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THE EFFECTS OF DENSITY ON THE GROWTH AND DEVELOPMENT OF REPRESSED LODGEPOLE PINE AND SUPPRESSED INLAND DOUGLAS-FIR

Final Report
on Contract Research Project EP 850.02
Submitted to
The Research Branch of the British Columbia Forest Service

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INTRODUCTION

Initial density of lodgepole pine (Pinus contorta var. latifolia) after fire is extremely variable. The number of seedlings per hectare established depends to a large degree on the intensity of the fire, age and vigor of the stand and level of site disturbance. When overly dense regeneration occurs, the height growth of dominants is repressed, often before the stand reaches two meters of site height. The geographic range of the phenomenon of repression has not been evaluated but it is believed to be quite extensive. Growth losses due to repression are as yet unknown, but the rotation length of a particular stand can be easily double or triple that of an adjacent stand which is achieving the site potential.

Repression is not an easy phenomenon to recognize. The site quality of many areas has probably been underestimated by using traditional site index procedures in areas where the height of dominants has been affected by density. Foreseeable shortages of timber may be ameliorated by site reassessment and intensive management since some productive areas have likely been classified as non-productive forest land.

A research project (EP 850.02) was initiated in 1980 which described the dynamics of repression of lodgepole pine stands near Williams Lake and Prince George, B. C. The project also evaluated the potential of repressed stands to respond to release. This paper reports on a continuation of EP 850.02. The purpose of this project is threefold: 1) use techniques and experience gained in the initial study to expand the data base to other sites and age classes; 2) to identify potential areas of further study so that repression can be more fully understood; and, 3) use the experience gained in assessing lodgepole pine to preliminarily evaluate the response of suppressed inland Douglas-fir (Pseudotsuga menziesii var. glauca) to overstory removal.

BACKGROUND

The following review of work completed in 1980 is included here for clarity. Refer to the Annual report dated March, 1980 for details not completely described below.

TESTING OF BELIEFS

Some commonly held beliefs about "stagnant" lodgepole pine stands prove to be incorrect. Research in 1980 discovered that repressed stands do add height growth, albeit at a reduced rate. They will become merchantable but at up to two or three times slower than the potential rate. Repressed stands are not excessively dense if the number of live stems at a particular site height is compared to a theoretical maximum. However, reduced height growth does result in excessive density at a particular age. Lodgepole pine differs from most species in that it can become established at densities up to 1,000,000 stems per hectare whereas other species regenerate at less than 5,000.

The phenomenon of repression is not obvious or easily recognizable. Trees in adjacent stands may appear to be equally healthy but differ in height. The difference may be attributed to age or site rather than repression. The data from 1980 show that stands generally become repressed before the stands reach two or three meters in height.

Crowns of individual trees do differentiate into classes. In fact, even super dominants are present in repressed stands. Individual trees will respond to release and regain full height growth potential if they are released dramatically along a fire boundary. No evidence of repression exists in the study stands if estimated initial density is below about 50,000 stems per hectare.

EXPLANATION OF REPRESSION

Several biological explanations for repression are possible. One is that excessive root competition may result in decreased height growth. Root excavation discloses that the root development of individual trees is not physically impeded by neighboring trees. In addition, no root grafting exists in the young stands which otherwise could interfere with intertree competition.

Limitations in light or, more likely, moisture may be causes of repression. Regeneration in burns is not successful within a distance of 4 or 5 meters of the original stand because excavation shows that the roots of edge trees respond quickly into the opening and usurp moisture. Light, however, seems to be abundant even in severely repressed stands.

The distribution of biomass within components of trees and stands does not appear to be a cause of repression, but rather a reflection of its impact. The biomass per hectare of all tree components of an 18 year-old stand increases with initial density to about 50,000 stems per hectare and decreases thereafter.

The amount of photosynthetic production relative to respirational demands appears to be important in repression. Photosynthate production is assumed to be proportional to foliar biomass. In two 18 year-old stands, foliar weight increases with estimated initial density until a maximum is reached at about 50,000 stems per hectare and decreases dramatically thereafter. However, the bole surface area, which is assumed to be proportional to the total respiratory demands, increases across the range of initial densities. The ratio of foliar weight (FW) to bole surface area (SA) is assumed to be an assessment of individual tree vigor. The height growth of individual trees is repressed when FW/SA falls below a critical value.

Foliar weight only provides a point estimate of photosynthetic potential. Bole increment (BI) is proportional to FW and can be determined for each year by stem analysis. The ratio of BI to SA can be used as an index to tree vigor and followed over the history of a tree. Height growth of a tree fails to achieve the estimated potential when BI/SA drops below about .125. This occurs early in the development of trees in a severely repressed condition and progressively later in trees from more open stands.

SOLUTIONS TO PROBLEMS

Two possible solutions to repression are hand spacing or strip thinning. Trees along fire boundaries recover from repression if the release is dramatic. Crowns do differentiate and dominant trees should be able to respond more quickly than suppressed. If strip thinning is selected, leave strips should be very narrow since only the one or two rows of trees along a fire edge respond to release.

Destroying repressed stands by fire is a third alternative which is dramatic, inexpensive, but possibly risky. This has advantages only if a large quantity of cones has not yet accumulated in the stand. The moderately dense stand that regenerates will quickly overtake the repressed parent stand.

1980-1981 RESEARCH

ONSET OF REPRESSION

Repression of height growth of dominant trees was not observed in the 1979 data if less than approximately 50,000 stems per hectare successfully regenerated after fire. The data base in stands of relatively low initial density needed to be strengthened to establish the regeneration level at which repression is a factor.

A study area northeast of Burns Lake, B. C., near Co-op Lake (Figure 1), was selected to provide additional information at lower densities. The stand became established after a 1952 wildlire and is adjacent to a juvenile spacing experiment established by Armit (1964). Plots were established around selected non-damaged dominant trees to evaluate the relationship between dominant height and estimated initial density. The results are shown in Figure 2. Note that in this study area, the effects of repression are evident at initial densities below 50,000 stems per hectare. Information is still weak below 10,000 trees per hectare because natural stands in the low ranges of initial density are rare. It is unlikely that height growth of young stands is affected appreciably by initial densities below about 8,000 stems per hectare. This is supported somewhat by results of a plantation spacing trial in the Prince George region established by John Revel (EP 549) in 1962. That study has not detected any statistical differences in height with planting densities ranging from 640 to 4300 stems per hectare.

It is still unclear whether repression can occur later in stand development. No trees or stands have yet been located in which effects of repression are evident above a height of three meters. It is theoretically possible that stands with initial densities below 10,000 become repressed later than this, but such

Figure 1. Geographic locations of study areas from 1977 (A), 1979 (B), 1980 (C).

