SOME FEATURES OF THE VEGETATION OF THE COLUMBIA RIVER GORGE WITH SPECIAL REFERENCE TO ASYMMETRY IN FOREST TREES[1]

By

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PREFACE

The earliest authentic information concerning the Gorge of the Columbia River was supplied by members of the famous Lewis and Clark Expedition, which passed through it on the last lap of the overland journey to the Pacific in October, 1805, and returned through it in April, 1806 (Thwaites, 1904-1905). Among earlier explorers, Lieutenant William Robert Broughton, of the Vancouver Expedition, had been the only one to ascend the river far enough to see the western portal of the gorge, which he had done in the fall of 1792 (Barry, 1932; Vancouver, 1901); but he did not enter the gorge itself. The first navigator to recognize the mouth of the Columbia was a Spaniard, Bruno Heceta, who had reached that region of the coast in the late summer of 1775; he had been unable to enter the river because of swift currents. Later navigators had seen the river mouth but its fearful bar had turned them away, and it was not until May 11, 1792, that Captain Robert Gray, of Boston, had successfully crossed the very difficult bar and named the great river in honor of his good ship "Columbia"; he seems to have been satisfied with this accomplishment, however, for he turned back to the ocean after having sailed upstream no more than a score of miles.

As the reports of Gray and Broughton, and especially those of Lewis and Clark became known, important posts of the fur trade were soon established on the Columbia, first near its mouth, at Astoria, and somewhat later about a hundred miles upstream, at Vancouver, which is within sight of the western portal of the gorge. Then the river rapidly became the main highway for the fur trade of the Northwest, which it was for many years. Subsequently emigrants from the East reached the rich agricultural regions west of the Cascade Mountains via the Columbia, which carried down through its gorge hundreds of rafts laden with settlers and their prairie-schooner wagons. In the first period of rapid agricultural and mining expansion in this region—roughly from 1850 to 1870—steamboats were the main means of transportation, for there was still no overland route through the gorge. Then a wagon road was built on the south bank, but it was little used because of its steep hills and sharp curves. That road was finally abandoned in 1883, with the completion of the first railroad through the gorge, which appropriated parts of its right of way. In 1908 a railroad was completed along the north bank, and in 1915 the Columbia River Highway was opened on the south side of the gorge. More recent developments in this region have included the completion of the Evergreen Highway on the north side, the construction of two interstate bridges to connect the two highways, and the establishment of a transcontinental aviation route through the gorge. In addition to these modern conveniences for rapid transportation, a network of trails on the gorge walls has recently been built by the United States Forest Service and the United States Civilian Conservation Corps; thus the whole gorge is now rather easily accessible. Embracing, as it does, a very broad range of climate, topography, and soils, and showing remarkable evidences of topographic and vegetational history, the gorge offers an inviting field for ecological studies of many kinds. In this paper are reported some results of such studies, which were carried out in the years 1933 to 1937. Funds and general equipment for four seasons of study in the field were made available by my parents, Mr. and Mrs. William C. Lawrence, of Portland, Oregon, and a number of ecological instruments were supplied by Professor Burton E. Livingston, of the Johns Hopkins University. My early interest in the Columbia Gorge was largely aroused through conversations with Professor William Mansell Wilder and Mr. John B. Yeon, both of Portland. Professor Burton E. Livingston and the late Professor Duncan S. Johnson, both of the Johns Hopkins University, have given many helpful suggestions and criticisms while the preparation of this paper was in progress; Dr. W. G. Lynn also of the Johns Hopkins University helped with the field work in the summer of 1933. My wife, Mrs. Elizabeth Gay Lawrence, has been a constant source of aid and encouragement.

PHYSICAL FEATURES OF THE COLUMBIA GORGE

WATER LEVELS AND RIVER GRADIENTS*

The Gorge of the Columbia River lies directly athwart the high barrier of the Cascade Mountain Range, joining the relatively low Columbia Basin on the east with the somewhat lower Willamette Valley on the west. The gradient of the river is remarkably gradual throughout its 55 miles within the gorge, except for a single 7-mile stretch—the Cascade Rapids—extending from Cascade Locks to Beacon Rock. (See Fig. 1.) Within that stretch the "adopted plane of low water" shows a fall from 41.4 feet to 5.8 feet above mean sea-level. At the foot of the rapids ocean tides of a foot or less are to be observed in times of low water; and in the gorge below the rapids the adopted plane just mentioned has a gradient of 0.125 feet per mile. The gradient becomes 0.250 feet per mile at very high flood stage. Above the rapids the gradient of the adopted plane is somewhat less and the full-flood gradient is somewhat greater, being 0.082 feet and 0.292 feet per mile, respectively. At the eastern portal of the gorge the level of the adopted plane is only 44.4 feet above mean sea-level.

Throughout the gorge the main river bed lies from 15 to 75 feet below the adopted level of low water; computed from deepest soundings (see Map

* Note: Since this paper was written water levels have been altered in some respects by the completion of the Bonneville Dam.

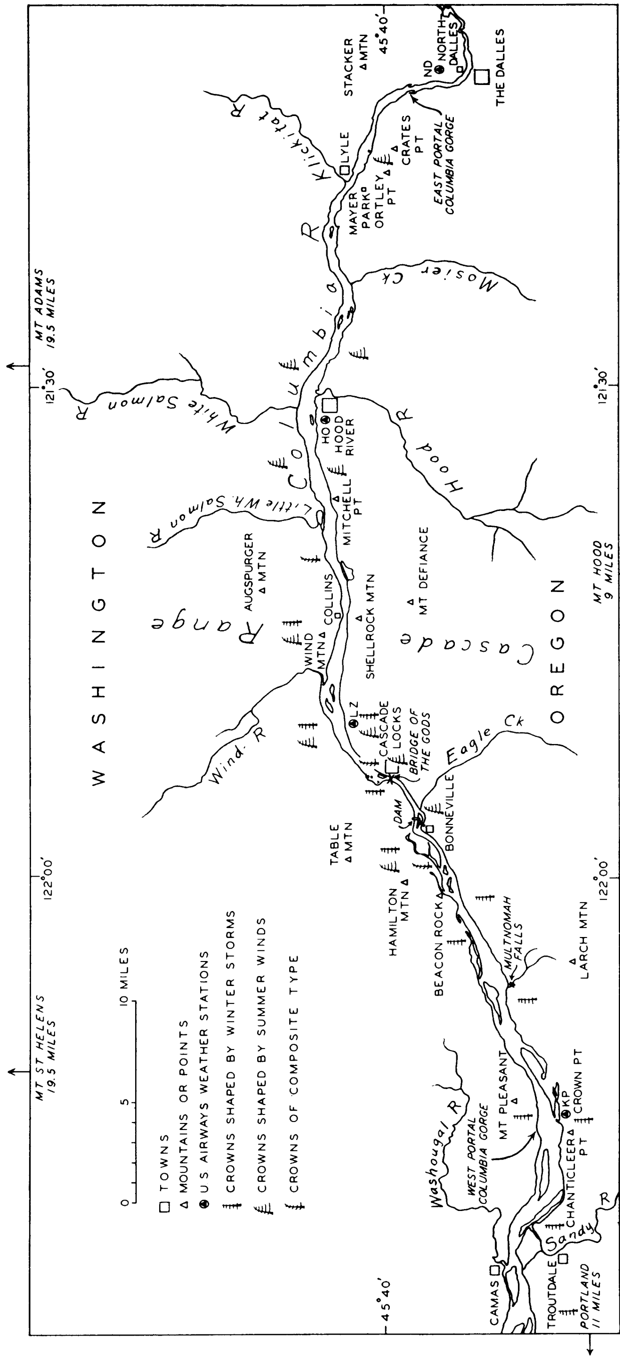

FIG. 1. Outline map of the Columbia River Gorge region. After U. S. Geological Survey (see Map Citation No. 2)

Citation No. 3) at mile intervals, the average depth of the bed below that level is 41.7 feet. For a stretch of several miles above the mouth of Wind River the channel bed is about 30 feet *below* mean sea-level and it is as much as 50 feet below mean sea-level near the west portal.

The nature of the gorge floor, and consequently the characteristics of the floor vegetation, are largely conditioned by very great and fairly regular seasonal changes of water level in the river. According to 55 years of record (1879-1933) at the upper pool at Cascade Locks, which marks the head of the rapids, an annual flood has usually occurred in June, less often in May. The highest stage recorded (June, 1894) is 92.9 feet above sea-level. On the other hand, the river has always been low in winter throughout this period of record, the lowest readings being shown for December, January, or February. The lowest recorded stage (February, 1929) is 38.9 feet above mean sea-level. The average elevation of low water at this pool in winter is 42.8 feet and that of high water in summer is 71.2 feet; thus, the average annual range of fluctuation amounts to 28.4 feet. The greatest annual fluctuation on record is 47 feet (1894) and the least is 14 feet (1926).

The Bonneville Dam, now being built under the auspices of the United States Public Works Administration, about 3 miles below the head of the Cascade Rapids, is planned to maintain at Cascade Locks a mean water level 73 feet above mean sea-level, the minimum being 72 feet, while a level of 92.9 feet would be maintained with all gates open even with a flood as great as that of 1894. Information concerning these levels and the above-mentioned gradients was kindly furnished by Mr. A. L. Darr and Mr. L. F. Henshaw, of the Bonneville Dam Project; part of this information has recently been published (U. S. War Dept., 1936).

Aside from its fluctuation with rise and fall of water level, the width of the water surface of the river naturally varies greatly from place to place according to the conformation of the gorge floor and walls. Its average width throughout the whole gorge is about 0.6 mile, at medium-high water. In its narrowest stretches, near Lyle and in the upper portion of the Cascade Rapids, a width of about 225 yards is maintained whether the river stage is high or low. A corresponding estimate of the river's greatest width—near Multnomah Falls, about eight miles above the west portal—is 1.3 miles at medium-high water.

The soils of the gorge flood plain, as well as its topography, have naturally resulted from river erosion and deposition, and great changes in these may occur in very short periods. Pronounced shifts in the channel and great alterations in channel depth result from every freshet. No long-continued records of erosion or deposition in the gorge are available, but reports indicate that the flood-lands below the rapids have in several instances received from the river in a single season alluvial deposits as much as two or three feet in depth.

