AN ABSTRACT OF THE THESIS OF

Darrell W. Ross for the degree of Master of Science in Forest Science presented on March 6, 1985.

Title: The Effects of Mechanical and Chemical Site Preparation on Ponderosa Pine (*Pinus ponderosa* Dougl. ex Laws.) and Lodgepole Pine (*Pinus contorta* Dougl. ex Loud.) Performance, Associated Vegetation, and Soil Properties in Southcentral Oregon Eight Years After Planting

Abstract approved: ______________________________
Dr. John D. Walstad

The effects of six alternative site preparation treatments were compared at three different sites in southcentral Oregon. Treatments included a logged-only control, ripping, brushblading, disking, chemical, and chemical followed by disking. Subplots containing ponderosa pine bareroot (2+0) and containerized (1+0) and lodgepole pine containerized (1+0) seedlings were also included in the experiment.

The study involved the remeasurement of the plots eight growing seasons after establishment. The treatments were evaluated based on changes in selected soil chemical and physical properties, the response of non-conifer vegetation, and the survival and growth of the planted pines.

Soil samples were analyzed for total N, total S, total C, and extractable phosphorus. Bulk density was also determined for each sample. In general, the brushblade and chemical/disk treatments caused the greatest reduction in nutrient levels and the greatest increase in bulk density compared to the control and other treatments.

The greatest differences in the amount of non-conifer vegetation among site preparation treatments were observed at the low elevation site (East Aspen), which supported an established shrub community prior to treatment. Total aboveground biomass of shrubs was highest on the control plot. Ripping had the second highest shrub biomass, followed by the disk, brushblade, chemical, and chemical/disk treatments. Plant communities at the higher elevation sites (Swede Cabin and Camp Nine) were primarily composed of grass, sedge, and forb species with scattered shrubs. In general, the control and rip plots had the highest canopy coverage of herbaceous vegetation at these sites, followed by the brushblade, disk, chemical/disk, and chemical treatments.

Pine survival was satisfactory for all treatments except the rip and control plots at East Aspen and Swede Cabin. Survival was low for all treatments at Camp Nine.

The greatest differences in conifer height growth among site preparation treatments occurred at East Aspen. At this site, the chemical/disk and chemical treatments resulted in a substantial increase in height growth compared to the control. Disking, brushblading, and ripping also increased height growth, but to a lesser extent. All of the treatments except ripping were equally effective at Swede Cabin in increasing height growth compared to the control. At Camp Nine, the effect of treatments with respect to height growth was the same as that at East Aspen, although the magnitude of the differences was less.

The results of this study indicate the importance of controlling competing vegetation in order to achieve maximum survival and early growth of planted pines in southcentral Oregon.

The Effects of Mechanical and Chemical Site Preparation on Ponderosa Pine (*Pinus ponderosa* Dougl. ex Laws.) and Lodgepole Pine (*Pinus contorta* Dougl. ex Loud.) Performance, Associated Vegetation, and Soil Properties in Southcentral Oregon Eight Years After Planting

by

Darrell W. Ross

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Completed March 6, 1985

Commencement June 1985

APPROVED:

Professor of Forest Science in charge of major

Head of Department of Forest Science

Dean of Graduate School

Date thesis is presented March 6, 1985

ACKNOWLEDGEMENTS

The completion of this thesis was made possible through the assistance, cooperation, and support of a number of individuals. I gratefully acknowledge the assistance of my major professor, Jack Walstad, who conceived of the idea for this project and provided valuable guidance and suggestions throughout its development. This work could not have been accomplished without the cooperation of the Weyerhaeuser Company. Specifically, I am indebted to Bill Scott, Ron Heninger, Martin Lugas, and Paul Figueroa of the Weyerhaeuser Company for providing the background and early records pertaining to the original study. Conversations with Stuart Childs, Kermit Cromack, and Dean Hanson were helpful in determining the procedures for collecting and analyzing the soil samples. Hank Froehlich and Phil Sollins graciously provided access to their laboratory facilities for the preparation and analysis of the soil samples. Special thanks go to Carol Glassman who patiently answered questions and provided suggestions during the preparation and analysis of the soil samples in the laboratory. Carolyn Wright and LaRea Dennis identified a number of plant specimens that could not be positively identified by the author at the research plots. Many fellow graduate students were supportive throughout the project, but Keith McClain, Joyce Bork,

and John Marshall provided encouragement in the early stages of the work that was particularly helpful. Finally, my most sincere thanks and appreciation go to my wife, Elise, who has unselfishly supported and encouraged my endeavors during the past two years.

TABLE OF CONTENTS

INTRODUCTION 1

LITERATURE REVIEW 6
  Description of the Klamath Region 6
  History of Land Use 11
  Present Condition of the Timber Resource 14
  Effects of Associated Vegetation 17
  History of Site Preparation 30
  Impact of Site Preparation on Soil and Site Productivity 39
  Long-term Benefits of Intensive Site Preparation 52

HISTORY OF RESEARCH INSTALLATIONS 56

DESCRIPTION OF STUDY LOCATIONS 63
  East Aspen 63
  Swede Cabin 66
  Camp Nine 68

METHODS 72
  Soils 72
  Vegetation 74
  Conifers 79

RESULTS AND DISCUSSION 83
  Soils 83
  Vegetation 94
  Conifers 107

SUMMARY AND INTEGRATION OF RESULTS 140

BIBLIOGRAPHY 151

APPENDICES 162
  Appendix I. Diagram of general plot layout. 163
  Appendix II. Description of the soil corer and the method of collecting soil samples. 164
  Appendix III. Tables of soil properties (including standard errors) by soil layer and site preparation treatment for each of the three study site locations. 167
  Appendix IV. Tables of woody and herbaceous vegetation characteristics by species and site preparation treatment for each of the three study site locations. 171

TABLE OF CONTENTS (continued)

Appendix V. Tables of biomass regression equation coefficients and statistics for non-conifer woody vegetation and conifers by species. 187

Appendix VI. Species codes and corresponding scientific plant names. 190

Appendix VII. a. Tables of survival and growth of planted pines (including standard errors) by species/stock type and site preparation treatment for each of the three study site locations. 192

b. Figures of current annual height increment by species and site preparation treatment for each of the three study site locations. . . . 199

LIST OF FIGURES

Figure		Page
1.	Klamath Falls site preparation study site locations.	71
2.	Ponderosa pine trees growing in a control plot at the East Aspen site after eight growing seasons.	114
3.	Ponderosa pine trees growing in a rip plot at the East Aspen site after eight growing seasons.	115
4.	Ponderosa pine trees growing in a brushblade plot at the East Aspen site after eight growing seasons.	116
5.	Ponderosa pine trees growing in a disk plot at the East Aspen site after eight growing seasons.	117
6.	Ponderosa pine trees growing in a chemical plot at the East Aspen site after eight growing seasons.	118
7.	Ponderosa pine trees growing in a chemical/disk plot at the East Aspen site after eight growing seasons.	119
8.	Total height of ponderosa pine trees planted at the East Aspen site following each of six site preparation treatments.	120
9.	Total height of ponderosa pine trees planted at the Swede Cabin site following each of six site preparation treatments.	121
10.	Total height of ponderosa pine trees planted at the Camp Nine site following each of six site preparation treatments.	122
11.	Total height of lodgepole pine trees planted at the Swede Cabin site following each of six site preparation treatments.	123
12.	Total height of ponderosa pine bareroot and plug seedlings planted at the East Aspen site.	131

LIST OF FIGURES (continued)

Figure		Page
13.	Current annual height increment of ponderosa pine bareroot and plug seedlings planted at the East Aspen site.	132
14.	Total height of lodgepole and ponderosa pine seedlings planted at the Swede Cabin site.	135
15.	Current annual height increment of lodgepole and ponderosa pine seedlings planted at the Swede Cabin site.	136
16.	Diagram of general plot layout that is replicated at each of the three study sites.	163
17.	Soil corer that was used to collect volumetric soil samples.	166
18.	Current annual height increment of ponderosa pine trees planted at the East Aspen site following each of six site preparation treatments.	200
19.	Current annual height increment of ponderosa pine trees planted at the Swede Cabin site following each of six site preparation treatments.	201
20.	Current annual height increment of ponderosa pine trees planted at the Camp Nine site following each of six site preparation treatments.	202
21.	Current annual height increment of lodgepole pine trees planted at the Swede Cabin site following each of six site preparation treatments.	203

LIST OF TABLES

Table		Page
1.	Klamath Falls site preparation study sites, elevation, and soil series (Duncan and Steinbrenner 1975).	57
2.	Conifer growth data collected at each location on the Klamath Falls site preparation research plots between 1976 and 1979.	60
3.	Soil properties for two soil layers at the East Aspen site after eight growing seasons following each of six site preparation treatments.	84
4.	Soil properties for two soil layers at the Swede Cabin site after eight growing seasons following each of six site preparation treatments.	85
5.	Soil properties for two soil layers at the Camp Nine site after eight growing seasons following each of six site preparation treatments.	86
6.	Characteristics of non-conifer vegetation at the East Aspen site after eight growing seasons following each of six site preparation treatments.	96
7.	Characteristics of non-conifer vegetation at the Swede Cabin site after eight growing seasons following each of six site preparation treatments.	97
8.	Characteristics of non-conifer vegetation at the Camp Nine site after eight growing seasons following each of six site preparation treatments.	98
9.	Ponderosa pine survival and growth at the East Aspen site after eight growing seasons following each of six site preparation treatments.	108
10.	Ponderosa pine survival and growth at the Swede Cabin site after eight growing seasons following each of six site preparation treatments.	109

LIST OF TABLES (continued)

Table | Page
11. Ponderosa pine survival and growth at the Camp Nine site after eight growing seasons following each of six site preparation treatments. 110

12. Lodgepole pine survival and growth at the Swede Cabin site after eight growing seasons following each of six site preparation treatments. 111

13. Ponderosa pine survival and growth by stock type at the East Aspen site after eight growing seasons. 130

14. Conifer survival and growth by species and stock type at the Swede Cabin site after eight growing seasons. 134

15. Soil properties for two soil layers at the East Aspen site after eight growing seasons following each of six site preparation treatments (including C:N and C:S ratios and standard errors for all soil properties). 168

16. Soil properties for two soil layers at the Swede Cabin site after eight growing seasons following each of six site preparation treatments (including C:N and C:S ratios and standard errors for all soil properties). 169

17. Soil properties for two soil layers at the Camp Nine site after eight growing seasons following each of six site preparation treatments (including C:N and C:S ratios and standard errors for all soil properties). 170

18. Canopy cover (area) of woody non-conifer vegetation by species at the East Aspen site after eight growing seasons following each of six site preparation treatments. 173

19. Canopy volume of woody non-conifer vegetation by species at the East Aspen site after eight growing seasons following each of six site preparation treatments. 174

LIST OF TABLES (continued)

Table | Page

20. Total aboveground biomass (ovendry weight) of woody non-conifer vegetation by species at the East Aspen site after eight growing seasons following each of six site preparation treatments. 175

21. Mean height of woody non-conifer vegetation by species at the East Aspen site after eight growing seasons following each of six site preparation treatments. 176

22. Density of woody non-conifer vegetation by species at the East Aspen site after eight growing seasons following each of six site preparation treatments. 177

23. Canopy cover (area) of herbaceous vegetation by species at the East Aspen site after eight growing seasons following each of six site preparation treatments. 178

24. Canopy cover (area) of woody non-conifer vegetation by species at the Swede Cabin site after eight growing seasons following each of six site preparation treatments. 179

25. Canopy volume of woody non-conifer vegetation by species at the Swede Cabin site after eight growing seasons following each of six site preparation treatments. 180

26. Total aboveground biomass (ovendry weight) of woody non-conifer vegetation by species at the Swede Cabin site after eight growing seasons following each of six site preparation treatments. 181

27. Mean height of woody non-conifer vegetation by species at the Swede Cabin site after eight growing seasons following each of six site preparation treatments. 182

28. Density of woody non-conifer vegetation by species at the Swede Cabin site after eight growing seasons following each of six site preparation treatments. 183

LIST OF TABLES (continued)

Table Page

29. Canopy cover (area) of herbaceous vegetation by species at the Swede Cabin site after eight growing seasons following each of six site preparation treatments. 184

30. Characteristics of woody non-conifer vegetation by species at the Camp Nine site after eight growing seasons following each of six site preparation treatments. 185

31. Canopy cover (area) of herbaceous vegetation by species at the Camp Nine site after eight growing seasons following each of six site preparation treatments. 186

32. Biomass regression equation coefficients and statistics for woody non-conifer vegetation by species. 188

33. Biomass regression equation coefficients and statistics for conifers by species and site. 189

34. Ponderosa pine survival and growth at the East Aspen site after eight growing seasons following each of six site preparation treatments (including crown width, crown area, bole biomass, and standard errors for all measures of tree growth). 193

35. Ponderosa pine survival and growth at the Swede Cabin site after eight growing seasons following each of six site preparation treatments (including crown width, crown area, bole biomass, and standard errors for all measures of tree growth). 194

36. Ponderosa pine survival and growth at the Camp Nine site after eight growing seasons following each of six site preparation treatments (including crown width, crown area, bole biomass, and standard errors for all measures of tree growth). 195

LIST OF TABLES (continued)

Table | Page

37. Lodgepole pine survival and growth at the Swede Cabin site after eight growing seasons following each of six site preparation treatments (including crown width, crown area, bole biomass, and standard errors for all measures of tree growth). 196

38. Ponderosa pine survival and growth by stock type at the East Aspen site after eight growing seasons (including crown width, crown area, bole biomass, and standard errors for all measures of tree growth). 197

39. Conifer survival and growth by species and stock type at the Swede Cabin site after eight growing seasons (including crown width, crown area, bole biomass, and standard errors for all measures of tree growth). 198

The Effects of Mechanical and Chemical Site Preparation on Ponderosa Pine (*Pinus ponderosa* Dougl. ex Laws.) and Lodgepole Pine (*Pinus contorta* Dougl. ex Loud.) Performance, Associated Vegetation, and Soil Properties in Southcentral Oregon Eight Years After Planting

INTRODUCTION

An increasing demand for forest products and a declining forest land base have been the reasons most often cited for intensifying forest management of commercial timberlands throughout the United States (Ellefson 1973). More recently, the nation's need to export more goods and the possibilities for using wood fiber as an alternative energy source have emphasized the need for more efficient timber management (Haines 1981). The first step to achieving maximum productivity from commercial timberland is the prompt establishment of a fully stocked stand of crop trees following any natural or man-caused disturbance that reduces stocking to below an acceptable level. Failure to immediately regenerate stands following a disturbance can result in substantial value and volume yield losses (Brodie and Tedder 1982). In addition to the economic reasons for prompt reforestation, many states, including Oregon, now have laws that require successful reforestation within a given period of time following harvest operations.

Proper planting of nursery grown stock is the most dependable method of regenerating lodgepole (Pinus contorta Dougl. ex Loud.) and ponderosa (Pinus ponderosa Dougl. ex Laws.) pines in southcentral Oregon (Adams 1970, Barrett 1979, Lotan and Perry 1983, Roy 1983). Natural regeneration can be slow and is often unpredictable (Cochran 1973a, Harrington and Kelsey 1979).

With the exception of a recent hot burn, most areas in this region that are in need of reforestation will require some type of site preparation (Zavitkovski and Woodard 1970, Barrett 1979). The primary purpose of site preparation is to control competing vegetation that can drastically reduce the survival and early growth of planted pines (Dahms 1950, Roy 1953, Baron 1962, Larson and Schubert 1969, Bentley et al. 1971, Stewart and Beebe 1974, Clark and McLean 1975, Crouch 1979, Tappeiner and Radosevich 1982). Secondary objectives of site preparation may include reducing the volume of logging residue or reducing the influence of potential seedling damaging animals and insects by altering their habitat (Crouch 1979, Lindstrand 1983). Spot treatments to control vegetation around planted seedlings have proven ineffective and more complete vegetation control is usually necessary to insure survival and adequate growth of conifers (Loewenstein et al. 1968, Larson and Schubert 1969, Thompson 1974, Barrett 1979, McDonald 1983).

The general types of site preparation that are available to forest managers include fire, mechanical, and chemical methods. These techniques may be used singly or in various combinations to achieve one or more objectives. The effective use of fire to control competing vegetation in southcentral Oregon is limited by the prevailing climatic conditions and the ecological characteristics of some of the more important weed species. Because of the danger of wildfire, prescribed burning is usually restricted to relatively short periods in the spring and fall in order to avoid the hot, dry weather conditions during the summer months. The prescribed conditions for broadcast burning may be met on only a few days, if any, each year because of unpredictable precipitation in the spring and fall seasons. Many of the forest weed species in this region are only top killed by fire and sprout vigorously after burning. Furthermore, the dormant seeds of some species are stimulated to germinate by the high temperatures associated with burning. Consequently, foresters in this region are generally restricted to mechanical and chemical methods of site preparation for vegetation control. Scarification by bulldozers equipped with brushrakes is the most common method of preparing pine sites for planting (Adams 1970, Schubert and Adams 1971, Stewart 1978). Recently, however, there has been increasing concern that intensive mechanical site preparation treatments could reduce long-term site productivity by altering physical and chemical soil properties (Haines et al. 1975, Will and Youngberg 1978).

A major concern of foresters is the cost of reforestation efforts. These costs must be carried for a long period of time and the rate of return on investments is typically low (Newton and Webb 1970). As a result, foresters must critically assess the cost/benefit ratio associated with all reforestation treatments, including site preparation. The increases in wood production anticipated from site preparation must be great enough to economically justify the high cost of treatment. Therefore, conifer performance will have to be evaluated over a long period of time in order to determine whether early increases in growth resulting from site preparation treatments will be maintained throughout the rotation.

This study compares six alternative site preparation treatments that result in various degrees of vegetation control and physical disturbance to the site.

The treatments include a logged-only control, ripping, disking, brushblading, chemical, and chemical followed by disking. The treatments are compared with respect to conifer performance, response of non-conifer vegetation, and changes in selected soil properties. The results are based on data collected following the eighth growing season after treatment.

The results of this study will allow forest managers to more accurately anticipate the effects of alternative site preparation treatments. The objective of this study was not to identify a particular site preparation treatment that is best in all situations, but to characterize the responses following a number of very different treatments under a variety of conditions. It is the responsibility of the forest manager to select the appropriate site preparation treatment for specific sites and to incorporate that treatment into the overall forest management plan. However, in order to make a knowledgeable choice from among the alternative site preparation treatments, the forest manager must have the kind of information that this study provides.

LITERATURE REVIEW

Description of the Klamath Region

All of the sites included in this study are located in the western third of the Basin and Range Province of southcentral Oregon. This area has a long and complex geologic history, but the present geomorphology is primarily the result of volcanism and faulting during the last 2 million years (Duncan and Steinbrenner 1975). This physiographic province is characterized by northwest trending fault block mountains with steep scarp slopes surrounding internally drained valleys. Elevations in this region range from about 1,200 m (3936 ft) to over 2,500 m (8200 ft).

Duncan and Steinbrenner (1975) divided this province into the high lava plains and the rimrock valleys. Most of the commercial timberland is found in the high lava plains portion of the province. The lava plains have a level to gently sloping topography interrupted occasionally by small volcanic hills and cinder cones. Slopes are generally less than 20 percent and rarely exceed 40 percent (Duncan and Steinbrenner 1975, Wenzel 1979). The primary drainage system is well developed, leading to the Pacific Ocean via the Klamath River. Smaller streams originating from springs or swampy areas meander across relatively level terrain until they drop into the larger river valleys. Consequently, much of the area has a bench-like appearance (Duncan and Steinbrenner 1975).

Soils developing on the lava plains are derived from fine volcanic ash over deeply weathered basalt, andesite, tuffs, and buried soils that developed from basaltic residuum and older volcanic ash. These soils are generally medium textured, stony, and reddish brown in color (Wenzel 1979). Within the basalt plains are pockets of rhyolitic rocks associated with dome-shaped eruptive centers. Soils originating from this parent material are shallow to moderately deep, coarse textured, gravelly, and weakly developed. Meadows that are interspersed throughout the region are found on clay-textured soils that developed where shallow lakes once existed (Duncan and Steinbrenner 1975). All of the sites in this study are located south of the area covered by the coarse textured pumice originating from Mt. Mazama and Newberry Crater. Soils in this region have been described and mapped on the Klamath Indian Reservation (U. S. Bureau of Indian Affairs 1958), Weyerhaeuser's Klamath Tree Farm (Duncan and Steinbrenner 1975), and the Fremont National Forest (Wenzel 1979).

The climate of southcentral Oregon is influenced by both maritime and continental air masses as buffered by the Cascade Range to the west, the Rocky Mountains to the east, and other lesser mountain ranges (Franklin and Dyrness 1973). Moving from the Cascades eastward, there is a general trend of decreasing precipitation, increasing summer temperatures, and decreasing winter temperatures. Variations in precipitation and temperature occur along this east-west gradient in response to local topographic features. Diurnal temperature fluctuations of 10° to 16° C (50° to 61° F) are normal. The January mean minimum temperature ranges from -6.0° to -12.0° C (10° to 21° F) and the July mean maximum temperature ranges from 27.0° to 31.0° C (81° to 88° F). Frost-free seasons are short and frost can occur any night of the year. The rain shadow created by the Cascade Range limits annual precipitation to a range of 250 to 500 mm (10 to 20 in). Precipitation is somewhat seasonal with 55 to 75 percent occurring between October 1 and March 31. Most of this precipitation occurs as snow. Summer months (late June through early September) are very dry (30 to 70 mm or 1 to 3 in of rainfall) with the only precipitation resulting from intense localized thunderstorms.

Changes in moisture availability and, to a lesser extent, temperature regimes that occur along altitudinal gradients are important determinants of the nature of vegetation in southcentral Oregon. The vegetation that can exist at any particular location depends upon the interaction of climatic and edaphic factors. In general, forests are restricted to the higher elevations where soil moisture is sufficient for the reproduction and survival of the component tree species. The most important tree species in this region are ponderosa pine, lodgepole pine, Douglas-fir (Psuedotsuga menziesii [Mirb.] Franco), and white fir (Abies concolor [Gord. & Glend.] Hildebr.). At lower elevations, the forests are replaced by shrub-steppe communities composed of sclerophyllous shrub, herbaceous, and grass species characteristic of xeric habitats. At the interface between the forests and shrub-steppes, an open savanna region dominated by western juniper (Juniperus occidentalis Hook.) is sometimes present. Common woody shrubs that are found alone or in association with trees include greenleaf manzanita (Arctostaphylos patula Greene), snowbrush (Ceanothus velutinus Dougl. ex Hook.), bitterbrush (Purshia tridentata [Pursh] DC.), rabbitbrush (Chrysothamnus spp.), curlleaf mountain-mahogany (Cercocarpus ledifolius Nutt.), currant (Ribes spp.), big sagebrush (Artemisia tridentata Nutt.), squawcarpet (Ceanothus prostratus Benth.), snowberry (Symphoricarpos spp.), serviceberry (Amelanchier spp.), and cherry (Prunus spp.). Two of the more important forbs in regard to timber management are mullein

(*Verbascum* spp.) and thistle (*Cirsium* spp.). Grasses from the genera *Agropyron*, *Bromus*, *Festuca*, *Poa*, *Sitanion*, and *Stipa* as well as sedges (*Carex* spp.) are found throughout the region.

In much of the Pacific Northwest, a considerable amount of effort has recently been directed toward identifying and describing typical plant communities to be used as an aid in making land management decisions. Dyrness and Youngberg (1966) were the first to describe plant communities in central Oregon. Their study was restricted to the coarse pumice soils in the northern portion of the Klamath Tree Farm. They identified six plant communties within the ponderosa pine and white fir zones in relation to soil properties. More recently, Dealy (1971) identified plant communities around Silver Lake with respect to the management of mule deer habitat. Franklin and Dyrness (1973) provided a thorough review of the ecological literature published prior to 1973 in describing the plant communities and successional patterns of eastern Oregon. The most current and comprehensive descriptions of plant communities in southcentral Oregon can be found in the Area Guides for this region published by the U.S.D.A. Forest Service (Volland 1976, Hopkins 1979a,b).

History of Land Use

The first known inhabitants of the Klamath Region were an ancient Indian tribe that lived in the area about 5,000 years ago (Good 1941). Little is known about this race or why they left the region, but judging from the artifacts that have been found they were apparently more advanced than the tribes that have inhabited the area in more recent times. When white men first began to settle the Klamath Region it was occupied by two tribes, the Klamaths and the Modocs, that together numbered about 2,000 (Good 1941). There is no evidence that any of these Indian tribes had more than a minor and localized impact on the vegetation of the region.

Prior to the arrival of settlers, fire was the major influence that determined the structure and composition of the vegetation in this region. Many fires were started by lightning and Indians probably caused some fires, either intentionally or by accident (Weaver 1943). Frequent, low intensity ground fires resulted in ponderosa pine forests with an open, park-like stand structure and a predominantly grass understory (Weaver 1961).

Grazing in the Klamath Region began in the mid-1850's, but permanent settlers did not arrive until 1867 (Good 1941). Large herds of cattle were grazed on open range in the southern portion of Klamath County beginning around 1870. Feuds between cattlemen and sheep herders that occurred in northeastern California did not affect Klamath County, although feuds between rival cattlemen were common (Good 1941, McDonald 1983). Overgrazing and misuse of the rangeland occurred for the next 60 years (Volland 1963). Beginning in 1930, the Indian Service administered a permit system to regulate grazing activities on the Klamath Indian Reservation. In 1961, the U. S. Forest Service purchased much of the land that was previously the Klamath Indian Reservation and this agency now regulates grazing on these lands.

Logging began in the Klamath Region in 1863 when the government built a small mill at Fort Klamath (Good 1941). Several other small mills began operating in the next decade, but logging did not begin in earnest until the railroad reached Klamath Falls in 1909. Between 1910 and 1923, logging in the Klamath Region increased dramatically with the construction of 39 mills and 8 box factories employing a total of about 4200 people (Good 1941). In the next 20 years the most significant addition to the lumber industry in Klamath Falls was the opening of the Weyerhaeuser Company plant in 1931. The Weyerhaeuser Company was at the time and still is today the largest lumber company in the Klamath Falls area.

Logging on private lands in the early 1900's has been described as economic clearcutting (Barrett 1979). Practically all trees over 51 cm (20 in) diameter-at-breast-height (d.b.h.) were harvested leaving a clumpy distribution of trees 30 to 51 cm (12 to 20 in) d.b.h. as an overstory (McDonald 1983). Cutting on Federal lands may have been somewhat lighter (Barrett 1979). Only scattered seed trees were left following harvest, and these were of poor form (Barrett 1979, McDonald 1983). Many of the residual trees in all size classes were damaged by logging activities (McDonald 1983). Slash was often left untreated or occassionally broadcast burned (Barrett 1979). Consequently, wildfires and insect infestations were common following harvest operations (McDonald 1983). After World War II, log trucks and crawler tractors replaced railroad logging and a trend toward lighter cuttings evolved (Barrett 1979). The even-aged stands that have developed following some of the early clearcuts are more a result of natural regeneration than of applied forest management.

Forest fire prevention activities developed concurrently with the logging industry. In 1908, the large timber owners organized a fire patrol system know as the "Weyerhaeuser patrol" (Good 1941). This evolved over the years into the Klamath Forest Protective

Association which was responsible for fire control on large and small timberland ownerships. The increase in forest fire control resulted in the development of dense conifer understories and shrub communities and a buildup of dead fuels that increased the chances of more destructive fires occurring (Weaver 1961). In 1918, 80,972 ha (200,000 A) burned in the Klamath Region due in part to the lack of firefighting resources because of World War I. Between 1939 and 1940, 8,097 ha (20,000 A) burned on the Klamath Forest and, in 1959, a single fire burned 6,073 ha (15,000 A) of ponderosa pine on the Klamath Indian Reservation.

Present Condition of the Timber Resource

There are an estimated 4.1 million ha (10.1 million A) of unreserved commercial timberland east of the crest of the Cascade Range in Oregon (Farrenkopf 1982). Over 1.2 million ha (3.0 million A) or 29 percent of this commercial forest land is located in Klamath and Lake Counties in southcentral Oregon. Of the 4.1 million ha of commercial timberland, approximately 3.1 million ha (7.6 million A) or 75 percent is public land and the remainder is privately owned. In Klamath and Lake Counties a larger proportion of the commercial timberland is currently in private ownership. In these counties roughly 40 percent of the commercial timberland is privately owned and most of this area is industrial forest land. Over half of the industrial forest land in eastern Oregon is located in Klamath and Lake Counties.

Despite heavy logging and poor reforestation practices in the past, most of the commercial timberland in eastern Oregon presently supports sawtimber sized stands. About 67 percent of the commercial timberland is classified as sawtimber stands, 22 percent as poletimber stands, 8 percent as sapling and seedling stands, and only 3 percent as nonstocked (Farrenkopf 1982). Although the small percentage of timberland classified as nonstocked is at first encouraging, this includes only those areas that are less than 10 percent stocked. Undoubtedly, there are many hectares of land that have more than 10 percent stocking, but which are less than adequately stocked for optimum timber production.

The two most common forest types in eastern Oregon are ponderosa and lodgepole pine. Ponderosa pine type occupies 1.8 million ha (4.3 million A) of commercial timberland and lodgepole pine type is found on another 0.7 million ha (2.5 million A). Together these forest types account for over 60 percent of the commercial timberland in eastern Oregon (Farrenkopf 1982). However, forest management practices are causing a reduction in the land area dominated by ponderosa pine

(Barrett 1979). Selective harvesting and increased fire control are the primary reasons for the change in forest type. Forest fire prevention and suppression has allowed more shade tolerant species such as true firs and Douglas-fir to become established in the understory of ponderosa pine forests. After the final overstory removal in these stands, the areas become mixed conifer or are occupied by a species other than ponderosa pine.

Timberland in eastern Oregon is generally less productive than timberland in more moderate environments. About 21 percent of the commercial forest land is capable of producing at least 5.9 m^3 of wood per ha (85 ft^3/A) per year and another 49 percent is capable of producing between 3.5 m^3 and 5.8 m^3 of wood per ha (50 to 84 ft^3/A) per year. The remaining 31 percent of the land can produce less than 3.5 m^3 of wood per ha (50 ft^3/A) per year (Farrenkopf 1982).

The total volume of growing stock on commercial timberlands in eastern Oregon is estimated to be 595 million m^3 (21,019 million ft^3)(Farrenkopf 1982). Ponderosa and lodgepole pines rank number one and two, respectively, in growing stock volume, and together these species constitute over 50 percent of the total growing stock volume. About 25 percent of the total growing stock volume is located in Klamath and Lake Counties.

The annual timber harvest in eastern Oregon has fluctuated around 2 billion board feet (Scribner scale) since the late 1960's (Farrenkopf 1982). Annual harvest currently exceeds net annual growth in growing stock volume by nearly 50 percent in this part of the state. This apparent imbalance between growth and harvest is not alarming, since much of the harvest comes from old growth stands (Barrett 1979). Eventually, net annual growth should equal or exceed annual harvest as the mature and overmature stands are replaced by vigorous young stands.

Effects of Associated Vegetation

Competition, as defined by Grime (1973), is "the tendency of neighbouring plants to utilize the same quantum of light, ion of a mineral nutrient, molecule of water, or volume of space." The competitive ability of a plant depends upon a combination of characteristics, including storage organs, height, lateral spread, phenology, growth rate, response to stress, and response to damage, that determine the extent and activity of the surfaces through which the plant absorbs resources (Grime 1979). However, competitive ability cannot be assessed simply as the aggregate of a number of plant characteristics, because of the effects of environment and vegetation management on the expression of competitive attributes.

Newton (1973) has proposed the term dominance potential to express a plant's ability to assume a dominant position in a plant community over a given period of time in a limited system. Dominance potential is a relative measure and, consequently, depends upon the environment in which the plant is growing. The dominance potential of a planted conifer seedling is almost always low in the short-term, but high in the long-term, if it survives (Newton 1981). Effective vegetation management can suppress the dominance potential of undesirable vegetation and enhance the dominance potential of crop trees by altering the seedling environment.

Woody and herbaceous vegetation can have deleterious effects on the survival and growth of planted conifers in at least two ways. Most importantly, competition from associated vegetation can limit the availability of site resources that are required for the proper physiological functioning of the planted seedlings. Without an adequate supply of moisture, nutrients, light, and space, seedlings may die or, at best, will grow at a rate well below their physiological optimum. Secondly, the associated vegetation may create a suitable habitat for insects and animals with the potential to damage or kill young seedlings. Local populations of these organisms can sometimes increase to a level that presents a serious threat to the success of reforestation efforts. Research throughout the range of ponderosa pine has clearly illustrated that effective vegetation control can increase site resources available to pines and reduce damage caused by destructive animals. The response of lodgepole pine to weed control has received much less research attention.

Woody vegetation, forbs, and grasses have been recognized as weeds in pine plantations for a long time. An early attempt to quantify the competitive effects of forest weeds considered the impact of manzanita and snowbrush on the establishment and growth of ponderosa pine in central Oregon (Dahms 1950). The results of this study indicated that the brush had no effect on natural regeneration of pines, but it greatly reduced the growth of established seedlings. Furthermore, manzanita had a more severe impact on height growth of pines than did snowbrush.

Two early studies in California observed the effects of competing vegetation on the survival of planted ponderosa pines. Roy (1953) found that 2-year survival of planted pines decreased consistently as the ground cover of shrubs and grasses increased. Baron

(1962) compared the survival of pine seedlings planted in a mixture of 1-year-old grasses to the survival of seedlings planted where grasses were absent. Survival was 70 percent without grass compared to only 20 percent where grasses were present.

More recent research has attempted to identify the site resources that limit the survival and growth of ponderosa pine and to more precisely quantify the effects of competition on pine performance. It is commonly accepted that in droughty areas the most important factor influencing the survival and growth of pine seedlings is the availability of soil moisture. A number of studies have shown that competing vegetation can significantly reduce soil moisture throughout the growing season. In an exploratory study, Tarrant (1957) evaluated the effect of manzanita on soil moisture in a central Oregon brushfield. He compared the soil moisture to a depth of 60 cm (24 in) under live and chemically killed manzanita. The soil moisture content was significantly lower at all depths under the live manzanita from June through September. By September, the soil moisture was two to three times lower under the live brush than it was under the dead brush.

