

A SUMMARY OF THE AVAILABLE INFORMATION ON THE HEIGHT TO DIAMETER RATIO

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Abstract

Competing vegetation reduces conifer growth and survival. In British Columbia for a conifer stand to be deemed free growing it must be free from competing brush. The current free growing standards are under review, and the height to diameter ratio has been suggested as an additional criteria. This paper assembles and summarizes published and unpublished information on the height to diameter ratio. The primary focus is on Douglas-fir, lodgepole pine and spruce (Engelmann, white and the hybrid). Three different competition levels were used to group the height to diameter ratios. Unfortunately, the competition groupings were general because in many trials the level of competition was not specified. Generally a larger height to diameter ratio indicated a less vigorous tree. Increased competition for light causes more allocation of resources to height growth which results in an increase in the height to diameter ratio. Variable results were observed when resources other than light were limited. The large variability in height to diameter ratio values may be due to the method by which the values were grouped, trial differences, site location, seedlot, type of competition, site prep or vegetation treatment used. The height to diameter ratio has potential to provide a morphological measure of how competing vegetation influences crop trees. More extensive research and trial data is required to fully understand the many factors that affect the height to diameter ratio.

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1.0 Introduction

The regeneration of conifers on logged sites has presented many problems. One of the primary concerns is competition. Hardwoods, shrubs and herbs are capable of delaying or interrupting the establishment of well stocked conifer stands following disturbance (Walstad and Kuch 1987). Competition during the establishment period has been found to influence the height of trees well into their life span (Newton and Hanson unpublished). Competing vegetation limits the availability of light, water, nutrients and growing space and can cause physical damage (Brand 1986; Newton and Comeau 1990; Coates *et al.* 1991; Bi and Turvey 1996) resulting in slowed growth, restricted morphological development and mortality (Harrington and Chan 1992). The severity of competition varies with site, competitor type and density (Cole and Newton 1987).

It is accepted that controlling unwanted vegetation improves the survival and increases both height and diameter growth of conifers (Knowe 1994; Comeau *et al.* unpublished 1998b). There are numerous types of vegetation control including herbicide application, manual brushing, livestock grazing and mechanical methods. Unfortunately vegetation management in forestry is a complex issue to which there is no simple solution. It is not yet known what amount of vegetation removal is most beneficial to conifers. A number of vegetation levels or thresholds have been developed (Wagner 1994). These include competition, predictive and visual thresholds. A competition threshold is the weed density at which competition causes a crop tree yield loss or the threshold at which control measures should be taken to avoid a larger weed infestation in the future (Wagner 1994). The threshold used most often by foresters in North America is the visual or "job-security" threshold which is the weed density that is subjectively determined to be consistent with good management practices (Wagner 1994). Unfortunately the thresholds used may not necessarily be the most biologically appropriate, but rather the most practical because other factors such as cost, site accessibility, public input and legislation play a major role in decisions about vegetation management.

Currently in British Columbia, the Forest Practices Code of B.C. Act (Forest Practices Code) requires a stand to meet certain criteria before it is considered free growing (B.C. Ministry of Forests 1995). The free growing requirements for each stand are determined before harvesting and it is the legal obligation of the forest licensee to ensure establishment of a healthy free growing stand of accepted crop trees. Regulations require that the appropriate species and stocking levels be selected, the stand reach a minimum age and be free from competing brush (B.C. Ministry of Forests 1995). Assessing the crop species, stocking density and age is relatively easy, however determining whether the stand is and will remain free from competing vegetation is more complex.

Currently a crop tree height to brush height ratio within a one-meter radius cylinder surrounding the tree is used to determine if a tree is and will remain free from competing vegetation. Depending on the site location, the crop tree must be 150 or 125

percent of the height of the competing vegetation (B.C. Ministry of Forests 1995). This method works well with non-persistent vegetation, however with persistent tall vegetation, such as hardwoods, there are some problems with the tree height to brush ratio. Persistent hardwood competition can lead to long term growth reduction depending on density and or distribution of the hardwoods. There has recently been some research to suggest that at a certain density, hardwoods may not be a threat to conifer stand development and may be beneficial to both long-term ecosystem health and productivity (Simard and Heineman 1996). Red alders may contribute to site nitrogen through nitrogen fixation (Comeau and Sachs 1992). Deciduous hardwoods can also add structural diversity and non-timber values, however at the same time they may reduce conifer survival and growth (Comeau and Sachs 1992).

Height to diameter ratio (HDR) may be useful as an additional criteria to determine if a stand is free from brush, while at the same time permit some hardwoods that do not have a negative effect on crop trees. It has been shown that stand density and competition affect morphology (Lanner 1985) and therefore a measure of morphology, such as the HDR should reflect the level of competition. Some studies have found that the HDR is a good indicator of over-topping and encroaching vegetation and possibly tree vigor (Cole and Newton 1987; Huges *et al.* 1990).

Draft guidelines presented in the Establishment to Free Growing Guidebook in the Prince George region, make use of the HDR values to help indicate a free growing stand (Kabzems 1997; Hoyles 1998). These guidelines include both mixedwood stands and those primarily stocked with conifers. The use of HDR values occurs only after requirements for a well-spaced tree of acceptable age and height have been met. The information used to determine the HDR values was based on the results of operational case studies, research trials, and operational experience in the north-central and boreal forests. These guidelines are only an interim guidance to be used during the field season, and later to be examined and reviewed.

The purpose of this paper is to assemble and summarize available information, published and unpublished, on the HDR of conifers. The focus of this review is on lodgepole pine, Douglas-fir and spruce (white and Engelmann). Summaries for each paper were written, and comparisons were made between the papers. Objective comments are provided on the value of using HDR as a free growing criteria. Areas that are lacking in available information or require further study are identified.

1.1 Background Information

In Europe the height to diameter at breast height (DBH) ratio, or slenderness coefficient has been used as a basis for thinning prescriptions as it considers stand structure and vigor of future crop trees (Weihe 1977; Kladke and Kenk 1997). It is considered that the higher the HDR, the greater the need for release. The height to DBH ratio is used as an indicator of stem form and resistance to windthrow or snow break (Smith 1986; Bi and Turvey 1994; Navratil 1996; Kladke and Kenk 1997). Trees with a

high HDR are considered to have an increased susceptibility to physical damage, a ratio of 80 has been recommended for snow break locations (Abetz 1976). Although the ratio is considered to be a density dependent stand level characteristic (Bi and Turvey 1996) it does not define stand density (Smith 1986). The HDR has been considered an integrator of past competition (Hasenauer and Monserud 1996). These uses support the potential use of the HDR as an additional criteria for free growing, but it is important to understand how and why competition and other factors affect the HDR.

Conifer growth is driven by genetic potential and physiological and morphological responses to environmental conditions (Harrington and Chan 1992). Many studies have found that as competition increases conifer diameter growth is reduced more rapidly than height growth (Lanner 1985; Kozlowski *et al.* 1990; Coates *et al.* 1991; Simard and Heineman 1996; Groninger *et al.* 1997; Mailly and Kimmins, 1997). A number of studies have found that the HDR (basal diameter and DBH) increases with increased competition (Newton and Hanson unpublished and undated; Cole and Newton 1987; DeYoe 1988; Simard 1990; Bi and Turvey 1994; Wagner 1994; Rose *et al.* unpublished 1998). After conifer release from competition there is little increase in height as growth is directed to diameter (Comeau *et al.* unpublished 1998b) thus reducing the HDR. One of the first visual signs of significant competition is a larger HDR than trees free of competing vegetation (Newton and Comeau 1990). The HDR of a seedling or tree reflects the proportion of resources that are allocated to height and diameter (Cole and Newton 1987). When the HDR is large the allocation of resources to diameter growth is reduced or rather the allocation of resources to height growth is increased.

Light is a very important resource that is often limited by crowding and overtopping due to competition, the reduced light intensity due to competition affects resource allocation thus affecting morphology (Brand 1986; Campbell and Wood 1992; Rose *et al.* unpublished 1998). The HDR has been found to change in relation to the light environment (Messier *et al.* unpublished 1998). Under low light or moderate to low competition etiolation has been observed (Drew *et al.* 1997; Comeau *et al.* unpublished 1998b). Etiolation is reduced diameter and crown growth in favor of height growth, (Comeau *et al.* unpublished 1998b) which results in a larger HDR. When seedlings are shaded they allocate more dry matter production to their shoot (Drew *et al.* 1977). Shade tolerant species generally allocate more biomass production to lateral and caliper growth than shade intolerant species (Kayahara *et al.* 1996). The effect that light has on resource allocation can be explained by source-sink phenology. A plant produces only a limited amount of photosynthate and other carbohydrates which are stored or currently produced at a source. These resources must be allocated to various areas for growth and maintenance. Sinks are the final destination for photosynthate and must compete with each other (Lanner 1985). Thus the sinks for height and diameter growth are in competition with each other.

The apical meristem is the sink for height growth and is considered the strongest photosynthate sink after developing cones (Lanner 1985). The apical meristem is a much stronger sink than the cambium, which is the sink for radial growth (Lanner 1985). The

apical meristem can use both stored and current photosynthate, whereas the cambium must rely only on current photosynthate (Lanner 1985). When light is plentiful, a large amount of photosynthate is produced, and neither height or radial growth is compromised. Under limited light conditions there are not enough resources available to meet the needs for maximum height and diameter growth. Because the cambium is a weaker sink reduced radial growth occurs when light is limited (Lanner 1985). Height growth is able to occur even during times of high stress (Lanner 1985).

Another difference between radial and height growth is they are often affected by different growing seasons. Radial growth continues throughout the growing season and is indeterminate as it depends on the current-year conditions and resources (Lanner 1985; Harrington and Tappeiner II 1991). Height growth in a number of species is determinate as it occurs largely from internodes contained in the previous season's terminal resting bud (Burdett *et al.* 1984; Harrington and Tappeiner II 1991). Shoot extension is determinate in lodgepole pine and Douglas-fir (Harrington and Tappeiner II 1991), in spruce it is largely determinate, however stem units sometimes elongate in the year that they are initiated (Burdett *et al.* 1984). The resources that height growth requires are obtained early in the growing season and thus height growth is usually not compromised when light is limited. Stem growth occurs later in the season only after foliage and root growth resource demands have been accommodated (Waring 1987). Vegetation management has been found to increase the length of growing season for cambial growth, but not height growth (Harrington and Chan 1992).

Non-crop vegetation can compete for light, however competition also limits other resources such as water, nutrients and growing space (Newton and Comeau 1990) which affect height and diameter growth differently than limited light. Nilsson (1994) has found that both height and diameter growth were reduced with increased competition. All other experiments with the same results have been on sites with relatively low fertility or site quality, and thus the limiting resources are considered to be nutrients and water rather than light (Nilsson 1994). Competition limits different resources on different sites (Brand 1986). On rich sites competition for light is greater than on poor sites because vegetation grows quickly, significantly reducing available light. In the moist rich sites of coastal British Columbia brush competition may particularly reduce the solar radiation available to planted trees (Brand 1986) and the effects of competition on these sites would be due to limited light not soil based resources.

In natural environments seedlings experience complex interactions between different environmental factors and other stresses may override the effect of light on carbon allocation (Messier and Puttonen 1995; Chen and Klinka 1998). On poor sites, there is only minimal competition for light because other resources are less plentiful and therefore reduce growth first. Kozlowski *et al.* (1990) found that on poor sites some species develop a stagnate physiological state. In Washington the HDR is used to determine when to perform conifer release treatments, however the ratio is used only on the west side of the Cascades (Belz pers. commun. May 1998). On the west side of the Cascades neither water nor nutrients are limited therefore competition limits light,

resources other than light are limited on the east side, affecting the HDR differently. The use of the HDR only on the west side of the Cascades is in support of the HDR being affected by site quality.

When light is not the limiting resource the findings have not been consistent as competition does not always affect diameter growth more than height growth. Nilsson (1994) found that when water and mineral nutrients were the limiting resource for growth both height and diameter growth were reduced. It has also been found that trees under water stress reduce their cambial growth before shoot growth (Harrington and Tappeiner II 1991). When competition limits soil water and possibly nutrients Douglas-fir shoots are affected as internode production and internode elongation is limited (Harrington and Tappeiner II 1991).

The availability of water is the most important environmental factor limiting the growth and distribution of trees (Zimmermann and Brown 1971). When plants are water stressed their leaf expansion and stem growth is reduced (Taiz and Zeiger 1991; Waring and Schlesinger 1985). Reduced growth occurs because it depends on cell expansion which is quantitatively related to turgor pressure which decreases with a decrease in water potential (Levitt 1980; Taiz and Zeiger 1991). Dehydration usually inhibits leaf growth earlier and more severely than photosynthesis or respiration because complete stomatal closure requires a lower water potential than growth reduction (Levitt 1980). When water is not limited the tension is low and water can move freely resulting in better efficiency of vital cell functions (Harrington and Chan 1992). When water is limited, the water tension is higher reducing cell efficiency and thus growth (Harrington and Chan 1992). Stem growth has been studied less than leaf expansion, but is probably affected by the same forces that limit leaf growth during water stress (Taiz and Zeiger 1991).

During mild water stress, carbohydrate uptake is normally not reduced, however shoot growth is inhibited and roots can actively grow (Waring and Schlesinger 1985). Carbohydrates are transported to the roots as they are closest to the water source and less stressed (Waring and Schlesinger 1985). Shoots will grow until their water uptake is limited, but roots will grow until their photosynthate demand is equal to the supply (Taiz and Zeiger 1991), therefore shoot growth is more significantly affected when the tree is under water stress. Trees grown under moisture stress usually have a shrubby appearance due to reduced growth and early loss of apical control (Zimmermann and Brown 1971). The resulting impact on the HDR is that it may be smaller when the tree is water stressed.

The symptoms of nutrient deficiency are expressed in carbohydrate allocation and are similar to those observed for drought (Waring 1987). When nutrients are limited it has been found that increasing amounts of carbohydrates move towards the roots and thus the canopy develops slowly (Waring and Schlesinger 1985). Soil nutrient deficiency results in increased root growth and decreased foliage growth (Waring and Schlesinger 1985; Waring 1987) which may affect the HDR.

Aside from competition related factors there are a number of other variables that may potentially affect morphology and HDR. These factors include air and soil temperature (Nilsson 1994), seasonal climate, tree age (Campbell and Wood 1992), elevation, site location, stock type, provenance and site quality (Newton and Comeau 1990). Wright (1975) found that seedlots from different areas of Europe affected the HDR, trees from the north (Siberia, northern Sweden and the Ural Mountains) had the highest HDRs and trees from Spain, Greece and Turkey were stockier with lower HDRs. A trial done to examine nursery regimes found that higher HDR were associated with higher temperatures during nursery growth (Van Den Driessche 1991). Different species will have different HDRs because of different stress tolerances and different morphological characteristics. It is thought that species like pines, spruce and birch should show more sensitivity to HDR than species like firs (Messier *et al.* unpublished 1998). Because of the many factors that affect a tree's morphology determining what influences the HDR and what HDR values are considered to indicate good vigor and low competitive stress is very difficult.

2.0 Methods

The main focus of the literature search was to locate papers with information on lodgepole pine, Douglas-fir and spruce (Englemann, white and the hybrid), however papers on other species were also considered. HDRs values were only included if they were from establishing stands and the root collar diameter was used. Many other papers were considered for their general information on competition, height and/or diameter growth and possible factors that may influence the HDR. Searches were done using keywords, references used by other papers and suggestions from personal communications.

The literature was summarized and grouped by species. The HDR values were further grouped according to relative competition levels based on treatments, authors' comments and other available information. These groupings were made to permit comparisons, but decisions were often arbitrary and compromises were made. The groupings were intended only as a means of general comparison. Not all values grouped together represent the same level of competition. The low to none competition grouping is the most consistent as values grouped there represent total vegetation control or vegetation control that was very efficient. The moderate level of competition grouping was not well defined, and the HDR values placed there should only be used to give a better idea of the range of values found. HDR values placed in the high competition groupings were usually from seedlings that had no vegetation control. The difficulty with the high level of competition is that some sites have a much greater vegetation problem than others, thus the level of competition varies even under no vegetation control. Another problem is that the groupings were based on competition levels, however not all papers considered competition therefore the groupings do not always apply. To fully understand the HDR values presented, it is important to refer to the reference.

Tables were used to summarize the HDR values found in each of the papers along with other relevant information. Using the values found in the papers, scatterplots were constructed to give a visual representation of the trends observed. Unfortunately the HDR values used to create the graphs are not very accurate because averages were used instead of ranges and very few variables were included. Paper summaries were written and included in the appendix. Primary References were summarized in detail, where as only the main points were summarized from other relevant papers. All information presented in the summaries was taken from the paper summarized except for the comments.

2.1 Calculating Height to Diameter Ratio

The HDR values were only examined if the values were calculated for individual trees. A difference of 2%-20% was found between calculating the HDR individually and using treatment means, (hypothetical and 5 year old spruce). Determining the HDR from the mean of the height and the mean diameter for a treatment, results in a number close to the HDR if the data is normally distributed because the means will overlap. If the data is skewed in any way the HDR calculated from the means will not be close the value calculated individually.

3.0 Results

The results for each species are discussed below. It was generally observed that the HDRs were slightly larger for Douglas-fir than spruce or pine. For the competition levels used for the purpose of comparison, it was found that the HDR was larger for those seedlings under higher levels of competition (Figure 1). There was only limited information available for lodgepole pine. The large variation in the 'other species' is due in part to the variety of species included.

3.1 Douglas-fir

There are two varieties of Douglas-fir, the coastal variety *Pseudotsuga menziesii* ssp. *menziesii* and the interior variety *P. menziesii* var. *glauca*. There are a number of differences between the two, coastal Douglas-fir can be up to 70m tall and sometimes 80 to 90m (Pojar and Mackinnon 1994) where as the interior Douglas-fir is only 25 - 35 m tall (Parish *et al.* 1996). The two varieties have different distributions, the coastal variety occurs mostly on the west side of the Cascades and Coastal mountains, where as the interior variety is distributed in central British Columbia (Parish *et al.* 1996). It is not yet clear whether variety will strongly affect the HDR, but it can be assumed that there is some difference as the interior variety is considered to be stockier (Pojar and Mackinnon 1994). Not all studies specify the variety, therefore site location may either be used to determine the variety planted, or the site alone may be the factor affecting the HDR.

The HDRs were generally higher for sites with high levels of competition and lower for sites with some type of vegetation control. The HDR for both varieties of Douglas-fir ranges from 36 to 78 (values taken at planting and treatment not included)

when there is little or no competition (Table 1). The HDR values for Douglas-fir seedlings under high competition or no vegetation control ranges from 60 to 106. Trees from the interior of British Columbia and slightly higher HDR values than trees from coastal British Columbia (Figure 2). Both HDR values for the interior and coastal Oregon fell within the ranges of the interior and coastal British Columbia (Figure 2). As tree aged or time on the site increased the variability in HDRs decreased (Figure 3), which may possibly be a result of fewer data points.

Currently, in the Prince George Region, for stands primarily stocked with conifers Douglas-fir is considered free growing when the number of deciduous stems per hectare is less than 500 and the HDR is less than 55 (Hoyles 1998). The paper by Mailly and Kimmins (1997) did not present HDR values, but they did find that the HDR decreased linearly with increasing relative light intensity (RLI).

3.2 Spruce

Engelmann spruce (*Picea engelmannii*), white spruce (*Picea glauca*) and the hybrid (*P. glauca x engelmannii*) (Parish *et al.* 1996) were examined together because of their similarity. They range in height from 25 to 40 m tall and have a trunk 30 to 90 cm in diameter, the only difference between the species is that white spruce has a more limited distribution than engelmann spruce (Parish *et al.* 1996). All three species are widespread, the hybrid is the most common spruce at low to mid elevations in central British Columbia (Mackinnon *et al.* 1992). Because of the similarity between the three types of spruce, species was not considered to affect the HDR.

There were no observable trends of HDR values for spruce as the time on the site increased (Figure 4). The HDR was generally lower for those trees that received vegetation control. The HDR for spruce seedlings under a high level of competition ranged from 47.3 to 71.6 (HDR values at planting not included) (Table 2). A HDR value of 89 (Lieffer and Stadt 1994) was found for seedlings under high competition, this value was not included in the range because it is much larger than other values. This relatively high value may in part be explained by the parameters of the trial as natural seedlings were measured, the trial site was in Alberta and seedlings were grouped based on light transmittance, not competition (Liefers and Stadt 1994). For seedlings under moderate competition, the HDR ranged from 41 to 84.7. The HDR range for those seedlings under low competition were found to be 35.8 to 68.5. For Coates' study (1987) there was little difference between those values grouped under none to low competition and high competition and the HDR values found for low competition were in fact slightly larger than values for high competition. This may be explained by the differences in HDRs at planting, as they were largest for those seedlings under none to low competition.

Sites in northern British Columbia tended to have higher HDRs and a much greater variation in values (Figure 5). Seedlings grown on sites in south central and south eastern British Columbia did not have HDRs that exceeded 70 (Figure 5). In all site groupings the lowest values for each competition level were found to be very similar.

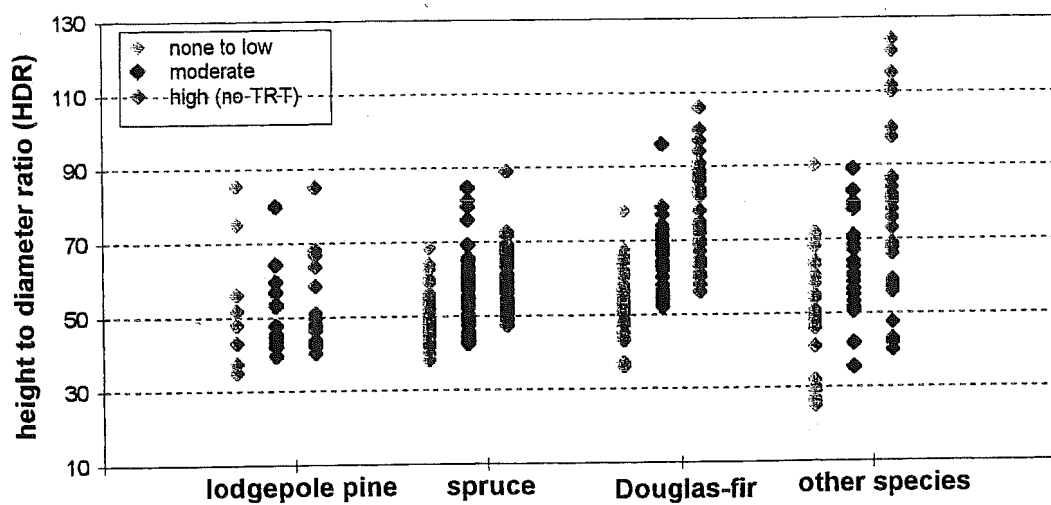


Figure 1. Scatterplot showing HDR values for all species by competition levels. 'Spruce' includes *P. engelmannii*, *P. glauca* and *P. glauca* x *engelmannii*. HDR values taken at planting and treatment not included in figure.

Table 1. Summary of mean HDR values for Douglas-fir. Competition groupings are for summary purposes. "TRT" refers to treatment.

Reference	stock type	Competition Level		time at site	site	notes
		none to low	moderate to high (no TRT)			
Belz May 1998**	all	45	60 to 56	all	west side of Cascades	used operationally for determining conifer release
Burton pers. commun. 1998	1+0 PSB 313	57.8 to 60.9	59.8 to 94.15	N/A	CWHdm near Maple Ridge B.C.	refer to paper summary for HDRs by dominant species
Cole and Newton 1987**	2-0 bareroot	65-70	70	5 years	Oregon coast	good discussion of findings
D'Anjou unpublished 1998 (FRDA 2.35/Dewdney)	2+0 bareroot	82 65 65 57 53 57 <50	68 to 92 63 to 70 67 to 73 60 to 71 60 to 72 65 to 81 60 to 70	at treatment 1 year 2 years 3 years 5 years 7 years	east of Mission	moderate values are the range for 4 cutting treatments and one glyphosate
D'Anjou unpublished 1998 (FRDA 2.35/Lilloet Lake)	1+0 PSB 313	117 78 64 60 61 52 60 <70	115 to 122 95 to 107 74 to 82 76 to 86 73 to 79 67 to 78 73 to 84 70 to 80	at treatment later in year 3 4 years 5 years 6 years 8 years 10 years	Lilloet Lake, east of Pemberton	moderate values are the range for 4 cutting treatments
D'Anjou unpublished 1998 (FRDA 2.12)	2+0 bareroot	N/A N/A N/A N/A N/A N/A <60	65 to 80 64 to 68 61 to 65 56 to 62 61 to 66 68 to 74 >70	at treatment 1 year 2 years 3 years 5 years 7 years	Okeover Inlet	moderate values are the range for 5 cutting treatments
DeYoe 1988	313	70* 43* 51 37 70* 43* 51 36	70* 50 to 62* 62 to 67 51 to 59 70 to 75* 50 to 65* 60 to 68 51 to 62	at planting 1 year 2 years 2 years at planting 1 year 2 years 2 years	near Nanaimo	treated in 1987 only treated in 1986 and 1987 treated in 1986 only treated in 1986 and 1987 values from the 15 sample
Hughes et al. 1990	2-0 bareroot	48 53	60 to 66 68 to 69	5 years 5 years	S. W. Oregon, understory treated understory not treated	

* values only approximate, taken from graphs

** references that did not provide trial data to support the HDR values presented shaded areas refer to values which are based on the author's observations and opinions

Table 1. Continued

Reference	stock type	Competition Level		time at site	site	notes
		none to low	high (no TRT)			
Newton and Comeau 1990**	N/A	44-55	low to mid 60's	all	N/A	not a scientific paper
Rose et al. unpublished 1998	1+1	high 40's, low 50's	mid 50's	3 years	western Oregon	not all tables and figures included with paper
Simard et al. 1998	N/A	52.1 52 48.5 54	55.2 54.3 52.6 55.4	at treatment 1 year 3 years 5 years	a number of sites throughout British Columbia	averages of HDRs for 9 different sites, see appendix for individual site HDR values
Simard 1990*	natural	45 50	70 62	7 to 11 years 7 to 11 years	Southern Interior, low quality Southern Interior, high quality	levels determined by competition thresholds
Tesh et al. 1993*	1+0 containerized	74 66 56 55 54 48	67 73 60 64 66 69	at planting 1 year 2 years 3 years 4 years 5 years	Southwest Oregon	good reference
Vegetation Management Research Cooperative 1997	N/A	47 50 58 50	48 to 56 50 to 57 58 to 66 48 to 56	N/A N/A N/A N/A	Summit OR, Coast Range Marocola, OR West Cascades Silver Lake, WA, West Cascades Pedee, OR, Coast Range	all treatments included for moderate range, total vegetation control (100ft ²) is low competition
Wagner 1989*	2-0 bareroot	72 62 50 50	72 70 to 72 64 to 73 64 to 80	at planting 1 year 2 years 3 years	central Oregon coast	projected HDRs for seedlings in association with various combinations of wood and herbaceous neighbour cover.

