Interpreting the timberline: An aid to help park naturalists to acquaint visitors with the subalpine-alpine ecotone of western North America

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INTERPRETING THE TIMBERLINE:

An Aid to Help Park Naturalists to Acquaint
Visitors with the Subalpine-Alpine Ecotone of Western North America

By

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Frontispiece 1. Timberline trees have an inspirational value for mankind. (Foxtail pine at 10,500 feet on Alta Peak, Sequoia National Park—a "double pickaback" trunk as discussed later)
Frontispiece 2. Also, the unique trees of timberline have outstanding scenic charm. (Subalpine larch stands "turn color" at 9000 feet in the Anaconda Range, Montana)
ACKNOWLEDGMENTS

Since ecological literature discusses relatively few of the timberlines of western North America, much of the information, especially in chapter V of this paper, was gathered through correspondence. The writer is particularly grateful for the data and advice received from several dozen people including rangers and others in the U.S. Forest Service; naturalists in the National Park Service; and ecologists, foresters, and land managers in the United States and Canada. Much of this correspondence is cited at the end of the paper.

The members of my graduate committee have been understanding and have offered helpful advice that has improved this paper, and brought it closer to achieving its goal. Their thoughtfulness has been especially important because of the unusual nature of this project—there were no guidelines to follow. Dr. L. C. Merriam, Jr. (forest recreation), School of Forestry, University of Montana, was my major professor until recently when he went to another university. Dr. R. D. Taber (wildlife) of the Forestry School has been my thesis-committee chairman, and Dr. G. M. Blake (silviculture) of the Forestry School and Dr. J. R. Habeck (forest ecology) of the Botany Department have been members of this committee.

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S. Arno
Missoula, Montana

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I. INTRODUCTION

My first acquaintance with "timberline" was made one day in grammar school, when our teacher read aloud an essay by Enos Mills (105) called "Trees at Timberline." Mills, known as the "Father of Rocky Mountain National Park," described this "forest frontier" in a colorful, inspiring manner; but the statement that was most astonishing to a 10-year-old follows:

From a stand of dead timber I cut eleven small trees and carried them in one load to my camp-fire. They were so gnarled and ancient-looking that they aroused my curiosity, and with a magnifier I counted the annual rings in each. The youngest was 146 years of age, and the oldest 258! The total age of these eleven trees was 2,191 years!

As Wardle (179) aptly put it, "Timberline is a biological boundary which doesn't escape even the most casual observer." The few highways that ascend to upper timberline1 in the western United States are especially popular with tourists partially because of their scenery. Many of the well-known roads to the timberline are in United States or Canadian National Parks or other publicly-owned recreation areas (e.g., Mount Rainier, Glacier, Olympic, Rocky Mountain, and Banff-Jasper National Parks; Mount Hood and the Ancient Bristlecone

1"Timberline" in this paper is taken to mean the entire environmental zone between the upper "forest line" and the "scrub line"; hence it is the scattered or broken forest and scrub zone common near the upper altitudinal limit of the forest belt. More explicit definitions follow in the next chapter.
Pine Forest of the U.S. Forest Service).

All of the major government agencies that now manage natural lands for recreation have become more than just mildly interested in orienting visitors to the natural outdoors which these agencies manage. The U.S. Park Service has long been active in interpreting natural history to the visiting public, and more recently the U.S. Forest Service, Canadian Park Service, Bureau of Land Management, Bureau of Reclamation, state park services, and, no doubt, others have begun to develop interpretation programs.

The professional naturalist is in charge of such interpretation, and his job includes some translating of the esoteric language of science for the layman. These interpreters have little time or facilities (e.g., in a remote national park) to delve headlong into technical literature in order to summarize the information on a particular facet of the natural history. Unlike the specialized research scientist, these naturalists must divide their efforts among the phases of the immense field of natural history. The material relayed to the public incorporates the work of many scientific fields (e.g., ecology, biology, geology, anthropology, climatology, geography). Although scientists provide naturalists with much detailed material, often what is most needed by the latter is an overall survey of the scientific findings, i.e., piecing the "story" together. There is a need for "general reviews" that help clarify obscured parts of the natural history.

This paper attempts to survey timberlines of western North
America in a manner primarily designed to serve public interpreters of natural history, such as park naturalists. Hopefully, this broad discussion of the timberlines will also be of interest to biologists and some members of the public. Much of the discussion is based upon personal observation of timberlines (see APPENDIX).

The emphasis of this paper is on trees of the timberline, though of course trees are only a part of the timberline habitat. The professional naturalist must relate a broader sketch of the environment called "timberline" in his particular location. This paper will not attempt to provide all the necessary information about all aspects of timberline. Moreover, it will not outline a precise program that can be followed by naturalists step by step to interpret timberline for the public.

This paper is designed to aid naturalists who are employed in many different localities, working under different programs with different limitations and goals. This report provides proposed definitions for the terminology relating to timberlines, a review of the causes of timberline formation, a comparatively detailed description of the timberlines of western North America, a discussion of the various tree species as timberline dwellers, and suggestions regarding the needs for and means of interpreting the timberline.

Particular emphasis is placed on the trees of timberline in this report for three main reasons. One is the realization that nothing short of a multi-volume work could discuss all phases of the timberline environment in significant detail. Secondly, since the subject must be restricted in scope, the tree growth at timberline seemed a logical
segment of the habit for discussion. That is, tree growth is the most obvious feature of timberline (as opposed to underlying geology, climate, animals, etc). Furthermore, the tree growth expresses the total environmental picture of the location at which it occurs.

The final reason for the emphasis on trees here is that despite the fact that trees are an obvious starting point for understanding the timberline, they are often skimmed over briefly in interpretation. It may be that many naturalists and others do not know the very interesting "story" of trees at the timberline (superficially, wildflowers or animals might seem to warrant more attention).

Hopefully, this paper will help the naturalist to initiate or improve the discussion of timberline which is presented to the public at his area.

It might seem adequate for a naturalist to read only the few parts of the following report that deal directly with his vicinity, or perhaps region—the idea being that this information is all that is necessary for formulating his presentation. In the past it might have been sufficient for a naturalist to discuss the environment at one location to interested visitors, who would unconsciously compare it to their home environment. However, today's visitors are more mobile, hence better informed about other environments. For instance, a traveler in Glacier Park, Montana, may have also been to Mount Rainier, Banff-Jasper, Colorado, and Alaska. At least these places do not seem so obscure to him as they might have to the average Glacier visitor 40 years ago.

The result of the better public comprehension of geography is
that a naturalist can now further the effectiveness of his informal visitor education by relating a broader natural history, contrasting the environment of his area with that of other well-known locations or regions. After reading about the variations in timberlines in relation to geographic positions, it is hoped that the naturalist will conclude that some of this "cross-country comparison" can fit into his scheme of interpretation regarding the timberline.
II. WHAT ARE TIMBERLINES

After perusing the ecological literature dealing with the upper altitudinal limits of tree growth one learns that there is a basic need for definition of terms. Authors have used the word "timberline" to denote the upper limit of the contiguous forest, the highest dwarf tree, a specific point in between, or the entire area in between. They may not have even offered the reader a clue as to what they meant by "timberline."

After consolidating terms presented in the literature, and trying to fit them into the most logical framework for description, the following terminology was derived. Often, more than one term is shown to designate a particular feature. In such cases only the first of these roughly synonymous expressions will normally be used in the text of this report.

"Timberline" Terminology

I. Upper Altitudinal Boundaries of Tree Growth (after 94)

A. forest line (forest limit). The general upper altitudinal limit of the contiguous, arborescent (tree-like) forest.

B. tree limit (tree line). Absolutely the highest elevation of arborescent growth; the highest point at which erect trees—10+ feet tall (96)—occur.

C. scrub line (krumholz line = elfinwood line = wind-timber line). The general upper altitudinal limit of the "elfinwood," or forest of shrub-like trees.
II. Other Boundaries of Forest Growth

A. **polar timberline** (arctic or northern timberline in this hemisphere). The upper latitudinal limit of forest growth, approaching the earth's poles (generally associated with lowlands).

B. **lower timberline.** The lower altitudinal limit of the forest on semi-arid mountain slopes, the "dry timberline."

III. Related Terms

A. **upper timberline = timberline = alpine timberline.** The transition zone or ecotone between the high-country forest and the alpine zone. Like polar timberline, alpine timberline is a "cold timberline." Timberline is taken here to mean the zone between forest line and scrub line; hence this is similar to what has been regarded by some as the Hudsonian Life Zone.

B. **alpine line.** The lower boundary of the alpine zone; the same as scrub line.

C. **krummholz limit (absolute tree limit).** The highest altitude at which any tree species exists. The point where the last shrub-like tree, sub-shrub, or degenerate seedling grows.

D. **commercial or economic timberline.** Upper limit of the merchantable forest. This may vary with changes in timber harvest and utilization technology, as well as with fluctuation of economic conditions.

E. **climatic timberline.** Upper timberline is generally implied to reflect limitations on forest growth inflicted by a severe climate. In some cases extreme exposure, etc. causes an unusually low-altitude timberline to form (as atop a rugged crag below normal timberline for the area). Such cases are denoted as "not a climatic (or "true") timberline."

*Figure 1 illustrates some of these expressions in use. They will henceforth be employed in this paper as defined here.*

1"Timberline" happens to coincide roughly with what some have described as the Hudsonian Zone for some regions; however "timberline" does not carry with it the stipulations set down for the Life Zones conceived by C. Hart Merriam. "Timberline," for instance, can describe generally an environmental zone in desert mountains, while the Life Zone concept fails. Daubenmire (40) has presented an interesting analysis of the Life Zone theory.
Not all upper timberlines have a distinct forest line, tree limit, and scrub line (e.g., in some areas there is an abrupt forest line with no appreciable arborescent or elfinwood growth beyond). "Timberline" itself was taken to mean a zone rather than a line, because it seems less specific than "forest line," "tree limit," or "scrub line," but it does an adequate job of implying a particular zone on the mountainsides.

Krummholz limit was not listed among the three main upper limits of tree growth because it is generally either hardest to define or the least significant boundary, perhaps both. Sometimes the highest shrub-like tree on a mountainside is a barely-existing "sub-shrub" covering half a square foot. Yet it is growing behind a sheltering rock, several hundred feet above the nearest other scrub. Such "accidentals" often go undetected, and the question is where the line should be drawn as to which high stragglers are significant.

Krummholz (shrub-like tree), no matter how tiny and matted the shrub, is "not strictly a part of the alpine itself" according to Hayward (75) and many other alpine ecologists. However, Cox (35), Clausen (28), and others have considered krummholz as "alpine." Above the scrub line, krummholz is usually so tiny and widely scattered that it has very little effect upon the otherwise strictly alpine environment. Below the scrub line, krummholz is a dominant feature of the habitat; hence scrub line seems to provide a good boundary between the timberline and the alpine.

Other related terminology also needs clarification:
alpine. The environmental zone above timberline on mountains, yet below the regional snowline—lower altitudinal limit of perpetual snow and ice.

In the 48 States only the Cascade volcanoes, North Cascades, and Olympic Mountains rise so high as to exhibit the snowline, or upper limit of the alpine. The lower limit of the alpine is the scrub line. The area between tree limit and scrub line—the krummholz belt—is the transition zone between timberline and alpine, just as timberline is the transition zone between forest and alpine.

In popular usage "alpine" often applies to all the country "high in the mountains," which may include subalpine and even the montane forest zones as well as the true alpine. It is more accurate to use the term "high-country" in this popular respect.

"Arctic-alpine," proposed by C. Hart Merriam, was once accepted as a good synonym for alpine. From the public naturalist's standpoint, "arctic-alpine" has the advantage of stressing the similarity between the arctic and alpine habitats; however, these are two distinct zones with important differences (discussed in following chapters), so it is preferable to use arctic and alpine separately.

subalpine. This refers to the timberline zone and the forest zone immediately beneath it, usually composed of the same species that form the timberline.

Meadows found in the broken forest of the timberline zone are most correctly termed subalpine meadows. "High-country meadows" and "mountain meadows" are broad, popular terms which encompass many zones and can be useful to interpretation. Alpine meadows is not often used correctly; it of course is not synonymous with subalpine meadows.

double timberlines. Two distinct and separate forest belts are sometimes formed on mountainsides, each exhibiting its own lower and upper timberlines. Probably the best example is that of mountains in the Great Basin described by Wardle (179). Here the singleleaf pinyon (Pinus monophylla), which composes the lower forest zone, may form krummholz at its upper limit of about 8000 feet. Yet, the only other forest trees are limber (P. flexilis) and bristlecone pines (P. aristata), which have

1. U.S. Forest Service tree nomenclature (96) is used in this paper. A summary of the common and technical names used appears at the end of Chapter VI.
their lower timberline near 9,500 feet\(^1\), and form their upper timberline around 11,000 feet elevation.

**Inverted timberline.** Russell (133) and Jepson (83) described this odd phenomenon as it occurs on the high plateaus of southern Utah. A subalpine forest grows atop gentle, 10,500-foot plateaus, but it forms an inverted timberline at the edges of the plateau, with krummholz barely descending into the badland amphitheaters. This upper lower-timberline is caused by extreme exposure to wind and drought.

### Characteristics of Tree Growth at Upper Timberline\(^2\)

- **Krummholz** = scrub = coniferous scrub (wind timber = wind cripples (139) = wind-scoured shrubs = alpine scrub (35) = elfinwood = crooked-wood).

  These terms are similar in applying to shrub-like trees that commonly grow near and above the tree limit on a mountainside. Extreme exposure to wind is the main factor causing tree species to exhibit this scruffy form, only a few feet tall—less than 10 feet maximum in accord with Little (96) or they are considered "trees."

- **Mat** (etc.). Extremely dwarfed krummholz. A dense prostrate "cushion" or "trailer" of wind-scoured branchlets forming a hedged surface perhaps only a foot off the ground constitutes a mat. Such severe dwarfing is common in shrubs at and above the scrub line.

- **Timber atoll.** A tiny cluster or circle of trees—particularly subalpine fir (Abies lasiocarpa)—characteristically develops between forest and tree lines in the following manner: One tree grows from a seed in an open area. As it matures its lower branches take root or "layer" and form a circle of younger trees (daughter trees) around it. This process continues, and the oldest member(s) of the group, in the center, dies and rots. The resulting hollow grove is a timber atoll (63).

---

\(^1\) Elevations used throughout this paper are in feet above mean sea level. Most often the word "elevation" will be implied, not stated. When parentheses are used, the symbol "()" will often be employed to replace the word "feet."

\(^2\) A further explanation of alpine zone and related terminology by Habeck et al. (67) is available from the Botany Dept., Univ. Montana, Missoula.
**skirt** (snow mat (63) = infranival cushion (179)). Trees near tree limit, especially fir and spruce, frequently have a luxuriant ring or skirt of long, prostrate, lower limbs, in striking contrast to the wind-battered foliage above, which is not protected by the snowpack throughout the long, harsh winter.

**flag** (supranival flag (179)). The top of trees and krummholz near tree limit is often reduced to a slender pole supporting but a few tiny branchlets on its lee side.
III. CAUSES OF TIMBERLINE FORMATION

Temperature

Just as the term "cold timberline" implies, lack of heat is apparently the most important factor limiting the altitude or latitude to which tree species can ascend. Shaw (138) stated long ago, however, that winter minimum temperatures probably do not have much effect on formation of timberlines. Woody plants that are not affected by a hard freeze can generally endure temperatures far below zero (F.). Furthermore, high-altitude trees and krummholz are often insulated from the atmosphere in winter by a blanket of snow.

Even minimum temperatures during the summer season may not be critical. Frost can occur frequently during the warmest summer months in most timberline areas. Moore (108), for example, found that temperatures below 18 degrees F. occurred below timberline in the European Alps during every month of the year.

Some of the less hardy species in the subalpine forest are kept from reaching the timberline by periodic hard freezes in late summer. For instance, near zero (F.) temperatures in Montana mountains in mid-September, 1965, killed new growth on many lodgepole pine and Douglas-fir growing near their upper altitudinal limits (see Plate 1).

Work by de Quervain (see 42) in 1903 showed that daily maximum temperatures in summer are closely associated with the position of cold timberlines. But even earlier research had brought to light a
Plate 1. Lodgepole (P. contorta var. latifolia) and whitebark pines (P. albicaulis) growing near 8000' on Saddle Mountain in the Montana Bitterroots. New foliage on the two lodgepole pine shown, at their upper limit, was killed by the hard September freeze, while the surrounding whitebark pine—like all other whitebark observed—showed no effect.

strong correlation between timberline and the mean 50-degree F. isotherm for the warmest month of the year.

Daubenmire (42) compiled climatic data illustrating that areas above the timberline are generally also above (i.e., in a location colder than . . .) this isotherm, while stations in or below the timberline zone have a mean temperature, for the warmest month, in
excess of 50 degrees. Additional weather records from Climax, Colorado—11,300' (152); White Mountains, California—10,150' (183); San Francisco Mountain, Arizona—11,500' (118); and elsewhere bear out this relationship. Griggs (64) found that some parts of the lowland, cold timberline in Alaska have been advancing rapidly, following the July, 50-degree F. isotherm which is retreating toward the north pole. Bliss (18) mentions the northern Nordenskjöld line (Scandanavian polar timberline) which has been found to coincide to the following temperature formula:

\[ V = 9 - 0.1K \]  

(V is the mean temperature of the warmest month and K is mean temperature of the coldest month in degrees Centigrade).

Daubenmire (42) has found that though the altitude of timberline is much greater at the equator than far to the north or south, altitude does not vary in a constant ratio with latitude. The 50-degree F. isotherm mentioned does seem to form a straight-line relationship with latitude north of 60 degrees N. along the Cordilleran Chain, primarily because this whole area is under the continental-polar climate. But, between central Canada and the southwestern United States, the isotherm (and therefore, timberline) rises in a curved relationship, increasing at a decreasing rate, with decreasing latitude. This is thought to reflect the alternate presence of maritime-tropical and continental-polar air masses.

Baker (11) has compiled some interesting information about the "Mountain Climates of the Western United States." He stresses the difference between "frostless season" and "growing season," the latter conventionally meaning that period when the mean temperature
16

is 42 degrees F. His data, for instance, indicate there is no frostless season at 6500 feet in the Washington Cascades, but the "growing season" in the same area is estimated at 100 days. There is also no frostless season at 6000 feet in the Oregon Cascades, but as high as 10,000 feet there is a "growing season" estimated at 30 days.

Baker gives rather detailed information on the average decrease in temperatures per 1000-foot increase in elevation at different times of the year. A rough average for the temperate zone is 3.3 degrees F. decrease in temperature per 1000-foot rise in elevation.

The importance of temperature as a cause of timberline formation is generally known, but the mechanism of its limitation on tree growth, and how to measure this, are yet to be discovered. (Additional information on particular causes of timberline formation is developed in following chapters.)

**Wind**

Though temperature is generally conceded to be the main factor limiting the maximum altitude to which tree species can ascend, wind is thought to be the principal cause of dwarfing and krummholz at most timberlines. Bates (13) measured the total miles of wind per month in the coldest part of winter on Pikes Peak (14,110'), Colorado. His results showed 5000 to 6000 miles of wind in a clearing high in the subalpine forest, 10,000 to 15,000 miles near tree limit, and 18,600 miles in January atop Pikes Peak, high in the alpine.

Mount Washington (6288') in the Presidential Range of New Hampshire is one of the windiest spots on earth, holding the world's...
record wind of 231 miles per hour, and having had winds of greater than 100 miles per hour in every month of the year (19). On its slopes the spruce forest dramatically reveals the effects of this wind. There is a steady, gradual reduction in height of the trees up the mountainside. Commercial timberline occurs at 4200 feet and the wind-battered elfinwood's upper line is around 5200 feet. In some places near the summit Griggs (64) noted that the soil mantle is over eight feet thick, yet the best growth tree species can attain here is in the form of "perfect carpets" just inches high.

Plate 2. A wind-scoured hedge of mountain hemlock (Tsuga mertensiana) krummholz growing atop a narrow ridge above 6000 feet in the Olympic Mountains.

Wind seems to have two primary ways of damaging timberline trees, during the long winter. One is mechanical damage to the
branches and crown. Not only are trees broken up by the frequent gale and hurricane-force winds themselves, but they are also battered by ice pellets, limbs, pebbles, and other debris that the wind blasts about.

Secondly, the wind causes a phenomenon known as "winter drought," which is dessication of foliage during temperature inversions in winter. A warm, winter wind—above freezing—can soon melt glaze or rime protecting a conifer's needles and then cause transpiration to take place. The result is wilted foliage, since the ground is still frozen and there is no water available for transpiration.

Mills (105) recalled walking for hours through the remains of a krummholz forest in Colorado that had apparently been killed by an unusual winter drought. The upper limit of living conifers had retreated nearly half a mile down the mountainside as a result.

Lawrence (92) concluded that prevailing summer winds (during the growing season) in part of the Columbia River Gorge has been responsible for the development of asymmetrical or "wind trained" trees. The succulent new growth on trees here is effectively "trained" by continuous pressure from westerly winds. Summer winds may also be influential in this way at some timberlines, though winter winds are probably most limiting upon tree growth.

The results of extreme exposure to wind are apparent in the growth form of conifers above the forest line. The wind bends limbs to the leeward and keeps growth pruned off the windward side of trees. Daubenmire (42) noted that tree limit may extend as much as 1700 feet higher on leeward than on the windward slope of a mountain.

Often an observer can find arborescent trees growing above the
tree limit proper because they are in a sheltered nook behind and beneath a rock outcrop. A conifer seed that germinates on the lee side of a boulder near scrub line will often form a long, trailing mat that extends parallel to the prevailing wind, with the rock sheltering its most luxuriant end and the far end being protected only by the shelter the shrub makes for itself.

Frequently, exposed peaks several hundred feet below the normal altitude of forest line exhibit dwarfed, flagged, and even krummholz trees caused by high winds. But, wind phenomena controlling tree limit is not universally important in all regions. Daubenmire (42) said, for example, that this factor is largely absent at upper timberlines in the tropics and South America. Beaman's (15) description of timberline on Mexican volcanoes indicates that wind is rather unimportant there. Also, wind is of little consequence at the arctic timberline and in interior Alaska.

Snow

Snow has both beneficial and detrimental effects upon growth and survival of trees at timberline. In studying the timberline on James Peak, Colorado, Cox (35) observed that, "The presence or absence of the tree species appears frequently to be a matter of enough but not too much snow." Klikoff (65) had similar conclusions in his central Sierra Nevada study.

The snowpack is beneficial to trees in protecting them from extreme cold, from freezing and thawing, and from drying winds. The krummholz community as a whole must depend upon a certain depth of
snowpack to protect it from drying-out and from sustaining mechanical
damage in winter. When twigs grow above the normal level of the snow-
pack, they are apt to be scoured off during the next winter.

Below tree limit, where flags and crowns project far above the
snowpack, the snow may aid wind in damaging the upper parts of the
trees (i.e., glaze and snow-covered crowns are more easily broken by
the wind). However, the skirt of lower limbs on the same trees are
protected by the snowpack.

Many naturalists visiting timberline areas in early summer have
noticed a phenomenon which Shaw (139) has explained. Groups of trees,
as dark objects, absorb heat and cause the snowpack to melt out away
from them sooner than from open areas above forest line. Still, snow
may linger so late as to stifle tree growth during some summers.

Shaw (139) observed that late-lingering snow in sheltered
valley heads in the Selkirk Mountains, British Columbia, kept the
upper limit of conifers down to about 5900 feet. Here the highest
conifers (Engelmann spruce, Picea engelmannii, and subalpine fir)
grow as trees because wind is not important. Shaw found, however,
that conifers grow to 7200 feet on exposed shoulders between the
basins. In this case, the snowpack is kept thin by the wind, and
krummholz can develop because there is a sufficiently long growing
season. Merriam (102) described a similar timberline situation on
the ridge spurs and intervening basins of Mount Shasta. In fact, this
phenomenon is prevalent throughout much of western North America.

Most observers in the high-country have probably noticed the
effect of a fungus (Herpotrichia sp.) which causes foliage trapped
for long periods in the snowpack to decay. Shaw (139) stated that a
great quantity of wet snow, such as the snowpack late in spring, may
"drown" a tree under some circumstances.

Heavy, wet snowfall, like that prevalent particularly in the
Pacific Coast Mountains, often clings to every inch of the tree, piling
up hundreds of pounds on a dwarfed conifer (see Plate 3). The result
can be snowbreak unless the trunk will bend prostrate. Observations of
subalpine larch in the Bitterroot Range, Montana, give evidence that
only slender trees can survive high in the krumholz zone because they
are bent prostrate by a load of snow for the winter (7). When such a
tree's trunk grows so large that it will no longer bend and still
remain undamaged, then it breaks.

Plate 3. Ice and snow weigh heavily upon mountain hemlock
and subalpine fir at 5000 feet in the central Olympic
Mountains.
Taylor (149) stated that he believed snow has a more important effect upon the upper limit of tree growth at Mount Rainier than does temperature. This conclusion may well apply for parts of a vast mountainous area (viz., the high Cascades, Olympics, North Pacific Coast Mountains, plus, to a somewhat lesser extent, the heaviest snowfall areas of the Rockies). However, even the snowiest timberlines have exposed, steep, and windswept slopes that do not hold sufficient snow to limit forest growth.

The snowpack in most timberline areas of western North America represents a great deal of water. Cool temperatures in spring allow much of the snow to remain until the short growing season begins, and the snowpack melts slowly thereafter, providing a relatively constant supply of water for plant roots. In most of the semi-arid West this snowpack is the only dependable water supply, and the distribution of the forest often coincides with that of the snowpack. Krummholz trees frequently "catch" a large quantity of snow that would otherwise be blown across the slopes they inhabit; consequently these dense shrubs improve their own water-supply for summer.

Precipitation

Pearson (118) made a rather detailed study of the forest distribution in the Southwest. He found that timberline trees are unable to grow at low elevation because of drought rather than high temperature. Where it is sufficiently moist at low altitudes the timberline species are possibly unable to compete with other vegetation. Timberline trees usually do quite well in low-altitude
gardens where they need not compete for water and growing room.

Daubenmire (42) concluded that in North America precipitation during the season of growth is not a factor limiting the upper advance of the forest. However, this factor is important in restricting species composition of the timberline (e.g., mountain hemlock might form timberline in the southern High Sierra, rather than pines, if a much larger quantity of precipitation fell during the summer).

Total precipitation is, of course, crucial in determining whether a forest can grow at all on a particular mountainside (see description of Steens Mtn., Oregon). The narrow bristlecone pine forest belt of the Great Basin mountains reflects steadily increasing drought toward its lower limit, with the low-altitude bristlecones (9500-10,000') having a shorter growing season than those at tree limit. The lower bristlecones can grow only until they use up the ground water supply resulting from last winter's precipitation. Then growth stops despite favorable temperatures (Fritts, 1964, see 88).

May Watts (180), in her excellent naturalist's account of traveling from lower to upper timberline in the Colorado Front Range, explained that she had gone from "drought to drought." The condition at the upper timberline was due to "winter drought." Summer drought may limit timberline tree growth locally in coarse rock slides, etc., but generally precipitation in and above timberline is adequate to sustain tree growth. Haugen (73) has found precipitation to be of only minor importance in timberline formation in Alaska.
Plate 4. Ancient bristlecone pines exhibit longevity in spite of, and because of, adversity under especially dry conditions below 10,000 feet in the White Mountains of California (more-detailed explanation follows).

Growth Medium

Many naturalists have observed large trees in the high-country growing from small cracks in massive granite (e.g., in the Sierra Nevada). Widespread examples show that tree growth is not prevented by the absence of soil per se. In the Southwest, Pearson (118) found that soil rarely acts as a limiting factor, except in conjunction with climate.

