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TITLE: EFFECTS OF INTERSPECIFIC PLANT COMPETITION ON DOUGLAS FIR GROWTH AND SURVIVAL

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ABSTRACT*

- The effects of interspecific plant competition on Douglas fir growth and survival are described using information derived mainly from the Pacific Northwest region of the USA and South Western Canada. Little information is available on the response to competition of different Douglas fir provenances.

- Competing vegetation has a significant effect on Douglas fir growth and survival. There is little information on long-term growth effects, but on studies up to age 15, removal of competing vegetation generally enhanced productivity with time.

- Herbaceous vegetation had a much larger impact on Douglas fir growth and survival than was originally anticipated, the effect often being attributed to competition for moisture; negative effects of competition from herbaceous vegetation have generally been greatest on drier sites.

- Overtopping shrub and hardwood vegetation has a large impact on Douglas fir growth and survival, especially on moist fertile sites where growth of these types of competitors is most vigorous. The mechanism of competition has been attributed to limited light availability.

- Seedling size at the time of planting has a large influence on future growth, irrespective of competitor effects.

- Several interspecific competition models have been developed for Douglas fir. On moist sites, the percentage cover of woody species exceeding one-half of the tree height (within a 2.1 m radius of the tree) is a suitable index for predicting stem diameter. The percentage woody species cover exceeding or equalling tree height was the best predictor of height. More work is required to define the best indices for assessing effects of herbaceous vegetation, especially on drier sites.

- Competition models are being incorporated into sophisticated, PC based decision support systems.

- The model **CLUMP** may be useful for describing the competitive effects of species such as buddleia that are scattered around a site in fairly low densities.

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* **Note: This material is unpublished and must not be cited as a literature reference.**

INTRODUCTION

Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) is the major timber species growing in both mixed and relatively pure stands throughout much of British Columbia, northern Idaho, Oregon, and Washington. The great commercial importance of the species has led to substantial investments in research and management, including a heavy emphasis on the subject of Douglas-fir growth in response to competing vegetation (Brodie and Walstad, 1987). It has long been recognised that weeds have an extremely important impact on the growth and survival of Douglas fir, and there is an extensive record of research into methods of weed control in Douglas fir stands, particularly in the Pacific North West of the USA. One of the most important methods of weed control has traditionally been using herbicides (Newton and Knight, 1981). However, with increasing pressures against the use of herbicides, and strict financial restrictions, it was seen as essential to develop objective approaches for making vegetation management decisions (Radosevich et al., 1990). Consequently, over the last decade there has been a shift in emphasis away from research into weed control tools (such as herbicides) and towards determining the quantitative responses of crop and weed species to treatments, and establishing the relationship of tree performance to the level of competition.

This paper presents a summary of research into interspecific plant competition between Douglas fir and associated plant species. Much of the content of this review is taken from research undertaken under the auspices of, or related to, the Oregon State University / Forest Industry **CRAFTS** (**C**oordinated **R**esearch on **A**lternative **F**orestry **T**reatment and **S**ystems) Cooperative. The cooperative was established in the early 1980s with the objective of coordinating research designed to improve the understanding about the management of competing vegetation on commercial forest lands of the Pacific North West. Report 1990. CRAFTS research focuses on three areas:

- techniques for vegetation control (mainly herbicide selection);
- plant response to vegetation control - quantifying growth and survival responses to treatments of various vegetation components in forest stands;
- fundamental studies relating to detailed investigations of mechanisms driving biological responses.

Largely as a result of this cooperative, vegetation management in Douglas fir forests has rapidly developed from an art to a sophisticated management system based on good scientific information.

The Pacific North west region of the USA and Canada (where, as mentioned above, most of the reported studies were undertaken) has a climate that is characterised by abundant water supply during winter, and extended dry periods during the growing-season (Gessel et al., 1990). Many soils in this region have low fertility and the trees often respond positively to the application of N fertiliser. Climatic and soil factors must be taken into account when translating the results of the reviewed studies to New Zealand sites. Coastal Douglas fir is generally considered as either intolerant or very intolerant to shade (Newton and Knight, 1981). This implies that Douglas fir will respond well to removal of competing shrubs or hardwoods.