* values only approximate, taken from graphs

** references that did not provide trial data to support the HDR values presented
shaded areas refer to values which are based on the author's observations and opinions

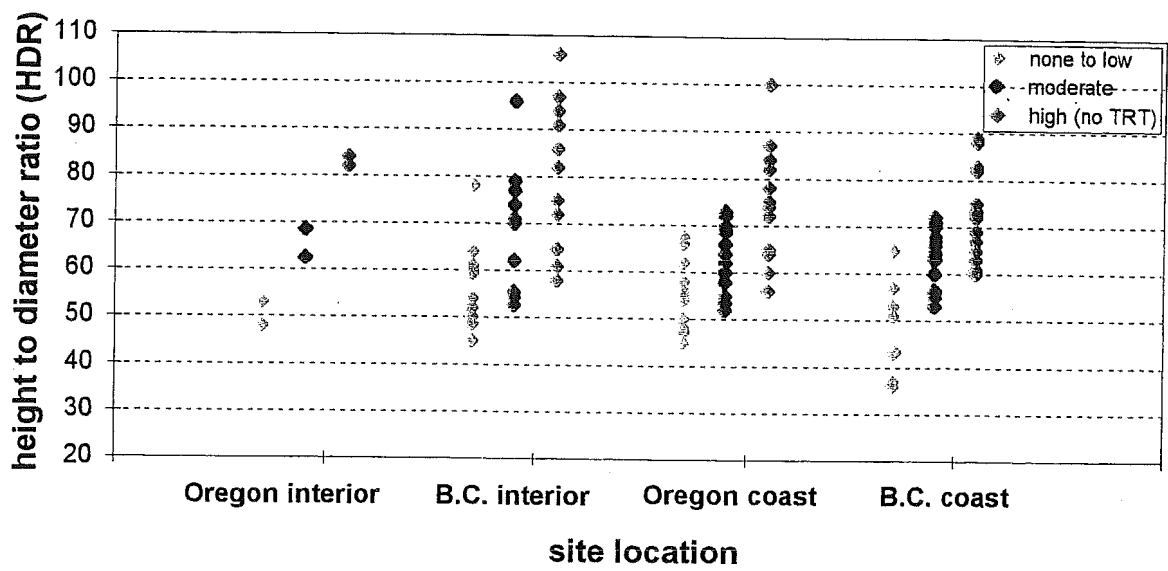


Figure 2. Scatterplot showing HDRs by site location for Douglas-fir. Groups are general so a number of data points would be available. HDR values taken at planting and treatment were not included in figure.

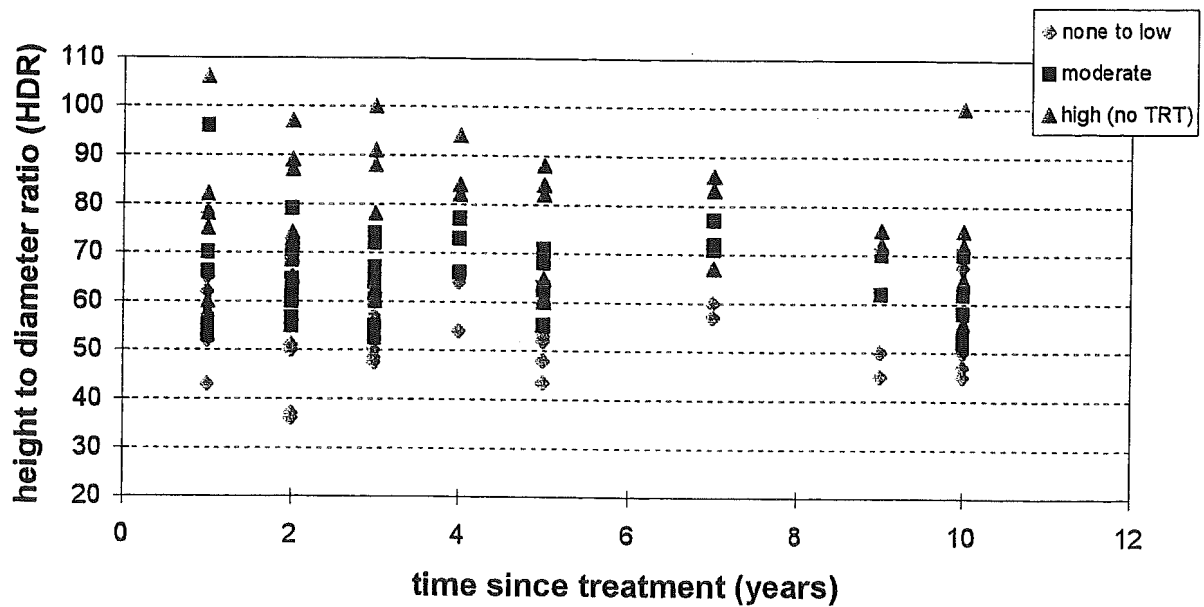


Figure 3. Scatterplot showing Douglas-fir HDRs for length of time since treatment. HDR values taken at planting and treatment were not included in figure.

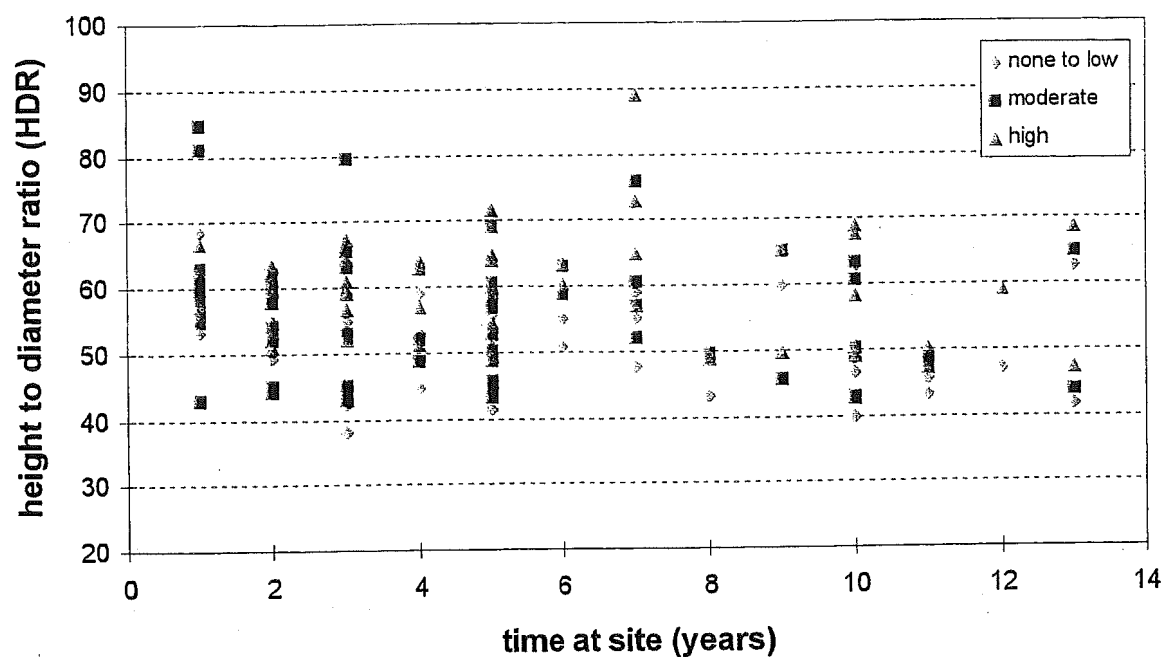


Figure 4. Scatterplot showing HDRs for length of time at site for spruce (white, Engelmann and the hybrid). HDR values taken at planting and treatment were not included in figure.

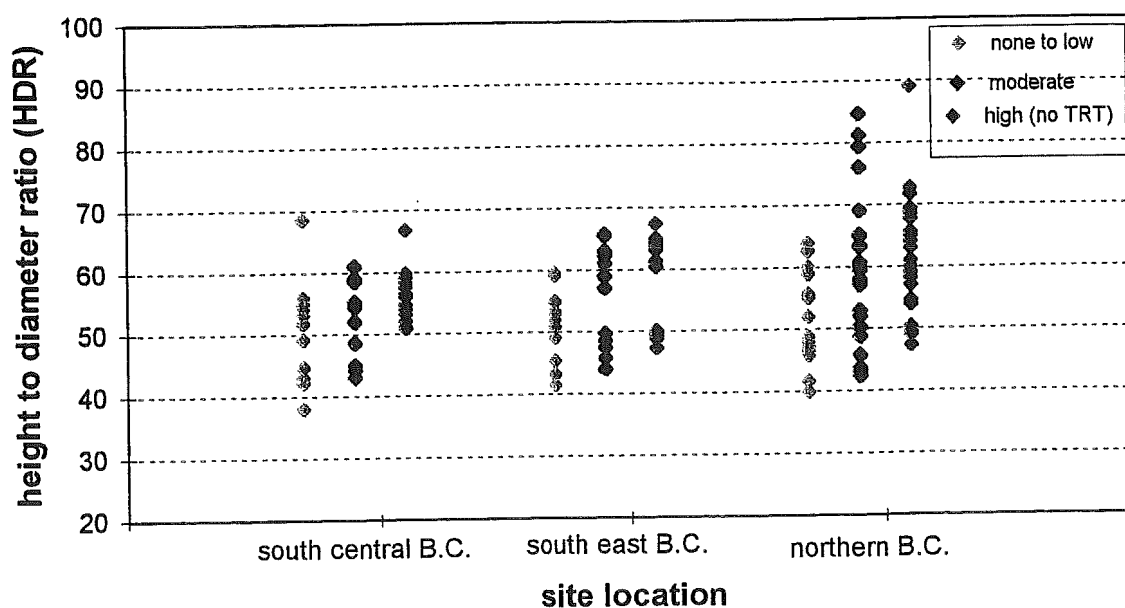


Figure 5. Scatterplot showing HDRs for spruce (white, Engelmann and the hybrid) by site location. The site in Alberta is included with the northern B.C. grouping. HDR values taken at planting and at treatment were not included in figure.

Table 2. Summary of mean HDR values for spruce (white, Engelmann and the hybrid). Competition groupings are for summary purposes. "TRT" refers to treatment.

Reference	Stock type	none to low	moderate	high (no TRT)	time at site	site	notes
Bedford <i>et al.</i> 1998	2+0 PSB 313	55.7	50.6 to 70.7	71.6	5 years	Inga Lake	the low to none values are the herbicide treatment, moderate range includes all other treatments
	2+1 bareroot	47.91	51.5 to 73	72.7	7 years	Wonowon	the low to none values are the herbicide treatment, moderate range includes all other treatments, large stock values not included
		48.84	51.1 to 69.9	67.7	10 years		
	2+0 bareroot	58.8	54.6 to 61	61	5 years	Coalmine	the low to none values are the herbicide treatment, moderate range includes all other treatments
		62.6	61.2 to 65.5	68.8	10 years		
		62.7	63 to 66.6	68.5	13 years		
Burdett <i>et al.</i> 1984		45.8	48.2 to 49.4	53.9	5 years	Mackenzie	the low to none values are the herbicide treatment, moderate range includes all other treatments
		39.9	39.3 to 45.6	50.4	10 years		
	1+0 PSB 313	41.7	40.6 to 46.8	47.3	13 years	Iron Creek	the low to none values are the herbicide treatment, moderate range includes all other treatments
		52	55.8 to 62.9	64	5 years		
		46.5	46.9 to 53.3	58.2	10 years	B.C. Interior	trial looking at stock type, not competition levels values under moderate competition, because no level of competition was given in paper
	1+0 PSB 313	63.9	65.6 to 72.5	69.3	5 years		
		60.14	61.1 to 69.2	65.56	9 years		
	bareroot	N/A	61	N/A	1 year		
		N/A	52	N/A	2 years	SBSnc zone	moderate range includes grad and edge treatments
	1+0 plugs	N/A	43	N/A	3 years		
Burton pers. commun. 1998		N/A	43	N/A	1 year		
		N/A	45	N/A	2 years		
Caza and Kimmins 1990		N/A	45	N/A	3 years		
		N/A	45	N/A			
Claveau & Messier pers. commun. 1998		48.2	51.5 to 65	71.4	10 to 15	near Vavernby, B.C.	good discussion of results
		35.8 to 40.3	N/A	47.9 to 56.4	3 years		
Coates 1987	cold	39.1 to 45.4	N/A	54.2 to 64	3 years		
	hot						
Goneau <i>et al.</i> unpublished 1998		<55	57	>65	N/A	Aleza Lake, SBS wk1 -07	based on % full sunlight, values from graph (approximate)
Coopersmith <i>et al.</i> 1998		47.1	39.6	39.5	at planting	near Clearwater	unexpected results, not on site very long may be due to vegetation type
		68.5	58.5	66.7	1 year		
Goneau <i>et al.</i> unpublished 1998		51.8	44.2	50.9	2 years		
Coopersmith <i>et al.</i> 1998	PBS 1+0	41.5	44	49.2	5 years	Soards Creek (near Mica)	
Harper <i>et al.</i> 1997a		N/A	54.5	N/A	at planting	Walker Creek	only uniform competition was used values are averages of all plots
		N/A	84.7	N/A	1 year		
Harper <i>et al.</i> 1997b		N/A	79.4	N/A	3 years	Fleet Creek	Fleet creek site has higher light levels
		N/A	81.2	N/A	1 year		
Harper <i>et al.</i> 1997b		N/A	63.2	N/A	3 years		
Harper <i>et al.</i> 1997b		47.13	N/A	59.13	12 years	near Dawson Creek	a remeasurement trial
		N/A	45.8	49.7	9 years	Mackay River/Horsefly	2,4-D ester and control averaged for high competition,

shaded areas represent unpublished references or the HDRs were not presented in the published paper
 * number of years refers to the time since treatment was applied

Table 2. Continued

Reference	Stock type	Competition Level		time at site	site	notes
		none to low	moderate to high (no TRT)			
Harper 1993	PBS 4150	53.2 54.1 54.9 49.2 53.2 44.8	55.3 58.9 59 54.3 62.1 48.8	1 year (Aug.) 1 year (Oct.) 2 years (June) 2 years (Aug.) 2 years (Oct.) 4 years (Sept.)	Nelson Forest Region Trout lake	PPFD values used to determine which treatments represented the different competition levels. the lowest PPFD was considered to have the highest competition.
Latchford 1996	2+1 barefoot	N/A N/A N/A N/A N/A N/A	55 to 59 59 to 61 57 to 61 52 to 56 50 to 54 51 to 55 50 to 54 41 to 45	at planting 1 year 2 years 3 years 4 years 5 years 7 years 10 years	Bowron River valley SE of Prince George	moderate ranges included all vegetation control methods
Lieffer and Stadt 1994	natural	59	76	(1-3m) tall	west central Alberta	no treatments applied, based on light transmittance
Newsome pers. commun. 1998	N/A N/A N/A	N/A N/A N/A	50.3 45.8 43.2	5 years 5 years 5 years	ESSFWK1 - 01 PLOT 1 ESSKW1 - 0505 PLOT 2 ESSFWK1 - 01 PLOT 3	moderate values are mal trees
Oswald and Brown 1992	PBS 313	52	57	5 years	SE British Columbia	many site preparation techniques used, based on % cover
Simard <i>et al.</i> 1998	N/A	61.1 56 43.1 44.6	56.3 to 58.7 54.5 to 55.5 47.9 to 56.4 44.7 to 52.7	at treatment 1 year* 3 year* 5 years*	a number of sites throughout B.C.	averages of HDRs for 22 different sites, see appendix for individual site HDR values
Whitehead and Harper 1998	PBS 313	59.5 59.1 59.1 55 49.1 45.5	60 to 64.1 64 to 67.4 60.7 to 64.5 62.5 to 63.4 49 to 50 47.7 to 49.4	2 years 3 years 4 years 6 years 8 years 11 years	north of Golden	moderate value is the range for the 2,4-D amine and manually treated plots the glyphosate treated plots were considered as the low competition level
Whitehead and Harper 1998	2+0 BR	59.2 53.4 54.8 53 50.9 43.9 43.2	62.7 to 63.3 60.8 to 61.2 65.2 to 65.9 61.9 to 63.6 58.8 to 59.3 48.3 to 48.9 47.5 to 47.3	1 year 2 years 3 years 4 years 6 years 8 years 11 years	north of Golden	moderate value is the range for the 2,4-D amine and manually treated plots the glyphosate treated plots were considered as the low competition level

shaded areas represent unpublished references or the HDRs were not presented in the published paper
* number of years refers to the time since treatment was applied

In the Prince George Forest Region, there are operational HDR guidelines for mixedwood stands and stands primarily stocked with conifers. In mixedwood stands white spruce are considered to be unimpeded from competing overstory deciduous crop trees if the HDR is 70 or less with a minimum inter-tree distance of 2.0 m between the spruce crop trees and deciduous crop trees (Kabzems 1997). Spruce stands primarily stocked with conifers are considered not free growing unless they have fewer than 1000 deciduous stems per hectare and a HDR of 60 or less (Hoyles 1998).

3.3 Pine

Lodgepole Pine (*Pinus contorta* var. *latifolia*) (Mackinnon *et al.* 1992) was the only variety of pine examined. It is a medium sized tree that grows 20 to 40 m tall, it is an adaptable species and can tolerate low nutrient conditions (Mackinnon *et al.* 1992; Parish *et al.* 1996). Lodgepole pine is widely distributed from low elevations to the treeline in northern and southern central British Columbia (Parish *et al.* 1996). Only a limited amount of information on the HDR of lodgepole pine was found.

In Prince George lodgepole pine are considered free growing in areas primarily stocked with conifers when there are less than 500 deciduous stems per hectare and the HDR is less than or equal to 50 (Hoyles 1998). Messier (pers. commun. 1998) found the largest HDRs in all competition levels (Table 3) and they were much larger than any other values. Because of the discrepancy between Messier's (pers. commun. 1998) findings and others, his values are not included in ranges to follow. The papers examined found that when under none to low competition the HDR of lodgepole pine seedlings ranged from 35 to 56 (values at planting not included) (Table 3). The range in HDRs grouped under high levels of competition was found to range from 47.3 to 68 (values at planting not include)(Table 3). The results found did not follow a strong trend of increasing HDR values as competition increased. There was no obvious trend observed in HDRs as the seedlings became established on the site (Figure 6).

3.4 Other species

HDR values were found for species other than Douglas-fir, lodgepole pine and white/Engelmann spruce. These species included western redcedar, grand-fir, subalpine fir, Scots pine, eastern white pine, red pine, jack pine, black spruce, western hemlock and western larch. For the competition groupings used the HDR generally increased as the amount of competition increased (Figure 7). HDRs for grand-fir ranged from 53 to 121 for seedlings under high competition. For seedling under none to low competition the HDR ranged from 47 to 72 (values at treatment not included) (Table 4). Western redcedar had similar ranges, for high competition the HDR was found to range from 68 to 124 and for none to low competition 46 to 90 (values at treatment not included) (Table 4). Subalpine fir had a HDR of about 58 for high competition, and less than 50 for low competition (Table 4). The HDRs for Scots pine, eastern white pine, red pine, jack pine and black spruce were much lower, ranging from 42 to 59 for seedlings under high

Table 3. Summary of HDR values for lodgepole pine. Competition groupings are for summary purposes. 'TRT' refers to treatment.

	stock type	Competition Level		time at site	site	notes
		none to low	moderate to high (no TRT)			
Bedford <i>et al.</i> 1998	1+0 PSB 211	42.6 to 43.4	42.1 to 48.3	5 years	Bednestil SBSdw	low range includes burn and bedding plow treatments, moderate range includes all other treatments.
		42.8 to 43.0	43.2 to 47.6	7 years		
		41.6 to 43.9	45.5 to 49.5	10 years		
	1+0 PSB 211	N/A	43.1 to 45.9	5 years	Tanil, SBSmc2/ESSFmv1	moderate range includes all treatments, accept the unburned control plot
Burton per. commun. 1998	N/A	45.71	40.8 to 42.9	10 years		
Claveau & Messier, pers. commun. 1998	N/A	<75	42.67 to 57.33	10 to 15 years	SBSMc zone	moderate range includes grad and edge treatments
	N/A		80.0	N/A	near Williams Lake	these are summary values based on % full sunlight
Coates 1987	N/A	32.1	31.6	at planting	near Clearwater	14 treatments were applied, HDR given only for 6 treatments
		47.8	45.0	1 year		
		37.3	42.1	2 years		
Newsome 1998	N/A	56.5	58 to 61	- 8 to 12 years	IDFdk, Cariboo Region	HDR values for densities less than 5 trees per plot
Simard 1989	PSB 211	47.2	46.1	at planting	Thompson Plateau	number of different minimal treatments, average was taken, but there was large differences in vegetation control?
		51.6	53.1	1 year		
		35.0	43.4	2 years		
Simard 1990	N/A	37.3	47.7	3 years	Southern Interior	moderate value is average of 3 treatments not significantly different
	N/A	N/A	57	at treatment	a number of sites throughout B.C.	HDR values are averages for 12 different sites, see appendix or individual site HDR values
Simard <i>et al.</i> 1998		N/A	64.3	1 year		
		N/A	56.7	3 years		
		N/A	53.5	5 years		

shaded areas are unpublished references or HDRs not presented in published papers
 * for detailed summary see spruce paper summaries

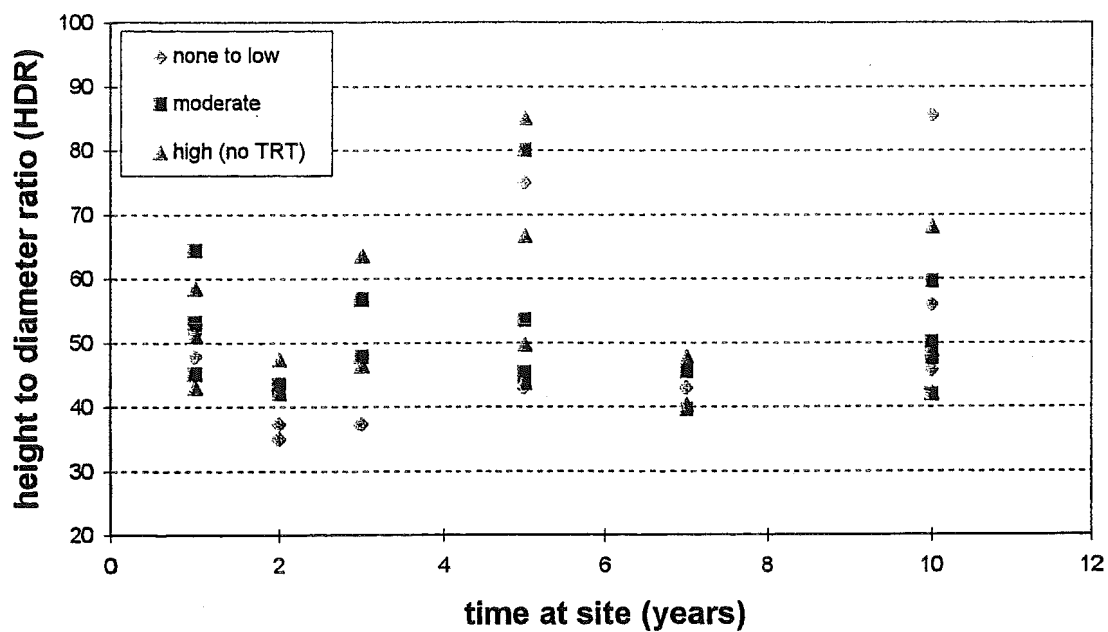


Figure 6. HDR values for lodgepole pine for length of time at site. HDR values taken at planting and at treatment were not included in the figure.

Table 4. Summary table of HDR values for species other than Douglas-fir, lodgepole pine and spruce (white Engelmann and the hybrid). Competition groupings are for summary purposes. "TRT" refers to treatment.

Reference	species	stock type	none to low	competition level moderate	high (no TRT)	time at site	site	notes
D'Anjou unpublished 1998 (FRDA 2.12)	grand-fir	2+0 bareroot	N/A	60 to 75	79	at treatment	Okeover Inlet	HDR ranges for moderate competition levels include all cutting treatments HDR values form the control (3100 sph alder) were used
			N/A	57 to 60	82	1 year*		
			N/A	53 to 57	76	2 years*		
D'Anjou unpublished 1998 (FRDA 2.35, McGuire creek)	grand-fir	2+1 bareroot	N/A	48 to 55	68	3 years*	McGuire Creek, southeast of Chilliwack	HDR ranges for moderate competition levels include cutting and hack and squirt treatments
			N/A	53 to 57	66	5 years*		
			N/A	57 to 64	69	7 years*		
D'Anjou unpublished 1998 (FRDA 2.13)	grand-fir	2+1 bareroot	<60	>70	N/A	at treatment	southeast of Chilliwack	HDR ranges are based on overtopping, high = control & overtopped seedlings, moderate is threatened seedlings, and low is not overtopped seedlings
			91	88 to 94	85	during first year*		
			72	75 to 91	86	1 year*		
Burton pers. commun. 1998	western redcedar	1+0 PSB 313	57.8 to 60.9	64.9 to 94.15	N/A	at treatments	CWHdm near Maple Ridge east of Mission	refer to paper summary for HDR by dominant species HDR ranges for moderate competition levels include all vegetation glyphosate and cutting treatments
			98	89 to 102	96	1 year*		
			72	76 to 82	86	2 years*		
Wang et al. 1994	western redcedar	1+0 PSB 313A	60	70 to 72	80	3 years*	Eastcap Creek, Vancouver Alpine Creek, Vancouver Cedar Creek, Vancouver	based on percentage of above canopy light
			55	67 to 70	76	5 years*		
			47	59 to 67	73	7 years*		
Burton pers. commun. 1998	subalpine fir	N/A	46	60 to 65	68	10 to 15 years	SBSmc zone near Williams Lake	moderate range, includes grad and edge treatments values based on % full sunlight, taken from graph
			<50	60 to 70	>70	N/A		
			90	N/A	124	20 years		
Claveau & Messier pres. commun. 1998	subalpine fir	N/A	71	N/A	112		Northern Sweden	low competition refers to the clear-felled areas and high competition refers to shelterwood
			63	N/A	115			
			32	48.9 to 53.7	58.3			
Fries and Nilsson 1990	Scots pine	3 provenances	<50	55	57+			
			49	N/A	43			

* refers to time since treatment application shaded areas refer to summary values which are based on the author's observations and opinions

Table 4. Continued

Reference	species	stock type	competition level			time at site	site	notes
			none to low	moderate	high (no TRT)			
Wagner <i>et al.</i> 1995; Wagner pers. commun. June 1998	eastern white pine	N/A	27	31 to 40	42	3 years	near Sault Ste. Marie, Ontario	moderate ranges include all treatments other than 3 consecutive years of control and no control 5 year results and summary values are unpublished (Wagner pers. commun. June 1998)
	red pine	N/A	25	N/A	45 to 50	5 years		
	jack pine	N/A	29	33 to 38	43	3 years		
	black spruce	N/A	26	N/A	40	5 years		
		N/A	32	47 to 54	56	3 years		
		N/A	30	N/A	55 to 60	5 years		
Burton pers. commun. 1998		N/A	41	34 to 50	59	3 years	CWHdm near Maple Ridge	refer to paper summary for HDR by dominant species
		N/A	30	N/A	55 to 60	5 years		
Chen and Klinka 1998			40's	50's to 70's	>100		near Okanagan falls	values are based on percent full sunlight, taken from graph
	western hemlock	1+0 PSB 313	49.9 to 71	71.8 to 104.2		N/A		
	western larch	container grown	60	80	100	3 years		

* refers to time since treatment application
shaded areas refer to summary values which are based on the author's observations and opinions

competition and 27 to 49 for seedlings under low competition (Table 4). The HDRs for western hemlock and western larch were much larger with values above 100 for high competition and about 60 for low competition (Table 4).

The HDR values were not looked at for trends by age or site location because of the limited number of values available. Groninger *et al.* (1995; 1997) found HDR values for loblolly pine ranging from 36.3 to 58. The values were not included in the summary table because of the difficulty determining competition levels. It was found in mixed stands with red maple and black locust that the HDR was lower than in pure stands (Groninger *et al.* 1995; Groninger *et al.* 1997).

4.0 Discussion

The literature search yielded a number of useful papers, however summarizing both the published and unpublished literature was a difficult task. As mentioned before the grouping of the HDR values into three competition levels (none to low, moderate and high) made a number of compromises. The groupings were designed to facilitate comparison across relatively gross levels of competition. It is important to refer to the referenced source to place HDR values within their proper context. Some trends were found, based on the groupings that were made, but these were very general and were not analyzed statistically.

