SILVICULTURAL TECHNOLOGY AND APPLICATIONS FOR FOREST PLANTATION ESTABLISHMENT WEST OF THE CASCADE CREST

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ABSTRACT

Research and operational trials have identified methods of forest plantation establishment that promote high rates of survival and early growth of tree seedlings in the Pacific Northwest. Primary reasons for this success are the intensive control of competing vegetation provided by herbicide treatments and the planting of high quality seedlings. This paper discusses the current state of the art in forest plantation establishment in Oregon and Washington west of the crest of the Cascade Range. It considers technologies developed in the last two decades that currently have widespread application on lands managed primarily for wood products. The focus of this review is on even-aged silviculture of conifer seedlings, especially coastal Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) but other species, silvicultural systems, and regions are considered where appropriate.

KEYWORDS: Vegetation management, nursery technology, tree planting, Douglas-fir.

BACKGROUND

In western Oregon and Washington (i.e., the "Westside"), nearly half of all timberland is publicly owned. The federal government owns 38% and state agencies control 11% of all timberland in this region. Remaining ownership is dominated by industrial (34%) and other private landowners (17%), including various tribal ownerships (Bolsinger et al. 1997, Alig et al. 2003, Haynes 2003, Campbell et al. 2004). Each of these landowner classes differs strongly in their management philosophies and constraints. In the last decade, federal forestry agencies have had to operate within a litigious environment, and as a result, their timber harvest currently is focused on salvage from fire and insect disturbances (Malmsheimer et al. 2004). State-managed forest lands work under a range of constraints and objectives including those of a federal Habitat Conservation Plan for lands of the Washington State Department of Natural Resources, various land trust concerns, and economic mandates (Coyner and Coyner 2004, OSDF 2004a, Washington DNR 2004). With the exception of tribal owners, private landowners operate under state Forest Practices Laws, the federal Clean Water Act, and the Endangered Species Act. The Sustainable Forestry Initiative includes additional self-imposed regulations by forest industry (SFB 2004). As a result of these various conditions and constraints, most of the timber harvest on the Westside comes from private land (87%). Only 2% of the harvest comes from federal lands with the remaining 11% from state-managed timberlands (Larsen and Nguyen 2004, OSDF 2004b).

The private forest industry faces increasing regulatory restrictions as urban and suburban interfaces move ever closer to its land. Increasing property values from real estate development are shifting land investment away from traditional forestry practices in some areas (Alig et al. 2003). Facing global competition for wood products, Westside industrial landowners are pushed towards intensive silviculture and lower rotation ages as they continue to protect public resources and control treatment costs (Talbert 2004).

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PREDOMINANT LIMITING FACTORS

Much of the forest land on the Westside is classified as the Western Hemlock (*Tsuga heterophylla* (Raf.) Sarg.) Zone because of the species' potential to establish and ultimately dominate most forest plant communities (Franklin and Dyrness 1973). Douglas-fir is the primary crop species, with occasional planting of western hemlock, western redcedar (*Thuja plicata* Donn ex D. Don), and red alder (*Alnus rubra* Bong.) (Briggs and Trobaugh 2001). Forest site quality is determined largely by soil depth, soil texture and rainfall (Steinbrenner 1981). Nitrogen is the macronutrient most limiting to forest productivity (Heilman 1981).

Douglas-fir seedlings require moderate to high levels of sunlight for optimal development. Mailly and Kimmins (1977) found that seedlings need at least 40% of full sunlight to ensure survival and continued morphological development, although maximum growth rate occurs under full sunlight conditions (Drever and Lertzman 2001). In contrast, western redcedar seedlings require only 10% of full sunlight to survive (Wang et al. 1994), and their maximum growth rate occurs at 30% of full sunlight (Drever and Lertzman 2001).

Experiments throughout the region testing two-aged and uneven-aged silvicultural systems have identified significant reductions in conifer seedling growth from overstory shade and other resource limitations (Brandeis et al. 2001, Mitchell 2001, York et al. 2004). Such multi-cohort methods of regeneration can be challenging to establish and maintain; thus, most of the wood-producing industrial forests on the Westside are managed using even-aged silvicultural systems with clearcutting the dominant method of regeneration (Smith et al. 1997).