The depletion of soil moisture by grasses has been studied throughout the arid regions of the western United States. Heidmann (1969) assessed the effect of perennial grasses on soil moisture in Arizona. He compared soil moisture in undisturbed, hand scalped, and chemically treated plots in a dense perennial grass community. The chemical treatment resulted in the highest soil moisture throughout the dry months for two years following application. Scalping increased the soil moisture content compared to the undisturbed plots, but not as much as the chemical treatment. The author attributed the difference between the chemical and scalping treatments to the presence of the dead grass mulch on the sprayed plots. However, the scalped plots had to be retreated three times during the two year study and it seems likely that water use by the sprouting grass root systems contributed to the difference also. The effect of the chemical treatment was greatest in the drier of the two years during which the study was conducted. By September of that year, the soil moisture in the 0-8 cm (0-3 in) layer in the control plots had reached the permanent wilting point, but in the chemically treated plots it remained well above that level.

Another study in Arizona compared the competitive influence of two grasses, Arizona fescue (*Festuca arizonica* Vasey) and mountain muhly (*Muhlenbergia montana* [Nutt.] Hitchc.), on ponderosa pine seedlings (Larson and Schubert 1969). Seedlings were grown alone and in competition with each of the grasses. Root and shoot growth of pines was significantly greater when grown in the absence of grass competition. Arizona fescue, a cool-season grower, was a more severe competitor for soil moisture and had a greater impact on the growth of pine seedlings than mountain muhly, a warm-season grower. Roots of both species grew at a rate 50 percent greater than pine roots and, at the end of two years, the dry weight biomass of grass roots was 11 to 16 times the weight of tree roots. As a result of more rapid root growth, the grasses depleted soil moisture faster and to lower levels than the pines. The only pines that survived were those that had roots extending below the 40 cm (16 in) depth where moisture remained high for all cover types.

More recently, a study in Nevada observed the depletion of soil moisture by perennial grasses (Eckert 1979). In this study, control of perennial grasses with atrazine resulted in increased soil moisture throughout the growing season for two years following treatment. During the first year of the study, soil moisture tensions at the 15 cm (6 in) depth were below 1.0 bar on treated and untreated plots until early June. Moisture tensions at the highest rates of atrazine remained below 2.0 bars at one site and below 10.0 bars at the other site throughout the year. On the control plots, however, moisture tensions exceeded 15.0 bars (permanent wilting point) by the middle of July. At the 30 cm (12 in) depth, moisture tensions remained below 1.0 bar throughout the year on treated plots, but reached 15.0 bars by the first of September on the controls. The beneficial effect of grass control on soil moisture was also apparent in the second year following treatment. Increased survival and growth of planted jeffrey (*Pinus jeffreyi* Grev. & Balf.) and ponderosa pines was attributed to the more favorable moisture conditions resulting from grass control.

Several recent studies in Oregon and Washington have shown that control of grasses can increase the survival and growth of planted pines, although soil moisture was not measured in any of these studies. In central Washington, chemical control of grasses significantly increased the survival of planted ponderosa pines (Stewart and Beebe 1974). The increase in survival over controls was greater on a heavy-textured residual soil than on a light-textured pumice soil, although total survival was highest on the pumice soil. Reduced mortality was due in part to less pocket gopher (*Thomomys* sp.) and meadow vole (*Microtus* sp.) activity on the chemically treated plots. Root and stem girdling by these species was reduced by 39 percent on the sprayed plots compared to the untreated plots.

A study in southcentral Oregon found that atrazine treatments increased the survival and growth of planted ponderosa pine seedlings by reducing herbaceous competition and losses to pocket gophers (*T. mazama* Merriam) (Crouch 1979). This study was installed in an area where the previous plantation had failed completely due to pocket gopher damage. After 10 years, survival was 55 percent on plots that received a fall application of atrazine following planting and only 25 percent on control plots. The number of pocket gopher mounds was reduced approximately eightfold on the sprayed plots. Total height averaged 222 cm (7.3 ft) on the treated plots and only 150 cm (4.9 ft) on the controls.

Inconsistent results were reported for a series of studies that evaluated the effects of herbaceous vegetation control on the survival and growth of planted ponderosa pine seedlings in eastern Oregon and central Washington (Dimock and Collard 1981). Although the herbicide treatments resulted in a wide range of herbaceous vegetation control in each study, survival and growth of conifer seedlings was improved in only two of the six trials. A mixture of dalapon and atrazine significantly improved survival in one study and greatly increased height growth in another. The authors attributed the lack of significant differences in conifer performance to the unusually cool and wet weather during the 1975 and 1976 growing seasons. Apparently, the droughty conditions that vegetation control was to ameliorate never occurred during these two years.

Published literature that considers the effects of competition on lodgepole pine is sparse. A greenhouse study in British Columbia compared the survival and growth of lodgepole pine growing in different densities of native and domestic grasses for six months (Clark and McLean 1975). Survival, height growth, and total biomass of lodgepole pine decreased with increasing density of grass and less frequent watering. This is consistent with the results of field experiments on other species such as those discussed above with ponderosa pine.

A number of studies in northern California have assessed the impact of brush competition on the performance of planted ponderosa pines. Bentley et al. (1971) found that competition from manzanita and snowbrush reduced height growth of pines in a 5-year-old plantation by as much as 50 percent. Mortality from the fifth to the seventh year after plantation establishment ranged from 25 percent where brush density was high to no mortality where brush density was low.

Oliver (1979) evaluated the effects of spacing and brush control on ponderosa pine performance in a 12-

year-old plantation. Total height, d.b.h., crown width, crown ratio, and branch diameter were all significantly greater where trees were growing free of brush competition. Losses in diameter growth were equivalent to nearly 3 years of growing time where brush density was highest. The author speculated that brush competition could delay the first commercial thinning by as much as six years if the diameter growth was suppressed by the same proportion over the next 15 years.

In the Sierra Nevada Mountains of California, control of bearmat (Chamaebatia foliolosa Benth.) significantly improved the survival and growth of planted ponderosa pines (Tappeiner and Radosevich 1982). After 19 years, survival was 9 percent in the undisturbed bearmat compared to 90 percent where bearmat was completely controlled. Average height of the trees in the treated plot was 5.7 m (18.7 ft) compared to only 1.6 m (5.2 ft) in the control. Based on the current height growth trends, the authors predicted that net wood production for a 50 year rotation could be reduced by 75 percent due to bearmat competition.

Lanini and Radosevich (In press) considered the effects of shrub suppression on microenvironmental factors and physiological responses of several conifer species. Predawn and midday water potential, total height, stem diameter, and canopy volume of conifers were greatest where shrub control was most complete. Ponderosa pine was found to be most responsive to increased light, although soil moisture was also important. Growth of the pines was influenced by the interaction of the two factors.

All of the studies discussed to this point have considered the effects of competition on planted seedlings. Competition from woody and herbaceous vegetation has also been shown to impact the growth of trees that are in a dominant position in the stand. A study in central Oregon found that understory vegetation consumed significant amounts of water in a stand of ponderosa pine saplings thinned to different densities (Barrett and Youngberg 1965). Water use on plots where the understory vegetation was undisturbed was 45 percent greater than on plots where all of the understory vegetation was removed. Since diameter growth of trees was greatly reduced on plots where understory vegetation was present, the authors concluded that the major effect of competing vegetation was its impact on soil moisture availability. Eight and twenty year results from this study were reported in other publications (Barrett 1970, Barrett 1982). Competition from understory vegetation had a highly significant effect on diameter, height, and volume growth of the pines throughout the 20 year period. After 8 years, volume growth reductions due to competition ranged from 40 to 56 percent at the three widest spacings (618, 309, and 153 trees/ha or 250, 125, and 62 trees/A). Volume growth reductions of roughly 40 to 50 percent at these spacings persisted until 16 years after thinning. During the next four years, the effect of understory vegetation on volume growth was diminished slightly at all spacings. However, the author speculated that the reduced effect of understory vegetation during this four year period was the result of a decline in the amount of understory vegetation on all of the plots caused by natural climatic factors. A particularly harsh winter in 1977-78, combined with a severe drought during the following summer, reduced the non-conifer vegetative cover on all of the plots. Growth reductions due to understory vegetation during all of the measurement periods decreased as stocking levels increased.

Oliver (1984) assessed the effects of tree spacing and brush competition on ponderosa pine growth in an 11-year-old plantation in northern California. The 11-year-old plantation was thinned to four different densities in 1970. Five years after thinning, tree growth had declined due to competition from understory vegetation, so a brush density treatment was superimposed on the original tree spacing study. All, none, or half of the understory brush was removed from one-third of each spacing mainplot. After five years, diameter, height, and volume growth of the pines were significantly greater only on the plots where all of the understory brush had been removed. Depending on spacing, complete brush removal increased diameter growth from 45 to 140 percent and height growth from 62 to 175 percent compared to tree growth on the plots where the understory vegetation was allowed to develop normally.

Another study in California evaluated the response of ponderosa pine to fertilization and brush removal in a 9-year-old plantation located on two different soil types (Powers and Jackson 1978). One year after treatment, significant increases in height and diameter growth were observed only for the combination of fertilization and brush removal on the less fertile soil. Increases in foliar biomass and nutrient content of trees on this soil indicated that growth gains would continue. On the more fertile soil, foliar biomass was increased 40 percent by brush removal, although no significant differences in diameter and height growth were observed. The increase in foliage weight suggested that growth gains could occur in the future.

The results of all of these studies indicate that where woody vegetation, forbs, or grasses are present the survival and growth of conifers can be increased by effective vegetation control. The choice between removing and leaving associated vegetation depends upon management objectives, environmental constraints, the species and amounts of vegetation present, the costs of alternative treatments, and the expected returns from weed control. However, mortality and losses in growth that occur as a result of delayed vegetation control can be considerable. The greatest benefits from vegetation management can be achieved by identifying and treating weed problems before mortality or growth losses occur. This is only possible through a thorough understanding of the ecology of all of the species in the system and a knowledge of how they will respond to disturbances.

History of Site Preparation

Site preparation has been defined as any planned measure used to prepare a site for either natural or artificial regeneration of a forest stand (Dingle 1976, Stewart 1978). This deceptively simple definition encompasses a very diverse group of activities that may be used singly or in various combinations to achieve one or more objectives. Those objectives may include the removal of flammable logging residues or other debris, suppression of competing vegetation, alteration of animal habitat, preparation of a mineral soil seedbed, improvement of soil conditions, creation of a favorable seedling microsite, or control of disease (Stewart 1978). Site preparation requirements will depend primarily on the crop tree species, the method of regeneration, and both the biotic and abiotic environment of the specific site.

Throughout this paper, site preparation will refer to activities that precede the planting of nursery grown lodgepole and ponderosa pine seedlings in southcentral Oregon. Under these circumstances, the primary objective of site preparation is usually to reduce competition for limited soil moisture, light, and nutrients. Secondary objectives often include alteration of animal habitat to reduce damage to seedlings and removal of organic debris to increase accessability and reduce fire hazards.

Site preparation methods may be broadly classified as mechanical, prescribed burning, chemical, or combinations of the three (Stewart 1978). Each of these general categories includes a large number of specific treatments. For example, mechanical treatments are available to disk, furrow, terrace, trench, strip, rip, punch, slit, drag, chop, till, churn, or crush the litter, logging slash, residual vegetation, and soil (Stewart 1978). Fortunately, past research and experience has identified particular treatments that work best for certain conditions, so that foresters are not faced with an overwhelming number of alternatives. However, each site is a unique entity and requires a prescription and application of treatments that are specific for that given set of conditions (Dingle 1976).

The development of techniques for preparing planting sites in southcentral Oregon is not well documented in published literature. Apparently, each land owner and agency responsible for managing timberlands in this region has gone through a trial and error process to identify the site preparation treatments that work best for them. Undoubtedly, foresters in this region have relied upon experience and research results from other areas to identify promising methods of preparing sites for planting. It is reasonable to assume that the development of site preparation techniques in southcentral Oregon has paralleled the development of techniques in other parts of the western United States.

Schubert and Adams (1971) have thoroughly described the history of site preparation in California. Prior to 1930, no effort was made to prepare sites for artificial seeding or planting. By 1930, it was apparent that some vegetation control would be necessary to regenerate conifers on nonstocked lands. Mechanical methods of site preparation were the first to be used for removing undesirable vegetation. Between 1930 and 1945, attempts to reforest brushfields involved planting in mechanically cleared strips that were 1.8 to 2.4 m (6 to 8 ft) wide and spaced about every 6.1 m (20 ft). Survival and growth of pines in these plantations was poor due to competition from encroaching vegetation and damage from insects and animals. The failure of these early plantations indicated a need for more thorough site preparation. Since the 1950's, complete site preparation has been a common practice and has produced the most successful plantations.

Research throughout the range of ponderosa pine has consistently found partial vegetation control to be less effective than more complete treatments. In central Washington, scalping to remove all vegetation within 30 cm (12 in) of seedlings did not significantly improve survival of planted pines (Stewart and Beebe 1974). After studying the root growth of pines and grasses, Schubert and Adams (1969) concluded that partial site preparation would not be adequate in the Southwest. They recommended a broadcast herbicide treatment or bulldozing to prepare planting sites. In Idaho, Loewenstein et al. (1968) found that plants located more than 60 cm (24 in) from pine seedlings were competing with the trees for soil moisture and nutrients. And finally, Thompson (1974) concluded from a series of planting trials with ponderosa pine in British Columbia that, " ...the more intensive the reduction (of vegetative competition) the better!"

In the pine region of northern California and southcentral Oregon, the most common method of complete site preparation has been to push the vegetation into windrows spaced at least 15.2 m (50 ft) apart (Adams 1970, Schubert and Adams 1971, Stewart 1978). Windrowing is most often accomplished by a bulldozer equipped with a toothed land-clearing blade, although other types of blades are sometimes used. The organic debris in the windrows is left to decompose or is burned when weather conditions are favorable. Variable amounts of litter and topsoil are also displaced into the windrows. Survival on brushraked sites has been very good, but the growth of seedlings on these areas has not been critically evaluated.

The Weyerhaeuser Company has identified several other mechanical treatments that are useful under certain conditions in southcentral Oregon (Gutzwiler 1976). On areas occupied by low brush and herbaceous vegetation, a D-9 tractor equipped with an 11-ton Rome disk and V-blade has provided good vegetation control and favorable soil conditions for planting. Contour ripping has been used to increase the plantability of rocky or high density soils. Ripped rows are created by a D-7 or larger tractor pulling one or two tines that extend from 45 to 60 cm (18 to 24 in) into the soil. Since ripping does little to control competing vegetation or remove organic debris, it is often preceded by some other site preparation activity. Other mechanical site preparation techniques that have been used in the Pacific Northwest are summarized by Gutzwiler (1976) and Stewart (1978).

The use of prescribed fire for site preparation in the inland Northwest has been limited due to the prevailing climatic conditions and the ecological characteristics of some of the important weed species. Historically, foresters east of the crest of the Cascade Range have been reluctant to deliberately set fires due to unpredictable weather and fire behaviour (Schubert and Adams 1971). When conditions are safe for burning, fires may not burn hot enough to effectively remove logging slash and control competing vegetation. Also, many of the grass and brush species that present an obstacle to reforestation are resistant to fire (Martin and Dell 1978). Although plants may be top killed by fire, most of the shrubs and grasses will sprout after burning. Furthermore, the dormant seeds of manzanita and snowbrush are stimulated to germinate by fire.

Despite these limitations, prescribed fire has been used in the inland Northwest for site preparation and to achieve other land management objectives. Current research in central Oregon may lead to the increased use of prescribed fire for site preparation and other silvicultural purposes in the future (Barrett 1979). The use of prescribed fire for site preparation in the Pacific Northwest in general is described by Stewart (1978) and for the inland Northwest by Martin (1976). Guidelines for planning a prescribed burn in the inland Northwest are thoroughly discussed by Martin and Dell (1978).

Chemical site preparation is a viable alternative for most forest lands in eastern Oregon. Herbicides were first tested on brush in central Oregon in the early 1950's. Dahms (1955) reported that an aerial application of 1.1 kg acid equivalent (a.e.) per ha (1 lb a.e./A) of low volatile ester 2,4-D resulted in 100 percent mortality of manzanita. This same treatment killed the aerial portion of only 18 percent of the snowbrush plants, but at a rate of 2.2 kg a.e. per ha (2 lb a.e./A) of 2,4-D the kill was increased to 48 percent. After further testing of the phenoxy herbicides, Dahms (1961) found 2,4-D and 2,4,5-T to be equally effective on manzanita when applied from early May to early July. Snowbrush was most suceptible to 2,4,5-T, but 2,4-D produced the same level of control at slightly higher rates. Snowbrush sprouted vigorously after all of the treatments. Since the 1950's, no further testing of herbicides on brush in central Oregon has been reported in published literature.

Herbicides have also been used to control herbaceous vegetation during site preparation. Atrazine and dalapon are the most widely used herbicides for grass control on forest lands throughout the western United States (Schubert and Adams 1971, Barrett 1979). In southcentral Oregon, Crouch (1979) found that a spring application of atrazine at the rate of 4.5 kg active ingredient (a.i.) per ha (4 lb a.i./A) was ineffective, but a fall application at the same rate significantly reduced the cover of grasses and forbs. A second atrazine treatment in the fall of the following year resulted in a further significant decrease in the amount of herbaceous vegetation. The reduction in herbaceous vegetation following one or two fall applications of atrazine was still apparent after 10 years. However, on these same plots there was a significant increase in the amount of woody vegetation. Still, the survival of planted ponderosa pines was doubled, and height growth was increased 48 percent during the first 10 years on the plots that received one or two fall atrazine treatments compared to the controls.

Although very little research has considered the effects of herbicides on forest weed and crop species in southcentral Oregon, herbicide recommendations can be made based on research in other areas. The susceptibility of most southcentral Oregon plant species to various herbicide applications has been studied in other locations. Herbicides are currently available that will kill or severely injure most of the important weed species in this region. Several recent publications have summarized the current state of our knowledge concerning the efficacy and selectivity of herbicides in the interior Northwest (Conard and Emmingham 1983, Conard and Emmingham 1984a,b, Miller and Kidd 1983). Chemical site preparation in the inland Northwest has been described by Stewart (1976,1978).

The number of specific site preparation treatments that have been tested in southcentral Oregon is obviously much greater than the few general types of treatments that have been discussed in the preceding paragraphs. The only record of many of these treatments is in the files of private companies and public agencies. An accurate and thorough history of site preparation activities in southcentral Oregon would involve a major effort to review and synthesize these records which is more than was possible for this brief summary. However, from the above discussion it should be apparent when each of the general types of site preparation were first used and the relative popularity of each. Mechanical treatments have been the most widely used in the past and may still be today. However, any of the three general types of site preparation or some combination of the three may prove to be the most appropriate for a particular situation. The factors that will determine which site preparation treatment should be used include the existing ground cover, physical site factors, site preparation requirements, available personnel and equipment, external constraints, environmental impacts, and cost (Stewart 1978).

Impact of Site Preparation on Soil and Site Productivity

Site preparation is usually employed as part of an intensive forest management plan aimed at optimizing the productivity of timberlands. Under these conditions, the purpose of site preparation is to ensure the rapid and successful establishment of a well stocked stand of crop trees that can fully utilize the growth potential of a site following a disturbance. The immediate objectives of site preparation are usually attainable using one or a combination of the methods that are currently available to foresters. However, some of these methods may reduce the productive capacity of a site by altering the chemical, physical, hydrological, and biological properties of the soil, thereby directly conflicting with the overall management objective.

The potential impact of site preparation on soil properties depends on the method used to prepare the planting site and the original soil conditions. Because of the holistic nature of an ecosystem, any site preparation activity will affect the soil characteristics to some extent. Changes in soil properties can be either beneficial or detrimental to the future productivity of the site. The challenge facing the forest manager is to select the site preparation techniques that will maximize positive impacts and minimize negative ones.

Of the three general types of site preparation (mechanical, prescribed burning, and chemical), chemical methods used alone tend to have the most subtle effects on soil properties. Since chemical site preparation causes no physical disturbance to the site, the only changes in soil properties that will occur following treatment (at least with non-persistent herbicides) are the indirect effects resulting from plant mortality. One of the most important and well documented changes is the increase in soil moisture content following chemical site preparation (Tarrant 1957, Heidmann 1969, Eckert 1979). Higher daytime soil temperature, lower soil surface temperatures at night, increased microbial activity, and greater nutrient losses due to leaching may also result from the removal of the vegetative cover (Gregory 1981). These impacts are probably minor and of short duration following a normal chemical treatment.

The effects of prescribed burning on soils that have been reported in the literature are highly variable (Wells et al. 1979). The variability in the effects of fire on soil properties can be attributed primarily to fire intensity and the temperature to which soils are heated. Prescribed burning to prepare a site for planting normally requires a hot fire to consume organic debris and kill the competing vegetation (Gregory 1981).

Intense fires remove the insulating vegetation and forest floor covers, volatilize large amounts of nitrogen and lesser amounts of sulfur, phosphorus, and chlorine, transform other elements to soluble forms that are more easily absorbed by plants or lost by leaching, disrupt soil structure, and may induce water repellancy (Wells et al. 1979). Exposed mineral soil may lead to decreased soil water storage, infiltration, and aeration, and increased runoff and erosion. Changes in chemical and physical properties also affect soil microorganism populations, but these interactions are not well understood. Some studies have found increases in ectomycorrhizal populations following fire and others have found that fire reduces ectomycorrhizal populations (Schoenberger and Perry 1982). Recently, Pilz and Perry (1984) found that the aboveground environment was a more important factor influencing the formation of major ectomycorrhizal types than were changes in soil chemistry or biology on freshly clearcut and burned sites in the western Cascades. Pathogenic fungi have been found to be stimulated in some cases and inhibited in others (Wells et al. 1979).

The frequency of burning and effects of management practices during the recovery period are important factors for evaluating the long-term impact of fire on site productivity (Wells et al. 1979). Despite the seemingly drastic changes caused by prescribed burning, most of the effects on soil are considered to be relatively minor (Haines et al. 1975, Wells et al. 1979).

The impact of mechanical site preparation on soil properties and site productivity is of particular interest to forest managers in southcentral Oregon who rely heavily upon these methods for preparing planting sites. Mechanical site preparation treatments can be divided into two general categories which differ widely in their potential to reduce site productivity (Gutzwiler 1976). The first category consists of those treatments that disturb and rearrange the vegetation, litter, and soil, but leave the treated materials distributed uniformly over the area. The second category includes those treatments that remove the vegetation, litter, and occasionally surface soil from all or a large part of the treated area.

Mechanical treatments that disturb the vegetation, litter, and soil, but leave these materials on the site, will generally have little if any effect on long-term site productivity (Gutzwiler 1976). When used properly, erosion and compaction following these types of treatments should not be a problem. On well aerated soils, treatments such as disking and bedding that incorporate organic matter into the soil will temporarily increase the availability of nutrients due to the increased rates of mineralization (Wollum and Davey 1975, Haines et al. 1975). The indirect effects on soil moisture and microenvironmental conditions associated with removing the vegetative cover that were mentioned for chemical site preparation may also occur following mechanical treatments.

The more intensive mechanical treatments that remove organic matter and soil from an area have a greater potential to reduce site productivity. These treatments may be detrimental to the site in at least two ways. First, removal of the litter, forest floor, and surface soils may significantly reduce the nutrient capital of the site. And secondly, compaction caused by the operation of heavy machinery on saturated soils may adversely affect soil structure. Although no studies have evaluated the effects of removing organic matter and soil from sites in southcentral Oregon, it is possible to speculate about the impact of such a treatment by considering the properties of soils in this area and the results of studies that have considered the impact of these treatments in other geographic locations.

In California, Zinke (1960) found a high correlation between the total nitrogen content of the soil and site index at 300 years for ponderosa pine. He concluded from these findings that any silvicultural practice that increased the total nitrogen content of the soil would enhance productivity and, conversely, any silvicultural practice that lowered the total nitrogen content of the soil would reduce productivity. Analogous results have been reported by Helms (1983) for 15-year-old ponderosa pine plantations in northern California. The response of ponderosa pine to fertilization on a number of soils in central and southcentral Oregon indicates that there is a general deficiency of nitrogen throughout this region. All of the fertilization studies on soils in this area have found significant increases in ponderosa pine growth following the addition of nitrogen (Youngberg and

Dyrness 1965, Cochran 1973b, Youngberg 1975, Cochran 1977, Cochran 1978, Cochran 1979a). Furthermore, the results of several studies indicate that these soils may be marginally deficient in phosphorus and sulfur as well (Youngberg and Dyrness 1965, Cochran 1978, Will and Youngberg 1978, Cochran 1979a). Significant increases in the growth of pole-size lodgepole pine have also been observed during the first eight years following the addition of nitrogen, phosphorus, and sulfur to a soil in southcentral Oregon (Cochran 1975, Cochran 1979b). Consequently, any forest management practices that remove large amounts of nitrogen, phosphorus, or sulfur, (and perhaps micronutrients as well) may reduce the future productivity of soils in this region.

The amount of nutrients that are removed from an area during site preparation will depend on how much soil and aboveground organic matter is displaced and on the distribution of nutrients in the soil profile. The amount of soil that is scraped from the site will depend on a number of variables, but figures that have been reported in the literature for normal scarification operations in New Zealand and North Carolina are 2.5 and 4.7 cm (1 and 2 in), respectively (Glass 1976, Ballard 1978). Older recommendations for areas occupied by sprouting vegetation in California called for removal of at least 15 cm (6 in) of soil (Schubert and Adams 1971).

Will and Youngberg (1978) found in a pot trial bioassay with central Oregon soils that most of the sulfur was located in the Al horizon. Among the soils tested, the Al horizon ranged from 5 to 15 cm (2 to 6 in) in depth. Gutzwiler (1976) reported organic matter, nitrogen, and phosphorus contents by horizon for two southcentral Oregon soils. As much as 50 percent or more of the total organic matter, nitrogen, and phosphorus are located in the Al horizons of these soils. For six soil types common in northeastern California, Zinke (1983) reported that from 50 to more than 80 percent of the total carbon reserve and from 41 to more than 80 percent of the nitrogen was contained in the surface 30 cm (1 ft) of soil. It is apparent that the removal of as little as 3 to 5 cm (1 to 2 in) of topsoil from a site in southcentral Oregon could significantly reduce the total soil nutrient reserves.

Besides removing soil organic matter and nutrients, scarification operations also remove most if not all of the aboveground organic matter. This organic debris represents a substantial nutrient reserve, retains large quantities of moisture, and can restrict air, sunlight, and large animal movement (Harvey 1982). If left in place, some of this surface debris would eventually become soil organic matter which is important for maintaining chemical, physical, and biological soil properties that are necessary for optimal conifer growth. The impact on site productivity of removing aboveground organic debris is not known, but its importance in a number of processes indicates that the complete removal of organic debris from a site should be avoided, if possible.

Soil compaction refers to increasing soil density by forcing soil particles closer together and eliminating macropore spaces. Reduction or elimination of macropore space will reduce infiltration rates, reduce percolation of water through the soil, reduce soil gas exchange, and restrict the growth of plant roots (Gutzwiler 1976). The result of compaction is a less favorable environment for the survival and growth of conifer seedlings.

The resistance of a soil to compaction depends on soil texture, organic matter content, horizon sequence, initial bulk density, and moisture content (Gutzwiler 1976). Bulk density normally increases with soil depth, so that any treatment that removes surface soil layers will result in seedlings being planted in soil of higher bulk density. Any operation that removes the cushion provided by the forest floor increases the chances of soil compaction occurring (Gutzwiler 1976). Furthermore, deeper soil horizons usually have a lower organic matter content that makes them more susceptible to compaction.

Most studies that have considered the effects of compaction on tree growth have dealt with conifers growing in skid trails created during ground based logging operations. Compaction resulting from site preparation will, in general, be less than that resulting from logging, since most of an area is passed over only once during site preparation (Gutzwiler 1976). However, the literature indicates that a relatively small increase in bulk density can lead to significant conifer growth reductions. In the southern Washington Cascades, Robbins (1984) found that an increase in soil density of 15 percent resulted in a 20 percent decrease in volume of 9 to 18 year-old ponderosa pine. In contrast, Helms (1983) measured bulk density and ponderosa pine plantation growth in northern California and found that bulk density only accounted for 10-20 percent of the variability in tree growth.

A study in east Texas considered the effects of site preparation on soil bulk density (Stransky 1981). The treatments that were replicated at each of three sites included a logged-only control, burning, chopping, and KG-blading. Three years after treatment, chopped and KG-bladed plots had significantly higher bulk densities than either the control or burned plots.

Unfortunately, the effects of soil compaction on the growth of planted loblolly pine (*Pinus taeda* L.) seedlings could not be separated from the effects of competition with associated vegetation in this experiment. The greatest survival and growth of planted pines occurred on the mechanically treated plots where bulk densities were significantly higher, but competition from hardwoods was significantly less, than on the control and burned plots. The effect of soil compaction on conifer seedling performance could have been elucidated if a treatment which provided good vegetation control without compacting the soil (such as herbicide-only) had been included in the experimental design.

The impact of scarification on the growth of planted conifers has been evaluated in two studies. Glass (1976) compared loblolly pine growing on a rootraked area and an adjacent broadcast-burned area in North Carolina. The rootraking operation pushed the vegetation, forest floor, and 4.7 cm (2 in) of topsoil into the windrows. After 20 years, the broadcast-burned area supported 98 m^3 per ha (11 cords/A) more wood than the rootraked area. Site index (base age 50 years) predictions were 24 m (79 ft) for the broadcast-burned area and only 20 m (65 ft) for the rootraked area.

In New Zealand, Ballard (1978) evaluated the effects of windrowing in a 7-year-old radiata pine (*Pinus radiata* D.Don) plantation growing on a yellow-brown pumice soil. An estimated 2.5 cm (1 in) of topsoil was moved into the windrows along with the vegetation and litter. The author did not state whether or not the windrows were burned, but comments in the paper suggest that they were not burned. Volume production on the windrows was increased 19 percent and between the windrows was decreased 40 percent compared to an adjacent unscalped cutover site. The author predicted that if the current differences were maintained, the volume loss over a 26-year rotation would amount to 2 years growing time or 50 m^3 per ha (714 ft^3/A) of wood production on the windrowed site. Volume losses would have been considerably greater if windrows had not been planted, since approximately one-third of the area was included in the windrows. Soil and foliage nutrient analyses did not clearly indicate that the slower growth of the inter-windrow trees was due to a nutrient deficiency. However, soil nutrient analyses did show a slight decrease in total nitrogen and a considerable reduction in exchangeable magnesium in the inter-windrow areas. The reduced growth of trees in the inter-windrow area was attributed to a restricted supply of nutrients, poorer soil physical conditions, and a higher incidence of red band needle blight (Dothistroma pini Hulbary) infection. The author speculated that artificial frost pockets may have been created between the windrows which also contributed to the difference in pine performance.

Although neither of these studies identify the reason for slower conifer growth on scalped sites, they do indicate that removal of organic debris and soil over large areas can be detrimental to future productivity. It is likely that the reduced conifer growth is the result of changes in a number of environmental factors brought about by the scarification operation. The interaction of all of these factors has resulted in an environment that is less favorable for the growth of the crop trees. Consequently, any treatments that achieve the site preparation objectives without displacing large amounts of organic debris and soil will leave a site in a more productive condition. The rate at which a site will recover from this type of disturbance under different conditions is not known. Therefore, it is not possible to predict whether the early reductions in growth rate that have been observed on scalped sites will persist throughout the current and future rotations.

Long-term Benefits of Intensive Site Preparation

Studies that document the long-term benefits of intensive site preparation are uncommon. However, as the cost of these treatments continues to rise, the need for data that accurately evaluate the long-term benefits of site preparation becomes increasingly apparent. High interest rates and the long period of time over which reforestation costs must be carried makes it imperative that the gain in crop tree growth attributable to site preparation be considerable and predictable.

Some of the oldest studies that assess the effects of intensive site preparation are located in the southeastern United States. Several site preparation studies with slash pine (*Pinus elliottii* Engelm.) in the Coastal Plain of Florida found that early increases in growth rate were not sustained throughout the rotation (Pehl and Bailey 1983). A study with loblolly pine in the Georgia Piedmont found that disking was the only treatment that resulted in significantly greater height growth after 10 years (Pehl and Bailey 1983). The authors predicted that a modest increase in site index (base age 25) of 0.6 m (2 ft) would occur if the growth gains due to disking were maintained. A study in the Upper Coastal Plain of Alabama compared six different site preparation treatments (Whipple and White 1965). After 22 years, the survival and growth of loblolly pine on all of the treated plots was significantly greater than on the control plots (Glover et al. 1981). The control plots supported only 1.6 m^3 of wood per ha (23 ft^3/A) while the treated plots supported from 115.6 to 271.8 m^3 of wood per ha (1652 to 3886 ft^3/A).

Several studies in northern California illustrate the long-term impact that brush can have in ponderosa pine plantations (Roy 1981). One study compared the growth of pines planted at five different spacings with and without competition from shrubs. The study area was prepared for planting immediately after removal of the mature overstory by pushing logging debris into windrows located outside of the plots. This operation was conducted using crawler tractors with care to avoid removing topsoil from the site. Half of each spacing mainplot was kept brush-free with a combination of chemical (2,4,5-T) and manual treatments. Brush was allowed to develop normally on the other half of each plot. After 14 growing seasons, cubic foot volume losses due to brush competition ranged from 31 to 57 percent depending on initial spacing. Another study considered the effects of various brush densities on the survival and growth of planted pines. This study location originally supported an established brush community. Prior to planting, the brush was pushed into windrows by crawler tractors. Windrows were not burned.

The plantation was subsequently used to test a variety of herbicide applications which resulted in a broad range of brush densities. After 19 growing seasons, the percentage of dead or suppressed trees ranged from 3 percent where trees were growing free of brush competition to 46 percent where brush biomass was greatest. Differences in volume growth converted to lost growing time ranged from 4 years with light brush cover to 10 years under heavy brush cover.

The fact that some studies have shown significant increases in wood production up to 22 years after site preparation, while other studies have observed little if any increase in conifer growth on intensively prepared sites, indicates a need for a better understanding of the effects of site preparation on site productivity. The data that are currently available are sparse and scattered among many different geographic locations, weed and crop tree species, soil types, climates, site conditions and methods of site preparation. Although limited data indicate that dramatic increases in wood production may be achieved on some sites through intensive weed control, more information is needed to identify the combinations of site and treatment that have the greatest potential for increasing wood production. The results of the present study should help forest managers in southcentral Oregon to predict the increases in yield that may result from intensive site preparation.