The chemical composition of the substrate material does, however, seem to have a definite effect upon the upper limit of tree growth in the White Mountains of California. Wright et al. (183) found that the forest proper--made up of bristlecone pine--extends higher and lower on dolomite than on sandstone or granite. Sagebrush
(Artemesia tridentata) was found to reach about 12,200 feet on sandstone and granite, but only 11,200 feet on dolomite.

**Atmospheric Rarity**

Alpine ecologists have long recognized that atmospheric rarity tends to increase evaporation (32). Shaw (138) mentioned that evaporation is more rapid at high altitudes, but that lower temperatures frequently offset the former effect.

Daubenmire (12) dismissed the importance of carbon dioxide deficiency as a limiting factor, except possibly at the highest timberlines, because it does not account for the changes in timberline with latitude and longitude.

**Light Intensity**

Excessive light—if there is such a thing—at high timberlines does not explain timberline relations (138 & 12). Temperature, rather than the photoperiod, or length of daylight, is decisive in determining the period of growth activity of timberline trees.

**Animals**

Shaw (139) mentioned the well-known observation that the highest tree growth in the Alps and Pyrenees has been significantly modified by the grazing of domestic animals. However, the forest line here has probably not been lowered significantly. Its altitude is about the same as that of forest line in the North Cascades and Olympics, developing under climatic conditions whose total expression appears to
be similar to that of the Alps (discussed further).

Local damage to krummholz and timberline trees can be traced to wapiti ("elk"), mountain goats, and other animals occasionally. Clark's nutcrackers and various rodents are no doubt important in transporting heavy pine seeds (e.g., whitebark pine, *P. albicaulis*) to higher-altitude or distant sites. Animals are very important in the regeneration and distribution of junipers (*Juniperus* spp.).

**The Mountain Mass**

Daubenmire (1962) said that exposure, proximity, and the height of nearby mountains are important in causing timberline formation. Timberlines are apt to be elevated on large mountainous plateaus because much of the body of any approaching air mass must rise to pass over the uplands. Following this concept, a small isolated range with great relief should be cooler at comparable altitudes when the same type of air mass envelopes it. Bailey (1910) believed that the altitude of timberline is linked to the elevation of regional base level (local lowlands), in a direct relationship. This effect correlates with Daubenmire's observation.

**Tree Species**

Spurr (1940) has stated:

Many ecologists ignoring the biotic aspects of the plants forming the timberline and their history, have attempted to define timberlines purely in terms of the site, and have tried to evolve rules defining the height of the timberline for a given latitude, aspect, and other physical aspects of the timberline position.
timberline is a result of the interaction of the trees and the site over a long period of time.

He explained, for example that on the South Island of New Zealand only Nothofagus spp. from the temperate tree flora form timberline, which is much lower than it would be if North American conifers were present. Lodgepole pine (P. contorta) through planting and seed reproduction from planted trees may form a new timberline over 1000 feet above the native trees according to Spurr.

The altitude of forest line, tree limit, and scrub line is certainly influenced by the particular species that happen to occupy the subalpine forest. Anyone who has observed several different upper timberlines will note that the different species of trees attain distinct altitudinal limits, and they adapt to the environment by exhibiting particular growth forms. Furthermore, many of the high mountains of western North America are sufficiently isolated from each other that their timberline tree communities reflect accidents of distribution.

An endless list of characteristics of the trees themselves might be considered important in timberline formation. Bates (13), for example, has found that bristlecone and limber pines are poor competitors under good forest-growth conditions. These pines have a "weedy" or multi-stemmed form and exhibit slow growth because they have very small stomata, which restrict their carbon dioxide intake. However, bristlecone and limber pines are the only tree species found on many dry, windy upper timberlines. They alone can survive because their small stomata reduce evapo-transpiration.
Other Factors

Snow avalanches and slides do not determine the upper altitudes of forest growth throughout the entirety of any mountain range, and in some mountainous areas (e.g., desert ranges) they are of small consequence. However, in some very precipitous mountains that receive heavy snowfall (e.g., Glacier Park, Montana) much of the high-country forest reflects the continual role of these powerful forces in preventing subalpine forest growth from achieving any semblance of "normal" development.

Solifluction or imperceptible downslope movements of the surface mantle due to continual freezing and thawing cause great root injury at arctic timberlines according to Spurr (140). He stated that low vegetation (i.e., tundra plants) is better adapted to survival under such conditions. Similar earth movement is also important at some alpine timberlines.

Lightning fire is a natural part of the timberline ecology (see Plate 5). Electrical storms are common in the high mountains of the West, particularly in mid-summer when the timberline is most combustible. Lightning strikes often high in the timberline, where isolated trees are the susceptible targets. Sometimes the fire spreads through vast tracts of mountain forest, but large areas of timberline are frequently skipped even during the largest conflagrations. The terrain this high up is usually so rocky and the growth so widely scattered that, though fire is frequent, it does not limit timberline growth as a whole. Very often in timberline pine stands
Plate 5. Lightning has struck this krummholz whitebark pine (6000' in Olympic Mtns.) causing the center of the tree to burn. Yet, the fire did not spread to either extremity of the whitebark, and it survives at both ends. Note also the brown foliage on the whitebark and on the common juniper (J. communis) mat in front of it; this is likely due to "winter drought."

lightning will turn one tree into an arborescent torch, yet the fire does not spread to other pitchy trunks because a large area of rocky slope surrounds each tree.

The Complex Interplay

Though the general categories of influences causing timberline formation were segregated to facilitate their discussion here, there should be no implication that temperature, wind, snow, biological factors, etc. act independently. Careful scrutiny of any particular timberline will reveal a vast and peculiar labyrinth of factors involved in its formation.
The following account of an odd timberline stand illustrates some of this complex interplay, though almost any case chosen would reveal an intricate set of relationships. This example occurs at 7800 feet elevation on the Idaho-Montana divide near the southern end of the Bitterroot Range.

The wind blows strongly from the west and deposits a large cornice on the east side of the ridge. Though this spot is a few hundred feet below forest line for this region, the wind creates such exposed winter conditions and summer drought on the rounded west slopes of the ridge that not even krummholz exists there. Snow is dumped on the sheltered, east side of the divide, forming a large cornice, or snowdrift, above a cirque basin that once held a glacier, nourished by snow from the same winds when the earth's climate was cooler.

Along the crest of the divide grows an almost perfect hedge-row of stunted trees, about 10 feet wide, but extending several hundred yards. This extremely well-defined band is composed of whitebark pine and subalpine fir less than 30 feet tall at maturity. The narrow strip site is suitable for tree growth, apparently because it lies next to the snowdrift to the east, which provides water. Moreover, it is out of the full force of the wind near ground level, because the westward slope is convex. This arborescent hedge aids its own survival by providing some of its own shelter (see Plate 6).

No tree species grow next to the "hedge" on the sheltered east side because the cornice lingers as a snowdrift into summer and causes a great deal of mechanical damage to everything in its path. Down the
steep slope beneath the cornice there is a gradual increase in size of the trees, which are mostly fir saplings. This probably reflects decreasing influence of the spring snow slides, originating at the cornice. Only slender, small saplings can exist near the snowdrift because they are buried in snow, and can bend down without breaking under the force of slides. Several dozen yards farther down the eastern slope a fir forest of normal dimensions exists.

The preceding situation would probably be interpreted somewhat differently by any other observer. Some study of almost any type of timberline tree growth will lead to an interesting interpretation of the multiple relationships.

Daubenmire (42) noted that despite the great variety of timberline components, the fact that a rather steady relationship
between timberline and altitude does exist indicates "a crucial autecologic principle." This principle is the correlation between summer warmth and the elevation of timberline, according to Wardle (179); however further study is necessary to clarify the nature of timberline relations. It is important to note that the relationship and principle cited by Daubenmire and Wardle applies to the northern hemisphere timberlines, whose evolution of conifers has occurred under temperate climes. It does not follow for unconnected timberlines which have evolved in the tropics (discussed further).
IV. TREES ADAPT TO THE ENVIRONMENT

Growth

Jensen (see 42) has pointed out that trees are the life form with the greatest unproductive, but matter-consuming mass (considering trunk, branches, and roots). Tree species have their upper limit along the scale of diminishing heat for growth, and the critical point occurs where yearly production of dry matter is equalled by the matter (carbon compounds) needed for respiration and formation of new leaves. At this point no dry matter is left over for wood accumulation. As Daubenmire (42) noted, this crucial spot on the scale of life is barely met by krummholz trees which are often foot-tall "seedlings" over 50 years old.

Hayward (75) remarked that in the Uinta Mountains alpine, all higher organisms but the pika either migrate or are dormant in winter. The tree species growing high in the timberline are less responsive to the coming of spring than animals. On a rough average buds on conifers near tree limit do not burst until July (though the metabolism increases earlier), and the succulent new growth must be "hardened off" in preparation to endure sudden, hard freezes within as little as two months.

But even this two months is far from ideal for growth. Bliss (18) has noted that drought is a normal condition during the summer
in the alpine zone of the Sierra Nevada and Colorado Rockies. This observation applies to upper timberlines throughout much of western North America. The short growing season is also marked by extremes in daily temperature.

Mills (105) wrote that the size of a timberline tree is no index to its age because of the hardships of growing in such an environment. Ring counts of high-altitude conifers yield the minimum probable age only. Hoasis (1933, see 63) found that tree trunks may shrink in many years of unfavorable conditions, such as when the snowpack does not release certain trees until the end of summer, or occasionally not at all during a season.

There is immense variability in the growth characteristics of the various species that inhabit timberline. Subalpine fir, Engelmann spruce, and others are noted for their development of skirts, flags, and timber atolls. Foxtail pine (P. balfouriana) and subalpine larch (Larix lyallii) develop a single trunk 40 feet tall while whitebark pine forms krummholz beneath them (see Plates 7-9). Bristlecone pine often maintains its "weedy," erect, and spreading form at the highest, most exposed sites, developing krummholz at some timberlines but not at others (107).

Recent studies by Clausen (28) have shed light upon the growth forms of the highest growing trees. He cited past work by himself and others in saying, "It is now generally admitted that growth forms are inherited among trees as well as among herbs." Elfin forms of woody plants have been naturally selected at wind-swept coasts as well as at the upper timberlines (27). At the latter site snow may protect
Plate 7. Arborescent subalpine larch share the bottom of a cool cirque with krummholz whitebark pine near 8500' in the Bitterroot Mtns., Montana.

Plate 8. Krummholz whitebark pine, complete with a mat and flags, occurs at 10,600 feet near Granite Pass in Kings Canyon National Park. Scattered whitebark can be seen all the way to the top of 11,220' "Mount Indiana" behind.
Plate 2. An erect foxtail pine with a prostrate limber pine at its base grows at the krummholz limit (11,000') along the Mount Whitney trail, Inyo National Forest. An alpine willow appears in the stark granite background.
low growing shrubs, and this form inhabits the warmest part of the atmosphere—the layer near the ground (42).

Clausen (27) said that the subalpine tree is often replaced at its tree limit by its "alpine elfinwood," which may represent a distinct race or ecotype of the tree species. It is not clear that Clausen proved these timberline "races" are in fact genetic by transplanting them into more moderate sites. He did mention that transplanting of some coastal "races" has confirmed that they are genotypes. Unless timberline "races" are similarly tested "growth form" or "phenotype" are probably the correct descriptives, not "race" or "genotype." Clausen stressed the importance of natural selection against growth forms not well adapted to sites at timberline; certainly the harsh environment at timberline must be influential in aiding natural selection.

In a study of the timberline near Mount Conness in the Sierra Nevada, Clausen (28) found that the three species of conifers present—whitebark and lodgepole pines, and mountain hemlock—differ in the altitude of their respective tree limits and in the extent of elfinwood evolution. Also, the species had different "slope preferences."

Clausen described the growth form of the four major "races" of whitebark pine he observed progressively higher up the mountainside: (1.) Tree with one trunk; (2.) multi-stemmed tree, not so tall as the former; (3.) intermediate between (2.) and (4.), spreading shrub with elfinwood skirt; and (4.) elfinwood—low krummholz, or mat, under three feet high. Whitebark pine is probably the most adaptable and highest dwelling of conifers in the Pacific Coast and Northern Rocky
Mountain States. Species that do not adopt a wide range of growth forms cannot inhabit such a wide range of environments.

Elfinwood is commonly forced to grow mainly in one direction, leeward. Griggs (63) found some six-inch-high seedlings at the "cripple line" in Grand Teton National Park. They showed about 30 rings of growth, but the small stems were so asymmetrical that growth had been as much as four times faster on the lee side. May Watts (180) has portrayed the development of one-sided "timber" at tree limit in Colorado via a series of sketches.

Bristlecone and foxtail pine trees survive for centuries by the existence of a narrow strip of bark extending up the sheltered side of their otherwise dead trunk (see Plate 10). These individuals illustrate asymmetry caused by the wind, as do the trailing mats of krummholz extending parallel to the wind up a mountainside. In some cases the exposed end of such a trailer is losing ground to the wind, while the sheltered end grows and takes root, with the result being movement of the trailer similar to that of an island in a river. The former moves downwind, the latter downstream. On a larger scale Wardle (179) pointed out that the relative abruptness of most timberlines is partially a result of the importance of mutual sheltering for tree growth.

Scott-Williams (137) noted that Engelmann spruce and subalpine fir are the most tolerant timberline trees in Colorado. They are the climax species on normal sites and they also are the pioneers coming in very slowly in two burned areas along the Trail Ridge Road, Rocky Mountain National Park. Daubenmire (11) found no significant seral
Plate 10. Two separate strips of bark extend up the sheltered side of this small foxtail pine, each nourishing one limb. Large foxtail snags sometimes have a broken band of bark still clinging to their lee side. This photograph was taken at 10,800' above Sphinx Lakes, Kings Canyon National Park.

relationships in timberline burns in northern Idaho. Reinvasion in destroyed stands at timberline seems to be very slow, almost universally, because of the marginal nature of the site for tree growth.

It is not surprising that seral relationships are not important (viz., first, establishment of pioneer conifers, then a gradual phasing out of these as the climax species take over). Survival at
timberline is so critical that only the best adapted species can exist, and they barely survive, as witnessed by their slow reinvasion and slow growth. In the forest proper, below timberline, competition is the main factor determining which species will be dominant; but at the upper limit of tree growth, "growing room" is usually ample, though the environment is severe. (see Plate 11)

Plate 11. Spiral grain in trees, a growth phenomenon commonly observed at timberline, is shown in foxtail pine at 10,050-foot Avalanche Pass, Kings Canyon National Park. These trees are unusual in that their grain twists in opposite directions though they grow side by side. Many interesting theories and "tales" have evolved to explain this phenomenon. A.F. Noskowiak has reviewed the scientific findings (1963. Spiral grain in trees: A review. Forest Prod. Jour. 13(7):266-275. Also available from Forestry Dept., Wash. State Univ., Pullman).
Reproduction

Griggs (64) observed that in the Rocky Mountains the highest trees usually produce little viable seed; seed blows in from the forest below. However, at least some of the pines at tree limit (i.e., whitebark and foxtail) frequently produce good cone crops that appear to have sound seed since squirrels and birds live off them. The writer has found the relatively heavy seeds of foxtail pine in alpine snowfields 1000 feet in altitude above the highest possible seed source. These observations may tend to contradict Clausen's statements about alpine "races"; however, both influences are probably important at timberlines.

Wardle (179) has stated, "... there is little doubt that the factors determining timberline act not on the tree but on the small seedling, and evidence from *Nothofagus* indicates that the first few months from germination are the critical ones." He had defined the upper limit for establishment of tree seedlings as the highest point where new growth can be produced and is able to "harden off" in time for winter cold.

Tiny degenerate seedlings of subalpine larch, Engelmann spruce, and others can exist above the regular krummholz limit, though they apparently cannot grow past the seedling stage. Thus timberline is not necessarily limited to the highest point where a seedling can become established, but rather to the point where such a seedling can do more than just exist.

Berner (184) has used reproduction as the basis for determining
the position of the "forest limit." He felt this biological boundary occurs at the highest point where, "... the stand, though expansive, barely maintains its present condition through its own reproduction, the surplus of which emigrates." The general position of this "forest limit" is not known, though probably occurs near or somewhat above our morphological measure, forest line.

Berner observed that above the biological "forest limit" lies the "forest extinction belt" extending to the limit of growth for tree species. The tree growth in this zone cannot maintain itself, but relies upon viable seed blown in from the forest zone immediately below. Berner has found that the so-called recession of the limit of forest growth in Switzerland, attributed to overgrazing, is merely destruction of the "forest extinction belt" instead. The "forest limit" has certainly not changed according to Berner; however, the extinction belt, which is by nature in a tenuous ecological balance, has been unable to repair and reproduce itself in the face of this disturbance.

Vegetative reproduction is often prominent at the timberline, as it is in other adverse environments. Cooper (33) noted that prostrate branches of trees, especially at high altitudes and high latitudes, are apt to take root and form a ring of daughter trees around the parent. Often, careful investigation of apparent fir, spruce, or hemlock seedlings shows them to be connected to the root system of a nearby grove, and to have been layered. Mayr and Heinrich (see 33) observed layering in Abies, Picea, Pinus, Larix, Pseudotsuga, Chamaecyparis, and other genera. Griggs (64) wrote that the high degree of success of layering in spruce and fir makes possible almost
infinite life for an individual tree. It may be that some layered trees are technically much older than the present record bristlecone pines (4000+ years).

**Dynamism of Timberline**

The timberline is a dynamic ecotone or boundary zone between the forest and the alpine. Changes in its position are often noted locally due to fire, insect blight, or some fluctuation in climate. The former cases would normally bring about recession of the timberline, possibly with a gradual reinvasion of subalpine meadows that might have taken over the site after the trees were killed. Griggs (63) described a meadow at Mount Rainier that was being invaded by trees, while the charred remains of logs were decaying in it. Similar cases are prevalent in most timberline areas of the western United States. Franklin et al. (55) found that a succession of light snowfall, or early melt years at Mount Rainier triggered a pronounced invasion of the luxuriant subalpine meadows by subalpine fir. Since the end of this moderate climatic period, however, no further invasion has been found.

Regional changes in the position of the timberline are usually less noticeable, because in human perception the world climate is changing slowly. However, regional movement of timberline has been detected in a few areas of North America. Griggs (61) has found a striking advancement of the forest line in some areas of Alaska, particularly onto the tundra at Kodiak Island. Changes in regional climate have more effect over the broad belt that forms the latitudinal
timberline, than on the narrow band comprising altitudinal timberline. It is as if the former were the vernier and the latter a regular scale.

On the other hand, Haugen (73) has pointed out that when significant climatic changes do occur, the alpine timberline can make a quicker response to the new conditions. In the case of a climatic warming trend, for instance, the alpine timberline growth can advance swiftly to the new, higher position of the July 50-degree F. isotherm. It would take the diffuse polar timberline vastly longer to carry out a similar adjustment to new conditions because the latter would have to migrate a distance over a hundred times as great. The result is that alpine timberlines are more "sensitive" to a marked climatic change.

Griggs (63) concluded that, "... in the Rocky Mountains, timberline and therefore climate is static, or more precisely, that any change which climate may be undergoing is at a rate of a different magnitude than at Kodiak, too slow to be detected by the methods employed." Griggs explained most examples of forest advance in the southern Canadian Rockies, for instance, in terms of reinvasion of the forest following fire, etc. (110).

Habeck et al. (66) have described an invasion of the meadows at Logan Pass, Glacier National Park by krummholz groves largely of subalpine fir. This phenomenon has been taking place over the past 100 years, but it too may be related to reinvasion after fire (66). The meadows surrounding these krummholz colonies represent fingers of alpine reaching down into the timberline. However, once invaded by stunted trees, the alpine meadow species die out from lack of light.
and an understory typical of the lower subalpine forest (Thalictrum occidentale and Vaccinium membranaceum) develops. Similar invasion observed at Garibaldi Park, British Columbia is discussed later (20).

Haugen (72) has noted that alpine timberlines in interior Alaska have held a rather stable position for the past five centuries. He found trees over 1,000 years old as well as large stumps at the current tree limit. However, he also discovered scattered, but well-formed young trees almost 200 feet above the stationary tree limit. These suggest a slight warming trend in the past century.

The documented recession of mountain glaciers in the northern hemisphere might lead one to think that timberline should be more or less universally advancing. Nevertheless, this does not appear to be the case. In fact there is even some evidence that timberline is now receding in some regions.

Griggs (64) observed old snags of what had been relatively fast-growing and less dwarfed trees above present timberline on Mount Washington, New Hampshire. Also, he mentioned that presently living krummholz in the area is in unusually poor condition, and there is a scarcity of 10-25-year-old trees in the timberline. All of these factors suggest recession of timberline.

LaMarche (90) and Mooney (107) have been examining a "fossil timberline" made up of snags and stumps of bristlecone pine at altitudes much higher than modern timberline in the White Mountains (Calif.), Snake Range, and elsewhere where bristlecone marks upper timberline in the Great Basin. LaMarche said, "It is clear evidence that the upper limit of tree growth has declined within the past few
thousand years, . . ." and perhaps this is only apparent in bristlecone

timberlines, "... because of the remarkable persistence of the wood
of dead trees of this species." There are very small segments of a
possible "fossil timberline" of foxtail pine in two locations of the
Sierra Nevada, nearly opposite the White Mountains.

Even if climatic factors were completely static, there could
be very slow movement of the timberline due to geologic changes
(viz., erosion, weathering, and soil formation; regional uplift or
sinking, etc.). But Mills (104) suggested another possible source of
long-term dynamism also:

With this environment [timberline] it would be natural for
these trees to evolve more hardiness than the present trees
have. This would mean trees better fitted to contend with,
and more likely to triumph over, the harsh conditions.
Evolutionary development is the triumphing factor at the
timber-line.

Dendrochronology, the study of past climate through the "records"
held in tree rings, correlates the dynamism in growth of timberline
trees and others in order to learn of the past. This type of research
has become quite sophisticated over the past few decades; such
perfection has been crucial since insect ravages, fire, or other
factors can decrease growth and superficially leave the appearance
in the tree rings that climate was the agent responsible (2).

Much of today's dendrochronology research is being undertaken
in the Great Basin bristlecone pine stands. Trexler (155) reported
that increment cores from living trees correlated with those taken
from an excellent fossil tree line on Mount Washington in the Snake
Range, Nevada, has "... extended the tree ring record for this
area back nearly 8,000 years." The White Mountains bristlecone pine
chronology has been extended back 7000 years (88).

The bristlecone chronologies are currently programmed for computer analysis (88). These dendroclimatic records translated in a varying ring-width pattern on the woody stems have been successfully cross-checked within and among the tree species. Even an analysis of 200+-year-old sagebrush stems correlates with the climatic records in the tree rings (51). Ring width for these arid-site species reflects directly the amount of winter precipitation. Such long-term records of the Southwest climate may have important implications for land management in predicting water yields, etc. according to Cermak (26). Development and use of such tools for exploring the past climate is just commencing, and great gains in knowledge can be expected in the coming years.

Dendrochronology is not, however, restricted to the arid Southwest. Giddings (57) reported that cross-datings of Alaskan tree growth rings extend back 500 years. Unlike the Southwest chronologies, the Alaskan ring records directly parallel fluctuations in temperature during the early part of the growing season. In both Alaska and the Southwest trees growing under stress (e.g., tree limit conditions) produce the best and longest records since they are more "sensitive." (see Plate 12)
Plate 12. The erect, dead Engelmann spruce here is at about 10,200 feet, a few hundred feet higher than present tree limit, in the Lost River Range of Idaho. Krummholz and small trees are barely visible below (extreme right).
V. TIMBERLINES OF WESTERN NORTH AMERICA

Introduction

Following the "Brief Orientation" and "Outline of Areas" sections, the body of this chapter describes timberlines throughout western North America. The outlining and description of the numerous timberlines is designed for purposes of this paper only. For instance, Colorado timberlines are considered a more or less homogeneous unit of the Rocky Mountain system; whereas small individual ranges in other areas are discussed separately because their timberlines are peculiar in composition and in other aspects. The extent of coverage for any given timberline area also reflects the amount of information available, and the immediate importance of the area to modern society. In the latter regard, the discussion of timberlines in the 11 Western States is much more intensive than that of the less accessible (and probably more homogenous) Far North.

The segments of this chapter dealing with given timberline areas are generally organized to first orient the reader to the geography of the area. The "Key Map" and Figure 7 should be an aid in this respect also. Secondly, timberlines of the area are described, and finally, visitor access to and use of the timberline country is often mentioned. However, because of the nature of this paper, there is no rigid adherence to a given format for discussion.
The content is developed in extent and form only in order to best meet the objectives of this report.

The outline of this chapter is generally oriented toward mountain geographical regions, rather than political areas (e.g., states). However, there is some utilization of political boundaries since many of these are convenient, well-known to both scientist and layman, and adaptable for use in ecological discussion. The states are sometimes used, also, as units for description of visitor access to timberlines, because the public is "state-oriented" and an interpreter will normally make use of both ecological and political regions in his presentation.

**Brief Orientation**

Upper timberline conditions in western North America are found on scattered high peaks in Mexico, on mountain ranges in each of the 11 Western States, throughout much of British Columbia and neighboring Alberta, and northward in Alaska and the Yukon to polar timberline. In Mexico this zone develops around 13,000 feet. In the western United States it occurs between altitudes of about 4,500 and 12,000 feet, at progressively lower altitudes to the north and west (see Figure 2). Canadian timberlines are found higher than 7,000 feet in their extreme southern Rockies, but steadily lower in altitude north and west toward the North Pacific and the Arctic Ocean.

As might be expected, the amount of timberline and alpine environment increases more or less steadily from Mexico to the Far North. However, the temperate zone timberlines of the western United
Figure 2. Average altitude of tree limit (climatic) on favorable exposures in the western United States.
States and extreme southern Canada are the most distinct and diverse. They are the most accessible and are generally the most attractive timberline environments for recreation.

For purposes of this paper western North America has been divided into four timberline regions: (1.) The Rocky Mountain system, from Mexico north to central British Columbia; (2.) Pacific Coast Mountains, from California to central British Columbia; (3.) Great Basin and intermountain ranges of the western United States; and (4.) the Far North—Alaska and western Canada north of about 55 degrees N. latitude (the "Key Map" and Figure 7 should be used for orientation).

Outline of Areas

The mountain ranges and isolated peaks listed here form a general index, by no means exhaustive, to the major areas in the western United States that support at least the lower part of a climatic timberline zone. The location of each area mentioned is plotted approximately by its number on the accompanying "Key Map."