Another concern associated with the competition groupings was, not all papers defined or considered competition. A number of papers considered only vegetation control or site preparation, and although this does affect the amount of competition this was not directly discussed in the papers. Other factors considered included crowding (Cole and Newton 1987), stock type (DeYoe 1988; Caza and Kimmins 1990), relative light intensity (Mailly and Kimmins 1997), site quality (Simard, 1990) and light transmittance (Lieffers and Stadt 1994). For the trials presented in the papers competing vegetation was controlled differently, some controlled herbaceous vegetation, some controlled hardwoods, some controlled ground cover and others did not specify what type of vegetation they were controlling. There were still other trials that did not even control vegetation.

From the data and literature compiled, it is generally apparent and accepted that as HDR increases tree vigor decreases. As the HDR increases, growth rates have been observed to decline and the tree becomes etiolated. A higher HDR indicates a greater susceptibility to windthrow and physical damage (Navratil 1996; Bi and Turvey 1994; Kladke and Kenk 1997; Smith 1986). The greatest growth rates have been found to occur below a HDR of 60 in Douglas-fir seedlings (D'Anjou unpublished 1998; Newton and Comeau 1990). Douglas-fir seeding with a HDR greater than 70 have been found to experience a rapid decline in height growth, which leads to suppression and death (Huges *et al.* 1990). There have also been many other values associated with decreased growth and maximum growth potential. Rose *et al.* (1998) suggested that Douglas-fir seedlings

with ratios in the high 40's to low 50's were nearing maximum growth potential. Seedlings with a larger HDR tend to have greater mortality than those seedlings with a smaller HDR (D'Anjou unpublished 1988). Generally it can be assumed that seedlings with a smaller HDR are healthier than seedlings with a larger HDR, however no one HDR value has consistently been found to indicate either a healthy or unhealthy tree.

For the competition groupings used, it was found that the HDR increased with increasing competition. This increase was not large and may not be found to be statistically significant, however the trend was apparent for all species. Douglas-fir had the greatest increase in HDR with increasing competition, and lodgepole pine had the smallest increase. This trend is probably due to a relatively unaffected height growth, and reduced diameter growth when competition limits light. Limited light causes more resources to be allocated to height growth rather than diameter growth (resources are channeled to height first, then diameter). A large range of overlapping values were found between all competition levels, indicating a lack of distinction between the competition groups used. The range of HDRs and the variability between papers was large. It was found that the variability of the HDRs decreased as seedlings became established on a site. The decrease in variability tended to be a loss in the higher HDR values rather than the lower HDR values. This trend during the establishment phase of a seedling may be due to changes in resource allocation moving from the nursery to plantation environment. In the field, seedlings may allocate more resources to root development than they did in the nursery.

There was higher variability when the HDRs were larger as compared to when the values were smaller. The reasons for this are not entirely clear, but healthier seedlings are in a more stable state thus have more consistent HDRs. Those seedlings with large HDRs are under more stress and the response of the seedlings is variable. This finding is contradictory to Harrington and Chan (1992) who found at high levels of competition trees perform similarly, but when competition is reduced there is a wider range of responses. This response occurs because when competition is absent, genetics, seedlot and other individual traits have a much larger impact on tree morphology (Harrington and Chan 1992).

Another cause of the large variation in HDR values may be attributed to the variability between trials. The trials were done at different sites, with different seedlots, in different years, different treatments were tested and different people measured the seedlings. There is also a lot of variability in what the HDR values mean. Newton and Cole (1987) found trees with a HDR greater than 100 showed poor tree vigor, thin crowns and little growth. It was also found that reduced growth occurred at a HDR of 70 (Newton and Cole 1987). In a later paper by Newton and Comeau (1990), it was stated that a HDR of 60 indicates that long term height and volume increments are jeopardized. The papers found very different results even though Newton was the primary author. This illustrates that not only is it difficult to determine the HDR value for poor vigor, but also what constitutes poor vigor.

The HDR values found for species other than Douglas-fir, lodgepole pine and white and Engelmann spruce, offered only a limited amount of information because only a few values were available. The grand-fir HDR values came only from D'Anjou's studies (unpublished 1998). Values for western redcedar came from two studies (Wang *et al.* 1994; D'Anjou unpublished 1998). Subalpine fir values also came from only two sources (Fries and Nilsson 1990; Claveau and Messier pers. commun. 1998). For all other species only one set of values were available. This limited amount of data, restricts comparisons between papers, sites and age and therefore offers little insight into the viability of the values found. More research will be required to understand the HDR trends in these species.

Not all papers support the findings that as competition increases the HDR increases. Coates (1987), found that those seedlings under higher competition had a slightly smaller HDR than those seedlings under no competition. These results may be explained by the initial heights of the seedlings, but there may also be other factors influencing seedling growth. For Douglas-fir, D'Anjou (unpublished 1998) and DeYoe (1998) found seedlings under high competition that had a HDR that fell within the range for moderate competition. A number of papers (Whitehead and Harper 1998), pine in particular (Coates 1987; Bedford *et al.* 1998) found very little difference between the HDRs of seedlings under different competition. There may be more examples where greater competition does not always result in a larger HDR. The reason for these findings is that many factors were found to affect the HDR however, in most cases it was not determined how they affected the HDR. Slope, aspect, stock quality, fertility and soil can affect seedling growth more so than excellent weed control (Rose *et al.* 1998 unpublished). Another factor that is particularly evident in Harper (unpublished 1998) paper is the effect that time of year has on the HDR. Harper's (unpublished 1998) results found that the HDR was smaller the later in the growing season measurements were taken. HDR changes throughout the season because the height growth occurs early in the season, whereas diameter growth continues throughout the growing season. There are a number of things that have been found to affect the HDR, however the extent to which they affect the ratio is not fully known. Because of the limited information and inconsistent results more trials and research is required to determine how site, climate, site preparation and other factors influence HDR.

Wood and Campbell (1992) suggested that HDR should not be used as an indicator of when to apply brushing treatments as it is not proactive. HDR indicates a competition problem after there has been a reduction in growth rate. HDR is however being used as a method to determine when to brush in Washington State on the west side of the Cascade Mountains (D. Belz pers. commun. May 1998). HDR is also being used as an additional free growing criteria in the Prince George Forest Region (Hoyles 1998) to assess whether seedlings are free from deleterious competition.

Concern has been noted over the potential use of HDR as a free growing criteria. Since HDR is an indicator of past competition, it does not indicate how future competition will affect the crop tree. A tree may have an acceptable HDR, but may be threatened by

competition in the near future. For example, hardwood ingress has been noted on some B.C. interior plantations (G. Newsome pers. commun. 1998). The use of HDR cannot predict or anticipate the development of rapidly growing persistent hardwood competition.

5.0 Conclusions

Height diameter ratio has generally not been used in forest establishment research. No studies were found that effectively explored the ratio of height and diameter in conifers. However, growth response evidence from conifer physiological studies provided good information to allow for general HDR response interpretations. Specifically, conifer response to light competition has resulted in increased HDRs. Factors affecting light availability will influence HDR. Some evidence in the literature and inconsistencies in field data suggest other factors such as moisture and nutrient availability, soil type, climate, etc. will directly or indirectly influence HDR. HDR appears to be independent of size and is considered by some as a morphological indicator of competitive stress (B. Wagner pers. commun. 1998).

In terms of tree morphology, large HDRs indicate a greater resource allocation to height rather than diameter growth. It has been found that larger HDRs are associated with less healthy trees. It was also found that HDRs increased as competition increased, however this trend is based on generalized competition groupings and is not associated with any statistical significance. It was found the variability or range in HDR values is large, and determining the numerous factors that cause this variation is difficult. Different types of vegetation may contribute to the variation in HDR values. Light is the primary resource influencing the HDR, therefore only vegetation that potentially limits light can properly be assessed by using the HDR. This includes over-topping vegetation which, at the free growing assessment time, primarily includes tall shrubs and persistent hardwoods. Other vegetation, although it may be considered to be at a high level may not have an impact on the HDR because it is not over-topping and therefore not in competition for light. Differences in shade tolerances between conifer species may also be a cause for variation. Shade intolerant conifers will show a large HDR under much less competition than a shade tolerant species. HDRs may have value in silviculture systems research where partial canopy removal treatments will influence light penetration and regeneration success.

There is some uncertainty as how the HDR should be measured. Ideally all HDRs need to be taken following the same method. Due to observations that time of year affects the HDR it should be specified when the measurements are to be done. It should be specified where on the stem the diameter is to be measured and what should be done if the basal diameter is below or above the ground level. If the base is swollen the diameter should be measured avoiding the swollen area (Wright 1975). When the bole is non-spherical it is necessary to take the average of 2 or 3 root collar measurements (Hoyles 1998). The HDR must be measured and calculated individually for each crop tree. The

accuracy of the height measurements must be determined and method of measuring height becomes increasingly important as the tree gets larger.

With the limited information presented in this report, HDR thresholds could not be determined that could be used with consistency as a free growing criteria. However, the potential exists to explore the possibility of general HDR thresholds within specific conifer species and plantation conditions. It is recommended that if HDR is used in free growing determination that it not be used alone but in concert with other criteria. The value of HDR in determining free growing condition may only be captured under specific conditions, such as when light is the limiting resource (ie. persistent hardwood competition) or, when additional information is required to facilitate difficult tree / plot/ stand level free growing decisions. The high variability of HDR restricts its use as a regulator criteria. Evidence suggests that, only within the boundaries of a morphological indicator of stress, does HDR have value. Use of HDR in silvicultural decisions will require detailed knowledge of conifer physiological responses. To date, the full spectrum of factors influencing conifer HDR response is unknown and as a result decisions based solely or in large part on HDR are not recommended.

Appendix 1 - Primary references used for introduction background information

Abetz, P. and F. Kramer. 1976. Contributions to our knowledge on the growth of trees: the height/diameter ratio is more than a measure of slenderness. Forst-und-Holzwirt. 31: 19, 389-393.

- the paper is in German, but an English abstract was found:

A discussion of the importance of the ratio h/d , mainly referring to Spruce (*Picea abies*) and Pine (*Pinus sylvestris*), based on the literature and on an unpublished paper by F. Kramer. The ratio is an important index related to position in the canopy, volume increment of individual trees and of stands, resistance to snow damage, etc. and deserves further study.

Bi, Huiquan and Nigel D. Turvey. 1994. Effects of *Eucalyptus obliqua* (L'Herit) density on young stands of even-aged *Pinus radiata* (D. Don). New Forests 8: 25-42.

- study done in Australia on 10-year-old even-aged stands
- found that higher *E. obliqua* density resulted in higher mean HDRs of *P. radiata*.
- P. radiata* HDR increased linearly with *E. obliqua* density on a natural log scale,
- the HDR of *E. obliqua* was generally greater than *P. radiata*
- diameter was taken at breast height, and is considered as a general indicator of stem form and tree stability against wind.
- a height to DBH ratio of 130 was considered a value at which *P. radiata* would be at high risk of wind damage on certain sites
- the reduction in canopy leaf area of *P. radiata* could result in smaller and less vigorous crown which would consequently lead to a higher HDR.

Bi, Huiquan and Nigel D. Turvey. 1996. Competition in mixed stands of *Pinus radiata* and *Eucalyptus obliqua*. Journal of Applied Ecology, 1996, 33. 87-99.

- study site in Australia, *P. radiata* site was 15 years old at time of study.
- diameter was measured at breast height
- competition reduces the supply of light, water and nutrients
- HDR is a density dependent stand level characteristic,
- HDR decreased with tree size and increased with neighborhood density and leaf area index for both species
- HDR was related to tree size and neighborhood LAI
- smaller trees of *P. radiata* seemed to achieve greater increases in HDR than larger ones, suggesting that stem growth distribution could be different in different sized trees
- patterns suggest that smaller trees that already have a high HDR may not be mechanically able to accommodate the greater increases in HDR like trees larger sizes can.

Brand, David G. 1986. Competition-induced changes in developmental features of planted Douglas-fir in southwestern British Columbia. Can. J. For. Res. Vol. 16.

- brush competition affects an establishing tree by changing in the availability of site resources, moisture, mineral nutrients and growing space

- on different sites, competition acts by limiting different resources
- separation of competition into light, moisture and nutritional effects sites would be helpful, as results do not indicate what resources competition limits
- brush competition may particularly result in a reduction in the solar radiation available to planted trees on the moist, rich sites of coastal British Columbia
- differences in light intensity have been shown to cause changes in the allocation of resources for growth

Campbell, Robert A. and James E. Wood. 1992. Plant Physiology and herbicide sensitivity Part II. Seminar on Spray Application Technology NIVMA Symposium Mar. 30 to April 1.

- the actual HDR varies with provenance and site factors
- tree morphology is affected by light intensity
- feels that the morphological changes caused by competition stress are not very good indicators of when to perform conifer release treatments
- by the time morphological changes are noticeable there has already been a loss in growth potential and it is too late
- morphological changes can be caused by many reasons: site conditions, provenance, seasonal climate and age of tree, thus specifying a threshold value is very difficult
- morphological changes might be useful to judge a tree's response to treatment

Coates, K.D., W.H. Emmingham, and S.R. Radosevich. 1991. Conifer-seedling success and microclimate at different levels of herb and shrub cover in a *Rhododendron-Vaccinium-Menziesia* community of south central British Columbia. Can. J. For. Res. Vol. 21

- diameter growth was most responsive to a reduction in vegetation,
- seedlings planted without competition had a much greater diameter (spruce - 44% and pine seedlings - 84%), then those seedlings with competition
- height growth was less responsive to a reduction in adjacent vegetation
- herb and shrub communities can compete with conifers for light, water or nutrients
- low nighttime temperatures have been shown to decrease engelmann spruce diameter and height growth
- better nutritional conditions may be a possible reason for the superior growth of both spruce and pine as shrub and herb interference decreased
- under field conditions isolating individual environmental factors is difficult

Comeau, Phil, Balvinder Bring and George Harper. unpublished 1998b. Conifer response to brushing treatments, a review of available information. Extension note 00. March 1998. Ministry of Forests Research Branch, Victoria B.C.

- brushing treatments are applied to control non-crop vegetation to improve the survival and growth of crop seedlings and to accelerate development of free-growing plantation

- in general, releasing conifers from low to moderate levels of vegetation cover results in little initial increasing height growth, may result in reduced height growth as growth is directed to diameter increment
- under low to moderate levels of competition etiolation causes enhancement of height growth at the expense of stem diameter and crown development
- height growth responses vary by vegetation complex, crop species, treatment type, and the amount of vegetation encountered

Comeau, Phil and Don Sachs. 1992. Simulation of the consequences of red alder management on the growth of Douglas-fir using FORCYTE-11. B.C. Min. For., Victoria, B.C. FRDA report 187.

- red alder can contribute to site productivity through symbiotic nitrogen fixation
- deciduous hardwoods can add structural diversity and non-timber values
- red alder has a rapid initial growth rate and therefore can over-top conifers and substantially reduce conifer survival and growth when it regenerates at sufficient rates.

Drew, Allan P. and William K. Ferrell. 1977. Morphological acclimation to light intensity in Douglas-fir seedlings. Can. J. Bot. Vol. 55.

- greater etiolation occurs under low light
- Douglas-fir shows marked ability to acclimate morphologically to changes in environment (not all species have this ability),
- the study supports the idea that shading seedlings increases the allocation of dry matter production to shoot growth, which is adaptive when light is limiting,

Harrington, Timothy B. and John C. Tappeiner II. 1991. Competition affects shoot morphology, growth duration and relative growth rates of Douglas-fir saplings. Can. J. For. Res. Vol. 21: 474-481.

- trees response to competition is hard to predict because it varies with site characteristics, vegetation abundance and proximity, and species composition,
- shoot growth largely occurs from internodes that developed the previous year's (determinate),
- cambial growth is dependent on the current year resources (indeterminate),
- trees under water stress typically reduce cambial growth before shoot growth,
- suggestion that competition-induced restrictions in soil water and nutrients affected the shoot growth by limiting internode production the year before, and by limiting elongation of internodes during the current year,
- the duration of basal area growth was reduced by competition, but the duration of height growth was not,
- morphological indicators, such as bud number, bud size and internode number can be used to judge tree response to treatment, as well as to diagnose the onset of severe competition stress,

Harrington, Timothy B., and Samuel S. Chan. 1992. Changes in physiology and morphology of conifer seedlings following forest vegetation management. In Proc.

Of a presentation at the workshop on forest vegetation management without herbicides, Oregon State University, Corvallis, February 18-19, 1992.

- conifer growth is driven by the physiological and morphological responses to environmental conditions and genetic potential
- at high levels of competition individual trees perform similarly, but with reduced competition there is a wider range of responses,
- environmental stress from competition can result in slowed growth, restricted morphological development and mortality,
- when water is not limited, the tension is lower and water can move more freely which results in better efficiency of vital cell functions.
- HDR indicate a degree of light deprivation,
- as light increases the HDR decrease from values over 100 for shaded trees to more optimal values near 50
- vegetation management increases the length of the growing season for cambial growth, but not height growth.

Hasenauer, Hubert and Robert A. Monserud. 1996. A crown ratio model for Austrian forests. Forest Ecology and Management. 84: 49-60.

- many different species in mature stands throughout Austria
- HDR is the most important size variable, and can be considered an integrator of past competition,
- increased HDR results in a shorter crown length, this corresponds to the shorter crowns in overly dense stands with relatively tall spindly trees or high HDR. (basal diameter)

Holbrook, N. Michele and Francis E. Putz. 1989. Influence of neighbors on tree form: effects of lateral shade and prevention of sway on the allometry of *Liquidambar styraciflua* (sweet gum). Amer. J. Bot. 76(12): 1740-1749.

- trees that allocate proportionately more biomass to height growth than to diameter increments incur a greater mechanical risk,
- light availability influences trunk and crown shape by causing differences in growth rates within tree crowns and variations in branch persistence
- stem allometry is expressed as the ratio of total height to stem diameter 50 cm from the ground
- trees guy-wired to prevent swaying were taller and had narrower and less conical stems than control trees
- the addition of lateral shade had an even more pronounced effect on stem allometry,
- very high HDRs are given (108, 125, 165), probably a factor of the tree type
- common to many studies of tree mechanics is the idea that there exists a critical HDR beyond which a tree would buckle under its own weight,

Kayahara, Gordon J., Han Y.H. Chen, Karel Klinka, and K. Dave Coates. 1996. Relations of terminal growth and specific leaf area to available light in naturally

regenerated seedling of lodgepole pine and interior spruce in Central British Columbia. Research Report, 09. Ministry of Forests Research Program.

- lodgepole pine is shade intolerant
- spruce has an intermediate shade tolerance
- it is found that soil moisture affects spruce growth more than pine growth
- in light limiting environments, shade tolerant species tend to allocate more biomass production to lateral and caliper growth,

Kladke, Joachim and Georg Kenk. 1997. Thinning and yields in Norway spruce stands in southwest Germany *In* Stand density management: planning and implementation, Proc. of a conference held November 6 and 7. Colin Bamsey (editor). Edmonton, Alberta. pp. 4-11.

- HDR (diameter taken at breast height) is used for thinning in Europe because it takes into account the stand structure and vitality of future crop trees
- the HDR is an appropriate measure for quantifying the competitive vigor and the mechanical stability of a tree against wind or snow break.
- the conclusion for thinning operations is, that trees with a high HDR need to be released much more than others,
- the HDR rules for the selection of crop trees say: trees with high HDR have to be released totally, the lower the HDR the fewer trees to be cut and future crop trees with low HDRs do not need to be released,
- trees with HDRs less than 80 are less endangered by snow break than others

Knowe, Steven A. 1994. Effect of competition control treatments on height-age and height-diameter relationships in young Douglas-fir plantations. Forest Ecology and Management 67: 101-111.

- diameter measured at 30cm above ground level,
- height to diameter relationship is not the ratio,
- individual tree height for a given diameter and age has been shown to increase in response to intraspecific and interspecific competition in young Douglas-fir stands
- initial height growth may be affected by factors unrelated to site quality such as weed and/or brush competition,
- height is relatively unaffected within a range of intraspecific competition and competition from woody vegetation,
- vegetation control has been shown to consistently increase height and diameter growth of several North American conifers,

Kozlowski, Theodore T., Paul J. Kramer and Stephen G. Pallardy. 1990. The physiological ecology of woody plants. Academic Press, Inc. Toronto.

- shaded branches lose their ability to obtain water and perhaps nutrients this inhibits photosynthesis,
- inhibition in root growth decreases water and nutrient absorption further decreasing growth,
- extensive literature shows that woody plants compete with other woody or herbaceous plants for light, water and mineral nutrients,

- increasing competition greatly reduces the rate of cambial growth and wood production,
- diameter growth reduction is partially caused by late initiation and early cessation of cambial activity and a decrease in growth rate,
- cambial growth is much more sensitive than height growth to competition
- these differences are associated with variations in sink strength and phenology of apical and lateral meristems
- after thinning there is an increased downward transport of carbohydrates and hormonal growth regulators, there is an eventual increase in cambial growth and redistribution of wood production along the tree stem,
- usually assumed thinning has little effect on height growth of residual trees, however sometimes, on poor sites, thinning may decrease height growth,
- on poor sites some species develop a stagnate physiological state and do not thin naturally,

Lanner, Ronald M. 1985. On the insensitivity of height growth to spacing. For. Ecol. Manage. 13:143-148.

- stand density affects morphology
- stand density has little effect on height growth
- mean diameter of trees in the stand is increased with increasing spacing
- sinks have to compete for resources
- radial growth results from a relatively weak sink, the cambium. - it must depend on current photosynthate, when little light is available there is little carbohydrate synthesized and therefore available, more light means more carbohydrates are synthesized and thus more radial growth occurs,
- radial growth continues throughout the growing season, and is influenced by competition more than height, the amount of cambial growth depends on the current-year conditions
- height growth occurs from the activity of a stronger sink, the apical meristem, thus its demand is made early in the growing season when stored carbohydrate is at its peak, and it can also draw current photosynthate as well.
- height growth can occur even during times of high stress

Levitt, J. 1980. Responses of plants to environmental stresses, 2nd edition, volume II water, radiation, salt and other stresses. Academic Press, Toronto.

- decreased cell growth must be the most sensitive response to water stress because cell growth is quantitatively related to cell turgor which decreases with a decrease in water potential,
- leaf enlargement is inhibited by dehydration earlier and more severely than photosynthesis or respiration,
- complete stomatal closure requires a lower water potential than for growth inhibition,

Messier, Christian and Pasi Puttonen. 1995. Growth, allocation, and morphological responses of *Betula pubescens* and *Betula pendula* to shade in developing Scots pine stands. Can. J. For. Res. 25: 629-647.

- no clear trends in water and light availability were found
- results suggest that growth in understory birch is mainly related to differences in light availability,
- HDR values presented for *B. pubescens* (hairy birch) and *B. pendula* (silver birch),
- the HDR increased with the increasing shade of the 20-year old age group,
- HDR values for *B. pendula* and *B. pubescens* were as follows: For the 7 year old Scots pine age group, HDR values were approximately 85, for the 11-13 age grouping HDR ~115, for the 20 age grouping HDR ~ 148.

Messier, Christian, René Doucet, Jean Claude Ruel, Martin J. Lechowicz, Yves Claveau and Colin Kelly. Unpublished 1998. Functional aspects of advance regeneration growth and survival up to pole size in boreal forests. GREF interuniversitaire. Montréal, Québec.

- gives a good background summary of how a tree responds to different light levels and other factors, concentrating on seedlings growing in understories.
- the allocation of resources to height growth, makes the tree a better light competitor and usually results in higher growth rates,
- the allocation of resources to fine roots allows a greater capacity for water and nutrient uptake
- the overall light requirement increases as trees get bigger
- after release, diameter growth usually increases immediately where as height growth returns to levels before release,
- HDR changes in relation to changes in light environment
- height growth is not more sensitive than diameter growth for balsam fir
- species like pines, spruce, and birch should show more sensitivity to HDR than species like firs

Navratil, S. 1996. Silvicultural systems for managing deciduous and mixedwood stands with white spruce understory. In: Silviculture of temperate and boreal broadleaf-conifer mixtures. P.G. Comeau and K.D. Thomas (editors). Province of British Columbia.

- discusses HDR as a slenderness coefficient used for determining a tree's wind resistance

Newton, Michael and Thomas J. Hanson. bias in site estimation from early competition. undated and unpublished paper.

- whether planted or natural regeneration, early competition during stand establishment influences height of trees well into their life spans, and affects the height/diameter relationship
- the various analyses of competitive interaction indicate that woody cover tends to cause a general increase in ratio of height to diameter,

- from an unpublished manuscript from Cole and Newton, they found that once a Douglas-fir reaches a HDR over 75, its future height growth will be reduced,
- competing vegetation may improve survival by shading and protecting from frost on hot, dry sites,

Nilsson, Urban. 1994. Development of growth and stand structure in *Picea abies* stands planted at different initial densities. Scand. J. For. Res. 9: 135-142.

- found that HDR was not significantly influenced by spacing, thought the limiting factor for growth was not light but mineral nutrients and/or water
- all other experiments that have found the same results have been on sites of relatively low fertility,
- low soil temperature may also be a factor,
- states previous material finds: with high densities the result is an increase in the height diameter ratio, and this ratio has been used as an indication of the severity of competition
- when water and mineral nutrients are limiting factors for growth, the tree seems to react with a decrease in both height and diameter increment.
- because both height and diameter were affected by spacing the HDR was not,
- they found that because of decreased height growth, the HDRs for closely spaced stands were the same as the more widely spaced stands,
- note, diameter was measured at breast height and the were stands mature

Simard, Suzanne and Jean Heineman. 1996. Nine-year response of Douglas-fir and the mixed-hardwood shrub complex to chemical and manual release treatments on a ICHmw2 site near Salmon Arm. FRDA report 257.

- trials studying lodgepole pine seedling release from competing vegetation show that stem diameter is the most sensitive measure of early response to treatment for that species.
- height has not been observed to respond to treatment until several years later,
- current research is finding a number of ways in which the presence of birch may be beneficial to both short and long-term ecosystem health and productivity

Smith, David M. 1986. The practice of silviculture 8th edition. John Wiley and Sons. Toronto.

- ratio of total height to DBH is a useful parameter for the guidance of thinning practice for Norway Spruce in Germany
- the ratio does not define stand density
- for spruce in southwest Germany the goal is to keep the HDR from dropping below 70,
- HDR focuses attention rate of diameter growth and defines degree of butt swell that governs the resistance against the mechanical loads of wind and frozen precipitation,

Taiz, Lincoln and Eduardo Zeiger. 1991. Plant physiology. Benjamin/Cummings Publishing Company, Inc. Redwood City, California.

- when a water deficit develops slowly enough to allow changes in developmental processes, water stress has several effects on growth
- water stress limits leaf expansion
- earliest responses to stress appear to be mediated by biophysical events rather than changes in chemical reactions due to dehydration,
- as the water content of the plant decreases the cells shrink and cell walls relax decreasing cell volume and turgor.
- cell expansion is a turgor-dependent process extremely sensitive to water deficit
- water stress limits the size of individual leaves and decreases the number and the growth rate of branches on indeterminate plants
- the process of stem growth has been studied less than that of leaf expansion, but is probably affected by the same forces that limit leaf growth during stress.
- a shoot will grow until water uptake becomes limiting, roots will grow until their demand for photosynthate from the shoot equals the supply,
- when water availability is reduced, leaf expansion is affected early, but photosynthetic activity is affected less, this allows a greater proportion of resources to be allocated to root growth (shoot consumes less),
- water stress decreases amount of photosynthate exported from leaves by decreasing photosynthesis,

Van Den Driessche, R. 1991. Influence of container nursery regimes on drought resistance of seedlings following planting. I. Survival and growth. Can. J. For. Res. Vol. 21.

