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Release and Management of Understory Western Redcedar: A Literature Review

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Release and Management of Understory Western Redcedar: A Literature Review

Jeffrey W. Fields and David L. Adams

Introduction

Although western redcedar (*Thuja plicata* Donn.) is a highly valued tree species in the Pacific Northwest both for aesthetic and economic reasons, information on how to actively manage the species is quite scarce. This may be because in years past the species has often been considered a "bonus" in mixed conifer stands, a tree to be harvested when found, but rarely a species to be managed for. In recent years there has been growing interest in the management of western redcedar, probably largely because of the decreasing supplies of naturally propagated western redcedar stands.

As the amount of old growth redcedar has declined, interest in how to pro-actively manage the species from seedling to desired end-product has increased. However, many foresters interested in managing forest ecosystems for western redcedar have come to realize that the amount of available information about the species is much less than that available for other commercially valuable conifers of the Pacific Northwest, and what is available is widely scattered in a variety of publications.

This report provides a comprehensive review of the published literature on the release of western redcedar advance regeneration and the subsequent management of the regeneration following release from its mixed conifer overstory. Ferguson (1994) defines advance regeneration as seedlings and saplings that become established prior to the partial or total removal (or death) of the overstory. They are usually shade-tolerant species that become established under mature trees, though it is possible for shade-intolerant species to become established in the canopy gaps of forest stands. This report attempts to provide enough site and research design information about the specific trials and experiments so that practicing foresters can identify which research is applicable to their particular situation.

SCOPE OF THE REPORT

It is important to note that this document is not a comprehensive guide to the silviculture of western redcedar. In order to put the report in context, some basic information on the autecology of the species has been included. The majority of this report however, focuses on issues directly related to the release and management of western redcedar advance regeneration. Its content is based on the current state of knowledge, as published in forestry and biology journals as well as United States and Canadian government research publications.

Additionally, it is important to note that there are some topics related to the management of advance regeneration which have not been addressed in this report because no published information on the topics were found. The economic costs and benefits of specific fertilization or pruning treatments are examples of topics on which no published information was found.

Seven information sources were searched for relevant information. These sources were:

1) CAB International Database. 1972 to present. This is an extremely large science database which includes the Forestry Abstracts, as well as the Agricultural and Biological Abstracts. Much relevant information can be found in this database.

2) AGRICOLA. 1972 to present. This database compiled by the National Agricultural Library of the U.S. indexes over 1,560 journals as well as monographs, theses, patents, software, audio-visual materials, and technical reports. This database includes some material that the CAB database does not consider "research quality" (Forest Service technical reports in particular).

3) UNCOVER. This database bills itself as "the world's largest article index", adding over 4000 citations daily.

4) Expanded Academic Index. Indexes over 1400 scholarly and general interest journals, primarily of a social science nature, but also including some general science citations. Updated monthly.

5) CRIS/ICAR. Contains citations from U.S. and Canadian researchers; aligned with AGRICOLA.

6) Westfornet. U.S. Forest Service online database.

7) Personal communications with researchers at the University of Idaho, University of Washington, University of British Columbia, and U.S. Forest Service Intermountain Research Station.

The Autecology of Western Redcedar, A Brief Review

Thuja plicata (Donn) is a member of the Cupressaceae family, a family which also includes junipers and a number of ornamental evergreen trees and shrubs. Like most of the related species it is characterized by small, scale-like leaves, with no distinct buds or bud-scales. Mature cones are cinnamon brown in color, 12-18 mm long and 4-6 mm wide (Edwards and Leadem 1988).

DISTRIBUTION AND HABITAT

Along the coast of the Pacific Ocean western redcedar grows from southern Alaska to Humboldt county, California. Inland from the coast there is a contiguous band of western redcedar east of the Cascade Range from central Oregon north to southern British Columbia. The species is also found along the western slopes of the Rocky Mountains, from Prince George, B.C. to northern Idaho and parts of eastern Washington and western Montana. The altitudinal range of the Inland Empire population ranges from a low of approximately 300m above sea level, to as high as 3457m above sea level (Neiman 1988).

According to the Daubenmire's classification of forest habitat types (Daubenmire and Daubenmire 1968) western redcedar is the major climax species on the *Thuja plicata/Pachistima myrsinities* (THPL/PAMY), *Thuja plicata/Athyrium filix-foemina* (THPL/ATFI), and *Thuja plicata/Oplopanax horridium* (THPL/OPHO) habitat types. Western redcedar is a minor climax species on the *Tsuga heterophylla/ Pachistima myrsinities* (TSHE/PAMY) habitat type, and an accidental on the *Abies lasiocarpa/Pachistima myrsinities* (ABLA/PAMY) habitat type (Graham 1981). In many cases the *Pachistima myrsinities* habitat types in the Daubenmire's classification corresponds to the *Clintonia uniflora* habitat type of Cooper et al. (1991). See Cooper *et al* for a more detailed comparison of these two typologies.

Though the species is often characterized as a wet site species, there is evidence that western redcedar is also adaptable to drier sites. Weetman and others (1988) state that western redcedar grows best on sites which are also suited for Douglas-fir, while other observers have noted that the species can be established on mesic, well-drained upland sites (Nystrom et al. 1984; Oliver et al. 1988).

Parker (1979) found that the best germination substrate was mineral soil covered with a shallow layer of moss. Germination frequency was next highest on rotten ground wood. While mineral soil is the best medium for germination, survival (seedlings two or more years old) was best in rotten woody material under mature stands. Parker and Johnson (1988a) found that in old growth cedar groves 94% of established seedlings were found on rotten wood and only 6% on mineral soil. This fact is more dramatic considering the small proportion of rotten wood to other potential seed beds. It is possible that on drier habitat types, the rotten wood provides moisture needed to enhance late season survival (Parker and Johnson 1988a).

In terms of total numbers of regeneration, the greatest number of seedlings was found on partially cut areas with a northern aspect, while clearcut south aspect sites had the least regeneration. Most seedling mortality was attributed to micro-site drought in which the shallow rooted seedlings could not find sufficient moisture in the upper soil layer (Parker 1979).

NUTRITION

Western redcedar appears to have a wide nutritional amplitude with an ability to take up nutrients on more humus soils (Weetman et al. 1988). For optimum growth, Krajina *et al* (1982) state that western redcedar requires nutrient-rich soil with a well balanced supply of both Ca and Mg, and with N in the form of nitrate. However, mineral nutrition studies do not explain whether the nitrate preference is real or induced as a result of a relatively high proportion of available nitrate produced by nitrification of western redcedar litter (Weetman et al. 1988).

Western redcedar is reputed to be a calciphile, yet calcium requirements are unclear and complex. Western redcedar has been reported to require Ca rich sites to grow on, yet the high level of Ca in the western redcedar foliage relative to other coniferous species may be attributed to an ability of western redcedar to accumulate Ca in excess of its nutrient requirements, thereby acting as a Ca pump to the site (Weetman et al. 1988). Imper and Zobel (1983), working in southwestern Oregon, suggest that western redcedar grows on soils with large amounts of Ca and N and high Ca:Mg ratios. Minore (1983) suggested that only low levels of S seem to be required by western redcedar.

GROWTH AND DEVELOPMENT

Western redcedar reproduces both sexually and asexually. Depending upon canopy conditions and the availability of moisture in the upper soil layers, reproduction can shift from one means to the other. Sexual reproduction is more prevalent in disturbed areas, such as clearcuts while in undisturbed areas regeneration is largely vegetative (asexual) because seeds either fail to germinate, or succumb to drought soon after germination.

Three types of asexual reproduction have been been noted: **(1)** layering, in which low hanging limbs of an erect tree come into contact with wet soil and develop adventitious roots; **(2)** rooting of fallen living branches that have been torn off the tree by wind or snow, and **(3)** "veglings," or regeneration of vegetative origin which are often formed when a fallen living tree develops adventitious roots from the trunk.

In dense shade veglings are the dominant mode of reproduction, facilitated by the form that western redcedar takes in low light conditions in which it is not unusual to find saplings with lateral branches as long as the tree is tall (Parker 1979).

Seed production normally begins when trees are 20-30 years old, but open grown trees may begin producing strobili by age 10. The cone producing cycle takes approximately 16 months, with cone initiation beginning in the spring and summer of the first growing season and halting during the winter, with pollination, fertilization, and embryo development occurring in the second growing season. The seeds are mature by the second fall.

Western redcedar is monoecious. Pollen-producing (male) strobili are found on less vigorous, older lateral branches, usually in the lower part of the crown. Seed cone producing (female) strobili develop near the tips of vigorous lateral branches which are of recent origin, usually in the upper part of the crown. By the end of the first growing season male strobili are 2-3mm diameter spherical, and dark brown or black in color. By this same time the female strobili are the same size, but are more oval-shaped and brown-green in color (Edwards and Leadem 1988).

In a study by Krasowski and Owens (1991) western redcedar seedling growth followed a sigmoid curve for most morphological characters. An initial slow phase of growth from germination until June was followed by rapid growth through July after which growth slowed again. Whether the regeneration is from seed or asexually, growth rates have been found to be nearly identical (Parker 1979).

Because western redcedar buds do not have preformed shoots, no strong initial whorls of branches are produced. The lack of preformed shoots also gives western redcedar the ability to be very responsive to environmental conditions. Western redcedar has been observed to stop growing in times of moisture stress, then resume later in the year after fall rains commence. During the growth period a series of more or less equal branches are produced. The existence of adventitious buds located at the swollen branch junctions of main stems gives western redcedar the ability to react relatively quickly to the loss of its terminal. It has been observed that less than a year after the original terminal was destroyed, it had been replaced by a new terminal (Parker and Johnson 1987).

Mature western redcedar trees often have a greater degree of stem taper and fluting than associated conifer species. Stem taper can be a consequence of the high shade tolerance of the species. Lower limbs stay alive because they are more shade tolerant, photosynthesizing in the shade. Lower limbs also stay alive when grown at wide spacing. In both cases photosynthate from these lower limbs is conducted downwards, allowing the lower stem to grow more.

Fluting often occurs beneath very suppressed limbs in tree species where there is little cross transport of photosynthate through the phloem. Fluting occurs because each limb "feeds" photosynthate to the cambium directly below it, and if a limb is suppressed it cannot "feed" as much to the cambium below it as is being fed to the surrounding cambium by more vigorous limbs higher in the canopy. Some fluting can also be caused by unusual rooting conditions brought about by excessively wet soil (Oliver et al. 1988).

While typically thought of as a climax species, western redcedar can be either seral or climax, depending on the particular site (Graham 1988). Western redcedar has the attributes of a shade tolerant, climax species because of its longevity, lack of debilitating diseases and insects, ability to survive suppression and later release, and ability to regenerate in a mature stand (often through vegetative reproduction). Western redcedar also has the attribute of a seral species in that it establishes its seedlings best on disturbed sites (Parker and Johnson 1988b). Juvenile western redcedar does not compete for dominant crown positions as well as associated conifers in the Inland Mountain West, prompting Haig (1941) and others to state that "redcedar makes the slowest early growth, and never achieves dominance in a young stand" (McCaughey and Ferguson 1988). It has been estimated that old growth western redcedar groves can contain some trees with ages in excess of 3000 years (Parker 1979).

In a study by Bower and Dunsworth (1988) Vancouver Island western redcedar from three elevations (60, 210, and 495 meters above sea level) were planted at each elevation to test for differences between the provenances in survival and height. After 5 years no significant differences were found within the individual planting sites between provenances. Additionally, local provenances were not consistently the best performers. The results suggest that western redcedar is phenotypically plastic, and genetically not very diverse. The lack of genetic diversity within western redcedar has several operational implications: intensive breeding programs may not be justified by survival and growth gains; in contrast, greater gains may be captured from improved nursery and stand management practices; lastly, seed transfer rules can be greatly simplified (Bower and Dunsworth 1988).

Release of Advance Regeneration

There are many questions surrounding the release of western redcedar advance regeneration. Questions include: What are the best habitat types on which to release and manage understory western redcedar? What methods of overstory removal will minimize logging damage and especially dieback? What is the best age at which to release western redcedar? Does the time of year at which the western redcedar is released have any effect on the amount of dieback?

Research into western redcedar release is relatively limited; some of the earliest work was done as recently as the late 1960's, and certainly many practical manage-ment questions remain unanswered. The available research is summarized in chronological order, identified by researcher. In many cases tables or figures from the original publication are included here to help summarize or illustrate research results.

1969 J.W. Koenigs

The plots Koenigs studied were located on a moderately steep, north aspect on shallow Jughead silt loam series soil (a Brown Podzolic soil) at 3600′ elevation on the Priest River Experimental Forest in northern Idaho. The site was estimated as fair for larch and Douglas-fir. At the time of release and thinning (1940) the understory western redcedar was approximately 80 years old. The plots were thinned from an average initial stocking of 3000 trees/acre and a density of 280 sq.ft. of basal area / acre to an average stocking of 465 trees/acre with 30 sq.ft. of basal area per acre. Plot data for western redcedar and all species is summarized in Table 1.