HISTORY OF RESEARCH INSTALLATIONS

The current study involved the remeasurement of research plots that were installed for a previous investigation. The original study was designed and initiated by Dr. William Scott, a research scientist with the Weyerhaeuser Company. The impetus for the original study was a concern for the possible deleterious effects that brushblading as a site preparation treatment might have on site productivity. The objective of the study was to compare six possible site preparation techniques for the Klamath Tree Farm that caused varying degrees of physical disturbance to the site. The treatments to be compared were a logged-only control, brushblading, ripping, disking, chemical followed by disking, and chemical only. The techniques were to be compared based on changes in soil properties and the survival and growth of planted conifers. The experiment was designed as a short-term study to be followed only until the fifth year after planting.

A split-plot randomized complete block design was used with the six site preparation treatments as mainplots. Subplots were species and stock type of planted conifers. Two replications were installed at each of four sites representing the major soil series in the area. The installation located on pumice soil was accidentally burned during the first year of the study and, consequently, was dropped from the experiment due to nearly complete seedling mortality. The three remaining study sites are listed in Table 1, along with the elevation and soil series for each location.

TABLE 1. Klamath Falls site preparation study sites, elevation and soil series (Duncan and Steinbrenner 1975).

Site	Elevation (m)	Soil series
East Aspen	1370	Pokegama
Swede Cabin	1610	Ze-eks
Camp 9	1950	Ze-eks

Site preparation treatments were conducted in the fall of 1975 and the spring of 1976. Planting followed in the spring of 1976. The control plots received no treatment other than the disturbance associated with the logging operations. All of the mechanical treatments were completed in the fall of 1975. Brushblading was performed by a crawler tractor equipped with a toothed land-clearing blade. Vegetation, logging debris, and surface soil were pushed by the tractor into windrows located outside of the research plots. Disking was done with a Rome 91 cm (36 in) disk pulled by a crawler tractor. This treatment exposed mineral soil, but did not remove vegetation, organic debris, or surface soil from the plot. Ripping was the least severe mechanical treatment. Parallel rip rows spaced approximately 1.2 m (4 ft) apart were formed by pulling a single-tooth rock ripper behind a crawler tractor. Herbicide treatments involved a broadcast application of glyphosate (Roundup®) on the chemical-only and chemical/disk (prior to disking) plots in late-summer of 1975. The glyphosate was applied with a Solo® backpack sprayer equipped with a mist blower. Prior to planting in the spring of 1976, a spot spray of 2,4,5-T ester was applied on the chemical-only plots to kill any brush that remained following the previous glyphosate treatment. The spot spray of 2,4,5-T was not conducted on the chemical/disk plots, since the disking had already crushed the vegetation on these plots. There is some disagreement as to whether or not a broadcast application of atrazine was applied to the chemical-only and chemical/disk plots at about the same time that the 2,4,5-T was sprayed in the spring of 1976. It is probably not important either way, because a spring application of atrazine would not have been effective due to the lack of sufficient rainfall following the treatment to leach the herbicide into the rooting zone of the grasses. At least one study in southcentral Oregon found that a spring application of atrazine was ineffective (Crouch 1979).

Ponderosa pine bareroot (2+0) and containerized[1] (1+0, 131 cm^3 or 8 in^3) seedlings were planted at each location, along with Douglas-fir containerized seedlings

---

[1] Containerized seedlings will also be refered to as plugs.

at East Aspen, lodgepole pine containerized seedlings at Swede Cabin, and white fir containerized seedlings at Camp 9. The Douglas-fir, white fir, and ponderosa pine containerized seedlings at Camp 9 only were never measured due to excessive mortality during the first year of the study. Seedlings were planted in a grid pattern at approximately a 1.2 m (4 ft) spacing except in the rip plots where inter-row spacing was dependent on the distance between rip rows. Subplots in the rip treatments are represented by rows of seedlings running parallel to the long axis of the mainplot. One hundred seedlings were planted in each subplot, of which a sample of 40 were measured annually for analysis. A diagram illustrating the general plot layout is included in Appendix I.

The sample trees were measured in 1976 and each of the following years until 1979. The total height was measured for all of the sample trees each year except in 1976. Total height was measured on all of the ponderosa pine bareroot at each site, but only on one replication for the ponderosa pine plugs at both East Aspen and Swede Cabin in 1976. No heights were measured on the lodgepole pine plugs in 1976. Diameters were measured at the soil surface for ponderosa pine only. No diameters were taken on lodgepole pine. Diameters were measured in 1977 and 1978 for all of the ponderosa pine bareroot at each site. Diameters in 1977 were taken only on one replication at each location for the ponderosa pine plugs. All of the seedlings were also given a vigor rating for each of the first three years using a visual system based on the amount of green foliage and the condition of the terminal bud. Table 2 indicates the conifer growth data that were collected between 1976 and 1979.

TABLE 2. Conifer growth data collected at each location on the Klamath Falls site preparation research plots between 1976 and 1979.

Site and species/stock type	1976	1977	1978	1979
East Aspen				
Ponderosa pine bareroot	H, V	H, D, V	H, D, V	H
Ponderosa pine plugs	H*, V	H, D*, V	H, V	H
Swede Cabin				
Ponderosa pine bareroot	H, V	H, D, V	H, D, V	H
Ponderosa pine plugs	H*, V	H, D*, V	H, V	H
Lodgepole pine plugs	V	H, V	H, V	H
Camp 9				
Ponderosa pine bareroot	H, V	H, D, V	H, D, V	H

H = total height, D = diameter at the soil surface, V = vigor rating.
*Only one replication measured.

The surface 30 cm (12 in) of soil was sampled at each site in the fall of 1975 and again in the fall of 1976. Unfortunately, the records describing the soil sampling procedures and analysis of the soils data are not in good condition. Nothing can be said for certain about the 1975 sampling, although it was probably done in a similar manner to the 1976 sampling. Apparently, three locations per treatment were sampled across both replications at each site in 1976. A single sample was collected at a depth of 18-30 cm (7-12 in) at each location in the mechanical treatments. In the chemical and control treatments, the soil was sampled in two layers. One sample was collected from a depth of 0-8 cm (0-3 in) and the other sample was collected at a depth of 9-30 cm (4-12 in) from the soil surface. Each soil sample was analyzed for organic matter content, total nitrogen, phosphorus, and total sulfur. Bulk densities were also determined for some or all of the soil samples. Due to the lack of information about the methods of soil sampling and the analytical procedures used in 1975 and 1976, no comparisons will be made between the results of the soil sampling in the current study and those of the previous study.

The results of this study were never published. The data from the first four years of the study were subjected to statistical analyses and a brief summary of the findings was presented in 1981 at a vegetation management workshop at Oregon State University (Scott 1981). The following paragraphs outline the results that were reported in that summary.

After four growing seasons, significant differences in height growth between the five site preparation treatments were found only at the low elevation site (East Aspen). Increases in height growth compared to the logged-only control ranged from 135 percent for the chemical/disk treatment to less than 20 percent for the rip treatment at this site. Although significant differences in height growth between the five site preparation treatments were not found at the higher elevation sites (Swede Cabin and Camp 9), the height growth in all of the treatment areas at both sites was greater than the logged-only controls.

Three year survival at East Aspen and Swede Cabin was highest for the chemical/disk treatment and ranged from 80 to 88 percent. The treatment with the next highest survival was brushblading followed by disking, chemical only, ripping, and the logged-only controls in that order. Survival on the logged-only controls was as low as 40 percent. No significant differences in three year survival were observed between the five treatments or logged-only controls at Camp 9 (the high elevation site). Survival was low for all of the treatments at this site and ranged between 47 and 59 percent.

Brushblading was the only treatment that significantly altered the soil nutrient status. Between 700 and 1,700 kg per ha (624 to 1514 lb/A) of nitrogen and 45,000 to 68,000 kg per ha (40,081 to 60,567 lb/A) of organic matter were moved into the windrows.

DESCRIPTION OF STUDY LOCATIONS

East Aspen

The East Aspen site is approximately 14 km west and slightly north of the town of Klamath Falls (Figure 1). This research installation lies within the NW1/4 NE1/4 Sec. 14, T. 38 S., R. 7 E., W.M. The study plots are located just north of the Weyerhaeuser Company road number 201-00 about 0.8 km east of the junction with road number 200-00.

The mixed conifer stand that originally occupied this site was burned by a wildfire in 1938. The area was salvage logged, but early attempts to regenerate the stand were unsuccessful. By 1976, the site was occupied by a diverse brush community that included snowbrush ceanothus, greenleaf manzanita, bitterbrush, cherry, serviceberry, snowberry, and willow (*Salix* spp.). The area was finally rehabilitated in 1976 at the same time that the research plots were installed. The area around the research plots was prepared for planting by first brushraking then ripping with crawler tractors. Survival of ponderosa pines that were planted in the rip rows was satisfactory, and the area adjacent to the study plots now supports a well-stocked plantation.

The terrain at East Aspen is flat to gently undulating. Slopes within the research plots range from

0 to 8 percent. The elevation at this site is 1,370 m, and there is a slight southwest aspect. The research plots are located on soil that has been classified in the Pokegama series (Duncan and Steinbrenner 1975). These soils are moderately deep, stony clay loams that are derived from fine volcanic ash over basalt. A typical soil in this series is characterized by a dark reddish-brown, sandy loam topsoil (23-38 cm deep) over a well-structured, stony clay loam subsoil (to a 90 cm depth).

The diversity of plant species that are found at East Aspen indicates that this site may be at an ecotone between two plant community types. The site has characteristics of both the ponderosa pine/bitterbrush/needlegrass type and the mixed conifer /snowbrush-squawcarpet/strawberry type (Hopkins 1979a). The site is definitely more similar to the mixed conifer/snowbrush-squawcarpet/strawberry type, but a considerable amount of bitterbrush as well as scattered western juniper and mountain-mahogany, which are not characteristic of this type, are also found at this site. Furthermore, nearby areas are obviously of the ponderosa pine/bitterbrush/needlegrass type.

A significant amount of insect damage to the planted pines was observed on the research plots at this location. Most of the damage was caused by the western pine-shoot borer (Eucosma sonomana Kft.), although some damage was the result of ponderosa pine tip moth (Rhyacionia zozana Kft.) activity. No more than 10 to 15 percent of the sample trees showed evidence of past insect damage. Although it has been reported that the shoot borer infests trees of all heights (Stoszek 1973), insect activity, in this case, seemed to be limited to the taller trees. Most of the damage was observed on trees greater than 120 cm in height. Consequently, the treatments that resulted in the best pine growth also had more trees damaged by insects. While losses resulting from tip moth damage are generally considered to be minor (Stevens 1971), the reduction in growth associated with a heavy shoot borer infestation may be quite large (Stoszek 1973). Stoszek (1973) has calculated that the wood volume losses over a rotation, resulting from shoot borer damage, could amount to 12 percent at the 40 percent infestation rate, and 22 percent when more than 70 percent of the trees are infested.

The impact of the shoot borer on ponderosa pine growth has been evaluated in plantations ranging from 40 to 49 years old by Weyerhaeuser personnel (R. L. Heninger, personal communication). They destructively sampled over 200 ponderosa pine trees and evaluated them for insect growth loss. The reduction in mean annual height growth per infested year was 3.8 cm. Volume loss ranged from 0 to 29 m^3/ha (420 ft^3/A) for the four plantations sampled.

Swede Cabin

The Swede Cabin site is approximately 13 km east and slightly north of the town of Bly (Figure 1). This research installation lies within the SW1/4 NW1/4 Sec. 24, T. 36 S., R. 15 E., W.M. The study plots can be reached from an unnumbered spur road leading north from the Weyerhaeuser Company road number 700-00.

The first logging activity in this area occurred in 1969. Following this harvest operation, some portions of the logged area were adequately stocked with residual trees and other portions were essentially nonstocked. The nonstocked sites were planted with ponderosa pine seedlings at the same time that the research plots were established. Consequently, the area currently supports a number of small plantations (approximately 1 to 15 ha) that are interspersed among the residual stands.

The research plots at Swede Cabin are located on a mid-slope bench within a plantation that covers approximately 10 hectares. Slopes within the research plots range from 0 to 12 percent. The elevation at this site is 1,610 m and there is a south aspect. The soil at this location has been classified in the Ze-eks series (Duncan and Steinbrenner 1975). These are fine-textured soils that are derived from fine volcanic ash over basalt and andesite. A typical soil in this series is characterized by a dark reddish-brown, granular topsoil (about 30 cm deep) over a well-structured clay loam subsoil (to a 100 cm depth). Rocks constitute 20 to 50 percent of the soil volume.

The vegetation at Swede Cabin indicates that this site, like East Aspen, may be at an ecotone between two plant community types. The site has characteristics of both the white fir-ponderosa pine/snowberry/starwort type and the white fir-ponderosa pine/manzanita-Oregon grape type (Hopkins 1979b). In general, the site matches the description of the white fir-ponderosa pine/snowberry/starwort type most closely, but the presence of manzanita, Oregon grape, and squawcarpet are more typical of the white fir-ponderosa pine/manzanita-Oregon grape type.

Several biotic agents have reduced the survival and growth of the pines in the research plots at Swede Cabin. Approximately 30 percent of the sample trees have been damaged by the shoot borer or the tip moth. The insect damage is more severe in some spots than others, but the damage does not seem to be associated with any particular treatment. Both ponderosa and lodgepole pines have been attacked by the insects.

Cattle have also caused localized, but intense, damage to some of the plots. Trees over 2 m in height have been killed or deformed when the cattle have used them as rubbing posts. In some cases, groups of four or more adjacent trees have been killed by the cattle activity. There is some evidence that the poor survival on the rip plots at this site may be the result of cattle using the rip rows as trails.

Camp Nine

The Camp Nine site is approximately 43 km north and slightly east of the town of Bly (Figure 1). This research installation lies within the NW1/4 SE1/4 Sec. 23, T. 32 S., R. 15 E., W.M. The research plots are located just east of the Weyerhaeuser Company road number 504-40.

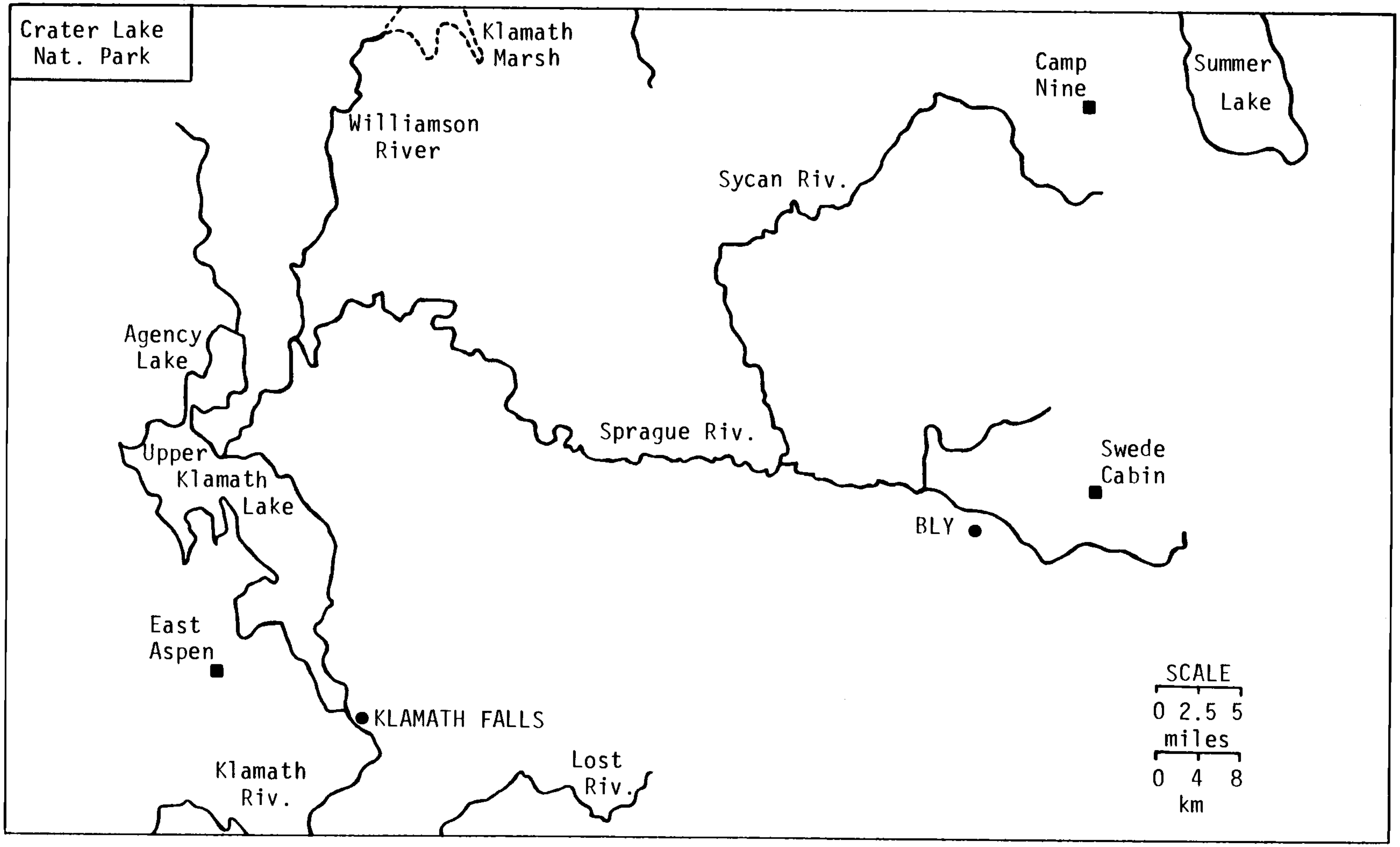
In 1955, a selection harvest removed about 40 percent of the volume from the stand that originally occupied this site. The residual overstory was harvested in 1974 resulting in a clearcut that covered several hundred hectares. The area was planted with ponderosa pine seedlings in 1976 at the same time that the research plots were established. Survival of the planted pines was satisfactory, and most of the plantation appears to be adequately stocked. However, the trees are growing at a relatively slow rate and are far from reaching the point of crown closure. Most of the area between the trees is occupied by a dense grass and sedge community with only widely scattered snowbrush ceanothus plants.

The terrain at Camp Nine is flat to slightly concave. Slopes within the research plots range from 0 to 10 percent. The elevation at this site is 1,950 m and there is a west aspect. The soil at this site has also been classified in the Ze-eks series (Duncan and Steinbrenner 1975) which was described previously for Swede Cabin.

The vegetation at Camp Nine does not resemble any of the plant community types described by Hopkins (1979b). Whether this site actually represents a different plant community type, or is simply atypical because of the major disturbance that has occurred, is unknown. The absence of all shrub species except an occasional snowbrush ceanothus plant is the most unusual characteristic at this site. For this reason, the area most closely resembles the white fir-lodgepole pine/long-stolon sedge-needlegrass type with the major exception that ponderosa pine was obviously a component of the original stand. However, ponderosa pine is sometimes present at the lower limits of this community.

No insect or cattle damage was recognized at this site. However, due to the high elevation and exposure, many trees have suffered snow damage. The larger trees commonly had one or two branches that were pulled out of the main stem due to the weighting effect of the snow. Some of the smaller trees were actually killed when the snow deformed and split the main stem.

FIGURE 1. Klamath Falls site preparation study site locations.



METHODS

Soils

Soil samples were collected at three randomly located points within each site preparation treatment plot. At each sample point a shallow soil pit was excavated and samples were collected at two depths. Volumetric samples were obtained by hammering a small corer (170.79 cm^3) into the side of the pit at the desired depths (See Appendix II for a description of the corer and its use). One sample was collected from the surface 10 cm of soil and the other sample was collected at a depth of 15 to 25 cm. Each sample was placed in a separate labeled plastic bag and all of the samples were stored in a cooler until they were transported to the laboratory.

Samples were transferred to weighed and labeled tins in the laboratory and dried at 100^o C for 24 hours. Total dry weights were determined by subtracting the weight of the empty tin from the weight of the tin containing the soil sample. Total dry weight and volume were used to calculate bulk density for each sample.

After weighing, the samples were put through a 10-mesh screen (2 mm openings). The material that would not pass this screen was separated into rocks and organic matter which were weighed separately.

Subsamples of the material that did pass this screen were ground to pass a 40-mesh screen (425 um openings). The 40-mesh soil was used for chemical analyses with the exception of the sulfur determinations. Samples used for sulfur analyses were ground further to pass a 140-mesh screen (106 um openings).

Each soil sample was analyzed for total carbon, total nitrogen, extractable phosphorus, and total sulfur. Total carbon was determined originally for a 0.06-0.08 g sample using a LECO induction furnace coupled to a LECO WR-12 carbon determinator (Nelson and Sommers 1982). The amount of carbon in some of the samples of this size was below the lowest standard used to calibrate the machine. All of the samples which originally gave a value for carbon below the range of the standards were rerun using a 0.3-0.4 g sample. The values obtained for all of the samples that were rerun were within the range of standards used for calibration. Total nitrogen was determined for a 0.3 g sample by the micro-Kjeldahl method using 75 ml flasks (Berg and Gardner 1978). Extractable phosphorus was determined for a 2.0 g sample by the sodium bicarbonate method (Berg and Gardner 1978). Total sulfur was determined by first converting all of the sulfur in a 0.2 g sample to sulfate by the dry ashing procedure of Steinbergs et al. (1962). The sulfate formed was extracted by adding 10 ml of 0.3 N HCl and warming the mixture on a hot plate. The mixture was filtered through a number 5 Whatman filter paper to give a clear solution. The sulfur in the solution was determined by a Jarrell-Ash ICP direct-reading spectrometer (Soltanpour et al. 1982). C:N and C:S ratios were calculated for each sample.

The soils data were analyzed separately for each site and layer by performing an analysis of variance on each soil property using a randomized complete block design. Where a significant F value indicated a treatment difference at the 0.10 probability level, the LSD procedure was used to compare and separate the means.

Vegetation

The shrub species were sampled separately from the grass and herbaceous vegetation. A belt transect 2 m wide and 15 m long was established diagonally across the middle of each subplot to sample the shrub layer of the vegetation. Only the subplots used to collect conifer data were sampled. This resulted in sampling a total of 60 m^2, 120 m^2, and 180 m^2 in each site preparation treatment plot at Camp Nine, East Aspen, and Swede Cabin, respectively. Belt transects in the ripped plots were established diagonally across the middle of the mainplot, since subplots in these areas consisted of rows of seedlings running the entire length of the mainplot. Belt transects in the ripped plots were 2 m wide and 30, 60, and 90 m long at Camp Nine, East Aspen, and Swede Cabin, respectively. Consequently, although the plot layout was different in the ripped plots, the same amount of ground area was sampled in each site preparation treatment plot within a site.

All shrubs rooted within the belt transects were recorded by species. The height and two perpendicular measures of crown width were determined to the nearest centimeter for each shrub canopy or part of a canopy which was located within the transect. The shrub canopy measurements were recorded by species.

Samples of all of the important shrub species were collected for use in developing predictive biomass regression equations. Samples of 10 to 12 indidviduals of each shrub species were collected from the area adjacent to the research plots. Sample plants were subjectively selected to cover the range in size of plants that were measured on the plots. Prior to harvesting, the height and crown width of each plant chosen for biomass sampling were measured in the same manner that they were on plants within the belt transects. The plants were then severed at the soil surface and placed in labeled plastic bags for transporting to the laboratory. The plants were air dried in the laboratory for several months before they were oven dried at 70° C for 48 hours. The ovendry weight for the total aboveground biomass of each shrub was measured to the nearest 0.1 g. Shrub canopy volume (length x width x height) in cubic centimeters was used as the independent variable (X) to predict total aboveground biomass (Y) in grams. Logarithmic transformation of both variables was necessary to correct for heteroscedasticity in the untransformed data. The form of the regression equation used was $LN(Y) = a + b\,LN(X)$. Since the error associated with repeated sampling for biomass regressions of forest trees has been shown to be much greater than the error attributable to logarithmic bias (Madgwick and Satoo 1975, Satoo and Madgwick 1982), no correction for logarithmic bias was used in the analysis.

Shrub canopy coverage was calculated for each individual plant using the equation for the area of a circle and the average of the two crown width (diameter) measurements. Canopy volume was calculated for each individual plant using the equation for the volume of a cylinder and the height and average of the two crown width measurements. The biomass regression equations were used to estimate total aboveground biomass for each plant. The biomass of the few individuals of species for which regression equations were not developed was estimated using the equation developed for a species of similar life-form.

Shrub canopy cover, canopy volume, total aboveground biomass, and density were calculated on a per hectare basis for each species and for the total of all species for each site preparation treatment. Average height for each species and for all species considered together was also determined for each site preparation treatment. The shrub data were analyzed separately for each site by performing an analysis of variance on the canopy cover, canopy volume, aboveground biomass, and density totals, and average height for all species using a randomized complete block design. Where a significant F value indicated a treatment difference at the 0.05 probability level, the LSD procedure was used to compare and separate the means.

The grass and herbaceous vegetation was sampled using a technique described by Daubenmire (1959). Ten microplots (20 cm by 50 cm) were randomly located within each subplot. Again, only the subplots in which conifer data were collected were sampled. This resulted in a total of 20, 40, and 60 microplots in each site preparation treatment plot at Camp Nine, East Aspen, and Swede Cabin, respectively. The appropriate number of microplots was randomly located throughout the ripped mainplots, due to the absence of a subplot structure in these areas. Canopy coverage of each grass and herbaceous species was estimated within the microplots using the following six class system:

Class	Percent Cover	Midpoint Value
1	0-5	2.5
2	6-25	15.0
3	26-50	37.5
4	51-75	62.5
5	76-95	85.0
6	96-100	97.5

Shrub species such as squawcarpet (*Ceanothus prostratus* Benth.) that grow appressed to the soil surface were sampled along with the grass and herbaceous species. Categories were also used to estimate percent ground cover of bare soil, rocks, and litter. For each species and cover category the average percent cover was determined by summing the corresponding midpoint values for each cover class recorded and dividing this total by the number of microplots sampled in each site preparation treatment plot. The total percent canopy coverage of all species was determined as the sum of the percent canopy coverages for each individual species. The grass and herbaceous data were analyzed separately for each site by performing an analysis of variance on the total percent canopy coverage of all species using a randomized complete block design.

Conifers

All of the surviving trees from the original sample of 40 in each subplot were used for data collection. The total height and height to each of the last three nodes were measured to the nearest centimeter using a telescoping leveling rod. Crown widths were measured on a subsample of at least 10 systematically chosen sample trees in each subplot, with the sampling process beginning from a random start. Two perpendicular measures of crown width taken at the widest point in the canopy were recorded for each tree. Crown widths were measured to the nearest centimeter using the leveling rod in a horizontal position. Due to the wide range in the size of sample trees, diameters were measured at a point equivalent to 10 percent of the total height of each tree. Diameters were measured to the nearest millimeter using vernier calipers. Only one diameter measurement was taken, unless there was an obvious abnormality of the stem at the point where the diameter was to be measured. If the stem was swollen, scarred, or obviously assymetrical in any way, the average of two diameter measurements, taken above and below the abnormality or taken at right angles to one another at 10 percent of the height, was recorded. The choice of which method to use in measuring the diameter was subjectively determined for each abnormal tree. Less than one percent of all the trees measured required more than one diameter measurement.

Sample trees were collected for use in developing predictive biomass regression equations. At each site a minimum of 18 planted ponderosa pines of the same age and seed source as the study trees were collected from the plantation surrounding the research plots. At Swede Cabin only 15 lodgepole pines from the research plots were harvested. The trees were subjectively chosen to cover the range in tree sizes that were found within the research plots at each site. At East Aspen and Swede Cabin, the largest trees that could be found in the operational plantations were slightly smaller than the largest trees in the research plots. Consequently, the biomass regression equations were used to predict the biomass of some trees that were slightly outside the range of the sample trees used to develop the equations. Height, diameter, and crown widths were measured on each of the biomass sample trees in the same manner that they were measured on the sample trees within the plots. The trees were then cut down at the soil surface, placed in labeled plastic bags, and brought to the laboratory for analysis. The foliage and branches were separated from the stems of each tree. After air drying for several months in the laboratory, the trees were ovendried at 70° C for 48 hours. The ovendry weights for the total aboveground portion of each tree and the stem only were recorded to the nearest 0.1 g. Diameter squared times height in cubic centimeters was used as the independent variable (X) to predict total aboveground biomass or stem-only biomass (Y) in grams. Logarithmic transformation of both variables in each regression was necessary to correct for heteroscedasticity in the untransformed data. The form of the regression equation used was LN (Y) = a + b LN (X). No correction for logarithmic bias was used in the analysis for the same reason that was stated above for the non-conifer vegetation biomass regressions.

Crown area and crown volume were calculated for each tree on which crown widths were measured. Crown area was calculated using the equation for the area of a circle and the average of the two crown width measurements. Crown volume was determined from the equation for the volume of a cone shape and the height and average of the two crown width measurements. The biomass regression equations were used to estimate the total biomass and stem biomass of every sample tree. Current annual height increment was determined for every tree from 1977 to 1983 by subtracting the height at the end of one growing season from the height at the end of the previous growing season. Yearly survival was determined for each plot as the percentage of the original sample trees that were still alive at the end of each growing season.

The survival and growth data were analyzed separately for each site by performing an analysis of variance on diameter, total height, crown width, crown area, crown volume, total biomass, bole biomass, current annual height increment, and survival using a split-plot randomized complete block design. The survival data was transformed by taking the arcsine of the square root of survival expressed as a decimal prior to all analyses. Where a significant F value indicated a treatment or species/stock type difference at the 0.05 probability level, the LSD procedure was used to compare and separate the means.

RESULTS AND DISCUSSION

Soils

The soil properties by soil layer and site preparation treatment at East Aspen, Swede Cabin, and Camp Nine are presented in Tables 3, 4, and 5, respectively. Similar tables including C:N and C:S ratios and standard errors for all of the soil characteristics are included in Appendix III. The concentrations of C[2], N, and P were considerably greater in the upper layer (0-10 cm) of soil than in the lower layer (15-25 cm) at each of the sites. In many cases, within a site and treatment, the concentration of any one of these elements in the lower layer was 50 percent or less of the corresponding concentration in the upper layer. This was expected, since it was observed while collecting the soil samples that the nutrient rich A1 horizon never extended deeper than 15 cm at any of the sites. The concentration of S also decreased with depth in the profile at each site, but not to the same extent as the other elements. Consequently, the differences

---

[2] Since all of the published pH values for forest soils in central Oregon are below 7.0 (Youngberg and Dyrness 1964, Dyrness and Youngberg 1966, Cochran 1978), it is reasonable to assume that total C represents organic carbon. Organic carbon is not synonymous with organic matter, but is directly related to organic matter by a constant (ranging from 1.7 to 2.0) that must be determined for each soil (Nelson and Sommers 1982). Total C is used here as an index of organic matter.

TABLE 3. Soil properties for two soil layers at the East Aspen site after eight growing seasons following each of six site preparation treatments.[1]

Soil layer and site preparation treatment	Total C	Total N	Extractable P	Total S	Bulk Density
Upper (0-10 cm)	...... percent	....	.... ppm	....	g/cm³
Control	4.38	0.220	16.3 AB	284.2	0.742 A
Rip	3.05	0.165	22.0 A	287.0	0.817 AB
Chemical	2.88	0.145	15.7 B	239.3	0.847 AB
Disk	2.50	0.125	11.8 BC	222.2	0.918 BC
Chem/disk	1.75	0.108	12.3 BC	228.0	0.948 BC
Brushblade	1.75	0.105	9.0 C	204.8	1.017 C
Lower (15-25 cm)					
Control	1.29 a	0.088 a	5.3 B	191.7 B	0.973
Rip	0.93 bcd	0.080 a	7.8 A	228.5 A	0.968
Chemical	1.07 abc	0.078 a	6.2 AB	191.3 B	0.965
Disk	1.24 ab	0.083 a	8.0 A	191.5 B	0.975
Chem/disk	0.78 cd	0.065 b	6.0 AB	175.5 B	1.033
Brushblade	0.68 d	0.065 b	4.7 B	177.7 B	1.022

---

[1] Within soil layers, values in the same column which are followed by the same lower case letter are not statistically different at the 0.05 level of significance and those followed by the same upper case letter or no letter are not statistically different at the 0.10 level of significance by the protected LSD procedure.

TABLE 4. Soil properties for two soil layers at the Swede Cabin site after eight growing seasons following each of six site preparation treatments.

Soil layer and site preparation treatment	Total C	Total N	Extractable P	Total S	Bulk Density
Upper (0-10 cm)	...... percent		.... ppm		g/cm^3
Control	6.92	0.263	28.3	329.8	0.687
Rip	3.20	0.147	30.8	235.8	0.928
Chemical	2.85	0.127	20.2	205.5	0.803
Disk	1.91	0.102	19.7	187.8	0.968
Chem/disk	6.10	0.253	27.7	354.5	0.732
Brushblade	4.14	0.165	32.7	235.8	0.820
Lower (15-25 cm)					
Control	1.88	0.100	15.8	175.7	0.938
Rip	1.14	0.082	16.7	183.2	1.078
Chemical	0.96	0.072	10.0	153.3	1.092
Disk	0.84	0.063	15.2	160.0	1.062
Chem/disk	1.77	0.098	15.2	186.3	1.075
Brushblade	1.05	0.078	14.2	177.0	1.117

TABLE 5. Soil properties for two soil layers at the Camp Nine site after eight growing seasons following each of six site preparation treatments.

Soil layer and site preparation treatment	Total C	Total N	Extractable P	Total S	Bulk Density
Upper (0-10 cm)	...... percent		.... ppm		g/cm^3
Control	3.23	0.147	20.2	187.3	0.707
Rip	4.17	0.183	21.5	271.7	0.615
Chemical	2.68	0.110	14.2	159.5	0.702
Disk	2.98	0.130	15.8	176.0	0.720
Chem/disk	1.39	0.085	10.8	138.8	0.733
Brushblade	1.65	0.085	9.8	157.0	0.847
Lower (15-25 cm)					
Control	0.78	0.060	9.5	135.5	0.990
Rip	0.78	0.063	9.2	136.5	0.973
Chemical	0.96	0.070	8.5	142.0	0.928
Disk	0.99	0.072	9.8	126.5	0.895
Chem/disk	0.84	0.063	9.7	123.2	0.905
Brushblade	0.72	0.060	7.5	131.8	0.963

among treatments for all of the soil properties were most pronounced in the upper layer of soil. However, significant ($P < 0.10$) treatment effects were found for only some of the soil properties at East Aspen. The lack of more significant treatment effects was probably due to the small number of replications (two) at each site and the inherent variation frequently encountered in soil conditions. Nevertheless, there were some consistent trends in the data which suggest the kind of effects that the various site preparation treatments can have on soil properties.

