AN ABSTRACT OF THE THESIS OF

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Title: STOMATAL ACTIVITY PATTERNS OF PROVENANCE PLANTATIONS OF ABIES CONCOLOR AND ABIES GRANDIS

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Dr. Donald B. Zobel

Seedlings from 25 provenances of Abies grandis and Abies concolor were studied at two plantations, 12 at Philomath, Oregon, and 13 at Camino, California. Native seedlings were studied at four of the provenances' field sites. Stomatal infiltration pressure measurements and plant moisture stress measurements were made throughout one summer on the plantation seedlings to identify their patterns of stomatal response to moisture stress. Stomatal distribution on the needle surface was used to determine the degree of resemblance of each provenance to the two Abies species. Seedlings from four provenances were also studied during December to determine which seedlings would retain the freshest Christmas tree characteristics after being cut, transported, stored and displayed, and whether their response could be predicted from stomatal behavior.

Three aspects of the stomatal response patterns differed from one provenance to another: (1) occurrence of daily stomatal closure or nonclosure, (2) time of closure and (3) degree of closure. The

stomata of the *Abies grandis* provenances tended to close daily while the stomata of *Abies concolor*-influenced provenances remained open during the day. The *Abies grandis* stomata also tended to close earlier in the day than those in provenances mildly influenced by *Abies concolor*, which did close daily to some degree. The provenances represented at Camino could be grouped as to their degree of stomatal closure. The members of each group were generally morphologically similar, indicating genetic relationship. The stomatal response data suggest that some genetic control of stomatal response to moisture stress does exist. These genetically controlled responses conceivably could affect the establishment of seedlings of certain genotypes in particular habitats.

The Christmas tree keepability experiment resulted in one provenance, 20, retaining its favorable characteristics relatively well, certainly better than the other provenances. Provenance 20 seedlings are, therefore, recommended to be used as Christmas trees due to their ability to retain fresh Christmas tree characteristics. Keepability was not predictable from the summer stomatal response, but was correlated with moisture stresses during display of the trees.

Stomatal Activity Patterns in Provenance Plantations of *Abies concolor* and *Abies grandis*

by

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STOMATAL ACTIVITY PATTERNS IN PROVENANCE PLANTATIONS OF *ABIES CONCOLOR* AND *ABIES GRANDIS*

INTRODUCTION

Abies grandis and *Abies concolor* have been shown to interbreed freely, producing intermediate populations. Morphological variation within these species is well documented. It has also been suggested, but not documented, that certain physiological variations, including stomatal response to moisture stress, also occur. It was my objective in this study to investigate to what extent stomatal activity patterns differ among *Abies grandis* and *Abies concolor* and their intermediates when they are grown in a common environment. From this I hoped to infer the degree to which stomatal reaction to plant moisture stress is genetically controlled. I also tested four provenances to determine if keepability could be predicted from stomatal activity patterns Keepability refers to the ability of a tree to retain fresh Christmas tree characteristics after being cut.

General distribution patterns of *Abies grandis* and *Abies concolor* have been outlined by several researchers (Daniels, 1969; Little, 1971; Liu, 1971; Griffin and Critchfield, 1972; Hamrick and Libby, 1972). *Abies grandis* is located in the middle elevations of the Rocky Mountains of northern Idaho and British Columbia and at lower elevations west of the Cascade Mountains in Washington and Oregon. The species also occurs along the northern California coast. Abies concolor occurs in southern Oregon, the higher elevations of the Sierra Nevada Mountains of California and south into Mexico. It also occurs in areas of Nevada, Arizona, Utah, Colorado and New Mexico (Figure 1).

Abies grandis is characterized by dark green needles with two broad, white bands of stomata on the abaxial surface. The tips of the needles are usually blunt and often notched. The interior periderm layers of the bark are reddish when cut. Abies concolor has needles that are dull green with two broad, white bands of stomata on the abaxial surface and, to a variable degree, stomata on the adaxial surface as well. Its periderm is yellowish when cut (Daniels, 1969).

This typical "textbook" manner of describing the distribution and characteristics of Abies grandis and Abies concolor does little to help the person who is aware of the considerable morphological variation that clearly exists within these two species; for example, the Sierra Nevada Abies concolor has been shown to be morphologically different from that of the Rocky Mountains (Hamrick and Libby, 1972).

The morphological variation of Abies grandis and Abies concolor throughout their ranges has been studied extensively. The most recent data describe patterns of variation which suggest that the two species interbreed freely in nature. Controlled crosses show that F_1

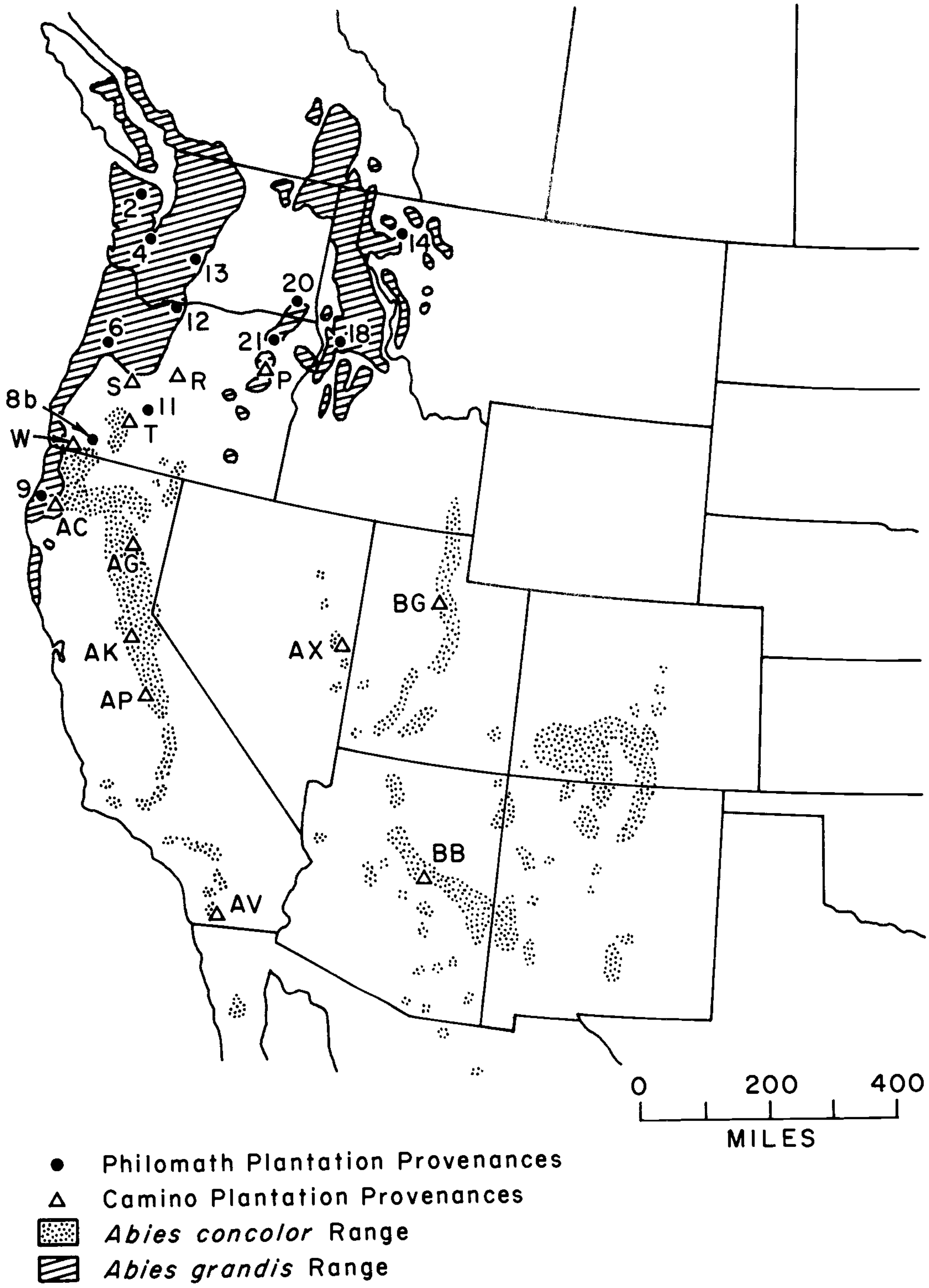

Figure 1. Geographic distribution of Abies concolor and Abies grandis, and location of provenances studied. Plantations studied were located approximately at Provenance 6 (Philomath) and Provenance AK (Camino).

hybrids are viable and can interbreed with other F_1 hybrid and parent trees. Daniels (1969) discusses variation and intergradation of Abies grandis and Abies concolor. He defines an area, from northwestern California through southwestern to northeastern Oregon and into central Idaho, in which intermediates between typical Abies grandis and Abies concolor occur (Figure 1). Hamrick and Libby (1972) investigated variation and selection in Abies concolor. They describe four major morphological divisions of the Abies concolor range. Because of my geographical location and because of this study's involvement with intermediate populations, of special importance to my study are division I (central Oregon and northwestern California) and division II (south-central Oregon and central and northeastern California). Hamrick and Libby suggest that the division I populations have resulted from the "hybridization and introgression" of the division II Abies concolor populations with Abies grandis. They go on to speculate that Abies grandis and Abies concolor may have evolved from a common ancestral taxon. More recently, as the ranges of the two species have come into contact, interbreeding and subsequent backcrossing have occurred, producing intermediate populations in parts of Oregon and northwestern California. Daniels (1969), Hamrick and Libby (1972) and Zobel (1973) have shown that needle morphology can serve as a convenient and reliable basis for establishing the degree of intermediacy of these populations.