THE GORGE WALLS

The walls of the gorge, which represent the truncated ends of the mountain ridges across which the river has cut its way, are in some places very steep while in other places they slope more gently toward the rim. They are broken by large and small lateral canyons, through which tributary mountain streams deliver to the Columbia. At the west portal of the gorge the rims rise to about a thousand feet above the river, and at the east portal their height is about twice as great. In the middle of the gorge, where it intersects the axis of the Cascade Range, the mountains rise to heights of from 3,000 to 5,000 feet. The west portal may be said to lie about 20 miles upstream from Portland (see Fig. 1); but it should be noted that the Oregon wall is continued west for about 5 miles beyond Crown Point, to the mouth of the Sandy River. The east portal is about 5 miles below the city of The Dalles (Fig. 1), but the north wall extends east beyond Stacker Mountain for many miles without significant interruption. The geographic middle of the gorge lies near Wind Mountain, about 8 miles above the town of Cascade Locks. Its walls are highest about two miles east of that point, where Augsburger Mountain, on the north, has an elevation of 3,684 feet and Mt. Defiance, on the south, reaches an elevation of 4,960 feet.

Within 40 miles of the middle three perpetually snow-capped and glacier-laden volcanic peaks—Mt. St. Helens, Mt. Hood, and Mt. Adams (Fig. 1)—rise to elevations of 9,671, 11,225, and 12,307 feet, respectively. Mt. Hood is but 22 miles south of the river and Mt. Adams is 33 miles north of the river. From these two peaks broad valleys lead downward to the gorge, facilitating air drainage as well as water flow. But, although Mt. St. Helens is only 37 miles northwest of the Cascade Rapids it is so cut off from the gorge by ridges and canyons that it can have but little direct influence on gorge conditions.

A general idea of the width of the george, which naturally varies greatly, may be obtained by averaging measurements read from a topographic map (see Map Citation No. 2) at 2-mile intervals throughout the entire length, first for an elevation of 100 feet and then for an elevation of 500 feet above mean sea-level. Thus derived, the average width of the gorge between opposite 100-foot contours is almost a mile, its narrowest width being about 530 yards—near the head of the Cascade Rapids and at Lyle—while its greatest width is about a mile and a half near Stevenson. For the 500-foot elevation, the average width is 1.7 miles and the narrowest width is about a mile—at a number of places above the rapids—while the greatest width is almost 6 miles—at the mouths of the Hood River and the White Salmon River. Between the rims the average width is about 5 miles. In general the Oregon wall of the gorge rises much more steeply than does the Washington wall, and the general elevation of the uplands adjacent to the rims is considerably greater on the Oregon side than on the Washington side.

The rims of the gorge are naturally not continuous, being broken into points and promontories by valleys of various depths and widths. They are deeply broken where the valley of the Hood River and that of the White Salmon River join the gorge from south and north. The valleys of Wind River, Mosier Creek, and Klickitat River also constitute pronounced interruptions where they open into the gorge. The map (see Map Citation No. 2) shows 63 streams entering the Columbia within the limits of the gorge, 31 from the south and 32 from the north. Their west-east distribution reflects the gradation of moisture conditions from the humid western end to the arid eastern end; 41 streams flow into the river west of Wind Mountain and only 22 enter it east of that point. Although an area of about 260,000 square miles of country is drained by the Columbia, only about one per cent of that area is drained by tributaries that enter the river between the two gorge portals. About 77 per cent of the gorge watershed lies on the Washington side while only about 23 per cent is on the Oregon side.

There are many waterfalls in side canyons and ravines, the majority of the spectacular ones occurring on the Oregon wall. They vary from mere rapids to sheer falls of 540 feet (Multnomah Falls). In some the stream descends vertically without wetting its more or less undercut cliff; in others the water cascades down a steep convex cliff, maintaining contact with the rock all the way from top to bottom. As a result of these differences and of differences in the type of basin into which the water tumbles there is much variation in the areas of cliff kept moist by spray.

ROCK FORMATIONS

The main bed rocks of the gorge (Williams, 1916) are worthy of cursory attention, especially because they have naturally played an important role in determining topography and soils. In the middle region of the gorge, where it cuts through the great uplift of the Cascade Mountains, may be seen a large variety of rock types. The lowest and oldest of these is the Eagle Creek formation, with an agglomerate and a conglomerate phase; the former is a volcanic tuff containing numerous angular blocks of andesitic lava, and the latter consists of well-rounded andesitic boulders and pebbles imbedded in sandy matrix. At many places fossils of Ginkgo and contemporaneous species are enclosed in shaly seams, and this formation has consequently been assigned to the upper Oligocene or lower Miocene (Chaney, 1920, 1927). Being rapidly eroded by running water, it has given rise to but few waterfalls. Its most extensive exposure occurs on the Washington side of the river, where the southeastward dip of its bedding planes has led to many landslides, the largest of which—whose remnants are to be seen at the Cascade Rapids—has received special attention in earlier papers (Lawrence, 1935, 1936, 1937).

Over the Eagle Creek formation lies Columbia River basalt up to 3,000 feet in thickness. This is a basic lava representing the series of lava flows that covered much of the present states of Oregon, Washington and Idaho, probably in Miocene time (Piper, 1932). Of the score of separate flows of this formation that are visible in the gorge (Smith, 1917), many of the thinner ones are characterized by coarse columnar structure, while the thicker ones frequently show coarse columnar structure below and non-columnar structure above; the columns when present are usually oriented vertically and the whole formation exhibits a pronounced tendency toward vertical fracture. To these characteristics may be attributed the many spectacular pinnacles and turrets that line the gorge walls. Over the vertical and overhanging cliffs of this basalt formation tumble most of the tributary streams that enter the gorge.

Next above the basalt lies the Satsop formation of Bretz (1917) and of Williams (1916), which is probably correlated with Buwalda and Moore's (1930) Hood River formation, Piper's (1932) Dalles formation, and part of Hodge's (1932) Madras formation. The Satsop is seen throughout the gorge and is composed largely of layers of gravels, sandstone, and ashy shales, except in the region adjacent to the Cascade Rapids, where it is composed of volcanic tuff. It is thought by some students to have been deposited in upper Miocene and lower Pliocene time (Piper, 1932).

On top of the Satsop beds are still other volcanic layers—tuffs, breccias, and andesitic and basaltic lavas—some of which are of comparatively recent origin. They form most of the present rims of the gorge and largely compose the uppermost rock layers of this portion of the Cascade Range.

In addition to these rock formations should be mentioned (a) the local granitoid intrusion represented by Wind Mountain and Shellrock Mountain, which because of its characteristic manner of fracturing and very frequent movement of surface debris, forms probably the most difficult habitat in the central portion of the gorge, and (b) the masses of glacial till that occur near the mouth of the Hood River. The till was formed by an arm of an ancient glacier that extended down to this point from the region of Mt. Hood. Other ancient glaciers may have descended other valleys to the river's edge, but the gorge itself has surely never been subjected to glaciation throughout its length.

THE GORGE SOILS

No calcareous beds of any sort are found within the gorge and its sedimentary deposits are all of igneous derivation. The soils are generally shallow, excepting some areas of relatively deep alluvium on the gorge floor. As might be expected from the volcanic origin of most of their mineral constituents, the soils of the gorge seem to be characterized by a notable chemical uniformity; they are in general well provided with the minerals necessary for plant growth, and alkali soils are apparently absent. As to physical characteristics, water-holding capacity, and drainage, the soils vary throughout a very wide range; clays, silts, loams, and sands are all to be found, usually with only a thin surface admixture of humus; but in places flat enough to accumulate plant remains, patches of predominantly humus soil have been formed. Soils of the slopes contain various amounts of rock debris and these soils naturally differ according to the nature and particle-size of the mineral material contained. Soil influence upon the plant life of the gorge is apparently mainly effective through water relations, or through relations dependent on soil aeration—which, in turn, depend largely on water content. Upon water relations are dependent most of the soil characteristics that differentiate the many widely various plant habitats of the gorge and furnish opportunity for the growth of such an extensive range of life forms as are found here in relatively close proximity.

Naturally the depth of soil is, in general, greatest on the gorge floor, especially in the stretch above the rapids, and it is generally least on the walls of the gorge. Much of the walls and large areas of the floor are of rock that is nearly or quite bare. In crevices, niches, and hollows of the exposed rock have accumulated restricted soil masses, in which many plants grow. The soil of cracks and crevices is usually finely powdered black humus, derived largely from lichens and mosses, which holds water in large volume and with great tenacity.

On the gorge floor the deep alluvial sands, silts, and clays are kept very wet by natural sub-irrigation throughout a large portion of each year and, judging from the character of their vegetation, are apparently more or less acid. Here the moisture supply for plant growth is never deficient, but the oxygen supply may be a limiting ecological condition in many places.

Dunes occur on the gorge floor in the extreme eastern part and also near the western end. In the east, where the climate is dry, the sandy material from the river flood plains, shifted by the strong west winds of summer, fails to become well anchored by vegetation and here the dunes are of the moving kind—many of them typically crescentic in shape. They form a continual hindrance to the railroads of that region. The dunes of the western part of the gorge, formed by the strong east winds of winter, are usually quickly fixed by plants during the growing season, for precipitation is abundant here. As a result of these striking differences in moisture and in seasonal distribution of the winds, the dunes of the west portal are far less conspicuous than those near the other end of the gorge.

GENERAL VEGETATIONAL FEATURES OF THE GORGE

VEGETATION TYPES

Within its fifty-five miles of length and its average breadth of about five miles, the Columbia Gorge presents a remarkably interesting range of vegetational characteristics. It constitutes a sort of transition corridor through the barrier of the Cascade Mountains, connecting hydric evergreen forest on the west with the microphyll desert of the Columbia Basin on the east (Shantz and Zon, 1924, Shreve, 1917)—a transition due chiefly to such general climatic differences as correspond to a marked diminution in the intensity of rainfall and cloudiness from west to east and to an equally pronounced increase in the intensity of summer evaporativity and solar radiation in the same direction. The west-east range of vegetation types is nearly equalled in diversity and extent by the range from rim to rim. The latter is related to diverse conditions of soil and drainage, to various inclinations of slope, to differences in elevation, and to differences in climatic influences such as those of evaporativity and solar radiation.

Piper's (1906) excellent classification of the vegetation types of Washington—which is a modification of Merriam's (1894, 1898) well-known general scheme of life zones of the United States generally fits to an admirable degree the regions adjacent to the gorge, such as the Willamette Valley, the Cascade Mountains, and the Columbia Basin; but within the gorge itself plants that are elsewhere restricted to different life zones may often be found growing close together. Piper's Humid Transition zone is well represented on the walls of the western part of the gorge, where the characteristic appearance of the vegetation is principally due to Douglas fir (*Pseudotsuga taxifolia* [Poir.] Britt.), which is accompanied by giant arbor vitae (*Thuja plicata* D. Don), red alder (*Alnus oregana* Nutt.), Oregon maple (*Acer macrophyllum* Pursh), and a large number of shrubs. The Timbered Arid Transition zone of Piper is represented by many areas in the eastern part of the gorge, especially on slopes near the east portal that are partly protected from direct radiation; there ponderosa pine (*Pinus ponderosa* [Dougl.] Lawson) is the most conspicuous tree, but Garry oak (*Quercus garryana* Dougl.), which is more characteristically found in the drier portions of the Humid Transition zone, is also abundant. Piper's Treeless Arid Transition zone is represented by exposed areas in the eastern part; it is there characterized by bunchgrass (*Agropyron spicatum* [Pursh] Scribn. and Smith). His Upper Sonoran zone is represented in the Columbia Basin east of the gorge, where the most conspicuous plants are sagebrush (*Artemisia tridentata* Nutt.) and antelope brush (*Kunzia tridentata* [Pursh] Spreng). In the mountainous regions north and south of the middle reach of the gorge, and not very far from its rims, are typical examples of Piper's Canadian, Hudsonian, and Arctic vegetations but, except to note that a number of their characteristic species descend to low elevations in the gorge, these zones are not included within the purview of this study.