1972 C.D. Leaphart and M.W. Foiles

Leaphart and Foiles's study was conducted in northern Idaho on the Kaniksu National Forest in a mixed conifer stand covering several thousand acres, resulting in relatively great variation in slope, with most aspects being northerly. Elevations ranged from 2,600′ to 3,200′. Soil type was fine sandy loam with a shale parent material. The average site index was 70 based on the height of western white pine at 50 years of age, and plots were located in TSHE/PAMY and THPL/PAMY habitat types. The overstory was approximately 74-year-old western white pine while the understory was predominantly western redcedar of approximately the same age.

Treatments consisted of cutting merchantable pole-blighted western white pine and poisoning non-merchantable western white pine over a period of 17 years. Only released trees greater than 3.5 inch d.b.h. were measured.

In all plots the western redcedar appeared healthy and vigorous and responded to release. Diameter growth varied considerably depending on the original diameter of the tree and the amount of space it was given. Mean diameter increment for all plots was 2.9" (for a period of 17 years). The largest trees and those with the least overstory competition generally responded the best to release.

1973 G.H. Deitschman and R.D. Pfister

Deitschman and Pfister's study was conducted in the Sand Creek drainage of the Kaniksu National Forest in northern Idaho, on the lower slope of a northerly aspect. The site was on a TSHE/PAMY habitat type of unknown site quality. In 1935 overstory grand fir and western hemlock were removed to release approximately 15-year-old western white pine and western redcedar. At the same time the stand was cleaned of fir and hemlock regeneration, reducing the stocking by 80% to approximately 3,500 seedlings/acre. At the time of the treatment the western redcedar averaged 4 feet in height and the western white pine averaged 8 feet in height.

Within 10 years of treatment, grand fir and western hemlock had recolonized the site and caught up to the height of the western redcedar seedlings. While the western white pine was able to maintain its dominance, the western redcedar lost its competitive advantage and reverted to the understory. See Figure 1 for a graphical representation of the stand development over time.

1981 R.T. Graham

The objective of Graham's study was to identify the tree, site, and stand characteristics which were associated with the diameter increment responses of western redcedar to various forms of release from overhead and/or surrounding competition. This study examined 15 western redcedar stands in northeastern Washington, northern Idaho, and western Montana. The majority of the stands were in two areas: (1) in a band stretching from near Colville, WA to north of Libby, MT and; (2) in a cluster to the southeast of Orofino, ID. Stand variables controlled for included: slope, aspect, soil type, and stand history. In other words, each stand examined was internally consistent in all of these areas, but there were differences between stands in one or more of these variables.

The 15 stands that Graham studied had a wide range in a number of characteristics, including: diameter at breast height (d.b.h.), height, density, basal area, and Crown Competition Factor (CCF) (as defined by Krajicek et al. 1961). The mean stand d.b.h. ranged from .8 inches to 3.0 inches. The mean stand heights ranged from 3.6 feet to 27.4 feet. The mean stand densities ranged from 1,296 trees/acre to 49,289 trees/acre. Mean stand basal area ranged from 27 square feet/acre to 291 square feet/acre. Mean stand CCF ranged from 30 to 267.

At the time of the study stand "growth sample trees" (which were taken from a sample frame of trees in the stand with a d.b.h. of 5 inches or greater) had mean ages

Tables & Figures

Table 1. Stocking and Growth Data for Western Redcedar Plots, Priest River Experimental Forest, Idaho[1]

		All Species		Western redcedar		
Plot Treatment	Observation date	Trees per acre	Basal area per acre	Trees per acre	Basal area per acre	Ave. d.b.h.
		No.	*Sq. ft.*	*No.*	*Sq. ft.*	*Inches*
A Nonreleased	1940	2,410	287	1,850	50	2.2
	1960	1,950	353	1,480	76	3.1
A Released	1940[2]	480	25	460	24	3.1
	1960	530	110	510	108	6.3
B Nonreleased	1940	3,750	273	3,230	61	1.8
	1960	2,710	224	2,380	83	2.4
B Released	1940[2]	450	35	450	35	3.8
	1960	680	127	520	126	6.7

[1] Table prepared from unpublished data recorded from one 1/10' acre sample plot in each of the released and nonreleased treatments of plots A and B.

[2] Measurements on released plots were taken immediately following treatment.

(Koenigs 1969)

Table 2. Analysis of covariance for treatment effects on western redcedar seedlings in an 8-year-old shrub-dominated clearcut.

Vegetation treatment = V	CUT	CUT	CUT	TIE	TIE	TIE	Control[a]
Shade level trt. (%) = S	0	40	80	0	40	80	Control
n=	7	8	7	7	8	8	7
Mean Initial Height (mm) = H (covariate)	414	466	443	477	526	507	499
std. dev.	100	74	81	41	97	88	83
Mean Season Growth (mm) = G (dependent variable)	123	155	114	41	79	62	102
std. dev.	47	50	42	31	58	20	47
Adjusted Mean G (mm)	128	156	117	41	76	59	

[a] = control data is for comparison and is not included in the analysis.

(Mahoney 1981)

Table 3. Data summary and significance of analysis for treatment effects on western redcedar seedlings growing in a shrub-dominated clearcut after 10 growing seasons.

Total 10-year height (m)			Total 10-year dbh (mm)		
Cut	Tie	Control	Cut	Tie	Control
2.59	2.16	1.77	17.6	11.2	4.8

Source	Results of Analysis Significance of F-Test	
	10-year height	10-year dbh
Vegetation	0.0029	0.0014
Cut vs. control	0.0018	0.0014
Tie vs. control	0.1188	0.1606
Cut vs. tie	0.0139	0.0053

(Adams & Mahoney 1991)

Table 4. Average dbh, height (H), crown width (CW), percentage live crown (CR%), and distance from breast height to base of live crown (D) in 1976.

		Square spacing, m					
Species	Variables	0.91	1.83	2.74	3.66	4.57	Closest /widest
Douglas-fir	dbh, cm	10.2	12.8	19.6	23.2	22.9	0.445
	h, m	14.6	14.5	16.7	16.1	16.1	0.907
	CW, m	2.4	3.0	5.0	5.8	6.3	0.381
	CR, %	52	61	69	75	80	0.650
	D, m	5.5	4.0	3.7	2.4	1.8	3.06
Western hemlock	dbh, cm	8.6	9.7	11.3	15.6	14.0	0.614
	H, m	9.6	10.7	9.7	10.6	10.4	0.923
	CW, m	1.8	3.0	3.7	4.9	4.1	0.440
	CR, %	50	75	82	83	86	0.581
	D, m	3.4	0.3	0.3	0.3	0.1	34.0
Western redcedar	dbh, cm	9.4	13.8	18.0	15.3	19.0	0.495
	H, m	9.8	10.6	11.7	10.1	11.0	0.891
	CW, m	1.5	2.8	3.7	3.5	4.1	0.366
	CR, %	48	75	83	83	83	0.578
	D, m	3.0	1.2	0.6	0.3	0.6	5.00

(Smith, J.H.G 1980)

Table 5. Average bole diameters, stem form, and crown dimensions of sample trees at age 25 in the 49-tree-plot trial, by species and by spacing [1]

Spacing	Height	RCD	DBH	D2.7	H/D	D2.7/DBH	CW	HLC	HDC	CL	CL/H	CL/CW
		Diameters			Stem form		Crown dimensions					
---Meters---		--Centimeters--					----Meters----					
						DOUGLAS-FIR						
0.9	20.1	17.0	14.6	14.0	138	0.96	2.7	12.2	--	7.9	0.39	2.9
	18.2	15.2	13.1	12.5	139	.95	2.5	11.6	--	6.6	.36	2.6
1.8	18.6	20.6	16.9	15.6	110	.92	2.5	11.1	--	7.5	.40	3.0
	20.9	19.3	16.2	15.0	129	.93	2.6	12.1	--	8.8	.42	3.4
2.7	20.5	26.5	21.5	19.8	95	.92	3.0	10.6	--	9.9	.48	3.3
	21.8	29.6	23.9	22.0	91	.92	3.2	10.8	--	11.0	.50	3.4
3.7	20.7	34.6	27.7	25.6	75	.92	3.8	8.9	--	11.8	.57	3.1
	22.1	31.9	25.9	23.9	85	.92	3.8	9.7	--	12.4	.56	3.3
4.6	21.2	35.9	29.3	27.2	73	.93	4.7	7.6	--	13.7	.64	2.9
	19.6	36.9	29.9	27.8	66	.93	4.6	6.8	--	12.8	.65	2.8
Average	20.4					.93						3.1
						WESTERN REDCEDAR						
0.9	12.3	16.7	10.4	9.8	119	.94	2.1	6.6	2.2	5.7	.46	2.7
	12.8	18.6	11.5	10.7	111	.93	2.6	5.0	2.1	7.8	.61	3.0
1.8	14.3	25.3	15.7	14.3	91	.91	2.8	6.4	2.3	7.9	.55	2.8
	14.3	25.8	17.2	15.2	83	.88	3.1	5.0	2.1	9.3	.65	3.0
2.7	13.6	34.5	21.0	17.5	65	.83	3.6	3.9	1.5	9.7	.71	2.7
	16.1	38.0	24.6	23.2	65	.94	4.2	3.9	1.8	12.2	.76	2.9
3.7	12.8	28.6	20.5	17.2	62	.84	4.0	2.1	.7	10.6	.83	2.6
	15.5	37.0	26.0	21.4	59	.82	4.6	2.4	0	13.1	.85	2.8
4.6	14.4	38.0	26.0	20.0	56	.77	5.5	2.1	0	12.3	.85	2.2
	15.2	31.3	27.0	22.0	56	.81	4.5	2.0	1.2	13.2	.87	2.9
Average	14.1					.86						2.8
						WESTERN HEMLOCK						
0.9	11.8	12.8	10.1	9.6	117	.95	2.4	2.5	2.1	9.3	.79	3.9
	11.5	10.8	9.2	8.5	125	.92	2.5	2.8	1.7	8.7	.76	3.5
1.8	12.3	14.9	11.8	10.9	104	.92	3.5	3.3	1.2	9.0	.73	2.6
	12.5	17.1	13.6	12.9	92	.95	3.5	2.8	1.6	9.7	.78	2.8
2.7	12.1	18.7	13.8	13.0	86	.94	4.6	2.7	1.6	9.4	.78	2.2
	12.0	20.2	15.0	14.4	80	.96	3.7	2.6	1.9	9.4	.78	2.5
3.7	13.2	19.5	17.1	16.0	77	.94	4.9	2.1	1.7	11.1	.84	2.3
	14.0	26.5	19.2	18.4	73	.96	4.5	2.3	1.6	11.7	.84	2.6
4.6	12.6	20.8	16.6	16.0	76	.96	4.4	1.8	0	10.8	.86	2.4
	12.8	23.1	17.4	16.5	73	.95	4.3	2.1	1.1	10.7	.84	2.5
Average	12.5					.94					.80	2.7

[1] Abbreviations: RCD = root collar diameter; D2.7 = diameter at a height of 2.7 m; H/D = ratio of height to d.b.h.; CW = crown width; HLC = height to live crown; HDC = height to dead crown; and CL = crown length. -- = not applicable.

(Reukema *et al.* 1987)

Table 6. Three-year height growth (cm) response of the western red cedar regeneration to fertilization: mean of five experiments.

	P + K regime				
	POKO	P1KO	POK1	P1K1	Mean
N regime					
N0	67	77	82	78	76*a*
N1	87	94	93	98	93*b*
N2	100	98	109	101	102*c*
N3	103	106	108	116	108*d*
Mean	89	98	94	99	
P0	92*a*				
P1	98*b*				

Note: Values followed by the same letters are not significantly different at $p = 0.05$. Values are covariance adjusted for initial 1985 basal area height as covariate.

(Weetman *et al.* 1989)

Table 7. Three-year basal area growth (cm^2/tree) response of the western red cedar regeneration of fertilization: mean of five experiments

	P + K regime				
	POKO	P1KO	POK1	P1K1	Mean
N regime					
N0	4.7	7.8	4.7	6.6	6.4*a*
N1	8.3	8.9	9.5	9.6	8.9*b*
N2	9.8	8.2	8.7	7.7	19.2*c*
N3	9.3	9.4	10.0	13.9	10.2*c*
Mean	8.0	8.8	8.6	9.3	
P0	8.3*a*				
P1	9.0*b*				

Note: Values followed by the same letters are not significantly different at $p = 0.05$. Values are covariance adjusted for initial 1985 basal area per tree as covariate.