The state of Oregon has been clearly defined as being the center of natural hybridization and introgression between *Abies grandis* and *Abies concolor* (Daniels, 1969). In the central Oregon Cascade Mountains, Zobel (1973) found that low elevation populations west of the Cascade crest resemble *Abies grandis*, while the high elevation, west-side populations occupying ridgetops and steep, dry slopes exhibit some traits of *Abies concolor*. East of the Cascades, the populations show greater influence of *Abies concolor*, but some variability does exist. The trees on north slopes tend to be more like *Abies grandis* and, on the south slopes, to be more like *Abies concolor*. Studies on plant moisture stress and stomatal closure by Zobel (1974) suggest that stomatal response patterns to plant moisture stress may also vary in these Oregon Cascade populations.

Researchers have described many examples of genetic variability within a species that enable that species to respond through the reproductive process to environmental selective pressures. These selective pressures encourage the establishment of local populations within a species that exhibit differing physiological characteristics. Such differences occur in *Pseudotsuga menziesii*, for example (Pharis and Ferrell, 1966; Ruetz, 1968). Foresters have realized for years that trees of a given species, originating from different locations in its range, exhibit different physiological characteristics. Seedlings grown for regeneration purposes from seeds collected in a particular seed zone are now planted back into that same zone at as close to the same elevation from which the seed was collected as possible. It is well known that seedlings generally grow best in the area in which the seed was collected. Christmas tree growers also recognize that the best Christmas trees seem to come from seeds collected in one particular area or another. Not only the appearance of the trees, but also their hardiness, disease resistance and other physiological characteristics, are affected (Douglass, 1972).

A pressure chamber and a stomatal infiltrometer were used extensively throughout this study and should be mentioned briefly. A pressure chamber measures the moisture stress a plant is experiencing (Scholander et al., 1965; Waring and Cleary, 1967). Generally, plant moisture stress is lowest just before dawn and increases throughout the day until it reaches a peak during the middle part of the day. A stomatal infiltrometer measures the pressure that is required to force a liquid, usually an ethanol solution, into the needle mesophyll through the stomata. A stomatal infiltrometer is used to measure the relative degree of openness of the stomata of a particular plant (Fry and Walker, 1966; Lopushinsky, 1969). Stomata tend to open and close in response to several factors, moisture stress being one major factor.

MATERIALS AND METHODS

Plant Materials

Stomatal Response Study

Two plantations were selected for use in this study. One plantation is located at about 1000 m elevation, about five km east of the Institute of Forest Genetics, which is operated by the United States Forest Service near Placerville, California (latitude 38° 45' N, longitude 120° 40' W). This plantation is referred to in the Institute's records as the *Abies concolor* Experiment 29, Camino Plantation III, 14 March 1966. I will refer to it as Camino. It was established as part of an *Abies concolor* seed source study by the Institute. The plantation is located on an old fruit orchard site and lies at the lower elevational limits of the *Abies concolor* range, but well within its limits of latitude and longitude. Thirteen of the provenances planted at Camino were used in this study (Table 1). Hamrick and Libby (1972) discuss seed collection, nursery procedures and plantation design in more detail. It is, however, important to note that the trees at Camino were raised from seed at the Institute and transplanted to their present site as two year old seedlings.

The second plantation is located at about 155 m elevation, 19 km south of Philomath, Oregon, within a Christmas tree plantation operated by the Holiday Christmas Tree Farms (latitude

Table 1. Provenances studied.

Camino Plantation			Philomath Plantation		
Provenance Designation	Seed Origin	Elevation (m)	Provenance Designation	Seedling Origin	Elevation (m)
P	Sumpter, Ore.	1500	2	Sequim, Wn.	500
R	Prineville, Ore.	1500	4	Olympia, Wn.	60
S	McKenzie Bridge, Ore.	1200	6	Corvallis, Ore.	200
T	Crescent, Ore.	1400	8b	Medford, Ore.	700
W	Cave Junction, Ore.	1600	9	Arcata, Cal.	200
AC	Salyer, Cal.	1600	11	LaPine, Ore.	1500
AG	Westwood, Cal.	1800	12	Mosier, Ore.	800
AK	Omo Ranch, Cal.	1300	13	Ellensburg, Wn.	1300
AP	Dinky Creek, Cal.	2200	14	Kalispell, Mont.	900
AV	Julian, Cal.	1700	18	Grangeville, Ida.	1100
AX	Baker, Nev.	2300	20	Pomeroy, Wn.	1400
BB	Young, Ariz.	2300	21	LaGrande, Ore.	1600
BG	American Fork, Utah	1700			

Provenances studied at each plantation and their geographical location. The provenance designations are those of the investigators who established the plantations.

44^{o} 25' N, longitude 123^{o} 25' W). This plantation will be referred to as the Philomath plantation. It was established by Bernard Douglass of the United States Forest Service, Region 6, as an *Abies grandis* provenance test to determine the best provenances for use as Christmas trees. Natural seedlings from field locations were transplanted to a nursery at Olympia, Washington in 1966 and 1967. In 1968 they were outplanted at Philomath. The Philomath plantation lies within the natural range of *Abies grandis* in the eastern foothills of the Oregon Coast Range. Twelve provenances at Philomath were used in this study (Table 1).

The provenances selected for study at the two plantations represent nearly the entire range of the *Abies grandis*-*Abies concolor* complex (Figure 1). However, in this study there is an intentional emphasis on the area where the two species intergrade, so the provenances selected provide as much overlap of populations between the two plantations as possible.

In addition to the plantation trees studied, provenances 6, 11, S and AK were studied in their natural habitats to determine how these trees were behaving in their natural environment during the same summer. It was hoped that there would be some correlation between the behavior of the trees of a given provenance in the field and in the plantation setting.

Keepability Study

A study was conducted as a continuation of the *Abies grandis* provenance test for Christmas tree characteristics being conducted by Bernard Douglass. This study was designed (1) to test for the overall capacity of provenances to retain fresh Christmas tree characteristics after being cut, transported, stored and displayed in simulated normal Christmas tree fashion and (2) to see if keepability might be predicted from summer stomatal behavior. Four provenances from the Philomath plantation were selected for study to represent various degrees of desirability as Christmas trees (Douglass, 1972), as well as representing a range of summer stomatal closure patterns. In Douglass' study, provenance 20 was ranked as the second best source for Christmas trees. Provenance 4 was ranked ninth, and provenance 11 and 6 were sixteenth and seventeenth, respectively. The summer stomatal behavior of each of these provenances will be discussed later.

Methods

Stomatal Response Study

It was hoped that each plantation could be studied at the beginning, middle and end of the summer of 1973. Due to rain during June, data were collected in Philomath only on July 10-14 (referred to as week II) and August 6-10 (week III). At Camino, data were collected on June 26-28 (week I), July 23-27 (week II) and August 26-28 (week III). During each week of data collection, measurements were made on four trees from each provenance at each plantation, except week III at Camino (three trees).

Stomatal infiltration measurements for each tree were taken at 2 to 2 1/2 hour intervals from approximately 0700 to 1600 hours using the technique of Fry and Walker (1966). Stark (1969) and Hinckley and Ritchie (1970) have shown that transpiration and stomatal aperture may vary throughout the height of Abies trees. Therefore, five needles from the top to the base of each tree were measured each time. Infiltration pressures (IP) were determined on year-old foliage from the shaded portion of the crown, since IP tends to vary less with time and place on that portion as compared to current-year needles or those taken from the sunny portion of the crown (Zobel, 1974). A 50 percent ethanol solution was used as the infiltrating solution. The pressure in the needle chamber was increased automatically at a rate of 0.07 bars sec^{-1}.

Plant moisture stress (PMS) was measured twice daily with a pressure chamber (Scholander et al., 1965; Waring and Cleary, 1967). The pressure in the chamber was automatically increased at a rate of 0.7 bars sec^{-1}. The first measurement was taken before dawn and is referred to as Predawn Moisture Stress (PDMS). It should be the minimum moisture stress experienced by the trees and is a function of the soil water potential. The second measurement, Midday Moisture Stress (MDMS), was taken on the shaded side of the tree at mid-afternoon and should represent the maximum moisture stress experienced by the trees.

Temperature and relative humidity were recorded continuously throughout each period of data collection, using a hygrothermograph (with a hair humidity sensor) placed on the ground in an instrument shelter. These two environmental factors are commonly measured and correlated with stomatal activity (Hodges, 1966; Stark, 1969; Hinckley and Ritchie, 1970).

