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A Pioneer Exotic Tree Search for the Douglas-Fir Region

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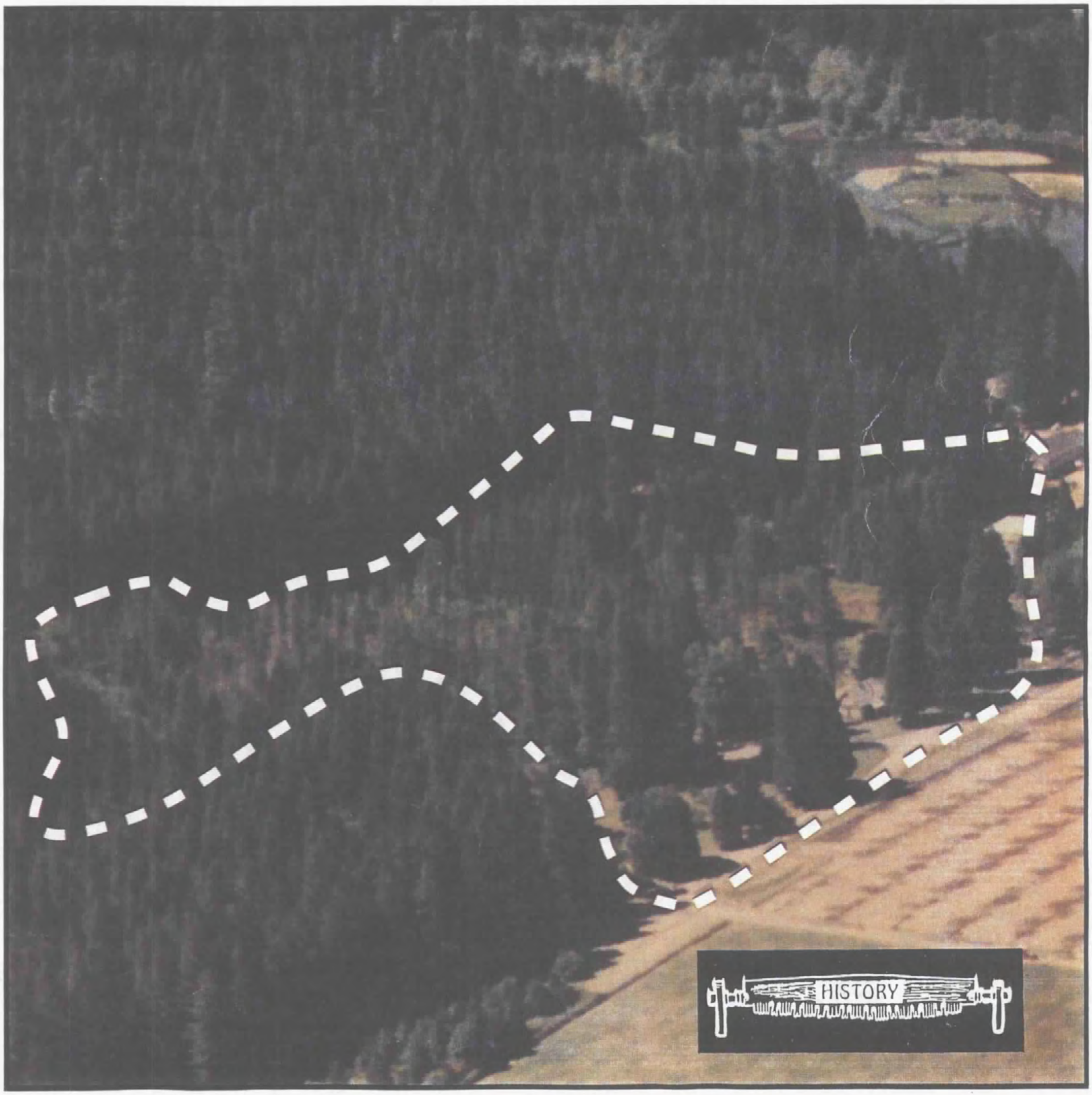

Authors

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Thornton T. Munger (1883 to 1975) pioneered the program of testing exotic tree species for use in the forest environment of the Pacific Northwest. An original sign shown at the Wind River Aboretum entrance (circa 1938) expressed this goal.

Abstract

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After three-quarters of a century of introduction of 152 conifer and broadleaf species, no promising candidate exotic was found for the Douglas-fir region. Growth curves spanning 50 years or longer are figured for many species. Firs, pines, larches, spruces, hemlocks, and cedars originating in northwestern North America had superior growth rates to those from other forest regions. The probable basis for these differences is discussed. The record highlights a general failure of introduced hardwoods, the slow decline of most introduced conifers, the long time needed to express failures, dramatic effects of climatic extremes or of introduced pests, failure of native species of continental origin at Wind River, striking similarities of growth rates for the species originating in each country, and many important contrasts between results from early reports and long-term conclusions.

Keywords: Plant introduction, forest genetics, arboreta, conifers, silviculture, growth curves, exotics, seed movement, introduced pests, climatic extremes.

Contents

Introduction

At the turn of the century, a worldwide search for fast-growing exotic trees stimulated forest research in every forest region. Such a search for the Douglas-fir Region began in 1912 at the Wind River Arboretum (fig. 1). After 76 years of testing of 152 conifer species or varieties, the overriding finding is the inherent superiority in the growth rates of species from western North America. Thus, the search has proved to be a one-way street: other regions have profited from our fast-growing species, but the record shows no promising species from any other country for our general forestry.

This report, probably the final one of a long Wind River Arboretum series, also highlights other experiences with very important forestry implications. The long time span required to express a species mismatch to the environment becomes clarified by this seven-decade record. Understocking and the failure to dominate the site became the most common expression of species maladaptation. Growth curves, often spanning more than half a century, now provide a long-time comparison of species performance within each coniferous genus at this average Douglas-fir Region site (fig. 2). One of the earliest observations at Wind River was the generally poor adaptation of introduced broadleaf species for the Northwest's typical summer-drought environment. The dramatic demise of several species and gradual fading of many others from a single climatic extreme is documented. Diseases and insects have often gradually determined what now survives among many species planted before 1930. The slow demise from needle diseases of our native tree species having continental seed origins provides an invaluable forestry lesson. A more profound finding is the similarity of growth between species within each of the world's forest regions. Finally, clear examples demonstrate how long-term forest research findings contrast with short-term results—the slow failure of promising exotics in general is the best example. But none of these implications overshadow the observation that North American firs, pines, hemlocks, cedars, spruces, larches, and redwoods, for reasons still speculative, outgrew their generic representatives from other world regions by wide margins.

Wind River Arboretum History, 1912 to 1986

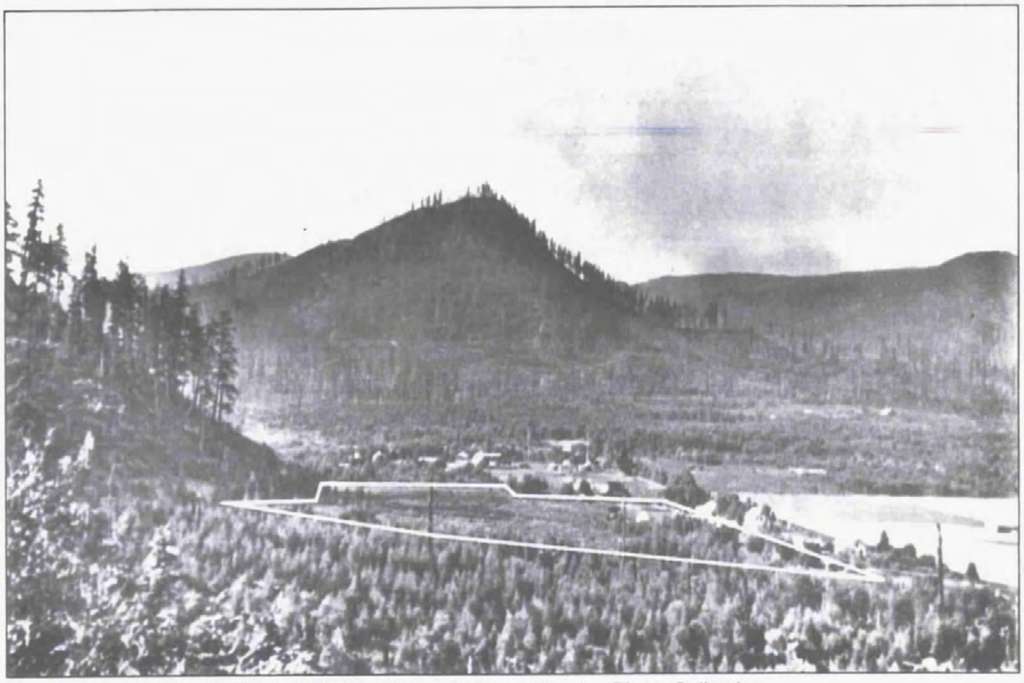
Background

Trees of North America impressed the earliest explorers by their giant sizes. Early travelers who carried seed from western North America back to Europe, Asia, Australia, New Zealand, South America, and South Africa found the firs, pines, spruces, and hemlocks grew substantially faster than their native species. In Europe, early-day foresters documented superior growth rates for Douglas-fir, Sitka spruce, lodgepole pine, and grand fir over their native conifers.[1] In the Southern Hemisphere, chance plantings of spreading-leaved pine (*Pinus patula*) in South Africa and Monterey pine in New Zealand and Australia displayed growth rates of high interest. For those plantings that displayed outstanding growth, the common early forestry explanation was a purported growth advantage from getting trees away from their native pests (Moulds 1957).

In the Douglas-fir Region, early settlers and seafarers also began planting seed lots from many parts of the world. Besides a general lack of documentation, these scattered and unorganized introductions were usually planted in urban settings, making forestry interpretations risky. Procurement of seed from Eastern United States species was begun in 1909 by USDA Forest Service personnel associated with Wind River Nursery. These species provided the nucleus for a formal arboretum established in 1912. For about a quarter century, this effort by the Forest Service was the only organized program of worldwide species introduction in the Northwest.

[1] Scientific names for all tree taxa mentioned are in appendix, table 1.

A



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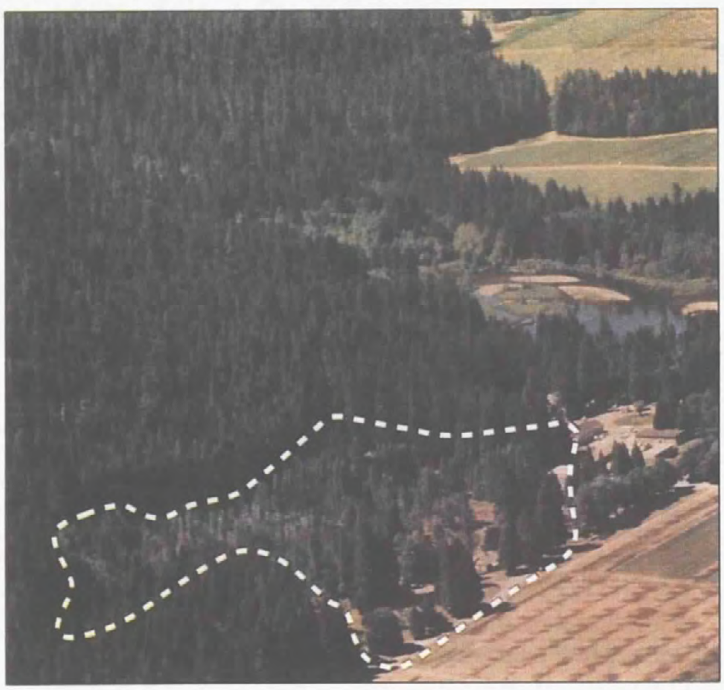

Figure 1—**(A)** Wind River Arboretum in about 1917. The cultivated area on the right is the Wind River Nursery. The surrounding trees are naturally grown Douglas-fir about 20 years old. **(B)** Aerial view of Wind River Arboretum at age 76 years (area outlined). The 11-acre site bordered by a 120-foot-high wall of Douglas-fir trees contemporary with the oldest plantings. Despite nearly complete planting of the site to 230 small blocks of trees representing 152 species and varieties of conifers from around the world, the area is now mostly open because of general failure of exotics. The scattered main groups of large trees within the Arboretum are almost entirely representatives of conifers native to the Cascade Range and the Sierra Nevada of Western North America, which here display a growth rate in each genus superior to any introduced tree. Had not tens of thousands of volunteer seedlings been removed, the 11 acres would also be like the surrounding Douglas-fir stand.

Figure 2—Wind River Arboretum entrance structure appropriately houses a cross section of the world-record Douglas-fir tree from western Washington. All Arboretum species are compared in height with average Douglas-fir of the same age on the site. Douglas-fir is the fastest growing species at Wind River.

The Wind River Arboretum was initiated by Thornton T. Munger, carried on into the 1940s by Ernest L. Kolbe, and maintained through the 1950s by Leo A. Isaac. Each of these men were research foresters of international stature. During their three overlapping careers, they introduced nearly every conifer of possible commercial interest for this region. Most of their introductions are now approaching rotation age. Thus, this paper represents a culmination of their search.

The first documentation that superior inherent growth rates, not escaping pests, was the probable explanation for the popularity of exotic species plantings arose from coniferous species planted into generic blocks on an average forest site at Wind River Arboretum (Silen 1962). Western North American species were observed to grow substantially faster than exotics at home as they had been observed to do abroad.

Of the arboreta of the Pacific Northwest, Wind River Arboretum has only two distinctions. First, it was the earliest. Most species have been tested half a century or longer—enough time for many of the slow environmental and genetic trends to run their course. And second, it is on an average Cascade forest site with a typically harsh environment. But this seeming disadvantage is also its advantage. The findings now apply better to average forest sites than data from exotic plantings in more gentle urban environments of the Region.

Arboretum Goals

Wind River Arboretum, located in the mile-wide Wind River valley near Carson, Washington, began in 1912 with the planting of a few species of introduced trees on stump land adjacent to the Wind River Nursery. The Nursery was already into its fourth season. Because tree seed of local species was hard to procure in commercial quantities, many of the first nursery lots were from seed of Eastern U.S. species, the source of the earliest Arboretum planting stock. Thus, the Arboretum ranks among the earliest forestry projects of an experimental nature still in existence in the Region. During the initial years, the objective evolved into testing the suitability of trees from temperate and subtropic zone forests of the world for forest planting under conditions generally prevailing west of the Cascade Range in Oregon and Washington. Trials of exotic and native species, planted in the Arboretum at 1,150 feet elevation on average site Douglas-fir land in the center of the Cascade Range, were assumed to provide forestry performance data that would be broadly interpretable for the Region. Nearly all the conifers native to the Cascades could be grown there. Hence, growth measurements and other observations were recorded, beginning with the earliest seedling lots.

This objective was later broadened to include establishment of as many forest-tree species as possible to serve for dendrological study and exhibition. The objective was finally broadened still further to provide for planting different races of species in an attempt to determine racial variation within certain species and hybrid strains. In all, 610 lots of seed or planting stock have been tried. Of these, performance of the 152 species or varieties of conifers that were tested in a commercial forest environment, often for half century or more, became its greatest contribution to forestry. In the 1950s, the Arboretum was placed in a maintenance status, but measurements and observations were continued at 10-year intervals until 1986.

The 11-acre Arboretum was arranged systematically to include space for species from most genera of conifers. A few hardwood species still remain from early plantings, but because of very poor results with almost all hardwoods, no attempt has been made since 1928 to establish additional broadleaf species.

Previously published reports (Munger and Kolbe 1932, Munger and Kolbe 1937, Munger 1947, Silen and Woike 1959, Silen 1967) describe history and performance of Arboretum acquisitions through 1967.

Location

Wind River valley extends in a north-south direction in the Cascade Range of southwestern Washington. Wind River Arboretum (latitude 46° N.) is at the western edge of the mile-wide valley floor at an elevation of 1,150 feet. Surrounding forested hills rise 1,000 to 3,000 feet. The Arboretum may be reached from U.S. Highway 84 in the Columbia Gorge and the Wind River road, which joins with U.S. highway 830 a few miles east of Stevenson, Washington. The Arboretum is 10 miles northwest of Carson, Washington. Wind River Nursery, the Experimental Forest, and Hemlock Ranger Station—all USDA Forest Service installations—are immediately adjacent.

Site

The Arboretum is on a site that was originally Douglas-fir forest with a site index of 130—near the regional average. The soil is a deep, coarse, sandy loam that is stony in places. It was deposited as an alluvial bench or fan on an approximate 10-percent slope along the edge of the valley, bordering the steep hills. The soil is fairly porous, appears to have no hardpan subsoil, and dries out very rapidly. Competing vegetation has been cut down periodically since 1912 and has never been allowed to seriously interfere with Arboretum trees. Such potential competition includes vine maple, hazel, whortleberry, huckleberry, alder, chinquapin, blueberry elder, and volunteer native and introduced conifer seedlings, which would gradually have turned the clearing into forest. Annual dense growth of bracken fern has covered the floor of the arboretum since its establishment. No attempt has been made to remove the bracken except around very small trees that could be shaded, lodged upon, or weighed down.

