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Competition and Critical Period Thresholds for Vegetation Management Decisions in Young Conifer Stands

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Highlights

- *Objectives for vegetation management should be based on the variable of tree growth that is of greatest interest to forest managers*
- *When achieving near maximum height growth is the principal management objective, preventing seedlings from ever becoming overtopped appears to be adequate in most cases.*
- *If maximizing early stand growth is a production silviculture objective, then all vegetation needs to be considered.*
- *Managing competition for belowground resources must be the main focus of early vegetation control*
- *Capturing maximum early growth rates requires that high levels of vegetation control occur at planting.*
- *Any delays in achieving effective vegetation control will require at least two years of extended vegetation control to compensate for one missed year immediately after planting.*

Abstract

Thresholds define the time when management action is required to prevent a loss in yield, but have remained relatively elusive in forest vegetation management. Hundreds of studies quantifying the effects of competing vegetation in young forest stands, however, have produced reasonably consistent patterns and magnitudes of tree responses. These consistencies reveal a set of general guidelines that can be used to assist forest managers in deciding when vegetation management treatments are needed. Among the variety of vegetation management thresholds that have been defined, competition and critical-period thresholds can be interpreted from existing forest vegetation research. Competition thresholds define the vegetation density at which yield loss begins to occur and varies depending on whether the manager's objective is to maximize survival, height increment, basal area growth, or biomass. These interactions also appear to vary depending on whether woody or herbaceous plants are the principal competitors. The critical-period threshold defines the time period when vegetation control must occur to prevent yield loss. Results from one critical-period study indicate that capturing the potential for conifer growth requires control of vegetation for the first several years after planting.

Introduction

Making sound prescriptions and financial investments for managing forest vegetation requires a clear understanding about how vegetation influences the survival and growth of tree seedlings. Inadequate understanding of these principles can lead to 1) failed plantations, 2) substantial reductions in early stand growth relative to that which could be achieved, and/or 3) wasted expenditures on vegetation control. Thresholds have been proposed as means for incorporating these principles into a decision-support tool for vegetation management.

Hundreds of studies quantifying the effects and mechanisms of vegetative competition in regenerating forest stands have been conducted over the past three decades. Consistencies in the patterns and magnitudes of tree responses to the manipulation of surrounding vegetation have emerged from these studies, and provide a set of general guidelines that can be used for managing vegetation in young conifer stands. These studies also indicate that similar principles apply in young forests ranging from tropical regions to those on desert fringes. Although the patterns described below are drawn from North American examples, the general relationships appear to hold for a wide range of tree species and site conditions.

Threshold Concepts

The idea of a threshold, or the time when some management action is required to prevent a loss in yield, has been an attractive concept in farming and forestry for decades. Threshold concepts have been central to the development of integrated pest management (IPM) approaches since the late 1950s. Although the concept of a threshold for management action appears simple at first glance, it is actually a deceptively complex idea that has proven difficult to define in practice, even for relatively simple systems. Cousens (1987) illustrates this difficulty by describing seven different types of thresholds (competition, statistical, economic optimum, economic, safety, visual, and predictive) for agriculture. All of these thresholds apply to forestry as well. More recently, Brown et al. (1999) expanded the idea to include ecological thresholds for managing vegetation that include ecosystem functions which can signal long-term losses in yield before they occur.

Competition and Critical-Period Thresholds

Despite the challenges associated with defining thresholds, research on vegetative competition in young conifer stands has produced a set of general patterns that can be used to assist managers in deciding when vegetation control treatments should occur. The *competition threshold* has been defined as the "weed density at which yield loss begins to occur" (Cousens 1987). For forests, the competition threshold has been defined as the level of vegetation abundance where there is an abrupt increase or decrease in the rate-of-change in tree growth or survival (Wagner et al. 1989).

Research on the responses of young conifers to competing vegetation suggests that competition thresholds vary with the attribute of stand growth being considered. For example, tree survival responds differently than stem volume growth. Height growth responds differently than basal area growth. Competition thresholds vary, therefore, depending on whether the stand management objective is to maximize survival, height increment, basal area growth, or biomass. And many of these interactions appear to vary depending on whether the chief competitors are woody or herbaceous plants.

The *critical-period threshold*, first developed in agriculture in the late 1960s (Zimdahl 1988), defines the time period during crop development within which weed control must occur to prevent yield loss. Recent work in agriculture has focused on developing critical periods of weed control for a wide variety of agricultural crops. There has, however, been only one controlled study examining critical-period thresholds for North American tree species (Wagner et al. 1999).