As might be expected, the vegetation types and plant communities of the gorge are clearly controlled in large part by conditions of climate and soil. Climate is very different on the two sides of the Cascade Range and the difference is reflected in the gorge; westward from the mountain axis, which is approximately marked by Wind Mountain, the climate is characteristically moist, while eastward from that point it is much drier. This probably accounts for most of the main vegetational differences between the western and eastern portions of the gorge.

Soil-moisture conditions in the gorge are partly controlled by drainage features, such as soil porosity, soil depth and height above the level of the river, and partly by amount and time-distribution of precipitation, evaporativity, and solar radiation. On account of pronounced differences between the north and south walls with respect to impinging solar radiation, the vegetation is correspondingly different on the two walls. In some instances mechanical wind effects, as well as wind influence on evaporativity, differ greatly on the two opposite sides.

HABITATS OF THE GORGE

Although it is difficult to picture a series of plant communities satisfactorily without reference to specific locations and habitats, still a rough idea of the vegetational diversity of the gorge may be obtained if the gorge habitats are grouped to form the four classes characterized below, a few conspicuous or dominant plants being mentioned as examples in each instance: (a) habitats of the gorge floor, (b) habitats of the south wall, (c) habitats of the north wall, and (d) habitats of the uplands adjacent to the rims.

a. *Habitats of the floor.*—The relatively level floor of the gorge is naturally composed partly of the present flood-plains, the major portions of which are usually under water for several weeks in late spring or early summer but whose higher parts may have been submerged only rarely, and partly of areas that show no evidence of having been reached by freshets within the last century or more.

The present flood-plains are largely of clayey soil, which is generally moist and poorly aerated even in the dry season. On them are found such trees as cottonwood (*Populus trichocarpa* T. and G.), ash (*Fraxinus oregana* Nutt.) and willow (*Salix fluviatilis* Nutt., *S. argophylla* Nutt., *S. sessilifolia* Nutt., *S. lasiandra* Benth.) ; the complete absence of coniferous trees is a notable feature of these plains in general. As to agriculture, these clayey soils are devoted to truck gardens or to the production of alfalfa hay in the east and to dairy-farming in the west.

Within these clayey areas of the plains there occur restricted patches of well-drained soil, of gravel or roughly broken rock fragments, which are usually drier and more thoroughly aerated than the clay, excepting at freshet time. On such patches may be observed a peculiar mingling of typically flood-plain and upland trees, generally including cottonwood, willow, black haw (*Crataegus douglasii* Lindl.), western choke cherry (*Prunus demissa* [Nutt.] Walp.), and occasional trees of Garry oak; where flooding has been least frequent a few Douglas firs are found on these soils in the western portion of the gorge, and a few ponderosa pines in the eastern portion.

Those parts of the gorge floor that lie above the level of the regular freshets of recent years include remains of very ancient flood-plains of clayey soil, also occasional small sand dunes and restricted rocky areas. On the remnants of ancient flood-plains are found a mixture of lowland and upland forms, such as cottonwood, willow, and Oregon maple—with Douglas fir frequent in the west and ponderosa pine in the east. Such areas are largely devoted to agriculture, being principally used in the west for hay, fodder, and pasture, and in the east for garden truck, apples, pears, and apricots. The dunes are found only at the west portal and in the far eastern portion of the gorge, as has been said. On them cottonwood and black haw are generally conspicuous, and sand dock (*Rumex venosus* Pursh) is characteristic. The rocky areas of the gorge floor bear trees and shrubs that characterize the adjacent gorge walls, also a number of herbaceous plants that appear to have spread westward from the dry region east of the gorge such as *Eriogonum compositum* Dougl., *Sisyrinchium grandiflorum* Dougl., and several grasses of xeric nature.

b. Habitats of the south wall.—The habitats of the gorge walls generally are soil-covered slopes and benches, taluses, cliffs, or ravines. In the west, the soil-covered areas of the south wall—unless in agricultural use—are occupied partly by virgin or second-growth forest and partly by logged-off or burned forest remains. In these forests are found Douglas fir, giant arbor vitae, hemlock (*Tsuga heterophylla* [Raf.] Sarg.), vine maple (*Acer circinatum* Pursh), blue elder (*Sambucus glauca* Nutt.), Oregon maple, hazel (*Corylus californica* [A.DC.] Rose), dogwood (*Cornus nuttalii* Audubon), and Scouler willow (*Salix scouleriana* Barr.). In the east the soil-covered parts of the south wall are occupied largely by ponderosa pine and Garry oak, with occasional Douglas firs, Oregon maples, hazels, and blue elders. The few small areas of this type that are in agricultural use are devoted to fur farming, grazing, and to orchards of apple and pear in the west and mid-gorge regions. In the vicinity of the Hood River Valley orchards of apple, pear, and cherry are very numerous; farther east grazing is more common and only a few small orchards occur.

The taluses of the south wall are generally almost barren of trees and shrubs but their rock surfaces are mostly covered with various lichens; in the west they bear also drought-resistant mosses and *Selaginella rupestris* [L.] Spring, with rock brake (*Cryptogramma acrostichoides* R. Br.) in the crevices.

Permanent waterfalls and wet or moist cliffs occur in the gorge almost exclusively west of the region of the Hood River and are especially numerous on the south side. The moist cliffs are generally richly covered with herbaceous forms, including the seed-plants *Sullivantia oregana* Wats., *Arnica amplexicaulis* Nutt., *Dodecatheon dentatum* Hook., *Senecio harfordii* Greenman, *Bolandra oregana* Watts., *Mimulus alsinoides* Dougl., *Oxalis oregana* Nutt., and *Saxifraga rufidula* [Small] Piper. Western maidenhair fern (*Adiantum pedatum aleuticum* Rupr.), *Selaginella douglasii* [Hook.]

Spring and many moisture-loving mosses are usually found here in great abundance. On the other hand, cliffs that are not kept moist most of the time bear a very different kind of vegetation, with fewer species as well as fewer individuals. Among the characteristic plants of these drier cliffs, especially toward the west, are *Penstemon rupicola* [Piper] Howell, *Campanula rotundifolia* L., *Sedum spathulifolium* Hook., and *Saxifraga bronchialis vespertina* [Small] Rosend. Toward the east end of the gorge *Penstemon richardsonii* Dougl., *Eriogonum compositum* Dougl., and *Haplopappus resinosus* [Nutt.] Gray are conspicuous.

The ravines of the south wall are generally filled with vegetation, which is of course more dense in the western portion than in the east. In the west, red alder is one of the commonest trees of these ravines; generally associated with it are Douglas fir, giant arbor vitae, Oregon maple, vine maple, and the shrubs ninebark (*Physocarpus opulifolius* [L.] Maxim.), red elder (*Sambucus callicarpa* Greene), and stink currant (*Ribes bracteosum* Dougl.); less common are devil's club (*Echinopanax horridum* [J. E. Smith] Dec. and Planch.) and Oregon yew (*Taxus brevifolia* Nutt.). In ravines near the eastern end of the gorge, which are generally relatively dry, are found Garry oak and ponderosa pine, together with species that grow abundantly on open walls farther west—Oregon maple, hazel, blue elder, and occasionally Douglas fir and dogwood.

c. Habitats of the north wall.—Because the north wall of the gorge generally receives much more solar radiation than the south wall, the two walls differ strikingly with respect to vegetation. The difference is usually

FIG. 2. Eastern portion of the Columbia Gorge; view east from Mayer Park, Oregon. August, 1933.

most pronounced in the eastern portion (see Fig. 2). Here the growing season is much less favorable for plant growth in general than it is anywhere else, because summer sunshine and summer evaporativity are most intense and summer precipitation is least, therefore local climatic differences are most clearly reflected in the vegetation.

In the western portion of the gorge burned-over areas are notably more extensive on the north wall than on the south wall, doubtless because the former is generally drier than the latter. Also some herbaceous species that are occasionally found on the drier north wall in the west have not been recorded for the more humid south wall except in the east. Gorman (1920) lists ten such species occurring on Hamilton Mountain (see Figs. 1 and 5) in the western part of the gorge. Indigenous to the semi-arid region of eastern Washington and Oregon, these appear to have migrated far westward on the drier north wall. They have been observed on the south wall only near the eastern portal. In the heart of the Cascade Range the vegetational difference between the two walls is emphasized by the difference in the relative abundance of ponderosa pines as compared with Douglas firs. Here, on the north wall many ponderosa pines occur among the firs, while on the south wall just opposite, the pines are absent. Ponderosa pines are not found in the western part of the gorge; there Douglas firs dominate both walls. In the eastern part between Hood River and Lyle pines appear conspicuously on both walls and probably exceed the firs in abundance. As one proceeds eastward from the middle of the gorge into the less humid region, the fir is seen to become progressively less frequent and east of the White Salmon River it fails altogether on the north wall. East of Lyle the north wall is essentially without either trees or shrubs. On the other hand, trees are still numerous on the south wall near the eastern end of the gorge, the dominant forms being oak and pine, with occasional firs and maples.

As to agriculture, suitable areas of the western north wall are used for orchards of prune, apple, and pear, and are occasionally devoted to grain. In the vicinity of the White Salmon Valley, apple and pear orchards are very common but still farther eastward agriculture is confined to grazing and a small amount of wheat culture.

The vegetation of the talus slopes of the north wall is similar to that occurring on similar slopes on the south wall, but it is notably more sparse on the Washington side.

With respect to their vegetation, the fewer moist cliffs of the north wall are not very unlike the more numerous ones of the south wall. *Sullivantia oregana,* which is common or frequent on southern moist cliffs (with northerly exposure), is very rarely found on moist cliffs of the north wall (with southerly exposure); *Saxifraga bronchialis vespertina,* which is characteristic of dry cliffs on the south wall, seems to be less abundant on the cliffs north of the river.

