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Response of advance lodgepole pine regeneration to overstory removal in eastern Idaho

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Abstract

Twenty-two stands of advance lodgepole pine released with overstory removal were sampled to determine height growth response. Tree and site characteristics correlated with release response were identified, and a mathematical model was developed to predict height growth in years 6 through 10 after release as a function of residual overstory basal area, height at release, percent rock cover, five-year cumulative growth prior to release, logging damage, stand elevation, and habitat type. Lodgepole pine responded to release with increased height growth in 97% of the trees sampled. Growth was similar to that of unsuppressed trees. Height growth is best when the entire overstory is removed and logging damage is avoided. Taller trees generally do not respond as well as shorter trees. However, trees growing fast before harvest continue to grow fast regardless of their height at release. Recommendations for selecting stands of advance lodgepole pine to release are provided.

Keywords: Advance growth; Growth response; Liberation cut; *Pinus contorta* var. *latifolia*; Release; Suppression

1. Introduction

Advance regeneration are trees that establish beneath an existing overstory as a result of succession by shade tolerant species and/or regeneration of shade intolerant species in gaps between overstory trees. Advance regeneration, a common component in western forests (Ferguson, 1994), typically survives in a suppressed state beneath the forest canopy. Once released, advance trees have been shown to increase diameter and height growth rates in response to increased sunlight, moisture, and nutrients. Although few trees die from exposure after overstory removal, growth response varies from tree to tree (McCaughey and Ferguson, 1988).

In the early 1960s, mountain pine beetle (*Dendroctonus ponderosae*) populations increased to epidemic levels on the Targhee National Forest. Over the next 15 years, the mountain pine beetle attack killed thousands of acres of slow-growing, mature lodgepole pine. Salvage harvesting from 1975 to 1979 (Jay, 1979), beetle-caused mortality, and unrelated past partial cutting substantially reduced overstory densities and

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allowed advanced lodgepole pine (*Pinus contorta* var. *latifolia*) regeneration to establish prior to planned regeneration harvests (Hamilton, 1989). As a result, Targhee National Forest managers were presented the opportunity to release advance regeneration through overstory removal in the late 1970s and early 1980s. However, numerous questions have arisen concerning the ability of advance lodgepole pine regeneration to respond to release.

Advance regeneration shortens rotation length, provides vertical and horizontal structure in harvested stands, ameliorates harsh environmental conditions by decreasing soil-water evaporation, wind speeds, and temperature extremes, and provides protection for later natural and artificial regeneration. Use of advance regeneration, however, may increase dominance of more shade-tolerant species susceptible to insect and disease problems and limits the use of fire as a management tool (Ferguson, 1994). Saving understory trees also requires additional care during harvest operations to prevent mechanical damage to leave trees.

Prior to releasing advance regeneration with overstory removal, foresters must determine whether or not regeneration will respond adequately and grow at site potential. If advance regeneration does not have the capability to adjust to new environmental conditions with increased height growth over a reasonable time period, new, vigorous regeneration will better utilize the growing space. This study was undertaken to

investigate the response of advance lodgepole pine regeneration to overstory removal,
identify tree, stand, and site characteristics correlated with release response, and
develop a mathematical model to predict post-release height growth in years 6 through 10 after release as a function of the above characteristics.

2. Investigation methods

The study area is on the Targhee National Forest west of Yellowstone National Park. Topography is relatively flat and the climate is quite harsh. Lodgepole pine is the most common conifer in the area due to extensive cold air drainage and impoundment. Even though more shade-tolerant subalpine fir (*Abies lasiocarpa*) or Douglas-fir (*Pseudotsuga menziesii*) are the late seral species, they are rarely found and, when present, are stunted by frequent frosts.

Stands with a component of advance lodgepole pine regeneration were located and sampled during the summer of 1994. Twenty-two stands were randomly selected on the Ashton and Island Park Ranger Districts based on criterion that the stand had been harvested with clearcut or overstory removal methods between 1977 and 1983. Candidate stands were also restricted to those harvested with a single entry and not pre-commercially thinned after harvest. Pre-harvest stands were moderately dense with 40% crowns and scattered openings. Overstory stands ranged from 100% lodgepole pine to combinations of lodgepole, Douglas-fir, and subalpine fir. Sample stands also included several on the Henry's Fork caldera, a large, basin-shaped depression consisting of volcanic material covered with loess.