The elevations listed are those of the highest point in the range, unless stated otherwise. The letter-code designations (defined below) are based upon the limited information available. These letters appear immediately following the listed elevations.

k = Scattered krummholz is found at or so near the summit that it seems unlikely a true alpine zone exists, though at least most of the timberline zone seems to be represented.

a = A true alpine environment exists, above the timberline.

g = A true alpine exists and active glaciers are an important feature of the area.
I. Rocky Mountain System

A. Southwestern Peaks
   1. Sierra Blanca (12,003')
   2. White Mountains (11,590')
   3. San Francisco Mountain (12,670')

B. New Mexican Rockies
   4. Sangre De Cristo Range (13,160')

C. Colorado and Vicinity (high peaks 12,000 to 14,431')
   5. Sangre De Cristo Range
   6. Wet Mountains
   7. San Juan Mountains
   8. Sawatch Range
   9. Front Range
  10. Park Range
   11. Medicine Bow Range

C. Wind River Range
   11. (13,785')

D. Northwestern Wyoming and Vicinity (high peaks 10,500 to 13,766')
   12. Wyoming Range
   13. Gros Ventre Range
   14. Teton Range
   15. Absaroka Mountains
   16. Beartooth Mountains

E. Bighorn Range
   17. (13,175')

F. Southwestern Montana Vicinity (high peaks 9,500 to 11,293')
   18. Crazy Mountains
   19. Bridger Mountains
   20. Gallatin Range
   21. Madison Range
   22. Tobacco Root Mountains
   23. Pioneer Mountains
   24. Beaverhead Mountains
   25. Anaconda Range

G. Northern U.S. Rockies (high peaks 8,000 to 11,498')
   26. Bitterroot Range
   27. Cabinet Mountains
   28. Mission Range
   29. Swan Range
   30. Lewis Range—main divide Rockies

II. Pacific Coast Mountains

A. Southern California Peaks
   31. San Jacinto (10,831')
   32. San Gorgonio (11,502')

B. Sierra Nevada
   33. (high peaks 11,500 to 14,496')
C. Northern California Peaks
31. Lassen Peak (10,457')
35. Mount Shasta (14,162')
36. Coastal Mountains (9025')
D. Southern Cascades (Oregon)
37. high volcanoes (10,053 to 11,245')
38. Cascade Range proper (highest peaks 7000 to 9495')
E. Northern Cascades (Washington)
39. high volcanoes (9677 to 14,110')
40. Cascade Range proper (highest peaks 7500 to 9511')
41. Wenatchee Mountains (9415')
42. Okanogan Range (6860')
F. Olympic Mountains
43. (7965')

III. Great Basin and Intermountain Ranges

A. Eastern Great Basin and Vicinity
44., 45., & 46. Markagunt, Aquarius, & Wasatch Plateaus (11,500')
47. Tushar Mountains (12,173')
48. LaSal Mountains (13,089')
49. Uinta Mountains (13,498')
50. Henry Mountains (11,615')
51. Abajo Mountains (11,357')
B. Western Great Basin and Vicinity
52. Charleston Peak (11,919')
53. Panamint Range (11,045')
54. Inyo Mountains (11,125')
55. White Mountains (14,242')
56. Toiyabe Range (11,775')
57. Toquima Range (11,807')
58. White Pine Range (11,513')
59. Schell Creek Range (11,890')
60. Deep Creek Range (12,103')
61. Snake Range (13,063')
C. Northern Great Basin Vicinity
62. Ruby Range (11,389')
63. Jarbridge Range (10,839')
64. Warner Range (9892')
65. Steens Mountain (9720')
D. Northern Intermountain Ranges
66. Strawberry Mountain (9052')
67. Blue Mountains (9105')
68. Wallowa Mountains (10,033')
69. Seven Devils Mountains (9393')
70. Sawtooth Mountains, Idaho Batholith (11,900')
71. Lost River Range (12,655')
72. Lemhi Range (12,197')
Regional Descriptions

ROCKY MOUNTAIN SYSTEM (north to 55 degrees N.)

Mexican Volcanoes

Seven major peaks (mostly volcanoes) in Mexico rise above 14,000 feet (112). The tallest of these is Citlaltepec (18,700'); but there is a dearth of literature describing vegetation on these mountains. Beaman (15) has observed the timberlines on Iztaccihuatl (17,343') and Popocatepetl (17,887'), the two giant volcanoes near Mexico City. The forest line here as elsewhere in Mexico occurs at about 13,100 feet elevation, with the highest krummholz at 13,750 feet. This marks the upper limit of the "Mexican mountain pine (38)," Pinus hartwegii, and the beginning of alpine meadows, barren rock and permanent snowfields.

The pine is rarely deformed at timberline, though it is of reduced stature. A dwarf juniper, Juniperus monticola, forms dense stands of krummholz here. The juniper is the only other conifer, and its normal growth form may not be tree-like. Beaman found that the oldest of eight comparatively large pine trees he bored near timberline was only 66 years. He felt that this indicated the normal life-span of these trees is very short; however, further study might have revealed recent invasion of the site by these trees.

The climate of the Mexican timberlines is quite different from that of timberlines to the north. These volcanoes are located at about 19 degrees N. latitude, within the tropical belt, roughly 1,000 miles...
south of the southernmost United States timberlines. Summer and winter are not very distinct on the Mexican volcanoes; little snow accumulates and moderate temperatures characterize the environment in marked contrast to all timberlines in the western United States and Canada. Nine small glaciers are reported to exist atop Iztaccihuatl.

Beaman (15) reported that the weather station at 11,600 feet on the west side of Iztaccihuatl recorded annual precipitation of 45 inches, and minimum and maximum temperatures for the year were very moderate—28 degrees F. and 70 degrees F. It is interesting to note that the lower timberline here, composed of P. hartwegii, is formed above 10,000 feet.

Beaman felt that low temperature may determine the upper limit of trees in this region. Snow, wind, precipitation, and many other influences appear unimportant because of the relatively uniform annual climatic cycle. If mean annual temperature were the same as it is, but with pronounced winter and summer differences (like those in the United States timberlines) timberline in Mexico would no doubt be much higher, perhaps around 15,000 feet. Under these hypothetical conditions, the trees would have a warm summer growing period, higher up the mountainside, and they could remain dormant through the more severe winters with little difficulty.

Southwestern Peaks

SIERRA BLANCA. Few mountain peaks between the Mexico City area and Santa Fe, New Mexico, approach the elevation necessary for formation of an upper timberline. An interesting exception is Sierra Blanca (12,003') on the Sacramento Range of south-central New Mexico. At
33 degrees N. latitude Sierra Blanca probably exhibits the southernmost upper timberline in the United States proper.

Sierra Blanca is located just inside the Mescalero Apache Indian Reservation, and little is known of its ecology. The Sierra Blanca Ski Area in the Lincoln National Forest north of the mountain has its upper terminal in an Engelmann spruce forest at 10,400 feet (127). The tip of Sierra Blanca peak, around 1-1½ acres, might possibly be considered tundra as it is devoid of trees; however arborescent Engelmann spruce extend to within about 100 feet of the summit on the north side (117). The dry, south slope of the mountain is treeless down to approximately 10,000 feet, where ponderosa pine (P. ponderosa), Douglas-fir (Pseudotsuga menziesii), and aspen (Populus tremuloides) are present. Corkbark fir (A. lasiocarpa var. arizonica), white fir (A. concolor), and limber pine (P. flexilis var. reflexa) are found with the spruce and aspen up to 10,500 feet on the north slope. Fire has disturbed the high-country vegetation in parts of the Sierra Blanca area to such an extent that it is difficult to judge what is a climatic timberline (1142).

Baker's (11) survey of climates indicates that the "growing season" at 12,000 feet in south-central New Mexico could be about 150 days. His estimate for "growing season" in the central Colorado Rockies at that elevation is about half as long. This data suggests that if Sierra Blanca were 14,000 feet, it might have a climatic timberline belt extending to 13,000 feet.

WHITE MOUNTAINS, ARIZONA. The White Mountains are another isolated southwest range about 230 miles west-northwest from Sierra Blanca,
in eastern Arizona. The White Mountains are Arizona's second highest range, with Mount Baldy 11,590 feet. Timberline on Baldy is not climatic, but the result of severe exposure at the summit (59 & 126). The timberline zone along the high ridge of Baldy is telescoped into a narrow band immediately below the crest, with "... quasi-alpine along the crest broken in a few places by strings of [Engelmann] spruce krummholz [126]." The subalpine forest is entirely of Engelmann spruce and corkbark fir. Southern slopes are often grassy balds, covered with Arizona fescue, mountain muhly, and others (59).

**SAN FRANCISCO MOUNTAIN.** San Francisco Mountain (12,670') in north-central Arizona exhibits the only alpine and climatic timberline environments in the state (95), and the southern-most alpine in the United States proper. The forest line occurs between 10,500 and 11,000 feet depending upon exposure, with the scrub line averaging about 11,500 feet. Engelmann spruce extends highest up the mountain, with corkbark fir its principal associate at forest line, and occasional groves of bristlecone pine. About two square miles of the mountain are said to be above the timberline (109). This alpine area supports 51 species of alpine tundra and vascular plants, most of them closely related to those of the Rocky Mountain system.

San Francisco Mountain is an extinct volcano characterized by broad, gentle slopes and having four distinct cones on top (185). The Arizona Snow Bowl chairlift runs the year-round, taking visitors to 11,600 feet (81). The Forest Service, Coconino National Forest, plans future interpretation of the mountain-top environment with interpretive signs beginning at the upper terminal of the chairlift, and extending.
to the summit. A 275-acre scenic area has been created in the timber-
line and alpine zones on San Francisco Mountain, in order to preserve
this environment, unique in Arizona, for "scientific study and public
enjoyment [166]." It has been named in honor of the late C. Hart
Merriam who studied this area in conjunction with creating his well-
known "Life Zone" classification.

New Mexican Rockies

North of Santa Fe, New Mexico, there is a fairly extensive
amount of timberline and even alpine habitat in the Sangre De Cristo
Range, particularly on the Pecos, Taos, Costilla, and Culebra
Mountains, according to Bailey (9). Forest line varies from 11,000
feet on northeast exposures to 12,000 feet on southwest aspects, with
krummholz limit about 1000 feet higher in both cases. Bailey said
the alpine zone in New Mexico is largely above 12,500 feet.

The highest summit in the Sangre De Cristos of New Mexico is
13,160-foot Wheeler Peak, which according to recent Forest Service
information (126), has an extensive alpine area above krummholz. The
upper forest is composed of Engelmann spruce, corkbark fir, and some
bristlecone pine (9 & 126). Bailey listed the following mammals
frequenting the timberline zone and birds which breed there or in the
alpine: Mountain sheep, marmot, pika, Colorado chipmunk, red fox,
weasel, shrew, pocket gopher, meadow mouse, Clark's nutcracker,
Rocky Mountain grosbeak, whitetailed ptarmigan, pipit, and rosy finch.

There is no automobile access to this timberline, and
recreational use is light except at Santa Fe Ski Basin where the ski
runs ascend to 12,200 feet. The New Mexican Rockies timberline is
apparently highest in the United States, and is no doubt quite interesting, though little ecological literature deals with this area.

**Colorado and Vicinity**

Colorado has an immense amount of timberline terrain bordering its approximately 5 million acres of alpine (104). Over fifty peaks rise to 14,000 feet, a few hundred surpass 13,000 feet (143), and the highest tree limit in the state is thought to be 12,300 feet. Some of the mountain ranges are the Sangre De Cristo, San Juan, Sawatch, Wet, Front, Park, Saguache, Never Summer, Snowy, Elk, and Medicine Bow Ranges along with many dozens of minor ranges rising above timberline.

Despite the vast amount of timberline found here, however, the composition and ecology of the whole is relatively uniform, especially compared to timberlines in other regions or states (e.g., California, Washington, Montana).

In describing the timberline habitat of Colorado, Cary (24) listed several altitudinal limits for the various ranges. The lowest forest line mentioned is 10,000 feet at Rollins Pass on the east slope of the Front Range. The literature indicates that forest line is most often found between about 10,500 and 11,000 feet in the northern part of the state, and almost 11,500 feet on the average in the south. The primary conifers are Engelmann spruce, subalpine fir, and limber and bristlecone pines.

Cary found that the krummholz limit often occurs about 1000 feet above forest line. Some of the highest dwelling conifers in the state are thought to be a stand of wind-battered, but upright
Scott-Williams (137) has been gathering data on tree growth at tree limit in Rocky Mountain National Park for several years. She reported that the "irreversible increase in size" principle for tree growth does not apply in this case as, "... trees continue to exist and grow under favorable conditions with severe setbacks in between."

Though snowfall in Colorado does not compare with that of the Pacific Coast Mountains, it is still great (averaging roughly 300 to 400 inches per year at the timberlines). Temperature, wind, and drought conditions are very severe, with the result that timberline is indeed a harsh habitat. This mountainous region is the source of many rivers that supply water to the southern Great Plains, and the timberline vegetation has great importance to watershed management. The "crooked wood" or krummholz spruce is instrumental in anchoring the snow on steep slopes. Thus it prevents excessive snowslides and avalanches.

Southern Colorado has a number of geological mass movements in the timberline zone, namely "rock glaciers" and "mud flows." The Bureau of Land Management has established the Lake Fork Recreation Area in the San Juan Mountains in an area where some of these phenomena occur (129). In fact, a major attraction of the area is two-mile-long Lake San Cristobal, which was impounded by the giant Slumgullion mud flow originating at timberline which is covered with a living forest of Engelmann spruce. Interpretation plans for the area involve explanation of the mass movements and alpine flora.

The timberline zone in Colorado is within the summer range of many animal species, and often provides shelter for birds and mammals.
the year-round. Mills (104) recounted observing a grizzly bear tear up a patch of krummholz one autumn day, while trying to dig out a marmot and some chipmunks. He noted a band of ptarmigan feeding on arctic willow buds at tree limit in winter. Cary (24) compiled a detailed list of the mammals and birds at and above timberline in Colorado, but he found that the pika, yellow-bellied marmot, and mountain sheep characterize the timberline.

Though the alpine timberlines of Colorado are among the highest in North America, they are the most accessible on this continent. Six year-round highway passes are between 11,000 and 12,000 feet high, two others above 12,000 feet are open in summer, and there are roads to the top of Pikes Peak (14,110') and Mount Evans (14,264'). Dozens of secondary roads climb to timberline or above and many main highway passes not tabulated here are between 10,000 and 11,000 feet in elevation (113).

The most outstanding access to the high-country is probably Trail Ridge Road which crosses the Continental Divide in Rocky Mountain National Park. This road is the highest (12,183') through highway (i.e., not a dead-end) in North America. More than 4 miles of it are above 12,000 feet elevation; 11 miles are above the scrub line, about 11,500 feet (113). The luxuriant alpine tundra is a major interpretive feature along Trail Ridge Road, but the krummholz and forest-line ecology is also interesting and exotic to the average park visitor.

MEDICINE BOW MOUNTAINS. The Medicine Bow Mountains of southeastern Wyoming support a subalpine forest of Engelmann spruce and subalpine
fir that is similar to its counterparts in northern Colorado. The forest line is apparently between 10,500 and 11,000 feet and the krummholz limit is said to be 11,600 feet (115). The highest peak in the range is only 12,013 feet, so there is little alpine habitat. Snowy Range Pass (10,800') on Wyoming 130 is an access to the timberline in Medicine Bow National Forest.

**Wind River Range**

The rugged Wind River Mountains form the backbone of the Continental Divide in west-central Wyoming. The summit of 13,785-foot Gannett Peak, highest in the state, is thought to be at the regional snowline (101). All of the largest glaciers in the American Rockies are located in the Wind River Range, several of these having areas of one square mile (48).

According to the Forest Service (144), forest line ranges from about 10,000 to 10,400 feet elevation, and timberline is dominated by whitebark pine. Engelmann spruce and subalpine fir are also present as well as a few scattered limber pine. At around 9000 feet whitebark pine is interspersed with the upper lodgepole pine stands. Here the whitebark is often suitable for lumbering, but above the lodgepole forest, whitebark develops its characteristic bulky and gnarled form.

The most frequently seen big game species at timberline in the Wind River Range are wapiti and bighorn sheep. In summer the wapiti stay close to timberline using the trees for cover and the meadows for food, while the bighorns range in the alpine zone (144).

1Several major mountain ranges rise high above the upper timberline in Wyoming. These include the Medicine Bow, Wind River, Wyoming, Gros Ventre, Teton, Absaroka, and Bighorn Mountains.
The Wind River high-country is only accessible for wilderness recreation; it includes superb mountain climbing terrain.

Northwestern Wyoming and Vicinity

TETON RANGE. The primary timberline trees of Grand Teton National Park are whitebark pine, subalpine fir, and Engelmann spruce, according to Dilley (45). Many of the whitebark reach large proportions and exhibit a picturesque, spreading form. The Teton Range is so steep and relatively dry that subalpine and alpine meadows are not prevalent though Bailey (8) stated that about one-third of the national park is above timberline.

There is no high-country road in Grand Teton Park, so public interpretation of the natural environment is centered upon the Jackson Lake area, which is near lower timberline. A major proportion of the roughly 2 million visitors coming to Grand Teton Park each season ride over 9658-foot Togwotee Pass, however. This pass is on national forest land at the Continental Divide just east of the national park. It is about 800 feet below the forest line (144).

YELLOWSTONE PARK AREA. Timberline is not a striking feature in Yellowstone National Park, primarily because few of the mountains seen along the park roads rise beyond tree limit (above 10,000'). Dunraven Pass (8859') is one point where the Yellowstone Loop Highway does go through a broken forest with subalpine meadows near forest line. Nearby Mount Washburn (10,243') is reached by a spur road leading to the Park Service lookout, and this peak is a popular trail climb. The summit is rocky and forested only with krummholz though tree limit is
only about 100 feet down slope. Whitebark pine, Engelmann spruce, and subalpine fir ascend to tree limit (74), though the extremely rocky terrain seems to disperse timberline growth.

THE BEARTOOTH AND OTHER LOCATIONS. The upper forest belt of the Wyoming, Gros Ventre, and Absaroka Ranges is probably similar to that of the Tetons; however Küchler (86) indicated very little alpine terrain is found in the former two. The Absaroka and neighboring Beartooth Mountains range upward to beyond 13,000 feet, and they extend northward into southern Montana, with considerable alpine terrain, including some small glaciers found in both states (48). U.S. Highway 212 leaving the northeast entrance to Yellowstone Park traverses the crest of the Beartooth Range along the Wyoming-Montana line.

The Beartooth Highway in the Shoshone (Wyoming) and Custer (Montana) National Forests compares with Trail Ridge Road in several respects. These two through highways alone in the 48 States ascend more than 500 feet above the scrub line. The Beartooth Highway travels through alpine habitat for 10 miles. The highest point is 10,940 feet (in Wyoming) and the highway makes an impressive entrance into Montana at 10,300 feet elevation. Timberline on the south side of the Beartooth Summit is composed of whitebark pine, Engelmann spruce, and subalpine fir, with forest line occurring about 9500 feet, tree limit just above 10,000 feet, and scrub line about 200 feet higher.

On the north side of the summit in Montana the highway descends to scrub line near 10,000 feet and forest line is around 9000 feet on
the steep slopes of picturesque Rock Creek Canyon. The Forest Service has completed a new visitor center just above 9000 feet in the canyon in view of some large and striking colonies of subalpine fir that have formed huge circular mats with wind-battered flags growing on the rocky slopes. Whitebark pine trees are prominent also. The Beartooth Highway passes through spectacular country that provides a splendid opportunity for improved public interpretation.

Bighorn Mountains

Wyoming's Bighorn Range is an isolated outcrop in the north-central part of the state, almost surrounded by the expansive western Great Plains. The highest summit is 13,175-foot Cloud Peak and there is a considerable extent of alpine habitat. Unlike most timberline areas in the American Rockies north of Colorado, the Bighorn Range does not support whitebark pine. Instead, lodgepole pine is a major tree-line component on warm exposure (134). Engelmann spruce and subalpine fir are prominent on all aspects (36).

Forest line on the west slope of the range occurs at 9600 to 9800 feet, and Powder River Pass (9666') on U.S. Highway 16 is at this ecological boundary. The Forest Service, Bighorn National Forest, is presently (1966) planning a self-guided nature trail that extends through a north slope, forest line environment from near the pass to 9500-foot High Park Lookout (141). The existing quarter-mile-long trail was used by so many visitors in 1964 (approx. 1000), that the Service has decided to develop the interpretive trail as a Visitor Information Service project.
Baldy Pass (9600') on the northern end of the range is a state highway access to timberline.

Animal residents of the Bighorn timberline include chipmunk, pine squirrel, pika, snowshoe rabbit, mountain ruffed grouse, and deer and wapiti in the summer months (36). A few moose on the east side spend the summers near timberline.

Southwestern Montana Vicinity

Ranges in southwestern Montana have rather arid upper timberlines and similar high-country environments. Major mountain ranges include the Crazy, Bridger, Gallatin, Madison, Tobacco Root, Pioneer, Beaverhead, and Anaconda Ranges. High peaks generally exceed 9500 feet, but the highest is under 11,500 feet. There is no large extent of alpine habitat, though many ridges rise above the scrub line, which is usually under 10,000 feet. Snow accumulation is not as great here as it is at much lower elevation in Glacier Park, or in parts of the Colorado Rockies.

The prominent trees at timberline are whitebark pine, Engelmann spruce, and subalpine fir. Limber pine is fairly common, but generally occurs on dry ridges in the lower forest zones. A lower timberline is formed along the base of most of these ranges, at an average elevation above 5000 feet. There is no general automobile access to the

1 A large number of mountain ranges in Montana rise above the timberline. There is great variety in types of timberlines present in the state; species of trees, and altitudes of timberline reflect different climatic and geographic conditions. Forest line in parts of Glacier Park occurs below 6000 feet, while 250 miles southward, near Yellowstone, forest line is as high as 9500 feet.
timberline country of this region, though there is considerable recreational use of the high-country—hunting, fishing, and horseback riding—by local residents.

**Northern American Rockies**

The Bitterroot, Cabinet, Mission, Swan, Flint Creek, and main divide ranges of the Northern Rockies of western Montana all ascend at least slightly above the scrub line, which averages 9000 feet in the south and below 8000 feet in the north. Whitebark pine dominates timberline except in the Glacier Park vicinity where subalpine fir and Engelmann spruce are most abundant.

Northern exposures in much of this region are occupied by stands of subalpine larch, which often forms tree limit a few hundred feet higher than the "evergreen" conifers. In October two distinct golden bands appear on some of the cool exposures of higher mountains, the lower belt consisting of western larch (*L. occidentalis*) and the zone at timberline subalpine larch. Some of the timberline is dominated by whitebark pine trees and krummholz on warm slopes and by subalpine larch trees on cool exposures, with spruce and fir present to a lesser degree in the actual timberline (see Figure 3).

The highest peaks in northwestern Montana seldom attain 10,000 feet, so there is little strictly alpine terrain. Forests in Glacier Park and the extreme northwest part of the state (and adjacent Idaho) reflect the influence of the Pacific Coast climate and its flora. Snowfall here is the heaviest in Montana. For instance, a persistent snowfield occurs at the low elevation of 5200 feet at Leigh Lake in
Figure 3. Coniferous forest distribution on the eastern slope of the Bitterroot Mountains in Montana (on a composite of aspects in the vicinity of 40° degrees N.). Arrows indicate approximate altitudinal range of each species. Dotted-line arrows signify shrub-like growth of the species (krummholz).
the Cabinet Range. The winter often comes early, too, in the Montana mountains; three feet of fresh powder snow covered the highest slopes of the Bitterroot Range in mid-September, 1965.

Besides the Beartooth Highway only one other in Montana ascends to timberline. This is the Going-To-The-Sun Road in Glacier National Park which crosses the Continental Divide at Logan Pass (6664 ft). Glacier Park has extremely precipitous topography coupled with a climate that seems to reflect the worst of both maritime and continental regimes (viz., heavy snowfall, rain, and cloudy coolness in summer from the maritime; extreme cold in winter and wind, from the continental climate). The result is a marked lowering of the forest belts, and an extremely wide zone of timberline environment.

Forest line occurs as low as 5500 feet along the Going-To-The-Sun Road, comparable to the altitude of some lower timberlines 150 miles southeastward. Extreme wind, snow, and avalanche conditions have been responsible in part for the development of superb subalpine meadows, interspersed with clumps of stunted fir and spruce (see Plate 13).

The new (1966) visitor center atop Logan Pass is amidst a vast belt of meadows, krummholz, and dwarfed trees, with sheer mountain walls as a backdrop. The scrub line extends up to 8000 feet where topography (and warm exposure) permits. Hiking trails are very popular with visitors to Logan Pass; however there is currently limited timberline interpretation and management practices for this area have resulted in some human impact (erosion) problems.
Plate 13. The popular trail from Logan Pass to Hidden Lake Overlook passes through subalpine meadows and scattered colonies of stunted subalpine fir trees and krummholz. This scene is near 7200 feet, about one mile from Logan Pass, looking east with Upper Saint Mary Lake in the background.

The effects of wind on the forest are particularly noticeable along the east side of the park, with considerable dwarfing of the aspen, Engelmann spruce, and limber pine along the ecotone between the Great Plains prairie and the Rocky Mountains forest. Two high summits (near 6000 feet) along the east-side highway between Saint Mary and Two Medicine junction are particularly impressive vantage points. The southern summit has krummholz of aspen, spruce and limber pine atop it.

Southern Canadian Rockies

Timberline country occurs all along most of the complex Rocky Mountain system in southern Canada, with forest line ranging from 7000...
feet in the southeast to perhaps 5500 feet in the northwest, along the
Pacific Slope in the latitude of Edmonton and Prince George (about $53\frac{1}{2}$
degrees N.). High peaks range from about 9000 to 12,972 feet for the
southern Canadian Rockies and the nearby Selkirk, Purcell, and
Monashee Mountains, and numerous minor ranges. Glaciers and even
rather extensive icefields occur in several of the higher ranges.

Seven national parks and a number of provincial parks are
located in this spectacular mountain region. Paved highways and good
forest roads provide access to the heart of the Rockies from the
International Boundary northwest to the Mount Robson area—an airline
distance of about 350 miles.

The Canadian Park Service is just now beginning to develop its
naturalist program, with the first permanent park naturalists having
been hired only recently.

Waterton Lakes National Park, adjacent to Glacier Park, Montana,
has topography like that of Glacier; but northward from Waterton the
slopes are not precipitous so consistently. Forest line averages
about 7000 feet in Alberta south of Banff Park, and scrub line occurs
around 8000 feet. The timberline trees are Engelmann spruce, subalpine
fir, subalpine larch, and some whitebark pine north into Banff Park.
Many mountain ranges extend parallel to the backbone of the Rockies,
both east and west of the main divide. Some of these subsidiary
ranges, particularly those eastward in Alberta, are much drier and
rather barren compared with the main divide ranges. The Selkirk
Mountains and other western Ranges in British Columbia are especially
lush in vegetation, and they exhibit lower-altitude timberlines.
Timberline northward, in the vicinity of Jasper is composed only of Engelmann spruce and subalpine fir.

Three auto passes are at the forest line in Alberta: Highwood Pass (7237') on the forestry Trunk Road, and Bow Pass (6785') and Sunwapta Pass (6675') in Banff and Jasper National Parks. The timberline highway on the north side of Sunwapta Pass leads by the snout of Athabaska Glacier (Columbia Icefield Lodge, etc.) and a new government visitor center. A spur of this "Icefield Highway" has led many thousands of visitors up along the edge of the glacier through a scenic zone of krummholz, to the well-known snowmobile ride terminal. At present the elaborate visitor center serves mainly as a question-answering station, with little interpretation of the natural environment.

Mount Edith Cavell road (to 6500'), Sunshine Resort (7150'), and the Jasper Sky Tram (to 7500') are areas of mass public recreation, respectively, just below, in, and above timberline in Banff and Jasper. In Banff the Mount Norquay chairlift ascends to 7000 feet and the Sulfur Mountain gondolas take visitors to the 7495-foot summit of that peak; both areas are in the timberline environment.

West of the Rocky Mountain divide in British Columbia the high-country is remote and inaccessible except by occasional trails. Shaw (139) studied timberline in the Selkirk Mountains of British Columbia and found heavy snowfall to be an important factor in the distribution of the trees. He found forest line to be above 6000 feet on the average and krummholz limit nearly 8500 feet. Subalpine larch is scattered about the southern part of the Columbia River mountains, and whitebark...
pine and mountain hemlock are found occasionally; but the bulk of the high-country forest is Engelmann spruce and subalpine fir.

A road in Mount Revelstoke National Park ascends to the summit of Mount Revelstoke (about 6200') in subalpine meadow and forest at the forest line. The Trans-Canada Highway in Glacier National Park, British Columbia, is a heavily-traveled tourist route that passes through the impressive Selkirk Range; however, the road stays far below timberline.