The critical-period and competition thresholds are determined by ecological interactions among plants and do not include economic or other considerations. The competition threshold focuses on spatial factors (e.g., vegetation density or competitor size) associated with competition. In contrast, the critical-period threshold focuses on the timing or temporal aspects of competitive interactions. Understanding the factors that determine both kinds of thresholds can provide forest managers with general indications as to when management actions are required, as well as provide the underpinnings for calculations of other kinds of thresholds.

This paper describes competition threshold relationships for conifer survival, height growth, and basal area growth. Results from a critical-period threshold study with four species of conifers also are described.

Tree Survival vs. Stem Volume Growth

Relatively few plant competition studies in forestry have simultaneously quantified changes in both tree survival and growth to increasing vegetation density. At least two studies with ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), however, indicate that tree survival and stem volume growth respond differently to the abundance of neighboring plants (Wagner et al. 1989). The curves have different shapes, and therefore, different competition thresholds (Fig. 1). A maximum-response threshold is achieved when further vegetation control does not produce an increased response. A minimum-response threshold indicates the degree of control that must be achieved before additional control measures can produce a response.

The upward shape of the stem volume curve indicates that maximum growth occurs under very low levels of competition or when all site resources are available. From these curves it is apparent that as

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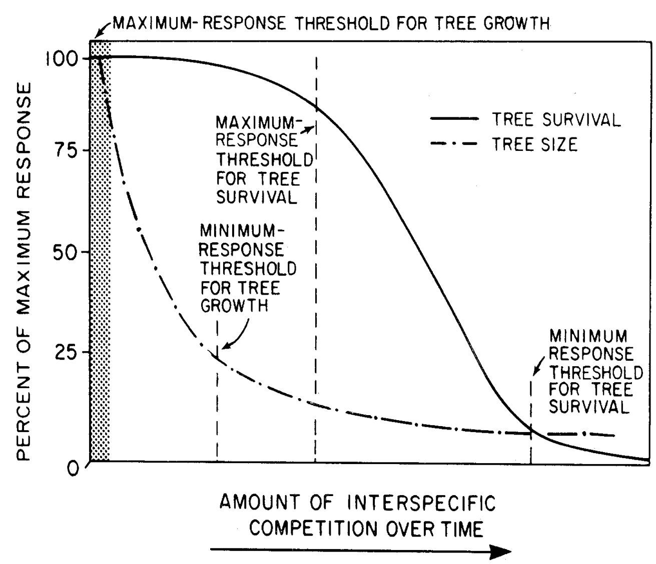

Fig. 1 - Hypothetical relationship between interspecific competition, and tree survival and volume growth. The maximum- and minimum-response thresholds for tree survival and growth occur at different levels of interspecific competition. The maximum-response threshold for tree growth occurs in the shaded region under nearly vegetation-free conditions. (From Wagner et al. 1989)

the density of competitors increases, stem volume declines rapidly and when trees are surrounded by relatively small amounts of vegetation. Conversely, most gains in stem volume growth do not begin until relatively low levels of competition are reached. The shape of the growth curve is consistent with plant yield-density relationships for a wide range of plant species and a wide range in site quality. As competition reaches high levels and trees lose their ability to plastically decrease growth any further, there is an increasing chance they will die. Consequently, the shape of the survival curve is different from that of volume growth.

Data for red pine (*Pinus resinosa* Ait.) data from two separate studies in the Lake States (Benzie 1977; Perala 1982) reveal a similar trend for the growth and survival of this species. Results from other studies around the world commonly find volume growth curves of the same shape for both intolerant and tolerant tree species. Although available studies are much more limited, hardwoods appear to have the same curves as conifers, in many cases being more sensitive to competing vegetation than conifers. Differences in tolerance among tree species are likely to affect the shape of the survival curve rather than the volume curve.

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It is apparent from these differing growth and survival curves that management objectives for regenerating stands need to be determined before objectives for vegetation management can be established. If maximum survival is most important, moderate densities of surrounding vegetation can be maintained in young forests. If maximum stem volume production is desired, substantially lower levels of vegetation abundance are required. Levels of vegetation control achieving 80-90% can often be required to appreciably increase stem volume growth. This level appears to be required on sites of both high and low productivity. The two curves will likely move up on productive sites and down on sites of lower productivity, but the relative shapes of the curves appear to remain the same. Wagner et al. (1989) also showed that the thresholds for survival and growth could be used to select the appropriate rate of herbicide application.