Needle morphology and sample tree height were determined as additional information important to this study. Ten needles from throughout the crown of each of the plantation trees were collected and observed. Measurements taken were (1) maximum number of stomatal rows on the adaxial surface of the needle and (2) the percentage of the length of the adaxial surface of the needle bearing stomata. The data on maximum number of stomatal rows were later converted to a percentage value of the highest number of rows that was counted. Mean values for both (1) and (2) were calculated and plotted for each provenance to determine the degree of intermediacy of each provenance.

Total height after the 1972 growing season, and the length of new growth during the 1973 growing season were recorded at Camino during August 26-28, 1973 and at Philomath on November 29, 1973.

Data from field site trees of provenances 11, S and AK were taken from ten trees at each site and at provenance 6 from nine trees during only one day at each site. Measurements were taken at Crane Prairie (11) on August 16, at McKenzie Bridge (S) on August 17, at Philomath (6) on August 20 and at Sly Park (AK) on August 27. With the exception of needle morphology, the same data were collected at these sites as were collected at the plantations.

Keepability Study

An attempt was made to simulate normal treatment of Christmas trees during cutting, storage and home display. Dr. Melvin J. Conklin[1] (1972 and personal communication) provided considerable assistance in this matter.

Twelve trees, three from each of the four provenances being studied, were cut from the Philomath plantation on December 6, 1973. They were transported by truck to a field where they were stored out-of-doors for seven days. The weather was rainy for most of that time. PMS measurements were taken on December 7 and December 9, during outdoor storage. From December 13, 1973 until January

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[1] Personal communication, 1973, Oregon State University, Corvallis.

3, 1974 (21 days) the trees were kept indoors in an upright position. They were not watered during this period. The temperature was maintained relatively constant, averaging 20°C (68°F) at night and 21°C (70°F) during the day. The only lighting in the room was provided by overhead flourescent lights which were left on for eight hours during the day.

During the 21 days of indoor storage, the trees were weighed periodically with an overhead Mettler balance to determine moisture loss. Using this set up, the trees were allowed to hang freely from the balance. At the end of the study, a mean total percent loss in weight was calculated for each provenance.

Needle drop was determined each day. The trees were dropped three times from a height of approximately 12. 7 cm (5 inches). The needles that fell off the trees were collected, weighed, dried at 70°C (158°F) for about 48 hours and reweighed. This procedure provided data for the calculation of percent water content of needles and fresh needle drop.

Frequently throughout the 21 days, PMS and IP measurements were taken with a pressure chamber and a pressure infiltrometer, respectively. No particular time of day was established for taking these measurements since the time of day seemed to have no effect on the results. The weight of the twigs used for PMS measurements and the needles collected after the needle drop procedure were taken into account in calculating weight loss of the trees.

Needle color was quantified on the third and twenty-first days of the indoor test period. Color of two needles from each of five branches on each tree were determined as Hue/Value/Chroma (Munsell, 1968). A mean hue change for each provenance for the test period was then calculated.

RESULTS

Stomatal Response Study

Needle Morphology

The scatter diagram of needle characteristics (Figure 2) illustrates that some provenances have few stomata on the adaxial surface, in terms of percent length covered by stomata and maximum number of rows, which is characteristic of Abies grandis (Daniels, 1969). These trees are located in the lower left portion of the diagram. Pure Abies concolor provenances are found in the upper right portion of the diagram. They possess more stomata on the adaxial needle surface according to both characteristics measured. Lying diagonally between these two portions of the diagram are several provenances with intermediate needle characteristics.

Provenances S, P, T and R in the Camino plantation are strongly characterized by Abies grandis features, with provenance W also being considerably influenced. Provenance S is particularly close to being pure Abies grandis. Philomath provenances 11 and 21, and to a lesser degree 20 and 13, display tendencies toward Abies concolor. Provenance 11 is most strongly influenced by Abies concolor. The presence of intermediate characteristics in these provenances was expected from earlier work (Daniels, 1969; Hamrick

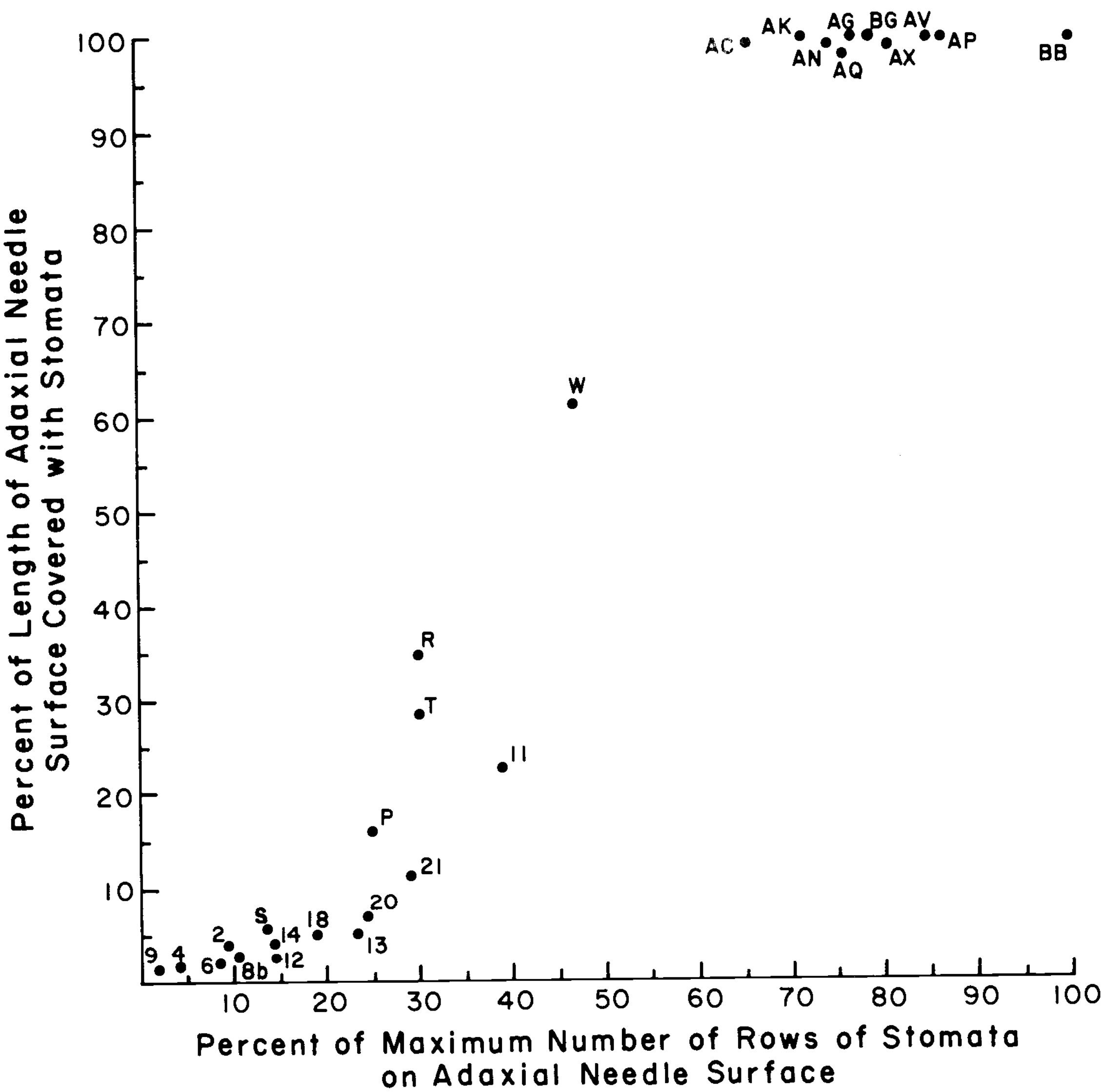

Figure 2. Scatter diagram of needle characteristics for provenances studied. The provenances located in the lower left corner of the diagram more strongly resemble *Abies grandis* while the provenances in the upper right corner more strongly resemble *Abies concolor*.

and Libby, 1972; Zobel, 1973).

Height Measurements

Height measurements at Camino (Table 2) show that Oregon provenances (P, R, S, T and W) and those from the intermountain region (AX and BG) grow slowly in the California climate; this is reflected by both total height and the 1973 growth. As could be expected, the more local provenances (AK and AG) grew rapidly. Provenances AC, AV and BB likewise grew well. Interestingly, BB surpassed all the other provenances in height even though it is not from the Camino area.

Philomath trees exhibited relatively more uniform heights. These heights do not indicate the true growth potential of these trees since they are sheared each year in preparation for their eventual use as Christmas trees.

At the field sites, sample trees were selected to be comparable in height to the plantation trees (Table 2). No age data were taken.

Environmental Factors

Maximum temperatures were quite similar at Camino and Philomath during the corresponding times of the summer (Table 3). Daytime relative humidities were also similar. Night-time low temperatures were higher at Camino, but only slightly. However, a

Table 2. Mean sample tree heights.