(Weetman *et al.* 1989)

Table 8

Table. 8 FERTILIZER RESPONSE IN WESTERN RED CEDAR

Location	Age	Stand and Site Characteristics	Treatments	Response	Reference
				2-year height growth	Weetman
1. Northern Vancouver	5-8 years	Planted 1000 sph; SI (100)	NO	44 cm (100)a	(unpubl.)
Island, B.C.		30-35 m; height: 1-2 m;	N75 kg/ha	57 cm (130)b	
		thick humus, well drained	N150	61 cm (139)c	
			N225	63 cm (143)c	
				2-year height growth	Weetman
2. Northern Vancouver	12-16 years	Natural, 5000 sph; SI (100)	No salal removal	83 cm (100)a	(unpubl.)
Island, B.C.		30-35 m; height: 2-4 m;	Salal removal	99 cm (130)b	
		thick humus; well drained			
			NO	82 cm (100)a	
			N200 gh/ha	99 cm (121)B	
			(ammonium		
			nitrate)	105 cm (138)b	
			N200 (urea)		
				3-year height growth	Weetman
3. Northern Vancouver	9 years	Natural, 5000 sph; SI (100)	Control	79 cm (100)a	(unpubl.)
Island, B.C.		30-35 m; height 1-3 m;	N100 P50 gh/ha	112 cm (143)b	
		thick humus; well drained	N200 P50	122 cm (154)b	
			N300 P50	130 cm (165)b	
			N300 P150	112 cm (142)b	
			N300 P150 K91		
			+ B, Cu, Zn,	124 cm (157)b	
			Mn, Fe		
				5-year height and	Harrington &
4. Coastal Washington	20-25 years	Natural, 5900sph, SI (50)	unthinned,	diameter growth	Wierman,
		18-22 m; thin humus;	unfertilized	170 cm (100)a	1987
		poorly drained	unthinned +	3.2 cm (100)a	(submitted for
			N300		publication)
			(an), P100,	280 cm (165)d	
			K100	5.8 cm (181)c	
			thinned (1100		
			sph),	210 cm (124)b	
			unfertilized	4.3 cm (134)b	
			thinned + N300		
			(u)	270 cm (159)d	
			thinned + N300	6.3 cm (197)d	
			(an)	250 cm (147)c	
			thinned + N300	5.9 cm (184)cd	
			(an) P100		
			thinned + N300	280 cm (165)d	
			(an) P100 K100	6.8 cm (212)e	
				280 cm (165)d	
				7.0 cm (219)e	

(Weetman *et al.* 1988)

Figure 1

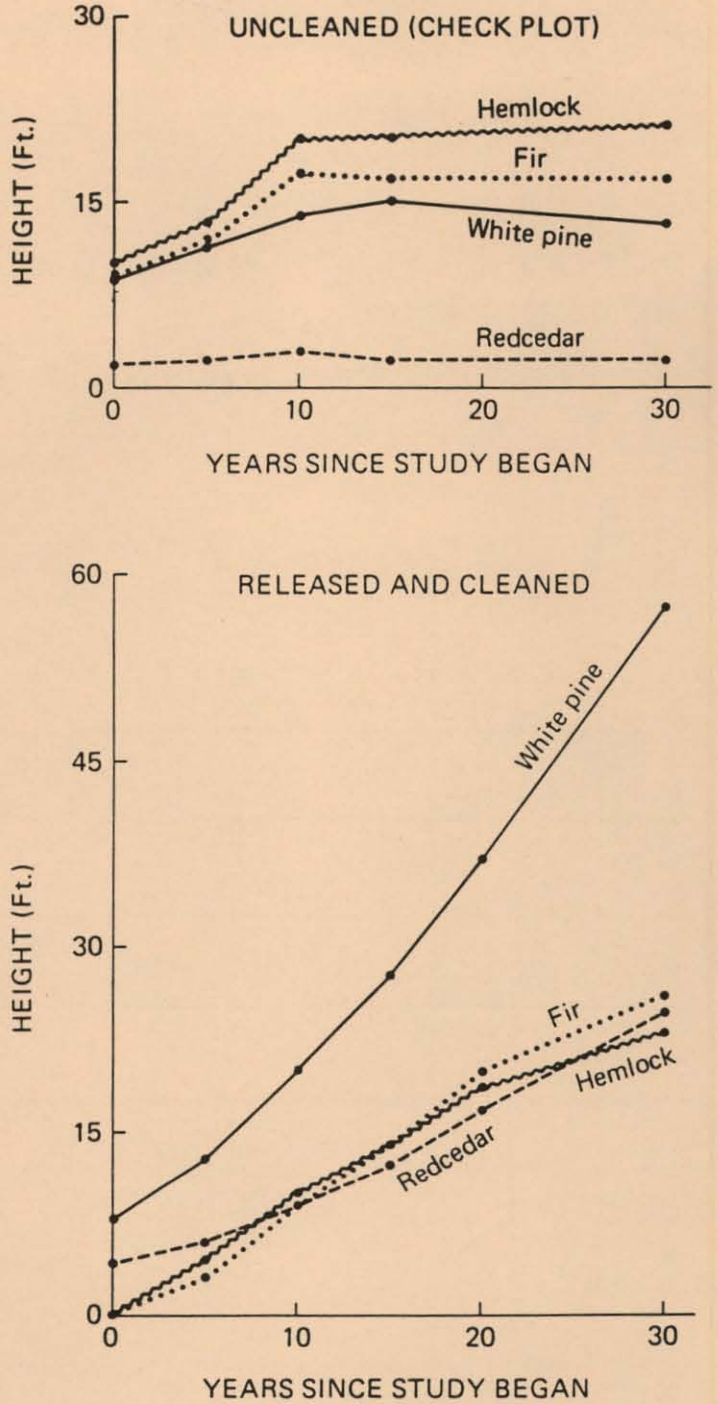

Figure 1. Effect of cleaning on the height growth of western white pine, grand fir, western redcedar, and western hemlock (based on the 100 tallest trees per acre of each species), Lower Sands Creek Study (Dietschman and Pfister 1973).

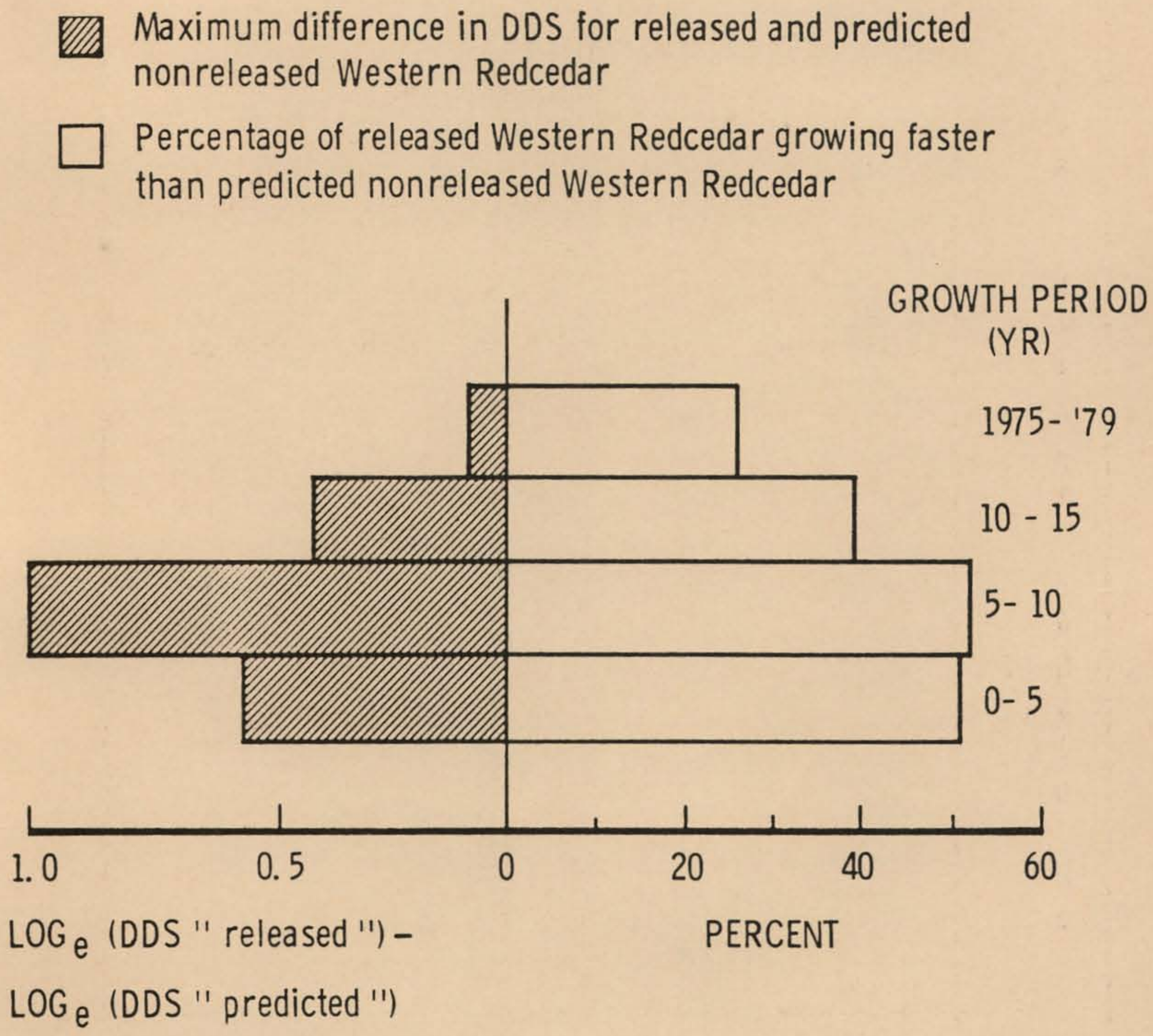

Figure 2. Maximum difference in DDS and percentage of released western redcedar trees having a positive response. DDS is the squared diameters of the growth sample trees measured in five-year increments (Graham 1982).

Figure 3

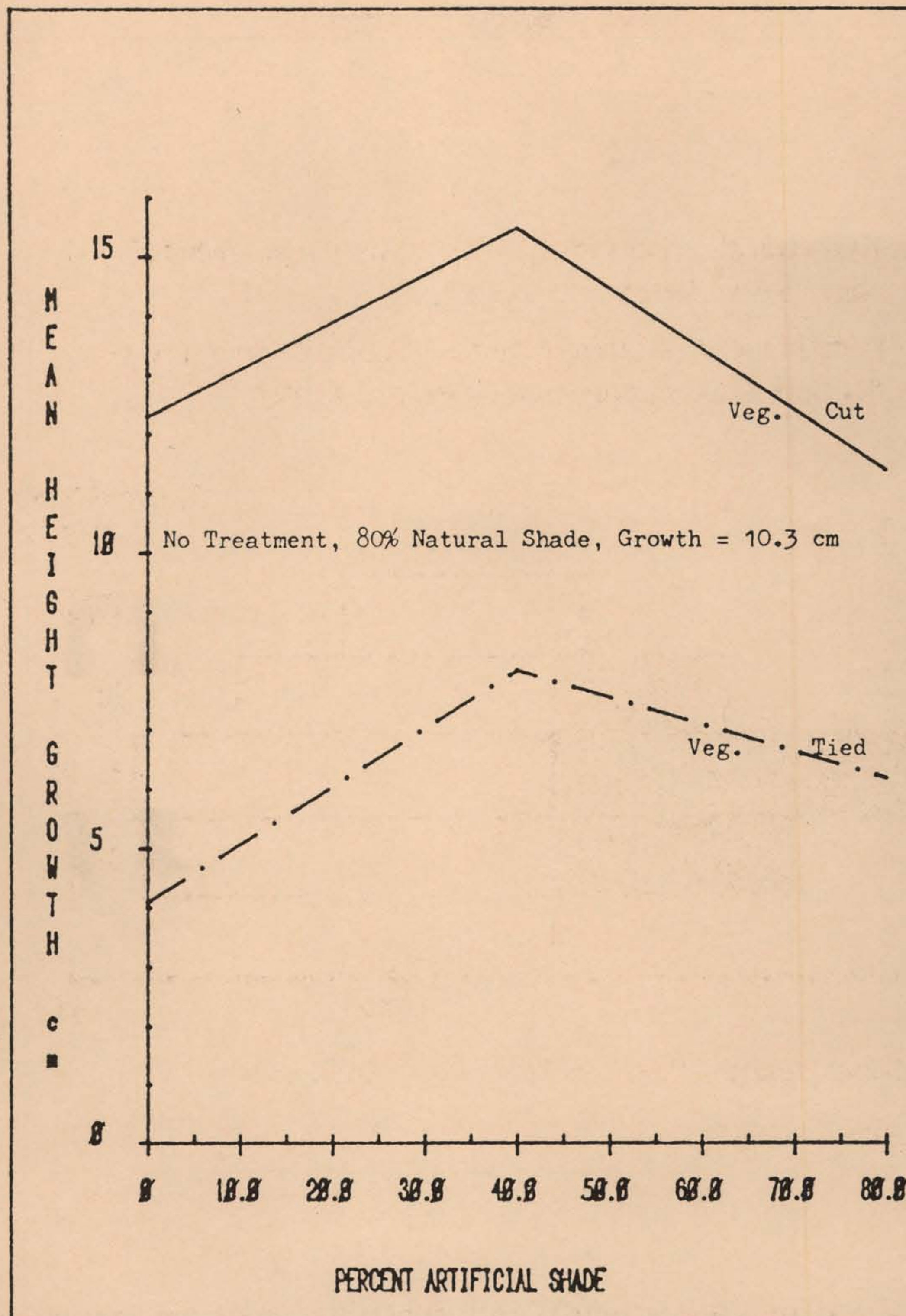

Figure 3. Effect of shade and vegetation treatment on the growth of western redcedar seedlings in an 8-year-old shrub-dominated clearcut (Mahoney 1981).