- Douglas-fir, Lodgepole pine and white spruce, never planted in the field,
- a greater HDR was associated with higher temperatures (at end of nursery growth),
- provides some evidence that HDR may be affected by temperature in the field, which would be controlled by location such as coastal versus, central BC.
- small HDR were associated with greater drought resistance

Wagner, Bob. 1994. To treat or not to treat: what is the threshold? The VMAP report, vegetation management alternatives program. Fall 94. Vol. 3 no. 2.

- discusses numerous thresholds, and the problems associated with determining the level of vegetation control that is required.
- a single competition index number is not a realistic possibility
- research indicates that height and stem growth respond differently to competing vegetation,
- diameter growth is more sensitive to surrounding vegetation than height growth, as height growth is relatively insensitive
- most diameter and biomass growth loss from competing vegetation is due to competition for soil water and nutrients, rather than reduced light
- height growth is one of the last growth variables to be affected under competitive stress, therefore height is a poor indicator of competitive stress,
- the difference between height and diameter responses to competing vegetation creates high stem HDRs

-tall, slender stems are often observed for trees under high competitive stress.

Waring, R.H. 1987. Characteristics of trees predisposed to die: stress causes distinctive changes in photosynthetic allocation. Bio. Science 37: 569-574.

- stem growth occurs after foliage and root growth resource needs have been met,
- the normal pattern for carbon allocation: buds and new foliage have priority, then new roots, carbohydrate reserves (in the canopy, stem and roots), then resources go into diameter growth and finally defense compounds,
- when a tree is experiencing drought, demands for shoot growth are immediately reduced, but may not completely halt photosynthesis
- the symptoms of nutrient deficiency, as expressed in carbohydrate allocation, are similar to those observed for drought
- drought slows mineralization and force roots to extract water from deeper soil horizons, where they obtain less nutrients
- soil nutrient deficiency leads to an increase in the proportion of carbohydrates allocated to growth of small roots,
- nearly any stress, if sustained, reduces the canopy, photosynthetic activity, and storage reserves throughout the tree

Waring, Richard H. and William H. Schlesinger. 1985. Forest ecosystems: concepts and management. Academic Press, Inc., Toronto.

- under mild drought, carbon uptake is not reduced that much, but shoot growth is inhibited, carbohydrates are transported to the roots because they are closest the water source and therefore the least stressed and can actively grow.
- inadequate light affects allocation differently, little photosynthate is exported from shaded branches, root and seed production are reduced and new foliage and terminal elongation are favored.
- when nutrients are lacking, increasing amounts of carbohydrates move towards the roots as canopy development slows,

Table A1.1 showing changes in carbon allocation patterns associates with various stress.

stress	root growth	stem taper	foliage growth	other
shade	reduced	reduced		umbrella-shaped crown
drought	increased	increased	reduced	loss of older foliage
mechanical		increased		asymmetrical shape of branches, bole, and large roots
nutrient deficiency	increased	increased	reduced	

Weihe, J. 1977. Correlation between stem diameter/height ratio, normal form factor and crown length ratio in spruce stands. Forstarchiv, vol. 48, no.10: 200-203 (translated from German).

- focus is primarily on the diameter/height ratio for application to thinning
- Abetz (1976 German reference) recommends a slenderness ratio (HDR) of 80 for snowbreak locations.
- does not support the use of the HDR because he feels it incorrectly interprets the relationships with growth, and does not deal with the relationship that exists between the stem diameter/height ratio and the normal form factor.

Wright, Jonathan W. 1975. Genetic Variation in the height-diameter ratio in Scotch Pine. In Proceedings of the fifteenth meeting of the Canadian tree improvement association. Part 2. 12th Lake States Forest Tree Improvement Conference. II. P. 113- 121.

- the diameters were measured at one foot above ground level to avoid butt swell
- the average HDR was measured (feet/feet) was 54 in all three plantations,
- for the tallest seedlots the HDR varied from 50 to 54 (not significantly different)
- trees from the north (northern Sweden, Siberia, and the Ural Mountains) were more slender (higher HDR) than the average with a HDR of 56 to 58.
- stockiest trees were from Spain (44), Greece (49), Turkey (50), and Northern Italy (50)
- different seedlots possibility have different HDRs when planted at the same sites
- for the best estimates of a tree's productivity, measure diameter at ground level and total height.
- the HDR will be larger if the diameter is measured higher than ground level, the effect will be greater for the smaller trees.

Zimmermann, Martin H. and Claud L. Brown. 1971. Trees: structure and function. Springer-Verlag, New York.

- light together with gravity is one of the most important constituents of the environment in determining the course of development in woody plants,
- the availability of water is the singly most important environmental factor limiting growth and distribution of trees,
- trees grown under moisture stress conditions usually have a shrubby appearance due to reduced growth and early loss of apical control,

Appendix 2 - Additional References

Dolph, Leroy K., Sylvia R. Mori and William W. Oliver. 1995. Height-diameter relationships for conifer species on the blacks mountain experimental forest. USDA Forest Service Res. Note PSW-RN-418.

- equation determined so that height of stand/tree can be determined using DBH
- it was found that more accurate and precise predictions of tree height could be made when the variables of site index and basal area were included in an expanded equation,
- the relationship found was not linear, and could not be used for young trees.

Filla, K. 1980. Sind Ertagstafellestade auch shneebruchsicher. Allgemeine Forstzeitung, 91 (11): 320.

- a reference in German, used by another paper (Hasenauer and Monserud 1996)

Hara, Toshihiko, Makoto Kimura and Kihachiro Kikuzawa. 1991. Growth patterns of tree height and stem diameter in populations of *Abies veitchii*, *A. mariesii* and *Betula ermanii*. Journal of Ecology, 79, 1085-1098.

- there are two extremes in the growth allocation patterns of trees: (1) photosynthetic assimilates are allocated more to plant height growth than to construction of lateral branches and foliage, and (2) assimilates are allocated more to construction of lateral branches and foliage than to plant height growth.
- the paper examines the allocation of resources to stem and height diameter growth with mathematical models.

Klinka K, Q. Wang, G.J. Kayahara, R.E. Carter and B.A. Blackwell. 1992. Light-growth response relationships in pacific silverfir (*Abies amabilis*) and subalpine fir (*Abies lasiocarpa*). Can. J. Bot. 70 ; 191 - 1930.

- uses a relative height increment to caliper ratio to look at the effects of different levels of canopy cover on seedlings, this ratio was found difficult to understand and relate the HDR,

Leibundgut, Von Hans. 1989. The silvicultural importance of the growth pattern and slenderness of trees. Schweizerische-Zeitschrift-fur-Forstwesen. 140:9, 791-800.

- this reference is in German, but an English abstract is:
The significance of the height/age and height increment/age curves, and the slenderness ratio (height:diameter), is discussed with special reference to growth of *Picea abies* and *Abies alba* in natural forests. It is shown that top height at a given age depends not only on the tree's genetic constitution and the site conditions but also on its growth when young. The relevance and application of these findings to thinning, and especially to the conversion of stands to selection forest are discussed.

Malcolm, D.C. and W. P. Studholme. 1972. Yield and form in high elevation stands of sitka spruce and European larch in Scotland. Scottish Forestry, 26: 4, 296 -308

- diameter was taken at breast height,
- found with Sitka Spruce that the diameter to height ratio increases with increasing elevation, between 350 and 600 m asl

Tange, Takeshi, Masanori Suzuki and Hisayoshi Yagi. 1995. Influence of site quality on the competition of weeds and planted seedlings in relation to weeding. In Popular summaries from second international conference on forest vegetation management. Rotorua , New Zealand March 20-24.

- the ratio of height growth to diameter growth increased as the exposure ratio of the crown decreased,
- the ratio of height growth to diameter growth increased as the shaded condition became more severe,

Wiklund, Karin, Bohdan Konopka and Lars-Owe Nilsson. 1995. Stem form and growth in *Picea abies* (L.) Karst in response to water and mineral nutrient availability. Scand. J. For. Res. 10:326-332.

- trial done on Norway spruce, mature stands
- looked at diameter to height ratio of stem taper
- water availability correlated inversely with average taper (Diameter to height ratio, taken at breast height),
- irrigation decreased the average taper,
- fertilization without irrigation had no influence on taper,
- investigations into the effect of fertilization on stem shape have revealed conflicting results, tree density, provenance and other factors may be the reason,
- irrigation increased both diameter and height
- artificial drought resulted in lower height, compared with the control, but the diameter was not differentiated significantly (this would mean that the HDR would actually be lower with water stress)

Wood, J.E. and E.G. Mitchell. 1995. Silvicultural treatments for black spruce establishment in boreal Ontario: effects of weed control, stock type and planting season. Northern Forestry Program. NODA/NFP Technical report TR-10.

- height diameter ratios were only calculated for planting stock,
- the HDR ranged from 124.1 ("Large" FH408 paperpots) to 46.7 (1.5 +1.5 transplants)

Yokozawa, Masayuki and Toshihiko Hara. 1995. Foliage profile, size structure and stem diameter-plant height relationship in crowded plant populations. Annals of Botany 76:271-285.

- the relationship between vertical foliage profile of an individual plant, competition between individuals, size structure and allocation patterns between stem diameter and plant height were investigated using canopy photosynthesis and two-dimensional continuity equation models,

-because there are two types of trees (height growth and diameter growth type), the relationship between stem diameter and tree height reflects a species characteristic,

Zedaker, Shepard M., Harold E. Burkhart and Albert R. Stage. 1987. General principles and patterns of conifer growth and yield. *In* Forest vegetation management for conifer production. John D. Walstad and Peter J. Kuch (editors). John Wiley & Sons. New York, NY. pp. 203-242.

-looks at DBH

-height and diameter must be considered together to determine the volume, weight or quality of fiber produced.

-height-diameter curves can be done by doing detailed stem analysis or individual trees are measured for their diameters and corresponding heights,

-the height diameter relationship is generally sigmoid in shape

-stand density affects mean tree diameter in a consistent pattern

-trees respond to the release of site resources first by building their crowns and increasing their diameters, mechanical stress causes a diameter increase just above the ground,

Appendix 3 - Summaries of current guidelines

Sue Hoyles (Silviculture Vegetation Officer)

Draft Vegetation Competition Guidelines in the Prince George Forest Region to assist districts in determining free growing on areas with basic silviculture obligations for the 1998 field season

Objective: To provide information to assist District Managers in determining whether the trees in a stand meet free growing criteria and whether vegetation competition is considered deleterious.

Site: Prince George Forest Region, not for mixedwood stands

Species: Douglas-fir, spruce and lodgepole pine

Information Provided: The document is considered to give general guidance only and must be reviewed, modified if necessary and approved by the District Manager before use in the District. Information is based on the results of operational case studies, research trials, and operational experience in the north-central and boreal forests. A healthy well spaced tree in a free growing stand must meet the required standards of the height of a tree relative to competing vegetation within a one meter radius cylinder of the tree trunk. HDR will be the primary measurement of consideration with percent cover and/or deciduous stem densities being considered as accompanying data when determining if competition within the one meter radius cylinder of a tree is acceptable during a free growing survey. Requirements for a well spaced tree of acceptable age and height will remain.

For the herbaceous/grass and low shrub complexes (vegetation less than 1.5 meters in height) the HDR will not be used as a criteria. For the Tall shrub complexes (vegetation greater than 1.5 meters in height) the HDR will be the primary measurement used. For the deciduous tree complexes a combination of minimum crop tree height, HDR for the crop trees and a maximum number of total live stems of deciduous trees per hectares within the stratum will be used to determine if vegetation is competing.

The maximum acceptable HDRs in order for a tree to be considered free growing are as follows: Spruce 60, lodgepole pine 50 and Douglas-fir 55. The HDRs are to be determined by measuring the total height in centimeters, the basal diameter in millimeters (avoiding abnormal swellings, and taking an average of measurements when the bole is non-spherical).

Comments: There is no specification as to which season the HDRs are to be measured in and depending on when in the growing season the HDR is measured it could be very different.

Source: Ministry of Forests, Prince George Region. Forest Practices Code Information note, May 1998.

Richard Kabzems (Research Ecologist)

Mixedwood stocking guidelines of deciduous coniferous mixedwoods in the BWS

Objective: Guidelines to supplement the sections on mixed species and broad-leaved regeneration found in the Establishment to Free Growing Guidebook, Prince George Forest Region and the Silviculture Surveys Guidebook.

Site: Prince George Forest Region, mixedwood stands

Species: white spruce

Information Provided: Only proposed as interim guidelines for a two year period beginning April 15, 1997. Applicable to stands where the net merchantable volume of deciduous is greater than or equal to 80% of the merchantable volume. Individual white spruce trees will not be considered to be impeded by competition from overstory deciduous crop trees if there is a minimum inter-tree distance of 2.0 m between the Sw crop tree and deciduous crop trees, and if the spruce trees have a height to basal diameter ratio of 70 or less. In such cases, the competing vegetation within a radius of one meter of the tree trunk will only refer to grasses, herbs, shrubs and non-commercial tree species. HDR is not used to determine free growing for trembling aspen and balsam poplar in the boreal mixedwood stands. In both leading deciduous mixedwood stands and leading coniferous mixedwood stands the white spruce must have a HDR of 70 or less to be considered free growing.

Comments: The accepted HDR is higher for mixedwood stands than it is for areas that are primarily stocked with conifers, thus indicating that a higher level of competition for light is accepted in mixedwood stands than in areas that are primarily stocked with conifers. There is only a limited number of trials that have found spruce to have a HDR greater than 70. There is the realization that the HDR is only a valid indicator of competition, when it is taller and therefore is competing for light.

Source: Ministry of Forests, Prince George Region, standard operating procedure, number 4-5. July 7, 1997

Appendix 4 - Paper summaries for Douglas-fir references

Douglas Belz

Use of HDR in Washington State for determining when to perform conifer release treatments

Objectives: Practical field method for classifying competition levels in order to determine treatment for conifer release from competing vegetation.

Methods: measure height (to the nearest half foot or foot) and diameter (nearest 1/10 of an inch) to determine the HDR or stress factor

Site: used in Washington State on the west side of the Cascades

Species: used for Douglas-fir and Western Hemlock

Factors considered: tree vigor and level of competition

Findings/Conclusions: When the HDR is >100 , high mortality or extremely slow growth is expected. For HDRs > 72 treatment is definitely needed because competition is causing reduced diameter and height growth. For HDRs from 62 to 70, you probably should treat as the trees are most likely over-topped, height growth is stagnant and diameter growth decreases. For HDRs of 56 to 60, treatment should be considered, there is generally no overtopping, but there is spatial crowding, growth is acceptable. For HDRs of 47 to 54, treatment may be needed in the future, but these values are typical for open growing conifers. For HDRs of 45 or less no treatment is required and these trees are considered vigorous, healthy and had a high probability of remaining dominant over other vegetation.

Comments: The same HDR is applied to both Douglas-fir and western hemlock but, the two species may not respond in the same way to competition and they may have different growth rates. The HDR is used as a method to determine when vegetation control is required, however by the time that the HDR is affected the growth rate of conifers has already been reduced. Measuring the height to the nearest foot or half foot does not give a very accurate ratio.

Source: Vegetation Survey Card for Conifer Release, from Douglas Belz, Washington State department of Natural Resources, May 1998. HDR values used are based on the VMRC Herb I and Herb II studies.

Dr. Phil Burton

Differences in Early Conifer Performance in Young Serial Vegetation of the CWHdm subzone

Objectives: To measure the competitive effects of the dominant, non-crop, plant species found in early, post-logging, successional vegetation.

Methods: Seedlings were planted across cutblocks logged and slash burned in 1987 to 1984

Site: two cutblocks in the dry maritime subzone of the Coastal Western Hemlock biogeoclimatic zone (CWHdm), in the UBC Malcome Knapp Research Forest near Maple Ridge, B.C.,

Species: 1+0 PSB 313 Douglas-fir, western hemlock and western redcedar

Factors Considered: Dominant species and canopy height, other factors were also looked at in published extension note 06.

Findings/Conclusions:

Table A4.1 - HDRs by dominate competition species for Douglas-fir, western redcedar and western hemlock.

Dominant species	subcanopy Irradiance (% full)	canopy height (m)	Douglas-fir	western redcedar	western hemlock
bare ground	100	0	60.85	56.94	49.88
Polytrichum jun.	97	0.06	57.76	62.09	71.02
Festuca occ.	51	0.68	69.69	65.52	78.81
Juncus eff.	24	0.83	71.3	77.89	94.28
Anaphalis marg.	32	0.81	64.93	75.17	81.8
Epilobium ang.	23	1.6	66.63	63.83	94.75
Pteridium aquil.	3.4	1.43	72.48	83.1	71.81
Gaultheria shall.	22	0.47	86.3	96.12	104.16
Rubus parv.	7.4	1.51	70.81	94.79	93.12
Rubus spect.	9.8	1.78	69.26	78.99	86.2
Spiraea doug.	15	1.74	59.77	82.8	88.25
Salix scoul.	21	2.34	69.07	94.48	74.14
Alnus rubra.	11	5.85	72.1	77.08	89.95
Betula papyr.	22	3.68	60.43	79.66	82.64
Populus trich.	23	2.76	82.35	89.91	91.38
Tsuga heter.	1.8	3.08	94.15	97.02	87.72
mixtures.	10	2.29	77.47	88.05	103.98
Overall			73.15	82.86	90.57

Comments: Because HDR values were not published there were no conclusions or discussion made.

Source: Extension note 06, Province of British Columbia Ministry of Forests Research Program, December 1996. HDR values were unpublished, From Phil Burton, June 1998.

Elizabeth C. Cole and Michael Newton

Fifth-year responses of Douglas-fir to crowding and nonconiferous competition

Objectives: To determine if juvenile Douglas-fir growth responds positively or negatively to interspecific crowding, to grass, or to alder at various densities.

Methods: seedlings were spaced 17 to 123 cm apart, three different competition treatments were examined: Douglas-fir only (1), Douglas-fir and grass (2) and Douglas-fir and red alder (1:1) (3).

Site: three sites were used on the Oregon coast: valley site with a warm dry summer climate; midrange site with a warm moist climate; coast site with a cool moist climate in a fog belt. Sites have an intermediate soil fertility and site index.

Species: 2-0 bare root Douglas-fir from a low elevation, mid Coast Range source, final measurements done after five growing seasons.

Factors considered: crowding and interspecific competition

Findings/Conclusions: The highest HDRs occurred at the highest densities even though the trees were short. A HDR > 100 showed poor tree vigor, the trees showed thin crowns and little growth. HDRs above ~ 70 showed a decreases in height growth. Maximum height growth occurred with HDRs between 65 and 70. It was found that crowding led to an increased HDR. The greatest effect of alder was seen at the coastal sites where light is most limiting and moisture is least limiting. HDR reflects the proportion of resources allocated to height and diameter. A large ratio indicates more allocation to height growth. Evidence suggests HDR is a good indicator of over-topping and encroaching vegetation and possibly tree vigor.

Additional Information: Severity of reduced growth depends on site characteristics, competitor type and density of trees and competitors. Competitors may be more efficient at utilizing the available resources or limitations on size, crown expansion, or root extension may place the resources beyond the reach of the trees.

Comments: The HDR of 100 for trees showing poor vigor is higher than any other study done, this may be because of how a tree is determined to be of poor vigor. A good reference for Douglas-fir.

Source: Can. J. For. Res. 17:181, 1987

Brian D'Anjou

**Influence of manual treatment timing on red alder re-growth and on conifer release
-ten year results; Project FRDA 2.12; Sx 83701V**

Objectives: To examine the effect of five cutting periods throughout the growing season and to determine the effect of alder removal on subsequent conifer growth and condition.

Methods: Five different cutting periods were tested as well as an untreated control

Site: Okeover Inlet, Coastal Western hemlock very dry maritime biogeoclimatic subzone, 80 to 120 elevation,

Species: 2 + 0 bareroot stock, Douglas-fir

Factors considered: treatment periods and tree vigor

Findings/Conclusions: Before treatment the HDR of seedlings was between 70 and 80 under high alder densities. After treatment the HDR declined to near 60. As the red alder recovered and increasingly over-topped Douglas-fir seedlings the HDR increased. In summary it was found that maximum growth occurred when the HDR was below 60, there was growth loss when the HDR was greater than 70 and mortality occurred when the HDR was larger than 80. There appeared to be little effect of treatment period on HDR.

Table A4.2 - Douglas-fir HDRs by treatment (cutting period) and years after treatment

	at planting	1 year	2 years	3 years	5 years	7 years
June 7th	65	64	63	60	64	71
July 5th	71	68	65	62	66	74
July 19th	77	64	64	60	63	71
Aug 2nd	76	65	61	56	61	68
Aug 30th	80	68	63	60	61	70
control	71	75	72	63	61	67

Comments: There was no treatment that had complete removal of all vegetation, the summary HDR given are based on tree vigor, not competition level.

Source: Unpublished data from Brian D'Anjou, June 1998, Research Silviculturist
Ministry of Forests, Nanaimo

Brian D'Anjou

Manual Cutting for Brush Control in a Douglas-fir Plantation in the Coast-Interior Transition; Project FRDA 2.35 - Lilloet Lake installation

Methods: Seven treatments were tested, including four different manual cutting treatments at different times of year, a glyphosate hack and squirt treatment, a total vegetation removal and an treated control. Treatments were applied when the seedlings were three years old.

Species: 1 + 0 PSB 313, Douglas-fir

Site: Lilloet lake east of Pemberton, IDFe1 biogeoclimatic variant, elevation 350m, soil moisture regime of fresh and nutrient regime of medium to rich.

Factors considered: types of vegetation control

Findings/Conclusions: The initial HDR were found to be very high, this may be because the trees were three years old before release treatments were performed. HDRs over 80 were found to show the lowest growth, especially in stem diameter, 7 years after the treatments were applied the seedlings that were not treated were about 2 growing seasons behind those seedlings that were treated. The maximum growth occurred with complete vegetation removal. Seedlings with a HDR between 70 and 80 are considered to have diameter growth between the two extremes.

Table A4.3. Douglas-fir HDRs by treatment and by years after treatment

	0	0.5	1	2	3	5	7
total removal	117	78	64	60	61	52	60
herbicide	109	81	71	75	67	64	69
cut 1	122	95	82	76	79	78	84
cut 2	116	95	79	80	73	72	79
cut 3	118	107	80	86	75	67	73
cut 4	115	100	74	80	75	75	78
control	106	106	94	97	91	82	86

Comments: The initial HDRs are very high and are at levels associated with mortality in other studies, it is interesting to note that the vegetation control treatments quickly reduced the HDR.

Source: Unpublished information from Brian D'Anjou, June 1998, Research Silviculturist Ministry of Forests, Nanaimo

Brian D'Anjou

Manual Cutting Techniques For Red Alder and cottonwood Control in a Redcedar and Douglas-fir Plantation; Project FRDA 2.35 - Dewdney installation

Methods: Seven treatments were tested, including four different manual cutting treatments at different times of year, a glyphosate hack an squirt treatment, a total vegetation removal and an treated control.

Site: CWHdm biogeoclimatic variant, east Mission, Fraser valley, elevation 20 m, soil moisture regime of fresh and nutrient regime of medium to rich

Species: 2 + 0 bareroot stock, Douglas-fir

Factors considered: types of vegetation control and tree vigor

Findings/Conclusions: After all treatments, except the control, the HDR decreased as the diameter increased. The seedlings treated with a single glyphosate application showed the greatest growth. Those seedlings with a HDR less than 50 were above competing vegetation, they had little mortality related to vegetation competition, they showed maximum height growth with an annual increment of 70 and had a maximum caliper increment of 10mm. Those seedlings with a HDR of 60 to 70 had a annual caliper growth of 7mm and a height increment of 55 cm, their survival was not affected. Seedlings with a HDR greater than 80 were over-topped, they had a mortality of 35%, their annual height increment was 30cm and the caliper increment was 6mm.

Table A4.4 - Douglas-fir HDRs treatments by years after treatments

	at planting	1 year	2 years	3 years	5 years	7 years
total removal	82	65	65	57	53	57
glyphosate	92	64	67	60	60	65
cut 1	78	69	68	68	72	81
cut 2	81	63	71	68	72	73
cut 3	68	65	73	71	66	68
cut 4	90	70	70	69	70	73
control	77	82	89	88	88	83

Comments: The HDR showed differences between treatments, however looking at the height and diameter individually the differences between treatments was not as great.

Source: Unpublished information from Brian D'Anjou, June 1998. Research Silviculturist Ministry of Forests, Nanaimo.

D.R. DeYoe, Woodlands Services Division, MacMillan Bloedel Limited.

Biological Economic Attributes of Different Reforestation Scenarios - Growth Results for 1986 and 1987

Methods: Seedlings were treated with different durations (none, 1 or 2 years) and intensities (0, 60, 80, 90 or 100%) of vegetation control.

Site: near Nanaimo

Species: 313 and 415 Douglas-fir

Factors considered: Duration and intensity of vegetation control and stock type

Findings: The HDR decreased from 60 to 40 as percent vegetation control increased to 100%. Allowing vegetation to recover in year 2 caused the HDR to return to near pre-control levels. Both 313 and 415 seedlings from the nursery had HDRs close to 70. The HDR decreased below 60 in response to vegetation control above 60% for both 313 and 415 seedlings.

Table A4.5. HDR by percent vegetation control and treatment.

Stock	control	percent vegetation control				
		none	60	80	90	100
313	86 only	69	62	67	63	51
	86 and 87	73	59	58	51	37
415	86 only	65	68	65	60	51
	86 and 87	74	62	53	51	36

Conclusions: The low HDR for those seedlings free of vegetation suggests that seedlings free of vegetation control place relatively more emphasis on caliper rather than height growth. HDR was calculated to provide an estimate of seedling balance for vigorous versus stressed trees. For a Douglas-fir seedling a HDR of 60 indicates that the seedling is at or near the threshold of vigor decline. Reducing competition induced stresses should decrease Ht/Cal ratios because in the absence "luxury consumption" of water and nutrients (nursery strategy to prompt rapid growth), the seedling would allocate more resources to roots and caliper to capture site resources (water and/or nutrients) that are less accessible.

Additional Information: Height is a less sensitive indicator of vegetative competition than caliper or volume calculation. The pipe model theory suggests that the quantity of sapwood basal areas for transport of water and nutrients is directly related to the quantity of roots.

Comments: Some good information on HDR, but there are few references given as to where the information originated. There is no information on site location, quality or other factors.

Source: 1987-1988 Progress Report for MacMillan Bloedel Limited, Woodlands services division, MB project No.: 314.6, MoFL S88 No. QV99010 (#39-022), 1988

Thomas F. Hughes, John C. Tappeiner II and Michael Newton

Relationship of Pacific Madrone sprout growth to productivity of Douglas-fir seedlings and understory vegetation

Objectives: To determine (1) the rates of initial growth and site occupancy of madrone sprout clumps at various densities, (2) the effects of madrone density on the understory density and the effect of both madrone and (3) understory density on the growth and establishment of Douglas-fir seedlings.

Methods: Four plot densities of madrone were used, with two plots each. High density (plot H), medium density (plot M), low density (plot L) and complete removal (plot O). For each density the understory was treated (T) on half the plots and not treated on the other half (NT).

Site: in Southwest Oregon, soils were of the Vermisa and Beekman series and are low in organic matter, site was slashed and burned in Spring before planting

Species: 2-0 Douglas-fir, planted in December

Factors considered: madrone and understory density

Findings: HDR was affected by madrone, but not by understory vegetation. With complete removal the HDR was 48 and 53. With medium density the HDR was found to be 65 and 69. For high density the HDR was 82 and 84. For the 10 largest trees the HDR for complete removal (51 and 53) was significantly less than that for high density (86 and 77). The HDR was found to be the dependent variable that most accurately predicted madrone density.

Conclusions: The HDRs of seedlings under high density (82 and 84) indicate that their growth rates are likely to decrease. The HDR suggests that as crowding and over-topping increase conifers allocate relatively more resources to height growth than to diameter growth. It has been observed that Douglas-fir seedlings with a HDR greater than 70 experience a rapid decline in height growth, which often leads to suppression and death. The suggestion is that on high and medium density plots there is a poor growth potential for Douglas-fir. HDR was found to be a good index of vigor.