	Camino Plantation 1973 Summer Growth (cm)		Camino Plantation Total Height (cm)		Philomath Plantation	Total Height (cm)		Field Sites	Total Height (cm)	
Provenance	Mean	Range	Mean	Range	Provenance	Mean	Range	Location	Mean	Range
P	19.3	15-29	81.0	67-92	2	171.8	161-190	Crane Prairie	215.0	50-350
R	20.8	11-29	86.0	53-104	4	203.3	172-222	McKenzie Bridge	150.0	75-300
S	22.5	11-32	79.8	44-108	6	196.3	167-212	Philomath	272.2	75-550
T	23.8	12-32	127.0	68-157	8b	180.3	160-201	Sly Park	119.1	71-275
W	27.3	22-32	107.8	71-145	9	185.5	153-245			
AC	37.0	25-43	149.3	95-199	11	134.8	75-178			
AG	38.5	24-49	154.8	125-175	12	192.8	184-207			
AK	41.0	23-50	140.5	109-161	13	184.8	139-214			
AP	32.8	26-43	119.0	84-145	14	157.0	129-172			
AV	38.0	29-49	133.8	107-165	18	194.8	186-210			
AX	21.0	19-25	86.5	67-110	20	196.3	139-214			
BB	39.8	20-50	199.8	106-270	21	95.5	69-111			
BG	19.0	16-20	79.8	63-89						

Summary of height measurements taken on trees studied at Camino, Philomath and the field sites. Measurements at Camino were taken from August 26 to August 28, 1973. Measurements at Philomath were taken on November 29, 1973. Measurements on the field site trees were taken on the same day the other data were taken at each location. The relatively uniform height of trees at Philomath is due to summer shearing.

Table 3. Weather conditions.

A. Plantation	Date	Mean Temperatures (°C) High	Low	Mean Relative Humidity (%) High	Low	Mean Vapor Pressure (mm Hg) High	Low	Skies
Camino	June 26-28	35.7	18.2	78	28	662	186	Clear
Philomath	July 10-14	33.2	12.1	89	24	563	111	Clear
Camino	July 23-27	32.3	12.9	69	26	530	120	Clear
Philomath	Aug. 6-10	28.8	10.0	99	34	414	93	Clear
Camino	Aug. 26-28	27.2	12.8	72	34	370	118	Clear

The weather conditions were measured at each plantation during each test period throughout the summer.

B. Field Location	Date	Mean Temperatures (°C) High	Low	Mean Relative Humidity (%) High	Low	Mean Vapor Pressure (mm Hg) High	Low	Skies
Crane Prairie (11)	Aug. 16	27.8	8.9	42	31	385	84	Clear
McKenzie Bridge (S)	Aug. 17	21.1	7.2	78	33	234	72	Clear
Philomath (6)	Aug. 20	22.2	<8.9	>81	34	255	< 84	Clear
Sly Park (AK)	Aug. 27	21.1	7.2	86	40	234	72	Clear

The weather conditions for the field sites were measured on the one day that tests were run on the field site trees at each location.

large difference in maximum night-time relative humidities was measured, Camino having a consistently lower reading than Philomath. This lower night-time relative humidity should have placed greater stress on the Camino trees than the Philomath trees.

Temperature and relative humidity at the field sites showed great variability during the measurement periods (Table 3). Sly Park (AK) experienced the highest temperatures and the lowest relative humidities of all the field sites. Undoubtedly, this environment placed great stress on the trees growing there during the day of measurement. At the opposite extreme, at McKenzie Bridge (S), the lowest temperatures and the highest relative humidities were measured. Philomath (6) and Crane Prairie (11) had temperatures and relative humidities somewhat intermediate, with Philomath (6) having slightly higher daytime temperatures and also higher night-time relative humidities. At all locations, the skies were consistently clear and sunny with, at the most, only scattered clouds.

Plant Moisture Stress

At the Philomath plantation, the mean PDMS ranged from 6.4 to 8.7 bars during week II and increased to 7.7 to 12.0 bars during week III (Table 4). The mean MDMS during week II ranged from 13.5 to 16.8 bars and increased to 16.2 to 18.3 bars during week III.

Table 4. Philomath Plantation plant moisture stress data.

Provenance	Pre-Dawn Moisture Stress (bars)				Mid-Day Moisture Stress (bars)			
	July 10-14		August 6-10		July 10-14		August 6-10	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
2	6.9	5.1-9.3	7.7	6.9-9.0	16.6	15.6-17.3	17.7	15.9-19.7
4	8.0	5.6-11.0	8.3	7.6-10.7	15.3	13.8-17.9	17.2	16.2-18.9
6	7.6	5.9-9.2	10.7	6.6-13.8	16.8	15.9-18.9	18.1	15.9-20.7
8b	7.8	6.9-9.0	10.2	7.9-12.6	15.9	13.8-17.3	17.8	16.6-19.4
9	6.8	5.1-7.9	7.7	5.9-9.7	13.8	12.0-16.6	17.2	15.9-17.9
11	7.1	4.5-10.4	10.1	6.6-15.6	15.4	13.8-17.3	18.1	16.6-21.0
12	6.6	5.1-7.6	8.2	6.6-9.7	14.4	13.8-15.1	16.2	15.1-17.9
13	7.5	5.8-9.0	9.0	7.6-10.0	16.1	14.8-18.3	16.9	16.6-17.9
14	8.4	5.8-11.0	9.2	6.6-12.8	16.2	14.5-17.6	17.8	15.9-18.9
18	8.7	7.6-9.7	10.8	9.7-11.7	16.1	13.8-17.4	17.7	16.6-18.6
20	6.4	4.8-7.9	9.3	5.9-10.0	13.5	12.8-14.5	16.7	15.6-17.9
21	7.6	5.8-9.0	12.0	7.9-14.5	15.5	13.8-16.9	18.3	16.9-18.9
Plantation Averages	7.4		9.5		15.5		17.5	

Pre-dawn and mid-day plant moisture stresses experienced during the test periods throughout the summer by trees studied at the Philomath Plantation. Each mean represents four trees.

Zobel (1974) observed similar increases in PMS from early to late summer at his Oregon field sites in 1971 and even larger increases in 1970.

Trees at Camino did not exhibit similar increases in PDMS and MDMS (Table 5). Surprisingly, the Camino PDMS remained consistently lower than the mean PDMS at Philomath throughout the entire summer. MDMS at Camino also did not rise significantly higher than the MDMS at Philomath (Table 5). The PMS of the individual provenances at each plantation were very similar to the other provenances at the same plantation.

PMS measurements on trees at the field sites demonstrated that the McKenzie Bridge (S) trees were under the least stress, Crane Prairie (11) and Philomath (6) were intermediate, and Sly Park (AK trees, on a rocky south-facing ridgetop) were under considerable stress (Table 6). Since all field site measurements were taken within eleven days, environmental differences, and not a time lapse effect, probably were the major cause of the differences measured. From the one-time measurements, no conclusions can be made regarding seasonal fluctuations at the field sites.

Stomatal Infiltration Patterns

IP measurements suggest the existence of three types of variability in stomatal patterns. The first can be referred to as a "daily

Table 5. Camino Plantation plant moisture stress data.

Provenance	Pre-Dawn Moisture Stress (bars)						Mid-Day Moisture Stress (bars)					
	June 26-28		July 23-27		Aug. 26-28		June 26-28		July 23-27		Aug. 26-28	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
P	5.7	5.1-6.2	5.3	4.5-6.2	5.5	5.1-6.2	16.7	16.2-17.3	15.1	13.8-17.3	13.8	12.9-14.8
R	6.2	4.8-7.2	5.9	4.8-6.6	6.2	4.8-7.6	16.0	14.5-17.6	14.8	12.8-15.9	14.3	8.2-15.9
S	6.6	5.9-6.9	8.0	5.9-10.0	7.1	6.6-7.9	16.0	14.5-16.9	17.5	15.9-20.4	15.8	9.3-16.6
T	5.9	5.1-6.6	5.3	4.8-5.9	5.7	4.8-5.9	15.3	14.5-16.2	16.0	15.1-17.3	12.3	10.4-13.8
W	5.9	5.1-6.2	5.8	5.6-5.9	5.9	5.4-6.2	15.7	14.8-16.2	16.4	15.1-18.6	15.2	13.8-16.6
AC	6.6	4.5-8.7	5.2	4.1-6.2	6.0	4.8-7.2	15.7	14.5-17.3	17.0	15.9-18.6	14.1	12.8-14.8
AG	6.1	5.6-6.9	5.7	5.1-6.6	6.2	6.2-6.2	15.3	13.8-17.3	15.6	13.5-19.7	14.3	11.7-15.9
AK	5.9	4.8-6.9	6.5	4.5-6.9	5.5	5.6-5.6	16.6	15.1-17.9	16.0	14.8-16.9	13.8	8.7-14.8
AN	6.4	6.2-6.6	-	-	-	-	15.3	14.8-16.6	-	-	-	-
AP	6.6	6.2-6.9	6.0	4.1-7.2	5.5	4.5-6.6	15.4	13.1-17.3	16.4	14.8-19.4	15.3	14.8-15.9
AQ	7.3	5.1-8.7	-	-	-	-	17.0	15.6-18.9	-	-	-	-
AV	7.4	6.6-8.2	5.8	4.8-6.6	7.1	6.9-7.2	15.7	14.1-17.3	16.6	14.8-17.9	14.3	13.8-14.8
AX	6.6	5.9-7.6	5.9	4.8-6.6	6.2	4.8-7.6	16.7	14.5-19.4	17.4	15.1-19.7	14.8	14.5-15.1
BB	5.8	4.8-7.2	5.7	4.8-6.9	5.2	4.5-5.9	17.3	13.5-19.7	15.5	13.5-18.9	15.2	10.1-16.2
BG	6.4	5.6-7.2	6.5	4.5-8.7	5.6	4.8-6.9	17.4	14.5-19.7	19.3	18.3-21.4	17.2	16.9-17.8
Plantation Averages	6.4		6.0		6.0		16.2		16.4		14.6	

Pre-dawn and mid-day plant moisture stresses experienced during the test periods throughout the summer by trees studied at the Camino Plantation. Each mean represents four trees except for August 26-28 which represent three trees.

