/fall
sulfometuron-methyl	low/moderate	low/moderate	spring/fall Coast only
triclopyr ester	n/a	low	dormant season

The most effective and efficient vegetation control is usually achieved through good chemical site preparation. The cost of release treatments on a per acre basis is generally much higher than pre planting treatments and the effective control is often lower.

Site Preparation

Chemical site preparation occurs prior to or immediately after planting of any conifer seedlings to assure plantation establishment. These treatments are initially used to control any vegetation that would prevent initial seedling establishment. Site preparation treatments may be applied by air or by ground and may be done prior to, or after logging operations occur. Any vegetation management that is done after the seedlings have been successfully established is considered release.

Pre-Harvest Site Preparation

One of the most effective and efficient methods of forest weed control is pre-harvest site preparation. This method was adapted from mid-rotation release treatments in the southeastern United States and from vegetation management research conducted on bear clover with glyphosate in the northern Sierra Nevada Range in California (Fredrickson 1994, Jackson & Lemon 1986). The process involves treating the most difficult to control woody brush species such as tan oak, golden chinquapin, snowbrush, whitethorn, etc, at least one year prior to logging as an under-story treatment in the stand to be harvested.

There are many benefits from a pre-harvest site preparation system.. The choice of chemical at this stage of the reforestation effort is basically open to any product registered in forestry for site preparation, as conifer tolerance is not an issue. A useful online reference document for the different herbicides described in this chapter is the 'Weed Control Methods Handbook' (Tu, et al. 2001). The primary herbicide used in forestry applications is imazapyr due to its unparalleled efficacy on difficult to control brush. Since imazapyr has conifer tolerance issues from both its foliar and soil activity, it is well suited for pre-harvest application where it will not damage young conifer trees. Prior to the registration of imazapyr in California and the development of pre-harvest applications, no herbicide registered could completely control any of the most difficult woody brush species mentioned above. Treatments with glyphosate, triclopyr, 2,4-D and hexazinone would cause initial brownout, but would not completely kill the root system. Rapid re-sprouting would occur and the need for re-treatments was necessary Fredrickson (2004) showed that units that were pre-treated with imazapyr saved on the average of $200 per acre due to a decrease in release treatment need over the first ten years of plantation establishment compared to non-pre-treated units and units that had been pre-treated with herbicides other than imazapyr.

The registration of imazapyr in California in both the original water soluble (Arsenal AC) and oil soluble (Chopper) formulations provided new tools that could completely control the most difficult to control species. Since imazapyr will also kill conifer seedlings, it can not be sprayed over seedlings. Post planting release treatments are also not possible due to soil uptake of the long lasting imazapyr in most soils in California. Post-logging site preparation applications made the year prior to planting can still cause significant damage from soil uptake in planted seedlings. Even worse damage can occur from foliar contact. Therefore the only practical application timing is pre-harvest.

Pre-harvest applications can be made with other herbicides as well depending on the type of vegetation present. For example, if under-story vegetation is dominated by manzanita or squaw carpet, 2,4-D or fluroxypyr applications would suffice. For heavy deerbrush or snowberry populations, glyphosate could be used. The use of imazapyr broadens the spectrum of control so much and so effectively that it is a rare occurrence for it not to be part of the prescription alone or in combination with other products. Tank mixes with imazapyr, glyphosate and a methylated seed oil greatly broaden the control spectrum and are commonly used in pre-harvest site preparation applications with very good results. When using imazapyr, the oil soluble formulation should be used for evergreen brush in combination with a methylated seed oil. The water soluble formulation does not work well on evergreen brush, but can be used for hack and squirt treatments or for foliar treatment on deciduous brush.

Two predominant application methods can be used with pre-harvest applications. Some method of foliar treatment is typically used to control smaller woody brush. Hack and squirt treatments involve the injection of an active herbicide into a fresh cut and are used to control large woody brush, and sprouting hardwood clumps or hardwood trees. The timing of foliar applications should be during the late spring to late summer when deciduous woody is fully leafed out and the maximum amount of vegetation has germinated on the site. Hack and squirt applications can be done almost year round, with the exception of the spring sap-flow period.

Foliar treatments with pre-harvest applications can be applied as broadcast treatments, directed treatments or a combination of both. Broadcast applications can be applied using the waving wand method with gun-jets, OC nozzles or adjustable tips depending on the size and density of the under-story vegetation. Gun-jet or adjustable tip applications are ideal when the brush is small and the under-story is open and free of obstruction from sub-merchantable conifers or large brush. OC nozzle broadcast applications can occur in denser brush and usually provide better coverage. When there is too much interception from conifers, large brush or the under-story is comprised of the more difficult to control woody brush species, directed spray applications with flat fan nozzles are usually the best choice. Most of the time some sort of hybrid broadcast and directed application occurs where the crew can broadcast apply where the stands are open and the brush is small, and then treat larger brush in a directed fashion as it is encountered. In these circumstances usually OC or flat fan nozzles are appropriate.

When stands have a large component of hardwood trees, sprouts or saplings, hack and squirt treatments are usually required on top of any foliar treatment. Hack and squirt applications in a pre-harvest situation are much more efficient and effective than treating re-sprouting hardwood clumps after logging. Issues with conifer tolerance are also avoided. Depending on the density of hardwoods in the stand, crews can either apply the foliar treatments first and then go back through with the hack and squirt treatment, or if there are not many hardwoods several people on the crew could be designated to hack and squirt while the others do the foliar application.

Figure 8.4 A typical forestry hack and squirt set up.

Figure 8.5 Hacks should be spaced evenly around the circumference of the tree and hacked deep enough to penetrate through the bark to the cambium.

A complicating factor with pre-harvest applications is the logistics surrounding the harvest plan completion, logging schedule and accessibility. In California, the Timber Harvest Plan approval process and all botanical surveys must be completed prior to treatment. Unit boundaries, stream courses, exclusion areas and property lines must all be marked as well. In many cases, new roads have not been built or road reconstruction has not occurred yet. Crews may have to walk or use an ORV to gain access where roads are not available, or in some cases, it may not be possible to pre-treat some units. The treatment schedule needs to consider all of these variables to be as efficient as possible. The treatment schedule may also need to change in the common situation when the logging plan changes. Once a harvest plan is completed and ready for treatment, it is best to treat all of the units in the same year. Trying to just treat units that will be logged the following year, may result in a change of logging plans that leaves the forester with logged units that were untreated.

Although there are many logistical issues to deal with, the benefits of pre-harvest site preparation are many. The long-term reduction in release treatments also means a reduction in overall chemical use while maximizing the amount of vegetation control. A secondary benefit is a reduction in the amount of chemical needed for herbaceous site preparation treatments prior to planting. Prior to the use of pre-harvest treatments, hexazinone was often used for site prep at rates of 2.5 to 3.0 pounds active ingredient per acre as some woody brush could be controlled along with the herbaceous vegetation at those rates. Since the woody brush is already controlled by the pre-harvest treatments, the following hexazinone rates may be significantly reduced as the herbaceous vegetation is the only target and is easier to control. Another unique benefit from the applications is in regard to fall planting. Since all of the vegetation in the unit is already treated, available soil moisture is significantly improved after logging since the units sit fallow through the summer free of trees and vegetation that would otherwise remove available soil moisture. This allows for fall planting to occur earlier and with more water available for planted seedlings (Fredrickson 2002). The need for mechanical site preparation (piling) is often times reduced or removed all together. Treated brush in the under-story has a full season to die and becomes brittle by the time logging operations occur. Often times the disturbance from the heavy logging equipment is enough to crush the existing brush, making the site plantable without any further mechanical site preparation needs.

Post Harvest Site Preparation

Prior to the advent of the pre-harvest site preparation applications, post-harvest treatments were much more common than they are today. The disadvantage of treating brush after harvest operations have occurred is that the majority of plants that survived logging are damaged and do not translocate the herbicide as effectively causing reductions in control (Newton & Knight 1981). The other problem relates to woody brush that has re-sprouted from existing root stocks. In this case, there is rarely enough leaf area after logging to be able to absorb enough chemical to translocate to the existing root system. Usually two to three years of re-growth is required to match the leaf area above ground with the root system below ground to obtain good control. Most often by the time the new seedlings are to be planted, not enough time has elapsed from logging disturbance for brush to recover or achieve the ideal size for treatment.

A different challenge for post-harvest woody brush site preparation occurs after wildfires. Often times woody brush germination is promoted by fire. Seedling populations can be dense and intermingled with surviving damaged brush or woody brush that has re-sprouted from previously existing root systems. In these instances, foresters have no option but to deal with woody brush post-harvest.

If post-harvest site preparation applications must occur, it is usually best to let damaged or re-sprouting brush to recover prior to treatment. Treating brush prior to it achieving adequate leaf area will most likely result in re-sprouting and the need for repeat treatments. The downside of waiting is losing a year or more on the rotation of the new stand. In situations where woody brush germination is primarily from seed, it is most cost effective to treat immediately after germination occurs. Treating seedling woody brush when it is small is magnitudes more cost effective and efficacious than waiting until brush gets larger. With some species on some sites, treatment prior to germination with a soil active herbicide may also be effective.

Whether or not woody brush has been controlled pre or post-harvest, some type of treatment to control herbaceous vegetation prior to planting is also required. The competitive ability of herbaceous vegetation on seedling survival and growth has been well documented (Rose & Ketchum 2002, White, Witherspoon-Joos & Newton 1990, White & Newton 1989, Peterson, Newton & Zedeker 1988, Newton & Preest 1988). Even in the wetter climates of western Oregon Douglas-fir seedlings experienced a 217 percent gain in volume when herbaceous vegetation was controlled over the first three years. Vegetation control on drier sites has been shown to triple volume growth of ponderosa pine (Powers & Reynolds 1999).

Post-harvest site preparation treatments can be applied by either air or hand. Aerial applications are applied broadcast. Suitability of aerial applications on brush is dependent on the type and size of brush. Usually evergreen species of woody brush are controlled more effectively with hand applications. Imazapyr treatments by air are highly effective on evergreen brush, but they should not be applied the year prior to planting due to potential conifer damage from soil uptake of Imazapyr. Treatments applied earlier than that should have no residual effect on conifers. Site preparation application by air over species such as deer brush or snow berry with glyphosate can be highly effective as can 2,4-D over smaller manzanita. When dealing with seedling woody brush, the smaller the plants, the more efficacious the treatment will be. Larger or re-sprouting brush from root stocks would probably be more suited to hand treatments.

Site preparation treatments on woody brush by hand can be applied by either broadcast or directed methods, depending on the size and species of brush. Similar to the aerial applications, broadcast treatments for brush by hand should focus on the easier to control species such as deer brush, snow berry or manzanita. The more difficult to control evergreen brush or hardwood sprout clumps should most likely have a directed hand spray treatment unless imazapyr is used more than one year prior to planting. Hardwood sprout clumps should also be treated with a directed hand spray or basal treatment depending on the species.

Herbaceous treatments either by air or by hand should be applied with a broadcast method. Soil active herbicides are used for broadcast herbaceous treatments almost exclusively. Occasionally glyphosate can be used in a post-emergent setting, but this is not the preferred treatment as it does not provide any soil residual. Soil active herbicides are dependent on rain to activate and the timing of application is critical to maximize the chances of getting the correct amount. Too much or too little rain can severely impact efficacy. Usually between three and twenty inches of rain is ideal for soil active products. The timing of application depends on seasonal rainfall total, elevation, snow level, access and soil type. Low elevation units that receive a high seasonal rainfall total should be applied in the spring at a time when the forester thinks the necessary amount of rain can be achieved. High elevation units that receive mostly snow should be applied in the fall to assure adequate moisture is received. Access to these sites in the spring may be impossible due to snow until after the spring rains have ceased. Areas on the east side of the Cascade or Sierra Nevada Range should also be applied in the fall as the majority of these sites are in high elevation, low rainfall sites that may only receive 15 or 20 inches of precipitation annually. A general rule of thumb that may be utilized in most areas is units under 4000 feet elevation should be treated with residual herbicides in the spring and those over 4000 feet elevation should be treated in the fall.

When using soil active herbicides for pre-plant site preparation, it is extremely important to know what species of conifers are going to be planted on the treated site and what their tolerance is to the chemicals being used (Table 8.4). While hexazinone provides the best overall control of any of the soil active herbicides, Douglas-fir (*Pseudotsuga menziesii*), white fir (*abies concolor*), sugar pine (*Pinus lambertiana*), incense cedar (*Calocedrus decurrens*) and western larch (*Larix occidentalis*) are to some degree intolerant to hexazinone. Some tolerance issues can be mitigated through rate reductions for species such as Douglas-fir and white fir, while other species have almost no tolerance for it. The use of sulfometuron methyl in the interior parts of California and southwest Oregon can cause root growth inhibition in almost all conifer species. The only two soil active herbicides registered for use in California that have virtually no tolerance issues are atrazine and oxyfluorfen plus penoxsulam.

Table 8.4 Tolerance of commercial conifers for the main soil active herbicides used in site preparation. * Douglas-fir tolerance to sulfometuron-methyl is low in the interior parts of California and moderate on the Coast.