PACIFIC COAST MOUNTAINS

Southern California Peaks

Three different ranges in southern California exhibit part of a timberline zone. The highest peaks are San Gorgonio (11,502') in the San Bernardino Mountains, San Jacinto Peak (10,831') in the San Jacinto Range, and San Antonio (10,064') in the San Gabriel Mountains. These peaks are all within 40 miles of the city of San Bernardino. The former is within the 35,000-acre San Gorgonio Wilderness. Administered by the Forest Service, this preserve is termed, "an island of wilderness in a sea of civilization [16]." About 8 million people live within 100 miles of this area.

Of the three mountains mentioned only San Gorgonio rises somewhat above the scrub line; however, there are tiny scattered mats of limber pine even on its exposed summit, according to Grinnell (65). Alpine vegetation is present here as well as on San Jacinto (68); nevertheless, it is doubtful that enough of this type exists to classify it as an alpine area.
Grinnell mentioned that San Gorgonio retains some persistent snow patches, and Hall (68) found several alpine plants high up on San Jacinto. Hall asserted that the very limited alpine zone (really questionable even as a "quasi-alpine" because erect trees grow in it) here is the southern-most in the United States. However, New Mexico's Sierra Blanca (12,003') is apparently better qualified for this "quasi-alpine" title, and it is about 30 miles farther south than San Jacinto. Of the 129 boreal species Hall found on San Jacinto, 114 occur in the Sierra Nevada and 16 or more are of the Rockies, with 10 being indigenous to southern California.

Limber pine alone ascends to the scrub line—probably 11,000 feet for all exposures—on San Gorgonio. Lodgepole pine occurs between 8500 and 10,000 feet on northern exposure, and 9000 to 11,000 feet on south slopes. Western juniper (J. occidentalis) is found as high as 9500 feet here, and some large juniper occur at about 9800 feet on Sugarloaf (65). San Jacinto has dwarf lodgepole and limber pine on its summit (68). San Antonio has stunted limber pine at its top (14).

Grinnell said that the yellow-headed chipmunk, rock wren, Sierra junco, Clark's nutcracker, golden eagle, Audubon warbler, California horned lark, and white-throated swift summer on and near the summit of San Gorgonio. Rapidly rising air currents bring up an abundance of insects for the birds.

**Sierra Nevada**

The High Sierra is an almost unbroken stretch of timberline and alpine environment extending along the Sierra crest from near
Sonora Pass (9626') to Olancha Peak (12,136'), an airline distance of around 170 miles. The range is composed of granite, with the highest peak being 14,496-foot Mount Whitney. Snowfall is very great in winter, but the summers are dry. Baker's (11) data indicates that less than one percent of the annual precipitation for the high-country falls in July and August. The alpine zone, beginning at an average elevation of 11,000 feet, is extensive, though it has only a small proportion of lush tundra-like growth because of the rocky terrain and summer drought.

Tens of thousands of backpackers and horsemen vacation in the High Sierra each summer, though the only highway access to the timberline environment is near the north end of this area at Tioga Pass (9941') in Yosemite National Park. Sequoia and Kings Canyon National Parks include much of the southern High Sierra, while almost all of this region not in the three parks is under Forest Service jurisdiction.

A large part of the southern High Sierra timberline is dominated by foxtail pine, which grows erect and attains gigantic proportions above tree limit for other high-altitude species—whitebark, lodgepole, and limber pines. Foxtail pine averaging 2 1/2 feet thick and 40 feet tall grow as high as 11,300 feet in some locations, but the average tree limit for all exposures is probably 11,000 feet or slightly less. Moreover, much barren granite landscape extends down as low as about 9500 feet without trees.

1"Thick" or "diameter," referring to a tree trunk will signify "diameter at breast height" (4 1/2' above ground) unless noted otherwise.
Whitebark pine is the highest coniferous dweller in the Sierra, sometimes attaining 12,000 feet, though here it forms tiny, scattered shrubs (28). Limber pine grows along the east side of the crest, filling in the niche left vacant by absence of the whitebark. Lodgepole is generally the fourth-highest dwelling pine in the Sierra Nevada, reaching its upper limit a few hundred feet below the others. Above the Sphinx Lakes, Kings Canyon National Park, however, lodgepole reaches its upper limit as krummholz near 11,500 feet, while foxtail pine (erect) ascend only to about 11,000 feet and whitebark krummholz occurs at 12,000 feet. Much of the timberline forest is so isolated by alpine and barren land that stands may be individually composed of any combination of the pine species (see Figure 4).

In the Yosemite area, the northern High Sierra, timberline occurs perhaps 200 feet lower on the average than farther south. A big difference is that foxtail pine is not present in the northern half of the High Sierra. Moreover, mountain hemlock is rather frequent in the north, while it is rare in the south. Wherever the hemlock occurs it is restricted to cool, moist exposures; its main distribution extends through the maritime North Pacific Ranges. In this and other respects the hemlock contrasts with its pine neighbors.

Western juniper (also known as "Sierra juniper) is not usually a tree of the timberline; but it often occurs on near-vertical cliffs and other sunny granite sites in the subalpine zone, higher up on such desolate slopes that other species cannot survive. It is sometimes found under such conditions at 10,000 feet where it merges with scattered foxtail pine growing upon gentler slopes above the cliffs.
Figure 4. Coniferous forest distribution on the western slope of the Sierra Nevada at Kings Canyon National Park. Arrows indicate the approximate altitudinal range of each species.

Legend:
- Whitebark Pine
- Whitebark Pine
- Lodgepole Pine
- Western White Pine
- Shasta Red Fir
- Sierra Juniper
- Jeffrey Pine
- Sugar Pine
- White Fir
- Giant Sequoia
- Incense Cedar
- Pinyon Pine
- Single-Leaf Pine
- Ponderosa Pine
- California Nutmeg
- Scrub Oak Chaparral
- Oak Savannah
- Grassland - Oak Savannah
- Great Central Valley

(not here, but northern and southern)
Northern California Peaks

LASSEN PEAK. Lassen Peak (10,457') is a recently active volcano at the southern tip of the Cascade Range in north-central California. This peak and the high, rugged volcanic land nearby comprise Lassen Volcanic National Park. The park highway is heavily used by summer visitors, and it ascends to 8512 feet in the timberline zone (60).

Carpenter (23) cited Gillet et al., A Flora of Lassen Volcanic National Park, saying that California red fir (A. magnifica var. magnifica) grows between 5700 and 8500 feet in the park. Presumably, forest line occurs a bit below 8500 feet on the average. The same source lists whitebark pine and mountain hemlock occurring at 9200 feet in scattered, wind-blown form, probably krummholz. Bailey (8) listed the krummholz limit as being 10,000 feet.

Though there is almost no alpine per se in the area according to Carpenter (23), the timberline zone is a main feature of the park. The vegetation of Lassen Park generally reflects a more moist Cascade-type environment as opposed to the drier, High Sierra habitat.

MOUNT SHASTA. Mount Shasta (14,162') is second highest of all the Cascade Range volcanoes. It is situated roughly 70 miles northwest of Lassen Peak in extreme northern California, and it rises over 10,000 feet above the valleys below. Five small glaciers cling to the mountain's upper slopes, above 9800 feet, yet Shasta is a distinctly dry mountain compared to the nearby Oregon Cascades, Lassen Peak, or the Coastal Mountains (31 & 167). Auto access to the timberline on the south slope of Shasta is made all year over the Everitt...
Memorial Highway which leads past Panther Meadow Campsite (7440') to Mount Shasta Ski Bowl at 7930 feet (176).

Forest line averages 8000-8500 feet on Shasta and the timberline is composed of whitebark pine, mountain hemlock, Shasta red fir (A. magnifica var. shastensis), common juniper (J. communis), and occasional white fir (31). Krummholz communities of whitebark pine extend as high as 9500 feet, with individuals occurring sometimes near 10,000 feet on ridges radiating from Shasta's summit. However, the draws between these windswept ridge spurs support their highest dwelling conifers as erect whitebark groves at 8000 to 8500 feet. Snow accumulation and shortness of the warm season depresses the conifer limit in these basins.

Though the red fir and hemlock occur in the krummholz community on the ridge spurs, they are secondary to whitebark pine (31). The red fir is more abundant in the forest around 7000 feet. The Forest Service information sheet on Mount Shasta (167) lists foxtail pine as being present here; but there is no mention of the presence of this species by others (31 & 102).

COAST MOUNTAINS. Only a few peaks in the Coastal Mountain Ranges of northwestern California are high enough to exhibit a climatic timberline environment. Mount Eddy (9025') in the Trinity Mountains and Thompson Peak (9002') in the Salmon Mountains are the highest points in the Coast Ranges. Both are southwest of Mount Shasta, and they have a more moist environment (31).

Foxtail pine, Shasta red fir, mountain hemlock, and whitebark pine occur on the high peaks though little detailed information is
available on the timberlines here (60 & 145). Griffin (60) reported that an unpaved road ascends the shoulder of Mount Eddy; but most of the high peaks in this region are relatively inaccessible. Climatic forest line may well occur near 8500 feet; the Forest Service (153) mentioned that Whaleback Mountain (8528') is "... covered with timber at the summit."

The Coastal Mountains of extreme northern California and southern Oregon mark the southern limit in the distribution of several timberline trees native to the Pacific Northwest and North Pacific mountains. These species include subalpine fir, Engelmann spruce, Alaska-cedar (Chamaecyparis nootkatensis), and Sitka spruce (Picea sitchensis). An interesting point is that none of these trees grows as high as the timberline zone at this southern limit of its range. Sitka spruce forms the timberline only in the northern end of its distribution. Brewer or "weeping" spruce (P. breweriana)--the rarest and least known American spruce (30)--occurs only in this region in moist canyons from 4000 to 7000 feet, but not so high up as timberline. Perhaps the distribution of trees in the Coastal Mountains of this area reflects that this site is the southernmost outpost of the northern maritime climatic regime. The principal reason for timberline-like development on many of the lower summits (below 8000-8500') is likely to be exposure.

Southern Cascades (Oregon)

A relatively small area of the Oregon Cascades is high enough to exhibit the alpine habitat. According to Bailey's (10) map there
is some alpine around the following mountains in the Oregon Cascades: Hood (11,245'), Jefferson (10,499'), Three Sisters (10,354'), Diamond Peak (8750'), Thielsen (9182'), Scott (8926'), and McLoughlin (9495'). This list is not entirely complete, but it should roughly convey the extent of alpine areas. Bailey indicated that forest line in the Oregon Cascades averages about 5500 feet on Mount Hood near the Columbia River, 6000 feet on Mount Jefferson (50 miles south of Hood), 6500 feet on the Three Sisters (40 miles farther south), and 7000 feet on Mount McLoughlin in southern Oregon. In each case except the latter, forest line occurs about 500 feet lower than average on northeast exposure (coolest) and roughly 500 feet higher than the average on southwest exposure (warmest). Bailey observed that the timberline belt has an average width near 1000 feet for these locations.

The National Park Service (84) reported that krummholz whitebark pine grows atop 8926-foot Mount Scott in Crater Lake National Park. The timberline is higher here than at Mount McLoughlin, 30 miles south-southwest, but this source explains that the gentle topography of the Crater Lake caldera may in part be responsible. Presumably the exposure is lessened under gentle topography and the slopes would not be excessively dry due to fast drainage. The Park Service suggested that a rain shadow effect may have some bearing; however, Crater Lake has the record snowfalls for Oregon, so a rise of timberline here above that of Mount McLoughlin seems unlikely from this respect.

Mountain hemlock and subalpine fir occur slightly lower than the whitebark on Mount Scott, and all three species are abundant around the caldera rim—which ranges from 6683 to 8156 feet elevation.
Shasta red fir and lodgepole pine grow along some parts of the rim, but are not so characteristic of the timberline as the former three species (84 & 174). The park roads around the rim ascend to over 8000 feet and pass through broken stands of dwarfed mountain hemlock and whitebark pine. The popular trail hike up Mount Scott takes visitors into the scrub zone.

Franklin (54) said that mountain hemlock and whitebark pine are predominant at the Oregon Cascade timberlines. The hemlock occupies moist, cool slopes while the pine occurs mostly on dry sunny aspects. The hemlock is more prevalent on the western slope of the Cascade Range with the pine more frequent on the rain shadow, eastern slope. Subalpine fir and Alaska-cedar occur sporadically at timberline in the southern Cascades, but are much more frequent north of the Columbia River, in Washington.

The only auto access to timberline in the Oregon Cascades is at Crater Lake in southern Oregon and at Mount Hood in the northern part of the state. The paved road to Timberline Lodge (6000') on the southwest slope of Hood provides a popular year-round access to forest line. The unpaved road to Cloud Cap on the northeast side of Hood reaches 6000 feet in the timberline zone. Lush subalpine meadows are a main summertime feature of the Mount Hood timberline, and in winter the ice-covered trees here and at Crater Lake are especially beautiful. The commercial ski slopes on Mount Hood extend up to 9100 feet elevation (above regional snowline), highest in Oregon or Washington.
Bachelor Butte (9060') on the east side of the Cascades in central Oregon also has a popular ski area that utilizes the timberline zone.

Northern Cascades (Washington\textsuperscript{1} and British Columbia)

Timberline and alpine habitat occurs throughout the Cascades in Washington, but it becomes increasingly abundant northward in that state. This effect occurs because the general upper altitude of the mountains increases northward as does the width of the Cascade Chain. Though the north-south airline distance along the Washington Cascades is 230 miles, there is little latitudinal effect on the elevation of timberline in the state. West-to-east rise in timberline is predominant even within the width of the Cascade Chain itself. In fact a 1000-1500-foot rise in timberline often results along a latitudinal transect of 30 miles. This is the result of decreasing influence eastward of the maritime climate with its heavy snowfall and cool, cloudy summers.

Forest line occurs at about 6000 feet on 12,307-foot Mount Adams just north of the Columbia, but it is found much lower on 9677-foot Mount Saint Helens 35 miles west. Forest line is around 5000 feet on the west slope of the Cascades near Snoqualmie Pass; but it averages near 6500 feet in the Stuart Range of the Wenatchee Mountains 30 miles east (see Figure 5). Just south of the Canadian Border

\textsuperscript{1}The western and central portions of Washington exhibit a large amount and great diversity of timberline and alpine environment within a relatively small region. The state's Olympic and Cascade rain shadows, causing much of this variety, are the most dramatic of any in the United States proper (186).
Figure 5. Coniferous forest distribution in the Cascade rain shadow (Wenatchee Mountains)—arrows indicate the approximate altitudinal range of each species. Solid-line arrows signify arborescent (tree-like) growth. Dashed-line arrows indicate shrub-like growth of the species (krumholz). Dotted-line arrows show that the species was found only in the form of degenerate seedlings (sub-shrubs), less than a foot high.
timberline occurs across the high Cascades over an east-west distance
of approximately 100 miles. Near the maritime end of this cross-
section, forest line is below 4500 feet on the northeast side of Mount
Baker. However, the same ecotone is found at 7000 feet on cool
exposure in the Okanogan Cascades 70 miles eastward, in the rain
shadow zone. Similar aspects on Harts Pass, on the Cascade Divide
between the two climatic extremes, have forest line near 6000 feet.

The timberline climate and vegetation also changes markedly
along this North Cascade\(^1\) transect. At the maritime end the weather
station at Heather Meadows (4450') has recorded a mean annual snowfall
of 516 inches and mean annual precipitation of 110 inches (170). Both
measures would probably be higher in the timberline belt here, a few
hundred feet higher. Mountain hemlock, subalpine fir, and some Alaska-
cedar compose the timberline, which is characterized by lush (even
rank) vegetation. The highway to 4630-foot Austin Pass was still
blocked off by large snowdrifts in mid-August of the moderate 1966
season. Comparatively large glaciers are common, many extending down
into the timberline. Regional snowline is as low as 6000 feet.

The Weather Bureau (171) estimated that about 60 to 70 inches
of precipitation occurs annually in the Harts Pass area. The timber-
line belt is made up primarily of subalpine fir, with whitebark pine,
subalpine larch, and Engelmann spruce secondary. A trace of mountain
hemlock and Alaska-cedar exists in the general vicinity. Subalpine
meadows are prevalent, but not so luxuriant as those westward. Only

\(^1\)The North Cascades is the remote, rugged, and heavily
glacierized region between Stevens Pass (U.S. Highway 2) and the
Canadian Border.

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a few tiny glaciers persist, usually above about 8000 feet, on some
of the highest peaks in this region—the Cascade Divide.

Annual precipitation in the timberline country of the Okanogan
Range (Cathedral Peak-Remmel Mtn. area) is thought to be around 30 to
40 inches (171). The timberline is composed of whitebark pine,
subalpine larch, Engelmann spruce, and subalpine fir. Persistent
snow patches are rare and there are no "glacierets." Subalpine
meadows are restricted to unusually moist areas, and are rather
scarce.

Thompson (151) has made an unusual study of timberline in the
North Cascades, relating the position of this forest ecotone to the
erosion of and resulting height of the "peak plane," or rather uniform
level of the highest summits. It has long been observed that the rate
of erosion in mountain ranges is slower in the forest zone than in
barren or alpine areas; but studies of the effect of timberline on
mountain geography have been scant.

Public access to timberline is made over several roads into
the Cascades of Washington. Forest roads ascend to 6500 feet on the
south side of Mount Adams. A state highway climbs to Timberline
Campground (4200') on the northeast side of Saint Helens. Paradise
(5557'), Chinook Pass (5410'), and Sunrise (6400') in Mount Rainier
National Park are three extremely popular timberline areas served by
highway. The new cross-state scenic highway through the North Cascades
will ascend almost to the forest line at Washington Pass (5250') and
Rainy Pass (4960'). The excellent forest road to Harts Pass (6200')
and Slate Peak (7488') is highest in Washington. It ascends a few
hundred feet above the scrub line. Mount Baker Lodge (4360') and Austin Pass (4630') are visited by thousands of people over a state highway each summer. Hiking and mountaineering are very popular recreational activities in the timberline and alpine zones of the Cascades in Washington.

**Mount Rainier.** Forest line at Mount Rainier National Park averages roughly 5200 feet with scrub line generally a bit below 7000 feet (21). In this timberline belt lies a great expanse of subalpine meadows, or "parks," which are noted for their abundance of colorful wildflowers. The Park Service conducts timberline interpretation at Sunrise and Paradise, with visitor centers, self-guided walks, conducted hikes, and illustrated campfire programs at each area (56). The Rainier timberline consists largely of subalpine fir, mountain hemlock, and Alaska-cedar. Whitebark pine and Engelmann spruce are present in the northeastern part of the park (21).

Bailey (10) described the occurrence of timberline approximately 1000 feet lower on the northeast exposure of Oregon volcanoes than on their southwest sides. This condition, due to the difference in radiation, is common throughout much of North America. However, timberline occurs higher on the northeast side of Mount Rainier, than on its southwest slope, presumably because of the mountain's rain shadow effect on snowfall, apparently more than compensating for exposure.

Paradise (5557') on the southwest slope holds the North American record for seasonal snowfall, with 1000.2 inches (83+ feet) during the
winter of 1955-56 (168). On March 10, 1956 the snowpack at Paradise was 367 inches and on July 15, 78 inches of snow remained. Mammoth snowfalls and delayed melting occur sporadically at Paradise (the mean annual snowfall is about 600 inches) and elsewhere in the maritime mountain ranges. It is not difficult to discern the great importance of snow in timberline formation in this maritime climate. To further illustrate the character of the maritime timberline climate as recorded at Paradise, on the average only two days per year have minimum temperatures as low as 0 degrees F., and just nine days each year have maximums of 75 degrees F. or more.

NORTH END OF THE CASCADES. The northern end of the Cascade Chain occurs in extreme southern British Columbia. Manning Provincial Park straddles the Cascade Divide along and immediately north of the International Boundary. The highest point in the park is 7960-foot Mount Frosty, one mile north of the border. The 8000+ foot summits that characterize the North Cascades of Washington end abruptly at the border (except in the Okanogan Cascades to the east, where such summits occur just inside Canada). Northward from the border the number of alpine summits diminishes rapidly.

A major provincial highway passes through the Cascades in Manning Park, and a few miles east of the divide the Provincial Park Service provides excellent interpretive displays at its Nature House. The Nature House is not as elaborate as most new visitor centers in the United States; but the interpretation (including living displays of the vegetation and small animals, along with cones,
foliage, and tree trunk cross-sections people can examine, etc.) is strikingly original and effective.

A park road nearby leads to 6500 feet on Blackwall Peak, just above forest line. Nature trails wind through subalpine meadows and scattered Engelmann spruce, subalpine fir, whitebark pine, lodgepole pine, and occasional subalpine larch. Forest line averaged around 6300 feet in this vicinity (157), with scrub line occurring near 7200 feet on the few peaks that rise above that height.

Eastward, the north end of the Okanogan Range of the Cascades appears similar to the Okanogans of Washington. The Cascades' only bighorn sheep summer in the Okanogan high-country near the International Boundary. Mountain goat is the prevalent dweller of the Washington Cascade alps, with about 8000 of them inhabiting the area between Mount Rainier and the Canadian Border (175).

Olympic Mountains

The Olympic Mountains form a large cluster of glacierized peaks on the Olympic Peninsula of western Washington. The climate is extremely maritime, causing development of the "Olympic Rain Forest" in deep westward facing valleys where average annual precipitation is about 150 inches. These valleys and others in the Olympics radiate from a central mountain mass whose high point is Mount Olympus (7965'). Average annual precipitation in the Mount Olympus vicinity is estimated at 200 inches by the Weather Bureau (171) and the University of Washington. Not only is this area probably the "wettest" in the 48 States, it is also believed to have the lowest regional snowline,
as low as 6000 feet (39), for its latitude in the northern hemisphere. Some small glaciers lie wholly below the upper tree limit.

The northeastern Olympics are within a rain shadow, and though their peaks are as high as the central Olympics, the former receive only about 50 to 60 inches of annual precipitation (171). As would be expected, timberline is elevated northeastward in the Olympics, but not so greatly as in the northern Cascades--the latter is a much wider mountain barrier to the maritime storm systems.

Forest line in the central Olympics averages below 5000 feet, with scrub line occurring around 6000 feet. Principal timberline trees are subalpine fir, mountain hemlock, and Alaska-cedar. The three often form dense, integrated communities of krummholz. The lingering snowpack seems to generally restrict coniferous growth except on exposed ridges and precipitous slopes. Wind is the dominant force up to krummholz limit on exposed sites and cool summer temperature probably inhibits growth of conifers beyond the krummholz zone (see Figure 6).

Forest line in the northeastern Olympics seems to average about 5500 feet. Tree limit occurs as high as 6500 feet, and scrub line on all exposures averages 6500 feet.

Eight different coniferous species occupy the timberline of this rain shadow zone (4). The highest dwellers in descending order appear to be: Common juniper, Alaska-cedar, whitebark pine, lodgepole pine, subalpine fir, mountain hemlock, and Douglas-fir and western white pine (P. monticola). One stand of Alaska-cedar krummholz extends up an east-facing cliff to 7200 feet on Gray Wolf Ridge.
Figure 6. Composite of the coniferous forest distribution in Olympic National Park—arrows indicate approximately the normal altitudinal range of each species.
Whitebark pine occurs only above about 5600 feet and mostly between 5800 and 6800 feet. The whitebark has a very limited distribution in the Olympics and some of it has been killed off by the white pine blister rust. Two prostrate whitebark pines growing near 6500 feet are estimated to be about 500 years old.

Lodgepole pine of the "shore pine" variety grows between sea level and about 1500 feet on the Olympic Peninsula. However, in the northeastern Olympics lodgepole, probably an inland form, grows between 4500 and 6800 feet.

Subalpine fir occurs as high as 6700 feet, but in the rainshadow mountains its companion, mountain hemlock, is scarce and seldom above 6000 feet. Douglas-fir and western white pine grow on rocky, warm exposures as high as 5500 feet, though both are unusually deformed in the timberline. Their normal development is reached below about 4000 feet.

Animals such as wapiti (the "Olympic elk"), Columbian black-tailed deer, mountain goat, and black bear are common summer residents of the timberline. The cougar is relatively abundant here, as are various hawks, the blue grouse, and ravens. The latter winter at Hurricane Ridge (5220'). The Olympic marmot lives at timberline year-round.

Most of the Olympic high-country is within the boundaries of Olympic National Park. Two park roads lead into the alpine zone, with the main attractions on them Hurricane Ridge and Deer Park (5500'), both in subalpine meadows. The Hurricane Ridge highway takes thousands of visitors to the mile-high ridge top with its views of the inner
Olympics, Straits of Juan de Fuca, Canada, the San Juan Archipelago, and the North Cascades. A new visitor center is being completed on the ridge, and timberline interpretation is carried out in conducted walks and outdoor displays. A branch road, the Alpine Drive, continues for nine miles along the high ridge to Obstruction Point (6200') at the lower alpine line. A dirt road also leading from the Port Angeles vicinity, climbs to Deer Park campground and Blue Mountain Lookout (6007'), commanding a 360-degree panorama.

**Canadian Coast Mountains**

The Coast Mountains of British Columbia are a complex system of ranges, some of which are heavily glacierized and up to 13,177 feet high (Mount Waddington). The only high-country area of this vast range which is frequented by visitors is the extreme southern end, largely in Garibaldi Provincial Park near Vancouver. Snowfall is very great here and tree limit is as low as 4500 feet on slopes nearest the sea (20). Twelve miles inland at Black Tush Meadows tree limit is about 6300 feet (20 & 157), and on the interior slope of the coast ranges it is near 7000 feet (20).

Brink has found that the conifers in the Black Tusk Meadows area, 5000-5500 feet (157), are invading the heath habitat (*Phyllodoce-Cassiope*) rather than the deep-soiled meadows. The principal conifers are mountain hemlock, subalpine fir, Alaska-cedar, and whitebark pine. The species occur in scattered clumps, but Underhill (157) has noted, "... each clump seems to regularly contain all four species, even though it may total only four or five trees." Forest line here occurs at roughly 4900 feet.
There is little information available on timberlines in the Coast Mountains north of Garibaldi. Whitebark pine is reported to occur at least as far north as Canoe Crossing Mountain in the Bella Coola Region, about 200 miles northwest of Garibaldi (100). Subalpine fir and mountain hemlock are the main constituents of this timberline area, with "tree line" (probably scrub line) occurring at 5200 feet elevation. Sitka spruce and mountain hemlock, with some Alaska-cedar compose the timberlines in the Coast Mountains of the Far North, discussed in a following section.

The mountains on Vancouver Island, the highest of which is 7219-foot Golden Hinde, are alleged to be similar in many respects to the Olympic Mountains of Washington. The timberline environment including climate, topography, larger mammals, and the flora is probably like that of the Olympics. Even whitebark pine occurs on the Vancouver Island mountains (46).

GREAT BASIN AND INTERMOUNTAIN RANGES

Eastern Great Basin and Vicinity

UTAH HIGH PLATEAUS. The Markagunt, Aquarius, Wasatch, and other high plateaus in southern and central Utah (ranging upward to 11,500 feet) exhibit some interesting timberline formation. The "inverted timberlines," described on page 11, occur along the plateau fringes at Bryce Canyon National Park. However, this feature is more emphatic at Cedar Breaks National Monument where the plateau rim reaches 10,700 feet and exhibits a subalpine forest of Engelmann spruce, subalpine fir,
bristlecone pine, some limber pine, and clones of aspen. Krummholz is formed because of extreme exposure along the plateau rims (both high and low), and a scrub line is formed descending the cliffs into the dry, limestone amphitheaters (83 & 133). The forests develop higher up on the gentle plateaus than might occur on mountain slopes since the plateau site limits wind exposure and holds moisture (133).

Visitation at Cedar Breaks was estimated at 220,000 for 1965 (83). The Park Service offers evening programs, conducted walks, orientation talks, and interpretive signing at overlooks. Also, visitors are told of the road to the top of nearby Brian Head (11,307') in the Dixie National Forest. This peak rises slightly above timberline, with an alpine habitat on top resembling that of the Central Rocky Mountains.