Competing Vegetation

Perhaps the most important biological constraint to establishment of Westside forest plantations is competition for limited resources from competing vegetation. Intense shade and early-season depletion of soil moisture occur when development of competing vegetation goes unchecked. For at least five decades, forest managers have been aware of the competitive pressure that results from tall-growing hardwoods and shrubs. Reductions in Douglas-fir height growth have been directly related to the amount of shade at or above half of the tree's height (Ruth 1956, Howard and Newton 1984, Wagner and Radosevich 1991a). In addition, severe competition for soil water can result from as little as 20% crown cover of woody vegetation (Oliver 1984, Shainsky and Radosevich 1986, White and Newton 1989).

About fifteen years ago, Westside foresters became keenly aware of the importance of competition from herbaceous vegetation (Newton and Preest 1988, Petersen et al. 1988, White and Newton 1989, Hughes et al. 1990, Wagner 2000). Many of the common grass and forb competitors invade recently harvested sites by wind dispersed seed. During the first three years of plantation establishment they compete strongly with conifer seedlings for soil water, sometimes depleting available supplies early in the growing season (Newton and Preest 1988).

Invasive species of all types are a continual threat to ecosystems throughout the United States (National Biological Information Infrastructure 2004). Recent changes in Westside plant communities resulting from invasion by non-native species may intensify the competitive pressure that already exists for conifer seedlings during plantation establishment. Species such as Scotch broom (*Cytisus scoparius* (L.) Link.), Himalayan blackberry (*Rubus discolor* Weihe & Nees), and Japanese knotweed (*Polygonum cuspidatum* Sieb. & Zucc.) establish soon after a site disturbance such as clearcutting. Once established, their seed or bud banks can survive for extended periods of time, making them long-term residents of Westside forest communities. Other species, such as English holly (*Ilex aquifolium* L.), English ivy (*Hedera helix* L.), and false-brome (*Brachypodium sylvaticum* (Huds.) Beauv.), are shade tolerant and capable of establishing in a wide range of light environments. Thus, they may already be present in a forest community at the time of timber harvest and able to quickly increase their abundance in response to the disturbance.

Wildlife Damage

Damage to conifer seedlings from black-tailed deer (*Odocoileus hemionus columbianus* Richardson), Roosevelt elk (*Cervus canadensis roosevelti* Merriam), and mountain beaver (*Aplodontia rufa pacifica* Merriam) can be particularly devastating during establishment of Westside forests (Black et al. 1979). Their effects on early growth of Douglas-fir seedlings are so significant that often silvicultural studies must be fenced to eliminate confounding of tree responses from animal damage. Western redcedar is particularly vulnerable to browsing by deer and elk because of its high palatability, whereas western hemlock is generally avoided. Brandeis et al. (2002) found that, when browsed for three consecutive years, cedar had only 56% of the stem volume of non-browsed seedlings

Root and Foliage Pathogens

The common root disease of Westside forests, laminated root rot (*Phellinus weirii* (Murr.) Gilb.), is generally considered a site-specific problem that impacts yield but does not destroy entire stands (Thies and Sturrock 1995). Since 1990, the foliage disease, Swiss needle cast (*Phaeocryptopus gaeumannii*), has reached epidemic status and caused significant growth losses in coastal Douglas-fir (Maguire et al. 2002). However, recent aerial surveys suggest that the Swiss needle cast epidemic may be stabilizing or even subsiding (Kanaskie et al. 2004). Sudden oak death (*Phytophthora ramorum*) is a potential future threat to forest stands because of its wide variety of plant hosts and ability to invade through either the stem or foliage, depending on the host.

Environmental Regulations

Although these biological constraints can pose some unique challenges to plantation establishment, often the overriding constraints to management activities are environmental regulations imposed by government agencies or self-imposed by forest industry. National and state environmental protection laws impact reforestation activities significantly. In addition, a relatively recent development in forest management is the emergence of an activist citizenry that has the time and resources to challenge specific management activities of public and private landowners. National Forests are often involved in years of administrative appeals prior to final adoption of management plans (Teich et al. 2004; Malmsheimer et al. 2004). These laws and/or social pressures can directly influence the entire range of forest management activities.