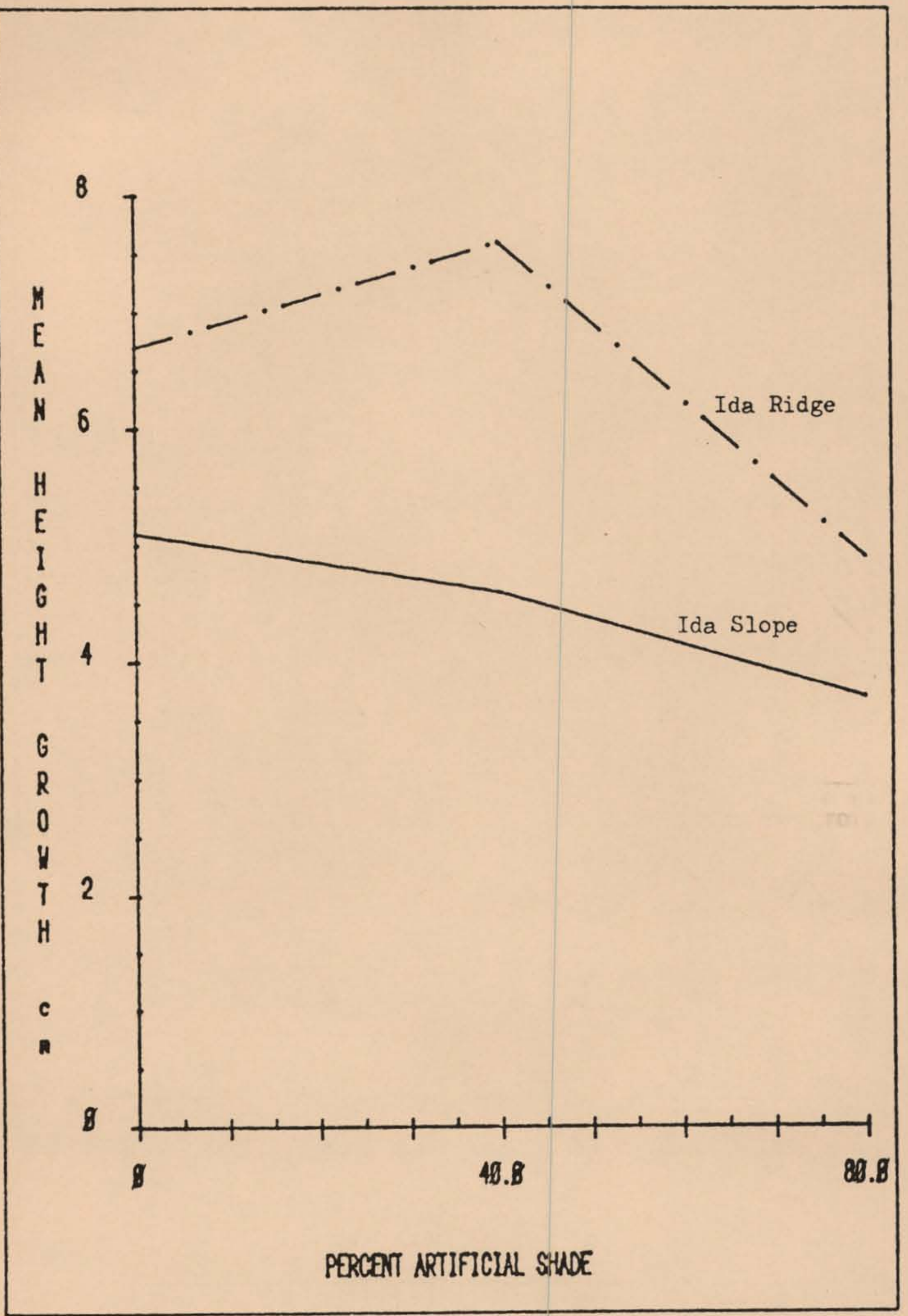

Figure 4. Effect of artificial shade and slope position on the growth of planted western redcedar (Mahoney 1981).

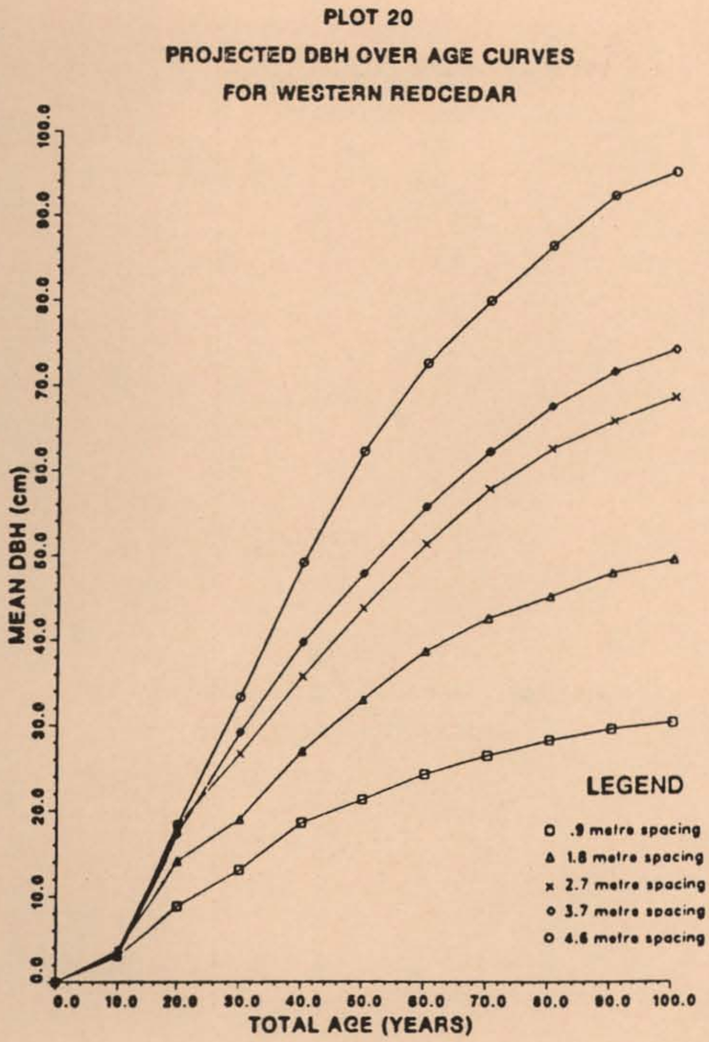

Figure 5.

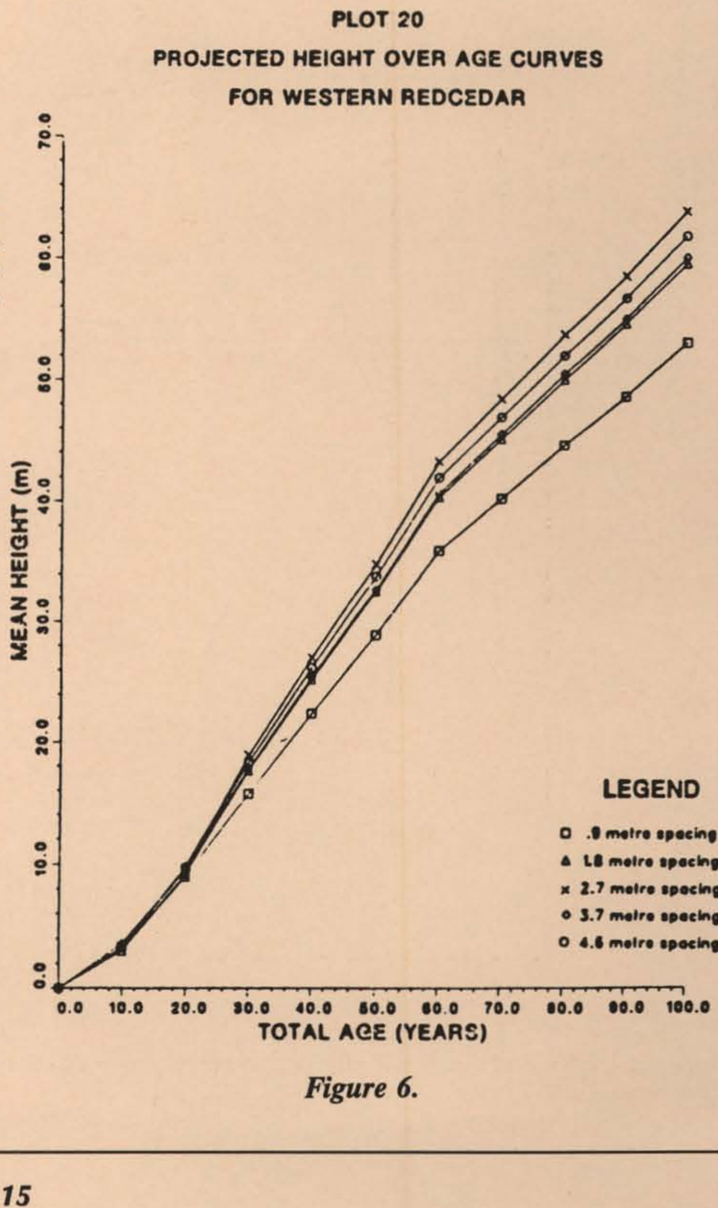

Figure 6.

Figures 5-12 are from J.H.G. Smith 1988.

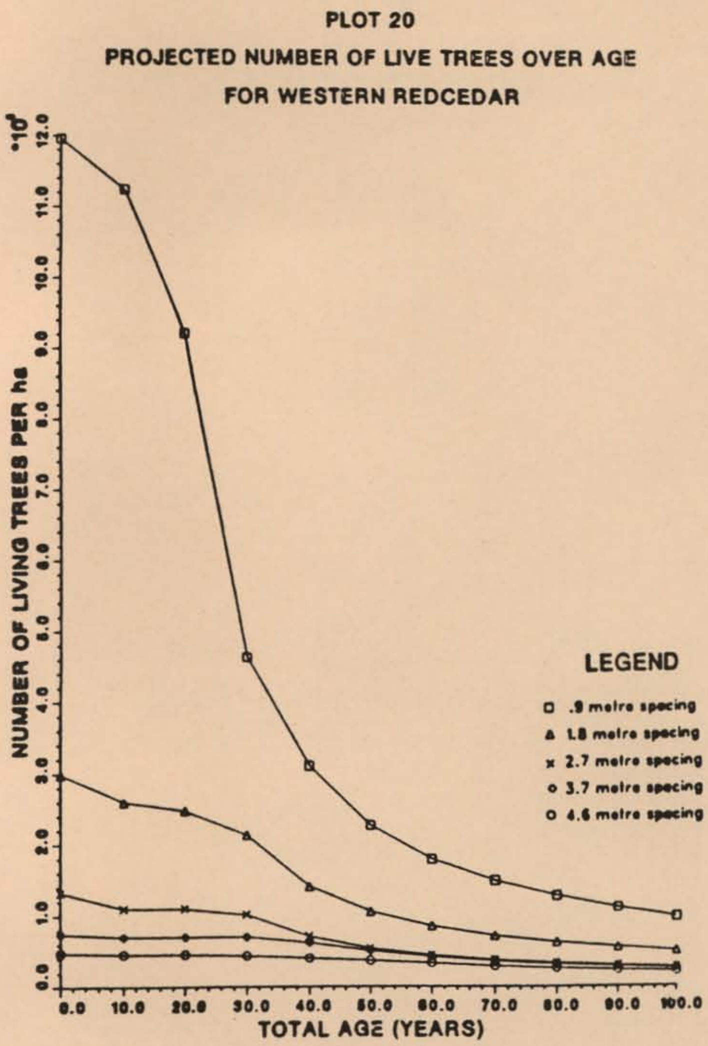

Figure 7.

