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# Postharvest height growth response of Picea engelmannii and Abies lasiocarpa understory

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# POSTHARVEST HEIGHT GROWTH RESPONSE OF PICEA ENGELMANNII AND ABIES LASIOCARPA UNDERSTORY

By

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Director: George M. Blake

This thesis describes 10-year height growth response of understory Engelmann spruce and subalpine fir following selection and overstory removal treatments. This study, on national forests in Idaho, Wyoming, and Utah demonstrated that both spruce and fir understory trees responded to release. Understory trees seemed to respond more in the overstory removal treatments than in selection treatments.

# ACKNOWLEDGMENTS

I thankfully acknowledge the Timber Management staff of the Forest Service Intermountain Region and the staffs of the Payette, Teton (now Bridger-Teton), Uinta, and Dixie National Forests for their parts in the conduct of this study. Also, I thank Arthur L. Roe (Intermountain Forest and Range Experiment Station, retired) and Al Dahlgreen (Intermountain Region, retired) for their help in establishing and conducting the original cutting trials that provided the conditions needed for this study, and Dr. Robert D. Pfister (Intermountain Forest and Range Experiment Station) for his support and help in classifying the ecological habitat types in the study areas. Thanks go to Orville Engelby (Intermountain Region Silviculturist) for his advice and support of this study, and Gayle Yamasaki and Michael Marsden (Intermountain Forest and Range Experiment Station) for statistical help.

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# CHAPTER I

# INTRODUCTION

Successful management of the Engelmann spruce-subalpine fir (*Picea engelmannii* Parry ex engelm.-*Abies lasiocarpa* [Hook] Nutt.) forests of the Intermountain West (south-central Idaho, western Wyoming, Utah, and Nevada) depends on rapidly and adequately regenerating cutover areas. Regeneration difficulties have plagued managers of these forests. Difficulties are generally most severe in the high elevation forests of the region in southern Utah with decreasing problems as you go north into the lower elevation forests of south-central Idaho (Roe and Schmidt 1964; Roe and others 1970). A number of silvicultural options using even- and uneven-aged management techniques are available--plant immediately, direct seed, rely on natural regeneration, retain adequate amounts of advance regeneration, or various combinations of these. Depending on the particular circumstances, each has some advantages. One of the most controversial, however, is the choice of utilizing the suppressed understory as future crop trees. Controversy generally centers on the expected response of the advance regeneration to release. Questions arise as to how soon, how much, or will it respond?

There are indications from other areas that understory spruce and fir will respond once released from the overwood. For example, in northeast California on the Swain Mountain Experimental Forest, Shasta red fir (Abies magnifica) and white fir (Abies concolor [Gord. and Glend.] Lindl. ex Hildebr.) developed rapidly after release even though they had been suppressed and had grown slowly for over 40 years (Gordon 1973). Engelmann spruce and subalpine fir understory trees also responded well following release from overwood in other studies in north Idaho (Roe and DeJarnette 1965).

Information about understory spruce and fir growth response in the Intermountain West is sparse. Results from this study provide clues for future studies concerning release of understory trees.

Foresters are interested in cutting methods favoring understory trees since this advance growth provides immediate growing stock, shade for subsequent seedlings, some continuity of green forests, and some soil protection. If these understory trees will not release, or succumb to mortality, their use for these purposes is questionable. Knowing when suppressed understory should be left and when it should be destroyed to provide growing space for subsequent reproduction is important for managing these forests.

The objectives of this study are to evaluate height growth release response of understory Engelmann spruce and subalpine fir trees after overstory removal and selection treatments.

# CHAPTER II

# REVIEW OF THE LITERATURE

## Release

Management intensity of spruce-fir forests has increased with managers being concerned with prompt restocking to reduce rotation time. In the Central Rocky Mountains spruce-fir forests contain a moderate amount of spruce advance regeneration (Alexander and Edminster 1980). In two high elevation stands in southern Utah, Hanley and others (1975) found that spruce and fir trees less than 4 inches comprised a high proportion of the all-aged understory. This existing resource is usually available for manipulation by forest managers if extreme care is taken to reduce logging damage.

Relationships between understory tree age and release response are usually overlooked by most studies. Assmann (1970) found European evidence that spruce and fir "can endure crown competition over several decades without it inhibiting their later growing capabilities." Assmann goes on to present some response data that indicate that once released, spruce and fir height growth essentially parallels the growth of trees that have been free to grow. His work does not show response to age, differences. Hatcher (1960), in a study of the growth of balsam fir (Abies balsamea [L.] Mill) following clearcutting operations in Quebec, found fir seedlings able to survive periods of suppression for more than 50 years. Once released they attained growth rates comparable to nonsuppressed seedlings. Cleve and Zasada (1976) found 70-year-old white spruce showed treatment response the first month after thinning and fertilization. In central Oregon, Seidel (1977) found that 43-year-old, suppressed, even-aged grand fir and Shasta red fir advance regeneration responded during the 5-year period after overstory competition was removed. These studies did not stratify response by age.

Release response of a tree can be expressed by increased diameter, crown, and height growth. In west-central Alberta, black spruce (Picea mariana [Mill.] B.S.P), white spruce (Picea glauca [Moench] Voss), and subalpine fir advance regeneration diameter growth response was immediate and progressive over a 10-year period (Crossley 1976). Diameter growth of released white spruce was 2.6 times greater on thinned plots than on control plots (Cleve and Zasada 1976). Diameter and height growth rates of grand fir (Abies grandis) and Shasta red fir seedlings and saplings increased two to three times their 5-year prerelease rates (Seidel 1977). In a study on the Penobscot Experimental Forest in Maine, Frank (1973) found that annual circumference growth significantly related to the degree of release. The growth trend was established the first year but significant differences were not evident until the third year. Trees with three and four sides released outgrew controls and trees with only one or two sides released by a 2:1 ratio.

An indicator of release response potential was shown by Ferguson and Adams (1979), working with grand fir understory trees in north Idaho. They found that 5-year height growth before release was the best predictor of height growth after release. Also, younger trees responded quicker, short trees more than tall trees, and undamaged trees sooner than damaged trees after release. Shade from scattered residual overstory trees was initially beneficial to release but detrimental to growth after trees adjusted to the new environment. Using past height growth as an indicator of posttreatment growth was supported by Crossley (1976) when he found that the past year's leader growth of grand fir and Shasta red fir was considered adequate for an assessment of height growth performance following release from suppression. In a later study, Seidell (1980) found that grand fir advance regeneration height growth was unchanged by release. His results showed that trees growing slowly before release usually grew slowly after release, whereas faster growing trees continued height growth at a faster rate.

Many studies have shown that tolerant understory trees will respond to release with increased height growth rates. An obvious unknown is how long the acceleration in growth will continue and when and at what rate it will level off. This will be a function of site and stand conditions and tree potential. Advance regeneration of subalpine fir and Engelmann spruce in British Columbia grew substantially faster than some of its natural regeneration counterparts 21 years after site treatment (Herring and McMinn 1980). Poor performance of natural regeneration on mineral soil was attributed to site degradation due to excessive scarification. Based on observations by Roe and DeJarnette (1965), Engelmann spruce and subalpine fir increased height growth may continue for at least 25 to 30 years.

## Physiological Shock

Overstory removal produces extreme microclimate changes affecting released understory trees. Air and soil temperatures were higher in clear and shelterwood cuts than in uncut areas (Tucker and Emmingham 1977). Increased air movement, along with higher soil and air temperatures, cause increased moisture stress on understory trees.

Increased light intensities after overstory removal greatly affect photosynthetic rates. Trees have sun and shade leaves which have differing leaf morphology and photosynthetic machinery. Sun leaves are smaller and thicker with more chlorophyll per unit leaf area than shade leaves. They have a higher rate of photosynthesis per unit of leaf area and are light saturated at higher intensities (Kramer and Kozlowski 1979). Kozlowski (1957) showed that high light intensities had inhibitory effects on photosynthesis. The decline of photosynthesis was thought to be a result of solarization which is a photo-oxidation process in which leaves consume oxygen in the light and use it in the oxidation of certain cell constituents, carbon dioxide being released in the process. Oxidation of cellular components, including chlorophylls, and a generally destructive effect on cells occurs (Meyer and others 1973). Kozlowski's results are supported by Ronco (1970) when he found that solarization occurred in unshaded spruce and had deleterious effect on photosynthesis. Effects of solarization, in his study, were severe chlorosis on both older and new needles and branches on open-grown seedlings dieing from top down and from the south- to north-facing scale. In new clearcuts in western Oregon, old western hemlock (*Tsuga heterophylla* [Raf.] Sarg) shade needles abscised prematurely and newly formed needles were smaller than normal (Tucker and Emmingham 1977). These physiological changes were apparently a result of increased water stress when shade needle stomata were unable to close after exposure to increased light intensities. Respiration rates quickly approached or exceeded the photosynthetic rates increasing tree water demands. By understanding the physiological effects on released understory trees, response interpretation will be easier.

# CHAPTER III

# METHODS

## Study Site Descriptions

Study areas were located on each of four National Forests extending from southern Utah to south-central Idaho. Study plots were established in 5-acre (2-ha) overstory removal and selection treatments and control areas on the Payette National Forest in Idaho, Teton (now Bridger-Teton) National Forest in Wyoming, the Uinta National Forest in central Utah, and the Dixie National Forest in southern Utah (fig. 1).

The Payette study area is near Cloochman Creek on the McCall Ranger District, at about 6,000 feet (1829 m) elevation with a west to southwest exposure. Slopes range from 0 to 30 percent and average around 10 percent.

Composition of the virgin stand was 77 percent Engelmann spruce, 18 percent subalpine fir, and 5 percent lodgepole pine (*Pinus contorta*). The mature stand was over 200 years at the time of cutting. Figure 1 in appendix A shows the diameter class distribution by percent of total stems in control areas. Age and height distributions of understory trees are shown on table 3 of appendix B.

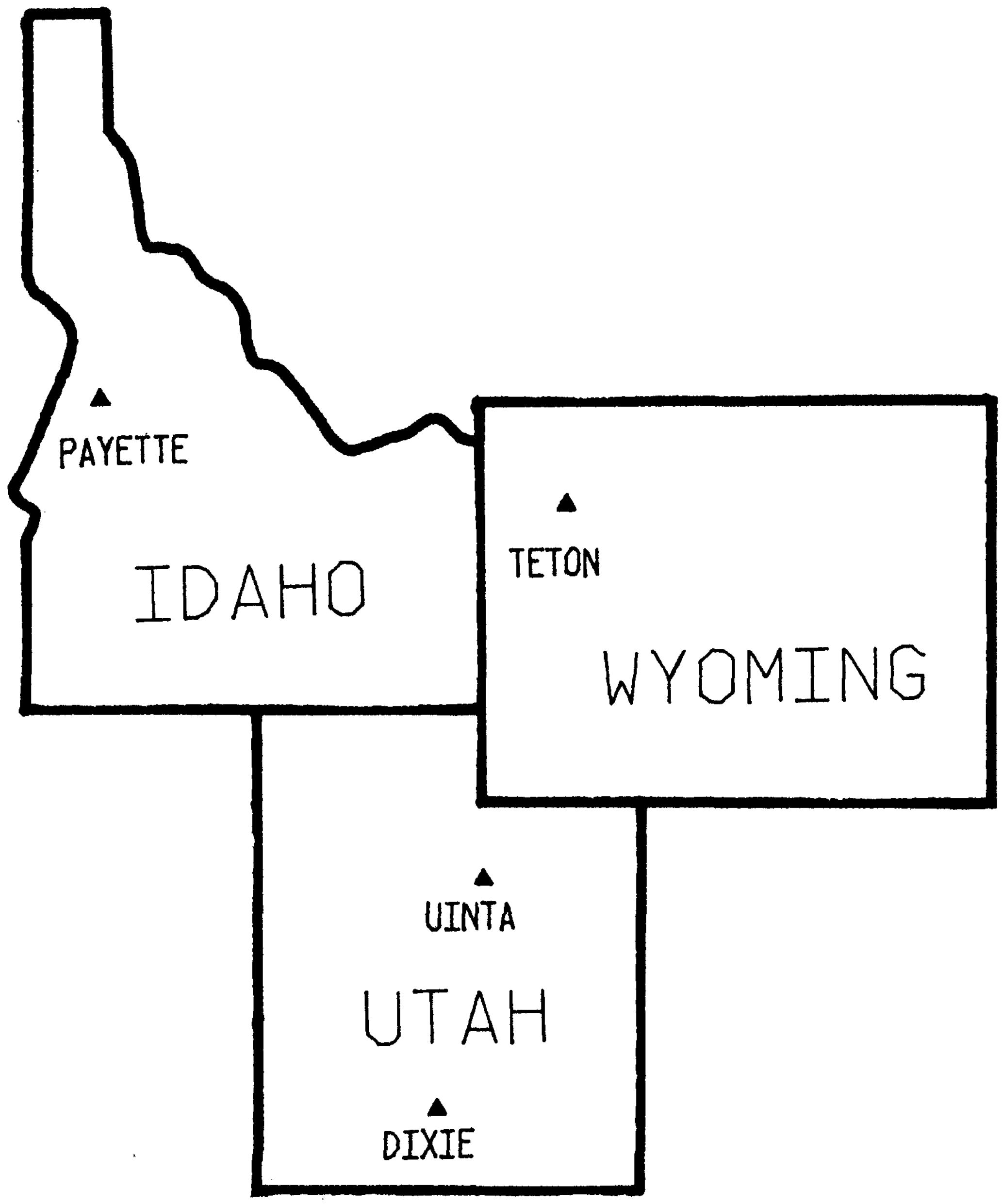



Figure 1. Study area locations on the Payette, Teton, Uinta, and Dixie National Forests.

Three habitat types are represented on the area (Steele and others 1981):

Dry - *Abies lasiocarpa*/*Xerophyllum tenax*, mostly *Vaccinium scoparium* phase,

Moist - *Abies lasiocarpa*/*Xerophyllum tenax*, *Vaccinium globulare* phase, and

Wet - *Abies lasiocarpa*/*Calamagrostis canadensis*, *Ligusticum canby* phase.

The Teton study area is located in Teton County, Wyoming, near East Leidy Creek on the Gros Ventre Ranger District, at approximately 8,600 feet (2621 m) elevation on generally north-facing slopes. Slopes range from 0 to 50 percent, with some pitches up to 70 percent.

The Teton has the largest variety of species found on any of the study areas. Stand composition was 85 percent Engelmann spruce, 8 percent subalpine fir, 6 percent lodgepole and limber pine (*Pinus flexilis*), and 1 percent Douglas-fir at the time of harvesting. The diameter class distribution by percent of total stems, in control areas, is found on figure 2 in appendix A. The age and height distributions of understory trees are shown on table 4 of appendix B.

Stand age of the mature overwood at the time of cutting was between 200 and 300 years old. The general stand condition was good with only minor bark beetle problems in some of the windthrown spruce.

Three habitat types were mapped on the study site (Steele and others [In press]):

Dry - *Abies lasiocarpa/Vaccinium globulare*,

Moist - *Abies lasiocarpa/Actea rubra*, and

Wet - *Abies lasiocarpa/Streptopus amplexifolius*.

The Uinta National Forest study area is in Wasatch County, Utah, on the Heber Ranger District. The plots are at Wolf Creek Pass at 9,500 feet (2896 m) elevation on a northerly aspect with slopes from 10 to 30 percent.

The mature overstory stand consisted of 95 percent Engelmann spruce and 5 percent subalpine fir. Aspen (*Populus tremuloides*) was present on the study site but comprised less than 1 percent of the stand.

General stand condition was good with minimal windthrow and light bark beetle damage. Diameter class distribution by percent of total stems, in control areas, is found on figure 3 in appendix A. The age and height distribution of understory trees are shown on table 5 of appendix B.

One habitat type was found on the area--*Abies lasiocarpa/Berberis repens*, *Berberis* phase (Pfister 1972).

The Dixie study units are located in Garfield County, Utah, on the Aquarius Plateau of the Escalante Ranger District at 10,300 feet (3139 m) elevation on nearly level terrain.

Stand composition of the mature forest was 90 percent Engelmann spruce, 10 percent subalpine fir, and a few small scattered aspen clones. Diameter class distribution by percent of total stems in control areas is found on figure 3 in appendix A. The age and height distributions of understory trees are shown on table 6 of appendix B.

General condition of the mature stand was good, but many snags indicated past beetle attacks. Recent bark beetle activity was light.

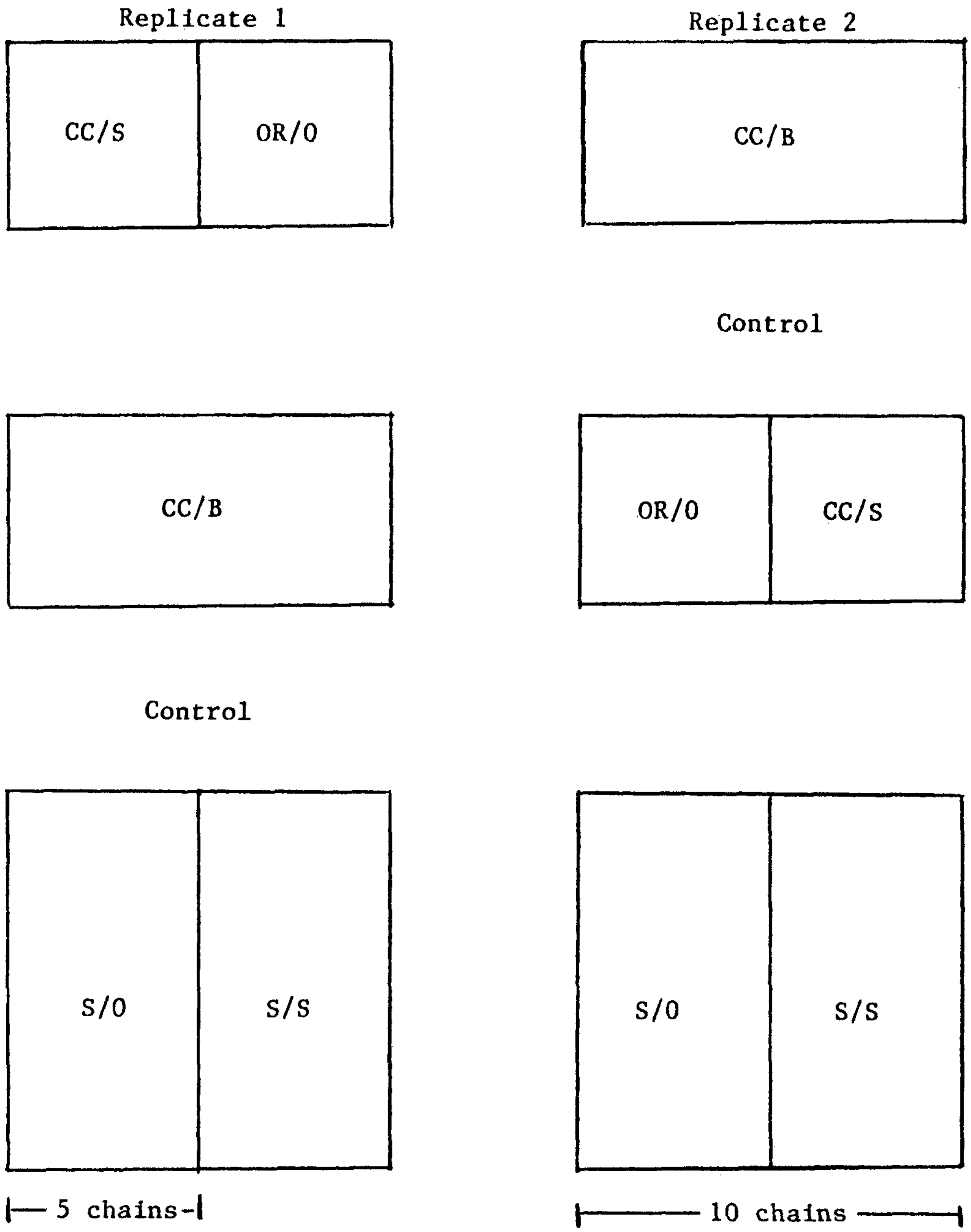
One habitat type, *Abies lasiocarpa/Ribes montigenum*, *Ribes* phase (Pfister 1972) was found on the study area.

## Field Measurement

This study is an offshoot of a 1967 spruce cutting trials study designed to test regeneration establishment on five seedbed combinations: (1) selection cut favoring understory (S/O), (2) selection cut with dozer scarification (S/S), (3) overstory removal favoring understory (OR/O), (4) clearcut with dozer scarification (CC/S), and (5) clearcut with broadcast burning (CC/B)[1]. Figure 2 shows a typical study layout. Ten sampling point locations were selected on each treatment area by

[1] The original spruce cutting trials referred to selection cut treatments as partial cuts and overstory removal treatments favoring understory as clearcuts. Clearcuts with dozer scarification and broadcast burning were correctly named.

Figure 2. Typical study area layout



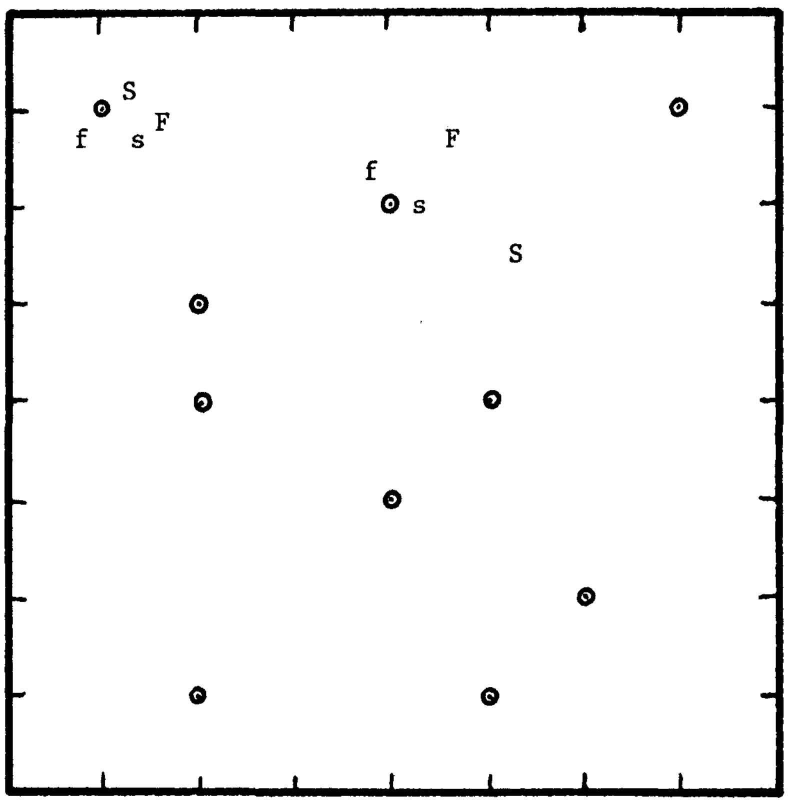

CC/S - Clearcut with dozer scarification
OR/0 - Overstory removal favoring understory
CC/B - Clearcut with broadcast burning
S/S - Selection cut with dozer scarification
S/0 - Selection cut favoring understory

superimposing grids over treatment area maps and randomly selecting coordinate pairs. Using the coordinate pairs, plot centers were then located on the ground. I used those established plot centers within the four treatments favoring understory trees. Uncut timber areas between treatments were used as control areas. The same plot selection procedure as previously described was used to establish 10 plots each in two control areas at each study location.

The majority of the understory trees were from 1 to 15 feet tall, therefore I stratified my samples of Engelmann spruce and subalpine fir understory into two height classes (1.0 to 4.5 feet [0.3 to 1.3 m] and 4.6 to 15.0 feet [1.4 to 4.5 m]). I sampled one tree of each species from each of the two height classes at each of the 10 randomly located plots within a treatment. Sample trees met three study criteria: (1) must be closest of that species and height class to the plot center, (2) cannot be used for more than one plot, and (3) must be at least one tree height (mature stand) distance from treatment edge. The distance criteria was used to eliminate edge effects. Figure 3 shows a typical layout of sample tree locations within a treatment.

Field measurements taken on each sample tree were total tree height to nearest one-tenth foot, live crown length to nearest one-tenth foot. Diameter at breast height (d.b.h.) to the nearest one-tenth inch was measured on all trees taller than four and one half feet. Each tree location was used as a plot center for overstory competition measurements. Two measures of competition were used: (1) crown density using

Figure 3. Typical layout of sample tree locations




Clearcut favoring understory

⊙ - Plot location

s - 1.0' to 4.5' Engelmann spruce

S - 4.6' to 15.0' Engelmann spruce

f - 1.0' to 4.5' subalpine fir

F - 4.6' to 15.0' subalpine fir

a spherical densiometer, and (2) basal area/acre using a variable plot basal-area angle gauge 10-factor (10 BAF). Height to the nearest foot and d.b.h. to the nearest one-tenth inch was measured and recorded for every tree within the variable plot.

Basal disks from sample trees were cut at ground level and used for aging. The bole portion of each tree was sent to Missoula for further measurements.

Tree boles were disected to determine yearly height growth for the past 15 years. Cross-sectional cuts were made to determine where each year's height growth began and ended. Yearly height growth was measured and recorded to the nearest one-tenth inch.

## Analysis

Segmented regression using a special case (two-linear phase) of the general multiple phase regression technique (Johnson 1968) was used to estimate when release response began. This technique is an overall least squares solution of two fitted submodels each having their own least squares solution (Hudson 1966) and a join point whose abscissa has to be estimated. The first submodel (Phase 1) represents the time period before the join point and the second submodel (Phase 2), the time period after the join point. Periodic height growth and time were the dependent and independent variables, respectively.