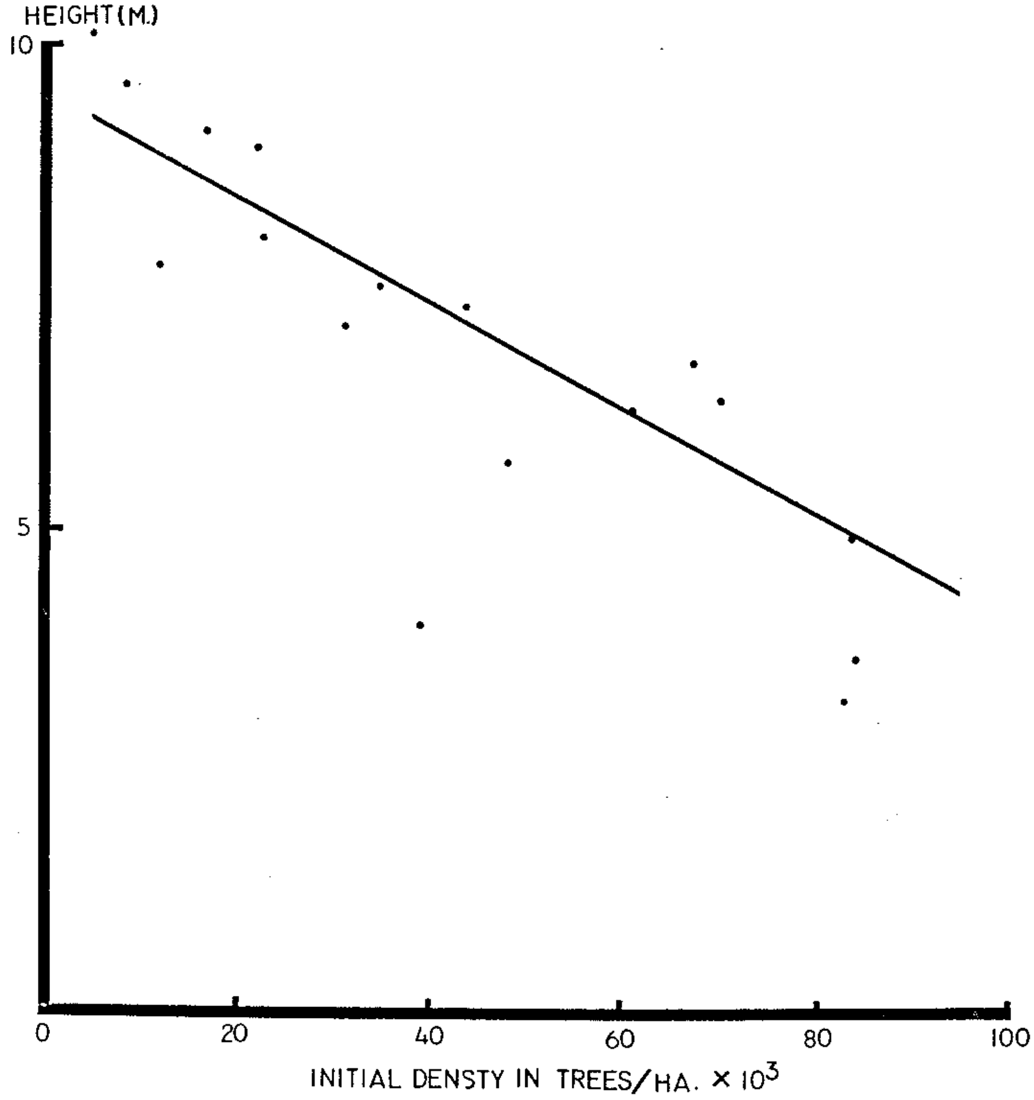

Figure 2. The relationship between dominant height and establishment density in a 27 year-old lodgepole pine stand near Burns Lake, B.C.

low densities in natural stands are difficult to find. Future research needs to be accomplished in the development of low density stands.

RELEASE OF REPRESSED TREES

Few long-term experiments have investigated juvenile spacing of lodgepole pine in British Columbia even though many areas are now being operationally spaced. Individual trees along the edge of several burns were analyzed in 1979 to determine if trees respond in height and diameter growth to release by fire. It was discovered that trees respond immediately in diameter growth but the response in height growth is often delayed or non-existent, depending upon the degree of release and vigor of the tree at the time of fire. Three stands were sampled in 1980 to add to the understanding of response to release. These stands were near Co-op Lake, Riske Creek, and Bowers Lake, B.C.

Co-op Lake

Release. Armit (1964) designed and established one of the only long-term research projects investigating juvenile spacing of lodgepole pine in B. C. (EP 630). Individual subject trees were released at age 12 by cleaning circles 0, 1.1, 1.5, 2.1 or 3 meters (0, 3.5, 5, 7, or 10 feet) in radius around the boles. The tree in the plot center and a comparable edge tree were tagged and measured through time. The study was designed as a randomized complete block experiment and replicated in three blocks. Homoky (1973) reported that cleaning produced a statistically significant increase in diameter growth. However, no effects on height growth were detected.

Armit's study provides an excellent opportunity to evaluate effects of thinning on individual tree growth. Several non-damaged subject trees were selected from the wider cleanings for non-destructive stem analysis. The height to each annual whorl and the diameter outside bark at breast height were recorded for the center tree and the tagged edge tree. The heights of the center and edge trees at time of spacing were determined. A third tree was selected for measurement from a nearby untreated portion of the stand which was approximately the same height at time of release.

Figure 3 shows the general results of the effect of cleaning on height growth. Table 1 shows the characteristics of the trees displayed in Figure 2. Little or no response in height growth is evident for the 2.1 or 3.0 meter thinnings. In fact, the height development of the plot edge trees is very similar to or less than that of the non-released trees. The recent height growth of the center trees is higher than the others but it is not clear whether this will continue. Future measurements and statistical analysis of this experiment will be useful in assessing response in height growth.

Thinning versus Destruction. The question arises whether a stand should be thinned or destroyed to overcome the effects of repression. In Figure 2, the site curve is positioned at the time of stand establishment and at time of thinning. The results here suggest that if thinning is selected, it should be dramatic. Destruction of the stand may be warranted if the economics of wide thinning are unattractive, since the subsequent stand may overtake the thinned parent stand within approximately 30 years. Further work needs to be accomplished in this area since the level of repression at time of release is certainly a factor in this assessment. Destructive stem analysis could indicate this factor but this was not possible here. Note that in this and subsequent discussions in this paper on destruction versus thinning, only the effects on height growth are addressed. They do not consider the effects on total volume production or the risks and economics involved in the decision.

