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Title: EFFECTS OF THERMOPERIOD ON THE EARLY GROWTH OF RED ALDER FROM DIFFERENT ELEVATIONS AND GEOGRAPHIC SOURCES

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This study was designed to help elucidate what differences, if any, exist within the species Alnus rubra Bong., grown naturally at various elevations and locations throughout the Pacific Northwest and coastal Alaska. Increasing importance of the species, including both economic and silviculture values, prompted the investigation into the early growth of red alder, an area in which detailed information is lacking.

Two areas of investigation that were established included, first, an elevational transect from Newport to Marys Peak in the Coast Range of Oregon and, second, a study of ten geographic sources located throughout the range of Alnus rubra. Both phases of this investigation were conducted under three growth regimes involving the use of a 16 hour photoperiod and three thermoperiods (day-night

temperatures are: 21°, 16°C; 10°, 10°C and 21°, 21°C).

The Transect Study showed differences between red alder conelets (weight and size) and seeds (weights and germination) from different elevations to be significant at the 1% level. The effect of the lower thermoperiod (10°, 10°C) in reducing the rate of germination was also shown. No significant differences were found between seedlings representing the various elevations. in other characteristics (height, diameter and leaf dimension).

The Geographic Study, involving wildlings supplied by the U. S. Forest Service, was concerned primarily with seedling height growth and leaf size. Significant differences were found between seedlings from different geographic locations but, because of the limited number of seedlings available, the reliability of the data to accurately express variation between these locations is questionable. The effect of thermoperiod within a single tested environment was also significant but with results that were opposite to those obtained in the Transect Study. In the Geographic Study the height growth of seedlings under the cold condition (10°, 10°C) was significantly greater than for seedlings grown under the other growth conditions. In the Transect Study, the seedlings grown under the cold condition were significantly shorter than those grown under the other regimes.

Effects of Thermoperiod on the Early Growth of Red Alder from Different Elevations and Geographic Sources

by

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INTRODUCTION

Throughout the world the forest resource is being drawn upon at an ever increasing rate. The constant demand for new and better forest products requires a continuing search into the opportunities for more intense use of world timbers. Research involving little known forest trees as well as popular species is needed if supply is to keep pace with demand.

For many years the United States has depended upon the timber resource of the Pacific Northwest to supply the major portion of its wood product needs. Many of the conifers from this region, especially Douglas-fir, are well known and have been studied for years. The species oftentimes neglected on the forested slopes of the Pacific Northwest are the hardwoods. These broadleaved trees which make up to 2% (51) of the overall forest are receiving more and more attention. As a wider range of uses is found for structural lumber and new wood properties are discovered, the role of hardwoods will reach new limits. For reasons such as these, a more "in depth" understanding of these often slighted trees has become a necessity. This paper is concerned with a study of one such tree--red alder (*Alnus rubra* Bong.).

Called the "great imitator," because of the ease with which it can be made to look like other woods, red alder is the most predominant hardwood tree in the Pacific Northwest and coastal Alaska. Oregon alone has 10 billion board feet of mature red alder saw timber (51). Not only of growing economic importance, red alder also appears to be of significant value in the biological community of the forest as it has been found to be a nitrogen fixing non-legume (47).

With red alder, however, there is a lack of basic information concerning the reproductive cycle, early growth, and relationships to other plant and animal life. Through a suggestion by the U. S. Forest Service, it was decided to conduct a study, under laboratory conditions, of the early growth of red alder. Such fundamental knowledge is needed if management of this species, indeed of the total forest environment, is to be effective.

In simplest terms, this study has been designed to help elucidate what differences, if any, exist within the species, Alnus rubra Bong., grown naturally at various elevations and locations throughout the Pacific Northwest and coastal Alaska.

LITERATURE REVIEW

Geographic Distribution

The genus Alnus B. Ehrh., a name derived from the Celtic, having reference to the growth of these trees along streams, is a member of the Betulaceae (birch family), one of the two families of the order Fagales (12). Having a place in the Eocene and Miocene forests of the Tertiary period of the old and new world, the members of this genus are quite ancient (14).

The alders, consisting of about 30 species of trees and shrubs, are found in swamps and on river bottom-lands as well as in high mountainous sites. They are chiefly distributed in the Northern Hemisphere and in the Andes Mountains of Peru, Bolivia and northern Argentina (37, 52). Little (27) lists nine principal members of the genus Alnus which are either native or naturalized species in the United States.

Genus Alnus B. Ehrh.

A. glutinosa (L.) Gaertn.	European alder
A. maritima (Marsh.) Muhl.	seaside alder
A. oblongifolia Torr.	Arizona alder
A. rhombifolia Nutt.	white alder
A. rugosa (Du Roi) Spreng.	speckled alder
A. serrulata (Ait.) Willd.	hazel alder

A. sinuata (Reg.) Rydb. Sitka alder

A. tenuifolia Nutt. thinleaf alder

A. rubra Bong. red alder

According to a classification established by the Society of American Foresters (40), red alder is the major hardwood of three cover types in Western North America--Red Alder (Type 221), Sitka Spruce (Type 223) and Sitka Spruce-Western Hemlock (Type 225). It is also found occasionally in Spruce-Brich (Type 202) and in Black Cottonwood-Willow (Type 222). Geographically speaking, *Alnus rubra* is found throughout the Pacific coast region of the United States and Canada. From its northern limit on the shores of Yakutat Bay in southeastern Alaska to its southern extreme, the canyons of the Santa Inez Mountains of Santa Barbara County in California, red alder can be found along stream banks and bottom-lands (37). Extending from latitude 60° southward to latitude 34°, red alder is ordinarily found within 100 miles of the coast and at elevations not exceeding 2500 feet. However, red alder does occur along streams in northern Idaho (50). Figure 1 shows the range of this species as it occurs naturally in the western United States.

Biological Comments

Red alder is the largest member of the genus Alnus and has a maximum age of approximately 100 years. On better sites maximum

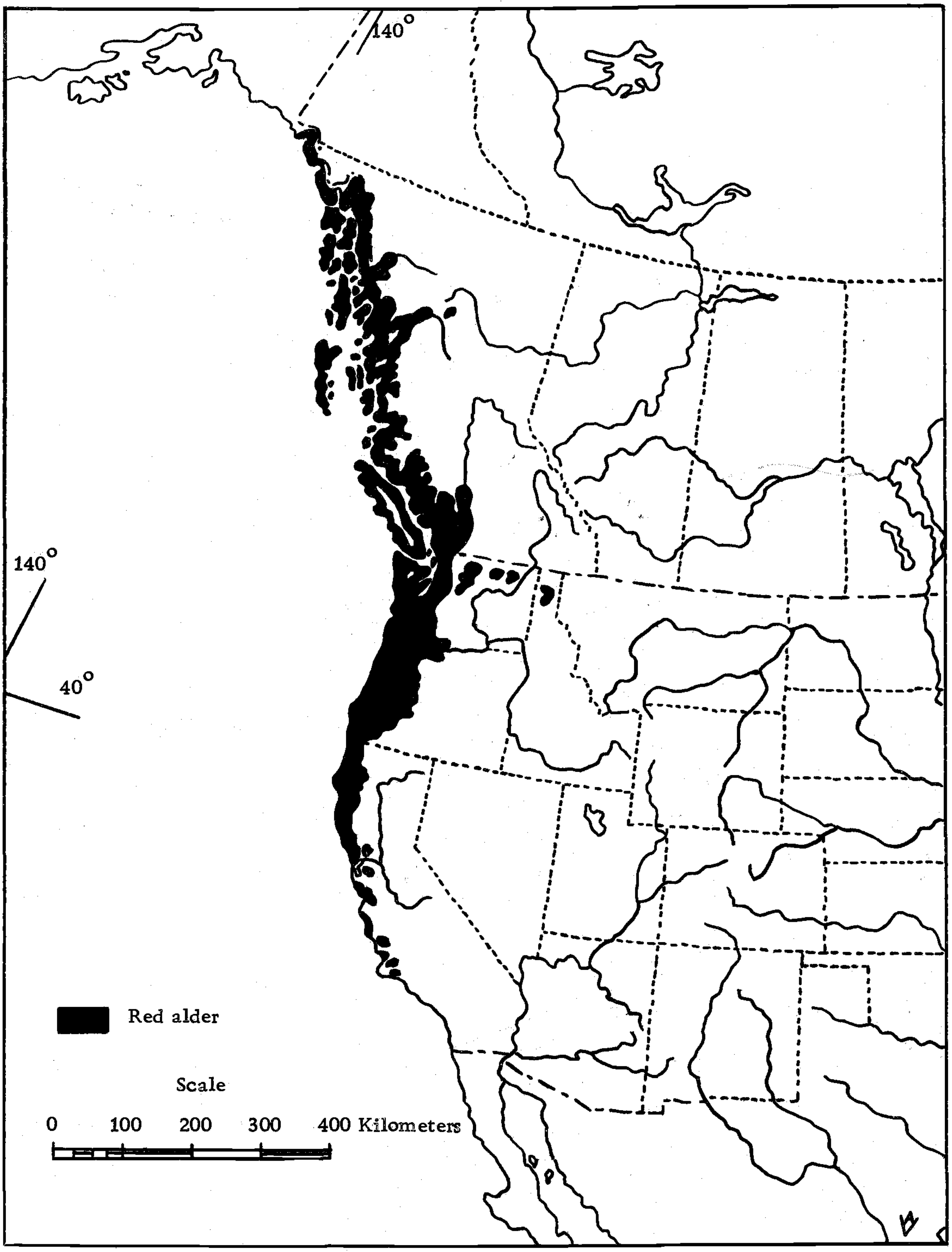

Figure 1. The range of red alder (Alnus rubra Bong.)

tree size is 24 to 36 inches in diameter and 65 to 100 feet in height. On better sites of red alder stands, maximum volume (800 to 1,500 board feet per tree) is reached in 50 to 70 years (20, 50). Pomeroy and Dixon (33) have reported the largest red alder on record to be 52.5 inches in diameter and 92 feet in height.

The leaves of this gray barked species range from 7.6 to 15.2 cm long and 3.8 to 7.6 cm wide. They have an acute apex and an obtuse or rounded base. Roughly elliptical in shape, red alder leaves have doubly serrate-dentate margins. The upper leaf surface is glabrous or glabrate and dark green in color. The pale lower surface has a rusty pubescence on the midrib and principal veins (17). Johnson (20) points out that bud and leaf size, leaf shape and pubescence are variable and should not be considered reliable identifying features. The illustration in Figure 2 shows the shape of the normal leaf of red alder.

In the spring, the monoecious flowers of red alder are produced in catkins which were formed the preceding season. These staminate catkins occur in small tassel-like clusters, 12.7 to 15.2 cm long and approximately 0.6 cm thick (43, 57). The brown conelets, containing 50 to 100 small, flattened nutlike seeds, vary from 1.3 to 2.5 cm in length and from 0.8 to 1.3 cm thick at maturity (50).

The production of seed in red alder begins at approximately 10 years of age and becomes optimum at about 25 years. A rather

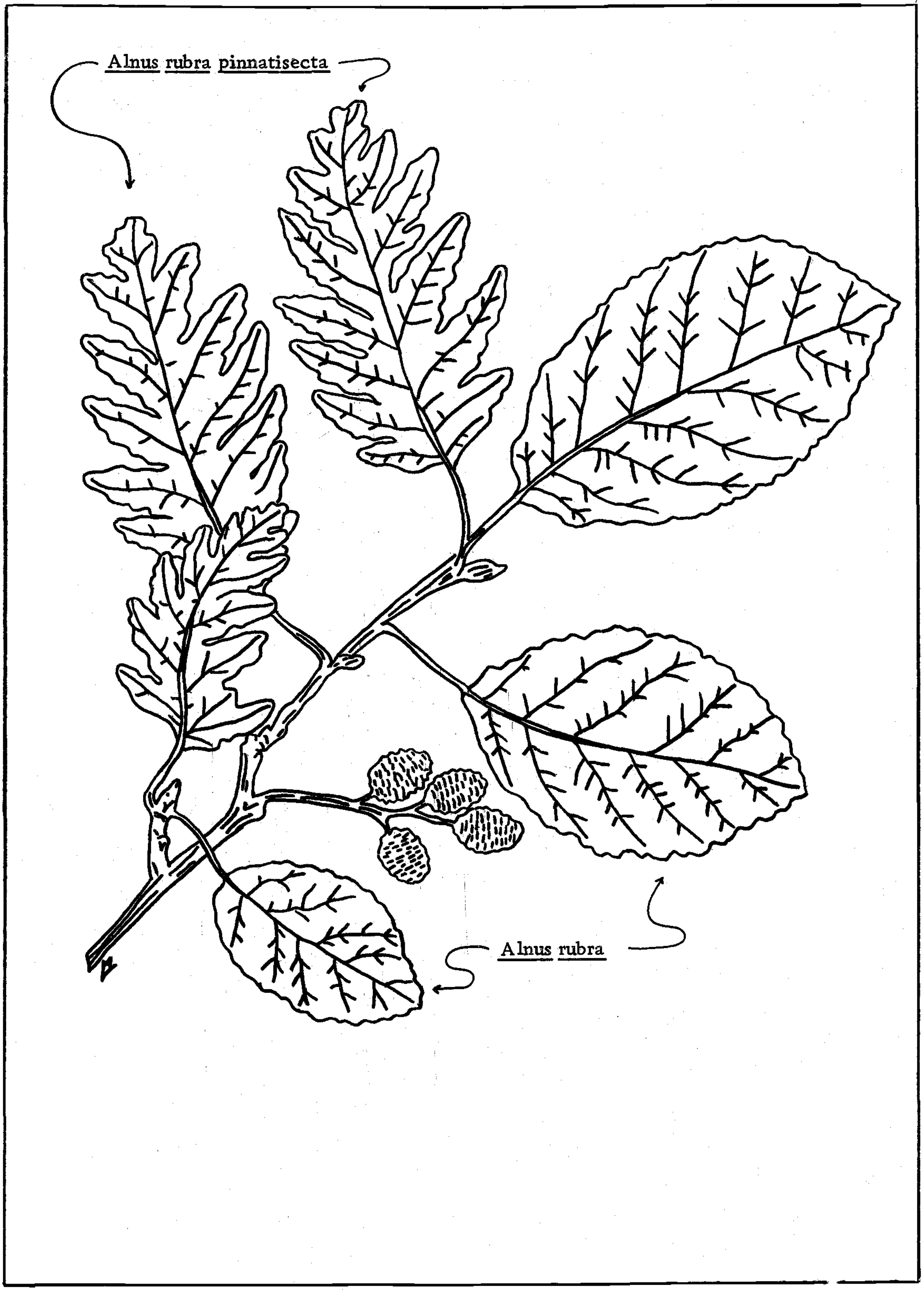

Figure 2. A branch of the genus Alnus showing leaves of Alnus rubra Bong. and its variety, Alnus rubra Bong. pinnatisecta. (Note: These two leaf types are shown on the same branch for illustrative purposes only. They have not been found this way in nature.)

prolific seed producer, red alder bears good seed crops about every fourth year. Averaging 666,000 seeds per pound, red alder seed is wind dispersed after conelets ripen in September (50, 57). Although mineral soil is best suited for germination, red alder seedlings can become established in litter (22).

In a study involving European alder (A. glutinosa), Enescu (11) found that, under favorable conditions, ripe seed germinates within 6 days. At temperatures exceeding 35°-36° C, viability is destroyed. He has also shown that A. glutinosa seed cannot germinate in the dark, and will lose its viability if kept in the dark for more than 45-50 days. The stimulating effect of alternating temperatures can, to a slight degree, compensate for lack of light (10).

Ruth (35, 36) has reported on the germination of artificially sown Alnus rubra seed on mineral soil. His studies indicate a low efficiency for alder establishment under a forest canopy. In one case, the seed-to-seedling ratio was 31 viable seeds to one established seedling. In another instance the ratio was found to be 46.7 viable seeds per seedling.

Although little work has been done on the storage of Alnus species, seeds can apparently be kept in good condition for at least 2-3 years under cold, dry conditions in sealed containers (18). Vincent's study (53) of A. glutinosa demonstrated that the germination capacity of seeds stored in bottles at 2°-4° C for 3 years remained essentially unchanged. He also recommended that to avoid damage by mould formation, the seeds should be dried for 48 hours at 30° C and bottled immediately.

There is some controversy concerning the tolerance of red alder to solar radiation. Most of the work on the tolerance of red alder to light has been summed up in the U.S.D.A. Handbook No. 271 (50), which describes the species as being quite intolerant. Baker (2) found it difficult to determine the tolerance of red alder and classified it as very uncertain. Ruth (36) showed that red alder appears to have at least some shade tolerance during its first and probably second growing season. He found that natural alder became established on mineral soil under dense timber stands and that neither the maximum nor the final number of alder seedlings per acre seemed to be related to solar radiation. A sharp reduction in height growth of red alder at high levels of solar radiation was also reported by Ruth (35). This is not what might be expected of an intolerant tree. Ruth pointed out that this reduced growth might have been caused by either an increase in radiation, a decrease in soil moisture or a combination of both.

Economic and Silvicultural Values

The uses of red alder are quite varied. Lumber, veneer, paper pulp and chemical derivatives head the long list of commercial products. The hardwood industry in Oregon has potential for substantial growth and action has been taken to revise federal policies that would offer more alder for sale.