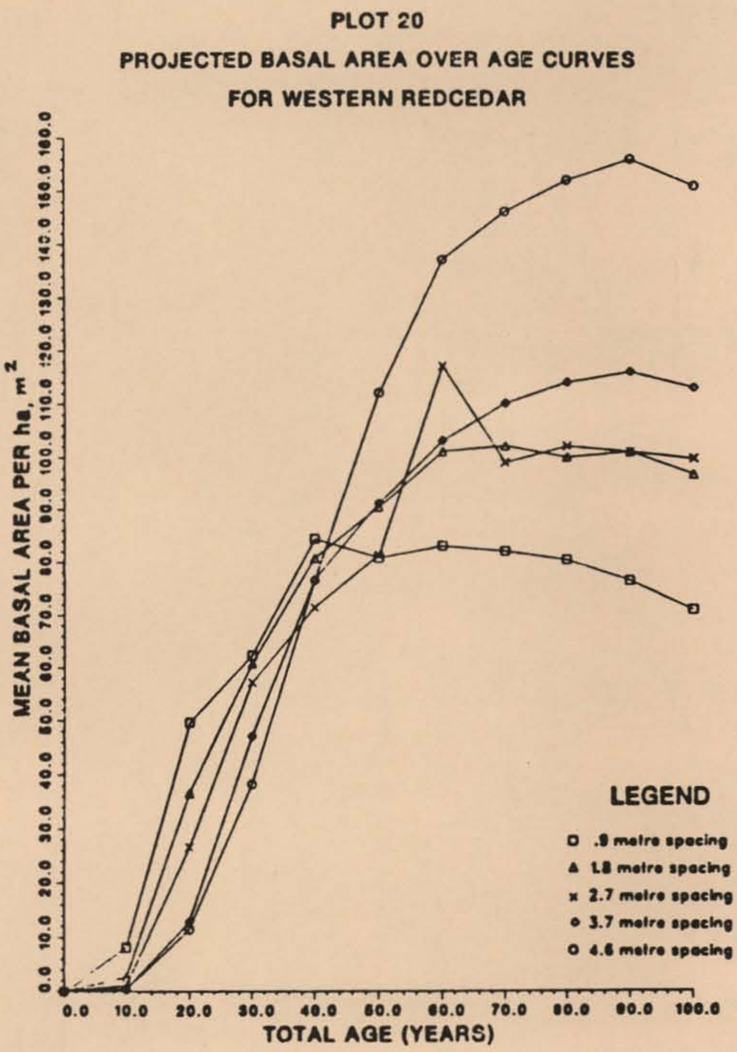

Figure 8.

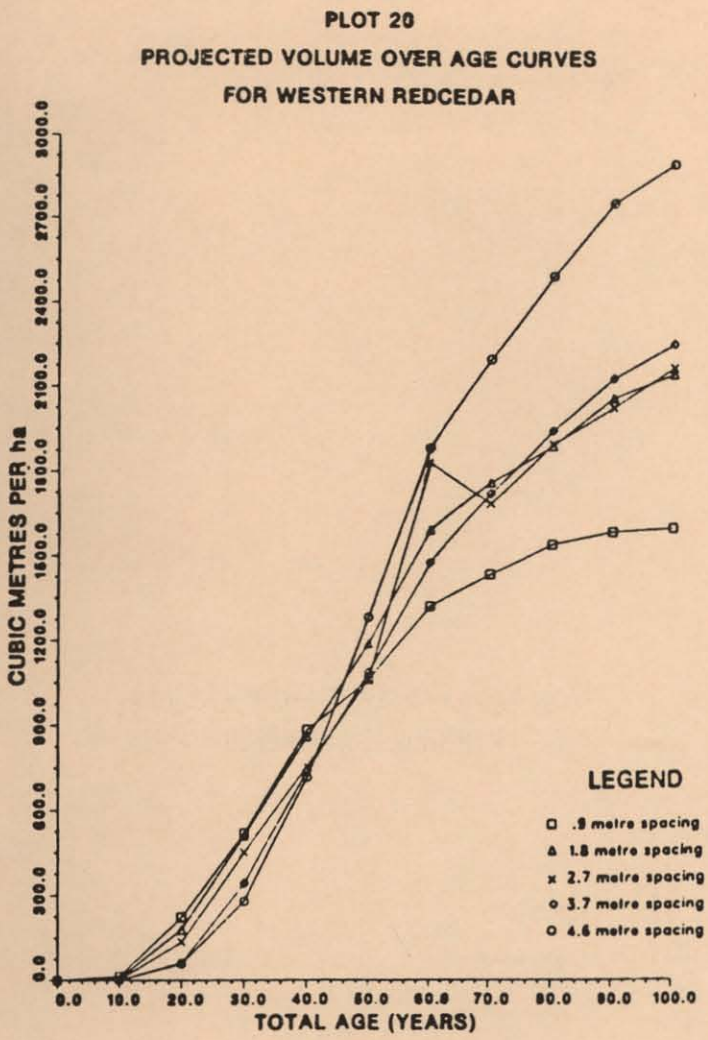

Figure 9.

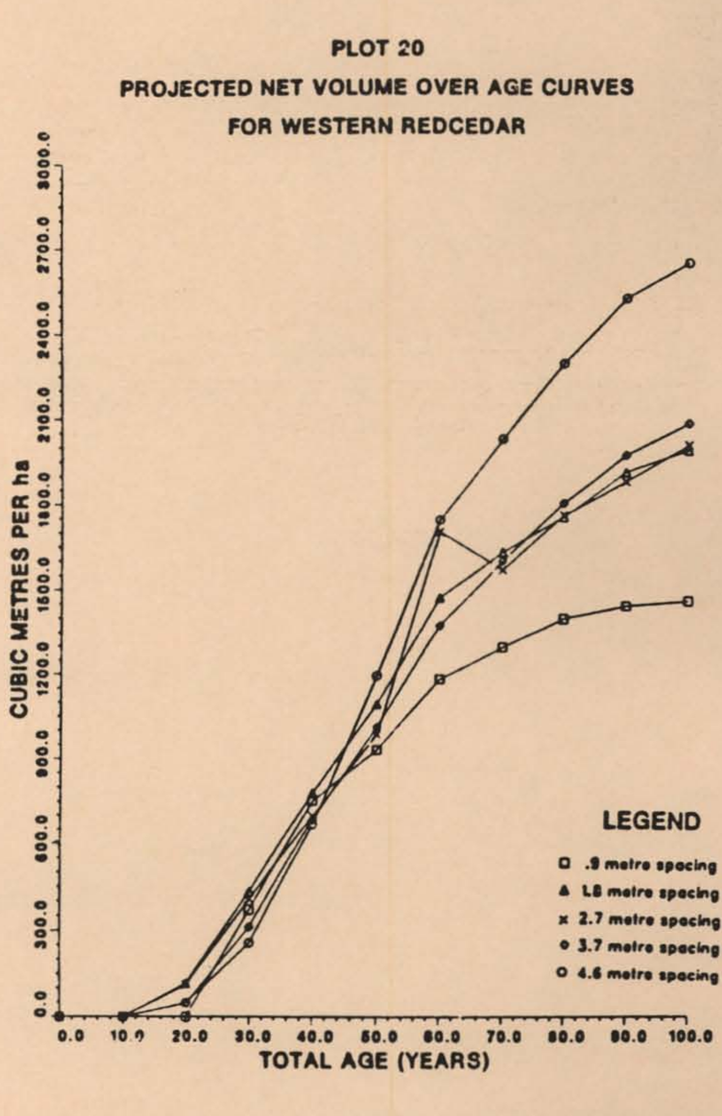

Figure 10.

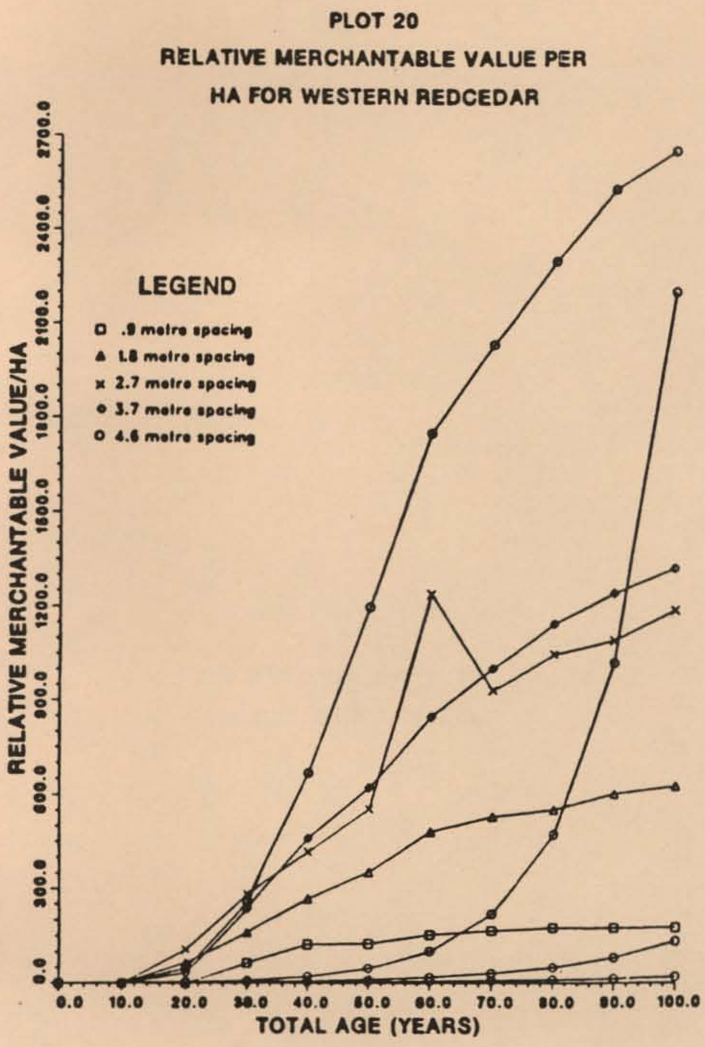

Figure 11.

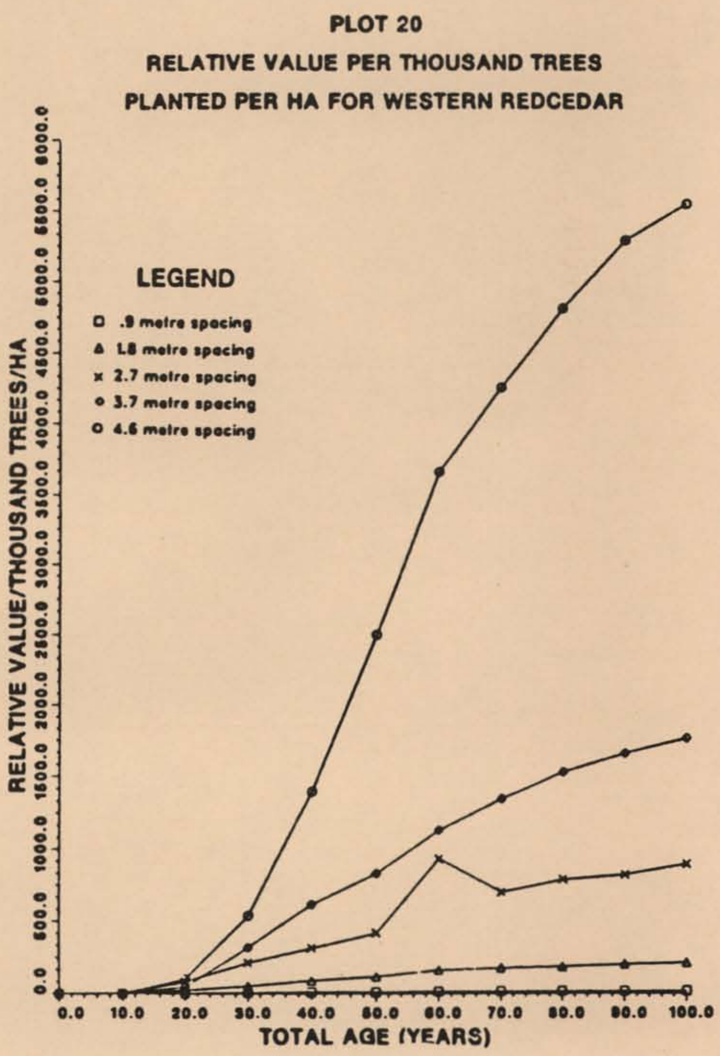

Figure 12.