Height vs. Stem Diameter

Height is often considered by foresters to be the most important aspect of tree growth for assessing the success of a regenerating stand. However, a large number of studies have demonstrated that height growth is relatively insensitive to the effects of competition (Zedaker et al. 1987). Therefore, height growth tends to be a poor indicator of competitive stress in young trees. Height appears to be insensitive to competition because it is among the first priority allocations for photosynthate (Larcher 1995), especially when growing in light-limited environments (Luxmoore et al. 1995). This is a useful strategy if trying to get foliage above that of neighboring plants in crowded forest conditions.

This insensitivity, however, does not mean that vegetation control cannot increase height growth. Vegetation control has often been shown to increase height growth. It is just that height is the least sensitive growth variable to competition, the magnitude of responses tend not to be large, and can take several years to be measured if it does respond. When height growth is reduced, it is generally an indication of a substantial level of competitive stress, occurring most often under the low light conditions produced by overtopping woody vegetation. When reductions in height growth do occur, they are likely to be most severe for intolerant tree species.

In some cases, height growth has been observed to increase for a short time under overtopping conditions (Cole and Newton 1987), apparently as a last effort to find light. Following this period of increased height growth, however, rates of height increment will generally decline each year if the tree has not achieved a position above its neighbors. When this annual decline in height increment is observed, trees are showing signs of extreme competitive stress and death is often imminent. Therefore, keeping trees from decreasing in height growth is a means to also reduce survival losses from competing vegetation.

In contrast to height, stem diameter (or basal area) is among the quickest variables of tree growth to be reduced by competing vegetation and therefore is a good indicator of competitive stress in young trees. Photosynthate allocation to cambial growth is apparently a lower priority (Larcher 1995) and thus quite sensitive to any depletion in environmental resources (light, water, and nutrients) caused by competition from neighboring plants. In addition to a consistently high level of sensitivity, competition experiments have revealed that the magnitude of reductions in stem diameter can be quite large. Because stem diameter also is closely correlated with the amount of foliage, roots, and the other biomass components of a tree (Ter-Mikaelian and Korzukhin 1997), it also is an important measure of overall stand production.

This differing sensitivity of height and stem diameter to the effects of competition means that the height/diameter ratio (H:D) for individual trees will vary with levels of competitive stress. H:D values of from 40 to 60 develop when trees are associated with low vegetation densities and values of from 60 to 90 or more are found when young trees are under heavy competition. Because the H:D is a ratio, it is applicable to trees of a wide range of sizes. H:D values also appear to differ among tree species, but the relative influence of competition on the H:D ratio appears to be relatively consistent among tree species.

Woody vs. Herbaceous Vegetation

Woody vegetation (shrubs and hardwoods) has generally been considered as the most competitive type of vegetation in young conifer plantations. Many shrub and hardwood species certainly have high dominance potential (Newton 1973) and are being capable of competitively excluding conifers for long-periods of time in forest stands. When managing the long-term outcome of stand dynamics, therefore, many shrub and hardwood species need to be considered as severe competitors. Some herbaceous species also can reduce the survival of planted trees in certain circumstances (e.g., on excessively dry sites), altering the long-term outcome of stand development. In these circumstances, herbaceous plants also are severe competitors and need to be controlled to ensure regeneration success.

Assessing the competitiveness of woody and herbaceous vegetation in the above circumstances is fairly obvious to most forest managers. Less obvious, however, are the relative competitive effects of woody and herbaceous vegetation in a production silviculture context. That is to say, if the long-term outcome of stand development is not threatened, which type of vegetation is most competitive in terms of reducing overall stand productivity? Research addressing this question has come to fruition over the past decade and can provide some guidance to forest managers interested in maximizing early stand productivity.

Experiments seeking to separate the competitive influence of woody and herbaceous vegetation have recently been conducted in the Pacific Northwest (Petersen and Newton 1985; Wagner and Radosevich 1998), Southeast (Miller et al. 1991; Zutter et al. 1995; Zutter and Miller 1998; Cain 1999), Lake States (Nichols et al. 1995); and Ontario (Bell et al. 2000). Despite substantial differences in tree species and sites conditions, these studies have consistently shown that removing woody vegetation alone can only generally capture about 20-30% of the early volume growth potential. Achieving the remaining 70-80% of the growth potential for a site requires effective control of herbaceous vegetation. Therefore, in contrast to the greater competitiveness of woody vegetation where long-term stand development is concerned, herbaceous vegetation appears to have a greater influence in determining the growth rates of young conifer stands until crown closure. These experiments have shown that only about half of the normal time is required to achieve crown closure when both herbaceous and woody vegetation are controlled for an extended period after planting.