Yoho, J. G., et al. (59) reported that red alder saw log production increased seven times and pulpwood eight times between 1953 and 1964. Furthermore, they noted that the total annual output for Oregon and Washington is presently over 80 million board feet of saw logs and over one half-million cords of pulpwood.

Although the physical properties of red alder are desirable for lumber production, pulpwood has been the more important product for about 15 years. Although standard sulfate and sulfite processes are used to pulp most alder, other research is being conducted to discover new and better methods. Such investigations include the neutral sulfite semichemical process by Worthington et al. (58) and Hansen's (16) two-stage high yield sulfite pulping process.

The future of red alder production and utilization depends on broader national and world markets. The high rate of economic growth on the west coast, together with a stabilized alder lumber and wood products industry makes the outlook promising.

There are special features of the genus Alnus which, because of their effect on the ecosystem, are becoming increasingly important. Worthington (57) noted the beneficial effects of the alders to the fertility of the forest through their nitrogen-fixing nodules. He also pointed out that alder leaves help build humus thereby increasing the moisture holding capacity of the soil.

There have been a number of studies made involving the contribution of red alder to soil fertility (4, 46, 47, 57). Nitrogen and organic matter have been found to be significantly greater in mixed alder and Douglas-fir stands than in pure Douglas-fir stands (48). Tarrant (45) has shown that there is definite improvement in the growth of Douglas-fir in mixed alder-fir stands as compared to pure Douglas-fir stands. He also noted that fungi are more numerous in the soil beneath pure fir stands. The presence of the alder apparently influences the ability of fungi (i.e., species of the genus *Poria*) to grow and thrive as they do in pure stands of Douglas-fir. Li, C.Y., *et al*. (24, 25) suggest that *A. rubra* mixed with Douglas-fir may be of potential value in the biological control of *Poria weirii*. The growth of this root pathogen is inhibited by linoleic acid, a lipid produced by alder.

Varieties and Hybrids

A rare variety of red alder (*A. rubra pinnatisecta*) has been discovered at four different locations. These include one area in Snohomish County, Washington; two widely separated points on Vancouver Island and a fourth area on a farm near Portland, Oregon. The leaves of this variety are deeply pinnately lobed having 5-7 pairs of oblong lobes (13, 50).

Starker (42) describes seven different trees, varying in height from 2 to 15 feet, growing with numerous other red alder trees bearing regular leaves. The irregularly shaped leaves were minutely pubescent beneath with the margins more or less serrate to dentate. The leaf shape is nearly ellipsoid and is slightly narrowed at the apex (Figure 2). The catkins and bark of this variety are similar to red alder. *Alnus glutinosa* and *Alnus incana* have similar varietal forms.

Swedish scientists have crossed *Alnus rubra* with *Alnus glutinosa*. Their main objectives were to increase height growth and improve stem form. The resultant hybrids did exceed *A. glutinosa* in height growth (50, 57).

METHODS AND PROCEDURES

This study was divided into two phases based on different material under investigation. The first phase is concerned with materials collected from an East-West transect through the Coast Range of Oregon. The second phase involves geographical source material obtained from a red alder provenance test currently being conducted by the U. S. Forest Service, involving seedlings collected from Alaska, British Columbia, Idaho, Washington and Oregon.

Phase I: Transect Study

The Newport-Marys Peak transect was chosen because it has two important characteristics. The first is that it extends through a wide belt of forest land which contains a high percentage of alder. The second characteristic is that the transect includes Marys Peak, the highest point in the Coast Range. All possible elevational sources in the Coast Range can be found on this transect.

From January through March, 1969, red alder conelets were collected from 5 separate trees, within a 1 acre plot, at each of 7 preselected 500 foot elevational changes, beginning at 0 elevation near Newport, up to 3000' elevational level below Marys Peak. Because of the possibility that red alder might not be found exactly on this specific line at the particular elevation needed, a transect width of 4 air-miles (i.e., 2 air-miles on each side of the center line) was established (Figure 3).

The red alder conelets were allowed to dry in paper bags, at room temperature, for one week to facilitate seed extraction. The seed was then placed in glass bottles which were in turn sealed and put in cold storage (1.7° C). The seed from each tree was stored separately by elevational source.

This phase of the project was subdivided into 3 areas of examination: A. Conelet, B. Seed, and C. Seedling.

Conelet

A random sample of 100 empty conelets per elevation (20 conelets per tree) were weighed and a second random sample of 50 empty conelets (10 conelets per tree) were measured as to length and width using a set of hand calipers. Color differences between conelets from the various elevational sources were also recorded. Color determinations involved a random sample of 100 conelets for each elevation.

Seed

Seed weights and color observations were made on June 2, 1969. Fifteen samples of 100 randomly selected seeds each, were weighed for each elevational source. The fifteen samples included three lots

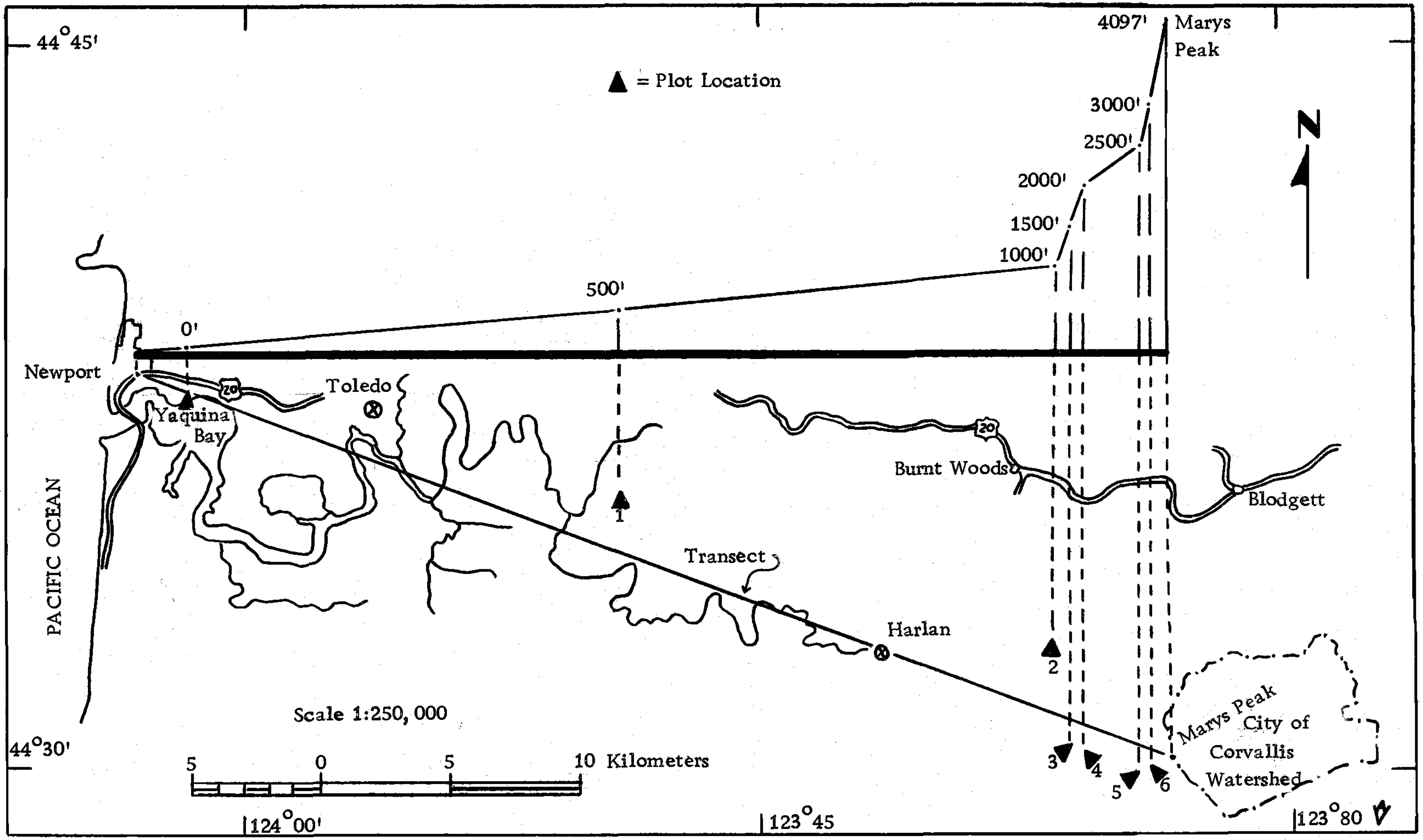

Figure 3. Transect Study. Red alder plot locations showing elevational proximities.

of 100 seeds for each of the five trees selected for each elevation.

On June 3, 1969, seed from each tree was pooled by elevational source. The seed pool was used to help reduce the chances of poor viability which might have arisen if only one of the 5 parent trees were selected to represent each elevation in the study.

On June 9, four replications (4 samples) of 100 seeds, representing each elevational source, were allowed to germinate on moist filter paper in sandwich boxes containing vermiculite. This germination test was repeated under 3 separate conditions (Table 1). No attempt was made to stratify the seed.

Table 1. Growth conditions established for both the Transect and Geographic phases of this study.

Growth Condition	Temperature (° C)		Photoperiod
	Day	Night	(hours)
1	21°	16°	16
3	10°	10°	16
4	21°	21°	16

The appearance of the radicle was taken to be the first sign of germination. A count of germinated seedlings was made each day beginning with the day following placement of the seed in the growth chambers. This procedure was discontinued when 0 counts were observed for two (2) successive days.

The total germination for each sample was calculated as was the rate per day at which the germination occurred.

In February of 1971, another seed study was made. A germination test was conducted involving 4 replications of 100 seeds each per elevational source. These seeds had been in cold storage (1.7° C) for 24 months. An attempt was made to select filled seed through visual observation. The seed was x-rayed to determine the accuracy of visual selection.

Seedling

When the radicles of the newly germinated seedlings protruded 0.5 cm or longer from the seed coats, the seedlings were planted in prepared boxes. These boxes were 50 cm long, 25 cm wide and 15 cm deep. The soil used for growing these seedlings was obtained from a known alder site at the 1500 foot elevational level. The soil was not from the same area on which the parent trees are located. Each box contained one row of 10 seedlings from each of the selected seed sources. The boxes were replicated 4 times under each of the growing conditions shown in Table 1. The arrangement of the seedlings in each box was randomly selected to eliminate position effects.

To eliminate possibilities of climatic variation, the seed was kept in the growth chambers from time of placement on June 9, 1969 until the conclusion of the growth chamber study on October 6, 1969.

Periodic height measurements were taken of all seedlings grown during the course of this study. The final height measurements, plus diameter measurements, of all seedlings were taken on November 6, 1969, one month following the removal of the seedlings from the growth chamber. On October 2, 1969, leaf dimension (length and width) were taken of 4 randomly selected leaves per seedling.

Phase II: Geographic Study

In 1968 the U. S. Forest Service initiated a red alder provenance test to compare and evaluate inherited differences of the species from various geographic strains. The Forest Service has pointed out that ecotypical characteristics of importance to industry include wood properties, insect and disease resistance, volume growth, height growth, stem straightness, branch shedding ability and climatic tolerance.

To accomplish these comparisons, test outplantings were established in Oregon and Washington in the spring of 1969. The Oregon planting site is located on the Cascade Head Experimental Forest on the Hebo Ranger District, Siuslaw National Forest. The Olympia, Washington plantation is located on an abandoned Washington State Nursery on the Capital State Forest.

The seedlings being used in the provenance test have come from 10 geographic locations. The seedlings from Alaska and Idaho were selected to show characteristics of red alder at the limits of its range. The Oregon and Washington sources are fairly evenly dispersed geographically. The Forest Service has assigned a provenance name and number to each source. Table 2 lists these sources together with their legal descriptions. The general location and relative geographic relationships of the sources can be observed in Figure 4.

The seedlings, collected by local cooperators, were wildings ranging from 12" to 24" in height. They were shipped directly to the seed processing plant near Webster State Nursery for cold storage (1.7° C) before sorting and planting. Some packages were rewrapped to insure sufficient moisture for root systems.

The geographic study (Phase II) included in this paper involves the use of seedlings from each of the ten sources indicated in Table 2. Though limited in number, the seedlings received from the Forest Service, were separated into 4 groups. Each group contained at least 1 seedling from each of the sources. Three of these groups were placed in growth chambers under the conditions listed in Table 1. The fourth group was set outside under natural weather conditions as a control. Because of their height, 15.0-55.0 cm, the seedlings were planted, individually, in pots containing soil from the Burnt Woods area.

The observations made during this phase of the study include

Table 2. Geographic Study. Seedling sources for Forest Service red alder provenance test.

Prov. No.	Provenance Name	State	County	Legal Description	Elev.
1	Juneau, Alaska	S. E. Alaska	---	T. 41 S., R. 72 E., Copper River Meridian	150'
2	River Jordan, B. C.	Vanc. Isle, B. C.	---	Lot 14, Renfrew Land District, B. C. (Lat. 48° 26'30") (Long. 124° 04' 45")	300'
3	Concrete, Wash.	N. W. Wash.	Skagit	Sec. 13, T. 35 N., R. 8 E., W. M.	100'
4	Olympia, Wash.	Cent. W. Wash.	Thurston	SW 1/4, Sec. 3, T. 16 N., R. 2 W., W. M.	250'
5	Amboy, Wash.	S. W. Wash.	Clark	NE 1/4, Sec. 11, T. 5 N., R. 2 E., W. M.	500'
6	Lincoln City, Ore.	Cent. W. Ore.	Tillamook	SE 1/4, Sec. 6, T. 8 S., R. 10 W., W. M.	300'
7	Cottage Grove, Ore.	Cent. W. Ore.	Lane	Secs. 4 & 5, T. 22 S., R. 3 W., W. M.	800'
8	Port Orford, Ore.	S. W. Ore.	Curry	Secs. 9 & 16, T. 31 S., R. 14 W., W. M.	900'
9	Sequim, Wash.	N. W. Wash.	Clallam	NE 1/4 Sec. , T. 30 N., R. 2 W., W. M.	200'
10	Sandpoint, Idaho	N. Idaho	Banner	NW 1/4, Sec. 23, T. 56 N., R. 1 W., W. M.	2300'

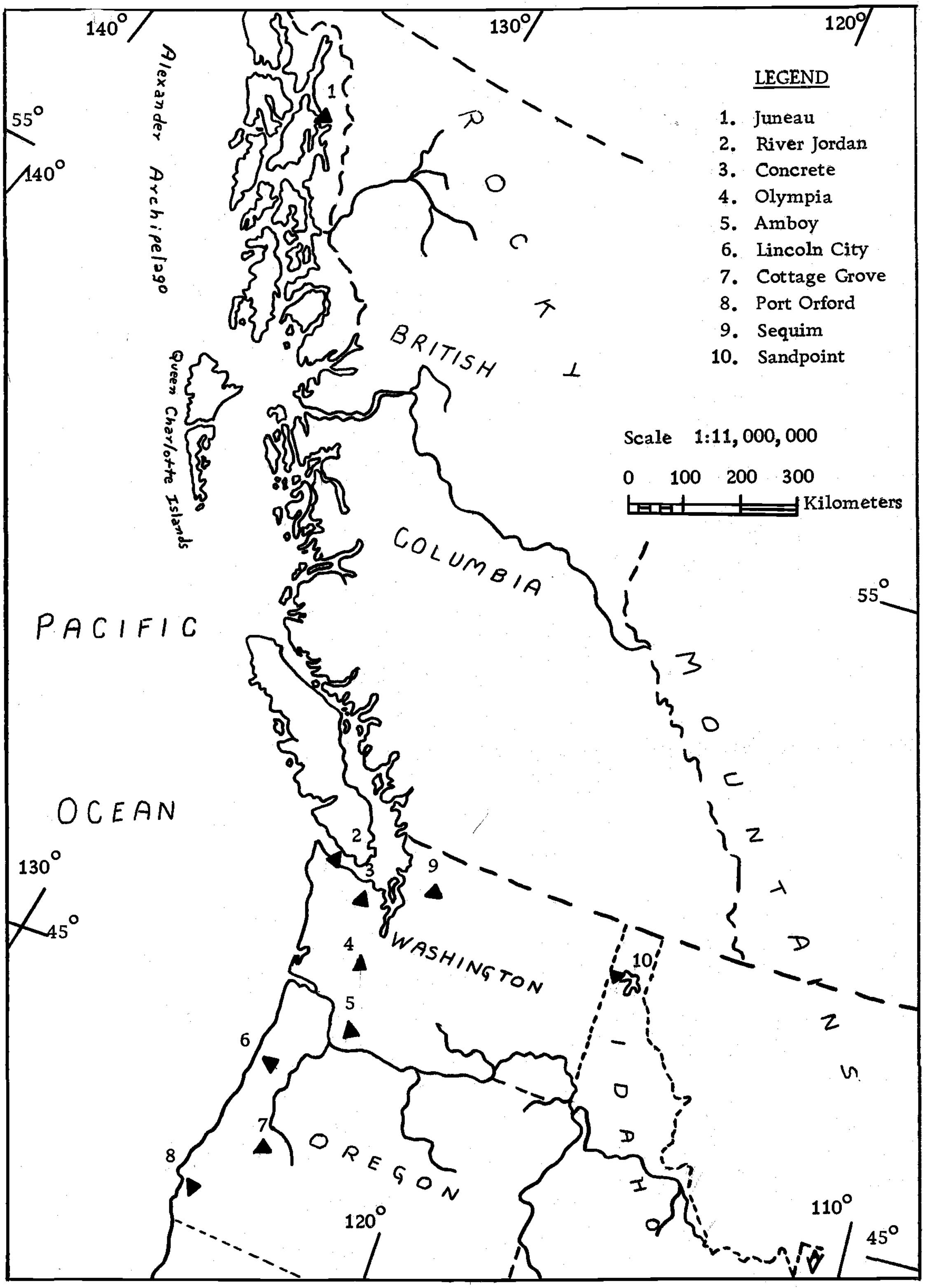

Figure 4. Geographic Study. Location of Forest Service red alder (*Alnus rubra* Bong.) collecting points.

periodic height measurements over a 6 month period from April 12, 1969 through September 6, 1969. Also on October 6, 1969 measurements of leaf dimensions (length and width) were made involving 10 randomly selected leaves per tree.

