AN ABSTRACT OF THE THESIS OF

Jerome Joseph Chetock for the degree of Master of Science

in Forest Management presented on August 13, 1976

Title: FIRST YEAR SURVIVAL AND GROWTH OF PLANTING STOCK

OF VARIOUS SIZE ON ADVERSE SITES

Abstract approved: <u>Signature redacted for privacy.</u>

Richard K. Hermann

First year survival of Douglas-fir seedlings outplanted in areas characterized by intense vegetative competition is heavily dependent on available soil moisture. To test this hypothesis, five distinct classes of Douglas-fir planting stock were planted on the south slope of McCulloch Peak in McDonald Forest in February of 1975. The stocking classes represented in this study are 2-2 transplants, 2-0 seedlings, one-year-old container-grown (plug) seedlings, 3-0 seedlings, and 2-1 transplants. Four treatments were applied in two replications: (1) a combination of irrigation and herbicidal control of competing vegetation; (2) irrigation; (3) herbicidal control of competing vegetation; and (4) no cultural treatment. The Scholander pressure bomb technique was used to determine the timing of the irrigation treatment. Whenever the average pre-dawn xylem pressure potential of the seedlings fell below -20 bars, irrigation was applied. The two replications corresponded to two distinct

vegetative communities: a brush-dominant community and a grass-dominant community. To eliminate the variable of wildlife pressure, every seedling was protected by a mesh animal exclosure. Seedling mortality was tallied at intervals throughout the summer, and leader elongation was measured in October of 1975.

The vegetation community in which a seedling was outplanted was of overriding importance to the seedling's potential for survival. Phenological development of the constituents of the vegetation community greatly influenced the availability of soil moisture so critical to seedling establishment. In turn, community structure determined the favorability, or lack thereof, of the microenvironment in which a seedling developed. In respect to both phenology and structure, the community dominated by grasses was more adverse to the introduction of Douglas-fir seedlings than was the community dominated by brush.

The importance of the type of vegetative cover was further underscored by the response to the various cultural treatments. In the brush-dominant community, irrigation, herbicides, and the combination of irrigation and herbicides proved equally effective as measures of site preparation. This was in contrast to the results in the grass-dominant community which showed that irrigation alone could not ensure acceptable seedling survival. Due to their inherent ability to disrupt the normal development of established vegetation, herbicides emerged as an especially effective means of ameliorating

adverse site conditions. In both communities, little additional benefit was realized by coupling irrigation to the herbicide treatment. As was expected, seedlings which received no cultural treatment performed poorly regardless of type of vegetative cover.

In regards to the performance of the various age-classes, the one-year-old container-grown seedlings showed a survival rate of nearly 90% in the grass community. Unable to match this performance, the 2-0, 2-1, 3-0, and 2-2 bare-rooted stock survived at the following rates: 45%, 44%, 36%, and 33%, respectively.

The container-grown seedlings were not, however, superior in the brush community. Both the 2-1 and 3-0 planting stock had higher survival, 76 and 71%, respectively, than the container-grown seedlings (70%) and the 2-2 transplants (68%). The 2-0 seedlings (56% survival) performed poorly in the brushy area; although they had the highest survival of the bare-rooted stock in the grass community.

Seedling morphological characteristics were meaningful to survival in the case of the 3-0 seedlings in the grass community and the container-grown seedlings in the brush community. In terms of height, diameter, and weight, the smaller 3-0 seedlings adapted to their new environment better than did larger 3-0 seedlings. For the container-grown seedlings, larger stem diameters were correlated with increasingly better survival.

As a check on the various seedlings' control of stomatal aperture, leaf water conductance was measured with a null balance diffusion porometer. Small seedlings tended to have higher rates of transpiration than large seedlings, but total transpirational loss under given environmental conditions was judged to be equivalent regardless of seedling size.

First Year Survival and Growth of Planting
Stock of Various Size on
Adverse Sites

by

Jerome Joseph Chetock

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Completed August 1976

Commencement June 1977

APPROVED:

_____

Professor of Forest Ecology
                in charge of major

_____

Head of Department of Forest Management

_____

Dean of Graduate School

Date thesis is presented ___ August 13, 1976 ___

Typed by Mary Jo Stratton for __ Jerome J. Chetock __

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FIRST YEAR SURVIVAL AND GROWTH OF PLANTING
STOCK OF VARIOUS SIZE ON ADVERSE SITES

I. INTRODUCTION

Close to 2.8 million acres of forest land have been planted in Oregon in the last two decades (U.S.D.A. Forest Service 1974). In spite of these efforts, a backlog of between one and two million acres of non-stocked and inadequately stocked forest lands exists in Oregon. Reclamation of many of these lands and prevention of excessive mortality in new plantations on severe sites is dependent upon planting stock of high quality suited for such sites.

Specific management goals in a regeneration program dictate the species desired in the new stand. Once the species has been chosen, however, its requirements become limiting factors in decision making. The wide diversity of conditions under which Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) grows makes a single prescription for regeneration impossible. Techniques must differ according to the locality and type of area to be regenerated, as, for example, recent timber harvests or established brushfields.

Even on a uniform site subtle differences exist, and numerous constraints to the successful establishment of seedling conifers operate simultaneously. This interaction of biotic factors in eco-systems must be evaluated and at least partially compensated for by site manipulation or by special adaptations of planting stock.

Unfortunately, uniform procedures for tests of planting stock do not exist. Development of methods which would permit objective evaluation of the performance of planting stock on a variety of sites would greatly facilitate recognition of unsuitable planting stock as well as institution of remedial measures. This study is intended as a step in that direction.

II. REVIEW OF THE LITERATURE

The relationship between seedling morphology and seedling adaptability to the plantation environment is complex and still poorly understood. In spite of this, morphological grades continue to be used widely as the principal criterion of seedling quality. Morphological grades held a special concern for Wakeley (1948) who described several studies intended to assess the accuracy of morphological grades. He concluded that the comparisons "showed unequivocally that morphological grades were not consistently dependable guides to the selection of good seedlings." An especially intriguing facet of the debate over morphological grades erupted in the southern pine region some years back when planters obtained better survival with free "culls" than was obtained by others who purchased "superior" stock (Wakeley 1948). Stone and Jenkinson (1971) have also reacted to the controversy over grading schemes:

> Grading of ponderosa pine nursery stock as now practiced has little, if any, bearing on whether the seedlings will survive in the field. Essentially it is a form of culling through which small or deformed seedlings and seedlings with large top-root ratios are discarded. Since the number of usable seedlings depends on sowing density, amount and speed of germination, cultural practices, and the grader's discretion, the number discarded varies from year to year and from nursery to nursery. Often seedlings morphologically graded as culls in one nursery may not be in another, and seedlings discarded one year may be utilized the next if slow germination, for example, results in smaller than average seedlings.

Nevertheless, the merits of morphological grades for characterizing quality of stock remain a point of contention to this day.

Seedling Size

Numerous studies have been undertaken to assess the survival and height growth of seedlings classified according to size of seedling at time of planting. Results of these experiments tend to fall into three categories, those indicating: (1) that large seedlings are best; (2) that small seedlings are best; (3) that size of seedlings at the time of planting is not of primary significance.

Lack of precise definition of seedling size may be responsible, in part, for the conflicting results of experiments with stock size. Criteria for size may include shoot length, root length, stem diameter, total plant weight, shoot/root ratio, or combinations of these. It must also be noted that size is relative; uniform standards for classifying large and small seedlings simply do not exist. The emphasis of this review of seedling size will be on reported relationships between seedling height, and/or stem diameter, and subsequent survival and height growth.

Large Planting Stock

A number of studies have conclusively stated that large seedlings survive outplanting better than small seedlings. The papers

referred to in Table 1 demonstrate such a superior survival potential

for large planting stock.

Table 1. Studies which have reported a positive relationship between seedling size and survival subsequent to planting.

Reference	Species
Clausin 1963	Betula pubescens, B. pendula
Ostrom and Ferrer 1942	Pinus resinosa
Meekins 1964	Pinus taeda, P. virginiana
Jaworsky 1958	Pseudotsuga menziesii
Clark 1966	Pseudotsuga menziesii
Illingworth and Clark 1966	Pinus ponderosa
Ruth 1956	Tsuga heterophylla
Knight 1967	Pseudotsuga menziesii
Ike 1962	Platanus occidentalis
Swearingen 1963	Pinus elliottii
Kummel et al. 1944	Pseudotsuga menziesii
Limstrom et al. 1955	Liriodendron tulipifera
Schubert and Adams 1971	Pinus ponderosa, P. jeffreyi
Adams 1964	Pinus ponderosa
Smith 1975	Pseudotsuga menziesii
Madison 1959	Picea sitchensis

In general, large seedlings demonstrated superior survival

potential on adverse sites characterized by strong plant competition,

rocky and stony ground, or exposed southern slopes. Mechanical

rigidity in withstanding the pressures of falling detritus and surface

soil movement also favors seedlings of larger stem diameter.

In some instances, high survival of large seedlings of

Douglas-fir (Clark 1966, Knight 1967, Hartwell 1969) and ponderosa

pine (Illingworth and Clark 1966) has been attributed to their low

vulnerability to animal damage. This low vulnerability can be explained by the fact that large seedlings tend to maintain a higher rate of absolute growth than small seedlings (Smith and Allen 1962, de Champs 1969, Richter 1971, Mullin and Svaton 1972). This relationship between seedling size and potential animal damage has also been examined by Newton and Black (1965) who observed that the frequency of browsing was inversely related to seedling height within the range of 30 to 101 cm. Similarly, Hines and Land (1973) reported that the frequency of deer browsing on planted Douglas-fir culminated at the 30-cm height class, decreasing rapidly with increasing size above that. Both Newton and Black (1965) and Hines and Land (1973) concluded that for all practical purposes, deer browsing ceased to be a major problem on seedlings over 60 cm tall.

With regards to height growth, a number of studies have clearly demonstrated the superiority of large seedlings over small seedlings. The references listed in Table 2 support such a height growth advantage for large planting stock. This height growth advantage of large planting stock is generally attributed to: (1) faster initial rate of growth, (2) a greater annual rate of growth, and thus, a competitive advantage on brushy areas, and (3) large seedlings are less affected by handling.

Table 2. Studies which have reported a positive relationship between seedling size and height growth subsequent to planting.

Reference	Species
Hough 1952	Pinus resinosa
Hetherington 1970	Pseudotsuga menziesii
U.S.F.S. 1960	Pseudotsuga menziesii
Brace 1964	Picea glauca
Fowells 1953	Pinus ponderosa, P. jeffreyi
Smith 1975	Pseudotsuga menziesii
Barber and van Haverbeke 1961	Southern pines
Clark and Phares 1961	Southern pines
McGee and Hatcher 1963	Southern pines
Shipman 1960	Southern pines
Zarger 1965	Southern pines

Recognizing that the critical period for survival is the first few years after planting, Smith and Allen (1962) recommended that anything that can be done to increase seedling rate of growth should be encouraged. In this regard, absolute increase in height is more important than percentage height growth, and large seedlings are thus superior to small seedlings.

Baker (1934) observed that under favorable planting conditions the importance of the shoot/root ratio decreased. The Washington State Department of Natural Resources has discarded the concept of balanced top/root ratio in an effort to overcome vegetative competition and animal damage. According to Nelson and Anderson (1966), some 2-3 Douglas-fir stock has had a top/root ratio of over 4 and survival and growth have been good.

Small Stock - Size Not of
Primary Significance

By no means have all studies of seedling survival and growth come out irrefutably in favor of large seedlings. The papers listed in Table 3 present data which indicate either that the size of planting stock had little or no effect upon subsequent seedling survival, or that smaller seedlings actually survived better than the larger planting stock.

Table 3. Studies which have reported that a positive relationship between seedling size and survival subsequent to planting does not exist.

Reference	Species
Rudolf 1950	Pinus resinosa
Hermann 1964	Pseudotsuga menziesii
Smith and Walters 1965	Pseudotsuga menziesii
Marquestaut et al. 1970	Pseudotsuga menziesii
Knight 1967	Pseudotsuga menziesii
Hunt and Gilmore 1967	Pinus taeda
Edwards and Holmes 1951	Picea sitchensis
Wakeley 1948	Pinus palustris
Walters and Kozak 1965	Pseudotsuga menziesii
Allen 1958	Pinus palustris
Bates 1934	Fraxinus spp.
Stoeckeler 1950	Pinus strobus
Korstian 1925	Pinus spp.

Seedlings must respond to a wide range of factors if survival is to be realized. Examples of equivalent or higher survival of relatively small plants might well have been a response to: (1) damage to

root systems during lifting and planting excessively large seedlings;
(2) greater drought tolerance of smaller seedlings, which generally
possessed a lower shoot/root ratio; and (3) suitability to machine-
planting operations.

Due to differences in experimental conditions and in size
criteria, interpretation of the literature concerning seedling size at
the time of planting and their subsequent performance is difficult.
A meaningful synthesis of the data from seedling studies is further
complicated by the interaction of seedling physiological condition and
environmental conditions on the planting site. Nevertheless, a few
relationships recur and should be noted:

1. Large seedlings should be utilized in areas characterized by
   strong plant competition and animal damage--particularly where
   soil moisture is not limiting.

2. Seedlings with well-developed root systems have a higher
   survival potential on droughty sites.

3. Morphological traits are not consistently reliable indicators
   of seedling quality.

Age-class

Morphological grading schemes are further complicated by
superimposing seedling age-class on the problem of seedling size.
Some researchers subscribe to the idea that survival of a particular

species is better correlated with age-class than size alone; although, of course, older seedlings are generally the larger. In noting the great variation in seedling quality which exists between different nurseries, and within a single nursery from one crop to the next, Limstrom (1960) felt that age could not be considered a reliable indicator of seedling quality. Others have formed similar opinions as a result of field experience with plantations designed to test the effect of age-class. For instance, Schopmeyer (1940) amassed survival data from 1, 150 plantations on 93, 878 acres in western Montana, northern Idaho, and northeastern Washington. The results showed that there were no significant differences in survival between age-classes of either ponderosa pine or western white pine. In a study to determine the class of Douglas-fir nursery stock most suitable for planting on potential brush sites, Illingworth (1966a) reported no detectable differences between age-classes after two growing seasons. Bean and Allen (1964) conducted tests which indicated that 1-0 seedlings at least three inches tall survived and grew as well as 2-0 seedlings. In measuring 1-0, 2-0, 1-1, and 2-1 stock 5 and 15 years after planting, Rudolf (1950) found no significant differences in height among the various age-classes.

Berntsen (1958) reported that 3-0 Douglas-fir seedlings had a higher potential for survival than 2-0 seedlings on a steep, south slope in the Oregon Coast Range, although height growth was similar

in the two-year period subsequent to planting. Berntsen attributed the higher survival potential of the 3-0 seedlings to their greater stiffness in withstanding surface soil movement. In a study comparing 2-0, 3-0, and 4-0 *Pinus resinosa* seedlings, Carmean (1971) found that in both first and second year survival, the 3-0 were best and 4-0 worst. Carmean's experiment emphasized the need for well-balanced planting stock as well as the control of competing vegetation.

Differences between transplants and seedlings as delineated by age-class have also come into question. Stoeckeler (1963b) found that first year survival of 2-1 red pine transplants was generally superior to that of 3-0 red pine seedlings. As demonstrated by Roy (1953), first and second year survival rates of ponderosa and Jeffrey pines were higher for transplants than for seedlings. After comparing 1-1 transplants with 1-0 and 2-0 seedlings, both Person (1937) and Sischo (1958) reported higher survival for the transplants. From studies conducted in the pine region of California, Show (1930) concluded that poor top to root balance of seedling stock rendered it unsuitable for field planting. Show recommended 1-1 transplants for favorable planting sites and 1-1-1 transplants for adverse sites.

Improved nursery practices, such as root-pruning, may have lessened the need for transplants. As reported by Stone et al. (1961) two tests of 2-0 and 3-0 root pruned Douglas-fir resulted in survival of over 90%.

Physiological Characteristics

With the widespread recognition of the inadequacies of the

morphological grades, a growing volume of research is devoted to

finding better criteria for the grading of nursery stock. In discuss-

ing the selection of planting stock, Smith (1962) stressed the

importance of physiological rather than morphological factors. He

stated:

> The initial survival of planted trees depends chiefly on the
> ability of their root system to re-establish contact with the
> soil promptly. This ability is primarily a function of the
> physiological condition of the plants; their size and other
> externally visible characteristics are actually important
> to survival only to whatever extent they reflect physiologi-
> cal conditions.

At times the physiological condition of nursery stock is apparent

from morphological characteristics, but often no evidence is visible.

Wakeley (1954) reported that the presence of winter buds indicated the

physiological condition of southern pines. However, Fowells and

Schubert (1953) conducted a field test of 1-1 ponderosa and Jeffrey

pines and found that differences in winter bud development had slight

effect on survival.

Carrying this one step further, the physiological condition of the

seedling is largely determined by the environment in which it is grown

and to which it is exposed after lifting; before and during the planting

operation. Following a study on the root-regenerating potential of

ponderosa pine, Stone et al. (1963) emphasized that the physiological condition of the seedling must be understood if a grading measure is to relate to survival. An earlier study by Stone (1955) had likewise suggested that there is some physiological condition associated with the ability of seedlings to produce roots, which he termed "root regeneration potential," and that this condition could not be associated with any specific external morphological feature. Root regeneration potential, also called root growth capacity, refers to the ability of a seedling to elongate present roots and/or initiate new roots in a new environment. Determination of root growth capacity has been thoroughly described in the literature (Stone et al. 1963, Stone and Jenkinson 1971).

Despite the inherent complications of nursery climate and cultural practices, a system for grading seedlings according to their capacity to grow roots represents a positive step in the effort to evaluate nursery stock before outplanting. As noted by Stone (1969), "grading seedlings according to root growth capacity will sophisticate quality control much as germination tests have for seed."