Using aerial photographs, candidate stands were partitioned into sections based on relatively homogeneous slope, aspect, overstory density, and physiographic position. Transect lines were then drawn through each section. These lines were located at least 45 m from stand boundaries and roads so that overstory conditions different from the sample stand did not influence height growth of sample trees. Sample points were located at 30.5 m intervals along each transect line.

At each sample point, a 0.04-ha circular plot was established. A visual search clockwise from the transect azimuth was conducted to locate the first released lodgepole closest to plot center that met sample criteria. The selected tree was then sampled. If no qualifying tree was located, the crew proceeded to the next point and repeated the procedure until a maximum of 15 trees were located and sampled within the unit.

Sample trees had to be at least five years old and <7.6 cm in diameter at breast height at the time of release. Trees with extensive disease problems, logging damage, stem distortions (crooks and sweeps), or observable broken or forked tops were originally not to be selected for sampling since height growth of severely damaged trees is not an accurate reflection of growth potential. However, flawless lodgepole pine were difficult to locate. As a result, trees with broken, dead, or forked tops in the past, stem scars, crooks, gall rust, and dwarf mistletoe having a Hawksworth rating of <4 were included in the sample population. This damage was assumed to be background damage sustained over a tree's life.

The selected tree became the center of a circular fixed area and a variable radius plot. Variables sampled in the 13.5 m^2 fixed plot included the number, height, and species of competing trees <7.6 cm in diameter at beast height; species, height, and percent canopy cover of competing herbaceous vegetation; percent rock cover on the ground surface; percent slope; aspect; physiographic position; and habitat type (Steele et al., 1983).

Measurements for the variable radius plot consisted of the number of live and dead residual trees and the average crown ratio of live trees. Residual trees were selected with a 2.3 m^2/ha/tree basal-area factor prism and had to be >7.6 cm diameter at breast height at the time of harvest. Pre-harvest overstory density was not reconstructed in this study to determine levels of understory suppression based on information provided from similar studies on grand fir (*Abies grandis*) and Douglas-fir (Ferguson and Adams, 1980; Maranto, 1993). Statistical tests conducted in these studies revealed that pre-harvest overstory was not a significant predictor of post-release height growth when other variables such as location, habitat type, elevation, slope, aspect, damage, five-year pre-release growth, height at release, and residual basal area were included in the regression equation. Pre-release growth explained the degree of suppression better than overstory, presumably because it "integrated the effects of previous overstory competition" (Ferguson and Adams, 1980).

Selected trees were cut at ground line and destructively sampled to measure annual height growth increments to the nearest 0.25 cm from 10 years after to 5 years before harvest. Beginning at the top of the tree and working downward, annual height growth was measured between true branch whorls until it became difficult to visually distinguish between true whorls and internodal branches. True whorls were then determined by cutting the bole on each side of branches and counting annual growth rings. A difference of one year in the ring count indicated the location of a true whorl. Lodgepole pine in eastern Idaho does not produce distinguishable nodal scars, so it was not possible to measure height increments by splitting the tree through the pith to locate nodal scars, as was done in similar studies.

On all 250 trees, height increments were recorded from five years before (−5) to 10 years after (+10), release. Some trees were released more than 10 years prior to sampling. For these trees, there were 143 increments for 11 years since release, 133 increments for 12 years, 118 increments for 13 years, 108 increments for 14 years, 53 increments for 15 years, and 48 increments for 16 years (Table 1).

Year of harvest was essential for a correct determination of the height increment series. When stand records were incomplete or harvest year did not agree with field observations, harvest year was verified through callus tissue dating of logging scars on residual trees.

Additional attributes recorded for each advance tree included total height, height at release, height to crown base, crown base width, current crown position (dominant to suppressed), total age, length and percent circumference of logging damage to bole, and the presence of insects, diseases, or other damages.

3. Results and discussion

During the summer of 1994, 250 trees were sampled in 22 stands throughout the Ashton and Island Park Ranger Districts. Table 1 summarizes statistics for the continuous variables that were sampled. Sample trees ranged from 5 to 70 years old at release and from 0.1 to 6.7 m tall at release with five-year height increments prior to release of 6.7 to 211.5 cm. Lodgepole pine regeneration were growing under a range of residual overstory basal areas, with numerous conifer and aspen competitors on the plot, and over a 244-m elevation range. Logging damage was recorded on 27% of the trees. In addition, the data include seven years of release (1977 through 1983) and six common habitat types in eastern Idaho.

Eighty-seven trees with no noticeable damage were sampled. The sample also included 35 basal crooks, 20 stem scars (other than logging related), 18 multiple tops which later separated into the terminal and a lateral branch, and 41 trees with Hawksworth dwarf mistletoe ratings <4. Ninety-two trees with broken or dead tops (including 15 with multiple damaged tops) were also included in the sample population. Many trees contained more than one damage.