Simple regressions were run to determine which measured variables were correlated with height growth release response. The dependent variable posttreatment 10-year height growth was regressed against each of the independent variables, pretreatment 5-year height growth, posttreatment basal area, and height, crown length, crown ratio, and age at time of treatment.

# CHAPTER IV

# RESULTS

## Combined Forests

Simple regressions of the dependent variable 10-year posttreatment height growth against each of the independent variables, 5-year pretreatment height growth, posttreatment basal area, and pretreatment height, crown length, crown ratio, and age showed little correlation. Correlation results are shown on tables 8 through 11 of appendix C. Natural logarithms of independent and dependent variables as well as cross product and quadratic terms were also tested with little or no improvement in correlations. Engelmann spruce and subalpine fir increased height growth within treated areas on the Payette, Teton, Uinta, and Dixie National Forests. Figure 4 with corresponding table values (Table 1) shows spruce and fir pre- and posttreatment mean periodic height growth for all four study areas combined. Both species within treated areas showed only small height growth increases in the first 5 years after treatment with no increase in control areas. Spruce and fir height growth was greater in the 6 to 10 year posttreatment period than in the 1 to 5 year posttreatment period. This trend was evident in both the overstory removal and selection cut treatments. Height growth was greatest in the overstory removal treatments,

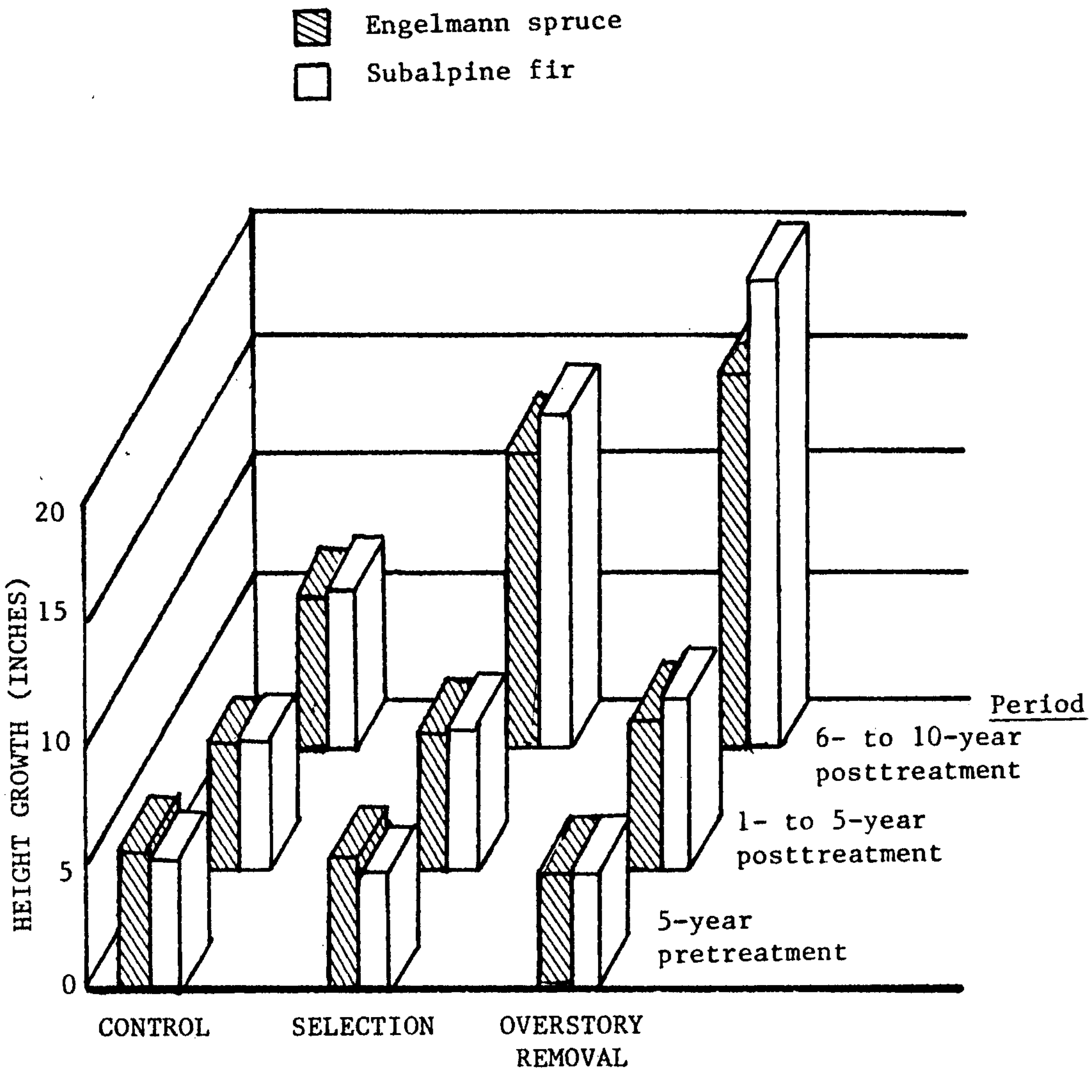



Figure 4. Mean periodic height growth of understory Engelmann spruce and subalpine fir 5-year pretreatment, 1- to 5-year posttreatment, and 6- to 10-year posttreatment on uncut controls, selection cuts, and overstory removal cuts for the combined Payette, Teton, Uinta, and Dixie National Forests.

TABLE 1

MEAN PERIODIC HEIGHT GROWTH OF UNDERSTORY ENGELMANN SPRUCE AND SUBALPINE FIR (HEIGHT CLASSES COMBINED) ON THE PAYETTE, TETON, UINTA, AND DIXIE NATIONAL FORESTS

| | | Control | | | Selection | | | Overstory Removal | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean height growth (ft) | V | n | Mean height growth (ft) | V | n | Mean height growth (ft) | V | n |
| 5-Year Pretreatment | ES | 5.7 | 24.4 | 159 | 5.5 | 21.1 | 158 | 4.7 | 12.4 | 149 |
| | SAF | 5.4 | 28.6 | 151 | 4.5 | 24.1 | 149 | 4.7 | 23.0 | 144 |
| 1- to 5-Year Posttreatment | ES | 5.1 | 15.1 | 159 | 5.9 | 15.1 | 158 | 6.1 | 15.4 | 149 |
| | SAF | 4.9 | 13.3 | 151 | 6.0 | 15.6 | 149 | 6.7 | 19.1 | 144 |
| 6- to 10-Year Posttreatment | ES | 6.2 | 29.2 | 159 | 12.1 | 84.4 | 158 | 15.2 | 93.5 | 149 |
| | SAF | 6.4 | 28.2 | 151 | 13.7 | 83.4 | 149 | 19.1 | 123.7 | 144 |

ES - Engelmann spruce
SAF - subalpine fir
V - variance
n - number of observations

intermedial in selection cut treatments, and none in control areas. Fir continued to show greater height growth resonse than spruce as time since treatment increased. Throughout the measurement period, the control areas showed no change in height growth.

## Payette National Forest

On the Payette National Forest, spruce and subalpine fir responded to release by increasing height growth over that of their pretreatment rate for both the 1- to 5- and 6- to 10-year measurement periods. Height growth increase was greatest in the overstory removal treatments, intermedial in selection cuts, and essentially none in uncut stands (fig. 5). Table values for figure 5 can be found on table 12 of appendix D. Height growth response was modest in the 1- to 5-year posttreatment period; but during the 6- to 10-year posttreatment period, both species in the overstory removal cuts grew about three and a half times more than their pretreatment measurement. In selection cuts, height growth response was just over three times their pretreatment growth. Response in both treatments was substantially greater than the controls, but not significantly different from each other. The Payette was one of two study sites where Engelmann spruce height growth responded about equal to or better than subalpine fir in both the 1- to 5- and 6- to 10-year posttreatment periods (fig. 5).

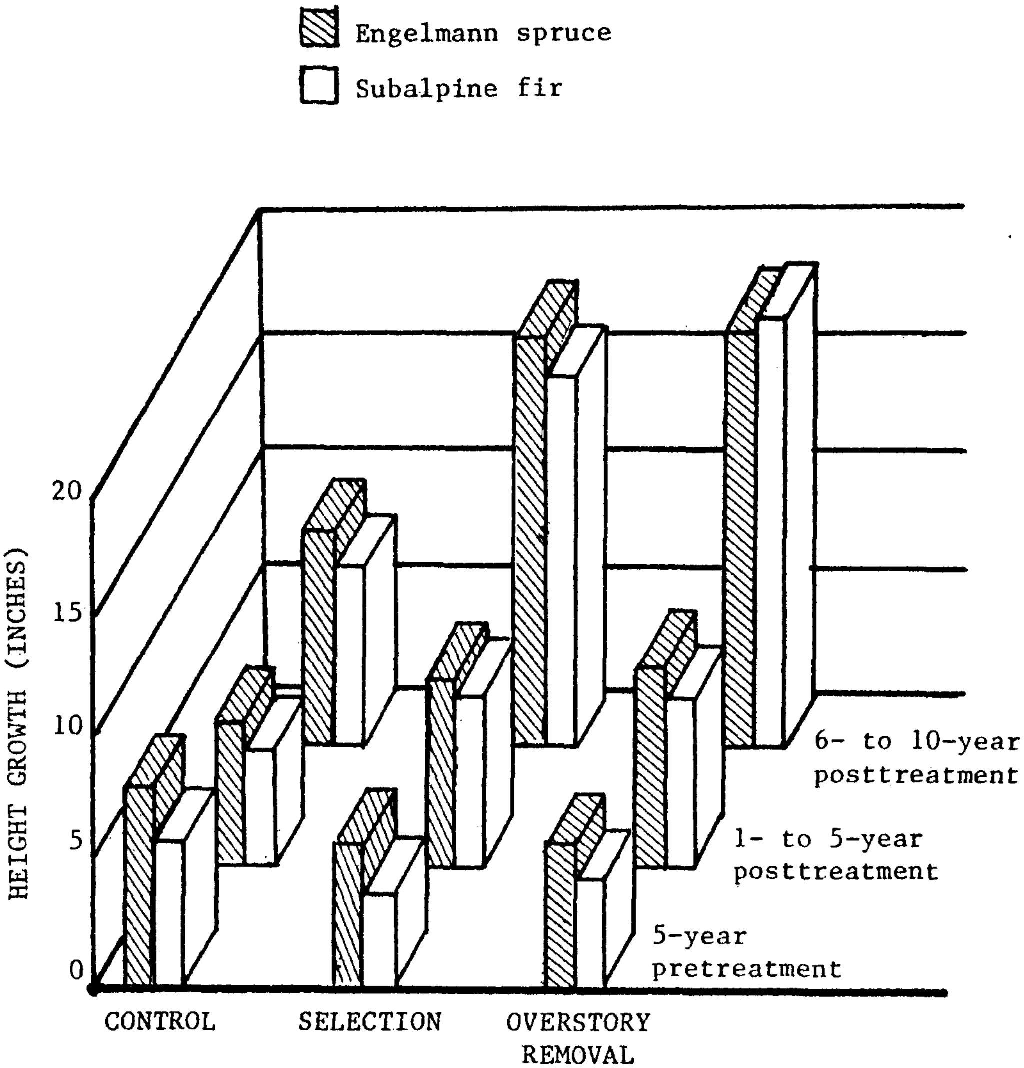



Figure 5. Mean periodic height growth of understory Engelmann spruce and subalpine fir (height classes combined) 5-year pretreatment, 1- to 5-year posttreatment, and 6- to 10-year posttreatment on uncut controls, selection, and overstory removal treatments on the Payette National Forest.

A severe windstorm in 1969 caused extensive windthrow of residual overstory on one selection cut creating a situation similar in appearance to the overstory removal treatment and may account for the relatively small difference in growth response between them. A minor amount of stand disturbance in the uncut controls from windthrow possibly accounted for minor increases in height growth in the 6- to 10-year posttreatment period.

Segmented regression analyses (figs. 6 and 7) show sample tree height growth rates increasing during the 5-year period following harvesting. Regression coefficients and statistics, output by the segmented regression computer program, are shown on table 16 of appendix E. Subalpine fir responded to release within 2 years, while Engelmann spruce took 3 to 5 years to accelerate height growth. The only exception occurred in the partial cut where the spruce upper height class (4.6 to 15.0 feet [1.4 to 4.5 m] tall) trees responded similar to the fir.

Subalpine fir of both height classes (1.0 to 4.5 feet [0.03 to 1.37 m] and 4.6 to 15.0 feet [1.38 to 4.57 m]) responded at about the same time, but grew more and faster than the shorter fir on both overstory removal and selection treatments. Engelmann spruce response patterns were similar to those of fir, but the time of response was inconsistent between tree sizes and stand treatments. Spruce height growth in the taller height class was greater but took place at rates

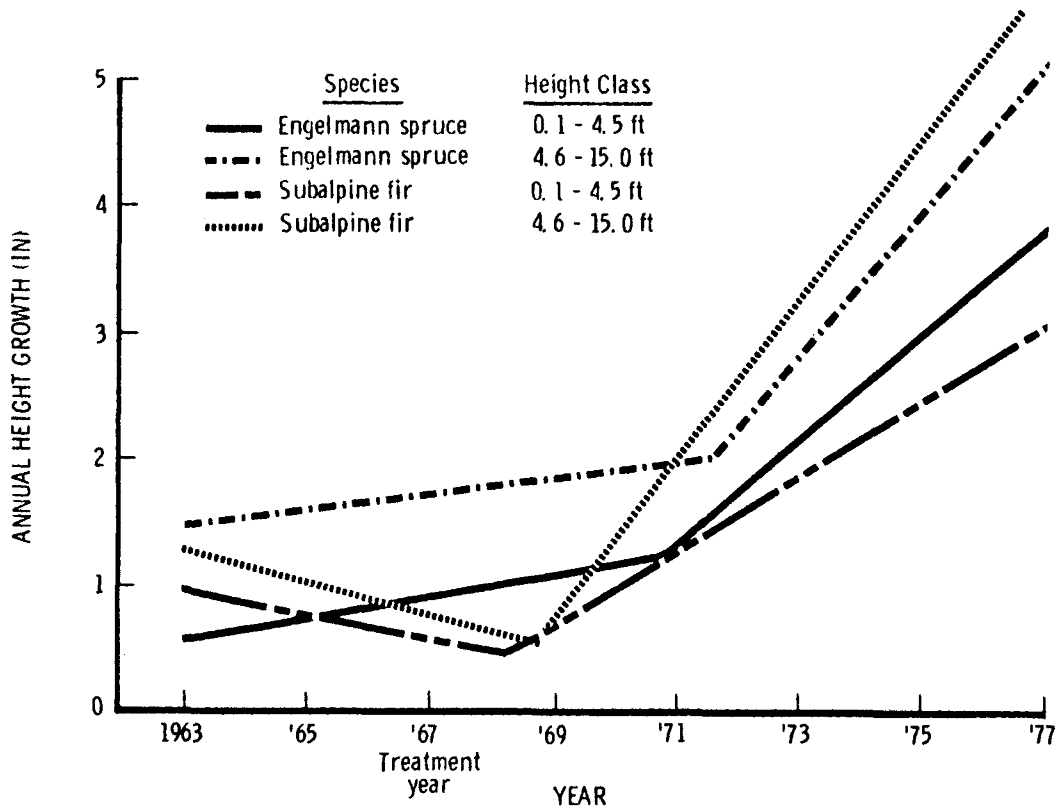



Figure 6. Annual height growth of Engelmann spruce and subalpine fir on overstory removal treatments on the Payette National Forest by year and height class. Lines are plotted from segmented regression values.

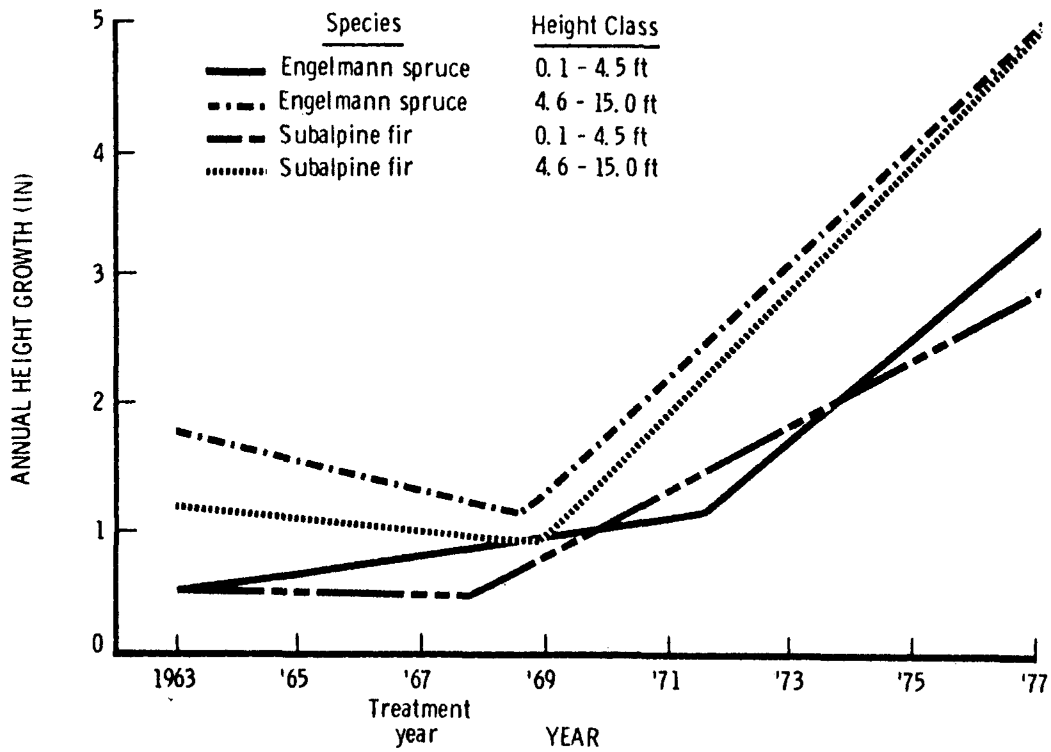



Figure 7. Annual height growth of Engelmann spruce and subalpine fir on selection treatments on the Payette National Forest by year and height class. Lines are plotted from segmented regression values.

similar to those of the shorter height class. In the controls, spruce and fir showed pretreatment growth patterns similar to trees within cut treatments. Values for control trees were not plotted since they showed no height growth response or windthrow influenced their growth.

## Teton National Forest

Height growth release response was substantial for both Engelmann spruce and subalpine fir on the Teton National Forest. Posttreatment height growth response was greatest in the overstory removal treatments, intermediate in selection treatments, and essentially none in the uncut controls (fig. 8). Table values for figure 8 can be found on table 13 of appendix D. During the 6- to 10-year posttreatment period, trees in overstory removal treatments grew an average of over four times their pretreatment growth and about twice that of their 1- to 5-year posttreatment period. Trees in partial cuts grew much less than trees in overstory removal treatments but still doubled their pretreatment growth.

Segmented regression results (figs. 9 and 10) like on the Payette National Forest show sample tree height growth rates beginning to increase within 5 years of treatment. Regression coefficients and statistics output by the segmented regression computer program are shown on table 17 of appendix E. Subalpine fir responded 2 years after overstory removal and spruce 3 to 4 years. This relationship was not

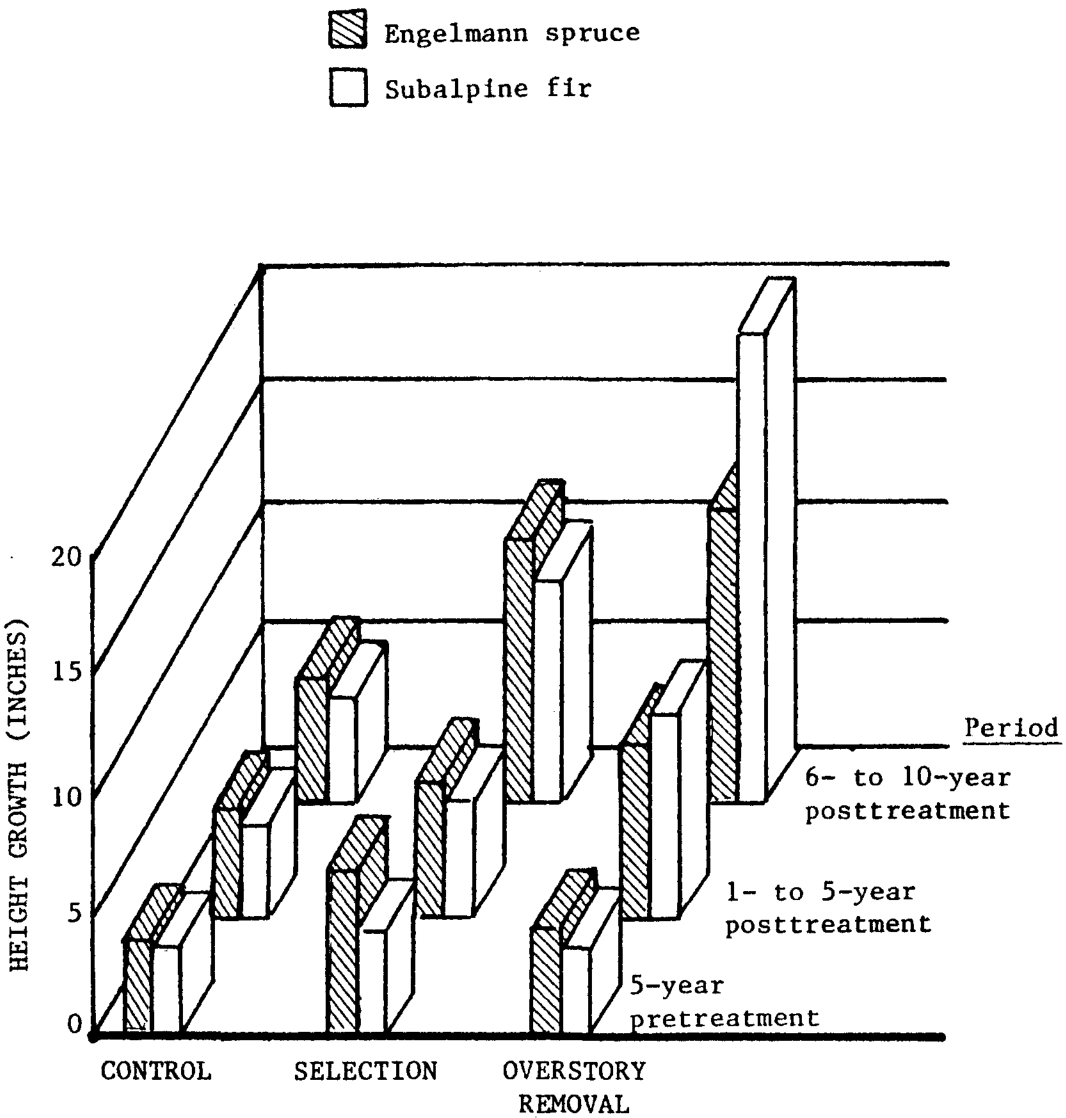



Figure 8. Mean periodic height growth of understory Engelmann spruce and subalpine fir (height classes combined) 5-year pretreatment, 1- to 5-year posttreatment, and 6- to 10-year posttreatment on uncut controls, selection, and overstory removal treatments on the Teton National Forest.

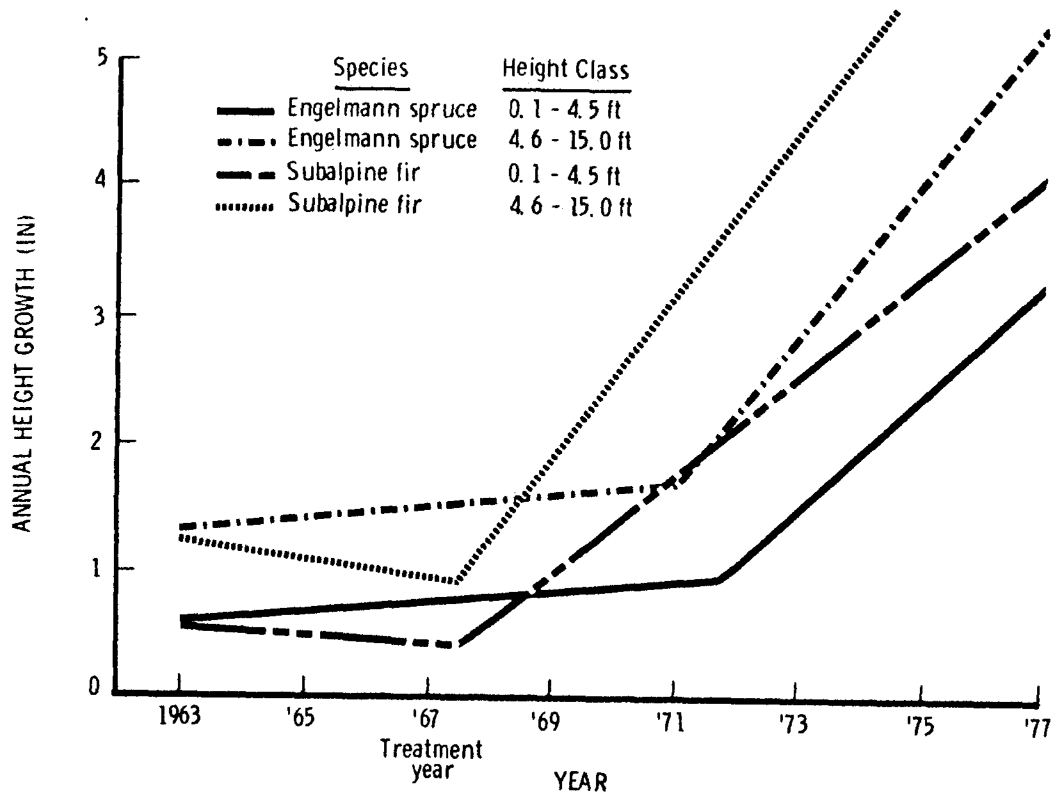



Figure 9. Annual height growth of Engelmann spruce and subalpine fir on overstory removal treatments on the Teton National Forest by year and height class. Lines are plotted from segmented regression values.