EFFECTS OF COMPETITION ON GROWTH AND SURVIVAL

Many studies, particularly herbicide screening trials, have documented the negative effect of plant competitors on Douglas fir growth and survival. The magnitude of the effect depends on, among other factors, the site and the competitor species. However, several studies have successfully classified or grouped competitors according to whether they have herbaceous or woody/shrub characteristics. The effects on Douglas fir growth can then be partitioned between competitors from either of these categories.

Herbaceous competition

Control of an herbaceous understorey (where there was no overtopping vegetation) for a 3 year period increased height growth of Douglas fir seedlings by 50% (Preest, 1977). Similarly, Dimock et al (1983) reported that 2 years of grass and herbaceous weed control, increased height and stem diameter of Douglas fir by about 70% over a 6 year period. This was equivalent to a threefold increase in stem volume production. Petersen and Newton (1982, 1985) found that D fir saplings competing with herbaceous weeds had only about 60% of the stem volume of trees that had been released 4 years earlier.

The magnitude of the effect also depends on the degree of weed control. For example, increasing rates of atrazine, which gave correspondingly greater levels of weed control, resulted in a high correlation between survival and the amount of grass (or level of atrazine application) (Newton, 1970). Survivals of 40% 88% 95% and 98% were recorded, corresponding with atrazine applications of 0, 2.25, 3.4 and 4.5 kg ai/ha. **It has been estimated by Newton (1967),that when establishing 2/0 Douglas fir seedlings in parts of Oregon and Washington, there is only 10% to 20% survival without weed control.** This compares with 70% to 95% survival with weed control, depending on the level of herbaceous and scrub weeds present.

Shrub competitors

In South Western Oregon and interior northern California, where there is a dry, Mediterranean-type climate, competition from established shrubs and hardwoods as well as germinating and sprouting shrubs species, is a serious problems facing young conifers (Gratkowski 1959, 1975; Bassett 1979; Pabst et al., 1990; Tappeiner et al 1984). For example, the basal area growth over a 10 year period of Douglas fir saplings competing with mature tanoak (*Lithocarpus densiflorus* Rehd.) and Pacific madrone (*Arbutus menziesii* Pursh) was only about 25% of that where these hardwoods had been controlled (Radosevich et al 1976). In a more severe example, snowbrush (*Ceanothus velutinus* Dougl.) competition over a 4 year period reduced the stem volume of Douglas fir saplings by up to about 60%, compared to trees that were free to grow unimpeded (Petersen and Newton, 1985). As with herbaceous species, the effect on tree growth of a given competitor species is correlated to the abundance of that species. For example, percentage cover of competing shrubs was negatively correlated with conifer root and shoot biomass (Tesch and Hobbs 1989).

General

One important question is what is the long-term effect on Douglas fir growth of early weed control. It has generally been assumed that early growth gains will be maintained until rotation age (Preest 1977) allowing for a shortened rotation or for a greater volume at the same age. Some long-term studies (15 or more years), suggest that variations in growth after releasing, increase with time. In a study to define predictors of competition intensity for 4- to 9-year-old Douglas fir saplings, it was concluded that the negative effect of interspecific competition on Douglas-fir increased with time (Wagner and Radosevich, 1991a). One reason for this effect is that tall shrub and hardwood species can exert their influence by competing for light for a long period. In New Zealand, where competition from tall, fast-growing hardwood species is not so prevalent, the duration of severe competition from species such as buddleia may be somewhat reduced.