Table 1
Data summary of 250 advance lodgepole pine regeneration

Variable	Extreme values	Mean	Standard deviation	Unit of measure
Annual height increment before (−) and after (+) release				
−4 years	0.3–46.0	5.64	5.09	cm
−3 years	0.9–37.8	6.56	5.53	cm
−2 years	0.9–35.0	7.11	5.49	cm
−1 year	0.6–49.4	7.52	6.15	cm
Release year	0.6–46.6	7.99	6.50	cm
+1 year	1.2–35.0	8.53	5.96	cm
+2 years	1.2–39.3	9.66	6.16	cm
+3 years	1.8–38.1	11.04	6.58	cm
+4 years	2.1–44.5	15.82	8.63	cm
+5 years	1.5–54.2	19.52	10.32	cm
+6 years	1.8–50.3	20.14	9.48	cm
+7 years	1.5–57.0	24.47	11.06	cm
+8 years	3.3–62.2	29.14	11.94	cm
+9 years	6.7–59.1	30.92	12.44	cm
+10 years	3.0–69.5	35.38	15.03	cm
+11 years ($n = 143$)	—	37.28	—	cm
+12 years ($n = 133$)	—	36.95	—	cm
+13 years ($n = 118$)	—	35.34	—	cm
+14 years ($n = 108$)	—	36.74	—	cm
+15 years ($n = 53$)	—	37.86	—	cm
+16 years ($n = 48$)	—	38.28	—	cm
Age at release	5–70	18.17	12.99	years
Height at release	0.1–6.7	0.87	0.89	m
Five-year height increment before release	6.7–211.5	34.82	26.10	cm
Residual basal area	0–24.75	2.43	4.50	m^2/ha
Trees in fixed plot	0–51	7.40	7.91	
Logging damage ($n = 67$)	10–65	25.10	9.86	%circ.
Stand elevation	1768–2012	1885	54.41	m
Rock cover in plot	0–30	2.50	5.55	%

The solid line in Fig. 1 represents the average annual height growth from five years before through 10 years after release. Growth in year 10 is similar to that of unsuppressed natural regeneration in the same geographic location. Targhee silviculturists estimate lodgepole pine grows an average of 20.32 cm on poor sites and 30.48 cm on good sites each year. Visual inspection of Fig. 1 shows that, on average, response to release was delayed three years while trees adjusted to new growing conditions. However, trees had not fully adjusted to release by year 6, as was anticipated. Height increments from sample trees released between 1977 and 1982 revealed that height growth leveled off at ≈37 cm per year in the years 11 through 16 after harvest (dashed line, Fig. 1). Our assumption that lodgepole pine need five years to adjust to new growing conditions was not validated by the data. On the harsh caldera sites, lodgepole took ≈10 years to fully adjust.

Height growth in year 6 (corresponding to 1989 for 43% of trees in Fig. 1) was less than expected. For lodgepole pine, and most other western conifers, terminal buds are formed the year prior to expansion (Lanner and Van Den Berg, 1973). As a result, bud primordia that elongated in 1989 were formed in 1988, the driest year on record for the Greater Yellowstone Area (Christensen et al., 1989; Schullery, 1989).

From the data, a mathematical model predicting cumulative height growth for years 6 through 10 after release was developed to explain the relationship between height growth and individual tree characteristics and site conditions. Height growth in years 6