Wagner and Radosevich (1998) were able to differentiate the relative influence of woody (primarily salmonberry [*Rubus spectabilis* Pursh] and thimbleberry [*Rubus parviflorus* Nutt.]) and herbaceous vegetation on the height and basal area growth of coastal Douglas-fir (*Pseudotsuga menziesii* [Mirb] Franco) during the first 5-years after planting. Douglas-fir height growth was determined primarily by the amount of overtopping woody vegetation. Shrubs and hardwoods surrounding seedlings that were greater than 125% of the seedling's height influenced height growth (Fig. 2). Woody and herbaceous vegetation under this relative height did not reduce height growth. As overtopping neighbors exceeded this 125% threshold, their competitive influence increased rapidly, becoming disproportionately more competitive as they got taller (indicating asymmetric competition). Therefore, keeping the heights of surrounding woody plants lower than 125% of the Douglas-fir's height should yield near maximum rates of height growth. The competitive influence of shrubs also was found to decrease rapidly with increasing distance from the seedling (Fig. 3). As a result, keeping an imaginary

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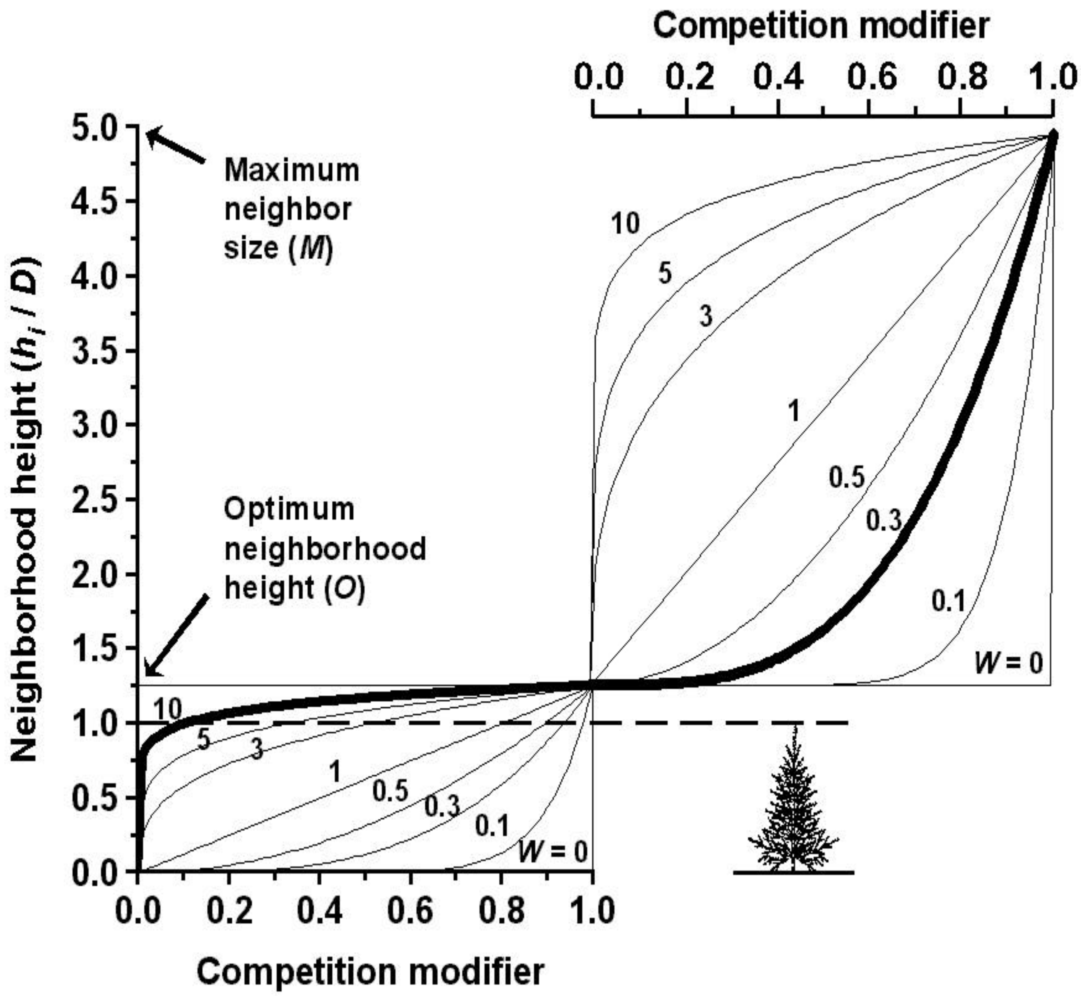

Fig. 2 - Relation between relative height (h_i/D) of surrounding shrubs and their competitive influence on the height growth of Douglas-fir. Thick line depicts shape of relationship. The competitive influence of shrubs is near zero under the height of the tree and rapidly increases as the height of the tree is exceeded. Thin lines depict the range of models tested. (From Wagner and Radosevich 1998)

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inverted cone above a seedling's leader, as suggested by Smith et al. (1997), can ensure that near maximum rates of height growth are achieved. However, this inverted cone appears not to be useful for managing stem diameter or basal area growth.