Conifer Species	Hexazinone	Atrazine	Sulfometuron Methyl	Oxyfluorfen + Penoxsulam
ponderosa pine	high	high	low	high
Douglas-fir	moderate	high	* low/moderate	high
white fir	low	high	low	high
incense cedar	low	high	low	high
sugar pine	very low	high	low	high
red fir	moderate	high	low	high
redwood	very low	high	moderate	high

Overall, site preparation applications have the most flexibility of any chemical treatments due to the lack of conifer seedlings and tolerance issues. The best money a forester can spend is on good site preparation. Controlling competing vegetation correctly from the start will save numerous applications, reduce overall herbicide use, increase survival and growth, reduce applicator exposure, and save thousands of dollars for the land owner. Remember this quote from Professor Emeritus Michael Newton of Oregon State University. "If you have a large release program, you're probably screwing up."

Release Applications

Weed control treatments after seedlings have been successfully established are referred to as release treatments. The trees are being released from the competitive effects of vegetation. These treatments can be the most expensive investment of any reforestation effort. Chemical choices are limited due to conifer tolerance issues and many of the treatments must be applied by hand (Table 8.4). Often times certain woody brush species cannot be effectively controlled because the ideal herbicides are not available for release.

Release treatments are most beneficial early in a plantations life. Delaying release treatments increases costs as well as diminishes the growth response of crop trees (Fiddler & McDonald 1999, Newton & Knight 1981). Significant increases in survival, stem diameter, height and volume have been well documented for herbicide release treatments in California (Fiddler, McDonald & Mori 2000, McDonald & Fiddler 1999, McDonald & Everest 1996). While some type of release treatment during plantation establishment is usually required, a truly successful reforestation program will minimize release needs as much as possible through good site preparation.

Chemical release has several advantages over other methods of release such as mechanical or manual methods. Effectiveness and cost are the major advantages, but chemical release treatments also have the least impact on the forest soil in terms of generating erosion or new infestations of weed species that require disturbance to germinate (Newton & Knight 1981).

Aerial Release Applications

Aerial release applications are the most cost effective method of release, but they are also the most limited. They are limited due to conifer tolerance issues with over the top applications. Soil active herbicides including atrazine and oxyfluorfen plus penoxsulam can be applied over the top of all conifers, but options with hexazinone and sulfometuron methyl are more limited. Surfactants are not usually needed with soil active products but should be avoided in most cases because they can reduce conifer tolerance. The exceptions to this are with atrazine or oxyfluorfen plus penoxsulam.

Not all herbicides are registered or have conifer tolerance for applications over the top of planted conifers. Two of the more common ones that do are clopyralid and glyphosate. With glyphosate applications, timing is the most critical factor to avoid conifer injury. Broadcast applications must be applied in the late summer or early fall after conifer seedlings have set bud and hardened off for the year. Application made earlier than that will result in conifer injury or death. Applications over the top of newly planted conifers with glyphosate products is not advisable and restricted on most labels.

The type of glyphosate product applied is also critical. Most formulations of glyphosate do not have an aerial release label approved for over the top applications. Rodeo is a non-surfactant formulation of glyphosate that is labeled for aerial release treatments. Since no surfactant is formulated into the product, one must be added to achieve adequate efficacy on the vegetation. Additional care must be taken in choosing an adjuvant. Most surfactants or adjuvants will increase conifer injury when added to a glyphosate formulation. Historically, only tallow-amine surfactants have had enough conifer tolerance to be safely added or formulated into glyphosate formulations. Currently Penetron is the only tallow-amine surfactant labeled in California for aerial release treatments with glyphosate. Other types of adjuvants such as drift control additives, acidifiers or oils can also increase the risk of conifer injury. With the large number of generic formulations of glyphosate, care must be taken to insure the product chosen is labeled for aerial release.

The species of vegetation that may be controlled with aerial glyphosate release applications is also limited to those species previously mentioned. Herbaceous vegetation control with soil active products does not differ from what was discussed for aerial site preparation applications.

Hand Release Applications

When aerial applications cannot be used or foliar herbicide tolerance to conifers is an issue, treatments must be applied by hand. All hand application methods are available for release needs. Similar to aerial applications, broadcast hand treatments are limited to those herbicides which have conifer tolerance when applied over the top such as glyphosate in the fall or the soil active herbicides as previously mentioned.

If more difficult species are present, another application method must be utilized. Where species such as tan oak, snowbrush, golden chinquapin or live oak (*Quercus chrysolepis*) are present, foresters are faced with tougher challenges. Where these species would have been easily controlled with imazapyr in a pre-harvest application, conifer tolerance issues prevent it from being used in most areas for release. In this case, the forester must determine the most efficacious and cost effective method to use. Choosing the type of herbicide is to a large degree dictated by the type of vegetation that is in need of control. Identification of a complex series of weed pests that are present in the application area is important. For example, a unit the has predominantly manzanita, snowbrush and chinquapin, the best choice of a herbicide for a release treatment might be 2,4-D plus triclopyr in the fall. If that vegetative complex also included cherry and deerbrush, it may be more prudent to apply glyphosate with a methylated seed oil during the growing season. Application timing and chemical choice are in some instances different in separate regions of California. It is best to consult local foresters that are licensed pest control advisors in any given area.

For these difficult to control evergreen species, in some areas directed spray applications of growth regulator herbicides or a high concentration glyphosate treatment may be the best option, in other areas basal bark or spot-gun applications may be best.

When glyphosate became generic the price dropped significantly. Most glyphosate products were always labeled for high concentration directed spray applications in the five to ten percent solution range, but prior to going off patent it was cost prohibitive for anything but scattered black oak treatments. The cost savings of generic products allowed foresters to treat larger areas and more species with higher rates of glyphosate, usually in combination with a methylated seed oil. Glyphosate is one of the safest and shortest lasting herbicides in the environment. It is also non-mobile and poses little risk to fish or wildlife when applied according to the label. Therefore, these applications had many attracting qualities. Timing is critical with glyphosate applications. Treatments from late spring to mid-summer are most effective on evergreens such as snowbrush, whitethorn and manzanita. Treatments later in the season have proven to be less effective in September and ineffective after the onset of cold weather. Tan oak and golden chinquapin are only partially controlled with glyphosate. These glyphosate treatments can reduce the amount of re-sprouting that occurs with snowbrush and whitethorn compared to treatment with growth regulators. Early season glyphosate treatments also allow foresters to control any existing herbaceous vegetation with lower volumes and glyphosate rates.

The high concentration glyphosate treatments can provide a very broad spectrum of control, however there is a tradeoff. The amount of solution volume required to control the more difficult evergreen species can increase labor costs significantly. These are not the most efficient applications from a labor stand point. Applicators also need to be careful not to exceed maximum label rates. The other drawback is that the timing for the best efficacy occurs when the tree seedlings are actively growing and the most intolerant of the chemical. Seedling protection is required when these applications occur. Some type of shield plus a spray bottle filled with water to wash trees accidentally sprayed should be carried.

High concentration glyphosate treatments have a very good fit for re-sprouting black oak clumps provided they are not too large. Ten percent solutions of glyphosate will adequately control black oak clumps and are applied at extremely low volumes and highly cost effective. Clumps can usually be treated safely to a height of about five or six feet tall. Once they grow larger than that too much over-spray occurs that may potentially injure conifer seedlings. These treatments are not as effective on other deciduous hardwoods such as dogwood or big leaf maple. Lower concentration glyphosate applications should be used if the target vegetation is mainly comprised of herbaceous vegetation and deciduous woody brush other than hardwood sprouts. Seedling protection is still required.

Growth regulator herbicides such as triclopyr, 2,4-D and fluroxypyr can also be used for directed spray applications when there is evergreen woody brush present. Foliar applications with growth regulator products on deciduous brush are not recommended due to high rates of re-sprouting following application. Growth regulators provide excellent burn down of most all vegetation and completely control some woody evergreens such as manzanita and squaw carpet. Results on most woody evergreen species result in at least some re-sprouting. Repeat treatments may be necessary on species such as snowbrush, chinquapin, tan oak and whitethorn. Seedlings are also highly sensitive to triclopyr and 2,4-D, and slightly less so with fluroxypyr but seedling protection is required in all cases. Volatilization is also a concern and applying in temperatures over 75 degrees should not occur.

Where there is a mix of deciduous and evergreen woody brush, growth regulator herbicides should never be mixed with systemic products such as glyphosate or imazapyr. The growth regulators do so much damage to the translocating tissue in the deciduous plants that neither glyphosate or imazapyr can get where it needs to go to work in the plant. Deciduous plants will re-sprout much like when treated with growth regulators alone.

Spot-gun treatments with liquid hexazinone can provide a highly effective and efficient treatment if the brush is not heavy. Snowbrush is usually the primary target and is controlled very effectively. Spot-gun can also be used on other brush such as deer brush, whitethorn and manzanita. If cover is very heavy, directed applications with glyphosate or growth regulators may have to be used.

Basal bark or hack and squirt applications may be utilized on more difficult to control hardwood sprouts such as big leaf maple, dogwood or live oak. Their use depends on the efficacy in the region and the conifer tolerance of the species planted on site. In general, hack and squirt should not be used with imazapyr where ponderosa pine is planted. Damage may not appear immediately, but imazapyr flashback can show up several years after the application. Basal bark or high concentration glyphosate applications may be more appropriate. Without the use of imazapyr, controlling hardwood sprouts other than black oak is difficult.

Cut stump applications for release are rarely used in forestry due to cost, but may occasionally have a fit if the amount of saw work is light.

It may appear that achieving adequate control with release applications is difficult. It is possible, but definitely more difficult than controlling vegetation as a site preparation application. The presence of conifer seedlings severely limits management options compared to site preparation. It is not hard to see that by controlling the more difficult evergreen species effectively during site preparation, cost, chemical used, worker exposure and vegetative cover can all be reduced while enhancing conifer survival and growth.

Project Level Considerations Before Choosing a Chemical Control Method

Treatment Objectives

The first thing you need to determine is the species of vegetation you are trying to control. There is no magic bullet. In defining your objectives for the treatment, you need to evaluate the vegetation complex and determine which species are the greatest problems. The most efficacious method can then be determined. Many species are not controllable with aerial applications, some are limited to certain types of hand treatments, and for some, there may not be a suitable control technique at all. Your objective is to determine what the main treatment need is and to do the very best that you can.

Cost

Your budget will dictate much of what you can and can't do as far as application methods go. Aerial applications are the least cost option due to the amount of area that can be covered in a very short amount of time. Aerial forestry applications are mainly limited to helicopters due to the topography, but where large tracts of flat clean ground exist, fixed wing aircraft applications may be possible. Ground treatments with a tractor or other ground equipment are fairly cost effective, but also very limited in use due to topography, slash loads and stumps. In increasing order of cost, application methods range from fixed wing aircraft to helicopter, then to tractor or other type of ground machine, with hand applications usually being the most expensive.

Much of the cost of hand applications depends on the type of treatment that is being done. Directed (or spot) treatments where individual plants are specifically being treated are the most expensive. Broadcast applications by hand are very efficient and can in certain types of treatments rival helicopter costs. Familiarity with all the different types of application methods and their availability is critical. When conducting sprays by hand, having a crew that can apply them efficiently and effectively will often reduce application costs more than anything else you could do.

Effectiveness

The different application methods will have varying results compared to each other mainly due to differences in coverage. This is mainly true for foliar applications where coverage on leaf surfaces is critical. Coverage from aerial applications is not as consistent, or as thorough as coverage from hand applications. When foliar contact herbicides like glyphosate, imazapyr, triclopyr, fluroxypyr or 2,4-D are used, efficacy is usually best with hand treatments compared to aerial applications depending on the type of vegetation treated.

The type and size of vegetation will also determine how effective an application technique will be. As woody brush gets larger, it gets more difficult to control by aerial methods. Deerbrush (*Ceanothus integerrimus*) is fairly easy to control by air with glyphosate when it is small. If large deerbrush is treated by air, it may only top-kill plants and result in subsequent resprouting. Evergreen brush such as tan oak (*Lithocarpus densiflorus*), golden chinquapin (*Chrysolepis chrysophylla*) and snowbrush (*Ceanothus velutinus*) are very difficult to control with aerial methods depending on the type of herbicide used.

Coverage for soil active herbicides like hexazinone, sulfometuron, oxyfluorfen, penoxsulam and atrazine is less critical than foliar applied herbicides. Soil active products tend to spread in soil when in contact with moisture, and are much more forgiving if coverage is not complete. Application method makes much less of a difference with soil active products provided that the application is done correctly. The greatest risk with hand applications and soil active products are skips and proper calibration.

Conifer Tolerance

Herbicide choice and conifer tolerance will also dictate what application methods you can and can't use. Broadcast applications over the top of established seedlings by aerial or ground methods are not possible with herbicides that provide little conifer safety. In this case, directed hand treatments may be the only option. Time of season may also dictate when over the top applications can occur with certain herbicides like glyphosate. Conifers are tolerant to over the top applications of glyphosate in the fall, after buds have hardened off. If treatments occur prior to that, conifer damage or mortality will occur.

Scope of Project

What type of application method you use may depend on the size of project and availability of local applicators. Aerial applications are well suited for large projects. Helicopter applications can usually treat up to 300 or more acres per day. Hand crews trained to do efficient broadcast applications can treat between 100 and 150 acres per day. If directed hand spraying is required, production rates may drop down between 30 and 60 acres per day depending on the size and density of brush, access, etc. Scheduling out your project to make sure you complete your objectives is critical. You should have a production plan and make sure contractors are completing the required amount of acres per day, weather permitting.