It is important to note at this point that there were not enough trees available from the Forest Service to make a detailed statistical analysis. The sample, because of shortage of material, was just too small. This does not mean that this phase of the study has no value. Some observations were made and conclusions drawn which can be of value in establishing the type of further investigation needed.

The results and a discussion of their values are included as an appendix to this thesis.

RESULTS

Phase I: Transect Study

The length of the transect from Newport to Marys Peak is 43.56 kilometers. As might be expected, most of the elevational sources located along this line are found within close proximity of Marys Peak. The '0' elevation plot is on the shore of Yaquina Bay. Because of rapid topographical changes near the summit of the Coast Range, the plot locations for the 1000-3000 foot sources were located within 6 kilometers of Marys Peak. The 500 foot source was chosen as a point approximately half way between the '0' and '1000' foot plots in an attempt to balance the overall plot location. Figure 3 shows the location of the red alder plots together with elevational changes.

Conelet

The conelets of red alder are generally brown in color. The conelets collected along the transect indicate a color range within this brown grouping and that the elevational source appears to have some bearing on the shade of color. The Munsell color charts (30) were used in an attempt to describe this variation in color shade that was observed among the conelets. The color bar in Figure 5 shows the various color shades encountered and their relationships to the

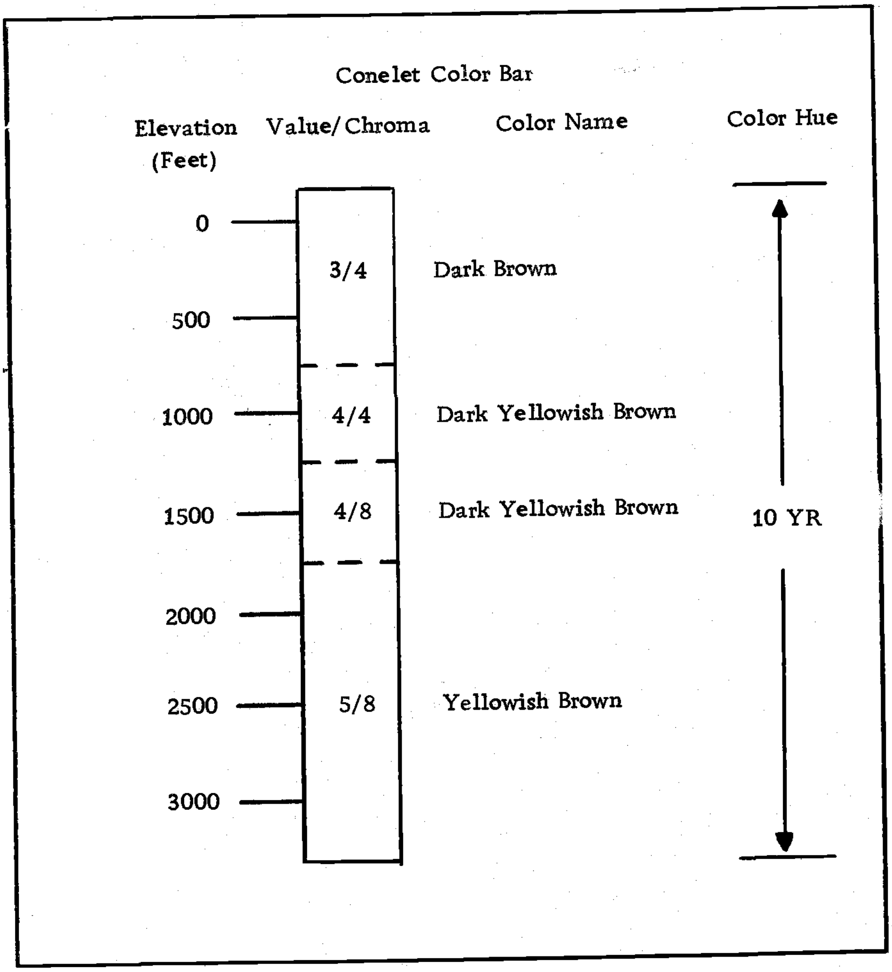

Figure 5. Color bar showing change in color shade of red alder conelets along the Newport-Marys Peak transect. Color names and codes are based on the Munsell Soil Color Charts (30).

elevation at which the conelets were collected. One hundred conelets were examined from each elevational source. The color differences described are subjective only and other investigators may reach different conclusions. The author invited two other individuals to use the Munsell color charts to key out colors for the conelets collected at each elevation. Working independently with different samples, they each came up with different color ranges. These three separate examinations, resulting in three different ranges based on the individual's color interpretation, did, however, show a variation in the color of conelets found at different elevations. Furthermore, this difference in color followed a pattern from low to high elevation. Although the difference in color was difficult, if not impossible, to detect between any two associated elevations (i.e., 1000'-1500'; 1500'-2000', etc.), a pattern of color difference was established when viewing the transect as a whole.

The average weight of all red alder conelets sampled was 0.26 grams. The weight of the conelets decreased from low elevation to high elevation by 54%. Figure 6 shows the relation of conelet weight to the elevation of the plot location. The graph indicates a general leveling off of cone weight between the 1500' and the 2500' elevations, then a sharp drop at the highest collection site. Results of the analysis of variance are shown in Table 4.

The figures for conelet dimensions (length and thickness) of the

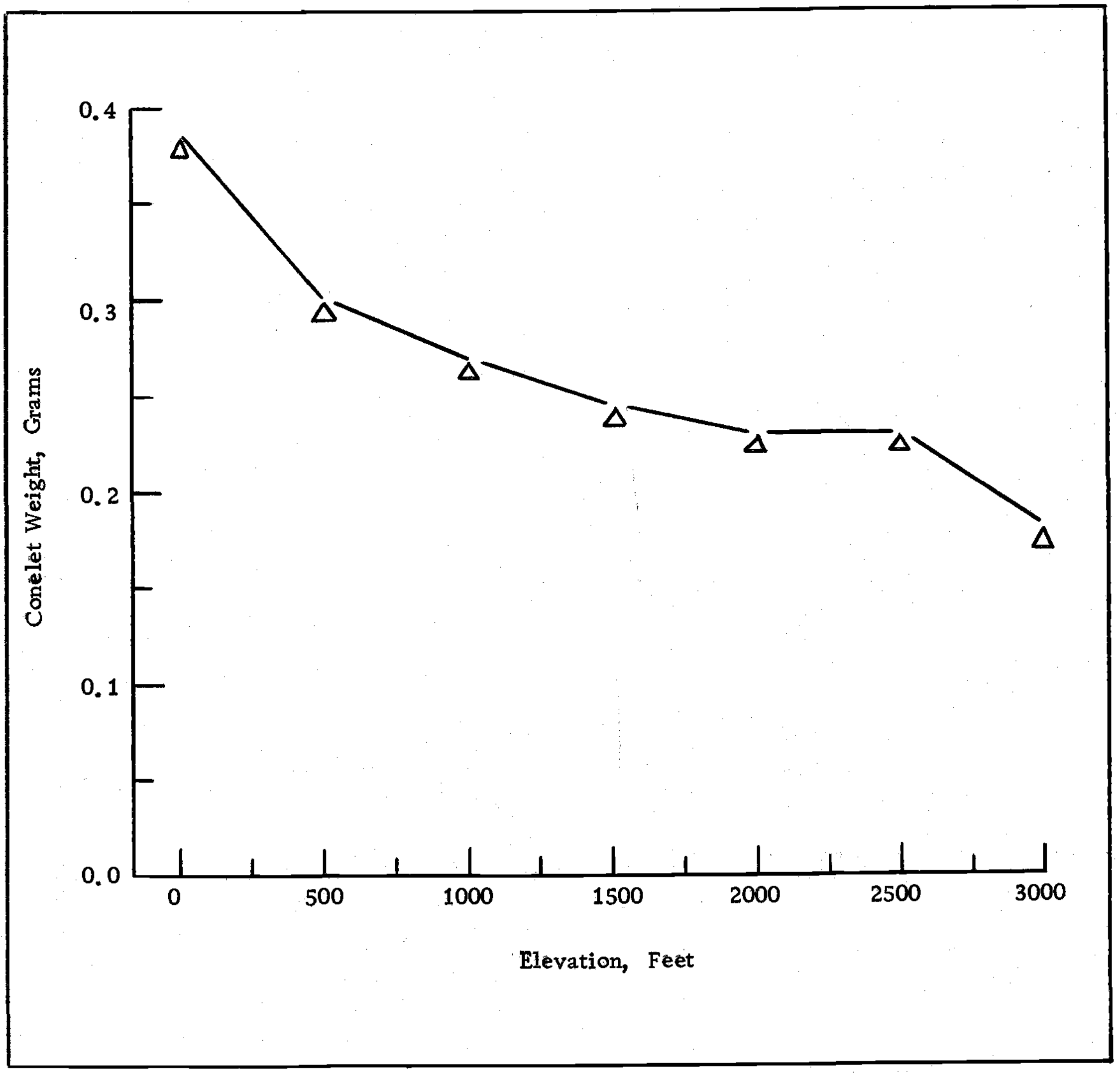

Figure 6. Relation of conelet weight to elevation of site of collection. Each value represents the mean weight of 100 individual conelets.

Table 3. Results of Analysis of Variance for conelet size.

Source of Variation	d.f.	Length S.S.	Length M.S.	Thickness S.S.	Thickness M.S.	Length x Thickness S.S.	Length x Thickness M.S.
Elevations	6	0.75	0.125**	0.22	0.0366**	3.33	0.5550**
Replications	4	0.10	0.025	0.03	0.0075	0.28	0.0700
Error	24	0.25	0.010	0.13	0.0054	1.09	0.0454
Totals	34	1.10		0.38		4.70	

Table 4. Results of Analysis of Variance for conelet and seed weights.

Source of Variation	d.f.	Conelet Weight S.S.	Conelet Weight M.S.	Seed Weight S.S.	Seed Weight M.S.
Elevations	6	51.15	8.53**	0.0087	0.00145**
Replications	4	4.61	1.15	0.0000	0.00000
Error	24	18.32	0.76	0.0010	0.00004
Totals	34	74.08		0.0097	

samples measured, agree with those reported in the Agricultural Handbook No. 271 (length: 1.3-2.5 cm; thickness: 0.8-1.3 cm) (50). The average dimensions of all conelets measured were 1.9 cm long and 1.2 cm thick. This study indicates an apparent variation in conelet size between elevational sources that follows the same pattern as the conelet weights illustrated in Figure 6. The relation of conelet size to the elevation of the collection site is shown in Figure 7. By themselves, the length and thickness of the conelets show very little variation between elevational sources; graphically portrayed, the curves tend to be fairly flat. However, using the combined dimensions, i.e., length X thickness, to produce a type of volume figure to represent conelet size, elevational variation then becomes more pronounced. The curve, although relatively flat between the 1500' and the 2500' elevations, does indicate a decrease in conelet size from low to high elevation. Results of the analysis of variance for conelet size is shown in Table 3.

Seed

The average weight of cleaned red alder seed from the combined elevational sources (105 samples of 100 seeds each) was 0.409 grams/1000 seeds or approximately 1,109,000 seeds/pound. This figure, 1,109,000 seeds/pound, is about 40% higher than the average weight per pound (666,000) and slightly higher than the high number of seed

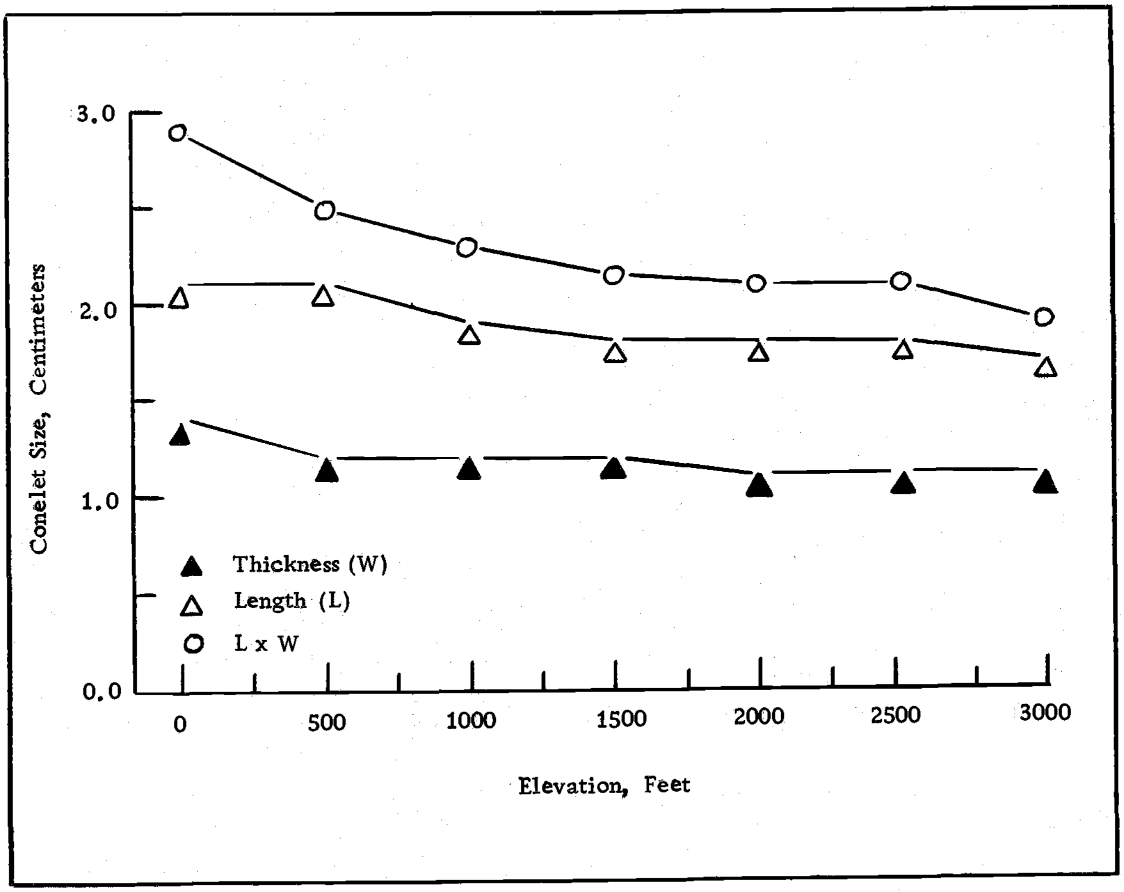

Figure 7. Relation of conelet size to elevation of site of collection. Each value represents the mean dimension of 50 individual conelets.

per pound (1,087,000) recorded in the Woody Plant Seed Manual (52). The variation in seed weight between elevational sources is illustrated in Figure 8. Results of the analysis of variance for seed weight is shown in Table 4.

The germinative capacity of red alder seed is somewhat in question. There were only two germination tests used for the production of data in the Woody Plant Seed Manual (52) and the data obtained from these tests provided low and high germinative capacity figures of 14% and 40% respectively. The germination study in this report involved 84 samples of 100 seeds each (12 samples/elevation) and resulted in germination percent figures ranging from 0.75-35.50%, with an overall mean of 15.5%. The bar graphs in Figure 9 illustrate the percent germination by elevational source and germination condition. The results of the analysis of variance are shown in Table 5.

The apparent low percentage of germination of two of the sources (1000' and 3000') prompted a germination check test. This additional test, which included 28 samples of 100 seeds (4 samples/elevation), was conducted under a constant temperature regime of 20° C. The results of germination were very poor. The average germination of all seeds was only 3%, of which 2.2% represented the 2000' and 2500' elevational sources.