Climate

The Arboretum has a summer-drought environment typical of the Douglas-fir Region that constrains or even halts summer growth. The climate is characterized by heavy precipitation, mostly between October and May; acute summer drought during July and August with hot, dry days; absence of excessively cold winters; accumulation of 6 to 10 inches of heavy, wet snow; a rather short frost-free period; and cool nights, even in summer. Because the valley is surrounded by mountains, precipitation is somewhat heavier than would be expected at this altitude and the frost-free period is shorter because of cold-air drainage common to these valleys. Climatological data from the Wind River weather station for 1911 to 1950, when the record terminated, are summarized as follows:

Mean annual precipitation (inches)	89.9
Maximum annual precipitation	142.6
Minimum annual precipitation	54.15
Mean annual temperature (°F)	48.1
Mean maximum annual temperature	59.7
Mean minimum annual temperature	36.5
Highest recorded temperature (°F)	107
Lowest recorded temperature	-18
Average July temperature (°F)	63.8
Average January temperature	31.5
Average season without frost (days)	131
Shortest season without frost	73
Longest season without frost	193
Clear days per year (percent)	34
Partly cloudy days per year	22
Cloudy days per year	44

The wet-winter, dry-summer climate is typical of major valleys for much of the area along the west slopes of the Cascade Range in Oregon and Washington. For example, climatological records at Prospect and McKenzie Bridge in Oregon and Darrington and Kosmos in Washington show similar temperature minima, and frost-free periods. Wide-valley locations, such as Albany and Corvallis in Oregon and Centralia in Washington, have recorded equally low minimum temperatures, even at elevations under 500 feet. Apparently, the location of the Arboretum, within 12 miles of the Columbia Gorge, has had minimal localized effect on extremes of weather as reflected in the climatological data.

Arrangement and Treatment of Arboretum Trees

Each year between 1912 and 1925, a few additions were made to the Arboretum, with little regard to uniform numbers, treatment, or systematic arrangement. Plantings of hardwoods were in at least equal proportion to those of conifer species. In 1920, several of the species were moved to an area adjacent to the Arboretum with the expectation of spreading the plantings over more area. Because many of the trees moved were already quite large, many died. The trees were moved back to the original Arboretum in 1924, with more loss resulting. Where such losses were serious, new seed lots were grown to replace them.

The almost universal early failure of introduced hardwoods indicated that they were poor risks in the long summer droughts and short growing seasons of the Cascade Range. After 1928, introduction of hardwoods was given up, and the Arboretum was devoted exclusively to conifers.

A plan for planting by a taxonomic pattern of species by genera was completed in 1925. A new section of the Arboretum was allotted to each coniferous genus, with the 1912-25 mixture of hardwoods and conifers left in the original site. Subsequent plantings have followed this plan so that now most species in a genus are found in blocks of an acre or more. Later plantings provided 2,500 to 3,000 square feet for each species; 16 to 25 trees, when available, were set 12 to 15 feet apart, avoiding regular rows.

Trees were usually about 1 foot high when planted. Care was usually limited to removing competition and spading the ground well around the planted tree. Some were shaded during establishment. Bracken fern was cleared away whenever necessary to prevent lodging. Snowbent or broken trees were guyed or braced with splints. Once established, trees were usually given the added care needed to assess suitability for use in this locality, especially species vigorous enough to show promise as forest trees. Poorer lots that might be lost from representation in the Arboretum were given great care, however. Water pipes were laid over most of the area in the 1930s, as a Civilian Conservation Corps project, largely for fire protection. Some watering was done to assist in establishing such lots, but most of the plantings have received no artificial watering. The water system was not used after World War II.

Sources of Seed and Planting Stock

Most of the planting stock used in the Arboretum was grown from seed in nearby nursery beds. Some stock, however, was shipped from as far away as the east coast States. Some earlier lots of seed were purchased from commercial seed houses, but almost all later lots were from original collections of forest experiment stations, agricultural explorers, or arboreta. Several plantings of native species were made with wildlings. Many individuals and organizations contributed seed and seedlings for the Arboretum, and gratitude is due them for their cooperation.

Of the 610 lots of seeds and plants acquired for the Arboretum since 1912, 192 were never adequately tested. Fifty lots, obviously unsuited for the climate, were sent elsewhere to a milder climate for trial. The remaining 142 lots either failed to germinate, were destroyed as seedlings by frost heaving or rodents, or arrived in poor condition. If these were species that were considered of commercial interest, an effort was made to test a second or third lot.

Disease and Pest Control

Both introduced and native pests have caused serious mortality. White pine blister rust reached the Wind River valley in the 1920s, and balsam woolly aphid by the 1950s. Both have decimated susceptible species. Chestnut blight has never appeared in the valley, which therefore provides a refuge for the slow-growing surviving members of a group of American chestnuts planted in 1925. Another surprising pest has been the native red-breasted sapsucker *(Sphyrapicus ruber)*—a bird that damages trees by pecking closely spaced rings of holes around the trunk (fig. 3).

Figure 3—Scotch pine damaged by the red-breasted sapsucker. Partial girdling by the closely spaced holes followed by fungal entry has caused severe damage from stem breakage. The bird seeks out exotic species of Eurasian origin.

The sapsucker definitely prefers species of European or Asiatic origin. Many trees were eventually killed by repeated attacks, probably associated with fungal entry. Deer browsing has been a continual problem with young trees but has been most severe in establishing the yew species. Root rots have become established in several lots of the pine species.

Pest-control efforts were limited to hunting or to screening seedlings from animals, to slowing the spread of blister rust and spruce gall aphid, and to a single unsuccessful spraying of trees susceptible to balsam woolly aphid *(Adelges piceae).*

In 1928, in an attempt to safeguard the Nursery and Arboretum from white pine blister rust, crews began removing native gooseberry *(Ribes)* species abundant in the locality. Eradication was continued through 1931, repeated in 1939, and again in 1941. In addition, for several years between 1939 and 1946, a program of excising stem cankers and removing infected limbs was carried out. In spite of these efforts at control, blister rust continued to appear on, and eventually kill, several species of five-needled pines. Several of the formerly best pine lots in the Arboretum are now virtually wiped out.

Susceptible fir lots were sprayed in 1956 in an attempt to control the balsam woolly aphid, and in 1957 European and Indian predator insects were liberated there, as well as elsewhere in the region, by Station entomologists (Mitchell and Wright 1976). An earlier minor effort attempted to control the Cooley spruce gall aphid *(A. cooleyi)* on Sitka spruce.

Except for sporadic hunting, little attempt was made to control the red-breasted sapsucker.

Climactic Factors

The period between 1949 and 1955 probably provided the most severe climatic test of suitability of introduced species since establishment of the Arboretum. During this period, many species that had shown promise as forest trees were damaged or killed by the very severe winter of 1949-50 and particularly by the exceptionally early and extremely low temperatures in November 1955.

A severe drought in the spring and summer of 1951, during which no appreciable rain fell from April to early September, provided a most severe test of drought resistance.

Snowbreak and the bending over of stems from the heavy wet snows of the site have been a problem for many introduced species, especially among the larches and pines (fig. 4). Some smaller trees below snow level have suffered severely from freezing of hard-packed snow to limbs and subsequent tearing of limbs from trunks.

In retrospect, however, documenting the full effect of these separate factors is difficult to distinguish from the gradual weakening of exotic species native to climates with summer rainfall grown year after year with little summer soil moisture.

Relative Growth Comparisons

A standard, termed "Growth Index," was used in previous Arboretum reports to quantify the relative growth rates of Arboretum tree lots compared with Douglas-fir of the same age native to the site. In 1956, 11 Douglas-fir saplings growing on the site were measured for height at each whorl, and yearly heights were measured since. Exact age of each tree was determined by boring to tree center at ground line. The 1986 ages ranged from 72 to 80 years. A graph of average height over age of the 11 trees was drawn. Douglas-fir height growth is slow initially, averaging only 7 feet the first decade on this site. After that, height growth averages over 20 feet per decade, at least to age 75. The index cannot be used beyond this age because all the measured Douglas-fir trees in the Arboretum were sold in a timber sale in 1988. The Growth Index is the ratio of height of the tallest tree in a lot to the height of average dominant Douglas-fir from the graph.

This Growth Index is purposefully conservative when the tallest tree in each Arboretum lot is compared with **average** Douglas-fir growth. The rationale for this conservatism is that perhaps better races of introduced trees might average the height of the tallest tree in the lot sampled in the Arboretum.

Now that most lots have grown for half a century, a still better comparison than Growth Index is the shape of the growth curve for each species. Graphs were prepared to compare species of interest in each genus with the growth curve of Douglas-fir. In early years, many species grew faster and thus had steeper slopes than Douglas-fir. But the latter years provide comparisons during the "grand period of growth" when the growth rate, hence slope, often changes little for decades. In this period, no curves are steeper for longer than Douglas-fir's, although some are steeper or equally steep for a decade or more initially. Some species lots—like grand fir, noble fir, and the Sierra redwood—started more slowly than Douglas-fir but now grow nearly as fast, hence their growth curves are now almost as steep. Others, like European and Siberian larches, began even steeper but soon flattened.

Genera often displayed characteristic growth patterns. In some, the species grew rapidly initially, then flattened. In others, they started slowly then attained steep slopes. Of even more interest is the comparison of curves by forest regions of the

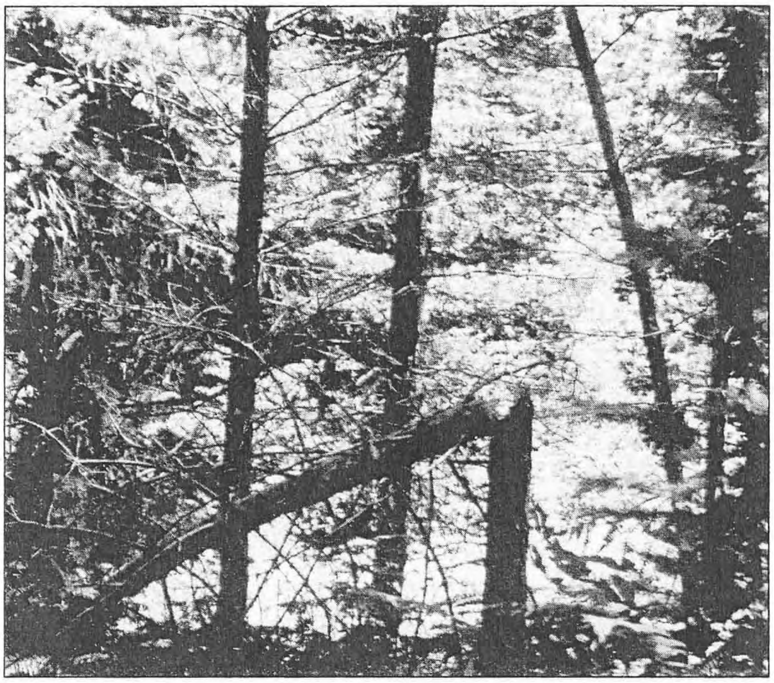

Figure 4—Heavy, wet snow common to the Cascades causes stem breakage or bending in many exotic conifers, such as in this group of Scotch pine.

world, a topic discussed in a later section.

Growth Index is provided for each Arboretum lot in table 1, and comparisons between species, as well as their comparative growth with that of Douglas-fir, are displayed subsequently in graphs of each genus.

Performance of Conifers

Table 1 (appendix) shows the condition of all living groups of conifers in the Wind River Arboretum in 1986. Explanation of the column headings are:

Species—Approved names (Little 1979) have been used for species native to the United States. Additional references, consulted for introduced species, are Critchfield and Little 1966, Dallimore and Jackson 1967, Kelsey and Dayton 1942, and Rehder 1940, 1949. Name changes of species were updated by Dr. Kenton L. Chambers, Curator, Oregon State University, and by Dr. John W. Duffield, retired.

Lot number—The serial number given each acquisition, beginning with number 1 in 1912, and continuing to 610 at present.

Range—Generalized range in four words or less.

Seed source—As listed in lot records. Many early listings are arboreta, forest center, or seed dealer locations. Some source records are more specific than listed.

Year sown—For fall-sown seed, this is the year of germination. A question mark indicates that stock was of indeterminate age or grown elsewhere, and that the date of sowing is approximate. Where seedlings of wild stock (labeled WS) were used, the year shown is the estimated year of germination.

Continue

Age in 1985—Last remeasurement age. Age is exact for plants grown at Wind River. Ages are best estimates for wildlings.

Number planted; number alive (1986)—Number planted does not include 1st-year replacements of trees that probably died from transplanting. Replacements were not made in many instances. For a few early lots, the ratio of trees alive to trees planted is not a good measure of the suitability of a species because some were moved when the trees were too large for successful transplanting. Some other lots were also mechanically injured or were killed by rodents.

Average height in 1986—Average height in feet of all living trees in each group at the end of the 1986 growing season.

Tallest tree in 1986—Height of tallest tree at the end of the 1986 growing season.

Growth index—Ratio of height of the tallest tree in each lot to the height of **average** dominant Douglas-firs of local seed source on the same site at the same age.

Condition/comment—Taken from field records to indicate the general condition and comments of each lot with regard to cone production, vigor, damage by insects, disease, weather, or other factor. Coded abbreviations in this column are listed at the end of table 1.

Because the most severe damage to the Arboretum lots occurred in November 1955 from a severe, early, regionwide freeze, information is repeated from past reports. After unusually mild weather, temperatures dropped rapidly to -1 °F, and remained below 32 °F for 6 days. Several lots were completely killed; in many lots, trees continued to die from cambial injury over a period of several decades. Usually, the injured species had previously or subsequently shown susceptibility to damage by freezing, as noted in the "Condition" column. Damage is listed in parenthesis as light (L), medium (M), or severe (S).

Performance by Genera

Firs *(Abies)*

In all, 28 species or subspecies of *Abies* have been tried at Wind River, one of the world's outstanding *Abies* collections. Of these, 24 are living, but the only species that have done well enough to maintain closed-canopy groups are those native to western North America north of 42° N. latitude (fig. 5). Seven of the 28 species, 6 from Asia and 1 from California, have been listed as unsuited for the Arboretum environment because of early mortality or very poor condition.

The graph (fig. 6) suggests that, other than starting more slowly, grand fir and noble fir growth rates are roughly comparable to that of Douglas-fir. In general, Eastern United States species grew at less than one-half the rate of Douglas-fir; Asiatic and European species grew at about one-third of that rate.

Many exotic fir species appeared promising and dominated their sites for several decades. Interest in them grew as balsam woolly aphid began to decimate some native Northwest fir species. Their slow growth, poor crown closure, and poor health leaves no exotic of forestry interest now.

Balsam woolly aphid became a serious threat among Arboretum firs after 1946. The periodic measurement that year makes no mention of it. Conclusive evidence shows

Figure 5—Noble (left) and grand fir (right), both native to the area, are among the tallest Arboretum plantings, some approaching 120 feet in height. The true firs (*Abies*) illustrate the Arboretum pattern of worldwide growth rates common also to the pines, spruces, hemlocks, cedars, and larches. These firs from western North America tower above firs from Europe, eastern North America, and eastern Asia. In each genus, the height ranking is usually in that same order by world region.

that it appeared shortly before 1949 in Fraser fir because tops of Fraser firs that died in 1949 are heavily gouted from the aphid attack (fig. 7). At the time, balsam woolly aphid was not known to be a serious problem in the Northwest, and extreme frost was thought to be the agent responsible for damage (Steele 1954).

The large number of fir species and varieties long established in the Arboretum provide a good opportunity for observing relative resistance to balsam woolly aphid attack, as had been done with blister rust among the pines two decades earlier. Fraser fir, alpine fir, and European silver fir, were heavily infested; balsam fir and corkbark fir were initially listed as having had moderate infestation; Spanish fir showed light infestation. After four decades, early indications proved unreliable. Corkbark fir is now completely eliminated, and alpine fir has been nearly eliminated by aphid attack. Surprisingly, European silver fir, though heavily aphid-infested, showed neither damage nor any apparent reduction in growth rate. Although grand fir is seriously attacked at sites of lower elevation in the region, no apparent injury occurred to the three lots in the Arboretum. Other species than those listed showed no observed infestation. All North American true firs, however, were shown to display the gouting reaction when deliberately infested with aphids by research entomologists working with the Arboretum specimens, or have been observed to be infested elsewhere (Mitchell and others 1990). Susceptibility of American and resistance of Eurasian species have added to the evidence that the aphid was introduced.

The true firs are of public interest because of their beauty. Noble, alpine, Shasta, red, Fraser, and Spanish firs are notably beautiful at some stage, often having blue or glau-

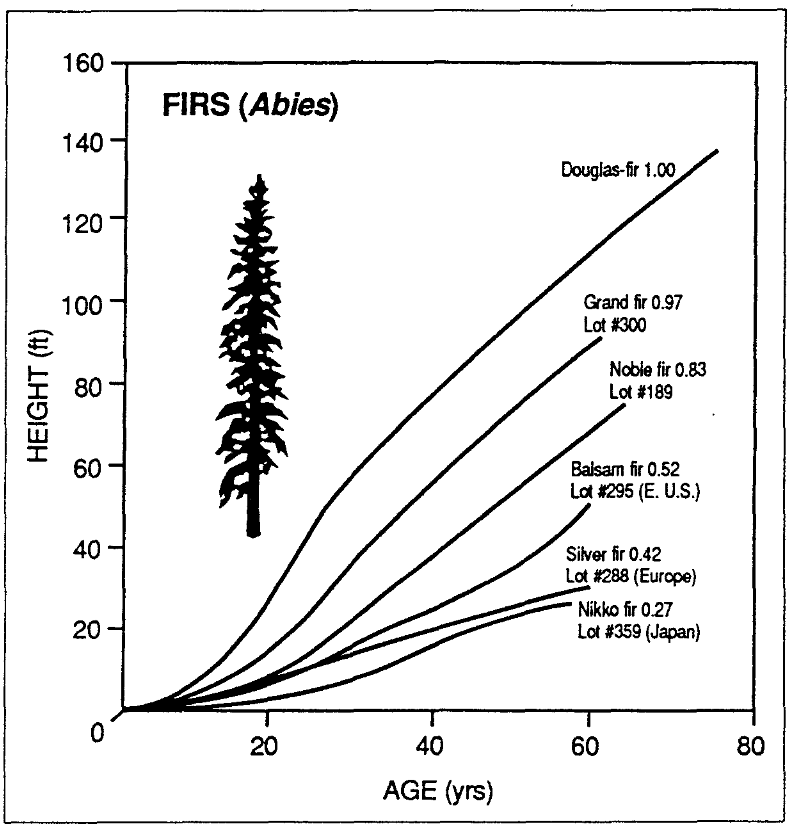

Figure 6—Height-age curves for true-fir (*Abies*) species selected to illustrate typical growth of representatives from western and eastern North America, Europe, and Asia. The curve for average Douglas-fir in the Arboretum is shown for comparison. Compare pattern with figures 8, 10, 11, 15, and 17.

cous foliage. How time has altered the appearance of individual lots at the Arboretum is interesting. Fraser and alpine fir became heavily infested and gouted by the woolly aphid. For the first 30 years, Shasta and red fir were among the most beautiful of the Arboretum lots, but have since faded and lost much of their foliage. Of remaining lots, noble fir retains much of its original beauty, even at its present 70- to 80-foot heights.