Container-grown Stock

Container-grown seedlings have become increasingly important in artificial regeneration. In 1974 the Pacific Northwest produced an estimated 42 million container-grown seedlings, nearly double the

quantity produced in the region the preceding year (Stein et al. 1975).

Artificial reforestation is experiencing an acceleration phase due to

more stringent state forest practice laws, new forestry incentive

programs, generally intensified management, and the uncertainty of

success with natural regeneration. Container-grown seedlings have

consequently been thrust into a favorable position largely because they

can be produced quickly in facilities that can be rapidly expanded. In

the Pacific Northwest, reforestation efforts with western hemlock and

the true firs have traditionally been hampered by the difficulties

encountered in producing bare-rooted stock of these species.

Experience has shown that raising these species in containers has by-

passed the problems experienced in the production of bare-rooted

stock. Another advantage commonly associated with the use of

container-grown seedlings is the extension of the planting season.

Greater flexibility in the production of seedlings is attained in the

greenhouse environment, making container-grown stock available for

planting when bare-rooted stock is not accessible or not properly

conditioned. Other advantages of containerized seedlings include:

more efficient use and control of genetically improved seed; produc-

tion of more uniform stock; better protection of seedlings; greater

opportunities for mechanization; and improved quality and speed of

planting (Stein et al. 1975). Perhaps the strongest attribute of

container-grown stock is greatly reduced disturbance of the root

system during handling and planting; thus, planting shock is minimized.

Field Results with Container-grown Stock

The survival of field-planted conifer stock has been a matter of

concern for some time in the northern Great Plains (George 1974).

Poor survival of bare-rooted stock intended for planting for windbreak

purposes led to the beginning of research in growing conifers in

containers as early as 1936. Although the containers employed

lacked the technical modifications common in today's containerized

programs, many trees started in such containers were planted in

permanent plantings which resulted in 100% survival. Efforts to

increase the survival of field-planted stock continued, and in 1954,

the North Dakota Farm Forestry Committee endorsed the use of

containerized stock as the surest method of establishing conifers in

the state.

Arnott (1974) reported the results from several studies which

compared the field performances of container-grown and bare-rooted

seedlings in British Columbia. In the coastal area of Brisith

Columbia, third year data showed that the survival of Douglas-fir

bullet-plugs compared favorably with that of bare-rooted seedlings in

two out of three years. Moreover, container-grown hemlock had

survival rates significantly superior to those of bare-rooted hemlock

seedlings. As to growth rates, the bare-rooted stock maintained its initial height advantage, especially in areas of heavy vegetative competition. Fifth year records from the same study indicated a correlation between the size of the container-grown seedling at planting and its subsequent field performance; large plugs showed consistently higher survival rates than small plugs.

Five years after planting in interior British Columbia, container-grown lodgepole pine and white spruce had survived better than 2-0 bare-rooted seedlings, whereas Douglas-fir container-grown and bare-rooted stock had comparable survival rates. Here again, the older and larger container-grown seedlings survived better than the younger and smaller container-grown stock, especially in the cases of white spruce and lodgepole pine (Van Eerden 1972, cited by Arnott 1974). As was found in the coastal plantings, survival of container-grown stock decreased when the seedlings were planted under progressively harsher growing conditions.

Reporting results from a number of comparisons involving five species on the Northern Plains, Hite (1974) showed that field survival after one and two growing seasons was consistently in favor of container-grown seedlings. In assessing incremental height differences, first year analysis indicated growth of the container stock ranging from slightly less than the bare-rooted seedlings to significantly greater. Also reporting on field trials conducted in the Rocky

Mountains of Montana and Idaho, Hite presented fourth and fifth year data which indicated that a significant increase in survival was attributable to the use of containerized stock. He concluded that container-grown stock may improve survival on the average by 20%.

Aycock (1974) reported that results from extensive plantings throughout the National Forests in the South show that all the southern pines can be used successfully in the containerized program. Extension of the planting season into June and July was cited as one of the biggest advantages of using container-grown southern pine seedlings. After conducting studies to investigate the possibilities of using containerized loblolly, slash, longleaf, and white pine stock to extend the planting season in North Carolina, Goodwin (1974) concluded that survival for summer-planted containerized stock was equal or better than for winter and spring planted bare-rooted stock. Longleaf pine appeared to be particularly well-adapted to the container-grown reforestation system. Goodwin further observed that height growth of container-grown stock would be equivalent to that of bare-rooted stock by the end of the second or third growing season.

In the extreme environment of the Southwest, Buchanan (1974) determined that container-grown seedlings were better suited to south and east aspects than were bare-rooted stock. In regards to the challenge presented by limited availability of soil water in the Southwest, Buchanan suggested that a containerized seedling operation

would provide greater flexibility (to take advantage of above normal winter precipitation, for instance) than is possible in a nursery stock operation.

Working with container-grown Jeffrey pine seedlings in the east-side Sierra Nevada mountains, Miller and Budy (1974) also determined that container-grown seedlings offer considerable potential for reforesting adverse sites.

Gutzwiler and Winjum (1974) summarized data obtained from nine different agencies on the outcome of trials with container-grown seedlings and bare-rooted stock in Oregon and Washington. The available growth data from these trials indicated that neither the container-grown seedlings nor the bare-rooted appeared to be consistently superior to the other. However, Gutzwiler and Winjum pointed out that the data used were from some of the earliest experiences with container seedling culture. They further suggested that today's container-grown seedlings are far superior, in size and vigor at the time of outplanting, to those which were produced in earlier years.

From several studies with white and black spruce in Ontario, Scarratt (1974) concluded that the spectrum of sites suitable for container planting is considerably narrower than that for bare-rooted stock. Emphasizing the importance of container-grown seedling age, and hence size, at planting, Scarratt determined that by increasing

seedling age at planting from 6 to 12 weeks, an average increase in gross survival amounting to 22% was achieved 4 years after planting. Age at outplanting was also shown to be highly correlated with growth performance after four growing seasons. Thus, despite early difficulties, container-grown seedlings are considered a biologically viable regeneration technique for use in Ontario; although it is seen as a supplement, not an alternative, to bare-rooted planting.

Early attempts to vegetate coal-mine spoils in Pennsylvania with container-grown seedlings met with little success due to the problem of frost-heaving (Davidson and Sowa 1974). Although the first growing season survival of spring-planted tubelings was comparable to that of bare-rooted red and scots pine seedlings, winter inspections showed that 84% of the tubelings had undergone some degree of frost-heaving.

Irrigation

Judging from the comparative scarcity of literature on the use of irrigation, little research has been done to evaluate its potential as a reforestation tool. Many of the reported studies view irrigation in terms of increased growth rather than establishment of plantations.

Noting that the loss of wood production in the South was largely attributable to the prevalence of soil moisture deficits, Manogaran (1973) developed a tree growth-climate model to estimate potential

growth under adequate soil moisture conditions, which irrigation could assure. The difference between actual growth and potential growth was taken as the benefit of irrigation. Converted to a dollar value, this additional growth was then compared with the cost of irrigation to test the economic feasibility of irrigating the forest regions of the South. In all areas from Florida to Texas, the model predicted additional growth from the use of irrigation, yet the costs were consistently in excess of the monetary benefits. The discrepancy between costs and benefits was less in areas where the price of timber was highest, suggesting that technological changes or increased wood prices may justify forest irrigation in the near future. Manogaran further surmised that trees planted this year may sell at a price 30 to 50 years hence that would justify their irrigation.

Recognizing the need to maximize wood production from a steadily decreasing forested acreage, Brewer and Linnartz (1971) conducted investigations into intensive cultural practices of loblolly pine in southeast Louisiana. One of these practices included irrigation whenever soil moisture dropped to 40% of field capacity. Conclusions from the 8-year study suggest that although irrigation produced only small gains in growth, its effect would be more pronounced during drought years, on soils with poor moisture-holding capacities, and in areas with less favorable rainfall during the growing season.

Many conifers of the temperate zone complete their height growth by early summer and begin to set buds in midsummer when drought is common. Working with red pine, Clements (1971) showed that irrigation, as opposed to drought, during the period of bud growth resulted in greater height growth the following year.

Schultz (1969) reported the 9-year results from a study designed to determine the effects of intensive cultural treatments on slash pine clonal stock. Irrigation was provided by a deep well and sprinkler system; at least 2 inches of total water (rainfall plus irrigation) was provided weekly from March through November, and at least one inch was provided weekly the other months of the year. Although irrigation increased cubic volume growth by 10% over non-irrigated plots, Schultz felt that the cost of establishing and maintaining the irrigation system rendered irrigation impractical for slash pine plantations. An interesting sidelight of the study was that much of the growth increase attributable to irrigation was evidenced in the branches rather than in the bole. Schultz suggested that with closer spacing (20 feet by 20 feet was used in this study) irrigation would increase bole growth even more than the observed 10%.

Baker (1973) conducted an investigation to determine the relative importance of nutrients, soil moisture, and competing vegetation on growth of slash pine on a Florida sandhill soil. Accordingly, fertilization, irrigation, and weed control were applied singly and in

factorial combination. Under the irrigation treatment, plots received at least 2.5 cm of water each week of the growing season (April through October) either in the form of rainfall or as irrigation water from a sprinkler. During the remainder of each of the 5 years of the study, these plots received at least 2.5 cm of water every other week. All cultural treatments, either singly or combined, resulted in significant increases in tree height, dbh, and volume growth. Of the three treatments, irrigation had the greatest influence on growth of the first flush, suggesting that deficient soil moisture in the fall and early spring was the major factor limiting first flush growth. In contrast, late season growth (second and third flushes) was generally influenced most by fertilization. Both weed control and irrigation increased available moisture in the soil, but irrigation had more effect. Whereas weed control reduced the period of moisture stress by 12%, irrigation reduced the stress period by 50%. Baker further commented that if irrigation had been applied on a plant-need basis rather than on an arbitrary weekly schedule, soil moisture stress could have been virtually eliminated.

In seeking to explain the highly variable stem growth response of Douglas-fir to nitrogen fertilization, Brix (1972) recognized the interaction of soil-water and nutrient status. Irrigation at a rate of one inch of water per week from June 4 until the end of August was effective in keeping the total soil-water potential above that of the

control; consequently, irrigation increased breast-height diameter growth by 15 and 12% in 1970 and 1971, respectively. Brix also noted that:

> Irrigation increased earlywood production by prolonging the period of its growth, and in 1970, by also increasing the rate of growth in July. The amount of latewood was not affected; the shorter period of production was offset by a higher growth rate.

Herbicides

Herbicides are valuable tools for plantation establishment through control of competing vegetation (Newton 1967, 1972) and are widely used. Herbaceous cover imposes limits primarily on the availability of moisture to planted seedlings (Newton 1964). Seedlings planted in a grass community need to be exceptionally hardy, or to be able to develop extensive root systems before moisture becomes severely limiting. The available evidence would suggest that few species and few seedling types are capable of evading drought at a rate consistent with the needs of typical Pacific Northwest grass-dominant communities.

III. METHODS

Site Description

Located on the south slope of McCulloch Peak in McDonald Forest (NW 1/4 Sec. 7, T11S, R 5W, W.M.), the study area can be characterized as an adverse site for reforestation. The forest cover of this site was clearcut in 1946, but the required slash burning was delayed until the fall of 1949. Between the time of logging and the time of the broadcast burn, natural seeding apparently provided successful conifer regeneration within the area. This was over-looked, however, and the slash burn subsequently destroyed most of the young conifer seedlings. Grasses, annual and perennial, and various brush species invaded the fresh burn and have persisted to the present day as a comparatively stable vegetative community. A few conifers and hardwoods dot the area, yet from a forest management perspective, the area is understocked and has been described as a signboard of poor forestry practice.

On February 11, 1975 two study areas were established on this south slope. The first of these, the upper area, is at an elevation of 1900 feet and has a slope of approximately 40%. Although a number of plant species occur on the site, the vegetative community is dominated by thimbleberry, bracken fern, and grass. Lower on the hill, the second area is at an elevation of 1500 feet with an

approximate slope of 30%. Several species of grass dominate over much of this area, but a variety of herbaceous plants and a handful of brush species are also established on the site. Soils on both areas are of the Ritner-Price complex, characteristically shallow and cobbly, although depth does increase and rock content decrease at the lower slope positions. Despite an annual average precipitation approximating 50 inches, these sites are dry and hot during much of the growing season and represent difficult sites for reforestation.

Experimental Design

In each of the two areas (hereafter referred to as the upper area and the lower area), four plots, each comprising 2000 square feet of area, were delineated. Each individual plot was divided into 20 clusters, the centers of which were 10 feet apart; the diameter of the individual cluster was approximately 5 feet (Figures 1 and 2). When the design was completed, each of these clusters contained five distinct age-classes of Douglas-fir seedlings, randomly planted within the cluster. Thus, each age-class was represented by 160 seedlings, each treatment was applied to 200 seedlings, and the total study involved 800 seedlings.

The five age-classes chosen for the study were 2-2, 2-0, 3-0, 2-1, and a container-grown (plug) seedling of one season's growth. Bare-rooted seedlings were lifted from nursery beds during the

Pressure

bomb

N

3

2

1

4
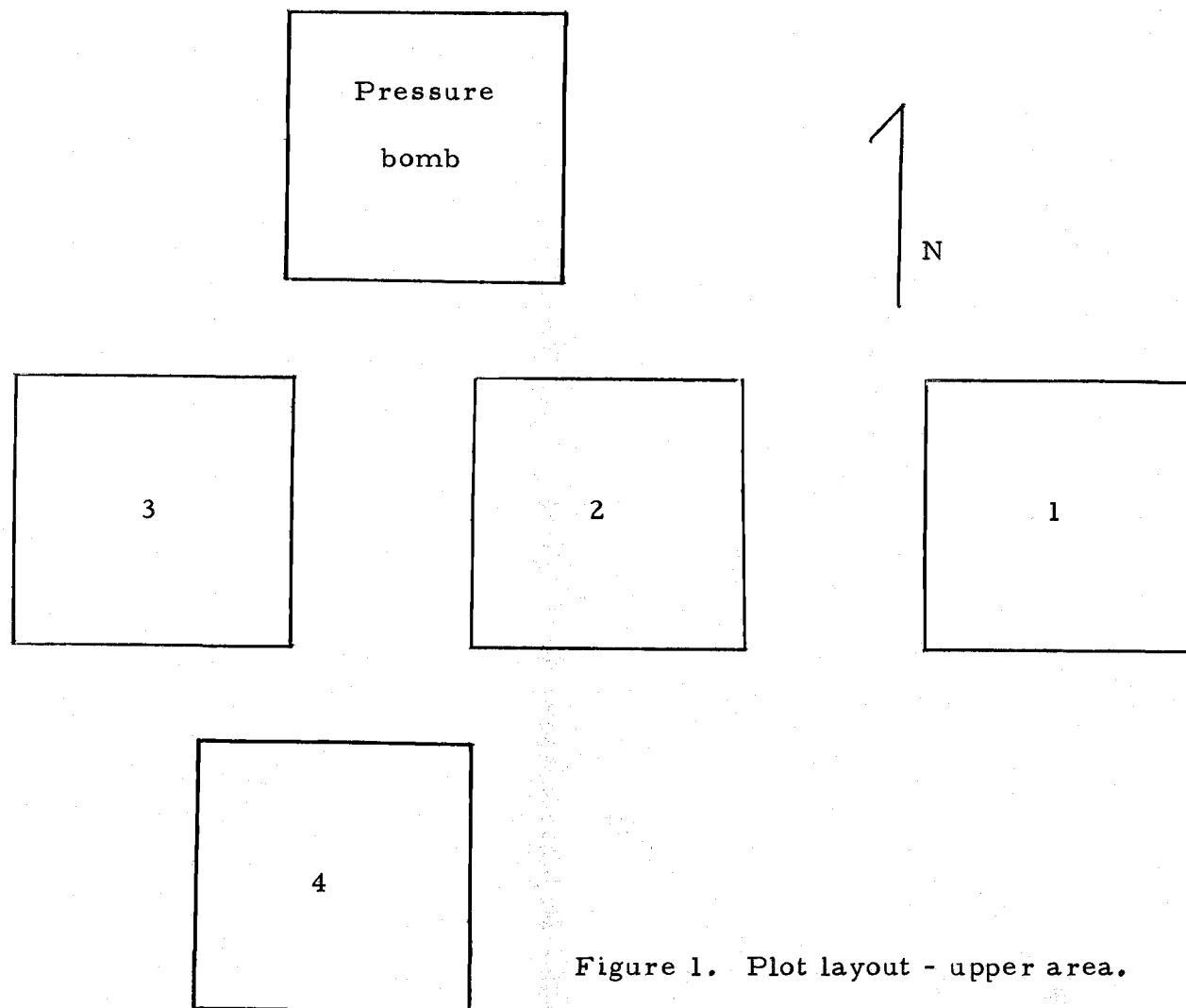
Figure 1. Plot layout - upper area.
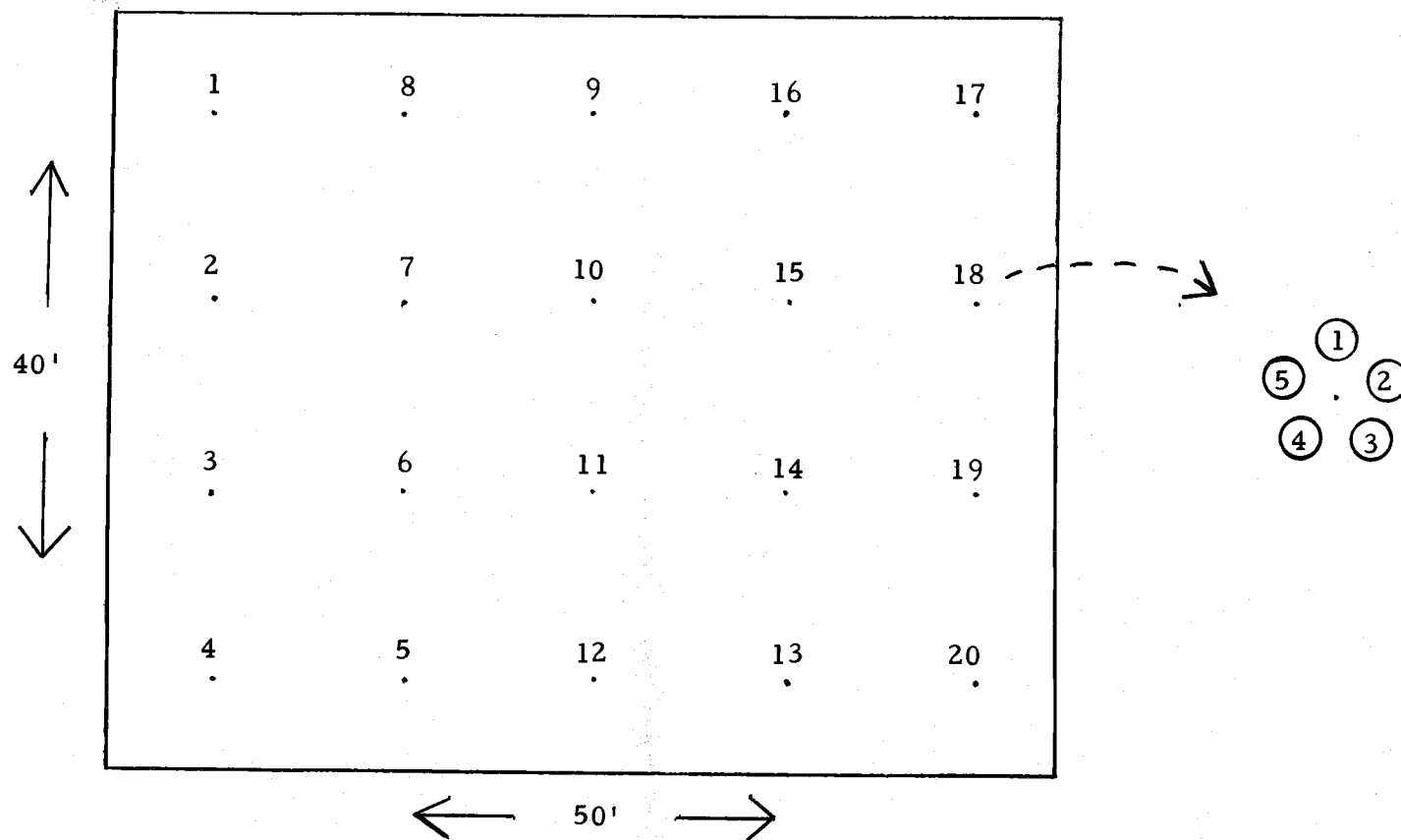
Figure 2. Cluster distribution within a plot and planting positions within a cluster.