Table 6. Field site plant moisture stress data.

Field Location	Date of Sampling	Pre-Dawn Moisture Stress (bars)		Mid-Day Moisture Stress (bars)	
		Mean	Range	Mean	Range
Crane Prairie (11)	August 16	9.4	4.5-12.4	16.6	12.7-21.4
McKenzie Bridge (S)	August 17	5.8	3.1-9.3	14.4	11.4-17.9
Philomath (6)	August 20	10.1	4.1-18.9	16.4	10.4-25.2
Sly Park (AK)	August 27	17.5	15.2-23.1	19.4	18.3-25.5

Pre-dawn and mid-day plant moisture stresses experienced during the test periods in the summer by trees at the field sites. Means represent nine or ten trees.

closure versus nonclosure" pattern. Provenances 11 and 21 in the Philomath plantation behaved somewhat differently than the other provenances at Philomath during week II and very differently during week III. All provenances closed during midday as PMS increased (Figures 3 and 4). However, the stomata of provenances 11 and 21 remained more open when compared with the others. Provenances 20 and 8b also consistently closed less, but their patterns were not as extremely different as those of provenances 11 and 21.

At Camino, provanance S consistently behaved differently than the other provenances. Its stomata tended to be open during the morning and closed later in the day as PMS increased (Figures 5, 6 and 7). Its pattern closely resembled those of most of the trees at Philomath. However, it differed markedly from the patterns of the other provenances at Camino, which displayed a consistent non-closure pattern, even better defined than that of provenances 11 and 21. Provenance BB opened and closed periodically throughout the day during the three weeks of data collection in no detectable pattern.

Of the field site populations sampled, only the Philomath site (6) displayed a distinct variation in IP (Figure 8). Even its variation was slight when compared to the plantation closure patterns. All other field site trees showed no variation. It should be noted that the Sly Park (AK) and Philomath (6) field site trees exhibited high IP throughout the entire day. Apparently, their stomata remained

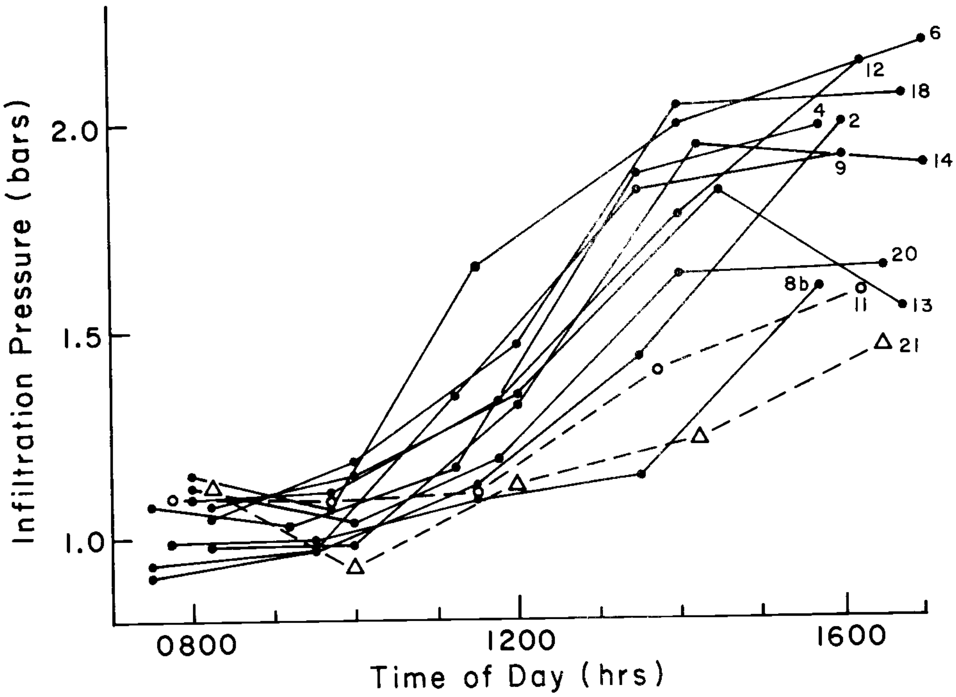

Figure 3. Average stomatal infiltration pressures of provenances studied at the Philomath plantation during the test period of July 10-14.

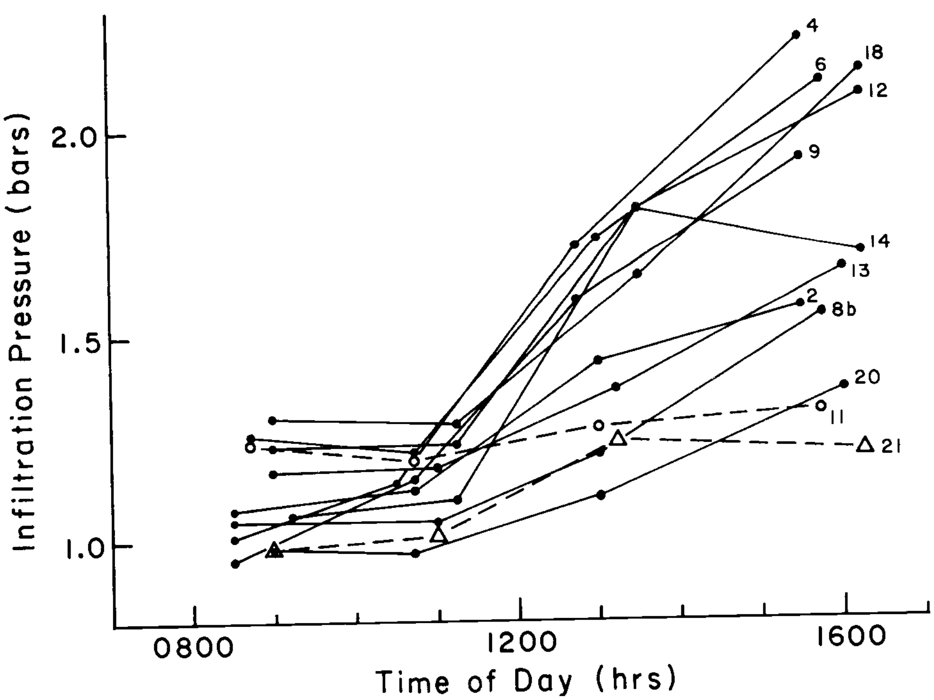

Figure 4. Average stomatal infiltration on pressures of provenances studied at the Philomath plantation during the test period of August 6-10.

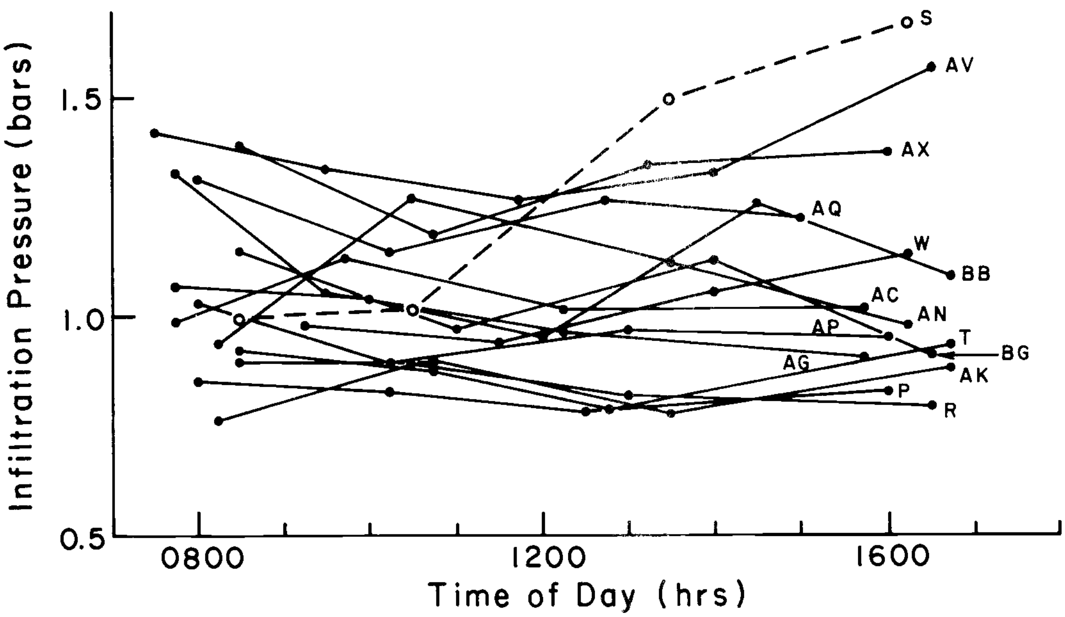

Figure 5. Average stomatal infiltration pressures of provenances studied at the Camino plantation during the test period of June 26-28.