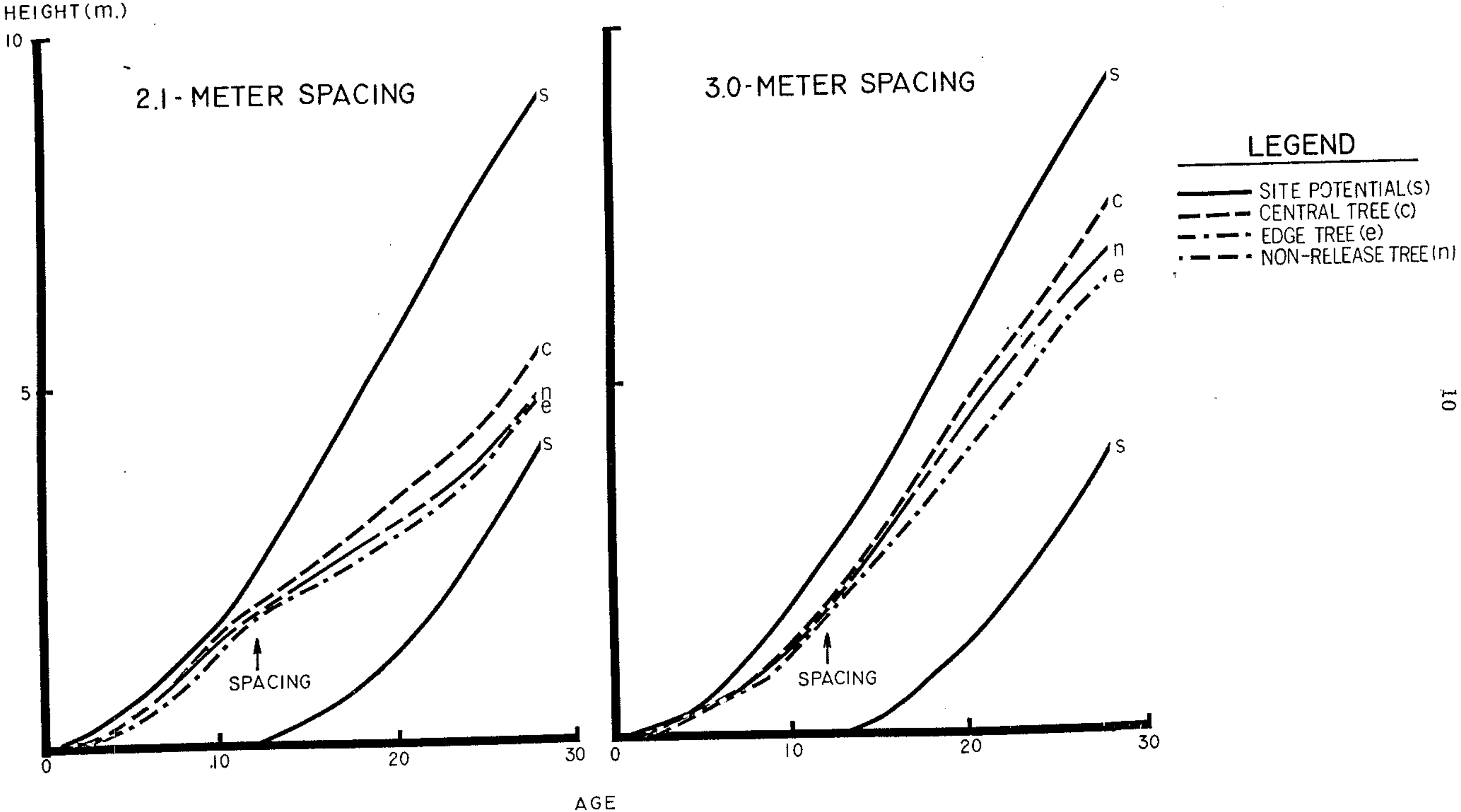

Figure 3. Development of height with age for lodgepole pine trees with differing levels of release at age 12.

Table 1. Characteristics and dimensions of 27 year-old lodgepole pine trees released to varying levels. Trees are from a juvenile spacing study near Burns Lake, B.C.

Spacing Level (meters)	Tree Description	Height at Time of Release (cm)	Height in 1980 (cm)	DBHOB in 1980 (cm)	Recent Height Growth (cm)
2.1	Center	196	545	7.5	33
	Edge	183	481	5.2	30
	Non-Release	192	491	4.2	24
3.0	Center	171	744	10.5	38
	Edge	179	640	6.4	30
	Non-Release	181	672	5.4	29
None	Site Potential	258	893	9.9	41

Riske Creek

Release. Alan Vyse located a 30 year-old stand within two kilometers of the 18, 48 and 70 year-old stands sampled in 1979. Portions of this 30 year-old stand were released in 1961 at age 11 by the same fire that released edges of the 48 year old stand at age 30. Edge trees in this stand provide a comparison of releasing trees at different ages on essentially the same site.

Figures 4a and 4b show the height-age development of five trees of varying conditions at time of fire and with differing degrees of release. Table 2 shows the characteristics of the trees.

Tree 1 was a vigorous tree in a relatively open area of the residual stand (estimated initial density of 15,000 stems per hectare) which had not been released by fire. It was the tallest and had the highest BI/SA coefficient of the five sample trees at the time of fire. Tree number 3 was an edge tree which was released for 300° by the fire. At the time of fire, tree 3 was 31 centimeters shorter than tree 1 and had a lower BI/SA value. It responded in height growth almost immediately and in 19 years has become almost identical in dimensions to tree number 1. Tree number 5 was approximately the same size as tree 3 at the time of fire but was somewhat less "vigorous". It responded in height growth to a 90° release after about seven years of crown buildup. In comparison to tree 3, approximately two meters of height growth was sacrificed because of the lower level of vigor and reduced degree of release.

Figure 4b shows the comparison of two trees which were similar to each other at time of release but smaller than trees 3 and 5. Tree number 2 was a non-released tree which was growing in a location with an approximate initial density of 60,000 to 70,000 stems per hectare. Tree number 4 was released by 180° and is over one meter taller than tree 2 after 19 years. The "response" shown by tree 4 was actually a lack of fall-off in height growth.