Logistics

Logistical concerns may also influence the type of application method you use. Access is critical for ground spraying operations. Without good access, costs can rapidly get out of control. In this case, aerial applications may be more appropriate. To make aerial applications efficient, heliports, road access, water sources, staging and storage areas all must be available and in good condition for a successful program.

Liability Issues

With any spraying operation, there are potential liability concerns. The land manager's responsibility is to anticipate and mitigate these concerns and therefore minimize liability to the landowner and risks to the environment. The risk of liability can also dictate what type of application method you choose. If you are spraying close to adjacent dwellings, a critical analysis of application method should be conducted, and aerial applications should probably not be the method of choice. Ground applications are a good choice when spraying around areas with water, wells, domestic ditches, property lines or other areas where herbicide buffers need to be precisely applied. Many times a combination of hand and aerial treatments can be used, where hand treatments are applied around sensitive areas and aerial methods are used to treat the remaining areas. Aerial applications can be made very precisely, but alleviating concerns utilizing alternative methods can go a long way in gaining trust and ensuring future projects progress according to plan.

Site Specific Issues with Chemical Vegetation Control

Variables That May Affect Chemical Applications

There are many things to consider that may affect your chemical application, any one of which may negatively affect the outcome if not considered and planned for. Probably the most important physical influence on spray operations is the weather. Weather can influence everything from efficacy to drift. As a land manager, it is imperative to know the conditions to avoid to achieve a safe and successful application.

Temperature can influence applications in several ways. As temperatures increase, smaller spray particles are suspended in the air for longer periods of time and can drift away from the application site (Barry 1984). Generally, as temperatures increase, the risk of offsite movement increases. Herbicides that are volatile ester formulations are subject to increased volatilization rates as temperature increases and humidity decreases. Volatilization occurs when temperatures rise, turning the ester herbicide formulation from a liquid into a gas phase (Gratkowski & Stewart 1973). The gas phase of the herbicide maintains its phytotoxic properties and can move off the application site causing damage to desirable vegetation. Volatilization can be exacerbated on open rocky sites or sites with light colored soils with little ground cover. Application of these types of chemical during extended periods of hot, dry weather may be infeasible. The herbicide labels of volatile esters often restrict application if the temperature is in excess of 75 degrees or is expected to exceed 75 degrees immediately after application. Most herbicide formulations now are either low volatile esters or amines. Low volatile esters have the potential to volatilize and cause off-site movement of the herbicide under adverse conditions, but are less likely to do so than regular ester formulations. Volatilization with amine formulations of herbicides are negligible and are more suitable for use in areas or under conditions where volatilization would cause an adverse effect. New choline formulations of herbicides almost do not volatilize at all.

Humidity and wind also play an important role in spray applications. Spray drift increases as humidity decreases and winds increase (Gratkowski & Stewart 1973), and if spray particles move offsite, both the efficacy on onsite target vegetation and the potential damage to offsite vegetation can be greatly affected. Generally, winds less than five miles per hour are acceptable for aerial applications and winds should be less than ten miles per hour for ground applications.

Temperature inversions are frequently referred to on pesticide labels as a weather condition that prohibits herbicide application. In a temperature inversion, cold air is trapped under a layer of warmer air. This phenomenon typically occurs in valleys or basins during periods of calm winds. If an application is made during a temperature inversion, spray particles can get trapped in the inversion layer and move great distances horizontally. Spraying under these conditions should be avoided due to the high potential for off-site movement (Dreistadt 2013).

Rainfall can have an effect on spray applications. For foliar active products, rainfall too soon after application can wash the active ingredient off of plant surfaces before penetration occurs, thereby reducing efficacy. Several hours are usually required for adequate drying of herbicide residues on plant tissue, but this time can be reduced with the addition of a spray adjuvant that increases penetration into leaf surfaces.

Soil active herbicides require rain to activate, and in this case, rainfall is a necessary part of the equation for successful applications. Too much or too little rain can have a major effect on efficacy and possibly conifer tolerance.

Timing

One of the most overlooked factors that contribute to successful herbicide applications is timing. Target vegetation is more or less susceptible depending on the time of year, and different types of herbicides have different application windows as well. Woody deciduous brush is usually most susceptible in late summer to early fall with systemic herbicides (Cole & Newton 1989), whereas, woody evergreen brush is usually more susceptible in the late spring to early summer with either systemic or growth regulator products (Jackson & Lemon 1986, Paley & Radosevich 1984). Herbaceous vegetation has a small treatment window in the early spring for foliar active products, before senescence occurs in the early summer.

The timing window for soil active herbicides depends on soil moisture availability, as these products require rainfall to activate. The timing usually depends on elevation, geography and annual precipitation patterns (White, Witherspoon-Joos & Newton 1990). Ideally, soil active products in lower elevations are usually applied in the spring to avoid the bulk of the winter precipitation, whereas high elevation sites where snowfall is the predominant precipitation are usually treated in the fall. It is essential to understand how much precipitation is too much or too little and base the application timing on the period you think will come closest to receiving the proper amount.

For foliar herbicide applications that are applied over the top of existing conifers as a broadcast application, the proper timing depends on when the trees are hardened off and tolerant to the herbicide. Conifer tolerance to foliar herbicides is usually greatest in the late summer or fall after buds have hardened off (Radosevich et al. 1980). The least tolerant period is when trees are actively growing. Since soil active herbicides are usually applied in the late fall or early spring when trees are still dormant, most soil active products can be applied over the top of planted seedlings without foliar injury.

Soil Type

Soil type plays a major role in how soil active herbicides work. The active ingredient in many herbicides adsorbs to organic matter in forest soils. The higher the percent organic matter, the more active ingredient is tied up in the soil and unavailable for plant uptake. Soils with high organic matter contents may require higher rates of herbicide, or the organic content may be so high that soil active herbicides may not work at all (Johnson 1987).

Soil texture also plays an important role with soil active herbicides. Soil active herbicides are more mobile in porous well drained soils with higher sand content and less mobile in soils with higher clay contents (Johnson 1987). Soils that are well drained with low organic matter contents also carry a higher risk of conifer damage due to the herbicide being more available for plant uptake. Risk of leaching also increases as organic matter decreases and porosity increases. Land managers need to be particularly concerned on steep slopes with well drained soils when there are sensitive areas that are at risk from leaching.

Topography

Topography can also play a role in how herbicides behave and can affect the quality of application. Steep slopes are more prone to leaching, especially in well drained soils or rocky sites. They are also more hazardous for the applicator, with both ground and aerial applications. Steep slopes usually require slightly larger buffers to assure contamination of watercourses does not occur. Even aspect can play a role regarding efficacy. Under drought stress conditions, hot south facing slopes can stress plants to the point that herbicide uptake is negatively affected.

Herbicide Formulation

It is important to understand how the herbicide formulation itself can affect efficacy. The herbicides used in forest applications are either liquid, granular or dry flowable formulations soluble in water. Liquid formulations are either formulated as amines or esters. Esters are soluble in oil, amines are only soluble in water. Esters can penetrate thick waxy cuticle layers on leaf surfaces easier than amine formulations, and this is why esters tend to be more efficacious on difficult to control woody evergreen brush than amine formulations. There is a drawback however. Ester formulations have a higher vapor pressure than amines and will volatilize at higher temperatures. Amines may be used at higher temperatures, but efficacy may suffer. Amines have shown excellent efficacy on deciduous woody brush or herbaceous broadleaved plants and grasses. Amine efficacy on woody evergreen brush has improved since the advent of the methylated and ethylated seed oil adjuvants.

The dry formulations present somewhat of a different challenge. With granular products that are spread over the landscapes surface and rely on rainfall to activate, the only real concern is making sure the distribution of material through the application system is adequate for even coverage. When dry products such as dry flowables, wetable powders, etc are used, constant agitation during mixing and application is critical to achieve consistent rates when applied. Today's dry flowable formulations go into solution well compared to older formulations.

Spray Application Technology

Understanding the interactions between application variables such as drop size, volume, rate and adjuvant can be very complicated and varies greatly by active ingredient and species to be controlled. However, understanding the basic principles can greatly improve both the efficiency and efficacy of applications.

Drop Size

Drop size can influence several different aspects of spray applications. For foliar applications, the smaller the drop size the greater the surface area of spray solution available to contact plant surfaces. This does not necessarily mean an increase in efficacy, just more efficient coverage of plant surfaces (Fredrickson & Newton 1998). The tradeoff is smaller drops tend to drift. Large drops reduce drift significantly but coverage is negatively affected (Akesson, Yates & Wilce 1970). For soil active herbicides, drop size does not affect efficacy, so it would make sense to use larger drop sizes to reduce risk of offsite movement.

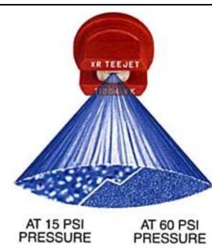
Several physical factors can influence drop size. Choice of nozzle size is the most obvious one. It is extremely important to know exactly what nozzles spray applicators are using for either ground or aerial applications. Your choice of nozzle will vary depending on the type of application you are doing. Certain applications may require smaller or larger droplets depending on the objective. The greatest liability with small drops is with aerial applications, and it is absolutely imperative that land managers are doing all they can to minimize the risk of offsite movement. Small drops should be avoided with aerial applications unless the risk of offsite movement is minimal.

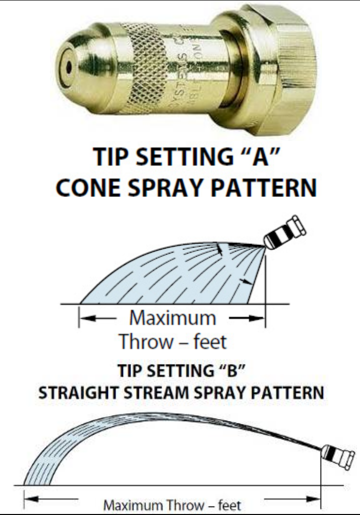
It is important to be aware of other factors that can reduce drop size. Pressure at the nozzle can affect drop size - as pressure at the nozzle increases, drop size decreases. Air or ground speed also affects drop size through shear at the nozzle. The faster the application equipment is moving, the smaller the drop size. Nozzle angle can influence drop size with aerial applications. Drop size is decreased as the nozzle angle increases from horizontal in the direction of travel. The greatest drop size is achieved with nozzles angled straight back, reducing nozzle shear (Yates, Cowden & Akesson 1985). For helicopter applications, boom length is a critical factor controlling drop size and spray deposition patterns. The shorter the boom relative to rotor length, the less rotor wash and liquid shear at the nozzle. As boom length increases, a significant vortex occurs from downward airflow created from the rotors, decreasing drop size.

Nozzle Characteristics

Since nozzle selection has the largest influence on drop size and drift, it is important to understand some basic nozzle characteristics (Table 8.5). Nozzle type will differ depending on the type of application. Selection of nozzles for aerial applications can be quite different from those used in ground treatments, although there can be some overlap depending on the application method.

Table 8.5 Common nozzle types used in forestry applications and their spray patterns.

Nozzle	Type	Pattern	Uses
11004	tapered flat fan		directed hand spraying, broadcast applications on a fixed boom.
8004	even flat fan		band applications
OC-12	off center		waving wand hand broadcast applications, roadside boom
D-6	disk		aerial broadcast, hand broadcast with a gun-jet, spot gun applications with a meter-jet

5500	adjustable tip		basal treatments, hardwood clump sprouts, waving wand hand broadcast applications

The most common nozzle used for hand directed spray treatments is the flat fan nozzle. Flat fan nozzles come in a wide range of sizes that produce anywhere from very small to very large drops. Flat fan nozzles are designated by a series of numbers. The first two or three numbers are the angle of the liquid that is emitted from the nozzle orifice. The last two numbers are the gallons per minute put out through the nozzle at a set pressure, usually 40 pounds per square inch (psi). An 8003 nozzle for example has a liquid spray angle of 80 degrees and each nozzle puts out a spray volume of 0.3 gallons per minute at 40 psi. The larger the last two numbers are, the greater the drop size. Flat fan nozzles are also made in two different spray patterns, tapered or even. Even flat fans maintain the same spray width from the center to the ends of the spray pattern. Tapered nozzles are widest in the center and get narrower at the ends of the spray patter to allow for overlap of the spray solution. Even flat fan nozzles are primarily used for banded applications in agriculture, whereas tapered nozzles are the main ones used in forestry. The specifications may vary somewhat depending on the nozzle manufacturer.

One of the most popular nozzles used for broadcast applications by ground in forestry is the off center (OC) nozzle. These nozzles produce a much different spray pattern than flat fan nozzles. The spray solution is emitted from one end of the nozzle and thrown out away from the applicator in an arcing pattern. This nozzle produces excellent coverage when the nozzle is attached to a hand held spray wand and waved side to side for broadcast applications. The nozzles are designated with two letters followed by a number. A popular off center nozzle used in forestry is an OC-12. The OC stands for "off center" and the number designates the gallons per minute emitted from one nozzle at 40 psi. In this case the 12 stands for 1.2 gallons per minute, whereas and OC-06 would emit 0.6 gallons per minute. Similar to flat fan nozzles, the larger the number, the larger the drop size.