Ravines of the north and south walls in the western part of the gorge are similar with respect to vegetation, but east of the Klickitat Valley fewer species of shrubs and trees, and fewer individuals of these, are found in the northern than in the southern ravines. In the northern ravines Oregon maple, Garry oak, hazel, and blue elder appear much dwarfed when compared with the same species as they occur in ravines of the opposite wall and on open slopes of both walls farther west.

d. Uplands adjacent to the gorge rims (see Map Citation No. 1).—North and south of the western and middle portions of the gorge the uplands—when not burned or cut over—are generally heavily timbered at elevations of from 1,000 to 3,000 feet, with a forest that contains immense specimens of Douglas fir, hemlock, and giant arbor vitae. At higher elevations, from 3,000 to 5,000 feet, as far east as the White Salmon Valley on the Washington side and a little beyond the Hood River Valley on the Oregon side, the characteristic trees are noble fir (*Abies nobilis* Lindl.), amabilis fir (*Abies amabilis* [Dougl.] Forbes), and western white pine (*Pinus monticola* Dougl.). Eastward from the regions just mentioned, ponderosa pine is the conspicuous tree of the uplands, which are here generally lower than 3,000 feet, but the upland forest is seen to be progressively more open as the observer approaches the east portal of the gorge. In the vicinity of that portal, especially south of the river, the upland is largely treeless, bearing predominantly grasses and thickets of scrub oak.

The cleared uplands of the western gorge region are used for raising grain, for small orchards, and for grazing of dairy cattle. A recently introduced and highly successful agricultural industry here is the production of narcissus bulbs. The valley of the Hood River and that of the White Salmon River have been artificially irrigated for many years, being intensively devoted to apple, pear, and cherry orchards up to an elevation of about 2,000 feet. Eastward beyond these valleys orcharding is also practiced on the south side of the Columbia, but by the methods of dry-farming. Elsewhere in the region of the eastern gorge the cleared or naturally open uplands are used for wheat growing and for grazing.

THE GORGE AS CORRIDOR AND BARRIER

It is apparent that the gorge has served as a sort of corridor for plant migration from east to west and from west to east through the great barrier of the Cascade Mountains, and migration is surely continuing. As examples of migrants from east to west may be mentioned sand dock, sumac (*Rhus glabra occidentalis* Torr.), large-flowered clover (*Trifolium macrocephalum* [Pursh] Poir.), *Penstemon richardsonii* Dougl., *Anogra pallida* [Lindl.] Britt., and *Piscaria setigera* [Hook.] Piper. Mainly confined to the very dry and treeless region east of the gorge, these species are frequent within the east portal, and they are sparingly found farther westward; the Piscaria occurs even beyond the west portal. In the more humid region these forms occur on dunes adjacent to the river, except for the clover and the Penstemon, which grow only on dry ridges and in dry shallow grottoes in cliffs, respectively. Among the plants that appear to have spread from west to east are Oregon ash, Garry oak, Oregon maple, vine maple, dogwood, and Oregon grape (*Berberis aquifolium* Pursh), which belong ecologically to the western humid region but occasionally occur as far east as the vicinity of the east portal.

On the other hand, there seems to be evidence that the gorge may have acted as a barrier to hinder the northward or southward spread of some plant forms. For example, *Castanopsis chrysophylla* [Dougl.] A. DC., *Delphinium trolliifolium* Gray, *Erigeron howellii* Gray, and *Sullivantia oregana* are almost completely confined to the Oregon side, while *Ranunculus triternatus* Gray, and *Penstemon variabilis* Suksd. occur on the Washington side but have not been reported from the Oregon side.

FLOOD TOLERANCE OF LIVING FIRS AND PINES ABOVE THE CASCADE RAPIDS

Although, as has been said, coniferous trees are entirely absent from the frequently inundated areas of deep silt on the gorge floor, which, as far as trees are concerned, are exclusively occupied by willows, ashes, and cottonwoods, yet a few healthy Douglas firs and ponderosa pines occur below the level of the highest floods in the region east of Cascade Locks. These exceptional trees are found only on occasional small areas of gravel or broken rock, which become much more quickly drained than the neighboring silt areas as each spring freshet recedes. In the summer of 1935 and with the aid of Elizabeth G. Lawrence, a number of firs and pines growing nearest to the level of the river surface on some of these gravelly or rocky areas were studied with reference to the elevations of their upper roots above mean sea-level and to the flood records, which for this part of the gorge are continuous since 1879.

A thorough search along both shores of the river eastward for 25 miles from Cascade Locks revealed only a few firs whose upper roots could possibly have been submerged at any time of their lives. Of the firs examined, the three growing nearest to the river level were young trees, the oldest being probably not more than 35 years of age. According to the flood records, the land upon which these trees stand had never been entirely submerged since the June flood of 1894; consequently the roots of these trees have never been submerged.

Five much larger and older firs, growing at somewhat higher elevations in as many different places, had surely had their roots submerged within the period of the flood records. The lowest of these trees, which was about 130 years old, had had its root system totally submerged only once in the last fifty-five years of its life; namely, in June, 1894, when its root system must have been completely under water for about two weeks. It appears that Douglas fir in this region cannot tolerate prolonged or frequent inundation of its roots.

On the other hand, ponderosa pine (which is not found in the gorge west of the Cascade Rapids) appears to be remarkably tolerant of flooding. Fifteen individuals of this species were found growing so near to the river level that their roots must have been flooded at least seven times in the past 55 years. The root system of the lowest-growing of these, which was about 100 years old, was about 11 feet lower than that of the lowest-growing fir. The flood records indicate that freshet water had stood above its upper roots 29 times in the last 55 years, that on 10 of these occasions the entire root system must have been submerged for at least 2 weeks, and that in 1894 it was submerged for over a month. Figure 3 shows the base of this particular tree. Its upper roots are largely exposed, through wave action at flood times, and pieces of driftwood lying about furnish additional evidence that this tree must have survived at least a number of floodings.

Near this lowest-growing pine stood several Garry oaks about 20 years of age, which were apparently in good health although their uppermost roots were at levels 5 or 6 feet lower than the upper pine roots, where they must have been flooded many times. It is thus evident that this oak also is highly tolerant to repeated flooding in this region of the gorge.

When a plant is killed as a result of the flooding of the soil about its roots the lethal influence may be directly or indirectly attributed to inadequacy of soil aeration—to inadequacy of oxygen supply to the roots—or to effects produced by micro-organisms in the water-saturated soil. Trees are often killed by piling soil about them in grading operations, even when no flooding occurs, and the injurious effect of such burying is also to be attributed to deficient aeration of the soil adjacent to the roots. In his study of oxygen-supplying powers of soils, Hutchins (1926) found that oxygen supply was almost completely stopped by a 16-inch layer of wet, firmly packed loam. That Douglas fir is unable to tolerate much flooding is indicated clearly by the indirect evidence presented above, and the writer has seen several trees of this species killed within a year as the apparent result of piling clay around them to a depth of 3 feet or less, although the added soil was kept away from the trunks for about a foot. It appears that this fir requires a rather plentiful supply of oxygen in the soil about its roots—a more abundant supply than is required by ponderosa pine and a much more abundant supply than is requisite for Garry oak.

That different plant species exhibit marked differences in their responses to the flooding or burying of the soils in which they are rooted is commonly known, but quantitative information concerning the penetration of oxygen into the soil and the oxygen requirements of plant roots seems to be very limited indeed. Free (1917) and Livingston and Free (1917) reported that potted plants of a willow known to thrive in very wet soils remained healthy for 10 months without any oxygen supply to their roots, excepting what might be delivered internally through leaves and stems; on the other

FIG. 3. Base of ponderosa pine near Collins, Washington, showing effects of floo August, 1935.

hand, their plants of Coleus and Heliotropium wilted promptly when the air of the soil about their roots was replaced with oxygen-free nitrogen. Bergman (1920) subsequently found that flooding the soil in which plants of Coleus and Pelargonium were growing caused the leaves of these plants to turn yellow and to drop off in about two weeks. Potted plants of *Coleus blumei* showed signs of wilting one or two days after their roots had been submerged. But when the water with which these roots were flooded was adequately aerated the plants did not wilt, but remained in good health as long as artificial aeration was maintained. With regard to their soil-oxygen requirements, it appears that the willows, cottonwood, and ash of the Columbia Gorge flood-plain may be similar to the willow plants of Livingston and Free's experiments, that Douglas fir may be similar to the Coleus, Heliotropium, and Pelargonium plants of those authors and of Bergman, and that ponderosa pine and Garry oak may be intermediate.

ASYMMETRIC CROWNS AND THEIR RELATION TO WIND AND WEATHER IN THE GORGE

THE ASYMMETRIC CROWNS

Introduction.—In Pacific Coast forests the Douglas fir trees are usually more or less nearly symmetrical as is the tree shown in Figure 4. Such symmetry of crown form is rarely to be seen, however, as one travels eastward from Portland to the treeless region of the Columbia Basin through the 60 miles of rugged and timbered Columbia Gorge; there, in the gorge, one is impressed by the remarkable one-sided crowns that characterize the needle-leaved trees in the western and eastern portions.

From Crown Point, at the lower end of the gorge, the splendid view extends about 25 miles up the river in a northeasterly direction, to Wind Mountain, in the heart of the Cascade Range. An idea of this view may be had from the photograph of Figure 5 which was obtained by means of dark red and infra-red rays only. Throughout this nearly straight stretch many of the fir trees that line the gorge are remarkable because of their conspicuous one-sided crowns; for almost all of their large branches extend in a westerly direction from the trunks. The gorge bends slightly toward the east where the first view terminates and, as one proceeds around the bend, it is soon noticed that the asymmetric fir trees seem to have faced about, with their larger limbs extending toward the east instead of toward the west. (Note the tree symbols on the map of Fig. 1.)