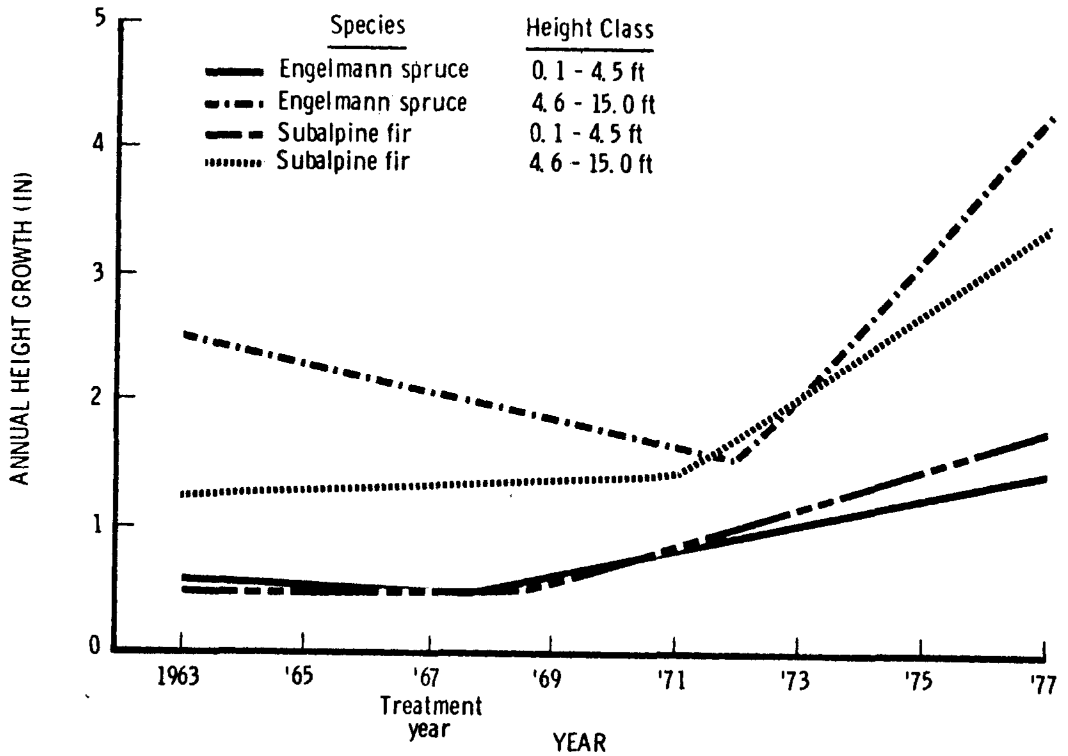



Figure 10. Annual height growth of Engelmann spruce and subalpine fir on selection treatments on the Teton National Forest by year and height class. Lines are plotted from segmented regression values.

apparent on selection treatments where taller trees (4.6 to 15.0 feet [1.40 to 4.57 m]) of both species responded later than shorter trees (1.0 to 4.5 feet [0.3 to 1.37 m]). Control tree response was essentially zero, therefore, values were not plotted.

Taller trees of both species generally responded more than smaller trees. The substantial differences in growth response between overstory removal and selection treatments held true for both large and small trees.

## Uinta National Forest

Engelmann spruce and subalpine fir posttreatment height growth response on the Uinta National Forest was similar to growth responses on the Teton National Forest. There were only modest increases in height growth in the 1- to 5-year posttreatment period and large increases in height growth during the 6- to 10-year posttreatment period (fig. 11). Table values for figure 11 can be found on table 14 of appendix D. Tree growth in the uncut controls remained essentially static.

In the 1- to 5-year posttreatment period, there were only minor increases in height growth. Average height growth of spruce and fir in the 6- to 10-year posttreatment period increased five to six times that of their pretreatment growth on both overstory removal and selection treatments. It should be noted, however, that pretreatment growth here was very low--only about an inch (2.5 cm) a year. Subalpine fir height growth was greater than Engelmann spruce on both overstory removal and selection treatments, particularly in the 6- to 10-year posttreatment period (fig. 11).

The year when sample tree height growth release response began on the Uinta National Forest is shown in figures 12 and 13. Regression coefficients and statistics output by the segmented regression computer program are shown on table 18 of appendix E. Engelmann spruce and subalpine fir in both height classes showed increased height growth rates within 5 years after treatment. Except for the lower height class spruce, height growth rates in both height classes and cutting treatments were similar. The upper height class fir were growing at the fastest rates. Sample tree growth rates within the controls were nearly static except for the taller upper height class fir which may have been influenced by the minor amount of windthrow that was observed.

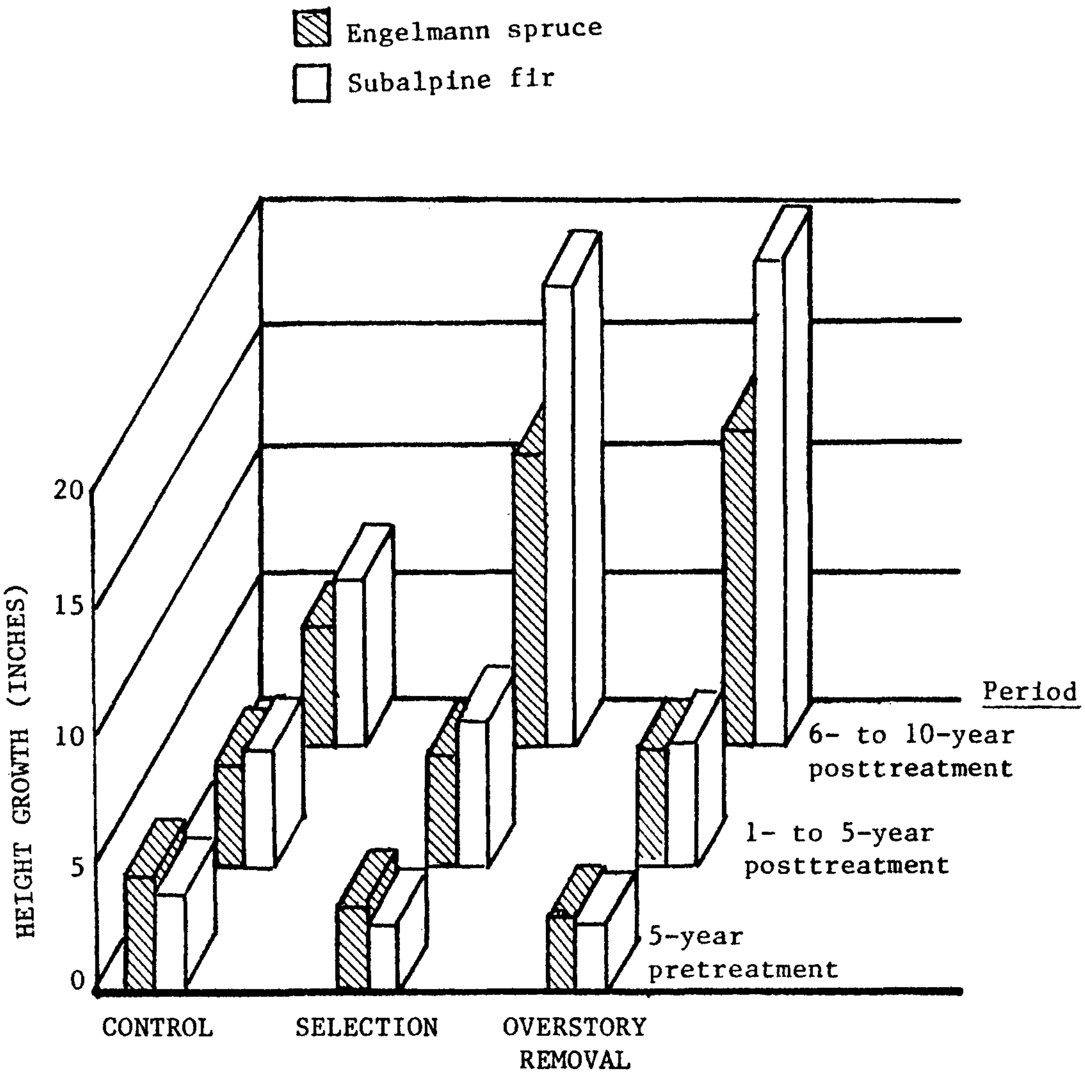



Figure 11. Mean periodic height growth of understory Engelmann spruce and subalpine fir (height classes combined) 5-year pretreatment, 1- to 5-year posttreatment, and 6- to 10-year posttreatment on uncut controls, selection, and overstory removal treatments on the Uinta National Forest.

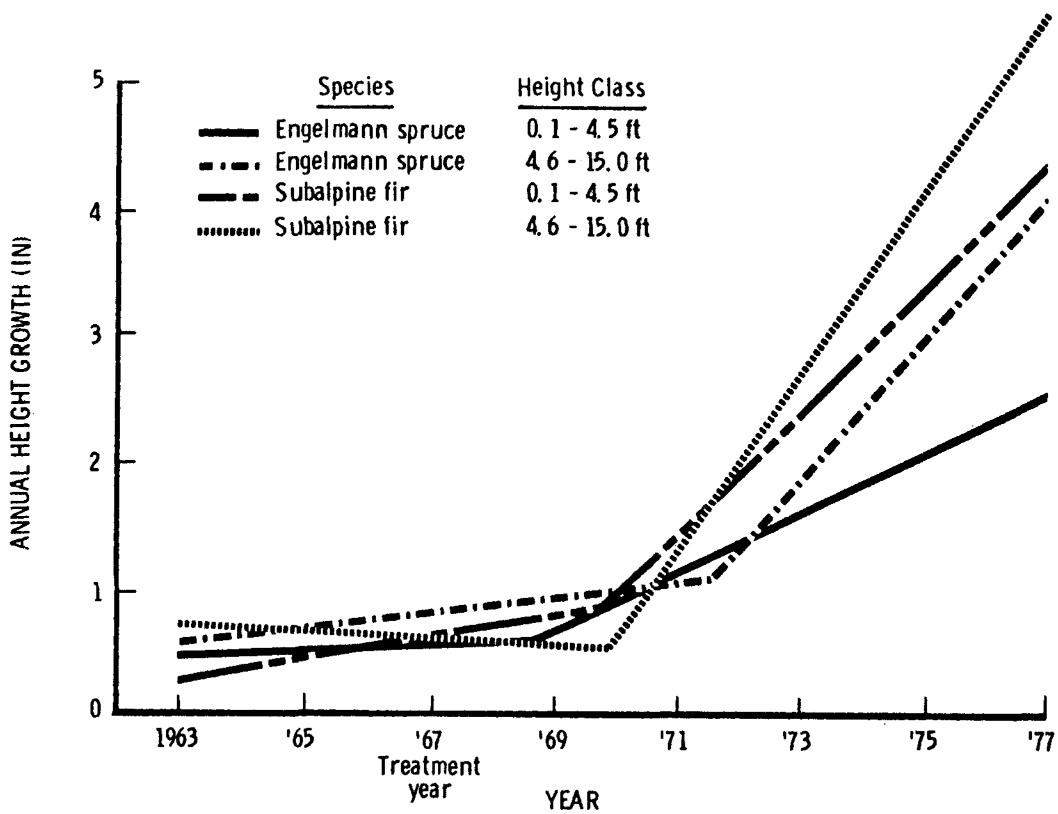



Figure 12. Annual height growth of Engelmann spruce and subalpine fir on overstory removal treatments on the Uinta National Forest by year and height class. Lines are plotted from segmented regression values.

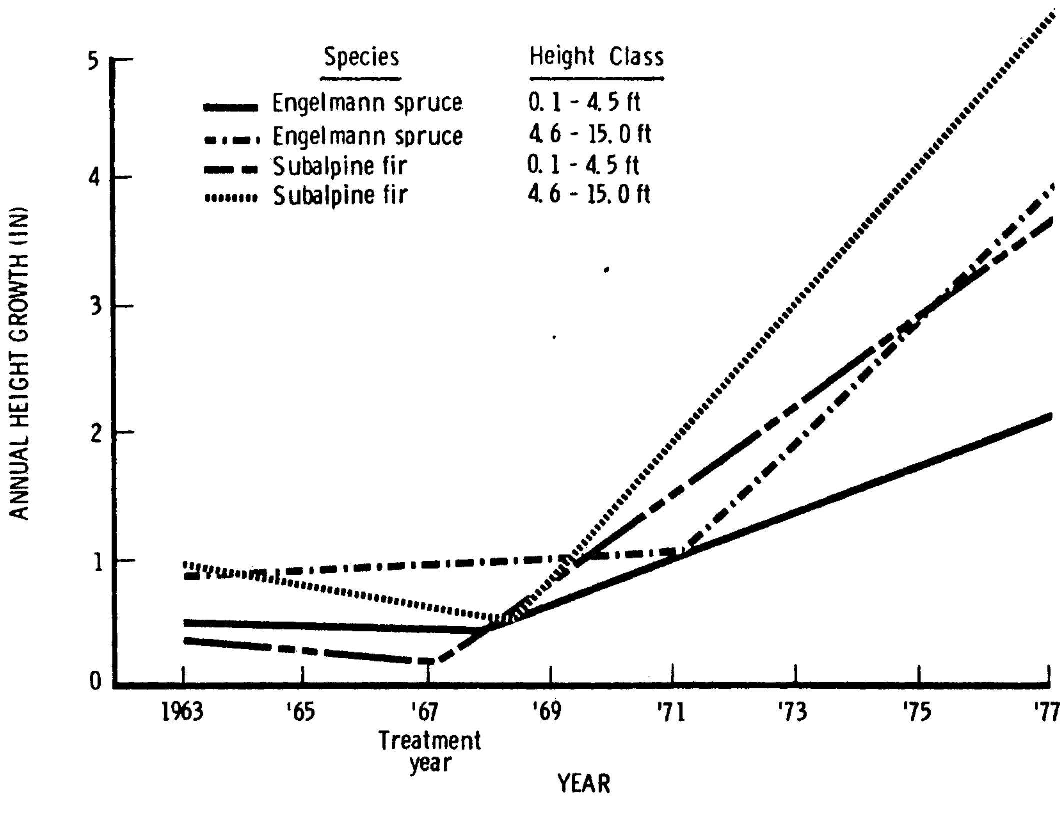



Figure 13. Annual height growth of Engelmann spruce and subalpine fir on selection treatments on the Uinta National Forest by year and height class. Lines are plotted from segmented regression values.

## Dixie National Forest

Engelmann spruce and subalpine fir responded substantially in height growth during the 6- to 10-year posttreatment period following both selection cutting and overstory removal on the Dixie National Forest (fig. 14). Table values for figure 14 can be found in table 15 of appendix D. Trees that were averaging 2 to 3 inches (5 to 8 cm) annual height growth under pretreatment conditions averaged over 6 inches (15 cm) annually during the 6- to 10-year posttreatment period.

Average height growth during the 1- to 5-year posttreatment period was about the same or slightly less than the pretreatment growth on both cutting treatments. Trees in uncut controls remained essentially static in height growth for the 15-year measurement period.

In the 6- to 10-year posttreatment period, trees within overstory removal treatments grew about a third faster than trees in selection treatments and more than doubled their pretreatment height growth. Trees in the selection treatments increased their height growth about 50 percent over their pretreatment growth.

Segmented regression results show sample tree, height growth, rates beginning to accelerate within 5 years after treatment (figs. 15 and 16). Regression coefficients and statistics, output by the segmented regression computer program, are shown on table 19 of appendix E. In overstory removal treatments, the taller height class Engelmann spruce and subalpine fir were growing more and at faster rates than their

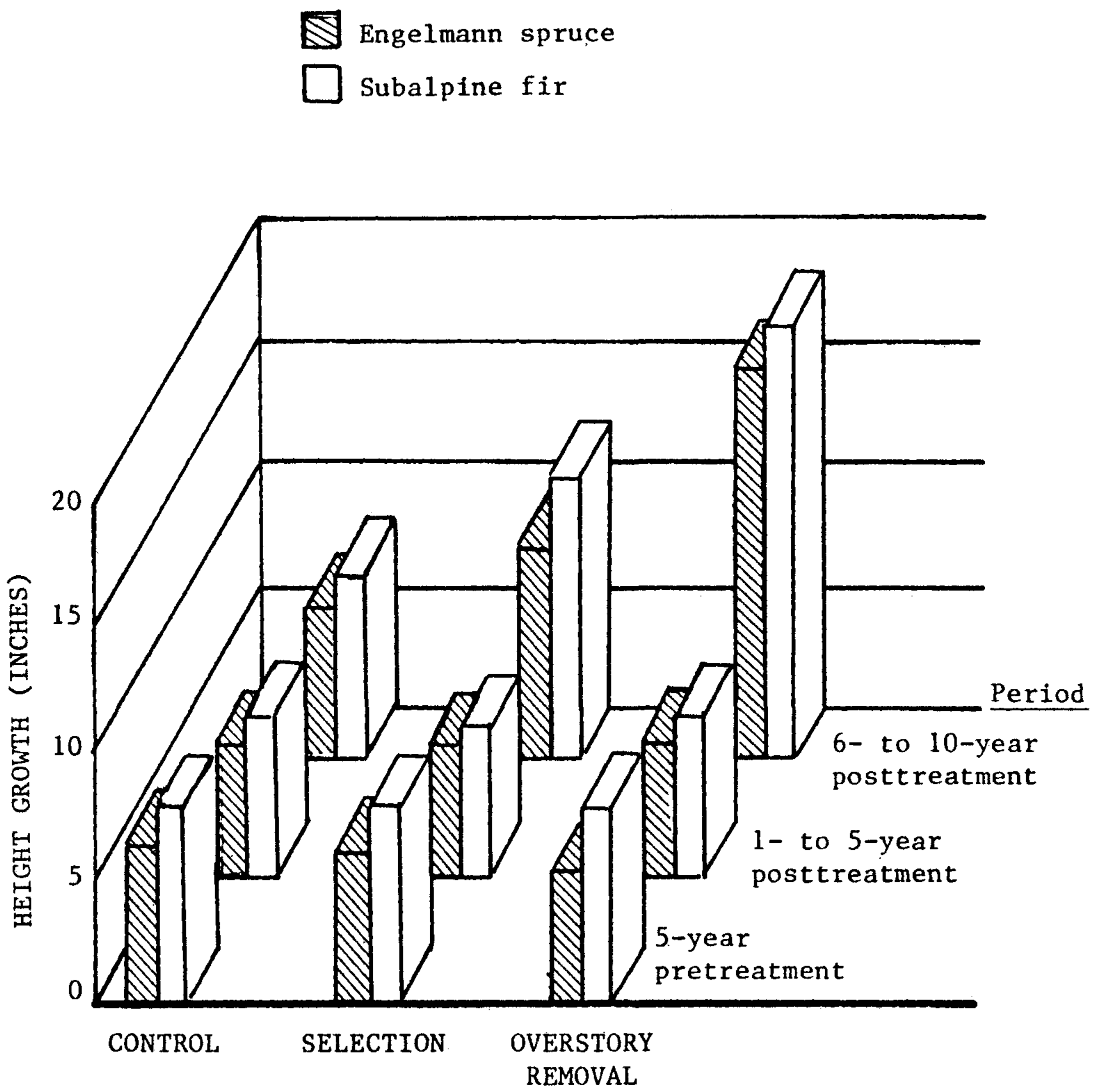



Figure 14. Mean periodic height growth of understory Engelmann spruce and subalpine fir (height classes combined) 5-year pretreatment, 1- to 5-year posttreatment, and 6- to 10-year posttreatment on uncut controls, selection, and overstory removal treatments on the Dixie National Forest.

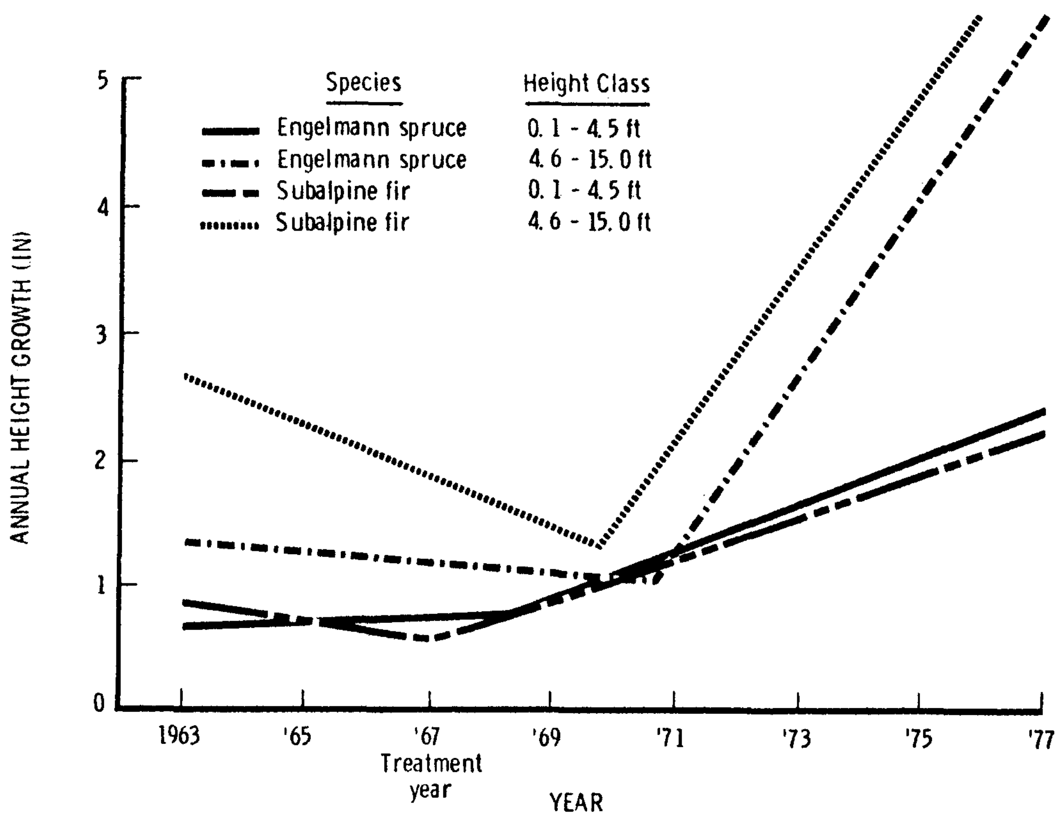



Figure 15. Annual height growth of Engelmann spruce and subalpine fir on overstory removal treatments on the Dixie National Forest by year and height class. Lines are plotted from segmented regression values.

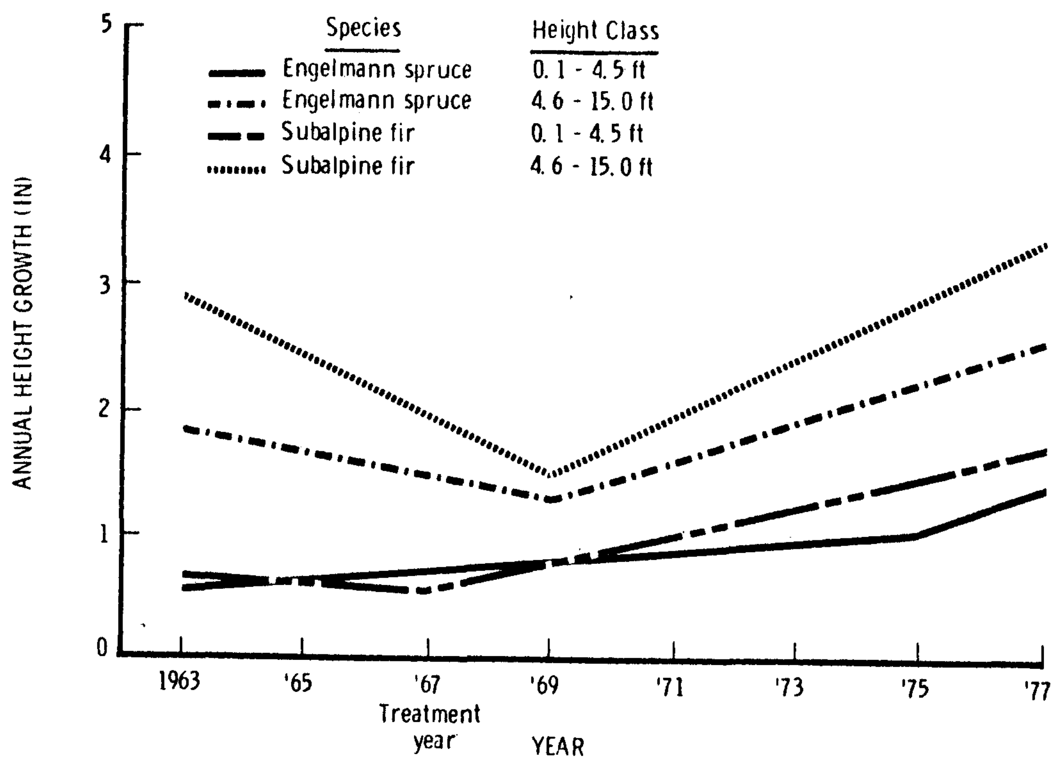



Figure 16. Annual height growth of Engelmann spruce and subalpine fir on selection treatments on the Dixie National Forest by year and height class. Lines are plotted from segmented regression values.

shorter counterparts after treatment response began. In the selection treatments the overall height growth of the taller spruce and fir was greater but height growth rates were similar. Height growth response of small spruce on the overstory removal treatments was essentially undetectable. Growth rates of all spruce and fir control trees remained static throughout the measurement period, therefore, they were not plotted on figures 14 and 15.