Aerial applications in forestry primarily use some type of disk or disk core nozzle that relies on air speed and nozzle angle as well as orifice size to manipulate the spray pattern and drop size produced. Disk nozzles produce a spray pattern in the form of a stream, and when a disk core is added to the nozzle, the spray pattern produced is a cone. The cone pattern produced by disk core nozzles can either be hollow in the center or completely covered. This is the difference between a hollow or full cone nozzle. Many aerial applicators choose to apply pesticides without a core and just use the disk orifice to produce a stream from the nozzle. In this case, the applicator relies on air speed and nozzle angle to shear the stream and produce a desirable spray pattern. This significantly reduces drift by creating larger drop sizes, but coverage may be affected as well.

The most popular aerial nozzles for helicopter applications currently used are probably the D series disk nozzles. With these nozzles, the D stands for disk nozzle and the number refers to the nozzle orifice size. In this case, the number does not specifically correspond to a certain volume per minute, but to an increase in orifice diameter. A D-8 disk nozzle puts out significantly more volume and a larger drop size than a D-4 nozzle. It is important to realize that the drop size produced from the nozzle on the ground while not moving is going to be much greater than when attached to a boom at a certain angle and traveling at a relatively fast air speed. As air speed increases and the mounted nozzle angle from horizontal increases, drop size decreases. D Series nozzles are also the one nozzle that is used for both aerial and hand applications. They are the main nozzle chosen for broadcast hand applications when using the gun-jet application method.

This is just a brief explanation of how some of the more commonly used nozzles work. There are many nozzles to choose from and the designations may vary slightly, but they all work under the same general principals. The are also many specialty nozzles that may have some limited use in forestry. The importance here is to realize that the choice of nozzle can have a significant effect on the success or failure of an application. The volume, rate, efficacy, deposition and cost per acre can all be affected by nozzle choice. If a hand crew is applying herbicides and the crew members do not all have the same nozzles, application rates between applicators can vary dramatically. The same can be said for a helicopter boom that is not fitted with all the same nozzles. It is imperative to pay attention to these application parameters.

Application Volume

Changing the application volume per acre can affect several spray parameters including cost. In general, volume per acre has little effect on efficacy with a few exceptions. Glyphosate has repeatedly shown to be more effective at low volumes per acre (Cranmer & Lindscott 1990, Buhler & Burnside 1987, Ambach & Ashford 1982). More than anything, volume per acre affects coverage. Coverage increases as volume per acre increases. A fairly large portion of spray volume is lost however due to large drops splashing off of leaf surfaces (Young, Hart & Hall 1987). Volume per acre can best be managed by nozzle size and travel speed.

The main drawback of using high spray volumes is cost. As spray volume increases, the time required to spray a given area increases as does the cost per acre. This is most dramatic with hand applications. Labor costs for hand applications can easily double just by doubling the spray volume. Often times, foresters mistakenly attribute increased efficacy to increases in the volume of herbicide solution applied. In reality, this is actually due to an increase in herbicide rate from higher volumes applied. Efficiency of applications can be significantly improved with higher rates and lower spray volumes (Fredrickson 1994).

Rate

The most important variable affecting efficacy is rate (Fredrickson & Newton 1998, Fredrickson 1994). Many times an increase in volume is mistakenly given credit for increased efficacy, when it was actually the inherent rate increase with increasing volume that was responsible. The challenge for foresters is to use the least rate possible to achieve maximum efficacy, hence increasing efficiency. Most herbicides are expensive and making applications as efficient as possible can easily justify the effort.

Adjuvants

Adjuvants are any type of additive to the spray mixture that changes the physical properties of the spray solution. Surfactants, spreaders, stickers, buffering agents, etc are all adjuvants. The main adjuvant type discussed here will be surfactants. Water has a high surface tension that causes droplets to bead up on leaf surfaces. Surfactants reduce surface tension causing spray droplets to spread over leaf surfaces maximizing coverage (Hess & Faulk 1990). Surfactants also aid in penetration of waxy leaf cuticles, increasing the amount of active ingredient absorbed into the plant (Geyer & Schnerr 1988). Rainfastness can be improved with the use of adjuvants by speeding up absorption rates into plant tissues (Sundaram 1990(a), Sundaram 1990(b), Stevens & Zabkiewicz 1990).

Surfactants are classified into several types. Nonionic, cationic, silicone based, petroleum distillates and methylated or ethylated seed oils are the main types used in forestry. All reduce surface tension and cause droplet spread. The silicone-based surfactants reduce surface tension the most and hence cause the most droplet spread. However, this doesn't necessarily correspond to increased control (Fredrickson 1994, Whitson & Adam 1990, O'Sullivan et al. 1981). Many herbicides have adjuvants formulated into the product already. In many cases adding a surfactant to a product that already has a surfactant formulated into it adds no additional benefit (Fredrickson 1994, Brewster & Appleby 1990, Babiker & Duncan 1974).

Historically, non-ionic and silicone based surfactants were mainly used with water soluble amines. Petroleum or seed oil based adjuvants were primarily used with oil soluble esters. This has changed in recent times. The seed oil products tend to work well with either amines or esters. Adjuvants are usually cheap insurance but it shouldn't be taken for granted that they are increasing efficacy. Furthermore, surfactants can also have a negative effect on conifer tolerance (Fredrickson 1994).

Application Method

The application method you choose will also have an effect on the physical properties of the application, but mainly from a deposition standpoint. Treatments made by hand are going to directly deposit the spray solution exactly where it needs to go. The risk of offsite movement is minimal. Aerial applications have the most dispersion of the spray solution and while they can be applied extremely accurately, the deposition cannot be placed as accurately as hand applications. Ground applications with tractors or off road vehicles fall somewhere in the middle. The big tradeoff between the methods is cost, with hand applications being the most expensive and aerial applications being the least.

Application Methods

Aerial Applications

Aerial applications are the most efficient method of applying herbicides. Large areas can be treated in a very short period of time. Rough topography, poor access, lower cost, and large acreages are all factors that favor aerial applications. Generally, helicopters can carry eight to ten acres worth of material per load depending on the elevation. Fixed wing aircraft is only a possibility on very flat open ground. Where it can be used, it is more efficient than helicopter applications. Up to 50 acres per load can be applied with most fixed wing aircraft. The majority of the discussion here will concern helicopter treatments.

Targeting Vegetation with Aerial Applications

Developing prescriptions for aerial applications requires a good understanding of what can and can't be controlled by air. Since the quantity of material applied is less with aerial applications compared to hand treatments, the control of hard to kill brush species is more difficult by air. Herbaceous vegetation can be controlled equally as well by air or ground methods.

Herbaceous vegetation can be controlled with either foliar or soil active products. The difference is the duration of control. Any of the foliar chemicals such as glyphosate, triclopyr, 2,4-D, imazapyr, fluroxypyr or clopyralid will cause mortality of established herbaceous vegetation with aerial applications. With the exception of imazapyr, the other products have very little or no soil activity to prevent further germination. In this case herbaceous vegetation will rapidly re-occupy the site follow the application.

Using soil active products such as hexazinone, atrazine, sulfometuron methyl, oxyfluorfen or penoxsulam, the duration of control is extended by using chemicals that have residual activity in the soil. Hexazinone, atrazine, oxyfluorfen and penoxsulam have excellent conifer tolerance and can be applied as a pre or post plant application. Conifer tolerance issues with sulfometuron methyl prevent it from being used in the interior part of California, but applications on Coastal sites in the redwood range are possible. Hexazinone has the best knock down of emerged herbaceous vegetation. Atrazine and oxyfluorfen plus penoxsulam are best suited to pre-emergent applications unless another herbicide can be added. Knock down of existing herbaceous vegetation with oxyfluorfen plus penoxsulam is better than atrazine and can be improved with the addition of a methylated seed oil adjuvant.

Control of brush with aerial applications is a little more difficult. The size and type of brush, product and rate, timing, and adjuvant have major influences on control. Deciduous brush such as deerbrush (*Ceanothus integerrimus*) and snow berry (*Symphoricarpos albus laevigatus*) are fairly easy to control with applications of glyphosate. As deerbrush gets larger, control gets more difficult by air. This is true for most woody brush. Deciduous hardwood sprouts also prove difficult to control by aerial methods. They use of imazapyr alone or in combination with glyphosate dramatically improves control of larger woody deciduous brush and the addition of methylated or ethylated seed oils improves control further. Late summer timings of this treatment are usually better than earlier scheduling due to carbohydrate movement down into the root system later in the season. Due to conifer tolerance issues with imazapyr, only pre-plant applications are possible the year prior to planting, and seedlings still may show some symptoms of imazapyr damage. Deciduous brush and hardwood sprouts should usually not be treated with growth regulator products such as 2,4-D or triclopyr by air. These growth regulators cause rapid brownout of deciduous foliage and heavy damage to the translocating tissue in the plant. The result is rapid re-sprouting. Deciduous woody brush and hardwood sprouts treated in this manner, usually require re-treatment with a different method and product to achieve satisfactory control.

Evergreen brush such as tan oak (*Lithocarpus densiflorus*), golden chinquapin (*Chrysolepis chrysophylla*), greenleaf and whiteleaf manzanita (*Arctostaphyllos patula & viscida*, respectively), whitethorn (*Ceanothus cordulatus*) and snowbrush (*Ceanothus velutinus*) can be very difficult to control by air. Again, small plants are much easier to control by air than larger ones. Best control of evergreen brush is usually achieved with the oil soluble formulation of imazapyr (Chopper or Polaris AC) alone or in combination with glyphosate plus a methylated seed oil (MSO). These two systemic herbicides work incredibly well in combination. Both are ALS inhibitors, but they each inhibit three different amino acids

(Ahrens 1994). Imazapyr inhibits valine, leucine and isoleucine, while glyphosate keeps the plants from producing tyrosine, tryptophan and phenylalanine. They both translocate very well within the plant and do very little damage to the translocating tissue. Coverage is usually the critical factor when aerial applications are used. Evergreen brush is easily controlled with this herbicide mix with hand applications, aerial treatments are usually less so but still acceptable.

Triclopyr ester, fluroxypyr and/or 2,4-D ester can also be used on the evergreen brush species, but results are slightly less acceptable than the glyphosate plus imazapyr combination. Applications of fluroxypyr and 2,4-D ester plus an MSO do control manzanita species well. Timing of application with evergreen species is a little different than deciduous brush. Early summer timings usually provide the best control with either the glyphosate and imazapyr combinations or growth regulator applications of 2,4-D, fluroxypyr or triclopyr esters. When applying the ester formulations of 2,4-D and triclopyr, volatility will be an issue if temperature exceeds much over 75 degrees. If temperatures are warm, these products should not be used near neighbors or crops as off site damage may occur.

Aerial Project Planning

The first part of any helicopter program is planning. Foresters must evaluate each site on a unit by unit basis to determine what units can be applied by aerial methods and which ones are better suited to ground treatments, as well as what herbicide prescriptions are needed. Most units can be applied by air unless there are a large number of water courses, sensitive areas or neighbor issues that limit the amount of ground that can be treated with a helicopter. From a cost perspective, large steep units with poor access are ideal for helicopter applications since hand treatments would be extremely cost prohibitive.

During initial site visits, foresters need to define unit boundaries, look for suitable heliports, water sources, access, any potential hazards or sensitive areas that need mitigation, and staging areas. Unit boundaries need to be clearly defined and very obvious. Usually clear cut boundaries are defined by the edge of mature timber or roads. However, in many cases such as when dealing with large burns with multiple land-owners, this often isn't the case. Unit boundaries, property lines, exclusion areas, etc may be difficult to see, especially when different landowners have treated their ground relatively the same. Defining property and boundary lines as well as exclusion areas can be done in several ways. Painting large spots (at least two foot diameter) with bright marking paint on rocks, stumps or logs about every 50 feet works well, especially with blue marking paint since it shows up well from the air. Large reflective pieces of foil or very heavy high visibility flagging can also be used. Remember, the pilot is going to be flying 50 to 100 feet above the ground traveling at roughly 50 mile per hour.

Suitable heliports can be difficult to find. Large landings work well provided they do not have any obstructions such as larger trees, saplings or landing piles to hinder ingress and egress. Heliports should have at least two clear directions for takeoff and landings. Helicopters prefer to take off and land into the wind so it helps to have multiple options. Ideally, having some slope also helps so that the helicopter can drop off the heliport. The heliports also need to be smooth and level. They also cannot be so dusty that the pilot's vision is impaired, and treating them with water during dry conditions may be necessary. Good access to heliports is a must as the batch truck will need to be within about 50 feet of the helicopter to fuel and load is with the spray solution. The number of heliports needed for the project depends on the size and number of units. A one mile radius should be roughly the maximum distance flown from each heliport unless there are no other options. Ferrying long distances is extremely expensive to the contractor, and if there are no other options, that needs to be made clear in the contract negotiation as it will affect the cost.

Ideally, the easiest way to obtain water for mixing is from a mill site, log yard, office or other property under your control. Creeks may be used, provided the drafting equipment on the batch truck is equipped with anti-backflow devices to prevent contamination. It is prudent to avoid drafting from streams or ditches where domestic water is obtained. It is always a good idea to test water sources for pH and cat-ions if you are unfamiliar with the sources, as high cat-ion contents indicated by a high pH can tie up some active ingredients in solution, thus affecting efficacy. Never batch near your water source. Whenever possible, batching should be done on the spray site.