As with radiata pine, Douglas fir height growth is not a good indicator of competitor effects (Cole, 1984; Wagner and Radosevich, 1991a). Once Douglas fir is established, height growth may continue to increase for many years even under severe competition, but at the expense of crown development, root expansion and diameter growth (Cole 1984). Therefore, data from studies that use height growth as an indicator of competition or response to competition must be treated with caution. Suppressed Douglas fir saplings have sparse crowns, spindly stems, and shade-adapted needles, and are susceptible to sun damage when suddenly exposed to open growing conditions. It can be several years before such trees respond to releasing.

Virtually all studies measuring the effect of plant competition on Douglas fir have only considered above-ground crop growth. However, Newton and Cole (1991) grew Douglas fir on a range of sites, either on its own or with a range of competitors and competitor densities. They measured the ratio of above-ground standing biomass to below-ground biomass and found it was the same for each competitor type. Shoot:root ratios averaged about 4:1, except in severely suppressed trees, where ratios dropped toward 1:1 in those near death. Neither shoot:root ratio, nor tree size was affected by planting-induced root deformities such as J- or L-rooting. By age 5, all root systems appeared to have fully compensated for planting deformities and future growth and stability was considered not to have been jeopardised.

Several studies have found that one of the most critical factors for predicting future seedling growth, irrespective of competition, was seedling size at the time of planting (Howard and Newton, 1984; Wagner and Radosevich, 1991a and b). It has been argued that planting larger seedlings and supplying minimal weed control is a more cost-effective option than planting smaller seedlings with a high degree of weed control (Balneaves, 1989; South, 1993).

MECHANISMS OF COMPETITION

One problem with trying to predict the response of Douglas fir to interspecific competition is that the response can vary considerably with site characteristics, vegetation abundance and proximity, species composition (Harrington and Tappeiner, 1991), and possibly provenance. Predicting tree response over a range of biological and environmental conditions requires an improved understanding of competition processes.

In the warm, dry, summer climate of Oregon, the mechanism of the competitive interaction between Douglas fir and associated plant species has often been attributed to a limiting supply of water. For example, control of grass and herbaceous weed competition resulted in reduced Douglas fir seedling moisture stress and significant improvements in survival and growth for several years (Barber, 1984; Gratkowski et al., 1979; Preest, 1977). One study demonstrated a high correlation (R=0.89) between Douglas fir survival and soil moisture content (Lowenstein and Pitkin, 1961). Topographic aspect can also influence water availability. In Oregon, Newton and Holt (1967) observed a strong interaction effect between topographic aspect and weed control on Douglas fir survival, with generally good survivals on north- facing slopes (cooler, moist, shaded slopes), irrespective of weed control. Satisfactory survival on flat ground, or south- facing slopes occurred only in conjunction with weed control. **Without weed control, survivals as low as 0, 5 and 10% were recorded.** By translating these findings to New Zealand situations, in the absence of weed control better survival could be expected on south-facing slopes; weed control on north facing slopes would be essential, at least on hot, dry sites.

Herbaceous broadleaves and grasses are well known to cause severe water depletion, at least towards the top of the soil profile (Preest, 1977). This effect can be so severe that control of these weeds can increase Douglas fir survival even in a wetter than average summer (White and Newton, 1984. There are also, however, some conflicting suggestions that grass control may not always be necessary to successfully establish Douglas fir in cool, moist habitats. For example, in a study by Howard and Newton (1984) on a low elevation, moist site, weeds that formed a low ground cover or encroached from the side, did not severely affect growth of Douglas fir seedlings, five and seven years after planting. However, overtopped seedlings, where competition for light was clearly an important factor, were smaller, and grew more slowly than those not shaded by adjacent vegetation. Once again, the planting of large transplants was advantageous. One problem with this study was that a weed-free control was not included. The majority of studies have shown that even after first year weed control, grasses can increase moisture stress and reduce Douglas fir growth until crown closure eliminates the grass . The effects of herbaceous species is proportionately greater on drier sites (Cole and Newton, 1986). White and Newton (1989) demonstrated that success of regenerating stands of Douglas fir, especially on hot dry sites, depends on availability of water resources.