# CHAPTER V

# DISCUSSION

This is a supplemental study of a 1967 administrative study plan designed to test regeneration establishment under two management alternatives: (1) even-aged management and (2) uneven-aged management. One study area was established on each of four National Forests (Payette, Teton, Uinta, and Dixie). Five cutting method-seedbed combinations were set up on each study area: (1) selection cutting favoring understory trees, (2) selection cutting with dozer scarification, (3) overstory removal favoring understory trees, (4) clearcut with dozer scarification, and (5) clearcut with broadcast burning. Two replications of each seedbed combination were established. Each study area was assumed to be within a large homogeneous Engelmann spruce-subalpine fir forest stand.

In the administrative study plan, the terms clear- and partial cutting described the two silvicultural systems used. Clearcutting is clearing an area of all trees, large or small. The treatments used for my study were overstory removal and selection cuts. The overstory removal treatments removed all mature trees taller than 15 feet with emphasis put on protecting the smaller understory trees. The selection cut treatments were single tree selection cuts on the Payette and Teton and small group selections on the Uinta and Dixie National Forests.

In spite of a wide geographical separation, understory tree components on the four study areas were very similar, with Engelmann spruce and subalpine fir predominating. Although lodgepole pine occurred on the Teton and Payette, limber pine on the Teton, and aspen on the Uinta and Dixie National Forests, the small numbers of these species were insignificant. The average basal area remaining after treatment on the four study areas is shown in table 7 of appendix B. Remaining basal area within the overstory removal treatments was due to residual understory trees. Some treatment areas had been altered due to natural disturbances. A severe windstorm in 1969 caused extensive blowdown of residual overstory on one selection treatment and control areas on the Payette National Forest. Small amounts of blowdown were observed on cut units and within uncut controls on all sample areas. This could be why the Payette and Uinta control areas showed some increased height growth in the 6- to 10-year posttreatment period.

Two factors, not well identified in this study, were the long-term effect of logging damage and mortality. Although some sample trees were damaged during logging, I found no evidence of decay. Ten years may be insufficient time, however, for decay to become apparent under these cold conditions. A measure of mortality was not incorporated into this study. This is an important factor since survival has a direct effect on postharvest understory tree stocking.

Comparing my data with subsequent or artificial (planting stock) regeneration from the same or adjacent areas is another weak point of this study. Hanley and Pfister, however, measured natural and planted regeneration on the Dixie National Forest in the proximity of our study area. Here, 8-year-old plantations of spruce have reached 2 feet (0.61 cm) in height and current annual height increments are approaching 6 inches (15.2 cm). Natural regeneration in the same period have reached a height of 1 foot (30.5 cm) with annual height increments of about 3 inches (7.6 cm).

Regression analysis showed little correlation between the 10-year height growth response and each of the six independent variables, 5-year pretreatment height growth, posttreatment basal area, and height, crown length, crown ratio and age at time of treatment. Segmented regression along with the trends shown on figure 4 indicate that time is an important factor in height growth response. The height growth trends for treated areas seem to be continuing but a more long term study would be needed to evaluate future trends. Relationships between response and measured variables were not evident. In future studies involving height growth release response of spruce and fir, new or finely stratified variables should be examined.

Age was originally assumed to be highly correlated with height growth response. Figures and tables in appendix F show pre- and posttreatment height growth for spruce and fir, on each national forest, stratified into six age classes (1-20, 21-40, 41-60, 61-80, 81-100, and 100+ years). The high degree of variability of height growth within and between age classes explains why age wasn't highly correlated with postharvest growth. Trees of younger age classes were expected to respond earlier and with greater height growth than older trees. Again the high variability of height growth data explains why younger age classes did not show stronger relationships. Ferguson and Adams (1979) found age of grand fir advance regeneration to be important for release potential. They recommended that trees older than 30 years should not be released. Seidel (1980) did not consider age in his study of diameter and height growth of suppressed grand fir saplings after overstory removal. Shoot growth, cambial growth, root growth and many other physiological processes tend to slow down with age, therefore, future studies should recognize age and stratify sampling to adequately represent the full range of ages and sizes of understory trees.

Tree data were stratified into two height classes (1.0 to 4.5 feet [0.3 to 1.3 m] and 4.6 to 15.0 feet [1.4 to 4.5 m]) which I thought would also stratify the sample into young and old trees. Trees three and four feet tall were found to be over 100 years old accounting for the poor correlation between age and height.

Understory trees under certain circumstances can be a valuable resource tool. The following list gives some of the advantages and disadvantages of utilizing understory trees.

Advantages:

1. Understory trees serve as immediate growing stock.

2. Understory trees provide shade needed for subsequent natural and artificial regeneration.

3. Understory trees may provide a sufficient continuity of "green" forest to help meet wildlife cover and esthetic objectives.

4. Soil protection is afforded by retaining at least some forest cover.

5. Time needed to grow merchantable-sized trees may be reduced.

6. The amount of site preparation needed for subsequent natural and artificial regeneration can be reduced.

7. Species diversity may be enhanced.

Disadvantages:

1. Logging damage to understory trees may predispose them to fungi, causing root and butt rots (Walters 1978).

2. Understory trees are already physiologically old and thus prone to insect and disease problems.

3. Utilizing understory trees can encourage disgenic practices by leaving unhealthy or slow growing trees.

4. Understory trees may shortsightedly be used on sites where more intensive management practices are justified.

5. Harvesting costs are increased because of the need to protect the understory.

6. Site preparation needed for subsequent regeneration is made more difficult.

Managers need to weight the alternatives before making decisions concerning our natural resources. Many of the spruce-fir stands of the Intermountain west contain large numbers of suppressed understory trees. This study indicates release does occur and hopefully, future studies will further quantify release response.

# CHAPTER VI

## MANAGEMENT IMPLICATIONS

Good management of spruce-fir forests has always been a difficult task. Most mature spruce-fir forests have an understory of suppressed trees which some managers regard as a hindrance and others regard as a salvation. As Roe and others (1970) concluded, understory trees should be evaluated before harvesting to determine whether it qualifies as acceptable growing stock and has management potential.

This study indicates that spruce and fir understory do respond to release. Trees showed more height growth response in overstory removal treatments than in selection cut treatments but when, how much, and how long response occurs is questionable. The highly variable understory height growth response will not justify a recommendation of using understory trees as future crop trees. The advantages and disadvantages of using understory trees should be carefully weighted before any decisions are made.

# CHAPTER VII

## SUMMARY

My objective for this study was to determine if, when, and how much Engelmann spruce and subalpine fir advance regeneration responds to release conditions created by overstory removal and selection cutting.

I destructively sampled 10 trees each of Engelmann spruce and subalpine fir from two height classes (1.0 to 4.5 feet [0.3 to 1.3 m] and 4.6 to 15.0 feet [1.4 to 4.5 m]) in overstory removal treatments, selection cut treatments, and control areas. There were two replications of each treatment on the Payette, Teton, Uinta, and Dixie National Forests. Total sample was only 956 trees since one treatment on the Teton National Forest did not contain enough advance regeneration.

Measurements taken on each sample tree were total age, diameter at breast height if the tree was taller than 4.5 feet, total height, live crown length, vigor, and yearly height growth for the past 15 years. Basal area per acre and overstory crown density were used as measures of overstory tree competition.

Segmented regression was used to estimate the time after release that height growth response began. Posttreatment height growth trends were shown for spruce and fir from control, overstory removal, and selection treatments on each National Forest.

One unknown of timber harvesting in the spruce-fir forests of the Intermountain Region has been the response potential of understory. This study begins to help define this response for the first 10 years after harvesting. It reports that these understory trees do show response after they have adjusted to their new environment even though they are probably a lot older than thought. Even though height growth increases dramatically percentage-wise, their absolute growth, even after 10 years of release, is modest.

Height growth response of both Engelmann spruce and subalpine fir understory trees exhibited a similar pattern throughout all four study areas. Their overall summary (fig. 3) shows the same general trends. From this summary the following generalizations can be made:

1. Both species responded to release by substantially increasing their height growth--greatest in overstory removal treatments, intermedial in selection cut treatments, and essentially none in uncut controls--a direct relationship to the amount of residual overwood.

2. Trees in overstory removal treatments grew an average of nearly four times faster during the 6- to 10-year posttreatment period than before treatment.

3. Although both spruce and fir responded by increasing their height growth during the first 5 years after treatment, increases during this period were relatively minor compared to those in the 6- to 10-year period.

4. Prior to release, spruce and fir height growth, with only minor exceptions, was about the same on all areas. Subalpine fir responded sooner, however, than Engelmann spruce on both selection and overstory removal treatments.

5. Height growth release began from 1 to 5 years after treatment, with fir response delayed an average of 1 to 2 years, and spruce 3 to 4 years (table 2).

6. Taller trees (4.6 to 15.0 feet [1.4 to 4.57 m]) responded 1 to 3 years later than shorter trees.

7. Spruce and fir height growth of both height classes and on both cutting treatments was still accelerating on all four forests 10 years after treatment.

TABLE 2

AVERAGE NUMBER OF YEARS AFTER HARVESTING BEFORE HEIGHT GROWTH RESPONSE STARTED BY HARVEST TREATMENT, SPECIES, AND HEIGHT CLASS

| Treatment | Species | Height Class<br>1.0 to 4.5 ft<br>(0.3 to 1.31 m) | <br>4.6 to 15.0 ft<br>(1.4 to 4.5 m) | Average |
|---|---|---|---|---|
| | | - - - - - - - - Years to respond | - - - - - - - - | |
| Overstory Removal | Spruce | 2.8 | 4.3 | 3.6 |
| | Fir | 1.2 | 1.9 | 1.6 |
| Selection Cut | Spruce | 3.4 | 3.1 | 3.2 |
| | Fir | 0.7 | 2.3 | 2.5 |
| | Average | 2.0 | 2.9 | 2.5 |

8. Understory tree height growth within the uncut controls remained virtually constant on all four study areas during the observed 15-year period. Some control trees showed a slight decline in growth over time, and some a slight increase where there had been minor disturbances, but both of these exceptions were minor.

9. Average ages of the understory trees were much higher than one would expect for trees under 15 feet (4.57 m) tall--spruce averaged 68 years and fir 74 years on the four study areas, with a total age range of 5 to 195. Sixty-eight percent of the spruce and fir sampled were in the age range between 31 to 104 years and 38 to 109 years, respectively. This compares well with age and successional data from earlier work in southern Utah (Hanley and others 1975). Height and age were poorly correlated.

10. With the best combinations of area, treatment, and species, annual height growth the 10th year after treatment averaged about 6 inches (15.2 cm). The overall average the 10th year was about 4.5 inches (11.4 cm) on in overstory removal treatments and 3.2 inches (8.13 cm) on selection treatments.

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# APPENDIX A

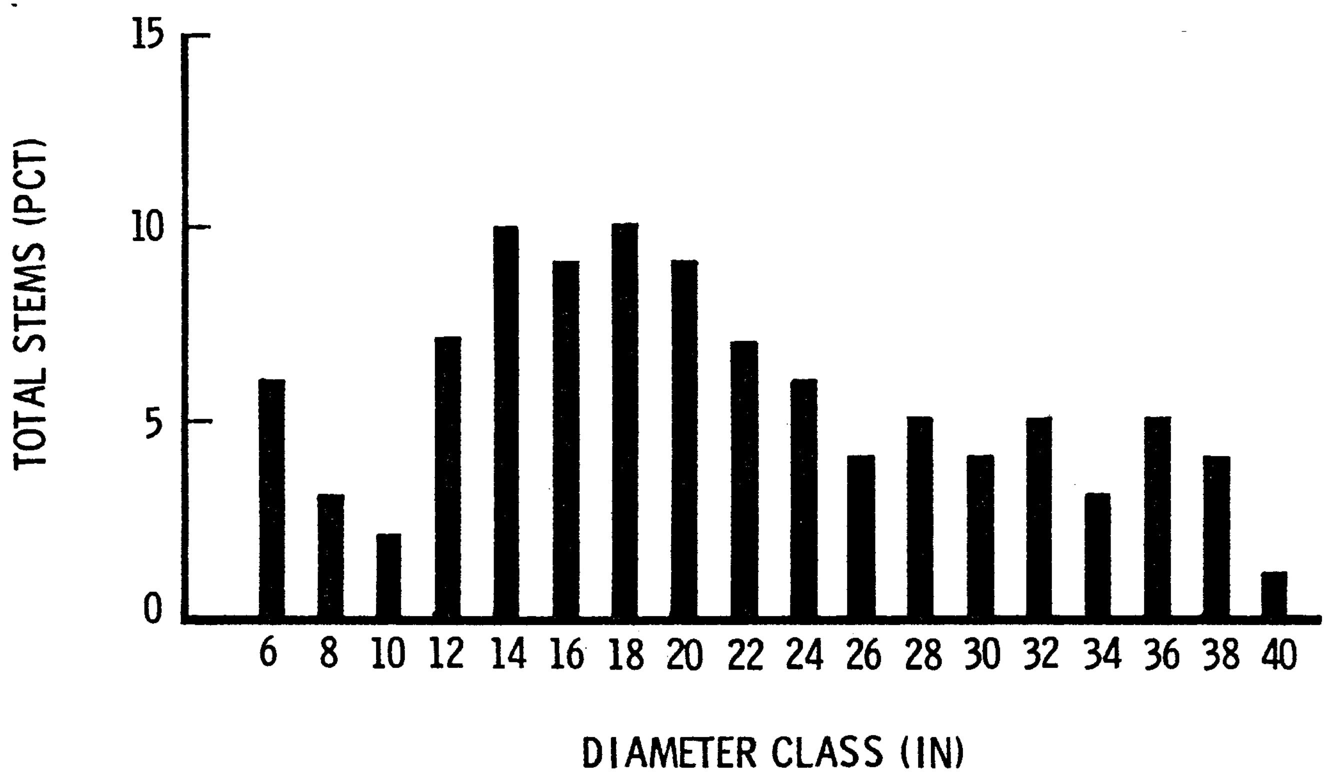


Figure 17. Percent of total stems for each 2-inch diameter class on the Payette National Forest.

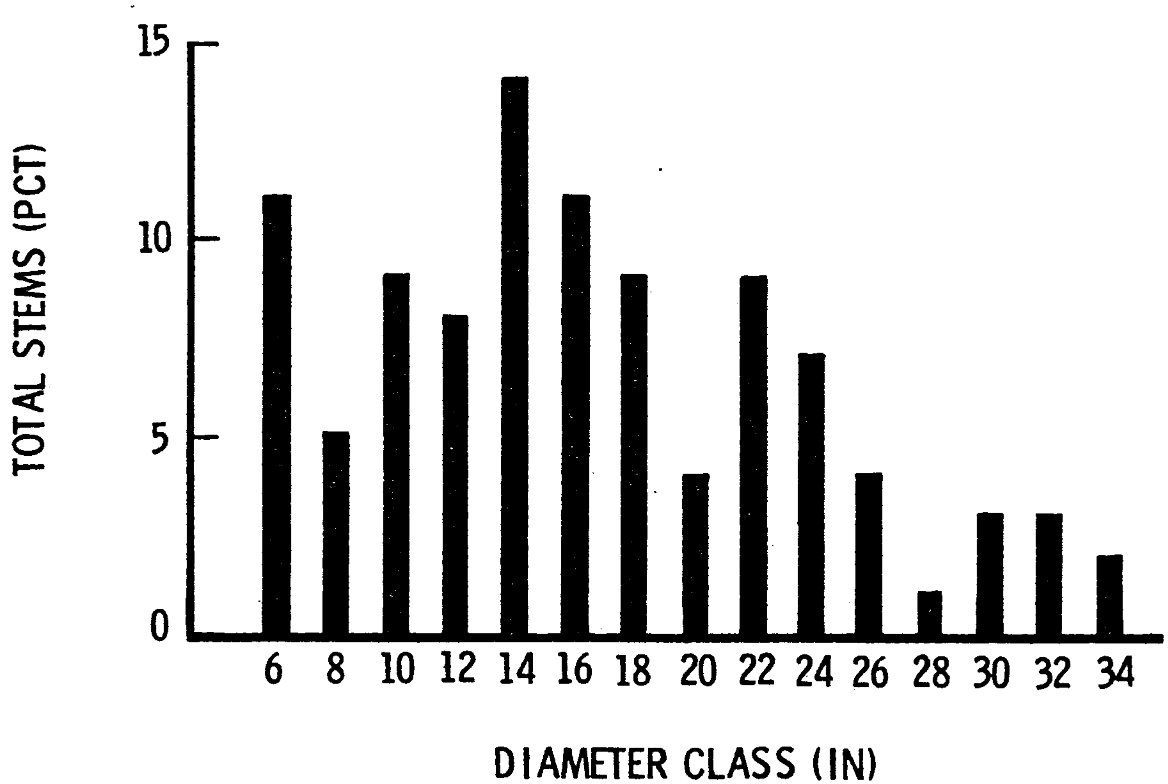


Figure 18. Percent of total stems for each 2-inch diameter class on the Teton National Forest.

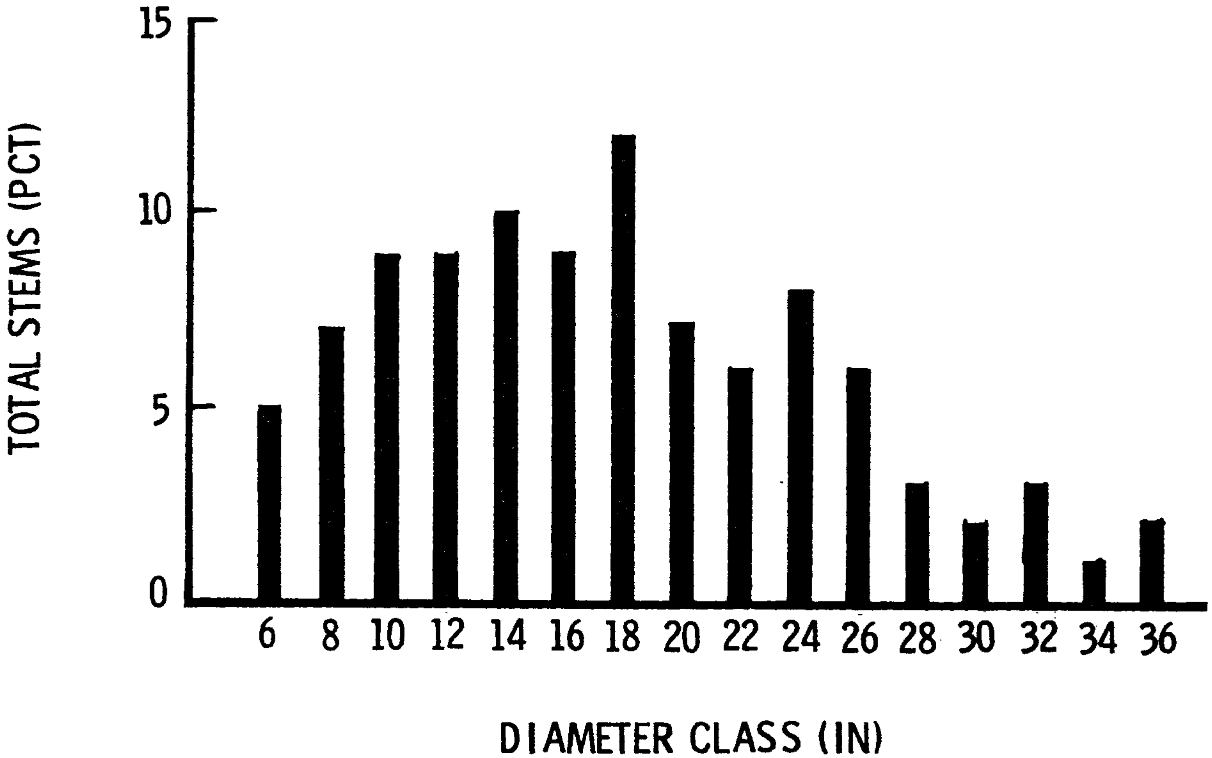


Figure 19. Percent of total stems for each 2-inch diameter class on the Uinta National Forest.

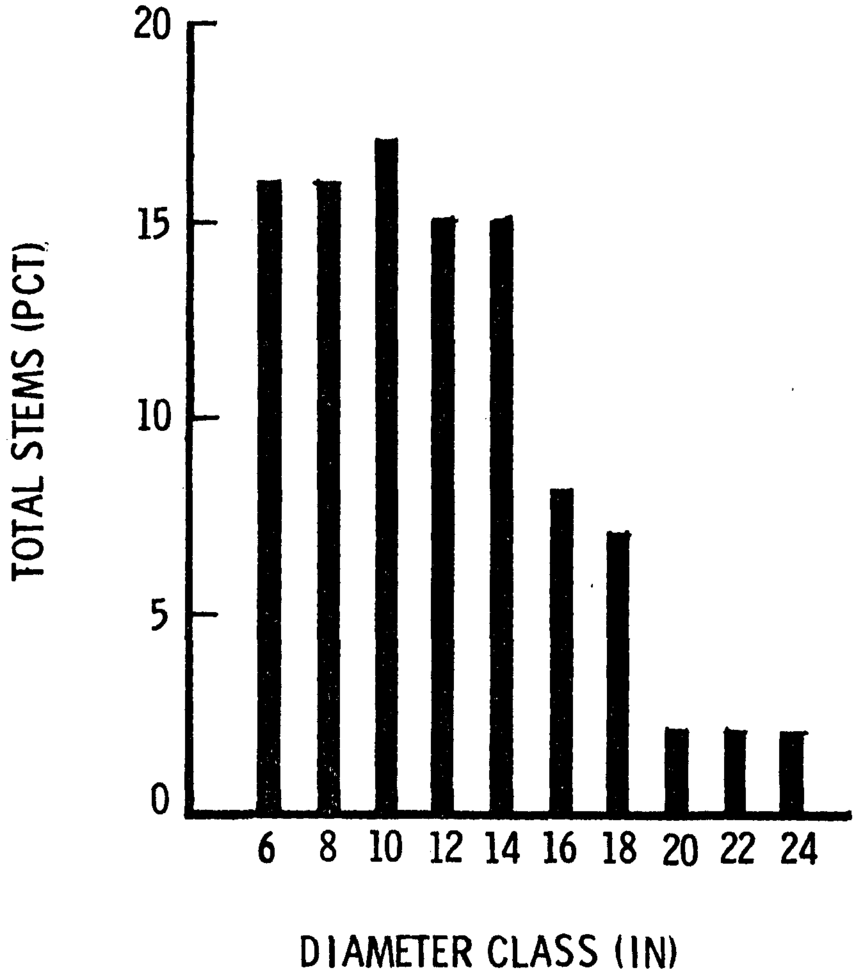


Figure 20. Percent of total stems for each 2-inch diameter class on the Dixie National Forest.