Comments: The study was done on a relatively nutrient and moisture poor site, thus the full effect of competition may not have been realized because the resources were limited with or without competition.

Source: Wet. J. Appl. For. 5:20-24 (1990)

D. Mailly and J.P. Kimmins

Growth of *Pseudotsuga menziesii* and *Tsuga heterophylla* seedlings along a light gradient: resource allocation and morphological acclimation

Objectives: To compare differences in mortality, growth, and biomass allocation with the light environment between the two species and to compare acclimation in leaf morphology between Douglas-fir and western hemlock along a natural light gradient.

Methods: Each study site included a small clear-cut and an adjacent mature Douglas-fir - western hemlock - western red cedar stand. Netting was used to protect against deer browsing and competing vegetation, herbs within a 1m radius of seedlings were removed.
Site: Coastal Western Hemlock drier maritime subzone (CWHdm), sites in the lower part of the UBC research forest in Maple Ridge. The associated soils were humo-feric podzols.

Species: container grown Douglas-fir and Western Hemlock, final measurements taken after two growing seasons.

Factors considered: relative light intensity (RLI) below a mature stand canopy

Findings/Conclusions: The HDR decreased linearly with increasing RLI for both Douglas-fir and western hemlock. This decrease in HDR indicates increased height growth relative to diameter growth with increasing light. No HDR values are given in the paper.

Additional Information: Shade tolerate and intolerant species have many physiological and morphological differences. Over-topping competition may reduced the light quality.

Comments: Because seedlings were so young when data was collected usefulness of the information may be limited. Competition was from the canopy of a mature stand, which is a different type of competition than would be present on recently logged sites. The differences between shade tolerant and intolerant species will probably also be reflected in different HDRs.

Source: Can. J. Bot. 75: 1424-1435 (1997)

M. Newton and P.G. Comeau

Control of Competing Vegetation

Species: Douglas-fir and crop trees in general

Factors considered: tree health and growth rates

Conclusions: Competition for light results in crop seedlings with a high HDR which increases their susceptibility to physical damage, this problem can be minimized by planting stock with a low HDR. One of the first visual signs of significant competition in plantations is an increase in HDRs above those of open grown trees. Ratios vary by species and by provenance in response to site factors. In Douglas-fir ratios of 45-55 are normal for plantations of 2 to 10 years of age. Greater crowding leads to greater ratios. Long term height and volume increments are jeopardized when the HDR of Douglas-fir exceeds 60 before release.

Additional Information: Release treatments improve tree growth by providing increased solar radiation, water and nutrients or by reducing physical damage. Several studies in the Pacific Northwest have shown that conifers perform best when competing vegetation is minimized. Presently there are no quantitative indexes available for assessing competition in conifer plantations in British Columbia.

Comments: HDRs are given for normal plantations, but a normal plantation is never described. It is also not stated how the HDRs were obtained, Newton and Cole's earlier paper (1987) considered Douglas-fir with HDR larger than 70 to experience reduced growth so it is not clear how the HDR value of 60 was determined.

Source: Ch.19 *In Regenerating British Columbia's Forests*. 1990. University of B.C. Press, Vancouver, B.C.

R. Rose, J.S. Ketchum and D.E. Hanson

Three - Year Survival and Growth of Douglas-fir Seedlings Under Various Vegetation-Free Regimes.

Objectives: To determine seedling growth response to different areas of spot vegetation control and to determine the relative influence of early wood and herbaceous competition on seedling growth.

Methods: Eight vegetation-control treatments were designed to provide vegetation-free zones of different types and sizes. Vegetation control was done with herbicides. Stem diameter taken 15 cm above ground.

Site: Three western Oregon sites, near towns of Summit (Apt soil series, site scarified with ripper blades and subsoiled) , Marcola (Nekia soil series, site scarified and ripped) and Pedee (Peavine soil series, site scarified and slash piles burned)

Species: 1+1 Douglas-fir, final data on 3 year old seedlings

Factors considered: area of vegetation control

Findings: The HDR was found to decrease with increased area of vegetation control at all sites. The decline was linear at summit and Pedee, but curvilinear at Marcola. The area of vegetation control accounted for more variability in HDR at Summit and Marcola. Seedlings on the untreated plots had ratios approaching 70, ratios in all other plots were below 55. As the control area increased the HDR decreased (supported by other papers).

Conclusions: Trees with HDR in the low to mid 60s are not achieving maximum potential as their diameter, height and subsequent stem-volume growth is reduced as a result of competition. Trees with HDRs in the mid 50s faced less severe competition and performed well. Trees with ratios in the high 40s and low 50s were nearing maximum potential. The greater the level of crowding or competitive stress, the greater the ratio. More research is required at varying competition levels to learn how tree age and overall size influences the HDR.

Additional Information: Allocation of more resources to height rather than diameter growth is a common response to crowding or over-topping. Factors such as slope, aspect, stock quality, fertility and soil compaction can affect seedling growth more so than excellent weed control.

Comments: The factors that were considered to affect growth, may also have an impact on the HDR. The HDRs found are generally lower than those found by other papers, this is mentioned in the paper, but no reasons are given.

Source: Unpublished paper, from Scott Ketchum, May 1998

S. Simard

A Retrospective Study of Competition Between Paper Birch and Planted Douglas-fir

Objectives: To examine the effects of paper birch, assuming that the main affect is through light competition although there are also other factors.

Methods: study done retrospectively neighborhood plots were sampled, plots were chosen to represent a wide range of competitive conditions low (0%) to high (100%) paper birch cover.

Site: five Mesic sites in the Interior Cedar Hemlock Zone of the southern interior of BC, sites were in different subzones

Species: Douglas-fir, 7 to 11 years old

Factors considered: site quality and level of birch competition

Findings: HDR increased as birch density and neighboring vegetation increased. The first ecological threshold occurs at 0 birch stems per hectare, the HDR at this threshold was between ~ 60 to 65 (site dependent). The second ecological threshold occurs when the Douglas-fir does not respond to further increases in red alder density, the HDR at this threshold was between ~ 65 to 68. The quality of the sites was found to affect the HDR values for the threshold levels. On the higher quality site the HDR was lower at the first ecological threshold and higher at the second ecological threshold. It is suggested that due to the better site quality the red alder had a greater initial size and faster height growth, therefore increased competition.

Conclusions: Diameter is more sensitive than height to competition. An increased HDR is considered to be a common response to low light conditions. Paper birch had a greater competitive effect on Douglas-fir on higher quality sites because the second ecological threshold occurred at lower birch density. With increased site quality, the conditions were better and more resources were available, thus birch grew more rapidly using up more resources. Ideally you want to keep the densities below the second ecological threshold, thus keeping the HDR below 65 or 68 depending on site quality. Birch density was found to be of value for predicting Douglas-fir HDR on all sites.

Additional Information: Competing birch can hamper Douglas-fir performance by modifying environmental conditions (e.g., temperature) and aggravating resource limitations (e.g., water, light and nutrients). In the ICH zone competition is primarily driven by light because nutrients and water are available.

Comments: The consideration of site quality in respect to its impact on HDR is valuable, and should be looked at in other studies.

Source: B.C. Min. For., Res. Br., FRDA Report 147. 1990

Simard, S., J. Mather, B. Zimonick, D. Sachs, A. Vyse.

PROBE Research in the Southern Interior.

Objectives: PROBE installations have been established in various vegetation complexes and biogeoclimatic zones in the southern interior to study and monitor vegetation and crop tree response to operational vegetation management treatments.

Methods: PROBE (Protocol for Operational Brushing Evaluations) was developed in the Kamloops Forest Region to monitor and evaluate operational brushing treatments. See PROBE Memos for specific information on the PROBE Protocol and site installations.

Species: Hybrid spruce, Douglas-fir, Lodgepole pine

Factors considered: operational vegetation management treatments compared to untreated controls.

Findings: See PROBE Memos and table A4.6.

Source: PROBE Memos. Second edition. 1998. B.C. Ministry of Forests, Kamloops Forest Region, Kamloops B.C.

Jean Mather, Don Sachs, Barb Zimonick, Suzanne Simard. June 1998. Pers. commun.

Table A4.6. HDR Means Data from replicated Probe treatment plots from Suzanne Simard, Kamloops Forest Region, June 1998.

		relative competition rating:						
crop species	post treatment year	low	medium		high	competition complex	Probe sites	
		glyphosate	manual	grazed	control		Project #	Sites
PI	0		56.96		56.59	aspen	IDF (MS)	27 Kathleen Lake - IDFdk2 -01
	1		57.17		58.26			58 Fowler Cr - MSdm2 -05
	3		75.58		87.02			66 McConnell Lake - IDFdk1 -01
	5		58.39		79.43			
PI	0		48.17		46.63	dry alder	IDF, MS	4 Buck Cr - MSdc -01
	1		45.98		49.52			23 Slate Cr - MSdm2 01
	3		48.76		52.36			55 Ross Lake - MSxk -01
	5		48.53		53.71			
PI	0		58.95		57.13	fireweed	ICH (ESSF)	50 Eagle Bay - ICHmw3 04
	1		52.13		58.08			65 Birk Cr - ICHmw3 -05
	3		46.76		46.15			49 Trophy Mtn - ESSFwc2 -04
PI	0		64.04		63.94	mixed-hardwood shrub	IDF / ICH	32 Amphitheatre Lake - ICHmk1 01
	1		61.82		67.82			41 Homestead FSR - ICHmw3 -05
	3		55.64		68.29			51 Spahats - NA
Se	0		55.12		55.88	ericaceous shrub	ESSF	20 West Gorge - ESSFwc2 -01
	1		52.9		55.33			106 Corbin Pass - ESSFvc -01
	3		51.84		56.8			110 Ladybird Cr - ESSFwc4 -01
	5		51		55.27			111 Howell Cr - ESSFdk -04
Se	0	62.97			62.96	fern(mixed shrub)	ICH	44 Ratchford River - ICHwk1 -01
	1	50.56			58.37			45 Ratchford River - ICHwk1 -01
	3	43			60.8			102 Bigmouth Cr - ICHvk1 -01
	5	45.62			54.81			
Se	0	59.3			54.3	fireweed	ESSF (ICH))	11 Chase Cr - ESSFwk2 -01
	1	61.5			59.65			47 Torrent Cr - ESSFwc2 -01
	3	43.11			50.76			122 Bush River - NA
	5	43.66			55.92			
Se	0			58.67	62.49	fireweed	ESSF	13 Caribou Mtn - ESSFdc2 -01
	1			55.45	57.51			48 Otter Cr - ESSFwc2 -07
	3			56.36	62.34			109 Scott Cr - na
	5			52.65	57.03			
Se	0		53.34		55.38	fireweed	ESSF	108 Bugle Cr - na
	1		53.22		56.11			124 O'Brien Cr - na
	3		48.44		50.05			125 Rory Cr - na
	5		45.88		52.3			
Se	0		60.22		59.98	mixed shrub (fern)	ICH	19 Legerwood Cr - ICHwk1 -05
	1		60.38		67.84			60 Finn Cr - ICHvk1 -01
	3		46		57.41			123 Westfall River - na
	5		38.04		52.9			
Se	0		56.41		56.43	wet alder	ESSF	24 Miner Cr - ESSFmw1 -01
	1		51.52		53.4			57 Palmer Cr - ESSFdc2 -02
	3		45.48		56.97			104 Beaverfoot River - na
	5		43.78		49.48			
Fd	0	52.1			53.26	mixed-hardwood shrub	ICH, IDF	1 John Cr - ICHmk1 -01
	1	51.95			59.82			2 Upper John Cr - ICHmw3 -01
	3	48.53			63.12	cut stump glyphosate		7 Larch Hills - ICHmw2 -01
	5	54.01			64.68			
Fd	0		54.83		48.69	mixed-hardwood shrub	ICH, IDF	3 Enterprise Cr - na
	1		54.23		54.58			12 Mabel Lake - ICHmw2 -01
	3		53.6		58.83	manual		29 Johnson Lake - ICHmk1 -01
	5		56.78		59.99			
Fd	0		55.49		71.41	mixed-hardwood shrub	IDF / ICH	15 Gordon Bay - ICHmw3 -01
	1		54.39		59.56			21 Scotch Cr - ICHmw3 -01
	3		51.58		61.06	girdling		30 Russell Cr - ICHmw3 -05
	5		54.01		67.53			

Steven D. Tesch, Ed J. Korpela, and Stephen D. Hobbs

Effects of sclerophyllous shrub competition on root and shoot development and biomass partitioning of Douglas-fir seedlings

Objectives: To examine the biomass allocation strategies (root or shoot growth) of planted Douglas-fir to determine the effect of sclerophyllous shrub competition on seedling growth and development.

Methods: Seedlings were planted among three levels of shrub competition: dead shrub sprouts 0.25m high (C1, minimal competition), stumps of mature shrubs slashed just before planting (C2, moderate competition) and shrub sprouts 0.5m high (C3, heavy competition).

Site: xeric site in southwestern Oregon in the Siskiyou Mountains, 1099m elevation, skeletal zerochrept soil type.

Species: 1 + 0 containerized Douglas fir seedlings, final measurements taken after five growing seasons.

Factors considered: reduced light levels because of competition

Findings: During the first growing season the HDR increased for C2 and C3, but decreased for C1. All HDRs declined in the second growing season. During the third growing season HDRs increased for C3 and C2 but decreased for C1. After five growing seasons the HDRs were, C1 ~ 48, C2 ~ 70 and C3 ~ 88, all were found to be significantly different. For both C1 and C3 HDR after five growing seasons was significantly different from those at the time of planting, but not for C2.

Conclusions: HDR increases with increased shrub competition. Seedlings in treatments C2 and C3 had HDRs that indicate the seedlings maintained height growth at the expense of diameter growth. The declining HDR of C1 seedlings suggests that both above and below ground resources were plentiful. Reduced light causes reduced photosynthesis, thus increasing competition results in relatively less diameter growth than height growth.

Additional Information: Local herbaceous vegetation, shrubs, and hardwoods compete with conifers for available water and nutrients, and may reduce availability. The study could not separate the effects of available soil water from light, but competition for both resources increased continually with increasing shrub cover.

Comments: Like a lot of studies the water, nutrient and light stress caused by competition could not be separated therefore all three factors may possibly be considered the competition effect. No information given about site quality. Root/shoot ratios and growth rates were examined in detail.

Source: Can. J. For. Res. Vol. 23:1415-1426 (1993)

Survival and Growth of Young Pacific Northwest Conifers in Various Sized Vegetation-free Areas (Herb I)

Objectives: To statistically compare conifer stand variables from planting through precommercial thinning among different vegetation levels and to determine the areas around the tree where associated vegetation cover must be maintained at zero percent to provide the greatest likelihood for maximum growth.

Methods: Vegetation was controlled within different sized areas surrounding the tree (0 ft, 4ft², 16ft², 36ft² and 64ft² and 100ft²). There was also a woody control only and a herbaceous control only, both within an area of 100ft².

Site: Four sites were used: Marcola (West Cascades), Silver Lake (West Cascades), Summit (Coast Range) and Pedee (Coast Range).

Species: Douglas-fir, but was not clearly specified in report

Factors considered: Area of vegetation control and herbaceous vs. woody control

Findings/Conclusions: Vegetation control significantly reduced the HDR, however there was no significant difference in HDR between the different areas of vegetation control. Trends across all sites were the same, however the HDR found did vary between sites. HDR of 65 (Newton and Cole, 1987) was considered to be approaching levels where significant growth reductions can be expected. HDRs of 47 to 56 were considered to be within the healthy range of saplings. Site quality appeared to affect growth rate, site preparation was also thought to be a factor affecting differences between sites.

Table A4.7. HDR for treatments by site

Treatment	Summit	Marcola	Pedee	Silver Lake
Check	65	56	64	75
herbaceous	50	50	53	58
woody	56	57	56	66
4ft²	52	50	53	61
16ft²	50	52	52	60
36ft²	51	54	48	56
64ft²	48	51	53	62
100ft²	47	50	50	58

Additional Information: The cost/benefit relationship of managing herbaceous vegetation is not clear because the spatial and temporal requirements of vegetation control for maximum tree growth response are not well understood.

Comments: The differences between sites were not extremely large but it does provide some evidence that there are many site specific factors such as soil fertility and hydrology that affect the HDR.

Source: Vegetation Management Research Cooperative, Annual Report 1996 - 97, April 1997, Oregon State University

Robert Gordon Wagner

Interspecific Competition in Young Douglas-fir Plantation of the Oregon Coast Range, Chapter four: Effects of interspecific competition from woody and herbaceous vegetation on the growth and survival of Douglas-fir seedlings in the Oregon Coast range

Objectives: To incorporate the best neighbourhood measures of interspecific competition into regression models predicting Douglas-fir basal-area and height growth, to compare the relative competitive abilities of wood and herbaceous vegetation and to quantify interspecific competition influences on the survival of Douglas-fir seedlings.

Methods: All shrubs were cut on all plots with chainsaws to within 15 cm of the ground, Seven vegetation removal treatments were used: one plot was not treated, on three plots 25%, 50% and 75% of the shrubs were removed in 2m wide corridors, on three plots all shrubs were removed and herbaceous vegetation was not removed, 50% removed or completely removed.

Site: Central Oregon Coast, 4 different sites

Species: 2 - 0 bareroot, Douglas-fir, 1 to 3 years old

Factors considered: herb and shrub competition

Findings: The HDR changed over time depending on the proportion of the neighbourhood that was occupied by woody and herbaceous vegetation. The HDR increased with time when the seedling's neighbourhood was occupied with by shrubs. The rate of increase was proportional to the total cover of shrubs. In three years a HDR of 99 was reached by those seedlings that were in neighbourhoods completely dominated by shrubs. For seedlings where both the woody and herbaceous vegetation was removed the HDR decreased to a stable HDR of about 50. Most of the variation in HDR was accounted for by the HDR in the previous year, shrub cover and herbaceous cover. Model simulations ere done to determine projected HDRs for various shrub and herb neighbourhood cover.

Conclusions: HDRs provided a simple morphological indicator of neighbourhood competitive effects that integrate both height and stem diameter. When under the influence of over-topping woody neighbours, seedlings exhibited an increasing HDR. The HDR may be an indicator of competitive stress that can be uniformly interpreted in trees ranging in age from seedling to maturity. Ratios over 90 indicate a high competitive stress, and ratios around 50 indicated that seedlings were growing near maximum potential growth rates.

Comments: HDR values and trends are consistent with other Douglas-fir papers.

Source: Ph.D. Thesis, Oregon State University, November 21, 1989

Appendix 5 - Paper Summaries for White, Engelmann and Hybrid Spruce

Bedford, L. et al. 1998.

Site Preparation for establishing white spruce and lodgepole pine in the Prince George Forest Region.

Objectives: To determine the effect of disc trenching, broadcast burning, disc trenching combined with burning, and planting without site preparation, mounding with various thicknesses of mineral soil capping, scarification, blading, and herbiciding on seedling performance of white spruce and lodgepole pine. Treatments applied at various sites located across the region.

Methods: site preparation treatments applied at various site locations. Various experimental designs. General treatment comparisons based on conifer response assessments. See table A5.1 and A5.2 for details.

Sites: Bednesti North, Tanli, Inga Lake, Wonowon, Upper Coalmine, MacKenzie, Iron Creek. See information to follow

Species: white spruce and lodgepole pine

Factors considered: site preparation through a range of mounding, blading, scarification, trenching, burning and herbicide treatments.

Findings/Conclusions: HDRs are presented in table A5.3 and figures A5.1 though A5.7.

Comments: Because of the numerous treatments and the difficulty in determining how the vegetation was affected, the only useful treatments are probably the untreated plots and those plots treated with a herbicide. There is also a difficulty comparing treatments because in most cases the initial HDR of the seedlings was different.

Source: published and unpublished reports, personal communications (L. Bedford 1998, L. Stordeur 1998).

B.C. Ministry of Forests. 1998. Bednesti Site - Testing the biological effectiveness of mechanical site preparation equipment (10 year results). B.C. Ministry of Forests, Forest Practices Branch, Victoria, B.C..

B.C. Ministry of Forests. 1989. FRDA 1.10 - Testing the biological effectiveness of mechanical site preparation equipment - Bednesti Site. Draft Establishment Report November 1989. B.C. Ministry of Forests, Victoria, B.C.

Bedford, L.R., M. Goldstein, M.A. Grismere, R.K. Scagel. 1998a. The effects of disc trenching on establishment and early growth of lodgepole pine in the SBSmc2. Unpublished draft report. Forest Practices Branch, Victoria, B.C.

Bedford, L., R.F. Sutton, L. Stordeur, and M. Grismer. 1998b. Site preparation for establishing white spruce in the Boreal White and Black Spruce Zone of interior British Columbia. Unpublished draft report. Forest Practices Branch, Victoria, B.C.

Macadam, A. and L. Bedford. 1998. Mounding in the Sub-boreal spruce zone of west-central British Columbia: 8-year results. *The Forestry Chronicle*, vol. 74, no. 3.

McMinn, R.G., L. Bedford, and A. Mackinnon. 1989. FRDA 1.10 - Testing the biological effectiveness of mechanical site preparation equipment - Inga Lake Site. Establishment Report Sept. 1989. B.C. Ministry of Forests, Victoria, B.C.

Sutton, R.F., L. Bedford, L. Stordeur and M. Grismer. 1998. Site preparation for establishing white spruce in interior British Columbia, Engelmann Spruce-Subalpine Fir and Sub-Boreal Spruce Zones. Unpublished draft report. Forest Practices Branch, Victoria, B.C.

SITE INFORMATION

TANLI SITE (Bedford et al . 1998a)

The site is located in the vicinity of Tanli Lake south of Vanderhoof in the Prince George Forest Region Lat 53.17 Long 124.28. The installation is gently undulating, with less than 10% average slope. It is situated at an elevation of 1240 m and is transitional between the SBSmc2 and ESSFmv1 biogeoclimatic zones. (Delonge, 1993) The site is snow free from May until early October. (*Rob we need Mike G. to give us growing degree days based on 5 degrees*)

The original stand consisted of mature (100+), pine, spruce and balsam, with a net stand volume of 248 m³/ha. Trees averaged 21.1 meters in height (Pers comm Scott Elo Westar Timber). The stand was clear-cut with feller bunchers and grapple skidded in 1985/86.

Soils range from an Orthic Dystric Brunisol to a Brunisolic Gray Luvisol and are part of the Deserters soil Association (Dawson 1989). The parent material is a fine, loamy morainal blanket with inclusions of a fine loamy Lacustrine veneer. Surface material is fine to medium textured, ranging from sandy loam near the top of the drumlins to silt loam in depressions. Soil moisture is mesic to subhygric with fine mottles in the B horizon. Prior to harvesting, the humus was a Hemimor ranging in depth from 4-6 cm.

Site Preparation

In the fall of 1986, half of the installation was broadcast-burned. Based on the burn impact rating system of Curran 1996, (*Tim this reference is page 60 of Mike Currans thesis*) burn impact was judged to be low. Trenching, with the Wadell cone scarifier, was undertaken on the burned and unburned areas in the fall of 1987.

The Wadell powered scarifier is equipped with cones which rotate against the direction of travel at a ground rotation speed of approximately 20 rpm (Hedin 1989..from FRDA 103). On the trial site the Wadell produced a relatively flat trench approximately 62 cm in width (*66 cm on the burn and 60 cm on the unburned*) and 11 cm in depth. The scarifier removed the forest floor and all of the relatively thin A horizon. On portions of the trench the mineral soil was removed down to the dense less fertile portion of the B horizon. Trench depth on the unburned portion of the trial was more variable, tending to be shallower in areas of more dense debris. A continuous berm approximately 20 cm deep and 55 cm wide consisting of mixed humus and mineral soil was deposited immediately adjacent to the trench. Mineral soil was concentrated towards the top of the

berm. The upper portion of the berm also remained relatively loose for several years after treatment. This resulted in a "mulching" effect for the first few years of the trial.

As the trial design made it difficult to reflect operational trench spacing the proportion of ground typically disturbed by this treatment was determined by assessing the operational area immediately adjacent to the research trial. At a trench spacing of slightly less than 3.5 meters it was found that approximately 18% of the area was in trenches, 16% of the area was covered by berm and 66% of the area was undisturbed.

Block Design and Treatments

This trial examines 3 planting positions; planting without disc trenching "raw planting", and planting on two microsites created by the disc trencher, the furrow and hinge. The three planting positions were replicated on burned and unburned ground (Figure 1).

The installation consists of eight treatment blocks, with four blocks situated on a burned area and four on a nearby unburned area. Each block contains 9 lines of 25 trees. The 3 planting positions i.e. the hinge, furrow and "raw planting" are randomly assigned to 3 lines per block for a total of 75 trees per planting position per block.

Data Collection

Stock type and Measurements

The site was planted in the spring of 1988 with Pli PSB 211 1+0 stock. This was considered the normal, operational Pli stock type for similar conditions throughout the 1980s and early 1990s in B.C. Seedling height and caliper were measured in the fall of 1988, the spring of 1989 and each fall thereafter including the fall of 1995 for a total of eight years

INGA LAKE SITE (McMinn et al. 1989)

The Inga Lake Site is located in the BWBSmw1 Subzone, approximately 85 km northwest of Fort St. John, B.C. (Fig. 1). It is accessed from the 170th Road at Mile 91 on the Alaska Highway (Fig. 2). The site is approximately 6 km south of the highway.

The Inga Lake Site is situated in a 3500 ha area which had been classified as MCBP-P. The Trial Site is approximately 20 ha. This portion was classified as NCBP-M. The predominant cover before treatment was aspen and willow, up to 6 m in height. This cover originated after wildfire in the mid 1950s. The area apparently has had no logging history. Initial rehabilitation treatment was shearing and piling during the winter of 1986/87 at a cost of \$175/ha. LFH layers were essentially undisturbed. The windows were burned in October.

Comparisons are being made among ten rehabilitation groups. The options include mechanical and herbicide treatments, planting in the burned windrows and no treatment other than winter shearing and piling. The test stock for all treatments is spring planted 2+0 PSB 313 interior spruce. The interaction between treatment and stock type is being examined in selected treatments by comparing the performance of the standard stock with spring planted 1+0 PSB 313, summer planted 2+0 PSB 313 and summer planted 2+0 PSB 323.

BEDNESTI SITE (B.C. Ministry of Forests 1989)

The Bednesti Site is approximately 45 km west of Prince George (Fig. 1) at an elevation of 700 m above sea level. It lies to the south of Cluculz Lake on either side of the Bobtail Forest Access Road between Km 17 and 18. The Site is in the Sub-Boreal Spruce Zone and is representative of the Dry Warm Southern SubZone, Cluculz Variant (SBSdw3). The predominant Site Series is Pine-Black Spruce-Stepmoss (SBSdw3/05), which is predominantly mesic and submesotrophic B. Clear-cut logging with 2 chain leave strips every 10 chains was undertaken in 1963-64. The leave strips were summer harvested in 1971 and the slash spot piled and burned. A stocking survey in 1986 showed that the area was NSR. The Silvicultural component was Pli 100 20-5.3-M-351

and the Inventory component was Pl1 60 Sx24 At12

Ep4 -20-5.3-M-2890. The majority of lodgepole pine potential crop trees were heavily girdled by squirrels. The spruce was primarily black spruce or black. Patches of overstocked lodgepole pine occurred along old skid trails and on landings. The area was knocked down and windrow piled in January and February 1987. The windrows were burned in October 1987. Knockdown and windrowing caused little disturbance of the snow-covered LFH layers.

The North Site, which covers approximately 12.5 ha, lies to the north of the Bobtail Road. Comparisons are being made among the nine different planting spots formed by five site preparation machines, by the effect of burning the windrows formed when the site was cleared, and by no treatment of the site, other than winter shearing.