Araucarias *(Araucaria)*

After more than seven decades, the two specimens of *A. araucana* from Chile have attained a height of 11 feet. They have been frozen back numerous times.

Incense-cedars *(Calocedrus)*

Incense-cedar, a species native to drier sites in western Oregon and California, has shown good vigor, although its growth is about half the Douglas-fir index. Survival of one of the two lots has also been excellent, but the other has lost all but one of its original 13 members.

Cedars *(Cedrus)*

Only two of the three *Cedrus* species still survive, growing at rates about three-tenths that of Douglas-fir. Atlas cedar, from Morocco, is in fair condition; the cedar of Lebanon is fading; and the Deodar cedar from the Himalayas lost its last survivor at age 60. Although some of the cedars grew quite vigorously in early years to attain heights of 50 feet, they were obviously unadapted to the Arboretum and faded in the last decades. All three species sustained repeated sapsucker and snow damage.

Figure 7—When balsam woolly aphid reached the Arboretum in the late 1940s, the 24 true-fir species or varieties provided a place to quickly judge their relative susceptibility. Twig gouting (left) by the aphid was initially most severe on the pictured Fraser firs (right), but most specimens are still alive. The aphid gradually killed every specimen of corkbark fir over the 40 years since its introduction, however.

White-cedars *(Chamaecyparis)*

The western American representatives, Port-Orford-cedar and Alaska-cedar, are the only two of the five representatives of the genus that are thrifty. They are growing at six-tenths and five-tenths the rate of Douglas-fir, respectively. Of the two representatives from Japan, Hinoki cypress lived for only 17 years, and Sawara cypress has low vigor with a growth index of 0.11. Atlantic white-cedar from the Eastern United States is also of poor vigor. The last three species have repeatedly frozen and resprouted.

Cypresses *(Cupressus)*

Of the eight species and subspecies of cypress tried, all but one have faded or died. Mediterranean cypress, and its close relative from the Himalayas, *C. duclouxiana*, as well as Mexican cypress, each were completely winter killed at ages 2, 3, and 4, respectively. Of the lots that grew to appreciable size, Gowen and Monterey cypress from California, and Arizona cypress survived for almost two decades before being killed by frost or winter damage. One of a lot of two McNab cypress from California hung on for nearly 60 years to become a 15-foot-tall specimen before fading.

The surviving species in the Arboretum, Modoc cypress from northern California, is a respectable group now more than 60 feet tall at age 60, with fair survival and growing at about six-tenths the rate of Douglas-fir. It, too, has had some past frost damage.

Junipers *(Juniperus)*

The four living juniper species of the eight tried (western, eastern, Rocky Mountain, and Chinese juniper) are all now in poor condition. None produced trees exceeding 15 feet in height after surviving five to seven decades. Four junipers *(J. ashei, J. excelsa, J. monosperma,* and *J. semiglobosa)* lived only 17 to 21 years at Wind River. All were subject to breakage by the heavy wet snow typical of the site, and frost kill is listed as the unsuitable climatic element of the site for the failed junipers.

Larches *(Larix)*

Introduced larches have had an interesting Arboretum history. For the first quarter century, several larches had markedly superior height growth over native species and all other trees in the Arboretum. Their good survival and vigor suggested them as potential candidates to occupy the replacement role for native species that exotic plantings were then beginning to play in other lands. But as the graph of height over age (fig. 8) shows, the last half century added little height to most European or Asiatic larches. European and Polish larch attained a Growth Index greater than 1.00 through nearly three decades, but their growth curves flattened after the fourth decade. Siberian larch (fig. 9), a most promising candidate, suffered severe snow breakage at about 35 years; few members still survive from the group. At age 70, the height of Douglas-fir averages 128 feet; the tallest larch is only 64 feet. Fortunately for the Northwest, little planting was being done before World War II when these exotic larches looked so commercially promising. Region-scale plantation failures might well have been the result.

Seven larch species, some with several varieties, plus one hybrid were tried. One species, mountain larch from a high-elevation Cascade Range source in western Washington, failed within the first 10 years. Of the remaining six, three are Asiatic, two European, and one from North America. Of the 19 lots planted in the larch block of the Arboretum, all before 1939, 18 still have one or more surviving member despite their poor adaptation. Two varieties of European, and three of Kurile larch, plus the hybrid Dunkeld larch are among them. This hybrid is also failing, as is the nearby Japanese larch lot, one of the parent species of the hybrid. Each lot now has only a single, remaining, snowbent tree.

In relative terms, the European larches are now doing better than Asiatic species. Arboretum representatives of American species have also done poorly. Tamarack, though slow growing, has suffered less snow damage than the other larch lots. Both lots of western larch are doing poorly. Early snow and frost damage, along with needle blight, has weakened the trees. Although this is a native western American species, seed for both Arboretum groups came from east of the Cascade Range, where climate is more continental and humidities are lower. Western larch native to the Wind River Valley is a large tree with growth rates comparable to Douglas-fir, but no lot of this race was planted in the Arboretum for comparison.

Spruces *(Picea)*

Most of the 16 species and one variety of spruces tried at Wind River Arboretum have been relatively successful. Although most are slow growing, they form dense stands that have remained relatively free of competing native conifers. One has displayed good growth, eight are doing fairly well, and another eight are fair to poor. One species from China *(P. likiangensis)* died after a few years.

Only Norway Spruce has done well enough to attract attention as a promising introduction. The best individual in the best of the two lots of the species has maintained a growth rate about 90 percent of the average Douglas-fir on the Arboretum site and is thus the Arboretum's fastest growing tree from another continent. That particular lot has displayed excellent growth, although it shows evidence of sapsucker injury and light frost damage. In a 26-year study on the Oregon and Washington coast to observe relative resistance of 10 species of American and Eurasian species to spruce weevil, Norway spruce again grew to heights comparable with Sitka spruce, but trees were smaller in diameter, hence had only about half the volume of Sitka spruce (Mitchell and others 1990).

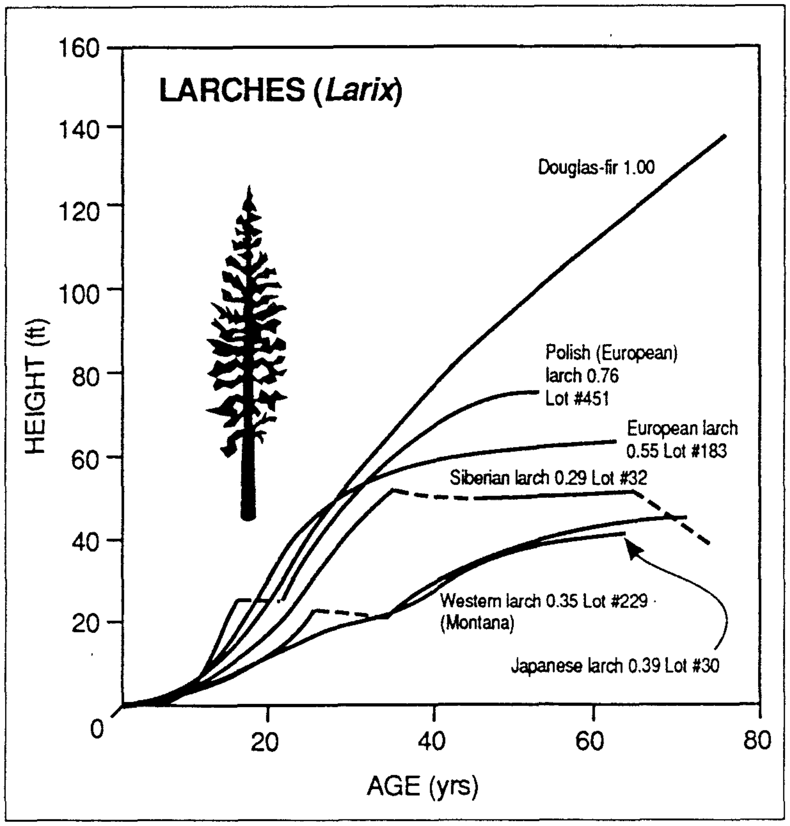

Figure 8—Height-age curves for selected larch species.

Asiatic spruces have grown less than half the Douglas-fir index rate, and western American spruces up to three-quarters the rate (fig. 10). No spruces are native to the Arboretum environment. Thus the three Northwest species in the Arboretum—Sitka, Engelmann, and Brewer spruce—each are elevationally or latitudinally outside their native range. In their own localities, each grows at rates comparable to the local Douglas-fir.

Gall aphids (Family Adelgidae), sapsuckers, and snowbending or breakage have been the main damaging agents. Engelmann, Sitka, and white spruce are attacked by gall aphids, and Engelmann, as well as Norway spruce, were damaged by sapsuckers. All of the species that are now failing are from the continent of Asia or from Japan. Chinese, Himalayan, and Koyamai spruce gradually died out. Tigertail and Alcock spruce have been repeatedly broken by snow.

Pines *(Pinus)*

Forty-nine species plus eleven varieties of pines have been tried at Wind River Arboretum. Of this number, only 37 are living, 16 are doing comparatively well, and 21 are declining in vigor or doing very poorly. None of the pines have canopies dense enough to keep out faster growing volunteer native conifers. The tallest is sugar pine, a native Northwest species, with a Growth Index of 0.87. The overall best-performing species of introduced pines are Corsican, Austrian, and Crimean pine, all races of the same pine species, with Growth Indexes of 0.73 to 0.82. This growth is better than for Arboretum lots of western white or ponderosa pine, both local species but from nonlocal seed sources. Races of these two species growing in the Wind River Valley at the same elevation have growth rates equal to Douglas-fir.

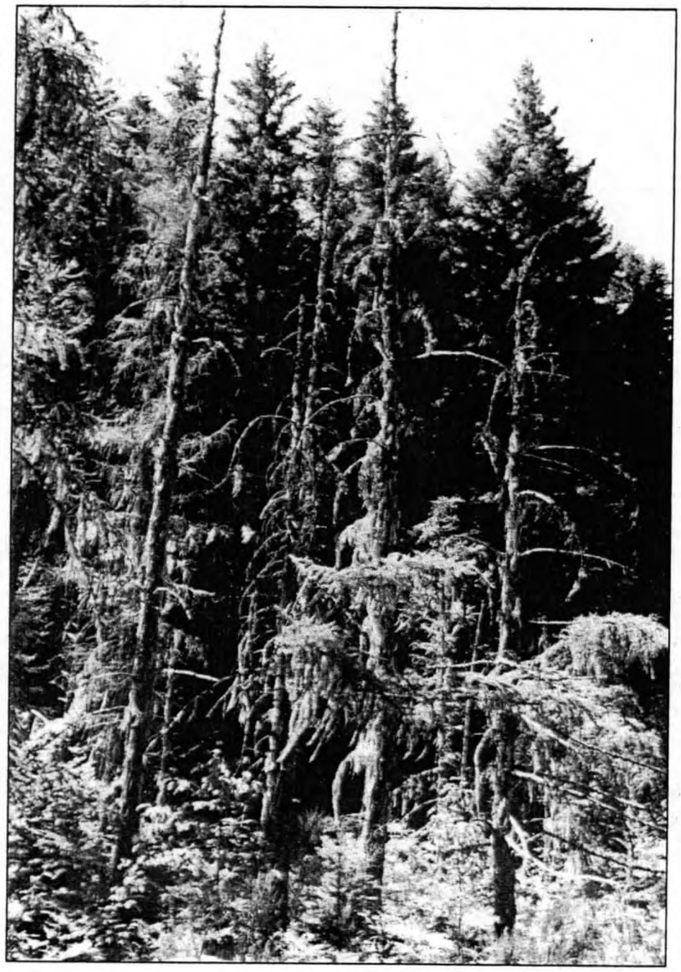

Figure 9—Siberian larch, a promising exotic for 35 years when it was one of the tallest and fastest growing, has faded in the last 35 years. Only a few specimens are still alive. The 120-foot-tall Douglas-firs in the background are about the same age.

Growth curves for best individual trees of selected examples of pine species from major world regions are shown in figure 11. Several (lodgepole, ponderosa, and Himalayan) grew faster than Douglas-fir in early years. But after the initial spurt, growth rate slowed for nearly all but the native pines. After 50 years, all growth curves were flattening, particularly for introduced pines. Even lodgepole pine from western Montana was taller than Douglas-fir at 20 years, but, at 73 years, its Growth Index is only 0.38. In contrast, native western white and sugar pine lots had basically steep curves for long periods, but the Arboretum lots are now so decimated by white pine blister rust that they no longer represent the growth potential for these species.

For pines, the five-needled group has been of particular interest because white pine blister rust was introduced into the region soon after establishment of the Arboretum. The interest, initially for growth, changed to relative rust susceptibility or resistance as the native species were threatened, and to find possible alternatives for threatened native species. The Arboretum was the earliest place that relative resistance could be assessed by species. By the mid-1930s, Asiatic members—Himalayan, Korean, and

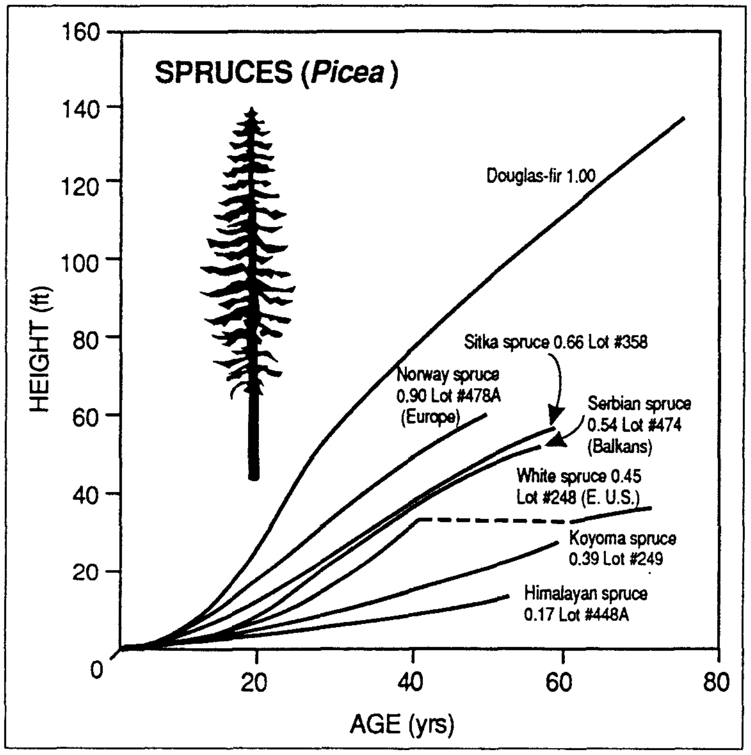

Figure 10—Height-age curves for selected spruce species.

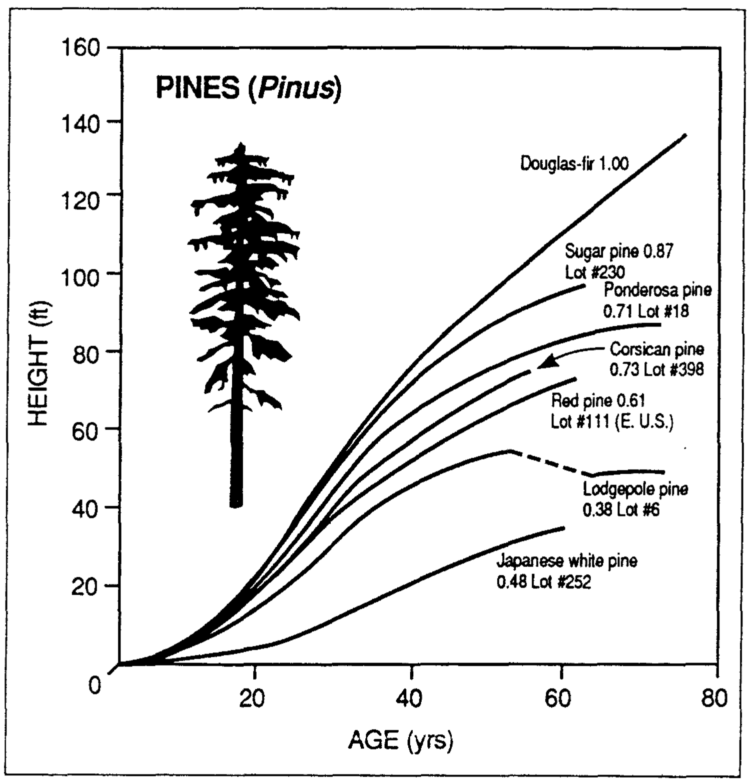

Figure 11—Height-age curves for selected pine species.

Balkan pines—were found to be virtually immune to blister rust. Of the American pines, Mexican white, foxtail, limber, and eastern white pine had shown some susceptibility. Of native species, western white pine was very susceptible, sugar pine was extremely susceptible, and whitebark pine was the most susceptible of all the white pines in the Arboretum. Only 4 specimens of 41 sugar and western white pine originally planted still survive, all with rust. This pattern of species resistance to blister rust was substantiated later for the West by Childs and Bedwell (1948).

None among the hard pines except ponderosa and lodgepole, both native species, are doing well enough to consider for planting as a timber tree in this climate. Although Growth Index ratings seldom exceed six-tenths of Douglas-fir, several exotic lots still appear healthy. Examples are Austrian, Crimean, and Swiss mountain pine, each having at least one planting with high survival. The plantings of Swiss mountain pine display unusual variability, ranging from some upright trees to prostrate forms, and with large variations in stem and foliage.