# APPENDIX B

TABLE 3

AGE AND HEIGHT DISTRIBUTION OF SAMPLE TREES ON THE PAYETTE NATIONAL FOREST

| | | Average | Range |
|---|---|---|---|
| Spruce | Age | 37 | 6 to 102 |
| | Height (ft) | 3.4 | 0.3 to 12.1 |
| | | (1.04 m) | (0.09 to 3.69 m) |
| Fir | Age | 52 | 5 to 166 |
| | Height (ft) | 3.2 | 0.2 to 12.4 |
| | | (0.98 m) | (0.06 to 3.78 m) |

TABLE 4

AGE AND HEIGHT DISTRIBUTION OF SAMPLE TREES ON THE TETON NATIONAL FOREST

| | | Average | Range |
|---|---|---|---|
| Spruce | Age | 65 | 7 to 168 |
| | Height (ft) | 3.5 | 0.3 to 10.8 |
| | | (1.07 m) | (0.09 to 3.29 m) |
| Fir | Age | 79 | 7 to 185 |
| | Height (ft) | 3.3 | 0.3 to 14.1 |
| | | (1.01 m) | (0.09 to 4.30 m) |

TABLE 5

AGE AND HEIGHT DISTRIBUTION OF SAMPLE TREES ON THE UINTA NATIONAL FOREST

| | | Average | Range |
|---|---|---|---|
| Spruce | Age | 71 | 5 to 170 |
| | Height (ft) | 3.9 | 0.2 to 12.6 |
| | | (1.19 m) | (0.06 to 3.84 m) |
| Fir | Age | 68 | 16 to 144 |
| | Height (ft) | 2.9 | 0.3 to 11.5 |
| | | (0.88 m) | (0.09 to 3.51 m) |

TABLE 6

AGE AND HEIGHT DISTRIBUTION OF SAMPLE TREES ON THE DIXIE NATIONAL FOREST

| | | Average | Range |
|---|---|---|---|
| Spruce | Age | 59 | 5 to 150 |
| | Height (ft) | 3.7 | 0.2 to 14.0 |
| | | (1.13 m) | (0.06 to 4.27 m) |
| Fir | Age | 57 | 8 to 126 |
| | Height (ft) | 4.0 | 0.2 to 11.8 |
| | | (1.22 m) | (0.06 to 3.60 m) |

TABLE 7

AVERAGE BASAL AREA REMAINING AFTER HARVEST CUTTING

| Average basal area | Uncut forest | Partial cut | Clearcut |
|---|---|---|---|
| | PAYETTE NATIONAL FOREST | | |
| $ft^2$/acre | 129.0 | 29.0 | 7.0 |
| $m^2$/ha | 29.6 | 6.6 | 1.6 |
| | TETON NATIONAL FOREST | | |
| $ft^2$/acre | 132.0 | 82.0 | 1.0 |
| $m^2$/ha | 30.3 | 18.8 | 0.2 |
| | UINTA NATIONAL FOREST | | |
| $ft^2$/acre | 146.0 | 109.0 | 42.0 |
| $m^2$/ha | 33.5 | 25.0 | 9.6 |
| | DIXIE NATIONAL FOREST | | |
| $ft^2$/acre | 141.0 | 40.0 | 6.0 |
| $m^2$/ha | 32.4 | 9.2 | 1.4 |

APPENDIX C

TABLE 8

SIMPLE CORRELATIONS OF 10-YEAR POSTTREATMENT HEIGHT GROWTH VERSUS SIX INDEPENDENT VARIABLES (HEIGHT CLASSES COMBINED) - PAYETTE NATIONTAL FOREST

| Independent Variables | Engelmann spruce (n-79) | | | Subalpine fir (n=77) | | |
|---|---|---|---|---|---|---|
| | r square | standard error | f value | r square | standard error | f value |
| 1. 5-year pretreatment height growth | .1920 | 1.0396 | 18.30 | .0463 | 1.0647 | 3.64 |
| 2. Posttreatment basal area | .0656 | 1.1180 | 5.40 | .0523 | 1.0613 | 4.14 |
| 3. Pretreatment height | .0000 | 1.1595 | 0.00 | .0045 | 1.0878 | 0.34 |
| 4. Pretreatment crown length | .0094 | 1.1511 | 0.73 | .0048 | 1.0876 | 0.36 |
| 5. Pretreatment crown ratio | .0139 | 1.1485 | 1.09 | .0011 | 1.0897 | 0.08 |
| 6. Pretreatment age | .0246 | 1.1422 | 1.94 | .0115 | 1.0839 | 0.88 |

TABLE 9

SIMPLE CORRELATIONS OF 10-YEAR POSTTREATMENT HEIGHT GROWTH VERSUS SIX INDEPENDENT VARIABLES (HEIGHT CLASSES COMBINED) - TETON NATIONTAL FOREST

| Independent Variables | Engelmann spruce (n-71) | | | Subalpine fir (n=66) | | |
|---|---|---|---|---|---|---|
| | r square | standard error | f value | r square | standard error | f value |
| 1. 5-year pretreatment height growth | .4677 | 0.8336 | 60.62 | .0547 | 1.1544 | 3.70 |
| 2. Posttreatment basal area | .0339 | 1.1230 | 2.42 | .2315 | 1.0408 | 19.28 |
| 3. Pretreatment height | .1983 | 1.0230 | 17.06 | .0056 | 1.1840 | 0.36 |
| 4. Pretreatment crown length | .3417 | 0.9270 | 35.81 | .0003 | 1.1871 | 0.02 |
| 5. Pretreatment crown ratio | .1608 | 1.0467 | 13.22 | .0705 | 1.1446 | 4.86 |
| 6. Pretreatment age | .0180 | 1.1320 | 1.27 | .0006 | 1.2459 | 0.00 |

TABLE 10

SIMPLE CORRELATIONS OF 10-YEAR POSTTREATMENT HEIGHT GROWTH VERSUS SIX INDEPENDENT VARIABLES (HEIGHT CLASSES COMBINED) - UINTA NATIONTAL FOREST

| Independent Variables | Engelmann spruce (n-79) | | | Subalpine fir (n=77) | | |
|---|---|---|---|---|---|---|
| | r square | standard error | f value | r square | standard error | f value |
| 1. 5-year pretreatment height growth | .1699 | 0.7746 | 15.43 | .0060 | 0.9163 | 0.45 |
| 2. Posttreatment basal area | .0559 | 0.8246 | 4.56 | .0010 | 0.9186 | 0.08 |
| 3. Pretreatment height | .0490 | 0.8276 | 3.96 | .0230 | 0.9084 | 1.77 |
| 4. Pretreatment crown length | .0915 | 0.8089 | 7.75 | .0074 | 0.9156 | 0.56 |
| 5. Pretreatment crown ratio | .0379 | 0.8324 | 3.04 | .0043 | 0.9171 | 0.32 |
| 6. Pretreatment age | .0042 | 0.8469 | 0.32 | .0661 | 0.8881 | 5.31 |

TABLE 11

SIMPLE CORRELATIONS OF 10-YEAR POSTTREATMENT HEIGHT GROWTH VERSUS SIX INDEPENDENT VARIABLES (HEIGHT CLASSES COMBINED) - DIXIE NATIONTAL FOREST

| Independent Variables | Engelmann spruce (n-78) | | | Subalpine fir (n=73) | | |
|---|---|---|---|---|---|---|
| | r square | standard error | f value | r square | standard error | f value |
| 1. 5-year pretreatment height growth | .2098 | 0.8474 | 20.18 | .3389 | 1.0303 | 36.39 |
| 2. Posttreatment basal area | .2325 | 0.8351 | 23.03 | .0147 | 1.2577 | 1.06 |
| 3. Pretreatment height | .0015 | 0.9526 | 0.11 | .1919 | 1.1390 | 16.86 |
| 4. Pretreatment crown length | .0362 | 0.9358 | 2.85 | .2479 | 1.0988 | 23.41 |
| 5. Pretreatment crown ratio | .0123 | 0.8929 | 10.61 | .0856 | 1.2116 | 6.64 |
| 6. Pretreatment age | .0141 | 0.9465 | 1.09 | .0627 | 1.2267 | 4.75 |

APPENDIX D

TABLE 12

MEAN PERIODIC HEIGHT GROWTH OF UNDERSTORY ENGELMANN SPRUCE AND SUBALPINE FIR (HEIGHT CLASSES COMBINED) ON THE PAYETTE NATIONAL FOREST

| | | Control | | | Selection | | | Overstory Removal | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean height growth (ft) | V | n | Mean height growth (ft) | V | n | Mean height growth (ft) | V | n |
| 5-Year Pretreatment | ES | 8.1 | 32.2 | 40 | 5.8 | 14.2 | 39 | 5.8 | 14.6 | 40 |
| | SAF | 6.0 | 16.7 | 40 | 3.9 | 8.0 | 38 | 4.4 | 9.5 | 39 |
| 1- to 5-Year Posttreatment | ES | 5.8 | 17.9 | 40 | 7.7 | 20.9 | 39 | 8.2 | 30.5 | 40 |
| | SAF | 4.7 | 10.6 | 40 | 6.8 | 19.3 | 38 | 6.7 | 14.4 | 39 |
| 6- to 10-Year Posttreatment | ES | 8.7 | 41.5 | 40 | 17.2 | 92.4 | 39 | 17.3 | 90.8 | 40 |
| | SAF | 7.1 | 27.8 | 40 | 15.4 | 82.7 | 38 | 17.6 | 105.9 | 39 |

ES - Engelmann spruce
SAF - subalpine fir
V - variance
n - number of observations

TABLE 13

MEAN PERIODIC HEIGHT GROWTH OF UNDERSTORY ENGELMANN SPRUCE AND SUBALPINE FIR (HEIGHT CLASSES COMBINED) ON THE TETON NATIONAL FOREST

| | | Control | | | Selection | | | Overstory Removal | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean height growth (ft) | V | n | Mean height growth (ft) | V | n | Mean height growth (ft) | V | n |
| 5-Year Pretreatment | ES | 4.0 | 9.8 | 40 | 6.9 | 40.7 | 40 | 4.5 | 8.2 | 31 |
| | SAF | 3.8 | 11.7 | 36 | 4.4 | 19.7 | 35 | 3.8 | 9.3 | 31 |
| 1- to 5-Year Posttreatment | ES | 4.5 | 8.4 | 40 | 5.9 | 22.8 | 40 | 6.2 | 16.3 | 31 |
| | SAF | 4.3 | 12.4 | 36 | 5.0 | 10.9 | 35 | 8.3 | 36.8 | 31 |
| 6- to 10-Year Posttreatment | ES | 5.2 | 14.0 | 38 | 11.0 | 85.1 | 40 | 15.3 | 98.1 | 31 |
| | SAF | 4.4 | 12.9 | 36 | 9.1 | 49.7 | 35 | 20.8 | 95.6 | 31 |

ES - Engelmann spruce
SAF - subalpine fir
V - variance
n - number of observations

TABLE 14

MEAN PERIODIC HEIGHT GROWTH OF UNDERSTORY ENGELMANN SPRUCE AND SUBALPINE FIR (HEIGHT CLASSES COMBINED) ON THE UINTA NATIONAL FOREST

| | | Control | | | Selection | | | Overstory Removal | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean height growth (ft) | V | n | Mean height growth (ft) | V | n | Mean height growth (ft) | V | n |
| 5-Year Pretreatment | ES | 4.2 | 9.1 | 39 | 3.3 | 6.0 | 39 | 2.8 | 3.4 | 40 |
| | SAF | 3.8 | 11.4 | 36 | 2.5 | 7.9 | 39 | 2.7 | 5.2 | 38 |
| 1- to 5-Year Posttreatment | ES | 4.4 | 8.5 | 39 | 4.6 | 5.8 | 39 | 4.8 | 3.9 | 40 |
| | SAF | 4.8 | 7.0 | 36 | 6.1 | 12.2 | 39 | 5.3 | 6.8 | 38 |
| 6- to 10-Year Posttreatment | ES | 4.9 | 15.9 | 39 | 12.2 | 70.4 | 39 | 13.0 | 79.5 | 40 |
| | SAF | 6.7 | 19.7 | 36 | 18.7 | 71.1 | 39 | 20.2 | 92.6 | 38 |

ES - Engelmann spruce
SAF - subalpine fir
V - variance
n - number of observations

TABLE 15

MEAN PERIODIC HEIGHT GROWTH OF UNDERSTORY ENGELMANN SPRUCE AND SUBALPINE FIR (HEIGHT CLASSES COMBINED) ON THE DIXIE NATIONAL FOREST

| | | Control | | | Selection | | | Overstory Removal | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean height growth (ft) | V | n | Mean height growth (ft) | V | n | Mean height growth (ft) | V | n |
| 5-Year Pretreatment | ES | 6.4 | 36.6 | 40 | 5.8 | 17.4 | 40 | 5.4 | 18.2 | 38 |
| | SAF | 7.9 | 62.9 | 39 | 7.5 | 49.5 | 37 | 7.8 | 54.8 | 36 |
| 1- to 5-Year Posttreatment | ES | 5.7 | 25.1 | 40 | 5.2 | 6.8 | 40 | 5.5 | 6.3 | 38 |
| | SAF | 6.3 | 21.8 | 39 | 6.0 | 17.9 | 37 | 6.6 | 17.6 | 36 |
| 6- to 10-Year Posttreatment | ES | 6.0 | 37.7 | 40 | 8.5 | 58.1 | 40 | 15.6 | 113.8 | 38 |
| | SAF | 7.6 | 51.8 | 39 | 11.1 | 79.7 | 37 | 17.8 | 205.1 | 36 |

ES - Engelmann spruce
SAF - subalpine fir
V - variance
n - number of observations

APPENDIX E

TABLE 16

REGRESSION COEFFICIENTS FOR EACH SEGMENTED REGRESSION SUBMODEL (PHASE 1 AND PHASE 2) ON THE PAYETTE NATIONAL FOREST

| | | Phase 1 | Phase 2 | n | Overall Model Sum of Squares For Error | Point |
|---|---|---|---|---|---|---|
| | | | Engelmann spruce | | | |
| Overstory Removal | A | Y = 5.016 + 0.805x | Y = -26.201 + 4.343x | 15 | 34.50 | 8.8 |
| | B | Y = 14.833 + 0.567x | Y = -39.095 + 6.120x | 15 | 148.82 | 9.7 |
| Selection | A | Y = 5.143 + 0.699x | Y = -27.314 + 4.127x | 15 | 45.52 | 9.5 |
| | B | Y = 18.805 - 1.062x | Y = -19.125 + 4.675x | 15 | 57.03 | 6.6 |
| Control | A | Y = 10.198 - 0.440x | Y = - 1.186 + 0.870x | 15 | 7.50 | 8.7 |
| | B | Y = 28.546 - 1.563x | Y = -26.114 + 3.907x | 15 | 173.27 | 10.0 |
| | | | Subalpine fir | | | |
| Overstory Removal | A | Y = 9.811 - 0.901x | Y = -14.368 + 3.037x | 15 | 36.18 | 6.1 |
| | B | Y = 13.727 - 1.239x | Y = -39.414 + 6.706x | 15 | 168.19 | 6.7 |
| Selection | A | Y = 5.210 - 0.140x | Y = -11.254 + 2.683x | 15 | 67.95 | 5.8 |
| | B | Y = 12.507 - 0.513x | Y = -24.481 + 4.964x | 15 | 14.44 | 6.8 |
| Control | A | Y = 7.916 - 0.143x | Y = - 2.676 + 0.916x | 15 | 12.95 | 10.0 |
| | B | Y = 19.833 - 0.999x | Y = -24.110 + 3.320x | 15 | 71.95 | 10.2 |

A - Trees 0.1 to 4.5 feet tall
B - Trees 4.6 to 15.0 feet tall

Y = Annual height growth (inches)

TABLE 17

REGRESSION COEFFICIENTS FOR EACH SEGMENTED REGRESSION SUBMODEL
(PHASE 1 AND PHASE 2) ON THE TETON NATIONAL FOREST

| | | Phase 1 | Phase 2 | n | Overall Model Sum of Squares For Error | Point |
|---|---|---|---|---|---|---|
| | | | Engelmann spruce | | | |
| Overstory Removal | A | Y = 4.948 + 0.437x | Y = -33.931 + 4.455x | 15 | 28.84 | 9.7 |
| | B | Y = 12.256 + 0.429x | Y = -39.784 + 6.151x | 15 | 166.40 | 9.1 |
| Selection | A | Y = 5.955 - 0.245x | Y = - 1.018 + 1.017x | 15 | 13.06 | 5.5 |
| | B | Y = 25.436 - 1.048x | Y = -37.885 + 5.396x | 15 | 99.31 | 9.8 |
| Control | A | Y = 5.132 + 0.124x | Y = - 2.394 + 0.703x | 15 | 4.94 | 13.0 |
| | B | Y = 9.954 + 0.331x | Y = 13.890 - 0.027x | 15 | 38.47 | 11.0 |
| | | | Subalpine fir | | | |
| Overstory Removal | A | Y = 5.347 - 0.381x | Y = -19.759 + 4.005x | 15 | 59.30 | 5.7 |
| | B | Y = 12.283 - 0.673x | Y = -28.170 + 6.573x | 15 | 282.64 | 5.6 |
| Selection | A | Y = 4.896 - 0.039x | Y = - 5.106 + 1.492x | 15 | 23.92 | 6.5 |
| | B | Y = 12.071 + 0.221x | Y = -11.650 + 2.856x | 15 | 43.25 | 9.0 |
| Control | A | Y = 4.844 + 0.087x | Y = 0.801 + 0.398x | 15 | 5.97 | 13.0 |
| | B | Y = 11.225 + 0.055x | Y = - 8.542 + 1.576x | 15 | 61.34 | 13.0 |

A - Trees 0.1 to 4.5 feet tall
B - Trees 4.6 to 15.0 feet tall

Y = Annual height growth (inches)

TABLE 18

REGRESSION COEFFICIENTS FOR EACH SEGMENTED REGRESSION SUBMODEL (PHASE 1 AND PHASE 2) ON THE UINTA NATIONAL FOREST

| | | Phase 1 | Phase 2 | n | Overall Model Sum of Squares For Error | Point |
|---|---|---|---|---|---|---|
| | | | Engelmann spruce | | | |
| Overstory Removal | A | Y = 4.023 + 0.231x | Y = - 9.743 + 2.378x | 15 | 42.81 | 6.4 |
| | B | Y = 4.989 + 0.598x | Y = -43.871 + 5.716x | 15 | 100.48 | 9.5 |
| Selection | A | Y = 5.140 - 0.084x | Y = - 6.986 + 1.913x | 15 | 42.15 | 6.1 |
| | B | Y = 8.497 + 0.237x | Y = -33.995 + 4.904x | 15 | 119.70 | 9.1 |
| Control | A | Y = 6.478 - 0.019x | Y = 4.635 + 0.165x | 15 | 8.36 | 10.0 |
| | B | Y = 13.385 - 0.695x | Y = 7.544 + 0.460x | 15 | 41.55 | 5.1 |
| | | | Subalpine fir | | | |
| Overstory Removal | A | Y = 2.237 + 0.746x | Y = -32.352 + 5.114x | 15 | 79.11 | 7.9 |
| | B | Y = 7.087 - 0.252x | Y = -46.999 + 6.974x | 15 | 183.02 | 7.5 |
| Selection | A | Y = 3.797 - 0.383x | Y = -17.794 + 3.655x | 15 | 143.82 | 5.3 |
| | B | Y = 10.208 - 0.767x | Y = -30.226 + 5.655x | 15 | 284.66 | 6.3 |
| Control | A | Y = 5.032 + 0.324x | Y = -12.100 + 1.610x | 15 | 23.83 | 13.3 |
| | B | Y = 12.578 - 0.696x | Y = 4.095 + 0.977x | 15 | 84.58 | 5.1 |

A - Trees 0.1 to 4.5 feet tall
B - Trees 4.6 to 15.0 feet tall

Y = Annual height growth (inches)

TABLE 19

REGRESSION COEFFICIENTS FOR EACH SEGMENTED REGRESSION SUBMODEL (PHASE 1 AND PHASE 2) ON THE DIXIE NATIONAL FOREST

| | | Phase 1 | Phase 2 | n | Overall Model Sum of Squares For Error | Point |
|---|---|---|---|---|---|---|
| | | | Engelmann spruce | | | |
| Overstory Removal | A | Y = 6.895 + 0.139x | Y = - 4.033 + 1.892x | 15 | 19.59 | 6.2 |
| | B | Y = 14.029 - 0.361x | Y = -52.589 + 7.297x | 15 | 190.40 | 8.7 |
| Selection | A | Y = 6.475 + 0.301x | Y = -12.600 + 1.805x | 15 | 22.23 | 12.7 |
| | B | Y = 19.375 - 0.902x | Y = 2.415 + 1.521x | 15 | 70.00 | 7.0 |
| Control | A | Y = 5.652 + 0.315x | Y = 10.338 - 0.271x | 15 | 12.12 | 8.0 |
| | B | Y = 20.341 - 0.502x | Y = 9.050 + 0.627x | 15 | 82.88 | 10.0 |
| | | | Subalpine fir | | | |
| Overstory Removal | A | Y = 9.172 - 0.720x | Y = - 3.035 + 1.704x | 15 | 27.77 | 5.0 |
| | B | Y = 28.226 - 1.928x | Y = -42.436 + 7.136x | 15 | 301.04 | 7.8 |
| Selection | A | Y = 7.120 - 0.252x | Y = 0.012 + 1.168x | 15 | 73.31 | 5.0 |
| | B | Y = 30.474 - 2.254x | Y = - 2.085 + 2.397x | 15 | 262.14 | 7.0 |
| Control | A | Y = 6.663 + 0.195x | Y = 17.118 - 0.609x | 15 | 12.82 | 13.0 |
| | B | Y = 29.436 - 1.389x | Y = 17.780 + 0.276x | 15 | 129.13 | 7.0 |

A - Trees 0.1 to 4.5 feet tall
B - Trees 4.6 to 15.0 feet tall

Y = Annual height growth (inches)

APPENDIX F

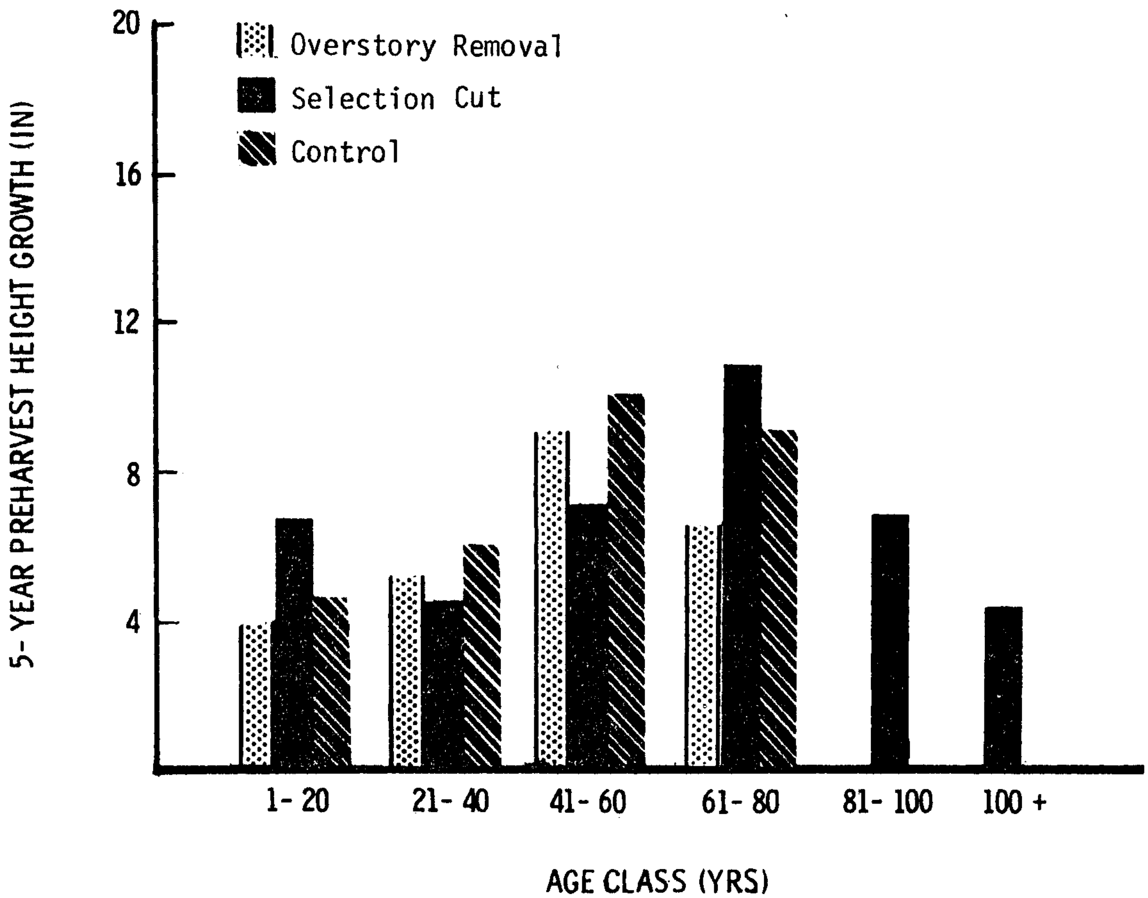


Figure 21. Engelmann spruce 5-year cumulative preharvest height growth on the Payette National Forest.

TABLE 20

TABLE VALUES FOR FIGURE 21

| | Age class | 5-year cumulative height growth | Standard deviation | Variance | (n) |
|---|---|---|---|---|---|
| | | (inches) | | | |
| OR | 1 | 4.1 | 2.25 | 5.07 | 13 |
| SE | 1 | 6.7 | 5.36 | 28.76 | 7 |
| CO | 1 | 4.6 | 2.35 | 5.52 | 4 |
| OR | 2 | 5.2 | 3.86 | 14.93 | 15 |
| SE | 2 | 4.5 | 2.26 | 5.12 | 18 |
| CO | 2 | 6.0 | 3.38 | 11.45 | 13 |
| OR | 3 | 9.1 | 4.26 | 18.18 | 9 |
| SE | 3 | 7.1 | 4.62 | 21.32 | 10 |
| CO | 3 | 10.0 | 6.76 | 45.71 | 19 |
| OR | 4 | 6.5 | 2.34 | 5.49 | 3 |
| SE | 4 | 10.8 | 0.00 | 0.00 | 1 |
| CO | 4 | 9.0 | 5.65 | 31.98 | 4 |
| OR | 5 | | | | |
| SE | 5 | 6.8 | 1.70 | 2.88 | 2 |
| CO | 5 | | | | |
| OR | 6 | | | | |
| SE | 6 | 4.2 | 0.00 | 0.00 | 1 |
| CO | 6 | | | | |

OR = Overstory Removal SE = Selection cut CO = Control

Age Class: 1 = 1-20 yrs 2 = 21-40 yrs 3 = 41-60 yrs
4 = 61-80 yrs 5 = 81-100 yrs 6 = 100+ yrs

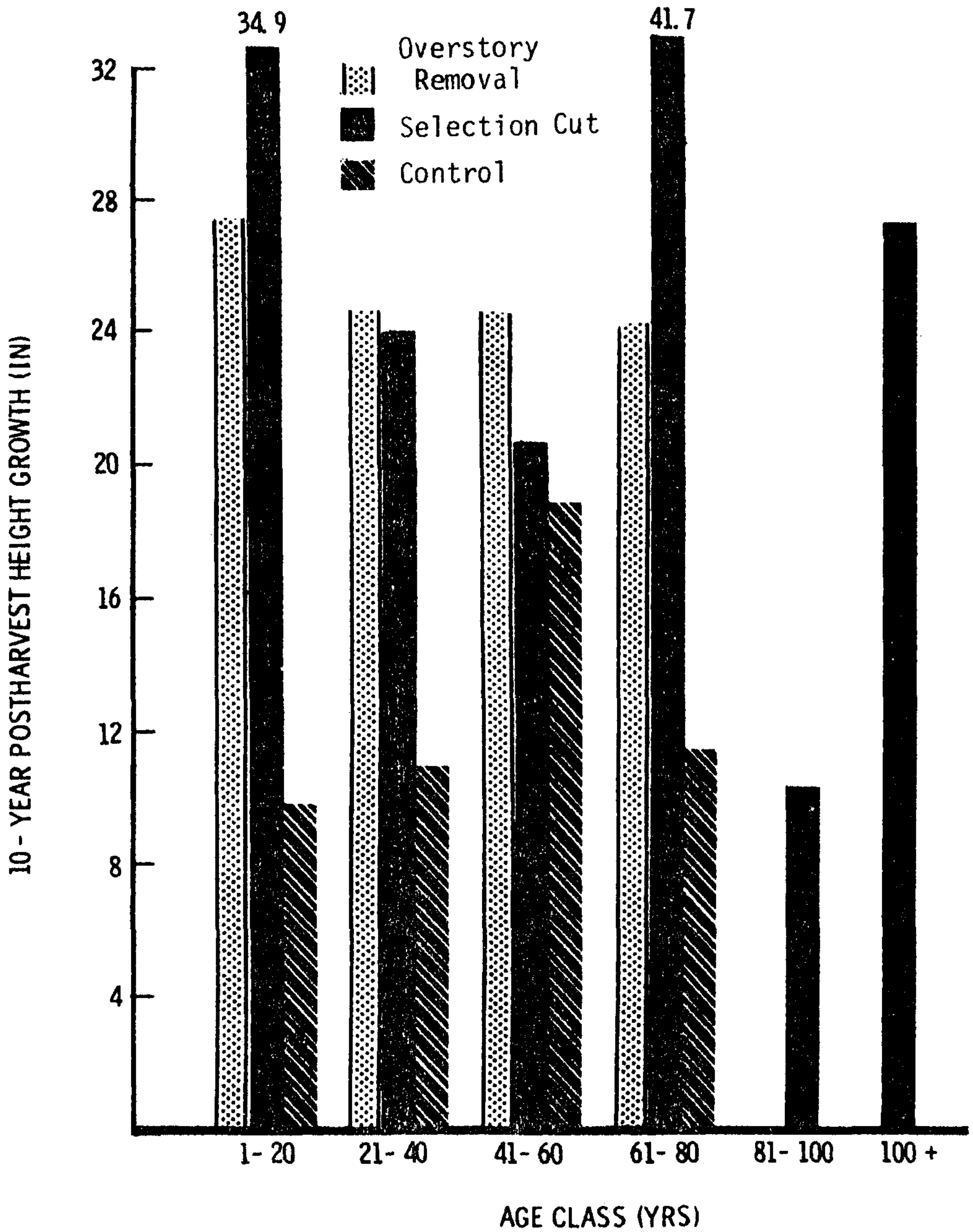


Figure 22. Engelmann spruce 10-year cumulative postharvest height growth on the Payette National Forest.