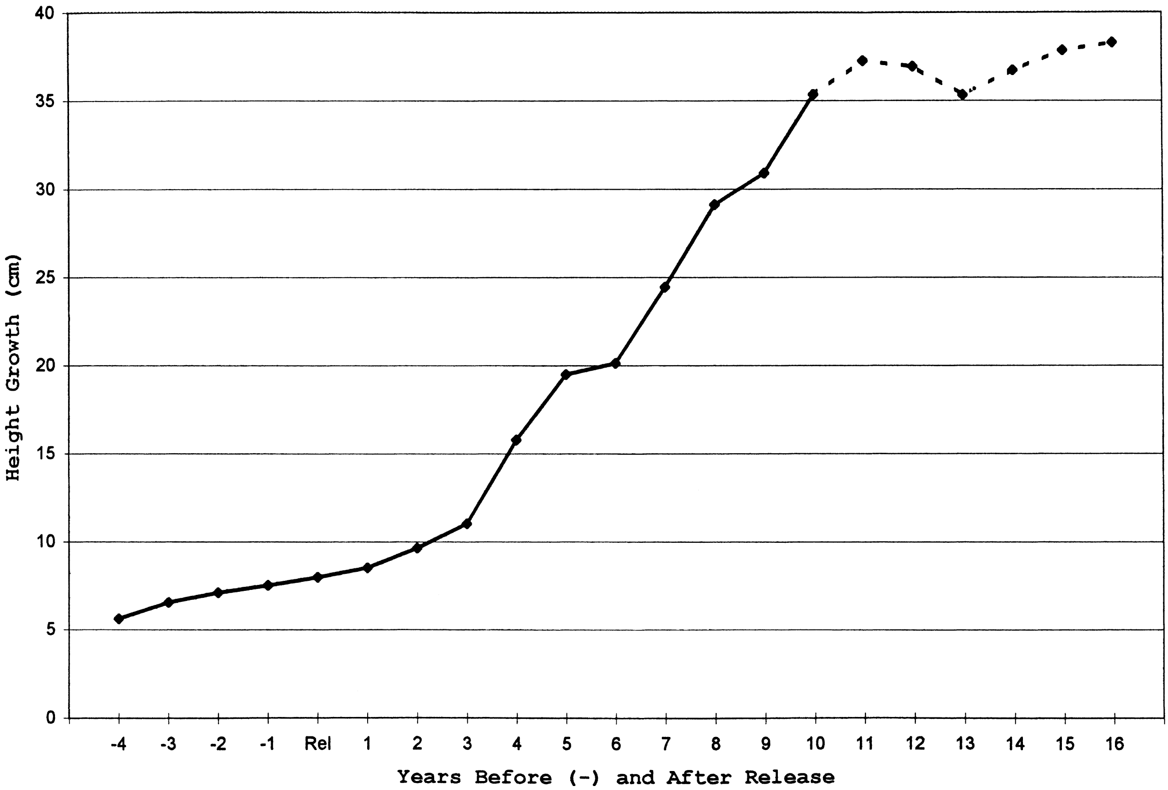

Fig. 1. Mean annual height growth before and after release. The solid line represents all 250 sample trees. The dashed line represents growth for the trees released between 1977 and 1982. Table 1 describes the number of trees sampled for each year.

through 10 represented growth of trees after a five-year adjustment period to the new site conditions. The model can calculate approximate release response based on pre-harvest information, prescribed residual overstory, and assumed damage.

Least squares analysis, using general linear model procedures (SAS, 1994) at the $p \leq 0.05$ level, was used to develop the equation. Coefficients of the independent variables, selected through stepwise regression, were calculated to minimize the sum of squared errors of prediction. The final independent variables are residual overstory basal area, height at release, percent rock cover, five-year cumulative growth prior to release, logging damage, stand elevation, and habitat type. Statistical assumptions of independence of residuals, normality, and constant variance of residuals were met. The growth model explains 41% of the variation in post-release height growth for years 6 through 10 for lodgepole pine regeneration. The model form and variable coefficients are listed in Table 2.

Significant differences were found in years 6 through 10 post-release height growth for independent variables included in the model. However, the graphs that follow show yearly height increments for various classes of raw data within each independent variable. Raw sample data were used to generate the following graphs rather than the five-year height increment model, since the raw data provide interesting insights into the response of lodgepole pine to release.

Residual overstory basal area is the best overall predictor of post-release height growth. Height growth of advance regeneration declines as overstory density increases (Fig. 2), especially when basal area is greater than ca. 6.75 m^2/ha. Retention systems in lodgepole pine, therefore, appear to hinder post-release height growth.

Table 2
Model form and coefficients $y = \exp(B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + B_4X_5 + B_6X_6)$, where: y = cumulative height growth for years 6–10 after release (cm); exp = base of the natural logarithm (ln) or 2.7183

$B_1 = -0.02581$	X_1 = residual basal area after harvest (sq.m/ha)
$B_2 = -0.00129$	X_2 = height at release (cm)
$B_3 = -0.01539$	X_3 = rock (percent of ground cover)
$B_4 = 0.17144$	X_4 = ln (cumulative five-year pre-release height growth (cm))
$B_5 = -0.00691$	X_5 = damage (percent of bole circumference)
$B_6 = -0.00169$	X_6 = elevation (m)
$B_0 = 8.20958$	IF=ABLA/VAGL habitat type
7.81853	PSME/SYAL habitat type
7.74803	ABLA/VASC habitat type
7.72040	PICO/CARU habitat type
7.63607	ABLA/CARU habitat type
7.43553	ABLA/SYAL habitat type

Fig. 3 illustrates that trees taller than 1.6 m at release have the lowest post-release growth and require three years to adjust to new growing conditions. This finding is in agreement with those for the grand fir (Ferguson and Adams, 1980) and Douglas-fir (Maranto, 1993) regeneration. While tall trees experienced a declining growth trend in the first three years after harvest, short trees continually produced larger annual height increments. Although age at release was not a significant factor in predicting release response, it is accounted for in release height since these variables are highly correlated (0.70). Data show that taller trees at release tend to be older. However, some of the taller trees were young with excellent pre-release growth.