The same general trend among treatments in C and nutrient concentrations was observed at East Aspen and Camp Nine (Tables 3 and 5). In the upper layer of soil at both of these sites, the chemical/disk and brushblade treatments had the lowest concentrations of C and nutrients. The chemical-only and disk treatments had C and nutrient concentrations in the upper layer that were higher than the corresponding concentrations in the chemical/disk and brushblade treatments, but they were still lower than the values for the controls. The rip treatment apparently had no effect on C and nutrient concentrations at either site. The concentrations of all of the elements in the upper layer were actually higher in the rip treatment than the control at both sites, except for C and N concentrations at East Aspen.

The concentrations of C and N in the rip treatment at East Aspen were second highest, behind the control.

Differences in the concentrations of elements among treatments at these sites were much smaller and less consistent in the lower layer of soil. However, with the exception of S, the brushblade treatment had the lowest concentration of each element in this layer at both sites. Chemical/disk and disking were the only treatments that had S concentrations in the lower layer that were less than the concentrations in the brushbladed plots.

Although the brushblade and chemical/disk treatments had similarly low C and nutrient concentrations at East Aspen and Camp Nine, the most likely reasons for the low values are quite different for each treatment. Brushblading removed logging slash, litter, vegetation, and some surface soil from the treated areas at both sites. This undoubtedly removed a large amount of nutrients and organic matter from the plots. Other studies have quantified the amounts of various nutrients that are displaced into windrows and have found that they can be considerable (Webber 1978, Morris et al. 1983). Furthermore, several studies in the Southeast found that, one year after treatment, organic matter and nutrient concentrations were significantly lower on brushbladed plots than controls

(Tuttle et al. 1982, Stransky et al. 1982). The chemical/disk treatment, however, did not remove anything from the site, but instead incorporated the logging slash, litter, and vegetation into the surface layer of mineral soil. Removal of the vegetative cover would have increased daytime soil temperatures and soil moisture levels (Gregory 1981). Both of these factors, combined with an abundant food supply, would create an environment conducive to microbial activity (Wollum and Davey 1975). Consequently, the lower C and nutrient concentrations on the chemical/disk plots were probably due to increased rates of mineralization and more rapid nutrient uptake by the vegetation. Similarly, the lower C and nutrient concentrations in the chemical-only and disk-only treatments were probably the result of increased rates of decomposition brought about by the removal of the vegetative cover. The nutrients that were released following the chemical/disk, chemical, and disk treatments were either taken up by the plants occupying the area (almost entirely planted conifers) or were leached from the site. Due to the limited amount of rainfall in this region, nutient losses through leaching were probably minor and of short duration. Unlike the brushblading treatment, most of the nutrients that were presumably released following the chemical/disk, chemical, and disk treatments were available to the planted conifers. Furthermore, eight years after site preparation all of these treatments had soil nutrient concentrations equal to or greater than those in the brushbladed plots.

The results of the nutrient analyses at Swede Cabin (Table 4) were not entirely consistent with the trend among treatments that was observed at the other two sites. The concentrations of C and nutrients in the upper layer of the control, rip, chemical, and disk treatments followed the same trend that was observed at the other sites, but the values for the chemical/disk and brushblade treatments were much higher than expected. This discrepancy was probably due to inherently more heterogeneous soil within the research plots at this site, which obscured the general treatment effects.

There is a great deal more topographic variability at Swede Cabin than there is at the other two sites. The research plots at Swede Cabin are located on a small, concave mid-slope bench on the south side of Gearhart Mountain (2,632 m). There are 50 percent slopes just above and below the research plots. The more complex geomorphology is an indication that soil characteristics may vary abruptly over short distances. Also, the soil survey of the Klamath Tree Farm (Duncan and Steinbrenner 1975) indicates that the research plots at this site are located very close to the interface between two soil series (Ze-eks and Coffeepot series). Therefore, it is not unreasonable to expect that there may be a conglomeration of soil types within the plots.

Some empirical evidence to support this hypothesis was obtained by considering the distribution of the individual soil samples collected at this site and the nutrient concentrations in each sample. The control and chemical/disk plots were adjacent to one another at the north end of replication number two. Four of the six soil samples collected from the upper layer in these plots (2 samples in each plot) had the highest concentrations of C and nutrients at this site. Three of these samples had exceptionally high values compared to those from the rest of the site. It would be difficult to explain why these adjacent samples had such high C and nutrient concentrations, even though they were collected from areas that received very different treatments, unless the soil on these plots was inherently more fertile than other parts of the research installation prior to treatment. The fact that C and nutrient concentrations in the lower layer were also generally higher for these sample locations lends further credence to this explanation. Other less obvious inclusions of dissimilar soils may have been spread throughout the research plots.

Another possible reason for the unexpected results at Swede Cabin may be that the mainplots were not uniformly treated due to obstacles such as stumps or other difficulties in maneuvering the machinery during site preparation. Soil samples were collected randomly from the plots without considering obstacles that may have prevented a given spot from actually receiving the site preparation treatment. Ballard (1978) mentioned that windrowing increased site variability between windrows in New Zealand. He attributed much of this variability to the distribution of stumps from the previous stand. However, this could have affected the results at both of the other sites as well, and it seems likely that the heterogeneous soil was the primary reason for the inconsistent results at Swede Cabin. Consequently, the real site preparation treatment effects on soil properties were probably more accurately illustrated at the East Aspen and Camp Nine sites.

Disregarding treatment effects, the C and nutrient concentrations at Swede Cabin were, in general, higher than those at East Aspen or Camp Nine. In particular, the P concentrations in both the upper and lower soil layers were considerably higher at Swede Cabin than the other sites. Apparently, the soil at Swede Cabin is inherently more fertile (as well as more variable) than the soils at the other research installations.

Bulk density is an indication of the degree to which soils are compacted. Operation of heavy machinery can compact soils resulting in reduced infiltration, percolation, aeration, and root penetration. The greatest differences in bulk density among treatments were found at East Aspen (Table 3). In the upper layer at this site, the disk, chemical/disk, and brushblade treatments had bulk densities that were significantly ($P < 0.10$) greater than the control. The bulk densities in the chemical/disk and disk treatments were slightly less than in the brushblade treatment. These three treatments also had the highest bulk densities in the lower layer at this site, although the differences among all of the treatments were much less at this depth. At Swede Cabin, with the exception of the chemical/disk treatment, the mechanically treated plots had higher bulk densities in the upper layer than the control or chemical treatments (Table 4). Differences among treatments were less pronounced in the lower layer, but all of the site prepared plots had bulk densities that were considerably greater than the control at this depth. At Camp Nine, brushblading was the only treatment that had an appreciably higher bulk density in the upper layer of soil when compared to the control (Table 5). The chemical/disk and disk treatments also had bulk densities that were higher than the other treatments in this layer, but the values for both of these treatments were well below that in the brushblade treatment. Differences among treatments were small in the lower layer at this site, where, suprisingly, the control had the highest bulk density.

Apparently, the general effect on soil chemical properties of all of the site preparation treatments, with the exception of ripping, was a reduction in organic matter (total C) and nutrient concentrations. Brushblading was the only treatment that directly removed nutrient rich materials from the site and, as a result, had the lowest soil C and nutrient concentrations. Reduced soil C and nutrient concentrations in the other treatments were probably the result of increased rates of nutrient cycling and uptake by the vegetation. Mechanical treatments clearly increased the soil bulk density at East Aspen and, with the exception of the chemical/disk treatment at Swede Cabin, caused smaller increases at the other two sites as well. Increases in bulk density were greatest in the surface 10 cm of soil.

Vegetation

The characteristics of the non-conifer vegetation after eight years for each site preparation treatment at East Aspen, Swede Cabin, and Camp Nine are presented in

Tables 6, 7, and 8, respectively. Tables that show the contribution of constituent species to each of these vegetative characteristics, as well as plant density at each site, are included in Appendix IV. The information provided by canopy cover, canopy volume, and total aboveground biomass of woody vegetation is somewhat related, but the three different measures of abundance are included here to facilitate comparisons with other studies that use only one or another of these measures of non-conifer vegetation.

Brush biomass and herbaceous cover varied considerably between the three sites (Tables 6-8). The East Aspen site, which was occupied by a diverse shrub community prior to treatment, had the greatest biomass of woody non-conifer vegetation. Depending on the site preparation treatment, brush biomass ranged from 1,100 to 6,700 kg/ha at this site. Greenleaf manzanita, snowbrush, bitterbrush, and snowberry together accounted for over 80 percent of the brush biomass regardless of site preparation treatment at East Aspen (Table 20, Appendix IV). Brush biomass was considerably lower at both Swede Cabin and Camp Nine compared to East Aspen. Brush biomass was less than 400 kg/ha for all of the treatments at Swede Cabin. Rabbitbrush, currant, and snowberry together accounted for over 90 percent of the brush biomass within four of the treatments at this site

TABLE 6. Characteristics of non-conifer vegetation at the East Aspen site after eight growing seasons following each of six site preparation treatments.[1]

Site preparation treatment	Woody				Herbaceous
	Cover^2	Canopy volume	Aboveground biomass	Height	Cover^2
	m^2/ha	m^3/ha	kg/ha	cm	percent
Control	6129.1 a	5624.5 a	6711.6 a	69.8 a	27.5
Rip	3403.9 b	3258.8 b	4027.7 b	48.5 bc	39.6
Disk	2288.4 bc	1875.5 bc	2049.3 bc	42.2 c	37.2
Brushblade	2136.4 bc	1340.5 c	1609.7 c	40.2 c	38.6
Chemical	1518.8 c	1277.2 c	1441.6 c	55.1 b	33.7
Chem/disk	1274.3 c	713.1 c	1139.9 c	39.2 c	29.3

---

[1] Within a column, values which are followed by the same letter or no letter are not statistically different at the 0.05 level of significance by the protected LSD procedure.

[2] To compare cover of woody and herbaceous vegetation, either divide cover of woody vegetation by 100 or multiply cover of herbaceous vegetation by 100.

TABLE 7. Characteristics of non-conifer vegetation at the Swede Cabin site after eight growing seasons following each of six site preparation treatments.[1]

Site preparation treatment	Woody				Herbaceous
	Cover[2]	Canopy volume	Aboveground biomass	Height	Cover[2]
	m^2/ha	m^3/ha	kg/ha	cm	percent
Brushblade	435.8 a	316.1 a	396.0 a	45.3	43.3
Rip	270.4 ab	263.6 ab	332.7 ab	66.6	45.9
Control	150.1 b	109.6 bc	137.2 bc	21.0	48.4
Disk	121.5 b	43.9 c	55.3 c	40.2	32.6
Chemical	37.2 b	45.4 c	58.8 c	32.0	28.7
Chem/disk	41.2 b	34.3 c	24.0 c	27.2	35.6

[1] Within a column, values which are followed by the same letter or no letter are not statistically different at the 0.05 level of significance by the protected LSD procedure.

[2] To compare cover of woody and herbaceous vegetation, either divide cover of woody vegetation by 100 or multiply cover of herbaceous vegetation by 100.

TABLE 8. Characteristics of non-conifer vegetation at the Camp Nine site after eight growing seasons following each of six site preparation treatments.

Site preparation treatment	Woody				Herbaceous
	Cover[1]	Canopy volume	Aboveground biomass	Height	Cover[1]
	m^2/ha	m^3/ha	kg/ha	cm	percent
Control	140.9	67.5	73.7	54.0	65.5
Rip	14.8	5.6	8.7	38.0	87.6
Disk	0	0	0	0	63.9
Brushblade	1.1	0.1	0.1	9.8	82.7
Chemical	17.4	5.0	4.9	26.0	59.8
Chem/disk	9.3	2.4	2.3	21.5	61.9

---

[1] To compare cover of woody and herbaceous vegetation, either divide cover of woody vegetation by 100 or multiply cover of herbaceous vegetation by 100.

(Table 26, Appendix IV). Greenleaf manzanita and bitter cherry (<u>Prunus</u> <u>emarginata</u> [Dougl.] Walpers), along with the three species listed above, were major components of the vegetation in the other two treatments at Swede Cabin. Widely scattered snowbrush and currant plants were the only species of woody non-conifer vegetation found at Camp Nine (Table 30, Appendix IV). All of the treatments at this site had less than 75 kg/ha of brush biomass. Herbaceous cover was greatest at Camp Nine where most of the site was occupied by a dense grass and sedge community. Herbaceous cover ranged from 60 to 88 percent at this site, depending on the site preparation treatment. Herbaceous cover was intermediate at Swede Cabin (29-48 percent) and least at East Aspen (28-40 percent).

Unfortunately, no vegetation sampling was conducted on these research plots prior to, or in the first eight years following, site preparation. Therefore, it must be assumed that the vegetation at each site was relatively homogeneous prior to treatment, and any large differences in the amount of non-conifer vegetation between the treatments reflect different degrees of vegetation control resulting from the alternative methods of site preparation.

The greatest differences in the amount of non-conifer vegetation among the site preparation treatments were observed at East Aspen (Table 6). At this site, all of the site preparation treatments had significantly ($P < 0.05$) less brush biomass than the control. Furthermore, the brushblade, chemical, and chemical/disk treatments had significantly less brush biomass than the rip treatment. Brush biomass on the disked plots was only 50 percent of that on the ripped plots, although the difference was not statistically significant.

The mean height of the brush at East Aspen followed the same trend among treatments as brush biomass, with one obvious exception. Although the chemical treatment had the second lowest brush biomass, the mean height of the brush in this treatment was second highest, behind the control. This discrepancy was probably due to the lack of any physical disturbance on the chemically treated plots. Any plants which were not killed by the chemical treatments had an immediate height advantage over plants growing in the mechanically treated plots. All of the mechanical treatments caused some degree of scraping, crushing, or chopping of the vegetation, so that many of the brush plants in these plots originated from root sprouts or seeds. The mean height of the brush in the rip treatment, which caused the least amount of physical disturbance to the vegetation, was intermediate between the chemical treatment and the more intensive mechanical treatments. The mean heights of the brush in the disk, brushblade, and chemical/disk treatments were similar and lower than all of the other treatments.

Differences in herbaceous cover among treatments at East Aspen were much less pronounced than the differences in brush biomass. In general, the trend among treatments with respect to herbaceous cover was the same as that observed for brush biomass, with one major exception. Instead of having the highest percent cover of herbaceous vegetation, the control treatment had the lowest. The low level of herbaceous cover on the control plots (28 percent) was probably due to the large amount of brush which excluded herbaceous vegetation from most of this area. The rip, brushblade, and disk treatments had similar levels of herbaceous cover (37-40 percent), which were somewhat higher than the levels of herbaceous cover on the chemical or chemical/disk treatments (34 and 29 percent, respectively). Herbaceous cover on the chemical/disk treatment was only slightly higher than herbaceous cover on the control.

Due to the small size of the research plots and the limited amount of brush at Swede Cabin and Camp Nine, the small differences in brush biomass between the treatments may not accurately reflect treatment effects. The treatment differences may have been due, in part, to the distribution of shrubs on, and surrounding, the research plots prior to treatment. In order to adequately evaluate the effect of alternative site preparation treatments on brush at sites such as Swede Cabin or Camp Nine, where individual shrub plants are widely scattered, a very large area would have to be treated and sampled to overcome the effect of variation in plant distributions.

Despite the problems associated with plant distributions and sample area size, the control and rip treatments tended to have the greatest brush biomass at Swede Cabin and Camp Nine, with one exception (Tables 7 and 8). At Swede Cabin, the brushblade treatment had more brush biomass than both the rip and control treatments. The disk, chemical, and chemical/disk treatments had similar and very small amounts of brush biomass at both sites. Although there were some treatment differences in brush biomass, the amounts of brush present in all of the treatments at these sites would probably have only a minor impact on the performance of planted pines.

Although brush biomass was low at Swede Cabin and Camp Nine, herbaceous cover was generally higher at both sites than at East Aspen. Cover of herbaceous vegetation was greatest in the control at Swede Cabin and only slightly less in the rip and brushblade treatments. The herbaceous cover ranged from 43 to 48 percent for these treatments. Herbaceous cover was somewhat lower, ranging from 29 to 36 percent, in the chemical/disk, disk, and chemical treatments at this site. At Camp Nine, the rip and brushblade treatments had over 82 percent cover of herbaceous vegetation, which was considerably higher than the levels of herbaceous cover on the control or any of the other treatments. Herbaceous cover on the control, disk, chemical/disk, and chemical treatments was between 60 and 65 percent at this site.

It has been observed in other studies that the herbaceous component of the vegetation may increase dramatically following site preparation by scarification. Kelpsas (1978) studied the response of vegetation to different types of site preparation in the Coast Range of Oregon. He concluded that scarification should be avoided on droughty sites due to the increased competition for soil moisture from grasses and forbs that could occur following this treatment. The results of the present study indicate that the herbaceous component of the vegetation has remained the same or increased following brushblading. Eight years after treatment, brushbladed plots had nearly as much or more herbaceous vegetation than the controls at all three sites.

The lack of more consistent and significant differences in herbaceous cover among the site preparation treatments at each of the sites was probably due to several factors. First, none of the chemical treatments used in this study would have provided thorough control of the herbaceous vegetation. Glyphosate was applied in late-summer when most of the aboveground portions of the herbaceous vegetation were dead due to the normal summer drought. Glyphosate, a foliage active herbicide with essentially no soil activity, would have had little effect on vegetation in this condition. Furthermore, atrazine was applied in the spring, if at all. Spring applications of atrazine have been shown to be ineffective in southcentral Oregon (Crouch 1979). Consequently, the chemical treatments probably had only a minor impact on the herbaceous vegetation. Second, the time of the year at which the herbaceous vegetation was sampled may have increased the error associated with the estimates of percent cover. The herbaceous vegetation was sampled at all three sites during the third week of September. By this time, most of the aboveground portions of the herbaceous vegetation were dead. Consequently, some of the dried plant canopies may have been dislodged or partly decomposed. Furthermore, the ocular estimation method used to sample the herbaceous vegetation may not have been sensitive enough to detect small treatment differences. Since the herbaceous vegetation had eight years to become established on the plots, it is not suprising that the differences between treatments were not very large at each site. In a study that considered the efficacy of atrazine for control of grasses and forbs in southcentral Oregon, the greatest differences in herbaceous cover between the control and the fall treated plots (35-70 percent differences) occurred between the second and fourth growing seasons after spraying (Crouch 1979). By the tenth growing season after treatment, the differences between the treated and untreated plots (16-25 percent differences) were much smaller.

In summary, the East Aspen site was the only study location where the non-conifer plant community had a substantial shrub component. In the control plots at this site, the brush formed a nearly continuous layer with only small isolated patches that were not occupied by woody non-conifer vegetation. All of the site preparation treatments had significantly less brush biomass than the control at this site. At both Swede Cabin and Camp Nine, the shrub component of the non-conifer plant community consisted primarily of scattered individual plants. Herbaceous cover was greatest at Camp Nine where most of the site was occupied by a dense grass and sedge community. Herbaceous cover was least at East Aspen, presumably due to the large amount of brush which has excluded herbaceous vegetation from much of the site. At Swede Cabin, herbaceous cover was only slightly higher, in general, than at East Aspen. Differences in herbaceous cover associated with the treatments were small and not significant ($P > 0.05$) at all of the sites. However, since herbaceous vegetation rapidly invades devegetated areas before being suppressed by later successional woody plant species, treatment differences in herbaceous cover may have been greater in the first several years following site preparation.

The combined percent cover of herbaceous and woody non-conifer vegetation ranged from 29 to 50 percent at Swede Cabin, depending on the site preparation treatment. This was considerably less than the cover of non-conifer vegetation at either East Aspen (40-89 percent) or Camp Nine (60-88 percent). Heavy cattle grazing may have been partly responsible for the limited establishment and growth of non-conifer vegetation at Swede Cabin. Throughout the field season in which the data was collected for this study, cattle grazing was much heavier at Swede Cabin than at the other sites. The high density of cattle at Swede Cabin may have been due to a nearby watering pond that congregated the animals in this area.

Conifers

The survival and growth of ponderosa pine by site preparation treatment after eight growing seasons at East Aspen, Swede Cabin, and Camp Nine are presented in Tables 9, 10, and 11, respectively. The survival and growth of lodgepole pine by site preparation treatment after eight growing seasons at Swede Cabin are presented in Table 12. Similar tables that include crown width, crown area, bole biomass, and standard errors for all of the growth parameters are included in Appendix VII.

Survival of ponderosa pine at East Aspen was highest in the chemical/disk treatment (87 percent). Survival in the chemical, disk, and brushblade treatments (78, 79, and 79 percent, respectively) was similar and only slightly less than in the chemical/disk treatment. The chemical/disk, chemical, disk, and brushblade treatments had significantly ($P < 0.05$) higher survival than the control which had extremely poor survival (30 percent). Survival in the rip treatment (62 percent) was intermediate between the control and the other treatments at this site.

Survival of ponderosa and lodgepole pines at Swede Cabin followed a pattern similar to the survival of

TABLE 9. Ponderosa pine survival and growth at the East Aspen site after eight growing seasons following each of six site preparation treatments.[1]

Site preparation treatment	Survival	Diameter[2]	Total height	Current annual height increment	Crown volume	Total aboveground biomass[3]	
						Bareroot	Plug
	percent	mm	cm	cm/yr	m^3	.... kg	
Chem/disk	87 a	54.6 a	178.8 a	32.6 a	0.908 a	1.819 a	1.841 a
Chemical	78 a	50.5 a	173.4 a	33.4 a	0.762 a	1.691 a	1.468 ab
Disk	79 a	42.5 b	144.4 b	28.8 a	0.499 b	1.052 a	0.996 bc
Brushblade	79 a	35.1 c	113.8 c	22.9 b	0.302 c	0.492 b	0.658 c
Rip	62 ab	24.9 d	87.8 d	20.1 bc	0.125 d	0.371 b	0.162 d
Control	30 b	16.2 e	65.0 d	15.3 c	0.049 d	0.118 c	0.060 e

---

[1] Within a column, values which are followed by the same letter are not statistically different at the 0.05 level of significance by the protected LSD procedure.

[2] Diameters were measured at 10 percent of the total height of each tree.

[3] Since the stock type by site preparation treatment interaction was significant ($P < 0.05$) for total aboveground biomass, the stock types were analyzed separately.

TABLE 10. Ponderosa pine survival and growth at the Swede Cabin site after eight growing seasons following each of six site preparation treatments.[1]

Site preparation treatment	Survival	Diameter[2]	Total height	Current annual height increment	Crown volume	Total aboveground biomass
	percent	mm	cm	cm/yr	m^3	kg
Chem/disk	83	64.7 a	190.5 a	37.1	0.925	2.779 a
Chemical	82	60.1 ab	180.6 a	34.5	0.775	2.134 ab
Disk	82	60.8 ab	182.5 a	35.6	1.000	2.069 ab
Brushblade	85	60.2 ab	180.3 a	33.5	0.839	2.229 ab
Rip	59	48.9 bc	138.6 b	30.2	0.435	1.137 bc
Control	58	42.7 c	120.5 b	25.8	0.340	0.731 c

---

[1] Within a column, values which are followed by the same letter or no letter are not statistically different at the 0.05 level of significance by the protected LSD procedure.

[2] Diameters were measured at 10 percent of the total height of each tree.

TABLE 11. Ponderosa pine survival and growth at the Camp Nine site after eight growing seasons following each of six site preparation treatments.[1]

Site preparation treatment	Survival	Diameter[2]	Total height	Current annual height increment	Crown volume	Total aboveground biomass
	percent	mm	cm	cm/yr	m^3	kg
Chem/disk	56	44.9 a	126.6 a	23.2 a	0.346 a	0.832 a
Chemical	60	39.4 b	113.6 b	22.3 a	0.221 b	0.592 b
Disk	58	36.1 c	104.2 c	20.0 b	0.185 b	0.476 c
Brushblade	64	34.6 c	97.1 c	18.3 bc	0.168 bc	0.394 c
Rip	58	28.3 d	79.4 d	16.1 c	0.091 c	0.239 d
Control	71	26.9 d	77.2 d	17.0 c	0.077 c	0.217 d

---

[1] Within a column, values which are followed by the same letter or no letter are not statistically different at the 0.05 level of significance by the protected LSD procedure.

[2] Diameters were measured at 10 percent of the total height of each tree.

TABLE 12. Lodgepole pine survival and growth at the Swede Cabin site after eight growing seasons following each of six site preparation treatments.[1]

Site preparation treatment	Survival	Diameter[2]	Total height	Current annual height increment	Crown volume	Total aboveground biomass
	percent	mm	cm	cm/yr	m^3	kg
Chem/disk	85 a	55.0	216.7	47.0	1.136	2.148
Chemical	80 a	52.2	214.8	45.9	0.945	1.905
Disk	86 a	53.6	225.1	49.3	1.071	2.053
Brushblade	80 a	45.7	188.0	40.2	0.750	1.243
Rip	50 b	40.9	150.2	37.4	0.464	0.823
Control	45 b	34.3	125.8	30.4	0.297	0.491

---

[1] Within a column, values which are followed by the same letter or no letter are not statistically different at the 0.05 level of significance by the protected LSD procedure.

[2] Diameters were measured at 10 percent of the total height of each tree.

ponderosa pine at East Aspen. Survival of ponderosa pine ranged from 82 to 85 percent in the chemical/disk, chemical, disk, and brushblade treatments at Swede Cabin. This was considerably greater than survival in either the rip or control treatments (59 and 58 percent, respectively), although the differences were not statistically significant. Survival of lodgepole pine ranged from 80 to 86 percent in the chemical/disk, chemical, disk, and brushblade treatments. Survival in all of these treatments was significantly greater than survival in either the rip or control treatments (50 and 45 percent, respectively).

Ponderosa pine survival was lower at Camp Nine than at the other two sites. Surprisingly, survival was highest in the control (71 percent) at this site, although the differences in survival were not statistically significant among any of the treatments. Survival was only slightly lower in the other treatments, ranging from 56 to 64 percent. Considering the high elevation, westerly exposure, and concave terrain prone to frost pockets at Camp Nine, temperature extremes at the soil surface may have been an important cause of mortality of planted seedlings. Cochran (1973a) studied factors affecting the success of natural regeneration of lodgepole and ponderosa pines in southcentral Oregon. He emphasized the detrimental effects of extremely high or low soil surface temperatures on the survival of young pine seedlings. Cochran recommended leaving a light cover of logging slash to reduce temperature extremes at the soil surface. The higher survival of planted ponderosa pines on the control plots at Camp Nine may have been due to less extreme soil surface temperatures resulting from the cover provided by the vegetation and logging debris that remained on these plots. However, any improvement in the survival of planted pines attributable to the presence of non-conifer vegetation would have to be evaluated in relation to any reduction in pine growth caused by competition for limited site resources.

The greatest differences in growth of ponderosa pine between the site preparation treatments were observed at East Aspen. At this site, the seedlings planted in the chemical/disk treatment were the largest in all respects after eight growing seasons (Table 9). For all of the measures of tree size, the chemical treatment had the second largest pine trees, followed by the disk, brushblade, rip, and control treatments. A series of photographs in Figures 2 through 7 contrasts the size of ponderosa pine trees in each of the six site preparation treatment plots after eight growing seasons at East Aspen. Total height was increased 175 and 167 percent by the chemical/disk and chemical treatments,

Figure 2. Ponderosa pine trees growing in a control plot at the East Aspen site after eight growing seasons.

Figure 3. Ponderosa pine trees growing in a rip plot at the East Aspen site after eight growing seasons.

Figure 4. Ponderosa pine trees growing in a brushblade plot at the East Aspen site after eight growing seasons.

Figure 5. Ponderosa pine trees growing in a disk plot at the East Aspen site after eight growing seasons.

Figure 6. Ponderosa pine trees growing in a chemical plot at the East Aspen site after eight growing seasons.

Figure 7. Ponderosa pine trees growing in a chemical/disk plot at the East Aspen site after eight growing seasons.

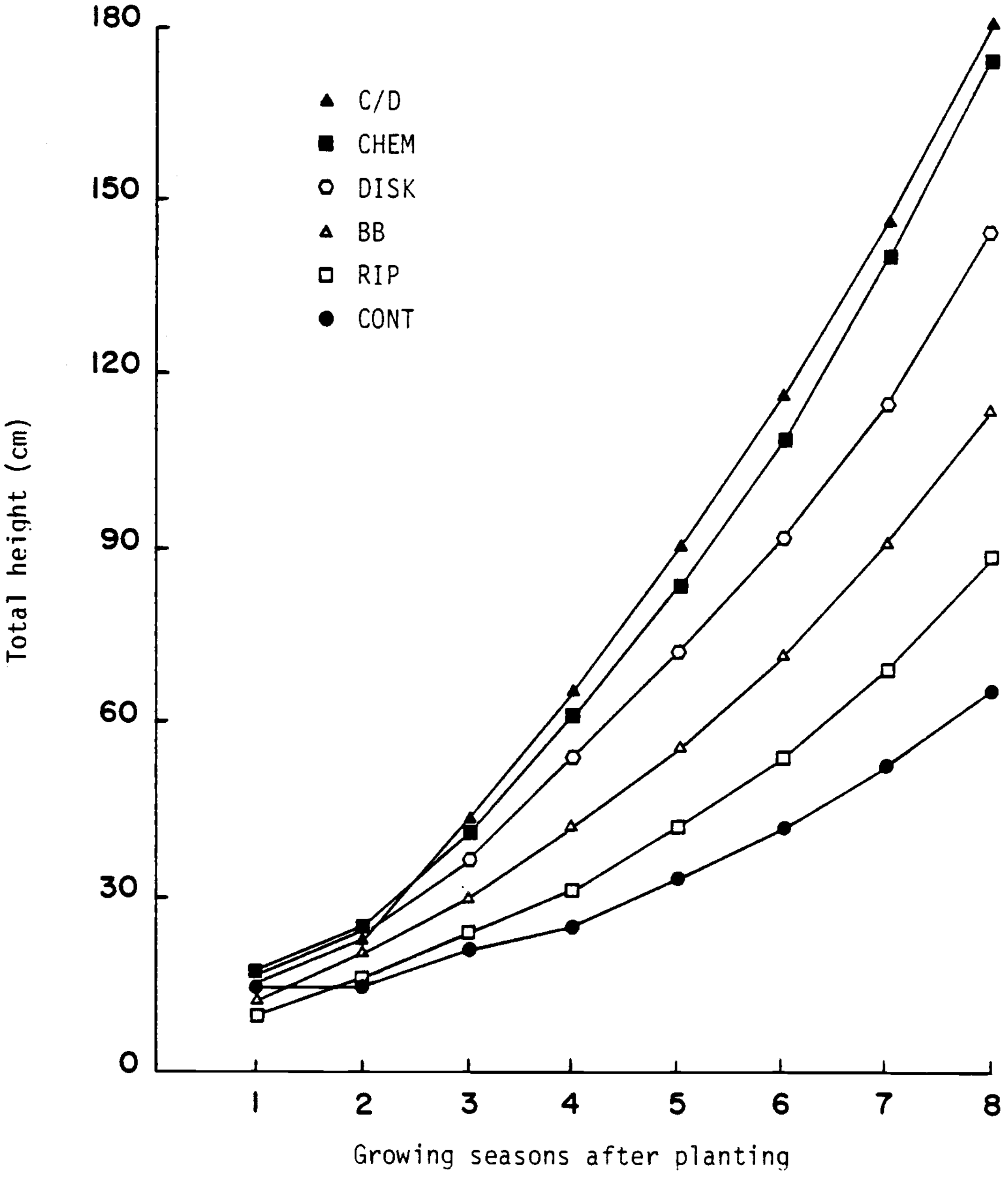


Figure 8. Total height of ponderosa pine trees planted at the East Aspen site following each of six site preparation treatments. C/D = combination of chemical and disking; CHEM = chemical-only; DISK = disking-only; BB = brushblading; RIP = ripping; CONT = control (no site preparation treatment).

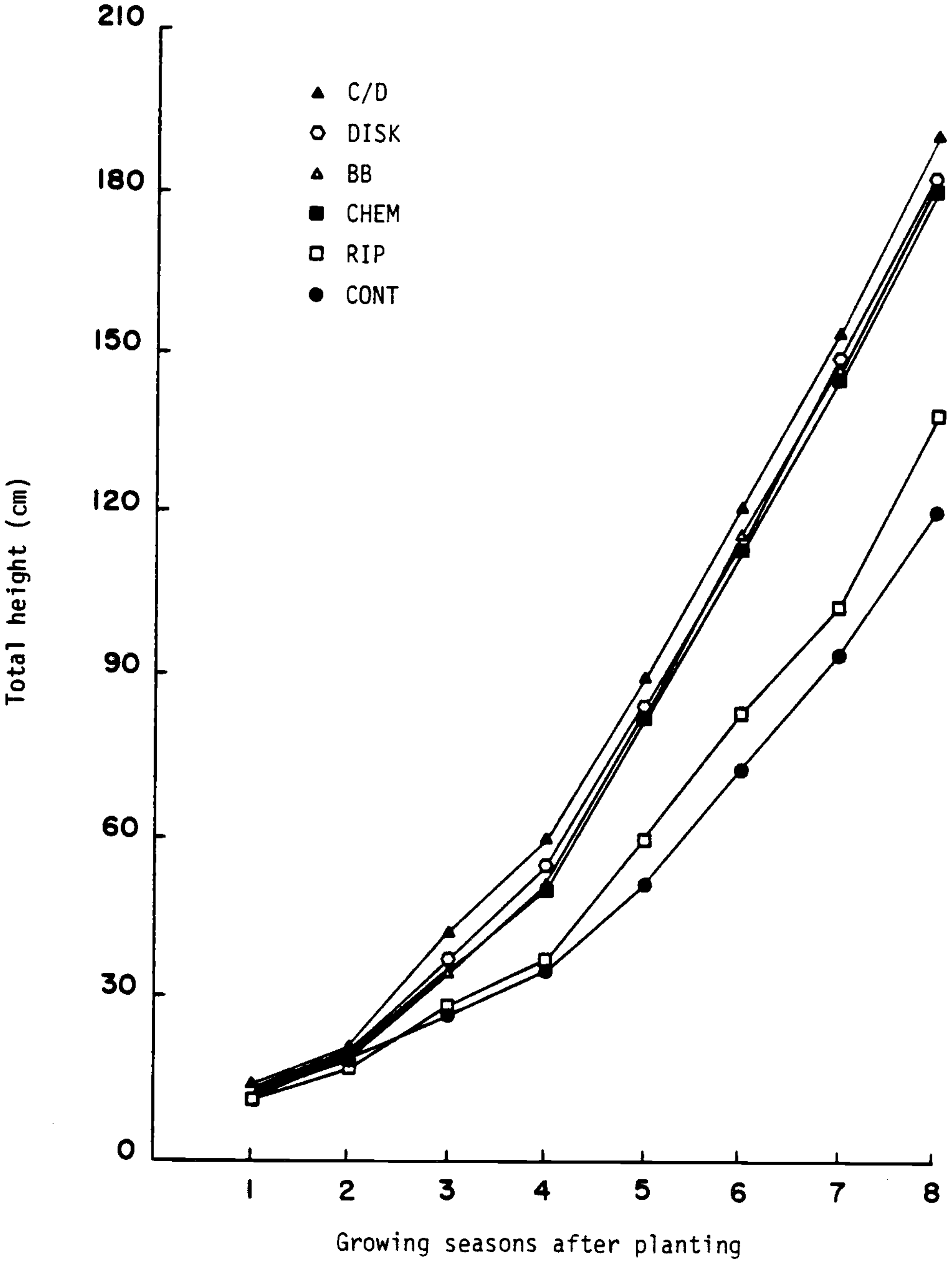


Figure 9. Total height of ponderosa pine trees planted at the Swede Cabin site following each of six site preparation treatments. C/D = combination of chemical and disking; DISK = disking-only; BB = brushblading; CHEM = chemical-only; RIP = ripping; CONT = control (no site preparation treatment).