TABLE 21

TABLE VALUES FOR FIGURE 22

| | Age class | 10-year cumulative height growth (inches) | Standard deviation | Variance | (n) |
|---|---|---|---|---|---|
| OR | 1 | 27.6 | 10.15 | 102.95 | 13 |
| SE | 1 | 34.9 | 13.36 | 178.49 | 7 |
| CO | 1 | 9.8 | 3.71 | 13.78 | 4 |
| OR | 2 | 24.7 | 14.52 | 210.95 | 15 |
| SE | 2 | 24.0 | 12.46 | 155.23 | 18 |
| CO | 2 | 10.9 | 7.32 | 53.60 | 13 |
| OR | 3 | 24.4 | 20.82 | 433.59 | 9 |
| SE | 3 | 20.4 | 13.86 | 192.23 | 10 |
| CO | 3 | 18.8 | 12.23 | 149.60 | 19 |
| OR | 4 | 24.1 | 4.54 | 20.65 | 3 |
| SE | 4 | 41.7 | 0.00 | 0.00 | 1 |
| CO | 4 | 11.3 | 5.87 | 34.43 | 4 |
| OR | 5 | | | | |
| SE | 5 | 10.0 | 1.59 | 2.54 | 3 |
| CO | 5 | | | | |
| OR | 6 | | | | |
| SE | 6 | 27.2 | 0.00 | 0.00 | 1 |
| CO | 6 | | | | |

OR = Overstory Removal  SE = Selection cut  CO = Control

Age Class: 1 = 1-20 yrs  2 = 21-40 yrs  3 = 41-60 yrs
4 = 61-80 yrs  5 = 81-100 yrs  6 = 100+ yrs

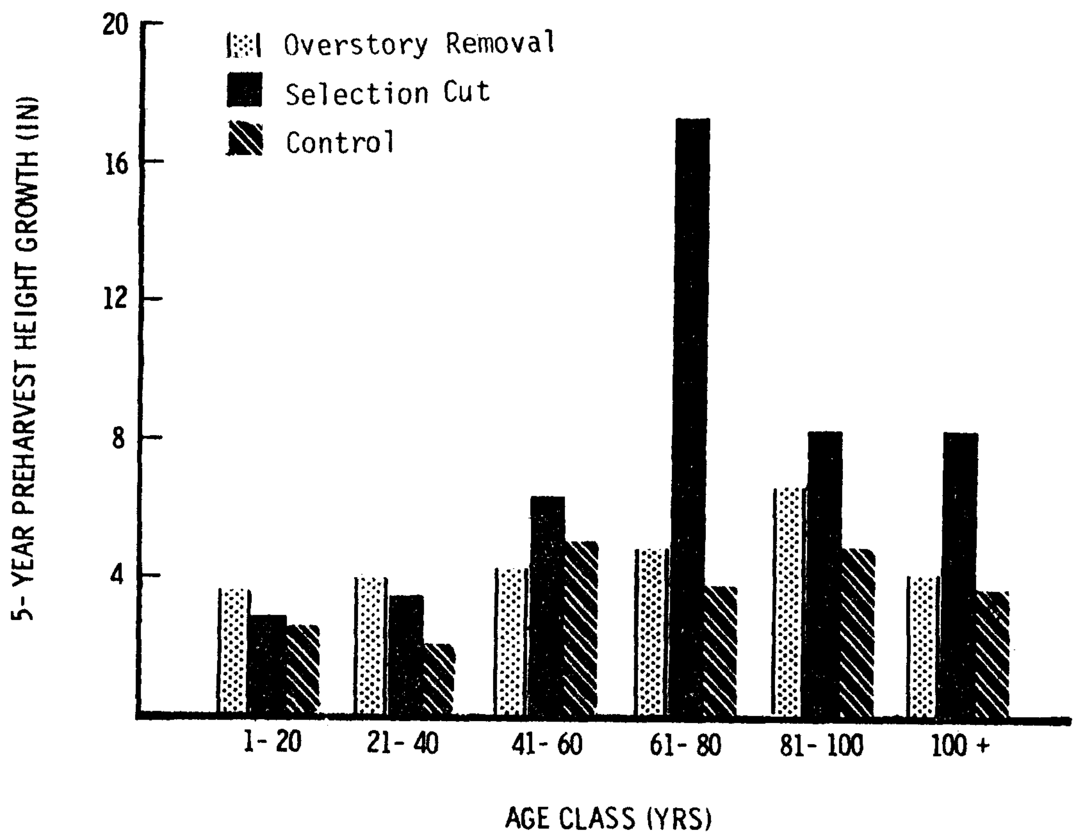


Figure 23. Subalpine fir 5-year cumulative preharvest height growth on the Payette National Forest.

TABLE 22

TABLE VALUES FOR FIGURE 23

| | Age class | 5-year cumulative height growth (inches) | Standard deviation | Variance | (n) |
|---|---|---|---|---|---|
| OR | 1 | 3.7 | 1.13 | 1.28 | 2 |
| SE | 1 | 2.8 | 2.03 | 4.13 | 4 |
| CO | 1 | 2.6 | 0.85 | 0.72 | 2 |
| OR | 2 | 4.0 | 2.95 | 8.75 | 11 |
| SE | 2 | 3.5 | 3.04 | 9.24 | 14 |
| CO | 2 | 2.1 | 1.05 | 1.11 | 6 |
| OR | 3 | 4.3 | 1.39 | 1.94 | 6 |
| SE | 3 | 6.2 | 4.63 | 21.43 | 9 |
| CO | 3 | 5.1 | 4.06 | 16.49 | 9 |
| OR | 4 | 4.8 | 3.61 | 13.00 | 2 |
| SE | 4 | 17.2 | 7.01 | 49.20 | 6 |
| CO | 4 | 3.8 | 1.01 | 1.02 | 6 |
| OR | 5 | 6.8 | 4.81 | 23.11 | 5 |
| SE | 5 | 8.2 | 4.10 | 16.82 | 2 |
| CO | 5 | 5.0 | 4.23 | 17.92 | 8 |
| OR | 6 | 4.1 | 1.70 | 2.89 | 5 |
| SE | 6 | 8.2 | 5.90 | 34.82 | 5 |
| CO | 6 | 3.7 | 2.88 | 8.32 | 9 |

OR = Overstory removal SE = Selection cut CO = Control

Age Class: 1 = 1-20 yrs 2 = 21-40 yrs 3 = 41-60 yrs
4 = 61-80 yrs 5 = 81-100 yrs 6 = 100+ yrs

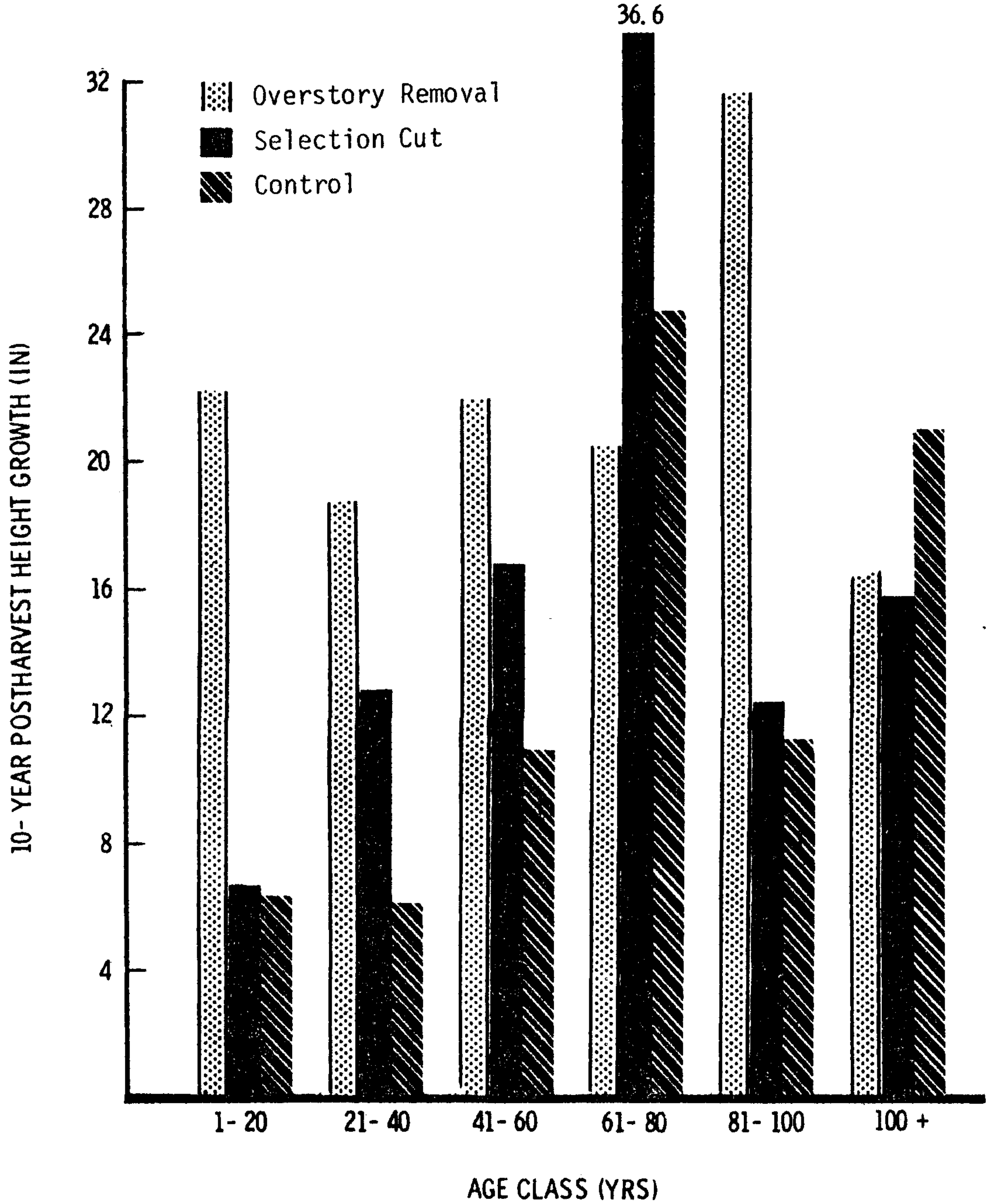


Figure 24. Subalpine fir 10-year cumulative postharvest height growth on the Payette National Forest.

TABLE 23

TABLE VALUES FOR FIGURE 24

| | Age class | 10-year cumulative height growth (inches) | Standard deviation | Variance | (n) |
|---|---|---|---|---|---|
| OR | 1 | 22.2 | 10.18 | 103.68 | 2 |
| SE | 1 | 6.6 | 5.81 | 33.77 | 4 |
| CO | 1 | 6.5 | 2.55 | 6.48 | 2 |
| OR | 2 | 18.7 | 9.69 | 93.85 | 12 |
| SE | 2 | 12.7 | 8.81 | 77.62 | 14 |
| CO | 2 | 6.1 | 1.79 | 3.20 | 6 |
| OR | 3 | 22.0 | 9.32 | 86.88 | 7 |
| SE | 3 | 16.8 | 8.03 | 64.55 | 9 |
| CO | 3 | 10.8 | 6.18 | 38.17 | 9 |
| OR | 4 | 20.4 | 21.21 | 450.00 | 2 |
| SE | 4 | 36.6 | 19.60 | 384.02 | 6 |
| CO | 4 | 24.7 | 38.21 | 1,459.93 | 6 |
| OR | 5 | 31.9 | 21.48 | 461.54 | 5 |
| SE | 5 | 12.2 | 3.25 | 10.58 | 2 |
| CO | 5 | 11.3 | 7.65 | 58.60 | 8 |
| OR | 6 | 16.7 | 12.50 | 156.33 | 6 |
| SE | 6 | 15.8 | 12.17 | 148.01 | 5 |
| CO | 6 | 21.1 | 31.55 | 995.67 | 9 |

OR = Overstory removal    SE = Selection cut    CO = Control

Age Class: 1 = 1-20 yrs    2 = 21-40 yrs    3 = 41-60 yrs
4 = 61-80 yrs    5 = 81-100 yrs    6 = 100+ yrs

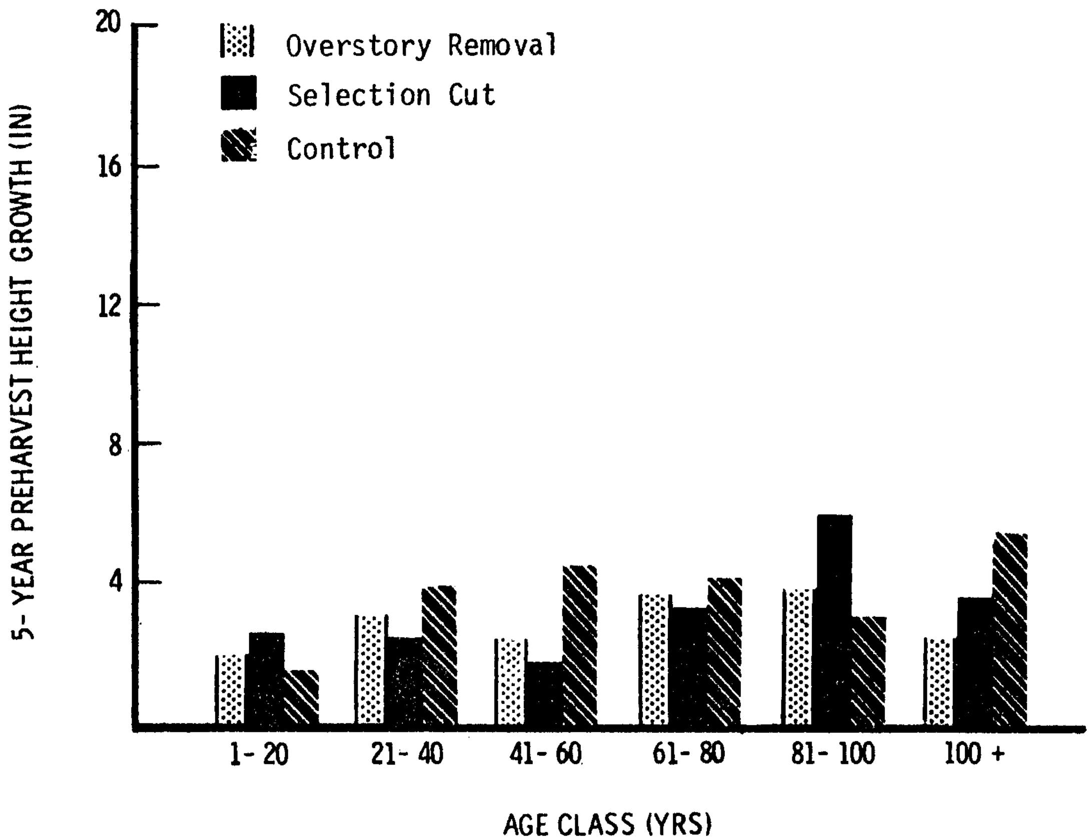


Figure 25. Engelmann spruce 5-year cumulative preharvest height growth on the Teton National Forest.

TABLE 24

TABLE VALUES FOR FIGURE 25

| | Age class | 5-year cumulative height growth (inches) | Standard deviation | Variance | (n) |
|---|---|---|---|---|---|
| OR | 1 | 2.0 | 0.66 | 0.44 | 8 |
| SE | 1 | 2.6 | 1.26 | 1.58 | 6 |
| CO | 1 | 1.7 | 0.35 | 0.12 | 2 |
| OR | 2 | 3.2 | 1.71 | 2.91 | 9 |
| SE | 2 | 2.4 | 0.59 | 0.35 | 4 |
| CO | 2 | 4.0 | 2.77 | 7.65 | 6 |
| OR | 3 | 2.4 | 1.51 | 2.28 | 4 |
| SE | 3 | 1.9 | 1.19 | 1.42 | 6 |
| CO | 3 | 4.4 | 4.35 | 18.93 | 6 |
| OR | 4 | 3.7 | 2.58 | 6.67 | 8 |
| SE | 4 | 3.4 | 1.88 | 3.54 | 7 |
| CO | 4 | 4.0 | 2.21 | 4.87 | 9 |
| OR | 5 | 3.8 | 2.75 | 7.56 | 3 |
| SE | 5 | 5.9 | 4.97 | 24.71 | 4 |
| CO | 5 | 3.0 | 1.15 | 1.32 | 6 |
| OR | 6 | 2.4 | 1.73 | 3.00 | 8 |
| SE | 6 | 3.8 | 2.52 | 6.36 | 12 |
| CO | 6 | 5.6 | 3.73 | 13.89 | 10 |

OR = Overstory removal   SE = Selection cut   CO = Control

Age Class: 1 = 1-20 yrs   2 = 21-40 yrs   3 = 41-60 yrs
4 = 61-80 yrs   5 = 81-100 yrs   6 = 100+ yrs

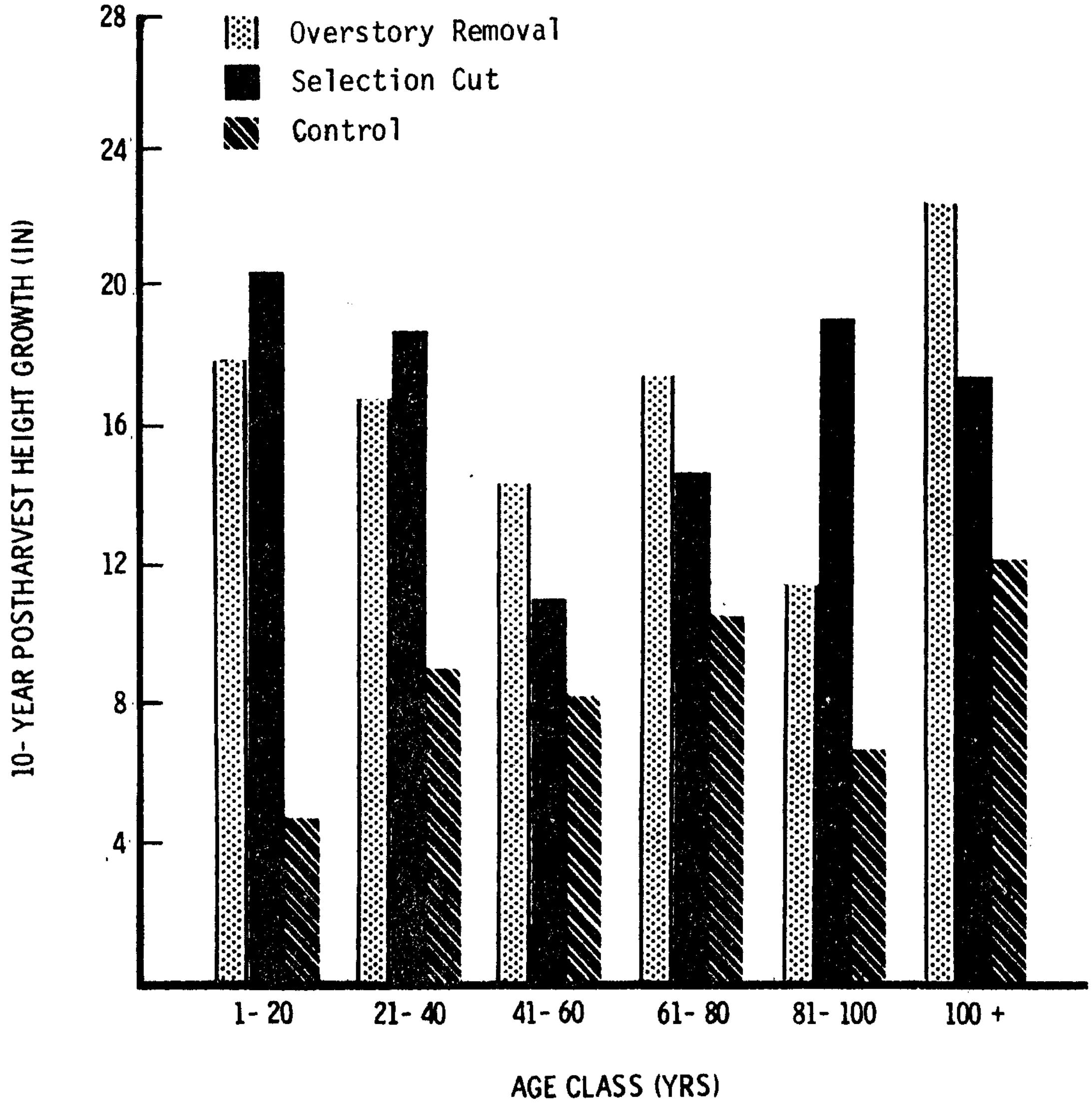


Figure 26. Engelmann spruce 10-year cumulative postharvest height growth on the Teton National Forest.