The South Site, to the south of the Bobtail Road, covers approximately 10.5 ha. The effect of aspect (orientation, that is whether the planting spot is facing north, south, east, west or is neutral) on the performance of seedlings planted in various planting spots formed by a disc trencher is being tested. A comparison of the performance of seedlings in planting spots prepared by high speed mixing, disc trenching, and no treatment are also being compared on the South Site.

The East Site, also to the south of Bobtail Road, compares the performance of seedling planted following a deep ripping treatment, with or without bedding plow treatment, and no treatment.

Table A5.1. Features of Wonowon, Iron Creek, and Stewart Lake experimentation in the BWBS Biogeoclimatic Zone (Bedford et al. 1998b)

Factor	Wonowon	Iron Creek	Stewart Lake
Latitude	56°37'N	56°37'N	55°55'N
Longitude	121°49'W	122°18'W	121°00'W
Elevation (m)	900 (mean)	820 (mean)	860 (mean)
Biogeoclimatic (BEC) zone	BWBSmw1 Boreal White & Black Spruce, Peace moist warm variant Site units 01 (Sw At-Step moss), 05 (Sw-Currant-Oak fern), 06 (Sw-Currant-Bluebells), 07 (Sw-Currant-Horsetail), and 08 (Sb-Labrador tea-Sphagnum). Site index (m @ 50 yr bh) 9-18.	BWBSmw1 Boreal White & Black Spruce, Peace moist warm variant Site units 01 (Sw At-Step moss), 03 (Sw-Wildrye-Peavine), 05 (Sw-Currant-Oak fern), 06 (Sw-Currant-Bluebells), 07 (Sw-Currant-Horsetail),. Site index (m @ 50 yr bh) 15-18.	BWBSmw1 Boreal White & Black Spruce, Peace moist warm variant. Site units 03 (Sw-Wildrye-Peavine), 07 (Sw-Currant-Horsetail). Site index (m @ 50 yr bh) 15-18.
BEC Climate	Precipitation mean annual 485 mm, mean May-Sept 290 mm. Temperature mean annual 1.1°C. Snowfall mean annual 190 cm. Frost-free period mean annual 150 days.	Precipitation mean annual 485 mm, mean May-Sept 290 mm. Temperature mean annual 1.1°C. Snowfall mean annual 190 cm. Frost-free period mean annual 150 days.	Precipitation mean annual 485 mm, mean May-Sept 290 mm. Temperature mean annual 1.1°C. Snowfall mean annual 190 cm. Frost-free period mean annual 150 days.
Topography	0-5% slope, N to NE	gently sloping fan	gently rolling drumlinized upland.
Soils	relatively stone-free lacustro-morainal till; organic layers < 45 cm deep in depressions; surface horizons underlain by compact clay loam to silty clay loam, Bt _g and Bt _h horizons at 15-30 cm.	lacustrine/lacustro-till, fine textured; < 5% coarse fraction; silty clay loam to clay loam	basal or lacustrine blankets 30-300 cm thick; sandy clay loam to clay loam often beneath surficial sands and silts; < 2% coarse fraction
Drainage	predominantly subhygric, mesic on convex areas, hygric in depressions	mostly imperfect, poor in depressions, moderately well drained on convex surfaces between channels: subhygric with some hygric and mesic	uplands well to moderately well drained, moderately to slowly pervious. Depressions poorly drained, slowly pervious
Organic layer	leptomoder, mullmoder, hydromoder < 45 cm	moder (mor), 11-14 cm thick	moder, peaty layer in depressions < 14-18 cm thick
Rooting depth	15-30 cm	9-25 cm	10-35 cm
History	120-year-old stands, partly lodgepole pine/white spruce c. 280 m ³ /ha, partly white spruce/aspen with some lodgepole pine c. 140 m ³ /ha conifers, clear-cut 1977 leaving some aspen; NSR regen survey 1982 (Menzies 1984)	selectively logged 1966, clear-cut 1977, sheared and windrowed winter 1985/6 (McMinn et al. 1990a).	intermittent selective logging for 30 years, burned by wildfire mid-1960s and 1971, sheared, windrowed April 1986 (McMinn et al. 1990b)

Table A5.1 cont'd.

Factor	Wonowon	Iron Creek	Stewart Lake
Experimental design	5 blocks, 1 plot of each treatment in each; about 80 seedlings per plot, 400 per treatment, all monitored	5 blocks, each microsite in each; 80 seedlings per 30- x 40-m plot, all monitored in mounding treatments, otherwise only the inner 48 monitored	5 blocks, 1 plot of each treatment in each; whole 30- x 40-m plot site prepared & 80 seedlings planted at 3 m spacing, all monitored in mounding treatments, otherwise only the inner 48 monitored
Site prepared	1983	1986	1986
Treatment 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	Bracke mound+20 cm Bracke mound+14 cm Bracke mound+6 cm Bracke mound (c 2 cm) Bracke patch Herbicide 5 kg a.i./ha Blade scarification Alternate stock Untreated	Sinkkila mound Sinkkila mound, fertilized Ministry mound Bracke mound (c 6 cm) Bracke patch Bracke patch, fertilized Breaking plow berm Herbicide 2.6 kg a.i./ha Alternate stock Untreated	Sinkkila mound Sinkkila mound, fertilized Ministry mound Bracke mound (c 6 cm) Bracke patch Bracke patch, fertilized Breaking plow berm Herbicide 2.9 kg a.i./ha Donaren 180 Untreated
Stock: standard alternate	interior spruce, bareroot 2+1 interior spruce 1P+2, large	interior spruce plug 1+0 PSB 313, seedlot 2665 lodgepole pine plug 1+0 PSB 211, seedlot 2199	interior spruce plug 2+0 PSB 313, seedlot 8782, cold stored --
Planted	1984 late June	May 28 - June 2 1987	May 20 - 23 1987
Treatment subsequent to planting	large residual aspen, girdled in 1983, felled 1985; aspen suckers encroaching on plots cut with brush blade 1988		
Additional information available	high competition potential, from aspen, alder, willow, reed grass, fireweed, horsetail, and rose; herbicide effect on plant species diversity (Boateng et al. 1997); root system development (Heineman 1997a); eco-stratification (Williams 1996), site index (Anon. 1997).	soils (Wehr 1989, Hakinen 1987); weather Aug.-Oct 87 (McLeod and Osberg 1988); mound morphology (Hedin 1987a,b, 1989); herbicide spraying (Hesse 1987); root egress (von der Gönna and Lavender 1988, von der Gönna 1989); herbicide effect on plant species diversity (Boateng et al. 1997), eco-stratification (Williams 1996), site index (Anon. 1997).	soils (Wehr 1989, Hakinen 1987); weather Aug.-Oct 87 (McLeod and Osberg 1988); mound morphology (Hedin 1987a,b, 1989); herbicide spraying (Hesse 1987); stock (von der Gönna and Lavender 1988, von der Gönna 1989), eco-stratification (Williams 1996); site index (Anon. 1997).

Table A5.2. Features of experimentation at Upper Coalmine and Mackenzie in the ESSF/SBS Biogeoclimatic Zones (Sutton et al. 1998).

Factor	Upper Coalmine	Mackenzie
Latitude	53° 37'N.	55° 13'N.
Longitude	121° 43'W.	123° 01'W.
Mean elevation (m)	1190 m.	760 m.
Biogeoclimatic zone	ESSFwk1 Engelmann Spruce - Subalpine Fir, lower margin (DeLong and Fahlman 1996). Dominant Site series: 04 (B1 - Twinberry - Lady fern) and 07 (Ladyfern - Horsetail). Site index of dominant Site series for Se (m @ 50 yr bh) 15.	SBSwk2 Sub-Boreal Spruce, Finlay-Peace wet cool variant. Dominant Site series: 01 (Sxw - Oak fern) and 05 (Sxw Devil's club). Site index of dominant Site series for Sx (m @ 50 yr bh) 18-21.
Climate: Precip mean ann. range ann. May-Sept range May-Sept Snowfall ann Temp mean ann range ann Grow degr days >5°C Frost-free period	Subalpine. 1044 mm n/a 426 mm 378-491 mm 538 cm -0.1°C -1.5 to 1.4°C 748 growing degrees 48 days	905 mm 55-1915 mm 335 mm 210-535 mm 1075 cm 1.0°C -0.1 to 1.7°C n/a 80 days generally in the SBSwk2, but frost can occur in any month at Mackenzie.
Topography	level with minor relief.	level, surrounded on 3 sides by higher ground.
Soils	Gleyed Gray Luvisol, compact horizon at 20-30 cm (Scagel et al. 1994). Predominantly silt loams.	Gleyed Regosols predominate. Locally Eluviated Dystric Brunisols occur on well to moderately well drained areas, with less common imperfectly drained Gleyed Eluviated Dystric Brunisols in shallow depressions. Soil texture generally loamy (silt loam to sandy loam) < 2% coarse frag- ments (McMinn et al. 1990).
Drainage	seasonally poor due to perched water table. Subhygric to hygric.	mostly imperfectly to poorly drained, but some areas moderately well drained. Mesic to subhygric, with pockets of hygric.
Organic layer	moders; predominantly 5-15 cm thick, < 35 cm in wetter areas.	moders/mors; mostly 5-20 cm deep only 1-2 cm (Hedin 1987a); along southern fringe, 5-10 cm incl. < 1 cm discontinuous (fire) H layer (McMinn et al. 1990).
Rooting depth	20-30 cm.	15-30 cm in the fine-textured soils.

Table A5.2 cont'd.

Factor	Upper Coalmine	Mackenzie
History	previous stand may have originated as advance growth on rotten wood released when mountain pine beetles killed the overstorey a decade or so previously.	logged 1977, chain-dragged 1978; the brush, grass and aspen on this site were more typical of post-logging condition than brush bladed sites such as Iron Creek and Stewart Lake (cf. Bedford et al. 1998a,b).
Experimental design	5 blocks, 1 plot of each treatment in each; nominally 80 seedlings per plot, actually 394-400 per treatment.	5 blocks, 1 plot of each treatment in each; 80 seed-lings per 30- x 40-m plot, all monitored in mounding treatments, otherwise only the inner 48 monitored.
Treatment begun	Mounds made August 1983, mineral soil cappings added manually August-September (category 1); remainder of mounds (category 2) manually made and capped May 1984.	1986; Bracke moulder 6 July, Sinkkila 9 September, and Ministry moulder 12,18 September.
Treatment 1 2 3 4 5 6 7 8 9 10 11 12 13	<p>Untreated Alternate stock</p> <p>-</p> <p>Bracke patch</p> <p>-</p> <p>-</p> <p>Bracke mound³</p> <p>Bracke mound +6 cm¹</p> <p>Bracke mound +14 cm^{1,2}</p> <p>Bracke mound +20 cm¹</p> <p>-</p> <p>-</p> <p>Blading</p> <p>¹ Mineral soil added to obtain a capping of mineral soil of the specified thickness.</p> <p>² 24-29 spruce excavated 1994.</p> <p>³ The early model of the Bracke Moulder made mounds capped by various thicknesses of mineral soil averaging perhaps 2 cm.</p>	<p>Untreated</p> <p>-</p> <p>Herbicide</p> <p>Bracke patch</p> <p>Donaren trench</p> <p>Donaren berm</p> <p>Bracke mound⁴</p> <p>-</p> <p>-</p> <p>-</p> <p>Sinkkila mound</p> <p>Ministry mound</p> <p>Blading</p> <p>⁴ Average 6 cm thick cap of mineral soil.</p>
Stock: standard	interior spruce Sx 2+0 seedlot 4050 RGC class 1.13.	interior spruce Sx 1+0 PSB 313, seedlot 29144.
alternate (treatment 2)	<p>interior spruce Sx PSB¹ 313 seedlot 4050, RGC class 2.56.</p> <p>¹PSB denotes polystyroblocs produced by Beaver Plastics, Ltd., Edmonton, Alberta; the first digit gives the approximate diameter (cm), the next two digits the depth (cm) of the container cavity.</p>	N/a
Planted	1984, late June.	1987, June 4-10.

Table A5.3. Forest Practices Branch site preparation trials-Prince George Region

SBSch BENEST PII		Bednest North Individual Measurements:										PII 1+0 PSB 211 April 25-29, 1988					
treatment	post year	Burn	Bedding Plow*	Delta Hinge	Breaking Plow*	Wadell Hinge	Brake Patch	Mineral Mound*	Delta Furrow	Madge	Untreated						
1988	1	39.1	39.8	50.2	39.4	51.4	54.5	43.4	51.4	45.2	50.9						
1989	2	42.2	38.8	47.2	38.7	47.1	52.3	45.8	54.4	37.9	53.8						
1990	3	43.8	39.6	43.7	40.4	44.6	47.6	45.7	52	40.2	49.3						
1991	4	45.3	42.7	46.4	44.5	45.5	48.7	47.1	52.2	43.5	51.3						
1992	5	43.4	42.6	46.6	45	43.4	45.2	43.5	48.3	42.1	49.6						
1993	6	42.3	42.3	44.6	44.8	43.1	44.4	43.4	48.1	42.9	48.2						
1994	7	42.8	43.04	45.4	46.4	44.5	44.5	43.8	47.6	43.2	47.7						
1995	8	42.5	42.8	45.6	46.9	44.6	46.6	44.6	50	45.5	48.3						
1996	9	43.3	43.8	47.5	48.3	45.5	46.5	45.9	49.8	46.6	48.8						
1997	10	41.6	43.9	47.3	48.5	45.5	46.2	46.2	49.5	45.8	48.7						
SBSm2/ESSFmvt TANLI PII																	
		Tanli - Individual Measurements															
		Trench Burn	Beim Burn	Control Burn	Trench Unb	Beim Unb	Control Unb										
1988	1	46.08	41.23	42.66	46.52	41.71	43.07	planting depth of treatments unknown									
1989	2	54.91	44.95	47.99	46.84	40.85	45.52										
1990	3	47.39	44.32	47.91	47.51	45.41	48.01										
1991	4	45.58	47.52	49.67	46.89	47.29	46.92										
1992	5	43.12	44.1	45.93	43.59	43.85	43.73										
1993	6	43.19	42.51	45.19	44.2	42.23	44.16										
1994	7	40.71	38.31	40.46	40.33	38.31	40.2										
1995	8	43.18	40.42	41.61	40.92	40.11	40.87										
1996	9	41.68	40.89	41.75	41.59	40.71	41.33										
1997	10	41.8	40.8	40.88	42.4	42.91	41.98										
BWSmvt INGA Sx		Inga Lake - Individual Measurements															
		Herbicide	Burn	Breaking Plow*	Madge	Double Tuttle*	Bedding Plow*	Single Tuttle*	Delta Hinge	Mineral Mound	Delta Furrow	Untreated					
1988	1	54.69	43.56	46.2	43.81	47.44	46.91	46.3	52.66	49.39	51.56	55.72					
1989	2	60.31	46.82	48.85	51.02	51.45	54.28	50.24	62.55	51.38	55.57	60.66					
1990	3	69.04	51.41	53.42	50.65	60.52	63.39	58.97	70.04	57.77	59.48	71.29					
1991	4	61.99	51.01	54	49.67	61.1	65.7	64.78	66.11	56.63	58.68	66.54					
1992	5	55.67	50.64	59.04	51.68	66.47	70.65	67.84	70.15	58.82	62.69	71.55					
1993	6	51.53	51.85	57.57	50.28	63.12	66.73	65.49	65.35	58.08	59.8	68.64					
1994	7	47.91	53.93	60.8	51.45	69.75	69.78	71.9	73.03	63.43	63.67	72.65					
1995	8	53.86	58.77	62.26	53.99	72.97	68.56	73.51	75.86	69.6	71.28	75.52					
1996	9	49.92	55.84	63.65	53.19	71.9	68.44	72.82	70.53	64.93	65.57	72.35					
1997	10	48.84	55.8	62.82	51.05	69.89	67.6	69.69	67.76	61.6	63.71	67.66					

*deep planting =5+ cms above root collar

Table A5.3. continued

BWBSMWT MONOWON Sx		Wonowon - Individual Measurements				Sx bareroot 2+1 late June 1984				
	Herbicide	20cm Mound*	14cm Mound*	6cm Mound*	1cm Mini Mound*	Bracke Patch	Blade Scarification	Alternate Stock	Untreated	
85	2	50.2	49.2	49	48.9	49.6	51.9	51.7	46.8	52.1
S85	2.5	54.8	50.9	51.7	51.8	52.4	53.6	53.2	50	55.7
F86	3	51.3	50.6	51.6	52.5	52.3	53.1	54.1	50.7	54.8
87	4	56.4	49.3	51.1	56	56.3	54.6	52.5	54.7	57.3
88	5	58.8	54.6	55.8	61	60.8	56.1	55.5	57.2	61
89	6	56.5	54.3	56.9	60.3	63.4	57.2	57.7	62	64.6
92	9	68.2	66.2	69.4	70.5	70.4	67.5	67.6	69.1	74.9
93	10	62.6	61.2	63.8	64.5	63.5	62	63.3	65.5	68.8
94	11	64.6	62.3	64.8	65.2	64.5	65.9	66.5	68.3	72.5
96	13	62.7	63	64	64.7	64.2	66.6	64.8	64.7	68.5
ESSFWKT COALMINE Sx		Coalmine - Individual Measurements				standard Sx 2+0 bareroot late June 1984 (26% survival in 1996)				
						alternate stock (large stock) Sx PSB 313				
85	2	43.9	43.5	43.5	45.7	45.4	45.7	77.4	49.2	
S86	2.5	41.6	40.9	41.5	46	45.3	44.6	75.6	52.1	
F86	3	43.8	43.3	44.3	47.5	46.2	46.7	67.9	52.4	
87	4	40.4	39.6	42.1	45.2	44.4	48.2	60.8	50.7	
88	5	45.8	45.1	46.5	49.4	46.7	48.2	59.6	53.9	
92*	9	46.1	45.3	47.2	46.8	52.3	47.5	60.8	55.3	
93	10	39.9	39.3	42.6	44.2	45.6	43.7	46.6	50.4	
96	13	41.7	40.6	43.2	44.5	46.8	44.6	43.6	47.3	
SBSWKT MACKENZIE Sx		Mackenzie - Individual Measurements				Sx 1+0 PSB 313 June 4-10, 1987				
87	1	53.1	59.7	49.3	58.6	57.9	58.8	51.7	48.7	58.8
88	2	33	48.2	41.2	51.3	44.7	40.5	43.8	39.6	45.5
89	3	46.7	54.7	48.5	58.1	53.8	51.4	54.5	48.9	52.8
90	4	48.5	55	55.3	58.1	56.7	50.7	58.6	55	61.6
91	5	52	60.4	56.3	59.9	60	55.8	62.9	57.5	64
95	9	54.6	58	50.8	56.1	57.7	53.7	57.7	57.2	65.5
96	10	46.5	53.1	46.9	52.4	51.6	48.5	53.3	54.7	58.2
BWBSMWT IRONCRK Sx		Iron Creek - Individual Measurements				Sx 1+0 PSB 313 May 28-June 2, 1987				
						alternate Pil 1+0 PSB 211				
1988	1	46.49	53.34	54.5	42.81	49.76	47	45.28	46.29	43.68
1989	2	53.34	59.5	62.65	49.87	57.88	54.31	51.71	54.68	52.4
1991	4	62.27	68.53	74.74	65.49	67.18	73.18	70.22	70.81	66.25
1992	5	63.85	67.62	71.39	66.55	65.63	72.54	69.51	70.49	62.07
1993	6	62.25	65.17	69.39	63.91	63.13	68.9	67.25	70.08	64.25
1995	8	61.96	66.74	68.64	64.16	61.18	70.24	69.92	71.36	61.42
1996	9	60.14	65.35	66.76	63.78	61.11	69.15	69.21	68.62	57.74

*deep planting =5+ cms above root collar

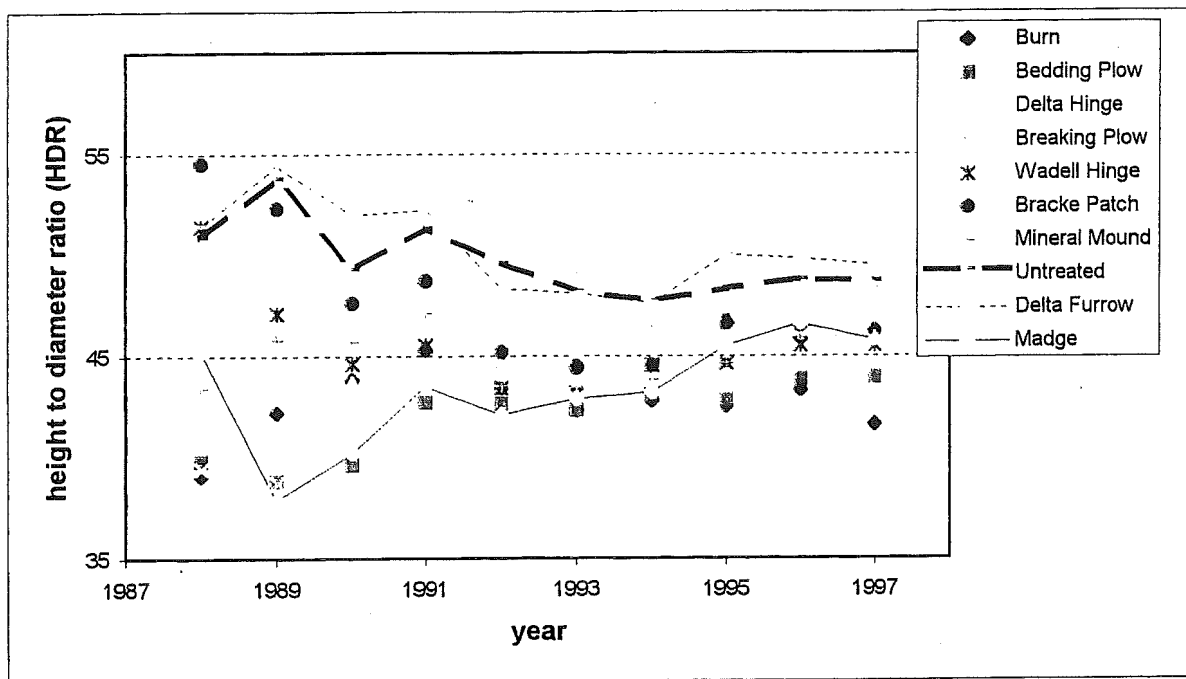


Figure A5.1. Bednesti North site, lodgepole pine HDR values for different treatments.

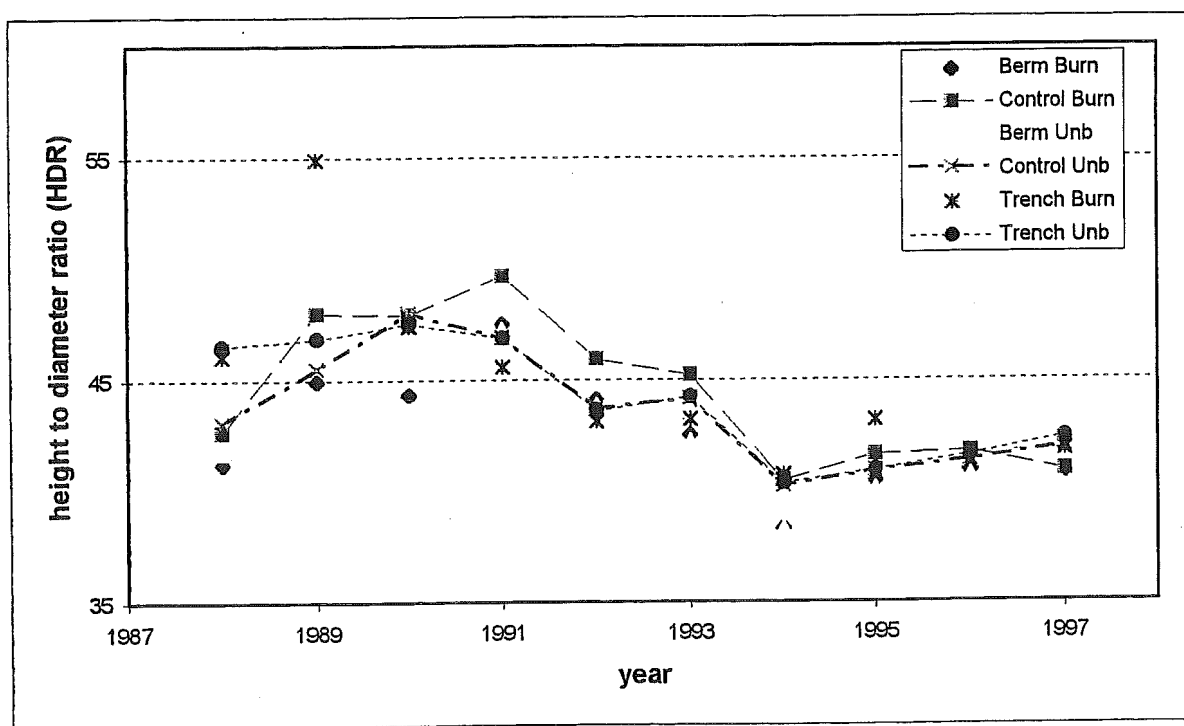


Figure A5.2. Tanli site lodgepole pine HDR values for different treatments.

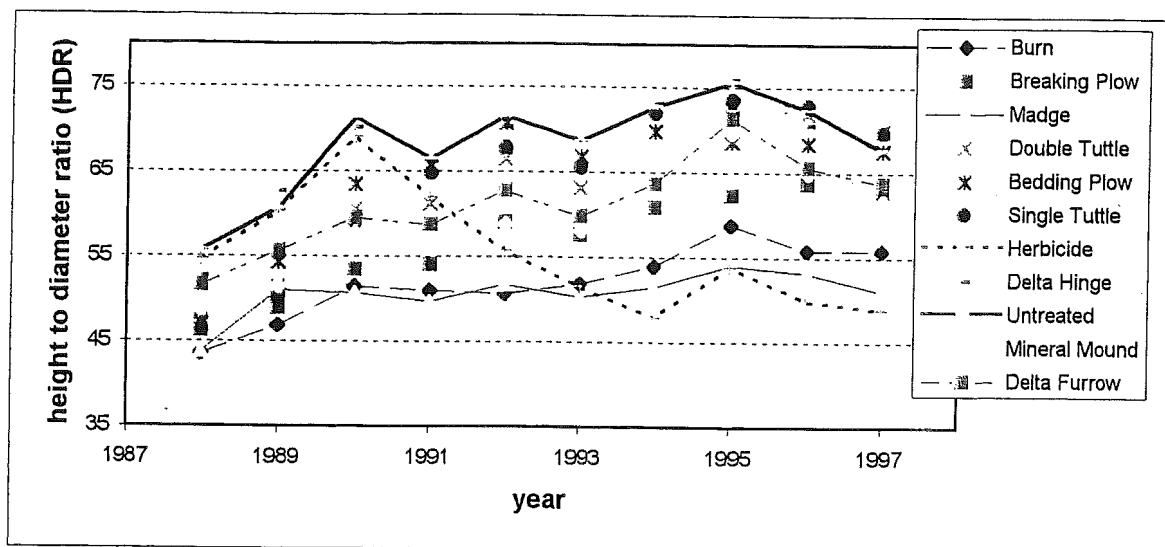


Figure A5.3. Inga Lake Site Interior spruce HDR values for different treatments

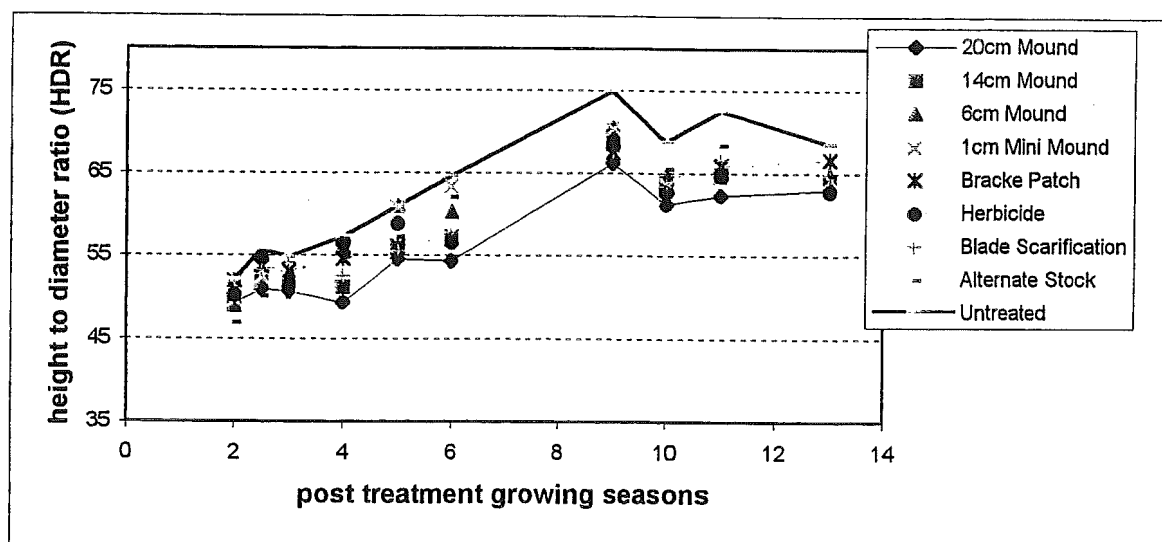


Figure A5.4. Wonowon site Interior spruce HDR values for different treatments.