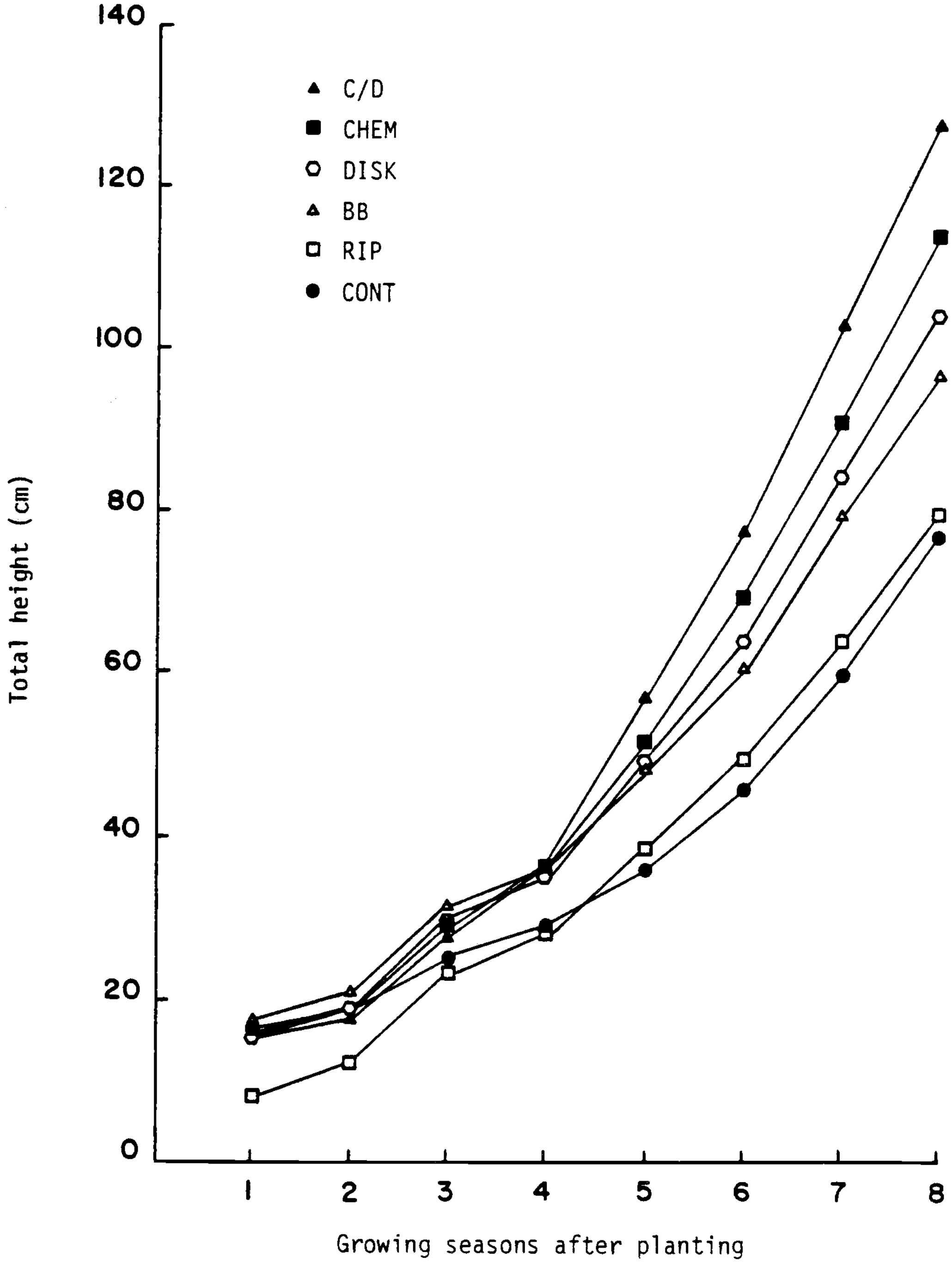


Figure 10. Total height of ponderosa pine trees planted at the Camp Nine site following each of six site preparation treatments. C/D = combination of chemical and disking; CHEM = chemical-only; DISK = disking-only; BB = brushblading; RIP = ripping; CONT = control (no site preparation treatment).

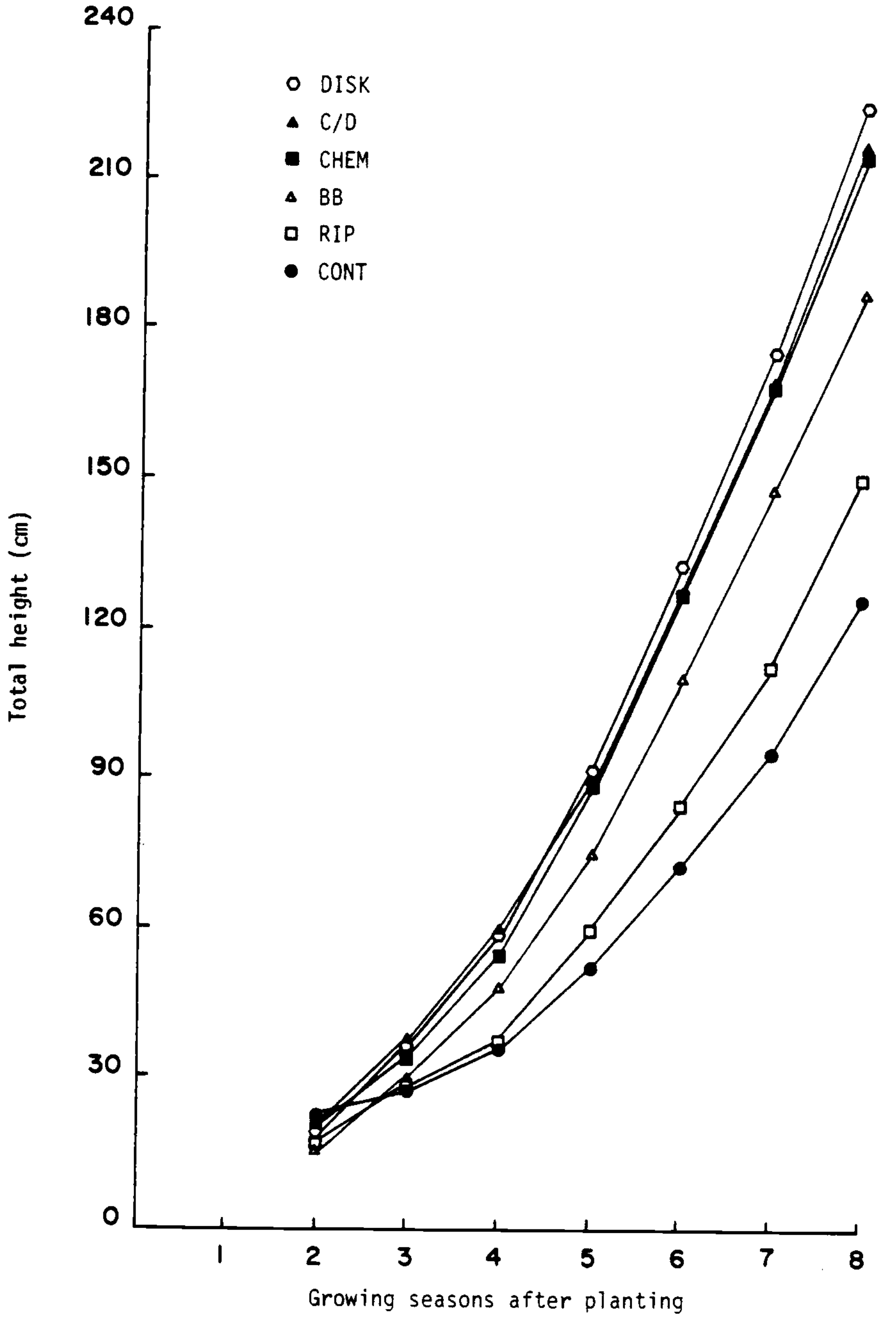


Figure 11. Total height of lodgepole pine trees planted at the Swede Cabin site following each of six site preparation treatments. DISK = disking-only; C/D = combination of chemical and disking; CHEM = chemical-only; BB = brushblading; RIP = ripping; CONT = control (no site preparation treatment).

respectively, compared to the control. The disk treatment resulted in a 122 percent increase in height, while the brushblade treatment lead to a 75 percent increase in height. The rip treatment increased total height only 35 percent. The order of treatments with respect to total height after eight growing seasons was established by the end of the third growing season after planting (Figure 8). The current annual height increments during the eighth growing season (Table 9; Figure 18, Appendix VII) indicated that the treatment differences in total height were still increasing, with one exception. During this year, height growth was 0.8 cm/yr greater in the chemical treatment than in the chemical/disk treatment. If this difference in height growth remains the same or increases, then the total height of the pines will be greater in the chemical treatment than in the chemical/disk treatment within 7 years. This was the only instance at East Aspen where the difference in total height of the pines between treatments was decreasing rather than increasing.

Total aboveground biomass was the only measure of pine growth for which the stock type by site preparation treatment interaction was significant ($P < 0.05$) at East Aspen. However, the order of site preparation treatments with respect to total aboveground biomass was the same for both stock types. Only the magnitude of the differences between treatments varied for the two stock types. In particular, the plug seedlings were considerably smaller than the bareroot seedlings in the rip and control treatments. This suggests that plug seedlings did not perform as well as bareroot seedlings where competition was severe. On the other hand, the plug seedlings were somewhat larger than the bareroot seedlings in the brushblade treatment. Since the stock type by site preparation treatment interaction was not significant for any of the other measures of tree size, it is difficult to assess the importance of these effects.

At Camp Nine, the ordering of treatments with respect to ponderosa pine growth was the same as that observed at East Aspen, although the magnitude of the treatment differences were less (Table 11, Figure 10). For all of the measures of tree size, the ponderosa pines were largest in the chemical/disk treatment followed by the chemical, disk, brushblade, rip, and control treatments. Increases in total height over the control ranged from only 3 percent in the rip treatment to 64 percent in the chemical/disk treatment. The order of treatments with respect to total height after eight growing seasons was not established until the fifth growing season after planting (Figure 10). The current annual height increments during the eighth growing season followed the same trend between treatments as total height, with one exception. During this year, the trees in the control grew 0.9 cm/yr faster in height than the trees in the rip treatment (Table 11; Figure 20, Appendix VII). If this height growth advantage is maintained or increased, then the trees in the control will be taller than the trees in the rip plots within 3 years. This was the only instance at Camp Nine where the difference in total height of the pines between treatments was decreasing rather than increasing.

Ponderosa pine growth at Swede Cabin was not affected as much by the method of site preparation as it was at the other sites. Once again, the greatest ponderosa pine growth occurred in the chemical/disk treatment (Table 10). However, ponderosa pines planted in the chemical, disk, and brushblade treatments grew at nearly identical rates through the first eight growing seasons and were only slightly smaller than the trees in the chemical/disk treatment. There were no significant differences in pine growth between the chemical/disk, chemical, disk, and brushblade treatments for any of the measures of tree size. Total height of the ponderosa pines was significantly greater in the chemical/disk, chemical, disk, and brushblade treatments than in the rip or control treatments after eight growing seasons (Table 10). Increases in height growth in the chemical/disk, chemical, disk, and brushblade treatments ranged from 50 to 58 percent compared to the control. Ripping resulted in only a 15 percent increase in height. Treatment differences in total height were not apparent until the third growing season after planting (Figure 9). From the third through the eighth growing seasons after planting, height growth in the chemical/disk, chemical, disk, and brushblade treatments was considerably greater than in the rip or control treatments (Figure 19, Appendix VII). Total height in the rip treatment was not appreciably greater than in the control until the fifth growing season after planting (Figure 9).

Treatment differences in lodgepole pine growth at Swede Cabin were similar to those observed for ponderosa pine at this site, with one exception. The growth of lodgepole pine in the brushblade treatment was substantially less than in the chemical/disk, chemical, and disk treatments, although growth in this treatment was still greater than in the rip or control treatments. The reduced growth of lodgepole pine in the brushblade treatment compared to the chemical/disk, chemical, and disk treatments may have been due to a microsite difference within one of the brushblade plots rather than an actual treatment effect. Two of the six subplots within one of the brushblade mainplots at Swede

Cabin were located on poorly drained soil. The growth of the trees in these two subplots was considerably less than the growth of the trees in the other four subplots within the brushblade mainplot. One of these aberrant subplots was planted with ponderosa pine plugs and the other was planted with lodgepole pine plugs. After eight growing seasons, the average total height of the lodgepole pine plugs was 172 cm in the well drained subplot and only 127 cm in the poorly drained subplot. The average total height of the ponderosa pine plugs was 142 cm in the well drained subplot and only 128 cm in the poorly drained subplot. Since there were four subplots of ponderosa pine (two each of plugs and bareroot) and only two subplots of lodgepole pine per mainplot, the impact of reduced growth in one subplot was greater for lodgepole pine than ponderosa pine. When the aberrant lodgepole pine subplot was excluded from the data, the average total height of lodgepole pine in the brushblade treatment was 208 cm instead of 188 cm. This was much closer to the total height of the pines in the chemical/disk, chemical, and disk treatments.

Lodgepole pine growth was similar in the chemical/disk, chemical, and disk treatments after eight growing seasons at Swede Cabin. Total height in these treatments was increased 71 to 79 percent compared to the control, although the differences were not statistically significant. Total height was increased 49 percent in the brushblade treatment and only 19 percent in the rip treatment. The treatment differences in total height were apparent by the third growing season after planting and were maintained through the eighth growing season (Figure 11). The current annual height increments during the eighth growing season followed the same trend between treatments as total height (Table 12; Figure 21, Appendix VII), indicating that the treatment differences in total height were still increasing.

Table 13 compares the survival and growth of ponderosa pine bareroot and plug seedlings at East Aspen after eight growing seasons. Survival was slightly higher for the plugs than the bareroot seedlings, but the difference was not statistically significant. Conversely, the bareroot seedlings were slightly larger than the plug seedlings in all respects. However, this difference in size was apparently the result of a difference in the size of the seedlings at the time of planting. Height growth of the plug and bareroot seedlings was similar throughout the first eight years after planting (Figures 12 and 13). Height growth was at most 3 cm/yr less for plug seedlings than for bareroot seedlings. The greatest differences in height

TABLE 13. Ponderosa pine survival and growth by stock type at the East Aspen site after eight growing seasons.[1]

Ponderosa pine stock type	Survival	Diameter[2]	Total height	Current annual height increment	Crown volume	Total aboveground biomass
	percent	mm	cm	cm/yr	m^3	kg
Bareroot	67	38.3	131.0 a	25.8	0.443	0.642
Plug	71	36.3	123.4 b	25.2	0.439	0.509

[1] Within a column, values which are followed by the same letter or no letter are not statistically different at the 0.05 level of significance by the protected LSD procedure.

[2] Diameters were measured at 10 percent of the total height of each tree.

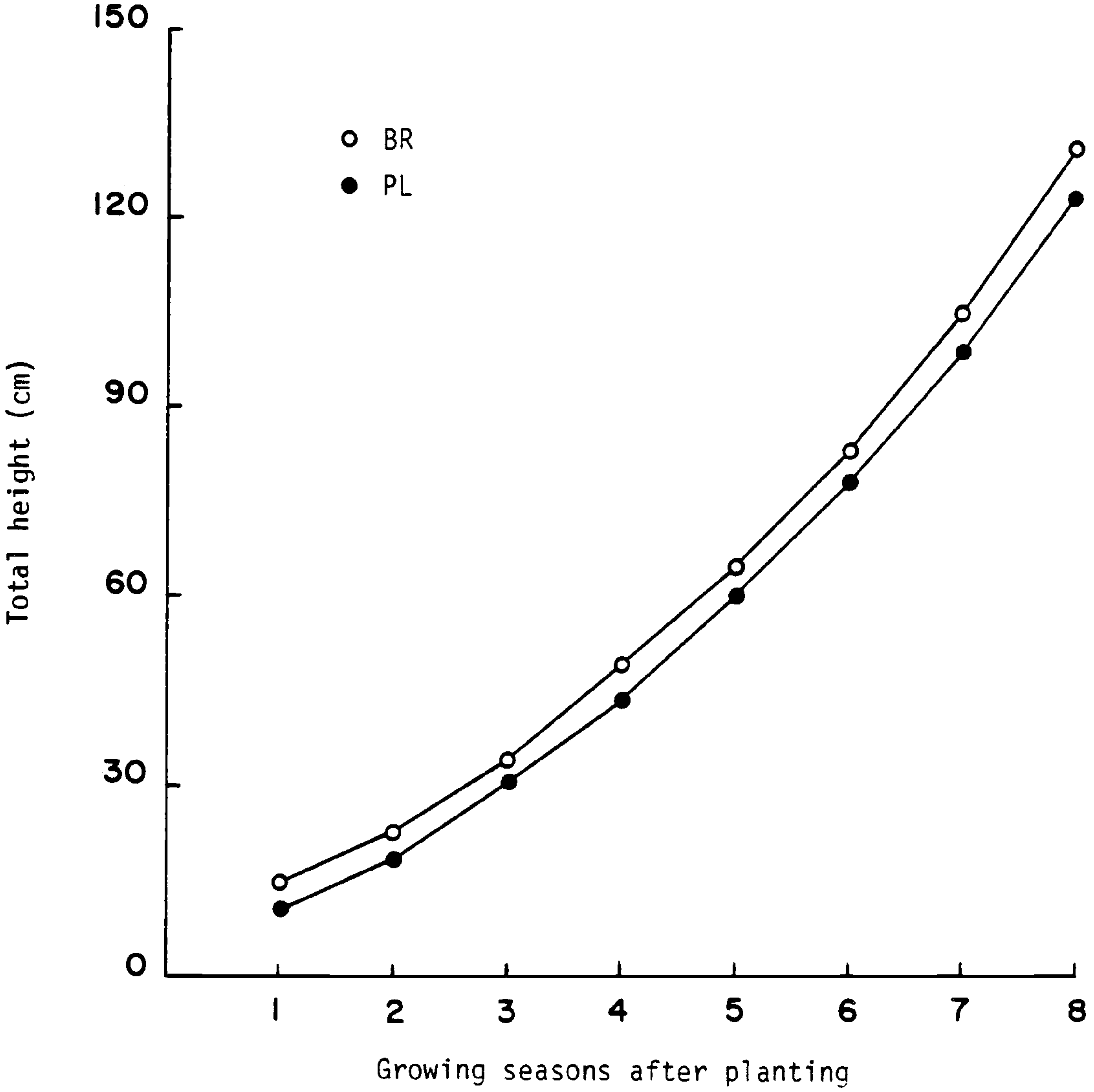


Figure 12. Total height of ponderosa pine bareroot and plug seedlings planted at the East Aspen site. BR = bareroot; PL = plug.

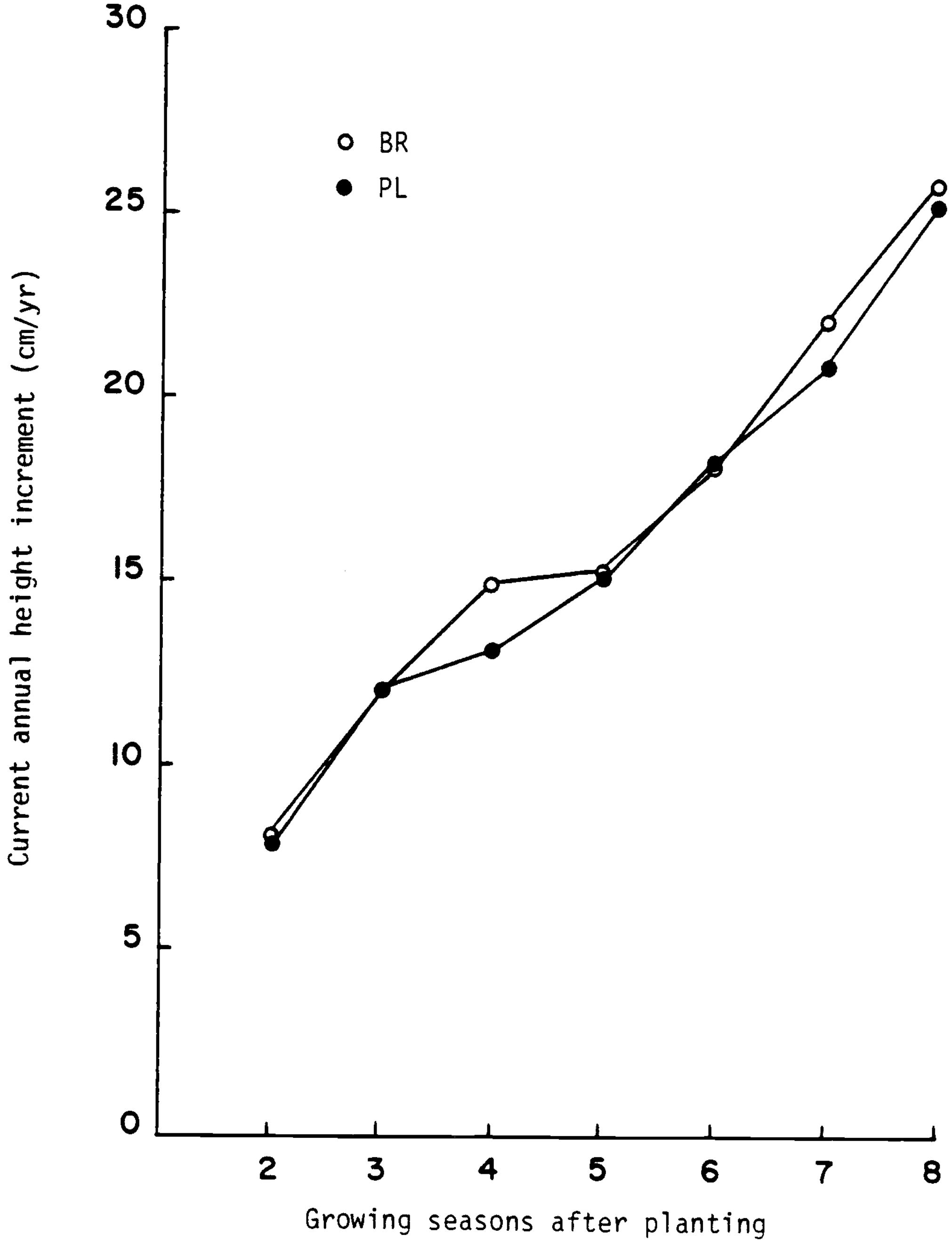


Figure 13. Current annual height increment of ponderosa pine bareroot and plug seedlings planted at the East Aspen site. BR = bareroot; PL = plug.

growth between stock types occurred during exceptionally dry years (growing seasons 4 and 7). This suggests that bareroot seedlings may perform better than plug seedlings on the most drought suceptible sites. In summary, there was little difference in the performance of ponderosa pine bareroot and plug seedlings at East Aspen.

Table 14 compares the survival and growth of ponderosa pine bareroot and plug seedlings and lodgepole pine plugs at Swede Cabin after eight growing seasons. Survival was significantly higher for ponderosa pine bareroot seedlings (80 percent) than for either ponderosa (70 percent) or lodgepole (71 percent) pine plugs, although the differences in survival were not very large. Ponderosa pine bareroot seedlings were significantly larger than ponderosa pine plugs for all of the measures of tree size. Total height of the ponderosa pine bareroot seedlings was 29 percent greater than the plugs. Unlike at East Aspen, this difference in height could not be attributed to differences in size at the time of planting. At the end of the first growing season, the ponderosa pine bareroot seedlings were only slightly taller then the plugs (Figure 14). However, the height growth of the ponderosa pine bareroot seedlings was consistently greater than the height growth of the ponderosa pine plugs from the

TABLE 14. Conifer survival and growth by species and stock type at the Swede Cabin site after eight growing seasons.[1]

Species and stock type	Survival	Diameter[2]	Total height	Current annual height increment	Crown volume	Total aboveground biomass
	percent	mm	cm	cm/yr	m^3	kg
Ponderosa pine bareroot	80 a	61.7 a	186.2 a	35.2 b	0.928 a	2.385 a
Ponderosa pine plug	70 b	50.8 b	144.8 b	30.4 c	0.510 c	1.189 b
Lodgepole pine plug	71 b	46.9 c	186.8 a	41.7 a	0.777 b	1.270 b

---

[1] Within a column, values which are followed by the same letter are not statistically different at the 0.05 level of significance by the protected LSD procedure.

[2] Diameters were measured at 10 percent of the total height of each tree.

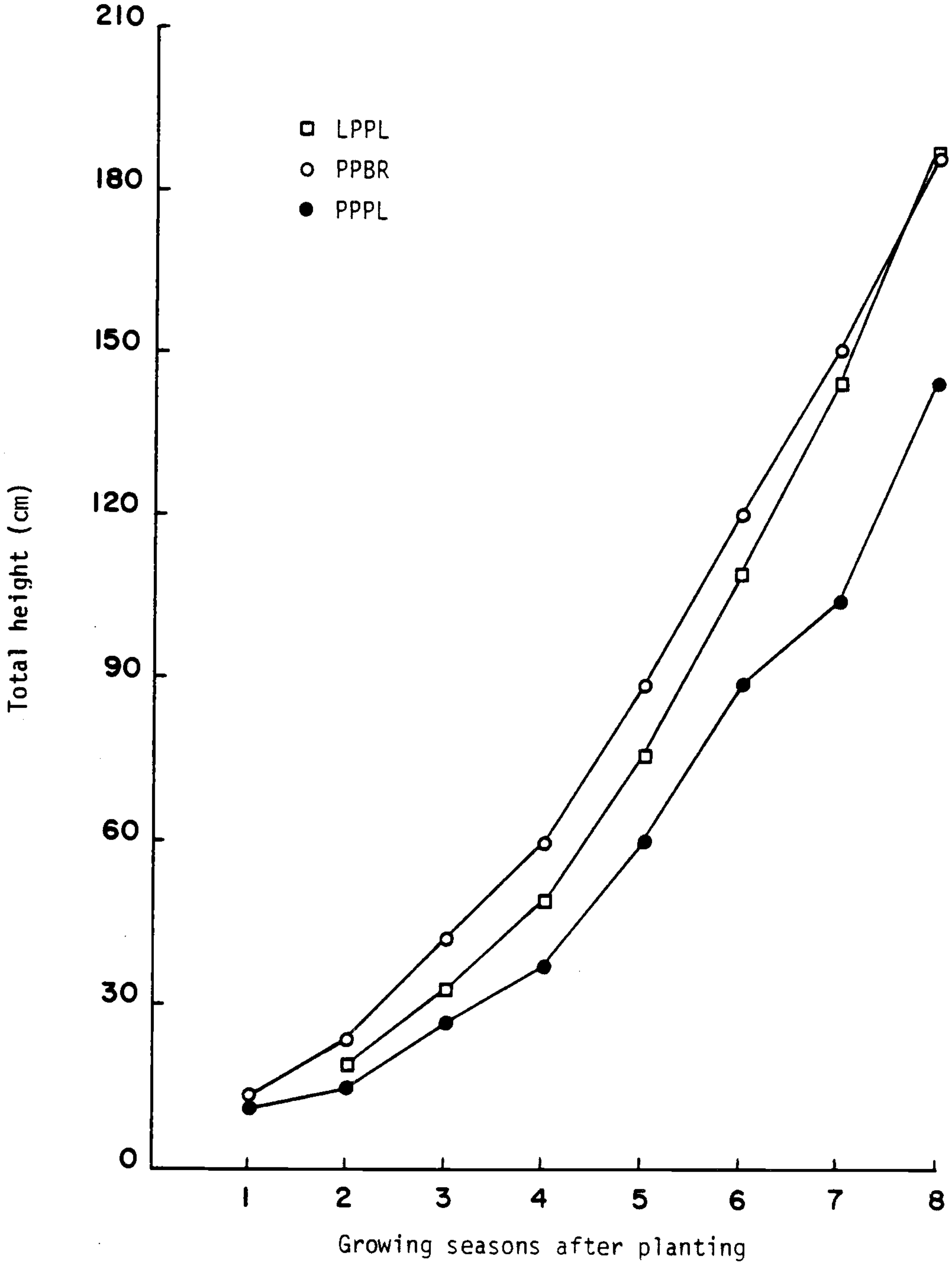


Figure 14. Total height of lodgepole and ponderosa pine seedlings planted at the Swede Cabin site. LPPL = lodgepole pine plug; PPBR = ponderosa pine bareroot; PPPL = ponderosa pine plug.

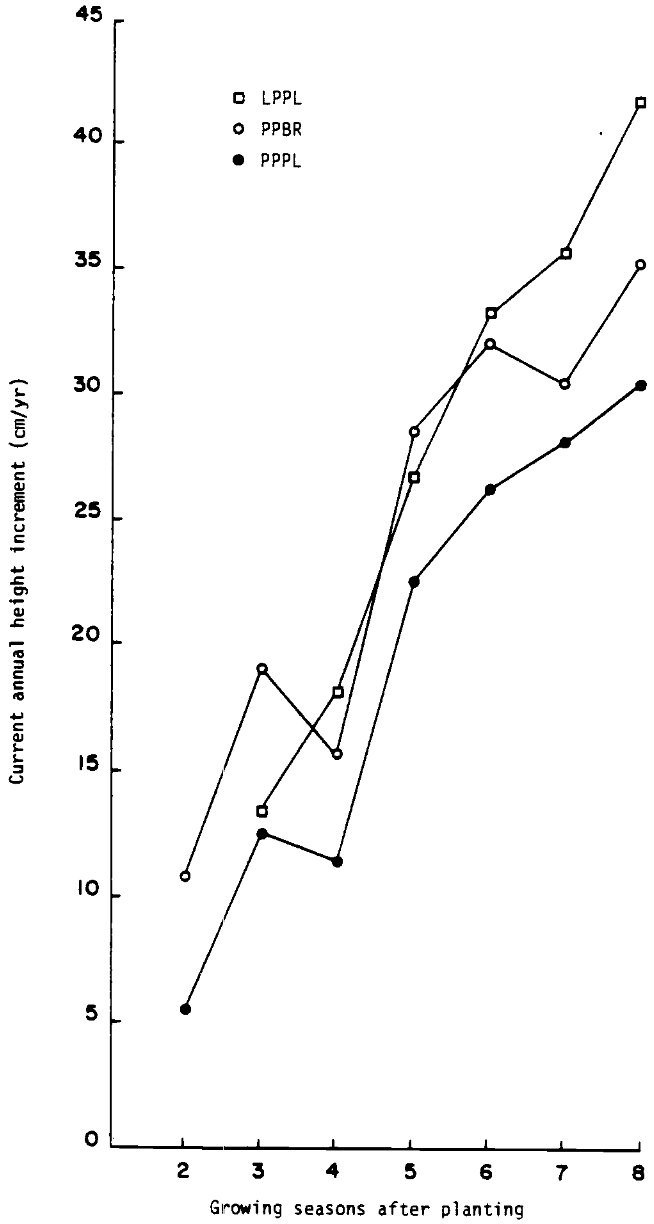


Figure 15. Current annual height increment of lodgepole and ponderosa pine seedlings planted at the Swede Cabin site. LPPL = lodgepole pine plug; PPBR = ponderosa pine bareroot; PPPL = ponderosa pine plug.

second through the eighth growing seasons (Figure 15). These results suggest that on productive sites, ponderosa pine bareroot seedlings may perform substantially better than ponderosa pine plugs.

After eight growing seasons, the diameter of the lodgepole pine plugs was significantly less than the diameter of either ponderosa pine stock type. Conversely, the height of the lodgepole pine plugs was greater than the height of either ponderosa pine stock type. The height growth of the lodgepole pine plugs was initially less than the height growth of the ponderosa pine bareroot seedlings, but greater than the height growth of the ponderosa pine plugs (Figure 15). During the eighth growing season, the height growth of the lodgepole pine seedlings was significantly greater than the height growth of either ponderosa pine stock type. Current height growth trends suggest that the lodgepole pine plugs will continue to increase in height faster than either stock type of ponderosa pine (Figures 14 and 15). These results are consistent with other published work on the growth patterns of lodgepole and ponderosa pines.

In summary, the survival of ponderosa and lodgepole pines within the site preparation treatments was similar at East Aspen and Swede Cabin. The chemical/disk, chemical, disk, and brushblade treatments were equally effective for improving survival at both sites. Survival in the chemical/disk, chemical, disk, and brushblade treatments was considerably higher than in the rip or control treatments at both sites. The rip treatment resulted in a substantial improvement in survival over the control only at East Aspen. Ponderosa pine survival was lower at Camp Nine than at East Aspen or Swede Cabin. None of the site preparation treatments improved survival at Camp Nine.