A widespread popular idea or belief is offered by dwellers in and near the gorge, in attempted explanation of this striking difference between the fir crowns east and west of the bend. According to this erroneous idea, the winds of the gorge, which are wrongly supposed to arise in the valley of the Wind River, first swirl about Wind Mountain and so become separated into two winds of opposite direction, which then pass forth from that region,

FIG. 4. Symmetrical Douglas fir near Portland, Oregon. (G. C. Stephenson, photo.)

simultaneously eastward and westward; a statement often made is that "the prevailing winds blow outward from the center of the gorge." That what appear to be cloud swirls are sometimes seen about the summit of Wind Mountain seems to lend a kind of support to this popular idea about the origin of the gorge winds; but that idea is wholly erroneous, for weather rec-

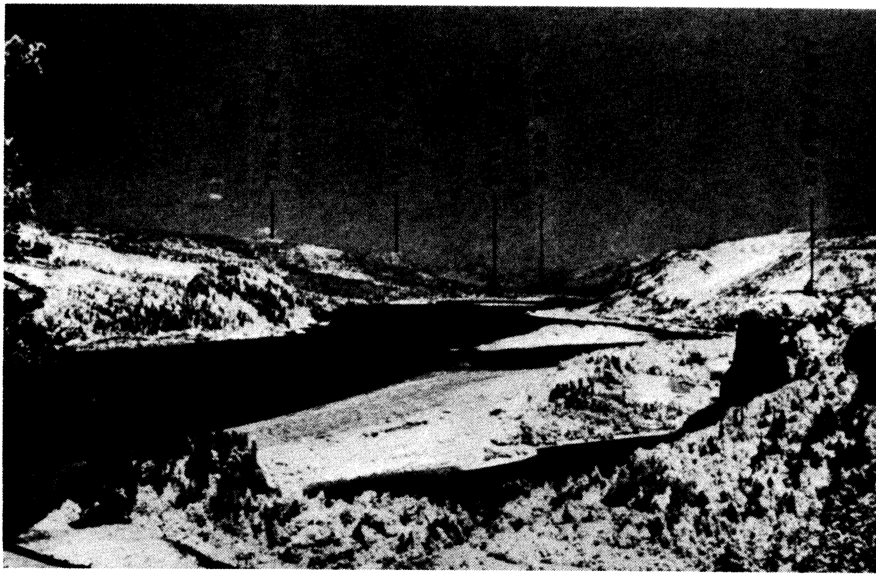

FIG. 5. Western portion of the Columbia Gorge; view northeast from near Chanticleer Point, Oregon, photographed with dark red and infra-red rays only. August, 1934.

ords show that at any one time the general trend of wind movement is continuous through the whole gorge, either eastward or westward from one portal to the other, and wind velocity generally increases greatly from the portal of entrance to the portal of exit. Although the deformations of the firs are indeed due primarily to wind influence, yet the relations actually involved are far too complex to be appreciated except through detailed examination of the trees themselves at different seasons of the year and through analytical study of the meteorological records of the gorge. Results of such examination and study are presented in the present section.

That this problem concerning the one-sided tree crowns of the Columbia Gorge has not previously been very thoroughly studied may have been largely due to the fact that access to many parts of the gorge has only recently been rendered relatively easy and inviting, through the development of automobile roads. Furthermore, the meteorological and climatological aspects of the problem could not be satisfactorily studied until within the last few years because the requisite meterological records and facilities for studying the weather of the gorge were not available.

Very satisfactory weather records for the gorge region, collected in the period since 1929, are now available, however, in the office of the Portland Municipal Airport, and free access to them was had through the friendly co-operation of Mr. J. C. Smith, of that office. Mr. Donald C. Cameron, formerly of the same office, has helped the writer very much in the study of the gorge winds. Much was gained also by prolonged studies of current meteorological observations as these were recorded on the teletype ribbons at the four meteorological stations within the gorge. These airway weather-reporting stations (of the United States Weather Bureau and the United States Bureau of Air Commerce) are about twenty miles apart, one being close to each portal of the gorge while the others are respectively near Cascade Locks and Hood River. (See the circled triangles on the map of Fig. 1.) Simultaneous hourly notes on atmospheric conditions at all four stations are promptly shown at every one of them; thus, at any time, day or night and at any station, one may study the current weather conditions throughout the gorge and follow weather changes, as they proceed. Through the courtesy of the resident observers, many pleasant and helpful hours were spent in that way.

Fir crowns of the western part.—The western type of fir crown deformation, in which most of the large branches project in a westerly direction from the trunks, is most strongly developed near the west portal of the gorge. Extreme examples from that region are shown in Figures 6 and 7. Observed in late summer near the end of the growing season the one-sided trees here present a characteristic rigid, tattered, and grotesque appearance. Their trunks stand nearly upright or lean a few degrees toward the west, but all are essentially straight. The crowns are usually narrow and spire-shaped, with many dead limbs and conspicuous jagged fragments among the longer branches. Much of the apical portion of the crown, for two feet or more back from the tip, is generally without foliage and appears bleached and weathered, as is seen in Figure 7. The rest of the crown is almost wholly confined to a vertical segment on the west side, which represents only about a quarter of the usual symmetric conical crown of an undeformed Douglas fir (compare with Fig. 4), but even within that segment, the branches are relatively short. They are generally covered with dense tufts of foliage twigs, irregularly distributed along the proximal parts of the branches while the distal portions often lack foliage entirely; the longest branches are sometimes completely bare and dead, as may be seen in Figures 6 and 7. When branches occur on the north and south sides of the trunk these show much evidence of pruning, with broken tips; and areas of sparse foliage and densely bunched foliage twigs occur in alternate regions of the branch. On the east side, where there are no long branches, short branch stubs, about four inches long, show that branches of from one to six years' growth have been broken away. Sometimes the outer portion of a longer branch still hangs leafless from its stub by a shred of wood. But this eastern side of the bole is usually densely clothed with short, vigorous branchlets and twigs of the last one or two seasons, which form a thick leafy mantle that often completely hides the middle region of the trunk on that side. These short branchlets and twigs extend outward from the trunk generally not more than about 6 inches, appearing as though clipped by a gardener's shears. In the lower portion of the crown, where the eastern mantle of branchlets is often incomplete or lacking, the trunk on that side is apt to be studded with fungous conchs and gnarled knots, where branch stubs have healed imperfectly. On the ground are to be seen the more or less completely decayed remains of the branches whose stubs are so conspicuous above.

Such summer observations make it evident that these trees must have been subjected to a very drastic natural pruning, effective especially on the east, less on the north and south and only slightly on the west. It is clear that this pruning must have occurred at some other season of the year, for it is obviously not in progress in summer. Furthermore, summer wind in the western part of the gorge is usually gentle and from the west; east winds at this season are rare and are not strong enough to cause the breakage of branches.

But east winds of excessive velocity do occasionally occur here in winter and these are sometimes accompanied by the freezing rain of very destructive glaze storms, which are locally called "silver thaws." Although winter gales without ice deposition sometimes cause considerable breakage of branches and trunks due to wind pressure alone, most of the drastic pruning just described is brought about by the combined action of the east wind and massive ice deposits on the trees.

The writer has not made extensive observations of the deformed trees here considered in the winter season but it is reported by Mr. Donald C. Cameron and by the official weather observer at Crown Point, Mr. William A. Johnson, that when the trees are examined shortly after the close of a glaze storm many newly fallen branches with green foliage still in place are to be found on the ground about the trunks and freshly formed stubs from which these branches have been broken very recently are also to be observed. Injury is most pronounced in the upper portions of the crowns and on the east and northeast sides of the trees; some breakage has usually occurred on the north and south sides but evidence of breakage is rare on the west sides. Although the effect of the glaze deposit on the dense mantle of short living branches and foliage twigs on the east side of each trunk has not been directly studied, the mantle probably remains essentially intact since it should be largely protected throughout the most severe part of the storm by a more or less complete covering of ice.

In addition to this one-sided storm-pruning to which these Crown Point firs are subjected during glaze storms, another form of winter injury occasionally takes place, which becomes manifest only at a much later time and is almost entirely unrelated to those storms. Sometimes when the trees are examined in early spring—in March or April of some years—most of the leaves on the eastern side of the crown, including those borne by the few projecting branches on that side as well as those of the bole mantle, are found to be dead and discolored, but still in place. At such times much of the east side of the crown is red-brown in color, appearing as though its foliage had recently been scorched by fire. This kind of delayed evidence of winter injury has been called "parch blight" by Munger (1916), who studied it in the vicinity of Portland as well as in the western part of the gorge. Near Crown Point it sometimes embraces the whole apical region of the crown for a distance of several feet from the tip. Farther down, the parch blight discoloration is incomplete and less pronounced on the northern and southern sides of the crown, but it is apt to include the longer branches even on the western side, where it is least evident. The tallest trees are most affected and the younger ones of a group frequently show little blight injury except on their eastern sides. When Munger's parch blight is observed in early spring the dead leaves are still in place but, as they fall off and the new foliage twigs and new leaves expand, the trees once more assume their normal green color.

This kind of injury is sometimes very severe. Trees that have been exceptionally exposed to the winter winds are in some cases killed outright, especially if the soil at their bases is unusually shallow. But parch blight does not occur every spring and it is seldom observed in consecutive springs; thus the injured trees usually have two or more growing seasons for recovery before they are again subjected to injury of this sort. It is consequently understandable how the fir forest of the western gorge is able to persist in spite of occasional drastic storm-pruning and extensive spring defoliation. The relations between these two forms of injury and winter weather will receive attention farther on.

Fir crowns of the eastern part.—Extreme examples of asymmetric firs of the eastern part of the gorge, with all branches extending eastward from the trunks, may be seen near Mitchell Point or near Ortley Point, which are respectively 35 miles and 53 miles east of Crown Point (see Fig. 1). Some of these trees are shown in Figures 8 and 9. They differ from the western ones not only in the direction of their asymmetry but also in other notable ways, especially in that they appear to be wind-trained rather than storm-pruned. They resemble to some extent wind-swept trees sometimes seen near the sea-shore but they are not at all dwarfed or gnarled. The trunks are commonly bowed slightly toward the east, especially above, and their slender tips are frequently strongly bent in the same direction, each one forming a graceful curve that may terminate in a line that departs as much as 30 degrees from the vertical. Leafless or dead branches and stubs of broken branches, which are so characteristic of the Crown Point trees are uncommon here, nor is there at any time of year any evidence of parch blight in these eastern trees. The boles are characteristically smooth, rarely marred by any evidence of injury of any sort, and the short branches and foliage twigs do not form characteristic dense trunk mantles such as are common on the eastern sides of the Crown Point trees. Numerous well-developed leafy branches, in excellent health, arise from all sides of the trunk, but those arising on the western, northern, and southern sides have been sharply bent around, so as to extend eastward along with those arising from the eastern side. Almost every long branch droops slightly but it is gently bowed upward toward its tip. The crown is thus essentially confined to a vertical segment representing little more than one-sixth of the cone represented by the crown of a symmetrical, undeformed tree (compare with Fig. 4). The origins of the older branches from the west side are commonly so overgrown, through bole enlargement, that the basal portions of their bends are concealed, and these bent branches consequently appear to arise south or north of their real origins.

The crowns of these eastern trees have obviously been molded by wind pressure alone; they have not been trimmed or pruned by breakage, as have their fellows at the western end of the gorge. Essentially free from breakage or lethal injury of any kind, they have been, as it were, trained into shape by persistent and powerful west wind which must have acted during the growing season rather than in winter. In the eastern part of the gorge such winds are indeed prevalent in late spring and in summer, especially by day—when the growing tissues of the fir branches are most readily bent by wind pressure.