Other high plateau country in Utah is probably similar in most respects to that of the Cedar Breaks area. The Aquarius and Markagunt Plateaus support some particularly fine stands of bristlecone pine, including two trees discovered in 1965 to be the oldest known in Utah (83).

The high plateau environment has a climate similar to that of other timberlines; wildflowers include shooting star, columbine, marsh marigold, penstemon, and more that are characteristic of other high-country areas. Animals of the Cedar Breaks plateau include the marmot and pika, often associated almost exclusively with timberline and alpine zones (83).

The Forest Service is improving the Skyline Drive road and developing this route for recreation along the crest of the Wasatch
Plateau in central Utah. High points on or very near the drive probably exhibit some features of the timberline zone (162).

**TUSHAR MOUNTAINS.** The Tushar Mountains of southwestern Utah exhibit a small amount of alpine environment. Tree limit averages just above 11,000 feet elevation (50), and the highest peaks, Mount Belknap (12,139') and Delano Peak (12,173'), have no coniferous vegetation on their summits, though common juniper does occur a few hundred feet below. The alpine plants are scattered with much barren, rocky site. Tree species at timberline include a mixture of Engelmann spruce, subalpine fir, and limber pine. The area receives little recreational use because the only roads reaching timberline are truck or jeep trails. Old mining roads in the high-country have caused erosion problems, common throughout much of the Utah uplands because of the instability of the surface mantle.

**LA SAL MOUNTAINS.** The timberline zone in the LaSal Mountains of eastern Utah occurs around 11,000 feet, with the principal conifers being Engelmann spruce and subalpine fir (114). The highest peak, Mount Peale, is 13,089 feet, and several other points rise high above timberline, though apparently little is known of the ecology of this mountain range. Alpine vegetation is sparse because much of the mountain-top terrain is composed of sliderock (114).

**UINTA MOUNTAINS.** The Uinta Mountains of northeastern Utah are unlike most other large ranges of the 48 States in that their crest extends latitudinally instead of being oriented north-south. There is a large
extent of alpine in the high Uintas (86), though there are no existing glaciers. The highest point in the range and in Utah is Kings Peak (13,498') and alpine habitat extends all along the crest of the range for roughly 75 miles (86).

Three main species are closely associated at timberline in the Uintas—Engelmann spruce, subalpine fir, and lodgepole pine (89). On the south side of the range, tree limit averages about 11,300 feet with krummholz of subalpine fir often extending higher. Limber and possibly whitebark pine are present also, but in at least some areas they occur only below timberline, on dry sites in the 8500-9000-foot belt.

A popular vacation highway climbs above 10,000 feet into the west end of the Uintas in the Mirror Lake area. The Wasatch National Forest maintains about six campgrounds with total capacity of 250 families between 10,000 and 10,400 feet elevation in this scenic area. Alpine mountain peaks rise directly above.

OTHER TIMBERLINE RANGES. The remote Henry Mountains of south-central Utah are a very dry range with summits as high as 11,615 feet. The Abajo Mountains to the east are of approximately the same height. Both ranges probably exhibit timberline formation on their highest peaks. The Wasatch Range of north-central Utah has several individual peaks which rise above timberline, including Mount Nebo (11,928') and Mount Timpanogos (12,008').

Western Great Basin and Vicinity

CHARLESTON PEAK. The Spring Mountains, located near Las Vegas, Nevada, form one of the most isolated high ranges in the 48 States (29).
Clokey (29) said that Charleston Peak, which at 11,919 feet is the highest point, "... is the only mountain in the southern Great Basin that rises above timber line (11,200-11,500 feet)." The nearest other high mountains are the Panamints, 75 miles to the west. Clokey found 13 new species on Charleston Peak and lists 31 as being endemic to this small range.

The timberline forest is composed of bristlecone pine and limber pine, with tree limit occurring near 11,500 feet, where some bristlecones still attain 20 to 30 feet in height (82). LaMarche (90) said that the bristlecone also occurs as krummholz from about 11,200 to 11,600 feet.

Above 11,700 feet very little vegetation of any type is found (82). This area is a tiny quasi-alpine; it should not be considered a true climatic alpine for two reasons: (1.) It is caused primarily by severe exposure on the tip of Charleston Peak. Winds of about 160 miles per hour have been recorded in similarly exposed areas nearby (82). (2.) None of the alpine flora of either the Sierra Nevada or the Rockies is present (29).

Limber pine grows near and below the 11,000-foot level and is usually not so stout and gnarled as the bristlecone (82). Insect damage is notable in both pines. White fir occurs sporadically as high as 10,800 feet and common juniper is found in the timberline (29).

Charleston Peak has local relief of almost 10,000 feet above the surrounding Mohave Desert, with a barren, creosote bush community enclosing its lower skirts (29). The Forest Service, Toiyabe National Forest, has established a recreational area on the mountain, with
trails, camp and picnic areas, and winter sport facilities. Wapiti transplanted from Yellowstone Park summer on the ridge tops (82).

**PANAMINT RANGE.** Telescope Peak (11,049') is the highest point on the Panamint Range which marks the western border of Death Valley in California. This peak rises 11,330 feet above Badwater, which is 17 miles eastward. Relief above the Panamint Valley to the west is over 9000 feet.

The summit is covered with a patchy forest of erect bristlecone pine and krummholz limber pine (90). Limber pine is said to occur at and above 9500 feet, and the upper limit of the singleleaf pinyon-Utah juniper belt is said to be 9000 feet (25), in which case a "double timberline" as described on page 10 may occur.

The feral burro is rather common at all levels of the Panamint Range, but few other animals occur atop Telescope Peak (25). A seven-mile-long trail leads up the peak from Mahogany Flat (8100'), Death Valley National Monument.

**INYO MOUNTAINS.** The Inyo Range is located northwest of Death Valley, directly across the Owens Valley from the southern High Sierra. The Inyos appear much like the Panamints or other high, desert ranges in the region. Some of the highest peaks are Waucoba Mountain (11,123'), Keynote (11,125'), and New York Butte (10,668'). Little information on the forest is available; however it is likely from overall appearance of the range that a pinyon-juniper zone occurs between about 6000 and 9000 feet, with limber and bristlecone pine occupying the upper slopes all the way to the summits.
WHITE MOUNTAINS. The White Mountains are situated east of Bishop, California, and north of the Inyo Range. They stretch roughly from Westgard Pass on the south to Montgomery Pass at their north end. The range forms part of the Inyo National Forest, with White Mountain Peak (14,242') being highest in the entire Great Basin. Several other high points are well above timberline including Montgomery Peak (13,465'), Mount DuBois (13,545'), and Piute Mountain (12,555').

In 1958 the Forest Service set aside a 28,000-acre botanical area called the "Ancient Bristlecone Pine Forest," to be managed for scientific study of the forest and for public enjoyment (165). The botanical area is located between Westgard Pass and White Mountain Peak on the south end of the range, and it is served by a good forest road.

Before the late Dr. Edmunk Schulman's 1958 feature in National Geographic on the "Bristlecone Pine, Oldest Known Living Thing (136)" made this forest known to the American public, he had discovered 17 bristlecone pines 4000+ years old here. The number of 4000+ year trees has been enlarged by further discoveries since then, but the 4600+-year-old called "Methuselah" which Schulman dated is still the oldest known living tree.

Bristlecone pine and limber pine compose the forest above about 9500 feet in the White Mountains, with singleleaf pinyon extending up about to this elevation from below. Limber pine seldom occurs above 11,000 feet (106), while the bristlecone tree limit averages roughly 11,500 feet (87). The bristlecone does not form krummholz even at its extreme upper limits in the White Mountains according to Mooney.
Kuehner (87) said that isolated trees occur as high as 12,100 feet.

The different substrates represented here—dolomite, granite, and sandstone—have a pronounced effect upon the vegetational communities which will develop upon them (106 & 183). Tree cover is much more prominent in dolomite than on the others at higher elevations.

However, climate seems to have had the greatest influence on the development of the unusual subalpine forest on the White Mountains. Billings (1951, see 106) observed, about the White Mountains:

"Although separated by the Owens Valley from the Sierra Nevada, by distances of as little as eight miles, the vegetational zonation is distinctly Great Basin in nature." Ten year records kept at Crooked Creek Laboratory (10,150') within this bristlecone forest show average annual precipitation as just 12.54 inches (Pace 1963, see 183). This is extremely low for a forested site even atop the Great Basin ranges.

Moreover, this adversely dry environment seems to foster the development of ancient bristlecones. The old trees are usually more dead than alive (e.g., only a narrow band of living tissue continues to grow on the otherwise dead, hardened trunk). Just a small part of the crown of the ancient trees continues to live. Such growth occurs on the driest of sites, usually near the bristlecone's lower limit, between 9500 and 10,000 feet (see Plate 4, p. 24). Under more moderate conditions (which paradoxically occur near tree limit!) fast-growing bristlecones having their bark intact and a full crown, tend to develop heart rot after attaining 8 to 10 inches radius (183).
Trees in the "ancient area" do not become uniformly "sickly" in such a manner; rather, most of their tissue dies outright (183). Such observations support Schulman's statement that longevity requires adversity for the ancients of the desert timberlines.

Intriguing examples of bristlecone growth in the area are numerous. The largest known bristlecone pine, called the "Patriarch," is a squatty, multi-stemmed tree almost 12 feet thick and 1500 years old (136), growing not far from tree limit at 11,320 feet (26). A curious dwarf bristlecone also pictured in the National Geographic is 3 inches thick, 3 feet high, and 700 years old. As much as 5 percent of the total rings have been found to be locally missing in a given increment core (53) and false rings do not occur; consequently ages thus estimated are considered minimum possible. Bristlecone pine trees growing on poor site may take as much as 250 years to expand one inch of radial growth, but the woody cells that do develop are so highly lignified and decay resistant that some trees are still standing 2,000 years after their death (interview with Ferguson cited by 88).

Some mammals observed in or near the bristlecone forest zone (80) include spotted skunk, badger, coyote, mountain lion, bobcat, yellow-bellied marmot, golden-mantled ground squirrel, least chipmunk, Colorado chipmunk, valley pocket gopher, porcupine, pika, mountain cottontail, white- and black-tailed jack rabbits, mule deer, pronghorn, and bighorn sheep. About 67 different species of birds have been observed at or above the 10,000-foot level in the White Mountains (79).
Academic research is currently being conducted in this bristlecone area by the University of California (Berkeley & Los Angeles), University of Pennsylvania, Harvard University, and the University of Arizona in the fields of genetics, plant physiology, ecology, and dendrochronology (165).

The Forest Service has provided self-guided trails, outdoor displays, and a seasonal naturalist to interpret this unusual area to visitors. Eventually, the Forest Service plans to extend the auto road to the summit of White Mountain Peak, with interpretive signing along the way. Visitation in 1965 totaled 18,000 people (26) and will continue to grow fast since this area is just now being "discovered" by the recreating public.

RANGES OF CENTRAL NEVADA. A number of isolated mountain ranges in central Nevada between the White Mountains and the Snake Range rise to the altitude characterized by a climatic timberline environment. Most of these mountains are remote, and have received little visitation from scientists or from the public. However, with widespread ecological interest in locating ancient bristlecone pine and other desert species, the future should bring researchers to most of these ranges. Public visitation should also increase as access is improved, and as population and mobility increase. Most of the mountain ranges mentioned are administered under the Toiyabe and Humboldt National Forests.

Mount Grant (11,125') in the Wassuk Range near Hawthorne may have a bristlecone pine forest. The Forest Service (99) reported that
there are no trees at or above 11,000 feet on Arc Dome (11,775'), highest point in the Toiyabe Range. The same source said that shrub-like limber pine grow to 11,500 feet on Mount Jefferson (11,807'), highest point in the Toquima Range. High peaks in the White Pine Mountains west of Ely attain 11,513 feet, those a few dozen miles southward (Troy Peak) reach 11,268 feet, and Haystack Peak in the Deep Creek Range northeast of Ely is 12,101 feet. Many other ranges have points above the 10,500-foot level.

A 3100-year-old bristlecone was found in the Schell Creek Range east of Ely a decade ago (Schulman, see 37). High peaks here include North Schell (11,890'). The Bureau of Land Management has set aside a 480-acre natural area in a bristlecone pine stand 15 miles north of Ely (16). The northern limit of bristlecone pine is reported to be Spruce Mountain, Nevada (Wright, 1963, see 88), presumably the Spruce Mountain (10,262') which is 90 miles north of Ely. But the area of greatest recent interest as far as bristlecone pine discovery is the Snake Range east of Ely.

SNAKE RANGE. Wheeler Peak (13,061'), the highest point in eastern Nevada's Snake Range, rises high above timberline. It is even reported to have a small, but active glacier upon it (76), the only one in the entire Great Basin. The highest portion of the range is in Humboldt National Forest, and the area around Wheeler Peak has been proposed for a Great Basin National Park. The Forest Service (131) reported that Engelmann spruce, limber pine, subalpine fir, and bristlecone pine are present in the timberline forest of the Snake Range. Currey
found Engelmann spruce and limber pine to be codominant in much of the timberline forest. The spruce extends higher than limber pine. In local areas where bristlecone pine grows, it and the spruce occur predominantly in the form of krummholz above about 11,200 feet (90). LaMarche found krummholz at altitudes over 12,000 feet. He also observed an excellent "fossil timberline" of "standing snags, stumps, and remnants of forest trees" which is "... clear evidence that the upper limit of tree growth has declined within the past few thousand years." A similar bristlecone "fossil timberline" has been observed in the White Mountains and elsewhere.

The most exceptional thing about the Snake Range timberline trees is the recent discovery of the "Once Oldest Living Thing." This is a 4900-year-old bristlecone pine cut down and aged by Donald Currey (37). The tree grew at 10,750 feet beneath the northeast face of Wheeler Peak. A dead stem stood 17 feet high and the tree had a circumference of 21 feet at a point 1 1/2 feet above the ground. The trunk was mostly dead and much eroded.

Currey counted 1,844 annual rings in a section to the pith taken 100 inches above the ground. He found that growth had averaged about 53 rings per inch. He cited Schulman and Ferguson (1956) finding that "intra-annual" or false rings were not a serious problem among bristlecone pine. Allowing for the tree to reach the section height of 100 inches (8 1/4"), and for missing growth rings Currey came up with an age estimate of 4900 years. If in fact there should be an allowance for missing rings, perhaps a more accurate estimate would be 5000 years, since Currey's 56-year allowance seems at best barely
adequate for covering the 100-inch height growth alone.

Several investigators have concluded this ancient tree was a "living freak," and that similarly old specimens will probably not be found in the area (155). It is most unfortunate that this "Once Oldest Living Thing" was killed in the name of science, when other workers in this field have consistently aged similar "ancients" by borings, without destroying them (155).

Currently, public visitation to the Wheeler Peak area timberline is slight, because access is gained only by a long hike (156). Interpretive development for the area is almost certain to come soon regardless of which agency administers it.

Northern Great Basin Vicinity

_**Northern Nevada Ranges**_. The Ruby Range near Elko, Nevada, is a high-country scenic area gaining popularity with hikers. The Humboldt National Forest administers the area. Several of the high peaks exceed 11,000 feet, with Ruby Dome (11,349') the tallest. Elevation of the forest line is about 10,500 feet, with subalpine fir, and whitebark and limber pines constituents of the highest forest (131).

The Matterhorn (10,839') is tallest in the Jarbridge Mountains just south of the Idaho Border, with the timberline similar to that of the Ruby Range, but probably without appreciable whitebark pine (131). The sporadic distribution pattern of high-country trees in the Great Basin area is particularly interesting. It apparently has resulted because of the great isolation of individual ranges.

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WARNER MOUNTAINS. The highest part of the Warner Range is located in extreme northeastern California, with the highest points being Eagle Peak (9892') and Warren Peak (9710'), both within the South Warner Wild Area, Modoc National Forest. Whitebark pine dominates the forest from 8500 feet upward (182), occurring as krummholz on the summits. Lodgepole pine is found up to about 8500 feet, and white fir to 8000 feet in a few spots. Above 9000 feet vegetation is sparse. Animals summering in the whitebark zone include mule deer, sage hen, and small rodents.

STEENS MOUNTAIN. Steens Mountain (9720') rises more than a vertical mile above the southeast Oregon desert. Its long, broad summit has an alpine environment, but there is no timberline as such simply because the mountain has no forest. There are scattered aspen woodlands in the gorges, cirques, and on gentle slopes between about 6000 and 7500 feet. The lowest skirts of the mountain support scattered juniper trees—apparently western juniper (31). There is also one small grove of white fir, though no other occurrence of this species is reported within a radius of 100 miles (172).

Nevertheless, there is no coniferous forest on this 50-mile-long fault-block mountain, though an alpine habitat complete with corresponding vegetation occurs all along an 11-mile stretch of the crest. This makes Steens Mountain phenomenal, perhaps unique, among high mountains of North America. Even the White Mountains' (Calif.) alpine is bounded along some of its sides by the bristlecone and limber pine forest. More unusual is the fact that this Steens
Mountain situation occurs in the Pacific Northwest, rather than the arid Southwest.

The Bureau of Land Management (172) reported that there is fair survival (possibly only short term) of ponderosa pine when planted along the lower slopes. Still, it seems unlikely that the absence of forest species is due entirely to imperfect distribution. The unusual climate would seem to be more critical.

Annual precipitation in the valleys beneath the mountain averages about 8 inches. This is very low, but not less than that of many other lowlands surrounding high mountains in the Great Basin. The unusual thing about Steens is that this tall massif does not receive much more precipitation than alkali desert below. The highest slopes are estimated to receive 10 to 12 inches annually (172). It may be that only the upper slopes of Steens Mountain are sufficiently moist to support ponderosa pine (P. ponderosa), the native forest tree requiring the least water. But, where it becomes moist enough for ponderosa to grow and reproduce, this point is too high and cold for its survival. The same might be true for all other naturally available conifers (Douglas-fir, whitebark pine, etc.). In effect the dry timberline may occur so high that it is above the cold timberline.

A rule of thumb for ponderosa pine distribution in southeastern Oregon is that stands will develop only where annual precipitation averages about 12 inches. Perhaps bristlecone pine would be able to survive here, though Steens Mountain is about 200 miles north of this species' distribution. Moreover, Steens Mountain is apparently drier than even the bristlecone ranges. Mats of common juniper do occur at
the edge of the alpine around 9000 feet on the western slope of the mountain (Plate 23).

Steens Mountain is part of an expansive landscape about 150 air miles from the nearest city—Boise, Idaho. However, it is gaining popularity as a scenic and hunting area. The Bureau of Land Management has completed a recreational loop road that passes through magnificent terrain in climbing up to the crest at above 9000 feet, and descending via an equally interesting route.

Northern Intermountain Ranges

STRAWBERRY MOUNTAIN. Strawberry Mountain (9052') near John Day is the highest point in the Strawberry Range of eastern Oregon. The summit projects above forest line (about 8000'), but trees are found almost to the top in sheltered draws (128). Species in the timberline apparently include subalpine fir, whitebark pine, Engelmann spruce, and some mountain hemlock. The high-country of the range is classified as the Strawberry Wilderness by the Forest Service.

BLUE MOUNTAINS. Only one area of the rather extensive Blue Mountain system of northeastern Oregon and adjacent Washington appears to be high enough to exhibit a timberline zone. This timberline area extends from Anthony Lakes along Elkhorn Ridge west of Baker, Oregon. High, rugged peaks include Rock Creek Butte (9105'), Red Mountain and Twin Mountain (both 8920'). The timberline zone is probably similar in elevation and composition to that of the nearby Wallowa Mountains, except that lodgepole pine occurs at timberline in the Anthony Lakes area (54), but is not common in the Wallowas' timberline.
A national forest ski area, resort, and campgrounds are located between 7100 and 7300 feet near Anthony Lakes. Hiking trails and one forest road extend into the timberline zone.

WALLOWA MOUNTAINS. The Wallowas are a cluster of high mountains occupying the northeast corner of Oregon. Nearly 40 peaks here surpass 9000 feet elevation and 34 lakes lie at or above the 7500-foot level, almost as high as forest line on cool exposures. Most of the timberline country is administered under the 216,000-acre Eagle Cap Wilderness by the Forest Service, Wallowa-Whitman National Forests.

Trees of the Wallowa timberline include whitebark pine, Engelmann spruce, and subalpine fir. Tree limit averages about 8500 feet on warm exposures, with scrub line about 9000 feet, the principal conifer at such heights being whitebark pine. The altitude of timberline is greatly depressed on cool aspects.

An alpine zone occurs above about 9000 feet on warm exposure and beyond about 8500 feet on cool aspects. However, widely scattered krummholz whitebark pine grows as high as the summit of Aneroid Peak (9702') and atop Eagle Cap (about 9600'). The two highest peaks, Matterhorn and Sacajawea (about 10,000'), appear to be completely bare of even whitebark mats for the last 500 feet.

No roads reach the high-country, but there is a 300-mile-long network of trails providing access for a few thousand summer and autumn recreationists annually. The climate is not unlike that of the Sierra Nevada, with heavy winter snowfall, but long dry summers. Permanent snow patches remain, though there are no existing glaciers.
SEVEN DEVILS MOUNTAINS. The Seven Devils Mountains across Hells Canyon (Snake River) from the Wallowas rise to a maximum of 9393 feet and have a timberline environment similar to that of the Wallowas, though not so extensive.

A forest road beginning at Rigging, Idaho, climbs to Seven Devils Campground (about 7500') and to a parking area at 8100 feet on Heavens Gate Peak. From here a 1/4-mile trail ascends the 8431-foot summit which is being developed as an interpretive viewpoint. Heavens Gate is in a timberline forest primarily of scattered, big whitebark pine. The view is exceptional, affording visibility into four states on a clear day (Idaho, Oregon, Washington, and Montana). On the west is Hells Canyon with the Snake River just out of sight over 7000 feet down. The viewpoint is at upper timberline, but with lower timberline (about 4000') apparent on the slopes still high above the Snake and Salmon Rivers. The Seven Devils Mountains are also imposing, and pikas occupy the coarse talus on this Heavens Gate Lookout. Forest Service plans include development of a Hells Canyon-Seven Devils Scenic Area of 130,000 acres.

IDAHO BATHOLITH. Eastward from the Seven Devils, the vast Clearwater, Selway, and Salmon River country mountains have many peaks that are too rugged and exposed to support normal forest growth; however, few are high enough to have a climatic tree limit (averaging 9000').

The Sawtooth, Boulder, and Pioneer Mountains, Whitecloud Peaks and other ranges of central Idaho south of the Salmon River have alpine summits. These ranges form a complex labyrinth of high,
rugged terrain in the center of the Idaho Batholith. High summits range from 10,000 to 12,078 feet and many hundreds of timberline lakes of glacial origin dot the area. Little ecological investigation has been made in these areas, however.

Highway U.S. 93 winds through the center of this massive uplifted complex, and outdoor recreation opportunities are abundant and diverse. Galena Summit (8752'), in the center of this area, is the highest highway point in the state, and is in the upper timberline. The area between Sun Valley and Stanley is especially popular with recreationists and will warrant much interest in public interpretation. Part of this vicinity has been proposed for a new Sawtooth National Recreation Area.

Most of the timberline forest is composed of whitebark pine, Engelmann spruce, and subalpine fir (22). There is an abundance and diversity of big game animals, many of which summer in the timberline zone. Most of the precipitation comes as deep winter snows, and permanent snowbanks persist below many of the high peaks. The timberline is very rocky, but is not as dry as that found eastward in the Lost River Range.

ARID EASTERN IDAHO RANGES. The Lost River and Lemhi Ranges have a very pronounced and interesting set of timberline zones, lower and upper. These ranges are parallel to each other, extending roughly 70 miles diagonally northwest-southeast. Both ranges are located in an arid area of eastern Idaho, in the rain shadow created by the central Idaho mountain complex. Both ranges are impressive fault-
blocks rising above broad, dry 6000-foot valleys. High summits along the Lost River Range vary from 11,000 to 12,655 feet while those on the Lemhi Range run from 10,500 to 12,197 feet.

The local base level below these ranges is high and there is so little moisture in the high valleys that lower timberline averages about 7500 feet. This is about as high as the alpine line in Glacier Park only 250 miles northward.

The upper forest line in the Lost River Range averages about 9500 feet, so the forest belt is a scant 2000 feet wide (see Plate 14). The forest that has developed exists under especially dry conditions, and on some warm exposures the forest belt is locally absent. Such complete breaks in the forest zone are not the result of fire, steep

Plate 14. Looking east to the Lost River Range from Highway U.S. 93A. Mount Berah (center, 12,655') rises 6350 feet above Thousand Springs Valley, but the forest belt is only 2000 feet wide.
topography, etc.; rather, they are due to extreme dryness, dry timber-line having been elevated locally to a point higher than the cold timberline.

Limber pine is present at both lower and upper timberlines on at least the southwest side of the Lost River Range. Here, on the flank of Mount Borah (12,655'), Douglas-fir is a forest component as high as 9000 feet. Engelmann spruce occurs only in the upper half of the forest belt, and limber pine occurs throughout, but predominates in the upper half of the forest.

The timberline zone is narrow with forest line about 9500 feet, tree limit near 9800 feet and scrub line about 100 feet higher. The highest krummholz discovered on Mount Borah were spruce at 10,500 feet. The alpine zone is rather extensive, but it is quite barren, too rocky, dry, and steep for the development of anything but the most dispersed plant community. The winter snowpack had melted off all but the sheltered slopes of the Lost River Range by the end of May, 1966, while much lower mountains in this region were mostly snow-covered above 8000 feet at that time.

Commercial and recreational uses of these arid ranges have been very slight, and are likely to remain so for some time. However, a major highway passes beneath the Lost River Range affording tens of thousands of travelers a good look at an intriguing piece of landscape.
THE FAR NORTH (Northward from 55 degrees N.; see Figure 7)

Far Northern Rockies

The Rocky Mountain system, north of 55 degrees N., is a vast and intricate network of mountains. Even a general description of the upper timberlines in this region could easily fill a book. However, the discussion that follows is extremely brief for several reasons: (1.) Very little information is available on the subject; (2.) the region is so remote that detailed discussion for the purposes of this paper is unwarranted; (3.) for most purposes the timberlines of that region can be considered rather uniform over broad areas, unlike the great variety of timberline types found in the western United States.

White spruce (Picea glauca), black spruce (P. mariana), lodgepole pine, subalpine fir, and possibly tamarack (Larix laricina) in about that order of abundance are the conifers growing at timberline in the Far Northern Rockies. The former is by far most frequent, and the shrub, common juniper is present throughout much of the area also.

Trutch Mountain summit (4134', 57°N. x 123°W.) British Columbia, along the Alaska Highway east of the Rocky Mountain Divide is well below forest line, covered with white and black spruce and lodgepole pine. Summit Lake (4200') on the highway (58°N. x 125°W.) is within an eastern range of the Rocky Mountains. Forest line occurs at the lake, with tree limit being almost 5000 feet. The interior spruces, white and some black, are the only prominent conifers at timberline. Willow shrubs a few feet high form krummholz on coarse rock piles a few hundred feet higher than any spruce (see Plate 27).
Figure 7. Northwestern North America, showing the continental tree limits (116).
Along the Canol Road, Yukon Territory (61°N, x 133°W.), timberline in the Pelly Mountains is apparent. Lodgepole pine are found at lower elevations, but the interior spruces form the forest line at above 3000 feet (see Plate 15). Porsild (124) traveled the entire 521-mile length of the Canol Road during the brief period in the 1940's when it was kept open. He studied the vegetation along the route, and made the following observations concerning the forest trees on the east slope of the Mackenzie Mountains, which form the boundary between the Yukon and Northwest Territories.