The most critical thing foresters need to locate and define are the areas within the spray project such as water courses, springs, wells, domestic ditches, lakes, ponds, property lines or other resources that need protection. Once located, they should be mapped and well defined on the ground so that the pilot is fully aware of their presence. Resources can be protected using the mitigation measures discussed earlier in this chapter.

If the project occurs near residences or other neighboring land owners, it is a good idea to make contact with them ahead of time. A written neighbor notification program is a valuable tool for training foresters and improving their ability to communicate what you are trying to accomplish and addressing any concerns they may have. Many problems can be avoided through good communication. Showing up unannounced at their doorstep with a helicopter first thing in the morning is not the way to meet your neighbors.

Roads are the one aspect of a spray operation that is often over looked. All roads accessing the project area need to be driven before spraying operations occur. Roads need to be cleared of debris and have to be passable for a 4,000 gallon batch truck. Water bars need to be lowered or removed if present, and any rolling dips or other drainage structures need to be passable. Helicopter time and auxiliary equipment are extremely expensive, and unexpected delays can't be tolerated.

A secure area needs to be established for a staging area where the helicopter and batch truck can be located when not spraying. The area should be where the spray equipment can be watched or in an area where access is restricted to company personnel.

It is also very important for the forester to have chemical for the project delivered ahead of time to avoid potential delays. In favorable conditions, helicopters can apply as much as 600 acres in a day. Transportation and storage of chemical also needs to be addressed before the project starts. The storage area needs to be a locked secure placarded area. Any opportunity to minimize the distance to haul chemical to the project should be encouraged.

Accurate mapping is a necessity. Global positioning systems (GPS) and geographic information systems (GIS) should be used in conjunction as much as possible. Unit boundaries, roads, stream courses, protected areas and property lines should all be accurately mapped using GPS and downloaded directly into the GIS. Most helicopters today come equipped with some type of GPS guidance system. Shape files for layers from the land owners GIS system (unit boundaries, roads, stream courses, lakes, ponds, ditches, property lines) can be downloaded directly into the helicopters GPS system. The GPS system not only shows the pilot an accurate map of all the layers in the system, but maps the spray swaths and helicopter position as the application occurs. This provides a very nice, mapped record of what was and wasn't sprayed, including aerial buffers, exclusion areas and the unit itself.

Spray contracts need to be prepared and contain all the necessary information and instructions to complete a successful project. Contracts should include a unit summary and treatment list, price per acre or other unit, project maps, application parameters, acceptable weather conditions, weather and application record keeping requirements and forms, licensing requirements, mitigation measures to follow, production schedules, chemical handling and transportation procedures, use reporting guidelines, container disposal guidelines and any other pertinent guidelines or information.

Aerial Project Implementation

When the aerial project is ready to begin, there are several things to consider. It is very helpful and wise to have two to three people working with the forester in charge of the project in the field. These extra people can be used to check weather conditions on units in advance of spraying, make sure units are clear of people, block access into the spray area, lead equipment in and out of spray units and keep weather records. By knowing what the weather conditions are on units yet to be sprayed, the project manager can efficiently move from one spray area to the next, saving valuable time and money.

When the helicopter arrives, it is pertinent to go over the spray plans, herbicide mixes, application volumes, mitigation measures, policies and calibration with the pilot and batch truck driver. Making sure the helicopter is calibrated prior to starting is critical to achieve the desired application rates. For reference on aerial calibration see Dreistadt (2013). Check the nozzle setup on the helicopter and make sure it is acceptable for your objectives. Based on the contract specifications, the helicopter should be set up the way you want it, but don't take it for granted.

Batching should be done on the spray unit at the start of each day to minimize traveling with a load of chemical in the batch truck. By batching on the unit, this also gives you an opportunity to assess weather conditions and batch the amount for what you think you can easily finish. When possible, it's best to avoid letting chemical sit over night in the spray tank. This will reduce problems with settling in the tank and potential vandalism issues.

Determining where to start your project may not make a difference much of the year, but occasionally in the fall with large projects bad weather can influence your program. In this case it is usually a good idea to start in the highest elevations first and work down in case snow becomes an issue. The opposite is true with large projects in the spring. Working from low to high usually makes the most sense as snow melts. One of the important things foresters will learn over time are the local weather patterns. This can save an inordinate amount of time and money figuring out where to start each day. Usually the wide temperature swings during the California day causes dramatic changes in wind patterns and direction. Before and after storm fronts pass through also bring in their own set of wind patterns. While all of this can effect spray operations, the patterns are fairly predictable.

Before starting to spray, the forester should recon the units with the pilot. The forester should show the pilot unit boundaries, water courses, property lines, sensitive areas, and anything else of concern. The forester can also give any special instructions such as when and where to utilize a split boom. The forester should also document the instructions given to the pilot in their daily spray records. Written notes are critical documentation in the event one ever gets taken to court over a spray application.

Finish spraying one unit before starting the next. As part of the forester's record keeping, each load and volume taken should be kept track of for each unit. It is imperative to know how much spray volume went on each unit. If the pilot is flying more than one unit at a time accurate records of how much volume went on each can not be kept. Keep in contact with the pilot during the application, but try and keep radio traffic to a minimum.

Be observant during the spray operation. Watch as creeks and drainages are flown to assure proper buffering is done and split boom applications are used. Make sure all the nozzles on the boom are working. Keep a watchful eye out for people or vehicles entering the spray area.

Accurate record keeping is invaluable. It allows you to keep track of the herbicide volume used, time, rates, mitigation measures used, costs, weather conditions and personnel. At a minimum, the forester should have two data sheets for record keeping. One for weather and one for each units spray record. At a minimum, the weather should be taken at least every hour, if not more and include time, wind speed and direction, temperature and humidity. The pilot is required to have weather records under California law. The unit summary data should include the unit name or number, acres, personnel present, contractor, herbicides used and rates applied, volume per acre, mitigation measures used, number of loads flown, volume used per load, total gallons flown, the time each load was flown, pilot name, and any other application notes pertinent to the job.

Hand Applications

A very expensive part of any reforestation effort is the labor cost of hand spraying. There are many application techniques and types of equipment that will help improve efficiencies and reduce costs. Making effective and efficient applications by hand is an art. As a result, hand spray labor is a very important area for a reforestation forester to focus their effort on when it comes to reducing costs. The more intimately familiar the forester becomes with the tools and techniques to operate efficiently and effectively, the more valuable the forester will be.

Having the Right Equipment

Usually hand spray crews are made up of 10 to 14 people. Any time the crew is waiting around and not spraying is extremely costly. Efficient application equipment should be built around the concept of reducing that time. If a crew has to spend much time waiting around for more water, or walking back to the batch truck to fill up their backpacks, costs can skyrocket.

The batch truck and associated equipment are the key to reducing costs in the field. Batch trucks should be set up with a spray tank large enough to carry a good supply of chemical. Five hundred gallon tanks are a good size. One of the real keys to reducing down time is to have a good supply of water. A water tender trailer is essential to reduce application costs. To work with the batch truck, a trailer fitted with at least a 750 gallon tank for water only is generally enough to supply a crew for an entire day. The water trailer should also be fitted with lockable metal storage bins to carry chemical, drafting equipment and other spray equipment. Drafting equipment should be kept in a separate storage container that is chemical free. Never put contaminated equipment into a water source to draft from. Storage containers need to be large enough to carry several 30 gallon containers of chemical. Having enough chemical on board to last several days will also help reduce costs dramatically.

Reducing the amount of time a crew spends walking without spraying is the key to reducing costs. Often times, reforestation units are large and when crews run out of spray solution in their backpacks, the time required to walk back to the batch truck to fill up can be substantial. Any efficient spray operation should have batch trucks set up with a power take off driven hose reel and pump system to bring the chemical to the crew instead of the crew to the chemical. A hose reel capable of holding at least 1200 to 1500 feet of high pressure hose and having the ability to pump uphill as well as down can save large amounts of time that would otherwise be spent walking. The hose reel itself needs to be set up with a power reel up system as hose with a full load of chemical can be extremely heavy. Usually hydraulic powered systems are best.

Good communication between the crew foreman and the batch truck driver is essential. Each should have a portable radio that the foreman can use to tell the batch truck where to move the truck to and when to pull or reel up the hose lay. This will also save a substantial amount of time.

In certain instances such as large wildfires with poor access it helps to have an off road vehicle equipped with a spray tank and delivery system to fill backpacks in the field. In remote areas where hose reels can not supply enough hose to reach the crew, an off road vehicle may provide an efficient alternative.

Managing access to units is critical. Too often roads that provide access to reforestation units are decommissioned immediately after logging operations cease. It is imperative to communicate with logging managers and plan writers the importance of leaving access to units open at least until the reforestation efforts are finished, which may be several years. Poor access will affect the cost of all reforestation activities, not just spraying.

Spray crews must be supplied with a wide variety of application equipment to achieve the desired objectives of the forester. Besides the standard backpacks and spray wands, crews should be trained and have the equipment to do broadcast, spot-gun, gun-jet and hack and squirt applications. A supply of meter jets, gun-jets, hatchets, and backpack injectors should be available. Having an extensive selection of nozzles including flat fans, off center and adjustable tip nozzles will also allow for a wide flexibility in the types of applications crews can do.

Directed Hand Spray Applications

Hand applications can consist of two types, broadcast applications where 100 percent of the ground area is treated at a specific rate per acre or some type of individual plant treatment. The first type of individual plant treatment discussed will be directed spray applications. This is the most common type of application used to control difficult woody brush. With this treatment individual plants are sprayed with a standard backpack and wand usually equipped with a flat fan nozzle. Nozzle types and characteristics are discussed in detail earlier in this chapter. The larger the orifice and angle of flat fan nozzles, the larger the drop size and wider the swath, respectively. Narrower angle nozzles give the applicator more control over what plants are covered. Occasionally, adjustable tip nozzles can be used for taller brush such as hardwood sprouts which allows the applicator to reach up higher on the plant.

Directed spray applications are used when the herbicide cannot be applied over the top of existing conifer seedlings without injury. In these types of applications, protection of the seedlings is necessary to prevent damage. Usually some type of shield with a handle is carried by each applicator. Seedlings are covered with the shield while the applicator sprays the vegetation around the tree, avoiding any contact.

With directed spray applications, it is very important to know what the target volume per acre should be. There are two reasons for this. The first is that you want to make sure that maximum label rates are not exceeded. Second, as volume per acre increases, crews slow down and hence, costs increase. By observing the crew spray a small known acreage at the beginning of the project, the forester can determine the volume per acre and adjust accordingly. It is a good idea to observe the spray pattern so the forester can tell by looking in the future whether crews are applying too heavy or too light. With directed applications, the use of dye is required to see what has and hasn't been sprayed.

Directed spray applications are usually batched on a percent solution basis. When that is the case, the forester needs to convert from percent solution to a rate per acre to determine if the application is being applied within the designated prescription rates. For example, if the maximum rate per acre of a given herbicide was one quart per acre and the crew was applying the mix at a 25 gallon per acre spray volume, the percent solution rate could not exceed one percent to avoid going over the maximum label rate. To adjust the volume per acre, nozzle size could be adjusted or the crew members could adjust the volume they are putting on each plant.

When planning directed spray projects, keeping costs to a minimum is essential. The smaller the brush, the less volume that is going to be applied and the cheaper it will be for labor and chemical. The crown volume of woody brush grows at an exponential rate from year to year. By delaying spray projects until brush gets large and dense, application costs can easily reach several hundred dollars per acre in just labor. Small seedling brush can be more easily controlled at a lower labor cost and a lower volume of herbicide applied. However, foresters need to be careful not to treat woody brush that has sprouted from old root systems too early before the plants have been able to put on enough crown to absorb enough chemical to control the existing root system.

Herbaceous vegetation treatments are usually not done using directed spraying with one exception. Occasionally landowners may want to apply glyphosate as a foliar treatment post-planting to control herbaceous vegetation. In this case, the glyphosate must be applied as a directed treatment since freshly planted conifer seedlings are not tolerant to over the top applications. Since there is no soil residual activity, residual weed seeds will not be controlled if the application is made before they have germinated. Likewise, if the application is made after the germinated plants have set seed, the new seed will then be present to germinate in subsequent growing seasons. For these reasons, the control of herbaceous vegetation using glyphosate needs to be critically considered and carefully timed. Longer lasting herbaceous treatments can be applied as a broadcast treatment with hexazinone, atrazine, sulfometuron methyl, or oxyfluorfen plus penoxsulam either as a pre or post plant application, unless conifer tolerance or company directives dictate otherwise.

Directed spray treatments can be used very effectively around sensitive areas such as water courses, lakes, ponds, property lines and other sites needing protection. Herbicides can be placed very accurately with this method with very minimal risk of off-site movement.

Broadcast Hand Treatments

The most efficient delivery method for herbicides by hand is applying them as a broadcast treatment, similar to a helicopter application. With broadcast applications, 100 percent of the ground area is treated in a systematic calibrated fashion. Depending on the conifer tolerance of the herbicide used, broadcast treatments may be applied pre or post plant. Broadcast applications are the most cost effective application method by hand. Depending on the type of equipment used, application costs can come close to that of a helicopter.

There are several methods that can be used to apply broadcast treatments. Boom spraying is a possibility, but not very practical with a large crew and requires a larger volume of spray solution than an individual can usually carry to be cost effective. Therefore, we will not discuss it here.