month of February and placed in cold, dark storage (Table 4). These

seedlings were subsequently measured for crown length, diameter at

cotyledon scar, and fresh weight. The container-grown seedlings

were obtained in "pocketbook" containers and were also placed in

cold, dark storage. These seedlings were later measured for crown

length and diameter at cotyledon scar. Planting was carried out from

February 18 until March 11, 1975.

Table 4. Seedling lifting dates and storage lengths.

Stock	Date of lifting	Length of storage (days)
2-2	Feb. 11	7-11
2-0	Feb. 18	7
plug	Feb. 18 (stored)	14
3-0	Feb. 21	11-15
2-1	late Feb.	14

The seed sources for the bare-rooted seedlings were:

Age-class	Seed zone
2-2	061
2-0	262
3-0	262
2-1	252

The container-grown seedlings were "rejects" from the Woods

Nursery and records as to provenance were unavailable.

Treatments

A Vexar animal-exclosure was placed around each seedling in

an effort to eliminate wildlife damage as a variable from the study.

As indicated in the description of experimental design, the two areas of the study were partitioned into four plots each. These plots correspond to the treatments here indicated:

Plot 1: Irrigation plus herbicide treatment
Plot 2: Irrigation
Plot 3: Herbicide treatment
Plot 4: Control

In addition to the four plots which were established on each of the two study areas, a destructive-sampling plot similar in design to the study plots was established on each of the areas. These sample plots were provided for the purpose of measuring seedling moisture stress by means of the Scholander pressure bomb. One-half of each destructive-sampling plot was irrigated, and the other half was left as a control.

The Irrigation Treatment

During the month of April, irrigation cans were set out next to each seedling on plots 1 and 2 of both the upper and lower areas. In addition, irrigation cans were placed beside one-half of the seedlings on each destructive-sampling plot. These cans (no. 10) had a volume of approximately one gallon and featured a 9 cm tube which extended from the bottom of the can down into the rooting zone of the seedling.

Measurements of seedling xylem pressure potential were taken before dawn, on both of the sample plots, on the following days:

June 11	Aug. 14
July 9	Aug. 27
July 19	Sept. 9
July 31	Sept. 18
Aug. 8	Oct. 1

Sampling for seedling xylem pressure potential was done at irregular intervals. Prevailing weather conditions were taken into account, and sampling under environmental conditions conducive to favorable plant moisture relationships was avoided.

The actual procedure followed was to visit the sample plots before dawn, select two sample trees (one irrigated, one non-irrigated) from each of the bare-rooted age-classes, and to determine xylem pressure potential through the use of the pressure bomb apparatus. The container-grown seedlings could not be used for sampling during the initial part of the summer due to their small stature and fragile, succulent laterals. Attempts were made to sample only those seedlings which appeared healthy, and to avoid the repeated use of sample trees. As the summer progressed, an adequate and representative sample size was increasingly difficult to obtain.

Irrigation was applied when the pressure bomb sampling procedure indicated that the xylem pressure potential of the seedlings was beginning to fall below -20 bars. Watering schedules were thus

variable; the following dates are those on which irrigation was

applied:

June 13	Aug. 4
July 11	Aug. 14
July 23	Sept. 11
	Oct. 2

The Herbicide Treatment

The initial application of herbicides was effected on March 12,

1975. The treatment consisted of applying a mixture of atrazine

(5 lb/acre, 4 lb active liquid) and 2, 4-D (1 lb/acre). Plots 1 and 3 of

both the upper and the lower area received the same initial herbicide

treatment.

In an effort to fully realize the benefits of vegetation manage-

ment, a follow-up application of herbicides was employed on July 2,

1975. Since the Douglas-fir seedlings were in a susceptible period

of their growth cycle, it was necessary to cover the seedlings with

plastic bags during the spraying operation. On the upper area where

brush competition was the predominant stress a 50-50 mixture of

2, 4-D and 2, 4, 5-T (1:100 in water; 5.5 lb/acre) was applied to plots

1 and 3. For the lower area on which grass was the major competi-

tor, cacodylic acid (1:100 in water; 5.5 lb/acre) was applied on plots

1 and 3.

Seedling Performance

Monitoring of seedling performance began on May 16, 1975 with

an inventory of seedling condition employing the following criteria:

bud swell, bud burst, borderline,[1] or mortality. A second evalua-

tion, undertaken on July 2, 1975, employed the criteria of: flush,

borderline, and mortality. On July 31, 1975, the third appraisal of

seedling performance described the condition of the seedlings as buds-

set, second flush, borderline, or mortality. A similar inventory,

the fourth of the season, was carried out on August 30, 1975 and

classified seedling condition as to buds-set, borderline, or

mortality. The fifth and final look at seedling performance for the

season was taken on October 24, 1975. Buds-set, borderline, and

mortality were again used to categorize seedling physiological con-

dition; in addition, measurements were taken on total leader elonga-

tion and extent of second flushing.

Soils Analysis

During the month of August, soil samples were collected with

the intent of analyzing for differences between the two areas of the

study, or between plots within an area. Two random samples were

---

[1]The borderline classification was applied to seedlings which
appeared dead externally, yet showed living stem tissue when
scraped with a knife blade.

taken from the A horizon on each plot; these were later combined by plot, sifted through screens, and submitted to the Soil Testing Laboratory at Oregon State University for analysis. Analysis of these soil samples included: soil reaction, phosphorus, potassium, calcium, magnesium, total nitrogen, cation exchange capacity, and percent organic matter.

Leaf Water Conductance

On September 18, 1975 xylem pressure potential was sampled by means of the pressure bomb apparatus beginning at the following times throughout the day: 0400, 0800, 1200, and 1530 hours. On both the upper and lower areas, one seedling from each of the five age-classes on each of the four plots (treatments) was sampled for xylem pressure potential. At the latter three sampling intervals, one cluster of the five age-classes on each plot was sampled concurrently for leaf water conductance. This was accomplished by using a null balance diffusion porometer (Beardsell et al. 1972) according to the field procedures of Running (1976). At each of the sampling inter-vals, the same seedlings were checked for leaf water conductance, but different seedlings were measured for xylem pressure potential. Other measurements taken at each sampling interval were air temperature and dew point; vapor pressure deficit, absolute humidity, and absolute humidity deficit were later calculated from these meas-urements.

The intent of these observations was to determine if there were any noticeable differences in rate of transpiration due to stomatal control among the various age-classes of seedlings. Assuming the absolute humidity deficit was constant for all age-classes at a particular time of day, the measured leaf water conductance estimated a seedling's rate of transpiration according to the following relationship:

$$Ts = (ABSHD) (LC)$$

where:

Ts = transpiration

ABSHD = absolute humidity deficit

LC = leaf water conductance

In order to relate leaf water conductance as measured by the porometer to rate of transpiration, it was necessary to determine the amount of leaf surface area which had actually been sampled. This was accomplished by collecting the needles from those portions of the seedlings sampled with the porometer; leaf surface area was then calculated by means of an optical planimeter technique (Miller et al. 1956).

Statistical Analysis

The chi-square test was used in all situations involving a statistical analysis of seedling survival. Measured as a discrete variable, survival count took the form of a binomial distribution; this

distribution function lent itself to chi-square analysis (Snedecor and Cochran 1967). The basic null hypothesis employed was that all classes (e.g., seedling age-classes or treatments) had equal probabilities of survival. The use of 2 x C contingency tables permitted the classification of data by two different criteria: into two classes by one criterion and into C classes by a second criterion. For instance, the first criterion classified survival and mortality, while the second criterion consisted of the five seedling age-classes.

Total leader elongation for the first growing season was statistically evaluated by analysis of variance with two-way classifications. Leader elongation was analyzed with respect to replications, treatments, seedling age-class, and the interaction of age-class and treatment.

IV. RESULTS

Survival by Area

By October, 1975, seedling survival on the upper area (Block I) of the study was significantly better (p = .01) than that on the lower area.

Table 5. Survival by area.

	% Survival
Upper area	68.3
Lower area	49.3

To determine if this difference in survival was due to differential response to cultural treatments or to conditions on the untreated plots, the control plots of both areas were excluded from the analysis. A second test indicated that the upper area again showed significantly better (p = .01) seedling survival than did the lower area.

Table 6. Survival by area (control plots excluded).

	% Survival
Upper area	80.3
Lower area	57.7

Survival by Treatment

Upper Area

A preliminary test of the effect of treatment on seedling survival indicated that there was a significant relationship ($p = .01$) between survival and treatment on the upper area. To determine if this relationship represented a difference in the effectiveness of the three cultural treatments, or merely a difference between treated and untreated plots, further analysis was conducted. It became apparent that the cultural treatments all ensured similar rates of survival, and that the difference in survival by treatment was due to the poor survival of seedlings on the control plot ($p = .01$).

Table 7. Survival by treatment - upper area.

	% Survival
Irrigation & herbicides	75
Irrigation	86
Herbicides	80
Control	32

Lower Area

On the lower area, seedling survival again differed significantly ($p = .01$) by treatment. By excluding the control plot from the analysis and comparing the cultural treatments, a significant difference

(p = .01) in survival among the cultural treatments was verified. By determining that survival on the irrigation plus herbicide plot and the herbicide plot was equivalent (p = .05), the irrigation treatment was identified as the source of the survival difference. Seedlings which received only irrigation did not survive as well as seedlings which received the other cultural treatments. However, the irrigation treatment was effective in increasing survival over that of seedlings on the control plot (p = .05).

Table 8. Survival by treatment - lower area.

	% Survival
Irrigation and herbicides	74
Irrigation	37
Herbicides	62
Control	24

Survival by Age-class

Upper Area

For the sake of statistical analysis, the five age-classes of seedlings were separated into bare-rooted and container-grown and then compared. On the upper area, there was not a significant difference (p = .05) in survival between bare-rooted stock and container-grown seedlings. However, by excluding the container-grown

Table 9. Bare-rooted vs. container-
          grown - upper area.

	% Survival
Bare-rooted	67.8
Container-grown	70.0

seedlings from the analysis and comparing the bare-rooted stock, a

significant difference (p = .05) in survival among the four bare-rooted

age-classes was demonstrated. As shown in the following table, the

survival of 2-0 seedlings was considerably poorer than that of the

other bare-rooted stock types.

Table 10. Survival of bare-rooted stock -
           upper area.

Age-class	% Survival
2-2	67.5
2-0	56.3
3-0	71.3
2-1	76.3

Lower Area

On the lower area, the container-grown seedlings showed

significantly better (p = .01) survival than did the bare-rooted stock.

In contrast to the upper area, survival of the bare-rooted stock was

not significantly related (p = .05) to age-class.

Table 11. Bare-rooted vs. container-grown - lower area.

	% Survival
Bare-rooted	39.4
Container-grown	88.8

Table 12. Survival of bare-rooted stock - lower area.

Age-class	% Survival
2-2	32.5
2-0	45.0
3-0	36.3
2-1	43.8

Survival by Height Class

In an effort to assess the importance of initial seedling size on survival, each of the five age-classes was broken into arbitrary height classes. These classes were based on the initial crown length of the seedlings; due to size differences among age-classes, each age-class was evaluated separately. An attempt was made to secure equal frequencies within the various height class divisions, rather than to keep the intervals of equal size. A complete listing of the various height classes is contained in Appendix A.

On the upper area, none of the age-classes showed a difference in survival (p = .05) that was attributable to initial crown length.

The situation on the lower area was somewhat different. For the 3-0 seedlings, there was a significant difference (p = .05) in survival due to initial crown length. Within each of the remaining four age-classes on the lower area, there was not a significant difference (p = .01) in survival due to initial crown length.

Table 13. Survival of 3-0 seedlings by height class.

Initial crown length (cm)	Frequency	% Survival
14.3-21.3	14	64.3
21.4-24.8	12	58.3
24.9-28.3	9	22.2
28.4-31.8	10	40.0
31.9-35.3	13	30.8
35.4-42.4	13	15.4
42.5-67.0	9	11.1

Survival by Diameter Class

In a manner similar to that of the height class evaluation, each of the five age-classes was broken into arbitrary diameter classes. These classes were based on stem diameter at the cotyledon scar before outplanting; again, each of the age-classes was assessed separately. An attempt was made to secure equal frequencies within the various diameter classes, rather than to keep the

Table 14. Container-grown survival by diameter class.

Initial diameter (cm)	Frequency	% Survival
0.16-0.21	8	25.0
0.22-0.23	11	90.9
0.24-0.25	5	40.0
0.26-0.27	13	61.5
0.28-0.29	17	58.8
0.30-0.31	12	91.7
0.32-0.41	14	92.9

Table 15. Survival of 3-0 seedlings by diameter class.

Initial diameter (cm)	Frequency	% Survival
0.42-0.59	15	66.7
0.60-0.68	10	40.0
0.69-0.77	12	66.7
0.78-0.85	17	17.7
0.86-0.94	4	0
0.95-1.00	2	50.0
1.10-1.20	15	20.0
1.30-1.70	5	0

intervals of equal size. A complete listing of the diameter classes is included in Appendix B.

On the upper area, first year survival was significantly related ($p = .01$) to initial diameter only in the case of the container-grown seedlings. The other four age-classes did not exhibit such a relationship.

On the lower area of the study, survival due to initial diameter was significant ($p = .01$) only in the case of the 3-0 seedlings. Within the other four age-classes a difference in survival due to initial diameter could not be detected.

Survival by Weight Class

In a like manner to the height and diameter class analyses, four of the age-classes were broken into arbitrary weight classes. Initial fresh weight could not be obtained for the container-grown seedlings, hence they were not included in this segment of the analysis. Weight classes were based on the fresh weight of the seedlings prior to out-planting. The weight categories of each age-class were analyzed separately; frequencies within the weight classes were kept as equal as possible. A complete listing of the weight classes is included in Appendix C.

On the upper area, none of the age-classes showed a statistical relationship (p = .05) between initial fresh weight and survival.

On the lower area, survival of the 3-0 seedlings was significantly different (p = .01) among the initial fresh weight classes. The other three age-classes showed no relationship between weight and survival.

Table 16. Survival of 3-0 seedlings by weight class.

Initial fresh weight (g)	Frequency	% Survival
15.3-32.7	13	69.2
32.8-50.1	18	50.0
50.2-67.5	16	31.3
67.6-84.9	11	9.1
85.0-119.7	10	50.0
119.8-276.3	12	0

Survival by Early Budburst (Age-classes)

A chi-square analysis was run to determine if seedlings which had begun their seasonal shoot growth by May 16 survived better than seedlings which showed a later date of budburst. On both the upper and lower areas, 2-0 seedlings which had burst buds by May 16 showed significantly better (p = .01) survival than did 2-0 seedlings which burst buds later. Within the other four age-classes, first year

survival was not statistically related (p = .05) to budburst by May 16

(Appendix D).

Table 17. Early budburst and survival of 2-0
           seedlings.

Budburst	Frequency	% Survival
Upper area		
early	16	87.5
late	64	48.4
Lower area		
early	35	62.9
late	45	31.1

Survival by Early Budburst (Treatments)

To further assess the importance of early budburst on first

year survival, a chi-square analysis was run comparing the inter-

action on the four treatments of the study. On the control plot of the

upper area, seedlings which burst buds by May 16 survived signifi-

cantly better (p = .05) than did seedlings which showed later dates of

budburst. In terms of survival, early budburst on the other three

treatments of the upper area was not statistically different (p = .05)

from later budburst.