TABLE 25

TABLE VALUES FOR FIGURE 26

| | Age class | 10-year cumulative height growth | Standard deviation | Variance | (n) |
|---|---|---|---|---|---|
| | | (inches) | | | |
| OR | 1 | 18.0 | 7.05 | 49.71 | 8 |
| SE | 1 | 20.5 | 9.19 | 84.40 | 6 |
| CO | 1 | 4.6 | 2.97 | 8.82 | 2 |
| OR | 2 | 16.8 | 10.18 | 103.69 | 9 |
| SE | 2 | 18.9 | 13.63 | 185.84 | 4 |
| CO | 2 | 9.1 | 9.53 | 12.12 | 6 |
| OR | 3 | 14.4 | 7.96 | 63.42 | 4 |
| SE | 3 | 11.1 | 7.92 | 62.67 | 6 |
| CO | 3 | 8.4 | 9.53 | 90.81 | 6 |
| OR | 4 | 17.6 | 7.46 | 55.66 | 8 |
| SE | 4 | 14.7 | 8.54 | 72.98 | 7 |
| CO | 4 | 9.7 | 6.64 | 44.13 | 9 |
| OR | 5 | 11.8 | 6.98 | 48.74 | 3 |
| SE | 5 | 19.0 | 12.96 | 167.90 | 4 |
| CO | 5 | 6.7 | 2.59 | 6.68 | 6 |
| OR | 6 | 22.6 | 15.93 | 253.80 | 8 |
| SE | 6 | 17.4 | 10.83 | 117.30 | 13 |
| CO | 6 | 12.1 | 7.93 | 62.94 | 11 |

OR = Overstory removal SE = Selection cut CO = Control

Age Class: 1 = 1-20 yrs 2 = 21-40 yrs 3 = 41-60 yrs
4 = 61-80 yrs 5 = 81-100 yrs 6 = 100+ yrs

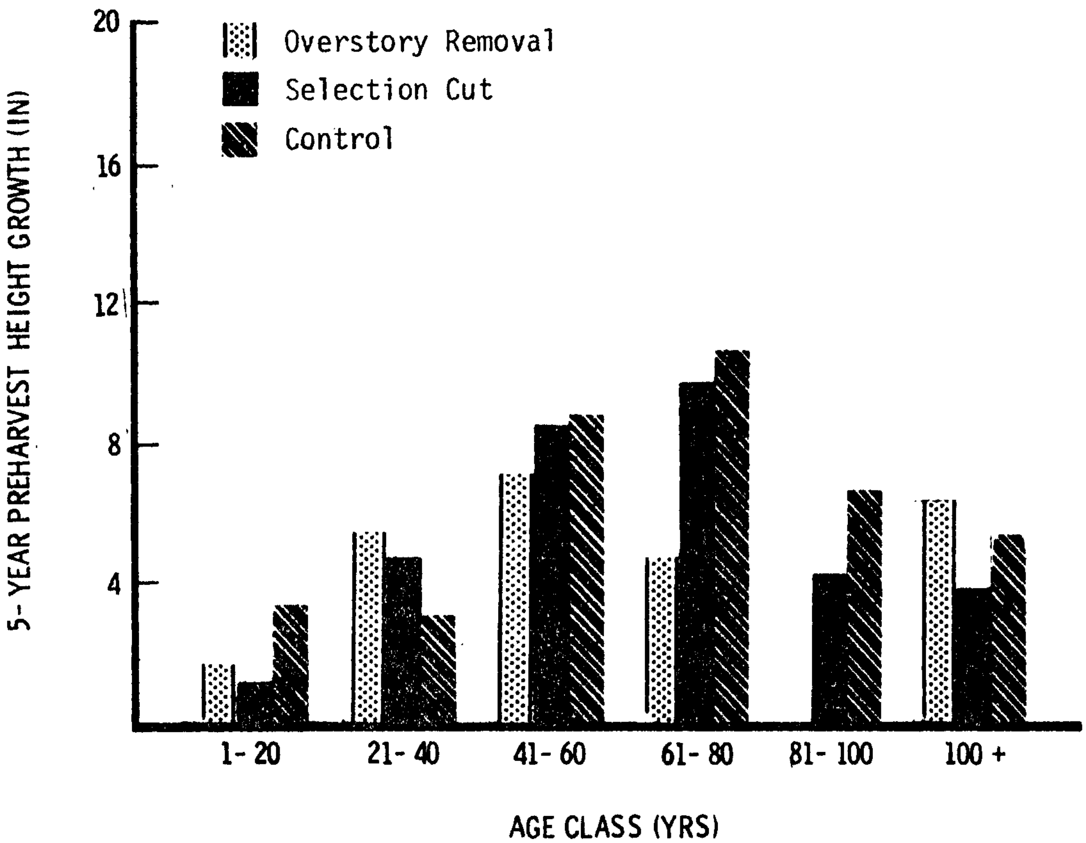


Figure 27. Subalpine fir 5-year cumulative preharvest height growth on the Teton National Forest.

TABLE 26

TABLE VALUES FOR FIGURE 27

| | Age class | 5-year cumulative height growth (inches) | Standard deviation | Variance | (n) |
|---|---|---|---|---|---|
| OR | 1 | 1.8 | 0.58 | 0.33 | 6 |
| SE | 1 | 1.4 | 0.28 | 0.08 | 2 |
| CO | 1 | 3.5 | 1.71 | 2.93 | 5 |
| OR | 2 | 5.7 | 4.22 | 17.81 | 11 |
| SE | 2 | 4.7 | 2.33 | 5.46 | 14 |
| CO | 2 | 3.1 | 1.03 | 1.05 | 9 |
| OR | 3 | 7.3 | 4.64 | 21.54 | 7 |
| SE | 3 | 8.7 | 4.24 | 18.01 | 9 |
| CO | 3 | 9.0 | 8.86 | 78.50 | 6 |
| OR | 4 | 4.8 | 2.76 | 7.64 | 6 |
| SE | 4 | 10.0 | 8.10 | 65.64 | 4 |
| CO | 4 | 10.8 | 9.35 | 87.42 | 8 |
| OR | 5 | | | | |
| SE | 5 | 4.2 | 2.30 | 5.28 | 7 |
| CO | 5 | 6.9 | 2.21 | 4.88 | 4 |
| OR | 6 | 6.4 | 5.53 | 30.62 | 8 |
| SE | 6 | 4.0 | 1.37 | 1.88 | 4 |
| CO | 6 | 5.3 | 2.39 | 5.71 | 8 |

OR = Overstory removal SE = Selection cut CO = Control

Age Class: 1 = 1-20 yrs 2 = 21-40 yrs 3 = 41-60 yrs
4 = 61-80 yrs 5 = 81-100 yrs 6 = 100+ yrs

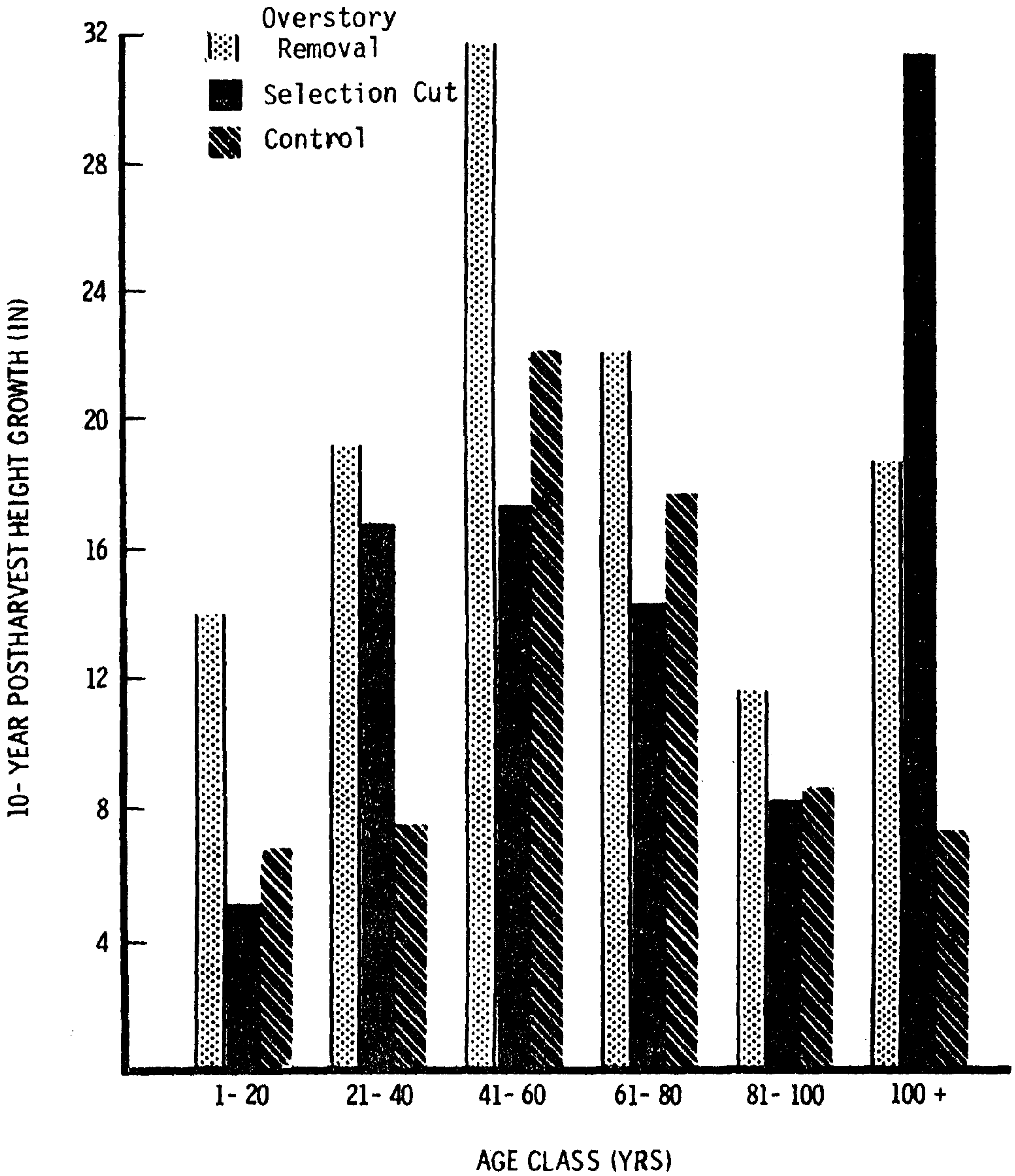


Figure 28. Subalpine fir 10-year cumulative postharvest height growth on the Teton National Forest.

TABLE 27

TABLE VALUES FOR FIGURE 28

| | Age class | 10-year cumulative height growth (inches) | Standard deviation | Variance | (n) |
|---|---|---|---|---|---|
| OR | 1 | 13.9 | 3.27 | 10.68 | 6 |
| SE | 1 | 4.9 | 0.85 | 0.72 | 2 |
| CO | 1 | 7.0 | 1.55 | 2.42 | 5 |
| OR | 2 | 19.2 | 10.26 | 105.24 | 12 |
| SE | 2 | 16.8 | 12.40 | 153.87 | 14 |
| CO | 2 | 7.4 | 3.67 | 13.44 | 9 |
| OR | 3 | 31.7 | 10.51 | 110.39 | 7 |
| SE | 3 | 17.5 | 7.05 | 49.73 | 9 |
| CO | 3 | 22.0 | 20.61 | 424.69 | 6 |
| OR | 4 | 22.0 | 12.54 | 157.48 | 6 |
| SE | 4 | 14.3 | 7.92 | 62.67 | 4 |
| CO | 4 | 17.7 | 11.05 | 122.04 | 8 |
| OR | 5 | 11.5 | 0.00 | 0.00 | 1 |
| SE | 5 | 8.3 | 3.81 | 14.52 | 7 |
| CO | 5 | 8.4 | 3.82 | 14.59 | 4 |
| OR | 6 | 18.6 | 14.42 | 208.01 | 8 |
| SE | 6 | 31.3 | 47.18 | 2,226.21 | 4 |
| CO | 6 | 7.4 | 3.10 | 9.60 | 8 |

OR = Overstory removal  SE = Selection cut  CO = Control

Age Class: 1 = 1-20 yrs  2 = 21-40 yrs  3 = 41-60 yrs
4 = 61-80 yrs  5 = 81-100 yrs  6 = 100+ yrs

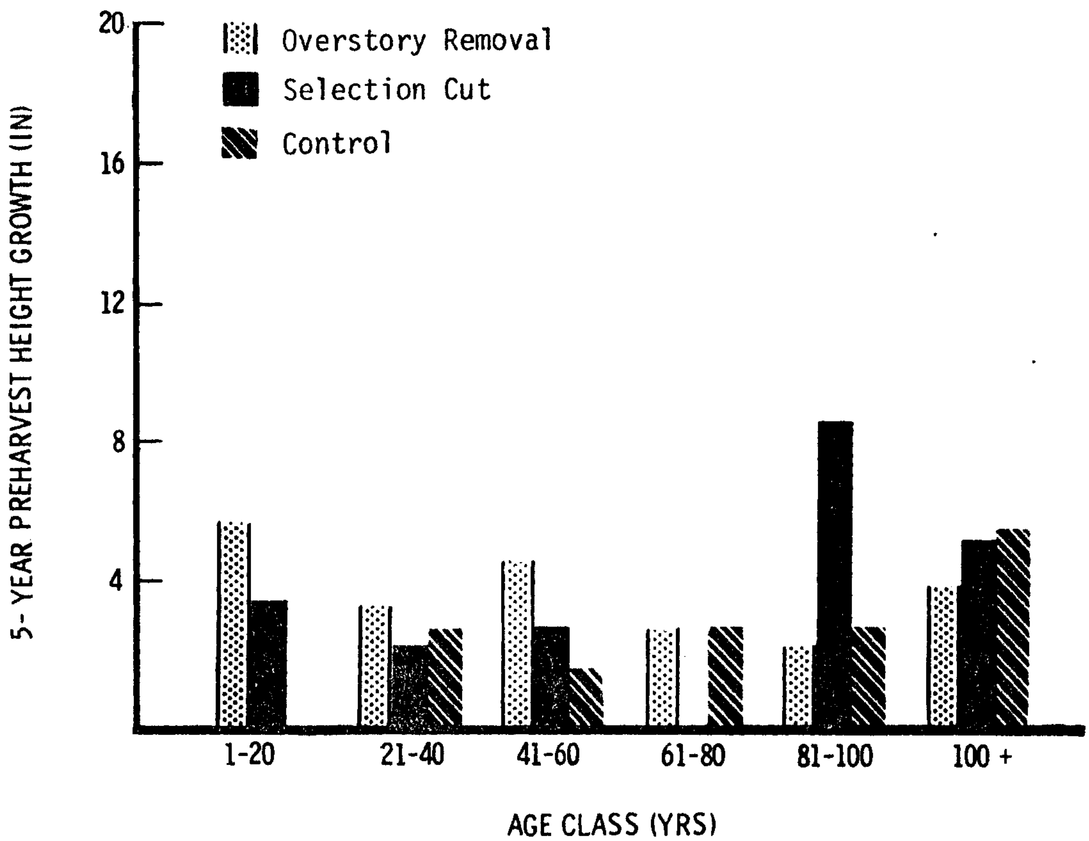


Figure 29. Engelmann spruce 5-year cumulative preharvest height growth on the Uinta National Forest.

TABLE 28

TABLE VALUES FOR FIGURE 29

| | Age class | 5-year cumulative height growth | Standard deviation | Variance | (n) |
|---|---|---|---|---|---|
| | | (inches) | | | |
| OR | 1 | 6.1 | 2.90 | 8.39 | 4 |
| SE | 1 | 3.7 | 1.84 | 3.38 | 2 |
| CO | 1 | | | | |
| OR | 2 | 3.6 | 1.93 | 3.73 | 7 |
| SE | 2 | 2.3 | 2.79 | 7.78 | 9 |
| CO | 2 | 2.7 | 1.50 | 2.26 | 4 |
| OR | 3 | 4.7 | 5.27 | 27.76 | 5 |
| SE | 3 | 2.8 | 2.91 | 8.44 | 7 |
| CO | 3 | 1.6 | 1.00 | 1.01 | 7 |
| OR | 4 | 2.8 | 2.59 | 6.72 | 8 |
| SE | 4 | | | | |
| CO | 4 | 2.8 | 0.55 | 0.30 | 3 |
| OR | 5 | 2.4 | 1.85 | 3.41 | 4 |
| SE | 5 | 8.8 | 7.94 | 63.01 | 4 |
| CO | 5 | 2.9 | 1.63 | 2.65 | 7 |
| OR | 6 | 4.2 | 3.27 | 10.70 | 3 |
| SE | 6 | 5.4 | 4.25 | 18.07 | 13 |
| CO | 6 | 5.8 | 4.44 | 19.70 | 15 |

OR = Overstory removal    SE = Selection cut    CO = Control

Age Class: 1 = 1-20 yrs    2 = 21-40 yrs    3 = 41-60 yrs
4 = 61-80 yrs    5 = 81-100 yrs    6 = 100+ yrs

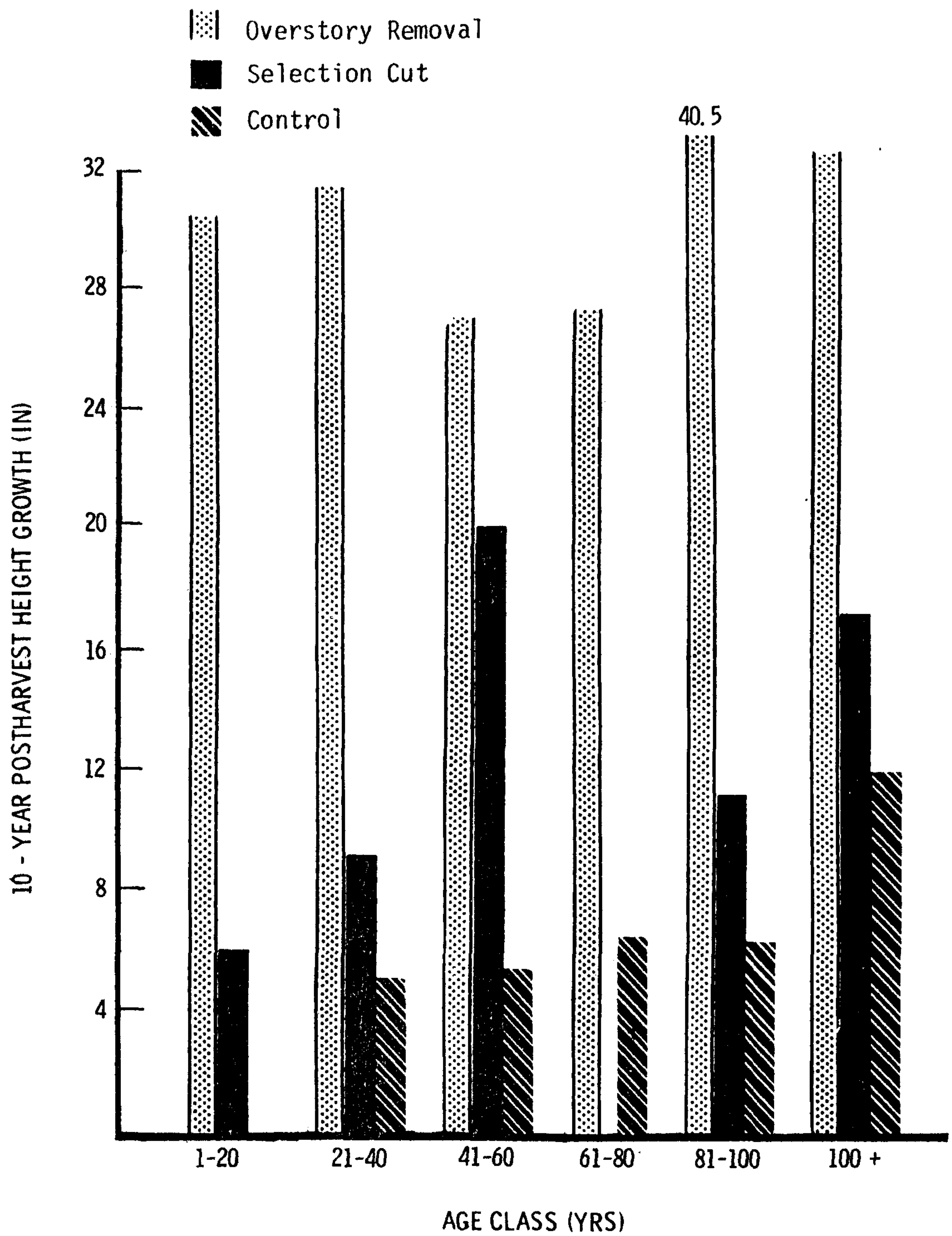


Figure 30. Engelmann spruce 10-year cumulative postharvest height growth on the Uinta National Forest.

TABLE 29

TABLE VALUES FOR FIGURE 30

| | Age class | 10-year cumulative height growth | Standard deviation | Variance | (n) |
|---|---|---|---|---|---|
| | | (inches) | | | |
| OR | 1 | 30.6 | 18.40 | 338.55 | 4 |
| SE | 1 | 6.0 | 1.95 | 3.80 | 3 |
| CO | 1 | | | | |
| OR | 2 | 31.4 | 16.01 | 256.22 | 8 |
| SE | 2 | 9.3 | 6.16 | 37.98 | 9 |
| CO | 2 | 5.4 | 3.35 | 11.20 | 4 |
| OR | 3 | 27.0 | 9.65 | 93.14 | 8 |
| SE | 3 | 20.0 | 17.11 | 292.81 | 8 |
| CO | 3 | 5.6 | 2.97 | 8.80 | 7 |
| OR | 4 | 27.1 | 12.34 | 152.31 | 9 |
| SE | 4 | | | | |
| CO | 4 | 6.5 | 1.87 | 3.48 | 4 |
| OR | 5 | 40.5 | 18.75 | 351.58 | 4 |
| SE | 5 | 11.2 | 6.41 | 41.09 | 5 |
| CO | 5 | 6.3 | 3.76 | 14.12 | 9 |
| OR | 6 | 33.7 | 14.43 | 208.15 | 7 |
| SE | 6 | 17.1 | 8.53 | 72.71 | 15 |
| CO | 6 | 12.0 | 8.70 | 75.75 | 16 |

OR = Overstory removal    SE = Selection cut    CO = Control

Age Class: 1 = 1-20 yrs    2 = 21-40 yrs    3 = 41-60 yrs
4 = 61-80 yrs    5 = 81-100 yrs    6 = 100+ yrs

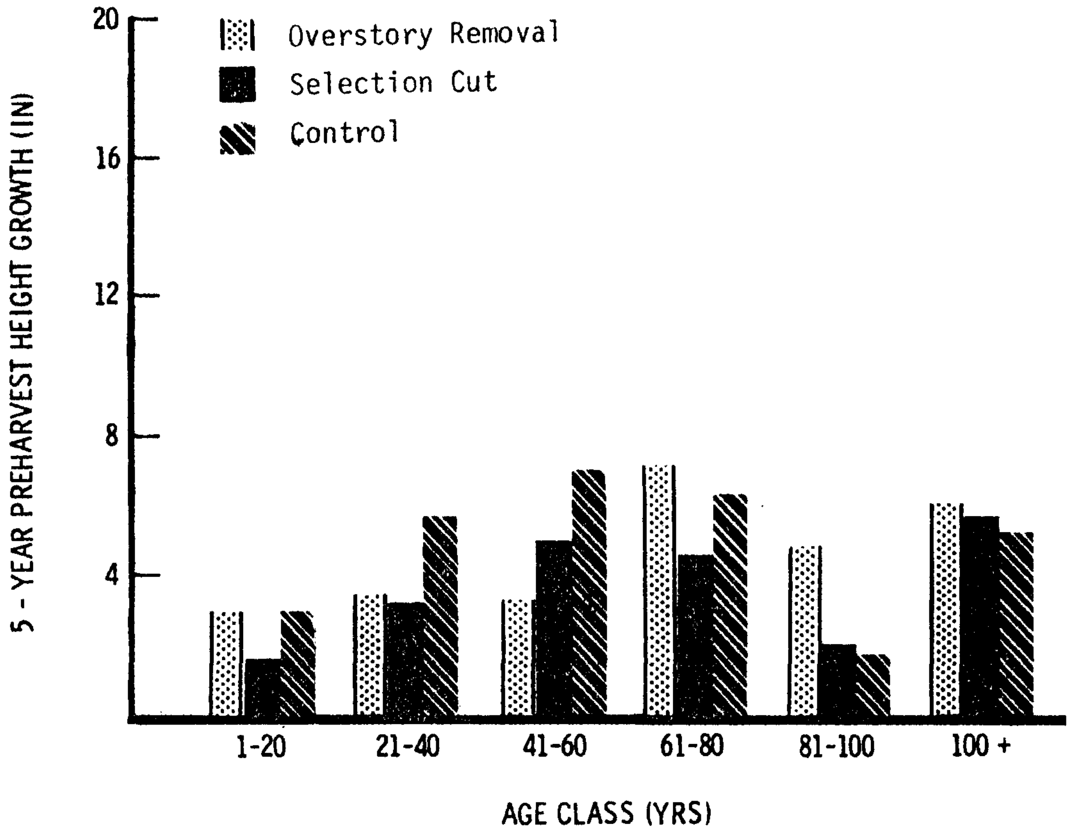


Figure 31. Subalpine fir 5-year cumulative preharvest height growth on the Uinta National Forest.