Most of the broadcast treatments are applied with what is known as the waving wand technique (Newton 2009). The technique can use either a conventional spray wand or a gun-jet application system. The wand is waved side to side at moderate speed so that the stream from the nozzle overlaps creating a solid swath as the applicator moves forward. To apply this method properly, the applicator must know the width of the swath they are producing, wave rapidly enough that coverage is solid, and calibrate the walking speed to achieve a target volume per acre.

The crew must be calibrated prior to making the application. To calibrate the waving wand method, first stand in one spot and spray, waving back and forth until the effective swath is visible on the ground. Measure the effective swath width. Then take a measured amount of water (one gallon) and put it in the backpack. Walk at a comfortable pace that can be maintained across an entire spray unit. Spray out the one gallon of water walking at the chosen pace waving the wand back and forth exactly as it was done to measure the swath with. Measure the distance traveled from where spraying started to when the backpack ran out of water. Calculate the area covered in square feet (swath width (ft) x distance traveled (ft)). Divide that number by 43,560 (square feet in an acre) to get the percentage of an acre sprayed. Divide the percentage of an acre sprayed into the volume sprayed out (in this example one gallon). That will tell you how many gallons per acre of spray solution you put out at that walking speed. That walking speed and waving technique must be replicated by all of the crew members and they must be spaced apart evenly so as to not overlap swaths too much or too little. Not being properly calibrated or trained in the application procedures can result in the wrong rates being applied, conifer injury or excessive skips left across the spray unit. This method is highly effective and efficient, but should only be applied by a properly trained and very experienced crew.

It is important to distinguish the difference between volume of solution applied per acre and the rate per acre of whatever herbicide you are using. In general, five to ten gallons per acre is the normal volume of solution applied (water and chemical) with waving wand applications depending on the method used. The rate per acre of herbicide is designated separately. For example, you can apply two quarts per acre of a glyphosate product in either five or ten gallons per acre of total solution. The two quart glyphosate would remain the same, but the dilution would change.

Several types of application setups can be used. For maximum production, gun-jet applicators can be used. This wand looks much different than a typical backpack wand and uses a disc nozzle similar to what is used in helicopter applications. The gun-jets have an adjustment where the spray output can be set at a straight stream down to a fine mist. The proper setting is to open the nozzle all the way so that it emits a straight stream and then begin to close it down to the point where the stream is just starting to become fractured. When waved side to side, swath widths of up to 30 feet can be achieved. Care must be taken to point the gun-jet away from the applicator as they walk so that they are not walking into the spray material. The gun-jet system is more suited for soil active herbicides as coverage is slightly variable. It is also highly sensitive to wind and worker exposure can be an issue if not properly applied. Adjustable tip nozzles can also be used with a normal spray wand that simulates a gun-jet application, but production and swath width are slightly less. This method is slightly slower, but is a little more forgiving regarding working exposure and drift.

The most effective and controllable waving wand application method is the off center nozzle system. In this case, a normal spray wand is utilized, but fitted with an off center nozzle (OC nozzle). This nozzle puts out an elongated spray pattern that when waved side to side provides superior coverage over any other waving wand method. It is also the method with the least applicator exposure, as the nozzle spray pattern is pointed downward and thrown away from the applicator as it is applied. This method can be used for either foliar or soil active products. Smaller orifice off center nozzles should be utilized for foliar applications for better coverage. Swath widths are reduced to about 12 to 15 feet with off center nozzles compared to the gun-jet system, but production rates are only slightly less. Swath width and walking speed increase as the size of the nozzle orifice increases. Hence, application costs are reduced with increasing nozzle size.

Topography can severely affect the pace of the spray crew when doing waving wand applications. Inherently, crews slow down on steep slopes or in units with heavy slash loads. The forester and foreman need to be aware of changing conditions that may affect the volume per acre applied. Changing nozzle size is a good way to deal with changes in topography. Using smaller nozzles on steeper slopes or units with heavy slash will adjust for a slower walking pace and maintain the same volume per acre used on easier ground.

One other limitation of the waving wand method is the height and density of brush. When brush gets more than about three or four feet tall and dense, waving the wand gets exceedingly difficult. Pace is more difficult to maintain, as is keeping the crew members together. To do these applications effectively, crew members need to stay together and keep in an organized line so that each one can see where the next has sprayed. The last applicator in line or the foreman, needs to flag the outside spray line so the crew knows where to follow back on when they turn around to make another pass.

A well trained crew in broadcast application techniques is an invaluable asset to a reforestation forester. Application costs can range as low as 25 to 45 dollars per acre for labor depending on the application and site. This is not the application type that you want to contract out as a low bid application. Broadcast applications by hand are very complicated and results can be poor if not applied properly. Foresters need to be aware that crews can cover a large amount of acreage in one day, and if not applied properly, the results could be very costly.

Hack and Squirt Applications

Hardwood trees and sprout clumps are extremely competitive to young conifer seedlings in California (Jackson & Lemon 1988). Sprouting hardwoods from cut stumps can occupy large areas within a reforestation unit in a very short amount of time, depriving seedlings of valuable light, nutrients and water

(DiTomaso, Keyser & Fredrickson 2004). Where hardwood populations are heavy, reforestation units could be entirely dominated by hardwood cover if not managed to some degree. It is wise to designate a certain number of hardwood trees and clumps for retention for wildlife concerns, but if left totally unmanaged this can cause significant problems for reforestation efforts.

Hack and squirt applications are one of the most important techniques we have for managing hardwoods. It is a very selective technique that allows for managing hardwoods at whatever density the land manager chooses. It is a fairly simple but extremely efficacious, efficient and cost effective treatment.

The tools required are a hatchet, a small gravity fed backpack and a calibrated veterinary syringe capable of delivering a specific amount of liquid (Figure 8.4). The veterinary syringe can be set to a specific amount of chemical to inject. In most cases the delivery amount is set at either one half or one full milliliter of liquid. The number of hacks made per tree is determined by using either a specific spacing around the circumference of the tree or designating one hack for every so many inches of tree diameter at breast height (Figure 8.5). For example, using circumference, a hack could be placed every six inches around the circumference of the tree. When using diameter as a guide, a tree could be injected using one hack per every three inches of diameter at breast height. In this case a 9 inch tree would receive three hacks. Once hacked, the appropriate amount of chemical would be injected into each hack using the veterinary syringe. The chemical is usually used undiluted.

In the case of treating hardwood clump sprouts where the stems are too small to hack on a circumference or diameter basis, the number of injections is usually determined by selecting a certain number of stems to inject per clump. Stems may either be hacked with a hatchet if large enough or snapped by hand and the chemical injected into the broken stem.

Trees and clump sprouts can be injected almost all year long, however spring treatments are not recommended when sap is flowing. At that time, chemical injected into the cuts can be pushed out of the hack area to the extent that it makes the treatment ineffective. Big leaf maple will begin flowing sap as early as late January in northern California. The most effective timing is usually late summer through the entire winter for most hardwoods (Ditomaso, Keyser & Fredrickson 2004).

The most widely used herbicide for injection treatments is imazapyr, and it is without a doubt the most effective. Conifer tolerance precludes its use as a release treatment in many situations, but it is ideal as a treatment for pre-harvest site preparation or pre-plant site preparation which will be discussed later in this chapter. It is important to realize that imazapyr does have soil activity and translocates very well with plant systems. Many hardwood species that are growing in close proximity to one another are known to form root grafts. Any tree that is root grafted to a treated tree may show visible symptoms or even death.

This is an important consideration when treating near property lines. Buffer zones may be needed to prevent inadvertent mortality across property lines or to trees intended to be retained for wildlife features (Ditomaso, Keyser & Fredrickson 2004). Imazapyr may also be exuded through the roots of treated trees into the soil where conifer seedlings could absorb it and be damaged.

One of the benefits of having a hack and squirt program is that crews can operate when windy or other weather precludes them from foliar spraying. The only weather condition that will prohibit hack and squirt applications is heavy rain as freshly injected chemical may be washed out of the cuts. Planning the total application program with the option of utilizing the crew for hacking when weather prohibits other application methods will provide a more consistent supply of work.

Application costs depend on the density and type of hardwood treatment. Labor costs with tree hack and squirt in the interior part of California in typical black oak (*Quercus kelloggii*) stands usually averages somewhere between 20 and 50 dollars per acre. Hack and squirt treatments on the Coast of California can be much higher due to heavy densities of tan oak (*Lithocarpus densiflorus*), as can stands with dense under-stories of other hardwood sprouts. Herbicide rate per acres needs to be closely monitored in stands that have very high stem densities as the maximum rate per acre could easily be exceeded.

Treating hardwoods prior to planting is much preferable than post-plant treatments. Benefits usually include lower costs, better conifer tolerance and better efficacy.

Cut Stump Treatments

Cut stump treatments are seldom utilized in forestry due to cost and the ability to use other more efficient and effective methods. Trees or brush can be treated with this method. Plants are treated by severing the stem or bole with a chainsaw or other cutting tool and then using a squirt bottle to apply either a high concentration solution or undiluted herbicide around the cambium of the stump. Herbicide need not be applied to the deadwood in the center of the stump. The key to applying cut stem treatments is to treat the stumps immediately after cutting because delaying the application will dramatically reduce translocation and efficacy.

Several herbicides can be used with cut stump applications. Triclopyr, glyphosate and imazapyr are the three that are most commonly used. It is imperative with triclopyr in warm weather to make sure that the amine formulation is used as the ester formulation will volatilize. Care must be taken with imazapyr if stumps are treated along property lines or right of ways where adjacent vegetation may be root grafted to treated stems. Cut stump applications are generally most effective in the late summer to winter, but may be treated most times of the year other than during spring sap flow.

The major deterrent to cut stump treatments is the labor cost associated with cutting of the vegetation. Chainsaw removal of large brush may cost as much as 300 to 400 dollars per acre in dense stands. These treatments are often used when brush is too tall to foliar spray but the land manager wants to treat the vegetation before clearing the ground for planting to avoid

re-sprouting. In the instance where vegetation is so large that it can not be foliar treated before mechanical site preparation activities occur, it may be more cost effective to pile the vegetation first and manage the re-sprouting vegetation. In general, it is best to treat the vegetation prior to removal to maximize efficacy and reduce costs.

Basal Bark Treatments

Basal bark treatments are used primarily to control re-spouting hardwoods and larger woody brush. The herbicide solution is applied to the bark of the lower stems of plant, near the ground line. Triclopyr ester and imazapyr are the main herbicides used with basal treatments. With basal applications, the herbicides are mixed with a basal bark oil as the carrier instead of water to get penetration through the bark. Bark thickness increases as plants get older and therefore, basal treatments are limited to stems with a maximum ground line diameter of three inches or less.

There are three types of basal bark applications - conventional, low volume and thin-line basal treatments. With convention basal treatments, stems of treated plants are sprayed around the entire circumference of each stem from the ground line up to a height between 18 and 24 inches depending on the preference of the land manager. It is very important to completely cover the circumference of every stem and to heavily cover the root collar area on the stump to insure control. Low volume basal treatments are applied in the same way, but the herbicide concentration is significantly higher than what is used with conventional basal treatments and the stems are only treated to a height of six inches above the ground line, reducing the total volume used.

Thin-line treatments are still applied to the base of the stems but in a much different way. Thin-line uses the highest concentration of solution of any of the methods, but also the lowest volume. The spray solution is applied through a nozzle that produces a straight stream. The stream is arced across the base of the stems from left to right to a height of about one foot above the ground line from three or four sides of the plant. The idea is to connect all of the arcs so that all stems receive some coverage. Unlike conventional or low volume basal treatments complete coverage around the entire circumference of the stem is not necessary due to the concentration of herbicide solution.

Labor costs are the most expensive for the conventional basal treatments followed by the low volume treatments, with thin-line treatments being the least expensive. The efficacy of basal bark treatments vary dramatically by geographic region. In the interior parts of California, basal treatments do not typically work as well as other treatments designed to treat hardwood sprouts such as foliar or hack and squirt treatments with imazapyr. Heavy re-sprouting usually occurs with basal applications on species like black oak (*Quercus Kellogii*) and dogwood (*Cornus nuttallii*). In Oregon, basal treatments with triclopyr ester are the most effective method on species such as tan oak and big leaf maple (*Acer macrophyllum*) (Gourley personal communication).

Spot-Gun or Meter-Jet Applications

Spot-gun and meter-jet applications are one and the same and will be referred to as spot-gun for the rest of this text. This is a very efficient application technique for controlling various types of woody vegetation that are sensitive to the herbicide hexazinone such as snowbrush (*Ceanothus velutinus*), whitethorn (*Ceanothus cordulatus*), deerbrush (*Ceanothus integerrimus*) or greenleaf manzanita (*Arctostaphyllos patula*). Spot-gun treatments are applied using a Meter-jet application system to individual plants or on a grid system if plant cover is too heavy to treat individual plants. The device delivers a measured amount of chemical with each pull of the trigger and can be adjusted to deliver a range of rates. The herbicide is applied undiluted to the soil about midway between the root collar and the branch tips. Generally, three milliliters of the liquid formulation of hexazinone per spot is applied. The number of spots a plant receives is dependant upon the size of the plant. Most plants receive a minimum of two spots. The spot where the herbicide is applied must be free of litter or other debris that may tie up the chemical.