Table 18. Early budburst and survival on control -
upper area.

Budburst	Frequency	% Survival
Early	20	86.8
Late	80	65.6

In sharp contrast to the results on the upper area, early bud-
burst proved to be a distinct advantage on the lower area. On all
treatments, seedlings which burst buds by May 16 survived signifi-
cantly better (p = .05) than did seedlings which showed later budburst.

Table 19. Effect of date of budburst - lower area.

Treatment	Budburst	Frequency	% Survival
Irrigation & herbicides	early	24	100.0
	late	76	67.6
Irrigation	early	28	84.1
	late	72	51.4
Herbicides	early	30	81.6
	late	70	62.9
Control	early	27	89.5
	late	73	20.8

Leader Elongation

An analysis of variance was run on total leader elongation for
the first growing season to determine if there were any differences in
performance among the stock types or among the cultural treatments.

Table 20. Description of subpopulations - leader elonga-
tion (cm).

	Mean	Variance	Frequency
Age-class			
2-2	5.7	14.6	80
2-0	4.8	4.7	81
plug	5.6	5.1	127
3-0	5.0	11.2	86
2-1	4.9	5.4	96
Treatment			
Irrig. & herb.	5.9	9.8	149
Irrigation	5.1	7.2	123
Herbicides	5.2	6.5	142
Control	3.7	4.6	56

Table 21. Results of soils analysis.

Plot	pH	P	K	Ca	Mg	Total N (%)	CEC	OM (%)
		-- ppm --		--meq/100 g--				
Upper area								
1	5.9	21	880	14.5	6.9	0.38	47.3	12.2
2	5.8	17	720	12.7	6.9	0.23	42.2	10.0
3	6.0	13	880	16.3	6.5	0.28	41.3	9.3
4	6.2	22	840	18.0	6.6	0.37	50.5	11.5
Lower area								
1	6.1	11	636	40.0	13.0	0.31	92.6	8.6
2	6.2	14	620	35.0	13.0	0.34	90.7	9.0
3	6.1	21	960	37.0	13.0	0.32	94.7	9.5
4	6.4	8	432	42.0	17.0	0.30	99.3	8.4

Results indicated that there was not a significant difference (p = .05) in leader elongation among the five age-classes. First year leader elongation also proved to be independent of the cultural treatments employed.

Soils Analysis

Laboratory analysis of the soil samples yielded the results shown in Table 21.

According to Youngberg,[2] the following levels of nutrients can be considered the minimum requisites for conifer seedling establishment in the vicinity of the Willamette Valley (Table 22). Comparison of these values with those determined for the study sites indicated that nutrients were not a limiting factor to conifer seedlings in the year of outplanting. It is possible, however, that the levels of certain of the nutrients (for instance, potassium) may have been excessive, or at least unbalanced, in relation to the levels of other nutrients.

Contrasting the two study areas, it was apparent that the upper area had lower levels of calcium, magnesium, and cation exchange capacity, but generally higher levels of phosphorus, potassium, and organic matter. Total nitrogen was somewhat variable within the

[2] C. T. Youngberg, Professor of Forest Soils, Oregon State University, personal communication, December, 1975.

Table 22. Nutrient requirements for seedling establishment.

P	K	Ca	Mg	Total N (%)
---- ppm ----		-- meq/100 g--		
5.0	100	4.0	1.5	0.15

upper area, but in general, the two study areas were similar with respect to soil nitrogen content.

Diurnal Moisture Stress and Leaf Water Conductance

On September 18, 1975, pre-dawn measurements of xylem pressure potential indicated that none of the five age-classes was under serious moisture stress. As would be expected, xylem pressure potential decreased as the transpirational demand on the seedlings increased with rising temperatures and greater radiation load (Figure 3). From 0400 to 0800 hours, xylem pressure potential decreased comparatively rapidly in all age-classes. After 0800 hours, this decrease was much more gradual. In the case of the container-grown seedlings and the 2-1 transplants, a plateau was reached at 0800 hours and xylem pressure potential remained fairly constant throughout the remainder of the day. Both the 2-0 and 3-0 seedlings showed an increasing level of xylem pressure potential during the afternoon hours. In contrast, the xylem pressure potential of the 2-2
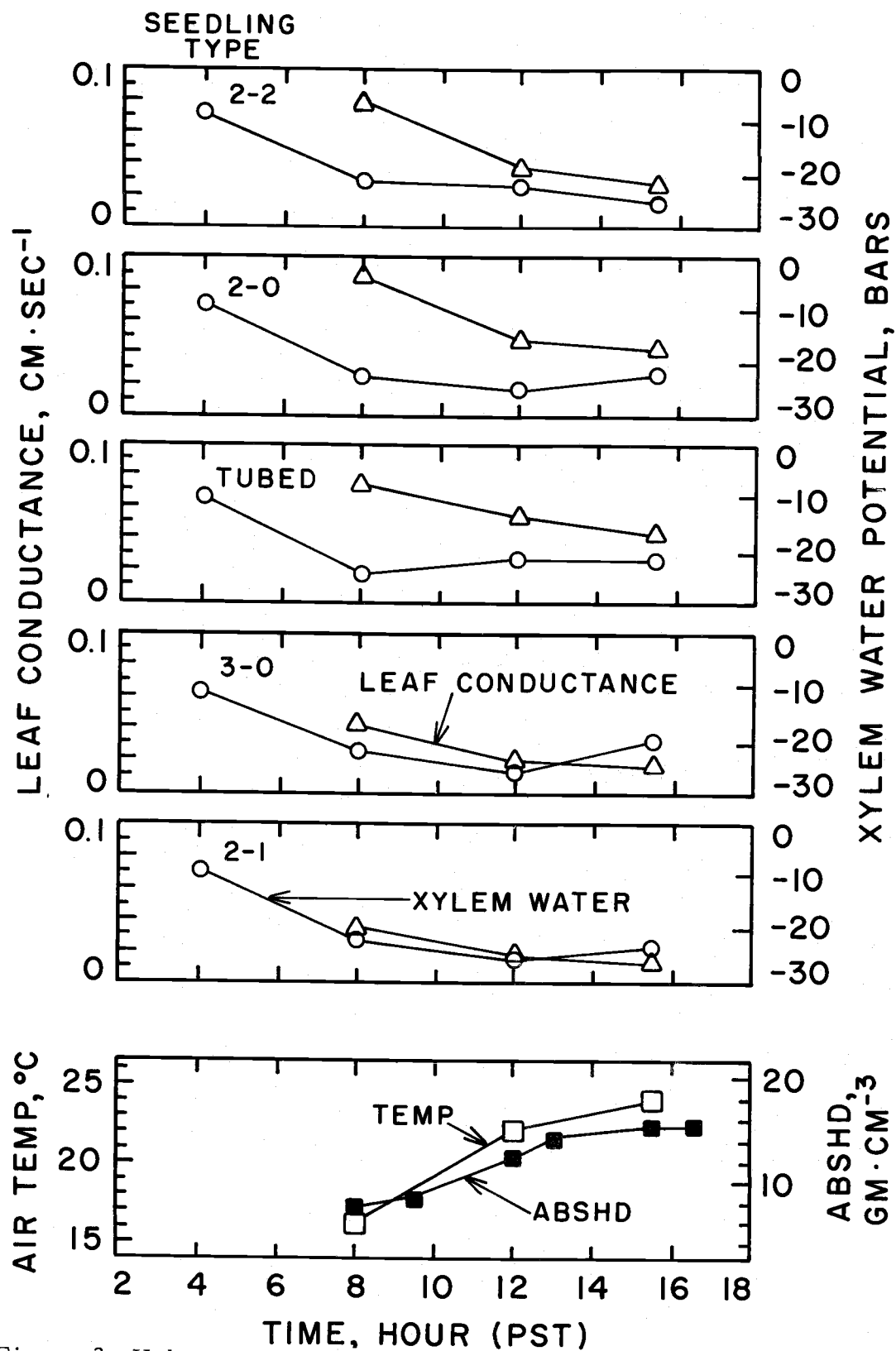
Figure 3: Xylem pressure potential and leaf water conductance of the age-classes.

seedlings leveled off between 0800 and 1200 hours, but then decreased again during the afternoon hours.

The effect of treatment on xylem pressure potential is best indicated in comparison with the moisture status of the control plot (Figure 4). Even before dawn, seedlings on the control plots showed a mean xylem pressure potential of -19.6 bars. The xylem pressure potential of the control seedlings decreased until 0800 hours, remained fairly constant until 1200 hours, and then decreased again during the afternoon hours. In contrast, seedlings from the other three treatments (irrigation, herbicides, and combination of both) exhibited a pre-dawn xylem pressure potential above -10 bars. Seedlings which received these cultural treatments showed a more rapid rate of decrease in xylem pressure potential than did control seedlings up to 0800 hours, yet the level of xylem pressure potential was consistently higher than that experienced by the control seedlings. It is interesting that the level and course of xylem pressure potential was highly similar for the three cultural treatments; moisture stress of those seedlings subjected to both irrigation and vegetation control was not noticeably different from that of seedlings receiving only vegetation control, and only slightly different from that of seedlings receiving only irrigation.

In regards to leaf water conductance, all of the five age-classes showed a characteristic declining trend throughout the day (Figure 3).
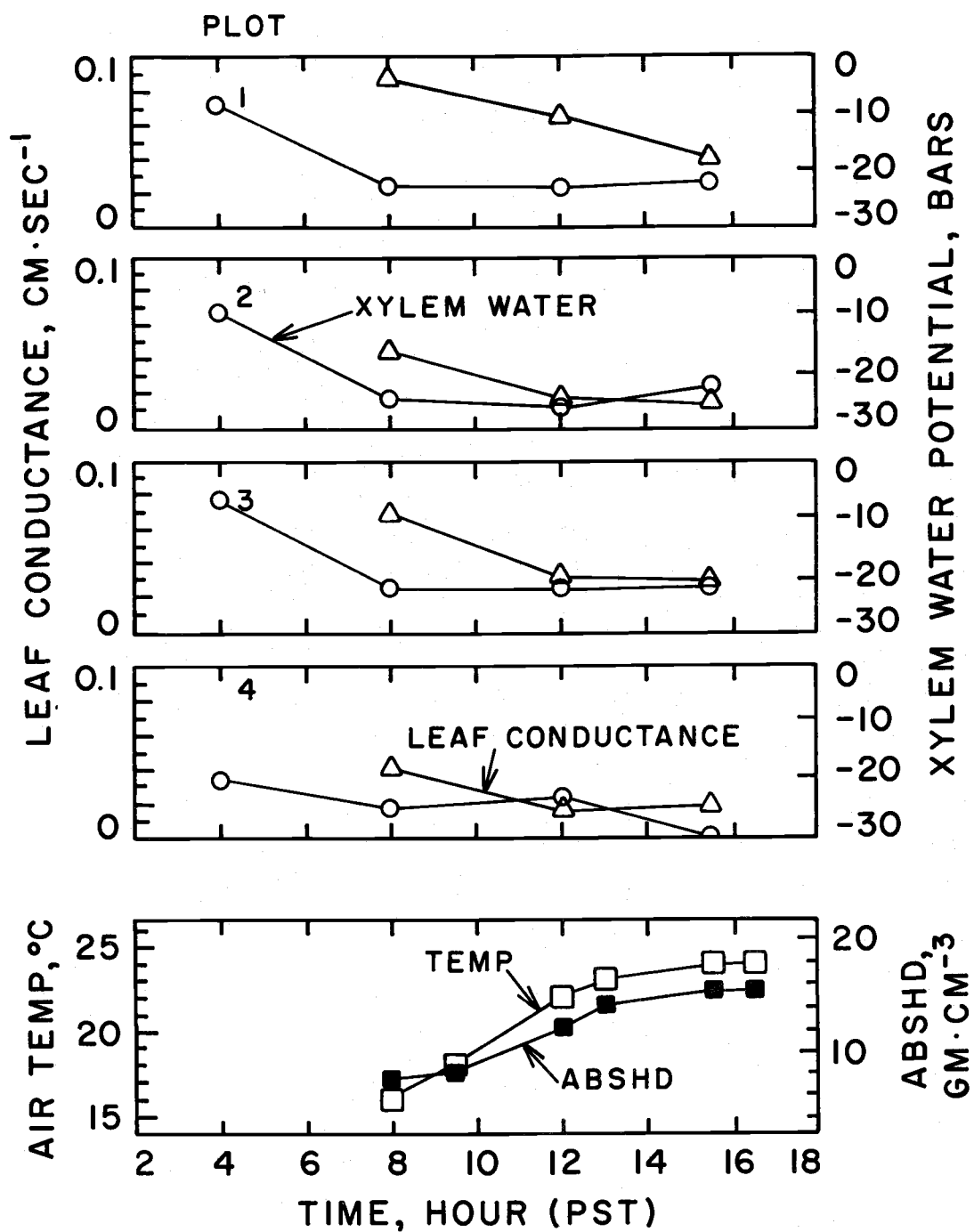
Figure 4: Xylem pressure potential and leaf water conductance on treatments.

In all cases leaf water conductance decreased from 0800 to 1200 hours, followed by a more gradual decrease between 1200 and 1530 hours. There were differences in relative levels of leaf water conductance, however. At each of the three sampling times, the 2-2, 2-0, and container-grown seedlings showed higher levels of leaf water conductance than did the 3-0 and 2-1 stock. The 2-1 transplants were consistently lowest in leaf water conductance, and the 2-0 and container-grown seedlings were consistently highest.

Considering the leaf water conductance of the seedlings as influenced by treatment (Figure 4), the characteristic decline in leaf water conductance throughout the day is again apparent. Seedlings from three of the treatments (irrigation, herbicides, and control) showed a decrease from 0800 to 1200 hours followed by a more gradual decrease from 1200 to 1530 hours. Those seedlings which received the combination of irrigation and herbicide treatments showed a somewhat different pattern of leaf water conductance. Although there was a decline from 0800 to 1200 hours, the rate of decrease in leaf water conductance was considerably less rapid than for those seedlings in the other three treatments. As a consequence, seedlings which received the combination of irrigation and herbicides exhibited a noticeably higher level of leaf water conductance at 1200 hours than did seedlings from the other treatments. Likewise, following an additional decrease from 1200 to 1530 hours, seedlings from the

combined treatments plot still showed a higher level of leaf water

conductance at 1530 hours than did seedlings from the other

treatments.

V. DISCUSSION

Diurnal Moisture Stress and Leaf
Water Conductance

Pre-dawn measurements of xylem pressure potential averaged
over the range of environmental conditions prevailing on September
18, 1975 indicated that there was very little difference in moisture
status among the five age-classes. Apparently, each of the age-
classes was equally capable of replenishing its internal moisture
content during the night, at least under the soil moisture conditions
which prevailed at this specific time. Over the course of the day,
none of the age-classes emerged as being significantly different in
regards to the development of moisture stress. Sampling throughout
the summer indicated that xylem pressure potential in seedlings
tended to be highly variable on any given day. Thus, a comparison
among mean xylem pressure potentials of a comparatively small
sample of seedling types must be weighted accordingly.

In terms of treatment, however, seedlings on the control plots
were under much greater moisture stress than were seedlings which
had received one of the cultural treatments. This, of course, was to
be expected. Seedlings on the control plots had been outplanted into
well-established vegetative communities and had been left to fend
for themselves. The competing vegetation with its established root

systems was in full occupancy of the site at the time the seedlings were introduced into these south-slope communities. Few seedlings coming from a nursery are adapted to survive under such stress. One result of this was that sampling for xylem pressure potential and leaf water conductance was severely restricted by the lack of control seedlings which had survived until September 18.

Among the cultural treatments (irrigation, herbicides, and the combination of both) consistent differences in seedling xylem pressure potential were evidenced over the course of the day. Of special interest was that vegetation control (herbicides) alone was equally as effective in promoting moisture availability to conifer seedlings as was the combination of irrigation and vegetation control. Both the herbicide treatment and the herbicide-plus-irrigation treatment showed slightly, but consistently, higher seedling xylem pressure potentials than did the irrigation treatment alone. Irrigation was effective in curtailing the development of seedling moisture stress, but had the drawback of promoting the well-being of the competing vegetation as well as of the Douglas-fir seedlings. Consequently, the recharge of soil moisture associated with irrigation tended to be short-lived.

In regards to leaf water conductance, all of the five age-classes showed a characteristic declining trend throughout the day. Although the rates of decline were similar, the respective levels of leaf water

conductance varied according to the type of seedling. Over the course of the day, the smaller, younger seedlings, namely the 2-0 and the container-grown, consistently had the highest rates of transpiration. In contrast, the 3-0 seedlings and the 2-1 transplants (larger and older seedlings in the context of this study) consistently showed the lowest rates of transpiration. Except for 0800 hours where they were comparable to the 2-0 and container-grown seedlings, the 2-2 transplants were intermediate in level of transpiration.

Due to the limited scope of the sample, it is difficult to draw generally valid conclusions from the measured leaf water conductance of the five age-classes. The extreme variability observed in seedling xylem pressure potential within an age-class further complicates the matter. With the hope of encouraging further, more intensive research along these lines, several hypotheses can be proposed. First of all, the larger, older seedlings may have been exhibiting a greater degree of stomatal control. This would correlate with the observed leaf water conductance values. Secondly, the smaller, younger seedlings may have had a more favorable shoot/root ratio which afforded them the luxury of higher rates of transpiration. This possibility is especially attractive in the case of the container-grown seedlings which featured dense, fibrous root systems.