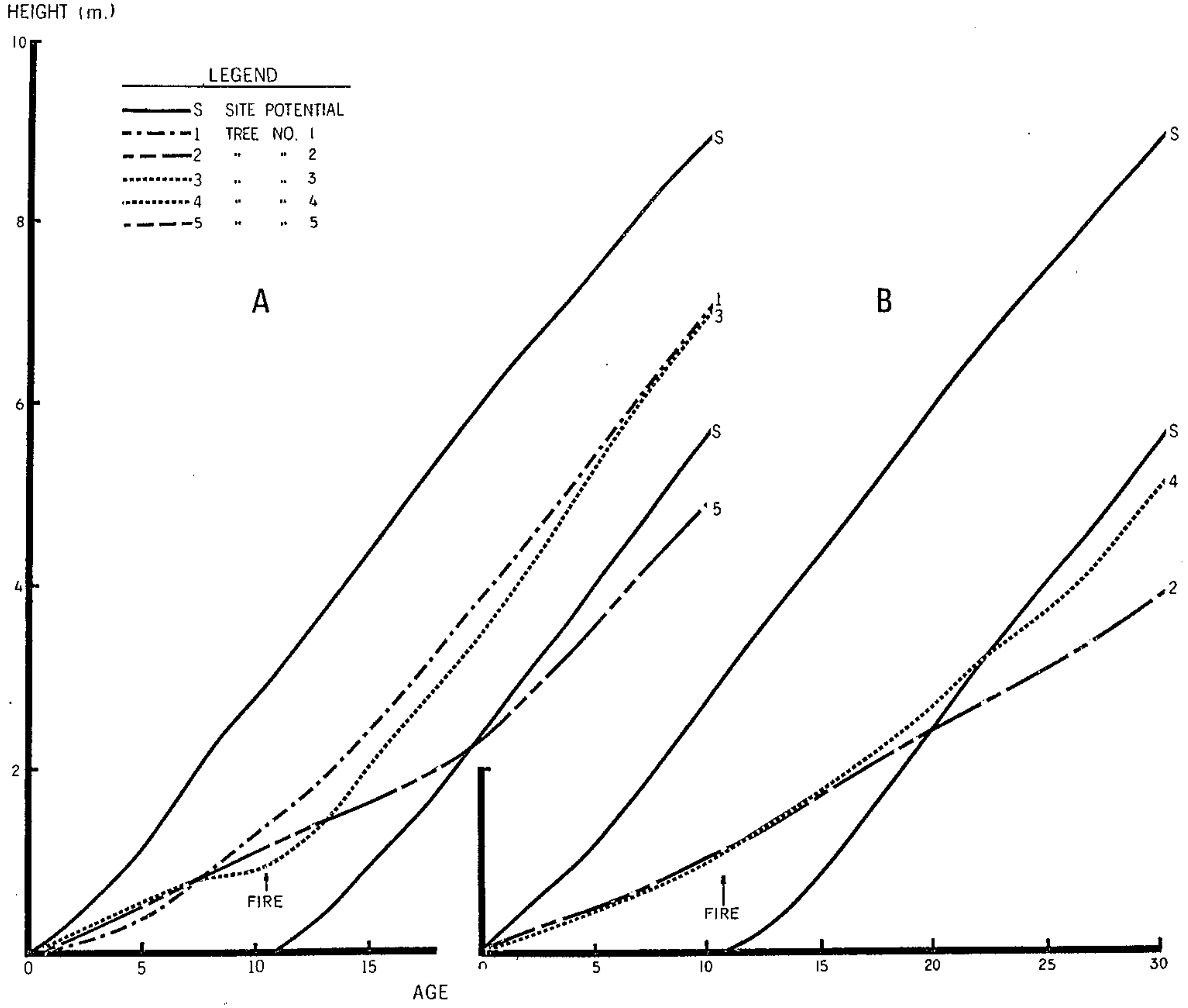

Figure 4. A comparison of the height-age development of released and non-released lodgepole pine growing near Riske Creek, B.C. Release by fire occurred in 1961 when the stand was 11 years of age. Groups of trees which were similar in size at time of release are separated into A and B. The site curve (S) is displayed at establishment and at time of release.

Table 2. Dimensions and characteristics of 30 year-old lodgepole pine trees growing near Riske Creek, B.C.

Tree Number	Level of Release (degrees azimuth)	Estimated Initial Density (stems/ha)	Dimensions at Time of Release			Dimensions at Time of Analysis			Recent Height Growth (cm/yr)
			Total Height (cm)	DIB at 70 cm (cm)	BI/SA Coefficient (cm)	Total Height (cm)	DIB at 70 cm (cm)	BI/SA Coefficient (cm)	
1	None	15,000	143	1.3	.185	702	9.9	.260	32
2	None	60,000	110	0.7	.082	400	2.9	.122	19
3	300	-	108	1.5	.125	698	10.1	.210	28
4	180	-	114	0.8	.100	513	6.1	.120	24
5	90	-	119	1.6	.110	480	5.5	.130	27

That is, tree 2 decreased in height growth at 2 meters but tree 4 did not. The low initial vigor of tree 2 did not allow the height growth to appreciably increase after release.

Note that all trees have shown effects of repression. The site potential suggests trees could be almost nine meters at 30 years of age rather than four to seven.

Age of Release. Figure 5 shows the comparison of releasing at 30 years (1979 data) versus 11 years of age. The results suggest that the earlier release may produce a faster response in height growth. The three 11 year-old trees had higher BI/SA coefficients than the older trees and were able to resume full height growth more quickly.

Thinning versus Destruction. In Figure 5, the site potential curve for the stand is positioned at 1931, 1950 and 1961 which correspond to the establishment of the 48, 30 and 18 year-old stands in the study area. To maximize height accumulation, burning and starting over would likely be the preferred option if performed before the stand reaches about 25 years-old on this site. If burned later than this, some accumulated height growth will likely be sacrificed. This comparison assumes the intensity of the fire and number of seeds would be such that regeneration would establish at less than 10,000 stems per hectare. In addition, it assumes that in a thinning, vigorous trees are selected and released dramatically (i.e. hand spaced).

Bowers Lake

Release. A 38 year-old stand on a more productive site was located approximately 30 kilometers east of 100 Mile House near Bowers Lake. A burn at age 10 resulted in the establishment of an adjacent widely-spaced stand which was 28 years-old