Among pines, Asiatic and European species were distinctly more susceptible to sapsucker attack than were North American species. Scotch (fig. 3) and Chinese pine were so severely and repeatedly attacked that most trees of original lots eventually died. The holes possibly served as entry courts for fungi because most trees ultimately became rotten at the point of attack and broke.

Heavy wet snows, typical of the Arboretum climate, have broken or borne down many of the pine trees. Frost has damaged or killed others so that survival of most cold-susceptible lots is usually low.

Of the 31 pine lots representing 18 species that have failed, most are from more southerly latitudes than the Arboretum. Eleven are native to the Orient, nine are from eastern, and eight from western North America below the 42d parallel. Three are from the Mediterranean climate of Europe or Turkey. But Corsican and Crimean pine from such a climate have survived well. Where the cause of failure has been recorded, low temperature was listed as the cause for species that lasted only a decade or two. Some species had done relatively well for 30 to 40 years before being killed by severe cold (fig. 12). Drought is not listed, but its annual debilitating effect likely contributed to mortality.

Douglas-Firs *(Pseudotsuga)*

Only the two American species, Douglas-fir and bigcone Douglas-fir, have been tested at Wind River (fig. 13). Seed lots of the three Asiatic species have either failed to germinate or died in the nursery. Bigcone Douglas-fir from southern California, planted in 1927, had only one survivor after the low temperatures of 1955, and it died at about 30 years of age.

As mentioned earlier, no lot of Douglas-fir native to the Arboretum was deliberately planted. But tens of thousands of the species seeded the 11 acres during the seven decades and had to be removed from competition with the planted lots. Without such cleanings, the site would be densely covered with 120-foot-tall Douglas-fir. In 1956, after the decision to rate introduced trees by average growth of Douglas-fir, a group of 11 dominant trees that had seeded into an unused corner since Arboretum establishment were tagged and measured for height. This group, the tallest in the Arboretum, has been regularly measured since.

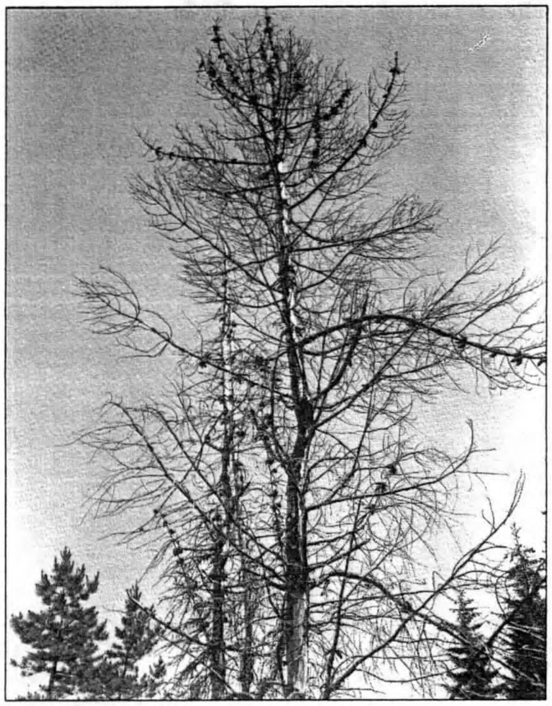

Figure 12—After growing well for 43 years, this group of knobcone pine was killed by low temperatures in November 1955, along with similarly aged groups of Coulter, Apache, and shortleaf pine. Decline of several other species followed this event as mortality from cambial damage continued for at least two decades.

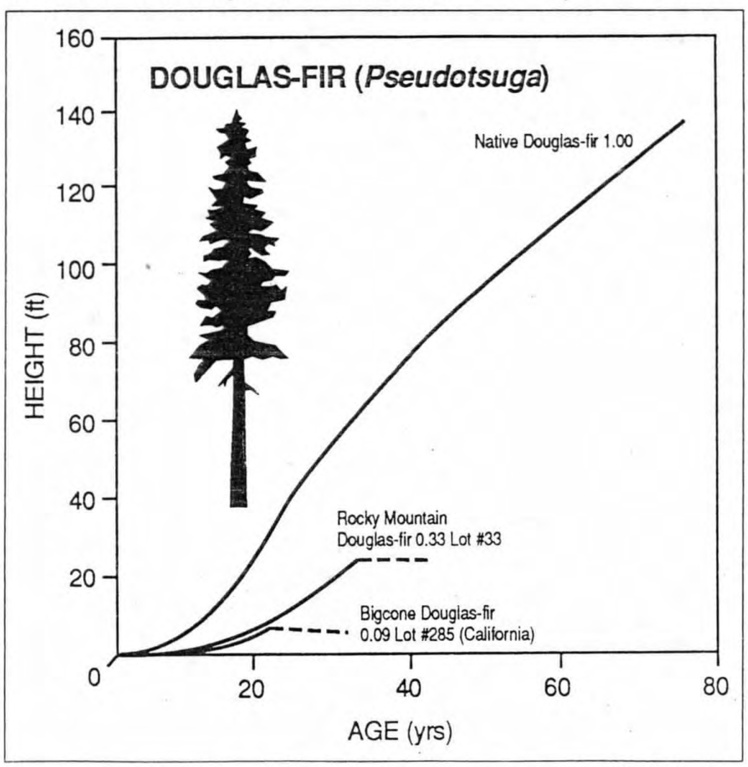

Figure 13—Height-age curves for two American species of the Douglas-firs. Coastal and interior Douglas-fir are shown here.

A contrast of high genetic interest is provided by a 20-tree lot of Douglas-fir from a Colorado seed source planted in 1914. By the 1950s when tree improvement began in the Northwest, the lot had grown slowly to nearly 30 feet in height, then began to suffer mortality from needle diseases. As the trees died in the following decade, the contrast became spectacular between this off-site seed source of Douglas-fir and the nearby similar-aged native Douglas-firs that by then formed a 60- to 80-foot-tall border on three sides of the Arboretum (fig. 14). By age 50, the entire Colorado-source group had died.

Ten lots of Douglas-fir, sown in 1948, were added to the Arboretum in 1952. These lots are from various locations throughout the West and now demonstrate racial growth variation within the species.

Bigtree *(Sequoiadendron)*

Of all the introduced species, the Sierra redwood has provided the most striking growth performance. Of the 31 trees planted in three lots, 25 survive to form a tall, densely stocked group with the tallest member 121 feet tall at 73 years. This is 95 percent of Douglas-fir growth on the site at the same age (fig. 15). Plot volume would probably be similar to a fully stocked Douglas-fir stand (fig. 16A and 16B). Six of the eight fast-growing lawn trees of the same lots have frozen tops from the 1955 freeze, but all 12 of the hardened Arboretum trees escaped injury, and have otherwise suffered in no other observable way.

Coast Redwood *(Sequoia)*

Coast redwood has had a completely contrasting record. Its scientific name meaning "always green" is appropriate. After 57 years in which all specimens have been repeatedly frozen, 20 of the original 37 members are alive. What is unusual is that most specimens have remained shorter than the bracken fern that covers the plot. The largest specimen is only 15 feet tall.

Yews *(Taxus)*

Both Pacific yew and English yew have barely grown at the site, the tallest specimen measuring 3 feet. Yet they continue to survive after a half century on the site. Deer browsing and freezing are reported in the early record as well as through later examinations as the cause of their poor perfomance.

Thujas *(Thuja)*

Four species of redcedars have been tried at Wind River, two of which failed to germinate. Of the four that did germinate, two are now living. The native western redcedar is thrifty and growing at about half the index rate of Douglas-fir. One of the group has suffered freezeback. Northern white-cedar from eastern North America has suffered light frost damage but is healthy. Japanese redcedar and Chinese arborvitae from northwest China survived only 13 and 20 years in the Arboretum.

Thujopsis *(Thujopsis)*

This single-species genus is represented at Wind River now by two healthy, but slow-growing specimens of Hiba arborvitae growing on a watered lawn near the headquarters building.

Hemlocks *(Tsuga)*

All five of the hemlock species in the Arboretum have had distinctive records. Western hemlock from a local collection grew slowly in the first two decades, but the present slope of the height-age graph indicates that its growth rate is now comparable to Douglas-fir (fig. 17). The record of mountain hemlock, from a nearby mountain source, is unusual. It grew thriftily at a moderate rate about four-tenths of Douglas-fir for

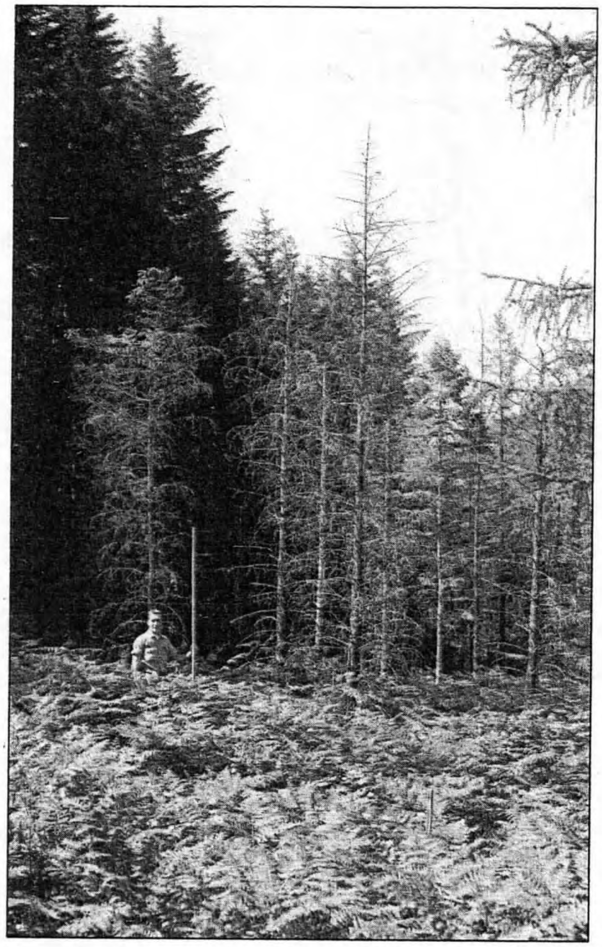

Figure 14—Strains of native species introduced from more continental climates have performed poorly at Wind River. Douglas-fir from a Rocky Mountain seed source was planted in 1914. The trees grew reasonably well in the first decades, but by 30 years they began to fade from repeated attack by needle diseases. The last tree of the lot survived nearly 50 years and is shown with the dead specimens in this 1959 photograph. The native Douglas-fir bordering the Arboretum on three sides is seen in the back ground at nearly twice the height. Similar poor performance has been seen for strains of ponderosa pine, western larch, and lodgepole pine from east of the Cascade Range.

nearly 60 years. In the 1956 Arboretum report, it was described as the "handsomest and hardiest" of the hemlocks. Both mountain hemlock lots suddenly began to die at about age 60 from an unknown cause, and all were dead in a 10-year period.

Eastern hemlock has survived well with a growth rate almost half of Douglas-fir, but with some snow injury, with thinning foliage, and a strong tendency to produce double stems. Carolina hemlock has performed similarly, but its foliage appears more vigorous. The only Asian representative, Siebold hemlock from Japan, is very slow growing and has suffered frost damage. All the hemlocks, except Siebold hemlock, are heavy cone producers.

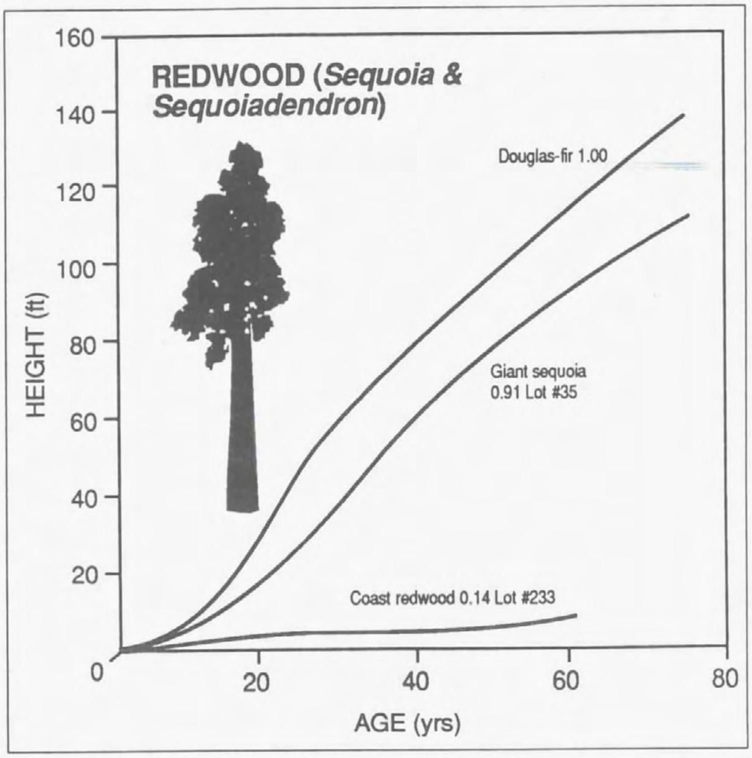

Figure 15—Height-age curves for coastal and Sierra redwoods.

16A

Figure 16—**(A)** Bigtree in 1991, with Roy Silen providing scale.

16B

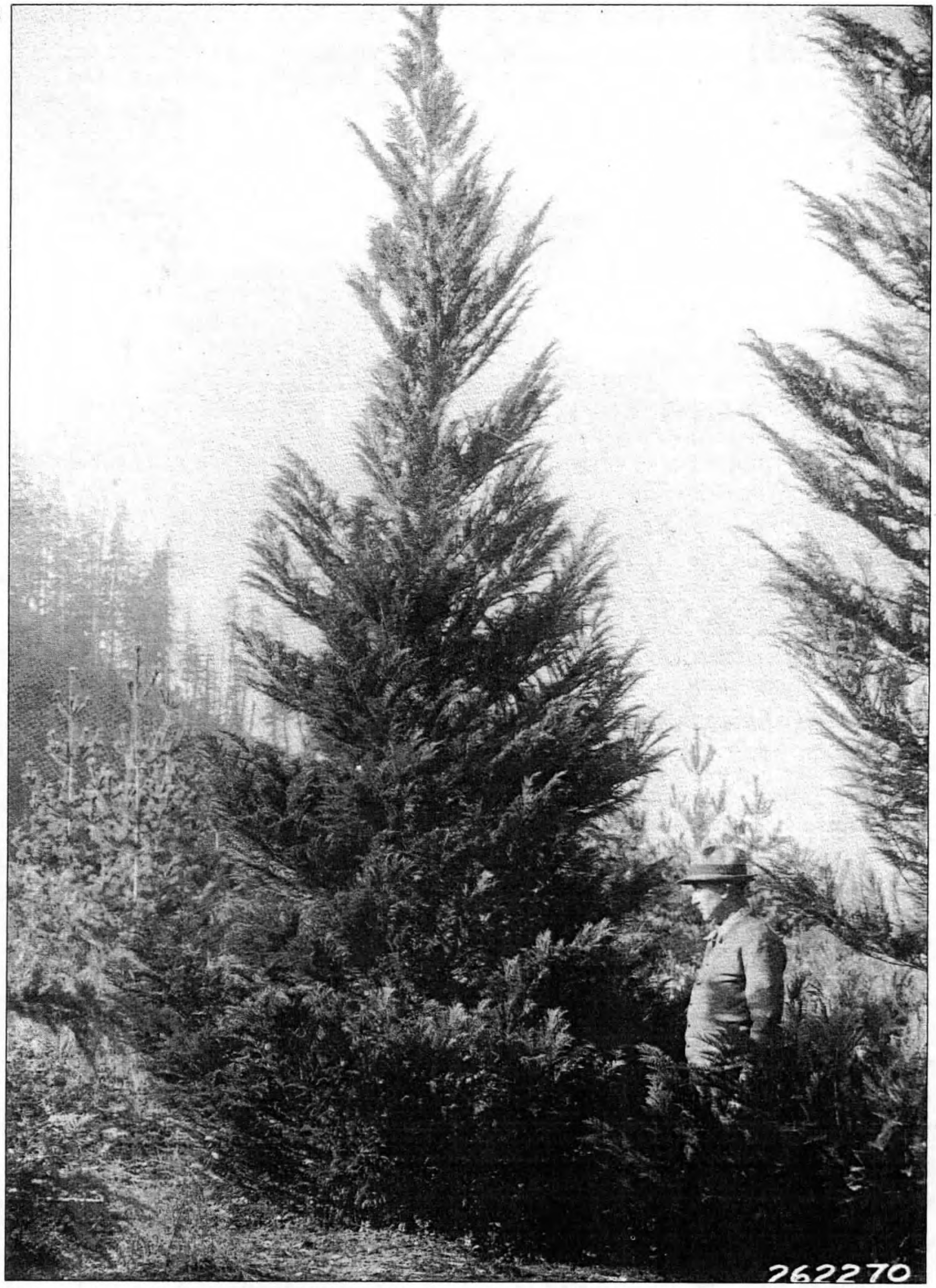

Photo courtesy of the National Agricultural Library, Forest Service Photo Collection.

Figure 16—**(B)** The bigtree *(Sequoiadendron)* plot, planted in 1912, at age 19 has produced a living volume comparable to Douglas-fir. Leo Isaac, research pioneer, provides scale.