To elucidate the reason for the low germination, x-ray photographs were taken of the red alder seed in an attempt to compare the

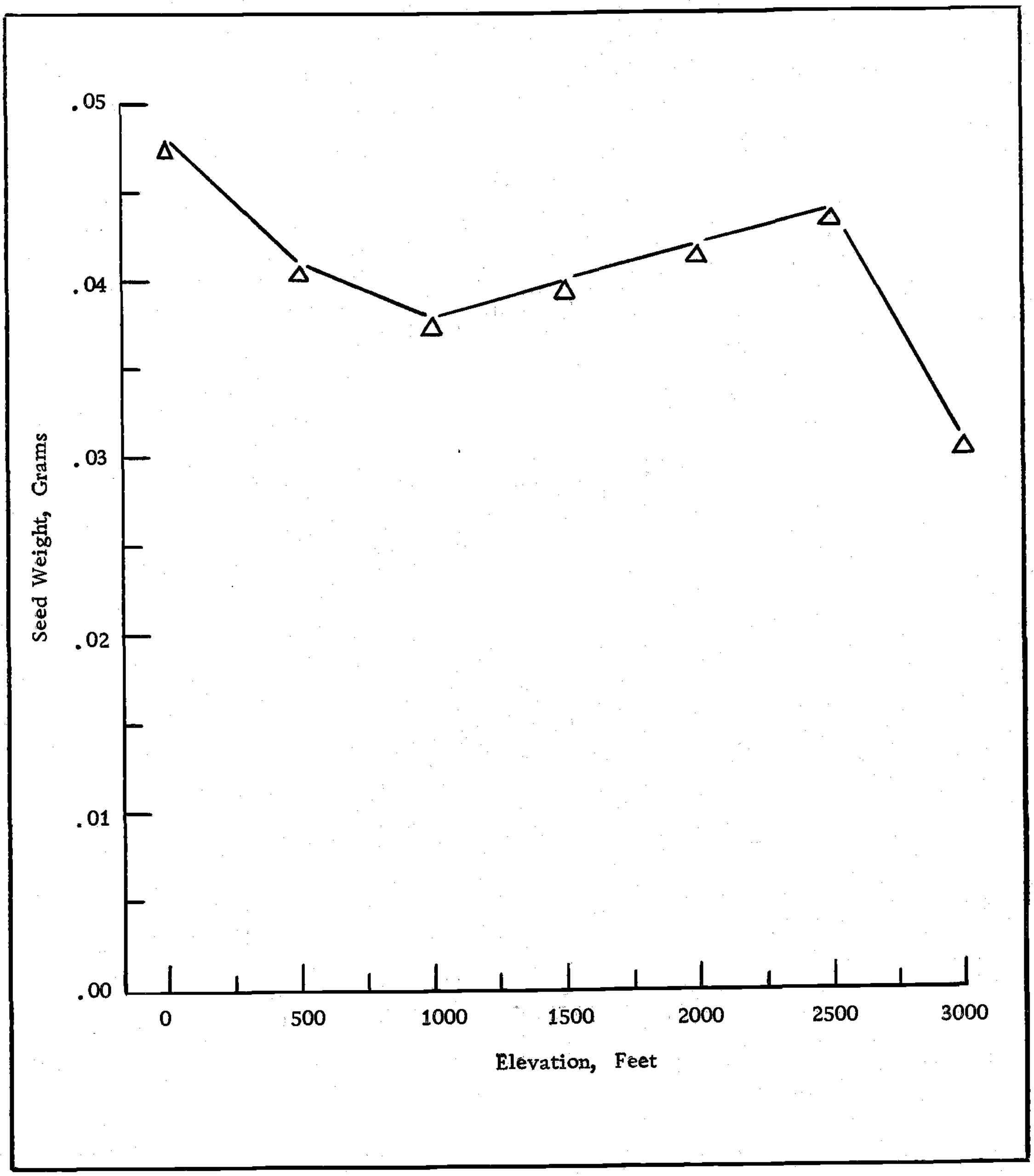

Figure 8. Relation of seed weight to elevation of site of collection. Each value represents the mean weight of 15 samples of 100 seeds each.

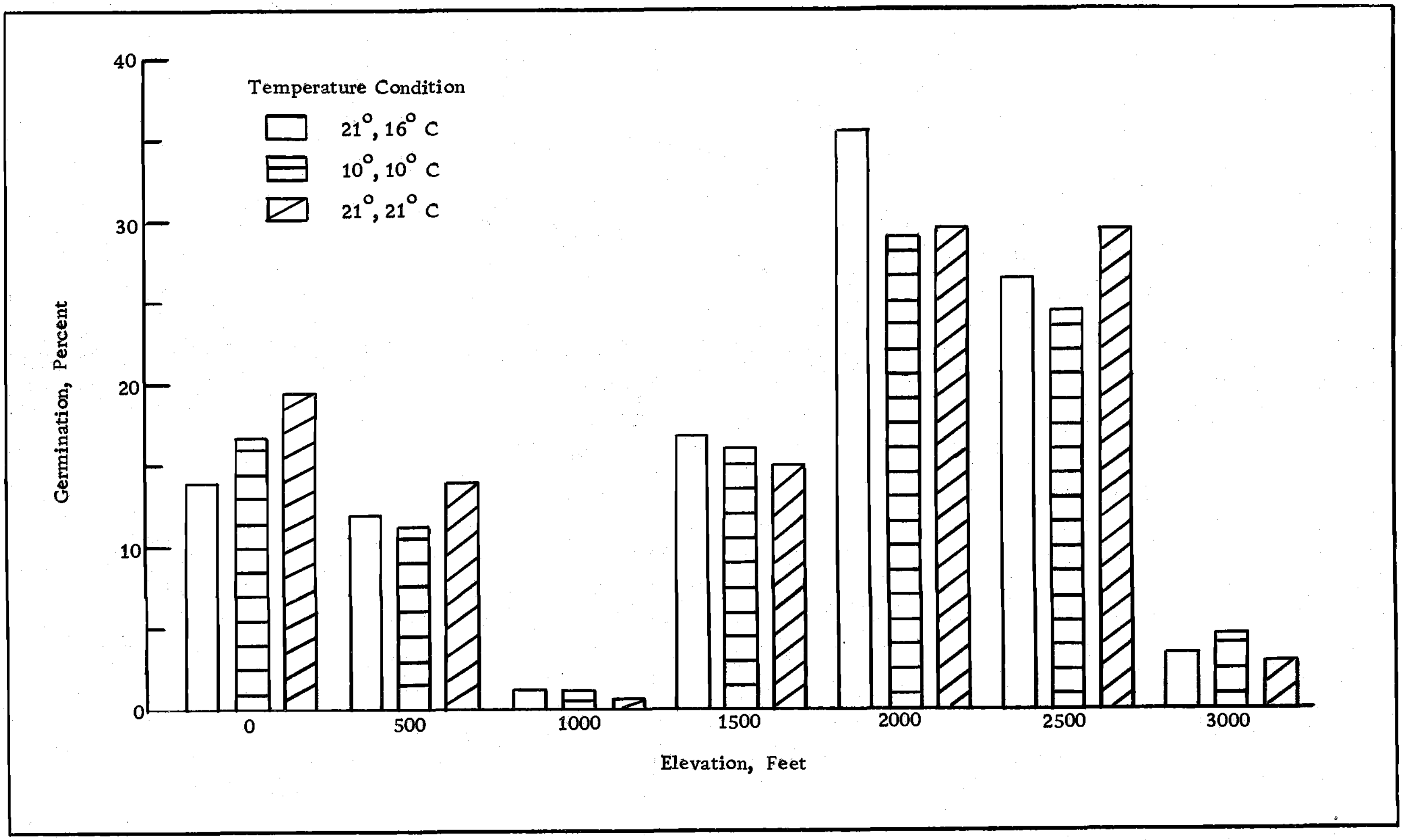

Figure 9. Germinative capacity (% germination) of red alder seed, by elevation, under 3 different temperature conditions.

Table 5. Results of Analysis of Variance for germinative capacity (percent of germination).

Source of Variation	d.f.	S.S.	M.S.
Main Plots			
Conditions (C)	2	11.15	5.58
Blocks	3	11.47	3.82
Error a	6	371.13	61.85
Sub-plots			
Elevations (E)	6	8,282.46	1,380.41 **
E x C	12	204.68	17.06
Error b	54	1,653.15	30.61
Total	83	10,534.04	

percentage of filled seed observed by the x-ray method with germination results. Since the use of x-ray photography to determine filled, partially filled (incomplete or abnormal embryo) and empty seed of grey alder (Alnus incana) and black alder (Alnus glutinosa) seeds has been already reported by Schalin (38), the same qualitative classification on different classes of seeds were used in this study. They are as follows:

0: empty.

1: incompletely developed, otherwise abnormal.

2: well-developed, with a complete endosperm with the embryo filling the major part of the embryonic cavity.

The results of separation of different classes of the red alder seed by means of x-ray photography are shown in Table 6. It was found that the percent of filled seed of each source did correspond somewhat with the original germination test completed in June of 1969.

The germination rates of red alder in the June, 1969 test were fairly rapid. No visible sign of germination occurred until the 5th day. Based on the final germination totals, the germination percentage for each temperature condition that had occurred by the end of that day are shown in Table 7.

Germination of red alder seed under the second temperature condition (10° C constant) was considerably slower than under the

Table 6. Qualitative classification of red alder seed using x-ray photography. (Each figure represents the percent of the x-rayed seed occurring in that class.)

Elevation (feet)	Class 0	Class 1	Class 2
0	86.9	0.6	12.5
500	96.9	0.0	3.1
1000	98.7	0.0	1.3
1500	85.0	3.1	11.9
2000	93.1	1.3	5.6
2500	91.2	0.7	8.1
3000	99.4	0.0	0.6

Table 7. Red alder germination percents at the end of the 5th day

Temperature Condition	Germination %
1. 21°, 16° C	77.3
3. 10°, 10° C	31.7
4. 21°, 21° C	78.8

other two conditions. Whereas more than 75% of the seed from all elevational sources had germinated by the fifth day under conditions 1 and 3, it was not until the tenth day that the 75% mark was reached under condition 2. It took seven days for 50% of the viable seeds to germinate under the constant cold condition. A comparison of the germination rates of the seed by germination condition is shown in Figure 10. The germinated seed from all sources was pooled by temperature condition.

Seedling

Planting the newly germinated red alder seed in prepared boxes (70 seedlings/box) turned out to be inadequate as far as the growing space is concerned, because of the rapidity of growth of the young seedlings and the abundance of leaves they produced. The spacing within the boxes was narrow and, as the seedlings began to grow, overcrowding became apparent. Toward the end of the first growing season, after being in the boxes only four months, the death of several seedlings and the growth retardation of a number of others was observed. Individual seedlings within the middle rows of the boxes were not developing as fast as those around the perimeters. By the end of this study the necessity for randomization to eliminate position effects as well as the need for several replications became obvious. The density of the stems of the 109 day old seedlings can be observed

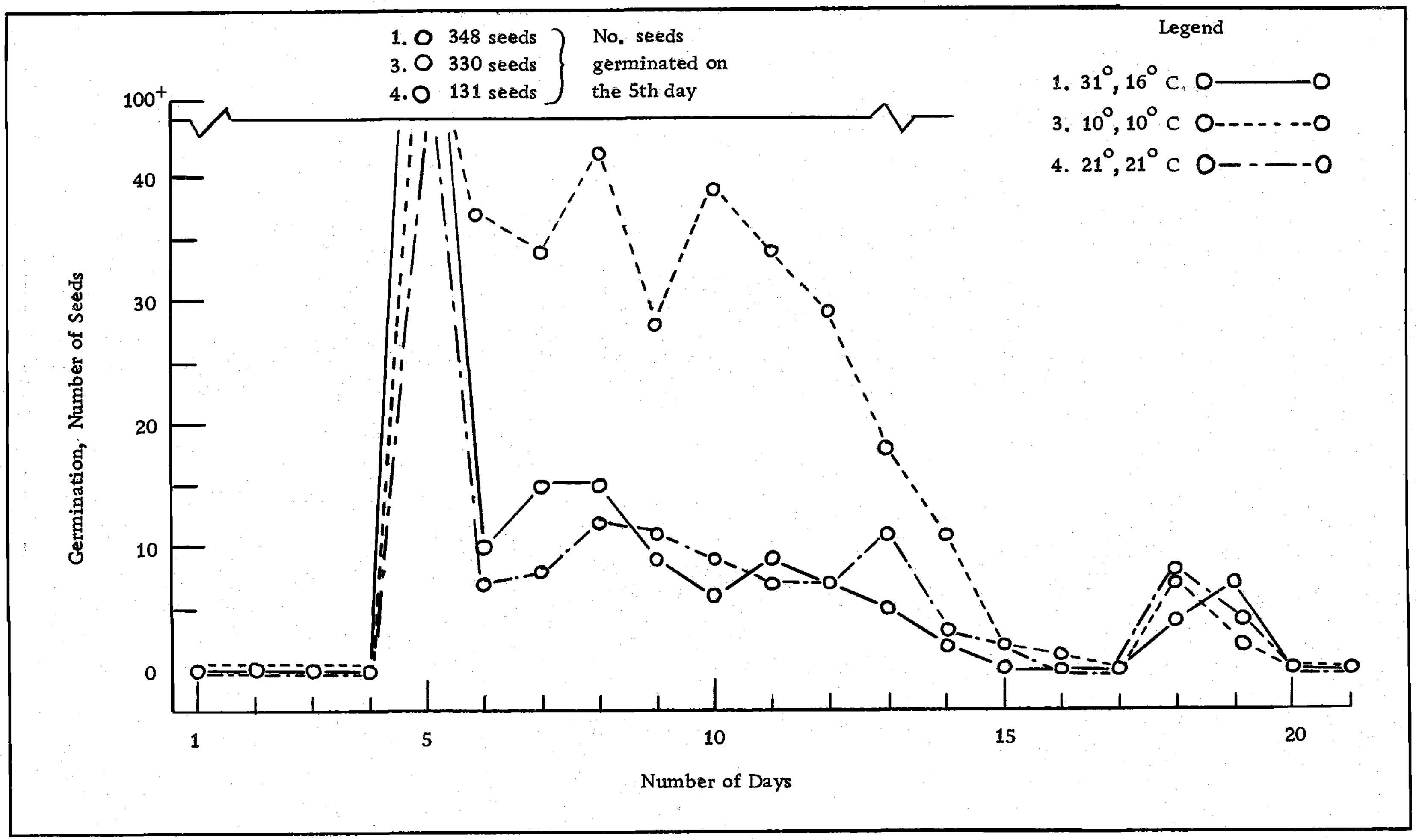

Figure 10. Comparison of germination rates of red alder seed under 3 different temperature regimes. A total of 2800 seeds (400/elevational source) were placed under each regime.

in the photographs in Figures 11-13. These pictures were taken on October 15, 1969.

Poor germination and the death of several seedlings resulted in the loss of a sufficient number of plants to cause deletion of two elevational sources. The 1000 foot source did not have enough seedlings to complete even 1 replication per growth condition. The 3000 foot source had 45 seeds germinate but only a handful survived. There were barely enough seedlings to complete one replication per growth condition and a number of these were so weak that they died within a few weeks. The remaining five sources survived and developed very well. Although the growth of a number of seedlings became retarded by the end of the study, all replications remained intact.

The results of the periodic height measurements which were taken of all seedlings during the course of this study are shown in Figure 14. Seedling growth by elevational source is recorded for each temperature condition. It was ten weeks before differences in growth rates between some of the elevational sources was noticed. The graphs in Figure 14 illustrate the variation in growth rate that was observed between sources from the tenth through the twentieth week.

By pooling the data from each elevational source by growth condition, the effects of temperature on seedling growth were determined. Figure 15 illustrates these effects graphically while the

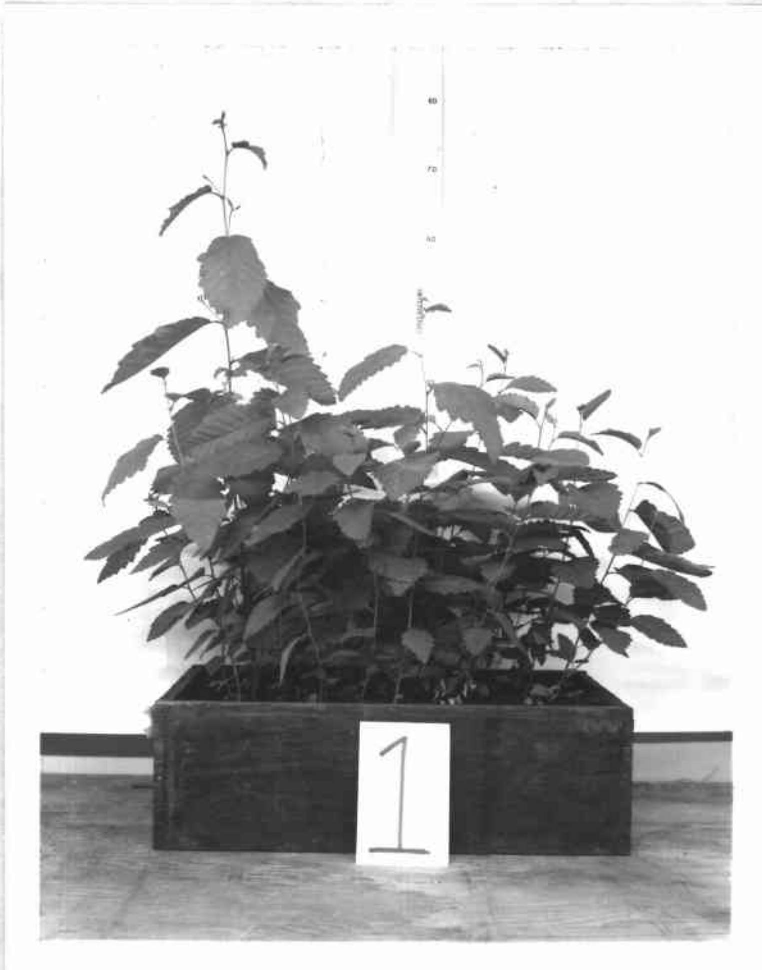

Figure 11. Transect Study. 109 day old red alder seedlings under temperation condition of 21°, 16° C.

Figure 12. Transect Study. 109 day old red alder seedlings under temperature condition of 10^{o}, 10^{o} C.