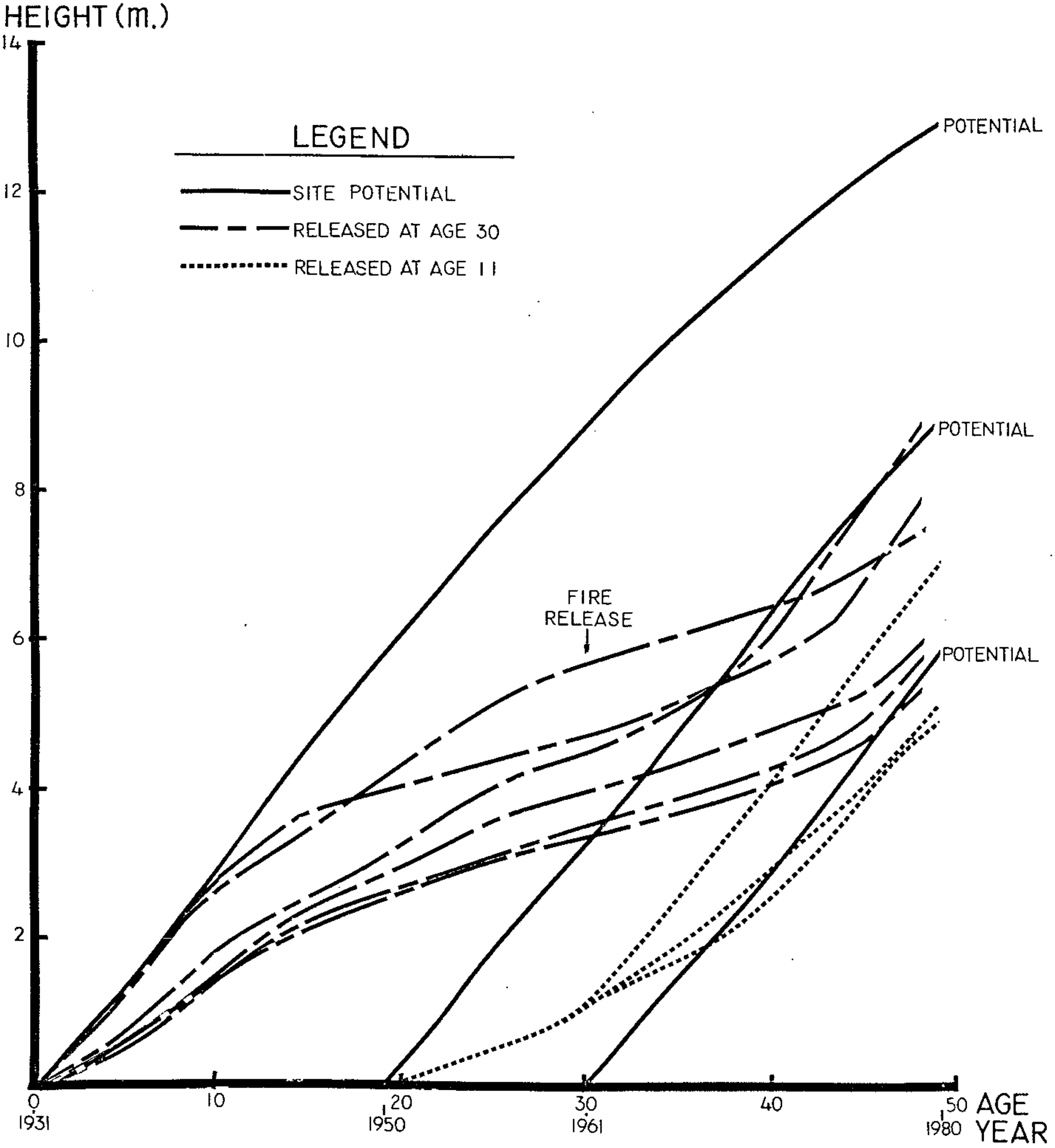

Figure 5. A comparison of the height-age development of fire released trees from 48 and 29 year-old stands growing on uniform site near Riske Creek, B.C. Release by fire occurred in 1961 when the stands were 30 and 11 years of age.

at the time of sampling. In another portion of the stand, trees were released at age 18 by the establishment of a road. The two disturbances provide a similar stand history to the Riske Creek area.

Pairs of trees were selected to evaluate the effects of release from both the fire and the road. The site potential was evaluated by analyzing the height growth of vigorous trees from the 28 year-old and 38 year-old stands. Residual trees along the edges of the fire and road were selected for analysis and compared to nearby trees in the interior of the stand which were similar in size at the time of release.

Figures 6a and 6b show the results of the release by the fire and Figure 6c the results of the release by the road. Note that the site potential curve is positioned at both the time of establishment of the 38 year-old stand and at the times of release. Table 3 shows the dimensions and BI/SA coefficients at the time of release and at the time of analysis. Note that the stump diameters of all the non-released trees were larger than the paired edge trees at time of release. One of the heights was slightly shorter (tree C2) than its comparable release tree.

Tree A1 responded almost immediately in height growth. It had a relatively high BI/SA coefficient at time of release and was able to respond quickly. It was approximately 2 meters taller than the paired tree (A2) at time of anlaysis.

Tree B1 was relatively low in "vigor" at time of release in comparison to its paired tree (B2) (BI/SA of .118 versus .135). Tree B1 significantly increased height growth after about seven years and eventually overtook B2 about 10 years after release. It is now about 2 meters taller in height and 1 centimeter larger in DBH.

The release by road at age 18 caused a similar difference in height. In this pair, the released tree (C1) was more vigorous and taller than the paired

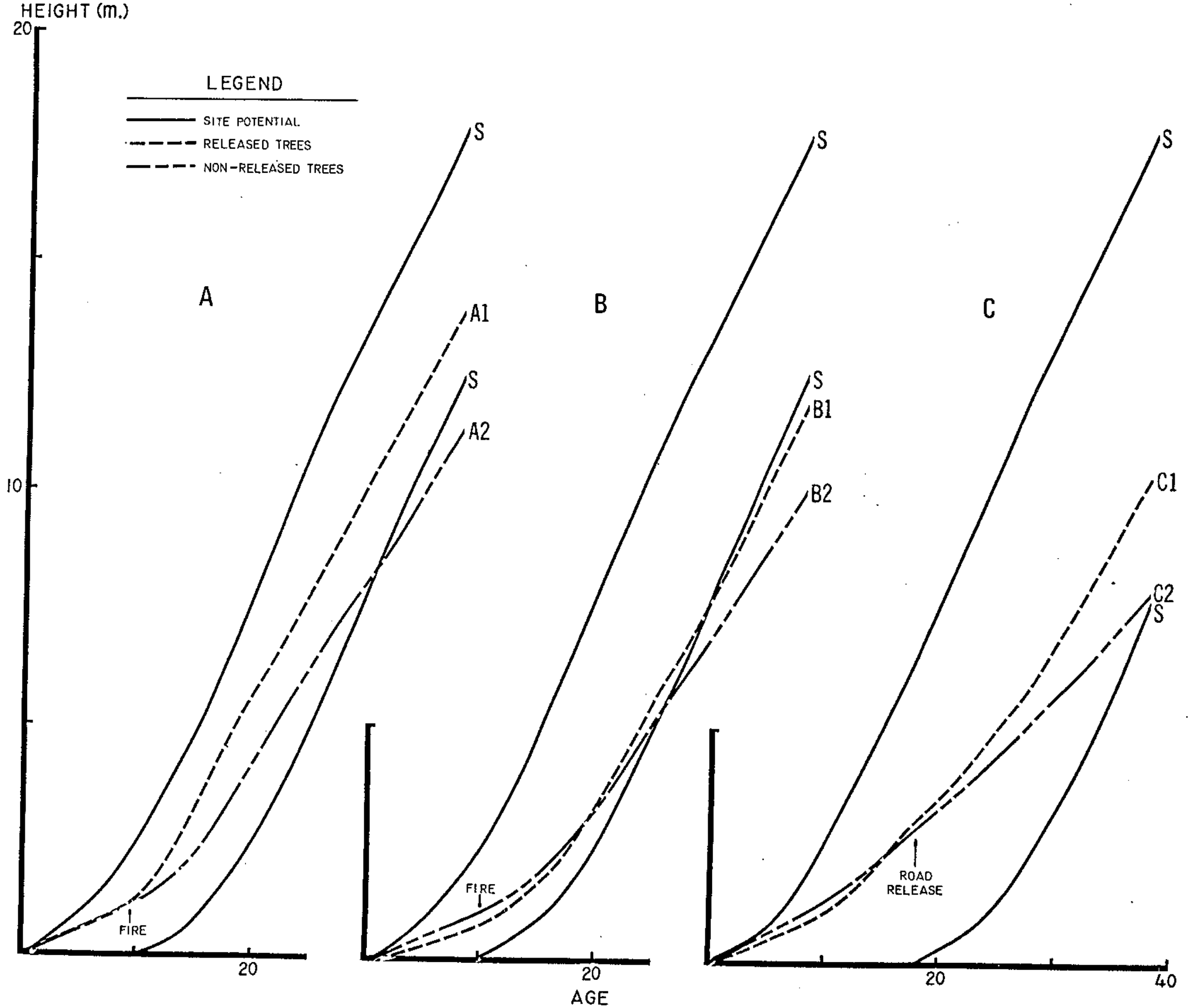

Figure 6. A comparison of released and non-released lodgepole pine growing on highly productive site near Bowers Lake, B.C. Trees A1 and B1 were released by fire at age 10 and tree C1 was released by road construction at age 18. Trees A2, B2 and C2 are paired non-released trees and curve S is the site potential for that area.