In contrast to height growth, basal area growth of Douglas-fir was influenced by the abundance or cover of all vegetation surrounding the seedling (Wagner and Radosevich 1998).

The degree of over-topping had little or no influence on diameter growth. As a result, the competitiveness of woody and herbaceous vegetation on basal area growth was nearly equal and correlated only with its abundance (indicating symmetric competition). These differing effects of woody and herbaceous vegetation on height and basal area growth produced contrasting effects on Douglas-fir during the first 5 years of development (Fig. 4).

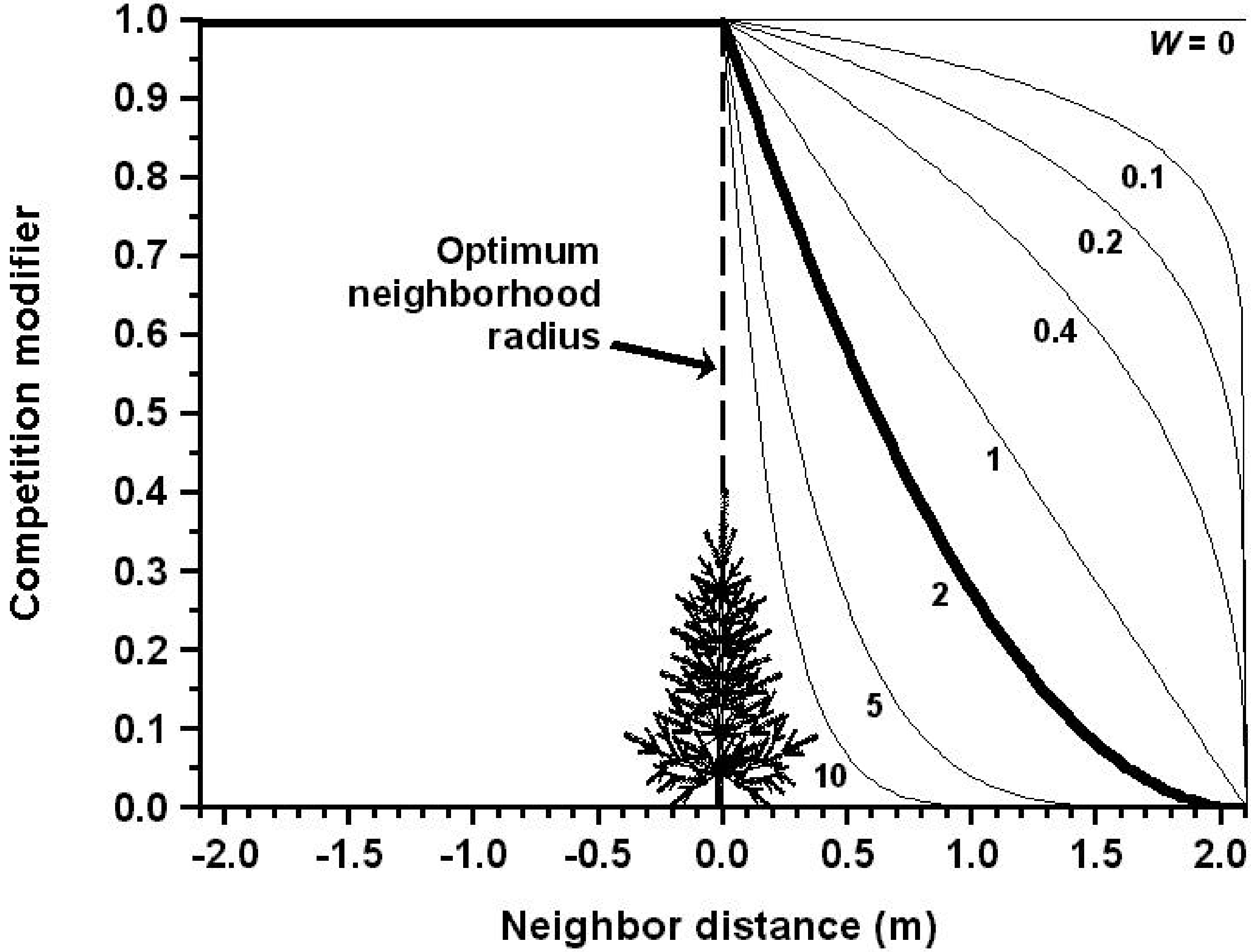

Fig. 3 - Relation between distance of shrubs (measured from crown edge of shrub to Douglas-fir's stem) and their competitive influence on Douglas-fir height and basal area growth. Thick line depicts shape of the relationship. Thin lines depict the range of models tested. (From Wagner and Radosevich 1998)