Forest line on the east slope of the Mackenzies (63°N, x 130°W.) occurs at about 3900 feet (124). The prominent tree species is white spruce, with black spruce restricted for the most part to lower country. Tamarack (L. laricina) was observed at 3600 feet, and a few stunted subalpine fir occur in MacMillan Pass (about 5000') on the Mackenzie Divide. Common juniper grows in many places. White spruce alone are found at tree limit (4650') east of 5000-foot Caribou Pass which is northeast of MacMillan Pass. Near its end (65°N, x 127°W.) the Canol Road climbed atop a strictly alpine plateau (5700') known as the Plains of Abraham.

Keno Mountain (6220') in the central Yukon Territory (64°N, x 135°W.) is probably the highest auto-accessible point in the Far North. This spot is located near the northern end of the Rocky Mountain system in the Ogilvie Range. White spruce and subalpine fir occur at tree limit (above 4000'), though there is very little krummholz formation. The unpaved road climbs to a parking area at 5500 feet in luxuriant alpine tundra. Ravens, ptarmigan, and grizzly
Plate 15. Far Northern marsh bordered by typical black spruce, near Fort Ross on the Canol Road, Yukon Terr., with the Pelly Mountains behind.

bear are common residents of the high-country in this rich mining district of the Yukon Rockies.

Coastal Alaska

Sitka spruce and mountain hemlock are the most common conifers at timberline in southeastern Alaska (71), with lesser amounts of Alaska-cedar and occasional subalpine fir and lodgepole pine (shore pine). Tree limit ranges from as high as 4000 feet near the southern tip of the Alaskan Panhandle to under 1000 feet in parts of the Prince William Sound area (34). In general the altitude of forest line decreases north and west along the Alaskan Coast (71); however this trend is by no means a steady progression. Local climatic patterns (particularly snowfall), exposure, and other factors often limit timberline in a specific vicinity.
The climate of the Alaskan southern coast is extremely maritime. Mean annual precipitation along the coast ranges from 60 to 70 inches at Seward and Valdez to 221 inches at Little Port Walter on Baranof Island (169). Annual snowfall in the timberline zone compares with that of western Washington, with the record 974.4 inches at Thompson Pass during the 1952-53 season, and an average over 600 inches there for the short period on record.

The following are brief descriptions of the timberline in some popularly visited areas of coastal Alaska.

On the west slope of Mount Roberts, which towers above the city of Juneau (58°N.), western hemlock is replaced by mountain hemlock at about 1000 feet. Mountain hemlock and Sitka spruce in that order make up the high-country forest; but the spruce alone ascends to scrub line, about 2000 feet. There is an abrupt timberline in much of this area, with a forest of 50 to 80-foot-tall trees growing to the edge of alpine in some spots. Sitka alder (Alnus sinuata), here as elsewhere all along the southern coast of Alaska, forms dense brushy groves extending several hundred feet above the coniferous tree limit.

The vegetation develops luxuriantly here, as at other coastal timberlines. For instance, Thompson (150) found alpine bog vegetation even on well-drained slopes at timberline near Whittier, in the Chugach Range. Though Sitka spruce reaches its upper limit near 2000 feet on Mount Roberts, Heusser (78) noted isolated Sitka spruce at almost 4000 feet on nunataks in the nearby Juneau Icefield, a seemingly hostile environment.

The Forest Service has erected a strikingly picturesque visitor
center at the nearby Mendenhall Glacier, and a naturalist is stationed there throughout the summer season. Timberline along the mountains immediately above this splendid vantage point is very noticeable, as is the case throughout much of coastal Alaska.

Along the Richardson Highway to Valdez, Thompson Pass (2722') in the Chugach Range is an impressive climb into the alpine zone, comparable to a mountain pass 10,000 feet higher than this in Colorado. Tree limit occurs below 2000 feet on the descent into the Port of Valdez, with Sitka spruce and Sitka alder the common tree species.

The Forest Service's new Portage Glacier Recreation Area is located at the base of the Kenai Peninsula about 50 miles from Anchorage. The Service has erected a new visitor center with many interesting interpretive displays overlooking Portage Lake and the glacier. Also, there is a self-guided nature trail that interprets, among other items, one sided crowns of windblown Sitka spruce. Sitka spruce is the dominant tree species, forming krummholz at or below 1000 feet elevation on the seaward slopes of the rugged Kenai Mountains. Nearby is the Mount Alyeska scenic chairlift that transports recreationists year-round to the 4000-foot level, high in the alpine (77).

Mount Marathon is a popular attraction rising above Seward and its fiord, Resurrection Bay (see Plate 15). The alpine zone on Marathon extends down to about 1500 feet. Mountain hemlock and Sitka spruce form the highest forest zone, but spruce krummholz again extends higher (1800') than other conifers. Everything in distant view at the
Plate 16. Seward fiord, showing the narrow spruce-hemlock forest belt (darkest green), sea level to 1500 feet, with Sitka alder shrub growth forming the next higher zone (medium green), and strict alpine above that.

2000-foot level is strictly alpine.

Behind the Coast Mountains

The climate and vegetation of the interior slope of the Coast Mountains differs markedly from that of the Pacific shore in Alaska. The interior slope is much drier and it has more pronounced temperature extremes. Permafrost occurs throughout much of the interior landscape, having an effect upon the vegetational community.

The forest species and elevation of timberline are similar to that of the Far Northern Rockies, except that lodgepole pine is not present in the Alaskan interior. White spruce is the dominant conifer at tree limit, followed by black spruce (177). Where the two spruces occur together at alpine timberline, white spruce is erect and
black spruce usually forms krummholz. This situation also occurs at tree limit in eastern Canada.

Tamarack (L. laricina), aspen (P. tremuloides), and paper birch (B. papyrifera) do not reach alpine or polar tree limits, though the birch may occur with spruce at tree limit temporarily as a result of fire (177). Balsam poplar (P. balsamifera), especially in Mount McKinley National Park, is found in small isolated groves as much as 1000 feet above the spruce tree limit. The poplar inhabits recent moraines and other coarse sites, and becomes conspicuous at a distance in autumn when its leaves turn yellow.

Tree limit averages about 3500 feet in the interior, but the timberline is usually indistinct. The upper forest is patchy and widely scattered about in most cases. Permafrost is the chief factor limiting forest development on the lowlands at polar timberline (73); however on upland slopes its main effect may be indirect. Haugen has found that the seasonal thaw of perennially frozen ground contributes to a superabundance of soil moisture which causes many upland slopes to creep (solifluction), thus limiting timberline. Some flat upland terrain, e.g., in McKinley Park, exhibits an erratic forest distribution that may be inversely related to the depth to permafrost.

Haugen has found that temperature is by far the most important factor determining the position of timberline in the Yukon-Tanana Uplands north of Fairbanks (73). Wind and snow are not of direct importance, and from the standpoint of these three factors the situation resembles that of the Mexican volcanoes. Haugen also said moisture is of minor consequence since the soil is nearly always
saturated at timberline.

The forests of the semi-arid Western States commonly occur only on the mountain slopes, since intervening valleys are too dry; however, an opposite pattern occurs in many areas of inland Alaska and the Yukon. The spruce forest often grows across broad valleys, but does not extend up even the lowest flanks of the mountains.

Mount McKinley National Park, on the north slope of the Alaska Range, is known as a "subarctic wilderness," because the vast alpine environment that covers most of the area is as closely akin to the nearby "Arctic" as to the "alpine" which we normally associate with high altitudes. Tree limit (disregarding the poplar) averages about 3000 feet in the McKinley area, with perhaps 90 percent of the park being above timberline (103), either alpine or permanent ice and snow (see Plate 17). Dwarf alpine willow occurs as high as 5000 feet in this area (8).

Between McKinley and the true Arctic lies the vast Yukon River drainage including several upland areas. The Steese Highway to Circle City climbs atop the Tanana-Yukon Uplands at 3880-foot Eagle Summit, about 100 miles northeast of Fairbanks. Forest line is about 3000 feet on these rolling hills, with the tree limit at 3500 feet. White spruce is the conifer forming timberline, and the road extends across the subarctic alpine tundra for 6 miles at this point.

Though Eagle Summit (65\(\frac{1}{2}\)ON.) is 70 miles south of the Arctic Circle, the view northward is across the Yukon River lowlands and the loft of this lookout allows it to receive the midnight sun at summer solstice (longest day of the year in the northern hemisphere, about
Plate 17. Mount McKinley (20,300') from a marsh near Wonder Lake at about 2000 feet, illustrating the very scattered occurrence of white spruce that characterizes much of this region.

June 22nd). This phenomenon brings to mind a basic difference between the temperate alpines, and subarctic alpines and true Arctic—the long periods of warm sunshine in the subarctic and arctic summers. But this is dealt with under the following section, on polar timberline.

Arctic and Alpine (lowland, cold timberlines)

In a general way, for the northern hemisphere, it is true that ascending a mountain is like traveling northward. The principal similarity between ascending altitudes and latitudes is that the environment becomes progressively cooler. Isotherms of mean temperature generally form a pattern resembling contour lines on a topographic map, except that the lowest mean temperatures occur at
the highest altitudes. Also, isotherms on the earth roughly form a pattern like the latitudinal lines. However, the cooling progression up a mountainside is extremely abrupt compared with the cooling progression toward the Arctic. Climbing 1000 feet in altitude may simulate traveling a few hundred miles north.

It is not surprising, then, that the northern timberline is much less distinct than alpine timberlines. In fact, polar timberline is generally a very diffuse zone many dozens of miles wide. As with alpine timberlines, the northern timberline, in northern Canada, "... broadly speaking follows the 50°F. (10°C.) isotherm for the warmest month of the year" [123]."

Nordenskjöld's arctic limit, which makes use of the mean temperature of the coldest and of the warmest month (formula, p. 15), also coincides roughly with the arctic tree limit over much of its extent (91). Larsen (91) said that in Alaska the 50 degree F. isotherm and the Nordenskjöld formula both fail; however he cited Hopkins (1959) who found a correspondence between the tiaga (circumpolar forest belt) and tundra using the number of degree-days above 50 degrees F. and the mean temperature of the coldest month. Larsen also noted a coincidence between the southern limit of permafrost and the northern limit of forest trees. He said that although geographic evidence indicates that there are causal relationships among these correlations, there has been little attempt to discover the mechanisms involved.

Larsen observed that past fires play an important part in the distribution of the northern timberline forest. LePage (93) felt
that the trees are limited to south of the 58 degree N. parallel in Quebec because north of this boundary soil is not present since cold prevents microbial activity. He said that black spruce and tamarack can live in the worst climate if they have soil. Perhaps this observation is better concluded, "if such a climate is warm enough to permit soil to develop."

Marr (97) studied the northern timberline belt at 53°-56° N. on the East Coast of Hudson's Bay and found that the climate at tree limit is favorable for forest growth. However, the scarcity of soil in this land of barren, glacially-overridden bedrock does not allow forests to develop.

There has been speculation concerning the fact that white and black spruce are best adapted to timberline growth in the Far North. Perhaps the spruces pervail because they are the most shallow-rooting of conifers, requiring less "soil" above permafrost than other species. Subalpine fir and Engelmann spruce, most prevalent at timberline in the southern Canadian Rockies, do not reach the northern-most timberlines.

Polunin (121) showed that the roots of Betula odorata, the tree which extends farthest into arctic Lapland, can actively conduct water through at least half a meter of hard-frozen soil. But these trees do not grow where the frozen layer is thicker because their roots cannot penetrate it. Birch or other species may behave similarly on this continent.

With the slow retreat of the arctic ice cap, a northward advance of the tree limit has been observed in much of Alaska (61),
eastern Canada (97), Scandinavia, and elsewhere. Griggs (64) noted that even the early Russian settlers had discovered that the forest near Kodiak, Alaska was migrating into former tundra. The Sitka spruce advancing at Kodiak grows vigorously and is advancing at a perceptible rate following the northward creeping July 50-degree F. isotherm. Griggs (62) said that this isotherm becomes the limiting factor about 250 miles beyond the present tree limit in this part of Alaska. Griggs (61) found that peat bogs on Kodiak Island received no spruce pollen between the last glaciation and the deposits made during the present.

In Alaska the northern tree limit is primarily an alpine tree line along the south side of the Brooks Range (177). White spruce grow to less than 3000 feet in the Brooks Range, and do not occur north of 69 degrees N. (47). However, spruce are found north of the east end of the Brooks Range in the Davidson Mountains along the Firth River in extreme northeastern Alaska (177). Furthermore, there are several small stands of balsam poplar reported along rivers on the north slope of the Brooks Range.

Though tamarack (L. laricina) does not occur at tree limit in Alaska, a close relative, the Dahurian larch, Larix gmelini, ascends farther north than any other conifer in the world. It grows as far as 72\textfrac{1}{2} degrees N. at the Arctic Coast near the Lena River in Siberia, about 80 miles farther north than Point Barrow, Alaska (116).

At the Alaskan polar timberline, altitude up to perhaps 2500 feet does not further limit tree growth. That is, trees may grow approximately as far north at sea level as at 2500 feet elevation,
under the arctic climate. It is interesting to note that tree limit
at Seward, for instance, is lower than in the Brooks Range 600 miles
north.

Alaska also has a "western timberline" on the lowland tundra
(see Figure 7) resulting from the severe climate along the West Coast
(177). Above the base of the Alaska Peninsula, this western timberline
becomes a "southern timberline" which roughly follows the 60 degree N.
parallel across southwestern Alaska (111). Tree growth is presumably
restricted to the area north of this boundary by the severe maritime
climate.

Primary differences between the growing conditions at arctic
and alpine timberlines include the following: Air pressure is lower
at alpine timberlines; this affects evaporation, carbon dioxide
relationships, etc. Superabundant snow and wind conditions are
important at alpine, but not generally at arctic tree limits. Summer
drought and ultra-rugged terrain and exposure are often crucial at
alpine timberlines, though not important at arctic timberline.
Nighttime temperatures drop to near and even below freezing at alpine
timberlines during the warmest month of the year, while the 24-hour
sunlight of the Arctic moderates daily temperature extremes in the
summer.

Permafrost is important at the arctic timberline, while it is
much less common at alpine timberlines. In the latter case mountain
slopes and coarser soils result in better drainage. Also, the
insulation of heavy winter snowpacks along with less-prolonged cold
temperature does not allow formation of widespread permafrost.
Still other differences between alpine and arctic timberlines include the presence of a luxuriant tundra mat at polar timberline, while trees at alpine timberline often have negligible competition from other vegetation. And, while the position of alpine timberlines is relatively static, northern timberline is advancing. In some areas of Alaska the lowland timberline's advance is limited by the speed at which the forest itself is able to spread (61).

Alpine timberlines in the interior of Alaska and in the Yukon are more like the arctic timberline in many of these respects than they are like alpine timberlines of the temperate zones. As previously noted, the terrain of Mount McKinley National Park has been termed "subarctic," rather than "alpine," though the latter is correct under present terminology. "Subarctic" is a descriptive that does "fit" this region, and perhaps it would be more appropriate to employ this term in discussing extreme northern alpine and timberline areas. For example, McKinley Park can be said to have a "subarctic alpine" and a "subarctic timberline." Such timberlines (subarctic) are those characterized by conditions as akin to arctic timberlines as to alpine timberlines. In contrast to McKinley, the low-altitude timberlines of the southeastern Alaskan Coast are definitely "alpine" timberlines.
Altitudinal Limits

As discussed previously tree limit occurs as low as about 1000 feet elevation on the Alaskan Coast and as high as 12,000 feet in the Rockies of New Mexico and Colorado. The same boundary is found near 13,500 feet in Mexico, but it is at least that high in the Himalayas, many degrees farther north, in the latitude of southern Texas. Swan's description (146) indicated tree limit (fir and tree rhododendron) is at least 13,500 feet, with dwarf rhododendron and juniper—probably J. squamata (17)—extending to a krummholz limit of 17,000 feet.

Ostenfeld et al. (116) cited findings of the Chinese larch, L. potanini, at 10,800-15,750 feet near 30 degrees N. in southwestern China. Assuming the upper altitude is correct, this may well be the world's highest coniferous tree species. The highest conifer in the western hemisphere is thought to be the "Mexican mountain pine" (P. hartwegii) or the juniper, J. monticola, the former occurring above 14,000 feet on Sierra Negra near Orizaba, and the latter reported this high also (181).

Daubenmire (42) has found that the highest altitude timberlines in the Americas occur at about 30 degrees N. and 25 degrees S. latitude, with a slight depression of timberline toward the equator. He believed that northward across the mid-latitudes in the Rocky, Coastal, and Appalachian Mountains the tendency is for timberline to drop about 360 feet per degree of latitude, under a given type of climatic regime.

The equatorial depression of timberline may occur elsewhere
around the world. Timberline in New Guinea, only about 5 degrees south of the equator, is reported to occur around 11,000 to 12,000 feet (179), though a maritime climate or tropical flora might be responsible for this low altitude. Giant groundsels (Senecio cottonii) form tree limit near 14,000 feet on Mount Kilimanjaro, at 3 degrees S. in East Africa (135); but these groundsels extend to 15,700 feet on the sheltered southwest flank of Mawensi, one of the peaks.

Tree limit occurs at about 12,000 feet in the Andes around 20 degrees S. latitude; but eastward in the Serra do Mar mountains of Brazil the transition to alpine is reported by Clausen (27) to occur at the surprisingly low elevation of 6400 feet. Temperatures recorded at 7200 feet, well within the alpine bush and grass zone here, are very moderate. The mean daily minima for the coldest month of the year is 41 degrees F. with slight frosts and snow only occasionally. The lowest temperature on record at this station is 22 degrees F. Clausen's data indicates that about 10 months of the year have mean temperatures above 50 degrees F. in this alpine area. He explained, however, that only tropical tree species are present, and since they have not evolved under temperate climes (like North American conifers) they have much higher heat requirements than the temperate zone species.

The highest known plant is a cushion plant (Stellaria decumbens) found at 20,130 feet in the Himalaya (146). Animals range much higher in this area. Yellow-billed black birds called "choughs" (Pyrrhocorax graculus) visited high camps of early Everest expeditions at nearly 27,000 feet, and bar-headed geese (Eulabeia...
Indica) fly directly over the top of Mount Everest (29,028').

One rather significant measure of a mountain's stature is the height it extends above the timberline zone. The tallest mountains by this measurement are, in general, those that are least hospitable to life. The environment becomes progressively less hostile extending down the altitudinal scale toward timberline. Under this measuring system the world's highest mountain would be Mount McKinley, 17,000 feet above the alpine line. Everest rises about 14,000 feet; the Alps 9000 feet; Mount Rainier 8000 feet; southern Canadian Rockies 6000 feet; Mexican volcanoes 5000 feet; North Cascades (excluding volcanoes), Sierra Nevada, and Wind River Range 3000 feet; Colorado Rockies and Glacier Park about 2500 feet; Olympic Mountains about 2000 feet; San Francisco Mountain and the White Mountains, New Hampshire 1000 feet; and many ranges of the western United States, from 0 to 3000 feet above the timberline belt.

West-East Effect on Timberlines

The latitudinal effects upon alpine timberline formation have long been noted; however the longitudinal (west-to-east) changes in timberline are often more dramatic and complex in western North America. Two factors are largely responsible for the marked eastward rise of the timberlines: (1.) The climatic pattern, with maritime influence decreasing eastward from the Pacific Coast; (2.) The geographic pattern, with north-south oriented mountain systems and with generally increasing elevation of base level of intervening

\[\text{1 disregard high peaks in Antarctica, which range up to 16,820 feet (112, but 1966 edition)}\]
lowlands eastward from the Pacific to the Continental Divide Rockies. The longitudinal changes in composition of the timberline also have an effect on the altitude of timberline. Composition changes are themselves influenced by the climate, but also by plant geography, or factors of distribution. Important to the latter case is that North American mountain ranges (outside of Alaska) extend north-south, facilitating migration of plant species latitudinally, while presenting barriers to their west-east migration.

The discussion of the North Cascades and Olympic Mountains of Washington dealt with west-to-east changes in timberline across the width of one mountain range. The following transects made along a parallel of latitude across the western United States illustrate the west-east differences in alpine timberlines (see Figures 8 & 9 and TABLES 1-3, which follow).

One of the reasons for the relative dearth of species in the coniferous forest of European mountains is thought to be the west-east orientation of the ranges, presenting barriers (intervening lowlands) to plant migration when glaciers came down from the north during various ice ages. This mountain-range orientation and dearth of species contrasts to the situation in western North America.
Figure 8. A rough cross-section of the Pacific Northwest along the 47\(\frac{1}{2}\)° N. latitude, showing the west-to-east rise in the timberline zone—represented here by the shaded belt. This chart can be correlated with Table 1, which follows.

1" = 70 mi.(approx.)
(sectioned distance approx. 60 miles)

Figure 9. A rough longitudinal section along the crest of the Rocky Mountain system, showing the rise in timberline (shaded belt) southward.

1" = 270 mi.(approx.)
(sectioned distance approx. 2,300 miles)
### TABLE 1. Timberlines along a transect of the western United States approximately following the 47\(\frac{1}{2}\) degree N. parallel

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<td>whitebark pine</td>
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<tr>
<td></td>
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<td>lodgepole pine</td>
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<td></td>
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<td>Alaska-cedar</td>
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<td>mtn. hemlock</td>
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<td>Estimated ave. ann. precip. at timberline (169&amp; 171)</td>
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<td>60&quot;</td>
<td>130&quot;</td>
<td>60&quot;</td>
<td>50&quot;</td>
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<td>Approx. local base level (nearby lowland)</td>
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<td>0-1000'</td>
<td>0-1500'</td>
<td>650-2000'</td>
<td>4000-4500'</td>
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TABLE 2. Timberlines along a transect of the western United States approximately following the $45^\circ$ degree N. parallel

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<th>9500'</th>
<th>9700'</th>
<th>10,000'</th>
<th>10,000'</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Dominant timberline tree spp. in approx. order of abundance</th>
<th>mountain hemlock</th>
<th>subalpine fir</th>
<th>whitebark pine</th>
<th>limber whitebark</th>
<th>whitebark lodgepole pine</th>
<th>lodgepole pine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approx. local base level (nearby lowland)</td>
<td>500'(W.)-3000'</td>
<td>5000-6000'</td>
<td>5500-6500'</td>
<td>6000' (E.)</td>
<td>3500-5000'</td>
<td></td>
</tr>
</tbody>
</table>

*Lemhi Range (113°W.) is probably similar to the Lost River Range.
### TABLE 3. Timberlines along a transect of the western United States approximately following the 37°.5 degree N. parallel

<table>
<thead>
<tr>
<th>Location and Longitude (W.)</th>
<th>Yosemite Nat'l Park, Calif.</th>
<th>White Mtns., California</th>
<th>Cedar Breaks N. Mon., Utah</th>
<th>San Juan Mtns., Colorado</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated average tree limit for all exposures</td>
<td>10,600'</td>
<td>11,500'</td>
<td>11,200'</td>
<td>11,700'</td>
</tr>
<tr>
<td>Dominant timberline tree species in approximate order of abundance</td>
<td>whitebark pine</td>
<td>bristlecone pine</td>
<td>Engelmann spruce</td>
<td>Engelmann spruce</td>
</tr>
<tr>
<td></td>
<td>lodgepole pine</td>
<td>limber pine</td>
<td>subalpine fir</td>
<td>corkbark fir (?)</td>
</tr>
<tr>
<td></td>
<td>mountain hemlock</td>
<td></td>
<td>bristlecone pine</td>
<td></td>
</tr>
<tr>
<td></td>
<td>limber pine (?)</td>
<td></td>
<td>limber pine</td>
<td></td>
</tr>
<tr>
<td></td>
<td>w. white pine (?)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Approximate local base level (nearby lowland)</td>
<td>sea level (W.)-6500' (E.)</td>
<td>4000-5500'</td>
<td>5000-6500'</td>
<td>6000-7000'</td>
</tr>
</tbody>
</table>
Timberlines Through Time

The position and composition of timberlines has varied with long-term changes in the climate of the world or that of any region. Hansen (69), for instance, found by analyzing peat bogs at 3300 and 4100 feet in the western part of Glacier National Park, that pollens of lodgepole and whitebark pine were the most numerous immediately following the retreat of the last continental glaciation (about 10,000 years ago). At that time this area on the lower slopes of the mountains was near the upper timberline.

Between about 8000 and 4000 years ago ponderosa pine pollen was the most prevalent in the same bogs (69). The inference is that a warm, dry climate prevailed and that timberline migrated far up the mountainsides (possibly correlating with the "fossil timberlines" of the Great Basin).

During the past 4000 years Engelmann spruce pollen has become the most numerous in these bogs. The climate has become cooler and wetter, probably lowering timberline and quite possibly causing its composition to change from the "dry site specialists," the pines, to spruce and fir, which are better adapted to the moist timberlines. The latter are now dominant in Glacier Park upper timberlines.

The two distributions of foxtail pine are separated by 300 miles and are atop mountain ranges which are not connected. The two distributions of subalpine larch are similarly isolated by about 130 miles. Such broken distributions of timberline species are further evidence indicating that continental glaciation has affected
Knowing about factors that influence timberline formation, it is not difficult to predict which reactions might be expected from timberline vegetation given a change in climate.

However, timberlines also react to short-term climatic changes. For instance, Franklin et al. (55) found that large-scale, sudden invasion of natural subalpine meadows has occurred in Mount Rainier National Park. Investigation of this phenomenon showed that, "... most of the invasion took place between 1915 and 1940 and that establishment of trees has ceased in recent years." After an examination of the possible causes for this invasion, the conclusion was that, "... a warmer, drier climatic period, in the first part of this century, is the probable cause."
VI. TREES OF THE TIMBERLINE

Introduction

The tree species that occur at upper timberline may differ from each other in a great number of respects; but they all have one thing in common. They have adapted to survival under the harshest, coldest growing conditions of nature that can sustain tree growth.

Descriptions of the timberline trees of the western United States and Canada follow. These accounts are brief and incomplete just as is mankind's knowledge of the ecology of the timberline trees. However, it is hoped that the information presented here will sketch a general likeness of the character of each species.

Photographs in this paper show 15 of the 16 conifers described as well as 2 willows. Plate numbers that apply to each species described will be listed in parentheses at the beginning of the discussion of each species. Those plates distinguished by an asterisk appear under the section discussing this tree (i.e., they will follow on the next page or two). Other plates are found elsewhere in the text of this paper and can be found using the "List of Illustrations."
Whitebark Pine (Pinus albicaulis)  
(Plates 1, 5, 2)  

**NATURAL RANGE:** This species occurs at or near upper timberline in the southern half of British Columbia—including Vancouver Island—and adjacent Alberta; northeastern Olympics, Cascade Range, northern California, Sierra Nevada; most mountains in Montana and Idaho south through western Wyoming. It also grows in northeastern Washington, eastern Oregon, northeastern Nevada, and occasionally in northern Utah.

Whitebark pine is well adapted to life at upper timberline on moderately dry mountain ranges, and is most abundant on warm exposures. Throughout much of its range the whitebark grows higher up warm mountain slopes and cliffs than its associates, often forming pure stands of krummholz. It occurs as a shrub at 12,000 feet in the Sierra Nevada, at 9700 feet in the Wallowa Mountains, and at 8300 feet in the northern Cascades rain shadow. Each of these locations is 500 feet above the upper limit of other conifers except for the common juniper.

One reason for the whitebark's success in inhabiting the upper limits of tree growth is its ability to grow in a variety of forms, though its physiological adaption is probably still more basic to its success. Whitebark can exhibit any form from that of a minute mat, bushy spreading shrub, erect multi-stemmed tree, or gnarled giant with one massive trunk in the timberline. The species develops a long tap

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1 The data regarding distribution comes from several references (164, 96, 55, 30, etc.) and from the writer's observations.
root to anchor it (30) and like its close relative, limber pine, the whitebark has branchlets so supple they can easily be tied in knots without breaking. Yet the wood on dead trunks is often whitened, weather polished and virtually "hard as stone."