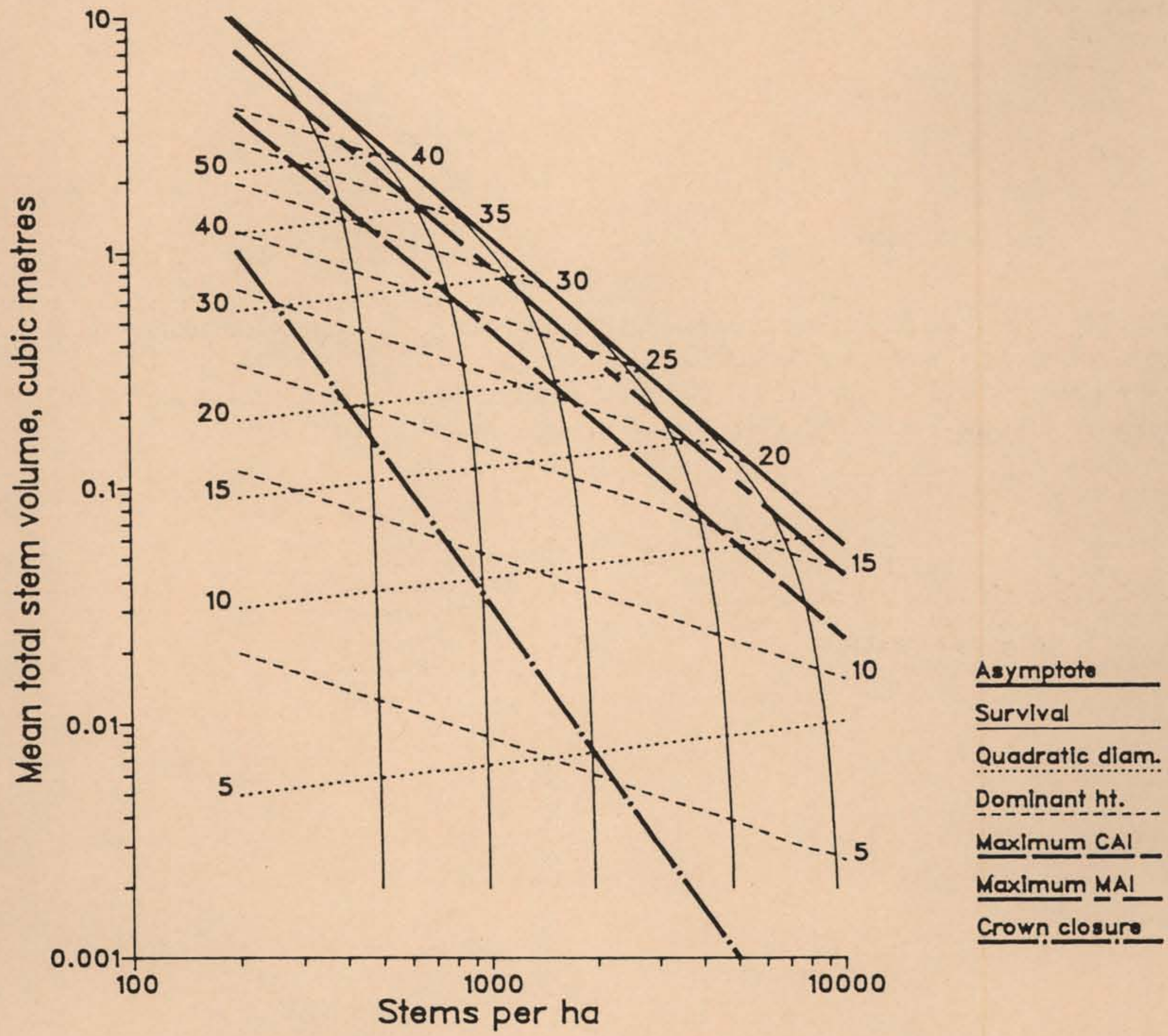

Figure 13. Stand density diagram for unthinned western redcedar stands (N.J. Smith 1989).

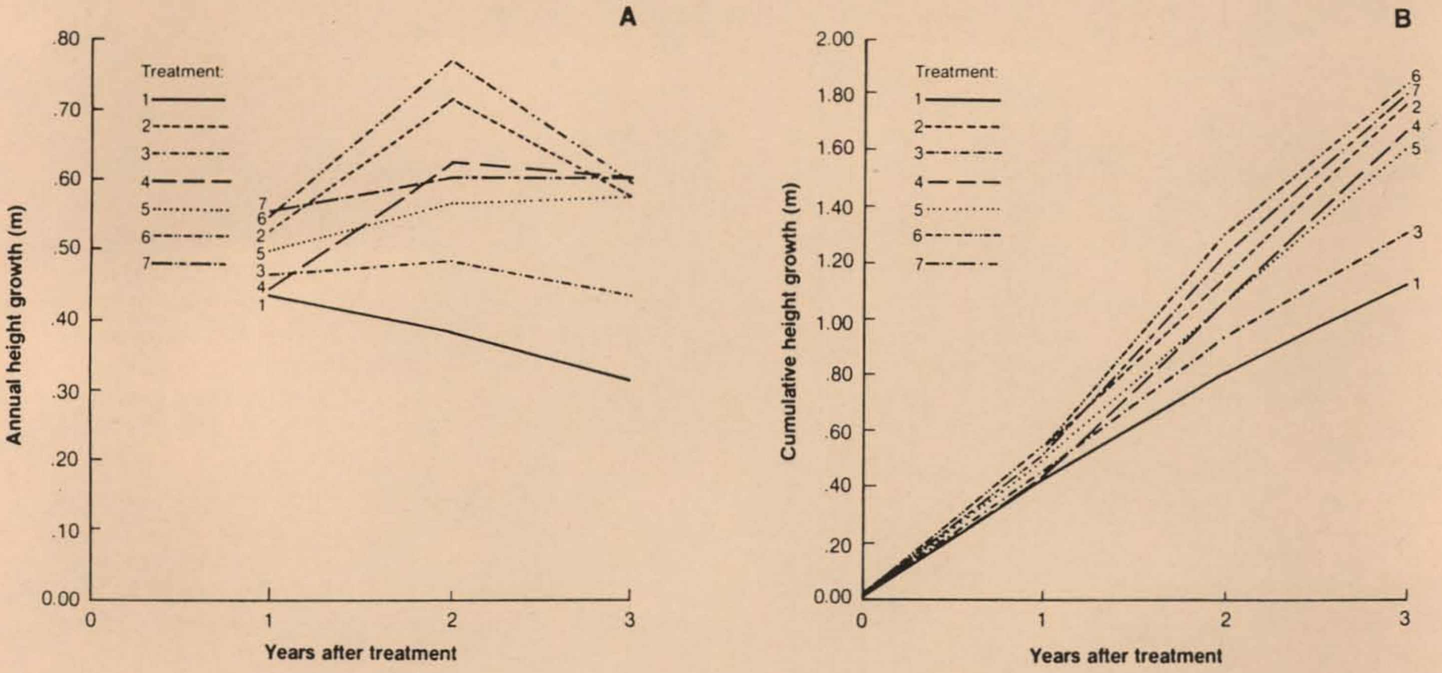

Figure 14. Height growth of the 20 smallest trees per plot by treatment: A, Mean annual height growth; B, Cumulative height growth. Treatment 1 = unthinned, unfertilized; 2 = unthinned, fertilized with N(AN), P-Ca, K-S; 3 = thinned, unfertilized; 4 = thinned, fertilized with N (U); 5 = thinned, fertilized with N(AN); 6 = thinned, fertilized with N(AN), P-Ca; 7 = thinned, fertilized with N(AN), P-Ca, K-S (Harrington and Weirman 1985).

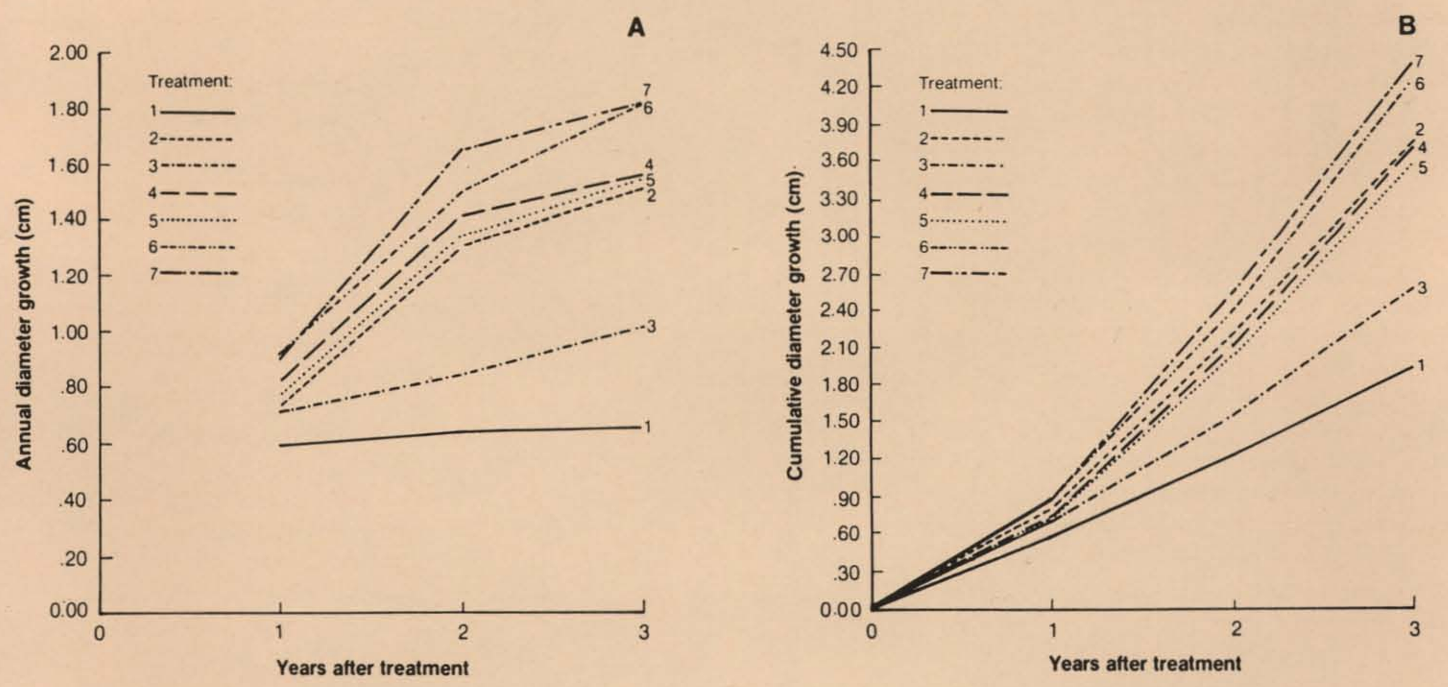

Figure 15. Diameter growth of the 20 smallest trees per plot by treatment: A, Mean annual diameter growth; B, Cumulative diameter growth. Treatment 1 = unthinned, unfertilized; 2 = unthinned, fertilized with N(AN), P-Ca, K-S; 3 = thinned, unfertilized; 4 = thinned, fertilized with N (U); 5 = thinned, fertilized with N(AN); 6 = thinned, fertilized with N(AN), P-Ca; 7 = thinned, fertilized with N(AN), P-Ca, K-S (Harrington and Weirman 1985).

ranging from 36 years to 169 years, with a mean age at time of release ranging from 17 years to 159 years. Diameter growth following stand release was measured on the growth sample trees. Non-released trees were not sampled in this study; instead, diameter growth for non-released trees was predicted through the use of a regression model built around the growth sample trees. The model was able to explain 69% of the growth variation ($R^2 = .69$). Regression analysis was used to identify the site, stand, and tree characteristics that were associated with the diameter growth response to release of western redcedar ($P < .05$).

Slope and aspect were shown to have significant relationships with the difference between observed diameter growth and the predicted non-released diameter growth. The best response occurred on the steep, north facing slopes and the poorest response occurred on steep, south facing slopes. Relatively larger diameter western redcedar had better response to release as compared to relatively smaller trees. In contrast, as tree age increased, the diameter growth response to release decreased. Stands with high Crown Competition Factors had a poor diameter growth response to release. Habitat type was also shown to be associated with the response to release. Trees growing on the THPL/PAMY type had the best response, which was significantly different from the response to release on the other three habitat types (THPL/AFTI, TSHE/PAMY, and ABLA/PAMY) studied. There were no significant differences between the responses among these three types. The greatest response to release came in the period from 5-10 years after release, however the favorable response continued for 15 years (the longest period studied). See Figure 2 for a graphical illustration of the growth response.

A further objective of the study was to identify the soil characteristics that are associated with the differences between the diameter growth rate of released western redcedar and the predicted non-released growth rate of the same trees. Variables included: pH, total soil nitrogen, organic matter, electrical conductivity, and the amounts of ten soil nutrients and minerals. Again, regression analysis ($P < .05$) was used to identify the soil variables significantly associated with the release of western redcedar. Results indicated that trees growing on soils with relatively larger amounts of nitrate, ammonium, sulfate, and potassium had greater response than trees growing on soil with relatively less of these nutrients. Results also indicated that response to release was greater on soils with relatively lesser amounts of copper and iron, and on soils with relatively lower pH values.

The final objective of the study was to identify the foliar characteristics associated with the differences between the diameter growth rate of released western redcedar and the predicted non-released growth rate of the same trees. Results indicated that western redcedar having foliage with relatively higher amounts of manganese and phosphorous had greater diameter growth response than western redcedar trees with lesser amounts of these nutrients. Results also indicated that the diameter growth of released western redcedar with relatively higher foliar concentrations of iron, sodium, potassium and sulfur was less than the growth of released trees with relatively lower foliar concentrations of these nutrients. Western redcedar with the more yellow foliage had the best growth response to release, while trees with more greenish foliage responded with less diameter growth.

1981 R.L. Mahoney

The objective of Mahoney's study was to identify and separate light effects from other competitive effects (i.e., nutrients and moisture) on the growth and release of western redcedar seedlings. Field study site was located on the Priest River Experimental Forest, Northern Idaho, on a north aspect TSHE/CLUN habitat type with a slope of 45%. The soil was composed of metasediment parent materials overlain with a silt loem loess. In areas which had not experienced past erosion the layer of ash derived A horizon averaged 30 to 40 cm deep. The study site consisted of an area that was clearcut in 1969 and broadcast burned the following year. The harvested stand was approximately 80 years old, having developed after a fire, and consisted of an overstory of Douglas-fir, western larch, and western white pine, with subordinate western redcedar and western hemlock.