The peculiar asymmetry of these eastern fir crowns, as contrasted with that of the western ones, is best appreciated by reference to Figures 6 to 9. Whereas the western crowns have been deformed by breakage and killing due to the glaze storms and strong east winds of midwinter, the eastern ones have been deformed by long-continued pressure of strong west winds of late spring and summer. It will be noted that the photographs of Figures 6 to 9 and also that of Figure 10, to which reference will be made below—all represent views looking northward; thus they are directly and readily comparable. Comparison of these photographs should bring out additional details concerning the forms and structures of these two very different types of crown.

Fir crowns of the middle region.—From Ortley Point westward, until the bend in the gorge is approached, the one-sided Douglas firs are all essentially similar to those of the eastern end—with wind-trained crowns east of the boles. Westward from the bend the one-sided crowns are like those around Crown Point—battered and broken and extending west of the boles. In the region of transition (which extends about twenty miles on both sides of the river from the vicinity of Beacon Rock to Mitchell Point and the Little White Salmon River) both types of crown are to be seen, also trees in which the two types are combined in various curious and interesting ways. In some instances the well-developed branches extend mainly northward and southward from the boles, both eastern and western sides being relatively

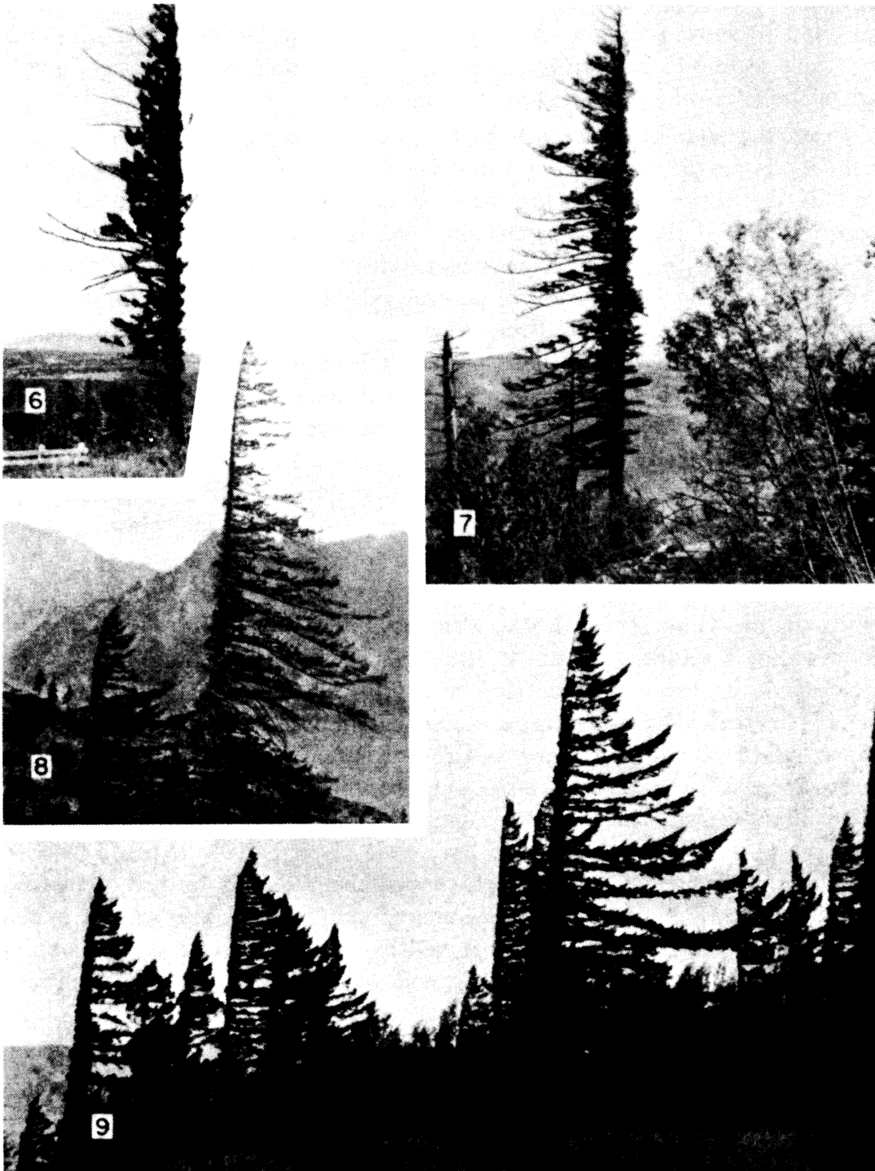

FIG. 6. Storm-pruned Douglas fir near Crown Point, Oregon; seen from the south. August, 1933. FIG. 7. Another Douglas fir near Crown Point, Oregon; seen from the south. May, 1937. FIG. 8. Wind-trained Douglas firs near Mitchell Point, Oregon; seen from the south. August, 1934. FIG. 9. Wind-trained Douglas firs near Ortley Point, Oregon; seen from the south. August, 1934.

free from long branches. In other instances the upper part of the crown conforms to one type while a lower part conforms to the other. And some trees fail to show pronounced deformation of either sort. Signs of parch blight are seldom to be seen in the region of transition except in trees growing on shallow soil in very exposed locations.

From the southern approach to the highway bridge called the "Bridge of the Gods," which crosses the Columbia River at Cascade Locks, near the bend of the gorge, tree crowns of both types are to be seen at once on opposite sides of the river; across the river and about a quarter of a mile away are trees with rugged crowns that extend westward, while in the near foreground on the south side are several graceful wind-blown forms, with crowns extending eastward. From very casual inspection it might appear that both forms might have been produced here so close together by some sort of wind swirl, but such a supposition will not bear scrutiny. The glaze-storm east winds that broke and battered the trees across the river blew in winter and the less harmful west winds that molded the nearby trees blew in summer; local topographic features of the gorge walls at this point apparently have acted to shelter the nearby trees from east wind, blowing down the river, but not from west wind, blowing up-stream.

An interesting combination form of fir crown is shown by a tree that stands on the Government Locks Property, near the eastern boundary of the town of Cascade Locks. It leans toward the east and most of the branches of its lower part extend in an easterly direction, but the upper part of its crown has largely been stripped of branches and the few that remain intact extend northward and southward. The lower portion of the crown appears to have been effectively sheltered from the very injurious east-wind storms of winter and to some extent from the summer west winds, while the upper portion appears to have been about equally exposed to both winds and consequently to have been shaped about equally by both. In general, it appears that the kind of asymmetry exhibited by a fir crown in the mid-gorge transition region is determined by the particular exposure of the tree in question, which seems to depend primarily upon local conditions of wind movement as influenced by local topography.

Other kinds of trees with one-sided crowns.—Because Douglas fir is by far the commonest tree in the gorge and because it occurs plentifully in both western and eastern parts, this tree presents the most striking and continuously consistent picture of crown deformation. For that reason it has been referred to throughout this descriptive account, but other species exhibit similar types of deformation. For example, Oregon maple and Garry oak (see Fig. 10), which are found sparingly throughout the gorge, might profitably be studied in this connection. In the eastern part of the gorge—to which it is confined—ponderosa pine frequently shows crowns deformed by west-wind pressure, which appear very much like the one-sided fir crowns

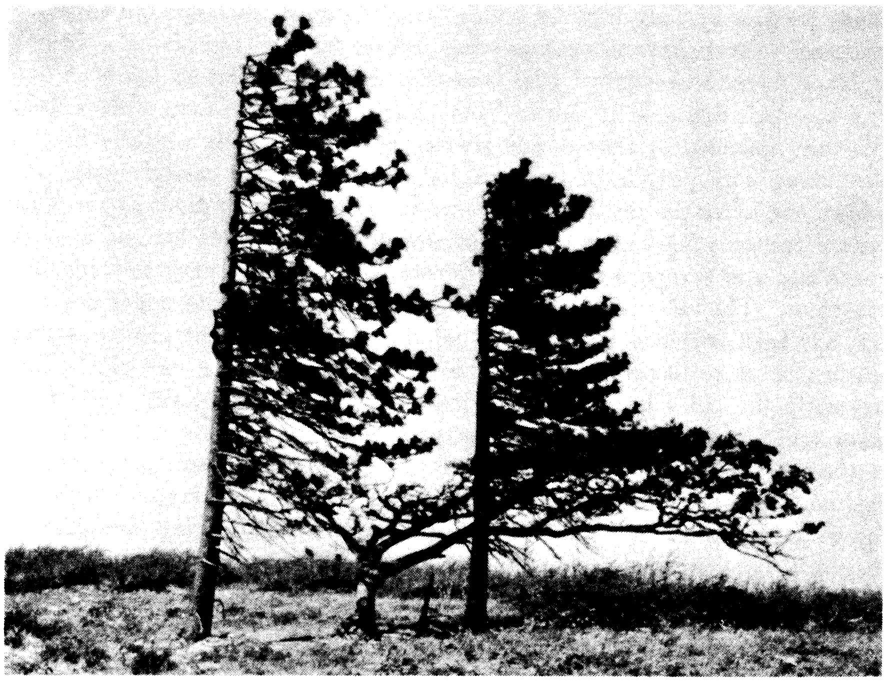

FIG. 10. Wind-trained ponderosa pines and Garry oak near Crates Point, Oregon; seen from the southwest on a calm day. June, 1937.

of the same region. Such a pine crown is shown by the photograph of Figure 10. Since the foliage of this species is less crowded than that of Douglas fir and since its branches are more rigid, the bending of the latter around the runk from west to east is very conspicuous indeed.

WEATHER CONDITIONS OF THE GORGE AS RELATED TO THE FIR CROWNS

Weather Effects in the Western Gorge

Trunks tilted westward by gales of fall and early spring.—In the western part of the gorge summer weather conditions induce no injury or permanent bending of the fir trees; their conspicuous deformation is produced by conditions that are effective at other times. Summer winds here seldom have excessive velocity, but easterly gales occur in autumn and in early spring and these appear to produce the common westward slant of the fir trunks while the easterly gales and glaze storms of winter are mainly responsible for the one-sided crowns.

Little or no rain falls anywhere in the gorge throughout the summer but in the western part the summer drought ends early in the fall, and heavy rains ensue. Toward the end of September or in early October protracted rain is generally followed by a high east wind, the first-fall gale. At Crown

Point its gust velocity may be greater than 40 miles an hour, but it is progressively less violent at stations lying farther up the river and the velocity at Hood River and North Dalles is at that time only about 10 miles an hour or less. This first gale at Crown Point is apt to last two or three days, being generally followed by shorter and shorter periods of gentle westerly breezes, alternating with periods of stronger and more prolonged easterly gales until midwinter, when the maximal east-wind velocities and durations are attained. As the season advances and spring comes on easterly gales become less frequent and less severe, and gentle westerly wind becomes progressively more prevalent. The gales of fall and early spring occur when the soil is unfrozen and has been softened by rain, and wind pressure upon the crown at these seasons tends to loosen and raise the roots slightly on the east side. Consequently the boles lean a little to leeward. This is especially true of the taller and more exposed trees. The gentler winds blowing from the west at these or other times are inadequate to restore tilted trees to the vertical position and they remain tilted year after year as they grow larger. Although the winter gales are stronger than those of autumn and spring and although they also blow from the east, still these are probably not very effective to make the trees lean westward, for they occur when the soil about the roots is apt to be solidly frozen to a depth of 1 or 2 feet, thus furnishing a very firm anchorage.