Possible explanations for poor performance of tall trees are low pre-release vigor, small crown ratio at release, and a higher probability of being damaged

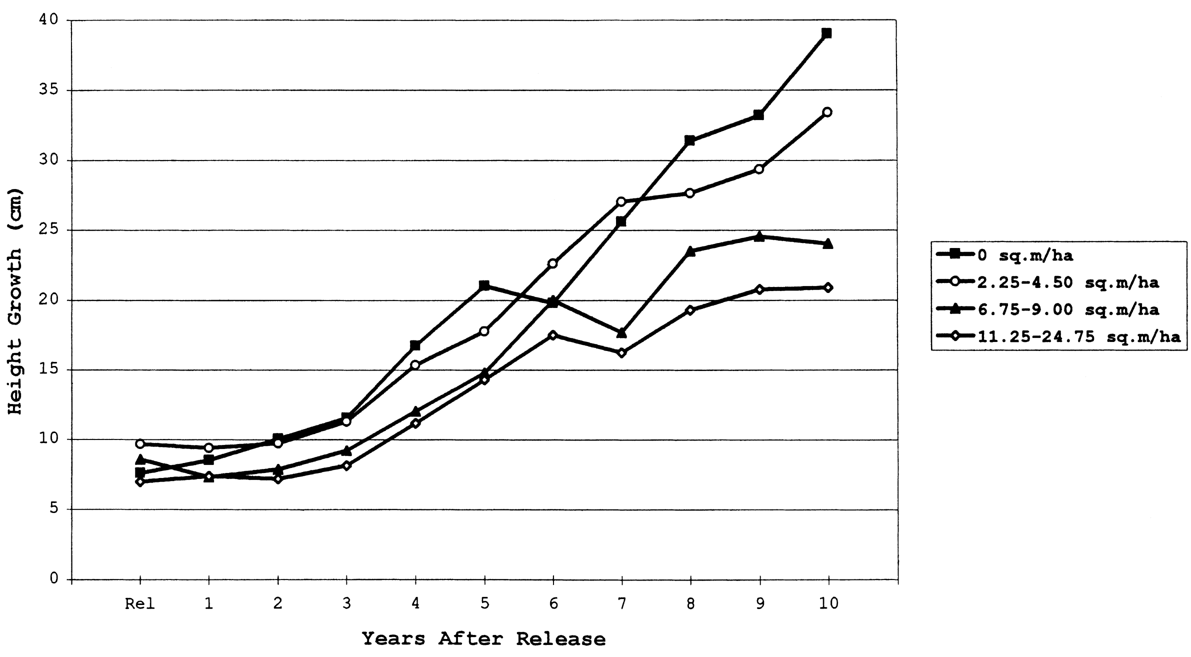

Fig. 2. Mean annual height growth after release for four classes of residual overstory basal area (sq.m/ha).