Still another hypothetical explanation is that the overall transpirational loss on this particular day was the same for all of the

age-classes. In other words, for a specific level of available soil moisture (as on an area subjected to a certain treatment) the amount of moisture lost through transpiration was determined by the prevailing atmospheric conditions (radiation, absolute humidity deficit, wind speed, etc.). Assuming that the transpirational demand on the two seedlings depicted in Figure 5 was the same for a given unit of leaf surface area, the total transpirational demand on seedling 2 would be twice that on seedling 1. However, the measured leaf conductances indicated that the smaller seedlings had a higher rate of transpiration than did the larger seedlings. Thus, it is hypothesized that the seedlings with greater leaf surface area (two leaves) and a lower rate of transpiration (0.5 g/cm/sec, for example) lost exactly the same amount of moisture as did the seedlings with less leaf surface area (one leaf) and a higher rate of transpiration (e.g., 1.0 g/cm/sec). Further substantiation of equal transpirational loss is lent by the equivalent xylem pressure potentials recorded for the various age-classes diurnally.

If the transpirational loss of a seedling is, indeed, determined by atmospheric demand and soil moisture availability, then the seedling's root system is of foremost importance. Vigorous, well-developed roots would enable a seedling to exploit the available soil moisture, thus filling the atmospheric demand, while concurrently ensuring survival. Seedling size would be of importance only in

Seedling 1   Seedling 2
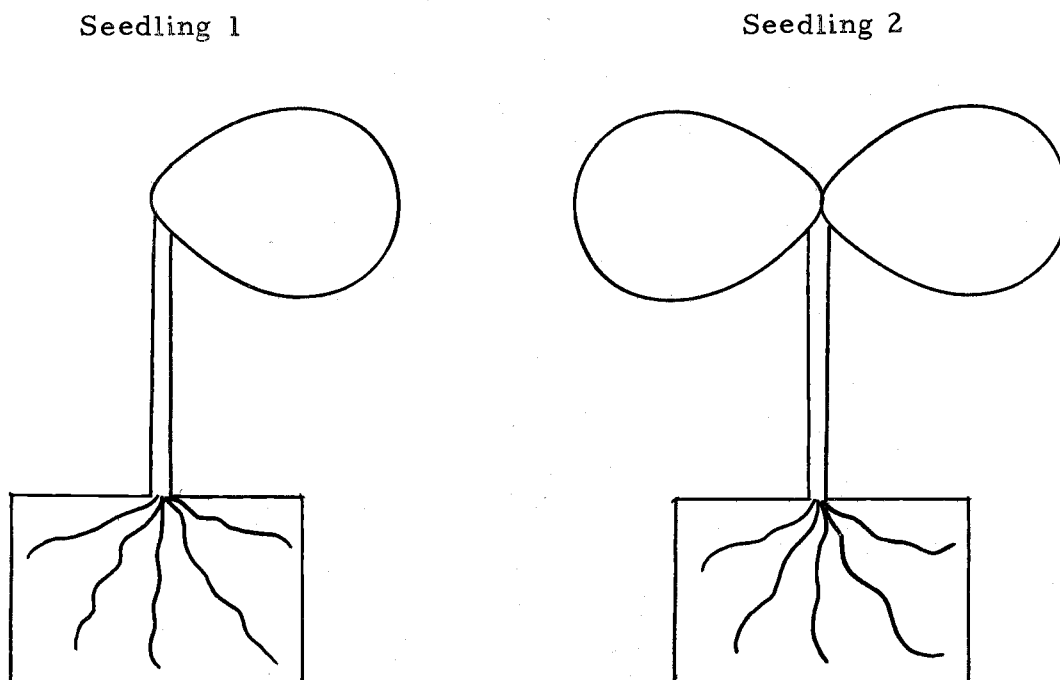
<u>Example</u>

$$A \cdot T_R = T_L$$

where:

A = leaf surface area
T_R = rate of transpiration
T_L = total transpirational loss

and

<u>Seedling 1</u>   <u>Seedling 2</u>

$(A) \cdot (T_R) = (T_L)$ $(A) \cdot (T_R) = (T_L)$

$1 \cdot 1.0 = 1$ $2 \cdot 0.5 = 1$

Figure 5. Illustration of equal transpirational loss (hypothetical).

respect to the ratio between shoots and roots. Stomatal control would also appear to be of secondary importance.

Considering the leaf water conductance of the seedlings as influenced by treatment, the characteristic decline in transpiration throughout the day was again apparent. Of special interest were the seedlings subjected to the combination of irrigation and vegetation control. At each of the sampling intervals, these seedlings consistently showed the highest rates of transpiration, and likewise, the most gradual rate of decrease in transpiration over the day. Apparently, a greater availability of soil moisture encouraged higher transpirational rates in these Douglas-fir seedlings. It was also interesting that these seedlings did not effectively cease transpiration at 20 atmospheres of moisture stress as did the 2-meter tall trees studied by Running (1976).

That the level of transpiration was dependent on the amount of available soil moisture was also shown by those seedlings growing on plots subjected to vegetation control alone. Although transpiration rate was less than, and decreased more rapidly than, for seedlings on the combined treatments plot, the rate was significantly higher than for seedlings on the other two treatment areas. It appears that, although vegetation control resulted in only a small decrease in xylem pressure potential over irrigation, the increase in available soil

moisture was sufficient to sustain the higher rates of transpiration observed in seedlings provided with vegetation control.

The Grass-Dominant Community - Lower Area

Survival differences between the upper and lower areas of the study indicated that the lower slope position was less favorable to the introduction of Douglas-fir seedlings. Much of this difference is attributable to the characteristics of the vegetative community. Although a variety of herbaceous and brush species occur on the lower area (Appendix E), annual and perennial grasses dominate the vegetative community and exert the most competition against intro- duced conifer seedlings. Due to their ability to complete their growth cycle comparatively early in the season, grass species are well-adapted to the dry south slopes of the eastern Coast Range. This early growth habit allows the grasses to utilize the soil moisture provided by winter rains, and then remain inactive during the subse- quent period of summer drought. Many herbaceous species exhibit a similar propensity for early growth, thus exploiting the moisture in the upper horizon of the soil before other vegetation has begun seasonal growth.

From a moisture standpoint, it would seem that conifer seed- lings featuring an earlier growth cycle would have a competitive advantage over later starters for introduction into an established

vegetative community. For the sake of comparison, May 16 was used as the dividing line between early and late budburst of the Douglas-fir seedlings. In respect to the phenological habits of grasses and herbs, this is not a particularly early date of active growth initiation. In the grass-herbaceous community, only the 2-0 age-class showed a relationship between early budburst and subsequent survival. Due to their small overall stature including a comparatively small root system, 2-0 seedlings apparently needed the earlier budburst trait in order to keep pace with the rapidly receding soil moisture. According to Heiner and Lavender (1972), the period of greatest root growth activity is in the weeks immediately preceding budburst. Since seedlings which initiate budburst earlier necessarily begin root growth earlier, these seedlings are in a better position to compete with the established vegetation.

The importance of early budburst in respect to subsequent survival was well-illustrated by comparing the relationship on the different treatments of the study. In the highly competive grass-herbaceous community, survival on all of the treatments was better if seedlings burst buds by May 16. Once again, the early moisture depletion characteristic of grass-dominant communities operated against those seedlings which initiated growth late. It is interesting that even vegetation control and irrigation were not able to overcome the tremendous advantage inherent in the phenological development of

grasses and herbs. Since early budburst is related to early bud set, part of the advantage may also have been evidenced at the conclusion of the seedling growth cycle. By completing their elongation and setting a bud early in the summer, seedlings reached the more drought-resistant state of pre-dormancy before environmental conditions posed the most extreme levels of stress. As the summer progressed, soil moisture became increasingly unavailable, temperatures in the seedling microenvironments increased, and the general conditions required for active growth deteriorated.

Another characteristic of the grass-herbaceous community which resulted in an environmental stress on the Douglas-fir seedlings was the structure of the community. In terms of height, grasses and herbs are low-growing species; seedlings outplanted in such a community are subjected to the full impact of solar radiation, including high temperatures and elevated transpirational demand. Since the level of light interception of the grasses and herbs corresponded with the crowns of the seedling conifers, shading was not a factor. In addition, the incoming solar radiation raised the temperatures of the intercepting surfaces provided by the vegetation, consequently increasing the general air temperature in the immediate vicinity. Such a situation resulted in maximum heat and minimum humidity around the crowns of the seedlings. Transpirational demand was

thus excessively high, and coupled with a general scarcity of soil moisture, contributed strongly to seedling mortality from drought.

In addition to adverse effects on soil moisture availability and temperature regime, some species of grass have been shown to exert phytotoxic effects on conifer seedlings (Rietveld 1975). Furthermore, this inhibition of growth of a species due to the liberation of phytotoxic substances from grasses appears to be a widespread phenomenon (Meyers and Anderson 1942; Grummer 1961; Jameson 1961; Patrick, Toussown, and Snyder 1963; Hoveland 1964; Holm 1969). Although direct tests were not employed to verify the existence of phytotoxic substances in the present study, an indirect evaluation may have been evidenced in the performance of the various seedling types. Where the grass community was especially dense, the container-grown seedlings had consistently higher survival than bare-rooted stock. This phenomenon may be at least partially explained by the fact that the roots of the bare-rooted seedlings were completely surrounded by the indigenous soil, whereas those of the container-grown seedlings were somewhat buffered by their potting medium. Better survival of seedlings with herbicide treatments than with irrigation treatments suggests that the presence of phytotoxic substances may have been dependent on the active growth of grass species. This relationship between herbicidal control of grasses and seedling survival was especially noticeable for the bare-rooted stock.

Survival by Treatment

The graph depicting percent survival by treatment over the course of the summer (Figure 6) illustrates the relative effectiveness of the various treatments in the grass-herbaceous community. During the period of active shoot growth for conifers (mid-May through early July), herbicidal control of competition was the most effective treatment from the standpoint of Douglas-fir seedling survival. During the same period, the combination of irrigation and vegetation control was slightly less effective. Of special interest is the rapid decline of seedlings which received only the irrigation treatment. This suggests that the benefits of irrigation were reaped by the established vegetation which was able to outcompete the newly planted Douglas-fir seedlings. Even those seedlings which received no cultural treatment faired better during this period than did irrigated seedlings. In stimulating the growth of indigenous grasses and herbs, irrigation actually accelerated the rate of mortality of seedling conifers.

Following this initial period of active vegetation growth and rapid soil moisture depletion, the effects of the various treatments became rather distinct. With few exceptions, irrigated seedlings which survived until mid-July were also alive at the final evaluation in October. Since most seedlings had entered dormancy induction by mid-July, and the competitive growth of the grasses was also ebbing, irrigation was sufficient to fill the moisture needs of the seedlings.
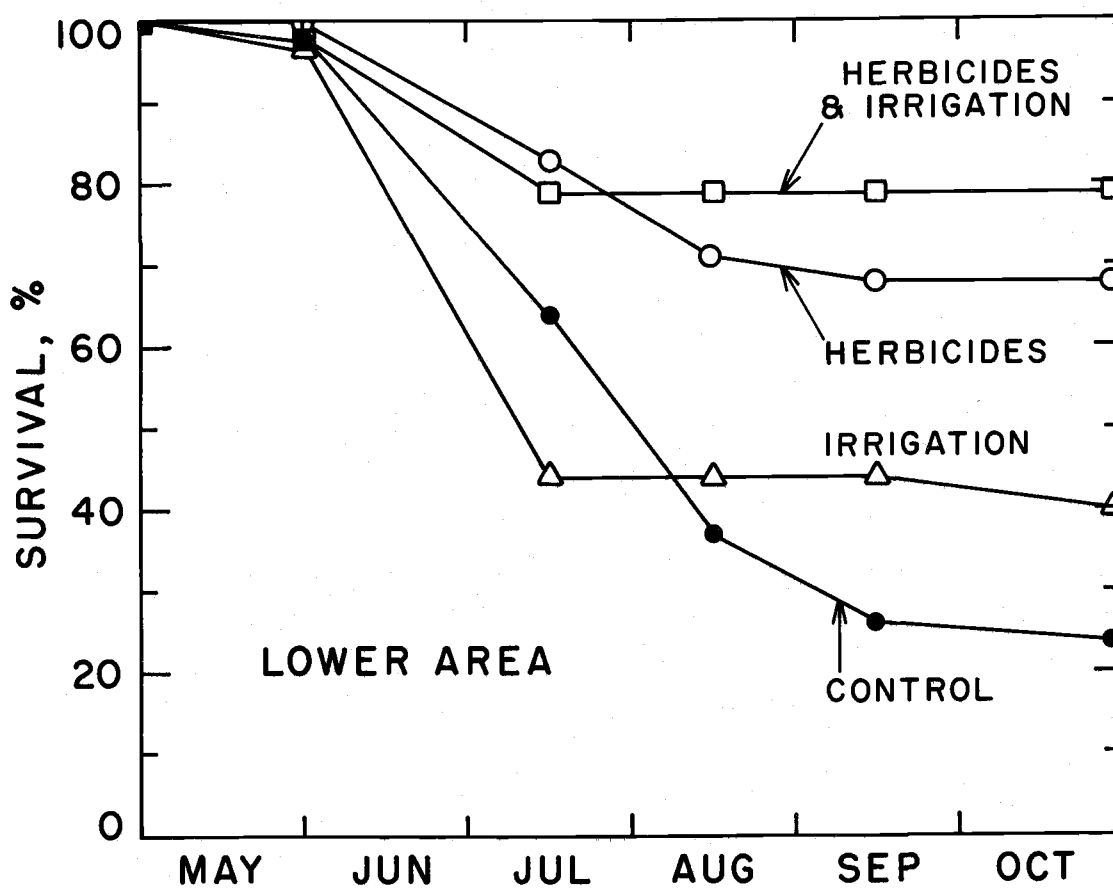
Figure 6: Survival by treatment (lower area).

This stabilizing effect was also exhibited by seedlings which received vegetation control in addition to irrigation. However, due to markedly less competition earlier in the season, more seedlings had survived the period of active growth on the combined treatments plot; hence, they showed much better survival rates in October.

Despite a second application of herbicides early in July, seedlings which received only vegetation control continued to suffer mortality until the middle of September. Yet even with the additional losses between mid-July and mid-September, the overall survival of these seedlings was better than that of those seedlings receiving only irrigation.

As could be expected, seedlings which received no cultural treatment suffered mortality throughout the entire growing season. After mid-September, the rate of mortality decreased substantially, but the overall survival of control seedlings was very poor.

Thus, in the grass-herbaceous community, the type of treatment employed drastically affected the subsequent survival of Douglas-fir seedlings. Herbicidal manipulation of the established vegetation proved effective in modifying the moisture regime to the benefit of seedling conifers. Although coupling irrigation to the vegetation control measures resulted in improved survival, the increase was not statistically significant. Certainly an improvement over no cultural treatment, irrigation alone could not insure acceptable survival of

conifer seedlings in the grass-dominant habitat. This was especially interesting since irrigation was timed to coincide with the moisture needs of the seedlings.

Apparently, the growth cycle of grasses and herbs must be drastically interrupted in order to secure successful introduction of Douglas-fir into the community. Since the seasonal growth and rate of curing of grasses hinges largely on the availability of moisture, providing irrigation merely prolongs the period of maximum water use of the grasses. Consequently, the adverse effects of high temperature associated with the structure of the grass-herbaceous community are also prolonged, and seedling conifers remain under conditions of extreme stress. Amelioration of these stresses is the underlying objective of vegetation management. Since plant communities tend to occupy a site fully, elimination of part of the community promotes the development of survivors; in this instance, the Douglas-fir seedlings. It is also conceivable that in preventing the normal development of the grasses, herbicides concurrently restricted the production of phytotoxic chemicals.

Survival by Age

In the grass-herbaceous community, some marked differences surfaced in regards to survival by seedling age-class (Figure 7). During the period of active growth from mid-May to early July, both
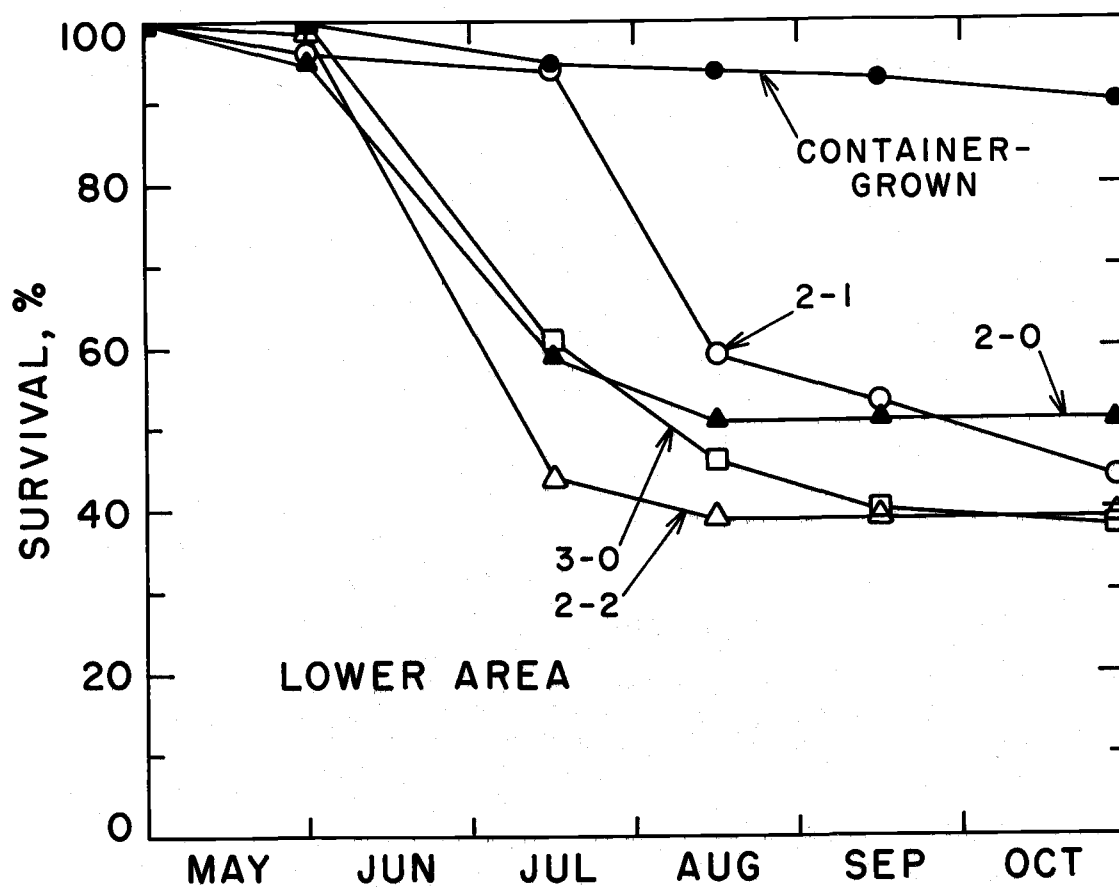
Figure 7: Survival by age-class (lower area).

the container-grown seedlings and the 2-1 transplants showed in excess of 90% survival. In contrast, the 2-0, 2-2, and 3-0 planting stock suffered heavy mortality during the same period.