Figure 13. Transect Study. 109 day old red alder seedlings under temperature condition of 21°, 21° C.

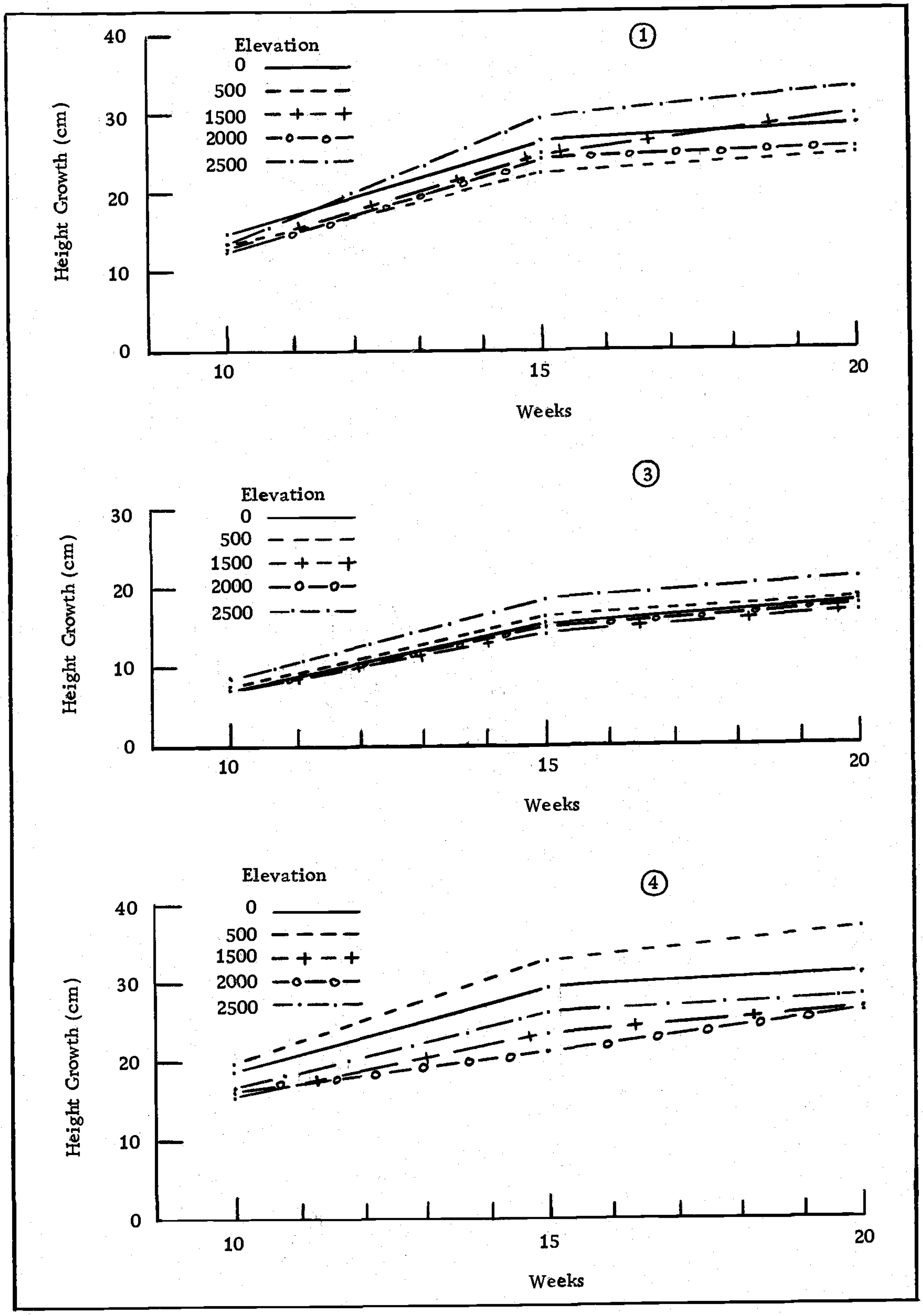

Figure 14. Seedling growth by elevational source. Temperature conditions are ① 21°, 16°C, ③ 10°, 10°C and ④ 21°, 21°C.

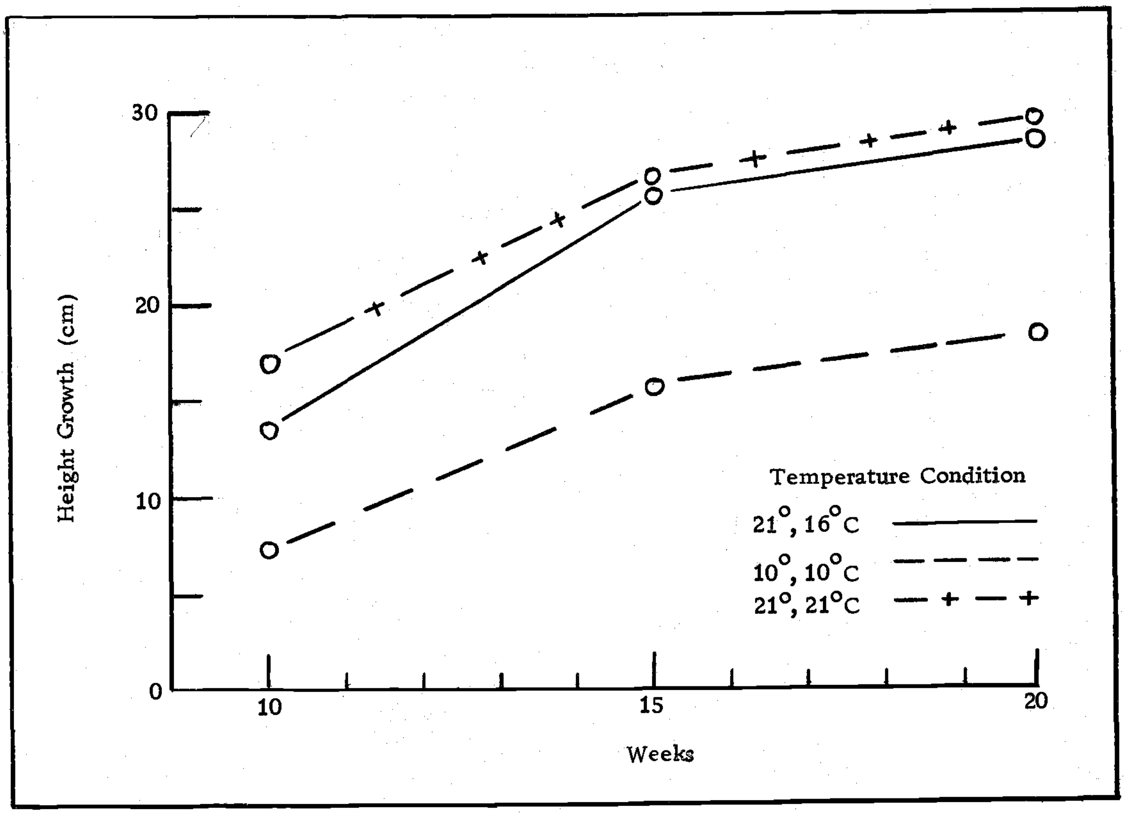

Figure 15. Seedling growth by temperature condition. Elevational sources are pooled.

photographs in Figures 11-13 depict the effects of the three temperature conditions visually. Both the graphs and the photos show that, overall, the seedlings are tallest under the constant temperature regime of 21 °C and shortest under a constant 10° C.

The results of the analysis of variance for seedling height and diameter growth are shown in Table 8. Figure 16 compares the total height and diameter growth by temperature condition.

During the 20 week period of the transect study the overall appearance, as well as the individual plants, of each box (replication) of seedlings were observed.

Other than the height growth of the seedlings, the development of their leaves became a point of comparison. Leaf measurements (length and width) were taken of every seedling. Observations were made of leaf shapes, margins, color of upper and lower surfaces and pubescence in an attempt to find differences between sources or even temperature regimes. Other than leaf sizes between temperature conditions no differences were observed (Table 9). The photographs in Figures 11-13 show the general appearance of red alder leaves under the three growing conditions.

The size of the leaves ranged from 4.5 cm in length in growth room two (10° C constant) to 8.4 cm long in growth room three (21 °C constant). The range in width was from 2.8 cm (growth room two) to 5.2 cm (growth rooms one and three). The results of the analysis

Table 8. Results of Analysis of Variance for seedling height and diameter growth. (Transect Study)

Source of Variation	d.f.	Height S.S.	Height M.S.	Diameter S.S.	Diameter M.S.
Main Plots					
Conditions (C)	2	1530.77	765.39**	2.92	1.46
Blocks	3	24.55	8.18	0.67	0.22
Error a	6	238.99	39.83	2.23	0.37
Sub-plots					
Elevations (E)	4	123.81	30.95	0.51	0.13
E x C	8	390.23	48.78	4.86	0.61
Error b	36	984.32	27.34	35.55	0.99
Total	59	3,292.67		46.74	

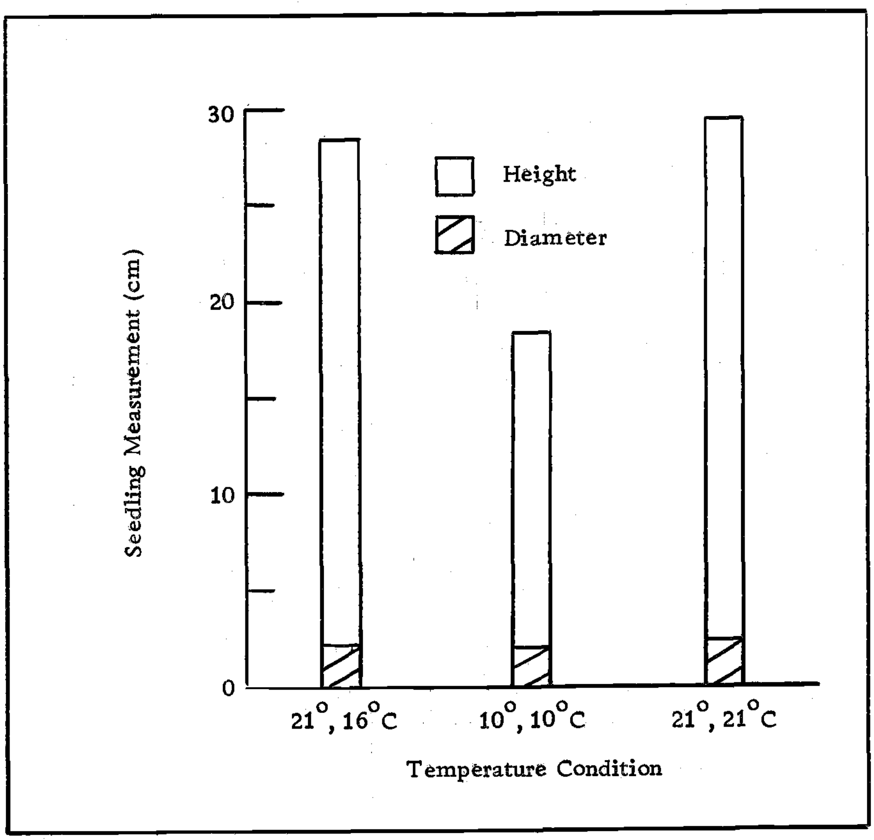

Figure 16. Comparison of total height and diameter growth by temperature condition. Seedlings were pooled by condition. (Transect Study)

of variance for leaf dimensions are shown in Table 9. Figure 17 illustrates the variation in leaf size due to growth condition.

Table 9. Results of Analysis of Variance for leaf dimensions. (Transect Study)

Source of Variation	d. f.	Length (L) S. S.	Length (L) M. S.	Width (W) S. S.	Width (W) M. S.	L x W S. S.	L x W M. S.
Main Plots							
Conditions (C)	2	39.69	19.85**	6.06	3.03*	1609.38	804.69**
Blocks	3	3.01	1.00	0.71	0.24	157.70	52.57
Error a	6	6.62	1.10	1.82	0.30	367.71	61.29
Sub-plots							
Elevation (E)	4	2.20	0.55	1.58	0.39	152.35	38.09
E x C	8	6.16	0.77	1.98	0.25	423.28	52.91
Error b	36	27.66	0.77	8.24	0.23	1462.61	40.63
Total	59	85.34		20.39		4173.03	

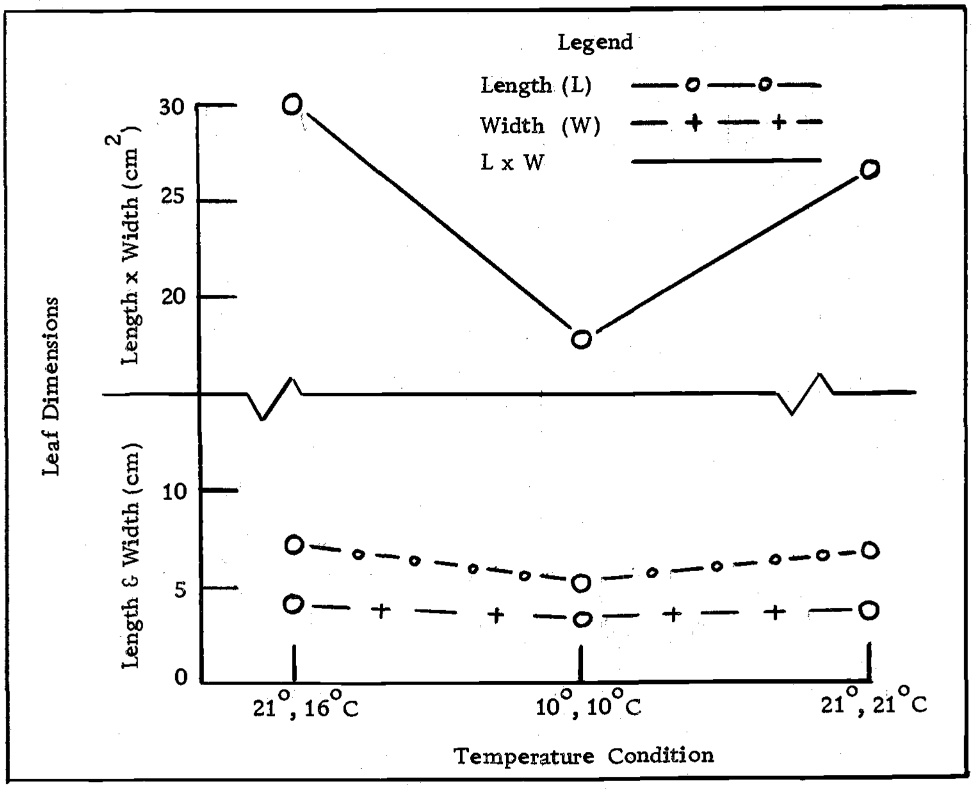

Figure 17. Comparison of temperature effects on leaf dimensions (length and width). Seedlings were pooled by condition. (Transect Study)

DISCUSSION

Phase I: Transect Study

From the beginning there was considerable debate as to the possibilities of discovering differences within the species *Alnus rubra*, between elevational sources, along the Newport-Marys Peak transect. Four major facts were responsible for this thinking.

1. The total length of the transect was short (43.56 kilometers) as compared with the overall range of red alder. Within species differences might be found when considering the entire geographic range of the species (Figure 1) but differences along this transect might not be evident.
2. Out of seven elevational sources selected, five were within 6 kilometers of the summit of Marys Peak (Figure 3), a rather short distance between collection points, although there was a rapid change in topography.
3. The entire length of the transect was located on the west side of the Coast Range. The influences of the maritime climate, such as amounts of precipitation and solar radiation (number of daylight hours) are nearly the same. Temperature differences due to elevational changes (0-3000 feet) constitute the major source of climatic variation.

4. All plots along this east-west transect have southerly aspects.

At the end of this study, considerable data was accumulated that would delineate the differences or similarities in red alder conelets, seed, seedling heights and diameters (21 weeks) and leaf characteristics (21 weeks) between elevational sources. Differences of growth between the three growth conditions (21°, 16°C; 10°, 10°C and 21°, 21°C) were found to be quite large.

The results of the transect study not only showed the expected differences (i.e., those between growth regimes) but also indicated differences within the species, Alnus rubra, between the elevations selected along the transect.

Conelet

The three characteristics (color, size and weight) of the conelets that were observed showed variation from low to high elevation. This variation, as might be expected, cannot be considered large between adjacent elevational sources but when observing the transect in its entirety, the cumulative effect of these differences becomes pronounced.

The color of red alder conelets has been described generally as being dark brown (52). This is indeed true when commenting on the color of the conelets in a general way. When investigations become more specific though, color variations become obvious.

The Munsell Soil Color Charts (30) that were used to explore these color differences helped to determine shades of color within the brown grouping. The color hue which closely fit the general conelet color was 10 YR. Within this hue, the colors ranged from dark brown to dark yellowish brown to yellowish brown (Figure 5). This range extended along the elevational gradient with the darkest conelets being collected from the lower plots and the conelets that were lightest in color gathered from the highest sources.

The most marked differences between elevational sources was found to be in conelet weight. The mean weight of 100 individual conelets collected from along the shore of Yaquina Bay was 0.38 grams. The weight of individual conelets collected from trees at the 3000 foot elevation averaged 0.18 grams. The analysis of variance (Table 4) shows the differences between elevations to be significant at the 1% level. These differences are portrayed graphically in Figure 6. There is a general decrease in conelet weight from low to high elevation along the transect.