For example, new forest practices laws for riparian zones (to safeguard threatened fish species) have significantly increased the area that is non-managed or managed at low intensity. Adjacency constraints in the Sustainable Forestry Initiative and state Forest Practices Laws can determine the location of future timber harvests and even reduce a landowner's planned harvest levels. Adjacency constraints also encourage managers to make large investments in silvicultural treatments to accelerate the development of young stands so they will meet the "green-up" requirements that enable the harvest of an adjacent stand. Air quality ("smoke management") rules have almost eliminated the use of broadcast burning for site preparation on the Westside.

TECHNOLOGY APPLICATIONS

A wide variety of research programs within universities, government laboratories, and private industry have developed successful approaches for regenerating Westside forests given the challenges posed by competing vegetation, animal damage, and pathogens. These techniques are contributing to an ever-increasing intensity of silviculture that accelerates the rate at which forest plantations become merchantable.

Vegetation Management

A considerable amount of research on plantation establishment has contributed to a conceptual framework of "crop" seedling responses to vegetation management. Many of these concepts have been borrowed from the agricultural literature (Cousens 1987) and applied successfully to forestry. The following are three major contributions to this conceptual framework.

(1) Competition thresholds-(Wagner et al. 1989, Monleon 1999) quantify the "breakpoints" in relationships of crop seedling performance to abundance of competing vegetation. The breakpoints signify large changes in seedling response, and therefore, dictate the abundance at which competing vegetation should be managed to ensure a reasonable return on investment from vegetation management.

(2) Critical-period thresholds-(Wagner et al. 1999, Wagner 2000, McDonald and Fiddler 2001, Rose and Rosner 2004) define the time period when competing vegetation should be controlled (i.e., duration of weed control) in order to prevent reductions in crop seedling performance.

(3) Minimum area of vegetation control-(Dougherty and Lowery 1991, Rose et al. 1999) quantifies the portion of a crop seedling's growing space that must be kept free of competing vegetation to maximize its performance. If the minimum area is less than 100%, a spot treatment can be prescribed that will potentially provide a cost-saving relative to a broadcast treatment.

Intensive control of competing vegetation early in stand establishment is being attempted on some forest sites as a means of maximizing productivity and accelerating the rate of stand development. Larger-scale use of backpack sprayer crews is providing forest managers with the flexibility to conduct vegetation management treatments in local problem areas. Pre-harvest herbicide applications are being used successfully in southwestern Oregon and northwestern California to provide more effective control of evergreen woody vegetation than from conventional post-harvest methods (Fredricksen 2005). While herbicides are a critical tool for Westside plantation establishment, all of the new products now in use have much lower toxicity to mammals and fish compared to older products. In addition, most of the newer products are effective at extremely low application rates (e.g., sulfometuron herbicide typically is applied at 3 ounces or less of active ingredient per acre).

Herbicide technology has improved considerably over the last two decades. Experimental comparisons have demonstrated the effectiveness of thinline applications of imazapyr or triclopyr ester herbicides for controlling bigleaf maple (*Acer macrophyllum* Pursh.), a rapidly growing and difficult-to-control competitor (Wagner and Rogozynski 1994). When added to fall site preparation sprays of imazapyr or glyphosate herbicides, sulfometuron provides effective control of herbaceous vegetation throughout the following growing season (Ketchum et al. 1999), thus, eliminating the need for an additional treatment in the spring. One of the newer herbicides, clopyralid, provides selective control of broadleaf herbs without injuring neighboring Douglas-fir seedlings.