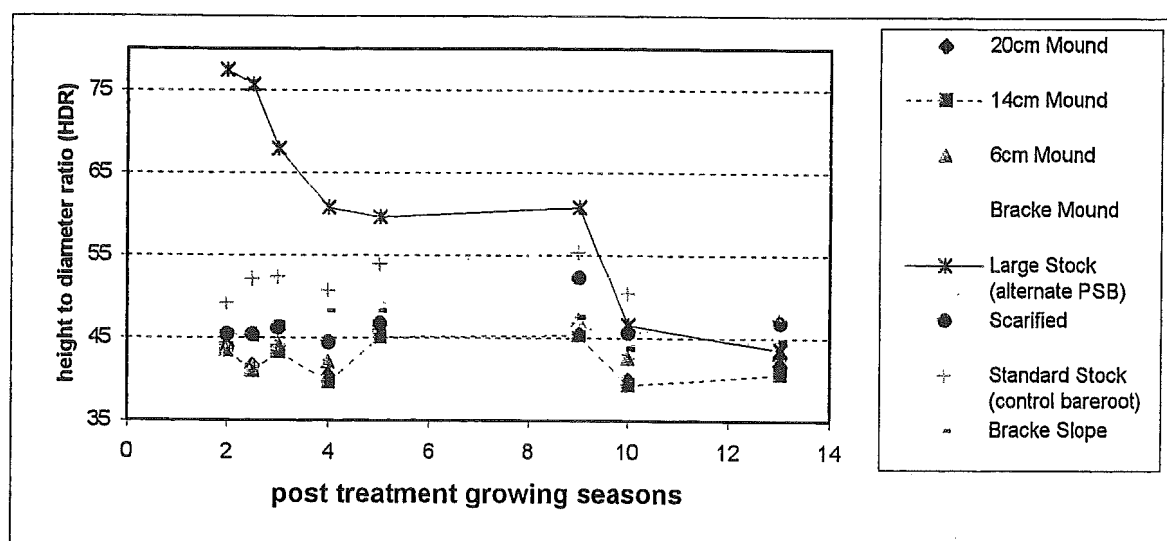


Figure A5.5. Upper Coalmine site Interior spruce HDR values for different treatments.

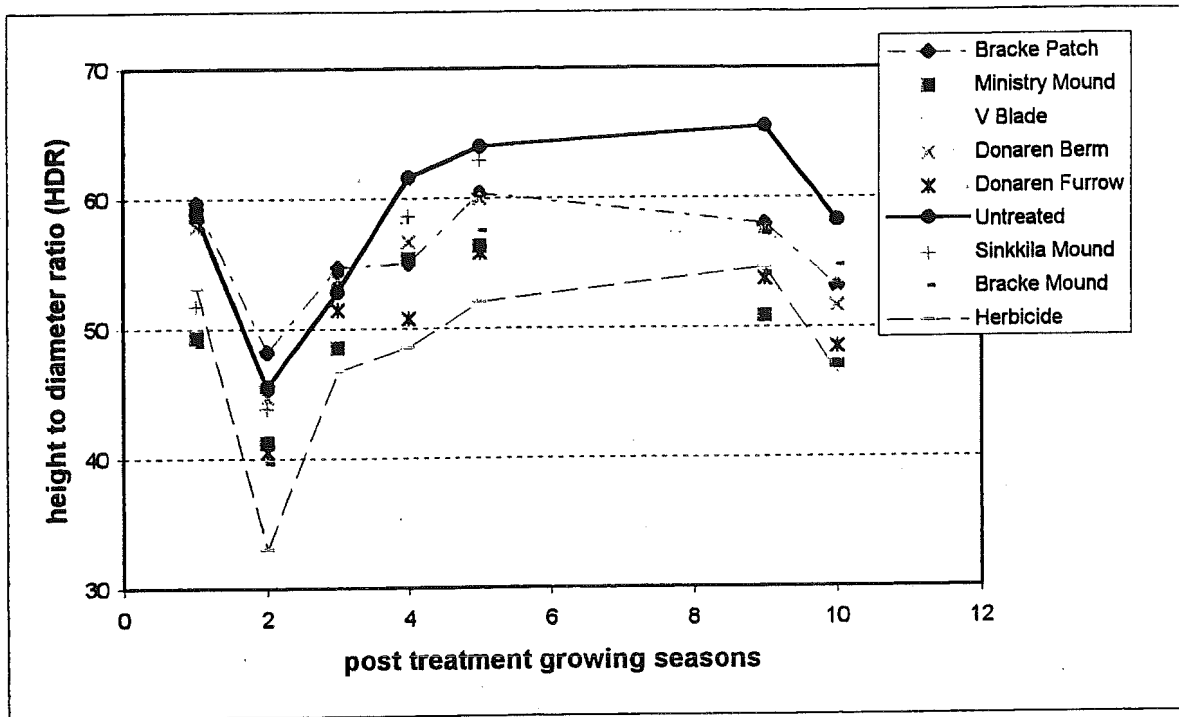


Figure A5.6. MacKenzie site interior spruce HDR values for different treatments.

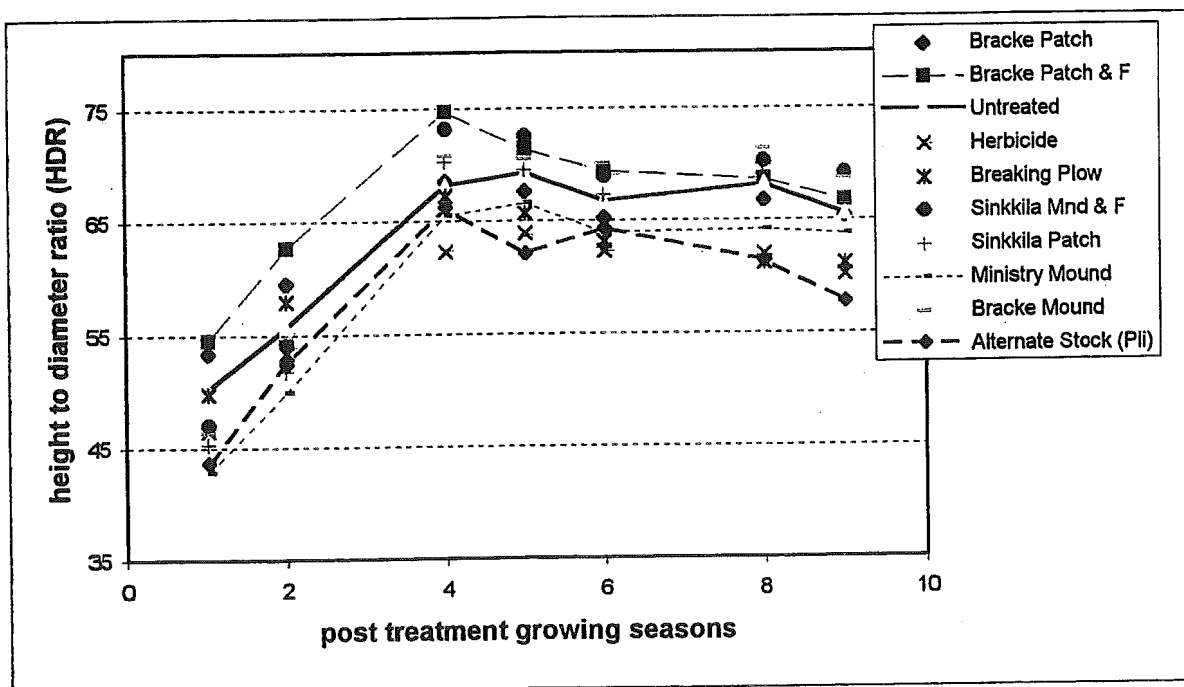


Figure A5.7. Iron Creek site Interior spruce HDR values for different treatments.

A.N. Burdett, L.J. Herring and C.F. Thompson

Early growth of planted spruce

Objectives: To look at the effect of stock types and fertilization on seedlings when planted in the field.

Methods: bareroot stock and container grown trees were planted for both species at the two sites, selected trees in each stock type were fertilized.

Site: Interior of British Columbia, white spruce: elevation 730 m, soil a sandy alluvium; Engelmann spruce: 1750 m elevation, the soil a silt loam, there was no competition on either site at time of planting

Species: white and Engelmann spruce

Factors considered: stock type and fertilization at planting

Findings: There was a large difference between HDR at the time of planting but this disappeared in the course of the first three growing seasons. At planting the HDR of the container stock was 73, by the end of the third growing season it had fallen to 43, which is very close to the HDR maintained by the bare-root plants throughout the 3 growing seasons.

Conclusion: The sharp reduction in HDR of the container stock indicates that height measurements alone can be a poor index of biomass accumulation in newly planted trees. Also to obtain rapid early height growth, planting stock with a low HDR should be used otherwise dry matter will be diverted largely to growth in stem diameter rather than height.

Additional Information: Planting check (reduced growth after planting) of spruce can have a major impact on yield by putting planted stock at a disadvantage in the competition with other vegetation. Measurements made at one site indicate that fertilization increased groundline diameter growth and percent stem volume growth by 50 and 66% respectively.

Comments: Looks at other factors other than competition that may influence HDR, what is interesting, is that the difference in HDRs disappeared after only three growing seasons, nursery treatments or stock types will have little effect on HDR.

Source: For. Research. 14:5, 644-651 (1984)

Dr. Phil Burton

**Height to Diameter Results extracted from FRBC research Project, SB96029-RE-
Effects of Block Edges and Patch Retention on Vegetation in the SBSmc**

Methods: crop seedlings examined across a number of stand types, open to the interior of a mature forest stand.

Site: SBSmc zone in the Morice and Bulkley forest districts

Species: subalpine fir, interior hybrid spruce and lodgepole pine, generally 10 to 15 years old.

Factors considered: stand type

Findings: See table A5.4.

Table A5.4. HDR values

position	subalpine fir		interior hybrid spruce		lodgepole pine	
	mean	Tukey grouping	mean	Tukey grouping	mean	Tukey grouping
open	31.99	B	48.18	D	45.71	CB
cc-grad	53.75	A	51.49	CD	42.67	C
cc-edge	48.92	AB	59.71	BC	53.75	BA
fr-edge	50.62	A	57.07	CDB	57.33	A
fr-grad	53.61	A	65.02	AB	46.46	A
interior	58.31	A	71.43	A	N/A	N/A

Comments: Only limited information available on site methods

Source: Personal communication with Phil Burton, June 1998.

The impact of non-coniferous vegetation on the performance of Engelmann spruce (*Picea engelmannii* Parry) on subalpine forest cutovers in south-central British Columbia.

Objectives: To study the response of planted Engelmann spruce seedlings to competitive interference from a perennial herb and ericaceous shrub complex that typically co-occur on not satisfactorily restocked cutovers.

Methods: Two stock types were examined (hot and cold) in response to 7 vegetation control treatments (3 clipped treatments, 3 controls and 1 bare), on two sites.

Site: ESSF zone, near Vavenby B.C.

Species: Engelmann spruce, cold stock and hot stock were used

Factors considered: stock type and vegetation control

Findings: HDR calculated: cold stock range: clipped treatments 35.8 ± 5.4 to 40.3 ± 6.5 ; control plots 47.9 ± 8.3 to 56.4 ± 9.8 , hot stock range: clipped treatment 39.1 ± 9.4 to 45.4 ± 6.9 ; control plots 54.2 ± 8.9 to 64.0 ± 13.2 . The HDRs of seedlings of both stocks on both sites were significantly greater in the controls than in the clipped and bare treatments.

Conclusion: For both stock-types, the HDR was significantly greater in the controls (not clipped), suggesting light as a limiting factor in these treatments. The HDRs of seedlings on the skid trail (low competition) were very similar to the HDRs of seedlings in the controls (high competition), however the biomass of the seedlings on the skid trail was much larger. Thus results found in the study suggested HDR was insufficient to characterize seedling response to competitive interference.

Additional Information: Findings have found that there is more variability in the absence of competition, because only some seedlings are able to respond to the better conditions. Height growth is relatively unresponsive to competition. Plants may shift their allocation of net growth between above and below ground biomass components in response to changes in the relative availability of light and limited soil resources. Competition for light may be one sided or asymmetrical (bigger seedlings will have a greater effect on smaller seedlings) where as competition for soil based resources may be two-sided (growth rate of all individuals would be reduced by the same amount).

Comments: The final measurements were taken after only 3 years in the field and the differences seen between the hot and cold planting stock may become less or even negligible after a longer time in the field.

Source: final report for FRDA Project 3.32, Faculty of Forestry, U.B.C., 1990

Unpublished data

Methods: height and diameter were measured at different levels of percent full sunlight, HDR was later calculated from these values

Site: The lodgepole pine and subalpine fir were located near Willams Lake in the biogeoclimatical subzone Moist Cool Interior Cedar Hemlock, Horsefly variant. The trees were on well drained soil and the lodgepole pine site had a drier climate. The spruce site was located at Aleza Lake Research Forest near Prince George in the biogeoclimatical subzone Willow Wet Cool Sub-Boreal Spruce.

Species: subalpine fir, hybrid spruce and lodgepole pine

Findings/Conclusions: Raw data was only provided and no comments were made on the results. For subalpine fir the HDR ranged from approximately 110 to 37. The general trend was for a slight increase in the HDR as the percent full sunlight decreased, however this average varied only between 50 and 57. There was a large increase in variability as the percent full sunlight decreased. For lodgepole pine, the HDR ranged from approximately 120 to 62. The general trend was for an increase in HDR as the percent full sunlight decreased. There was a large amount of variability for all levels of percent full sunlight and there was no distinctive trend. For hybrid spruce the HDR ranged from approximately 40 to 125. There was a very clear trend of an increase in HDR as the percent full sunlight decreased, at 20% full sunlight the HDR increased dramatically.

Comments: The HDR results for subalpine fir can be explained by the tree's high shade tolerance, the spruce results clearly show the expected trend. The HDRs found for lodgepole pine may be affected by factors other than light availability, the pine site was drier than other sites, therefore water or other factors may have been the limiting resource.

Source: personal communication with Yves Claveau, June 1998. GREF Interuniversitaire, Université du Québec à Montréal.

Dave Coates

Effects of Shrubs and Herbs on Conifer Regeneration and Microclimate in the *Rhododendron-Vaccinium-Menziesia* Community of Southern-Central British Columbia Summarized for Engelmann Spruce

Objectives: To identify limitations to seedling growth and establishment by the ESSF climate, measure changes in microclimate associated with varying amounts of shrubs and herbs, develop a model of conifer response to varying proximity and abundance of shrubs and herbs and to measure the response of the dominate shrubs and herbs to disturbance treatments.

Methods: There were 14 treatments with varying levels for shrub and/or herb removal and soil disturbance.

Site: high -elevation engelmann spruce -subalpine fir zone in Kamloops, elevation 1550m

Species: Engelmann Spruce, measured over two growing seasons.

Factors considered: many different environmental conditions were examined, but not directly considered to affect the HDR

Findings/Conclusion: At the time of planting the mean HDR of spruce was 40.0. At the end of the first growing season trees in treatment 1 (no herb or shrub removal) had a HDR of 50.9 which was similar to the HDR of trees in treatment 13 (no competition) 51.8, however the trees in treatment 1 were much smaller. The similarity between HDRs suggests that seedlings in both treatments were similar in how they were morphologically balanced. Height growth did not respond to shrub and herb levels to the same degree as diameter growth. Height growth may only be improved by complete removal of vegetation, where as diameter growth improves with increasing levels of vegetation control.

Additional Information: Seedling growth responded more so than survival to varying levels of competition. Low night-time temperatures can dramatically decrease height and diameter growth. Water stress may be a result of poor water uptake because of cold soils. Suggestion that competition acts to limit the upper boundary on the size that an individual can obtain, but below this boundary individual size can vary widely.

Comments: The HDR values for the treatment of complete shrub and herb removal are the highest of all treatments, this may be because they had the highest HDR at time of planting and they had not been on the site long enough to adjust. The reason may also be that resources other than light are limiting.

Source: Master of Science Thesis paper, Oregon State University, 1987

P.G. Comeau, G.S. Biring and G.J. Harper.

Effectiveness of repeated manual cutting for release of engelmann spruce from mixed-shrub herb vegetation

Objectives: To examine the effectiveness of single and repeated manual cutting treatments and a single herbicide application for controlling mixed shrub-herb communities and for releasing planted engelmann spruce seedlings.

Methods: Manual cutting treatments were done on all plots, the herbicide (VISION®) was applied to 3 study plots.

Site: Soards Creek, Interior Cedar Hemlock very wet cool BGCzone, elevation 860m, rich soil moisture regime. Site was mechanically prepared.

Species: Engelmann spruce

Factors considered: type of vegetation control

Findings/Conclusions: Repeated cutting and VISION® application were found to significantly reduce the 5th year HDR compared to untreated control seedlings. The HDR of single brushing treatments was not found to be significant. HDR of seedlings in the control plot was found to be 49.2, the HDR for seedlings in treatments c,d,e,f and g have a HDR of ~41.5

Source: Unpublished, Progress report for EP 1135.01, Ministry of Forests, Research Branch, Victoria B.C., February 18, 1998a.

Dave Coopersmith, Stuart Taylor, Mike Jull, Bruce Rogers, Kerry Deschamps and Nick Humphreys

A Comparison of the Growth of Planted White Spruce Seedlings in Small Openings and Beneath Hemlock Looper Attacked Cedar/Hemlock Stands in the Robson Valley, Prince George Forest Region

Objectives: To identify what levels of basal area removals of dead and damaged stems would be necessary to get acceptable levels of growth in the underplanted conifers.

Methods: Seedlings planted in four different understory plots at two different sites

Site: stand near Walker Creek in Robson Valley Forest District, stand was seriously defoliated by western hemlock, A second site was located at Fleet Creek

Species: white spruce, planted in 1994

Factors considered: site differences

Findings/Conclusions: The average HDR increased sharply during the first two years, but leveled off, and may be decreasing. HDRs rose from 54.5 in 1994 to 84.7 in 1995 (Table A5.5). By 1997 the average had decreased to 79.4. Two explanations are the amount of light increased, or because one in five seedlings died, HDR values at the high end of the range were removed. Evidence suggests that both phenomenon are at work. The observed HDR values at Walker Creek were less than optimal for spruce seedlings and likely that additional mortality will occur. Reduced light produced severely etiolated seedlings, with high HDR values, indicating that most of the underplanted spruce are suffering from stress due to low light levels. At the Fleet Creek site, the average HDR decreased from 81.2 in 1995 to 63.2 in 1997 (Table A5.5), it appeared as if the seedlings at Fleet Creek went through a period of stress following outplanting, but then adapted to the site and grew well. The Fleet Creek site is more open and therefore more favorable to greater diameter growth, thus smaller HDR values.

Table A5.5: HDR for Walker Creek and Fleet Creek.

Site	plot	1994	1995	1997
Walker Creek	1	56.89	85.81	81.59
	2	55.62	81.24	81.71
	3	50.34	89.46	70.27
	4	54.94	82.65	81.19
	average	54.47	84.69	79.35
Fleet Creek	4	N/A	85.68	65.70
	10	N/A	74.62	61.46
	18	N/A	82.01	64.86
	22	N/A	82.17	67.88
	23	N/A	84.78	63.31
	24	N/A	79.04	56.08
	average	N/A	81.20	63.20

Additional Information: HDR values below 60 are considered optimal for plantation grown spruce seedlings in the Peace River area of North-eastern B.C. HDRs of 35 have been recorded for 10 year old spruce trees growing on very good sites free from shrub competition near Fort St. John (Coopersmith, in preparation). HDR values greater than 80 are considered to indicate spruce seedlings are suppressed.

Comments: The level of competition was not controlled, and thus no comparisons can be made between different competition levels. Little information is provided on the Fleet creek site.

Source: unpublished paper April 1998, received from Dave Coopersmith (Prince George Forest Region) June 16, 1998

George J. Harper

Hybrid spruce Response to time of manual Brushing in the ICHmw - a detailed growth analysis

Objectives: To study the effectiveness of time and frequency of operational manual brushing treatments.

Methods: Two trials were established, one involved 54 treatment combinations (6 levels of timing, 3 levels of opening size and 3 levels of brushing frequency), a second study was done with seedling centered, circular treatments plots and was established in concert with the main study. The secondary study was designed to follow a small subset of the time of manual brushing treatments to provide detailed physiological information on seedling response. This paper describes the results from the second study.

Site: in the Nelson Forest Region, Interior Cedar-Hemlock biogeoclimatic zone, 850m elevation, site was broadcast burned

Species: mixture of one and two year old container hybrid spruce (PBS 415D), measurements done after 4 years in the field.

Factors considered: timing of manual brushing

Findings/Conclusions: Early summer brushed seedlings consistently had a lower HDR than late summer and control treatments, however significant differences only occurred during the Aug. 1995 and Sept. 1997 assessments. The HDRs did not exceed 60, but the smaller ratio of the early summer brushed seedlings indicates that this early release from moderate competition effects the carbon allocation to height and basal diameter growth. The trend in all treatments was for the HDR to decrease with increasing time on the site. Competition at the sites was found to be at a level to affect spruce seedling growth, but not survival.

Comments: The low HDR on all sites including the control can be explained by the level of competition which was not extremely high. Measurements were taken at different times of the growing season, and this has an effect of the HDR, the HDR tends to be lower in later part of the growing season.

Source: unpublished progress report for EP 1199, (not for general circulation) April 9, 1998, Research Branch, B.C. Ministry of Forests, Victoria B.C.

G.J. Harper, B. S. Bring, and J. Heineman

Mackay River Herbicide Trial: Conifer Response 9 Years Post-treatment

Objectives: To determine the long-term treatment impacts (9 years post treatment) on spruce seedling growth and vigor, stocking levels and the cover and height of non-crop vegetation.

Methods: Remeasurement of previously established vegetation management research trials. 5 treatments were applied, an untreated control, manual brushing and three herbicide treated plots (2, 4-D amine, 2, 4-D ester and glyphosate).

Site: Mackay Creek, ESSFwk1/05, elevation 1200m.

Species: hybrid spruce, final measurements when nine years old

Factors considered: type of vegetation management

Findings/Conclusions: The 2,4-D ester had the highest HDR of 50.1 and was not significantly different than the HDRs of the control which was 49.3. All other treatments were significantly lower, manually treated seedlings had a HDR of 46.9, the glyphosate treated seedlings had a HDR of 45.9 and the 2, 4-D amine treated seedlings had a HDR of 44.8.

Comments: Because the HDR data was not included in the paper, it was not discussed.

Source: Research Report 11, Ministry of Forests Research Program, Victoria, B.C. 1997
HDR values unpublished from George Harper, Ministry of Forests Research Branch,
personal communication June 1998.

G.J. Harper, L.J. Herring, and W.J. Hays-Bly

Conifer and Vegetation Response in the BWBSmw1 12 Years after Mechanical and Herbicide Site Preparation

Objectives: To look at the effect of different types of site preparation techniques by remeasuring previously established vegetation management research trials.

Methods: Three vegetation management treatments were applied, glyphosate and hexazinone were aerially applied to two plots, and third plot was an untreated control.

Site: Boreal White and Black Spruce BGC zone new Dawson Creek, elevation 935 m,

Species: white spruce, final measurements after 11 growing seasons

Factors considered: type of vegetation treatment applied

Findings: There was significant differences between herbicide treated and the control plots. The spruce HDR was larger in the control area than in the herbicide treatment area. The HDRs are, control - 59.13, Hexazinone - 47.03 and Glyphosate - 47.22. Both herbicide treatment areas could be considered free-growing plantations because the number of free-growing stems per hectare were greater than the minimum 700. The control areas were not considered to be free growing because they had less than 70 free-growing stems per hectare.

Conclusion: Data suggests that degree of white spruce suppression in the control area was not severe (e.g. 70+) (Ministry of Forests unpublished data; Leiffers and Stadt 1994). The larger HDR of those spruce in the control area indicates a light limited environment. Increases in white spruce HDRs were related to a decrease in overstory transmitted light.

Additional Information: Height and diameter results suggest that spruce growth is not compromised by the alder; however the added wildlife may increase the incidence of leader and lateral damage.

Comments: HDRs are given for each treatment, although this does reflect the level of competition, it is important to look at the vegetation assessment results to determine the level of competition when comparing with other results.

Source: Working Paper 29, Ministry of Forests Research Program, 1997

V.J. Lieffers and K.J. Stadt

Growth of understory *Picea glauca*, *Calamagrostis canadensis*, and *Epilobium angustifolium* in relation to overstory light transmission

Objectives: To determine the cover, frequency, and height growth of *C. canadensis* and *angustifolium*; the cover of low shrubs; and the height growth and other characteristics of *P. glauca* under a range of mixed hardwood and softwood stands.

Methods: sites with relatively uniform understory and overstory were selected, no treatment was applied to the sites.

Site: Lower Boreal Cordilleran in west central Alberta

Species: natural white spruce, selected if height is between 1 and 3 meters.

Factors considered: light transmittance

Findings/Conclusions: HDR of the tree decreases with light transmittance. Increases in white spruce HDR was related to a decrease in overstory transmitted light. Data showed the reduction in height to diameter ratio at full light, which indicates *p. glauca* will add more biomass at light intensities above 40% of full light, although competitive status can be sustained at 40% transmitted light.

Additional Information: Also looked at the percent of full light transmittance that would eliminate *C. canadensis* from a site.

Comments: Useful information is limited, but it does give a clear indication that light transmittance significantly effects the HDR.

Source: Can. J. For. Res. Vol. 24 1994

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Source: Can. J. For. Res. Vol. 24 1994

Newsome, G.

Mulch mat treatments in the ESSFwk1 on Hybrid Spruce - Sixth Year Results (SX93701C)

Objectives: To evaluate the use of Tredegar plastic mulch mats in a hybrid spruce plantation.

Methods/Site: "In the spring of 1993 I put in a trial in the Likely area using some free Tredegar Vegetation Mats that I received. The trial consisted of a Randomized Block Design with 3 plots. The trial is located in the ESSFwk1, plots 1 and 3 are more typical 01 site, but plot 2 is on a better 05/06 site. The area was planted by Weldwood of Canada in the spring of 1992 with a Sx and Pl mix. The mats were applied only to the Sx. The 3 plots consisted of 3 transect lines with 100 trees on each line being treated by installation of a vegetation mat, and an additional tree beside each of the matted trees being selected as a control stem. Data was collected in the spring and fall of 1993 and in the fall of years 1994, 1995 and 1997. The data in the attached file is the fall 1997 data."