The order of treatments with respect to ponderosa pine growth was the same at East Aspen and Camp Nine, although the magnitude of the treatment differences was greater at East Aspen. At both sites, the largest increase in pine growth compared to the control occurred in the chemical/disk treatment, followed by the chemical, disk, brushblade, and rip treatments. Pine growth at Swede Cabin was less dependent upon the method of site preparation. At this site, the chemical/disk, chemical, disk, and brushblade treatments resulted in similar increases in pine growth. The rip treatment produced only a modest increase in pine growth compared to the control at Swede Cabin.

With respect to ponderosa pine stock type, the bareroot and plug seedlings performed equally well at East Aspen, but both survival and growth were considerably greater for the bareroot seedlings than for the plugs at Swede Cabin.

SUMMARY AND INTEGRATION OF RESULTS

In the previous section, the results of the soil, vegetation, and conifer sampling were presented and discussed independently of one another. In this section, the results will be briefly summarized by integrating the results of the soil, vegetation, and conifer sampling at each site. Because of the similarity of the results at East Aspen and Camp Nine, these sites will be discussed first, followed by a discussion of the results at Swede Cabin. Finally, the implications of the observed increases in survival and growth of the pines following site preparation will be addressed.

At East Aspen, competition with brush species for the available site resources was apparently the primary factor limiting the growth of the pines. Pine growth at this site was inversely related to the amount of brush present within each treatment. With only one exception, as brush biomass within a treatment decreased, the growth of the pines increased. Brushblading was the only treatment that deviated from this pattern. Although the brushblade treatment had less brush biomass than the disk treatment, the pines were significantly larger in the disk treatment. Furthermore, the brushblade and chemical treatments had nearly identical amounts of brush, but the growth of the pines was significantly greater in the chemical treatment for all of the measures of tree size. This implies that although the brushblade and chemical treatments resulted in similar levels of vegetation control, the physical disturbance associated with the brushblade treatment produced an environment that was less favorable for the growth of the pines. Changes in soil properties caused by the brushblade treatment were probably a major factor contributing to the differences in pine growth. After eight years, the C and nutrient concentrations were higher and the bulk densities were lower in the chemical treatment than in the brushblade treatment for both soil layers (Table 3). Besides reducing soil nutrient levels and increasing bulk density, the brushblade treatment may have adversely affected the biological and hydrological properties of the soil as well. Any changes in the microclimate caused by the removal of the vegetation and litter from the brushbladed plots were not documented, since no microenvironmental measurements were collected following site preparation. It is possible that temperature extremes at the soil surface may have contributed to the poor growth of the pines in the brushbladed plots.

Although the brushblade and chemical/disk treatments had similar soil C and nutrient concentrations at East Aspen, the total aboveground biomass of vegetation within these treatments was very different. Brush biomass within these treatments was similar, but the chemical/disk treatment had a much greater amount of pine biomass[3] than the brushblade treatment. The combined biomass of brush and pines was approximately 2.5 times greater in the chemical/disk treatment (11,847 kg/ha) than in the brushblade treatment (4,665 kg/ha). Consequently, the aboveground component of the ecosystem C and nutrient reserves was substantially greater in the chemical/disk treatment than in the brushblade treatment.

Ponderosa pine survival was less sensitive than pine growth to the method of site preparation at East Aspen. Survival in the chemical/disk, chemical, disk, and brushblade treatments was similar, despite treatment differences in brush biomass and herbaceous cover. Still, survival was highest in the chemical/disk treatment which had the least brush biomass and herbaceous cover. Initially, pine survival may be similar over a wide range of site conditions, but pine growth in subsequent years may vary considerably, depending on the development of competing vegetation. Nevertheless, survival was substantially lower in the

---

[3] Pine biomass per hectare was calculated for each treatment at each site based on the initial stocking of the plots, survival after eight years, and the average biomass per tree for that treatment.

rip and control treatments which had the greatest amounts of brush biomass.

Interpreting the treatment effects at Swede Cabin and Camp Nine was more difficult than at East Aspen for a number of reasons. At both Swede Cabin and Camp Nine, the conifer overstories were harvested, at most, several years prior to the installation of the research plots. Consequently, the non-conifer vegetation at these sites still reflected the influence of the conifer overstories at the time of site preparation. There was probably a considerable amount of variation in the species composition and structure of the non-conifer plant communities associated with the distribution of trees in the previous stands. For example, the plant community beneath the canopy of a white fir tree would be very different than that beneath the canopy of a ponderosa pine tree or in an opening. In contrast, the conifer overstory at East Aspen had been removed about 36 years prior to the installation of the research plots. Much of the influence of the previous conifer stand on the non-conifer plant community would have diminished over this period of time as plants became established on unvegetated spots and secondary succession proceded throughout the site. Therefore, the non-conifer plant community at East Aspen was probably more homogeneous prior to site preparation than were the plant communities at the other two sites.

The harsh microclimate at Camp Nine exerted a strong influence on pine survival and growth that tended to overwhelm any influence which competing vegetation had on pine performance. Many of the trees at Camp Nine were killed or deformed by the accumulation of snow on boles and branches. Nevertheless, all of the site preparation methods led to better growth of the pines, compared to the control plots.

At Camp Nine, ponderosa pine survival was similar and low for all of the treatments. Evidently, the climatic conditions at this site influenced survival more strongly than the method of site preparation. However, there were significant differences in ponderosa pine growth between the site preparation treatments.

The relationship between ponderosa pine growth and the amount of non-conifer vegetation after eight growing seasons was not as strong at Camp Nine as it was at East Aspen. Still, the treatments with the greatest brush biomass and herbaceous cover tended to have the smallest trees. The most surprising result of the vegetation sampling was the low percent cover of herbaceous vegetation on the control plots compared to other treatments. Although the growth of the pines was least in the control, herbaceous cover in this treatment was less than in the brushblade or rip treatments and only slightly higher than in the disk, chemical/disk, and chemical treatments. The control did have the greatest amount of brush biomass, but shrubs were so sparse at this site that their influence on pine growth was probably relatively minor. Since herbaceous vegetation rapidly invades devegetated sites and then declines, treatment differences in herbaceous cover may have been greater in the first few years following site preparation.

Treatment differences in the growth of ponderosa pine at Camp Nine were not apparent until the fourth and fifth growing seasons after planting (Figure 10). At East Aspen and Swede Cabin, the treatment differences in ponderosa pine growth were apparent by the third growing season after planting (Figures 8 and 9). The slow response of the trees to site preparation at Camp Nine may have been due to the high elevation. The colder temperatures at high elevations result in slower rates of decomposition and release of nutrients from organic matter. Consequently, it may have taken several years before the nutrients contained in the vegetative debris in the chemical/disk, chemical, and disk treatments were available to the planted pines. Furthermore, pine growth itself is slower under these conditions resulting in delayed response to silvicultural treatments. The pines in the chemical/disk, chemical, and disk treatments grew considerably faster than those in the brushblade treatment from the fifth through the eighth growing seasons after planting (Figure 4; Figure 20, Appendix VII).

As was the case at East Aspen, the chemical/disk and brushblade treatments had similarly low soil C and nutrient concentrations at Camp Nine. However, the combined biomass of brush and pines was approximately two times greater in the chemical/disk treatment (3,316 kg/ha) than in the brushblade treatment (1,696 kg/ha). This indicates that the aboveground component of the ecosystem C and nutrient reserves was considerably greater in the chemical/disk treatment.

Several uncontrolled factors may have affected the results at Swede Cabin. Particularly heavy cattle grazing at Swede Cabin may have suppressed non-conifer vegetation and was the cause of mortality and deformation of many planted conifers. Furthermore, the inherent variability in pretreatment soil conditions at Swede Cabin probably contributed to the site preparation treatment effects.

The performance of the planted pines at Swede Cabin was not influenced as much by the method of site preparation as it was at the other sites. The survival and growth of ponderosa pine was similar in the chemical/disk, chemical, disk, and brushblade treatments. Furthermore, the survival and growth of lodgepole pine was also similar in the chemical/disk, chemical, disk, and brushblade (when corrected for the aberrant subplot) treatments. However, the survival and growth of both species of pine in these four treatments were substantially better than in the rip or control treatments. The similar performance of planted pines in the four best treatments at Swede Cabin may have been due to the combination of fertile soils and relatively small amounts of non-conifer vegetation.

In general, the concentrations of soil C and nutrients were higher at Swede Cabin than at East Aspen or Camp Nine. Consequently, the soil at Swede Cabin may have been less susceptible to the impacts of site preparation. Increased rates of decomposition or removal of surface soil and organic matter during site preparation may have had less of an effect on the soil nutrient capital at this site. Furthermore, the site preparation treatments may have been less severe at Swede Cabin, since the amounts of non-conifer vegetation were apparently low at the time of treatment. For example, the amount of soil displaced by brushblading, as evidenced by the windrows, was considerably less at Swede Cabin than at East Aspen or Camp Nine. Evidently, the chemical/disk, chemical, disk, and brushblade treatments were equally effective for controlling the competing vegetation and creating an environment favorable for the survival and growth of the planted pines at Swede Cabin. These results suggest that the method of site preparation may not be as important on productive sites as it is on less productive sites for obtaining optimal performance of planted pines, providing the amounts of competing vegetation are low.

The primary objective of reforestation efforts is to establish a well stocked stand of a desirable tree species adapted to the site. If timber production is the foremost objective of the land owner, then maximizing the growth of the young seedlings is also important. Consequently, any treatment that increases the survival and growth of the crop trees without adversely affecting long-term site productivity or secondary land management objectives is desirable, provided that the discounted revenues attributable to the treatment are greater than the discounted costs. In order to evaluate the economic efficiency of silvicultural practices, it is first necessary to understand the growth response of the crop trees to those practices.

The results of this study indicate that effective site preparation can significantly increase the survival and growth of pines in southcentral Oregon through the first eight growing seasons after planting. Site preparation substantially improved pine survival at two of the study locations and significantly increased pine growth at all of the sites. Without some type of vegetation control, most plantations will not be able to fully utilize the productive capacity of a site. Furthermore, matching the appropriate site preparation treatment to the specific site conditions will result in the optimal performance of planted pines.

At the present time, it is not possible to predict with certainty the future growth of lodgepole or ponderosa pines that are less than 15-20 years old. However, after eight growing seasons, the best site preparation treatments at each site resulted in increases in height growth over the controls equivalent to at least 2 to 4 years of growing time (Figures 8 through 11). Also, with very few exceptions, the treatment differences in total height were still increasing during the eighth growing season. Any speculation about the ultimate effects of the various site preparation treatments over an entire rotation will have to await future remeasurements of these or similar plots. As these trees approach the age at which most ponderosa and lodgepole pine growth models begin (20 years), it will be possible to extrapolate the growth trajectories over a rotation to estimate the increases in yield that are likely to be achieved as a result of the alternative methods of site preparation.

BIBLIOGRAPHY

Adams, R. S. 1970. Ponderosa pine regeneration problems in the West Coast states, pp. 12-18. In Herman (ed.), Proc., Regeneration of ponderosa pine. For. Res. Lab., Sch. For., Oreg. State Univ., Corvallis. 125 p.

Ballard, R. 1978. Effect of slash and soil removal on the productivity of second growth radiata pine on a pumice soil. N. Z. J. For. Sci., 8:248-258.

Baron, F. J. 1962. Effects of different grasses on ponderosa pine seedling establishment. USDA For. Serv., Pac. S.W. For. and Range Exp. Stn., Res. Note 199. 8 p.

Barrett, J. W. 1970. Ponderosa pine saplings respond to control of spacing and understory vegetation. USDA For. Serv., Pac. N.W. For. and Range Exp. Stn., Res. Pap. PNW-106. 16 p.

Barrett, J. W. 1979. Silviculture of ponderosa pine in the Pacific Northwest: The state of our knowledge. USDA For. Serv., Pac. N.W. For. and Range Exp. Stn., Gen. Tech. Rep. PNW-97. 106 p.

Barrett, J. W. 1982. Twenty-year growth of ponderosa pine saplings thinned to five spacings in central Oregon. USDA For. Serv., Pac. N.W. For. and Range Exp. Stn., Res. Pap. PNW-301. 18 p.

Barrett, J. W. and C. T. Youngberg. 1965. Effect of tree spacing and understory vegetation on water use in a pumice soil. Soil Sci. Soc. Amer. Proc. 29:472-475.

Bentley, J. R., S. B. Carpenter, and D. A. Blakeman. 1971. Early brush control promotes growth of ponderosa pine planted on bulldozed sites. USDA For. Serv., Pac. S.W. For. and Range Exp. Stn., Res. Note PSW-238. 6 p.

Berg, M. G. and E. H. Gardner. 1978. Methods of soil analysis used in the soil testing laboratory at Oregon State University. Oregon Agric. Exp. Stn., Special Rep. 321. Oreg. State Univ., Corvallis.

Brodie, J. D. and P. L. Tedder. 1982. Regeneration delay: Economic cost and harvest loss. J. For. 80:26-28.

Clark, M. B. and A. McLean. 1975. Growth of lodgepole pine seedlings in competition with different densities of grass. B. C. For. Serv. Res. Note 70. 10 p.

Cochran, P. H. 1973a. Natural regeneration of lodgepole pine in southcentral Oregon. Pac. N.W. For. and Range Exp. Stn., Res. Note PNW-204. 18 p.

Cochran, P. H. 1973b. Response of individual ponderosa pine trees to fetilization. USDA For. Serv., Pac. N.W. For. and Range Exp. Stn., Res. Note PNW-206. 15 p.

Cochran, P. H. 1975. Response of pole-size lodgepole pine to fertilization. USDA For. Serv., Pac. N.W. For. and Range Exp. Stn., Res. Note PNW-247. 10 p.

Cochran, P. H. 1977. Response of ponderosa pine 8 years after fertilization. USDA For. Serv., Pac. N.W. For. and Range Exp. Stn., Res. Note PNW-301. 7 p.

Cochran, P. H. 1978. Response of a pole-size ponderosa pine stand to nitrogen, phosphorus, and sulfur. USDA For. Serv., Pac. N.W. For. and Range Exp. Stn., Res. Note PNW-319. 8 p.

Cochran, P. H. 1979a. Response of thinned ponderosa pine to fertilization. USDA For. Serv., Pac. N.W. For. and Range Exp. Stn., Res. Note PNW-339. 8 p.

Cochran, P. H. 1979b. Response of thinned lodgepole pine after fertilization. USDA For. Serv., Pac. N.W. For. and Range Exp. Stn., Res. Note PNW-335. 6 p.

Conard, S. G. and W. H. Emmingham. 1983. Herbicides for shrub control on forest sites in northeastern Oregon and northern Idaho. Special Publ. 5. For. Res. Lab., Coll. For., Oreg. State Univ., Corvallis. 8 p.

Conard, S. G. and W. H. Emmingham. 1984a. Herbicides for forest brush control in southwestern Oregon. Special Publ. 6. For. Res. Lab., Coll. For., Oreg. State Univ., Corvallis. 8 p.

Conard, S. G. and W. H. Emmingham. 1984b. Herbicides for grass and herbaceous weed control in Oregon and Washington. Special Publ. 7. For. Res. Lab., Coll. For., Oreg. State Univ., Corvallis. 8 p.

Crouch, G. L. 1979. Atrazine improves survival and growth of ponderosa pine threatened by vegetative competition and pocket gophers. Forest Sci. 25:99-111.

Dahms, W. G. 1950. The effect of manzanita and snowbrush competition on ponderosa pine reproduction. USDA For. Serv., Pac. N.W. For. and Range Exp. Stn., Res. Note 65. 3 p.

Dahms, W. G. 1955. Chemical brush control on central Oregon ponderosa pine lands. USDA For. Serv., Pac. N.W. For. and Range Exp. Stn., Res. Note 109. 5 p.

Dahms, W. G. 1961. Chemical control of brush in ponderosa pine forests of central Oregon. USDA For. Serv., Pac. N.W. For. and Range Exp. Stn., Res. Pap. 39. 17 p.

Daubenmire, R. 1959. A canopy-coverage method of vegetational analysis. Northwest Sci. 33:43-64.

Dealy, J. E. 1971. Habitat characteristics of the Silver Lake mule deer range. USDA For. Serv., Pac. N.W. For. and Range Exp. Stn., Res. Pap. PNW-125. 99 p.

Dimock, E. J., II and E. B. Collard. 1981. Postplanting sprays of dalapon and atrazine to aid conifer establishment. USDA For. Serv., Pac. N.W. For. and Range Exp. Stn., Res. Pap. PNW-280. 20 p.

Dingle, R. W. 1976. Principles of site preparation, pp.107-116. In Baumgartner and Boyd (ed.), Proc., Tree planting in the inland Northwest. Washington State Univ., Pullman. 311 p.

Duncan, S. H. and E. C. Steinbrenner. 1975. Soil survey of the Klamath Falls Tree Farm. Weyerhaeuser Company. Tacoma, WA. 43 p.

Dyrness, C. T. and C. T. Youngberg. 1966. Soil-vegetation relationships within the ponderosa pine type in the central Oregon pumice region. Ecology 47:122-138.

Eckert, R. E. 1979. Establishment of pine (Pinus spp.) transplants in perennial grass stands with atrazine. Weed Science 27:253-257.

Ellefson, P. V. 1973. Forest Service Appraisal: The outlook for timber in the United States. J. For. 71:8-9.

Farrenkopf, T. O. 1982. Forest statistics for eastern Oregon, 1977. USDA For. Serv., Pac. N.W. For. and Range Exp. Stn., Resource Bull. PNW-94. 28 p.

Franklin, J. F. and C. T. Dyrness. 1973. Natural vegetation of Oregon and Washington. USDA For. Serv., Pac. N.W. For. and Range Exp. Stn., Gen. Tech. Rep. PNW-8. 417 p.

Garrison, G. A., J. M. Skovlin, C. E. Poulton, and A. H. Winward. 1976. Northwest plant names and symbols for ecosystem inventory and analysis. USDA For. Serv., Pac. N.W. For. and Range Exp. Stn., Gen. Tech. Rep. PNW-46. 263 p.

Glass, G. G., Jr. 1976. The effects from rootraking on an upland piedmont loblolly pine (Pinus taeda L.) site. Tech. Rept. No. 56, Sch. of For. Resour., N. C. State University, Raleigh. 44 p.

Glover, G. R., S. A. Knowe, and D. H. Gjerstad. 1981. Fayette site preparation study - 22 year results. Silvicultural Herbicide Cooperative, Note Number 1. Dept. of For., Auburn University, Auburn, Alabama. 4 p.

Good, R. A. 1941. History of Klamath County, Oregon: Its resources and its people. Klamath Falls, Oregon. 598 p.

Gregory, J. D. 1981. Impacts of forest weed control on soils, pp. 231-236. In Holt and Fischer (ed.), Proc., Weed control in forest management. Dept. of For. and Nat. Resour., Purdue University, West Lafayette, Indiana. 305 p.

Grime, J. P. 1973. Competition and diversity in herbaceous vegetation - a reply. Nature 244:310-311.

Grime, J. P. 1979. Plant stategies and vegetation processes. John Wiley & Sons, New York. 222 p.

Gutzwiler, J. R. 1976. Mechanical site preparation for tree planting in the inland Northwest, pp. 117-133. In Baumgartner and Boyd (ed.), Proc., Tree planting in the inland Norhtwest. Washington State University, Pullman. 311 p.

Haines, L. W. 1981. Integrated pest management and competing forest vegetation, pp. 1-9. In Holt and Fischer (ed.), Proc., Weed control in forest management. Dept. of For. and Nat. Resour., Purdue University, West Lafayette, Indiana. 305 p.

Haines, L. W., T. E. Maki, and S. G. Sanderford. 1975. The effect of mechanical site preparation treatments on soil productivity and tree growth, pp.379-395. In Bernier and Winget (ed.), Proc., Forest soils and forest land management. Univ. Laval Press, Quebec, Canada. 675 p.

Harrington, M. G. and R. G. Kelsey. 1979. Influence of some environmental factors on initial establishment and growth of ponderosa pine. USDA For. Serv., Intermountain For. and Range Exp. Stn., Res. Pap. INT-230. 26 p.

Harvey, A. E. 1982. The importance of residual organic debris in site preparation and amelioration for reforestation, pp. 75-85. In Baumgartner (ed.), Proc., Site preparation and fuels management on steep terrain. Washington State University, Pullman.

Heidmann, L. J. 1969. Use of herbicides for planting site preparations in the Southwest. J. For. 67:506-509.

Helms, J. A. 1983. Soil compaction and stand growth. Final rep. to U.S.D.A. For. Serv., Amendment to supplement 42, Master agreement 21-395. Dep. of For. and Resource Mgmt., Univ. of Calif., Berkeley. 77 p.

Hopkins, W. E. 1979a. Plant associations of south Chiloquin and Klamath Ranger Districts, Winema National Forest. USDA For. Serv., Pac. Northwest Region 6, R6-ECOL-79-005. 96 p.

Hopkins, W. E. 1979b. Plant associations of the Fremont National Forest. USDA For. Serv., Pac. Northwest Region 6, R6-ECOL-79-004. 106 p.

Kelpsas, B. R. 1978. Comparative effects of chemical, fire, and machine site preparation in an Oregon coastal brushfield. M.S. Thesis. Oregon State University, Corvallis. 97 numb. leaves.

Lanini, W. T. and S. R. Radosevich. In Press. Coniferous responses to increased resource availability as a result of shrub manipulation.

Larson, M. M. and G. H. Schubert. 1969. Root competition between ponderosa pine seedlings and grass. USDA For. Serv., Rocky Mtn. For. and Range Exp. Stn., Res. Pap. RM-54. 12 p.

Lindstrand, L., Jr. 1983. Site preparation practices, pp. 103-104. In Robson and Standiford (ed.), Proc., Management of the eastside pine type in northeastern California. Northern Calif. Soc. of Amer. For., Arcata, California. 139 p.

Loewenstein, H., L. P. McConnel, and F. H. Pitkin. 1968. Root development and survival of planted ponderosa pine seedlings as influenced by competing vegetation. Univ. of Idaho For., Wildlife, and Range Exp. Stn., Paper No. 5. Moscow, Idaho. 13 p.

Lotan, J. E. and D. A. Perry. 1983. Ecology and regeneration of lodgepole pine. USDA For. Serv., Agricultural Handbook No. 606. 51 p.

Madgwick, H. A. I. and T. Satoo. 1975. On estimating the aboveground weights of tree stands. Ecology 56:1446-1450.

Martin, R. E. 1976. Prescribed burning for site preparation in the inland Northwest, pp. 134-156. In Baumgartner and Boyd (ed.), Proc., Tree planting in the inland Northwest. Washington State University, Pullman. 311 p.

Martin, R. E. and J. D. Dell. 1978. Planning for prescribed burning in the inland Northwest. USDA For. Serv., Pac. N.W. For. and Range Exp. Stn., Gen. Tech. Rep. PNW-76. 67 p.

McDonald, P. M. 1983. Weeds in conifer plantations in northeastern California ... management implications, pp. 70-78. In Robson and Standiford (ed.), Proc., Management of the eastside pine type in northeastern California. Northern Calif. Soc. of Amer. For., Arcata, California. 139 p.

Miller, D. L. and F. A. Kidd. 1983. Shrub control in the inland Northwest - a summary of herbicide test results. Potlach Forestry Research Note, RN-83-4. Lewiston, Idaho. 56 p.

Morris, L. A., W. L. Pritchett, and B. F. Swindel. 1983. Displacement of nutrients into windrows during site preparation of a flatwood forest. Soil Sci. Soc. Am. J. 47:591-594.

Nelson, D. W. and L. E. Sommers. 1982. Total carbon, organic carbon, and organic matter. In Black (ed.), Methods of soil analysis, Part 2. Agronomy Monograph 9:539-579.

Newton, M. 1973. Forest rehabilitation in North America: Some simplifications. J. For. 71:159-162.

Newton, M. 1981. Ecological principles of weed control in forestry, pp. 14-25. In Holt and Fischer (ed.), Proc., Weed control in forest management. Purdue University, West Lafayette, Indiana. 305 p.

Newton, M. and W. L. Webb. 1970. Herbicides and management of young pine, pp. 94-99. In Hermann (ed.), Proc., Regeneration of ponderosa pine. For. Res. Lab., Sch. For., Oreg. State Univ., Corvallis. 125 p.

Oliver, W. W. 1979. Early response of ponderosa pine to spacing and brush: Observations on a 12-year-old plantation. USDA For. Serv., Pac. S.W. For. and Range Exp. Stn., Res. Note PSW-341. 7 p.

Oliver, W. W. 1984. Brush reduces growth of thinned ponderosa pine in northern California. USDA For. Serv., Pac. S.W. For. and Range Exp. Stn., Res. Pap. PSW-172. 7 p.

Pehl, C. E. and R. L. Bailey. 1983. Performance to age ten of a loblolly pine plantation on an intensively prepared site in the Georgia Piedmont. Forest Sci. 29:96-102.

Pilz, D. P. and D. A. Perry. 1984. Impact of clearcutting and slash burning on ectomycorrhizal associations of Douglas-fir seedlings. Can. J. For. Res. 14:94-100.

Powers, R. F. and G. D. Jackson. 1978. Ponderosa pine response to fertilization: Influence of brush removal and soil type. USDA For. Serv., Pac. S.W. For. and Range Exp. Stn., Res. Pap. PSW-132. 9 p.

Robbins, R. W. 1984. The influence of soil compaction on early conifer growth in the southern Washington Cascades. M.S. Thesis. Oregon State University, Corvallis. 96 numb. leaves.

Roy, D. F. 1953. Effects of ground cover and class of planting stock on survival of transplants in the eastside pine type of California. USDA For. Serv., California For. and Range Exp. Stn., Res. Note 87. 6 p.

Roy, D. F. 1981. Effects of competing vegetation on conifer performance. Paper presented at Forest Vegetation Management Workshop, Oreg. State Univ., Corvallis. 54 p.

Roy, D. F. 1983. Natural regeneration, pp.87-102. In Robson and Standiford (ed.), Proc., Management of the eastside pine type in northeastern California. Northern Calif. Soc. of Amer. For., Arcata, California. 139 p.

Satoo, T. and H. A. I. Madgwick. 1982. Forest biomass. Martinus Nijhoff/Dr. W. Junk Publishers, The Hague. 152 p.

Schoenberger, M. M. and D. A. Perry. 1982. The effect of soil disturbance on growth and ectomycorrhizae of Douglas-fir and western hemlock seedlings: A greenhouse bioassay. Can. J. For. Sci. 12:343-353.

Schubert, G. H. and R. S. Adams. 1971. Reforestation practices for conifers in California. State of California, Dept. Conserv., Div. For., Sacramento. 359 p.

Scott, W. 1981. Mechanical-chemical site preparation: Impact on ponderosa pine plantation performance. Paper presented at Forest Vegetation Management Workshop, Oreg. State Univ., Corvallis. 2 p.

Soltanpour, P. N., J. B. Jones, Jr., and S. M. Workman. 1982. Optical emission spectrometry. In Black (ed.), Methods of soil analysis, Part 2. Agronomy Monograph 9:29-65.

Steinbergs, A., O. Iismaa, and J. R. Freney. 1962. Determination of total sulphur in soil and plant material. Anal. Chim. Acta 27:158-164.

Stevens, R. E. 1971. Ponderosa pine tip moth. USDA For. Serv., Forest Pest Leaflet 103. 5 p.

Stewart, R. E. 1976. Chemical site preparation in the Inland Empire, pp. 158-173. In Baumgartner and Boyd (ed.), Proc., Tree planting in the inland Northwest. Washington State University, Pullman. 311 p.

Stewart, R. E. 1978. Site preparation, pp.99-129. In Cleary, Greaves, and Hermann (ed.), Regenerating Oregon's Forests. Oregon State University Extension Service, Corvallis. 287 p.

Stewart, R. E. and T. Beebe. 1974. Survival of ponderosa pines following control of competing grasses. West. Soc. Weed Sci. Proc. 27:55-58.

Stoszek, K. J. 1973. Damage to ponderosa pine plantations by the western pine-shoot borer. J. For. 71:701-705.

Stransky, J. J. 1981. Site preparation effects on soil bulk density and pine seedling growth. Southern Jour. of App. For. 5:176-179.

Stransky, J. J., L. K. Halls, and K. G. Watterston. 1982. Soil response to clearcutting and site preparation in east Texas, pp. 54-58. In Jones (ed.), Proc., Second biennial southern silvicultural research conference. USDA For. Serv., Southern For. and Range Exp. Stn., Gen. Tech. Rep. SE-24. 514 p.

Tappeiner, J. C., II and S. R. Radosevich. 1982. Effect of bearmat (Chamaebatia foliolosa) on soil moisture and ponderosa pine (Pinus ponderosa) growth. Weed Science 30:98-101.

Tarrant, R. F. 1957. Soil moisture conditions after chemically killing manzanita brush in central Oregon. USDA For. Serv., Pac. N.W. For. and Range Exp. Stn., Res. Note 156. 4 p.

Thompson, C. F. 1974. Tenth year remeasurements of planting trials with ponderosa pine. B. C. For. Serv. Res. Note No. 65. 13 p.

Tuttle, C. L., M. S. Golden, and R. S. Meldahl. 1982. Effect of surface soil removal on selected soil properties and loblolly pine seedlings after the first growing season, pp. 18-22. In Jones (ed.), Proc., Second biennial southern silvicultural research conference. USDA For. Serv., Southern For. and Range Exp. Stn., Gen. Tech. Rep. SE-24. 514 p.

U. S. Bureau of Indian Affairs. 1958. Soils of the Klamath Indian Reservation (interim report). (Soil Conserv. Serv. and Oreg. State Univ. cooperating). 297 p.

Volland, L. A. 1963. Phytosociology of the ponderosa pine type on pumice soils in the Upper Williamson River Basin, Klamath County, Oregon. M.S. Thesis. Oregon State University, Corvallis. 166 numb. leaves.

Volland, L. A. 1976. Plant communities of the central Oregon pumice zone. USDA For. Serv., Pac. Northwest Region 6, R6 Area Guide [no.] 4-2. 113 p.

Weaver, H. 1943. Fire as an ecological and silvicultural factor in the ponderosa pine region of the Pacific Slope. J. For. 41:7-15.

Weaver, H. 1961. Implications of the Klamath fires of September 1959. J. For. 59:569-572.

Webber, B. 1978. Potential increases in nutrient requirements of Pinus radiata under intensified management. N. Z. J. For. Sci. 8:146-159.

Wells, C. G. et al. 1979. Effects of fire on soil: A state-of-knowledge review. USDA For. Serv., Washington, D.C., Gen. Tech. Rep. WO-7. 34 p.

Wenzel, D. L. 1979. Soil resource inventory, Fremont National Forest. USDA For. Serv., Pac. Northwest Region. 282 p.

Whipple, S. D. and E. H. White. 1965. Response of planted loblolly pine following various conversion methods. Alabama Agricultural Experiment Station, Bulletin 362. Auburn University, Auburn, Alabama. 26 p.

Will, G. M. and C. T. Youngberg. 1978. Sulfur status of some central Oregon pumice soils. Soil Sci. Soc. Am. J. 42:132-134.

Wollum, A. G., II and C. B. Davey. 1975. Nitrogen accumulation, transformation, and transport in forest soils, pp. 67-106. In Bernier and Winget (ed.), Proc., Forest soils and forest land management. Univ. Laval Press, Quebec, Canada. 675 p.

Youngberg, C. T. 1975. Effects of fertilization and thinning on the growth of ponderosa pine. Soil Sci. Soc. Amer. Proc. 39:137-139.

Youngberg, C. T. and C. T. Dyrness. 1964. Some physical and chemical properties of pumice soils in Oregon. Soil Sci. 97:391-399.

Youngberg, C. T. and C. T. Dyrness. 1965. Biological assay of pumice soil fertility. Soil Sci. Soc. Amer. Proc. 29:182-187.

Zavitkovski, J. and E. S. Woodard. 1970. Role of brush in ponderosa pine establishment, pp. 100-104. In Hermann (ed.), Proc., Regeneration of ponderosa pine. For. Res. Lab., Sch. For., Oreg. State Univ., Corvallis. 125 p.

Zinke, P. J. 1960. Forest site quality as related to soil nitrogen content. Int. Congr. of Soil Sci., Trans. 7th. (Madison, Wis.) III:411-418.

Zinke, P. J. 1983. Soils of the eastside pine type and their properties in relation to forest management, pp. 17-28. In Robson and Standiford (ed.), Proc., Management of the eastside pine type in northeastern California. Northern Calif. Soc. of Amer. For., Arcata, California. 139 p.

APPENDICES

APPENDICES

Appendix I.	Diagram of general plot layout.
Appendix II.	Description of the soil corer and the method of collecting soil samples.
Appendix III.	Tables of soil properties (including standard errors) by soil layer and site preparation treatment for each of the three study site locations.
Appendix IV.	Tables of woody and herbaceous vegetation characteristics by species and site preparation treatment for each of the three study site locations.
Appendix V.	Tables of biomass regression equation coefficients and statistics for non-conifer woody vegetation and conifers by species.
Appendix VI.	Species codes and corresponding scientific plant names.
Appendix VII.	a. Tables of survival and growth of planted pines (including standard errors) by species/stock type and site preparation treatment for each of the three study site locations. b. Figures of current annual height increment by species and site preparation treatment for each of the three study site locations.

Appendix I

Diagram of general plot layout.