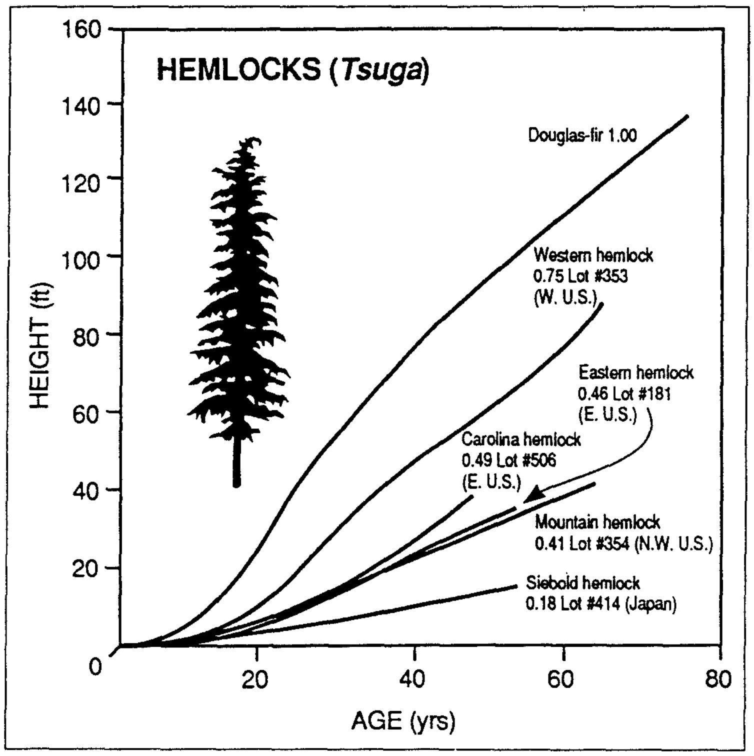

Figure 17—Height-age curves for selected hemlock species.

Performance of Broad-Leaved Trees

After many earlier failures, no attempt has been made to establish hardwoods in the Arboretum since 1928. By then, 26 lots representing 12 species had been tried. Of these, 17 lots representing 10 species have surviving trees (appendix, table 2). Early reports attribute the poor success to the long rainless period during July and August, to low humidity, and to the porous, gravelly soil. Some species that failed in the Arboretum have done well on watered lawns at Wind River. Some freezeback has been noted from the freeze of November 1955.

Introduced eastern hardwoods grew very poorly; only northern red oak and basswood approached size and form in early years expected in their native habitat. After six or more decades, the height of the tallest oak is now 43 feet and the tallest basswood is 32 feet. In contrast, a lawn specimen of Norway maple is 53 feet. Other maple species no longer survive.

Of the various hardwood introductions listed (appendix, table 3), some are of special interest. The American chestnut has five of the original six surviving. They bear fruit regularly and have good vigor, although only 45 feet tall at 61 years. The isolation of this tree group from sources of chestnut blight suggests that this refuge may be secure for a long time if needed as breeding material to preserve the species.

Of the hardwoods introduced from the Pacific Northwest, golden chinquapin was unusually vigorous for the first half century. The trees are tall, straight, and regularly bear fruit. The trees have produced a large number of natural seedlings throughout the Arboretum. The group has shown loss of vigor in the last decade and appears to be fading after 72 years; however, this age may be approaching the pathological rotation of the species.

Continue

Conifers Found Unsuited to the Wind River Site

Of 152 conifer species tested at Wind River, 55 have died, often after having been tried several times (appendix, table 3). Among those living, many are of poor vigor or are sustaining repeated damage, hence are a fading component to the collection. The most obvious of this category are listed in the table as "living, but in poor condition."

Cause of a species failure, though recorded, is difficult to evaluate. Some lots died between examination dates, leaving questionable causal evidence. Winter killing is listed for over 30 percent of the lots, whereas a combination of causes was recorded for 57 percent—including winter damage, competition, drought, and disease. Often, several different causes were listed for individual trees within the same lot. Fourteen percent had no cause of death listed.

Diseases or insects, though important killers of individual trees, had not been listed as causing the loss of any species until recently. White pine blister rust had been present in the Arboretum for nearly half a century before the first of two lots of sugar pine was killed completely. Likewise, infestation of true fir species by balsam woolly aphid had not killed out any single species during the first three decades of attack. Corkbark fir was the first; the last tree died between the 1976 and 1986 examinations. With both of these pests, the species predicted as most susceptible was not necessarily first to die out. Sugar pine was rated as most susceptible for the rust, and one of the two lots was first to die. But Fraser fir was considered the most susceptible to the aphid attack. Fraser fir has actually recovered somewhat, but corkbark fir did not. Attacks by this insect appears to have subsided through the last decade.

Several species continue to live year after year, even though they are repeatedly damaged by frost, snow, or some other factor. Although alive, these species are considered unsuited to the Wind River site.

General Comments on Performance

Although optimism persisted through the early years for introduced species and interest in some exotics still existed after a half century of testing, by the seventh decade, clearly no exotic tree species is likely to outgrow Douglas fir and its associated native species in the Wind River environment. Those exotics that formed dense stands earlier gradually became seriously understocked, the most common expression of poor adaptation. Many exotics do much better in unstressed, low-elevation sites in western Oregon and Washington than at Wind River Arboretum. Some even grew reasonably well at Wind River on watered lawns. Many also did well in their youth under culture in the Arboretum. Hence, the use of exotics cannot be ruled out by the long-term failures at Wind River. Still, the Wind River area, which is low site III for Douglas-fir and at an elevation of 1,150 feet, certainly provides a conservative test of adaptability for plantings on commercial forest land over much of the Pacific Northwest region. The risk of planting a species that did poorly at Wind River would be considerable, even in milder parts of the region. For the Douglas-fir Region, the Arboretum record clearly shows that forest productivity would probably drop precipitously if, for any reason, this Region had to depend on exotics.

Inherent Growth Rates

In addition to the general observation that the world's tallest firs, pines, cedars, hemlocks, spruces, larches, and redwoods are western American species, the Arboretum record clearly suggests that these species also have inherently faster growth rates. This observation is reinforced from experience of other regions of the world by the generally superior productivity of these trees over native species. A parallel situation for hardwoods is the tallness and superior growth rates of some eucalyptus from

Australia and Tasmania planted as exotics in other lands. Why western North America and Tasmania should have developed such superior tree species can only be speculated upon. This question is still a basic one in forestry.

The length of observation period on more than 600 seed lots acquired since 1912 has provided rare growth data, particularly when graphed over time against growth of average local Douglas-fir. Many tested species have characteristic growth curves. Several western American firs, hemlocks, pines, and redwoods have curves of the same sigmoid shape as Douglas-fir, characterized by a slow start and a steep and very long "grand period of growth." For these species, the uniform slope during this period is as steep as that of Douglas-fir, but often delayed a few years by their slower startup period. Exotic species more typically had growth curves with shallower slopes during this "grand" period, whether they grew faster or slower than Douglas-fir initially. Still another pattern, typical of most larches and some pines, was rapid early growth followed by a leveling off after the first half century. Some patterns can be typical for exotics of an entire genus or for the majority of species tried in them. A glance through the growth graphs of the various genera reveals clear examples of these three patterns. The only pattern of forestry interest for this Region is the sigmoid growth curve with the major slope about as steep as for Douglas-fir.

Summer Drought a Crucial Factor

The relative importance of summer drought in survival and growth of each tested lot should be emphasized. Although drought is seldom listed as a cause of mortality in the conifer record, several kinds of evidence indicate that the single most important limiting factor of the Arboretum environment for the long-lived tree lots may be the virtually desertlike summers with low humidities and soils near wilting point. Although much damage came from frosts and snow, and killing cold events occasionally occurred, many of the failed species came from regions with worse cold extremes. Early Arboretum reports attribute the failure of Eastern United States and European hardwoods primarily to summer drought. The most dramatic evidence for the importance of summer drought is the fact that many of the same species of exotic conifers that failed in the Arboretum are reasonably healthy on watered lawns in urban settings throughout the Northwest. The general good health of species planted on the headquarters lawn adds particularly pertinent evidence. The most striking example is the Jeffrey pine lot planted in 1912. Of the 12 trees, 11 were planted in an Arboretum block and one was planted on the headquarters lawn. Only one tree now survives in the Arboretum; it is 91 feet tall and 18 inches in diameter. In contrast, the lawn specimen has about 6 times more volume, attaining a 40-inch diameter and a height of 115 feet—one of the largest specimens of the Arboretum record (fig. 18). Its foliage has recently begun to thin, however.

Arboretum exotics from other major temperate forest regions of the world (Eastern United States, central and northern Europe, and eastern Asia) all have climates characterized by summer rainfall. Native western American species are genetically programmed to become quiescent or dormant during the summer drought. Much of the gradual fading of the Arboretum exotic species must have arisen from their annual genetic programming for the most active period of summer growth just as Arboretum soils approached the wilting point. The general fading of introductions from regions of ample summer rainfall must often start from weakening that results from failure to adjust to this gene-environment mismatch. Although no documentation was possible in the Arboretum record, over the years previous authors of the record have agreed

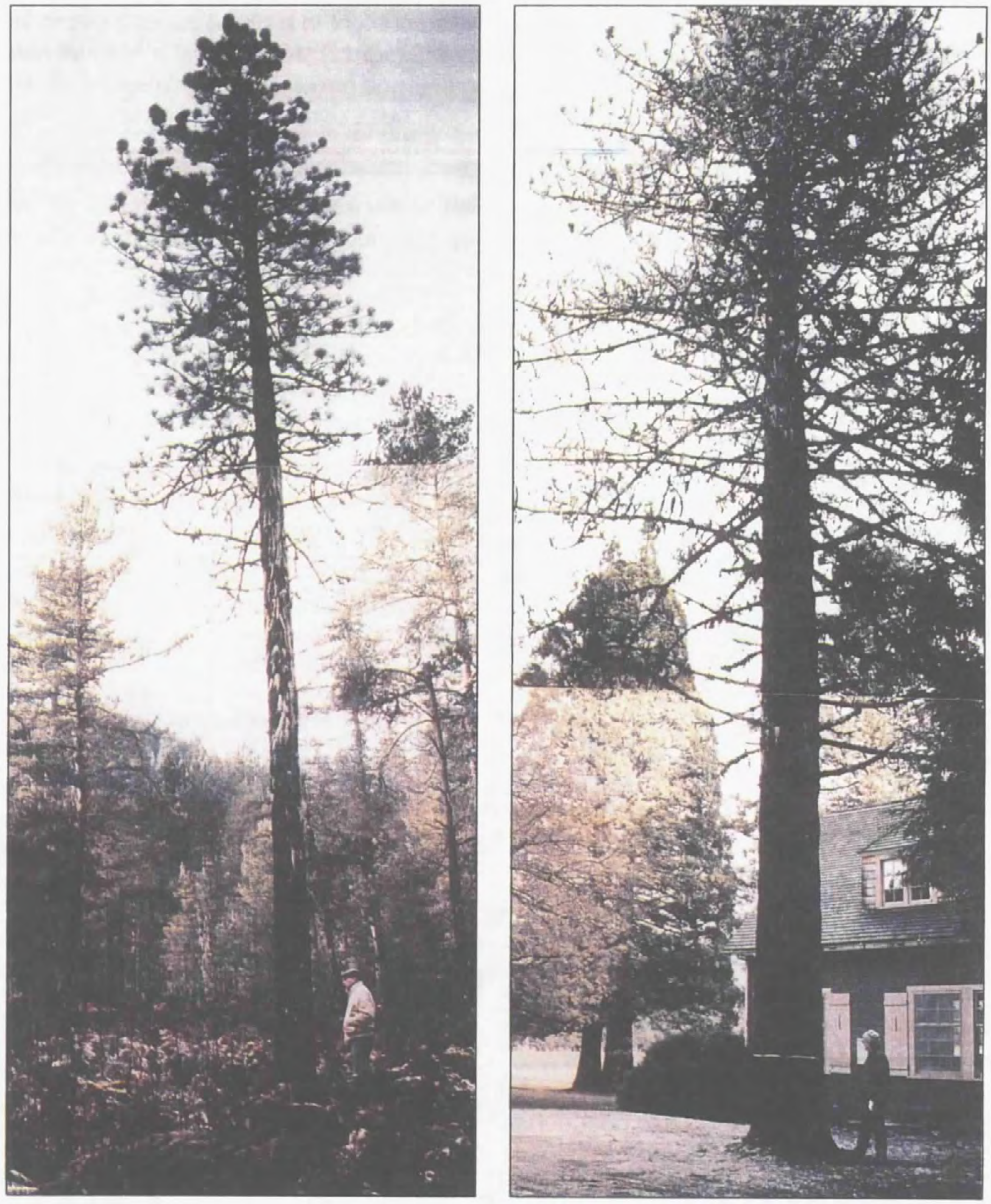

Figure 18—In 1913, 12 of 13 Jeffrey pines were planted in the Arboreturm, the other on the watered headquarters lawn. The Arboretum specimens gradually died, and now only one remains (left); it is 91 feet tall and 18 inches in diameter. The specimen on the lawn (right), now 115 feet tall and 40 inches in diameter, with 6 times the volume of the Arboretum specimen, is a clear example of the constraint that droughty summers have on tree growth in the Arboretum environment.

that summer drought was involved with poor vigor of the exotics. In a region where water resources are already overcommitted in summer, little prospect exists for irrigating commercial forests as a solution to summer drought.

Climatic Extremes

Many of the obviously unsuited exotics failed in the first decade or two because of frost or snow damage, but several species that did well for more than three decades were damaged or killed outright in a single climatic event—subfreezing temperatures in early November 1955 (fig. 12). After nearly a week of mild weather, temperatures fell precipitously to -1 °F and remained below freezing for 6 days. Native conifers in the area had hardened, but a portion of the Arboretum exotics were still growing. Excellent groups of Coulter, Apache, knobcone, and shortleaf pine, already 30 to 40 years old, were killed outright. Individual trees in many other species, such as bigcone Douglas-fir, also died. Many trees with cambial areas still active were damaged, lost vigor, and died—often as much as two decades later. This pattern of slow weakening and death from the 1955 freeze was first documented in a contemporaneous study of Douglas-fir families of known parentage. Although the nearby Wind River plot of this study sustained no damage because the trees were sufficiently frost hardened by early November, damage was extensive on two plots on milder sites with identical races and families. Some Douglas-firs still actively growing were killed, but most of the mortality from this freeze turned out to occur over a 20-year period. Each such damaged tree abruptly declined in cambial growth after the 1955 growth ring, lost vigor, and gradually faded. The pattern was clearly recorded in the cross section of each dead tree.

The same pattern of abrupt decline after 1955 was seen in the Arboretum for several frost-prone exotics, as well as with some races of native species. Of the 21 severely damaged lots, 4 were completely killed. For the 17 remaining lots, 51 percent of the trees were killed, compared to an average mortality of 11 percent for the Arboretum in general between the 1946 and 1956 examinations. During the next 20 years, 72 percent of the remaining trees in these lots died, compared with only 21 percent for lots that showed no damage. Thus, both studies indicate at least as much loss was from lingering effects as from the outright killing from this single climatic event.

Growth Patterns by World Forest Regions

Cold and drought susceptibility plus a wrong inherent day-length sensitivity were probably major factors in generally poor performance. Many of the 152 species tried were from more southerly or northerly latitudes than the Arboretum (46° N.). Perhaps a regional commonality of phenology and resistances is why species from each forest region of the world reacted so similarly in survival. For example, all the five species from Mexico, seven from the Mediterranean, four from the Southeastern United States, and four from southern China had no survivors after 40 years. A commonality for growth was also found; species from Japan, Kurile Island, Korea, or the Asiatic coast above 45° N. latitude seldom attained a Growth Index above 0.60 and usually had poor survival or other problems. Species from coastal Europe or the Alps grew somewhat better, with growth rates five-tenths to nine-tenths of Douglas-fir. Of the nine species from the Atlantic seaboard States, four failed completely and the remainder grew at four-tenths or less the growth rate of Douglas-fir. Species from North Carolina north to the Lake States and Maritime Provinces of Canada displayed growth rates of about half of Douglas-fir, and among those from upper elevations of the Rocky Mountains, or from east of the Cascade Range, some attained about seven-tenths this rate. And, as brought out before, species that sustained growth rates nearly matching Douglas-fir after several decades were its associates from the west coast, the Cascade Range, and the Sierras of North America. The exceptions to these regional conformities were relatively few, and more often were failures than better performances. The only important exception was Norway spruce. Its growth curve once surpassed Douglas-fir but is dropping somewhat in recent decades.

Consistency of Growth Index between species, and even between genera from each of the world's forest regions, deserves further comment. Figure 18 and appendix table 4 provide a remarkable comparison of genera when all species lots in the major genera are averaged, including failed lots for which a zero value was used. Within-genus ranking of regions is markedly similar from one genus to the next. Even across genera, the averages seldom vary one-tenth in Growth Index. Larger variations are usually among regions of poor growth where one or more lots had no surviving trees. The conjecture here is that, within each region, associated species are selected for very similar phenologies, growth rates, resistances, and other traits, and differed mainly in some unique way to dominate an appropriate ecological niche.

Another interesting comparison is made in figure 19. Paterson (1956) compiled maps and tables for the forests of the world based on an index of basic productivity he calls the CVP index (Climate-Vegetation-Productivity). He considers his index best for temperate zone forests. His estimated CVP value for Wind River was 700. We were curious to see if his index values for each region correlated with our growth index. The second set of figures for each point on figure 18 is an estimate of the region's corresponding CVP value. If species from lower latitudes are excluded because nearly all failed at Wind River, the correlation was 0.73. Considering all the potential sources of error, this is a good correlation; it suggests that about half of the differences in temperate-region inherent growth rates may have been a response to genetic selection for each region's productivity class.

Performance of Native Species of Continental Seed Origin

Growth rates similar to those of Douglas-fir are documented for native pine, fir, larch, and hemlock species in the Arboretum or growing in the nearby valley. But Arboretum strains of the same species from east of the Cascade Range have all done poorly. Colorado Douglas-fir, western larch of Montana, and ponderosa pine of eastern Oregon have been highlighted. The common debilitating factor has been native needle diseases, to which the interior strains seem particularly susceptible. Most are also susceptible to damage or breakage from the heavy wet snows of the Cascades.

Why Do Western American (and Australian) Exotics Perform Best?