Destructive glaze storms of winter.—The characteristic glaze storms of the western gorge, to which the one-sided fir crowns of that region are almost wholly due, occur in midwinter or somewhat later. They occur at irregular intervals according to the records, some winters have been characterized by several of them while others have passed without any such occurrence. A glaze storm at Crown Point is regularly preceded by a freezing winter gale without precipitation, which blows through the gorge from the east for a week or longer (Cameron and Carpenter, 1936). Sooner or later, relatively warm coastal air begins to move inland over the gorge from the west, the velocity of the persistent east wind begins to abate and precipitation results. At first this has the form of ordinary snow, accompanied by strong east wind and by slowly rising temperature. At Crown Point the initial snow is apt to change within a few hours into graupel[2] and somewhat later into small spherical globules of clear ice now technically called sleet;[2] these solid particles which are driven westward almost horizontally, at perhaps 30 miles an hour or more may bring about some injurious abrasion of the fir needles and young twigs, especially on the eastern sides of the crowns, but that is probably of no more than minor importance.

After the fall of graupel or sleet has continued for an additional period

[2] *Graupel* and *sleet* are used here in the senses agreed upon by American meteorologists and adopted by the United States Weather Bureau. Photographs and descriptions of these two solid forms of precipitation have been published by Talman (1931). *Graupel* is used to denote frozen precipitation in which the small, rough, nearly spherical particles are white and opaque; the word is derived from the German for pearl barley or groats, and this kind of precipitation is known as "tapioca snow" in the george region.

of a few hours the freezing rain of the typical glaze storm supervenes. Driven by strong east wind, with velocity still not greatly diminished, this precipitation solidifies as it strikes, and it rapidly builds up an armor of ice on trees and other objects. This thickening ice glaze accumulates mainly on the eastern side of each tree, covering every needle and twig of the crown and even the bole itself on that side. As this deposition proceeds the intercepting surfaces become continuously more extensive, and separate portions coalesce to form great masses of ice. The ice surfaces offer increasing resistance to the wind and the ice burden becomes progressively greater on all coated branches and branchlets.

A glaze storm may continue for 24 hours or more, with east-wind velocities between 25 and 30 miles an hour, while branches and twigs on the east and northeast sides of a fir crown may become covered with ice coatings as much as three or four inches thick. Large branches that may have withstood earlier glaze storms, or that may have developed since the last preceding storm of this sort, are apt to be broken and carried away, because of their great ice load and the persistent strong east wind pressure. But, as has been said, the short and crowded twigs of the mantle on the eastern side of each fir trunk probably become completely encased and covered and so must be well protected from wind pressure while their load of ice should be well supported against the bole.

A meteorological description of a severe storm of this kind has been given by Wells (1921). Mr. William A. Johnson, who has been mentioned before in this regard, has kindly furnished the writer with much observational information concerning the glaze storms of the Crown Point region and their effects on the trees, and it seems safe to conclude therefrom and from the observations of other winter residents that most of the drastic pruning of firs of the western part of the gorge occurs in the later periods of such glaze storms. A glaze storm lasting less than twenty-four hours may result in the breakage and removal of branches that have been several years in growing.

As a glaze storm comes to its end the air temperature and the rain become warmer and the east wind abates and is supplanted by gentle southwest breeze. Temperature continues to rise and warm rain continues for several days; consequently the storm ends in a rapid thaw and the ice soon disappears from the trees. During the thaw a little additional breakage is apt to occur through the falling of heavy masses of ice from the upper portions of the trees on to lower branches. Finally, after all ice has disappeared, east wind and clear weather supervene, usually with rapidly falling temperature.

As one ascends the gorge from Crown Point to the mid-gorge region, glaze-storm injury is seen to be progressively less pronounced. But the explanation of this is not to be sought in any marked difference in wind velocity, because the wind velocity of a glaze storm is generally about the same in the mid-gorge region as farther west. The main reasons are apparently to be found in a notable eastward *increase* in the proportion of total precipitation that occurs in solid form (mostly as snow, but also as graupel and sleet) and in a correspondingly marked *decrease* in the proportion of freezing rain. Thus a glaze storm generally deposits a much more destructive ice load on the trees near Crown Point than on those near Cascade Locks.

From Cascade Locks to the east portal of the gorge the total precipitation accompanying one of these winter storms is progressively less, as are also wind velocity and the thickness of the ice deposit on the trees. Between the east portal and the Hood River both wind velocity and ice formation are so slight that tree injury from these winter storms is neither common nor severe; such injury of this sort as does occur in the eastern region is apt to affect the tree crowns about equally on all sides.

Parch blight induced by drying winter winds with low temperature of air and soil.—Besides the glaze storms just described, the western part of the gorge—and sometimes also the region lying west of the west portal—occasionally experiences cold, drying winter gales lasting a week or more at a time. At Crown Point such gales have velocities of from 40 to 50 miles an hour and on several occasions even hurricanes of 120 miles an hour have been recorded (Cameron, 1931a, 1931b, Cameron and Carpenter, 1936). These pour great volumes of very cold air from the Columbia Basin westward through the gorge. Near the east portal the temperature of the air stream may be as low as –25° F. The air becomes warmer as it moves westward, but near Crown Point its temperature is still well below the freezing-point of water. Its hygrometric deficit naturally increases with rising temperature and its velocity, which is not excessive near the east portal, is also rapidly increased with its progress through the gorge. Consequently at this season evaporativity is not remarkably intense in the east but it is very great in the west. These persistent winds are also often accompanied by bright sunshine in the daytime, which must add very considerably to the pronounced drying influences of excessive hygrometric deficit and excessive wind velocity in the west. It follows that air conditions favoring transpirational water loss from the fir needles and twigs of the Crown Point region must be unusually intense in the periods of these winter gales.

Furthermore, after a week or more of a cold dry gale of this sort, foliage, branches, and trunks must be very cold and their vascular sap may be largely frozen, especially in the more exposed parts. Consequently the conducting power of the tissues that supply the leaves with water must be greatly reduced at such times. This should be notably true even if the sap of twigs and leaf veins should remain liquid, for the viscosity of water increases markedly with decreasing temperature, and the conducting power of these parts must be very low indeed if their vascular sap has been largely frozen. These considerations apply also to large branches and trunks, though perhaps to a less degree, and to root systems likewise. Turning to the water-absorbing roots, their absorbing power as well as their conducting power must be reduced as soil temperature is lowered. It thus appears that in these periods of winter gales the drying influence of aerial conditions is greatly aggravated while absorbing and conducting powers of the tree itself are greatly reduced at the same time.

As to the water-supplying power of the soil adjacent to the absorbing surfaces of the root system, that may also be considerably or even greatly reduced throughout these periods of intense cold. The capacity of moist soil to supply water to root surfaces must become less as soil temperature falls and it must become very low indeed in so far as the soil in question becomes frozen. Finally, the soil from which water is absorbed by the tree roots may tend to become unusually dry at these times, through evaporation into the air, and any decrease in the water content of a mass of moist soil should lower the water-supplying power of the latter even if soil temperature were not lowered at the same time.

From all of the considerations just suggested it appears that many circumstances accompanying these winter gales conspire to cause the removal of transpirational water from leaves and branches more rapidly than it can be supplied to these parts. This state of affairs naturally leads to unusually advanced degrees of drying. Wherever drying becomes too advanced, leaves, and even twigs and branch tips, are killed and the ultimate outcome is parch blight.

Occasionally in the western gorge are observed fir crowns the upper parts of which project above a sheltering ridge; often the exposed portions of these crowns have been killed by excessive desiccation but the lower portions being effectively protected from the gale remain alive. Cooper (1917) described similar injury of redwoods in the Santa Cruz Mountains of California resulting from desiccation by a strong north wind in spite of the fact that at the time soil moisture was ample. His observations indicated in addition that the redwood is far more susceptible to this type of injury than is the Douglas fir for when the two species side by side had been equally exposed to the wind the foliage of the redwood was dead and that of the fir still alive.

As should be expected, this form of injury in the gorge is most frequently observed on the east side of each affected fir tree, in the upper part of the crown and at the ends of the longer branches, where exposure to the gale has been most drastic; also around the crown from east to southeast, where the sunshine of the early forenoon warms the foliage while the rest of the tree is still at about the air temperature of the preceding night.

As the conditions thus envisaged for the western part of the gorge continue from day to day throughout the period of one of these dry winter gales, the most affected needles on the fir trees of that region die because of excessive drying. They subsequently lose their original green color, becoming red-brown as spring comes on, but just how much time elapses between the actual death of the needles and the first appearance of the red-brown color is not known. The killed needles usually remain in place till the following midsummer, and in some instances the resulting conspicuous red-brown blotches have been observed to persist in the crowns of parch blighted firs till the dead needles are swept away by gales of the following winter.

Parch blight in the western part of the gorge is apparently not induced to any considerable extent by the east winds of fall and spring presumably because the complex of conditions favoring excessive drying of foliage is at those times much less effective than in the dry gale periods of winter. This form of injury is essentially confined to the western part of the gorge, being almost wholly absent east of Wind Mountain. As has been said, the air movement that produces the dry winter gales in the west is of much lower velocity in the east, and the hygrometric deficit of the moving air becomes excessive only after the latter has been considerably warmed in its westward passage. Also, at the times of these dry winter gales in the western gorge region the weather there is usually clear, while the sky over the eastern part is generally overcast at those times. It is therefore safe to suppose that evaporativity is much more intense in the western part. From Wind Mountain westward, parch blight is progressively more common and more severe, occurring oftenest and most conspicuously in the region of the west portal, near Crown Point.

According to Munger (1916), who studied parch blight in this general region and who gave it its name, the buds adjacent to the blighted fir needles generally open in the usual manner and send forth new shoots the following spring. He noted, however, that many of the branchlets and smallest branches in blighted regions on the eastern sides of the crowns failed to produce spring growth, indicating that they as well as the needles had been killed by the drying-out process. On the whole, parch blight injury does not constitute a very serious menace to Douglas fir, and this form of injury appears to play a secondary part in producing the one-sided crowns of the western part of the gorge.