TABLE 30

TABLE VALUES FOR FIGURE 31

| | Age class | 5-year cumulative height growth | Standard deviation | Variance | (n) |
|---|---|---|---|---|---|
| | | (inches) | | | |
| OR | 1 | 3.2 | 1.41 | 1.98 | 4 |
| SE | 1 | 1.7 | 0.74 | 0.55 | 4 |
| CO | 1 | 3.1 | 0.78 | 0.60 | 2 |
| OR | 2 | 3.6 | 2.38 | 5.65 | 17 |
| SE | 2 | 3.5 | 2.08 | 4.35 | 14 |
| CO | 2 | 5.9 | 3.04 | 9.22 | 14 |
| OR | 3 | 3.4 | 1.27 | 1.62 | 6 |
| SE | 3 | 5.2 | 2.78 | 7.75 | 7 |
| CO | 3 | 7.2 | 5.88 | 34.55 | 12 |
| OR | 4 | 7.3 | 3.03 | 9.20 | 6 |
| SE | 4 | 4.7 | 3.60 | 12.95 | 8 |
| CO | 4 | 6.4 | 3.00 | 9.02 | 8 |
| OR | 5 | 5.0 | 4.68 | 21.94 | 4 |
| SE | 5 | 2.0 | 1.34 | 1.80 | 3 |
| CO | 5 | 1.8 | 1.41 | 2.00 | 2 |
| OR | 6 | 6.2 | 8.06 | 64.98 | 2 |
| SE | 6 | 6.0 | 6.43 | 41.40 | 2 |
| CO | 6 | 5.3 | 3.68 | 13.52 | 2 |

OR = Overstory removal SE = Selection cut CO = Control

Age Class: 1 = 1-20 yrs 2 = 21-40 yrs 3 = 41-60 yrs
4 = 61-80 yrs 5 = 81-100 yrs 6 = 100+ yrs

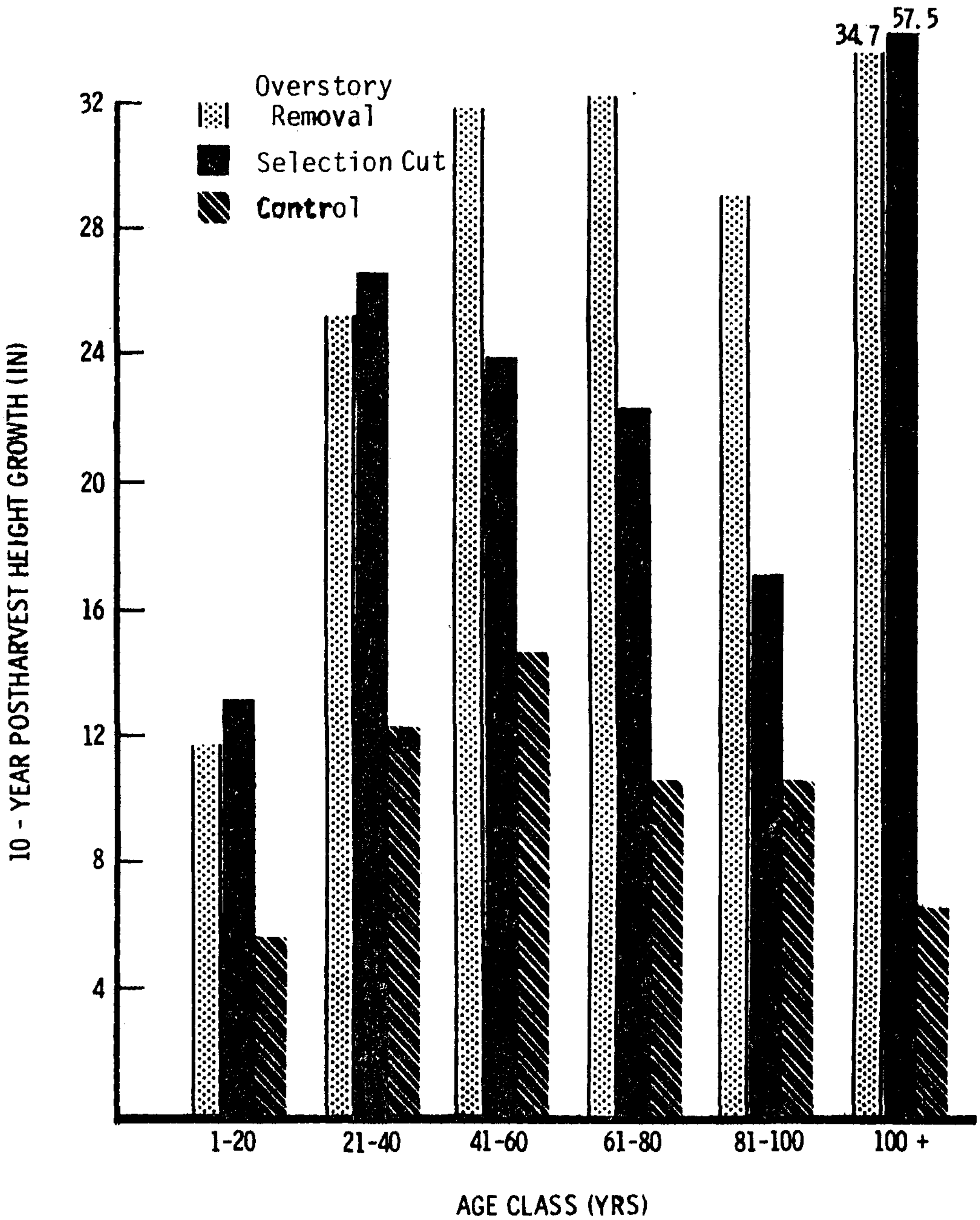


Figure 32. Subalpine fir 10-year cumulative postharvest height growth on the Uinta National Forest.

TABLE 31

TABLE VALUES FOR FIGURE 32

| | Age class | 10-year cumulative height growth (inches) | Standard deviation | Variance | (n) |
|---|---|---|---|---|---|
| OR | 1 | 11.9 | 2.32 | 5.38 | 4 |
| SE | 1 | 13.1 | 5.41 | 29.25 | 4 |
| CO | 1 | 5.8 | 2.33 | 5.45 | 2 |
| OR | 2 | 25.3 | 24.49 | 599.93 | 17 |
| SE | 2 | 26.5 | 11.73 | 137.59 | 15 |
| CO | 2 | 12.2 | 5.14 | 26.40 | 14 |
| OR | 3 | 31.8 | 9.92 | 98.31 | 6 |
| SE | 3 | 24.0 | 12.53 | 156.98 | 7 |
| CO | 3 | 14.4 | 12.87 | 165.67 | 12 |
| OR | 4 | 32.1 | 18.13 | 328.71 | 6 |
| SE | 4 | 22.2 | 16.49 | 271.93 | 8 |
| CO | 4 | 10.4 | 4.56 | 20.76 | 8 |
| OR | 5 | 29.0 | 13.51 | 182.64 | 5 |
| SE | 5 | 17.1 | 7.90 | 62.48 | 4 |
| CO | 5 | 10.4 | 9.33 | 87.12 | 2 |
| OR | 6 | 34.7 | 4.67 | 21.78 | 2 |
| SE | 6 | 57.5 | 65.48 | 4,287.38 | 2 |
| CO | 6 | 6.7 | 0.64 | 0.41 | 2 |

OR = Overstory removal SE = Selection cut CO = Control

Age Class: 1 = 1-20 yrs 2 = 21-40 yrs 3 = 41-60 yrs
4 = 61-80 yrs 5 = 81-100 yrs 6 = 100+ yrs

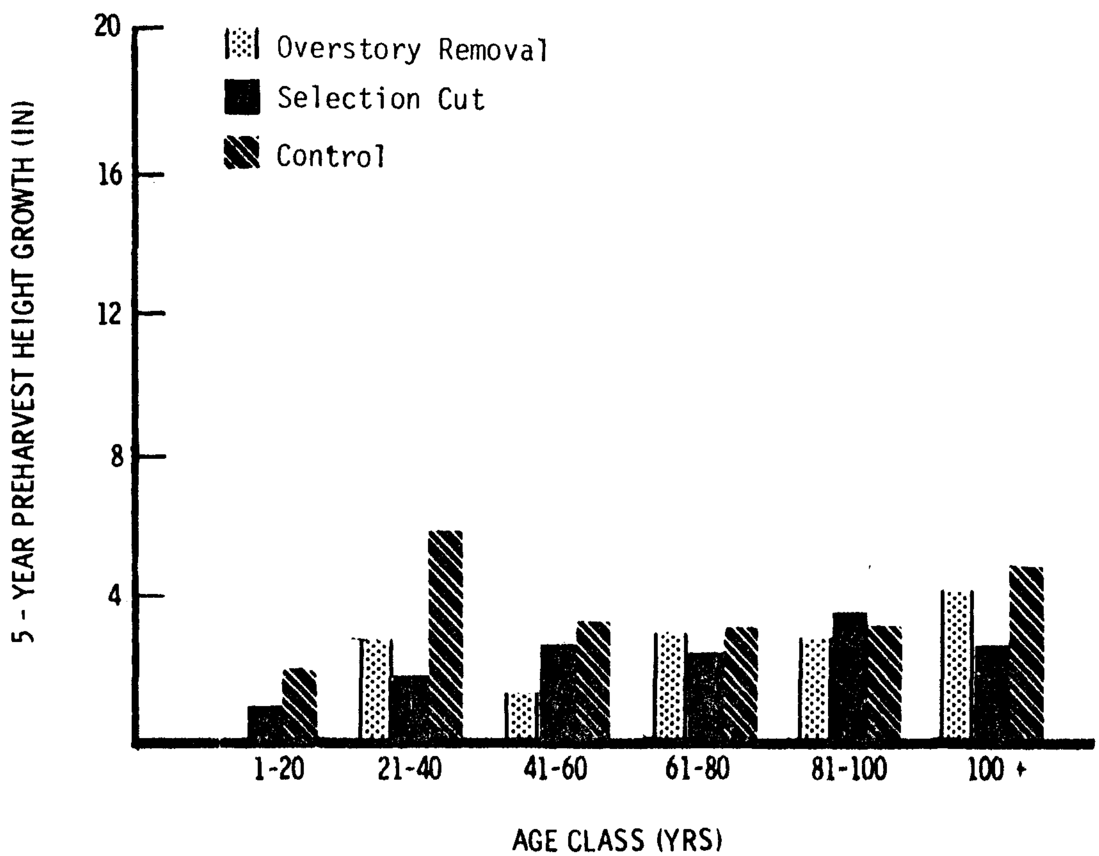


Figure 33. Engelmann spruce 5-year cumulative preharvest height growth on the Dixie National Forest.

TABLE 32

TABLE VALUES FOR FIGURE 33

| | Age class | 5-year cumulative height growth (inches) | Standard deviation | Variance | (n) |
|---|---|---|---|---|---|
| OR | 1 | | | | |
| SE | 1 | 0.8 | 0.28 | 0.08 | 2 |
| CO | 1 | 2.0 | 0.99 | 0.98 | 2 |
| OR | 2 | 2.9 | 2.36 | 5.57 | 8 |
| SE | 2 | 1.9 | 1.26 | 1.58 | 7 |
| CO | 2 | 6.0 | 5.67 | 32.10 | 6 |
| OR | 3 | 1.4 | 1.03 | 1.06 | 9 |
| SE | 3 | 2.7 | 3.74 | 13.96 | 6 |
| CO | 3 | 3.3 | 1.63 | 2.64 | 8 |
| OR | 4 | 3.1 | 3.00 | 9.00 | 8 |
| SE | 4 | 2.6 | 3.22 | 10.34 | 11 |
| CO | 4 | 3.2 | 3.47 | 12.05 | 9 |
| OR | 5 | 2.9 | 1.46 | 2.12 | 10 |
| SE | 5 | 3.6 | 3.84 | 14.74 | 5 |
| CO | 5 | 3.3 | 2.23 | 4.96 | 8 |
| OR | 6 | 4.2 | 4.32 | 18.70 | 3 |
| SE | 6 | 2.5 | 2.49 | 6.19 | 8 |
| CO | 6 | 4.9 | 4.55 | 20.73 | 3 |

OR = Overstory removal SE = Selection cut CO = Control

Age Class: 1 = 1-20 yrs 2 = 21-40 yrs 3 = 41-60 yrs
4 = 61-80 yrs 5 = 81-100 yrs 6 = 100+ yrs

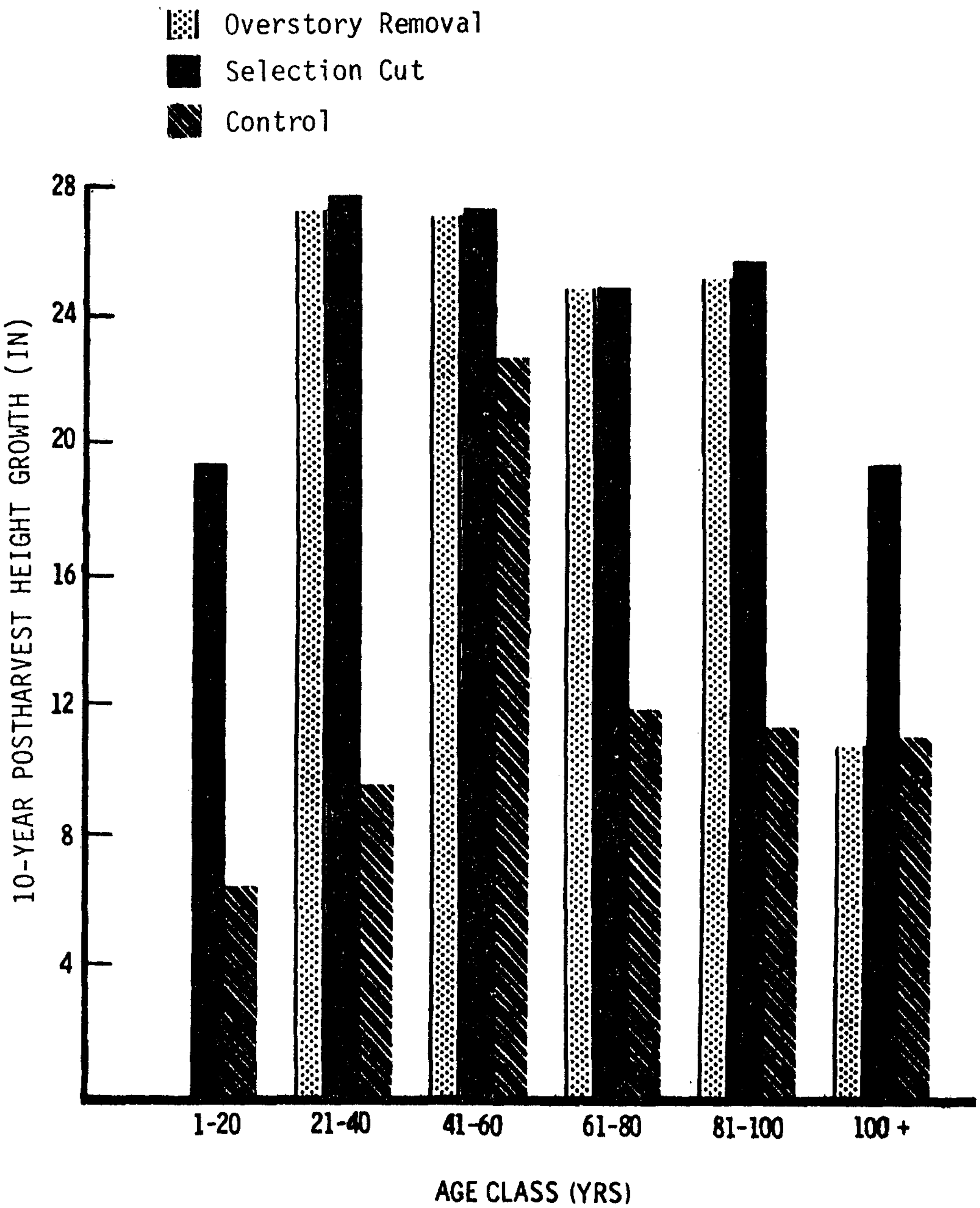


Figure 34. Engelmann spruce 10-year cumulative postharvest height growth on the Dixie National Forest.

TABLE 33

TABLE VALUES FOR FIGURE 34

| | Age class | 10-year cumulative height growth (inches) | Standard deviation | Variance | (n) |
|---|---|---|---|---|---|
| OR | 1 | | | | |
| SE | 1 | 19.5 | 12.45 | 154.88 | 2 |
| CO | 1 | 6.4 | 2.69 | 7.22 | 2 |
| OR | 2 | 27.3 | 12.26 | 150.36 | 9 |
| SE | 2 | 27.9 | 12.58 | 158.27 | 8 |
| CO | 2 | 9.7 | 5.44 | 29.56 | 6 |
| OR | 3 | 27.3 | 7.53 | 56.69 | 9 |
| SE | 3 | 27.3 | 5.83 | 33.96 | 6 |
| CO | 3 | 22.8 | 32.50 | 1,056.15 | 9 |
| OR | 4 | 24.9 | 13.86 | 192.02 | 8 |
| SE | 4 | 25.1 | 15.37 | 236.10 | 11 |
| CO | 4 | 12.0 | 7.86 | 61.75 | 10 |
| OR | 5 | 25.1 | 9.05 | 81.87 | 11 |
| SE | 5 | 25.7 | 9.09 | 82.60 | 5 |
| CO | 5 | 11.5 | 5.91 | 34.90 | 10 |
| OR | 6 | 10.9 | 5.67 | 32.17 | 3 |
| SE | 6 | 19.6 | 6.13 | 37.58 | 8 |
| CO | 6 | 11.3 | 5.21 | 27.09 | 3 |

OR = Overstory removal    SE = Selection cut    CO = Control

Age Class: 1 = 1-20 yrs    2 = 21-40 yrs    3 = 41-60 yrs
4 = 61-80 yrs    5 = 81-100 yrs    6 = 100+ yrs

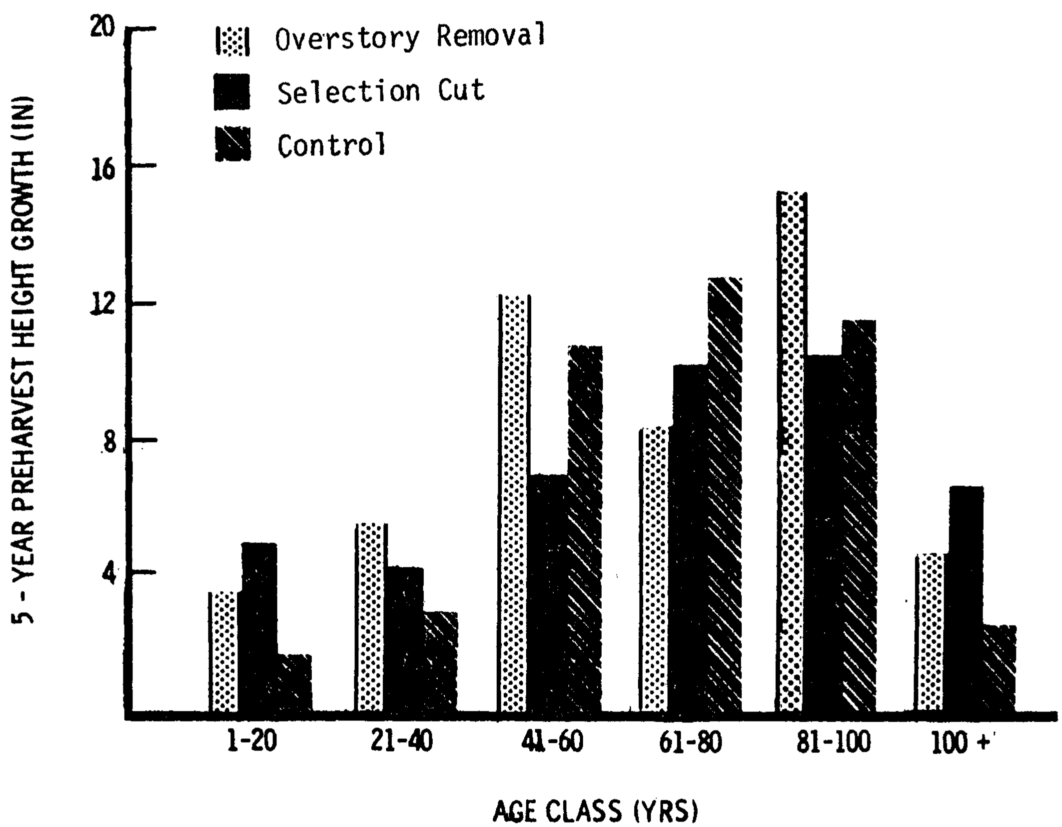


Figure 35. Subalpine fir 5-year cumulative preharvest height growth on the Dixie National Forest.

TABLE 34

TABLE VALUES FOR FIGURE 35

| | Age class | 10-year cumulative height growth (inches) | Standard deviation | Variance | (n) |
|---|---|---|---|---|---|
| OR | 1 | 1.7 | 0.83 | 0.68 | 5 |
| SE | 1 | 4.7 | 0.00 | 0.00 | 1 |
| CO | 1 | 1.8 | 0.38 | 0.14 | 3 |
| OR | 2 | 5.6 | 5.61 | 31.53 | 8 |
| SE | 2 | 4.2 | 4.06 | 16.51 | 8 |
| CO | 2 | 2.9 | 1.95 | 3.80 | 10 |
| OR | 3 | 12.2 | 11.45 | 131.14 | 8 |
| SE | 3 | 6.8 | 10.53 | 110.96 | 9 |
| CO | 3 | 10.7 | 5.42 | 29.33 | 9 |
| OR | 4 | 8.3 | 3.96 | 15.72 | 8 |
| SE | 4 | 10.0 | 4.75 | 22.57 | 11 |
| CO | 4 | 12.7 | 13.77 | 189.62 | 7 |
| OR | 5 | 15.4 | 4.85 | 23.56 | 3 |
| SE | 5 | 10.5 | 7.24 | 52.38 | 4 |
| CO | 5 | 11.6 | 5.90 | 34.84 | 7 |
| OR | 6 | 4.7 | 2.65 | 7.03 | 4 |
| SE | 6 | 6.7 | 7.85 | 61.64 | 4 |
| CO | 6 | 2.5 | 1.21 | 1.45 | 3 |

OR = Overstory removal    SE = Selection cut    CO = Control

Age Class: 1 = 1-20 yrs    2 = 21-40 yrs    3 = 41-60 yrs
4 = 61-80 yrs    5 = 81-100 yrs    6 = 100+ yrs

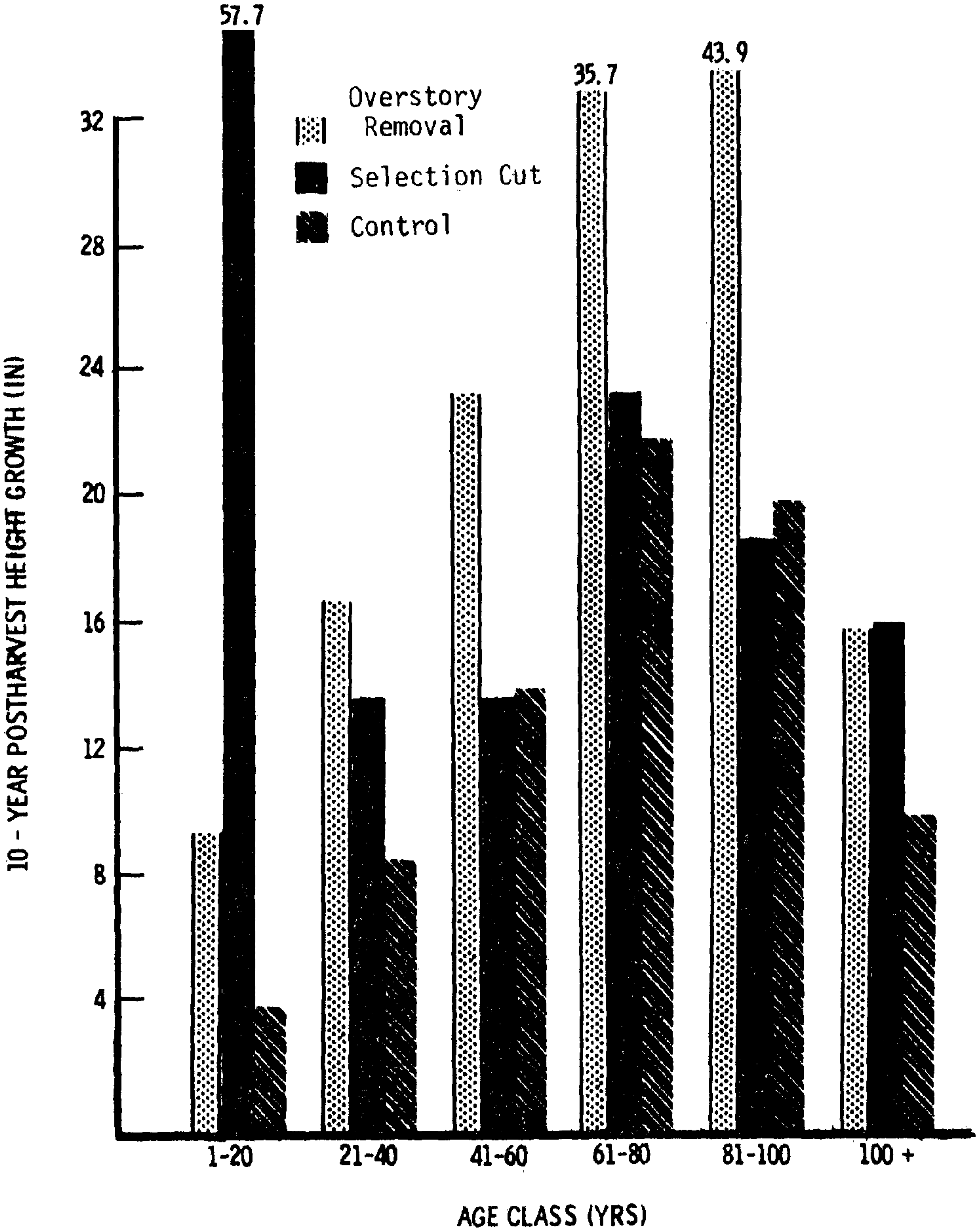


Figure 36. Subalpine fir 10-year cumulative postharvest height growth on the Dixie National Forest.

TABLE 35

TABLE VALUES FOR FIGURE 36

| | Age class | 10-year cumulative height growth (inches) | Standard deviation | Variance | (n) |
|---|---|---|---|---|---|
| OR | 1 | 9.6 | 2.68 | 7.19 | 5 |
| SE | 1 | 57.7 | 74.81 | 5,596.82 | 2 |
| CO | 1 | 3.9 | 0.95 | 0.90 | 4 |
| OR | 2 | 16.7 | 11.95 | 142.83 | 12 |
| SE | 2 | 13.9 | 11.27 | 126.99 | 10 |
| CO | 2 | 8.6 | 6.06 | 36.67 | 10 |
| OR | 3 | 23.4 | 15.59 | 242.89 | 8 |
| SE | 3 | 13.9 | 13.01 | 169.30 | 9 |
| CO | 3 | 14.0 | 6.50 | 42.27 | 9 |
| OR | 4 | 35.7 | 17.94 | 321.83 | 8 |
| SE | 4 | 23.6 | 13.54 | 183.36 | 11 |
| CO | 4 | 22.1 | 18.96 | 359.58 | 7 |
| OR | 5 | 43.9 | 23.49 | 551.89 | 3 |
| SE | 5 | 18.9 | 10.09 | 101.87 | 4 |
| CO | 5 | 19.6 | 10.45 | 109.30 | 7 |
| OR | 6 | 16.0 | 4.55 | 20.72 | 4 |
| SE | 6 | 16.0 | 5.95 | 35.35 | 4 |
| CO | 6 | 10.0 | 3.33 | 11.08 | 3 |

OR = Overstory removal SE = Selection cut CO = Control

Age Class: 1 = 1-20 yrs 2 = 21-40 yrs 3 = 41-60 yrs
4 = 61-80 yrs 5 = 81-100 yrs 6 = 100+ yrs