Why should exotics of commercial forestry importance worldwide arise primarily from American and Australian sources? Although the Arboretum record provides information for only a piece of the puzzle, and the answer may never be completely elucidated, it is fitting to ask the question as the record is completed at Wind River Arboretum.

The Arboretum record simply documents that under the reasonable care given 152 conifer species and varieties, and in an environment near the average for a wide-ranging species like Douglas-fir, western American species grew substantially faster than their counterparts, genus by genus. This might not be noteworthy, except that the worldwide experience is that they also grow substantially faster than their counterparts in each genus when planted in other forest regions of the world. It is the substantial addition to the previously scanty documentation of performance in Western America that is the Arboretum's contribution.

The simplest explanation may be that the long exposure to removal of the best individuals in every forest of the Old World has depauperized populations of the faster growing genotypes to a substantial extent. Indeed, this could have happened locally in many Eurasian regions, considering the length of time the best individuals and stands have been cut. Fast-growing, low-elevation forests have disappeared in some regions of the world. Certainly the documentation of excellent natural forests in early writings, and preservation of some materials from them in artifacts, suggests that

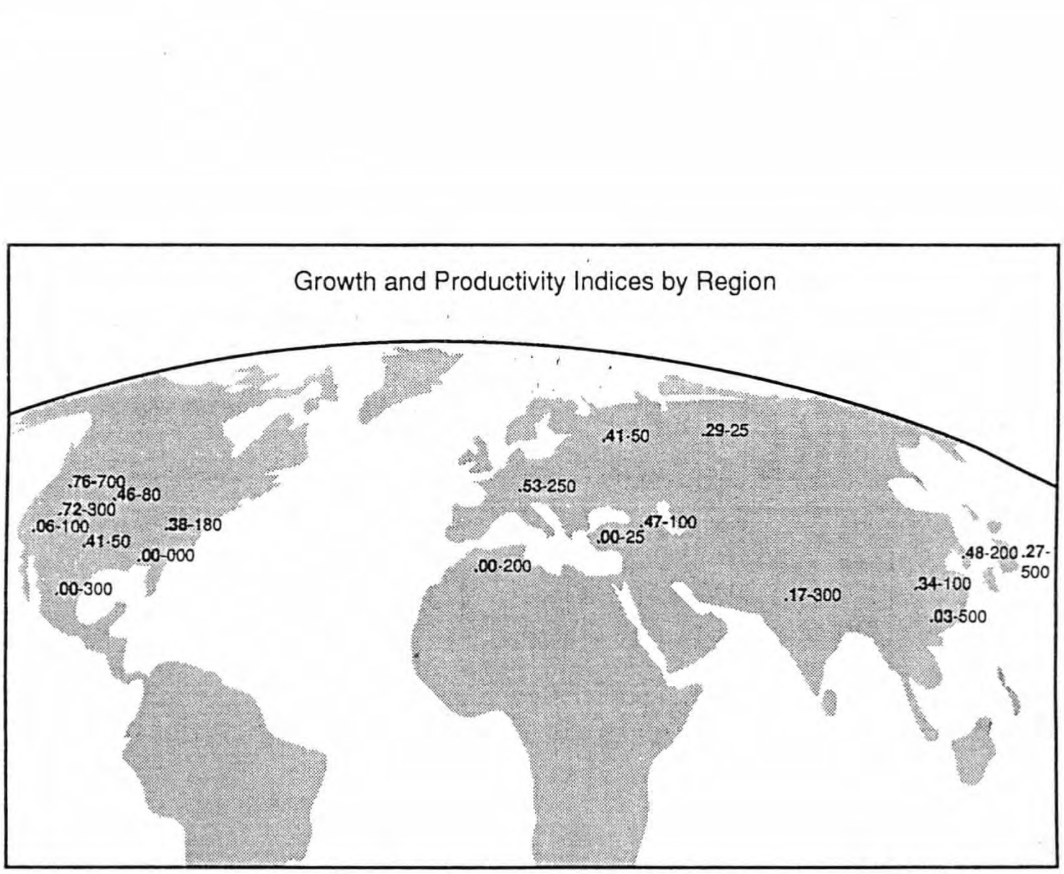

Figure 19—Species from each region of the world display a strong tendency to be similar in growth rate in the Wind River environment. The first figure at each point on the map shows the Growth Index average of all lots tested for that region. Table 4 provides more detail, with a comparison of genus averages within these regions. The second figure at each point is an index of basic productivity proposed by Paterson (1956). For the temperate-zone (but not subtropical) species, the two values are well related, suggesting selection for appropriate growth rates to fit basic productivity of each region.

such depauperization has taken place. In contrast, the forests of America and Australia are only now experiencing this impact.

Another possibility has a geological explanation (Duffield 1956, Silen 1962). The east-west orientation of mountains and seas of the Eurasian land mass could have blocked southward migration and depauperized forest populations of all but cold-hardy, slow-growing genotypes. In contrast, the north-south orientation of mountains of the New World and Australia provided open migration routes southward during climatic fluctuations of the Ice Ages.

The third possibility is that a special kind of double selection for unusually rapid growth rates occurred in the forested regions of America and Australia. Proposing a unique environmental common denominator for these two continents that would favor such genetic selection is not easy. One such explanation comes to mind, however. Many of the world's successful exotic conifers are native to western North America, which typically has growing-season droughts. This climate also characterizes much of eastern Australia. How could a droughty climate favor faster, not slower growth rates? Selection for drought tolerance is usually considered to be at the expense of rapid inherent growth and argues against this third possibility. On the other hand, ample reliable springtime moisture strongly favored very dense, high-biomass stands and intense tree-to-tree competition for light; hence, selection was for rapid growth. But the certainty of growing-season drought may additionally favor trees that grow even faster in a shortened growing season—truncated as summer drought begins and quickly reinitiated in fall as soils remoisten for a short period of growth before frosts. The relative rapidity with which species can develop summer quiescence or dormancy may be a mitigating factor.

Perhaps all three possibilities have contributed, but thorough study of the subject is unlikely, despite its importance. Prospects of having undisturbed natural populations for study was best with the pioneer researchers and is rapidly disappearing, particularly in the areas of the world where best growth rates developed.

Conclusion

After seven decades of record, the end has been reached in this search by pioneer forest scientists for the same success with exotic species as was achieved in other parts of the world. Unfortunately, all their efforts proved in vain. The main reason was that these foresters happened to work in a region with the tallest and inherently best representative in many of the most important coniferous genera. They could not be very sure of an unsuccessful outcome during their lifetimes, although the trends were already apparent to Munger, Kolbe, and Isaac. Future forestry may find that this search was inadequate or that the world climate will change, so that exotic forest species may eventually find a prominent place in the Douglas-fir Region. For now, exotic trees are only specialty trees useful for certain niches.

But the pioneer efforts were well spent in the information that was documented. Northwest foresters can work with native forests in full confidence that their species will probably provide substantially better growth than the most appropriate alternative in each genus from other forest regions. The Douglas-fir Region would substantially depress its high productivity if it had to depend upon exotic species. Indeed, no introduced tree group comes close to matching the Douglas-fir trees bordering the Arboretum on three sides. Moreover, the Region's foresters can be assured that conifer forests are generally a good bet and that introduced hardwoods were tested enough to conclude they would almost certainly be low-yielding and have survival problems except in special situations.

Differences in the characteristic growth patterns of various species and genera were documented, which was especially important for species that initially outgrew Douglas-fir for several decades. Had large-scale planting started in this Region several decades earlier, large acreages planted with some early-promising, fast-growing ones would by now be failing.

The early forester's pioneering efforts also make a good case history for the importance of long-term research (fig. 20). Even foresters accustomed to thinking in long rotations seldom appreciate how slowly life-threatening changes develop with trees. Sometimes severe climatic events such as the 1955 freeze cause dramatic injury and quick killing. But the slow decline and general failure of the introduced species often took many decades to verify, especially for species that grew rapidly in their youth. Disease and insect attack, or occasional frost damage, was particularly slow in displaying a gradually debilitating effect. Repeated snow damage over the seven decades became a major factor by slowly reducing tree numbers in many lots. Sapsucker injury followed by stem rots took many years before important mortality occurred. To observe that Eurasian species were much more prone to sapsucker attack required records spanning several decades. The observation that native species from more continental climates, such as from east of the Cascades, gradually lost vigor from needle diseases and wet snow damage required decades of observation. A half-century of growth records was minimal to conclude that growth rates of associated species from each region of the world tended to be much alike, suggesting that a balance of common inherent growth rates and hardiness traits tend to develop, just as they are now displayed here for the associates of Douglas-fir in the Arboretum. Such conclusions came primarily during the last few decades of the record; they could not have been observed in the early years.

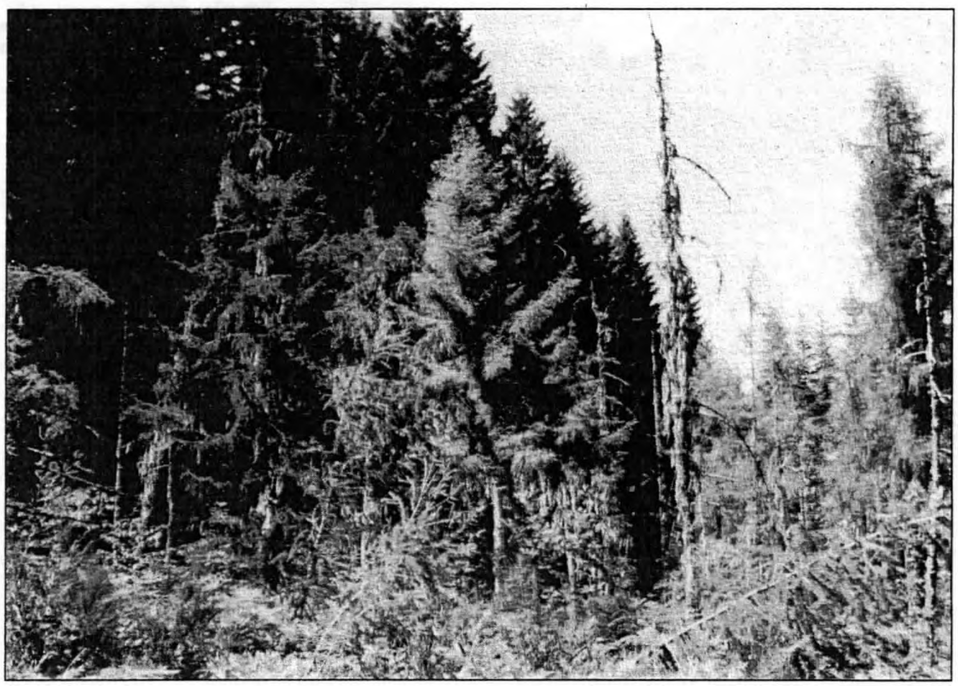

Figure 20—This photograph of the larch block, showing several of the larch plantings now 50 to 76 years old, shows the decimated condition of many exotic plantings from snow breakage, drought, freezing, insects, and diseases. The entire valley was open land in 1912 when the Arboretum began, but soon seeded naturally to Douglas-fir. The Arboretum is bordered on three sides by a 120-foot wall of these trees. The background trees in this picture show that border on the west, providing a contrast of the growth potential for the site.

Much of this kind of information is unlikely to develop from other sources for the Douglas-fir region. Despite only a scattered worldwide sampling of genetic material planted on the 11 Arboretum acres and the project's many scientific shortcomings, one grows to appreciate the genetic precision that is showing through the statistical chatter of the measurement data. Nature's millstones are indeed "grinding very slowly but exceedingly fine." Even though most of these conclusions were not anticipated when Munger, Isaac, and Kolbe carried on their work, they are now important enough that all practicing foresters and biologists know of them as part of their educational background.

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Metric Conversions

1 inch	=	2.54 centimeters
1 foot	=	0.304 meter
1 square foot	=	0.093 square meter
1 acre	=	0.33 hectare
1 mile	=	1609 meters
1 degree F	=	5/9 degree C

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Appendix
Table 1— Status of living conifer species, Wind River Arboretum

Species: Scientific name	Species: Common name	Lot number	Range[a]	Seed source	Year sown[b]	Age in 1985	Number planted; number alive	Average height 1985	Tallest tree 1985	Growth index	Condition/comment[c]	
The (Balsam) Firs—*Abies*												
abla Mill.	European silver	288	C, S Europe	Switzerland	1927	58	20/20	26.2	46.0	.42	CM; VG, SD, MS, SS, WA	
amabilis (Dougl.) Forbes	Pacific silver	190	W N. America	Pinchot NF (WA)	1922	63	19/15	61.5	81.0	.69	CM; VG, FC	
		484	W N. America		1933	52	5/4	47.7	55.0	.55	CL; VF, FC	
balsamea (L.) Mill.	Balsam	295	E N. America	PA	1924	61	11/2	51.5	60.0	.52	CN; VP, S	
bracteata (D. Don) Nutt.	Bristlecone	511	Monterey, CA	Los Padres NF (CA)	1938	47	16/1	33.5	33.5	.37	CN; VX	(S)
cephalonica Loud.	Greek	491	Greece, S Eur.	Austria	1935	50	20/11	19.5	36.0	.37	CN; VF, FD	(S)
delavayi Franch.	Faber	365	SW China	Yunnan, China			7/0	All dead in 1975				(S)
fraseri (Pursh) Poir.	Fraser	286	Allegheníes	Mt. Mitchell, NC	1927	58	21/6	10.7	20.0	.18	CL; VF, WA, ND	(S)
grandis Lindl.	Grand	236	W N. America	Umpqua NF (OR)	1926	59	20/11	90.2	105.0	.95	CM; VX	
		280	W N. America	Pinchot NF (WA)	(1924)	61	20/4	39.7	69.0	.60	CN; VG, S	
		300	W N. America		(1925)	60	7/7	91.7	109.0	.97	CM; VX	
		356	W N. America	Pinchot NF (WA)	(1926)	59	6/6	93.7	116.0	1.05	CM; VX	
		473	W N. America	Eldorado NF (CA)	1931	54	7/2	68.5	86.0	.84	CN; VX, NND	
		529	W N. America	Clatskanie, OR	1942	43	4/4	66.7	83.0	.99	CL; VX, NND	
grandis (hybrid)	Johnson	529A			1950	35	1/1	9.0	9.0	.13	CN; VG, S	
holophylla Maxim.	Manchurian	124	Manchuria, Korea	Fukuoka, Japan	1925		4/0	All dead in 1975				(S)
		272	Manchuria, Korea	Korea, Japan	1926		2/0	All dead in 1975				(S)
		425	Manchuria, Korea	Korea, Japan	1931		20/0	All dead in 1975				(S)
homolepis Sieb. & Zucc.	Nikko	359	C Japan	Keijyo, Korea	1926	59	20/1	30.0	30.0	.27	CN; VP, SX,SS, LD	(L)
koreana Wils.	Korean	412	Korea	Chii-zan, Japan	1931	54	21/14	25.1	37.0	.36	CN; VP, SS,SX, LP, YN	
lasiocarpa (Hook.) Nutt.	Subalpine	276	W N. America	Pinchot NF (WA)	(1923)	62	10/3	29.2	45.0	.39	CN; VF, YN, NRWA	
		485	W N. America		1933	52	5/1	26.0	26.0	.26	CN; VF, YN, NRWA	
lasiocarpa var. *arizonica* (Merriam) Lemm.	Corkbark	294	AZ, NM, S CO	AZ	1927	58	21/0	All dead by 1985				(L)
magnifica A. Murr.	California red	291	S OR, CA	Carson Pass, CA	1927	58	20/16	55.9	71.0	.65	CN; VD, LD, LP	
magnifica var. *shastensis* Lemm.	Shasta red	277	S OR, CA	Umpqua NF (OR)	(1923)	62	6/5	60.4	71.0	.62	CM; VX, TC	
		406	S OR, CA	Umpqua NF (OR)	1927	58	20/19	44.7	83.0	.76	CM; VX, TC	
mariesii Mast.	Maries	464	C Japan		1931	54	20/4	30.7	38.0	.37	CN; VF, YN, SS	
nephrolepis (Trautv.) Maxim.	Khingan	411	NE Asia, Korea	Hosan, Japan	1931	54	20/5	31.8	39.0	.38	CN; ND, FD	
pinsapo Boiss.	Spanish	492	S Spain	Austria	1935	50	21/15	18.2	35.0	.36	CL; VP, TC, LD, LP	(S)
procera Rehd.	Noble	34	W OR, WA	Pinchot NF (WA)	1913	72	15/10	79.6	99.0	.75	CM; VX, SS	
		189	W OR, WA		1922	63	8/8	75.3	97.0	.83	CM; VX, SS	
sachalinensis (Fr. Schmidt.) Mast.	Sakhalin	125	Hokkaido, Kurile Is.	Fukuoka, Japan	1925	60	20/2	46.5	52.0	.46	CN; VG, LD, SS, FC	(L)
sibirica Ledeb.	Siberian	463	N Asia		1931	54	20/5	16.4	30.0	.29	CN; VP, YN, FD	(S)
veitchii Lindl.	Veitch	462	C Japan	Suwa, Japan	1931	54	25/3	34.7	38.0	.37	CN; VP, LP, SS, ND, LD	(M)

Table 1— (Continued)