As the season progressed, the container-grown seedlings suffered a gradual diminution of their number, yet managed to survive at an impressive rate. The 2-1 stock which had performed well up to July showed a rapid decline in survivors during July, and mortality continued the remainder of the season. Both the 2-0 and 2-2 stock stabilized by early August, but by this time survival percentages were down to 50 and 40 respectively. Survival of the 3-0 seedlings decreased throughout the season, although the rate of loss also decreased throughout.

The rather remarkable performance of the container-grown seedlings was far superior to that of the bare-rooted stock in the grass-herbaceous community. Obviously, the container-grown seedlings had some advantage or adaption which the bare-rooted stock lacked. Considering the severe competitive pressure for soil moisture, the rooting system of the plug seedlings stands out as an especially important advantage. These root systems were very well suited for moisture uptake because they were fibrous, dense, and finely branched. In addition, these root systems were subjected to little physical disturbance during storage and outplanting, and remained within their potting medium even when outplanted in the

field. The subsequent field performance suggests that these root systems experienced little transplant shock and were able to resume normal growth in response to environmental stimuli. With a good root system functioning to keep pace with the distribution of soil moisture, the container-grown seedlings were well-suited to the requirements of the site.

The fact that the container-grown seedlings had comparatively little foliage area in combination with copious root surface area was likely a further advantage on this site. With ample potential for water uptake and relatively little potential for expending moisture, the plug seedlings would have been able to remain within the limits of tolerable moisture stress. Even with an exceptionally high atmospheric drain on moisture via transpiration, seedlings with healthy, well-formed root systems would have the potential for moisture recharge once the transpirational demand lessened.

An especially intriguing facet of the comparison between age-classes was the performance of the 2-1 transplants. Until early July, this stock type was surviving well; after that time, survival fell rapidly. Analyzing this occurrence in respect to the grass-herbaceous community, early July was also the approximate time at which the grasses terminated active growth and entered a period of aestivation. The growth cycle of south slope grass communities is closely linked to available soil moisture; indicating, therefore, that

soil moisture in the surface horizons was depleted by early July.
Apparently, the 2-1 transplants were not able to adapt to the ensuing
droughty conditions. This lack of adaptation may have been due pri-
marily to insufficient root extension into the deeper soil horizons.
Coupling this to the large leaf surface area of the 2-1 stock and the
severe transpirational demands of the summer atmospheric con-
ditions, it can be postulated that the transplants were eventually
overcome by drought.

In contrast to the 2-1 transplants, the other three bare-rooted
stock types did not perform well in the early weeks of the growing
season. This suggests that the 2-0, 3-0, and 2-2 stock types were
particularly ill-adapted to the pressures of the grass-dominant
community. Failure to initiate active root growth and accompanying
absorptive functions would seem to constitute the greatest cause of
early season mortality. Poorly developed root systems may have
been detrimental of themselves, or shortcomings in the nursery
management of these seedlings the previous year may have resulted
in reduced vigor and increased susceptibility to environmental
extremes.

Survival by Size

Initial measurements of, and subsequent observations on,
seedling size were included as part of the evaluation of first year

survival on adverse sites. Although by no means a rigid linear relationship, seedling size is generally correlated with age, and for the grass community, survival proved to be independent of bare-rooted stock age. In regards to the performance of container-grown seedlings, the effects of nursery cultural treatment were probably more important than the chronological age of the plants.

In the grass-herbaceous community, seedling size at the time of outplanting was correlated with subsequent survival only in the case of 3-0 seedlings. With respect to initial crown length, diameter at cotyledon scar, and fresh weight, the smaller 3-0 seedlings had higher survival than the larger 3-0 seedlings. It is unfortunate that data on shoot/root ratios are not available for these seedlings since that type of relationship is suggested by the performance of the 3-0 stock. Lesser heights generally improve the relationship between transpirational and absorptive surfaces so long as the root mass is not proportionately decreased. Smaller diameters can be indicative of a smaller crown, but the relationship is not axiomatic. The criterion of fresh weight is all-inclusive and falls short of quantifying the size or character of the root system. Despite these shortcomings, it was apparent that the smaller 3-0 seedlings showed better adaptability in the harsh environment of the grass-herbaceous community.

That survival of 3-0 seedlings in the grass community was related to smaller size suggests that the previous year's nursery management practices may have been of overriding importance. It is a well-established fact that the nursery environment has a profound effect on potential seedling performance (Lavender and Cleary 1974). Irrigating nursery beds beyond mid-July could have encouraged additional height growth, and hence larger 3-0 seedlings, but would also have upset the normal sequence of dormancy development. As a result, those seedlings (i.e., the larger 3-0 seedlings) would not have been properly conditioned for winter chilling, which is necessary to assure prompt, vigorous growth of shoots and roots in the spring of outplanting.

In a harsh environment, it is likely that small differences are greatly magnified over time. The general physiological condition of the planted seedling seems to have been of foremost importance in assuring survival in the grass-herbaceous community.

Leader Elongation

Lack of differences among both age-classes and treatments with respect to leader elongation in the year of outplanting further demonstrated the importance of the nursery environment. Assuming minimal "planting shock," the extent of leader elongation manifested by the seedlings in the year of outplanting was largely determined by

the number of cells laid down in the vegetative buds the previous year. Hence, the growing conditions which prevailed in the nurseries at the time of bud set are reflected in the height growth observed in the year of outplanting. Although the various seedling types were obtained from different nurseries, the growing conditions maintained at each of these were apparently similar enough to result in no statistical differences in subsequent seedling growth.

Differences can be expected in the future, however. The various cultural treatments employed in the grass-herbaceous community afforded varying levels of survival. As previously explained, survival differences among treatments were largely due to the relative availability of soil moisture. Improved moisture relationships on the area treated with both herbicides and irrigation, for instance, can be expected to induce greater height growth in seedlings the second year on the site.

The Brush-Dominant Community - Upper Area

In contrast to the grass-herbaceous community of the lower area, the brush species on the upper area were more phenologically in-phase with the Douglas-fir seedlings. Dominated by thimbleberry and bracken fern, this community was also characterized by tree species (dogwood and bigleaf maple), other brush species (ocean spray, huckleberry, rose), and a component of grasses and herbs

(Appendix F). The diverse character of the community makes it apparent that differences in the timing of growth initiation certainly existed. Yet overall, the planted Douglas-fir seedlings were not subjected to the overwhelming disadvantage of early soil moisture depletion within their rooting zone. As the brush-dominant community progressed through its active growth cycle, competition for soil moisture naturally intensified. However, the conifer seedlings were developing coincidentally with the brush species, thus maintaining a competitive position of their own. Nonetheless, the poor survival on the control plot within the brush community indicated that few conifer seedlings were hardy enough to survive the competition on their own. Those seedlings which did survive without the aid of cultural treatments showed a correlation with budburst prior to May 16. As evidenced in the grass-herbaceous community, in situations where the established vegetation retains control over the moisture regime, introduced seedlings have a better chance of surviving if they can initiate growth earlier.

With regards to seedling age-class, only the 2-0 seedlings showed a relationship between early budburst and subsequent survival. Due to their small overall stature including a comparatively small root system, 2-0 seedlings needed the earlier budburst habit in order to effectively compete for the limited available moisture in the soil surface horizon.

Another factor which operated in favor of the seedling conifers on the upper area was that of shade from the brush species. Although light can at times be a limiting factor to Douglas-fir survival, the radiation load on these south slopes was such that even when over-topped, seedlings showed no signs of light starvation. The major benefit of this shade was undoubtedly manifested as lower air temperatures and higher humidities in the seedling microenvironment. Since moisture was the limiting factor on these sites, shade would have been beneficial from the standpoint of reducing the transpira-tional demand on the seedlings. Although frequently exposed to rather severe stresses, seedlings in the brush community were in more favorable microenvironments overall than were seedlings in the grass-herbaceous community.

Survival by Treatment

The graph depicting percent survival by treatment over the course of the summer (Figure 8) illustrates the relative effectiveness of the various treatments in the brush-dominant community. The slightly poorer initial performance of the seedlings on the plot treated with both irrigation and herbicides may have been an expression of the selectivity of herbicides. A large component of thimbleberry occurred on this area and proved to be resistant to control by 2, 4-D and atrazine. As a consequence, the well-established thimbleberry
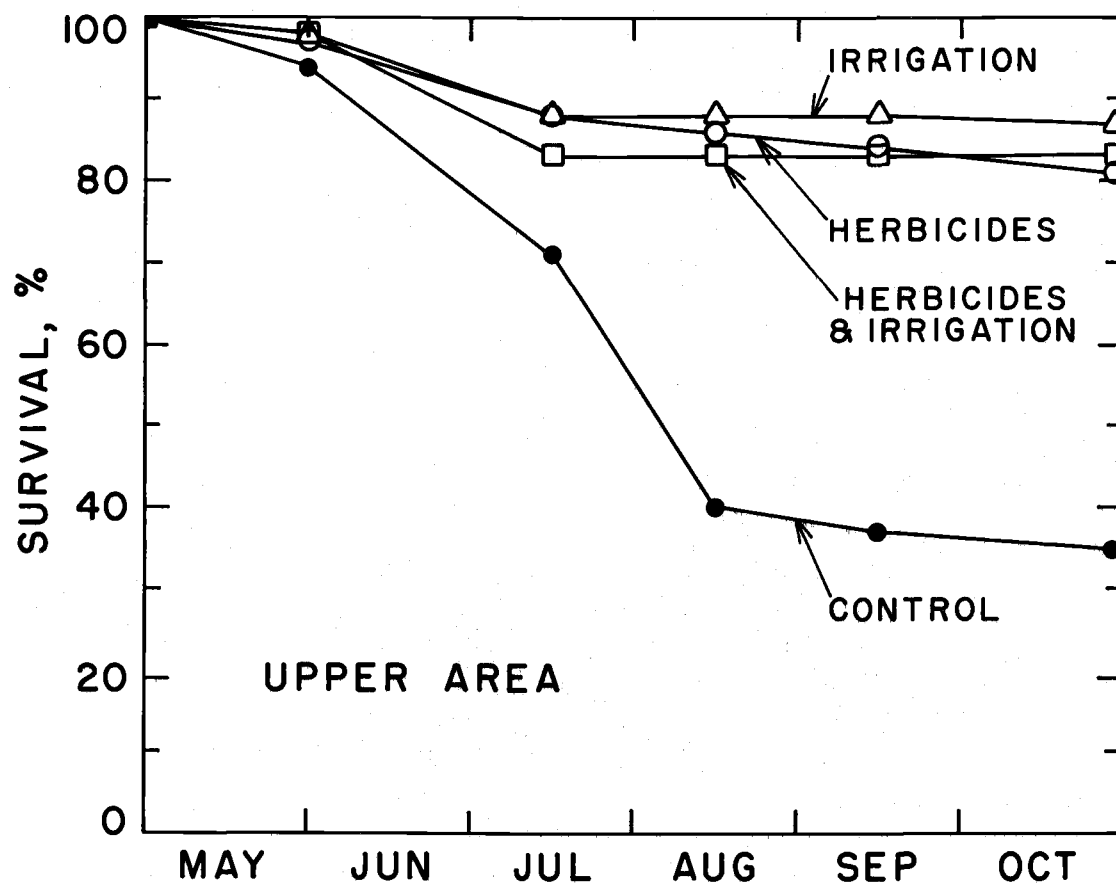
Figure 8: Survival by treatment (upper area).

was actually released when some of the associated vegetation succumbed to the vegetation control measures. Of course, the newly planted Douglas-fir seedlings also benefited from the vegetation control, but were still subjected to the competitive pressures exerted by the vigorously growing thimbleberry. Although the same herbicides were applied to the plot receiving only vegetation control, thimbleberry was not as ubiquitous in this area; consequently, seedlings benefited somewhat more by the release.

Seedling survival rates throughout the initial growing season were not statistically different among the three cultural treatments. As previously noted in the case of the grass-herbaceous community, seedlings which received irrigation reached a point of equilibrium beyond which little mortality occurred. In the brush community, this stabilizing effect was realized early in July, approximately one month ahead of irrigated seedlings in the grass community. This seems to present a paradox since the plant species in the brush community featured growth cycles which extended further into the summer than did those of grass species. To resolve this, it is necessary to consider the structure of the brush-dominant community and the phenological development of the conifer seedlings. Most of the seedlings had completed their active foliar growth by early July and had begun the natural sequence of dormancy. Coupled to this phenomenon was a comparatively low transpirational demand in the seedling

microenvironment due to the effects of shading. Since irrigation was timed to the moisture needs of these seedlings, and directed to the rooting zone, the benefits extended over a longer period than if transpirational demand were excessively high; good survival was the realized outcome.

As in the case of the grass-herbaceous community, manipulation of the brush-dominant community with herbicides insured that the naturally present soil moisture was adequately available for seedling conifer use. Although the herbicide treatment reduced the positive effects associated with shading, the tradeoff for more favorable soil moisture conditions was of greater benefit to the seedling conifers. Interestingly enough, combining irrigation with vegetation control did not result in significant improvement over one of the treatments alone. The poor performance of seedlings on the plot with no cultural treatment clearly indicates, however, that most seedlings are not of themselves adapted to the pressures of established brush communities. It is also noteworthy that the stresses imposed by the brush-dominant community were more readily modified by cultural treatments than were those of the grass-herbaceous community.

Survival by Age-Class

Of the five age-classes, four performed comparably in the

brush-dominant community, and no statistical differences were detected between the survival of bare-rooted stock and container-grown seedlings. Only the 2-0 seedlings showed comparatively poor survival in the brush community; yet the 60% survival rate was still better than any of the bare-rooted stock had managed in the grass-herbaceous community. Furthermore, all bare-rooted age-classes exhibited better survival in the brush community than in the grass community.

Unlike the bare-rooted stock, the survival of container-grown seedlings was not better in the brush community. At least part of this anomaly can be attributed to the initial condition of the container-grown stock (Figure 9). As of the middle of May, container-grown seedling survival on the upper area had already fallen below 90%; this was in contrast to 90% survival in mid-October on the lower area. This suggests that some of the seedlings outplanted in the brush community suffered mortality from causes other than a lack of adaptability to the site. These seedlings may well have been in poor physiological condition due to adverse experiences in any part of the pre-planting operations. Improper handling or planting, for instance, could easily have caused the subsequent mortality of these plants. Or, more realistically, this may merely reflect a chance occurrence. Exclusive of these early losses, container-grown seedling
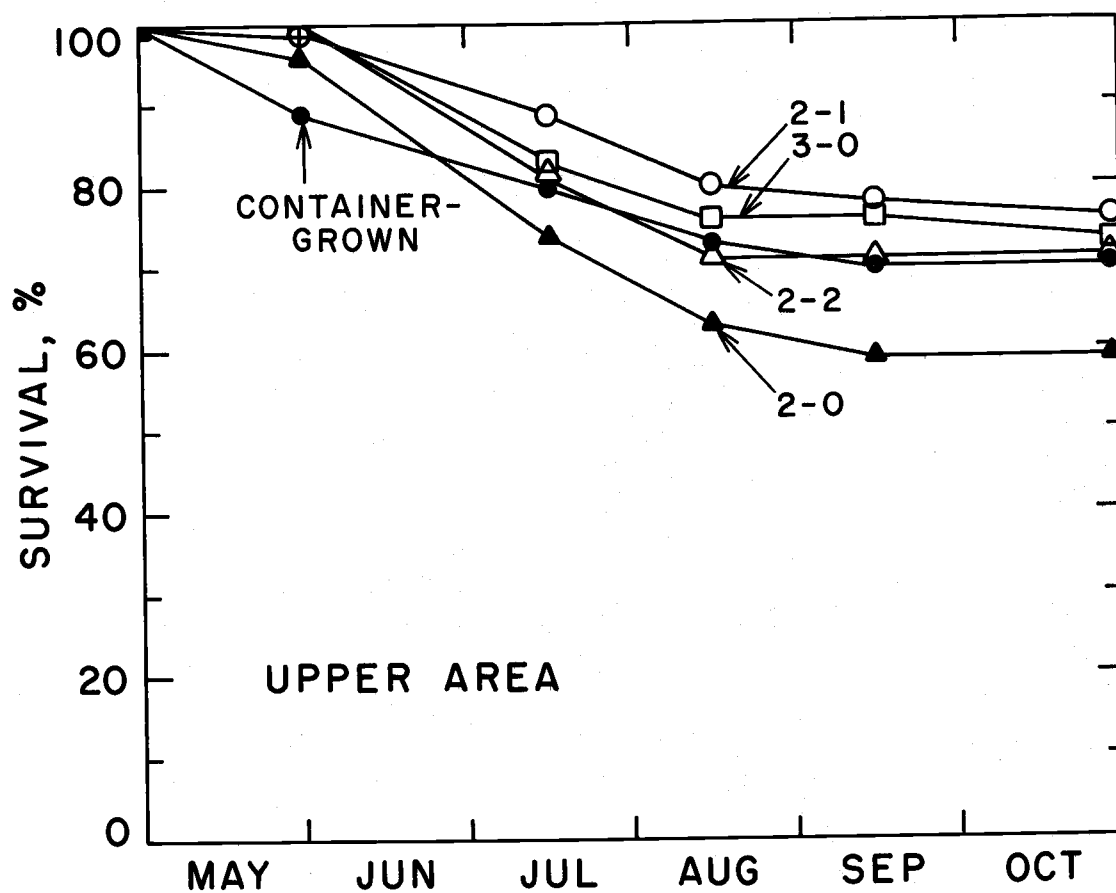
Figure 9: Survival by age-class (upper area).

survival was again better than that of the bare-rooted stock, although not significantly so.