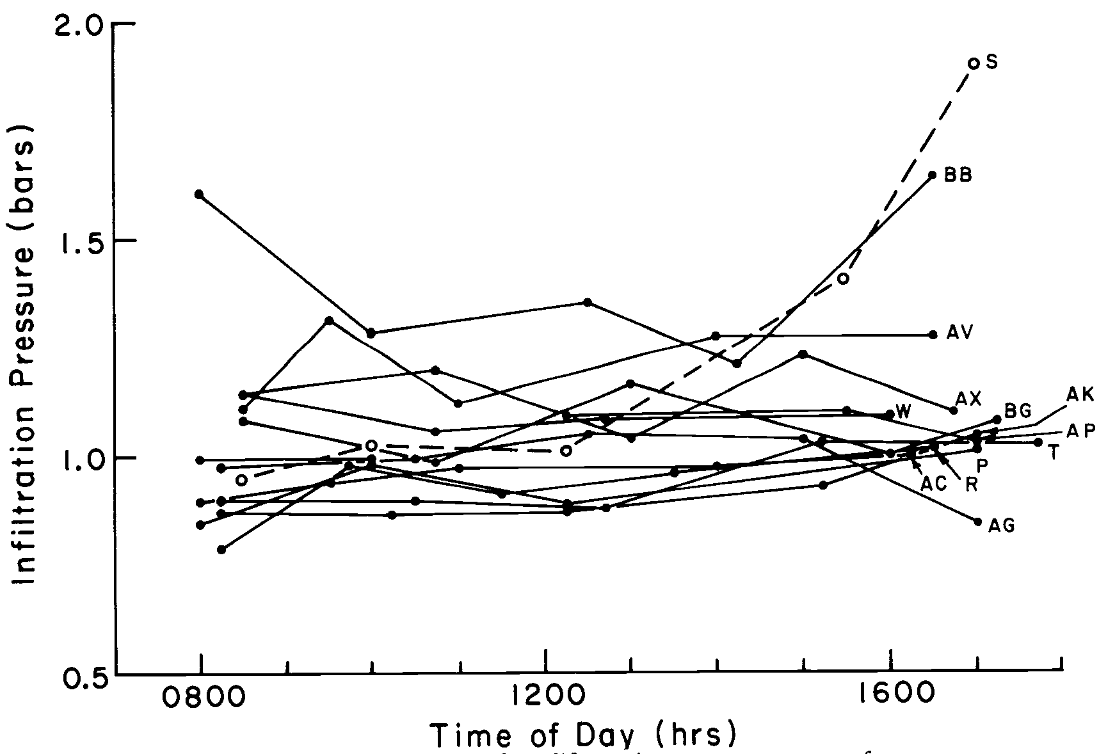

Figure 6. Average stomatal infiltration pressures of provenances studied at the Camino plantation during the test period of July 23-27.

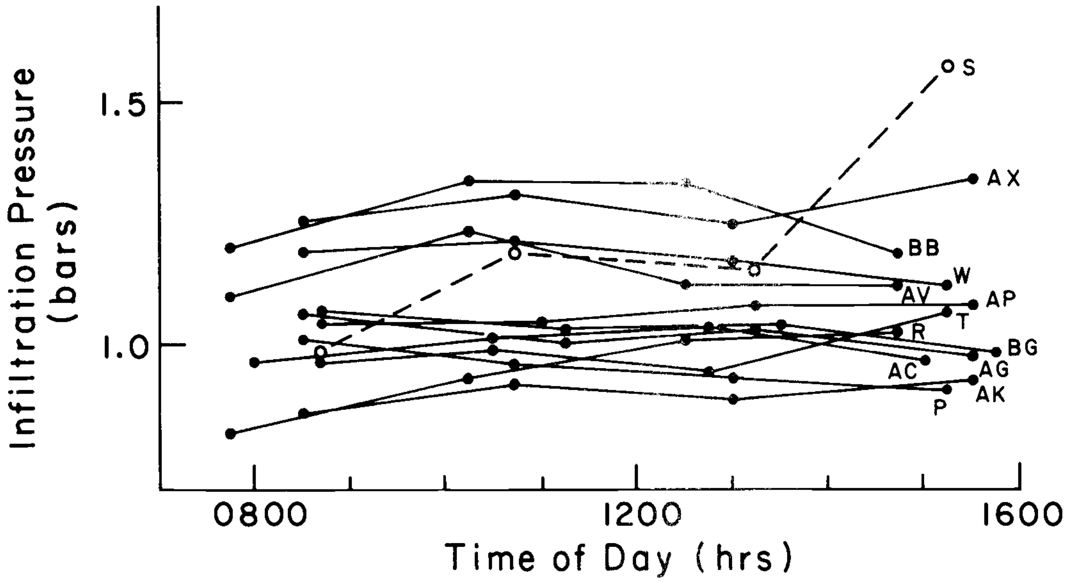

Figure 7. Average stomatal infiltration pressures of provenances studied at the Camino plantation during the test period of August 26-28.

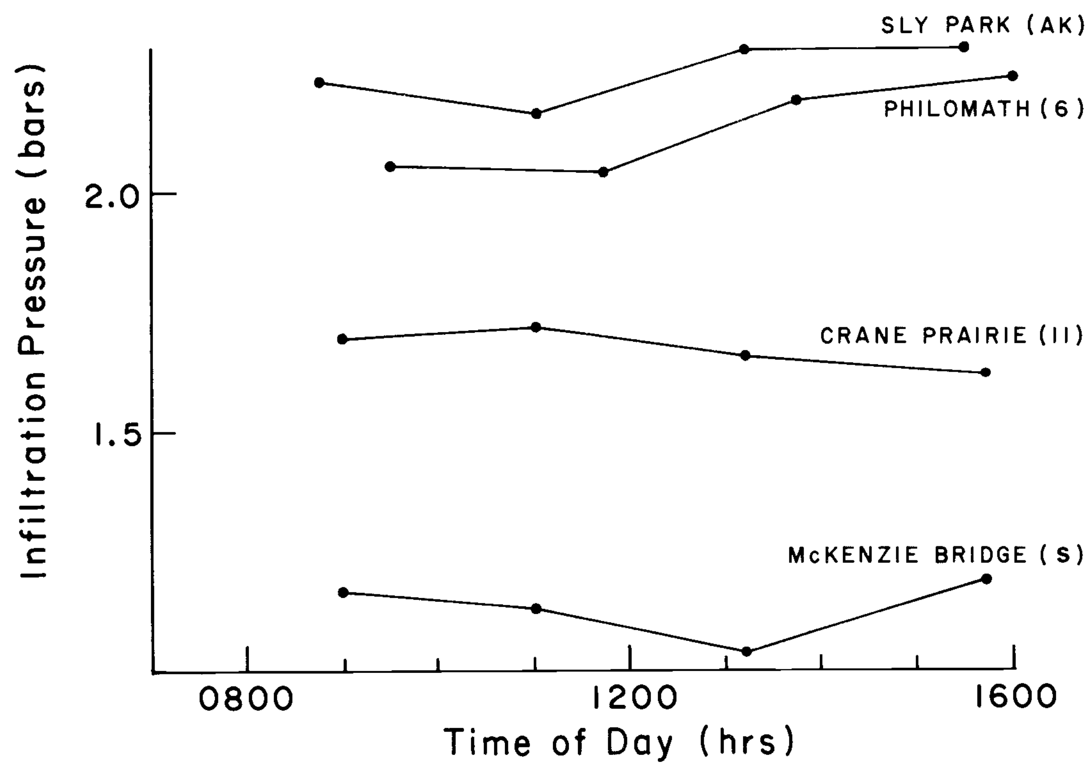

Figure 8. Average stomatal infiltration pressures of field location trees. Samples were taken on a single day at each field location between August 16 to August 29.

almost closed during the day, thus allowing little or no daily fluctuation of IP.

The second aspect of variability in stomatal patterns is the "time of closure" pattern. Although provenances 20 and 8b did exhibit more stomatal closure than provenances 11 and 21, along with the other Philomath provenances, they consistently closed later than the others. This late closure and the final intermediate tightness of closure of provenances 20 and 8b suggest a greater degree of tolerance to PMS than the other Philomath provenances except for provenances 11 and 21.