Table 3. Dimensions and characteristics of 38 year-old lodgepole pine trees growing near Bowers Lake, B.C.

Tree Number	Level of Release (degrees azimuth)	Age at Time of Release (years)	Dimensions at Time of Release			Dimensions at Time of Analysis			Delay in Response in Height Growth (years)
			Total Height (cm)	DIB at 10 cm (cm)	BI/SA Coefficient (cm)	Total Height (cm)	DBHOB (cm)	BI/SA Coefficient (cm)	
A1	170	10	93	1.1	.135	1376	12.5	.212	1
A2	0	10	93	1.4	.100	1136	8.0	.162	-
B1	140	10	57	0.7	.118	1218	8.1	.192	7
B2	0	10	80	0.8	.135	1001	6.9	.090	-
C1	120	18	310	3.2	.147	1015	9.5	.220	9
C2	0	18	290	4.0	.138	798	6.9	.117	-

tree (C2) at time of release. Tree C1 took about 9 years to show a significant shift in the height-age development. It had a reasonably high BI/SA coefficient but was released only 120 degrees aximuth.

Thinning versus Destruction. In Figure 6 the site potential curves positioned at times of release strongly suggest that, again, early destruction results in a widely spaced stand that quickly surpasses the residual stand in height. It should be pointed out that trees A1, B1 and C1 were all released less than 180°. More complete release may change the results somewhat.

BRANCH GROWTH IN RELATION TO DENSITY

Early work in natural stands had suggested that the relationship between height growth and branch growth changes across densities. In particular, it appeared that trees in dense stands had narrower crowns above the point of crown contact than trees in more open stands. If true, this would be important in repression since crowns of dominant trees in dense stands would be less able to shade trees of lower vigor.

Revel's (1962) (EP 549) plantation spacing trial in the Prince George region provides an excellent opportunity to assess this in the range of management densities normally encountered. Trees were planted on three sites in spacings ranging from 2.13 to 3.96 meters with two replications of each spacing in each area. An additional spacing trial of 1.52 meters was introduced in one of the locations in 1963.

Two of the study sites were sampled, including the one containing the additional 1.52-meter trial. Six healthy trees from each replication of each density were selected for non-destructive stem analysis. Figure 7 shows that essentially no difference or trends in average branch growth in relation to height growth were evident. Future monitoring of these valuable installations

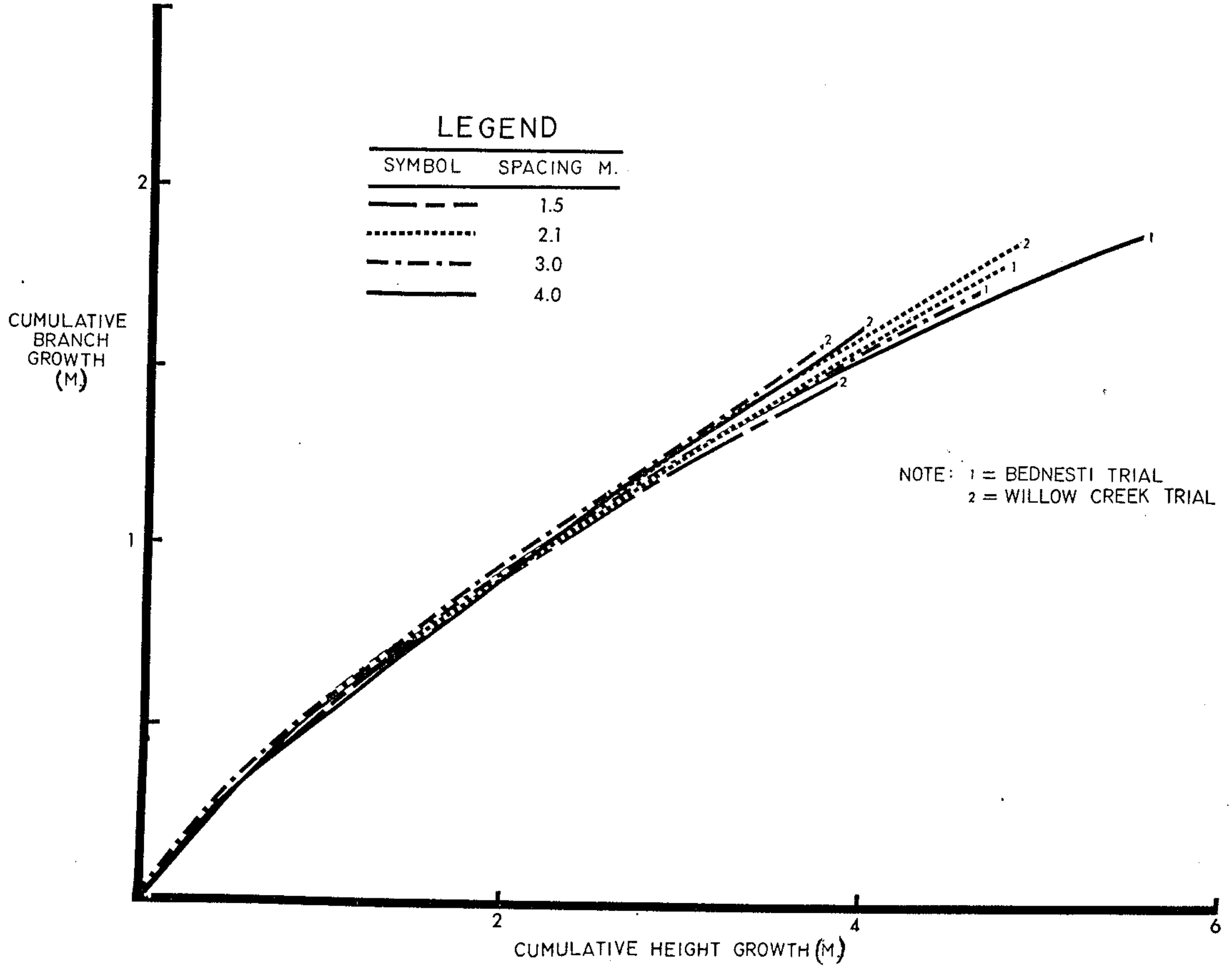

Figure 7. Relationship between cumulative branch growth and cumulative height growth for lodgepole pine planted at four spacings in two locations. Curves shown are averages of several trees per spacing.

will help answer many questions about lodgepole pine development (as well as for other species).

The relationship between density and branch growth in dense natural stands is still unclear. Future analysis may answer this question.

BOLE INCREMENT/SURFACE AREA

The BI/SA coefficient discussed previously proved useful in 1979 in describing the effects of excessive density on height growth of individual trees. The height growth of trees from the Riske Creek study area was reduced from an estimated potential when BI/SA fell below about .125.