Munger suggested that the occurrence of parch blight only in the western part, despite the fact that Douglas fir is plentiful throughout the gorge might perhaps be related to hereditary physiological differences between the firs of the two regions. He pointed out that the firs of the eastern gorge have varietal characters resembling those of the Rocky Mountain form of this species, while those of the western gorge are like the less hardy coastal form. Thus the latter might be readily susceptible to this blight injury and the former might generally escape because of a lower degree of susceptibility. Whether the Douglas firs of the gorge really differ with regard to their susceptibility to the development of excessive water deficit, is of course uncertain, but—as has been noted—the environmental aridity of the eastern part is unquestionably much *less* intense than that of the western part in periods of dry winter gales, when the injury here considered occurs. It may be that even the firs of the eastern gorge might prove just as susceptible to parch blight as are the possibly less hardy ones of the western gorge if both were exposed to the very drastic environmental conditions of the dry winter gales of the Crown Point region.

Weather Effects in the Eastern Gorge

As has been said, glaze storms, which are so largely responsible for crown asymmetry in the western portion of the gorge, are neither common nor destructive in the eastern portion, where east winds are not strong at any season. With the beginning of spring in the eastern gorge, the gentle winds of winter, mostly from the east, give place to persistent west winds, which gradually increase in velocity until maxima of about 30 miles an hour are attained in June and July. These west winds are but gentle breezes in the western part, but their velocity increases eastward and by the time the moving air reaches the middle and eastern region it exerts considerable pressure. After midsummer wind movement declines until fall, when gentle variable and easterly breezes once more prevail in the eastern portion of the gorge.

The effectiveness of the west winds to train the fir crowns in the growing season is enhanced by a sort of daily pulsation, which is most pronounced near the east portal but is evident throughout the eastern region of the gorge. This pulsation occurs to some extent at other seasons of the year, but it is most striking in the growing period, from May to August. The velocity of the eastward air flow increases rapidly each day, from about sunrise on, attaining a diurnal maximum of about 30 miles an hour in the afternoon. It then diminishes gradually and night velocities are often less than 10 miles an hour. This diurnal fluctuation in wind velocity appears to be caused by a sort of large-scale air drainage through the east portal of the gorge into the great open stretches of the Columbia Basin. There the lower air layer regularly becomes greatly heated by sunshine in the daytime, and its consequent rise induces an eastward flow of cooler air from the gorge, thus accelerating the general eastward movement and inducing high velocities by day.

The high daytime wind velocities must be more effective to deform the tree crowns than are the much lower night velocities, although the night winds continue to exert considerable pressure on the branches; the daily maxima of eastward wind pressure occur in those hours when the enlarging young branches and branchlets should be least rigid and elastic, when the turgor of their tissues should be lowest and enlargement and tissue hardening may be nearly or quite at a standstill (Krasnoselsky-Maximov, 1917, Livingston and Brown, 1912, Maximov and Krasnoselsky-Maximov, 1924). Some recovery from eastward bending may take place at night, but if that occurs it is obviously generally far from complete. In the latter part of the growing season nocturnal recovery may be greatly retarded or prevented because of inadequate water supply, for the soil here is usually remarkably dry in midsummer. Bent strongly toward the east each day by the daytime wind and largely kept bent throughout the night by the less rapid night wind, the branches are wind-trained as they develop. As has been said, the crowns of the eastern gorge show essentially no evidence of breakage.

CROWN ASYMMETRY IN GENERAL AND ITS RELATIONS TO WIND DIRECTION, WIND VELOCITY, AND WIND DURATION

Two distinct types of mechanical wind influence on the trees of the Columbia Gorge.—It appears that the type of crown asymmetry, which is so notably developed in the western part of the gorge, has not before been described as resulting chiefly from glaze injury and it may consequently be presumed that asymmetry resulting from that agent is of rare occurrence. On the other hand, the wind-bent type, which is equally well developed in the eastern part of the gorge, is not uncommon throughout the world; wind deformations of this general sort have been mentioned or described by many writers for many different countries and localities. Both types depend on wind, but the former is produced by a combination of wind pressure and a very peculiar kind of precipitation—i.e., glaze storms—while the latter depends wholly or almost wholly on wind pressure alone.

Characteristics of effective wind.—In order to envisage the general manner in which wind pressure may be effective to produce asymmetric tree crowns it is desirable to consider four different characteristics by which winds differ from time to time and from locality to locality; namely, direction, velocity, and what may be considered as two phases of duration. At any moment, an air current flowing past any station may be satisfactorily defined by stating its direction and its velocity; it may blow from any range of compass points and it may have any velocity from what approaches a dead calm to what constitutes a hurricane. For the sake of convenience in ascertaining the characteristics of effective wind the great range of direction may be reduced to the eight major compass points and the range of velocity may be subdivided into the eight major degrees of intensity recognized by the United States Weather Bureau. In the present brief discussion the vertical component of wind direction may be neglected, air flow being considered essentially horizontal. But since the deformation of tree crowns by wind is not brought about by momentary action, for the present purpose a useful analysis of wind movement at any station must involve two special analyses of wind duration. The first analysis is to characterize the wind in question by showing how long each major degree of intensity of velocity has been maintained with each major direction of flow, and the second analysis must involve definite reference to both diurnal and seasonal periodicity as it is related to direction and velocity. Furthermore, descriptions of special environmental conditions (such as glaze deposition, low air and soil temperatures, the presence of much salt spray or abrasive material in the air), which occur in various regions at certain times, must supplement the foregoing information. For example, with respect to intensity of velocity and to certain environmental conditions accompanying the wind of any particular direction, the results of the present study indicate that crown deformation in the western part of the Columbia Gorge is almost wholly due to wind of easterly direction, which although it acts for only a small portion of the year is of such great velocity and so coincides with glaze deposition and with low soil and air temperature that it becomes extremely effective in producing tree crown asymmetry. In this western gorge region west wind is the *prevailing wind*[3] for the year but it is not at all effective in this respect.

Another case in point described by Wells and Shunk (1937) shows that salt spray whipped up by winds off the sea make the wind from that direction the effective wind in producing asymmetrical crowns whether or not that is the prevailing wind direction for the year.

A third example, brought out in the present study indicates that crown deformation in the eastern part of the Columbia Gorge is wholly due to winds of summer—when shoots are rapidly elongating and their tissues have not yet become hardened—and that it is largely due to diurnal, rather than nocturnal, winds at that season. As to direction, these effective winds are westerly—as is clear from the compass orientation of the crowns—and their diurnal velocities in summer are of the order of 25 to 35 miles an hour. Nocturnal summer winds and the winds of autumn, winter, and early spring, whatever may be their velocities and directions, evidently play no part in producing the wind-bent crowns of this eastern region; furthermore, if winds of easterly direction were of considerably greater velocities in winter than they are here in the eastern gorge they would presumably fail to counteract the influence of the diurnal summer winds. Although west wind here is also the prevailing wind for the year, wind-trained crowns are due to certain peculiar west wind conditions that obtain for perhaps less than half of each day throughout a period of much less than half of each year; it is to be emphasized that this summer period of wind is effective because it coincides essentially with the growing season for the trees.

For any wind velocity, the bending pressure exerted on the branches and twigs of a tree is of course proportional to the extent of the effective surface presented to the air stream by those parts. The extent of surface presented to wind by such evergreen trees as Douglas fir and ponderosa pine may not

[3] According to climatological terminology annual *prevailing wind* refers to the wind of that direction which is maintained for a greater portion of the year than any other; it has no reference to wind velocity or to accompanying peculiar environmental conditions.

fluctuate greatly throughout the year, but deciduous trees, such as Garry oak and Oregon maple, for example, present much greater resistance to wind in summer than in winter; consequently a persistent wind of velocity adequate to maintain the leafy twigs and branches of a tree in wind-bent positions or to break them in a summer period may be quite inadequate to produce permanent deformation when such a tree is without leaves. Also, the earlier portion of the leafy season of the year for deciduous trees coincides with their annual period of most rapid enlargement, when twigs and branches are most readily bent by wind pressure and when they are most likely to remain deformed after the wind that bent them has abated.

While some effects of wind-training may be occasionally observed in most localities where trees grow (Jefferson, 1904), such perfect examples of one-sided crowns as are found in the eastern part of the Columbia Gorge can develop only under very peculiar environmental conditions, in places where neither salt spray nor abrasive materials occur in the air and where wind direction and wind velocity act together in very special ways at recurring periods when the trees concerned are in a physiological state that facilitates wind-pressure deformation and its subsequent fixation by tissue growth and the hardening processes of tissue maturation. The baffling intricacy of the influences that take part in the formation of these remarkable tree crowns is seen to involve climatological, aerological, mechanical, anatomical, and physiological conditions. The ecological problems thus suggested are rendered even more complex and difficult when it is borne in mind that the tendency of a bent branch to straighten and to resist further action of one-sided external pressure not only operates in accordance with the ordinary principles of mechanics but also is generally enhanced through special growth activities that are stimulated by the modified tissue tensions that arise from bending. Much experimental study of pressure effects on trees, as well as much observational study of the natural development of one-sided crowns, will be required before the phenomena here considered superficially may be satisfactorily understood.

SUMMARY

Some of the main physical features of the Columbia Gorge are discussed, including geology, topography, soils, flood history, and tributary drainage systems. Notable vegetational features are described, with special reference to habitat conditions as these differ from west to east and from north to south. The gorge appears to have acted as an east-west corridor for and as a north-south barrier to plant migration.

A number of observations concerning flood tolerance of firs and pines are presented, from which it is concluded that Douglas fir is very intolerant, and that ponderosa pine is considerably more tolerant.

The peculiar and conspicuous one-sided tree crowns of the western and eastern regions of the gorge, especially those of Douglas fir, are described

in detail, with photographic illustrations, and the weather conditions to which these two very different types of crown asymmetry are apparently due are described and discussed.

In the western part, the firs are prevailingly and drastically pruned through mechanical breakage due to the action of occasional easterly winter gales that are accompanied by heavy deposition of ice. These crowns characteristically extend only in a westerly direction from the trunks. The firs of the western part are also characteristically subject to parch blight in many instances, a form of injury in which the foliage and branchlets on many unbroken branches are winter-killed. The killed needles gradually become brown as spring comes on but they generally remain in position for several months, giving rise to discolored patches that are conspicuous in spring and early summer.

In the eastern part, the firs show little or no signs of storm breakage or parch blight, but they are characteristically wind-trained, through the action of persistent strong westerly winds of summer; their crowns generally extend only in an easterly direction from their trunks, branches arising on the west being bent around the trunks so as to extend toward the east.

In the middle region of the gorge, in the vicinity of the Cascade Rapids, both forms of fir crown may be seen, and some crowns exhibit the combined effects of both storm-pruning in winter and wind-training in summer.

The western, storm-pruned type of tree asymmetry resulting chiefly from glaze injury has apparently not been described for any other part of the world; but the eastern, wind-trained type is not uncommon in localities where strong winds of persistent direction and velocity occur in the growing season.

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