Although many studies have implicated water as a primary limiting factor in competitive relations between Douglas fir and competing plant species, the role of nutrients must also be considered. Much of the soil in the Douglas fir region of the Pacific North West USA has low fertility, and Douglas fir, generally responds to N fertilisation (Gessel et al., 1990). Thus it might be expected that competition for nutrients would also be an important factor on many sites. In fact, in a review on the relative importance of water and nutrients on Douglas fir growth in the Pacific Northwest, Gessel et al. (!990) concluded that compared with nutrition, moisture does not seem to be a major limiting factor for Douglas fir growth. However, the studies reported in this review did not consider competitive interactions with other non-crop plants. Studies that have been designed to investigate the mechanisms of competition between Douglas fir and herbaceous broadleaves or grasses have generally concluded that competition is primarily for water (Cole and Newton, 1986). However, there will clearly be interactions with site fertility and competitor species, and broad generalisations on the relative importance of competition for water and nutrients would be unwise.

On moist, highly productive sites, where competition for water may not always be a critical factor, conditions are generally conducive for fast-growing brush species. These species are severe competitors with Douglas fir and no brush control, results in reduced growth and irregular mortality within the stand (Brand, 1986a). Studies on the interaction of light, moisture, and nutrient limitations on growth on moist sites suggest that light is the dominant factor influencing tree vigour and growth when there is overtopping vegetation (Eissenstat and Mitchell, 1983; Reed *et al*, 1983); moisture and nutrient availability influence growth most strongly only when light intensity is acceptable (Brand, 1986a). Several studies have shown that trees acclimate various developmental characteristics to changes in resource availability (Brand, 1986b). On these moist, productive sites brush competition effects on plants are expressed through developmental acclimation to reduced light intensity with less evidence of changes in development related to water or nutrient availability, thus supporting the hypothesis that competition for light is the most critical factor (Brand, 1986b).

Over recent years there have been several studies reported that have begun to examine the processes involved with competition between Douglas fir and competitor species, including complex situations where more than one competitor species or category of competitor is present. In one example, the effects of intra- and inter-specific competition on root and shoot biomass of 5-year old Douglas-fir and red alder (*Alnus rubra* Bong.) were studied over a range of densities and proportions of each species (Shainsky, Newton, and Radosevich, 1991). Alder overtopped Douglas fir in all mixed stands, and alder density influenced the root and shoot biomass of both species more than Douglas fir density. While increasing the density of each species reduced root and shoot biomass per tree, allocation of biomass to roots and shoot was not affected by competition, nor were the allometric equations relating biomass to stem diameter and stem volume index. In another case, the effects on Douglas fir growth of competition from mixtures of herbaceous and woody vegetation were considered. Results suggested that in the Coast Range of Oregon, shrub and herbaceous vegetation have similar competitive influences on basal area growth of Douglas fir, whereas overtopping hardwoods and shrubs impose the greatest limitations on height growth of Douglas fir (CRAFTS report, 1990). In each year following the removal of both shrub and herbaceous vegetation, basal area growth of Douglas fir increased exponentially over that of trees in herb-dominated plots. By contrast, significant negative correlations between Douglas fir height increment and vegetative cover were not detected until the third year of the study. Herbaceous vegetation did not limit light availability to neighbouring Douglas fir. However, for the same amount of cover, herbaceous species reduced soil-water availability at the 30 cm depth more than shrub species.

MODELLING COMPETITIVE EFFECTS

Competition models that predict crop growth losses due to specific levels of competition are useful management tools in terms of prioritising areas to be treated (Brand, 1986a), making decisions on whether weed control is necessary and to what degree it is required, and for selecting cost-effective treatments. There is, however, a lack of standard quantitative techniques for evaluating the effects of interspecific competition (Walstad and Kuch, 1987). Effects of interspecific competition on forest trees have been quantified by either whole-stand or individual-tree (neighbourhood) approaches (Tappeiner and Wagner 1987). Whole-stand approaches estimate the yield of the average tree or whole stand from average measures of vegetation abundance throughout the stand (Lanini and Radosevich, 1986; Ross et al., 1986). The individual tree or neighbourhood approach estimates individual tree yield based on some measure of abundance of neighbouring plants. Although the two approaches project similar growth losses in young conifer stands as vegetation abundance increases, competition processes among plants cannot be examined in detail with the whole-stands approach (Wagner and Radosevich 1991a).