It follows that increases or decreases in conelet weight should be accompanied by comparable increases or decreases in conelet size. Measurements taken of red alder conelets collected along the transect show this to be quite true. There is a decrease in the length and width of the conelets from low to high elevation. This trend is not as pronounced as those for conelet weight if the dimension, length and width, are viewed independently. If however, these traits are combined (length × width), the decrease in size (or volume) becomes more obvious (Figure 7). The analysis of variance for conelet size (Table 3) shows that there is a significant difference between elevations at the 1% level.

These differences (color, weight and size) found in the conelets of Alnus rubra may be, at least in part, explained by variations in soil characteristics (i.e., soil type or soil nutrients) although soil regimes on which the parent trees are located were not analyzed. Also, the age of the tree might be a determining factor in the size of the cones. This has been found to be the case in Douglas-fir (56). Studies of this nature involving red alder cones are not known to the author. The age of the mother-trees involved in the transect study ranged from 25 to 40 years. Based on the data accumulated and analyzed during this study there does seem to be an expression of clinal variation in red alder conelets (color, weight and size) from west to east.

Seed

The average weight of Alnus rubra seed obtained from this study (i.e., 1,109,000 seeds/pound) is slightly higher than the high number of seeds per pound (1,087,000) recorded in the Woody Plant Seed Manual (52). Neither the size nor the location of the four samples used to supply the data in that Forest Service publication is known. There were 105 samples (15 samples/elevation), each of which contained 100 seeds, weighed during this portion of the transect study. Since adequate sampling of the total population (all possible red alder trees along the transect) is assumed, the difference in the average number of seeds per pound is apparently not due to improper sampling. The samples reported in the Woody Plant Seed Manual (52), coming from a population different than that reported in this study, may represent a wide range of geographic sources or even a much more restricted population than the Newport-Marys Peak transect. Both methods of sampling, a very wide range or a very narrow range, could result in substantial variation in the average weight of red alder seed. The number of samples used in the Forest Service publication may have been too small to be representative of the average seed weight, just as the seed weighed for the transect study could not necessarily be expected to represent the weight of red alder seed throughout the entire geographic range of the species.

The analysis of variance for seed weights showed differences between elevational sources to be significant at the 1% level (Table 4). There were no differences found between the sample trees within the elevational plots (replications). The variation in seed weights between elevational sources shown in Figure 8, can be interpreted, at least in part, from the results of seed germination.

The germinative capacity (% germination) of red alder seed was tested for each elevation under three different temperature regimes. The analysis of variance (split-plot design) for germinative capacity showed a high degree of significance in the differences between elevations but no significance for differences between temperature conditions (Table 5).

The differences in the germination percents between elevations shown in Figure 9 follow the same pattern as the seed weights in Figure 8. Germinative capacity, at least in this instance, is associated with seed weight. Heavy seed had a higher germination percent than light seed. Both the 1000' and 3000' elevational sources had exceptionally low numbers of seed germinate. Although the germination check-test showed poor results, the x-ray photographs did show that the seeds from these two sources had the highest percentage of empty seeds (98.7% and 99.4% respectively). The poor germination results were due, in large part, to empty seeds.

The low percentage of germination that was observed in the germination check-test was apparently due to loss of viability during storage. The storage procedures used followed the recommendations of Holmes and Buszewicz (18) and Vincent (53) who had worked on other species of Alnus, particularly Alnus glutinosa. The seeds for the transect study were stored in sealed bottles in a room kept at approximately 1.7° C. Under these conditions the germinative capacity of Alnus glutinosa seed would, reportedly, have remained essentially unchanged. This was not the case for Alnus rubra. Precautions against mold formation, drying the seed at room temperature for 48 hours, were taken prior to bottling. At the end of 20 months of storage, the seeds had apparently lost nearly all their viability.

Seed germination began within five days. This is in agreement with Enescu's work (11) with Alnus glutinosa. Germination was quite rapid, with the peak being reached on the fifth day, when 65.3% of all the seed that would eventually germinate had done so (Figure 10).

There was no significant effect of temperature on the germination percent of red alder seed (Table 5) but there was on the germination rate. The rate of germination was significantly slower but not otherwise affected under the 10° C constant condition (Figure 10). The beneficial effect of this delay or slowing down of the germination process would result in at least some seed remaining in a more or less semi-dormant condition. Such a feature would help many seeds, after having been induced to rapid germination by late winter or early spring warming weather, to avoid the possible occurrence of cold and killing frost.

Seedling

Total height and diameter measurements after 20 weeks of seedling growth, showed no significant differences between elevations under any of the growth conditions. The effects of temperature on height growth (elevational data pooled) were significant at the 1% level. There was no significant effect of temperature on diameter growth during the period of this study (Table 8). Figure 16 shows the effect of temperature on overall height and diameter growth within each growth regime. After 20 weeks, the total height growth of seedlings under the growth condition of 10° C constant was considerably less than the total height growth under the other two conditions. The effect of temperature (elevational data pooled) on the rate of growth (Figure 15) was as expected. The growth regime with the highest overall temperature (21° C constant) produced the tallest trees.

Considering it possible to find significant between-elevation differences in red alder growth rates, if not in total height, the periodic height measurements that were made during the course of this study were plotted on graph paper. The results are shown in Figure 14. The measurements taken during the first ten weeks were omitted from the graph because the growth between elevations, within each growth regime, was so nearly the same that the lines representing rates of height growth would be nearly superimposed upon one another. It was not until the tenth week that a spread between lines (growth rates) could be considered noticeable.

The pattern of growth rates shown in Figure 14 shows only a possibility for variation between elevations. Although this tendency is shown mostly by the seedlings under the warmest growth condition (21 °C constant), it is still overshadowed by the fact that the analysis of variance for height showed no significant differences between elevations by the end of the 20 week period. Continuation of this study might have shown this tendency for variation to be more substantial.

Observations of red alder leaves did not result in the discovery of any differences other than leaf size between growth regimes. Comparisons of leaf dimensions (length, width and length × width) showed no significant differences between elevations. The differences between growth conditions, were significant at the 5% level for leaf width and at the 1% level for leaf length and length × width. Figure 17 shows the effect of temperature on leaf size. The combination of length × width, to produce a surface area type of measurement, showed the leaves within the coldest growth condition (10° constant) to be considerably smaller in size than those under the other two conditions. This follows from the fact that seedlings were shorter under this condition.

The development of the seedlings within each growth regime resulted in some observations concerning the shade tolerance of red alder. The growth of these seedlings, in agreement with Enescu's work (9), was very slow for the first 10 weeks. With increasing height growth and leaf development, the seedlings began to show signs of competition within the planting boxes. This was true especially with the seedlings under the conditions of 21°, 16° C and 21°, 21° C. Since the soil moisture problem is assumed to be minimal because of daily watering, competition for light was apparently becoming more important. By the end of the study it had become serious.

The photographs in Figures 11-13 show the height variation within the planting boxes, particularly along the perimeters. This height variation is not as acute in the case of the seedlings grown under the coldest condition (10° C constant). Although Ruth (35) reported that Alnus rubra showed surprising tolerance for shade, during the first and second growing seasons, the seedlings with which he was concerned grew under natural conditions on mineral soil under dense timber stands. The seedlings in this study were grown in competition with each other. The shade tolerance in this case resulted in different findings. Red alder is apparently somewhat tolerant of the overhead shade of a variety of species under natural conditions. It is, however, apparently very intolerant of shade produced by members of its own species.

Under natural conditions the density of red alder stems would probably not be as much of a problem as it was in the planting boxes under controlled conditions. Indeed, shade from conifer stands may, under some conditions, be beneficial to the establishment of red alder seedlings (36). The shade can help prevent soil moisture loss during the initial stages of seedling development as well as protect the newly germinated seedling from high soil temperatures caused by direct solar radiation.

SUMMARY AND CONCLUSIONS

The investigation of the effects of thermoperiod on the early growth of red alder (Alnus rubra Bong.) show that differences within the species, grown naturally at various elevations and geographic locations, do exist.

The study involving the Newport-Marys Peak transect showed clinal variation between cones (size, weight and color), and seed (weight) collected from the seven elevational sources (0', 500', 1000', 1500', 2000', 2500' and 3000'). No significant differences were found between seedlings (heights, diameters, leaf characteristics and sizes) representing the various elevations. However, the fact that no significant differences were found in the twenty week old seedlings does not preclude the possibility of significant differences appearing in older seedlings. The trend toward increasing variation in seedling growth by the end of the twenty week period (Figure 14) shows this to be a possibility.

The second area of investigation, the Geographic Study (Appendix), showed differences between seedlings from different geographic locations. The seedlings from two of the ten geographic sources (Juneau, Alaska and Sandpoint, Idaho) exhibited marked differences from those representing the remaining eight locations. Observations of the morphological characters of the seedlings from these two sources alone suggest the possibility that they belong to different populations, either of clinal or ecotypic origin. The Sandpoint seedlings, because of their morphological differences (i. e., multiple leaders and leaning stems) and their geographically isolated location from the main continuous range of the species (Figure 1) are highly suggestive of ecotypic variation.

Differences found in red alder from different elevations and geographic locations open up avenues for new fields of study. Now that such differences are apparent, further investigations into reasons for them are suggested. One such field, that of ecological preconditioning, has been suggested by Rowe (34). He explained that phenotypic expression can be frequently understood in the context of preconditioning. Environmental influences, such as climate and soil, have a preconditioning effect on seed germination behavior and plant development. Rowe pointed out that there is evidence that the effect of these environmental influences may extend over several generations.

Both the Transect and Geographic Studies, demonstrated the effects of thermoperiod on seedling development. The results showed that a different developmental trend apparently exists at various stages during the establishment and growth of red alder seedlings. In the Geographic Study, the height growth of seedlings under the cold condition (10°, 10°C) was greater than for seedlings grown under the other growth conditions. In the Transect Study, the seedlings grown under the cold condition were significantly shorter than those grown under the other regimes. Further investigation may be desirable to discover at what stage, and for what reasons, in the life of red alder seedlings this developmental change takes place.

Recognition of economic as well as biological importance of the species *Alnus rubra* Bong. is steadily growing. Although still considered a weed species by many in the Douglas-fir region of the Pacific Northwest, red alder is, nevertheless, the predominant hardwood species. In these days of increasing population pressures and environmental awareness, needless waste of the forest resource must be brought to an end. The increased need for more diversified forest products, while at the same time maintaining a biologically sound forest community, is apparent. Research involving the minor species, such as red alder, is greatly needed if we are to gain a proper understanding of the place of these species in the environment and the economy.

REFERENCES

1. Andresen, J. W. Collecting can for small tree-fruit. Tree Planters Notes, no. 35. p. 17-19. 1959.

2. Baker, F. S. A revised tolerance table. Journal of Forestry 47 (3):179-181. 1949.

3. Berntsen, Carl M. Growth development of red alder compared with conifers in 30-year-old stands. (U. S. Department of Agriculture. Forest Service. Pacific Northwest Forest and Range Experiment Station Research Paper 38). 20 p. 1961.

4. Bollen, W. B., C. Chen, K. C. Lu and R. F. Tarrant. Influence of red alder on fertility of a forest soil, microbial and chemical effects. Corvallis (Oregon State University. School of Forestry. Research Bulletin no. 12). 61 p. 1967.

5. Cherstvin, V. A. Yield and quality of seed of Alnus glutinosa as affected by time of collection of cones. [Israel Program for Scientific Translation, Jerusalem, 1966] Lesn. Ž. Arhangel'sk. 6(1):163-164. 1963.

6. Chen, Chi-Sin. Influence of interplanted and pure stands of red alder, Alnus rubra Bong., on microbial and chemical characteristics of a coastal forest soil in the Douglas-fir region. Ph. D. thesis. Corvallis, Oregon State University. 163 numb. leaves. 1965.

7. Cochran, W. G. and G. M. Cox. Experimental design. 2nd ed. John Wiley and Sons, Inc. New York. 611 p. 1968.

8. El-Hassan, Babiker Ahmed. Juvenile development of Douglas-fir, red alder and snowbrush associations in western Oregon. M. S. thesis. Corvallis, Oregon State University. 52 numb. leaves. 1967.

9. Enescu, V. Vigor and growth of Alnus glutinosa seedlings during their first year. Rev. Pădurilor 75(11):644-646. 1960.

10. Enescu, V. Studies of the influence of light on the germination of Alnus glutinosa seed. Comunicările Academiei Republicii Populare Romîne, Bucureşti 13(7):605-612. 1963.

11. Enescu, V. The ripening, after-ripening and pretreatment of Alnus glutinosa seed. Stud. Cerc. Inst. Cerc. For., Bucureşti 24:51-63. 1964.

12. Everett, T. H. Living trees of the world. New York, Doubleday and Company. 315 p. [1968].

13. Garman, E. H. Pocket guide to the trees and shrubs of British Columbia. 2nd (rev.) ed. (British Columbia Forest Service Publication B. 28) 102 p. 1953.

14. Green, G. R. Trees of North America. Vol. II - the broadleaves. Ann Arbor, Edward Brothers, Inc. 334 p. 1938.

15. Haddock, P. G. A problem child reforms: new perspectives in the management of red alder. University of Washington Forestry Club Quarterly 22(2):9-15. 1949.

16. Hansen, E. D. Two-stage high-yield sulfite pulping of red alder, Alnus rubra Bong. M. S. thesis. Corvallis, Oregon State University. 60 numb. leaves. 1967.

17. Harlow, W. M. and E. S. Harrar. Textbook of dendrology. 4th ed. New York, McGraw-Hill. 651 p. 1958.

18. Holmes, G. D. and G. Buszewicz. The storage of seed of temperate forest tree species. Forestry Abstracts 19(4):455-476. 1958.

19. Holzer, K., and K. Liebeswar. The progeny of a supposedly mixoploid mother tree of Alnus glutinosa. Silvae Genetica 17: 69-73. 1968.

20. Johnson, Frederic D. Taxonomy and distribution of northwestern alders. In: Biology of Alder. (U. S. Department of Agriculture. Forest Service. Pacific Northwest Forest and Range Experiment Station, Portland.) p. 9-22. 1968.

21. Johnson, Herman M. Alnus oregona: its value as a forest type on the Siuslaw National Forest. Journal of Forestry 15:981-987. 1917.

22. Johnson, H., E. J. Hanzlik, and W. H. Gibbons. Red alder of the Pacific Northwest: its utilization, with notes on growth and management. (U. S. Department of Agriculture. Bulletin no. 1437) 46 p. 1926.

23. Krueger, K. W. and R. H. Ruth. Comparative photosynthesis of red alder, Douglas-fir, Sitka spruce and western hemlock seedlings. Canadian Journal of Botany 47(4):519-527. 1969.

24. Li, C. Y., K. C. Lu, J. M. Trappe, and W. B. Bollen. Selective nitrogen assimilation by Poria weirii. Nature 213:814. 1967.

25. Li, C. Y., K. C. Lu, J. M. Trappe, and W. B. Bollen. Inhibition of Poria weirii and Fomes annosus by linoleic acid. Forest Science 16(3):329. 1970.

26. Li, Jerome C. R. Statistical inference I. Edwards Brothers, Inc. Ann Arbor 658 p. 1964.

27. Little, E. L., Jr. Check list of native and naturalized trees of the United States (including Alaska). (U. S. Department of Agriculture. Forest Service. Washington. Agriculture Handbook No. 41) 472 p. 1953.

28. Lynn, M. Ionizing radiation in forests and forestry (excluding the use of radio-active tracers). Forestry Abstracts 28(1):1-18. 1967.

29. Mirov, N. T. and C. J. Kraeble. Collecting and handling seeds of wild plants. Civilian Conservation Corps Forestry Publication no. 5. 42 p. 1939.

30. Munsell soil color charts. Munsell Color Company, Inc. Baltimore. 1946.

31. Nichols, G. E. The influence of exposure to winter temperatures upon seed germination in various native American plants. Ecology 15:364-373. 1934.

32. Partridge, A. D., and F. D. Johnson. New records of forest fungi in Idaho. Northwest Science 38(4):134-137. 1964.

33. Pomeroy, K. B. and D. Dixon. These are the champs. American Forests. 72(5):14-35. 1966.

34. Rowe, J. S. Environmental preconditioning, with special emphasis reference to forestry. Ecology 45(2):399-403. 1964.

35. Ruth, R. H. Differential effect of solar radiation on seedling establishment under a forest stand. Ph.D. thesis. Corvallis, Oregon State University. 165 numb. leaves. 1968.

36. Ruth, R. H. First-season growth of red alder seedlings under gradients in solar radiation. In: Biology of Alder. (U. S. Department of Agriculture. Forest Service. Pacific Northwest Forest and Range Experiment Station, Portland.) p. 99-105. 1968.

37. Sargent, C. S. Manual of the trees of North America (exclusive of Mexico). Boston, Houghton Mifflin. 910 p. 1933.

38. Schalin, Ilmari. Germination analysis of grey alder (Alnus incana) and black alder (Alnus glutinosa) seed. In: Biology of alder. (U. S. Department of Agriculture. Forest Service. Pacific Northwest Forest and Range Experiment Station, Portland.) p. 107-113. 1968.