Pre-emergent herbicides have the potential to prevent germination and suppress growth of shrub and hardwood competitors. For example, a greenhouse study demonstrated that hexazinone herbicide reduced germination and suppressed growth of varnishleaf ceanothus (*Ceanothus velutinus* Dougl.), deerbrush ceanothus (*C. integerrimus* H. & A.), and thimbleberry (*Rubus parviflorus* Nutt.) (Rose and Ketchum 2002b). Similarly, hexazinone reduced the survival and growth of seedlings of the invasive shrubs, Scotch broom and Portuguese broom (*Cytisus striatus* Hill) (Ketchum and Rose 2003). Figueroa (1994) found that sulfometuron significantly reduced germination of red alder seedlings.

Non-herbicide methods for controlling competing vegetation also are being developed. After two decades of research on methods for controlling red alder with cutting treatments, Belz (2003) concluded that the greatest mortality occurred when trees were cut at six to seven years of age and 13 to 15 weeks after budbreak, presumably when carbohydrates reserves were at their lowest level. Tappeiner et al. (1996) observed reductions in crown volume and area of bigleaf maple sprout clumps if the parent trees were cut at 1-ft height one or two years before stand harvest. Mulches are being used successfully to both conserve soil water and reduce abundance of competing vegetation adjacent to conifer seedlings (McDonald and Helgerson 1990). Mulching is most effective when the material has high longevity and is applied early in the growing season before soil water has been depleted.

The timing, intensity, and duration of competing vegetation control are essential features to consider for any vegetation management treatment because often they determine treatment cost-effectiveness. Wagner et al. (1999) found that the duration of vegetation control resulting in a continued increase in stem volume index varied among conifer species from two to four years. Manually removing competing vegetation around ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) seedlings provided similar tree growth responses regardless of whether the treatment occurred in years 1-3, years 4-6, or years 1-6 after planting (McDonald and Fiddler 2001). Ten-year growth of Douglas-fir was similar when grown with densities of varnishleaf ceanothus of 0 to 2700 plants/acre, but it decreased by 41% when density exceeded 6070 plants/acre (Monleon et al. 1999). However, regardless of ceanothus density, Douglas-fir growth increased following removal of herbaceous vegetation. Rose et al. (1999) found that Douglas-fir growth increased with area of vegetation control, with maximum values occurring when either 60% (one site) or 100% (two sites) of growing space was treated. Reporting on a large study that compared various levels of vegetation control in western Oregon, Rose and Rosner (2004) found that increases in stem volume were proportional to the total number of years of control for all four conifer species tested. Seedling growth after four years of control resulted in 3- to 18-fold increases in stem volume relative to non-treated seedlings.

Seedling Quality

Quality of Douglas-fir planting stock has improved greatly in the last two decades. These improvements have been prompted by studies attesting to the benefits of large planting stock (Wagner and Radosevich 1991b, Roth and Newton 1996, Rose and Ketchum 2003). In addition, the "target seedling concept," which links specific morphological and physiological traits with field performance, has improved methods of plantation establishment by defining tangible seedling characteristics for nursery managers to cultivate and for foresters to select (Rose et al. 1990). The plug+1 and 1+1 bareroot stock-types are currently accepted standards for plantation establishment on the Westside and have replaced the mainstay of the 1980's, the 2+0 bare root. Exponential nutrient loading is a relatively new concept for nursery fertilization regimes (Timmer 1996) in which fertilizer is applied at an exponentially increasing rate to maintain seedling nutrient content at a constant level, and therefore free from nutrient stress. This approach has been used effectively in forest productivity research to test the upper limit of tree growth responses to fertilization (Powers and Reynolds 1999).

Planting Techniques

Given the current focus on large seedlings, planting is almost entirely done with a planting shovel, replacing the former planting tool of choice, the hoedad. The shovel enables planters to set the roots of large stocktypes in a hole of adequate width and depth, thereby avoiding potential problems associated with shallow planting and deformity of the taproot. Although use of careful planting methods continues to be recommended, (Rose and Morgan 2000), taproot deformity at planting may not cause significant problems to the developing plantation. Surprisingly, Haase et al. (1993) did not find any differences in 10-year survival and growth of Douglas-fir seedlings planted with straight, "L"-shaped, or "J"-shaped root systems. Planting in the fall, as opposed to the winter or early spring, has been used in coastal areas to take advantage of warm soil temperatures in the fall that should translate into increased root growth following planting; however, the authors are not aware of any published research on the benefits of this practice.