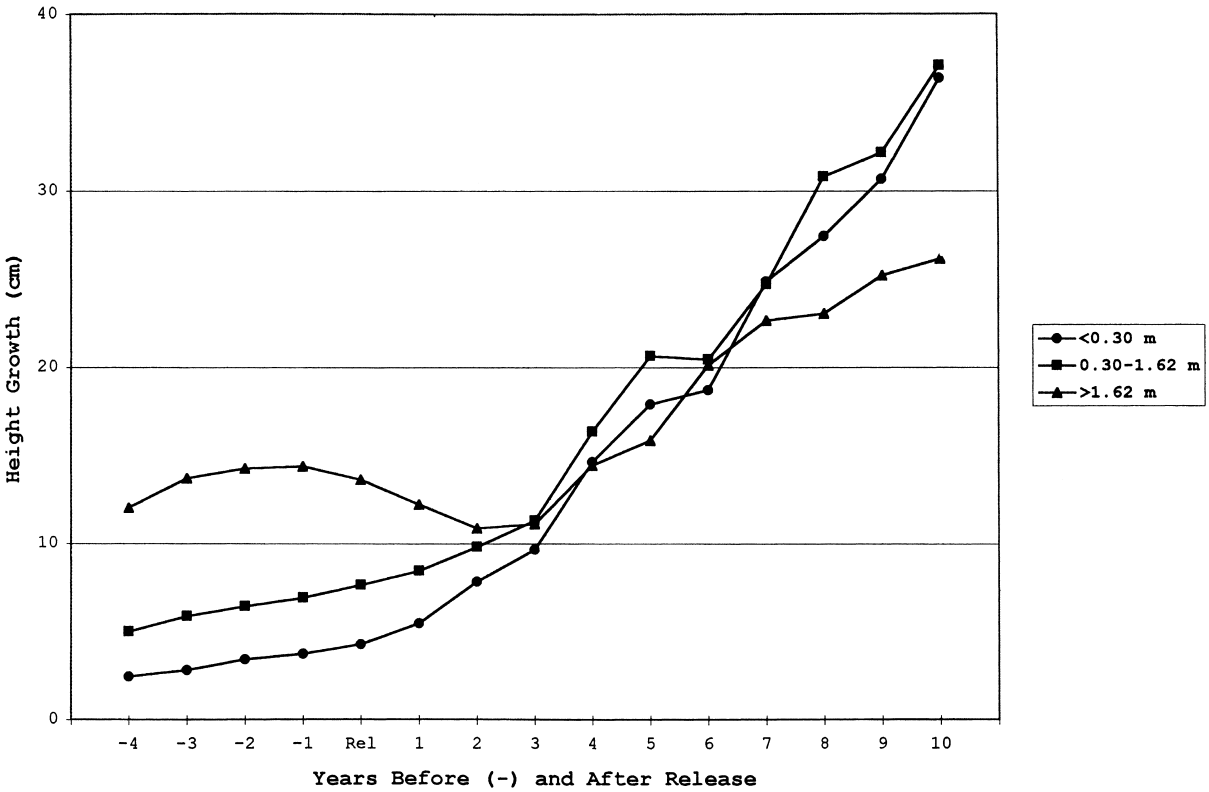

Fig. 3. Mean annual height growth for three classes of height at release (m).

during harvest. In this study, the mean height at release for damaged and undamaged trees was 1.45 and 0.66 m, respectively, which supports the possibility that taller trees have a greater chance of sustaining damage during overstory removal.

Soil classification information from the Ecological Unit Inventory of the Targhee National Forest (Bowerman et al., 1994) was analyzed and found to be an inconclusive indicator of growth for the relatively small geographic area sampled. Rock content in the soil, however, did prove to be a significant indicator of release response. Advance regeneration growing on rocky sites produced less annual growth than trees on better sites, especially in drought years.

Pre-release height growth is typically viewed as an indicator of tree vigor or, conversely, the degree of suppression beneath the overstory. Trees with the greatest pre-release growth continued to outperform less vigorous trees after overstory removal, regardless of initial height (Fig. 4). Height at release for these trees ranged from 0.7 to 6.7 m (2.2 m average). The initial reduction in growth may have been a result of tree height since taller trees are slower to respond to release. By about eight years from release, even highly suppressed trees were growing as well as the trees that were least suppressed.

Mechanical damage sustained in the course of overstory removal was recorded on 67 sample trees as percent circumferential damage to the bole. Damage ranged from 10% to 65% with a mean of 25%. Fig. 5 illustrates less height growth over time for damaged vs. undamaged regeneration. This finding is consistent with that of Schmid and Mata (1993), who found tissue damage encircling 1/4 to 1/3 of the bole's circumference significantly reduced lodgepole pine growth.

This study covered a 244-m elevation range. Trees released in low elevation stands produced greater post-release height growth than trees at higher elevations. The greater height growth evidenced in low elevation