Timing of Competition

Using a *critical-period threshold* analysis in young forests, Wagner et al. (1999) examined the timing of herbaceous vegetation control on the growth of jack pine (*Pinus banksiana* Lamb.), red pine, eastern white pine (*Pinus strobus* L.), and black spruce (*Picea mariana* (Mill.) B.S.P.) during the first five years after planting in Ontario, Canada. The critical period defines the time period during early stand development when competition from other vegetation reduces tree growth and is determined by the relationship between two curves. The weed-free curve describes the length of time vegetation control efforts must be maintained after planting to prevent significant yield loss. The weed-infested curve describes the length of time vegetation can be associated with the trees before yield is significantly reduced. The linear distance between the points where yield declines significantly on the weed-infested curve and yield levels off on the weed-free curve determines the length of the critical-period. In practical terms, the critical period is the time period between the point when competition begins to reduce tree size and the point when additional vegetation control no longer increases tree size.

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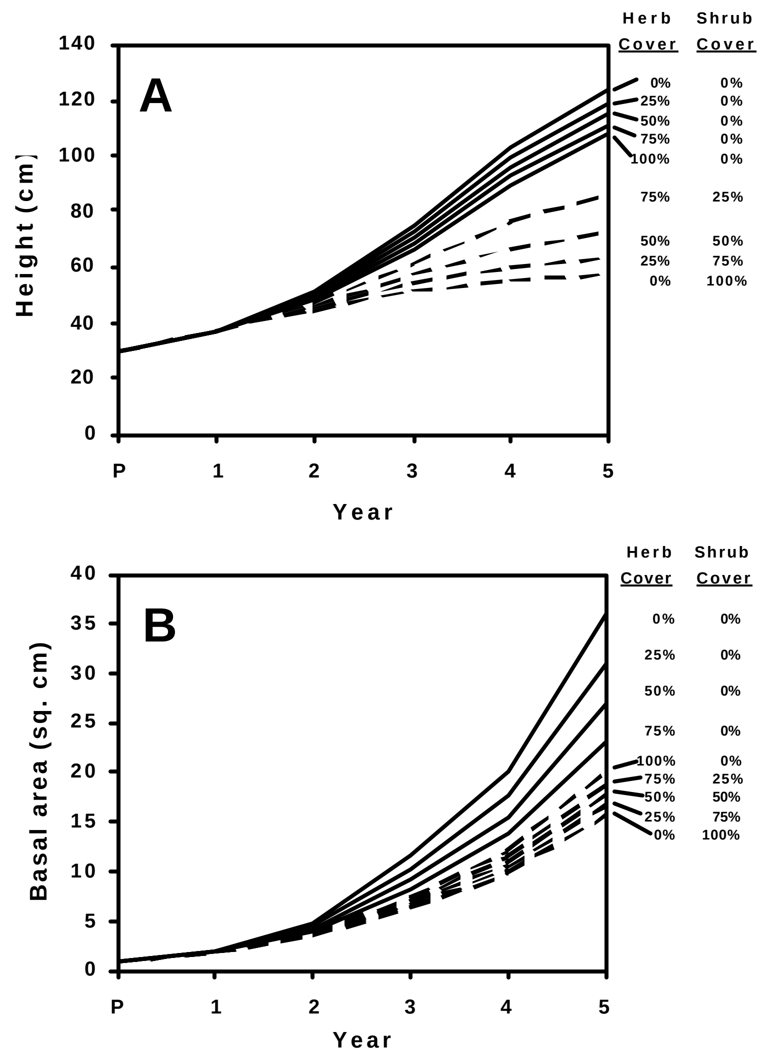

Fig. 4 - Influence of varying amounts of overtopping shrub and herbaceous vegetation cover on the 5-year height (A) and basal area (B) growth of planted Douglas-fir in the Oregon Coast Range. (Derived from equations of Wagner and Radosevich 1998)