Indices of competition

To develop competition models that can be usefully applied by field managers, it is necessary to have some simple and rapid means of assessing competition. Thus, there has been a considerable effort to develop indices of competition that can be used to predict future Douglas fir growth. Useful indices of competition should be effective through the range of conditions over which they will be applied, sensitive to the size of the crop trees, and easily measurable under field conditions.

It is generally considered unlikely that a single measure of competition will provide a suitable competition index that can be applied over all sites and with all competitor species. However, it is possible that useful competition indices can be derived that are applicable to a category of competitors e.g. shrub/woody species or herbaceous species. Brand (1986a) developed a competition index for Douglas fir plantations on moist, highly productive sites of coastal British Columbia. On these sites, no brush control results in reduced growth and irregular mortality. Since absolute measures of crop height or basal area tend to be influenced more by tree size or past performance than by current vigour; it is important to use either tree size as an independent variable or covariate in the analysis, or to use relative growth rates as the response variable when developing the competition index. Brand (1986a) successfully developed a competition index for predicting changes in tree vigour measured as relative production rate. The index (based on measures of light competition around the tree crown, because light was assumed to be the main factor limiting growth) included measures of brush proximity, relative height, percent ground cover, appears to act as a measure of light interception around the tree crown. It was concluded that tree vigour was largely a function of the age of the tree from planting and the competition index (R^2= 0.71). Brand (1986b) also listed a number of Douglas fir developmental variables that proved useful for assessing competition stress. The most effective variables were again those that were responsive to reduced light intensity from the brush competition i.e. the specific leaf area of foliage (cm leaf area/g dry wt), the allometric relation of height to basal area, and bud production on nodal shoots.

One of the most extensive studies designed to define indices for predicting the effects of plant competition on Douglas fir growth was undertaken over nine sites in the Oregon Coast Range (Wagner and Radosevich, 1991a). Various measures of non-coniferous woody vegetation (abundance, height, distance and spatial arrangement) were correlated with individual crop tree size. The experiment was retrospective because the existing non-crop vegetation was measured at the same time as the trees (aged 4 - 7 years on the various sites) and it was assumed that the correlation of the competitors with tree size resulted from a strong relationship between the present and historical abundance of competitors within the neighbourhood of individual trees. The relationship of the following factors was related to the height and stem diameter of individual Douglas fir saplings:

- seven measures of competitor abundance, three based at the species level and four at the individual plant level;
- size (height and diameter) of the neighbourhood (or plant competition zone) around individual trees;
- distance from the central crop tree to adjacent competitors;
- spatial arrangement of the competitors around the crop tree.

It was concluded that the best single interspecific competition index for predicting Douglas-fir height and stem diameter was a visual estimate of total percent cover for all woody species within a 2.1 m radius. Visual subjective estimates of neighbour cover were superior to objective measures of crown area, possibly because visual estimates may integrate some feature of the vegetation that is not quantified with objective 2-dimensional measures of plant abundance (Wagner and Radosevich, 1991a). The cover of woody species equalling or exceeding one-half the height of the tree provided the best index for predicting stem diameter, and woody species cover equalling or exceeding tree height was the best predictor of height (Figure 1). Once again, these results suggest that competition for light was possibly the predominant factor of importance. Accounting for spatial arrangement of neighbouring woody plants did not improve the competition index. The age-adjusted competition index accounted for 11% of the variation in height and 19% of the variation in stem diameter. Other important factors included in the models were tree age, animal damage and initial seedling size (overall $R^2 = 0.64\text{-}0.73$) (Wagner and Radosevich, 1991b). Unfortunately, because of its design this study could not be used to incorporate the influence of herbaceous species in the competition index. Where there is a variable (patchy) herbaceous cover on a site, it is most likely that this competition index would have to be modified, especially on dry or nutrient impoverished sites. As discussed earlier, herbaceous vegetation has a much greater competitive effect than was contemplated at the beginning of these studies.