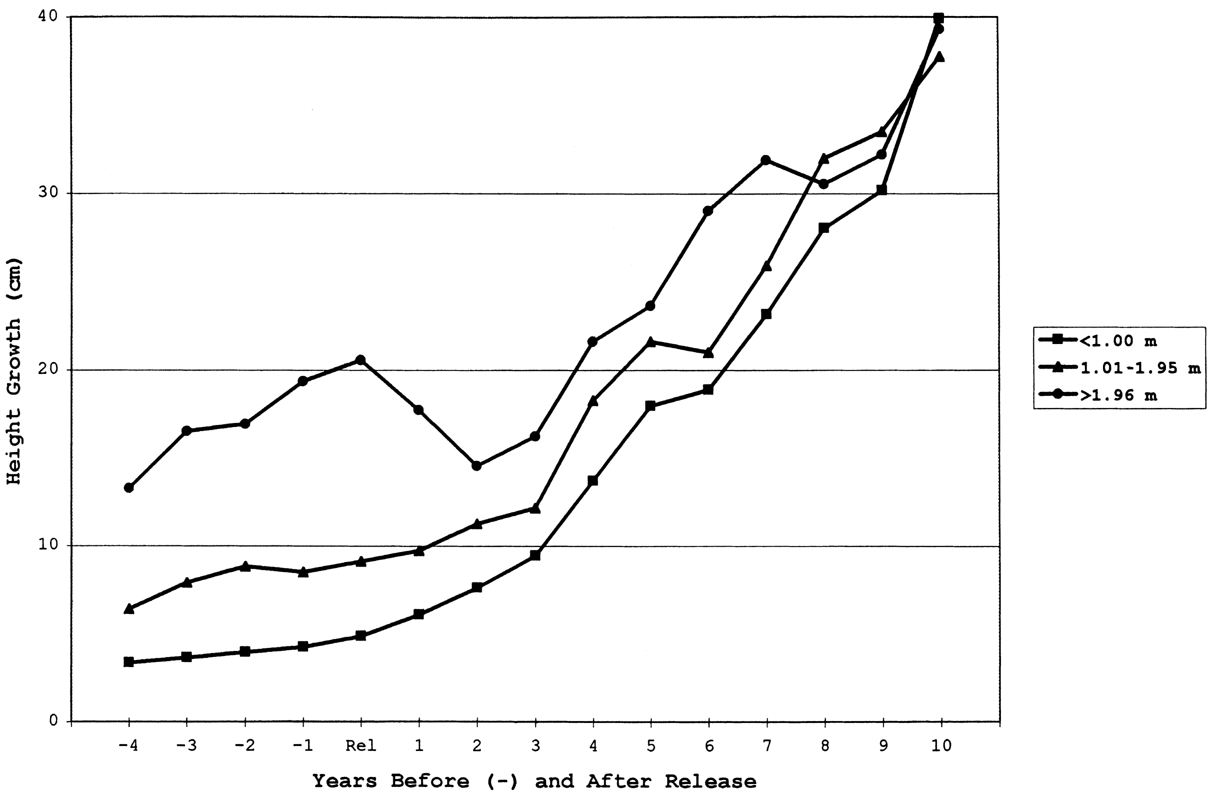

Fig. 4. Mean annual height growth for three pre-release growth classes. Each class represents cumulative height growth in the five years before harvest.

stands is the result of longer growing seasons and warmer temperatures compared to higher elevation sites.

Released trees grew best on the subalpine fir/blue huckleberry (*Abies lasiocarpa/Vaccinium globulare*) habitat type. Lodgepole pine on the subalpine fir/snowberry (*Abies lasiocarpa/Symphoricarpos albus*) habitat type grew the least following release. Intermediate growth response was found on the other four habitat types: Douglas-fir/snowberry (*Pseudotsuga menziesii/Symphoricarpos albus*), subalpine fir/grouse whortleberry (*Abies lasiocarpa/Vaccinium scoparium*), lodgepole pine/pinegrass (*Pinus contorta/Calamagrostis rubescens*) community type, and subalpine fir/pinegrass (*Abies lasiocarpa/Calamagrostis rubescens*). The average difference in height growth for years 6 through 10 after release between the subalpine fir/blue huckleberry and subalpine fir/snowberry habitat types was 0.59 m.

4. Management application

The mathematical model developed provides valuable insight into post-release height growth potential of advance lodgepole pine associated with particular tree characteristics and site conditions. Lodgepole pine was found to be a vigorous grower that adapts to new growing conditions once released. Almost all (97%) advance regeneration sampled responded with increased annual height growth after a three-year time lag. Trees responded even if pre-release growth had been significantly suppressed. By the tenth year after release, advance regeneration was growing at an annual rate similar to unsuppressed natural regeneration.