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Both similarities and differences in responses among tree species were found (Fig. 5). Gains in stem volume associated with increasing duration of vegetation control (expressed by weed-free curves) differed among species. In contrast, declines in stem volume index with increasing duration of competition after planting (expressed by weed-infested curves) were equal among species. Critical periods for stem volume were shorter for intolerant jack and red pine (1 and 2 years after planting) than for more tolerant white pine and black spruce (1 to 3 years for spruce and 1 to 4 years for white pine). Based on where the weed-free and weed-infested curves intersect (the time of equal interference), a single year of vegetation control within the first 2 years after planting produced the same volume growth response as 2 years of vegetation control applied later. In this regard, tolerant and intolerant conifer species were injured equally by delays in vegetation control. The intolerant species had greater absolute stem volume growth, but smaller relative declines from continuous association with herbaceous vegetation (85, 81, 78, and 67% for white pine, black spruce, red pine, and jack pine, respectively). Herbaceous vegetation did not affect survival and had a variable influence on height growth

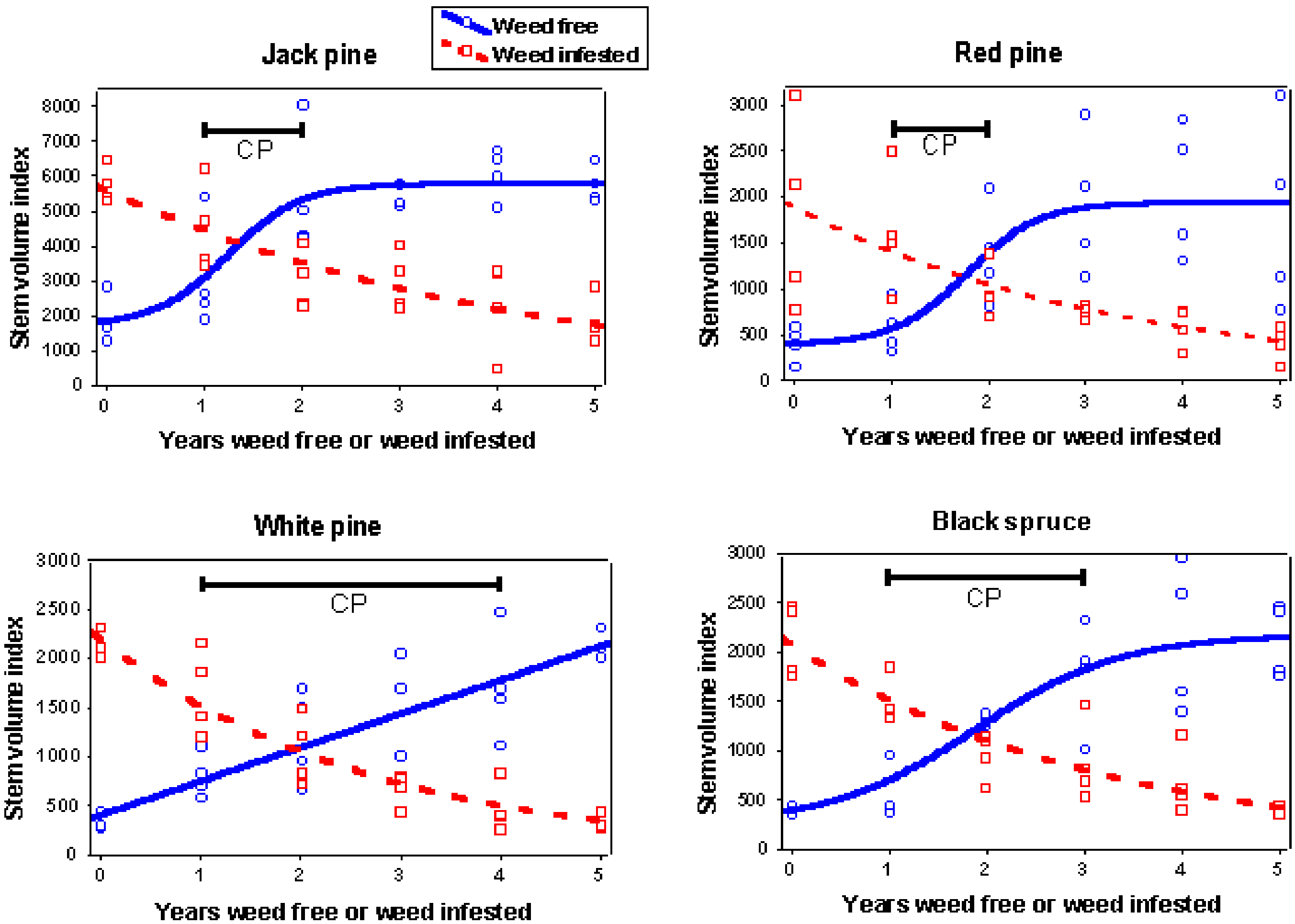

Fig. 5 - Weed-free and weed-infested curves for jack pine, red pine, white pine, and black spruce based on 5-year stem volume index. Line indicated by CP is the critical period. (From Wagner et al. 1999)

of all species. Site quality is also likely to be important to the length of the critical period, but has not been tested.