39. Snedecor, G. W. and W. G. Cochran. Statistical methods. 6th ed. Ames, Iowa State University Press. 593 p. 1968.

40. Society of American Foresters. Forest cover types of North America (exclusive of Mexico). Washington. 67 p. 1954.

41. Squillace, A. E. Geographic variation in slash pine. Forest Science. Monograph 10. 56 p. 1966.

42. Starker, T. J. A new alder. Journal of Forestry. 37(5):415-416. 1939.

43. Sudworth, G. B. Forest trees of the Pacific slope. U. S. Department of Agriculture. Forest Service. Washington. 441 p. 1908.

44. Sziklai, O. Preliminary notes on variation in cone and seed morphology of Douglas-fir, Pseudotsuga menziesii (Mirb.) Franco. Second World Consultation on Forest Tree Breeding, Washington. Voluntary Paper. 11 p. 11 August 1969.

45. Tarrant, R. F. Stand development and soil fertility in a Douglas-fir - red alder plantation. Forest Science 7(3):238-246. 1961.

46. Tarrant, R. F., L. A. Isaac, and R. F. Chandler, Jr. Observations on litter fall and foliage nutrient content of some Pacific Northwest tree species. Journal of Forestry 49(12):914-915. 1951.

47. Tarrant, R. F., K. C. Lu, W. B. Bollen, and J. F. Franklin. Nitrogen enrichment of two ecosystems by red alder. (U. S. Department of Agriculture. Forest Service. Pacific Northwest Forest and Range Experiment Station, Portland. Research Paper No. PNW-76.) 8 p. 1969.

48. Tarrant, R. F. and R. E. Miller. Accumulation of organic matter and soil nitrogen beneath a plantation of red alder and Douglas-fir. Soil Science Society of America Proceedings 27(2): 231-234. 1963.

49. Toma, C. Some peculiarities in the leaf structure of Alnus. Rev. Padurilor 84(11):557-560. 1969.

50. U. S. Department of Agriculture. Forest Service. Silvics of forest trees in the United States. Washington. (Agriculture Handbook No. 21) 762 p. 1965.

51. U. S. Department of Agriculture. Forest Service. Timber resources for America's future. Washington. (Forest Resource Report No. 14.) 713 p. 1958.

52. U. S. Department of Agriculture. Forest Service. Woody-plant seed manual. Washington (Miscellaneous Publication No. 654). 416 p. 1948.

53. Vincent, G. Storing the seed of broadleaved species in sealed bottles. Sborn. Ĉsb. Akad. Zemĕd. Ved. (Lesn.) 6(1):31-46. 1960.

54. Voight, G. K. and G. L. Steucek. Nitrogen distribution and accretion in an alder ecosystem. Proc. Soil Scientist Society of America 33(6):946-949. 1969.

55. Wallis, G. W. and G. Reynolds. The initiation and spread of Poria weirii root rot of Douglas-fir. Canadian Journal of Botany 43(1):1-9. 1965.

56. Willis, C. P. and J. V. Hofmann. A study of Douglas-fir seed. Proceedings of the Society of American Foresters. 10(2):141-164. 1915.

57. Worthington, N. P. Silvical characteristics of red alder. (U. S. Department of Agriculture. Forest Service. Pacific Northwest Forest and Range Experiment Station, Portland. Silvical Series no. 1) 15 p. 1957.

58. Worthington, N. P., R. H Ruth, and E. E. Matson. Red alder; its management and utilization. (U. S. Department of Agriculture. Miscellaneous Publication 881.) 44 p. 1962.

59. Yoho, J. G., D. E. Chappelle, and D. L. Schweitzer. The marketing of red alder pulpwood and saw logs. (U. S. Department of Agriculture. Forest Service. Pacific Northwest Forest and Range Experiment Station, Portland. Research note PNW-96.) 7 p. 1969.

APPENDIX

APPENDIX

Phase II: Geographic Study

The red alder seedlings obtained from the U. S. Forest Service to be used in this study were too few in number and, in several instances, too weak to survive for more than a few weeks. A total of 112 seedlings were received on April 9, 1969. Trees from some of the sources, such as the Cottage Grove lot had been severely root pruned. As a result of improper root pruning and other unknown factors 9% of all seedlings received died and were subsequently unavailable for measurement purposes. The percent survival of each source is listed in Table 10.

The growth rates of the red alder seedlings from the ten geographical sources showed variation between sources and between growth conditions. Comparisons between sources within the four growth regimes are plotted in Figures 18-21. Each figure represents the results of 21 weeks of height growth measurements of red alder seedlings from each geographical source within a specific growth regime.

A comparison of growth condition effects on seedling height can be observed in Figure 22. Similar

Table 10. Red alder seedlings obtained from the U.S. Forest Service indicating number received, number of deaths, percent survival, and growth characteristics.

Source No.	Source Name	No. Seedlings Received	No. Seedlings Died	Percent Survival	Growth Characteristics
1	Juneau, Alaska	17	1	92	Shrubby growth, all had multiple leaders, good vigor
2	River Jordan, B.C.	12	3	75	Good form, poor vigor
3	Concrete, Wash.	16	1	93	Good form and vigor
4	Olympia, Wash.	16	1	93	Good form and vigor
5	Amboy, Wash.	4	--	100	Good form and vigor
6	Lincoln City, Ore.	4	--	100	All had double leaders, good vigor
7	Cottage Grove, Ore.	8	3	63	Several multiple leaders, poor vigor
8	Port Orford, Ore.	5	1	80	Good form and vigor
9	Sequim, Wash.	16	--	100	Good form and vigor
10	Sandpoint, Idaho	14	--	100	Several multiple leaders, good vigor
	Total	112	10	91	

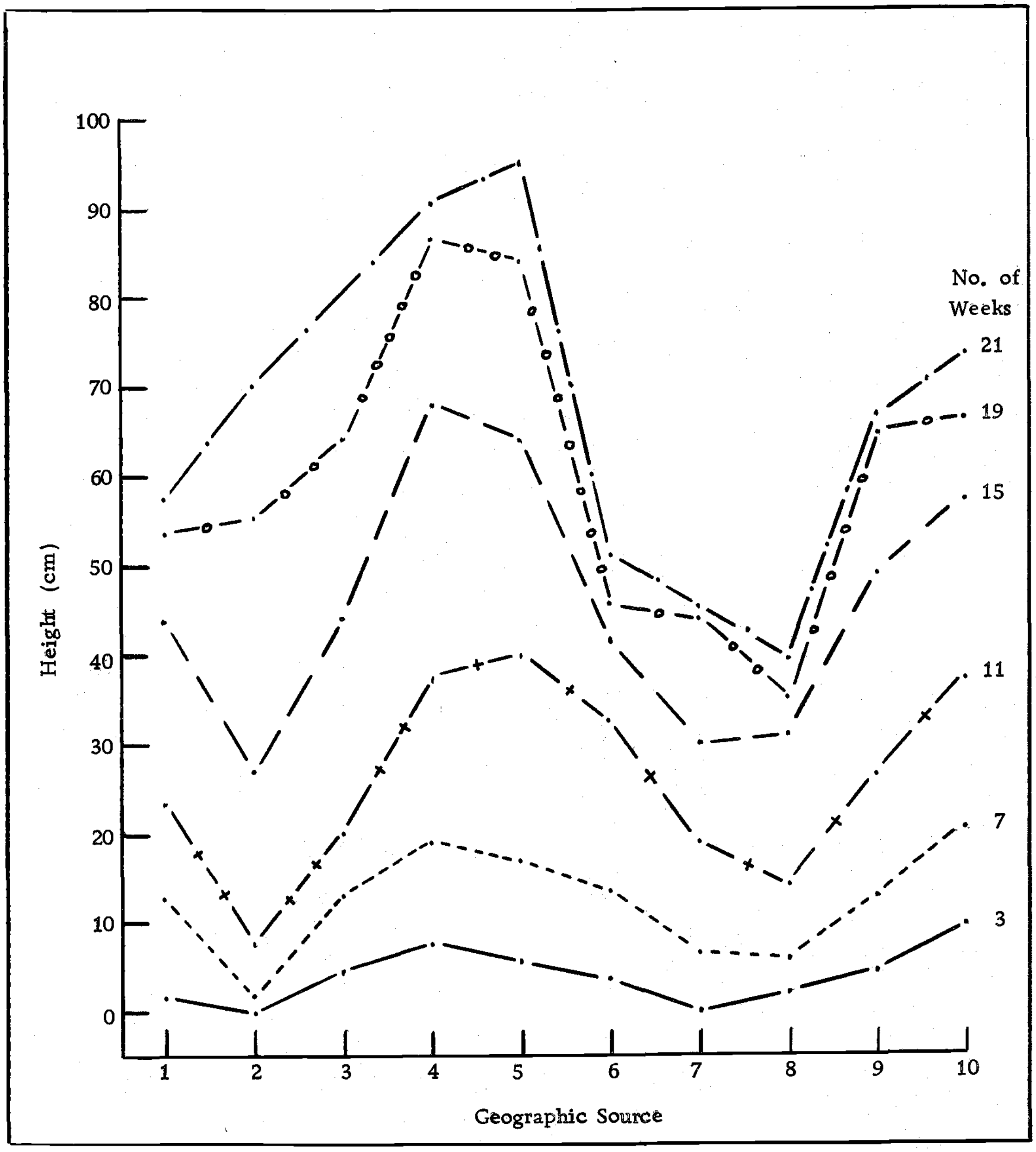

Figure 18. Comparison of red alder growth rates by geographic source. Temperature regime is 21°, 16°C. The upper line of the graph represents the total growth of the seedlings during the 21 weeks under this growth condition. See Table 2 for location of geographic source (Provenance No.).

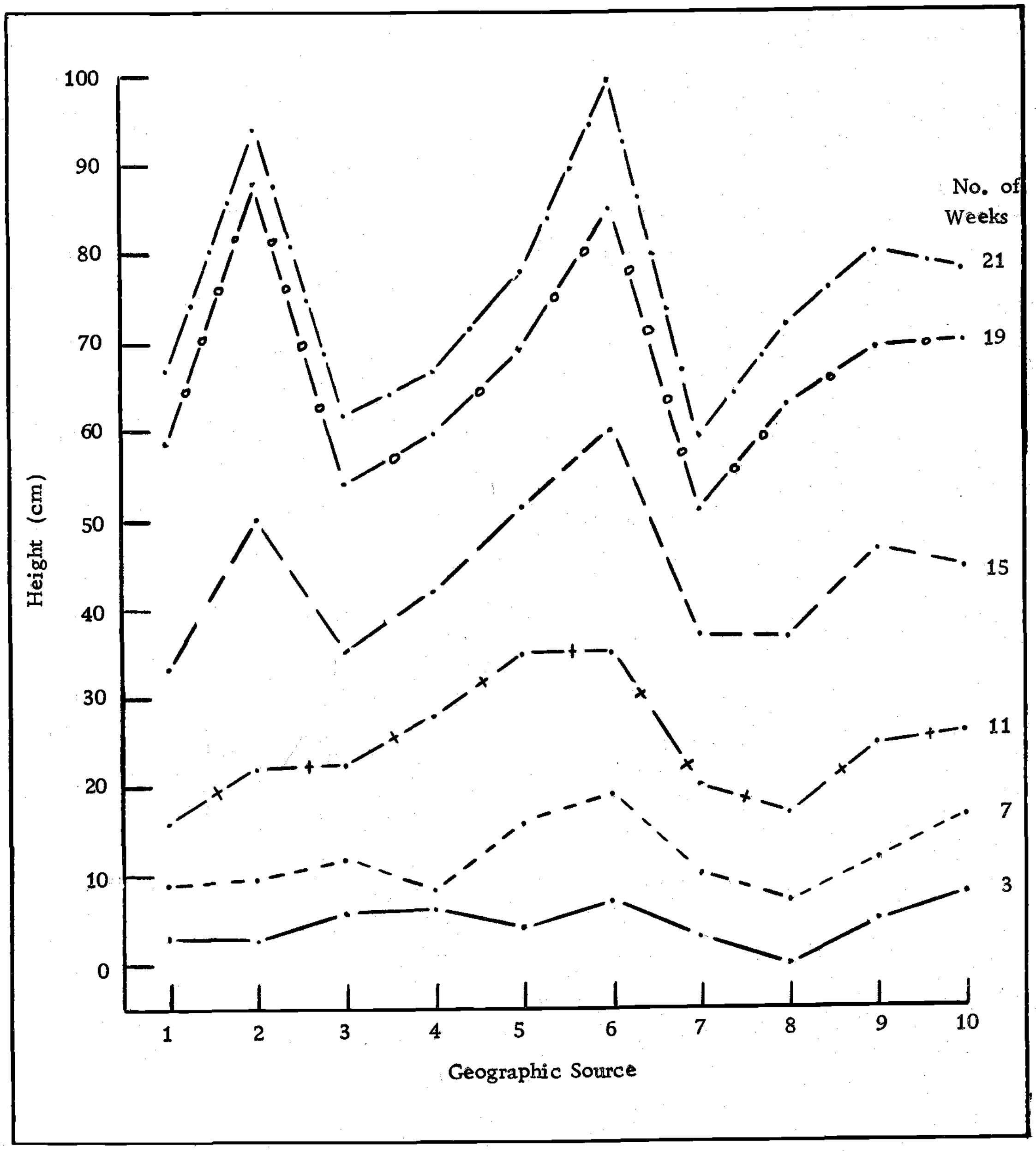

Figure 19. Comparison of red alder growth rates by geographic source. Temperature regime is 10°, 10°C. The upper line of the graph represents the total growth of the seedlings during the 21 weeks under this growth condition. See Table 2 for location of geographic source (Provenance No.).

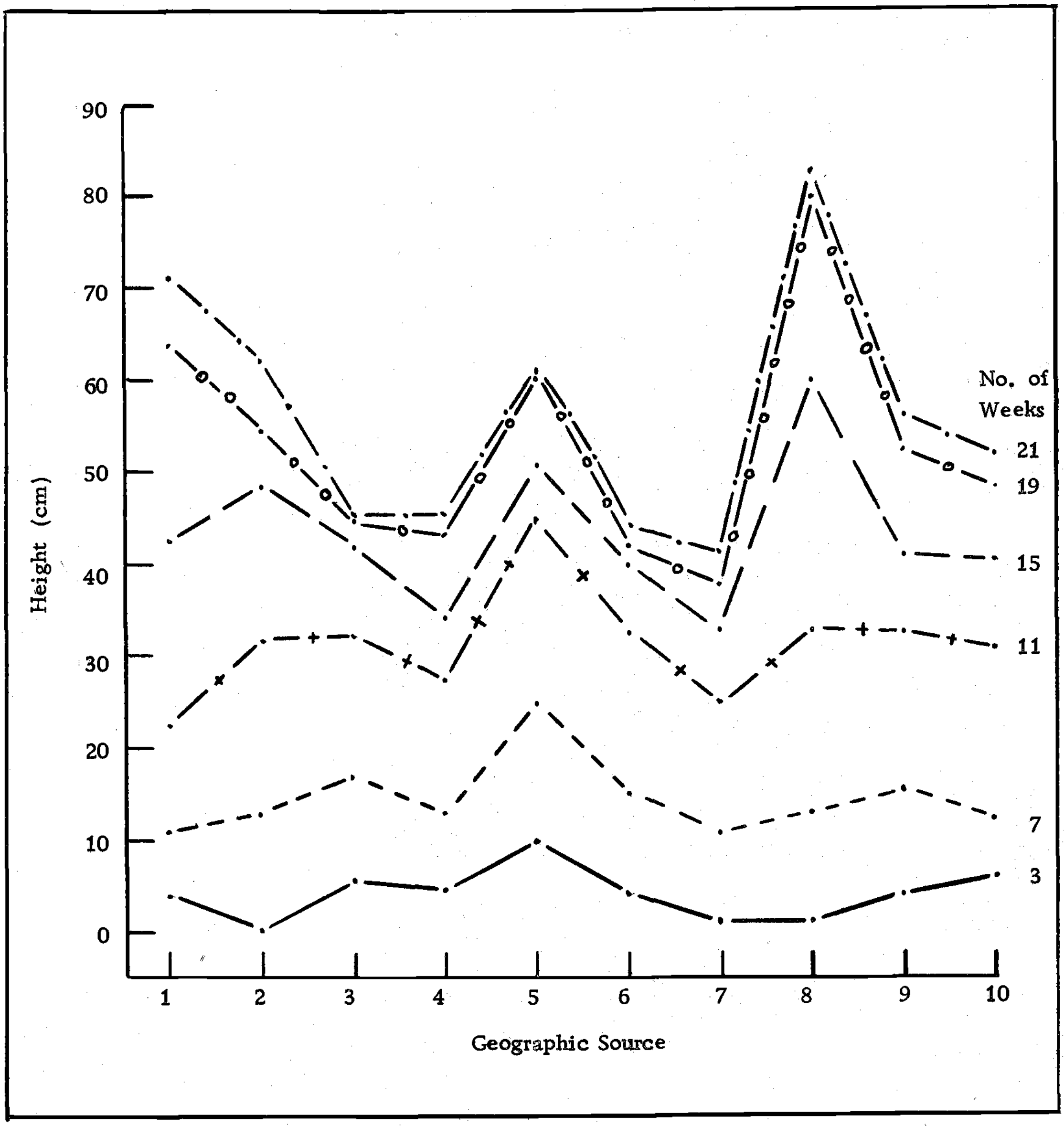

Figure 20. Comparison of red alder growth rates by geographic source. Temperature regime is 21°, 21°C. The upper line of the graph represents the total growth of the seedlings during the 21 weeks under this growth condition. See Table 2 for location of geographic source (Provenance No.).