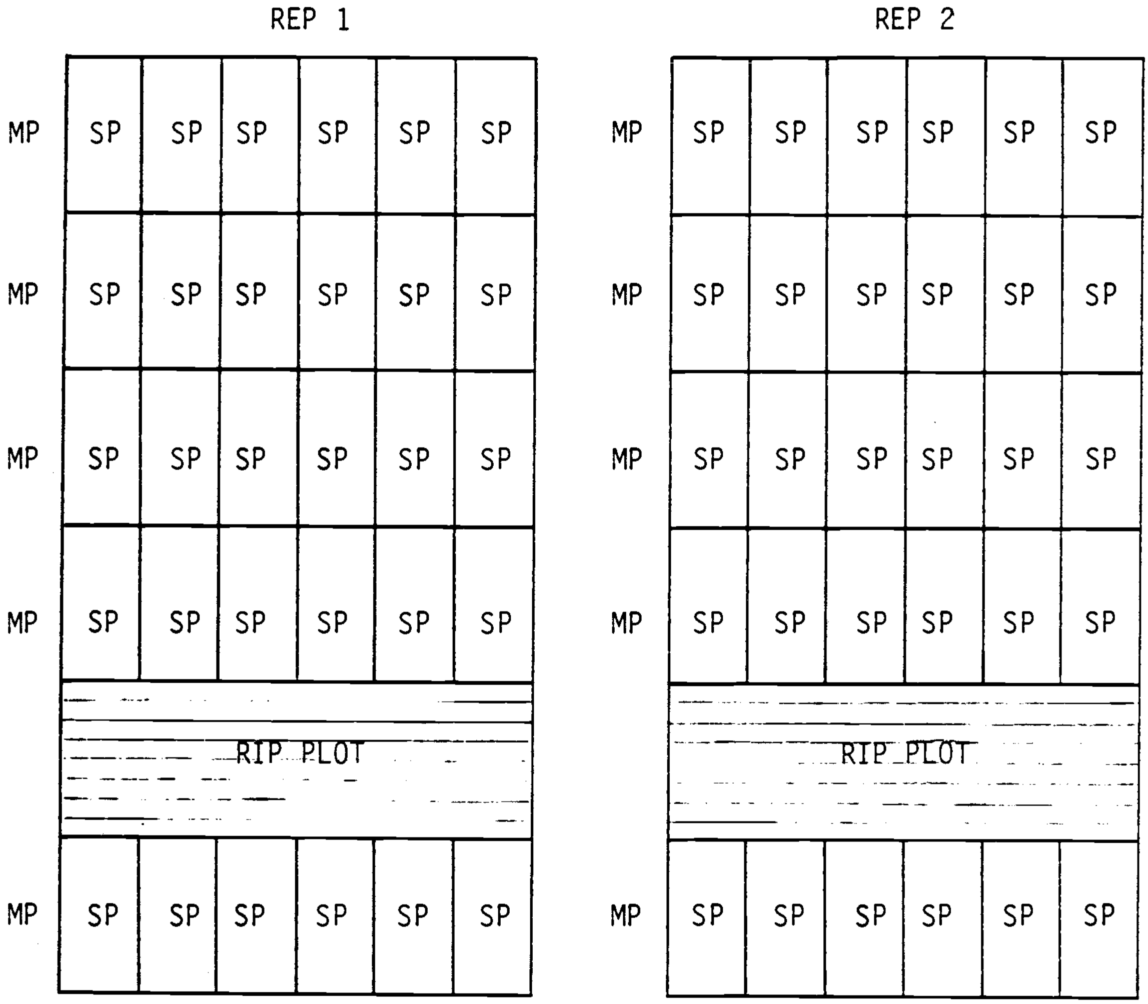


Figure 16. Diagram of general plot layout that is replicated at each of the three study sites. MP = mainplot = site preparation treatments; SP = subplot = species/stock type of pine. The mainplot and subplot treatments for each site are described in the text. Each species/stock type combination was replicated twice within each mainplot. That is, the six subplots represent only three different species/stock type combinations. The split subplots were pooled for statistical analyses.

Appendix II

Description of the soil corer and the method of collecting soil samples.

Due to the stoniness of the soil at two of the three sites, it was not feasible to use the normal type of bulk density sampler that is pressed into the soil from above. It was felt that the risk of hitting a rock could be reduced by digging a soil pit and driving a corer into the side of the pit.

A corer was made for this purpose by the shop at the Forest Research Laboratory. The corer was made from a section of steel pipe 8.65 cm long with an outside diameter of 6.02 cm (i.d. 5.28 cm). A stainless steel cap was made for one end of the pipe. A flange on the cap allowed half of the depth of the cap to enter the pipe. A set screw in the pipe held the cap in place. The cap was easily removed for emptying the corer by loosening the set screw. A hole about 6 mm in diameter was drilled in the center of the cap to facilitate determining when the corer was full. The opposite end of the pipe was beveled to provide a cutting edge for the corer. The final inside dimensions of the corer were 5.28 cm in diameter by 7.80 cm in depth. A photograph of the soil corer, in use, is included in Figure 17.

The corer was hammered into the soil with a large wooden mallet. By observing the hole in the cap it was possible to determine with reasonable accuracy when the corer was full. Undoubtedly, some compaction and disruption of soil structure occurred with this procedure that would affect the bulk density determinations. However, this error was not considered significant, since the primary objective was to compare the treatments, and samples were collected from all treatments in an identical manner. After the corer was driven into the soil until it was full, a small garden trough was used to carefully dig the soil from around the top of the corer until the beveled edge was recognizable. A piece of sheet metal with a sharpened edge was pushed into the soil flush with the open end of the corer. The corer was lifted out of the ground with care to keep the sheet metal cover flush with the open end of the corer. The open end of the corer was inspected to see if there was any obvious damage to the soil core. If the core appeared intact it was emptied into a labeled plastic bag and the sampling continued. If the core was not intact it was discarded and another sample was collected from that soil pit at that depth.

Figure 17. Soil corer that was used to collect volumetric soil samples.

Appendix III

Tables of soil properties (including standard errors) by soil layer and site preparation treatment for each of the three study site locations.

Table		Page
15.	Soil properties for two soil layers at the East Aspen site after eight growing seasons following each of six site preparation treatments (including C:N and C:S ratios and standard errors for all soil properties).	168
16.	Soil properties for two soil layers at the Swede Cabin site after eight growing seasons following each of six site preparation treatments (including C:N and C:S ratios and standard errors for all soil properties).	169
17.	Soil properties for two soil layers at the Camp Nine site after eight growing seasons following each of six site preparation treatments (including C:N and C:S ratios and standard errors for all soil properties).	170

TABLE 15. Soil properties for two soil layers at the East Aspen site after eight growing seasons following each of six site preparation treatments.[1,2]

Soil layer and site preparation treatment	Total C	Total N	Extractable P	Total S	Bulk Density	C:N ratio	C:S ratio
Upper (0-10 cm)	...... percent		.... ppm		g/cm^3		
Control	4.38	0.220	16.3 AB	284.2	0.742 A	19.3	147.2 A
	(1.30)	(0.053)	(1.3)	(34.8)	(0.108)	(1.4)	(27.5)
Rip	3.05	0.165	22.0 A	287.0	0.817 AB	17.7	100.0 BC
	(0.30)	(0.007)	(3.3)	(1.7)	(0.047)	(0.4)	(5.9)
Chemical	2.88	0.145	15.7 B	239.3	0.847 AB	19.6	118.8 AB
	(0.12)	(0.007)	(0.3)	(26.0)	(0.047)	(0.7)	(9.4)
Disk	2.50	0.125	11.8 BC	222.2	0.918 BC	18.1	103.6 BC
	(0.89)	(0.019)	(0.5)	(8.8)	(0.145)	(3.7)	(30.6)
Chem/disk	1.75	0.108	12.3 BC	228.0	0.948 BC	15.6	72.7 C
	(0.32)	(0.014)	(4.0)	(27.0)	(0.019)	(0.3)	(2.1)
Brushblade	1.75	0.105	9.0 C	204.8	1.017 C	16.7	84.5 BC
	(0.01)	(0.007)	(1.0)	(14.8)	(0.017)	(1.2)	(6.4)
Lower (15-25 cm)							
Control	1.29 a	0.088 a	5.3 B	191.7 B	0.973	14.8	68.0 a
	(0.01)	(0)	(0)	(16.7)	(0.023)	(0.1)	(5.3)
Rip	0.93 bcd	0.080 a	7.8 A	228.5 A	0.968	11.5	42.6 bc
	(0.02)	(0.007)	(1.8)	(18.8)	(0.016)	(0.6)	(3.5)
Chemical	1.07 abc	0.078 a	6.2 AB	191.3 B	0.965	13.6	56.5 ab
	(0.09)	(0)	(0.5)	(28.3)	(0.028)	(0.3)	(3.8)
Disk	1.24 ab	0.083 a	8.0 A	191.5 B	0.975	14.4	63.9 a
	(0.17)	(0)	(0.3)	(11.2)	(0.012)	(2.6)	(14.9)
Chem/disk	0.78 cd	0.065 b	6.0 AB	175.5 B	1.033	11.9	44.3 bc
	(0.09)	(0)	(0)	(1.5)	(0)	(1.1)	(5.0)
Brushblade	0.68 d	0.065 b	4.7 B	177.7 B	1.022	10.3	38.2 c
	(0)	(0)	(0)	(12.0)	(0.007)	(1.0)	(3.2)

---

[1] Within soil layers, values in the same column which are followed by the same lower case letter are not statistically different at the 0.05 level of significance and those followed by the same upper case letter or no letter are not statistically different at the 0.10 level of significance by the protected LSD procedure.

[2] Numbers in parentheses are the standard errors.

TABLE 16. Soil properties for two soil layers at the Swede Cabin site after eight growing seasons following each of six site preparation treatments.[1,2]

Soil layer and site preparation treatment	Total C	Total N	Extractable P	Total S	Bulk Density	C:N ratio	C:S ratio
Upper (0-10 cm)	...... percent		.... ppm		g/cm^3		
Control	6.92	0.263	28.3	329.8	0.687	25.8 A	201.1 a
	(2.11)	(0.070)	(4.3)	(31.5)	(0.067)	(1.2)	(40.7)
Rip	3.20	0.147	30.8	235.8	0.928	21.2 BC	148.0 bc
	(0.49)	(0.020)	(8.2)	(82.2)	(0.038)	(0.8)	(29.1)
Chemical	2.85	0.127	20.2	205.5	0.803	22.2 ABC	142.6 bc
	(0.22)	(0)	(3.2)	(29.5)	(0.014)	(1.4)	(30.4)
Disk	1.91	0.102	19.7	187.8	0.968	17.8 C	99.2 c
	(0.40)	(0.014)	(1.0)	(46.8)	(0.062)	(0.9)	(6.1)
Chem/disk	6.10	0.253	27.7	354.5	0.732	23.9 AB	162.1 ab
	(2.79)	(0.100)	(1.3)	(100.5)	(0.035)	(2.4)	(34.4)
Brushblade	4.14	0.165	32.7	235.8	0.820	24.9 AB	187.8 ab
	(0.06)	(0.021)	(3.3)	(61.8)	(0.110)	(2.6)	(47.6)
Lower (15-25 cm)							
Control	1.88	0.100	15.8	175.7	0.938	16.0 AB	98.3
	(0.55)	(0.014)	(4.2)	(18.7)	(0.028)	(0.6)	(30.4)
Rip	1.14	0.082	16.7	183.2	1.078	13.6 BC	71.5
	(0.25)	(0.012)	(3.7)	(68.5)	(0)	(0.9)	(11.6)
Chemical	0.96	0.072	10.0	153.3	1.092	13.2 C	63.0
	(0.24)	(0.012)	(1.0)	(43.0)	(0.016)	(1.2)	(2.3)
Disk	0.84	0.063	15.2	160.0	1.062	12.7 C	52.8
	(0.24)	(0.014)	(4.2)	(39.3)	(0.098)	(1.0)	(2.4)
Chem/disk	1.77	0.098	15.2	186.3	1.075	16.9 A	89.8
	(0.53)	(0.019)	(6.2)	(42.3)	(0.168)	(1.9)	(6.1)
Brushblade	1.05	0.078	14.2	177.0	1.117	13.0 C	59.7
	(0.38)	(0.019)	(0.5)	(57.7)	(0.020)	(1.8)	(1.3)

---

[1] Within soil layers, values in the same column which are followed by the same lower case letter are not statistically different at the 0.05 level of significance and those followed by the same upper case letter or no letter are not statistically different at the 0.10 level of significance by the protected LSD procedure.

[2] Numbers in parentheses are the standard errors.

TABLE 17. Soil properties for two soil layers at the Camp Nine site after eight growing seasons following each of six site preparation treatments.[1]

Soil layer and site preparation treatment	Total C	Total N	Extractable P	Total S	Bulk Density	C:N ratio	C:S ratio
Upper (0-10 cm)	...... percent		.... ppm		g/cm^3		
Control	3.23	0.147	20.2	187.3	0.707	20.2	159.8
	(1.45)	(0.047)	(6.5)	(28.0)	(0.100)	(2.8)	(46.5)
Rip	4.17	0.183	21.5	271.7	0.615	22.3	150.1
	(0.83)	(0.023)	(0.5)	(31.0)	(0.019)	(1.6)	(13.9)
Chemical	2.68	0.110	14.2	159.5	0.702	23.7	164.4
	(0.06)	(0)	(1.2)	(7.8)	(0.038)	(0.1)	(4.5)
Disk	2.98	0.130	15.8	176.0	0.720	22.2	168.2
	(1.19)	(0.040)	(3.5)	(7.7)	(0.107)	(2.4)	(60.3)
Chem/disk	1.39	0.085	10.8	138.8	0.733	16.2	103.9
	(0.15)	(0)	(2.2)	(29.2)	(0.007)	(0.7)	(9.0)
Brushblade	1.65	0.085	9.8	157.0	0.847	18.8	110.5
	(0.46)	(0.016)	(0.5)	(39.0)	(0.026)	(1.5)	(0.2)
Lower (15-25 cm)							
Control	0.78	0.060	9.5	135.5	0.990	12.6	56.2
	(0)	(0)	(1.5)	(2.5)	(0.020)	(1.0)	(0.5)
Rip	0.78	0.063	9.2	136.5	0.973	12.4	63.0
	(0.05)	(0)	(0.2)	(21.5)	(0.020)	(0.8)	(16.1)
Chemical	0.96	0.070	8.5	142.0	0.928	13.6	73.0
	(0.11)	(0.007)	(0.2)	(22.7)	(0.007)	(0.1)	(10.3)
Disk	0.99	0.072	9.8	126.5	0.895	13.4	81.8
	(0.32)	(0.016)	(0.5)	(8.5)	(0.017)	(1.7)	(30.3)
Chem/disk	0.84	0.063	9.7	123.2	0.905	13.1	66.6
	(0.02)	(0)	(1.0)	(5.5)	(0.017)	(0.2)	(1.6)
Brushblade	0.72	0.060	7.5	131.8	0.963	11.9	59.7
	(0.17)	(0)	(0.5)	(18.8)	(0.077)	(2.3)	(2.4)

---

[1] Numbers in parentheses are the standard errors.

Appendix IV

Tables of woody and herbaceous vegetation characteristics by species and site preparation treatment for each of the three study site locations.

Table		Page
18.	Canopy cover (area) of woody non-conifer vegetation by species at the East Aspen site after eight growing seasons following each of six site preparation treatments.	173
19.	Canopy volume of woody non-conifer vegetation by species at the East Aspen site after eight growing seasons following each of six site preparation treatments.	174
20.	Total aboveground biomass (ovendry weight) of woody non-conifer vegetation by species at the East Aspen site after eight growing seasons following each of six site preparation treatments.	175
21.	Mean height of woody non-conifer vegetation by species at the East Aspen site after eight growing seasons following each of six site preparation treatments.	176
22.	Density of woody non-conifer vegetation by species at the East Aspen site after eight growing seasons following each of six site preparation treatments.	177
23.	Canopy cover (area) of herbaceous vegetation by species at the East Aspen site after eight growing seasons following each of six site preparation treatments.	178
24.	Canopy cover (area) of woody non-conifer vegetation by species at the Swede Cabin site after eight growing seasons following each of six site preparation treatments.	179
25.	Canopy volume of woody non-conifer vegetation by species at the Swede Cabin site after eight growing seasons following each of six site preparation treatments.	180

Table Page

26. Total aboveground biomass (ovendry weight) of woody non-conifer vegetation by species at the Swede Cabin site after eight growing seasons following each of six site preparation treatments. 181

27. Mean height of woody non-conifer vegetation by species at the Swede Cabin site after eight growing seasons following each of six site preparation treatments. 182

28. Density of woody non-conifer vegetation by species at the Swede Cabin site after eight growing seasons following each of six site preparation treatments. 183

29. Canopy cover (area) of herbaceous vegetation by species at the Swede Cabin site after eight growing seasons following each of six site preparation treatments. 184

30. Characteristics of woody non-conifer vegetation by species at the Camp Nine site after eight growing seasons following each of six site preparation treatments. 185

31. Canopy cover (area) of herbaceous vegetation by species at the Camp Nine site after eight growing seasons following each of six site preparation treatments. 186

TABLE 18. Canopy cover (area) of woody non-conifer vegetation by species at the East Aspen site after eight growing seasons following each of six site preparation treatments.

Plant species codes[1]	Treatments					
	Control	Rip	Disk	Brushblade	Chemical	Chemical/disk
	....	....	.... m^2/ha	....	....	....
AMELA	0	8.0	199.9	16.3	22.7	0
ARPA	228.2	44.8	172.6	360.1	102.0	904.0
BERE	71.2	31.6	0	9.9	0	0
CEVE	4340.4	986.4	892.3	431.5	1053.1	8.2
CHNA	0	9.2	0	0	0	1.4
HABL	0	0	0	178.5	0	0
PREM	63.4	351.7	64.4	27.7	48.7	106.2
PRSU	3.5	0	0	0	0	0
PUTR	1230.6	1228.5	248.0	104.6	137.9	171.3
RIBES	0	0	0	0	0	25.0
ROSA	6.0	44.7	93.7	134.0	1.4	0
SALIX	0	0	0	61.0	0	0
SYMPH	185.8	699.0	617.5	812.8	153.0	58.2
Total[2]	6129.1 a (602.0)	3403.9 b (518.5)	2288.4 bc (714.3)	2136.4 bc (333.2)	1518.8 c (100.0)	1274.3 c (497.2)

---

[1] Species codes follow Garrison et al. 1976. A list of codes and corresponding plant names is included in Appendix VI.

[2] For totals, values followed by the same letter are not statistically different at the 0.05 level of significance by the protected LSD procedure. Numbers in parentheses are the standard errors for the totals.

TABLE 19. Canopy volume[1] of woody non-conifer vegetation by species at the East Aspen site after eight growing seasons following each of six site preparation treatments.

Plant species codes[2]	Treatments					
	Control	Rip	Disk	Brushblade	Chemical	Chemical/disk
	.... m^3/ha					
AMELA	0	12.5	278.3	12.5	39.6	0
ARPA	187.1	20.3	129.7	248.1	70.4	407.5
BERE	32.4	14.7	0	6.9	0	0
CEVE	3799.4	914.4	928.1	437.0	899.7	3.8
CHNA	0	5.7	0	0	0	0.9
HABL	0	0	0	124.3	0	0
PREM	52.0	408.4	54.0	20.2	63.8	112.4
PRSU	1.9	0	0	0	0	0
PUTR	1497.0	1636.3	224.8	70.0	145.2	149.1
RIBES	0	0	0	0	0	20.8
ROSA	1.7	12.0	30.1	63.6	0.3	0
SALIX	0	0	0	110.3	0	0
SYMPH	53.0	234.5	230.5	247.6	58.2	18.6
Total[3]	5624.5 a (674.0)	3258.8 b (406.0)	1875.5 bc (739.4)	1340.5 c (317.8)	1277.2 c (120.4)	713.1 c (380.5)

---

[1] Canopy volume was computed as the volume of a cylinder for each species.

[2] Species codes follow Garrison et al. 1976. A list of codes and corresponding plant names is included in Appendix VI.

[3] For totals, values followed by the same letter are not statistically different at the 0.05 level of significance by the protected LSD procedure. Numbers in parentheses are the standard errors for the totals.

TABLE 20. Total aboveground biomass[1] (ovendry weight) of woody non-conifer vegetation by species at the East Aspen site after eight growing seasons following each of six site preparation treatments.

Plant species codes[2]	Treatments					
	Control	Rip	Disk	Brushblade	Chemical	Chemical/disk
	kg/ha					
AMELA[3]	0	5.4	158.8	5.0	19.1	0
ARPA	354.1	41.7	255.0	479.7	141.4	829.8
BERE	53.4	24.5	0	11.6	0	0
CEVE	4040.4	1015.6	1057.2	494.8	991.2	3.5
CHNA	0	7.0	0	0	0	1.0
HABL	0	0	0	203.6	0	0
PREM	20.8	196.8	18.9	8.2	30.6	53.6
PRSU[3]	0.7	0	0	0	0	0
PUTR	2187.6	2501.1	321.2	92.2	202.5	206.0
RIBES	0	0	0	0	0	27.2
ROSA	0.9	6.4	12.2	18.2	0.2	0
SALIX[3]	0	0	0	48.4	0	0
SYMPH	53.7	229.2	226.0	248.0	56.6	18.8
Total[4]	6711.6 a	4027.7 b	2049.3 bc	1609.7 c	1441.6 c	1139.9 c
	(840.4)	(334.0)	(1127.1)	(575.7)	(60.5)	(482.6)

---

[1] Aboveground biomass was determined using the regression equations in Appendix V.

[2] Species codes follow Garrison et al. 1976. A list of codes and corresponding plant names is included in Appendix VI.

[3] Due to the small number of plants that were found on the research plots, total aboveground biomass for these species was estimated using the equation developed for <u>Prunus emarginata</u>.

[4] For totals, values followed by the same letter are not statistically different at the 0.05 level of significance by the protected LSD procedure. Numbers in parentheses are the standard errors for the totals.

TABLE 21. Mean height of woody non-conifer vegetation by species at the East Aspen site after eight growing seasons following each of six site preparation treatments.

Plant species codes[1]	Treatments					
	Control	Rip	Disk	Brushblade	Chemical	Chemical/disk
	....	....	.... cm	....	....	....
AMELA	0	156.0	83.6	77.0	130.7	0
ARPA	67.4	32.8	39.0	39.1	38.8	37.2
BERE	41.7	49.7	0	56.0	0	0
CEVE	74.4	87.0	69.7	68.8	74.3	43.5
CHNA	0	62.0	0	0	0	64.0
HABL	0	0	0	59.2	0	0
PREM	59.2	71.9	63.1	74.0	92.5	63.1
PRSU	40.0	0	0	0	0	0
PUTR	98.7	87.1	63.5	50.2	53.8	50.9
RIBES	0	0	0	0	0	83.0
ROSA	26.4	26.2	32.8	44.6	20.5	0
SALIX	0	0	0	181.0	0	0
SYMPH	28.5	28.6	32.6	28.9	31.0	25.3
Overall means[2]	69.8 a (0.2)	48.5 bc (5.4)	42.2 c (7.0)	40.2 c (2.1)	55.1 b (7.0)	39.2 c (4.0)

---

[1] Species codes follow Garrison et al. 1976. A list of codes and corresponding plant names is included in Appendix VI.

[2] For overall means, values followed by the same letter are not statistically different at the 0.05 level of significance by the protected LSD procedure. Numbers in parentheses are the standard errors for the overall means.

TABLE 22. Density[1] of woody non-conifer vegetation by species at the East Aspen site after eight growing seasons following each of six site preparation treatments.

Plant species codes[2]	Treatments					
	Control	Rip	Disk	Brushblade	Chemical	Chemical/disk
	.... plants/ha					....
AMELA	0	42	333	42	208	0
ARPA	292	167	833	583	625	4706
BERE	458	292	0	42	0	0
CEVE	2416	458	541	250	583	125
CHNA	0	42	0	0	0	42
HABL	0	0	0	375	0	0
PREM	292	1083	208	42	42	583
PRSU	83	0	0	0	0	0
PUTR	1250	1125	583	292	333	625
RIBES	0	0	0	0	0	42
SALIX	0	0	0	42	0	0
Total[3]	4791 (1124.6)	3209 (791.4)	2498 (333.2)	1668 (208.2)	1791 (41.6)	6123 (1374.4)

---

[1] Density was not computed for *Rosa* spp. and *Symphoricarpos* spp., due to the difficulty of distinguishing individual plants.

[2] Species codes follow Garrison et al. 1976. A list of codes and corresponding plant names is included in Appendix VI.

[3] Numbers in parentheses are the standard errors for the totals.

TABLE 23. Canopy cover (area) of herbaceous vegetation by species at the East Aspen site after eight growing seasons following each of six site preparation treatments.

Plant species codes[1]	Treatments					
	Control	Rip	Disk	Brushblade	Chemical	Chemical/disk
	.... percent	....	....	....	....	....
ACMI	0.1	0.1	2.3	1.8	0	1.8
AMSIN	0	0.1	0.1	0	0	0
BERE[2]	3.0	0.1	0	0.9	0	0
BORAG*	0	0.1	0	0	0	0.1
CEPR	4.8	0	0	0	3.2	2.0
CIVU	0	0	0	0.1	0	0
COLLO	0.5	2.0	0.4	1.4	0.4	1.1
EPAN	2.9	0.1	1.7	2.0	0	0
EPILO	0.1	5.9	4.1	7.7	0.5	2.2
ERLA	2.3	4.8	5.3	7.0	0.9	1.2
ERUM	0	0.2	0	0	0	0
FEID	0	0	0.8	0.8	0	0
FRAGA	4.1	0	1.3	0.9	5.9	0.8
GRAMI*	6.6	25.7	20.9	13.6	19.2	19.2
LINUM	0	0.4	0	0.4	0.8	0
LUPIN	0	0.1	0	0	0	0.1
PHACE	0	0	0.2	0.1	0	0
SYAL	3.1	0	0	0	0	0
SYMPH[2]	0	0	0.1	1.9	2.8	0.8
Total[3]	27.5	39.6	37.2	38.6	33.7	29.3

---

[1] Species codes follow Garrison et al. 1976, except those followed by an asterisk. A list of codes and corresponding plant names is included in Appendix VI.

[2] The values for these species include only plants less than 15 cm in height. Data for plants greater than 15 cm in height are included in the tables for woody vegetation.

[3] Analysis of variance was performed with the arcsine squareroot transformation of percentages for the totals. Treatments were not statistically different at the 0.05 level of significance by the protected LSD procedure. Standard errors are not applicable to the untransformed values.

TABLE 24. Canopy cover (area) of woody non-conifer vegetation by species at the Swede Cabin site after eight growing seasons following each of six site preparation treatments.

Plant species codes[1]	Treatments					
	Brushblade	Rip	Control	Disk	Chemical	Chemical/disk
	.... m^2/ha	....				
ARPA	37.9	1.0	4.2	35.3	1.1	3.7
CEVE	0.3	1.3	0.7	0	1.0	0.2
CHNA	47.8	30.6	134.5	4.7	0.1	0.6
CHVI	0	0	2.7	0	0	0
PREM	0	0	0	0	0	30.2
RIBES	179.5	213.8	7.2	3.1	35.0	6.5
SYMPH	170.3	23.7	0.8	78.4	0	0
Total[2]	435.8 a	270.4 ab	150.1 b	121.5 b	37.2 b	41.2 b
	(62.6)	(5.3)	(110.2)	(65.3)	(33.4)	(23.1)

---

[1] Species codes follow Garrison et al. 1976. A list of codes and corresponding plant names is included in Appendix VI.

[2] For totals, values followed by the same letter are not statistically different at the 0.05 level of significance by the protected LSD procedure. Numbers in parentheses are the standard errors for the totals.

TABLE 25. Canopy volume[1] of woody non-conifer vegetation by species at the Swede Cabin site after eight growing seasons following each of six site preparation treatments.

Plant species codes[2]	Treatments					
	Brushblade	Rip	Control	Disk	Chemical	Chemical/disk
	.... m^3/ha	....				
ARPA	12.8	0.2	0.9	12.4	0.2	0.8
CEVE	0.1	0.4	0.1	0	0.2	0.02
CHNA	50.4	23.1	101.4	4.3	0.03	0.2
CHVI	0	0	1.4	0	0	0
PREM	0	0	0	0	0	27.6
RIBES	199.3	231.6	5.4	3.1	45.0	5.7
SYMPH	53.5	8.3	0.4	24.1	0	0
Total[3]	316.1 a	263.6 ab	109.6 bc	43.9 c	45.4 c	34.3 c
	(54.4)	(24.9)	(90.9)	(14.6)	(44.6)	(21.4)

---

[1] Canopy volume was computed as the volume of a cylinder for each species.

[2] Species codes follow Garrison et al. 1976. A list of codes and corresponding plant names is included in Appendix VI.

[3] For totals, values followed by the same letter are not statistically different at the 0.05 level of significance by the protected LSD procedure. Numbers in parentheses are the standard errors for the totals.

TABLE 26. Total aboveground biomass[1] (ovendry weight) of woody non-conifer vegetation by species at the Swede Cabin site after eight growing seasons following each of six site preparation treatments.

Plant species codes[2]	Treatments					
	Brushblade	Rip	Control	Disk	Chemical	Chemical/disk
	kg/ha					
ARPA	26.0	0.4	1.9	25.3	0.5	1.5
CEVE	0.05	0.4	0.05	0	0.2	0.02
CHNA	61.1	28.9	126.0	2.8	0.03	0.2
CHVI[3]	0	0	1.5	0	0	0
PREM	0	0	0	0	0	13.9
RIBES	255.4	294.8	7.5	3.7	58.1	8.4
SYMPH	53.5	8.2	0.3	23.5	0	0
Total[4]	396.0 a (75.6)	332.7 ab (37.6)	137.2 bc (113.6)	55.3 c (20.7)	58.8 c (57.6)	24.0 c (5.0)

---

[1] Aboveground biomass was determined using the regression equations in Appendix V.

[2] Species codes follow Garrison et al. 1976. A list of codes and corresponding plant names is included in Appendix VI.

[3] Due to the small number of plants that were found on the research plots, total aboveground biomass for this species was estimated using the equation developed for *Chrysothamnus naseosus*.

[4] For totals, values followed by the same letter are not statistically different at the 0.05 level of significance by the protected LSD procedure. Numbers in parentheses are the standard errors for the totals.

TABLE 27. Mean height of woody non-conifer vegetation by species at the Swede Cabin site after eight growing seasons following each of six site preparation treatments.

Plant species codes[1]	Treatments					
	Brushblade	Rip	Control	Disk	Chemical	Chemical/disk
	....	....	.... cm	....	....	....
ARPA	31.2	18.0	20.0	31.3	17.2	18.2
CEVE	21.0	34.0	10.0	0	20.0	12.0
CHNA	81.5	53.5	19.2	91.0	28.0	32.0
CHVI	0	0	51.0	0	0	0
PREM	0	0	0	0	0	31.3
RIBES	70.2	103.6	54.0	100.0	29.4	88.0
SYMPH	26.8	32.0	51.0	36.5	0	0
Overall means[2]	45.3	66.6	21.0	40.2	32.0	27.2
	(8.1)	(25.0)	(0.4)	(5.6)	(13.0)	(5.7)

---

[1] Species codes follow Garrison et al. 1976. A list of codes and corresponding plant names is included in Appendix VI.

[2] Numbers in parentheses are the standard errors for the overall means.

TABLE 28. Density[1] of woody non-conifer vegetation by species at the Swede Cabin site after eight growing seasons following each of six site preparation treatments.

Plant species codes[2]	Treatments					
	Brushblade	Rip	Control	Disk	Chemical	Chemical/disk
	plants/ha					
ARPA	306	56	83	195	83	278
CEVE	28	28	28	0	28	28
CHNA	83	28	1863	0	0	28
CHVI	0	0	28	0	0	0
PREM	0	0	0	0	0	417
RIBES	278	139	28	0	139	0
Total[3]	695	251	2030	195	250	751
	(27.8)	(27.8)	(556.0)	(27.8)	(27.8)	(528.2)

---

[1] Density was not computed for <u>Symphoricarpos</u> spp., due to the difficulty of distinguishing individual plants.

[2] Species codes follow Garrison et al. 1976. A list of codes and corresponding plant names is included in Appendix VI.

[3] Numbers in parentheses are the standard errors for the totals.

TABLE 29. Canopy cover (area) of herbaceous vegetation by species at the Swede Cabin site after eight growing seasons following each of six site preparation treatments.

Plant species codes[1]	Treatments					
	Brushblade	Rip	Control	Disk	Chemical	Chemical/disk
	.... percent					
ANTEN	0.8	0	0	0	0	0.2
ASTER	0.8	0.8	1.9	0	1.5	0
BERE[2]	3.2	1.6	2.9	0.1	0.6	1.4
CARYO*	0.1	0.6	0.4	0.5	0.6	0
CEPR	1.0	0.8	2.1	0.1	1.9	0.1
CIVU	4.1	5.1	2.1	3.1	4.1	6.4
COCA2	0.1	0	0	0	0	0
EPILO	2.1	1.8	1.1	0.1	0.1	4.1
ERNU	0	0	0	0	0.8	0
FEID	4.8	2.7	0.8	3.1	0	3.0
FRAGA	1.8	0.1	2.4	0.1	0	0.8
GRAMI*	23.8	32.2	34.7	24.1	17.3	19.0
PHACE	0	0.1	0	0	0	0
SIOR	0.1	0	0	0	0	0
SYMPH[2]	0.5	0	0	0.8	0.1	0
VETH	0.1	0.1	0	0.6	1.7	0.6
Total[3]	43.3	45.9	48.4	32.6	28.7	35.6

---

[1] Species codes follow Garrison et al. 1976, except those followed by an asterisk. A list of codes and corresponding plant names is included in Appendix VI.

[2] The values for these species include only plants less than 15 cm in height. Data for plants greater than 15 cm in height are included in the tables for woody vegetation.

[3] Analysis of variance was performed with the arcsine squareroot transformation of percentages for the totals. Treatments were not statistically different at the 0.05 level of significance by the protected LSD procedure. Standard errors are not applicable to the untransformed values.

TABLE 30. Characteristics[1] of woody non-conifer vegetation by species at the Camp Nine site after eight growing seasons following each of six site preparation treatments.

Plant characteristics and species codes[2]	Treatments					
	Control	Chemical	Rip	Brushblade	Disk	Chemical/disk
	.... m^2/ha					
Cover:						
CEVE	140.9	17.4	0	1.1	0	9.3
RIBES	0	0	14.8	0	0	0
	.... m^3/ha					
Canopy volume:						
CEVE	67.5	5.0	0	0.1	0	2.4
RIBES	0	0	5.6	0	0	0
	.... kg/ha					
Aboveground biomass:[3]						
CEVE	73.7	4.9	0	0.1	0	2.3
RIBES	0	0	8.7	0	0	0
	.... cm					
Mean height:						
CEVE	27.0	26.0	0	9.8	0	21.5
RIBES	0	0	38.0	0	0	0
	.... plants/ha					
Density:						
CEVE	167	167	0	250	0	167
RIBES	0	0	83	0	0	0

---

[1] A total of only 10 plants were sampled on both replications combined at this site. Therefore, no statistical analyses were performed on the data.

[2] Species codes follow Garrison et al. 1976. A list of codes and corresponding plant names is included in Appendix VI.