This application system requires an experienced crew to properly apply the treatment. Crews must be careful not to exceed the maximum label rate. Crop trees may be damaged or killed if too much hexazinone is applied in any given area. If the vegetation is too heavy to treat individual plants and a grid system must be used, another treatment method should probably be considered as grid applications are not nearly as effective. Spot-gun applications are best suited to low brush densities. Conifers can also be severely injured or killed in stands adjacent to treated areas as root uptake occurs. Large cedars and sugar pines are at the highest risk in close proximity to the treatment area and may be killed if not given a large enough buffer. It is also important to adjust the spot placement when treating on steep slopes. Spots should be placed around the upper sides of the plant so the herbicide does not move down slope away from the root system.

Rainfall is required to activate the hexazinone. The majority of spot-gun applications are applied in the fall as the main target is snowbrush which occurs in the upper elevations. It is important not to get too much or too little precipitation for the herbicide to work correctly. Generally, between three and twenty inches of rain is desired for effective hexazinone applications. Lower elevation species such as deer brush could theoretically be treated in the spring if an adequate moisture window still exists. Spot-gun applications are highly effective and very efficient from an application standpoint. The cost per acre is generally very low and labor costs usually range between $25 and $35 per acre.

Tractor or ORV Applications

Opportunities to utilize tractor or ORV mounted spraying systems in forestry are minimal. Usually terrain, stumps, brush, rocks, snags and residual conifers prohibit efficient use of such systems. There are instances where it may be possible such as roadsides, pasture conversions or very flat and clean clear cuts relatively free of slash.

Where it is possible, the applications are similar to aerial traetments. They are primarily broadcast applications to be applied at a certain volume per acre with the potential exception of roadside applications. In this case, calibration of the system and traveling speed is critical (see Dreistadt 2013 for calibration of tractor mounted systems). The choice of herbicides used will depend largely on what vegetation is present on the site and whether or not conifer seedlings have been established. Pre or post plant applications can be made with a tractor or ORV system provided tree height and conifer tolerance is not an issue.

The delivery system for these applications is primarily through a mounted boom. For forestry applications shorter booms are better. Unique configurations of flood-jet and off-center nozzles could also be used to reduce boom lengths and increase the maneuverability in reforestation units. Roadside applications usually either have a hand-held nozzle system mounted to the spray or a half-boom with off-center or flood-jet nozzles to treat roadsides.

The main benefits of tractor or ORV mounted systems is control of the spray deposition. The spray solution can be accurately placed along stream buffers, property lines and other sensitive areas to make sure contamination does not occur. Application costs are relatively cheap and are along the lines of broadcast hand applications.

Acknowledgements

The authors wish to thank the following for their reviews of the draft version of this chapter: Herb Baldwin, Danielle Lindler, and Martin Ritchie.

References

Ahrens, W.H. Editor. 1994. Herbicide Handbook-7th Edition. Weed Science Society of America. Champaign, Il. 352 P.

Akesson, N.B., R.E. Cowden and W.E. Yates. 1985. Atomization of Herbicide Simulants with Hollow Cone and Raindrop Nozzles. USDA Forest Service. Forest Pest Management.
FPM 85-1. 103 P.

Akesson, N.B., W.E. Yates and S.E. Wilco. 1970. Key to safe and Effective Aerial Application: Controlling Spray Atomization. Agrichemical Age. December. Pp 10-17.

Allen, B.H. and J.W. Bartolome. 1989. Cattle Grazing Effects on Understory Cover and Tree Growth in Mixed Conifer Clearcuts. Northwest Science. 63(5): 214-219.

Ambach, N.H. and R. Ashfored. 1982. Effects of Variation in Drop Make-up on the Phytotoxicity of Glyphosate. Weed Science. 30:221-224.

Arno, S. F., M.G. Harrington, C.E. Fiedler and C.E. Carlson. 1996. Using Silviculture and Prescribed Fire to Reduce Fire Hazard and Improve Health in Ponderosa Pine Forests. Proc. 17th Ann. Forest Vegetation Management Conference. Redding, Ca pp. 114-118.

Babiker, A.G.T. and H.J. Duncan. 1974. Penetration of Bracken Fronds by Asulam as Influenced by the Addition of Surfactant to the Spray Solution and by pH. Weed Reasearch. 14: 375-377.

Barry, J. W. 1984. Drop Size: Drift and Effectiveness of Herbicide Sprays. Forest Vegetation Management Workshop. Oregon State University. July 17-19. pp 1-22.

Beaudry, P.G. 1990. Downslope Movement of the Herbicide Hexazinone in the SBS Zone. B.C. Ministry of Forests. December 1990.

Brevis, Juan C., T. Lanini, K. Giles, D.C. Slaughter, D. Downey and C. Gliever. 2004. Weed Control Using a Prescision Application System with Image Vision. Proc. Cal. Weed Sci. Soc. 56: 139-140.

Brewster, B.D. and A.P. Appleby. 1990. Effect of Rate, Carrier Volume, and Surfactant on Imazamethabenz Efficacy. Weed Technology. 4: 291-293.

Buhler, L. and O.C. Burnside. 1987. Effects of Application Variables on Glyphosate Phytotoxicity. Weed Technology. 1:14-17.

Busse, M.D., N.G. Rapaport, and R.F. Powers. 2000. Tolerance of Soil Organisms to Herbicide Applications in Ponderosa Pine Plantations. Proc. 21st Ann For. Veg. Mgt. Conf. Redding, Ca. pp 33-38.

Chandran, R.S. and L.W. Jett. 2009. Weed Management in Vegetables. West Virginia University Extension. Extension Bulletin. 2009.

Chase, C. A., J.M. Scholberg and G.E. MacDonald. 2004. Preliminary Evaluation of Nonsynthetic Herbicides for Weed Management in Organic Orange Production. Proc. Fla. State Hort. Soc. 117:135-138.

Coates, K.D., M.J. Douglas, J.W. Schwab and W.A. Bergerud. 1993. Grass and Legume Seeding on a Scarified Coastal Alluvial Site in Northwestern British Columbia: Response of Native Non-Crop Vegetation and Planted Sitka Sprice (Picea sitchensis(Bong.) Carr.) Seedlings. New Forests. 7:193-211.

Cole E.C. and M. Newton. 1989. Seasonal Efficacy Comparison of Two Glyphosate Formulations. Proc. Western Soc. Of Weed Sci. 42:136-141.

Craig, S. and J. McHenry. 1988. Mulch Collars for Preventing Vegetation Around Conifer Seedlings: A Test of Several Methods. Proc. 9th Ann For. Veg. Mgt. Conf. Redding, Ca. pp 142-150.

Crammer, J.R. and D.L. Lindscott. 1990. Droplet Make-up and the Effect on Phytotoxicity in Glyphosate. Weed Science. 38:406-410.

Curran, W.S., D.D. Lingenfelter and C.B. Muse. 2005. Effectiveness of Vinegar and Clove Oil for Control of Annual Weeds. Poster Session. Weed Science Society of America. 2005. 1 P.

D'Anjou, B. 1990. Growth Response of Several Vegetation Species to Herbicides and Manual Cutting Treatments in the Vancouver Forest Region. FRDA Report #135. B.C. Ministry of Forests. 6 P.

DiTomaso, J.M., G.B. Kyser and E.A. Fredrickson. 2004. Control of Black Oak and Tan Oak in the Sierra Nevada Range. W. Jor App. For. 19(4):268-276

Dreistadt, S.H. 2013. Forest and Right of Way Pest Control. Second Edition. University of California. ANR Pub 3336. 340 P.

Evans, Glenn J. and R.R. Bellinder. 2009. The Potential Use of Vinegar and a Clove Oil Herbicide for Weed Control on Sweet Corn, Potato and Onion. Weed Tech. 23(1): 120-128.

Fan, Z., J.A. Moore, B. Shafii and H.L. Osborne. 2002. Three Year Responses of Ponderosa Pine Seedlings to Controlled Release Fertilizer Applied at Planting. West. J. Appl. For. 17(3): 154-164.

Fiddler, G. O. and P.M. McDonald. 1997. Mechanical and Chemical Release Applied to a 12 Year Old Pine Plantation. USDA Forest Service. Pacific Southwest Forest and Range Experiment Station. Research Paper. PSW-RP-232. 12 P.

Fiddler, G. O. and P.M. McDonald. 1999. Treatment Duration and Time Since Disturbance Affect Vegetation Development in a Young Ponderosa Pine Plantation. USDA Forest Service. Pacific Southwest Research Station. Research Note. PSW-RN-424. 8 P.

Fiddler, G. O., P.M. McDonald and S.R. Mori. 2000. Mechanical and Chemical Release Applied to a 16 Year Old Pine Plantation. USDA Forest Service. Research Note. PSW-RN-425. 10 P.

Fisk, J.N. 1984. Estimating Effects of Competing Plants on Conifer Growth and Yield, and Determining Release Needs. Proc. 6th Ann. For. Veg. Mgt. Conf. Nov 1-2, Redding, Ca. pp. 129-143.

Fredrickson, E. A. 1994. Efficiency of Forest Vegetation Control with Herbicides. Oregon State University. M.S. Thesis. 204 P.

Fredrickson, E.A. and M. Newton. 1998. Maximizing Efficiency of Forest Herbicides in the Sierra Nevada and Oregon. User Guide. Corvallis, Or. Oregon State University. Research Contribution 19. 45 P.

Fredrickson, E.A. 2002. Fall Planting in Northern California. USDA Forest Service. Rocky Mountain Research Station. Proc. RMRS-P-28. pp 159-161.

Fredrickson, E.A. 2004. Pre-Harvest Site Preparation with Herbicides. Abstract. 25th Ann. For. Veg. Mgt. Conf. Redding, Ca. p. 79.

Fredrickson. E.A. 2005. The Influence of Initial Stock Size on Seedling Survival and Growth. Presentation for the 26th Ann. For. Veg. Mgt. Conf. Redding, Ca.

Fuller, J. L. 2002. Assessing the Safety of Biological Weed Control: A Case Study of the Cinnabar Moth. M.S. Thesis. Oregon State University. 59 P.

Fullmer, D.G. 1986. Sheep Grazing for Plantation Release: A Foresthill Ranger District Case Study. Proc. 8th Ann. Forest Vegetation Management Conference. Sacramento, Ca. pp. 149-163.

Gratkowski, H. and R. Stewart. 1973. Aerial Spray Adjuvants for Herbicide Drift Control. USDA Forest Service. Pacific Northwest Forest and Range Experiment Station. General Technical Report. PNW-3. 18 P.

Harper, G.J., P.G. Comeau and B.S. Biring. 2005. A Comparison of Herbicide and Mulch Mat Traetments for Reducing Grass, Herb and Shrub Competition in the BC Interior Douglas-Fir Zone- Ten Year Results. West. J. Appl. For. 20(3): 167-176.

Harrington, T. B. and S.D. Tesch. 1992. Manual Cutting In Forest Vegetation Management. Proc. Forest Vegetation Management Without Herbicides. Oregon State University. pp 112-117.

Haywood, J. D. 1999. Durability of Selected Mulches, Their Ability to Control Weeds, and Influence Growth of Loblolly Pine Seedlings. New Forests. 18: 263-276.

Haywood, J. D. 2000. Mulch and Hexazinone Herbicide Shorten the Time Longleaf Pine seedlings are in the Grass Stage and Increase Height Growth. New Forests. 19:279-290.

Helms, J.A., C. Hipkin, and E.B. Alexander. 1986. Effects of Soil Compaction on Height Growth of a California Ponderosa Pine Plantation. West. Jor. App. For. 1: 104-108.

Hess, D. and R.H. Faulk. 1990. Herbicide Deposition on Leaf Surfaces. Weed Science. 38:280-288.

Hollaway, J.K. 1964. Projects in Biological Control of Weeds. P. Debach editor. Biological Control of Insect Pests and Weeds. Reinhold Publishing Corp. New York. pp 650-670.

Hudson, B.D. 1994. Soil Organic Matter and Available Water Capacity. Jor. of Soil and Water Cons. 49(2): 189-194.

Isaacson, D. and M.H. Brooks. 1999. Weed Control: Extended Abstracts from the 1997 Interagency Noxious Weed Symposium. USDA Forest Service FHTET-98-12, June. 59 P.

Jackson, N.E. and M.D. Lemon. 1986. Timing of Application Studies with Roundup Herbicide for Control of Bear Clover (*Chamaebatia foliolosa*) in California Forestry. Proc. 8th Ann. For. Veg. Mgt. Conf. Nov 5-6. Sacramento, Ca. pp. 113-119.

Jackson, N.E. and M.D. Lemon. 1988. *Roundup herbicide for control of bear clover (Chamaebatia foliolosa) in California forestry*. Paper presented at the 8th Annual Forest Vegetation Management Conference.

Johnson, S.A. 1987. Pronone Herbicide: A Granular Hexazinone Formulation for Site Preparation and Conifer Release. Proc. 9th Ann. For. Veg. Mgt. Conf. Nov 3-5. Redding, Ca pp:34-42.

Kauffman, J.B. 1992. Prescribed Fire in Forest Vegetation Management: A Research Synthesis. Proc. Forest Vegetation Management Without Herbicides. Oregon State University. Corvallis, Or. Feb 18-19. pp 25-28.

Kelpas, B., & Landgren, C. (2018). Forestry and Hybrid Cottonwoods In E. Peachy (Ed.), *Pacific Northwest Weed Management Handbook [online] https://pnwhandbooks.org/weed* Corvallis, Oregon: Oregon State University.