Provenances' stomatal activity patterns varied in a third aspect, their "degree of closure." It was most evident at Camino. Provenances AK, P, T and R had consistently lower IP throughout the day than the other Camino provenances. Provenances BB, AX and AV had consistently higher IP than the others. Intermediate between these extremes were AC, AP, BG and AG, with provenance W lying between the higher and intermediate IP groups. Provenance S, which displayed daily closure, was among the lower IP provenances in the morning and then closed in the afternoon even tighter than the higher IP provenances.

At Philomath, the pattern was somewhat more complex. In the mornings, provenances 9, 8b, 14 and 2 had the lowest IP during weeks II and III. Provenances 18, 13, 11, 12 and 6 had the highest morning IP. In the afternoons, provenances 12, 6, 4 and 18 closed the tightest. As discussed earlier, provenances 21, 11 and 20 consistently closed the least.

At the field sites, there was a definite order of the IP. Sly Park (AK) had the highest IP throughout the day as might be expected from the high PMS. Philomath (6) was slightly lower. Crane Prairie (11) was significantly lower than Philomath (6) and McKenzie Bridge (S), with the lowest PMS, was much lower than Crane Prairie (11).

The three stomatal response patterns discussed above, "daily closure versus nonclosure," "time of closure" and "degree of closure," are convenient descriptions of the general tendencies observed. At Philomath, where all three patterns were observed, there is a complete gradient of responses within each pattern. However, the tendencies of each provenance can be described by the three patterns.

Keepability Study

By the end of the twenty-first day of indoor storage, calculations of percent water loss from each tree and percent water content of needles remaining on each tree showed that provenance 20 retained water the best, followed by provenance 4 (Table 7). Overall percent weight loss suggests that provenance 6 lost more water than

Table 7. Christmas tree characteristics data.

Provenance	Mean Total % Loss in Weight	Mean Final % H_2O Content of Needles	Mean Total Dry Weight of Needle Drop (gm)	Mean Color Change (Hue)
20	39.7	13.1	27.0	2
4	44.7	5.3	12.4	4
6	46.9	2.0	51.9	4
11	48.8	4.5	152.2	5

Miscellaneous data taken on three trees of each provenance during the keepability study to quantify the changes observed from the beginning to the end of the study.

provenance 20 and 4 but less than provenance 11. However, percent water content of needles (Table 7) shows that needles of provenance 11 had more moist needles than provenance 6. Both sets of data demonstrate that provenance 20 retained more water than the other three provenances.

Needle retention data proved to be as variable as Conklin (1972) reported. Mean weight of needles lost (Table 7) clearly suggests that provenance 11 dropped more needles than the other provenances. Such a conclusion is not totally correct since great variation occurs within provenances. One individual tree from provenance 11 dropped over 400 grams of needles while the other two trees dropped less than 20 grams. The provenance 4 trees dropped fewer needles than the other provenances with one tree dropping 26 grams and the other two dropping 11 and 10 grams. Needle drop from the three provenance 20 trees were 17, 53 and 11 grams. Provenance 6 trees dropped 93, 44 and 18 grams of needles. More trees would be needed to determine any significant difference between provenances. However, from these data, it is fairly clear that provenance 4 dropped the least needles.

An attempt was made to strip the needles from each tree to allow needle drop to be reported as a percent of total needles on each tree. Unfortunately, the needle collecting technique proved to be so difficult and time consuming (with the collected needles containing much foreign material) that it was terminated after completing five trees. One tree of provenance 20 dropped 0.9% of its needles, one tree from provenance 4 dropped 0.8%, one provenance 6 tree dropped 1.2% and two provenance 11 trees dropped 1.6% and 54.1% of their needles. This procedure shows potential and it is suggested that if attempted, the trees should be dried until the needles fall off easily when being stripped.

Differences between provenances in color change of needles were evident (Table 7). Needles from each of the provenance 20 trees faded by 2.5 hues (7.5GY to 5GY) while each provenance 11 tree faded by five hues (7.5GY to 2.5GY). Both provenance 4 and 6 had two trees which faded by five hues (7.5GY to 2.5GY) and one tree which faded by 2.5 hues (7.5GY to 5GY) for an average change of 4.2.

IP measurements taken 24 hours after the trees were brought indoors showed that stomata on all trees were tightly closed; they remained closed throughout the entire test period.

PMS data (Table 8) indicated differences between provenances. On day three, PMS measurements for all trees were nearly the same, but by day 13 and day 14, differences were evident. Provenance 20 had the lowest PMS, followed by provenance 4 and 6, and then provenance 11. On day 19, all provenances had PMS above 65.5 bars except for provenance 20 which was 49.4 bars. By day 22, all trees

Table 8. Keepability moisture stress data.

Provenance	Moisture Stress Means (bars) on Selected Days					
	Day 3	Day 8	Day 13	Day 14	Day 19	Day 22
20	15.3	25.3	32.9	35.5	49.4	>65.5
4	15.5	23.7	36.1	41.2	>65.5	>65.5
6	16.1	23.9	39.2	40.3	>65.5	>65.5
11	16.1	27.4	43.2	49.2	>65.5	>65.5

Summary of moisture stress data taken daily during the keepability study. Day 3 represents December 9, 1973, the third day after the trees had been cut.

were above 65.5 bars.

Before concluding this experiment, general observations were made of the trees and a ranking system was established. Top ranking trees were those whose needles retained a fresher appearance and feel. From these observations, the top five ranking trees were, in order, from provenances 20, 11, 20, 20 and 4. All the other trees were distinctly more poorly preserved. One tree from provenance 11 was by far the poorest, having lost over half of its needles.

DISCUSSION AND CONCLUSIONS

When considering the results of this study, it is important to understand that the trees studied at the Philomath plantation were transplanted as seedlings from the woods where they had naturally established. The morphological and physiological characteristics observed for each tree should represent typical characteristics that could be observed in trees still located at the original collection site of each provenance. The natural selection process had already been at work on these seedlings.

The trees at Camino were started in the plantation beds from seeds that were collected in the woods. Thus, they should exhibit a broader spectrum of characteristics than what the natural selection process would allow to survive. At Camino, the potential characteristics of the provenances are being observed more than the characteristics that naturally exist, as is the case at Philomath.

The measurements on the individual trees within the provenances were not identical. The individual measurements did, however, follow the same general patterns that are reported as means for the provenances. Because of the consistency of the general patterns of the individual trees of a provenance and because of the overall correlation of the results from this study at Philomath, Camino and the field sites, I do not think the nursery establishment procedures affected my results. However, care should be taken not to consider the results of this study as being definitive of what occurs in the natural habitats.

The use of pressure infiltrometers for measuring stomatal aperture, as was done in this study, involves some uncertainties. Some studies suggest that in true firs mesophyll resistance may play a major role in total leaf resistance (Lopushinsky, 1969; Running, 1973). It has been argued that since pressure infiltrometers only measure stomatal opening, they would not reflect this major influence, reducing the value of their readings. However, other data demonstrate that a reasonable correlation exists between IP and transpiration and net assimilation and that, in *Abies procera* in particular, changes in stomatal resistance as measured by a pressure infiltrometer are associated with changes in both transpiration and net assimilation (Fry and Walker, 1966; Hinkley and Ricthie, 1972; Reed and Waring, 1974; Zobel, 1974). Regardless of the exact role stomata play in leaf resistance, IP is a useful measurement in that it does reflect a response of the plant to PMS.

For this current study, the pressure infiltrometer was used because we were interested in changes in stomatal opening in response to PMS and were not trying to measure total leaf resistance. The infiltrometer provided the quick, portable and widely used method of measuring stomatal aperture that was required for this study.

The pressure chamber was used in this study to determine the moisture stress levels to which the trees were exposed during the tests. The pressure chamber is commonly used to measure plant moisture stress (Scholander et al., 1965; Waring and Cleary, 1967) and is a good indicator of plant water potential of woody species if certain precautions are observed (Boyer, 1967; Kaufmann, 1968; Ritchie and Hinckley, 1971). Water potential has generally been accepted to have an influence over guard cell turgor and, in turn, over stomatal aperture. Lopushinsky (1969), Barker (1973) and Zobel (1974) have shown that a definite stomatal response to changes in PMS exists in *Abies grandis* and *Abies concolor*, in at least some circumstances. The pressure chamber data can thus be used to assist in the understanding of the stomatal activity patterns observed.

No rain fell after mid-June at either Camino or Philomath. Relative humidity and temperature data, however, suggest that the Camino trees should have been under more stress than the Philomath trees. Such was not the case. The PMS measurements were very similar at Camino and Philomath. The unexpectedly low PMS at Camino can be partially explained in that the Camino site was once an orchard and the soil is deep and fertile (L. C. Johnson,[2] personal

[2] L. C. Johnson is curator of the Institue of Forest Genetics, Placerville, California.

communication, 1973). Also, the trees were watered during their first few years in the field, probably leading to the establishment of deep and extensive root systems.