This study shows that investments in vegetation control after this early critical period appear to provide rapidly diminishing returns. A declining importance of interspecific competition on conifer growth over time also has been demonstrated in studies with coastal Douglas-fir (Harrington et al. 1995; Wagner and Radosevich 1998).

Conclusions

Objectives for vegetation management should be based on the variable of tree growth that is of greatest interest to forest managers (Fig. 6). If maximizing seedling survival is the primary interest, thresholds for vegetation control can generally be restricted to preventing overtopping by surrounding vegetation for extended periods of time until the desired trees have closed crown. The only exception appears to be on sites where competition for soil moisture can reduce survival, in which case vegetation control needs to focus on reducing the transpiring leaf area of all competitors.

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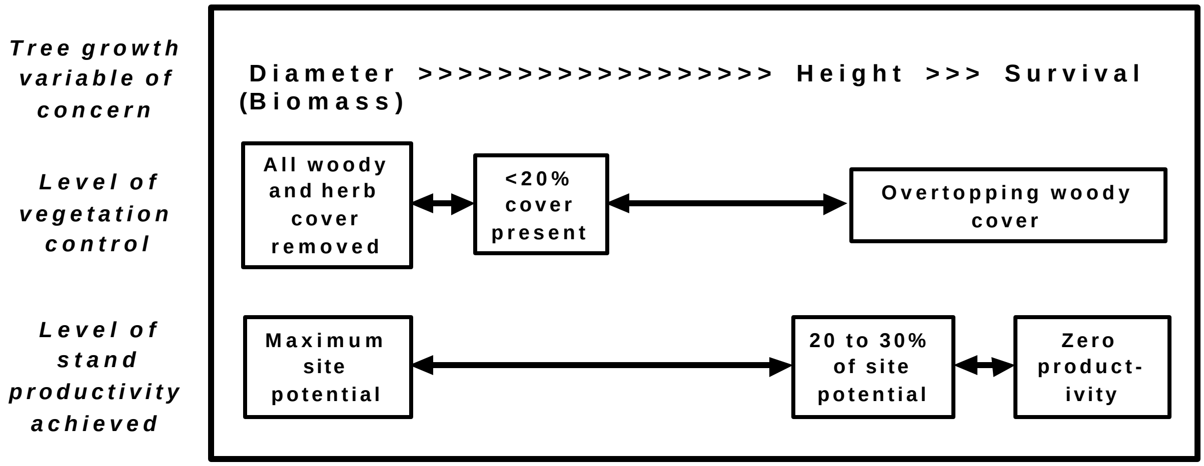

Fig. 6 - Relation between tree growth objective, target level of vegetation control, and level of stand productivity achieved.

"If maximizing early stand growth is a production silviculture objective, then all vegetation needs to be considered. Managing competition for below-ground resources (nutrients and soil water) must be the main focus of early vegetation control."

When achieving near maximum height growth is the principal management objective, preventing seedlings from ever becoming overtopped appears to be adequate in most cases. Preventing vegetation from occluding any portion of an inverted 60 to 90 degree cone that is projected upward from the base of a seedling's leader should be sufficient. It should be recognized, however, that total stand growth (measured as stem diameter, basal area, stem volume, or biomass) under these circumstances will only be achieving about 20 to 30% of the growth potential for the site, and appears to be independent of site quality.

If maximizing early stand growth is a production silviculture objective, then all vegetation needs to be considered. Managing competition for belowground resources (nutrients and soil water) must be the main focus of early vegetation control. The majority of studies indicate that the cover of all vegetation needs to be maintained below 20%. Most gains in growth have been shown to occur at levels of vegetation cover that are under 5 or 10%. One critical-period study, as well as interpretations from several other experiments, indicate that these low levels of vegetation abundance only need to be maintained for several years after seedlings are planted. Two to four years of control immediately after planting appears adequate for conifer seedlings to achieve their early genetic potential for growth. The critical period appears to be shorter for intolerant than tolerant conifer species. Capturing maximum early growth rates requires that these high levels of vegetation control occur at the time of planting. Any delays in achieving effective vegetation control will require at least two years of extended vegetation control to compensate for one missed year immediately after planting.

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