Whitebark is classified under the group Cembrae, the "stone pines," rather than with the other five-needle white pines, like western white pine (30). Its cones are alone among all pines in that they fall apart on the tree, like fir cones, scattering scales and seeds all about. That is, they disintegrate on the tree when not harvested first by a chipmunk, Clark's nutcracker or other creature.

The tasty whitebark seeds are about half as large as pinyon nuts (average 3600/lb.(16l)) and often most of the crop is gathered by animals. In the Wallowa Mountains after chipmunks and pine squirrels harvest huge quantities of whitebark cones, they often bury them farther down the mountainside. Black bears sometimes locate these caches and unearth the delicacies (44). The buds and even needles of whitebark and its associates often make up winter rations for blue grouse, gray jays, red squirrels and other animals.

Whitebark nuts are dispersed more effectively than their heavy weight would suggest. For instance, in the Olympics lone sentinels and seedlings of the species grow along alpine ridges often a few miles from the nearest possible source of seed. Birds and rodents probably "plant" a substantial amount of whitebark seed.

John Muir is said to have counted 75 annual rings in a whitebark twig one-eighth inch in diameter (30). A tree 17 inches thick was found to be 800 years old. Whitebark pine below tree limit often
develop a single trunk 3 or 4 feet in diameter (dbh) and 50 to 70 feet tall. Such large specimens probably average 400 to 800 years; however, most of them have hollow trunks or at least rotten heartwood. Among the whitebark pine's enemies are lightning, white pine blister rust, and bark beetles.

Throughout its range the whitebark pine is usually restricted to near or above the forest line. However, what appears to be its lowest occurrence in the United States, if not for its entire range, is almost 2500 feet below forest line. This occurrence is at least as low as 3600 feet elevation near Government Camp on the southwest slope of Mount Hood (54).

Bristlecone Pine (Pinus aristata)

(Plates 1,18*,19*)

NATURAL RANGE. Bristlecone pine is widely scattered about high in the mountains of central and southern Colorado and northern New Mexico; San Francisco Mountain, Arizona; southern and central Utah and Nevada; White, Inyo, and Panamint Ranges of California.

Bristlecone pine occupies only arid sites, usually in or near the upper timberline. The bristlecone usually ascends as high as any of its associates (e.g., limber pine and Engelmann spruce) and frequently higher than them in Nevada and California. Bristlecone pine is reported to occur as high as 12,400 feet on San Francisco Mountain (160), probably in the form of a tiny krummholz mat. It grows at or slightly above 12,000 feet in instances in California, Nevada, and Colorado. However, the species is sometimes found in the
mid-altitudes on an extremely dry site. It is one of the few trees that can survive the badlands at 7500 to 9000 feet in Bryce Canyon National Park (8).

Characteristically the bristlecone has an ungainly, weedy form, often with much dead wood, eroded and polished by ice and sand; hence its name "living driftwood." The discovery of the 4900-year-old bristlecone pine on Wheeler Peak, and numerous others 4000+ years of age reveals that this species is the "oldest known living thing," achieving longevity in spite of and because of adversity.

The bristlecone is one of the two "foxtail pines," group Balfouriane, so named because its short needles densely clothe the last 10 or 12 inches of long branchlets, making them resemble a fox's tail. The needles are in clusters of five and are only about an inch long. The name "bristlecone" is derived from the long, persistent prickles that arm each cone scale.

Seeds of bristlecone pine are frequently eaten by rodents (158), and are winged so they are dispersed by the winds. Bristlecone has provided shelter for wildlife at all seasons; however only recently has the species really been "discovered" by mankind. Its scenic and inspirational values are immeasurable, but real. Also, the human race is learning more of the bristlecone's great scientific value through dendrochronology.

The bristlecone pines, living and dead, hold records of climate dating back almost to the last great ice age because they are particularly "sensitive" to wet or dry years (26 & 88). Their ring width reflects the climate so effectively that living bristlecone
Plate 18. A typical high-altitude bristlecone pine at 11,000 feet in the White Mountains, California. Although this scene is in early June, very little snow remains.

Plate 19. Beneath the bristlecones in the last plate was an old bighorn ram horn; but the bristlecone wood is so hardened and weather polished that it resembles the bone.
ring chronologies can be correlated with each other, and with bristlecone snags dead for a few thousand years. The precisely dated bristlecone wood is now being used to check the accuracy of radiocarbon (carbon-14) dating—a process widely used in science. The bristlecone ring records are being used here to determine the magnitude of radiocarbon error caused by varying amounts of this isotope in the atmosphere.

In one case Ferguson et al. (52) have used bristlecone pine wood to calibrate radiocarbon measurements of wood from the ancient Swiss Lake Dwellings. The dwellings were thus determined to be 5700 years old, though conventional radiocarbon dating would have been in error by about 800 years.

**Foxtail Pine (Pinus balfouriana)**

(Natural Range. The species grows at timberline in the southern High Sierra Nevada and atop some high summits in the northwestern California Coast Mountains.

Foxtail pine is one of perhaps the two least known timberline trees (along with subalpine larch), yet it is also among the most unusual and intriguing. The foxtail dominates much of the southern High Sierra, particularly in Sequoia and Kings Canyon National Parks, but, for no apparent reason it does not occur northward in the Yosemite region. Its only other range is on a few isolated peaks, such as Mount Eddy and South Yolla Bolly in northern California's
Coastal Mountains, fully 300 miles from the Sierra distribution.

At about 10,500 to 11,300 feet elevation in the Sierra, where other conifers usually form small several-stemmed trees or krummholz, the foxtail develops a single, erect trunk of immense proportions (3). Furthermore, it always grows erect in the Sierra even under the most exposed conditions (3,8, & 119).

Foxtail pine, closely related to bristlecone pine, is distinguished from the latter by its single-trunk growth form at all altitudes and by having somewhat smaller cones armed with deciduous prickles. These two species are separated in their natural distributions only by the broad Owens Valley between the White and Sierra Nevada Mountains.

Like the bristlecone, foxtail pine inhabits barren rocky sites where summer drought is common. The large trunks are often stripped of bark except for a narrow band of living tissue nourishing a few living limbs on the sheltered side of the massive stem. One foxtail pine at 10,400 feet atop Silliman Ridge is a hollowed-out and dead-appearing stump about 5 feet thick. It has a narrow band of sound wood extending upward and a narrower strip of living bark clinging to this. This remnant forms a 20-foot life-line that supports two 6-inch-thick limbs bearing a heavy crop of needles and cones. Yet a man can easily climb inside the rotting stump and observe its state of complete decay (3).

The "largest known foxtail pine" grows on a granite ledge close to the Mount Whitney trail at 10,750 feet (123 & 3). Limber pines nearby are sprawling, but the record foxtail is 7\(\frac{1}{4}\) feet thick and 35
151

feet tall. Its stem is buried below breast height, twisted spirally, partially stripped of bark, and dead throughout its top; but this condition is not unusual for a high-altitude foxtail pine.

The largest of several big foxtails on Alta Peak (11,204'), Sequoia National Park, is 6½ feet thick and 60 feet tall, though at 10,500 feet it grows higher up this mountain than do any other coniferous species. This tree has a "double pickaback" trunk (see Frontispiece 1--this is a similarly developed foxtail nearby). This resulted because after the main trunk succumbed to the elements, a branch on its leeward side grew erect, forming a new trunk. This second trunk eventually died and a branch on its sheltered side took over. Now this third or "grandson" trunk is in the process of dying and a branch near its base appears to be preparing for a career as main trunk number four.

Estimated minimum ages for several of these large foxtail pines ranged from about 1000 to 1400 years, though it seems likely some specimens attain 2000 years (5). One millennium does not seem a long time for a tree to reach such great dimensions growing under severe conditions, when much of its circumference is dead. Like the bristlecone and other timberline pines, the foxtails develop a deep and spreading root system in order to survive the dry summers. Pure "wide-open" stands of foxtail pine averaging 30 to 50 feet tall and 3 to 5 feet diameter often develop several hundred feet up the rocky mountainsides from the forest proper, composed of other species.

Foxtails are most common above 10,000 feet in the Sierra, though they occasionally occur somewhat lower. In their lower sites the
foxtails often have a distinctive spire-like crown, sometimes 100 feet tall and in such instances they are again usually much taller than their associates.

These trees furnish shelter for thousands of summertime hikers in the Sierra Nevada and for various animals the year-round. Also, the foxtail adds greatly to the aesthetic appeal of its home in the southern High Sierra.

Lodgepole Pine (Pinus contorta)

(Plates 1 & 20*)

NATURAL RANGE. The species occurs throughout most of western North America, being absent or rare only in Mexico, New Mexico, Arizona, Nevada, and Alaska outside the panhandle. Three commonly acknowledged regional varieties occur: Shore pine, Sierra Nevada lodgepole pine, and Rocky Mountain lodgepole pine. For most purposes, however, it is probably sufficient to distinguish only two types—shore pine and the inland or mountain form(s) of lodgepole. Shore pine is usually restricted to lowlands in its natural distribution, along the Pacific Slope from northern California through southeastern Alaska. The inland forms of lodgepole are most commonly found in the mid-altitude forest belt; however, they occur at timberline in the Sierra Nevada, San Bernardino, Olympic, Uinta, and Bighorn Mountains, and in a few other localities.

Lodgepole pine is well known as a seral (transient) species dependent upon fire and other disturbances for its perpetuation in many areas. Mills (104) recounted walking through a burned stand
near timberline in Colorado while the ashes were still warm. He noticed tiny brown flakes fluttering down all about him and found them to be lodgepole pine seeds.

Many lodgepole pines have serotinous cones (i.e., they cling to the tree for several years without opening) which are stimulated to open through the intense heat of a forest fire. Sometimes cones attached to a young lodgepole stem will remain so long that the trunk grows around and completely envelops them. Boards made from lodgepole occasionally have these overgrown cones sectioned within them.

Lodgepole pine is a prolific seed producer, and after a fire in Montana as many as 300,000 1-year-old seedlings per acre have become established (164). Studies have also revealed 175,000 8-year-old seedlings per acre averaging two feet high. In Colorado a 22-year-old stand had an average of 64,000 spindly trees per acre. The overstocking and stagnation that characteristically results from lodgepole regeneration after fire is probably the most extreme stagnation of any tree species in North America (164).

At timberline in the Sierra Nevada and other areas, lodgepole is often not a fire species, as it inhabits rocky open slopes above the forest proper. The largest recorded lodgepole is 6 1/2 feet thick and 110 feet tall growing in the San Bernardino National Forest (123); however the species is seldom over 2 1/2 feet thick and 40 feet tall at forest line.

Usually other conifers associated with the lodgepole ascend higher up the mountainsides; but lodgepole is sometimes found at tree limit and higher as krummholz. The species occurs as high as 11,500
feet in Colorado (164) and in at least one instance in the Sierra Nevada.

In the rain-shadow zone of the Olympic Mountains sprawling lodgepole pine shrubs occur as high as 6800 feet, above the scrub line in the alpine zone. This is probably the inland form of the species, as it inhabits terrain only near or above forest line. However, in the surrounding lowlands, shore pine occurs between sea level and about 1500 feet.

One stand of lodgepole pine at 6500 feet on Gray Wolf Ridge in the Olympics (see Plate 20) consists of stocky trees which become progressively shorter toward the ridge crest. At a saddle atop the windy ridge some lodgepole trunks attain the same proportions (1-2 feet thick and 20 feet tall) as their counterparts just below; but

Plate 20. Lodgepole pine "trees" growing horizontally atop a 6500-foot saddle in the Olympic rain shadow.
the former stems grow straight and horizontally leeward along the stony ground. An increment borer revealed that some of these trees are about 300 years old. Subalpine fir krumholz occurs only in the shelter of such lodgepole. Barely over the crest a hunched-over lodgepole shelters a tiny plot so effectively that a luxuriant snowberry shrub and subalpine lupine grow here more as if there were in a greenhouse environment than high above their natural range.

"Lodgepole" pine (inland form) is well known for its use as tepee poles by certain Indian tribes. Also, the inner bark has been prepared as food and made into baskets by Indians of the Northwest and Alaska (30). Anderson (1) said that the sap, which has a "delicious orange-like flavor," has been consumed by Indians in liquid state and as dried cakes.

Limber Pine (*Pinus flexilis*)

(Natural Range. Limber pine grows on dry, windy sites throughout much of the Rocky Mountain Chain from northern Mexico to the southern Canadian Rockies. It is absent from northern Idaho and Montana west of the Continental Divide, but occurs throughout much of Utah, Nevada, Arizona, and eastern and southern California. It grows in the Black Hills, in the southwest corner of Nebraska, and in far western Texas.)

Limber pine is mainly a tree of dry, exposed sites in or around the forest belt, whether high or low. It forms picturesque squatty trees along the windy eastern skirts of the Rockies in Glacier Park, Montana. Throughout the majority of its range north of Colorado.
it occurs in the mid-altitudes or near lower timberline. In Colorado, the Great Basin, and the Pacific Southwest it generally inhabits the upper half of the forested altitudes. Limber pine grows as low as 3000 feet along the Kickinghorse River in British Columbia and perhaps as high as 12,000 feet in the Sierra Nevada (1145).

The species is most closely related to whitebark pine, and the only reliable way of differentiating between the two in the field is by their cones. Limber pine cones are about twice the size of whitebark cones and the former do not disintegrate. However, the two species do not often grow side-by-side.

At lower altitudes in relatively favorable sites the limber pine sometimes grows to be a medium-sized well-formed tree, but this is not common. The tree usually has a somewhat weedy form, like that of the bristlecone, though it is usually less bulky than the latter. Limber pine, like the whitebark, readily forms krummholz; however, limber does not commonly grow higher up the slopes than all of its associates as does the whitebark.

Because of its particular affinity for dry, exposed slopes limber pine extends from lower timberline through upper timberline on some arid mountains, such as the Lost River Range in Idaho (Plate 14). Also, it may possibly compose the entire forest belt on some ranges in central Nevada, or at least the entire forest above a pinyon-juniper woodland (99).

Limber pine trees at upper timberline often form grotesque living snags, large sprawling shrubs, and wind-scoured krummholz (see Plate 21). The oldest dated limber pine is about 2200 years (87) and
Plate 21. Limber pine snags, krummholz, and trees of the pine and Engelmann spruce (background) at 9500 feet in the Lost River Range of Idaho.

the largest is almost 8 feet thick and 14 feet tall (123), though this latter specimen—in the Cache National Forest, Utah—probably does not grow near upper timberline.

Engelmann Spruce (*Picea engelmannii*)

(Natural Range. This species grows throughout most mountainous areas southward from southern British Columbia and adjacent Alberta through the Rocky Mountain and eastern Great Basin regions almost to the Mexican Border. It occurs on the inland slope of the Pacific Coast ranges in British Columbia, Washington, and Oregon. In the United States it inhabits only the 11 Western States, and its distribution in California and Nevada is very limited.)
Engelmann spruce occupies cool, moist environments in the lower forest zones west of the Continental Divide in the northern part of its distribution. It is common as a basic part of the high-country forests throughout its natural range, usually occurring in the timberline.

Engelmann spruce grows as low as 2500 feet in British Columbia (164) and probably that low in northern Idaho in sheltered canyons. It can be found along streams below 4000 feet and as krummholz above 9000 feet in the Bitterroot Mountains of Montana. To the south it has been reported above 12,000 feet in Nevada, Arizona, and Colorado, and probably occurs highest in northern New Mexico, quite possibly as a tiny mat near 13,000 feet. Sudworth (145) reported an elevational limit of 12,500 feet for the species, which may well make this spruce the highest coniferous tree species in the United States.

Engelmann spruce is the most common tree at timberline in Colorado and the Pacific Southwest, forming much of the "wind timber" associated with the Colorado heights. But, unlike the pines, this spruce is shallow rooting, so it is not often abundant on dry, exposed sites. Engelmann spruce is commonly the first conifer to invade bogs as they slowly become dry enough to support forest growth.

This spruce is characteristically slow growing, and it attains moderate age for a timberline tree—probably 500 to 600 years in extreme cases (145). The species is tolerant of shade and it forms the climax forest especially throughout much of its southern distribution. Beside a small spring at the forest line Engelmann spruce becomes a "wolf tree," with a 5-foot-thick short trunk heavily
limbed to the ground. As a tree it is readily recognized at some
distance by its narrow crown with thousands of tassel-like branchlets
hanging down from the main limbs. The ultra sharp spruce needles
serve as an easy identification even for the novice; but this same
feature often adds a special annoyance to travel through dense
timberline growth.

In the Pacific Northwest and southern Canada, Engelmann spruce
is sometimes rather scarce in the timberline zone, with subalpine fir,
whitebark pine, and/or subalpine larch predominant. Nevertheless, the
spruce can often be found as an occasional tiny mat or "subshrub"
existing near or even above krummholz limit for the other species.

White Spruce (Picea glauca) &
Black Spruce (Picea mariana)

(Plates 15 & 17)

NATURAL RANGE. Both of these spruces occur from the northeastern
United States across southern Canada to central British Columbia and
Alaska, extending north to the arctic timberline all across the
continent. White spruce extends south along the Rockies into the
Glacier Park area of Montana, and occurs in the Black Hills area of
South Dakota and barely into Wyoming. The variety occurring in the
southern Canadian Rockies is termed "western white spruce" or "Alberta
spruce."

1Taylor (148) has concluded that Engelmann and white spruce
are subspecies not distinct species, and that western white spruce is
their hybrid so its name should be dropped. There is much taxonomic
controversy about North American spruces.
White and black spruce characterize the northern boreal forest. The former inhabits relatively well-drained sites while the latter is most frequent in swampy areas. Neither is a timberline tree throughout the majority of their extensive range; however, in the mountains of the Far North and at the polar limit of trees, these species are the most frequent.

The white spruce is more common than black spruce at timberline. It forms timberline in the White Mountains of New England. Black spruce mats occur at timberline on Mount Katahdin (5267') in Maine (43). At polar timberline in eastern Canada white spruce grows erect while black spruce occurs as krummholz.

The white spruce usually develops a regular, pyramidal crown in the Far North, while black spruce often has a narrow, irregular crown with an extensive growth of lichens hanging from the limbs. The latter looks like a tree of the northern swamps, and it is. Both spruces are small slender trees, though the white spruce attains medium-sized proportions for a forest tree under favorable circumstances. The record trees of these species for the United States occur in Minnesota and are only about 3\(\frac{1}{2}\) feet thick and 100 feet tall (123).

The shallow-rooting habit of these spruces is one factor that allows them to extend into the permafrost zone of Canada. The lowland groves of spruce near the arctic tree limit occur only along streams where permafrost has been degraded (73).

White and black spruce are unusually hardy, being able to withstand temperatures such as the official continental minimum of...
-81 degrees F. recorded at Snag airport in the Yukon (112). The northernmost spruce, about 69 degrees N. in the Northwest Territories (164) are in sunshine continuously for about two months in summer. The spruces of Far Northern timberlines provide cover for many animals. Their seeds are sought by birds and rodents (164), and the needles, buds, and inner bark provide food for various creatures when little else may be available.

Sitka Spruce (Picea sitchensis)

(Natural Range) Sitka spruce grows along the Pacific Coast from Kodiak Island, Alaska, south to northern California.

Sitka spruce, also known as "tideland spruce," is a particularly interesting and unusual species. It is advancing into the tundra beyond the former western timberline on Kodiak Island (61). It makes up much of the coastal forest belt in Alaska, from sea level extending upward to become the highest krummholz conifer. Southward, it occurs along the coast, but no longer ascends to timberline. The highest record of Sitka spruce in British Columbia is 2500 feet (164); it probably is not found above 2000 feet in Washington, and in northern California the Sitka spruce trees are restricted to narrow strips along coastal streams (164). Unlike most other timberline trees, Sitka spruce is found at progressively lower altitudes southward throughout most of its range.

Another unusual feature of Sitka spruce is that in coastal Alaska it adapts well to both the lowland forest and the timberline.
In fact, throughout its range, as well as where it has been planted in Great Britain, the Sitka spruce is a large, fast-growing tree. In Olympic National Park many specimens are over 12 feet thick with two standing spruce measured to be about 295 and 298 feet tall (4). A fallen Sitka spruce in the Olympic Rain Forest was precisely 300 feet. But even the largest of these giant spruce are probably not over 600 years old.

At timberline in coastal Alaska this same species is reported to reach 5000 feet elevation at Taku Pass and is the highest growing conifer in Alaska (49). It also forms krummholz growing on nunatacks at nearly 4000 feet in the vast Juneau Icefield (78). But Sitka spruce is such a vigorous tree that it may grow relatively fast even as krummholz. Like other spruce it has extremely sharp needles, but the Columbian black-tailed deer and other animals seem to relish the succulent new leaves, before they "harden off." Sitka spruce is at its best in the ultra-moist and cool climate of the North Pacific fog belt.

Subalpine Fir (Abies lasiocarpa) &
Corkbark Fir (A. lasiocarpa var. arizonica)

NATURAL RANGE. Subalpine fir occurs throughout most mountains of western North America north of Mexico. It is more abundant in the northwestern United States and western Canada than elsewhere, but it does not reach the polar timberline. It may be entirely absent in California, and is rare in Nevada and Alaska. A variety known as
corkbark fir makes up most of the Southwest distribution of this species (164).

The range of subalpine fir is similar to that of its associate Engelmann spruce. However, unlike the spruce, the fir is a more dominant high-country tree in the northwestern United States and southwestern Canada. Subalpine fir extends northward with sporadic occurrences throughout the southern Yukon. The fir also occurs in the maritime mountain slopes of Washington and southern British Columbia with occasional stands in the Alaska Panhandle, unlike Engelmann spruce.

Subalpine fir has other things in common with Engelmann spruce. Both species reproduce in the upper timberline largely by layering, though the fir is most frequently layered (179). Both species develop the same general growth form, although the fir's crown is more spire-like with stiff short branches and no hanging branchlets (see Plate 22). The foliage of the two species is superficially similar, though the fir's needles are stiff and not sharp. Both species attain roughly the same proportions, are very shade tolerant (12), and are climax species over most of their distribution. Often they form a climax forest together; hence the derivation of the "spruce-fir" forest in the Rocky Mountains.

Subalpine fir is the principal timberline tree associated with popularly visited areas in the Pacific Northwest. Its deep green picturesque crowns are limbed to the ground and shaped like cathedral spires. The erect purple cones with "frosting-like" pitch are grouped
Plate 22. Subalpine fir and meadows near forest line (6000') on Mount Revelstoke, British Columbia.

in the tree-top which resembles a massive candelabra. Such trees average about 40 to 70 feet tall just above forest line and are dispersed in clumps among the subalpine meadows in Olympic and Mount Rainier National Parks, Mount Hood and elsewhere. Krummholz subalpine fir and tree-limit specimens with flagged tops and huge basal skirts occur at previously mentioned locations and at roadside in Glacier Park, the Beartooth Highway, and southward in Colorado.

Subalpine fir is very susceptible to fire, disease, and rot. The wood is light and brittle, and the trees are short lived (rarely reaching 250 years). Still, the species is able to prosper largely because of its effective habit of reproduction by layering, forming "family groups [21]." The branches are extremely stiff, apparently a disadvantage for a timberline tree. However, they are exceedingly
tough and since they are so short and densely packed together on the trunk, the result is that the crown is like an "A frame" snow roof; damage to the crown is minimized.

The largest known subalpine fir (it grows in Olympic National Park) is indeed extraordinary since it measures 6.7 feet in diameter and 129 feet tall (123); it may also be the oldest living trunk of this species, since at least 500 years would probably be required to produce this massive stem.

In Colorado and southward subalpine fir does not ascend as high in and above the timberline zone as do Engelmann spruce, limber, and bristlecone pines. Here the fir is usually located between 9000 and 11,500 feet and it seems to require more moisture than the other species forming krummholz. An interesting sidelight is that although the fir endures temperatures from below -60 degrees F. to 90 degrees it reportedly suffers winter injury when planted in New England (30). Subalpine fir generally occurs in areas where the snowpack insulates it from extreme cold, freezing and thawing. Perhaps the New England climate is lacking in this dependable "snow protection."

Corkbark fir, a regional variety of subalpine fir, occurs—often mixed with typical subalpine fir—in southwestern Colorado, New Mexico, and Arizona. It usually grows at or below forest line in the Southwest and is readily distinguished from the other true firs by its thick, corky bark, which lacks resin blisters (70).
California Red Fir (Abies magnifica) &
Shasta Red Fir (A. magnifica \textit{var. shastensis})

\textbf{NATURAL RANGE.} The two varieties of California red fir, i.e., typical California red fir (\textit{A. magnifica var. magnifica}) and Shasta red fir, occupy the southern Oregon Cascades, Mount Shasta, the northern California Coast Mountains, and the Sierra Nevada including the peaks in Nevada adjacent to Lake Tahoe.

There is considerable confusion about the range of the two varieties of California red fir; however the only apparent difference between them is the bracts between the cone scales. The bracts are shorter than the scales on California red fir cones; but they are longer than the scales on Shasta red fir cones, thus the bracts project. Red fir cones are barrel shaped and are largest of any American fir, averaging 6 to 9 inches long (70).

Shasta red fir occurs in the timberline forest at the rim of Crater Lake (174), and is found as high as 8800 feet on the eastern slope of the Cascades in southern Oregon (149). Shasta red fir grows in the krummholz community on Mount Shasta (31); but California red fir is present around forest line in Lassen Park (23). However, the red firs are nearly always more numerous in the area below forest line. They do not reach upper timberline in the Sierra Nevada, but form much of the cool forest zone between about 7000 and 9000 feet. Here they frequently grow to be 6 feet thick and 150 feet high, with extremely thick, rich russet-colored bark.
Outside of the Mount Shasta area red fir probably does not usually form krummholz, and though it is associated with high country throughout its range, it is rarely a tree of the timberline.

In the Sierra Nevada at least, red fir seeds are sometimes observed to "root into the snowpack" by a "precocious" radicle two or three inches long. The "seed leaves" or cotyledons of such germinants do not develop, and when the snow melts the tiny tree is unable to take root into the soil below. This habit of germination may be common among other conifers also.

**Common Juniper (Juniperus communis)**

**(Plate 23*)

NATURAL RANGE. This is the most widely distributed tree species in the northern hemisphere (145). Its several varieties occur throughout much of North America, on Greenland, in Europe, and Asia (49 & 145); however in western North America it occurs only as a shrub.

A shroud of confusion surrounds the ecology of common juniper. It is reported to attain heights of 30 to 40 feet in northern Germany (145), and to form a similar small tree in New England (96). However, the largest recorded United States member of the species is listed as 3 feet thick and 1½ feet tall, growing at Dunes State Park, Indiana (123). Elliot (49) stated that a common juniper in Sweden was reported to be 5 feet in diameter, tree-like, and estimated to be 2000 years old.

In western North America the common juniper has an extensive, though ill-defined distribution. It occurs in the timberlines of most (probably "nearly all") mountain ranges and is also found throughout
the forest belt in many areas. In the lower forest zones it frequently forms a spreading shrub radiating limbs in a circle of 20 feet diameter. In such cases it is often 3 to 5 feet high.

In and above the timberline zone, common juniper usually forms a heather-like shrub covering large areas and being under a foot high (see Plate 23). It often occurs higher than any other krummholz tree since it is hardy and because it has readily formed a mat so low that it is best suited to survival on rugged, alpine slopes.

Common juniper is the only conifer of the western United States and Canada that is always a shrub, unlike another timberline conifer, foxtail pine, that apparently always grows as a tree. Like other conifers, the common juniper attains several centuries of age, but detailed information on ages is not available.
Perhaps part of the reason for the species' extensive distribution is the fact that its "berry-like" cones, as with other juniper cones, are widely used as food, especially by birds. Much juniper seed does not germinate readily unless it has passed through the alimentary tract of some bird or animal (113). Phillips estimated that bird dissemination of juniper seed makes up 60 to 70 percent of the total in natural stands, but perhaps 80 to 90 percent under some circumstances (120).