Delay Time

Another potential use of BI/SA is in predicting the *delay time* of response in height growth to release. Here, delay in response is subjectively defined as the number of years after release until the height-age curve shows a significant upward shift in growth rate. Figure 5 shows that this can vary from 1 to 20 years in the trees from the Riske Creek area. A total of 12 trees released by fire or road has been destructively stem analyzed since 1979. A multiple regression of delay time (DT) versus the natural logs of BI/SA at time of release and degrees of azimuth (DA) of release produced the following coefficients:

$$DT = 9.657 = 6.932\ (\ln (BI/SA)) - 3.475\ (\ln (DA))$$

$$r^2 = 0.462$$

$$s = 4.28$$

$$n = 12$$

$$\text{Mean DT} = 9.7 \text{ years}$$

The level of BI/SA was significantly related (alpha = .05) to DT but the degrees azimuth was not. The sample size is small but the fact that the slope is negative on both variables is of interest. The higher the "vigor" and degree of release, the lower the delay time. This should not be used as a prediction equation since most of the trees were from one area and the effect of DA is not significant.

Prediction of BI/SA

The above results suggest that BI/SA may be a useful variable for other applications. Unfortunately, it is difficult and time consuming to measure. The prediction of difficult variables such as BI/SA from easily measured tree characteristics is desirable.

Bole increment (BI) in cubic centimeters should be proportional to area increment (AI) in square centimeters. Bole surface area in square centimeters should be proportional to either diameter (D) or total height (HT) in centimeters. Except for the constant, π, average annual AI equals $(D_1^2 - D_0^2)/n$, where n is the number of years between D_1 and D_0, and D is diameter inside bark at breast height (DBHIB). Here, n is the 5 years previous to the current year so that DISQ is $(D_{-6}^2 - D_{-1}^2)/5$. The ratio of BI and SA should be proportional to the ratio of DISQ and HT. For trees from 2 to 30 meters tall, the best relationship found is:

$$BI/SA = -0.0391 + 3.0282\ (DISQ/HT)^{0.5}$$

$r^2 = 0.82$

$s = 0.0288$

$CV = 20.9\%$

$n = 58$

Since DISQ is difficult to determine for short trees, BI/SA was related to DBHIB, height increment (HI) and HT. The following equation applies to trees between 1.5 and 3.0 meters tall:

$$BI/SA = 0.2021 + 0.9157\ ((DBHIB)(HT)/HT)^{0.5}$$

$r^2 = 0.892$

$s = 0.048$

$CV = 19.8\%$

$n = 51$

Note that site productivity was unimportant in the above relationships.

Further work with the coefficient should be accomplished in conjunction with a tree physiologist so that the relationship between BI/SA and actual physiological processes can be verified. It may prove useful as an indicator of individual tree vigor which is important in many applications (e.g. entomology, mortality, silviculture, etc.).

DOUGLAS-FIR RELEASE

Techniques developed for investigating the release of lodgepole pine were used to preliminarily evaluate the response of suppressed inland Douglas-fir to overstory removal. Several released trees growing in a clearcut block west of Enterprise, B.C. (Figure 1) were cut down and stem analyzed. The area was logged in 1971. Several understory trees growing in an adjacent uncut block, which were similar to a released tree in diameter and height at time of logging, were cut down and also analyzed.

Figure 8 and Table 4 show the characteristics of some of the typical groups of trees. Note that the height growth of the released trees responded dramatically after a surprisingly consistent four-year delay. This delay is likely due to the replacement of shade needles with sun needles and the expansion of the root systems. The average height growth since 1975 of the released trees is 33 cm/yr as compared to 12.3 cm/yr for suppressed trees.

Diameter growth of six out of the seven trees is displayed in Figure 9. The groupings of trees are the same as Figure 8 except that the diameter development of one of the trees shown in Figure 8c was not measured. Note that all of the released trees responded in diameter within three years of treatment. The almost immediate response in diameter growth is similar to previous work in lodgepole pine.

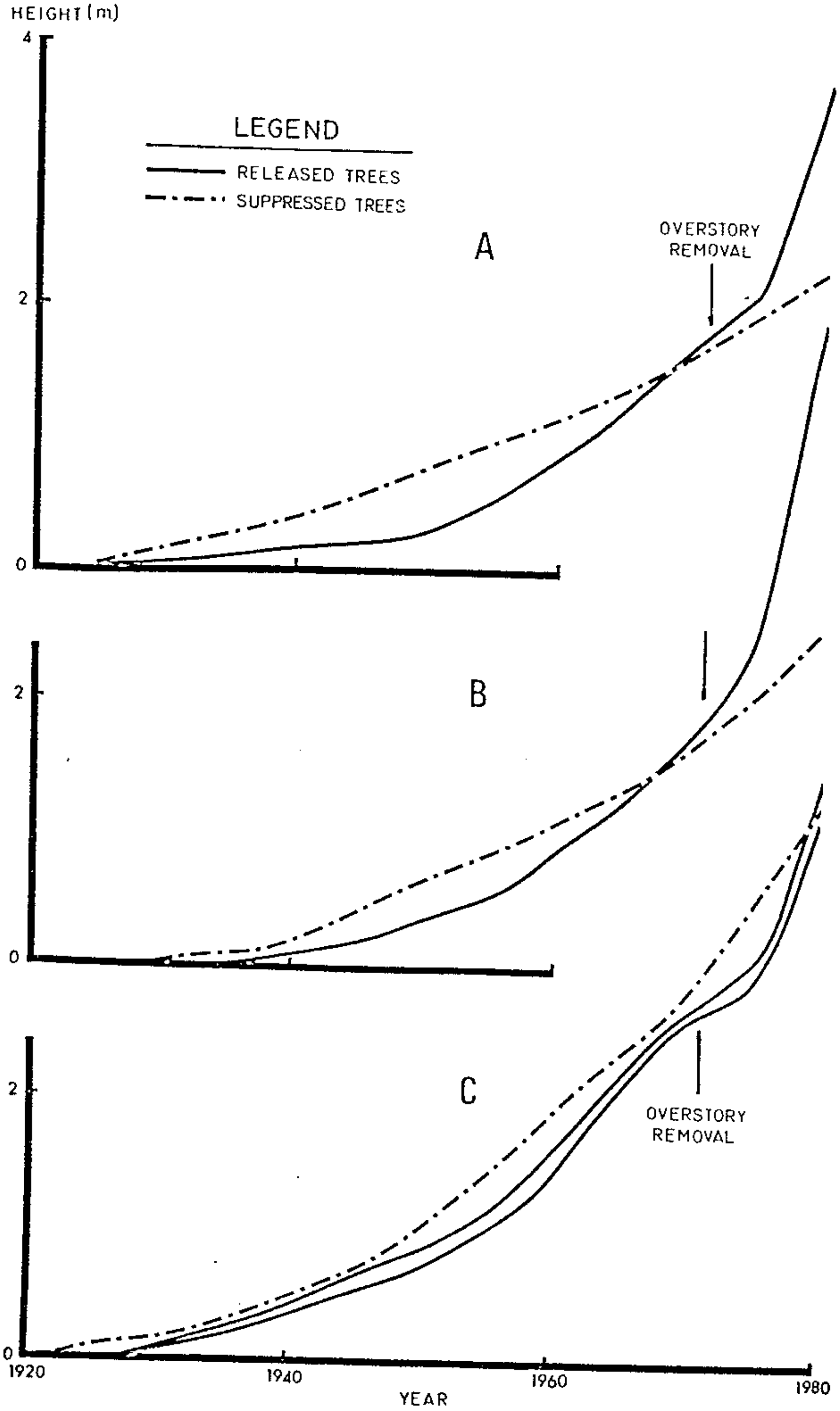

Figure 8. Height-age development of three groups of released and suppressed inland Douglas-fir growing west of Enterprise, B.C. Of the trees shown, four were released by overstory removal in 1971 and three were growing in the understory of an adjacent uncut block.