Planting Density

Although planting density continues to be an item of debate, most plantations are established at 400 to 500 seedlings/acre. Recent research has indicated that higher planting densities (up to 1200 trees/ac) may stimulate short-term increases in both diameter and height growth of Douglas-fir (Scott et al. 1998; Flewelling et al. 2001). This effect may be the result of a phytochrome response that modifies seedling allometry (Ritchie 1997). Because the growth stimulation associated with high initial densities is relatively short-lived, and reverses after several years, pre-commercial thinning must follow soon thereafter if potential benefits are to be captured. It remains to be seen if these early growth gains due to higher initial densities justify the cost of planting more trees per acre and the need for early pre-commercial thinning.

Genetic Improvement

Possibly more resources have been directed towards genetic improvement of conifers on the Westside than any other yield-improvement treatment. Regional tree improvement cooperatives are now well into second generation testing and breeding efforts. Nearly all large private landowners and some public agencies utilize various levels of genetically improved seed in their regeneration efforts. A recent realized genetic gain study in Oregon estimated a 28% stem volume gain for Douglas-fir (St. Clair et al. 2004). Greater genetic gains than this may be achievable with increased selection differentials (Jayawickrama and Ye 2004). Current programs select for wood quality and stem form factors in addition to increased growth rates. Although the genetic source of seedlings can significantly contribute to stand productivity, research on ponderosa pine indicates this may only happen when they are grown without competing vegetation (McDonald et al. 1999). In the absence of competing vegetation, full-sibling families averaged 1.3 ft taller than "woods-run" families six years after planting; whereas, their heights were not significantly different in the presence of competing vegetation.

Seedling Fertilization

Seedling fertilization is being considered as a technique for accelerating juvenile growth of Douglas-fir. New, slow-release products have been developed that can be combined with the soil medium of container stock or placed directly into the planting hole. Rose and Ketchum (2002a) found that fertilization of Douglas-fir seedlings resulted in increased growth only on sites having adequate soil water. The growth increases associated with fertilization were smaller and more transient than those from control of competing vegetation, probably because the latter is associated with increases in both soil water and nutrients. Roth and Newton (1996) reported decreases in Douglas-fir survival following fertilization with 200 lbs N/ac, a response they attributed, in part, to N-stimulated increases in the abundance of competing vegetation. Powers and Reynolds (1999) found that stem growth responses of ponderosa pine to competing vegetation control and repeated fertilization varied according to the inherent fertility and soil water availability of a given site, with greater responses to fertilization occurring on the less droughty sites.

Treatment Combinations

Various combinations of treatments have been tested during plantation establishment to determine whether they interact to produce synergistic, antagonistic, or simple additive responses of crop seedlings. Synergistic responses indicate that the combined effect of two or more treatments is greater than the sum of responses to the individual treatments applied alone. Antagonistic responses indicate that the combined effect is less than the sum of individual treatment responses, while additive responses occur when the combined effect is equal to the sum of the responses. For example, the addition of repeated fertilization to a sustained vegetation control regime caused neutral, additive, or synergistic responses of ponderosa pine growth, depending on whether the dominant factor limiting tree growth was soil water or fertility (Power and Reynolds 1999; R.F. Powers, personal communication). Rose and Ketchum (2002a, 2003) detected only additive responses of Douglas-fir growth to combinations of seedling size, fertilization, and area of vegetation control. Growth increases from fertilization were greatest on sites with adequate soil moisture, similar to the findings of Powers and Reynolds (1999), but these responses were short-lived as opposed to the sustained responses to vegetation control. Roth and Newton (1996) found that N fertilization had no effect on first-year survival and growth of Douglas-fir when the treatment was combined with control of competing vegetation, but in the absence of vegetation control it reduced seedling performance.

Alternative Crop Species

A wide range of factors are motivating forest managers to consider alternative crop species to Douglas-fir. Among many, these include development of new markets, declining availability of certain raw materials, and increased incidence of forest diseases. The widespread outbreak of Swiss needle cast has prompted increased interest in planting western hemlock on sites formerly planted with Douglas-fir. A survey of all major Westside forest landowners conducted by Briggs and Trobaugh (2001) showed the percentage of western hemlock planted either in mixture with Douglas-fir or by itself began a steady increase in 1999.