Species: Scientific name	Species: Common name	Lot number	Range[a]	Seed source	Year sown[b]	Age in 1985	Number planted; number alive	Average height 1985	Tallest tree 1985	Growth index	Condition/comment[c]	
The Araucarias—*Araucaria*												
araucana (Molina) K. Koch	Monkey-puzzle	102	Chile, Argentina	Buenos Aires	1913	72	2/2	11.0	11.0	.08	CN; VF, RFB	(S)
The Incense-cedars—*Calocedrus*												
decurrens (Torr.) Florin	Incense-cedar	36	S OR, CA	CA	1912	73	13/1	64.0	64.0	.48	CM; VF	(S)
		318	S OR, CA	CA	1926	59	24/22	44.8	59.0	.53	CM; VF	(L)
The Cedars—*Cedrus*												
atlantica (Endl.) Carr.	Atlas	47	Algeria, Morocco		1913	72	8/4	45.3	51.0	.39	CN; VF, SS, LP	
deodara (Roxb.) G. Don	Deodar	244	Himalayas	Los Angeles, CA	1926		13/0	All dead in 1985				
libani A. Rich.	Cedar-of-Lebanon	48	Lebanon		1913	72	19/5	34.0	40.0	.30	CN; VD, SS	(L)
		528	Lebanon	Palestine	1938	47	3/2	9.2	11.5	.13	CN; VD, SD, SS	(M)
The White-cedars—*Chamaecyparis*												
lawsoniana (A. Murr.) Parl.	Port-Orford	39	SW OR, NW CA		1912	73	13/5	56.2	78.0	.59	CM; VG, SS, DC	(L)
		440	SW OR, NW CA	Coos Bay, OR	1929	56	20/14	53.0	71.0	.67	CH; VX, SS, FC, DC	(M)
nootkatensis (D. Don) Spach	Alaska	404	W N. America	Wenatchee NF (WA)	1927	58	23/20	41.2	57.0	.52	CM; VG, TC	
pisifera (Sieb. & Zucc.) Endl.	Sawara false-cypress	564	Japan		1947	48	27/13	4.8	10.0	.11	CN; VP, RFB	(M)
		305	Japan		1931	54	21/1	8.0	8.0	.08	CN; VP	
thyoides (L.) B.S.P.	Atlantic white	480	Atlantic, Gulf States	NJ	1931	54	25/6	8.8	11.0	.11	CN; VP, RFB	(S)
The Cypresses—*Cupressus*												
macnabiana A. Murr.	MacNab	42	CA	IL	1913		2/0	All dead in 1975				
bakeri Jeps.	Modoc	117	Siskiyous	Umpqua NF (OR)	1925	60	18/15	54.8	66.0	.59	CM; VG, LD, FD	(S)
		242	Siskiyous	Umpqua NF (OR)	1926	49	3/2	56.0	58.0	.61	CM; VG, LD, FD	
The Junipers—*Juniperus*												
chinensis L.	Chinese	472	NE Asia,Japan	Japan	1931	54	20/12	6.3	13.0	.13	CM; VP, SX	(S)
occidentalis Hook. f.	Western	269	W N. America	Whitman NF (OR)	WS		6/0	All dead in 1975				(M)
		279	W N. America	Whitman NF (OR)	(1923)	62	12/4	3.3	6.5	.06	CN; VP, SX	(M)
		598	W N. America	Prineville, OR	1950		12/0	All dead in 1975				(S)
scopulorum Sarg.	Rocky Mountain	228	Rockies	Wallowa, OR	(1922)	63	14/7	10.4	14.0	.12	CN; VD, LP	(M)
virginiana L.	Eastern red	40	E,C N. America	Garden City, KS	1912	73	13/1	3.0	3.0	.02	CM; VP, SX	(L)
		301	E,C N. America	Garden City, KS	1925	60	8/3	7.0	10.0	.09	CM; VP, SX	(L)
		317	E,C N. America	Garden City, KS	1926	59	3/2	7.7	11.5	.10	CM; VP, SX	(L)
		481	E,C N. America	Garden City, KS	1933	52	6/6	8.3	10.3	.10	CM; VP, SX	(L)

Table 1— (Continued)

Species												
Scientific name	Common name	Lot number	Range[a]	Seed source	Year sown[b]	Age in 1985	Number planted; number alive	Average height 1985	Tallest tree 1985	Growth index	Condition/comment[c]	
The Larches—*Larix*												
decidua Mill.	European	183	Europe		1923	62	3/1	63.0	63.0	.55	CL; VD, LP	(L)
		302	Europe		1925	60	6/3	52.7	57.0	.51	CL; VD, LP	(L)
		308	Europe		1925	60	10/6	37.2	51.0	.45	CM; VD, LP	(L)
decidua x *kaempferi* (x *eurolepis* Henry)	Dunkeld	422	UK	England	1931	54	19/1	9.0	9.0	.09	CM; VD, SD	(L)
decidua var. *polonica* (Racib.) Ostenfeld & Syrach-Larsen	Polish	451	Poland & NW Ukraine	Skarzyoko, Poland	1932	52	20/12	42.4	76.0	.76	CL; VD, BT, SD	
gmelinii (Rupr.) Kuzn.	Dahurian	459	E Asia	Mozan, Japan	1933	52	20/7	38.6	52.5	.53	CN; VD	
		459A	E Asia	Mozan, Japan	1934	51	15/4	39.3	59.0	.60	CN; VX, GE, GN	
gmelinii var. *japonica* (Reg.) Pilger	Kurile	451A	Poland, NW Ukraine	Skarzyoko, Poland	1933	52	2/1	37.0	37.0	.37	CN; VD, SD	
gmelinii var. *japonica* (Reg.) Pilger	Kurile	112	E Asia	Kovia Stn., Finland	1924	61	19/12	29.2	36.0	.31	CM; LP, VD, SS	
		265	E Asia	Kurile Is., Japan	1926	59	1/1	38.0	38.0	.34	CN, LP, VD, SS	
gmelinii var. *principis-rupprechtii* (Mayr) Pilger	Prince Rupprecht	128	Korea, Manchuria	Fukuoka, Japan	1925	60	6/1	38.5	38.5	.34	CN; VD, LP	
		241	Korea, Manchuria	Pjung-San, Japan	1926	59	14/3	30.0	41.5	.40	CN; VP, LP, L	
laricina (Du Roi) K. Koch	Tamarack	184	E N. America		1923	62	1/1	18.5	18.5	.16	CM; VD	
		530	E N. America	Lake States Exp. Stn.	1939	46	13/9	24.2	44.0	.49	CN; VP, SB	
kaempferi (Lamb.) Carr.	Japanese	30	Japan	Japan	1913	72	10/1	45.0	45.0	.34	CH; VD, DCC	(S)
occidentalis Nutt.	Western	192	Pacific NW	Wenatchee NF (WA)	1922	43	10/0	All dead in 1965				(S)
		229	Pacific NW	Wallowa-Whitman NF (OR)	(1925)	63	11/1	41.0	41.0	.35	CN; VF, LP, LD	(S)
russica (Endl.) Sabine ex Trautv.	Siberian	32	NE Russia, W Siberia	Siberia	1913	72	12/1	38.5	38.5	.29	CM; VD, DCC	
The Spruces—*Picea*												
abies (L.) Karst.	Norway	26	Europe	Prussia, Germany	1912	73	10/5	67.1	77.0	.58	CM; VD, LP, SS	(L)
		478A	Europe		1936	49	8/6	60.1	85.0	.90	CM; VD, LP, SS	(L)
bicolor (Maxim.) Mayr	Alcock	247	Japan	Siewa Nagavo, Japan	1926	59	11/5	9.8	15.0	.14	CM; VF, SX, GC	
breweriana S. Wats.	Brewer	360	Siskiyous	Siskiyou NF (OR)	1925	60	8/6	35.0	41.5	.37	CN; VX	
		469	Siskiyous	Crater Lake NP (OR)	1931	54	16/13	25.0	31.5	.31	CN; VX, NND	
engelmanii (Parry) Engelm.	Engelmann	25	W N. America	N ID	1913	72	13/8	53.2	60.5	.46	CM; VF, SG	
		405	W N. America	Pinchot NF (WA)	1926	59	7/4	65.5	76.0	.69	CM; VX	
glauca (Moench) Voss	White	24	N N. America	Cloquet Exp. Stn. MN	1914	71	15/10	36.0	58.0	.45	CN; VG, SG, LP, ND	(L)
glauca var. *albertina* (S. Brown) Sarg.	Western white	495	N N. America	Colville NF (WA)	1937	48	20/20	38.6	68.0	.73	CN; VG, SG	
jezoensis (Sieb. & Zucc.) Carr.	Yedd	470	NE Asia & Japan	Hokkaido U. Japan	1931	54	14/10	17.8	41.0	.40	CN; YN, SB	

Table 1— (Continued)

Species: Scientific name	Species: Common name	Lot number	Range[a]	Seed source	Year sown[b]	Age in 1985	Number planted; number alive	Average height 1985	Tallest tree 1985	Growth index	Condition/comment[c]	
koyama Shiras.	Koyoma	249	C Japan	Siewa Nagauo, Japan	1926	59	20/15	26.8	43.0	.39	CM;VF,LP,SB	
mariana (Mill.) B.S.P.	Black	27	N N. America	N MN	1913		4/0	All dead in 1985				
		467	N N. America		1931	54	20/16	30.5	46.0	.45	CH; VG, GC	
		532	N N. America	U. of CA	1941	44	7/5	21.8	33.0	.39	CN; DC	
omorika (Pancic) Purkyne	Serbian	474	Yugoslavia		1929	56	20/14	52.1	57.0	.54	CM; ND, LP	
orientalis (L.) Link	Oriental	266	NE Anatolia & Caucasus	Caucasus	1919	66	21/21	49.4	57.5	.47	CH; VX, SS, DC, LP, ND	
polita (Sieb. & Zucc.) Carr.	Tigertail	478	Japan	Japan	1934	51	18/2	9.0	16.0	.16	CN; VG	(L)
pungens Engelm.	Blue	28	Rockies	Wasatch NF (UT)	1915	70	14/5	46.5	65.0	.51	CN; SS	
		243	Rockies		1920	65	12/1	37.0	37.0	.31	CN; VF	
rubens Sarg.	Red	312	NE N. America	Mt. Mitchell, NC	1928	57	7/6	26.4	33.5	.31	CH; VG	
		468	NE N. America		1931	54	19/12	28.9	46.0	.45	CH; VG	
sitchensis (Bong.) Carr.	Sitka	29	Coastal W N. America	N WA	1913	72	10/5	65.2	83.5	.64	CM; VG, LP, SG	
		358	Coastal W N. America		1927	58	18/13	56.7	72.0	.66	CM; VF, ND, SG, LP	
smithiana (Wall.) Boiss.	Himalayan	448A	W Himalayas	Punjab, India	1933	52	12/2	13.0	17.0	.17	CN; VD, YN	(L)
		523	W Himalayas	Turkey	1940		All dead in 1965					
The Pines—*Pinus*												
albicaulis Engelm.	Whitebark	1	W US	Deschutes NF (OR)	1917	68	10/2	48.5	52.0	.42	CL; VP, IX, BR, YN	
aristata Engelm.	Bristlecone	2	Rockies	AZ	1913		12/0	All dead in 1961				
		9	Rockies	Cibola NF (NM)	1912	73	7/1	32.0	32.0	.24	CN; VF, GN, LP	
		466	Rockies		1931		20/0	All dead in 1965				
balfouriana A. Murr.	Foxtail	498	CA	Sequoia NP (CA)	1938	47	28/10	9.1	13.0	.14	CN; VF, SB	
banksiana Lamb.	Jack	8	Lake States	MN	1914		11/0	All dead in 1965				(L)
bungeana Zucc.	Lacebark	209	China		1922		9/0	All dead in 1961				(S)
		296	China		1924		2/0	All dead in 1961				
contorta Dougl. var. contorta	Shore	539	W Coast N. America	Taft, OR	1947	38	20/16	27.0	66.0	.89	CH; VX, SD, HV	
contorta var. *latifolia* S. Wats.	Lodgepole	6	W N. America	W MT	1913	72	11/2	50.0	50.0	.38	CN; VF, SX, LL	(S)
		604	W N. America	Wind R., WN	(1951)	34	20/17	31.2	46.0	.70	CL; VX, ND, LP	
densiflora Sieb. & Zucc.	Japanese red	130	Japan	Fukuoka, Japan	1925	60	8/0	All dead in 1965				(L)
		175	Japan	Japan	1923	62	21/3	32.2	41.0	.36	CL; VD	(L)
echinata Mill.	Shortleaf	178	E US	PA	1923	62	18/2	43.5	64.0	.55	CN; VP, ND, SX, ID	(M)
		270	E US	Ashville, NC	(1923)	62	13/1	13.5	13.5	.12	CN; VP, ND, SX, ID	(S)
echinata x *rigida*	Hybrid	389	CA	Eddy Stn.	1929	56	9/5	31.2	40.0	.38	CN; VF, SD	(N)
engelmannii Carr.	Apache	16	SW US, Mexico	AZ	1912	73	11/0	All dead in 1965				
		409	SW US, Mexico	SW AZ	1930	55	30/3	37.0	55.0	.53	CN; VP, ND, SD, ID	
flexilis James	Limber	299	SW US		1925	60	9/5	52.0	56.0	.50	CL; VG, LP, ND	
		407	SW US		1927	58	10/3	54.7	61.0	.56	CL; VG	

Table 1— (Continued)

Species: Scientific name	Species: Common name	Lot number	Range[a]	Seed source	Year sown[b]	Age in 1985	Number planted; number alive	Average height 1985	Tallest tree 1985	Growth index	Condition/comment[c]	
heldreichii Christ var. *leucodermis* (Ant.) Markgraf	Bosnian	339	S C Europe	Yugoslavia	1928	57	18/11	9.6	26.0	.24	CN; VP, ND	
jeffreyi A. Murr.	Jeffrey	13	Sierras	CA	1912	73	11/2	89.0	93.0	.70	CN; VG, ND, ID, BB	(L)
koraiensis Sieb.& Zucc.	Korean	131	E Asia	Fukuoka , Japan	1925	60	23/13	36.1	50.0	.45	CN; VG, ND, LD	
lambertiana Doug.	Sugar	14	W US, Mexico	CA	1911	74	10/0	All dead in 1985				(M)
		230	W US, Mexico	Butte Falls, OR	1924	61	10/3	77.7	99.0	.87	CN; VG, ND	
massoniana Lamb.	Masson	392	SE China	China	1929	56	22/14	35.8	50.0	.47	CM; VF, ND, LP	
mugo Turra	Swiss Mountain	476	C, SE Europe	Switzerland	1929	56	20/19	35.2	45.0	.42	CM; VF, LP, ND, CP	
mugo var. *mugo*	Mugho Swiss Mt.	282	C, SE Europe		1925	60	3/3	17.0	17.0	.15	CM; VX, ND, SB	
mugo uncinata Mirb.	Tree Swiss Mt.	341	C, SE Europe	Denmark	1928	57	20/11	35.0	46.0	.43	CN; HV, ND, CP	
monticola D. Don	Western white	17	W N. America		1912	73	21/1	56.0	56.0	.42	CM; BR	
nigra var. *caramanica* (Loud.) Rehd.	Crimean	180	Balkans		1923	62	15/11	77.8	95.0	.82	CM; VG, ND, DT	
nigra Arnold var. *nigra*	Austrian	4	S, C Europe	Russia	1912	73	7/6	77.3	88.0	.66	CN; VX	
		4A			1914	71	5/3	88.3	93.0	.72	CN; VX	
nigra Arnold var. *maritima* (Ant.) Melville	Corsican	15	Corsica-Italy	Russia	1912	73	12/3	57.3	65.0	.49	CN;VF,ND,LP	
		398		Yugoslavia	1929	56	21/19	58.9	77.0	.73	CM; VG, SX, SS	
		503			1936	49	20/18	51.8	72.0	.76	CM; VX, SD	
parviflora Sieb. & Zucc.	Japanese white	252	Japan	Kiso, Japan	1926	59	22/16	35.4	53.0	.48	CM; VF, LP, LD	
peuce Griseb.	Balkan	351	S, C Europe		1928	57	3/3	33.0	38.0	.35	CM; VP, ND	(L)
		505			1936	49	17/17	30.0	43.0	.45	CN; VX, SD	
ponderosa Dougl.	Ponderosa	18	W N. America	Pinchot NF (WA)	1912	73	18/6	74.8	94.0	.71	CN; VP, ND	
ponderosa (hybrid)	Ponderosa	599-603	W N. America	Eldorado NF (CA)	1950	35	60/37	24.7	46.0	.68	CN; VD, ND, NSB	
ponderosa var. *scopulorum* Engelm.	Ponderosa	330	W N. America	Flagstaff, AZ	1928	57	20/10	48.8	61.0	.57	CM; VG, LP, LD	
pungens Lamb.	Table-Mountain	177	E N. America		1923	62	18/7	40.1	60.0	.52	CM; VF, LP, LD	
resinosa Ait.	Red	19	E N. America	MN	1914	71	8/3	70.0	75.0	.58	CN; VX	
		111	E N. America	Lake States Exp. Stn.	1924	61	20/18	64.1	70.0	.61	CN; VG, LP, ND	
rigida Mill.	Pitch	20	E N. America	GA	1914	71	15/10	28.4	60.0	.46	CN; VF, SD, BT	
		475	E N. America	NJ	1929	56	15/2	29.0	38.0	.36	CN; VF, SD	
sabiniana Dougl.	Digger	274	CA	Weaverville, CA	1926	59	18/0	All dead in 1985				
strobiformis Engelm.	Mexican white	408	Rockies, SE CA	Gila NF (NM)	1930	55	42/8	55.0	70.0	.67	CL; VF, ND, LP	
strobus L.	Eastern white	21	E N America	N MN	1912	73	8/2	74.5	83.0	.62	CM; VF, BR, ND, LP	
sylvestris L.	Scotch	22	Europe, W, N Asia	Russia	1912	73	14/3	49.0	54.0	.41	CN; VP, SS, ND	
		179	Europe, W, N Asia		1923	62	18/6	46.0	59.0	.51	CL; VG, ID, SS	
sylvestris var. *mongolica* Litw.	Scotch	361	Europe, W, N Asia	Manchuria	1929	56	20/7	51.1	58.0	.55	CN; VF, ND, SS, SD, ID	
sylvestris L.	Scotch	605	Europe, W, N Asia	Germany	1957	28	38/19	27.5	38.0	.73	CM; VG, ND, SX	

Table 1— (Continued)