At the time the study was initiated in 1979 the western redcedar regeneration was consistently six or seven years old, indicating that the species had not successfully reproduced until the second or third year after the site was exposed. The overstory was dominated by shrubs and some trees, and was consistently nine years old. Percent cover at the site was ocularly estimated to average 180 percent with none of the 70 plots having less than 140 percent cover. The mean height of the western redcedar seedlings at the beginning of the study was 47.6 cm.

The experiment consisted of ten replications of seven different treatments to individual seedlings. The treatments included: a "do nothing" control (treatment 1); plots with the vegetation cut away from the seedling to create a 1.33-mil-hectare plot combined with either 0, 40, or 80 percent artificial shade (treatments 2-4), and plots with the shade-producing overstory vegetation tied back but otherwise allowed to occupy the site, and either 0, 40, or 80 percent artificial shade (treatments 5-7). It was estimated that the shade levels from the overstory species was approximately 80 percent; the artificial shade levels were chosen to represent no, half, and complete release to full sunlight.

Heights were measured at the outset of the study, and then bi-weekly through the end of the 1980 growing season.

The seedlings in the cut vegetation plots grew significantly ($P < .05$) more than either the control plot seedlings or the tied plot seedlings. Additionally, the tied plot seedlings showed less growth than the control plot seedlings. Variations in growth according to shade levels were statistically insignificant, but the 40-percent shade level treatment did show higher growth than the other two treatments. See Table 2 for a complete growth summary.

Data collected in 1989, ten growing seasons after the initial treatments, demonstrate that the reduction in competition can have longlasting positive effects on seedling height and diameter growth. The cut vegetation treatment resulted in a mean seedling growth of 2.59 meters compared to growth of 2.16 meters in the tied vegetation treatment and 1.77 meters in the control (Adams and Mahoney 1991). See Table 3 for a summary of the ten-year results.

Unshaded seedlings in the cut plots grew 3 times faster than unshaded tied seedlings and 20% faster than the control seedlings. It was assumed that the removal of all other vegetation in the cut plots greatly reduced both the loss of soil moisture to transpiration by other plants and the competition for nutrients. Under these conditions the seedling at each cut plot center had sufficient soil moisture to accommodate the transpirational demands of full exposure to sunlight. In contrast, the seedlings in the tied plots had a sub-surface competitive situation for moisture and nutrients similar to the control plots, and all the additional transpiration stresses of the cut plots due to full exposure to the sun. This effect is graphically demonstrated in Figure 3.

The conclusions of this study were supported by results of a second study conducted by Mahoney at the same time at a nearby site. In the second study nursery-grown seedlings were planted at two sites under the same varying degrees of shade described in Study One. Ida Slope was chosen to be an "ideal" site for western redcedar while it was believed that Ida Ridge would be a "severe" site even though both sites had residual western redcedar in the pole, sapling, and seedling size classes. The soils on Ida Ridge had lost their ash-cap horizon, and the site was more exposed than the northerly aspect of Ida Slope.

It was hypothesized that the more protected slope would have lower transpiration stresses and hence better growth, but in fact the ridge site proved to have better growth. See Figure 4 for an illustration of mean periodic growth increment for the two sites.

Transpiration stress is largely dependent on soil water potential and plant stomatal control. Water potential is determined by the physical properties of the soil, while stomatal control is a function of the species in question. Mahoney concluded that the ridge top soils, being higher in clay content, could hold a larger amount of water at field capacity than could the sandier soils of the north facing slope. This resulted in more available moisture for the western redcedar on Ida Ridge, and a reversal of growth patterns from what was expected.

It is concluded that edaphic conditions (especially soil moisture) rather than light intensities are most significant in relation to height growth of western redcedar seedlings. However, light intensity is a factor, as shown by the consistently better growth of seedlings grown under intermediate intensities compared to those grown under higher or lower shade levels.

Western Redcedar Release Conclusions

The research described above leads to a number of conclusions about when, where and how to best release advance regeneration of western redcedar. The available research indicates:

1) Soil temperatures should be kept at a relatively low level by maintaining crown or understory cover in order to decrease the likelihood of root rot outbreaks.
2) Pole-sized or larger western redcedar trees (>3.5" dbh) can respond well to release, and maintain their dominance.
3) Gradual release over a period of years is likely to show better results than quick release.
4) Vegetatively propagated seedlings will respond as well to release as seedlings grown from seed.
5) Smaller western redcedar trees (< 5 feet tall) will respond to release but will likely not be able to maintain canopy dominance due to the reinvasion of less shade tolerant conifers.
6) Growth of western redcedar seedlings is more likely to be affected by root zone competition for moisture and nutrients than by light intensities. Adequate soil moisture is a key to seedling growth.
7) All other things being equal, advance regeneration of western redcedar is more likely to successfully release:
    - On *Thuja plicata/ Clintonia uniflora* habitat types
    - On steep, northerly aspects
    - When it is relatively larger, and relatively younger
    - When it has a crown ratio of at least .50
    - On sites relatively higher in nitrate, ammonium, sulfate and potassium
    - On sites with relatively low pH, and relatively low levels of copper and iron
    - If it has relatively yellower foliage.

Additionally, response to release is likely to be greatest in the period from 5-10 years after the release operation.

General Comments About Conifer Release

In addition to the specific information listed above there are some general guidelines which have proven useful in the management of other species which may also have utility for the management of western redcedar. Ferguson (1994) advocates following three general guidelines if the release of advance regeneration is the management objective: 1) avoid logging damage to the advance regeneration; 2) generally favor the most vigorous trees, and 3) wait 2-5 years before evaluating the release response.

Logging damage can be avoided by restricting the logging season. Damage is often greater during the spring and early summer, times when the sap is flowing and the bark is loose. The area disturbed and the number of trees damaged can be further reduced if the trees harvested are directionally felled to minimize skidder maneuvering and load pivoting. The optimally felled tree will be in a herringbone pattern in relation to the skid trail. When damage is unavoidable, skidder operators can be instructed to choose among species and size classes to be damaged or saved based on the rationale that injury to an individual which is larger or of a more desired species is more serious than injury to a smaller, less desired species individual. Other recommendations include: keep the area of disturbance as narrow as possible. If damage can be held to strips less than the width desired in a pre-commercial, thinning then there may be a positive thinning result from logging (Gravelle 1977; Aho et al. 1983).

It is important to wait the 2 to 5 years before evaluating the success of the release because the trees may not respond with increased height or diameter growth immediately. Response to release can be extremely variable, even within a species on a single site. Therefore, it is generally recommended to wait to remove the slow growing trees in clumps of advance regeneration until after it is readily apparent which have responded the best to release (McCaughey and Ferguson 1988).

Management of Advance Regeneration

The treatments used to release advance western redcedar regeneration and those used to subsequently manage the trees may not always be mutually exclusive. For example, in some cases the advance regeneration may be released by a cleaning; in other cases a cleaning could be performed on a previously released stand. At this point suffice it to say that if stands comprised of small diameter stock are released, it is likely that they will have to be cleaned or weeded so that ingrowth from less tolerant species does not compete with the western redcedar for water, nutrients, and light. While for some species, notably western white pine, it has been recommended that cleaning and weeding occur prior to age 30 (Graham et al. 1988), available evidence suggests that western redcedar has the potential to successfully respond to treatments up to a much older age.

Questions relevant to the management of released western redcedar include: Is thinning advisable? Should thinning occur from above or below? What are desirable leave-tree characteristics? What spacing is appropriate to grow high quality sawlogs? What spacing is appropriate to grow utility poles? What is known about fertilization of western redcedar? What are the economic costs and benefits of fertilization? What is the effect of pruning on product development? What are the economic costs and benefits of pruning? What are the disease implications of releasing western redcedar advance regeneration?

Forestry researchers have answered some of these questions, but many questions remain. As with the research on release of western redcedar, the amount of research that has been done on management of the species is also quite limited, resulting once again in the absence of generally accepted principles for its management. Again, the provision of as much site and study design information as was available in the published results of the studies will hopefully allow forest managers to critically assess the applicability of research findings to the sites they manage.

The available research is summarized by subject area. In many cases tables or figures from the original publication are included to help summarize or illustrate research results.

INITIAL SPACING

Before presenting the research on spacing of western redcedar, a caveat is in order. The growth and yield research for different spacings of western redcedar reported here has been conducted in plantations of pure, even-aged stands raised from seed. It is possible that these seedlings, having developed in an environment of near full or full sunlight, and having had the benefit of weedings and prunings, will have a much different response to various spacings than a recently released, ten-foot-tall, 80-year-old sapling.

In 1957 researchers at the University of British Columbia Research Forest in Maple Ridge, B.C. began spacing trials with a variety of species, including western redcedar. Bareroot stock was planted at square spacings ranging from .91 meters to 4.57 meters, and the plantation was cleaned and weeded several times over the years. In 1977 the trees were pruned to a height of 6 meters. These trees were measured at age 20. A 1980 study by J.H.G. Smith (J.H.G. Smith 1980) analyzed the effect of the various square spacings on the crown ratios and diameter growth of western redcedar trees planted on this very good site (site index = 180' at 100 years for Douglas-fir). See Table 4 for details of spacings and growth. While total height and crown ratio increased with larger spacing, Smith concluded that the best combination of spacing and tree size occurred at 2.7 meter square spacing. At greater spacings diameters and heights did not increase substantially, and at tighter spacings tree dimensions decreased substantially.

The same site described above was remeasured at age 25 (Reukema et al. 1987). Data were collected on various parameters of bole dimensions and form, crown size and shape, and stand development per hectare. For spacings 1.8 meters square and larger, there was little effect on average height up to age 25. As the spacing increased (up to 4.6m x 4.6m) d.b.h. increased, bole taper increased, height to live crown decreased, and crown ratio and crown width increased. For lumber production the 3.7m square and 4.6m square spacings were optimum, and when combined with pruning, those spacings should also provide clear lumber and veneer. The 2.7 meter square spacing can produce high yields where thinning is economically feasible, however the .9 meter and 1.8 meter square spacings should be considered only if biomass production rather than large piece size is the goal. Summary results of the study are given in Table 5.

J.H.G. Smith (1988) later projected tree and stand growth for this site to age 100. Because of the high survival of the planted western redcedar and rapid diameter growth on the site, all spacings show growth trajectories which are "surprisingly high in comparison to Douglas-fir and hemlock" (J.H.G. Smith 1988). These data are summarized in figures 5 through 12.

Further information on initial spacing of western redcedar is very limited. Oliver and others (1988) assert that "the desirable initial spacing would be that which allowed the trees to grow to minimal merchantable diameters before growth curtailed... a two meter spacing allows the trees to grow to 15 centimeters in diameter before growth is severely curtailed (2400 trees/ha.). ... as an estimate 750 to 1000 trees/ha (3.6 meters square to 3.1 meters square) would probably allow trees to reach 25 cm. d.b.h. at time of extreme diameter growth slowdown." Based on J.H.G. Smith's data from the high quality University of British Columbia site, Graham suggests that 3 meter square spacing is appropriate for most young stands of western redcedar (Graham 1988; Graham et al. 1988).

Wider spacings however, can present a problem because of the likely increases in stem taper and fluting, and the number of large limbs and knots which accompany wider spacing. All of these conditions will reduce the economic value of the tree. The condition of large limbs and subsequent large knots can be especially prevalent in trees that have been overtopped, then later released. Under these circumstances lateral branches seem to escape from the strong epinastic control (whereby the terminal maintains control over the length and direction of the lateral branches so that a relatively cone-shaped crown is maintained) normally found when the terminal is in full sunlight. When this happens the lateral branches have a tendency to grow to great lengths, and much of the increased growth on redcedar released from overhead shade is added to these large lateral branches (Oliver et al 1988). For these reasons Oliver et al. advise that overtopped western redcedar "probably should not be released when overtopped as often occurs in mixed stands" (Oliver et al. 1988).

PRUNING

Pruning the lower branches of western redcedar is seen as an ecologically viable method of increasing the economic value of the crop trees. Reukema et al. (1987) recommend pruning to a height of 6 meters in order to produce clear wood on relatively short rotations. The University of British Columbia's J.H.G. Smith (1988) notes that "the best grades in the Vancouver Log Markets limit knot size to 2 cm., meaning that the largest branch could be only 2 meters long." He goes on to state that "pruning has the greatest promise of ensuring that high quality wood will be grown on butt logs. Natural pruning will be so slow that only 1 or 2 percent of clear lumber would be grown in typical rotations." Oliver et al. (1988) consider pruning a potential alternative to narrow tree spacing as a method of reducing knot size, fluting, and stem taper. However they state that "the effect of pruning on wood quality is currently unknown" (Oliver et al. 1988).