Table 4. Characteristics of groups of suppressed and released inland Douglas-fir growing near Enterprise, B.C.

		CHARACTERISTICS AT RELEASE			CHARACTERISTICS AT ANALYSIS		
Group[1]	Released?	Height	DBHIB[2]	Age (years)	Height	DBHIB[2]	Age (years)
A	Yes	183	0.8	43	368	3.3	52
	No	178	1.0	44	260	2.1	53
B	Yes	186	1.1	36	495	5.5	45
	No	178	1.0	44	260	2.1	53
C	Yes	272	2.0	35	412	Missing	44
	Yes	277	1.9	43	447	4.6	52
	No	298	2.4	48	430	3.9	57

[1] Refers to groups shown in Figures 8 and 9.

[2] Diameter at breast height inside bark.

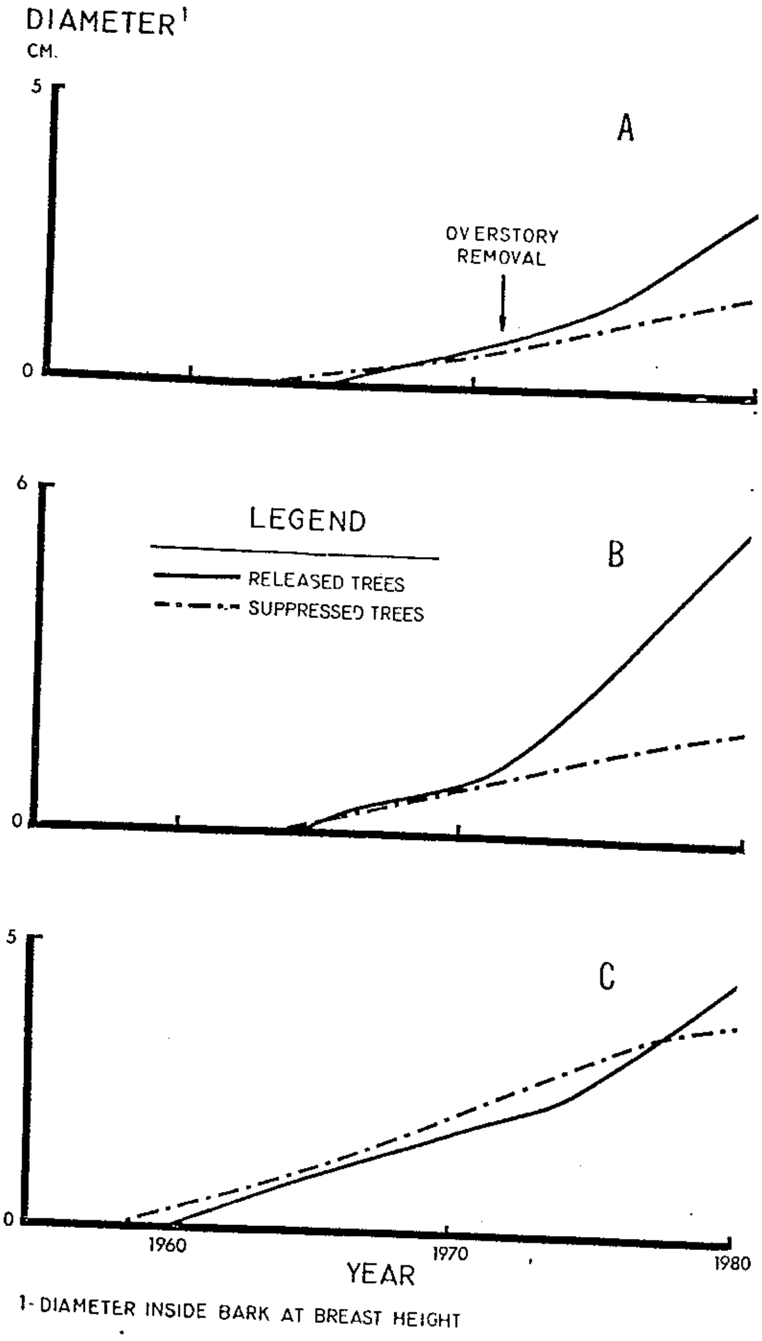

Figure 9. The development of diameter at breast height inside bark for pairs of suppressed and released inland Douglas-fir growing west of Enterprise, B.C.

DISCUSSION AND SUMMARY

Most of the original findings of EP 850.02 were supported by additional data from other sites and age classes. One exception is that effects of repression are evident below an initial density of 50,000 stems per hectare. A precise estimate of the initial conditions that lead to repression is still unavailable, but 8,000 to 10,000 initial stems per hectare seem to be likely.

Dramatically released trees along roads and fire boundaries are able to respond in height growth after a delay of from one to 20 years, depending upon the "vigor" of the tree and degree of release. Trees from the thinning experiment near Co-op Lake show less of a response to clearings. The difference in response between the fire boundaries and the thinning is probably in part due to differences in soil temperature. In the juvenile spacing experiment, the residual stand around each circular clearing was left uncut and is shading the exposed soil, especially early in the growing season when the angle of the sun is low. This is the time when soil moisture is highest, but is possibly less available to the roots due to low temperature. Along an east, south or west fire boundary or road edge, the soil is exposed to direct sunlight early in the season and is warmed. Differences in soil albedo and nutrient availability are also likely to be influential.

The age of release seems to be important in the amount of delay time for response in height growth. Earlier release (10-15 years) allows trees to recover from repression more quickly because trees have not reached a low level of vigor.

Destruction of severely repressed stands should be considered as a silvicultural treatment. It should be performed before the stand reaches 25 years of age, but after sufficient cones have developed for moderate natural regeneration to occur. If performed later than 25 years, some accumulated height growth will probably be sacrificed. Field experiments are needed to test this conclusion.

The growth of branches above the point of crown contact is not affected by normal management densities through 20 years of growth. Future work in older plantations is needed to investigate the effect of density on branch growth later in stand development.

The ratio of bole increment to surface area proved useful in describing the delay time for response in height growth. It can be estimated from easily measured tree characteristics and may prove useful in future research.

Techniques used in analyzing repression of lodgepole pine are helpful in analyzing the response of inland Douglas-fir to overstory removal. Unlike lodgepole, a consistent four-year delay in response in height growth was observed. This is probably due to the more tolerant nature of inland Douglas-fir and/or to the more uniform growing conditions before and after overstory removal. Diameter growth responded quickly which is similar to findings in lodgepole pine.

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