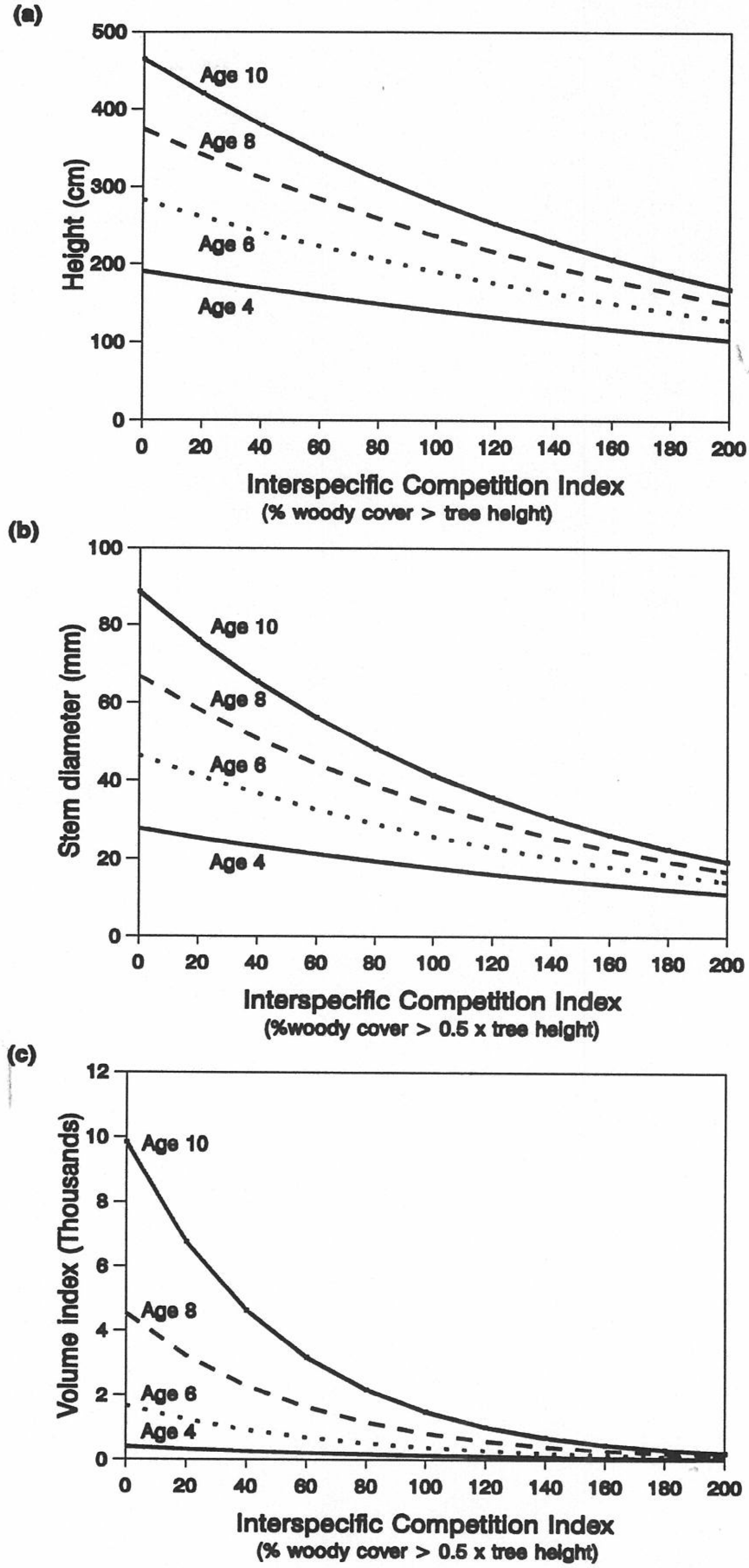

Figure 1: The cover of woody species cover equalling or exceeding tree height was the best predictor of height (a) and the cover of woody species equalling or exceeding one-half the height of the tree provided the best index for predicting stem diameter and volume (b and c).