Because most juniper fruits mature in the fall and cling to the tree until the following spring, they are one of the best bird food supplies. Furthermore, the fleshy layer covering the seed is a rich food of rapid digestibility (120). Phillips noted that Dr. E. A. Mearns found that 900 berries of Rocky Mountain juniper (J. scopulorum) passed through one Bohemian waxwing in 5 hours.

Western or "Sierra" Juniper (Juniperus occidentalis)

NATURAL RANGE. Western juniper occupies the dry hills of the Columbia Basin in Washington, much of eastern Oregon, and the interior of California. It is also found sporadically near the Pacific Coast States and in British Columbia and Baja California.

The western or Sierra juniper is not strictly a timberline tree in the Sierra Nevada though it frequently occupies the subalpine belt there (58). Elsewhere, it is found scattered in open sagebrush range-land or in the coniferous woodland zone, often below the ponderosa pine forest belt.
In the Sierra Nevada this juniper forms a gnarled and burly tree growing high up on granite cliffs. Its large roots extend through crevices in the rock, anchoring it to sites that have such severe growing conditions other conifers cannot survive there. Often the cliffs and rocky slopes that western juniper occupies are south-facing, making them especially dry. Glock (58) observed the following about the species in its Sierra Nevada occurrence: "The extraordinary

Plate 2h. An exposed western juniper near 8800 feet on the High Sierra Trail, Sequoia National Park—estimated minimum age from increment borings is 1000 years (5).
vitality of the junipers permits them to live on what appears to be almost sterile granite or on coarse gravels deficient in large quantities of mineral nutrients."

In Sequoia and Kings Canyon National Parks, the western juniper is found between 6500 and 10,500 feet. Though the juniper seldom grows at the climatic timberline, its picturesque, enduring form and its common position in a physiographic-edaphic timberline gives it much in common with the timberline trees.

Throughout its natural distribution, western juniper commonly grows as an "advance guard [30]" where few trees can exist. For example, it is reported as low as 500 feet elevation in arid canyons of eastern Oregon (1145).

Western juniper may be second only to bristlecone pine in age among trees of the timberline. The largest and perhaps oldest of this species is the "Bennett juniper" growing at 8500 feet elevation near Sonora Pass in the northern High Sierra (58). Glock (58) has conservatively estimated this tree to be 3000 years old. The Bennett juniper may be the largest of any of the world's junipers. It is 14.3 feet thick and 87 feet tall (123).

The erratic distribution of western juniper in Sequoia and Kings Canyon National Parks, with individual trees sometimes a mile or more from the nearest seed source, emphasizes the role of birds and other animals in dissemination of juniper seed. Indians are said to have used the pitch of western juniper for fastening feathers to arrow shafts, and also by rubbing the pitch into these shafts they made their arrows more durable (8).
Alaska-cedar (Chamaecyparis nootkatensis)

(Natural Range. The species has sporadic occurrences from Prince William Sound south-eastward along the Alaskan Coast, Pacific Coast ranges of British Columbia, Washington, and Oregon. It is also reported locally in extreme northern California, Blue Mountains of Oregon, and southeastern British Columbia.

Alaska-cedar (or "Alaska yellow-cedar") is an ordinary timberline tree in the sense that it is distinctive and unusual. It is normally characteristic of cool, moist, sheltered sites in or near the upper timberline. Alaska-cedar krummholz communities also form scrub line on exposed, rocky sites in the Pacific Northwest.

This species is the highest tree species growing out of rock cliffs in the Olympic rain shadow, ascending beyond 7000 feet. Alaska-cedar krummholz also occurs a bit higher than its associates in alpine tundra communities in this part of the Olympics. Krummholz of this species seems to have an advantage over the more numerous subalpine fir in having more flexible branchlets, less apt to be scoured off.

Another attribute of Alaska-cedar that adds to its success in a severe environment is the durability of its wood. Decay of living trees must be slight compared to subalpine fir, mountain hemlock, and others. For example, a stand of Alaska-cedar along the Paradise Valley highway in Mount Rainier National Park was killed by fire in about 1885 (21). However, some of the wood was harvested nearly 50 years later and was used to furnish much of the interior of the
The roots of krummholz Alaska-cedar are frequently exposed and partially stripped of bark as they extend across a rocky slope (Plate 25). Near Mount Angeles in the Olympics, one such root about 4 inches thick stretches, exposed, about 75 feet along a steep slope before disappearing into a patch of mineral earth. The tip of this root is about 100 feet from the small shrub it helps support. Adventitious

Plate 25. Alaska-cedar shrubs cling to the rocky terrain near Mount Angeles in the Olympics. Note the red cap and ice axe for scale.
rooting or layering has been noted in this species, and it is thought that new stems may sprout from exposed roots (164). Such processes probably explain the scrub-line development of Alaska-cedar shrubs whose foliage forms a circle of nearly 50 feet diameter (4).

Alaska-cedar trees are slow growing and long-lived. One with a hollow trunk almost 6 feet thick is reported to have shown 1040 growth rings in its 1-foot-thick outer shell (Munday as cited by 164). Individuals of this species have been estimated to attain ages of as much as 3500 years; however, 2000-2500 years may be a more reasonable maximum. The durability of Alaska-cedar wood sets this species apart from all other timberline trees growing in the Pacific maritime environment (except common juniper), where decay is perhaps the chief factor limiting age.

Within its narrow geographical range the Alaska-cedar exhibits a wide altitudinal distribution and reveals its unusual adaptability. It probably occurs on the greatest variety of sites in Washington, growing between 2000 and 7500 feet altitudes here (164). About 140 miles north of the United States Border near Mount Waddington, British Columbia, the lower limit of Alaska-cedar reaches sea level (Perry, see 164). Here, and farther north the species occurs throughout the rather narrow forest belt. Southward, in Oregon it becomes far less common (54), and its elevational distribution shrinks. Here the species seldom ascends into the climatic timberline.

Alaska-cedar apparently cannot compete with Sitka spruce and western hemlock (Tsuga heterophylla) except on poorer, colder, and wetter sites (164). This characteristic may explain its apparent
inability to occupy extensive forest tracts.

The Alaska-cedar is distinctly a northern maritime tree, but its spotty occurrence in Alaska might be explained by considering that present stands are remnants of a much more extensive forest that was largely destroyed by the last glacial advances (Grant et al., see 164). In Alaska this species is reported to be especially susceptible to winter drought.

"Yellow cedar," the wood of Alaska-cedar, is prized in boat building, but it gives off such a pungent odor that old-time sawyers are reputed to have disliked cutting it because it had a laxative effect on them.

Subalpine Larch (Larix lyallii)

NATURAL RANGE. This species occupies the Inland slopes of the northern Pacific Northwest, and adjacent Canada; particularly, north-central Washington, Montana west of the Continental Divide, and the Canadian Rockies north into Banff and Yoho Parks (7).

Subalpine or "alpine" larch is the only deciduous conifer of the western timberlines. It seldom grows more than a few hundred feet below forest line, and then only on the coolest, rockiest sites. Sometimes subalpine larch extends higher on cool exposures that even krummholz of other species; yet here it grows as an erect tree as much

\(^1\)Arno (7) has presented an argument in favor of the use of this older common name for Larix lyallii.
Subalpine larch is generally restricted to the timberline zone in remote mountain ranges, and it is little known to science or to the public. The species has many unique characteristics, including its outstanding addition to mountain scenery in early autumn when its foliage turns golden in color. The larch forms krummholz in some areas, though not at others. Like the foxtail pine, its limited occurrence is in two separate regions—the Rocky Mountain system and the northern Cascades. These distributions are apparently 130 miles apart at their closest known points.

The species may have an unusually low heat requirement even among timberline trees. Erect subalpine larch trees commonly grow a few hundred feet higher on cold exposures than do other tree-like conifers. In the Bitterroot Range, the Okanogan Cascades, and elsewhere (Figures 3 & 5), the larch predominates the sheltered basins and northern slopes at timberline while whitebark pine dominates exposed ridges and south-facing aspects.

Subalpine larch often forms park-like stands of slender trees averaging 40 feet tall, allowing krummholz of other species to develop as an understory (Plate 7). Sudworth (187) discussed the larch’s advantages over its less vigorous associates. Among these are lightweight foliage which is shed in winter, preventing winter dessication and lessening wind and glaze damage. Also, the subalpine larch has a slim, strong trunk, and firmly anchored root system. The branches are tough and withy.

The species seems more sensitive than its associates to improved
weather conditions; it is able to break dormancy faster when summer comes. Observations in the Rockies reveal that subalpine larch foliage and flowers begin to emerge at the end of May, while its timberline companions do not commence such activity for about a month.

Subalpine larch is most often observed by the public as patches of golden color on high mountainsides in early fall. The species occupies about 1100 acres of Glacier National Park's back-country (8), and has been designated as the "Park Tree" (132); but it is not readily visible from any highway there. It is seen turning color above major roads in Banff National Park and at various other locations throughout its range. The new cross-state highway in the North Cascades and the nearby recreational forest road to Harts Pass and Slate Peak (7488') pass by and among subalpine larch.

The larch attains a moderate age at an average growth rate for timberline trees. Ages of 350 to 650 years are normal for the large trees, which are about 2 feet thick and 60 feet tall (7). The record-sized subalpine larch grows at 8200 feet several yards from the Idaho Border in the Montana Bitterroots. It is $4\frac{1}{2}$ feet thick, 50 feet tall (123), and approximately 1200 years old. A tree in the Wenatchee Mountains of Washington is over $3\frac{3}{4}$ feet thick and roughly 1000-1200 years old (6).

Subalpine larch seems to be very exacting in its need for moisture (159). It grows on the rockiest slopes, sometimes out of cracks in glacially overridden massive granite, as long as there is sufficient moisture. One low-altitude (5800') subalpine larch grove noted in the Wenatchee Mountains consists of stout old trees.
growing in a pile of granite boulders many of which are as big as trucks (6). But the site is cool and moist. Because of its adaptability to growth on sheltered slopes, the subalpine larch has been considered by Swiss scientists for planting in order to control avalanches (130).

Mountain Hemlock (*Tsuga mertensiana*)

*Plates 2 & 3*

**NATURAL RANGE.** This species grows along the Alaskan Coast from the Kenai Peninsula southeastward, coastal mountains of British Columbia, and Pacific Coast Ranges south through most of the Sierra Nevada. It is also of limited occurrence in southeastern British Columbia, northern Idaho and adjacent Montana, and locally in the Blue, Wallowa, and Strawberry Mountains of Oregon.

Of the timberline trees having a coastal distribution only mountain hemlock seems to occur in the expected pattern. It is found in most of the moist, cool sites southward along the Pacific Slope from Alaska to central California at a consistently increasing altitude southward. Also, it inhabits the most humid and cool inland ranges—the Selkirk and northern Bitterroot Mountains, etc.

At the northern end of its distribution, mountain hemlock grows from sea level to scrub line, which is usually under 2000 feet on seaward slopes. Near Juneau the species occurs mainly above 1000 feet. In Washington it is normally between 3500 and 6500 feet and in the High Sierra it occurs between 8000 and 11,000 feet.

Wherever it is found mountain hemlock characterizes the cool,
wet coastal high-country, though it is apparently more tolerant of continental-type climatic conditions than most other conifers of the North Pacific. Its luxuriant foliage and abundant cone crop, together with its slightly drooping, heavy crown gives the mountain hemlock a lush appearance befitting its habitat. In the Cascades and Olympics mountain hemlock often dominates vast timberline areas, but in the High Sierra it is restricted to the cool, moist sites.

In the maritime Cascades and Olympics mountain hemlock is often a giant of the timberlines, sometimes forming a bulky trunk 3 feet thick and 70 feet tall near tree limit. In the krummholz zone mountain hemlock often becomes a massive, sprawling shrub with so many upturned branch-trunks that one tree appears to be a small stand. One such mountain hemlock in the Olympics is estimated to be around 700 years old (1). Radial growth on the outer shell of an 11-inch stem of this individual showed about 260 annual rings in 1.2 inches.

Though mountain hemlock attains moderate age (probably 400 years average), its heartwood is quite susceptible to rot. The largest recorded mountain hemlock is nearly 7 feet thick and 118 feet tall, growing near the northern end of the High Sierra (123).
Broadleaf Trees at Timberline

Quaking aspen, balsam poplar, Sitka alder, and various species of mountain ash, birch, and willow occur in some timberlines of western North America. Broadleaf tree species are seldom as imposing at timberline as the conifers, since most of the former occur only as rather low shrubs throughout the timberline zone. Though broadleaf species are interesting and important plants at many timberlines, they are not regarded as fully "trees of the timberline" in this paper. The following are a few brief notes regarding some of the broadleaf species at timberline.

Quaking aspen (Populus tremuloides) is one of the most widely distributed, scenic, and interesting tree species in North America. In the western mountains it grows below lower timberline for the coniferous forest and in the lower and mid-altitude forest zones; but in the Far North aspen occurs near the polar timberline (147). Aspen seed is among the lightest for any tree species, averaging about 3,600,000 seeds per pound (161). Buoyed by long silk hairs, it can be carried for many miles in the air currents (164). But the aspen usually reproduces vegetatively through root suckers forming pure groves composed of dozens of trunks that arose from the original root stock. All of the trees in any one such grove or "clone" are genetically the same, and the life of such a clone can no doubt be perpetuated at least for many centuries. Aspen clones are similar to layered groups of fir or spruce, except that the former are more extensive and are the dominant form of the species' occurrence. When
observed in autumn, some aspen clones will have lost all their golden leaves, while clones beside them are in the height of their turn, and others still have green foliage.

Balsam poplar (*Populus balsamifera*) occurs all across the northern part of the continent, extending in places to the polar limit of trees. The sites it inhabits range in their average annual precipitation from about 7 inches to 55 inches (164). Small stands of this species as much as 1000 feet above the spruce tree limit are especially noticeable when turning color in autumn on the slopes of the Alaska Range. The species is also reported to grow in places along streams north of the Brooks Range, beyond the polar limit of spruce (177 & 147).

Sitka alder (*Alnus sinuata*) often forms a tall shrubby jungle of stems growing from sea level past the limit of conifers in Coastal Alaska. It covers vast amounts of coastal terrain that has recently been released from glaciation. The species also occurs south in the coastal mountains to California, but in the southern part of its distribution it is limited to the mid-altitude forest zones. Sitka alder occurs, too, in Asia, but more interesting is the range of its shorter associate in Alaska, the American green alder (*A. crispa*). The latter occurs throughout much of Alaska outside the panhandle, across Canada to Labrador, Greenland, New York and the mountains of North Carolina, Michigan, Oregon, and also across northern Europe and Asia (147).

Several species of low-growing birch and willow extend northward to the Arctic Coast of Alaska (147). Some of these same species and
other members of the two genera occur usually as shrubs in the timberline and alpine zones of the western United States and Canada. The various alpine willows are particularly interesting from an ecological standpoint and are widespread in their occurrence. For example, a pygmy "forest" of one such willow completely covers a filled-in cirque lake basin at 5300 feet in the northeastern Olympics. The flat, soggy site covers several acres, and the pure stand of willow that occupies it is only 6 inches high (Plate 26).

Another willow occupies moist alpine slopes at 11,200 feet in upper Cloud Canyon in the southern High Sierra. On August 1, 1965, the only above-ground parts of the dwarf alpine willow (Salix petrophila) here were erect catkins less than two inches high. The network of branches was beneath the ground surface. This willow grows in company with an extensive stand of blueberry plants two inches high and loaded with a profusion of pink flowers at that time of year. Such observations illustrate the odd types of growth exhibited by willows and other broadleaf "trees" in and above timberline (see Plate 27). Polunin (122) has described the unusual birch stands of Greenland, where Betula pubescens seldom 20 feet tall is the only "forest" species on that huge, icy island.
Plate 26. A dwarf willow blankets this filled-in lake in the Olympic rain shadow at 5300 feet.

Plate 27. This willow shrub grows above the spruce krummholz limit at slightly over 5000 feet elevation near Summit Lake (58° N.) in the northern Canadian Rockies.
Rare Residents of the Timberline

In addition to the conifers described as trees of the timberline, a few other species occasionally extend into the lower edge of this habitat under certain conditions. Both stunted Douglas-fir (*Pseudotsuga menziesii*) and western white pine (*Pinus monticola*) trees grow on exposed, rocky sites above forest line in the northeastern Olympics. Each species is sometimes found in the timberline on warm exposures throughout much of its range. White fir (*Abies concolor*) has a limited occurrence in the krummholz zone on Mount Shasta (31). Pacific silver fir (*A. amabilis*) is occasionally found at the forest line. Brewer (*Picea breweriana*) and blue spruces (*P. pungens*) might possibly extend upward to forest line under unusual circumstances.

**Common and Scientific Names for Tree Species Mentioned**

**CONIFERS.**

- Pacific silver fir                        *Abies amabilis* (Dougl.) Forbes
- white fir                                *Abies concolor* (Gord. & Glend.) Lindl.
- grand fir                                *Abies grandis* (Dougl.) Lindl.
- subalpine fir                            *Abies lasiocarpa* (Hood.) Nutt.
- corkbark fir                             *Abies lasiocarpa var. arizonica* (Merriam) Lemm.
- California red fir                       *Abies magnifica* A. Murr.
- Shasta red fir                           *Abies magnifica var. shastensis* Lemm.

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1Reference for nomenclature is Little (96).
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<td>P. contorta var. latifolia Engelm.</td>
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1 Common names in parentheses are used also and seem to better delineate the species for interpretive purposes than the common name suggested by Little (96).
limber pine
Jeffrey pine
sugar pine
singleleaf pinyon
  (singleleaf pinyon pine)
western white pine
ponderosa pine
Digger pine
Douglas-fir
giant sequoia
Pacific yew
western redcedar
California torreyana
  (California-nutmeg)
western hemlock
mountain hemlock

BROADLEAF TREES.
American green alder
Sitka alder
paper birch
balsam poplar
quaking aspen

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<td>California torreyana</td>
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</tr>
<tr>
<td>western hemlock</td>
<td>Tsuga heterophylla</td>
</tr>
<tr>
<td>mountain hemlock</td>
<td>Tsuga mertensiana</td>
</tr>
<tr>
<td>American green alder</td>
<td>Alnus crispa</td>
</tr>
<tr>
<td>Sitka alder</td>
<td>Alnus sinuata</td>
</tr>
<tr>
<td>paper birch</td>
<td>Betula papyrifera</td>
</tr>
<tr>
<td>balsam poplar</td>
<td>Populus balsamifera</td>
</tr>
<tr>
<td>quaking aspen</td>
<td>Populus tremuloides</td>
</tr>
</tbody>
</table>
VII. TIMBERLINE AND PUBLIC INTERPRETATION

Timberline and the Visiting Public

There is probably no need to embark upon a detailed analysis of visitation to outdoor recreation areas in the high mountains of the western United States and Canada. It should be sufficient to remind the reader that the United States and Canadian public is traveling to such areas in ever-increasing numbers. Several national parks now receive more than one million visitors annually.

Few highways ascend to the upper timberline, and those that do are often heavily traveled scenic routes. A relatively small number of unpaved roads climb into the timberline. Many of these are located on public lands, and provide increasing recreational use. Management plans include further development of campgrounds, picnic areas, and other facilities including interpretive displays. Some timberline areas now receive what can be considered mass public use even though they are reached only by foot or on horseback (e.g., the John Muir Trail area in the High Sierra, which tens of thousands of recreationists use annually).

Almost all public naturalists and biologists should also be well acquainted with the human impact problems associated with heavily-used natural areas. "Trampling" and "deterioration of the site" are terms that are frequently employed to describe the effect of
unregulated over-use by people in recreation areas.

Ecologists are particularly concerned about over-use in timberline and alpine environments because the slowness of plant growth here prevents the rapid healing of damaged areas. Also, the steep slopes, shallow soils, and rigorous climate combine to make erosion of trampled areas severe. Yet, while many roadside attractions and even some back-country areas show the effects of trampling, management agencies have not often made significant progress in dealing with the problem. Carrying out ecological management with additional restriction of visitor freedom (formally or informally) is not easy and it conflicts with the traditional "boost visitation" approach of most agencies (this approach has been deemed necessary by agencies since visitation figures have been used in obtaining operating funds).

Timberline and Man's Psychological and Intellectual Needs

Many writers have taken an interest in describing the timberline, but perhaps none so colorfully as Enos Mills (104). He called timberline the "forest frontier" saying that while the trees were trying to grow beyond, the "... elements batter and defy them in a never ending battle along the timber-line."

Mills further asserted:

Timberline in the high mountains of the West wakes up the most indifferent visitor. The uppermost limit of tree-growth shows nature in strange, picturesque forms, and is so graphic and impressive that all classes of visitors pause to look in silent wonder. This is the forest frontier.
The trees of timber-line are stunted by cold, crushed by snow, and distorted by prolonged and terrific winds.... though crippled, bent, dwarfed, and deformed, they are stocky and strong old warriors, determined, no weaklings, no cowards.

It should be apparent that while ecologists have found timber-line to be a most interesting study, this striking ecotone inspires many other types of people also, particularly those who admire natural scenery. Still others would likely find it interesting to explore various aspects of the "forest frontier," once they were introduced to what timberline represents.

The timberline environment is often "nature at its scenic best," and in this sense, timberline is important in fulfilling the basic need many people have for finding a respite from their daily lives in a realm of natural beauty.

As Wagar (178) and others studying the outdoor recreationist have discovered, the quality of the recreational experience often varies inversely with the amount of human crowding at the natural area recreation site. It is probably that the better educated and more sensitive people are first to notice the adverse effects of high human impact upon their recreational experience in a natural environment. To most of these people—a group which includes many conservationists—this overcrowding and its results seem undesirable or even deplorable.

Role of Public Interpretation

It is not within the scope of this paper to delve into a detailed justification of public interpretation. The National Park
Service Administrative Manual states the case aptly: "Through interpretation, understanding; through understanding, appreciation; through appreciation, protection." Several public agencies are now enlarging their interpretive programs.

A better informed visiting public would probably facilitate the conservation of natural recreation areas and also stimulate the evolution of better management for such areas. Interpretation plays a role here, but it can also enrich the outdoors experience of some visitors by sparking an interest in the natural world which seemed to them obscure or uninteresting before.

Interpretation has been responsible for some of today's public interest in the conservation movement. Improved interpretation can help to further judicious management of our natural resources—something which is of great importance to mankind. Improved interpretation of the timberline is especially challenging, since accessible timberline areas are especially unusual and attractive to the traveling public, and they have numerous management problems.

Many visitors to popular timberlines—usually in federal recreation areas—are mildly interested in learning about this natural environment which they regard as "scenic" and "different."

Conservation, as used here, means a system(s) of management that allows for maintaining the productivity—in goods and services—of the land and its resources (non-depletion). Conservation attempts to provide for society's natural-resource needs—present and future. This includes some "preservation" of natural lands. A conservation goal is to provide not only adequate amounts, but also a sufficient diversity of types of recreation areas so that the demands of all user groups can be met.
But the naturalist or interpretive devices must be thought-provoking, not tedious, since they have to reach people accustomed to commercial advertising.

Various types of public interpretation include brochures, pamphlets, outdoor displays, signs, and visitor centers. Such media generally reach a large number of people, but the effectiveness of interpretation to the individual visitor is probably much greater through personal contacts. Thus, the strong point in National Park Service interpretation has long been the "ranger-naturalist" (and the "ranger") who talks with visitors informally and also conducts nature walks, hikes, talks, and illustrated campfire programs. The all-day (or overnight) hikes led by a naturalist are the highest quality means of interpretation, though of course a full array of types of interpretation must be used to reach the largest quantity of people with the best possible quality.

Tilden (154) has called the Park Service naturalists "the middlemen of happiness." Kuehner (88) stressed that successful interpretation, rather than teaching, motivates the visitor to learn, and to discover things for himself. The visitor is stimulated by that which touches his personality.

The timberline and its trees have a great deal to offer in this respect, for this is a zone of pronounced and unusual beauty, remote from mankind's influence. The environment is peaceful, yet incredibly harsh. The trees and animals represent a hardy biota whose "struggle for existence" against adversity may inspire people, who may identify with members of the natural community.
This paper has made no formal attempt to "direct" interpretation of the timberline, since there are too many variables to be dealt with to consider all the types of naturalist programs in western North America as a unit. Rather, it is hoped that this paper can be useful as a reference; that it will stimulate naturalists and others involved in interpretation to consider how they can improve their presentation regarding timberline. Naturalists are, as they must be, creative people accustomed to fashioning and improving their interpretive program. Hopefully the particular "interpretations" compiled here will aid the naturalists' efforts to promote public enjoyment and well-being.
LITERATURE CITED


4. _______. 1964. (Approx. 18 misc. reports of observations of conifers in Olympic Mtns.). Copies on file, Chief Naturalist, Olympic N.P., Port Angeles.


7. _______. 1966 or 1967. Alpine larch and its natural occurrence. School of Forestry, Univ. Montana, Missoula. (publ. in process. abt. 50 pp.).


1The last 4 entries are not alphabetized.


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52. ______, B. Huber, and H. E. Suess. 1966. Determination of the age of Swiss Lake Dwellings as an example of dendrochronologicalradiocarbon dating. Zeitschrift Fur Naturforschung (Tubingen). Band 21z, Heft 7 (pp. 1173–1177).


91. Larsen, J. A. 1965. The vegetation of the Ennadai Lake area

92. Lawrence, D. B. 1939. Some features of the vegetation of the


136.

95. Little, E. L., Jr. 1941. Alpine flora of San Francisco

96. ______. 1953. Check list of native and naturalized trees of
41. 472 pp.

97. Marr, J. W. 1948. Ecology of the forest-tundra ecotone on the

98. ______. 1961. Ecosystems of the east slope of the Front
8. 134 pp.

Ltr. dated Mar. 11. ref. 200.


101. Meier, M. F. 1951. Glaciers of the Gannett-Fremont Peak area,

102. Merriam, G. H. 1899. Results of a biological survey of Mount

103. Merry, W. P. (Acting Park Naturalist, Mount McKinley N. P.,


105. ______. 1920. Trees at timberline. An essay in, Essays of
our day, edited by Bertha E. Ward. 1937. D. Appleton-


   Post-Intelligencer, Weekender Mag. (Sept. 3) p.6.


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APPENDIX

Timberline Areas Observed by the Writer

CONTERMINOUS UNITED STATES

California.  Southern High Sierra (two summers)
           White Mountains

Oregon.    Steens Mountain
           Wallowa Mountains (several trips)

Washington. Olympic Mountains (several summers)
             Cascade Range (trips of varying length to many areas)

Wyoming.   Yellowstone Park, Beartooth Highway

Idaho.     Lost River Range
           Seven Devils Mountains
           Salmon-Clearwater Mountains

Montana.   Bitterroot Range (many trips)
           Anaconda, Flint Creek, Mission, Swan, Cabinet, and Glacier
           Park mountains.

CANADA

British Columbia. Cascades (Manning Park); Selkirks (Mount Revelstoke
               & Kokanee Park); Northern Rockies (Summit Lake); Northern
               Coast Ranges (Chilkat Pass area—extreme nw. corner of
               B.C.)

Alberta.   Rocky Mountains (Trunk Road, Banff & Jasper Parks)

Yukon.     Keno Hill; Dawson City to Alaska road; Haines Jct. areas

ALASKA      Coast Ranges (Juneau, Valdez, Seward, Portage Glacier)
           Interior (McKinley Park & Denali Highway, Steese Hwy.)

1Unless otherwise noted such observational trips consisted of
one or a few days, but the timberline zone was visited in each case.
All trips were made since 1961 and have been at writer's expense in
conjunction with avocational interests.

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