In the brush-dominant community, all seedling age-classes showed a rapid rate of mortality in the first half of the growing season. This period of poorer performance corresponds with the maximum use of soil moisture by all plant species. Not until the competing vegetation completed its active growth were the Douglas-fir seedlings able to stabilize their own status within the community.

Within the bare-rooted age-classes, the 2-0 seedlings were definitely the smallest in size; hence, the implication of larger seedlings surviving better must be considered. However, the container-grown seedlings were even smaller, on the average, than the 2-0 stock, and showed competitive survival rates. It is apparent that any generalization concerning the importance of seedling size must be explicitly qualified. For instance, the effect of enclosing the seedlings in Vexar cages virtually eliminated the stress generally imposed by wildlife on outplantings. On the other hand, the relatively extreme deformation of large seedlings by Vexar cages could have partially negated the size advantage of large seedlings. These exclosure also provided an artificial rigidity against the mechanical pressures typically asserted by brush species. Although difficult to assess, the use of animal exclosures in this study undoubtedly influenced the first year survival of seedlings of various size.

Survival by Size

In the brush-dominant community, seedling size at the time of outplanting was statistically correlated with subsequent survival only in the case of the container-grown seedlings. Increasingly large diameters of container-grown seedlings resulted in increasingly better survival. Container-grown seedling culture typically involves dense seedbeds and optimum levels of irrigation and fertilization. Under such uniform conditions, it is reasonable to assume that seedlings with the larger diameters represent the more vigorous and competitive of the lot. Such an assumption would help to explain why the larger diameter seedlings performed well in the brush community.

Leader Elongation

In the brush-dominant community, first year leader growth proved to be independent of both seedling age-class and type of cultural treatment. As previously explained for the grass community, this lack of difference in growth suggests that the effects of the nursery environment retain significance throughout the year of outplanting. Judging from the similar survival rates of the various treatments, future growth differences may also prove to be minimal.

An interesting occurrence observed during the middle part of the growing season was the frequency of second-flushing. Although

the occurrence of second-flushing resulted in only slightly increased total elongation, it was probably indicative of the favorable moisture status some of the seedlings had managed to attain.

In both the brush and grass communities, the container-grown seedlings exhibited a distinct tendency to second-flush. Of the bare-rooted stock, the 2-0 seedlings showed a higher frequency of second-flushing than did the other stock types. It is interesting that the seedlings which second-flushed tended to be the smaller seedlings in terms of crown length. A small crown of itself would not account for the recurrence of growth, however. A well-developed root system, such as that characteristic of the container-grown seedlings, would enable a seedling to exploit favorable soil moisture conditions. In those specific cases where a seedling possessed a small top and good roots, an advantageous adaptation for second-flushing was evidenced.

VI. SUMMARY AND CONCLUSIONS

Moisture was a major limiting factor to seedling establishment on the sites investigated. From the pressure bomb sampling technique, xylem pressure potential was observed to be highly variable in recently outplanted seedlings. Morphological characteristics were of little value in estimating a seedling's moisture status on a given day, although the leaf water conductance investigation showed that smaller seedlings had higher rates of transpiration than larger seedlings.

The vegetation community in which a seedling was outplanted was of overriding importance to the seedling's chances for survival. Phenological development of the constituents of the plant community greatly influenced the availability of soil moisture so critical to seedling establishment. In turn, community structure determined the favorability, or lack thereof, of the microenvironment in which a seedling developed. In respect to both phenology and structure, the grass-dominant community was more adverse to the introduction of Douglas-fir seedlings than was the brush-dominant community.

The importance of the plant community was further underscored in the response to the various cultural treatments. In the brush-dominant community, irrigation, herbicides, and the combination of irrigation and herbicides proved equally effective as measures of site

preparation. This was in contrast to the results in the grass-dominant community which showed that irrigation alone could not ensure acceptable seedling survival. Due to their inherent ability to disrupt the normal development of established vegetation, herbicides emerged as an especially effective means of ameliorating adverse site conditions. In both communities, little additional benefit was realized by coupling irrigation to the herbicide treatment. Seedlings which received no cultural treatment performed poorly regardless of vegetative community.

In regard to the performance of the various age-classes, the one-year-old container-grown seedlings showed a survival rate of nearly 90% in the grass community. Unable to match this performance, the 2-0, 2-1, 3-0, and 2-2 bare-rooted stock survived at the following rates: 45, 44, 36, and 33%, respectively.

The container-grown seedlings were not, however, superior in the brush community. Both the 2-1 and the 3-0 planting stock had higher survival, 76 and 72% respectively, than the container-grown seedlings (70%) and the 2-2 transplants (68%). Only the 2-0 seedlings (56% survival) performed poorly in the brushy area, although they had the highest survival of the bare-rooted stock in the grass community.

Two conclusions seem warranted concerning type of planting stock: the container-grown seedlings were well-adapted to the

grass community; and the 2-0 seedlings were ill-adapted to the brush community.

Seedling morphological characteristics could be related to survival in the case of the 3-0 seedlings in the grass community and the container-grown seedlings in the brush community. In terms of height, diameter, and weight, the smaller 3-0 seedlings adapted to their new environment better than did larger 3-0 seedlings. For the container-grown seedlings, larger stem diameters were correlated with increasingly better survival.

Although difficult to assess, the physiological condition of the seedlings at time of outplanting was undoubtedly of foremost importance in assuring acclimation. As evidenced by the 2-0 seedlings, a vigorous flush of growth early in the growing season imparted a survival advantage to those seedlings. Since seedlings which initiate budburst earlier necessarily begin root growth earlier, these seedlings are in a better position to compete with the established vegetation.

It is a well-established fact that the nursery environment has a profound effect on potential seedling performance (Lavender and Cleary 1974). This effect was expressed in the level of vigor with which a seedling initiated its active growth, and also in the extent of leader elongation the year of outplanting.

BIBLIOGRAPHY

Adams, R.S. 1964. Age class and size grade tests of ponderosa pine planting stock in the central and northern Sierra Nevada. Calif. Division of Forestry. State Forest Note No. 20, 9 pp.

Allen, R.M. 1953. Large longleaf seedlings survive well. Tree Planter's Notes No. 14:17-18. U.S.D.A., Washington, D.C.

Armit, D. 1970. A planting trial with white spruce, Fort Babine. Res. Note B.C. For. Serv. No. 50, 5 pp. (4 refs.)

Armson, K.A. and R.D. Carman. 1961. A manual for forest tree nursery soil management. Timber Branch, Dept. Lands to Forests, Toronto, Ont. 74 pp.

Arnott, J.T. 1974. Performance in British Columbia. Proceedings of the North American Containerized Forest Tree Seedling Symposium, Denver, Colorado. August 26-29, 1974. Great Plains Agric. Council Publ. No. 68. pp. 283-290.

Aycock, O. 1974. Field performance of containerized seedlings in the southern region, U.S.D.A., Forest Service. Proceedings of the North American Containerized Forest Tree Seedling Symposium, Denver, Colorado. August 26-29, 1974. Great Plains Agric. Council Publ. No. 68. pp. 321-323.

Baker, F.S. 1934. Theory and practice of silviculture. McGraw-Hill Book Co., New York. 502 pp.

Baker, J.B. 1973. Intensive cultural practices increase growth of juvenile slash pine in Florida sandhills. Forest Science 19(3): 197-202.

Barber, J.C. and D.F. Van Haverbeke. 1961. Growth of outstanding nursery seedlings of _Pinus elliotti_ Engelm., and _Pinus taeda_ L. U.S.F.S. Southeastern Exp. Stn. Pap. No. 126, 12 p.

Bates, C.G. 1934. The plains shelter belt project. Jour. For. 32(9):978-991.

Bean, S.D. and J.C. Allen. 1964. Comparison of survival and growth of 1+0 and 2+0 white pine. Tree Planters' Notes No. 65: 9-11.

Beardsell, M.F., P.G. Jarvis, and B. Davidson. 1972. A null-balance diffusion porometer suitable for use with leaves of many shapes. J. Appl. Ecol. 9:677-690.

Berntsen, C.M. 1958. A test planting of 2-0 and 3-0 Douglas-fir on a steep south slope. PNW For. and Range Exp. Sta. Res. Note 165, 4 pp.

Brace, L.G. 1964. Early development of white spruce as related to planting method and planting stock height. Publ. No. 1049. Forest Research Branch, Dept. of Forestry, Ottawa, Ont. 15 pp.

Brewer, C.W. and N.E. Linnartz. 1971. Results of eight years of intensive cultural management of loblolly pine in southeast Louisiana. LSU For. Note, La. Sch. For. No. 95, 4 pp.

Brix, H. 1972. Nitrogen fertilization and water effects on photo-synthesis and earlywood-latewood production in Douglas-fir. Can. J. Forest Res. 2:467-478.

Buchanan, B.A. 1974. Containerized seedlings on the Lincoln National Forest. Proceedings of the North American Con-tainerized Forest Tree Seedling Symposium, Denver, Colorado. August 26-29, 1974. Great Plains Agric. Council Publ. No. 68. pp. 359-365.

Carmean, W.H. 1971. Large, well-balanced stock and control of grass competition needed for red pine plantings on sandy soils. Tree Planters' Notes 22(1):8-10.

Champs, J. de. 1970. Observations sur la croissance juvenile du Douglas en Limousin. In: AFOCEL Annual Report 1969. pp. 269-302.

Clark, F.B. and R.F. Phares. 1961. Graded stock means greater yields for short leaf pine. Central States For. Exp. Stn. Tech. Pap. 181, 5 pp.

Clark, M.B. 1966. Douglas-fir planting trials. B.C. For. Serv. Res. Rev. 1966. 67 pp.

Clausen, K.E. 1963. Nursery selection affects survival growth of birch. Lake States For. Exp. Stn. Res. Note LS-31. 2 pp.

Clements, J.R. 1971. The effect of late summer irrigation on red pine buds and shoot lengths. Tree Planters' Notes 22(2):4-5.

Corson, C.W. and H.A. Fowells. 1952. Here's how - a guide to tree planting in the California pine region. Calif. For. and Range Exp. Stn. Misc. Pap. 8. 26 pp.

Curtis, R.O. 1955. Use of graded nursery stock for red pine plantations. Jour. For. 53(3):171-173.

Davidson, W.H. and E.A. Sowa. 1974. Early attempts to vegetate coal-mine spoils with container-grown seedlings. Proceedings of the North American Containerized Forest Tree Seedlings Symposium, Denver, Colorado. August 26-29, 1974. Great Plains Agric. Council Publ. No. 68. pp. 372-376.

Diller, J.D. 1955. Survival and heights of various grades of red spruce transplant stock. Jour. For. 53(11):843.

Edwards, M.V. and G.D. Holmes. 1951. Experimental work in the nursery. pp. 12-24. Forestry Commission Report on Forest Research for the Year Ending March 1950. Forestry Commission, London, England.

Evans, R.W. and W. Duyker. 1964. The influence of height and age of nursery stock on initial plantation growth of *Callitris intratrysica* (Benth. et Hook. F). Australian For. Research 1(1):21-27.

Forestry Commission, U.K. 1959. Report on forestry research 1958. Her Majesty's Stationery Office, London.

Fowells, H.A. 1953. The effect of seed and stock sizes on survival and early growth of ponderosa and Jeffrey pine. Jour. For. 51:504-507.

Fowells, H.A. and G.H. Schubert. 1953. Planting-stock storage in the California pine region. Calif. For. and Range Exp. Sta. Tech. Pap. 3. 12 pp.

George, E.G. 1939. Tree planting on the drier sections of the northern Great Plains. Jour. For. 37(9):695-698.

George, E.J. 1974. Planting container-grown tree stock in North Dakota. Proceedings of the North American Containerized

Forest Tree Seedling Symposium, Denver, Colorado. August 26-29, 1974. Great Plains Agric. Council Publ. No. 68. pp. 369-371.

Grümmer, G. 1961. The role of toxic substances in the interrelationships between higher plants. Soc. Expl. Biol. Symp. 15: 219-228.

Gutzwiler, J.R. and J.K. Winjum. 1974. Performance of containerized coniferous seedlings in recent forest regeneration trials in Oregon and Washington. Proceedings of the North American Containerized Forest Tree Seedling Symposium, Denver, Colorado. August 26-29, 1974. Great Plains Agric. Council Publ. No. 68. pp. 291-297.

Hartwell, H.D. 1969. Control of damage by snowshoe hares on forest plantations. pp. 80-81 in Wildlife and Reforestation in the Pacific Northwest (H.C. Black, ed.). School of Forestry, Oregon State University. 92 pp.

Heiner, T.D. and D.P. Lavender. 1972. Early growth and drought avoidance in Douglas-fir seedlings. Forest Research Laboratory, Res. Pap. 14. School of Forestry, Oregon State University, Corvallis. 7 pp.

Hermann, R.K. 1964. Importance of top-root ratios for survival of DF seedlings. Tree Planters' Notes 64:7-11.

Hetherington, J.C. 1970. A study of Douglas-fir planting stock on high-site land subject to dense plant cover. B.C. For. Serv., Res. Div., Victoria. 9 pp.

Hines, W.W. and C.E. Land. 1973. Blacktail deer and Douglas-fir regeneration in the Coast Range of Oregon. pp. 133-138 in Wildlife and Forest Management in the Pacific Northwest (H.C. Black, ed.). Symposium Proceedings, September, 1973. Oregon State University, School of Forestry, Corvallis.

Hite, W.A. 1974. Container field performance in the Rockies and Plains. Proceedings of the North American Containerized Forest Tree Seedling Symposium, Denver, Colorado. August 26-29, 1974. Great Plains Agric. Council Publ. No. 68. pp. 306-309.

Holm. L. 1969. Chemical interactions between plants on agricultural land. Down to Earth 25(1):16-22.

Hough, A.F. 1952. Relationships of red pine seed source, seed weight, seedling height, and height growth in Kane test plantation. Northeastern For. Exp. Stn. Pap. 50. 14 pp.

Hoveland, C.S. 1964. Germination and seedling vigor of clovers as affected by grass root extracts. Crop Sci. 4:211-213.

Hunt, E.V., Jr. and G. Gilmore. 1967. Effect of initial height on loblolly pine seedling growth and survival. Jour. For. 65(9):632-634.

Ike, A.F. 1962. Root collar diameter is a good measure of height growth potential of sycamore seedlings. Tree Planters' Notes 54:9-11.

Illingworth, K. 1966a. A study of DF planting stock on high-site lands subject to dense cover. B.C. For. Serv. For. Res. Rev. 1966:66.

Illingworth, K. 1966b. The survival and initial growth of various types of planting stock. B.C. For. Serv. For. Res. Rev. 1966:64-65.

Illingworth, K. and M.B. Clark. 1966. Planting trials with ponderosa pine in British Columbia. B.C. For. Serv. Res. Note 41, 34 pp.

Jameson, D.A. 1961. Growth inhibitors in native plants of northern Arizona. Rocky Mt. For. and Range Exp. Stn. Res. Note 61, 2 pp.

Jameson, D.A. 1968. Species interactions of growth inhibitors in native plants of northern Arizona. U.S.D.A., For. Serv. Res. Note RM-113, 2 pp.

Jaworsky, J.M. 1958. Some problems concerning Douglas-fir nursery stock reflected in experimental planting at Sutoon Creek, Spring 1954 and 1955. Assoc. of B.C. Foresters Thesis. Faculty of Forestry, Univ. of B.C., Vancouver, B.C. 118 pp.

Knight, H. 1967. Growth and survival of experimental plantations of Douglas-fir. B.C. For. Serv. Res. Note 33, 22 pp.

Korstian, C.F. 1925. Forest planting in the Intermountain region. For. Serv., U.S.D.A. Bull. 1264. 56 pp.

Kummel, J.F., C.A. Rindt, and T. Munger. 1944. Forest planting in the Douglas-fir region. PNW For. and Range Exp. Stn., 154 pp.

Lavender, D.P. and B.C. Cleary. 1974. Coniferous seedling production techniques to improve seedling establishment. Proceedings of the North American Containerized Forest Tree Seedling Symposium, Denver, Colorado. August 26-29, 1974. Great Plains Agric. Council Publ. No. 68. pp. 177-180.

Leech, R.H. 1964. Reforestation of a sand plain in Ontario. Research Report No. 51. Research Branch, Dept. of Lands and Forests, Ontario, 81 pp.

Limstrom, G.A. 1955. Planting stock grades for yellow poplar. Jour. For. 54(1):28-32.

Limstrom, G.A. 1960. Forestation of strip-mined land in the central states. U.S.D.A. Agric. Handbook 166, 74 pp.

Little, S. and H.A. Somes. 1964. Root system of direct-seeded and variously planted loblolly, short leaf, and pitch pines. Northeastern For. Exp. Stn. Res. Pap. N.E. 26, 13 pp.

Madison, R.W. 1959. Growth and survival of a Sitka spruce plantation in coastal Oregon. PNW For. and Range Exp. Stn. Res. Note 178, 6 pp.

Manogaran, C. 1973. Economic feasibility of irrigation in southern pines. Water Resources Research 9(6):1485-1496.

Marquestaut, J., G. Drovin, and H. Thibout. 1970. Quelques observations sur le reboisement dans le Massif Central. In: Compte Rendu d'Activite 1969. AFOCEL, Paris. pp. 109-151.

McGee, C.E. and J.B. Hatcher. 1969. Deep planting small slash pine on old field sites in the Carolina sandhills. Jour. For. 61:382-383.