Successful release of advance regeneration is dependent on several factors. The most important is residual overstory density. Retention systems above advance lodgepole pine regeneration, with the excep-

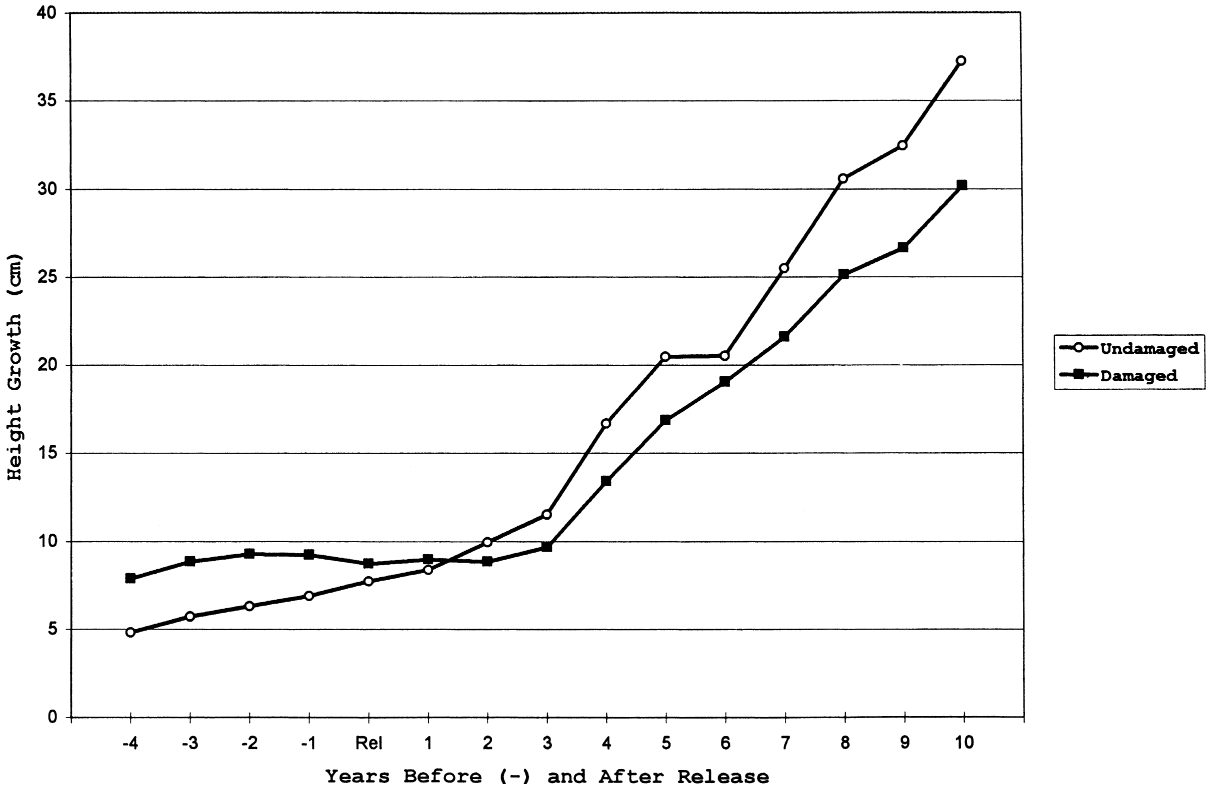

Fig. 5. Mean annual height growth for 67 damaged and 183 undamaged trees.

tion of very light seed tree cuts, do not produce height growth as effectively as clearcuts. If fast growth is the management objective for the stand, the entire overstory should be removed during harvest.

Within the growth limits defined by the overstory retained, release potential will be greatest in stands of advance regeneration that are <1.6 m tall and express good pre-release growth. However, even tall trees with excellent vigor will release adequately if undamaged. Trees with good height growth rates before harvest will continue to grow well.

Stands will not grow as predicted, based on overstory density, pre-release growth, height, and site variables, if harvest is conducted when tree cambiums are active and consideration for regeneration is ignored. Damaged lodgepole do not appear to have the capability to produce height growth equivalent to undamaged trees. Timing and harvest method, therefore, may determine whether or not advance regeneration should be retained and utilized as the next crop.

Retention of advance lodgepole pine regeneration may be necessary, especially where harsh environmental conditions prevent successful establishment and survival of post-harvest natural and planted regeneration. In the sampled caldera stands, the predominant regeneration was advanced. A majority of the regeneration established after harvest was found in or adjacent to concentrations of advance regeneration. Advance regeneration, therefore, may be a necessary component on harsh sites (as a nurse crop) to ameliorate site conditions so that regeneration (natural or planted) may successfully establish.

Advance lodgepole pine regeneration can shorten rotation length of a stand. Growth rates of released regeneration are similar to those of unsuppressed trees, and released regeneration has a head start on diameter and height growth. Advance regeneration also presents the opportunity to utilize on-site seed sources which are adapted to the specific site.

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