Other competition models

In another study, Harrington et al. (1991) examined the effects of hardwoods (tanoak and Pacific madrone) on average annual growth and size distribution of Douglas fir saplings. Their objective was to derive a biologically plausible description of competition effects over time (as opposed to the correlations of single-year measurements of tree size or growth with the current or past abundance of associated vegetation). The authors noted that vegetation management treatments are usually applied to stands rather than individual trees, therefore managers require stand-level information, such as mean tree size and crown cover, to evaluate growth. Their general model was:

G = PG * COMP

where G = annual tree growth increment; PG = potential annual growth increment (no competition); COMP = a competition modifier. Thus equations were required to predict tree growth, competitor growth (particularly in terms of measures that reflected useful competition indices as described in the previous section), and the interaction between the crop and competitor. A Weibull function was used to characterise the influence of competition on size distributions of Douglas-fir saplings. These equations proved extremely successful and accounted for 90% of the variation in the average annual increment of crop basal area growth.

In trials that experimentally manipulated the cover of shrub and herbaceous species around individual Douglas fir seedlings it was concluded (as described above) that vegetative cover above 50% and 100% of tree height most strongly limited the annual growth in stem basal area and height, respectively. These results formed the basis for developing **Df et al.**, a multispecies growth model for young Douglas fir stands that incorporates effects of competition.

Other growth models have been developed to account for the effects of a single competitor species. One example of this is **CLUMP** (**C**ompetition **L**osses **U**sing **M**aple **P**rojections)

Sprout clumps of bigleaf maple (*Acer macrophyllum* Pursh) often occur at low densities or as isolated stands in Douglas fir plantations. CLUMP is a growth model for projecting height and crown development of neighbouring Douglas fir and maple. This type of model may be particularly appropriate for including shrub species such as buddleia in New Zealand. The model uses growth equations for bigleaf maple to predict overtopping cover for neighbouring Douglas fir. The competitive effects of overtopping cover on Douglas fir height and diameter growth are then simulated by the same routines as in the **Df et al.** young stand model. The simulation model provides an "aerial view" of the stand on the screen. Bigleaf maple is randomly distributed in the stand at the requested density and the screen tracks the development of the crowns through time. If a Douglas fir seedling is heavily overtopped (> 80% maple cover) for 10 consecutive years the tree dies. At stand age 25-30 years, all surviving Df are taller than the bigleaf maple. Beyond this time, the output from CLUMP will be used to drive conventional stand simulators. An updated version of CLUMP, CLUMPS, will incorporate effects of vegetation management on bigleaf maple e.g. it will predict rates of sprout clump recovery after treatment and the subsequent effects on Douglas fir.

RECENT RESEARCH DIRECTIONS

Recent research on vegetation management in Douglas fir plantations has focussed on the development of microcomputer models to predict the response of young stands of Douglas fir and associated species to vegetation management. The first step in this direction was the development of **VEGPRO**, (a herbicide selection optimisation database) in the late 1980s. It is envisaged that **VEGPRO** and **Df et al.** (described above) will be integrated into a single software package capable of providing site-specific analyses of Douglas fir stand development for various vegetation management scenarios. A primary objective is to produce assessments that can be used for prescribing treatments according to the guidelines in the environmental impact statement on managing competing and unwanted vegetation. **VEGPRO** is also to be expanded to include mechanical and manual techniques.