Species: Scientific name	Species: Common name	Lot number	Range[a]	Seed source	Year sown[b]	Age in 1985	Number planted; number alive	Average height 1985	Tallest tree 1985	Growth index	Condition/comment[c]	
tabulaeformis Carr.	Chinese	253	C W China	Garhei, Korea	1926	59	18/5	24.2	50.0	.45	CM; VF	
		264	C W China	Mozan, Korea	1926	59	18/9	41.2	58.0	.53	CL; VF, SS	
		314	C W China	Monterey, CA	1928	57	20/0	All dead in 1965				
thunbergii Parl.	Japanese black	132	Japan	Fukuoka, Japan	1925	60	18/1	61.0	61.0	.54	CN; VF, NSB, ND	(S)
virginiana Mill.	Virginia	176	E N. America	Mt. Alto, PA	1923	62	16/1	42.0	42.0	.36	CN; VG, SD	(M)
		488	E N. America	Asheville, NC	(1933)	52	20/1	39.0	39.0	.39	CN; VF, NSB	(S)
wallichiana A.B. Jacks	Himalayan	534	Himalayas		1945	40	1/1	45.0	45.0	.58	CN; VG, ND, BRM	
The Douglas-firs—*Pseudotsuga*												
macrocarpa Mayr.	Bigcone	285	S CA, Mexico	Los Padres NF (CA)	1927	58	24/0	All dead in 1965				(S)
menziesii (Mirb.) Franco	Douglas-fir	33	Rockies	San Juan NF (CO)	1914	71	20/0	All dead in 1985				
		556	W N. America	NM 9000ft	1948	37	14/1	29.0	29.0	.40	CN; ND	
		557	W N. America	MT 3100ft	1948	37	12/10	22.3	31.0	.43	CN; TC	
		558	W N. America	ID 2200ft	1948	37	12/10	30.6	58.0	.81	CN; TC	
		586	W N. America	Sierra NF (CA)	1948	37	12/4	18.3	33.0	.46	CN; ND	
		587	W N. America	Olympic NF (WA)	1948	37	11/8	42.3	67.0	.93	CN; S	
		588	W N. America	Siuslaw NF (OR)	1948	37	7/4	34.0	56.0	.78	CN; S	
		589	W N. America	Fidalgo Is., WA	1948	37	11/9	26.8	41.0	.57	CN; S	
		593	W N. America	Flathead NF (MT)	1948	37	12/8	16.1	40.0	.56	CN; VP	
		594	W N. America	Nezperce, ID	1948	37	12/6	7.8	12.0	.17	CN; ND	
		597	W N. America	Tucson, AZ	1948	37	10/3	6.3	10.0	.15	CN; VP	
The Redwoods—*Sequoia*												
sempervirens (D. Don) Endl.	Redwood	233	Coastal S OR, CA	Contra Costa County, CA	1926	59	21/5	8.5	15.0	.14	CN; VF, RFD	(S)
The Sequoias—*Sequoiadendron*												
giganteum (Lindl.) Buchh.	Big tree	35	W slope of Sierras	CA	1912	73	14/9	111.8	121.0	.91	CN; VX	
		461	W slope of Sierras	Whittaker For., CA	1932	53	2/1	17.0	17.0	.17	CN; VP, RFD	(S)
		479	W slope of Sierras	Whittaker For., CA	1928	57	16/15	55.0	103	.95	CN; VG, HV	
The Yews—*Taxus*												
baccata L.	English	421 & 432	Europe, Iran, Algeria	Carson, WA	1931	54	29/10	1.5	2.0	.02	CN; VP, RFB	(S)
brevifolia Nutt.	Pacific	357	W N. America	Pinchot NF (WA)	(1925)	60	21/2	2.5	3.0	.03	CN; VP, RFB, S	(S)
The Thuja-cedars—*Thuja*												
occidentalis L.	Northern white	182	E N. America		1923	62	20/2	25.0	31.0	.27	CH; VF, YN, TC	(L)
plicata Donn	Western red	37	W N. America	Pinchot NF (WA)	1912	73	10/9	71.3	82.0	.62	CN; VX, SS	(L)
		497	W N. America	Pinchot NF (WA)	(1933)		17/4	24.3	39.0		CM; VF, RFB	(S)

Table 1— (Continued)

Species		Lot number	Range[a]	Seed source	Year sown[b]	Age in 1985	Number planted; number alive	Average height 1985	Tallest tree 1985	Growth index	Condition/comment[c]
Scientific name	Common name										
Thujopsis—*Thujopsis*											
dolabrata (L.F.) Sieb. & Zucc.	Hiba arborvitae	256	Japan	Tsugarn, Aomori, Japan	1926	59	5/2	42.5	51.0	.46	CM; VG
The Hemlocks—*Tsuga*											
canadensis (L.) Carr.	Eastern	181	E N. America		1923	60	18/12	42.4	52.0	.46	CH; VG, SD, TC, MS
caroliniana Engelm.	Carolina	506	SW VA		1938	47	8/8	39.1	42.5	.47	CH; VG, SX, MS
heterophylla (Raf.) Sarg.	Western	353	W coast, N. America	Pinchot NF (WA)	(1923)	63	16/10	88.4	95.0	.81	CH; VX, GC, NND
mertensiana (Bong.) Carr.	Mountain	278 & 354	W N. America	Pinchot NF (WA)	(1925)	60	19/0	All dead in 1985			
sieboldii Carr.	Siebold	414	S Japan	Kiso, Japan	1931	54	12/4	15.6	19.0	.18	CN; VF, FD (M)

Coding of Condition and Comments

BB - Bark beetles
BR - Blister rust
BRM - Blister rust, severe or multiple cankers
BT - Broken top
CH - Cones, heavy
CL - Cones, light
CM - Cones, moderate
CN - Cones, none
CP - Pollen only
DC - Dense crowns
DCC - Distress cone crop
DT - Dead top
FC - Frost cracks
FC - Frost damage
GC - Good color
GN - Green needles
HV - High variability
ID - Ice damage
IX - Ice break, trunk
LP - Lichen present
LD - Lower limbs dying
LL - Lichens on limbs
LT - Lichen on main trunk
MS - Multiple stems
ND - Needle disease
NND - No needle disease
NRWA - No recent woolly aphid damage
NSB - No snow or ice damage
PMS - Pitchy main stem
RFB - Repeated freezeback
RFD - Recovering from frost damage
S - Suppressed
SB - Snow bend, trunk
SD - Snow damage
SG - Spruce galls (*Adelges coolyei*)
SS - Sapsucker damage
SX - Snow break
TC - Thin crowns
VD - Vigor, declining
VF - Vigor, fair
VG - Vigor, good
VP - Vigor, poor
VX - Vigor, excellent
WA - Woolly aphid (*Adelges piceae*)
YN - Yellow needles

[a] C = central, E = east, N = north, S = south, W = west, NF = National Forest, NP = National Park.
[b] Estimated dates are in parentheses.
[c] Comment/condition abbreviations are listed at end of table.

Table 2—Status of living broad-leaved species, Wind River Arboretum

Scientific name	Common name	Lot number	Year sown	Height 1985	Number planted; number alive	Condition/comment
Acer macrophyllum Pursh var. *kimballiae* Harrar	Kimball bigleaf maple[a]	525	1940	All dead in 1957		
Acer platanoides L.	Norway maple[a]	95	1913	53.0	8/1	Good
Acer saccharum Marsh.	Sugar maple	69	1912	Dead in 1957		
Castanea dentata (Marsh.) Borkh.	American chestnut	191	1924	45.1	6/5	Multiple stem, improving, chestnuts
Castanea mollissima Bl.	Chinese chestnut	53	1914	Dead in 1957		
Castanopsis Chrysophylla (Dougl.) A. DC.	Golden-chinkapin	54	1913	55.3	14/10	Growth slowing
Fraxinus americana L.	White ash	72	1912	30.0	16/2	Many 2-foot sprouts
Fraxinus latifolia Benth.	Oregon ash	74	1913	14.5	16/11	Poor, low vigor, sapsucker damage
Fraxinus nigra Marsh.	Black ash	73	1912	Dead in 1957		
Fraxinus pennsylvanica Marsh.	Green ash	75	1912	15.5	15/7	Fair, resprouts from frost kill
Liriodendron tulipifera L.	Yellow-poplar	63	1911	27.8	17/13	Good
Lithocarpus densiflora (Hook. & Arn.) Rehd.	Tanoak	120	1925	All dead in 1975		
Populus berolinensis Dipp.	Berlin poplar	49	1916[b]	20.1	3/1	Poor, repeated freezeback, sapsucker damage
Populus petrowskyana (Reg.) Schneid.	Petrowsky poplar	273	1926	All dead in 1975		
Prunus serotina Ehrh.	Black cherry	64	1913	All dead in 1975		
Prunus sp.	Patagonian cherry	283	1927[b]	All dead in 1975		
Quercus alba L.	White oak	188	1923	23.3	16/2	Good, no acorns
Quercus chrysolepis Liebm.	Canyon live oak	119	1925	10.7	12/7	Fair, bush-like, repeated freezing
Quercus garryana Dougl. ex Hook.	Oregon white oak	55	1913	25.9	7/4	Fair, many dead twigs
Quercus kelloggii Newb.	California black oak	121	1925	39.0	16/9	Fair, thin foliage, no acorns
Quercus prinus L.	Chestnut oak	187	1923	34.2	14/6	Fair, dead interior limbs
Quercus rubra L.	Northern red oak	57	1912	43.5	16/13	Good, mostly single stems
Quercus velutina Lam.	Black oak	56	1914	Dead in 1985		
Rhamnus purshiana DC.	Cascara buckthorn	239	1925	13.9	18/19	Fair, freezing and resprouting
Tilia americana L.	American basswood	70	1912	32.0	6/3	Multiple stems from freezing
Ulmus americana L.	American elm	62	1912	20.0	13/3	Poor, frost injury

[a] Planted on watered lawn.

[b] Cuttings or plants set that year.

Table 3—Conifers unsuited to Wind River Arboretum

Species	Range	Seed source	Reason for unsuitability	Age at death
				Years
Dead				
Abies bracteata (Don) Nutt.	CA	S CA	Repeated frost damage	?
Abies delavayi (Nutt.) Franch.	W China	China	Reapeatedly frozen	50
Abies firma Sieb. & Zucc.	Japan	Japan	Repeated winter damage	20
Abies veitchii Lindl.	Japan	Japan	Repeated winter damage	20
Abies holophylla Maxim.	Manchuria, Korea	Japan	Repeatedly frozen	60
Abies lasciocarpa var. *arizonica* (Merriam) Lemm.	AZ	AZ	Killed by balsam woolly aphid	53
Calocedrus formosana (Florin) Florin	Formosa	Japan	Frost killed	2
Chamaecyparis pisifera (Sieb. & Zucc.) Endl.	Japan	Orient	Frost and winter killed	30
Cedrus deodara (Roxb.) Loud.	Mediterranean	?	Probably frost damage	58
Cephalotaxus harringtonia var. *drupacea* (Sieb. & Zucc.) Koidzumi	Japan	Austria	Frost killed	18
Cryptomeria japonica (L.f.) D. Don	Japan	Japan	Died gradually	15
Cupressus arizonica Greene	SW US	AZ	Frost killed	18
Cupressus duclouxiana Hickel	Himalayas	Austria	Winter killed	2
Cupressus goveriana Gord.	CA	S CA	Frost killed	18
Cupressus lusitanica Mill.	Mexico	Mexico	Stock died in nursery	3
Cupressus macnabiana A. Murr.	?	?	Low vigor for long period	60
Cupressus macrocarpa Hartw.	SW US	S CA	Winter damage	20
Cupressus sempervirens L.	S Europe, W Asia	Mediterranean	Winter killed	4
Ginkgo biloba L.	E China	Japan	Repeatedly killed back	8
Juniperus ashei Buchholz	E US, Mexico	?	Frost killed	17
Juniperus excelsa Bieb.	Mediterranean	Austria	Frost killed	19
Juniperus monosperma (Engelm.) Sarg.	SW US	SW US	Died gradually	21
Juniperus semiglobosa Reg.	Asia minor	Russia	Frost killed	19
Larix lyallii Parl.	Pacific NW	E WA	Died in nursery and arboretum	13
Picea likiangensis (Franch.) Pritz.	W China	China	Died out in arboretum from frost	30
Pinus armandi Franch.	C W China	China	Repeated freezeback	31
Pinus attenuata Lemm.	W US	CA	Frost killed	43
Pinus canariensis C. Smith	Canary Is.	Canary Is.	Winter killed in nursery	
Pinus coulteri D. Don	Mexico, CA	S CA	Frost killed	39
Pinus densiflora Sieb. & Zucc.	Japan	Japan	Gradually died, probably cold	
Pinus edulis Engelm.	SW US	SW US	Frost and winter killed	20
Pinus elliottii Engelm.	SE US	SE US	Winter killed in nursery	4
Pinus gerardiana Wall.	Himalayas	India	Did poorly for several years, killed by rust disease	34
Pinus halepensis Mill.	Mediterranean	SC Europe	Died out in nursery and arboretum	8
Pinus kesiya Roy. ex Gord.	N Burma	India	Winter killed in nursery	1
Pinus leiophylla Schlech. & Cham.	SW US, Mexico	Mexico	Winter killed in nursery	5
Pinus montezumae Lamb.	Mexico	Mexico	Winter killed in nursery	6
Pinus palustris Mill.	SE US	SE US	Winter killed in nursery	5
Pinus patula Schlech. & Cham.	Mexico	Mexico	Killed in nursery	5
Pinus pinaster Ait.	Mediterranean	Holland	Frost killed	27
Pinus radiata D. Don	CA	S CA	Winter killed	12
Pinus roxburghii Sarg.	Himalayas	Himalayas	Winter killed in nursery	3
Pinus taeda L.	SE US	SE US	Gradually died off; finally killed by frost	43

Table 3—(Continued)

Species	Range	Seed source	Reason for unsuitability	Age at death
				Years
Pinus torreyana Parry	CA	S CA	Winter killed in nursery	5
Pseudotsuga macrocarpa Mayr	S CA	S CA	Frost and needle disease	37
Pseudotsuga menziesii (Mirb.) Franco	Interior W US	MT	Needle disease	60
Taxodium distichum (L.) Rich.	S US	LA	Died after a few years	10
Thuja orientalis L.	N, W China	Japan	Frost and winter killed	20
Thuja standishii (Gord.) Carr.	Japan	Japan	One small lot failed after 5 years in the arboretum	13
Tsuga mertensiana (Bong.) Carr.	NW N. America	W WA	Died suddenly after good growth and survival	50
Living, but in poor condition				
Abies sibirica Ledeb.	USSR	Not given	Repeatedly frozen	—
Chamaecyparis thyoides (L.) B.S.P.	E US	NJ	Repeatedly frozen	—
Juniperus occidentalis Hook.	W US	E OR	Low vigor, snow breakage	—
Larix eurolepis Henry hybrid-*decidua* x *kaemferi*	Europe, Japan		Only 1 left of 19 planted	—
Picea bicolor (Maxim.) Mayr	Japan	Japan	Gradually dying off	—
Picea polita (Sieb. & Zucc.) Carr.	Japan	Japan	Repeated snow breakage	—
Picea smithiana Boiss.	Himalayas	India	Repeated snow breakage	—
Pinus aristata Engelm.	SW US	S CA	Two of 3 lots dead, 1 survivor in 3d lot	
Pinus bungeana Zucc.	NW China	China	Repeatedly frozen back, (2 alive but very poor)	—
Pinus virginiana Mill.	E US	NC	Frost, gradually dying off	—
Pinus wallichiana A.B. Jacks.	Himalayas	Himalayas	Frost, 1 of 2 lots killed	—
Pinus sabiniana Dougl.	CA	N CA	Frost	—
Pinus thunbergii Parl.	Japan	Japan	Frost, gradually dying off	—
Sequoia sempervirens (D.Don) Endl.	CA	S CA	Repeatedly frozen	—
Taxus baccata L.	Eurasia, N Africa	Austria	Repeatedly frozen	

Table 4—Growth index averages for all arboretum lots by world forest regions

Region	*Abies*	*Larix*	*Picea*	*Pinus*	*Tsuga*	*Pseudotsuga*	$\bar{x}$
Western OR, WA	0.76(7)[a]		0.52(5)	0.75(4)	0.77(4)	0.83(1)	0.71
Sierras, CA	.74(2)			.69(2)			.71
W. Europe, Alps, Balkans	.39(3)	0.52(5)	.59(1)	.59(10)			.57
Korea	.41(3)	.56(2)		.46(3)			.47
NE North America	.36(2)	.32(2)	.33(5)	.43(10)	.44(1)		.39
Japan	.21(5)	.34(1)	.27(4)	.34(4)	.18(1)		.27
China	.03(4)	.35(4)	.00(2)	.34(3)			.20
Siberia	.29(1)	.29(1)					.29
California coast	.18(2)			.00(4)			.06
Mediterranean				.00(3)			.00
Mexico				.00(5)			.00

[a] Number of arboretum lots in average.

Silen, Roy R.; Olson, Donald L. 1992. A pioneer exotic tree search for the Douglas-fir region. Gen. Tech. Rep. PNW-GTR-298. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 44 p.

After three-quarters of a century of introduction of 152 conifer and broadleaf species, no promising candidate exotic was found for the Douglas-fir region. Growth curves spanning 50 years or longer are figured for many species. Firs, pines, larches, spruces, hemlocks, and cedars originating in northwestern North America had superior growth rates to those from other forest regions. The probable basis for these differences is discussed. The record highlights a general failure of introduced hardwoods, the slow decline of most introduced conifers, the long time needed to express failures, dramatic effects of climatic extremes or of introduced pests, failure of native species of continental origin at Wind River, striking similarities of growth rates for the species originating in each country, and many important contrasts between results from early reports and long-term conclusions.

Keywords: Plant introduction, forest genetics, arboreta, conifers, silviculture, growth curves, exotics, seed movement, introduced pests, climatic extremes.

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