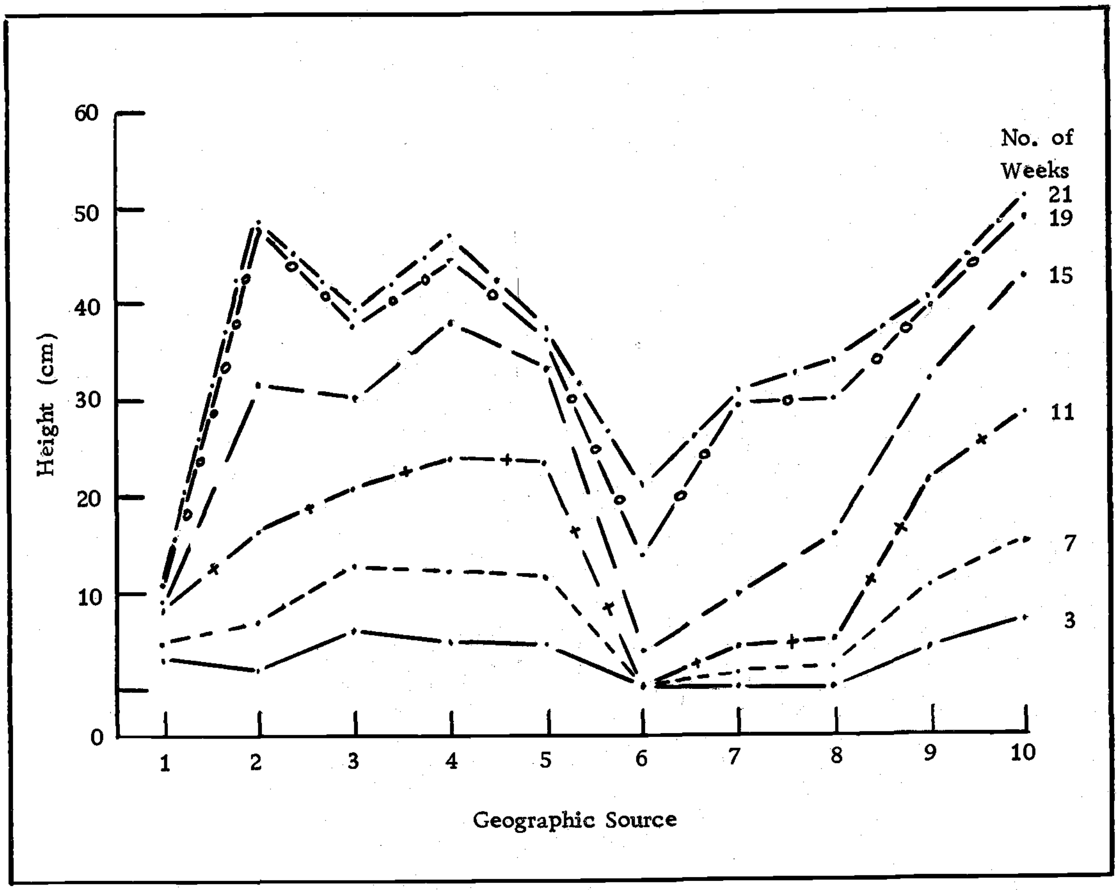

Figure 21. Comparison of red alder growth rates by geographic source. Temperature regime is Control. The upper line of the graph represents the total growth of the seedlings during the 21 weeks under this growth condition. See Table 2 for location of geographic source (Provenance No.).

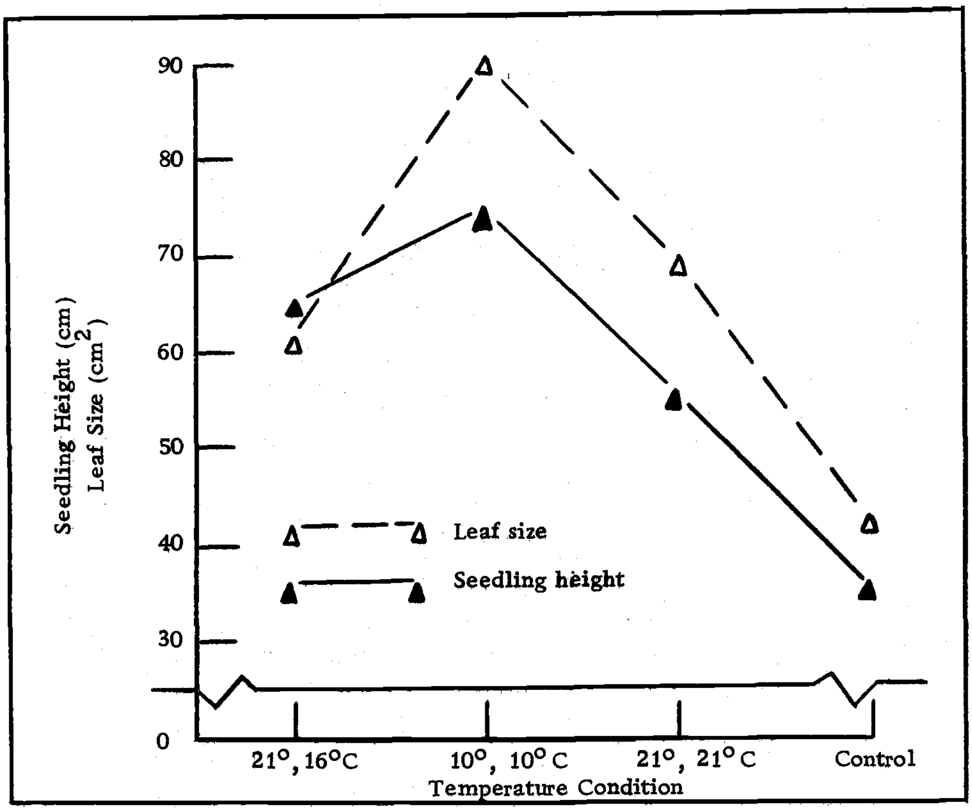

Figure 22. Comparison of temperature effects on seedling height and leaf size (length x width). Seedlings are pooled by condition (Geographic Study).

information involving leaf dimensions is shown in the same figure. By plotting the total height growth of these red alder seedlings and their corresponding leaf measurements on the same graph, a comparison of temperature effects on both seedling height and leaf size can be shown.

A further comparison, i. e., leaf sizes between geographic sources, can be observed in Figure 23. These bar graphs show the relative size of the leaves between sources under the four different growth conditions.

During the course of this study of the red alder seedlings from the various geographic sources, observations of overall seedling development were made. These included, as in the Transect Phase, such items as leaf shapes, margins, and coloration. No differences among leaves, other than variation in size, was observed. General observations of differences between growth characteristics are recorded in Table 10. The characteristics listed are those found irrespective of growth condition and include only those seedlings received from the Forest Service to be used in this particular study.

The photograph in Figure 24 was taken on October 15, 1969, 27 weeks after the seedlings were received from the Forest Service. Each pot contains two seedlings from the Control group. The seedlings from these three sources (A. River Jordan, B. C., B. Juneau,

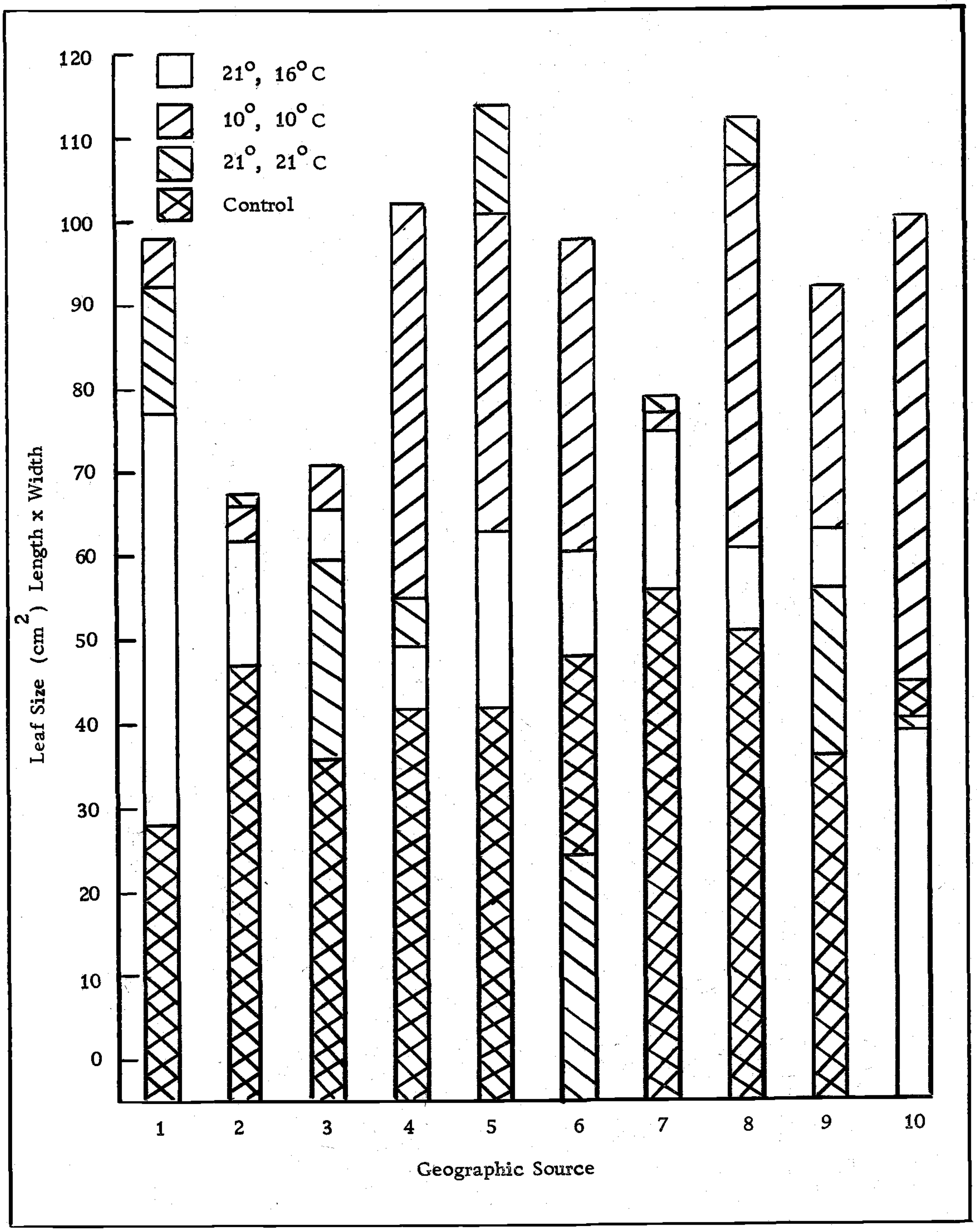

Figure 23. Comparison of leaf size (length x width) by geographic source and growth condition. See Table 2 for location of geographic source (Provenance No.).

Figure 24. Geographic Study. The general appearance of red alder seedlings from 3 geographic sources. Each pot contains 2 seedlings from the Control group. The seedlings of these 3 sources (A. River Jordan, B. C., B. Juneau, Alaska and C. Sequim, Washington) were about the same height (within 1 cm.) when received from the Forest Service on April 9, 1969. The photograph was taken 27 weeks later, on October 15, 1969.

Alaska and C. Sequim, Washington) were about the same height (within 1 centimeter) when received.

Figures 18-21 compare seedling growth for each geographic source under the four growth conditions. The differences between geographic sources, shown by this data, are obvious. However, the reliability of this data to express actual differences between Alnus rubra collected from the 10 geographic locations is subjected to further tests. The practical solution for the problem of an insufficient number of samples is to use the results of this study to decide if further investigation into the clinal or ecotypic origin of differences is warranted or if these differences could be actually caused by improper sampling (i. e., samples not representative of the geographic location).

The geographic source which showed the greatest variation in form from the other sources was from Juneau, Alaska. Seedlings of this source had multiple leaders and exhibited stunted appearances (when first received) when compared with the seedlings from each of the other sources (Table 10). Although the Juneau source was not the slowest growing or the shortest when final height measurements were taken (except for the Control where this source only grew 10 cm during the entire 21 week period) they, nevertheless, retained their shrubby appearance at the end of the study. The photograph in Figure 24 shows red alder seedlings from the Juneau, Alaska, source.

There was also variation between the seedlings from Sandpoint, Idaho, and the remaining nine sources. A number of the Sandpoint seedlings had multiple leaders similar to those from Juneau, Alaska, but they did not have the characteristic of exhibiting shrubby growth. The stems of the Sandpoint seedlings did not stand upright but had a characteristic lean or sweep to them. The seedlings from this source also showed a different response to the temperature regime of 21°, 16°C than the seedlings from the other sources (Figure 24). The leaves of the Sandpoint seedlings were smallest under this condition, whereas leaves of seedlings from other sources were smallest under the control condition. Generally speaking, though, the leaf sizes between seedlings grown under the different temperature regimes varied with seedling height growth.

The red alder seedlings from sources 2, 3, 4 and 9 (River Jordan, B. C., Concrete, Olympia and Sequim, Washington) were classified as having good form. They had single straight stems, giving evidence that they might develop into the typical, tall grey barked trees which are characteristic of Alnus rubra found on good sites.

The seedlings from the remaining sources, 5, 6, 7 and 8, showed varying characteristics. They were few in number (Table 10) and, for that reason may not be representative of the main population of seedlings from the same locations. Therefore, no attempt is made to describe them.

The major differences observed between the sources were the slower than average growth and multiple leaders of the seedlings from Juneau and the leaning stems and multiple leaders from Sandpoint. The source from Juneau, represents the northern extreme of the red alder range. The other source from Sandpoint, represents the eastern extreme--actually an isolated island of red alder, not connected with the main continuous range of the species (Figures 1 and 4). Observation of the seedlings from these two sources alone suggest possibilities that they belong to different populations, either of clinal and even ecotypic origin (especially the Idaho source) considering some of the morphological characteristics of the species.

The seedlings from geographic source No. 4 (Olumpia, Washington) reacted differently under the different growth conditions. Under the 21°, 16°C regime, the seedlings from Olympia grew rapidly and ranked second in height growth among all ten sources. In the control group, seedlings from this source ranked third in height growth. Under the constant conditions of 10°, 10°C and 21°, 21°C the seedlings from the Olympia source dropped to eighth place in height growth when compared with the seedlings from the remaining nine sources. Fluctuating growth conditions (i. e., temperatures) appear to induce favorable response in height growth among seedlings from this source (Figures 18-21).

The seedlings from geographic sources No. 6 and 8 (Lincoln City and Port Orford, Oregon) also demonstrated varying reactions to the different growth conditions. The seedlings demonstrating the greatest height growth of any source, under any condition, were those from Lincoln City, under the 10°, 10° C regime. Seedlings from this same source, showing the least height growth of any source, under any condition, occurred in the Control regime. Both extremes, the greatest and the least growth, were demonstrated by seedlings from the Lincoln City source (Figures 19 and 21).

In the case of the Port Orford Seedlings (source No. 8), a comparison of reactions under two growth regimes, 21°, 21° C and 21°, 16° C, showed quite the opposite results. This source demonstrated greater height growth than the other nine sources under the 21°, 21° C condition. However, under the 21°, 16° C regime, the Port Orford seedlings grew the least when compared with the remaining nine sources (Figures 18 and 20).

Any interpretation of these height growth results, of seedlings from geographic sources No. 6 and 8, should take into account the fact that only one seedling was available for data accumulation under each growth regime.

As in the Transect Study, the effect of temperature condition on height growth and leaf size of the red alder seedlings was apparent (Figure 22). The results obtained from the Geographic Study, however, were just the opposite. Under the cold condition of 10°, 10°C (Figures 16 and 17), the Transect Study seedlings were shortest and had smallest leaves, whereas in the Geographic Study, seedlings produced the greatest growth in height and leaf size. Ruth (35) found a similar phenomenon which he termed the "unexpected" results of the effects of solar radiation on seedlings established under a forest stand. His discovery was a sharp reduction in height growth of red alder seedlings at high radiation levels. This was not what might be expected of an intolerant tree. He contributed this reduction to either increasing radiation, decreasing soil moisture or some combination of these variables. The results of both phases of this investigation (Transect and Geographic Studies) appear to indicate that decreasing soil moisture is not necessarily a contributing factor to reduced growth. All seedlings within the studies received ample watering. Also, increasing radiation may not, by itself, be the reason for reduction in height growth. As mentioned above the effect of the cold condition (10°, 10°C) resulted in reduced growth of the transect seedlings and the apparent growth stimulation of the geographic seedlings. The warm condition (21°, 21°C), on the other hand, had the reverse effect in that the growth of the geographic seedlings was reduced and there was increased growth of the seedlings in the Transect Study. Table 11 shows these results in a rather simplistic form.

Table 11. Comparison of temperature effects on the growth of seedlings from the Transect and Geographic Studies. (S = seedlings of slowest growth, F = seedlings of fastest growth.)

Temperature Condition	Transect Study	Geographic Study
10°, 10° C	S	F
21°, 21° C	F	S

These results suggest that a different developmental trend exists at various stages during the establishment and growth of red alder seedlings. Under conditions of low constant temperature, initial growth is slow but later speeds up. Under conditions of high temperature, initial height growth is rapid but soon slows down and may even fall behind seedlings grown for a comparable period of time under low temperature conditions.