To meet these objectives a Regional Vegetation Management Model (RVMM) is being developed to help managers in deciding where, when, and how to control associated vegetation in young conifer plantations. Ultimately the RVMM will provide stand- and tree-level predictions for Douglas fir and associated hardwood species in the Pacific North west, linking stand responses to vegetation treatments with rotation age growth and yield models. Many of the models required to develop the RVMM are already in existence (see above) and some are currently being further refined.

The components of the RVMM are as follows:

- a conceptual model depicting (a) interrelationships among growth models for Douglas fir, associated competitors (hardwoods, shrubs, herbs), (b)interface with growth models for older stands and the vegetation management treatment effects sub-model.

- data collection protocols consisting of (a) a matrix to ensure adequate representation of the site productivity classes, abundance and intensity of vegetation types, tree sizes, and (b) plot layout and measurements for conifers, single- and multi-stemmed hardwoods, woody shrubs, and herbaceous vegetation to facilitate development of either stand- or tree-level models.

- Preliminary relationships in the data, which suggest that percent hardwood basal area will be useful for describing interspecific competition effects on Df basal area and crown dimensions.

With the increasing complexity of the decisions that have to be made and the range of models on which to base these decisions, a PC based DSS as described will provide a powerful management tool.

DISCUSSION AND CONCLUSIONS

Competing vegetation has a significant effect on Douglas fir growth and survival. There is little information on long-term growth effects, but on studies up to age 15, benefits generally increased with time. Herbaceous vegetation has a much larger impact on Douglas fir growth and survival than was originally anticipated. The mechanism of competition by herbaceous species is most often attributed to competition for moisture, and negative effects of herbaceous vegetation have generally been greatest on drier sites. Overtopping shrub and hardwood vegetation also has a large impact on Douglas fir growth and survival, especially on moist fertile sites where growth of these types of competitors is most vigorous. The mechanism of competition has been attributed to limited light availability and in general, indices of competition are effectively measures of this resource.

Seedling size at the time of planting has a large influence on future growth irrespective of competitor effects. This is a major factor and it suggests that this should be a priority area for Douglas fir establishment research. For example, the merits of 1-0 versus 2-0 stock need to be evaluated in the context of planting costs and also competitive effects.

Several interspecific competition models have been developed for Douglas fir. On moist sites, the percentage cover of woody species exceeding one-half of the tree height (within a 2.1 m radius of the tree) is a suitable index for predicting stem diameter; the percentage woody species cover exceeding or equalling tree height was the best predictor of height. More work is required to define best indices for assessing effects of herbaceous vegetation. It would be useful to validate these results (with shrub species) on New Zealand sites with competitors such as buddleia or broom. Effects of herbaceous species should also be quantified, given the prevalence on oversowing.

At Oregon State University, competition models are being incorporated into sophisticated, PC based decision support systems. If possible, these models should be evaluated for use in New Zealand. The model **CLUMP** may be especially useful for incorporating species such as buddleia that are scattered around a site in fairly low densities, and the approach of Harrington et al., (1991) should be further evaluated. One possible means of establishing better communication and collaboration with Oregon State University, which would be of undoubted benefit to this Coop, would be to develop some joint research projects. One possibility would be the installation of a competition trial, designed to meet some of the needs outlined above. Preliminary discussions with Dr M. Newton have already commenced to this end. Dr Newton has established a wide series of competition trials with Douglas fir and has a very large database of competitive effects. Collaborative work may give this Coop access to this information and allow us to test and apply models derived from this work.

RECOMMENDATIONS

1. Trials should be established to evaluate the effects and economics of nursery handling, planting size, provenance, and weed control/competition (after planting) on seedling Douglas fir growth and survival in the field.

2. Some form of formal collaboration with the CRAFTS cooperative at Oregon State University should be sought. This would provide immediate benefits in the form of existing competition models. These would have to be validated for NZ conditions.

3. One approach to initiating this collaboration would be to install a trial that would effectively compliment the Oregon State University database of competition trials. Preliminary discussions to this end have already commenced with Dr M. Newton.

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