Meekins, E.H. 1964. A case for planting graded stock. Tree Planters' Notes 66:7-8.

Miller, E.E., C.A. Shadbolt, and L. Holm. 1956. Use of an optical planimeter for measuring leaf area. Plant Physiol. 31(6):484-487.

Miller, E.L. and J.D. Budy. 1974. Field survival of container-grown Jeffrey pine seedlings outplanted on adverse sites. Proceedings of the North American Containerized Forest Tree Seedling Symposium, Denver, Colorado. August 26-29, 1974. Great Plains Agric. Council Publ. 68. pp. 377-383.

Mullin, R.E. 1959. An experiment on culling and grading of white spruce nursery stock. Part A. The percentage of cull. Ontario, Dept. of Lands and Forests Res. Pap. 38, 62 pp.

Mullin, R.E. 1963. Planting check in spruce. For. Chron. 39(3): 252-259.

Mullin, R.E. and J. Svaton. 1972. A grading study with white spruce nursery stock. Commonwealth For. Rev. 51(1):62-69.

Myers, H.E. and K.L. Anderson. 1942. Bromegrass toxicity vs. nitrogen starvation. J. Am. Soc. Agron. 34:770-773.

Nelson, W.A. and H.W. Anderson. 1966. Handling large nursery stock. Proceedings Tenth Biennial Western For. and Cons. Assn. Western Forest Nursery Council Mtg., Placerville and Davis, Calif. 1966. pp. 33-41.

Newton, M. 1964. Seedling survival and vegetative competition. In: Western Reforestation. Western For. and Cons. Assn., Spokane, Wash. pp. 39-42.

Newton, M. and H.C. Black. 1965. Large planting stock of Douglas-fir helps evade damage by animals and sprouting brush on favorable sites. Western Weed Control Conf. Res. Prog. Reports, 46.

Newton, M. (ed.). 1967. Herbicides in vegetation management in forest, ranges and noncrop lands. Symposium Proceedings. School of Forestry, Oregon State University, Corvallis. 356 pp.

Newton, M. 1973. Environmental management for seedling establishment. School of Forestry, Oregon State University, Corvallis. Res. Pap. 16, 5 pp.

Ostrom, C.E. and M.J. Ferrer. 1942. Species and size of stock for planting in northwestern Pennsylvania. Allegheny For. Exp. Stn. Tech. Note 37. (Northeastern For. Exp. Stn.)

Owston, P.W. and W.I. Stein. 1972. First year performance of Douglas-fir and noble fir outplanted in large containers. U.S.D.A. For. Serv. Res. Note, Pacific NW For. and Range Exp. Stn. PNW 0174. 10 pp.

Patrick, Z.A., T.A. Toussoun, and W.C. Snyder. 1963. Phytotoxic substances in arable soils associated with decomposition of plant residues. Phytopathology 53:152-161.

Pawsey, C.K. 1972. Survival and early development of Pinus radiata as influenced by size of planting stock. Australian For. Res. 5(4):13-24.

Pearson, G.A. 1950. Management of ponderosa pine in the southwest. U.S. For. Serv., U.S.D.A., Agric. Monog. 6. 218 pp.

Person, H.L. 1937. Commercial planting in redwood cut-over lands. U.S.D.A. Cir. 434, 39 pp.

Pomeroy, K.B., F.K. Green, and I.B. Burkett. 1949. Importance of stock quality on survival and growth of planted trees. Jour. For. 47(9):706-707.

Richter, J. 1971. Das Umsetzen van Douglasien im Kulturstadium Allg. Forst und Jagdztg. 142(3):65-69.

Rietveld, W.J. 1975. Phytotoxic grass residues reduce germination and initial root growth of ponderosa pine. Rocky Mt. For. and Range Exp. Stn. Res. Pap. 153, 15 pp.

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

Rudolf, P.O. 1950. Forest plantations in the Lake states. U.S.D.A. Tech Bull. 1010, 171 pp.

Running, S.W. 1976. Environmental control of leaf water conductance in conifers. Can. J. For. Res. 6(1):104-112.

Ruth, R.H. 1956. Plantation survival and growth in two brush-threat areas in coastal Oregon. Pacific NW For. and Range Exp. Stn. Res. Pap. 17, 14 pp.

Scarratt, J.B. 1974. Performance of tubed seedlings in Ontario. Proceedings of the North American Containerized Forest Tree Seedling Symposium, Denver, Colorado. August 26-29, 1974. Great Plains Agric. Council Publ. 68, pp. 310-320.

Schopmeyer, C.S. 1940. Survival in forest plantations in the northern Rocky Mountain region. Jour. For. 38(1):16-24.

Schultz, R.R. 1969. What is being learned from intensive management of slash pine. Forest Farmer 28(6):8-9.

Shipman, R.D. 1960. Survival and growth of graded longleaf pine nursery stock. Jour. For. 58:38-39.

Show, S.B. 1930. Forest nursery and planting practice in the California pine region. U.S.D.A. Circ. 92, 75 pp.

Sischo, P.C. 1958. Tree planting in southern California. Calif. Div. of For. 28 pp.

Smith, D.M. 1962. The practice of silviculture. 7th ed. John Wiley and Sons, Inc., New York. 578 pp.

Smith, J.H.G. and G.S. Allen. 1962. Improvement of Douglas-fir planting stock. Res. Pap. 55. Faculty of Forestry, Univ. of B.C., Vancouver. 16 pp.

Smith, J.H.G. and J. Walter. 1963. Planting-check (reduction in height growth) of planted Douglas-fir seedlings. Res. Note 40. Faculty of Forestry, Univ. of B.C., Vancouver. 4 pp.

Smith, J.H.G. and J. Walters. 1965. Influence of seedling size on growth, survival, and cost of growing DF. Res. Note 50. Faculty of Forestry, Univ. of B.C., Vancouver. 7 pp.

Smith, J.H.G. 1975. Big stock vs. small stock. A paper prepared for the Western Reforestation Coordination Committee session. Dec. 3, 1975. Vancouver, B.C. 26 pp.

Snedecor, G.W. and W.G. Cochran. 1967. Statistical methods. 6th ed. The Iowa State Univ. Press, Ames. pp. 199-257.

Stein, W.I., J.H. Edward, and R.W. Tinus. 1975. Outlook for container-grown seedling use in reforestation. Jour. For. 73(6):337-341.

Steven, H.M. 1928. Nursery investigations. Forestry Comm. Bull. 11 (London). 181 pp.

Stoeckeler, J.H. 1950. Can nurserymen produce white pine seedling stock comparable to transplants? Lake States For. Exp. Tech. Note 339, 2 pp.

Stoeckeler, J.H. 1963a. Early survival of planted trees in southwestern Wisconsin by species, age, class, and site factors. Lake States For. Exp. Stn. Res. Note LS-27, 4 pp.

Stoeckeler, J.H. 1963b. Ground preparation costs and first year survival of planted red pine in southwestern Wisconsin. Lake States For. Exp. Stn. Res. Note LS-28, 4 pp.

Stone, E.C. 1955. Poor survival and the physiological condition of planting stock. For. Sci. 1(2):90-94.

Stone, E.C., E.E. Gilden, D.W. Cooper, and R.J. Malain. 1961. Planting dates for Douglas-fir seedlings in California forest lands. Calif. Agric. 15(8):15-16.

Stone, E.C. 1969. Variation in the root-growth capacity of ponderosa pine transplants. pp. 40-45 in Symposium proceedings, Regeneration of ponderosa pine (R.K. Hermann, ed.). School of Forestry, Oregon State Univ., Corvallis.

Stone, E.C., G.H. Schubert, R.W. Benseler, F.J. Baron, and S.L. Krugman. 1963. Variation in the root regenerating potentials of ponderosa pine from four California nurseries. For. Sci. 9(2):217-225.

Stone, E.C. and J.L. Jenkinson. 1971. Physiological grading of ponderosa pine nursery stock. Jour. For. 69:31-33.

Swearingen, J.W. 1963. Effects of seedling size and depth of planting on early survival and growth of slash pine. Tree Planters' Notes 58:16-19.

U.S. Forest Service. 1960. Annual report. Pacific SW For. and Range Exp. Stn., Berkeley, Calif. 80 pp.

U.S.D.A., Forest Service. 1973. Report. Forest planting, seeding, and silvical treatments in the United States. 18 pp.

Van Eerden, E. 1972. Influences affecting container seedling performance near Prince George, British Columbia. pp. 92-100 in Proceedings of a workshop on container planting in Canada (R.M. Haldron, ed.). Can. Dept. Environ. Can. For. Serv. Dir. Prog. Coord., Inf. Rep. DPC-X-2.

Wahlenberg, W.G. 1928. Experiments with classes of stock suitable for forest planting in the northern Rocky Mountains. J. Agric. Res. 36(12):977-1000.

Wakeley, P.C. 1948. Physiological grades of southern pine nursery stock. Proceedings Soc. Am. Foresters, Washington, D.C. pp. 311-322.

Wakeley, P.C. 1954. Planting the southern pines. U.S.D.A. Monog. 18, 233 pp.

Walters, J. and A. Kozak. 1965. Effects of seedling size on survival and growth of plantations with particular reference to Douglas-fir. Faculty of Forestry, Univ. of B.C., Vancouver. Res. Pap. 72, 26 pp.

Zarger, T.G. 1965. Performance of loblolly, short leaf, and eastern white pine super seedlings. Silvae Genetica 14(6):182-186.

APPENDICES

APPENDIX A

HEIGHT CLASSES

Height class (cm)	Frequency	Height class (cm)	Frequency
2-2		**2-0**	
12.0-27.2	18	5.6-11.9	26
27.3-31.0	23	12.0-13.4	31
31.1-34.8	26	13.5-15.0	33
34.9-36.7	21	15.1-16.6	36
36.8-38.6	20	16.7-29.2	34
38.7-42.4	28		
42.5-69.0	24		
Plugs		**2-1**	
11.9-18.8	16	22.9-31.6	24
18.9-20.5	19	31.7-34.5	18
20.6-22.3	19	34.6-37.4	20
22.4-24.0	20	37.5-40.3	26
24.1-25.7	23	40.4-43.2	13
25.8-27.5	26	43.3-46.1	20
27.6-29.2	16	46.2-49.0	21
29.3-37.9	21	49.1-66.5	18

APPENDIX B

DIAMETER CLASSES

Diameter class (cm)	Frequency	Diameter class (cm)	Frequency
2-2		**2-0**	
0.29-0.63	16	0.19-0.23	16
0.64-0.70	18	0.24-0.25	17
0.71-0.77	13	0.26-0.27	17
0.78-0.80	15	0.28-0.29	17
0.81-0.83	15	0.30-0.32	17
0.84-0.90	16	0.33-0.37	20
0.91-0.94	14	0.38-0.42	20
0.95-0.97	15	0.43-0.87	18
0.98-1.11	23		
1.12-1.31	15		

2-1

Diameter class (cm)	Frequency
0.36-0.49	20
0.50-0.53	16
0.54-0.58	21
0.59-0.62	22
0.63-0.67	19
0.68-0.71	16
0.72-0.75	11
0.76-0.80	16
0.81-1.02	19

APPENDIX C

WEIGHT CLASSES

Weight class (g)	Frequency	Weight class (g)	Frequency
2-2		**2-0**	
8.6-37.6	17	1.6-4.1	28
37.7-52.2	24	4.2-5.4	23
52.3-66.6	24	5.5-6.6	23
66.7-81.2	25	6.7-7.9	24
81.3-95.7	25	8.0-9.1	23
95.8-124.7	30	9.2-14.1	24
124.8-444.2	15	14.2-39.1	15

2-1

Weight class (g)	Frequency
9.6-16.9	12
17.0-24.3	26
24.4-31.7	23
31.8-39.1	21
39.2-46.5	26
46.6-61.3	23
61.4-76.0	15
76.1-120.3	14

APPENDIX D

EFFECTS OF DATE OF BUDBURST ON SURVIVAL

Age-class	Budburst	Frequency	% Survival
Upper area			
2-2	early	2	50.0
	late	78	67.9
plugs	early	50	72.0
	late	30	66.7
3-0	early	3	100.0
	late	77	70.1
2-1	early	1	100.0
	late	79	75.9
Lower area			
2-2	early	1	0
	late	79	32.9
plugs	early	66	87.9
	late	14	92.9
3-0	early	7	57.1
	late	73	34.3
2-1	early	0	0
	late	80	41.2

APPENDIX E

PARTIAL LIST OF LOWER AREA VEGETATION

Common name	Scientific name
Vetch	Vicia americana
False dandelion	Hypochaeris radicata
Wild strawberry	Fragaria spp.
Spring queen	Syntheris reniformis
Iris	Iris tenax
Bracken fern	Pteridium aquilinum
Thistle	Cirsium spp.
Deer fern	Struthiopteris spicant
Pearly everlasting	Anaphilis margaritaceae
Hazel	Corylus cornuta
Bigleaf maple	Acer macrophyllum
Trailing blackberry	Rubus vitifolius
Wild rose	Rosa gymnocarpa
Ocean spray	Holodiscus discolor
Thimbleberry	Rubus parviflorus
Snowberry	Symphoricarpus albus
Poison oak	Rhus diversiloba
Oregon grape	Berberis spp.
Sword fern	Polystichum munitum
Climbing honeysuckle	Lonicera ciliosa
Douglas-fir	Pseudotsuga menziesii
Grand fir	Abies grandis
Wild blue rye	Elymus glauca
Dogtail grass	Lynosurus echinatus
Velvet grass	Holcus lanatus
Red fescue	Festuca spp.
Bromes	Bromus spp.
Lupine	Lupinus spp.
Western yarrow	Achillea millefolium
Tansy ragwort	Senecio spp.

APPENDIX F

PARTIAL LIST OF UPPER AREA VEGETATION

Common name	Scientific name
Spring beauty	Dentaria tenella
Wild strawberry	Fragaria spp.
Bracken fern	Pteridium aquilinum
Iris	Iris tenax
Spring queen	Syntheris reniformis
Vetch	Vicia americana
False hellebore	Veratrum caudatum
Thimbleberry	Rubus parviflorus
Wild rose	Rosa gymnocarpa
Trailing blackberry	Rubus vitifolius
Hazel	Corylus cornuta
Western dogwood	Cornus nuttallii
Ocean spray	Holodiscus discolor
Bigleaf maple	Acer macrophyllum
Douglas-fir	Pseudotsuga menziesii
Grand fir	Abies grandis
Lupine	Lupinus spp.
Huckleberry	Vaccinium spp.
Wild blue rye	Elymus glauca
Velvet grass	Holcus lanatus
Red fescue	Festuca spp.
Bromes	Bromus spp.

APPENDIX G

LEAF WATER CONDUCTANCE - Age classes

Age-class	Mean	Variance	Std. Dev.
0800 hours			
2-2	.0799	.0040	.0688
2-0	.0889	.0016	.0448
plug	.0754	.0014	.0408
3-0	.0429	.0003	.0213
2-1	.0355	.0004	.0220
1200 hours			
2-2	.0385	.0018	.0468
2-0	.0484	.0009	.0335
plug	.0545	.0024	.0530
3-0	.0200	.0001	.0130
2-1	.0174	.0000	.0100
1530 hours			
2-2	.0266	.0004	.0223
2-0	.0414	.0005	.0255
plug	.0433	.0005	.0257
3-0	.0174	.0001	.0122
2-1	.0121	.0000	.0040

APPENDIX H

XYLEM PRESSURE POTENTIAL - September 18, 1975 (-bars)

Age-class	Mean	Variance	Std. Dev.
0400 hours			
2-2	9.5	14.16	4.123
2-0	9.2	33.93	6.227
plug	9.1	12.31	3.790
3-0	11.1	69.05	8.975
2-1	9.7	18.06	4.590
0800 hours			
2-2	22.1	3.61	2.083
2-0	21.6	11.24	3.622
plug	23.9	10.53	3.505
3-0	22.1	33.35	6.174
2-1	22.4	7.36	2.973
1200 hours			
2-2	22.4	15.60	4.266
2-0	24.8	12.88	3.932
plug	21.8	10.30	3.432
3-0	26.0	61.75	8.608
2-1	24.5	15.25	4.277
1530 hours			
2-2	24.4	27.95	5.711
2-0	21.8	12.41	3.806
plug	21.3	4.26	2.307
3-0	19.9	8.38	3.128
2-1	23.9	16.36	4.431

APPENDIX I

XYLEM PRESSURE POTENTIAL - Treatment (-bars)

Plot	Mean	Variance	Std. Dev.
0400 hours			
1	8.5	14.4	4.00
2	9.2	7.4	2.85
3	6.6	2.9	1.79
4	19.6	44.1	7.43
0800 hours			
1	21.7	14.9	4.06
2	22.9	15.2	4.11
3	21.9	9.8	3.30
4	24.5	20.3	5.19
1200 hours			
1	22.6	11.3	3.55
2	26.8	35.9	6.31
3	21.9	19.9	4.70
4	23.5	2.2	1.80
1530 hours			
1	22.0	19.8	4.68
2	24.1	6.9	2.78
3	20.4	15.9	4.23
4	29.8	156.2	14.43

1 = Irrigation and herbicides
2 = Irrigation
3 = Herbicides
4 = Control

APPENDIX J

LEAF WATER CONDUCTANCE - treatments (cm/sec)

Plot	Mean	Variance	Std. Dev.
0800 hours			
1	.0895	.0024	.0526
2	.0456	.0003	.0192
3	.0702	.0028	.0567
4	.0407	.0001	.0119
1200 hours			
1	.0664	.0026	.0538
2	.0186	.0000	.0101
3	.0334	.0006	.0267
4	.0158	.0000	.0062
1530 hours			
1	.0425	.0007	.0282
2	.0165	.0000	.0072
3	.0308	.0005	.0241
4	.0187	.0001	.0112

1 = Irrigation and herbicides
2 = Irrigation
3 = Herbicides
4 = Control