Stomatal Response Study

Ample evidence exists which demonstrates that trees originating in different sites and trees of different species respond differently to various environmental influences (Pharis and Ferrell, 1966; Ruetz, 1968; Unterscheutz, 1969; Unterscheutz et al., 1974). Zavitkovski and Ferrell (1968) showed that physiological processes such as respiration, transpiration and photosynthesis in Pseudotsuga menziesii seedlings originating in a xeric environment respond differently to drought than do those processes in trees originating in a mesic environment. Lopushinsky's (1969) and Barker's (1973) studies show that Abies grandis and Abies concolor respond differently than other species in their stomatal response patterns to moisture stress. They suggest that Abies grandis and Abies concolor are quite insensitive to high PMS with stomata closing slowly at very high PMS. Zobel (1974) found differences in stomatal activity patterns between populations of Abies grandis and Abies concolor trees at several locations in Oregon and raised the question as to whether or not the observed differences were of genetic origin or simply controlled by the environment. My data do suggest that some genetic control of stomatal activity patterns exists in provenances of Abies grandis and Abies concolor. The provenances studied that were more heavily influenced by Abies concolor tended to have stomatal activity patterns which responded less to daily increases in PMS; the stomata tended to remain open throughout the day at the PMS levels they experienced. Provenances of, or resembling, Abies grandis, on the other hand, seemed quite sensitive to PMS. They exhibited daily closure patterns. Unfortunately, only mild PMS was experienced by all the plantation trees during testing (Tables 2, 3).

The stomatal activity patterns of 11 and 21 were different than the others at Philomath. They exhibited a nonclosure stomatal activity pattern while the other provenances exhibited definite daily closure patterns (Figures 3 and 4). Both provenances 11 and 21 originated on the east side of the Cascade Mountains and they are the provenances at Philomath most strongly influenced by Abies concolor (Figure 2).

At the Camino plantation, provenance S was the only one that showed any consistent tendency toward stomatal closure (Figures 5, 6 and 7). Provenance S originated from the west side of the Cascade Mountains in a region occupied by populations strongly resembling Abies grandis. Of all the provenances located at Camino, it has the needle characteristics most like Abies grandis (Figure 2).

Lopushinsky (1969) found that the stomata of his Abies grandis remained open until a PMS of 25 atm was reached. Barker (1973) found that the stomata of his Abies concolor remained open throughout the day, but they only experienced a PMS of 15 atm. Zobel (1974) found that the stomata of his typical Abies grandis trees closed on days when MDMS was as low as 9 bars. His Lookout population with a mild Abies concolor influence exhibited stomatal nonclosure early in the summers of 1970 and 1971 even though the MDMS reached 20 bars in 1970. However, late in both summers, the stomata exhibited daily closure patterns even though MDMS was as low as 12 bars in 1971. Zobel's populations most resembling Abies concolor, BBN and BBS, exhibited daily stomatal nonclosure patterns when exposed to about 15 bars MDMS. The stomata of my Abies grandis trees closed when MDMS was about 15 bars and the stomata on trees resembling Abies concolor remained open at about 15 bars MDMS.

Analysis of the results of these several studies on stomatal response patterns of Abies grandis and Abies concolor suggests that, with the exception of Lopushinsky's study, a general trend may exist. Lopushinsky's trees, however, originated from eastern Oregon and Washington and were likely to be at least mildly influenced by Abies concolor (Daniels, 1969; Figure 1). His results, then, would be consistent with the others.

It is difficult to correlate the field site data with the plantation data since PMS varied so much between the individual sites and the plantations. The Sly Park trees, representing typical Sierran *Abies concolor*, exhibited very little change in IP during the day at a MDMS of 19.4 bars. However, the PDMS was at 17.5 bars and the IP was high all day. The stomata may have simply remained closed all day. Crane Prairie trees, from a zone of intergradation between species, exhibited stomatal nonclosure at a MDMS of 16.1 bars. The IP was low so it appears that the stomata remained open. The trees at McKenzie Bridge, in an area with a slight *Abies concolor* influence (Zobel, 1974), also exhibited daily stomatal nonclosure at a MDMS of 14.0 bars; this is in contrast to their behavior in the plantation where the PMS was comparable. The only field site trees to exhibit daily stomatal closure were from the Philomath site. They exhibited a slight stomatal closure pattern at the MDMS of 15.9 bars. However, like Sly Park, the IP was high throughout the day. We may infer that the stomata were almost closed in the morning and the slight increase in IP reflected the final closing of the stomata. The field data are consistent with the data discussed earlier in that the typical *Abies grandis* trees did exhibit some stomatal closure while the others did not. However, stomatal closure at McKenzie Bridge, expected from the behavior of provenance S, did not occur.

Provenance BB is from an area strongly influenced by Abies concolor; however, its IP patterns are not similar to either Abies concolor or Abies grandis trees. Its IP varies in no consistent pattern. The provenance may have its own unique responses to PMS which are not similar to the other Abies concolor studied. This is possible since the provenance originated from a fairly isolated area of Arizona where some characteristics could have evolved without interference from the rest of the species. However, the reliability of the IP results for provenance BB could be questionable. The needles are covered with an unusually heavy coating of wax which made it difficult to see the end points of the infiltration measurements.

The daily Δ PMS (MDMS minus PDMS) for the provenances and the absolute PMS values at Camino and Philomath were very similar for all the provenances studied. Therefore, the differences in the stomatal response patterns of the different provenances could not be correlated with differences in PMS or Δ PMS.

In conclusion, the data suggest that trees closely resembling Abies grandis tend to exhibit daily stomatal closure while a mild to strong Abies concolor influence, as reflected in needle morphology, is accompanied at low moisture stress by a lack of daily stomatal closure. This conclusion elaborates my earlier statement that some genetic control over stomatal response to PMS in Abies grandis and Abies concolor populations does exist.

The "daily closure versus nonclosure" stomatal response pattern is not the only stomatal activity pattern in which differences between provenances occur. Provenances 20 and 8b at Philomath consistently exhibited later stomatal closure ("time of closure" pattern) than the other provenances at Philomath. As illustrated by the scatter diagram in Figure 2, both are very weakly influenced by Abies concolor. That small amount of Abies concolor influence may be resulting in more moderate or slower stomatal closure in these two provenances.

The "degree of closure" stomatal activity pattern is somewhat associated with the geographical origin of the provenances, which in turn is associated with the needle morphology. Provenances AK, P, T and R all had consistently low IP throughout the day at Camino. AK is the only provenance among these four that is not from the Oregon-Northwest California Zone, as described by Hamrick and Libby (1972). However, all four do exhibit more Abies grandis influence than most of the other Camino provenances that exhibited daily stomatal nonclosure. The provenances with consistently high IP were BB, AX and AV. Both provenances BB and AV are from the South California-Arizona Zone. AX is in the East Nevada-West Utah Zone. All three are similar morphologically and very strongly

Abies concolor by both Hamrick and Libby's data and my data. Provenances AC, AP, AG and BG all are in an intermediate category of "degree of closure." AP and AG are in the Sierra Nevada-Northeast California Zone, with AC and BG being in two other zones. Provenances AP, AG and BG are morphologically similar by both Hamrick and Libby's and my data. They lie on the scatter diagram between the provenances that exhibit low IP and those that exhibit high IP. Provenance AC does not fit nicely into this morphological grouping. Provenance W also does not fit into the described group patterns. Its "degree of closure" ranges between the intermediate and high IP pattern provenances and yet morphologically it should be grouped with the low IP provenances from the Oregon-Northwest California Zone. The "degree of closure" groupings may indicate differences in the ability of the groups' stomata to be infiltrated by the solution or the groups' stomatal response patterns. Whatever causes these different stomatal infiltration patterns, it appears that there is a geographical and genetic basis for the differences.

Keepability Study

In his study of Christmas tree characteristics, Bernard Douglass of the U. S. Forest Service summarized his initial observations by ranking the various provenances as to their desirability (Douglass, 1972). Provenance 20 was ranked second, provenance 4 was ranked ninth, provenance 11 was ranked sixteenth and provenance 6 was ranked seventeenth of the 22 provenances studied.

The results of my keepability study support Douglass' conclusion that provenance 20 should be ranked the highest for desirability of the four provenances I studied. It ranked first in all but one of the six tests conducted, in which it ranked second. Provenance 4 exhibited the second highest keepability in all tests except the one in which it ranked first, just ahead of provenance 20. It is more difficult to rank provenance 6 and 11. Three of the six tests, including the final observations, rate 6 above 11. Two of the tests rate 11 above 6. The PMS results rate the two virtually equal.

I had hoped that after ranking each of these four provenances for keepability, I would be able to use the summer stomatal activity patterns to establish some method of predicting Christmas tree keepability characteristics in Abies grandis. I could determine no correlation between stomatal response and keepability. Provenance 11 exhibited stomatal nonclosure and provenance 20 exhibited slow and moderate stomatal closure. Both of these stomatal response patterns suggest a certain degree of drought resistance. However, provenance 11 ranked in last place for keepability while provenance 20 ranked first. Provenance 4 and 6 both exhibited strong daily stomatal closure patterns, but provenance 4 ranked much higher than provenance 6 for keepability.

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