THINNING

Thinning is another area of interest to forest managers in which data is extremely scarce. A systematic and comprehensive search of North American literature data-bases revealed only one published experiment of controlled thinning. The study area is located in northwestern Washington state approximately 6 miles from the Pacific Ocean. Precipitation averages 2700 mm/year (106 inches/year). The soils on the site belong to the Kydaka series, which is composed of moderately deep, poorly drained, silty clay loams. Soil pH was 4.6, and overall site quality is described as poor, with slopes averaging less than 10 percent. The treated stand consisted primarily of western redcedar which had naturally regenerated from seed following a clearcut. The site also included some western hemlock, pacific yew, Pacific silver fir, Sitka spruce, red alder, and shrub species common to the area. At the time the study was initiated (1980) the western redcedar trees averaged 15 to 20 years old and 5 to 6 meters tall, with an average stocking of 5900 stems per hectare. The treatment consisted of spacing the trees at approximately 3m x 3m spacing, choosing the biggest trees with the best form as crop trees.

Thinning resulted in significant ($P<0.04$) increases in growth over the five years of the trial. In comparisons of the 20 tallest trees in each plot, the thinned plot showed a 24% advantage in height growth and a 34% advantage in diameter growth. After 5 years total basal area was lower in the thinned plot than in the control plot, but the higher growth rates imply that the thinned treatment may in time catch up to the control. In a thinning trial in Great Britain western redcedar responded slowly to treatment; therefore it may be necessary to wait longer for results with western redcedar than with other species (Harrington and Weirman 1990). Even if the total basal area remains lower in a thinned stand, that volume will be concentrated on fewer, selected better quality trees (Graham 1988; Harrington and Weirman 1990). Additionally, the overall vigor and health of the stand can be improved through thinning because it can result in reduced mortality from insects, disease, and competition.

Stand density diagrams are graphical tools which allow for a general assessment of stand density control, i.e., when to thin. Stand density diagrams are a valuable tool in crop planning because they allow the user to look at a variety of management options to achieve a target stand. Through the use of these diagrams stand density can be related to tree size and stand yield. In practical terms, the diagram allows the manager to determine whether a stand of trees is approaching various growth zones, including the zones of maximum current annual increment (CAI), maximum mean annual increment (MAI), or the "zone of imminent competition caused mortality." A stand density diagram for western redcedar has been devised using data from a data set of natural and planted stands in British Columbia. This diagram is shown in Figure 13.

The diagram can be entered by determining quadratic diameter and stems/hectare. This diagram (created by N.J. Smith; see N.J. Smith 1988 and N.J. Smith 1989) provides an additional tool that forest managers can use to help devise management prescriptions.

FERTILIZATION

The thinning trial described above was undertaken in conjunction with a fertilization trial on the same site. The study utilized a total of seven treatments for a five-year period. The seven treatments were coded as follows: (1) UT-UF (control, no treatment); (2) UT-NPK (unthinned, fertilized with ammonium nitrate, dicalcium phosphate, and potassium sulfate); (3) T-UF (thinned, unfertilized); (4) T-Ur (thinned, fertilized with urea); (5) T-N (thinned, fertilized with ammonium nitrate); (6) T-NP (thinned, fertilized with ammonium nitrate and dicalcium phosphate); (7) T-NPK (thinned, fertilized with ammonium nitrate, dicalcium phosphate, and potassium sulfate). Elemental rates of fertilizer application were 300 kg N/ha (urea or ammonium nitrate), 100 kg P/ha and 129 kg Ca/ha (dicalcium phosphate), and 100 kg K/ha and 41 kg S/ha (potassium sulfate). The fertilizers were applied by hand in late March and early April 1981 in cool and wet conditions.

Height and diameter growth were subsequently analyzed using an analysis of covariance ($p<.001$). The best treatment resulted in a 65% increase in 5-year height growth and a 106% increase in 5-year diameter growth over the control plots. See Figures 14 and 15 for specific response rates.

Though the study does not address the long term, it does show that short term increases in height and diameter growth on a poor soil, coastal site can be substantial. Three-year height and diameter growth of the twenty tallest trees/plot averaged 1.8m and 4.4cm in the thinned plots fertilized with ammonium nitrate, monodicalcium phosphate, and potassium sulfate, while the control averaged 1.1 meter height increase and 2.0cm diameter increase. Both urea and ammonium nitrate were equally effective in improving height and diameter growth.

Response to fertilization without thinning was also quite good. The unthinned plot fertilized with the NPK combination had six times as many trees as the thinned plot but there was no difference in the 3-year height growth increment, and the 3-year diameter growth increment was 86% of that found in the thinned plot (Harrington and Weirman 1985; Harrington and Weirman 1990).

Commenting on this study, Oliver *et al* (1988) note that "it is unclear how readily evenly spaced, exactly even-aged plantations would differentiate into crown classes. Later thinnings would probably allow a dramatic increase in stem growth, provided the released trees had not become overtopped before being released. It may be desirable to delay thinnings until lower limbs are dead to prevent fluting after release."

A fertilizer trial reported by Graham and Tonn (1985) tested the growth response of an 18-year-old mixed conifer stand growing on a THSE/PAMY habitat type to the application of 200lb N/ac. The stand was a uniform mix of the following species: western white pine, western larch, Douglas-fir, lodgepole pine, western hemlock, western redcedar, Englemann spruce, and ponderosa pine. The study site was located in the Priest River Experimental Forest in northern Idaho on a soil classified as a typic cryochrept, derived from gneiss parent material. The stand was cleaned two years prior to fertilizer application. After the cleaning the remaining dominant and codominant trees were uniformly spaced at 12 foot square. At the time of fertilization (1973) the mean stand dbh was 3.3 inches and the mean stand height was 21.7 feet. The N was applied in the form of urea with a hand spreader in early spring 1973.

Diameter and height growth were periodically recorded until 1982. Analysis of the results showed that the application of nitrogen fertilizer had little influence on tree growth. When taken as a whole, the mean periodic diameter growth of the treated area was not significantly ($p<0.05$) different from the diameter growth of the untreated stand. The mean periodic height growth was significantly, if only slightly, different for the first five years after treatment. In this first five years the treated area had a mean height gain of 2.18 feet, compared to a height gain of 2.00 feet for the untreated area. However, ten years after treatment there was no significant difference in height growth between the treated and untreated areas.

A third study, conducted by Weetman et al. (1989) examined the effects of fertilizing chlorotic planted and naturally occurring western redcedar regeneration in salal (*Gaultheria shallon* Pursh) dominated areas in coastal British Columbia. The soils in the treatment area are classified as deep mor-humus Podzols, developed on well- to poorly drained deep till soils. The areas were clearcut and burned between 1978 and 1980, and at the time of the experiment (fertilizer was applied in March 1985) the western redcedar seedlings ranged from .5 to 1.6 meters in height and were "free-growing" above the salal understory. The fertilizers were applied in a 4 x 2 x 2 factorial treatment design (four levels of nitrogen and two each of phosphorous and potassium). In addition to the control (N0), nitrogen in the form of ammonium nitrate was applied at three rates: 75 kg N/ha (N1); 150 kg N/ha (N2); and 225 kg N/ha (N3). In addition to the control (P0), phosphorous in the form of triple superphosphate was applied at a rate of 75 kg/ha (P1). In addition to the control (K0), potassium in the form of muriate of potash was applied at a rate of 75 kg/ha (K1).

The three-year height growth of the 800 sampled trees showed a trend of increasing response with increasing N additions. Additionally, a minor but statistically significant ($P<0.05$) response to P was evident. The addition of K did not result in any additional height growth.

The three-year diameter increment showed a pattern similar to the height response for the addition of N and P. However, in contrast to the height response, the addition of K did significantly increase the diameter above the gains shown by the application of N and P. See Tables 6 and 7 for details of growth response to these treatments.

FERTILIZATION CONCLUSIONS: Weetman *et al* (1988) provides a comprehensive review of what is known about western redcedar nutrition needs and also summarize the results of four fertilizer trials from coastal British Columbia and coastal Washington state. See Table 8 for a summary of the trials they review.

These four trials indicate that western redcedar responds in a conventional way to N additions both in height and diameter growth. Urea seems to be equally or more effective than ammonium nitrate. Treatment with urea led to higher N concentrations in the foliage, and the increased height and diameter growth is related to this. There is some evidence of response to added P above the response to N (P being in the form of dicalcium phosphate), but the addition of potassium sulfate did not yield any additional height growth, though it did increase diameter growth slightly. Weetman et al. go on to state that the apparent responsiveness of western redcedar to fertilizers and its ability to outproduce Douglas-fir are very positive features that require further exploration. They caution however, that firstly "it will be important...to distinguish between adequate nutrition and optimum nutrition," and secondly "the finding (Radwan and Harrington 1986) that interior and coastal western redcedar stands have differing foliar nutrient concentrations suggests different fertilization strategies for these areas."

DAMAGE AGENTS

Like any other tree species western redcedar is susceptible to damage from a variety of sources, both biotic and abiotic. However compared to many of its associated conifer species, young western redcedar is considered "remarkably free of pests" (van der Kamp 1988). A short listing of the well known damage agents is given below. The severity of damage caused by these agents will of course vary with the age and condition of the stand, but generally speaking there is no evidence in the literature which links the release of advance regeneration to an increased tree damage.

- *FOLIAGE DISEASES*

***Didymascella thujina* (Durand) Maire.** Occasionally causes significant defoliation of young trees or in the lower crowns of larger trees. Severe infections of seedlings can lead to mortality, especially where there is strong competition from surrounding vegetation (van der Kamp 1988). The disease is usually found in areas of high humidity and stagnant air, such as is found in dense stands or under late spring snows (Parker 1979).

• *ROOT ROTS*

Armillaria obscura **(Pers.) Hendrick.** Girdles and kills young trees readily. Older trees are not readily killed, but the fungus often causes a cat face by killing a triangular area of bark at the base of the stem directly above the affected root. In such cases the bark remains attached and the damage does not become apparent until several years later when the bark sinks into the underlying pocket of decay.

• *BUTT ROTS*

Poria subacida **(Peck) Sacc.** This fungus can cause extensive butt rot in pole-sized trees. Instances have been observed in association with intermediate cutting at Maple Ridge, B.C. It is hypothesized that the fungus enters the healthy trees via the cut stumps after thinning.

Phellinus weirii **(Murr.) Gilbn.** Especially in the inland portions of its range, western redcedar is commonly attacked by this fungus, resulting in extensive decay of the lower bole at an early age. The strain of *P. weirii* which attacks western redcedar is different from the strain which kills Douglas-fir and other conifers in this area, and therefore western redcedar may be grown as an alternative species in infected areas (van der Kamp 1988). Parker (1979) asserts that "yellow ring rot caused by Poria weirii is probably the most wide-spread and important heart-rot causing fungus. Young, vigorous trees were as susceptible to decay as overmature trees, but the decay impact was greater in the overmature class." According to Schowalter and Filip (1993) there is a particular group of *Phellinus weirii* that can attack western redcedar, but even then redcedar is known to be able to regenerate in brush- filled root disease centers, along with western hemlock.

• *INSECTS*

Trachykele blondeli. The flat headed borer can attack healthy trees, and in some cases the larva can cause considerable damage to the heartwood. The insect is common in some areas, but rare in others.

Mayetiola thujae **(Hedlin).** The cone midge feeds on cones and can cause serious damage to seed crops.

Other insects which feed on western redcedar attack mostly dead or dying trees, or have alternate preferred host species.

• *MAMMALS*

Deer and elk show a high preference for browsing on young western redcedar trees, and western redcedar is a major winter food for these animals in the northern Rocky Mountains (Parker 1979; Mahoney 1981; Minore 1983). A recent study by Sullivan (1993) of damage to tree saplings by black bears indicates that western redcedar is potentially more at risk than its associated species. The site he studied consisted of western hemlock (72% of stems), western redcedar (13% of stems), and amabilis fir (14% of stems) with an average stocking of 585 stems/ha after thinning in 1980. Stand age ranged from 23 to 26 years, average height was approximately 15 meters, and average diameter was approximately 15 centimeters. In this vigorous, naturally regenerated and thinned stand western redcedar was most often used by bears stripping bark and feeding on sapwood. In the thinned stand 23% of the western redcedar were completely girdled, and an additional 65% were more than 50 percent girdled. In this study there was no significant difference in the incidence of attack in the thinned stands versus the control stand, but other studies have reported that bears preferred thinned, vigorous stands to dense or poor site stands.

• *HERBICIDES*

There is very little information on herbicide damage to western redcedar. In a 1989 study, Prasad examined the effects of glyphosate on western redcedar seedlings (Prasad 1989). The glyphosate was applied at a rate of 2.1 kg/ha to 2+2 seedlings under greenhouse conditions. Western redcedar seedlings exhibited some herbicide damage even when treated 12 weeks after the flush of new foliage. It is concluded that in order to avoid herbicide damage a minimum of 12 weeks is needed for the new foliage to "harden." Western redcedar was the most sensitive of the three species tested (Douglas-fir and Sitka spruce were the other two species). After 12 weeks the phytotoxicity percentage for western redcedar was 12.1 %.

In another study Reynolds et al. (1989) found that western redcedar aerially treated with 2 Kg ai/ha of glyphosate showed terminal leader damage the first year after application, but in subsequent years growth returned to pretreatment levels. In all years tested (1983-1987) there was no significant difference in height or root collar diameter growth between treated and untreated seedlings.

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