Species: hybrid spruce

Factors considered: plastic mulch mats compared to untreated planted stock

Findings: "In reviewing the data, you will notice that I have sorted the data by the condition code, 1 for straight stem and 2 for bent, forked or dead leader. I think that the sorted number will give a more realistic HDR for the stand, though the difference is not much."

Table A5.6. Height diameter ratio means for 1997 (sixth post treatment growing season).

Location	Mat trees	Control trees
Plot 1 ESSFwk1 - 01		
HDR Code 1	51.1	60.7
HDR All Trees	50.3	59.9
Plot 2 ESSFwk1- 05/06		
HDR Code 1	46.4	56.1
HDR All Trees	45.8	54.6
Plot 3 ESSFwk1 - 01		
HDR Code 1	44.6	50.7
HDR All Trees	43.2	49.5
All Plots Code 1	47.6	56.0
HDR All Trees	46.6	54.9

Conclusions: Within each plot, the trees treated with the mats consistently had better HDRs than the control, so the mats do make a difference for diameter growth. The trial results show that there is no significant difference with survival, leader growth or total height growth between the matted and control trees. The area was logged in 1989-90 for plots 1 and 2 and in 1990-91 for plot 3. These blocks would be eligible for free growing declaration starting in 1998 or 1999. Though a large proportion of the stems are too short, the current leader growth on the trees will make a majority of the stems taller than 1.5 meters in only a few more years.

Source: Guy Newsome, Stand Tending Silviculturist, Cariboo Forest Region (pers. commun. June 1998).

E.T. Oswald and B.N. Brown

Vegetation and Seedling Development Following Site Preparation in the ESSFwm Subzone of Glenogle Creek, Nelson Forest Region, British Columbia: A Case study

Objectives: To look at the response of vegetation and planted engelmann spruce seedlings to operational site preparation procedures for reforestation.

Methods: Five site preparation techniques were tested: brush blade with contour, brush blade across contour, FMC blade with contour on gentle to moderately steep terrain, FMC dip and dive on steep slopes, and prescribed burning on moderately steep slopes.

Site: South Eastern British Columbia

Species: PSB 313 2 +0 Engelmann spruce, final measurements five years after planting

Factors considered: type of site preparation

Findings/Conclusion: Significant differences were found between the HDRs of the slashburn (58) treated sites and all other sites treatments (avg. ~ 49.3). The average HDR for the untreated sites was 51.8, note that seedlings in the untreated sites are natural and somewhat older, therefore were not included in statistical tests. The most measurable effect of shading was on HDR. The highest density of shading resulted in tall seedlings with proportionately smaller basal diameters in comparison to seedlings with no cover. The HDR of seedlings ranged from 65 (> 89% cover) to 48 (<10% cover).

Additional Information: The paper attributes the variation in seedling height growth within a treatment to either microsite conditions or genetics

Comments: Possible cause of the larger HDR for seedlings in the slashburn treatment is that more nutrients were readily available for uptake. Seedlings in other treatments may "catch-up" with time. The amount of vegetation cover between treatments was not found to be significantly different, and thus vegetation cover is an unlikely cause for the HDR difference. It is not clear how % cover HDR values were calculated.

Source: Forestry Canada, Pacific Forestry Center, Victoria B.C., FRDA report 188, July 1992.

R. Whitehead and G.J. Harper

A comparison of four treatments for weeding Engelmann spruce plantations in the Interior Cedar Hemlock Zone of British Columbia: ten years after treatment

Objectives: To compare the effectiveness of four vegetation treatments on the cover and height of a *Rubus-Epilobium* brush complex and the survival and growth performance of planted Engelmann spruce seedlings.

Methods: Four treatments were applied: Glyphosate herbicide; 2,4-D amine herbicide, manual brushing and an untreated control. The site was planted in 1984 and then fall planted in 1986 because of poor survival.

Site: Warm Interior Cedar Hemlock BGC subzone, elevation 900 m, site prepared with ground skidding and broadcast burning

Species: Engelmann spruce, 2+0 bareroot 1984 plant and 1+0 PSB 313 B 1986 plant

Factors considered: Types of vegetation control treatments

Findings: The initial HDR was ~60 in both plantings (1984/86), but declined to less than 50 over the duration of the experiment. A sharp reduction relative to other treatments was seen after glyphosate treated plots. The mean HDR remained steady or declined in the glyphosate group for the first five years post-treatment, but tended to rise in all other treatments.

Conclusion: Indicators of competitive stress such as HDR and competition indexes were reduced following glyphosate treatment. Conifer growth responses were related to degree of vegetation control thus it implies that competition was limiting seedling growth, this is supported by the HDR and competition index.

Additional Information: One of the first visual signs of seedling stress due to competition is an increase in HDR (Newton and Comeau, 1990).

Comments: The HDR change observed was relatively small compared with other studies..

Source: Information report BC-X-379, Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria B.C. 1998

Appendix 6 - Paper Summaries for Lodgepole Pine

Dave Coates

Effects of Shrubs and Herbs on Conifer Regeneration and Microclimate in the *Rhododendron-Vaccinium-Menziesia* Community of Southern-Central British Columbia *Summarized for Lodgepole Pine*

Objectives: To identify limitations to seedling growth and establishment in the ESSF climate, measure changes in microclimate associated with varying amounts of shrubs and herbs, develop a model of conifer response to varying proximity and abundance of shrubs and herbs and to measure the response of the dominate shrubs and herbs to disturbance treatments.

Methods: There were 14 treatments with varying levels for shrub and/or herb removal and soil disturbance.

Site: high -elevation engelmann spruce -Subalpine Fir zone in Kamloops, elevation 1550m

Species: lodgepole pine, measured after two growing seasons.

Factors considered: many different environmental conditions were examined, but not directly considered to affect the HDR

Findings/Conclusions: Chapter 1: At the time of planting the mean HDR of pine was 30.5. At the end of the first growing season the HDR had increased to 45.5, and there was no significant difference between treatments. Chapter 2: HDR was one of the most sensitive growth variables when regressed against interference.

Additional Information: Seedling growth responded more to competition than did seedling survival. Poor survival of seedlings associated with the harsh ESSF climate, interference from other vegetation and interactions between the climate and vegetation. Water stress may be a result of poor water uptake because of cold soils. Suggestion that competition acts to limit the upper boundary on the size that an individual can obtain, but below this boundary individual size can vary widely.

Comments: In chapter two there are values given for the second growing season, but their significance is not clear.

Source: Master of Science Thesis paper, Oregon State University, 1987

Teresa Newsome

Retrospective study of Pine-Aspen Competition in the IDFdk Progress Report (EP 1152)

Methods: A retrospective study, sites were selected with a range of alder densities. A transect was established through the stand and a given number of trees within each percent cover class (0%, 1-15%, 16-30% and >30%) were selected. Percent cover did not exceed 40%.

Site: Three stands in the IDFdk (Meldrum Creek, Moffat Creek, and Raven Lake)

Species: pine, average age 8 to 12

Factors considered: density of competitors

Findings: There was very little variation in the HDR, until the density per plot exceeded three. The HDR for densities of 2 per plot were 56 to 58, the HDR increased for densities of 4 (68) and 5 (74). After a density of five trees per plot, the ratio varied and no strong trends were observed. There was considerable variation around the mean, for trees with no competition the HDR ranged from 44 to 70.

Conclusions: Pine total diameter and diameter growth were affected first at a density of approximately 2 trees per plot, before this pine growth was unaffected. A decrease in leader growth was observed at approximately 5 trees per plot. The HDR emphasizes the loss of diameter growth at 3-4 trees per plot, as diameter growth is slowing down, but height growth is not reduced. If the stand objective is to maintain optimal pine growth the HDR can be used to indicate if growth is being lost due to competition. Because of variation in HDR when used a number of samples should be taken for each stand.

Additional Information: Retention of some aspen in conifer stands is becoming a more accepted practice for a number of reasons. Aspen may enhance soil properties and alleviate weather extremes, and increase the biodiversity. Aspen also have economic values and removal can be expensive. Defining competition appears to be important for explaining the amount of competition.

Comments: The high variability in HDR values at densities greater than five may be because as the density increases the sample size decreases, and thus limited data is available.

Source: Unpublished data and draft report from Teresa Newsome (Cariboo Forest Region, no 17, 1998)

Suzanne Simard

Competition Among Lodgepole Pine Seedlings and Plant species in a Sitka-Alder Dominated Shrub Community in the Southern Interior of British Columbia.

Chapters 1 and 2 are summarized separately.

Chapter One

Objective: To examine the effects of the sitka alder shrub community on the performance of lodgepole pine seedlings and the levels of environmental resources and conditions.

Methods: Seven treatments were applied which covered wide ranges in density of Sitka alder (0 to 2514 clumps/ha) and percent cover of herbs (0 to 100%)

Site: Montane Spruce zone-dry region (Thompson Plateau), elevation 1400m, soil is a Brunisolic Gray Luvisol

Species: Lodgepole pine, measurements done after two years.

Factors considered: alder and shrub density

Findings: At planting there was no difference in HDR (45.7). At the end of the first growing season the mean HDR was 52.6. After the second growing season the HDR was lower at 42.8. Seedlings in treatment 7 (no competition) were more sturdy (HDR 35) compared to treatment 1 (100% alder and 100% herbs)(HDR 47.3). Seedlings grown in alder free environments had smaller HDRs (38.23) than seedlings grown with alder (HDR 46.13). HDRs decreased with alder and herb densities. Seedlings in treatment 1 were under more water stress than those seedlings in treatment 7. Complete vegetation removal resulted in warmer soil temperatures.

Conclusions: Alder increased height growth, but decreased diameter growth thus produced spindly seedlings. Greater resource allocation to height relative to diameter growth has been observed in conifers as a response to low light intensities, or increased alder competition.

Additional Information: Little is known about the interactions between planted seedlings, competing vegetation and the physical environment. Competing vegetation can affect pine by modifying environmental conditions (temperature) and causing resource limitations (water, light and nutrients). Height alone is not a good indicator of competition. Height growth is affected by the previous year's competition and diameter is affected by the entire growing season. Seedlings growing under high competitive stress have small crowns and therefore need less stem tissue.

Comments: It is a good study, however HDR values may be inconsistent because seedlings had only been in the field for two growing seasons.

Chapter Two

Objective: To look at neighborhood competition among lodgepole pine seedlings and plant species in a sitka alder-dominated shrub community, focusing on size and light availability.

Methods: Seven treatments were applied (same as in chapter 1), retrospective neighbourhood study.

Site: Montane Spruce zone of the southern interior, in 1977 was mechanically prepared and left for natural regeneration.

Species: Lodgepole pine, community was 10-years old

Factors considered: shrub coverage

Findings: Percent coverage of all shrubs and sitka alder explained the most variation in HDR. Percent cover of all shrubs and all herbs explained 16% of the variation in HDR and only 9% of the variation in diameter. The proportion of full sunlight decreased with increasing herb and shrub coverage.

Conclusions: The intensive indices that explained the most variation in HDR were distance, height, angular dispersion. Stem diameter and HDR were the most responsive performance variables to measures of inference (competition indices). Only 16% of the variability in HDR was explained by shrub and herb cover and 4% was explained by light intensity.

Additional Information: Competition occurs when plant population densities are high enough that individuals modify the environmental conditions and supply of resources to each other. Light availability account for partial reductions in seedling growth, however other factors also affected seedling performance.

Comments: Looked mostly at what caused the variation in different values, there were no mean values given for HDR, so it is difficult to apply what was found.

Source: Masters Thesis February 1989. Oregon State University, Corvallis Oregon

Appendix 7 - Paper summaries for species other than lodgepole pine, Douglas-fir and spruce (white, englemann and the hybrid)

Han Y.H. Chen and Karel Klinka

Survival, growth, and allometry of planted *Larix occidentalis* seedlings in relation to light availability

Objectives: Questions addressed in the study: How does survival of western larch seedlings vary with light availability and seedling development stages? How do different measures of growth (base diameter, height and biomass components) change in response to light availability? Are there any changes in allometry and SLA with the change in light availability?

Methods: Seedlings were planted along irregularly spaced transects extending from 60 m inside the clear-cut, through the stand edge, to about 60 m inside the adjacent stand. The surrounding herbs and shrubs within 1m diameter from the planted seedlings were removed immediately after planting and twice each year after.

Site: three sites near Okanagan Falls, British Columbia, two sites were within the Interior Douglas-fir zone and one site was within the Montane Spruce zone, the soil type was Dystric Brunisol

Species: 1 year old container grown western larch, measurements taken after three growing seasons.

Factors considered: percent full sunlight

Findings/Conclusions: The ratio of height to base diameter significantly increased with decreasing light. The mean HDR changed from 100 in low light conditions (5% full sunlight) to 60 in high light conditions (100% full sunlight). Values taken from graph are as follows: HDR for 20% full sunlight is approximately 90, HDR for 50% full sunlight is approximately 80 and HDR for 80% full sunlight is approximately 70. The height growth of planted western larch was not significantly affected by light. By investing more resources in terminal rather than diameter growth may imply the strategy of some canopy species to reach a higher level of light resources in a light limiting environment.

Additional Information: Generally, shade tolerant species develop thinner leaves and have higher height-to-diameter and shoot-to-root ratios in response to decreasing light availability. With decreasing light availability, significant decreases in diameter growth have been found in planted and naturally regenerated coniferous and broad leaf tree species. Seedlings grown in natural environments experience complex interactions between different environmental factors, which may override the effect of light on carbon allocation patterns (Bazzaz and Wayne 1994;Messier and Puttonen 1995)

Comments: This paper shows a significant relationship between light availability and HDR. Competition is not considered as the herbs and shrubs are removed. Only the effects of limited light are examined, however competition also limits other resources.

Source: Forest Ecology and Management 106 (1998) 169-179

Brian D'Anjou

Influence of manual treatment timing on red alder regrowth and on conifer release - ten year results; Project FRDA 2.12

Objectives: To examine the effect of five cutting periods throughout the growing season and to determine the effect of alder removal on subsequent conifer growth and condition.

Methods: Five different cutting periods were examined as well as two untreated controls (9750 sph alder and 3100 sph alder)

Site: Okeover Inlet, Coastal Western Hemlock very dry maritime biogeoclimatic subzone, 80 to 120 elevation,

Species: 2 + 0 bareroot stock, grand-fir

Factors considered: treatment timing

Findings/Conclusions: Grand-fir generally has a lower HDR than Douglas-fir. Trees with a HDR greater than 70 are growing slower than saplings with a HDR below 60. The control with 750 sph alder had a lower HDR (54) after seven years than the control with 3100 sph alder (69). The HDR of the cutting treatments ranged from 57 to 64, the highest HDR occurred in the plots that had been cut in July (61 and 64).

Table A7.1. Grand Fir HDR by treatment and years after treatment

year	Jun 7th	Jul 5th	Aug 2nd	Aug 30th	control (750 sph alder)	control (3100 sph alder)
0	60	62	71	75	63	79
1	57	58	58	58	63	82
2	56	53	56	53	64	76
3	50	52	55	48	46	68
5	56	53	57	43	52	66
7	58	61	64	57	54	69

Additional Information: Grand-fir can tolerate high alder densities.

Source: Unpublished data from Brian D'Anjou, Research Silviculturist, B.C. Ministry of Forests, Nanaimo. June 1998

Brian D'Anjou

Manual Cutting Techniques for Red Alder and cottonwood Control in a Redcedar and Douglas-fir Plantation: Project FRDA 2.35 - Dewdney installation

Methods: Seven treatments tested for conifer release including four manual treatments completed at different times of the year, a glyphosate hack and squirt treatment, a total vegetation removal and an untreated control.

Site: east of Mission, Fraser valley; CWHdm biogeoclimatic variant

Species: 1+0 PSB 313 Western redcedar

Factors considered: type of vegetation removal

Findings/Conclusions: All manual cutting treatments improved growth, primarily diameter growth, although there was little difference between the four treatments. The total vegetation removal had the largest growth response. Seedlings with a HDR below 50 were above all competing vegetation, the maximum annual height growth increment was 70 cm and maximum caliper increment was 17mm. The survival of seedlings with a HDR of 60 to 70 was not affected, but they grew less than seedlings with a lower HDR. Over-topped seedlings had a HDR of 70 or greater, there was little mortality, but their diameter growth was less than 50% of the fastest growing seedlings. The annual height increment was 30cm and the diameter increment was about 6 mm.

Table A7.2. HDRs for western redcedar, treatment by year

year	cut 1	cut 2	cut 3	cut 4	glyphosate	complete removal	control
0	89	93	97	102	102	98	96
1	76	81	82	79	81	72	86
2	72	72	70	72	70	60	80
3	70	67	68	68	67	55	76
5	65	67	64	66	59	47	73
7	65	64	63	63	60	46	68

Additional Information: Cedar is shade tolerant in nature, because it has little mortality when over-topped.

Comments: All HDR, in all treatments deceased significantly throughout the study period.

Source: Unpublished data from Brian D'Anjou, Research Silviculturist, Ministry of Forests, Nanaimo, June 1998

Brian D'Anjou

Evaluation of triclopyr ester as a conifer release treatment: Project FRDA 2.13

Methods: Two application rates of the herbicide triclopyr ester tested as conifer release treatments on a three year old grand fir plantation, the higher rate was not more effective than the lower rate, but was inadvertently sprayed aerially with glyphosate thus reducing the cover.

Site: southeast of Chilliwack, CWHxm biogeoclimatic variant, elevation 350m

Species: 2+1 bareroot Grand fir

Factors considered: type of vegetation removal

Findings/Conclusions: Seedlings with a HDR less than 50 were growing free of alder over-topping during most measurement periods, the annual height growth was up to 1 meter per year. Seedlings with a HDR of 50 to 80 were over-topped by a range of alder densities, mortality was low and the height growth was between 50 and 60 cm. Seedlings with a HDR greater than 80, were generally over-topped from the beginning of the measurement period, the surviving trees showed poor vigor and had an annual height growth of less than 30 cm.

Table A7.3 - HDRs of grand fir by treatment and year

year	not over-topped		threatened		over-topped		control
	1.4kg	2.9 kg	1.4 kg	2.9 kg	1.4 kg	2.9 kg	
0	68	75	82	85	77	88	97
1	65	71	71	85	71	85	91
2	60	67	73	82	74	85	99
3	66	74	88	90	94	93	101
5	46	61	54	66	60	77	91
7	42	54	47	59	57	66	80
9	45	50	49	53	63	63	82

Source: Unpublished data from Brian D'Anjou, Research Silviculturist, B.C. Ministry of Forests, Nanaimo. June 1998

Clas Fries and Urban Nilsson

Development of Underplanted *Pinus sylvestris* in a *Betula pubescens* Shelterwood in Northern Sweden

Objectives: To find out to what extent planted Scots pine is affected by competition in a shelterwood of European birch under harsh climatic conditions in northern Sweden during the first 20 years after planting.

Methods: The growth of pine in a clear-felled area and a European birch shelterwood were examined. Diameter was measured 30 cm above ground.

Site: in the northern most province of Sweden, at lat. 67°03' N, long. 20°18' E

Species: 20 year old Scots pine, four different provenances, seedlings were 4 years old at planting (Gallivare) or 6 years old (Kesavaara, Rahavaara and Mala)

Factors considered: provenance and stand type

Findings: HDR was presented for three provenances (Gallivare, Kesavaara and Rahavaara), it was found that the HDR differed significantly between pines on the clear-felled area (mean HDR 49) and those in the shelterwood (mean HDR 62). Height classes were found to have little affect on the HDR, as the ratio was almost constant for different height classes in both stand types.

Conclusions: The smaller HDR on the clear-felled areas shows that the pines in the shelterwood are suffering from competition from the birches. It has been found that in northern Sweden, light probably did not limit the height development of naturally regenerated Scots pine seedlings. It has also been found that seedling survival and height development could be explained to a large extent by root competition.

Additional Information: Plants compete for light and carbon dioxide above ground and for water, nutrients and oxygen below ground. One finding about competition is that the total growth rate of a single tree decreases with increasing competition among trees. Another effect of competition is the change in the allocation of growth. Diameter growth decreases more than height growth as a result of competition.

Comments: Four different provenances were planted, but measurements were only presented for three, it was unclear as to why values for the fourth provenance were not shown. The suggestion that competition was for below ground resources is possible, however determining this is difficult. The high HDR found are consistent with other studies where light was considered to be the limiting factor.

Source: Scand. J. For. Res. 5:525-534, 1990

John W. Groninger, Shepard M. Zedaker and Todd S. Fredericksen

Stand Characteristics of Inter-Cropped Loblolly Pine and Black Locust

Objectives: To determine the role of species proportion in the development of pine locust mixtures as well as to evaluate how herbaceous cover affects stand development through the first five years.

Methods: Sites prepared for planting in the fall of 1988 with glyphosate, the treatments were several competitive arrays (stand types) in a split plot design with four replications. There was two levels of weed control: weed-free conditions and closed ground cover.

Site: Reynolds Homestead Forest Research center near Critz Virginia

Species: (1-0) loblolly pine measurements were taken after the fifth growing season

Factors considered: ground cover and stand type

Findings/Conclusions: The HDR decreased as the proportion of pine decreased. This indicates that the intensity of competition for above ground resources was directly related to the proportion of pine in the stands. Loblolly pine HDR was unaffected by ground cover but showed a significant response to stand type, grown in monoculture (HDR 58) and 75% (HDR 56) mixture had a higher HDR than individuals from 50 (HDR 50) and 25% (HDR 47) pine stands. Increased HDR supports data suggesting that pines grown in monoculture and 75% pine stands are experiencing more intense competition for resources and are nearer the age for thinning.

Additional Information: Benefits to wildlife and aesthetic considerations are considered benefits to mixed stand management. Height growth is less sensitive to competition than diameter growth.

Comments: Because of the difficulty determining the various competition levels the HDR values are presented in table A7.5.

Source: For. Ecology and Management. 91: 221-227 (1997)

John W. Groninger, Shepard M. Zedaker, John R. Seiler, Todd S. Fredericksen and Richard E. Kreh.

Growth and Physiological Characteristics of Planted Loblolly Pine and Red Maple Grown in Pure and Mixed Stands

Objectives: To quantify the effects of herbaceous vegetation and forest stand composition on physiology and growth of loblolly pine and red maple, for the first five years following establishment from 1-0 seedlings.

Methods: site prepared with glyphosate in Fall 1988. It was a split plot design with two levels of weed control: weed free or closed ground cover. Loblolly pine and red maple were planted both in pure stands and mixtures of 50:50. Subplot borders were trenched and lined with plastic sheets after the third growing season.

Site: near Virginia Tech's Reynolds Homestead Forest Resources Research Center in Critz, VA. Site is an abandoned field, soil is a Cecil clay loam.

Species: 1-0 loblolly pine and red maple

Factors considered: herbaceous control and stand type

Findings/Conclusions: Herbaceous vegetation suppressed height growth. The HDR was sensitive to herbaceous vegetation as well as growth in mixed or pure stands. Loblolly pine HDR was more strongly influenced by growth in monoculture versus mixture than by presence of herbaceous competition. The HDR of weed-free stands became greater suggesting that competition from trees became more important than herbaceous vegetation by the end of the fifth growing season. HDR calculated for red maple and black locust as well.

Additional Information: As long as loblolly pine does not become suppressed, planted hardwood species may act as nurse crops by increasing self pruning. HDR may be a useful index of competitive stress based on the observation that diameter is affected by competition while height is affected to a considerably lesser extent. As competition intensifies during crown closure greater allocation of resources to height growth at the expense of diameter growth may allow an individual to maintain a favorable status for light capture. Once crown closure occurred stand species composition became increasingly important.

Comments: HDRs are given for pure and mixed stands, weed-free and tall fescue, however they are not separated to give say pure stands that are weed-free, which may have provided more information. Because of the difficulty determining the various competition levels the HDR values are presented in table A7.5.

Source: Proceedings of the Eighth Biennial Southern Silvicultural Research Conference, Auburn, AL, Nov. 1-3, 1995.

Table A7.5 . HDR for loblolly pine grown near Virginia Tech's Reynolds Homestead Forest Resources Research Center.

Reference	time at site	weed-free	closed ground cover	pure stands	mixed stands	species mixed with
Groninger <i>et al.</i> 1995	1	36.3	37.5	37.2	36.7	red maple
	2	43	50	49.1	44.8	
	3	51.3	54.7	55	50.5	
	4	50.2	48.9	52.6	46.5	
	5	55.5	53.8	57.7	51.6	
Groninger <i>et al.</i> 1997	5	54	52	58	50*	black locust

* stand is a 50:50 mix, other stand types were used in trial, see written summary for values

Robert G. Wagner, Thomas L. Noland and Gina H. Mohammed

Timing and Duration of Herbaceous Vegetation and Control Around Four Northern Coniferous Species

Objectives: To identify and compare critical periods of herbaceous vegetation control for planted back spruce, jack pine, eastern white pine and red pine during the first 5 years after planting.

Methods: Six patterns of vegetation control were examined: 3 consecutive years, first year only, first two years, second and third years, third year only and no vegetation control.

Site: 50 km north of Sault Ste. Marie, Ontario

Species: G+2 medium bareroot black spruce, container jack pine, G+1.5 bareroot eastern white pine and 2+0 medium bareroot red pine

Factors considered: period of vegetation control

Findings: HDR decreased as the degree of vegetation removal increased. Substantial differences in stem diameter were found among vegetation treatments for all species. Stem diameter increased with increasing years of vegetation control. The HDR after 3 consecutive years of vegetation control was 27, 29, 32, and 41 for white pine, red pine, jack pine and black spruce, respectively. Under untreated conditions, the HDR increased to 42, 43, 56, and 59 for white pine, red pine, jack pine, and black spruce respectively.

Conclusions: The HDR was a good indicator of competitive stress for all species, a similar range of HDR values was obtained for all conifer species. The advantage of the HDR is that it can be used for a wide range of sizes. The HDR has generally been found to increase when seedlings are shaded.

Additional Information: The insensitivity of height growth to diameter growth has been generally observed in vegetation management. Decreases in diameter growth associated with herbaceous vegetation are likely to be related to competition for light, soil, water and nutrients.

Comments: A good discussion about what is known about the HDR. Species do not apply to British Columbia, but the effect of treatment is interesting.

Source: New Zealand Journal of Forestry Science 26 (1/2): 39-52 (1996) and Advancing Boreal Mixedwood Management in Ontario, Canadian Forest Service, 1995.

G.G. Wang, H. Qian and K. Klinka

Growth of *Thuja plicata* seedlings along a light gradient

Objectives: to improve understanding of light growth response relationships in western red cedar.

Methods: On each site the seedlings were planted on transects extending from a clear-cut to the interior of an adjacent old-growth stand.

Site: Three sites in two watersheds of the Greater Vancouver Watershed District, Eastcap Creek was in the Capilano watershed, and Alpine and Cedar creek were in the Coquitlam watershed. Sites were moist and nitrogen rich

Species: one year old container grown (PSB 313A) red cedar seedlings, measurements taken after three growing seasons

Factors considered: percentage of above canopy light

Findings: PACL class I ($\leq 20\%$ of PACL) showed an increase in the HDR. PACL class V ($> 80\%$ of PACL) showed decreases in the HDR. Height to caliper ratio decrease as light increased, which suggested that caliper growth decreased at a greater rate than when light decreased.

Conclusions: A consistent decrease of HDR with increasing light showed that under low light there was a greater suppression of caliper growth relative to height growth, this relationship should not be interpreted as a tendency to etiolate but as a better adaptation to grow in low light, in view of a high survivorship and increased specific leaf area in low light.

Additional Information: Red cedar, like western hemlock and Pacific silver fir tolerate very low light conditions. Compared with other associated shade-tolerant species, indeterminate western red cedar maintains the highest rate of terminal growth in low light.

Source: Can. J. Bot. Vol. 72: 1749-1757 (1994)

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