[3] Aboveground biomass was determined using the regression equations in Appendix V.

TABLE 31. Canopy cover (area) of herbaceous vegetation by species at the Camp Nine site after eight growing seasons following each of six site preparation treatments.

Plant species codes[1]	Treatments					
	Control	Chemical	Rip	Brushblade	Disk	Chemical/disk
	....	....	percent	....	....	....
AMSIN	0	0	0	0	0	0.1
ANTEN	1.9	0	0	0.1	0.1	0.1
BORAG*	0	0	0.2	0	0	0
CAREX	15.6	21.1	53.1	42.5	15.6	17.1
CARYO*	0	0.1	0	0.1	0	0
CIVU	0.8	0	0	0	0	0
EPAN	0.6	0	0.1	0	0.4	0
FRAGA	6.6	6.2	2.6	2.2	2.1	0.2
GRAMI*	39.3	29.6	31.5	35.8	44.6	43.4
LUPIN	0	1.9	0	0	0.2	0
PHACE	0	0.1	0	0.1	0.1	0.2
PHLOX	0.6	0.8	0.1	1.9	0.8	0.8
VETH	0.1	0	0	0	0	0
Total[2]	65.5	59.8	87.6	82.7	63.9	61.9

---

[1] Species codes follow Garrison et al. 1976, except those followed by an asterisk. A list of codes and corresponding plant names is included in Appendix VI.

[2] Analysis of variance was performed with the arcsine squareroot transformation of percentages for the totals. Treatments were not statistically different at the 0.05 level of significance by the protected LSD procedure. Standard errors are not applicable to the untransformed values.

Appendix V

Tables of biomass regression equation coefficients and statistics for non-conifer woody vegetation and conifers by species.

Table		Page
32.	Biomass regression equation coefficients and statistics for woody non-conifer vegetation by species.	188
33.	Biomass regression equation coefficients and statistics for conifers by species and site.	189

TABLE 32. Biomass regression equation coefficients[1] and statistics for woody non-conifer vegetation by species.

Species code[2]	X variable range	a	b	$s^2_{y.x}$	r^2	n
	cm^3					
ARPA	1,560 - 2,103,904	-6.1575	0.9789	0.036	0.994	10
BERE	1,152 - 362,496	-5.9299	0.9415	0.105	0.969	10
CEVE	21,924 - 3,588,480	-7.6750	1.0475	0.045	0.989	10
CHNA	1,170 - 1,787,520	-7.1034	1.0130	0.022	0.997	10
HABL	490 - 546,720	-6.8245	1.0152	0.033	0.994	10
PREM	11,760 - 6,551,454	-9.2957	1.1059	0.097	0.986	11
PUTR	8,208 - 4,348,610	-7.9366	1.0837	0.127	0.980	10
RIBES	616 - 2,307,888	-6.0076	0.9399	0.326	0.948	10
ROSA	1,001 - 136,500	-4.3939	0.6480	0.014	0.989	10
SYMPH	4,485 - 590,426	-6.6729	0.9619	0.047	0.977	12

Note: $s^2y.x$ = variance associated with an equation (MSE), r^2 = coefficient of determination, and n = sample size.

[1] All of the regression equations were of the form LN (Y) = a + b LN (X) where Y = total aboveground biomass in grams and X = canopy volume (length x width x height) in cubic centimeters.

[2] Species codes follow Garrison et al. 1976. A list of codes and corresponding plant names is included in Appendix VI.

TABLE 33. Biomass regression equation coefficients[1] and statistics for conifers by species and site.

Species code[2]	Site[3]	Y[4]	X variable range	a	b	$s^2_{y.x}$	r^2	n
			cm^3					
PIPO	EA	Total	30.0 - 17,255.4	0.5146	0.8268	0.013	0.994	22
PIPO	EA	Stem-only	30.0 - 17,255.4	-0.7754	0.8552	0.006	0.998	22
PIPO	SC	Total	83.2 - 33,405.8	-0.1696	0.9104	0.015	0.994	18
PIPO	SC	Stem-only	83.2 - 33,405.8	-1.3820	0.9323	0.010	0.996	18
PIPO	C9	Total	23.5 - 10,125.1	0.1115	0.8575	0.026	0.988	20
PIPO	C9	Stem-only	23.5 - 10,125.1	-1.3541	0.9067	0.012	0.995	20
PICO	SC	Total	74.5 - 19,518.8	-0.3258	0.9203	0.024	0.990	15
PICO	SC	Stem-only	74.5 - 19,518.8	-1.4862	0.9537	0.006	0.998	15

Note: $s^2_{y.x}$ = variance associated with an equation (MSE), r^2 = coefficient of determination, and n = sample size.

[1] All of the regression equations were of the form LN (Y) = a + b LN (X) where Y = biomass in grams and X = diameter (taken at 10% of total height) squared x height in cubic centimeters.

[2] Species codes follow Garrison et al. 1976. A list of codes and corresponding plant names is included in Appendix VI.

[3] Abbreviations for site are: EA = East Aspen, SC = Swede Cabin, and C9 = Camp Nine.

[4] Abbreviations for Y variables are: Total = Total aboveground biomass and Stem-only = Bole wood and bark biomass only (excludes branches and needles).

Appendix VI

Species codes[1] and corresponding scientific plant names.

Grasses and forbs:

ACMI	*Achillea millefolium* L.
AMSIN	*Amsinckia* spp. Lehm.
ANTEN	*Anternnaria* spp. Gaertn.
ASTER	*Aster* spp. L.
BORAG*	Boraginaceae
CAREX	*Carex* spp. L.
CARYO*	Caryophyllaceae
CIVU	*Cirsium vulgare* (Savi) Airy-Shaw
COLLO	*Collomia* spp.
COCA2	*Conyza canadensis* (L.) Cronq.
EPILO	*Epilobium* spp. L.
EPAN	*Epilobium angustifolium* L.
ERNU	*Eriogonum nudum* Dougl. ex Benth.
ERUM	*Eriogonum umbellatum* Torr.
ERLA	*Eriophyllum lanatum* (Pursh) Forbes
FEID	*Festuca idahoensis* Elmer
FRAGA	*Fragaria* spp. L.
GRAMI*	Graminaceae
LINUM	*Linum* spp. L.
LUPIN	*Lupinus* spp. L.
PHACE	*Phacelia* spp. Juss.
PHLOX	*Phlox* spp. L.
SIOR	*Sidalcea oregana* (Nutt.) Gray
SYAL	*Sisymbrium altissimum* L.
VETH	*Verbascum thapsus* L.

Shrubs:

AMELA	*Amelanchier* spp. Medik.
ARPA	*Arctostaphylos patula* Greene
BERE	*Berberis repens* Linol.
CEPR	*Ceanothus prostratus* Benth.
CEVE	*Ceanothus velutinus* Dougl. ex Hook.
CHNA	*Chrysothamnus naseosus* (Pall.) Brit.
CHVI	*Chrysothamnus viscidiflorus* (Hook.) Nutt.
HABL	*Haplopappus bloomeri* Gray
PREM	*Prunus emarginata* (Dougl.) Walpers
PRSU	*Prunus subcordata* Benth.
PUTR	*Purshia tridentata* (Pursh) DC.

---

[1] Species codes follow Garrison et al. 1976, except those followed by an asterisk.

RIBES .... *Ribes* spp. L.
ROSA .... *Rosa* spp. L.
SALIX .... *Salix* spp. L.
SYMPH .... *Symphoricarpos* spp. Duhamel.

Trees:

PICO .... *Pinus contorta* Dougl. ex Loud.
PIPO .... *Pinus ponderosa* Dougl. ex Laws.

Appendix VII

a. Tables of survival and growth of planted pines (including standard errors) by species/stock type and site preparation treatment for each of the three study site locations.

Table Page

34. Ponderosa pine survival and growth at the East Aspen site after eight growing seasons following each of six site preparation treatments (including crown width, crown area, bole biomass, and standard errors for all measures of tree growth). 193

35. Ponderosa pine survival and growth at the Swede Cabin site after eight growing seasons following each of six site preparation treatments (including crown width, crown area, bole biomass, and standard errors for all measures of tree growth). 194

36. Ponderosa pine survival and growth at the Camp Nine site after eight growing seasons following each of six site preparation treatments (including crown width, crown area, bole biomass, and standard errors for all measures of tree growth). 195

37. Lodgepole pine survival and growth at the Swede Cabin site after eight growing seasons following each of six site preparation treatments (including crown width, crown area, bole biomass, and standard errors for all measures of tree growth). 196

38. Ponderosa pine survival and growth by stock type at the East Aspen site after eight growing seasons (including crown width, crown area, bole biomass, and standard errors for all measures of tree growth). 197

39. Conifer survival and growth by species and stock type at the Swede Cabin site after eight growing seasons (including crown width, crown area, bole biomass, and standard errors for all measures of tree growth). 198

TABLE 34. Ponderosa pine survival and growth at the East Aspen site after eight growing seasons following each of six site preparation treatments.[1,2]

Site preparation treatment	Survival	Diameter[3]	Total height	Current annual height increment	Crown width	Crown area	Crown volume	Total aboveground biomass[4]		Bole biomass[4]	
								Bareroot	Plug	Bareroot	Plug
	percent	mm	cm	cm/yr	cm	m^2	m^3	kg			
Chem/disk	87 a	54.6 a (0.6)	178.8 a (3.8)	32.6 a (1.0)	130.9 a (3.0)	1.414 a (0.037)	0.908 a (0.016)	1.819 a	1.841 a	0.636 a	0.644 a
Chemical	78 a	50.5 a (2.3)	173.4 a (7.2)	33.4 a (2.0)	118.8 ab (3.4)	1.182 b (0.058)	0.762 a (0.061)	1.691 a	1.468 ab	0.590 a	0.510 ab
Disk	79 a	42.5 b (1.5)	144.4 b (4.5)	28.8 a (0.8)	106.5 b (3.9)	0.940 c (0.062)	0.499 b (0.040)	1.052 a	0.996 bc	0.362 a	0.341 bc
Brushblade	79 a	35.1 c (2.1)	113.8 c (8.9)	22.9 b (1.5)	88.2 c (3.9)	0.675 d (0.058)	0.302 c (0.044)	0.492 b	0.658 c	0.165 b	0.222 c
Rip	62 ab	24.9 d (2.0)	87.8 d (7.2)	20.1 bc (1.5)	59.6 d (5.1)	0.331 e (0.051)	0.125 d (0.026)	0.371 b	0.162 d	0.123 b	0.052 d
Control	30 b	16.2 e (1.5)	65.0 d (4.9)	15.3 c (0.9)	40.9 e (3.7)	0.166 e (0.025)	0.049 d (0.009)	0.118 c	0.060 e	0.038 c	0.019 e

---

[1] Within a column, values which are followed by the same letter are not statistically different at the 0.05 level of significance by the protected LSD procedure.

[2] Numbers in parentheses are the standard errors. Since the statistical analyses of the survival and biomass data were performed on transformed values, the appropriate standard errors are not applicable to the untransformed values presented in the table.

[3] Diameters were measured at 10 percent of the total height of each tree.

[4] Since the stock type by site preparation treatment interaction was significant ($P < 0.05$) for total aboveground biomass and bole biomass, the stock types were analyzed separately.

TABLE 35. Ponderosa pine survival and growth at the Swede Cabin site after eight growing seasons following each of six site preparation treatments.[1,2]

Site preparation treatment	Survival	Diameter[3]	Total height	Current annual height increment	Crown width	Crown area	Crown volume	Total aboveground biomass	Bole biomass
	percent	mm	cm	cm/yr	cm	m^2	m^3	.... kg	....
Chem/disk	83	64.7 a (2.9)	190.5 a (10.6)	37.1 (2.2)	127.8 (9.1)	1.363 (0.176)	0.925 (0.157)	2.779 a	1.004 a
Chemical	82	60.1 ab (3.4)	180.6 a (11.3)	34.5 (2.0)	117.4 (8.1)	1.170 (0.142)	0.775 (0.129)	2.134 ab	0.767 ab
Disk	82	60.8 ab (5.2)	182.5 a (18.1)	35.6 (2.8)	126.1 (11.8)	1.366 (0.228)	1.000 (0.242)	2.069 ab	0.742 ab
Brushblade	85	60.2 ab (5.1)	180.3 a (17.6)	33.5 (2.8)	120.5 (13.2)	1.239 (0.234)	0.839 (0.212)	2.229 ab	0.802 ab
Rip	59	48.9 bc (3.4)	138.6 b (11.5)	30.2 (1.5)	96.6 (8.3)	0.806 (0.134)	0.435 (0.113)	1.137 bc	0.402 bc
Control	58	42.7 c (3.7)	120.5 b (12.8)	25.8 (1.7)	89.8 (4.8)	0.709 (0.065)	0.340 (0.052)	0.731 c	0.256 c

---

[1] Within a column, values which are followed by the same letter or no letter are not statistically different at the 0.05 level of significance by the protected LSD procedure.

[2] Numbers in parentheses are the standard errors. Since the statistical analyses of the survival and biomass data were performed on transformed values, the appropriate standard errors are not applicable to the untransformed values presented in the table.

[3] Diameters were measured at 10 percent of the total height of each tree.

TABLE 36. Ponderosa pine survival and growth at the Camp Nine site after eight growing seasons following each of six site preparation treatments.[1,2]

Site preparation treatment	Survival	Diameter[3]	Total height	Current annual height increment	Crown width	Crown area	Crown volume	Total aboveground biomass	Bole biomass
	percent	mm	cm	cm/yr	cm	m^2	m^3	.... kg	
Chem/disk	56	44.9 a (0.2)	126.6 a (3.1)	23.2 a (0.4)	92.3 a (2.4)	0.709 a (0.025)	0.346 a (0.003)	0.832 a	0.281 a
Chemical	60	39.4 b (1.3)	113.6 b (5.4)	22.3 a (1.4)	78.8 ab (8.1)	0.525 b (0.098)	0.221 b (0.058)	0.592 b	0.196 b
Disk	58	36.1 c (1.3)	104.2 c (5.8)	20.0 b (1.2)	74.9 bc (4.1)	0.470 bc (0.054)	0.185 b (0.037)	0.476 c	0.156 c
Brushblade	64	34.6 c (1.8)	97.1 c (5.6)	18.3 bc (0.3)	69.9 bcd (7.5)	0.435 bcd (0.074)	0.168 bc (0.036)	0.394 c	0.127 c
Rip	58	28.3 d (0.1)	79.4 d (0.1)	16.1 c (0.4)	58.8 cd (0.1)	0.297 cd (0.001)	0.091 c (0.002)	0.239 d	0.075 d
Control	71	26.9 d (1.1)	77.2 d (3.2)	17.0 c (0.6)	55.8 d (0.7)	0.272 d (0.004)	0.077 c (0.002)	0.217 d	0.068 d

---

[1] Within a column, values which are followed by the same letter or no letter are not statistically different at the 0.05 level of significance by the protected LSD procedure.

[2] Numbers in parentheses are the standard errors. Since the statistical analyses of the survival and biomass data were performed on transformed values, the appropriate standard errors are not applicable to the untransformed values presented in the table.

[3] Diameters were measured at 10 percent of the total height of each tree.

TABLE 37. Lodgepole pine survival and growth at the Swede Cabin site after eight growing seasons following each of six site preparation treatments.[1,2]

Site preparation treatment	Survival	Diameter[3]	Total height	Current annual height increment	Crown width	Crown area	Crown volume	Total aboveground biomass	Bole biomass
	percent	mm	cm	cm/yr	cm	m^2	m^3	.... kg	
Chem/disk	85 a	55.0 (0.5)	216.7 (7.5)	47.0 (0.6)	132.2 (0.5)	1.433 (0.008)	1.136 (0.033)	2.148	0.900
Chemical	80 a	52.2 (1.2)	214.8 (5.2)	45.9 (1.5)	121.2 (4.4)	1.221 (0.101)	0.945 (0.127)	1.905	0.794
Disk	86 a	53.6 (2.9)	225.1 (9.5)	49.3 (1.2)	125.4 (10.5)	1.328 (0.209)	1.071 (0.225)	2.053	0.858
Brushblade	80 a	45.7 (9.6)	188.0 (38.4)	40.2 (7.7)	106.3 (20.1)	0.998 (0.344)	0.750 (0.352)	1.243	0.510
Rip	50 b	40.9 (1.4)	150.2 (4.4)	37.4 (5.9)	96.0 (9.0)	0.784 (0.133)	0.464 (0.104)	0.823	0.333
Control	45 b	34.3 (2.8)	125.8 (11.6)	30.4 (2.4)	82.8 (8.7)	0.596 (0.102)	0.297 (0.052)	0.491	0.195

---

[1] Within a column, values which are followed by the same letter or no letter are not statistically different at the 0.05 level of significance by the protected LSD procedure.

[2] Numbers in parentheses are the standard errors. Since the statistical analyses of the survival and biomass data were performed on transformed values, the appropriate standard errors are not applicable to the untransformed values presented in the table.

[3] Diameters were measured at 10 percent of the total height of each tree.

TABLE 38. Ponderosa pine survival and growth by stock type at the East Aspen site after eight growing seasons.[1,2]

Ponderosa pine stocktype	Survival	Diameter[3]	Total height	Current annual height increment	Crown width	Crown area	Crown volume	Total aboveground biomass	Bole biomass
	percent	mm	cm	cm/yr	cm	m^2	m^3	.... kg	
Bareroot	67	38.3 (4.0)	131.0 a (12.7)	25.8 (2.0)	91.6 (8.7)	0.782 (0.125)	0.443 (0.093)	0.642	0.217
Plug	71	36.3 (4.4)	123.4 b (13.5)	25.2 (2.2)	90.1 (10.8)	0.787 (0.147)	0.439 (0.101)	0.509	0.170

---

[1] Within a column, values which are followed by the same letter or no letter are not statistically different at the 0.05 level of significance by the protected LSD procedure.

[2] Numbers in parentheses are the standard errors. Since the statistical analyses of the survival and biomass data were performed on transformed values, the appropriate standard errors are not applicable to the untransformed values presented in the table.

[3] Diameters were measured at 10 percent of the total height of each tree.

TABLE 39. Conifer survival and growth by species and stock type at the Swede Cabin site after eight growing seasons.[1,2]

Species and stock type	Survival	Diameter[3]	Total height	Current annual height increment	Crown width	Crown area	Crown volume	Total aboveground biomass	Bole biomass
	percent	mm	cm	cm/yr	cm	m^2	m^3	.... kg	....
Ponderosa pine bareroot	80 a	61.7 a (2.5)	186.2 a (8.6)	35.2 b (1.4)	125.6 a (5.8)	1.327 a (0.113)	0.928 a (0.112)	2.385 a	0.859 a
Ponderosa pine plug	70 b	50.8 b (2.9)	144.8 b (8.9)	30.4 c (1.5)	100.4 c (5.1)	0.891 c (0.085)	0.510 c (0.071)	1.189 b	0.421 c
Lodgepole pine plug	71 b	46.9 c (2.6)	186.8 a (12.3)	41.7 a (2.3)	110.6 b (6.2)	1.060 b (0.105)	0.777 b (0.109)	1.270 b	0.522 b

---

[1] Within a column, values which are followed by the same letter are not statistically different at the 0.05 level of significance by the protected LSD procedure.

[2] Numbers in parentheses are standard errors. Since the statistical analyses of the survival and biomass data were performed on transformed values, the appropriate standard errors are not applicable to the untransformed values presented in the table.

[3] Diameters were measured at 10 percent of the total height of each tree.

b. Figures of current annual height increment by species and site preparation treatment for each of the three study site locations.

Figure Page

18. Current annual height increment of ponderosa pine trees planted at the East Aspen site following each of six site preparation treatments. 200

19. Current annual height increment of ponderosa pine trees planted at the Swede Cabin site following each of six site preparation treatments. 201

20. Current annual height increment of ponderosa pine trees planted at the Camp Nine site following each of six site preparation treatments. 202

21. Current annual height increment of lodgepole pine trees planted at the Swede Cabin site following each of six site preparation treatments. 203

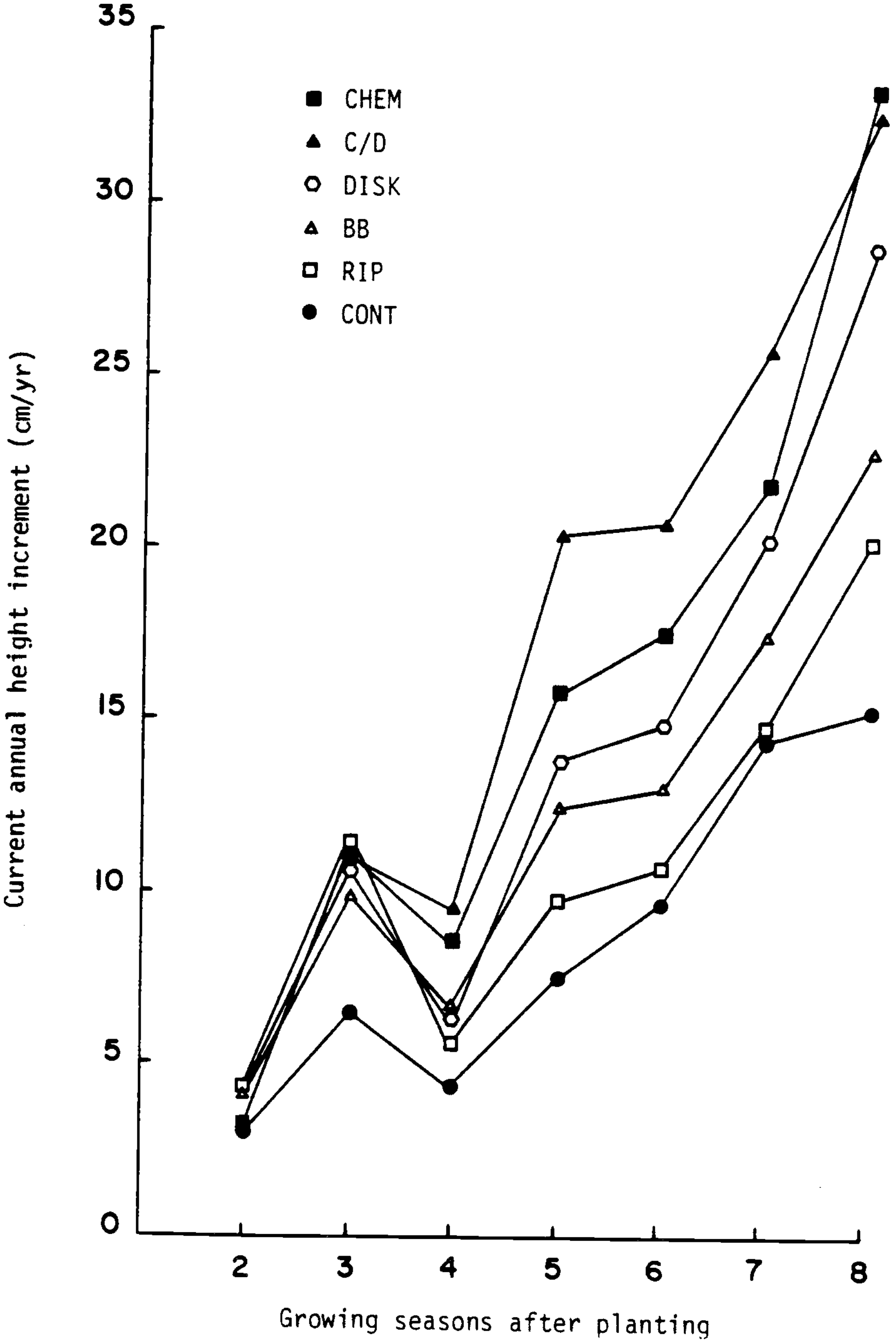


Figure 18. Current annual height increment of ponderosa pine trees planted at the East Aspen site following each of six site preparation treatments. CHEM = chemical-only; C/D = combination of chemical and disking; DISK = disking-only; BB = brushblading; RIP = ripping; CONT = control (no site preparation treatment).

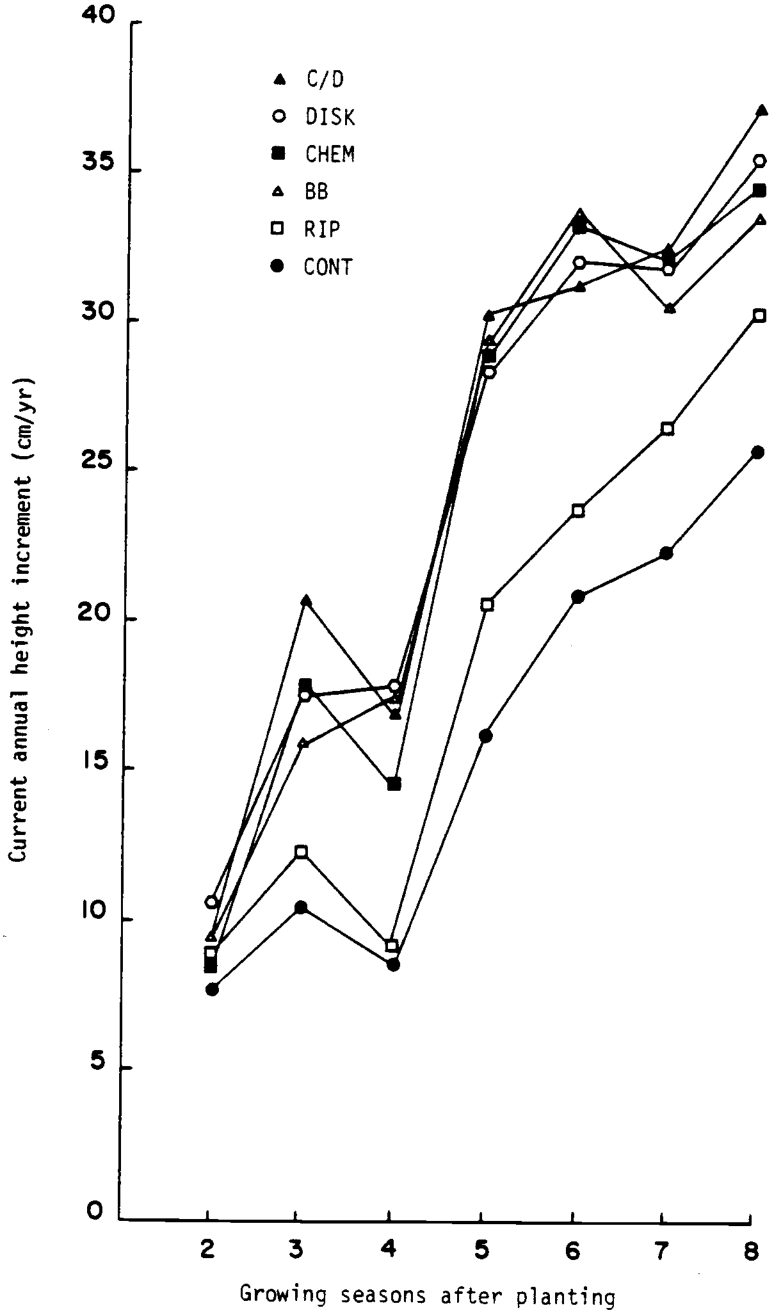


Figure 19. Current annual height increment of ponderosa pine trees planted at the Swede Cabin site following each of six site preparation treatments. C/D = combination of chemical and disking; DISK = disking-only; CHEM = chemical-only; BB = brushblading; RIP = ripping; CONT = control (no site preparation treatment).

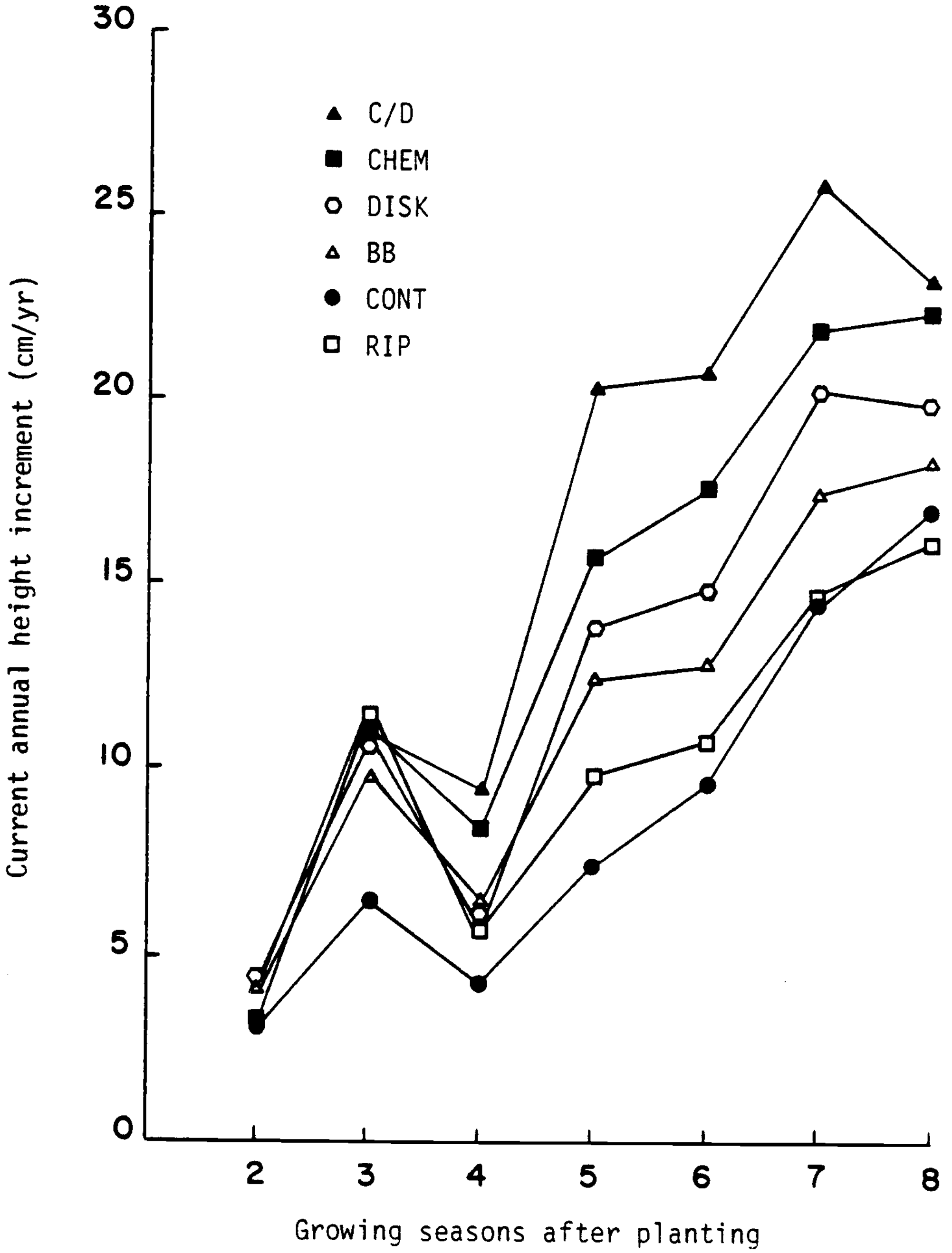


Figure 20. Current annual height increment of ponderosa pine trees planted at the Camp Nine site following each of six site preparation treatments. C/D = combination of chemical and disking; CHEM = chemical-only; DISK = disking-only; BB = brushblading; CONT = control (no site preparation treatment); RIP = ripping.

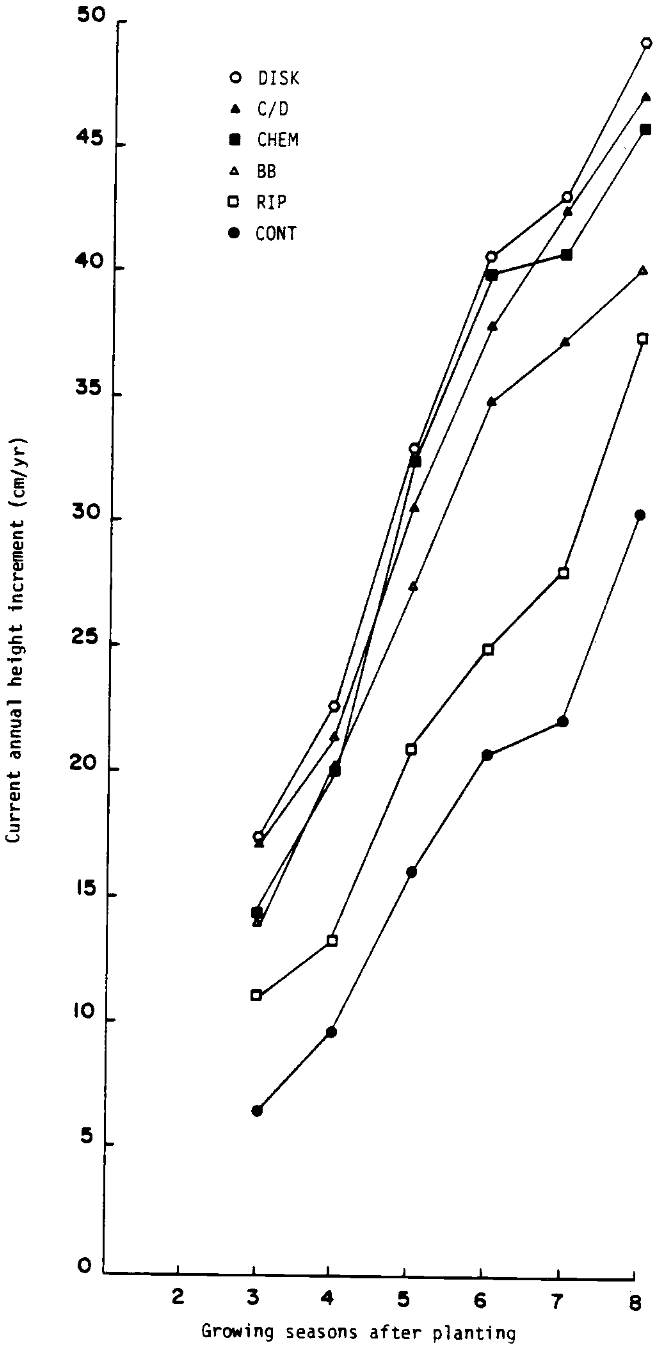


Figure 21. Current annual height increment of lodgepole pine trees planted at the Swede Cabin site following each of six site preparation treatments. DISK = disking-only; C/D = combination of chemical and disking; CHEM = chemical-only; BB = brushblading; RIP = ripping; CONT = control (no site preparation treatment).