Ketchum, J.S. and R. Rose. 2000. Interaction of Initial Seedling Size, Fertilization and Vegetation Control. Proc. 21st Ann. For. Veg. Mgt. Conf. Jan 18-20. Redding, Ca. pp 63-69.

Knowe, S. A. 1992. Manual Techniques for Managing Woody Competition: An Overview. Proc. Forest Vegetation Management Without Herbicides. Oregon State University. pp. 90-91.

Kruger, W.C. and M. Vavra. 1984. 20th Year Results from a Plantation Grazing Study. Oregon Agricultural Experiment Station. Special Report 715: 20-24.

McDonald, P., G.O. Fiddler, R.A. Tucker and A. Colaninno. 1989. Manual Release in an Old Douglas-Fir Plantation Increases Diameter Growth. USDA Forest Service. Research Note. PSW-405. 3 P.

McDonald, P. and G.O. Fiddler. 1990. Ponderosa Pine Seedlings and Competing Vegetation: Ecology, Growth and Cost. USDA Forest Service. Research Paper. PSW-199. 10 P.

McDonald, P.M. and G.O. Fiddler. 1992. Mulching and Grubbing Techniques in Forest Vegetation Management: A Research Synthesis. Proceedings of a Workshop on Vegetation Management without Herbicides. Oregon State University. Corvallis, Or. Feb 18-19. pp 92-98.

McDonald, P. M. and G.O. Fiddler. 1993. Vegetative Trends in a Young Conifer Plantation After Ten Years of Grazing by Sheep. USDA Forest Service. Research Paper. PSW-RP-215. 9P.

McDonald, P. M., G.O. Fiddler and W.T. Henry. 1994. Large Mulches and Manual Release Enhance Growth of Ponderosa Pine Seedlings. New Forests. 8:169-178.

McDonald, P.M. and G.A. Everest. 1996. Response of Young Ponderosa Pines, Shrubs and Grasses to Two Release Treatments. USDA Forest Service. Pacific Southwest Research Station. Research Note. PSW-RN-419. 8 P.

McDonald, P.M. and C.S. Abbott. 1997. Vegetation Trends in a 31-Year-Old Ponderosa Pine Plantation: Effect of Different Shrub Densities. USDA Forest Service. Pacific Southwest Forest and Range Experiment Station. Research paper PSW-RP-231.

McDonald, P. and G.O. Fiddler. 1999. Recovery of Bear Clover (Chamaebatia foliolosa) Plant Community After Site Preparation and Planting of Ponderosa Pine Seedlings. USDA Forest Service. Research Note. PSW-RN-423. 7 P.

McDonald, P.M. and G.O. Fiddler. 2001. Timing and Duration of Release Treatments Affect Vegetation Development in a Young California White Fir Plantation. USDA Forest Service. Pacific Southwest Forest and Range Experiment Station. Research paper PSW-RP-246.

McDonald, P. and G.O. Fiddler. 2007. Development of Vegetation in a Young Ponderosa Pine Plantation: Effect of Treatment Duration and Time Since Disturbance. USDA Forest Service. Research Paper. PSW-RP-251. 23 P.

McHenry, W.B., A. Scarlett, T.F. Robson and L. Lindstrand Jr. 1982. Chemical and Mechanical Grass Control. Proc. 4th Ann. Forest Vegetation Management Conference. Eureka, Ca. pp.47-55.

Milliman, L.J. 1999. Effects of Sheep Grazing to Control Weeds in a Pine Plantation on Weed Reproductive Success, Trees and Sheep Performance. M.S. Thesis. Oregon State Univiersity. 82 P.

Moran, P.J. and S.M. Greenberg. 2006. Winter Cover Crops and Vinegar as Weed Control Techniques in Sustainable Cotton production. Proc. National Cotton Council Beltwide Cotton Conference. San Antonio, Tx. pp. 2188-2195.

Neary, D.G., P.B. Bush and J.E. Douglas. 1983. Off-site Movement of Hexazinone in Stormflow and Baseflow from Forest Watersheds. Weed Science. 31: 543-551.

Newton, M. and F.N. Dost. 1984. Biological and Physical Effects of Forest Vegetation Management. Final Report, Washington Department of Natural Resources. 423 P.

Newton, Michael and D.S. Preest. 1988. Growth and Water Relations of Douglas-Fir (Pseudotsuga menziezii) Seedlings Under Different Weed Control Regimes. Weed Science. 36: 653-662.

Newton, M. and E.C. Cole. 1993. Tall Planting Stock for Enhanced Growth and Domination of Brush in the Douglas-Fir Region. New Forests. 7:107-121.

Oester, P. T., W. Emmingham, P. Larson and S. Clements. 1995. Performance of Ponderosa Pine Seedlings Under Four Herbicide Regimes in Northeast Oregon. New Forests. 10:123-131.

Oliver, W.W. 1984. Brush Reduces Growth of Thinned Ponderosa Pine in Northern California. USDA Forest Service. Pacific Southwest Forest and Range Experiment Station. Research paper PSW-172.

O'Sullivan, P.A., J.T. O'Donovan, and W.M. Hamman. 1981. Influence of Non-ionic Surfactants, Ammonium Sulphate, Water Quality and Spray Volume on the Phytotoxicity of Glyphosate. Can. Jor. of Plant Sci. 61: 391-400.

Owen, M. D. 2002. Acetic Acid (Vinegar) for Weed Control Revisited. Extension Bulletin. Iowa State University. July 8, 2002.

Paley, S.M. and S.R. Radosevich. 1984. Effect of Physiological Status and Growth of Ponderosa Pine (Pinus ponderosa) and Greenleaf Manzanita (Arctostaphylos patula) on Herbicide Selectivity. Weed Sci. 32:395-402.

Pendl, F. and B. D'Anjou. 1990. Effect of Manual Treatment Timing on Red Alder Regrowth and Conifer Response. FRDA Report #112. B.C. Ministry of Forests. 14 P.

Peterson, T.D., M. Newton and S.M. Zedaker. 1988. Influence of Ceonothus Velutinus and Associated Forbs o the Water Stress and Stemwood Production of Douglas-Fir. For. Sci. 34(2): 333-343.

Pitcairn, Michael, J. 1999. Advancements in Biological Control of Weed Species Via Insects and Fungi. Proc. 20th Annual Forest Vegetation Management Conference, Redding, Ca. pp. 60-63.

Potter, D.A. 1984. Control of Bear Clover. Proc. 6th Ann. For. Veg. Mgt. Conf. Nov 1-2. Redding, Ca. pp 144-150.

Powell, R. L. 1992. Prescribed Fire for Conifer Regeneration in the Oregon Coast Range. Proc. Forest Vegetation Management without Herbicides. Oregon State University, Feb 18-19. pp.33-38.

Powers, R.F. and G.O. Fiddler. 1997. The North American Long-Term Soil Productivity Study: Progress Through the First Five Years. Proc. 18th Ann. For. Veg. Mgt. Conf. Jan 13-16. Redding, Ca. pp 88-102.

Powers, R. F. and P.E. Reynolds. 1999. Ten Year Responses of Ponderosa Pine Plantations to Repeated Vegetation and Nutrient Control Along an Environmental Gradient. Can. Jor. For. Res. 29: 1027-1038.

Radosevich, S.R., E.J. Ronconi, S.G. Conard, and W.B. McHenry. 1984. Seasonal Tolerance of Six Coniferous Species to Eight Foliage-Active Herbicides. Forest Science. 26:3-9.

Radosevich, S.R. 1984. Interference Between Greenleaf Manzanita (*Arctostaphylos patula*) and Ponderosa Pine (*Pinus ponderosa*). Seedling Physiology and Reforestation Success. Duryea, M.L. and Brown, G.N. editors. Martinus Nijhoff and Dr. W. Junk publishers. Boston. pp 259-270.

Rhodes, R.C. 1980. Studies with C14-Labeled Hexazinone in Water and Bluegill Sunfish. Agricultural and Food Chemistry. 28(2): 306.

Rose, R. and S.J. Ketchum. 2002. Interaction of Vegetation Control and Fertilization on Conifer Species Across the Pacific Northwest. Can. J. For. Res. 32:1-17.

Sharrow, S.H. 1992. Animal Grazing in Forest Vegetation Management: A Research Synthesis. Proc. Forest Vegetation Management Without Herbicides. Oregon State University. pp.53-60.

Simard, S. and J. Heineman. 1996. Nine Year Response of Douglas-Fir and the Mixed Hardwood-Shrub Complex to Chemical and Manual Release Treatments on an ICHmw2 Site Near Salmon Arm. FRDA Report #257. B.C. Ministry of Forests. 15 P.

Sparks, B.D., A. Sundaram, L. Kotlyar, J.W. Leung and R.D. Curry. 1988. Physiochemical Properties Deposition Pattern of Some Newtonian Spray Mixtures of Glyphosate Containing Two Spray Modifier Adjuvants. Jor. Env. Sci. Health. B23(3): 235-266.

South, D.B., J.L. Rakestraw and G.A. Lowerts. 2001. Early Gains from Planting Large Diameter Seedlings and Intensive Management are Additive for Loblolly Pine. New Forests. 22:97-110.

Steen, Ordell and A. Smith. 1991. Grass and Legume Seeding for Vegetation Control on Blade Scarified Sites in the ICH and ESSF Zones in the Central Interior of British Columbia. FRDA Report #182. B.C. Ministry of Forests. 23 P.

Stevens, P. J. G. and J. A. Zabkiewicz. 1990. New Formulation Technology-Silwet Organosilicone Surfactants have Physical and Physiological Properties which Enhance the Performance of Sprays.

Proc. 9th Australian Weed Conference. Editor J.W. Heep. August 6-10. Adelaide Convention Center. Adelaide, South Australia. pp 327-331

Sundaram, A. 1990 (a). Effect of Nalcotrol 11 on Bioavailability of Glyphosate in Lab Trials. Jor. of Env. Sci. Health B 22(3): 319-346.

Sundaram, A. 1990 (b). Influence of Two Polymeric Adjuvants on Physical Properties, Droplet Spreading and Drying Rates, and Foliar Uptake and Translocation of Glyphosate in Vision Formulation. ASTMSTP 1086. American Society for Testing and Materials

Tappenier, J.C. and S.R. Radosvich. 1982. Effect of Bearmat (*Chamaibatia foliolosa*) on Soil Moisture and Ponderosa Pine (Pinus ponderosa) Growth. Weed Science 30:98-101.

Taylor, S.W., B.C. Hawkes, R.H. Silversides and M.G. Weber. 1991. Initial Effects of Prescribed Fire and Mechanical Site Preparation on Seedling Environment and Establishment on a Backlog NSR Site in Central Interior British Columbia. FRDA Report #177. B.C. Ministry of Forests. Canadian Forest Service. 29 P.

Thomas, D.F. 1983. The Use of Sheep to Control Competing Vegetation in Conifer Plantations. Proc. 5th Ann. Forest Vegetation Management Conference. Sacramento, Ca. pp. 138-142.

Timmer, V.R. 1997. Exponential Nutrient Loading: A New Fertilization Technique to Improve Seedling Performance on Competitive Sites. New Forests. 13: 279-299.

Wagner, R.G., and M.W. Rogozynski. 1994. Controlling Sprout Clumps of Bigleaf Maple with Herbicides and Manual Cutting. Western. Jor. App. For. 9(4): 118-124.

Wall, R.E. 1996. Pathogenicity of the Bioherbicide Fungus Chondrostereum purpureum to Some Trees and Shrubs of Southern Vancouver Island. Report. B.C. Ministry of Forests. Canadian Forest Service. 18 P.

Wall, R.E. and S.F. Shamoun. 1990. Experiments on Vegetation Control with Native Pathogenic Fungi in the Southern Interior of British Columbia. FRDA Report #134. B.C. Ministry of Forests. Canadian Forest Service. 17 P.

Weatherspoon, P. C. 1987. Prescribed Burning for Vegetation Management: Effects on *Ceonothus velutinus* Seeds in the Deff and Soil. Proc. 9th Ann. Forest Vegetation Management Conference. Redding, Ca. pp. 125-141.

Webster, J. and E.A. Fredrickson. 2005. Lessons Learned on 50,000 Acres of Plantation in Northern California. USDA Forest Service. Pacific Southwest Forest and Range Experiment Station. Gen. Tech. Rep. PSW-GTR-198

White, D. E. and M. Newton. 1989. Competitive Interactions of Whiteleaf Manzanita, Herbs, Douglas-Fir and Ponderosa Pine in Southwest Oregon. Can. J. For. Res. 19: 232-238.

White, D. E., L. Witherspoon-Joos and M. Newton. 1990. Herbaceous Weed Control in Conifer Plantations with Hexazinone and Nitrogen Fertilizations. New Forests. 4:97-105.

Whitehead, R. and G.J. Harper. 1998. A Comparison of Four Treatments for Weeding Engelmann Spruce Plantations in the Interior Cedar Hemlock Zone of British Columbia: Ten Years After

Treatment. Information Report BC-X-379. Canadian Forest Service, Victoria British Columbia. 21 P.

Young, B.W., C.A. Hart and F.R. Hall. 1987. The Use of "Dial-a-Drop" Concept in the Study of Droplet Impaction with Leaf Surfaces. Aspects of App. Biol. 14:23-33