Previous research has shown how Douglas-fir, a species of moderate to low shade tolerance, tends to occur in the upper canopy while western hemlock, capable of living in lower light conditions, will occur in the lower canopy of natural stands (Oliver and Larson 1996, Lewis et al. 2000). The ability of these species to occupy different niches suggests that mixtures of them may be more productive than pure stands (Vandermeer 1989). Recent research assessing the differences between Douglas-fir and western hemlock growing in pure and mixed plantations has shown that only at high densities (700 trees/acre) will the cubic volume of mixed stands exceed that of pure stands of either species. Lower densities – 200 and 450 trees/ac – did not show productivity increases from the mixture (Amoroso et al. 2004).

Red alder has become a viable species for plantation silviculture on the Westside. Seed collection, nursery, and planting guidelines have been developed (Hibbs and Ager 1989, Ahrens et al. 1992). Recent interest has developed for planting hybrid poplar (hybrid of *Populus trichocarpa* Torr. & Gray and *P. deltoides* Bartr. ex Marsh.) on farmland in the Willamette Valley of Oregon because of its rapid growth and high yield on poorly drained clay soils (Hibbs et al. 2003). Such stands have produced up to 4000 ft^3/acre in six years on soils considered poor for agriculture.

Minimizing Browse Damage

Although a variety of barrier products exist for protecting conifer seedlings from deer and elk browse (Schaap and DeYoe 1986), many of these can restrict and deform shoot growth if not maintained properly. Gourley et al. (1990) compared growth of tall (2 ft) Douglas-fir seedlings following six methods of protection with or without control of competing vegetation. Control of competing vegetation had the dominant effect, increasing fifth-year height an average of 1 ft regardless of method of protection. In plots where vegetation was controlled, the methods of protection had neutral or negative effects relative to seedlings receiving no protection. It is likely that smaller seedlings, as well as those growing under intense competition, may benefit from protection because their smaller initial size may prolong the time period when they are susceptible to being browsed.

Protecting Soil Productivity

A better understanding of the effects of soil disturbance on forest productivity has been developed (Miller et al. 2004). For example, research in northern California has shown that soil compaction effects on seedling growth can be negative, neutral, or even positive depending on soil texture and soil water regime (Gomez et al. 2002). Reductions in Douglas-fir growth from soil compaction following ground-based harvesting have been shown to last as little as two years in coastal Washington and up to seven years in the Oregon Cascade Mountains (Heninger et al. 2002).

FUTURE NEEDS

Many of the advances in Westside silviculture have been the result of research aimed at providing greater understanding of the mechanisms of tree responses. In following with this approach, areas of research likely to advance the technology of Westside plantation establishment include:

(1) Species- and site-specific competition thresholds- How do tree responses to competing vegetation vary with species and site characteristics? Can models predicting these responses be used to refine vegetation management prescriptions and improve their cost-effectiveness?

(2) Seedling fertilization-What are the reasons for the limited responses of planted seedlings to fertilization, and what are methods that can be used to overcome these limitations?

(3) Minimizing animal damage-While considerable research has gone into developing various products and practices that protect seedlings from animal damage, very few have been shown to be cost-effective. Continued research and development is needed in this area to develop products or practices that reduce these growth losses.

(4) Silvicultural treatment interactions-Can treatment responses be predicted according to the limiting factors on a given site? A general model is needed that links seedling resource needs with the resource supplying power of the site and of specific silvicultural treatments.

(5) Predicting young stand development-New yield models and plantation site index equations are needed to forecast the differential growth rates resulting from various silvicultural treatments during plantation establishment.

(6) Plantation silviculture for alternative crop species- Advanced technology exists for establishing Douglas-fir plantations, yet basic information on seedling responses to treatment is still lacking for western hemlock, western red-cedar, and red alder. These information gaps must be filled if intensive management is to be applied to these alternative crop species.

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