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INTRODUCTION

The Willamette Valley of western Oregon lies within the cedar-hemlock climax of the Coast Forest (Weaver and Clements, 1938). The two chief dominants of this formation, western hemlock *(Tsuga heterophylla)* and western red cedar *(Thuja plicata)*, however, are not common in the Willamette Valley. Their scarcity may be due to the low summer precipitation. The mean annual rainfall is about 42 inches, which is greater than in many parts of the Puget Sound region, where both of these species are abundant and maintain their climax status. The Willamette Valley has a modified marine climate because of its proximity to the Pacific Ocean about 50 miles to the west. Less than 25 per cent of the annual rainfall falls from May to October inclusive, with little or no precipitation from the middle of June to the middle of September (Climatic Summary, 1930). The Willamette Valley is classified as having a humid, microthermal climate, with inadequate summer precipitation (Thornthwaite, 1931). It lies within the Humid Transition life zone (Merriam, 1898). Pollen analyses of sedimentary columns indicate that hemlock has never been abundant in the valley during postglacial time (Hansen, 1941, 1942, 1945).

Douglas fir *(Pseudotsuga taxifolia)* and Oregon white oak *(Quercus garryana)* are the most common tree species throughout the area. Lowland white fir *(Abies grandis)* is locally abundant on moister sites. White oak persists in dense forests chiefly as old, large, decadent, relict specimens. In more open areas, it may occur in young pure stands or in association with Douglas fir, which gradually replaces it as the forest canopy closes over. Other hardwoods of this area are bigleaf maple *(Acer macrophyllum)*, Oregon ash *(Fraxinus oregona)*, red alder *(Alnus rubra)*, and cottonwood *(Populus trichocarpa)*. The last three species occur chiefly on floodplains. On the south slopes of the Coast Range foothills, grassland areas are prevalent, but these are being invaded by oak and Douglas fir. Most of the valley floor is cultivated, but scattered groves of oak and Douglas fir are present.

Settlers in large numbers first migrated to the Willamette Valley from 1945 to 1855, and hearsay assigns great fires to this period. Prior to that time the Indians are said to have burned the country repeatedly to facilitate game hunting and to maintain various plants for food. David Douglas on September 27, 1826, wrote in his journal as he botanized from a camp 58 miles up the Willamette River, that there was hardly a blade of grass unburned except along the fringes of the streams (Morris, '34). Ring growth studies in stumps reveal that this country was frequently burned for at least 296 years or since 1647. Fires have not been so severe nor so frequent since 1848, as suggested by the presence of a large number of trees of the 90-year age class. The persistence of groves of oak and Douglas fir, in both pure and mixed stands, in spite of intensive cultivation and the continued burning of the past, suggests that forests of these

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species would occupy most of the valley floor if succession was uninterrupted. South slopes of foothills and knolls would perhaps support limited areas of grassland, because of drainage and exposure.

In the cedar-hemlock formation, western hemlock, western red cedar, and the balsam firs *(Abies grandis, A. amabilis, A. nobilis)* represent the climax dominants. The most abundant tree, however, is Douglas fir which is a subclimax type that has been able to persist in predominance because of recurring fire down through the ages. After fires, this species invades the deforested area, and forms pure, dense, even-aged stands. It is unable to maintain itself, however, because of its shade-intolerence. The climax dominants, whose seedlings thrive on the forest floor, gradually invade and increase in abundance and size. In the meantime, Douglas fir matures and becomes decadent, and is thinned out by insects, disease, windthrow, and lack of reproduction. The more tolerant climax dominants eventually assume predominance, and a stabilized forest of these species develops if fire or lumbering do not prepare the way for a new Douglas fir invasion. A study of the composition of forests of various ages shows that without fire or logging, a Douglas fir forest would be converted to the climax type in five or six centuries (Munger, 1940). In the Willamette Valley and on the east slope of the Coast Range lying to the west, Douglas fir is probably the climax species, because it is too dry for hemlock and cedar. In this region, the mature Douglas fir forest is not replaced by hemlock even though fire be absent for a few centuries (Munger, 1940). On moister sites, lowland white fir may become predominant.

The purpose of this study was to determine the successional trends in the oak-Douglas fir forest of the Willamette Valley and the adjacent Coast Range foothills. The data for these interpretations have been obtained by a statistical analysis on a representative area. It is possible that the results and conclusions of this study may serve as a silvicultural basis for farm woodland management and grazing practices in this area. Principles of plant succession have been applied successfully in maintaining the desired type of vegetative cover in both forestry and range management. For example, in the cedar-hemlock climax of the Puget Sound region, Douglas fir is a subclimax type as well as the most important commercial species. By clear cutting and providing an adequate seed source as security against subsequent loss by fire, even aged stands of Douglas fir can be obtained. The climax type can be maintained by tree selection cutting (Munger, 1939, Isaac, 1943).

DESCRIPTION OF THE AREA

The area of detailed study lies within the McDonald Forest of the Oregon State College, School of Forestry, at Corvallis. The forest is in Townships 10 and 11 South, Range 5 West, Willamette Meridian. Its area is about 4,800 acres, lying west of U. S. Highway 99W and about 6 miles north of Corvallis. It is representative of the eastern foothills of the Coast Range and the western fringe of the Willamette Valley, where the Coast Range descends abruptly eastward to the Willamette Lowland. The topography has been largely determined by the relative resistance of the Tertiary rocks. The highest peaks are the result of volcanic rocks contemporaneous with or intruded into them. The low mountain range of this section is of Eocene age and probably has never been very high (Fenneman, 1931).

The McDonald Forest includes almost the entire width and 6 miles of the length of a large ridge extending northeast and southwest. The elevations range from 450 to 1550 feet above sea level. In general, the streams and ridges extend northwest and southeast from the main ridge. The study was made on the southwest end of the McDonald Forest in sections 17, 18, 19, and 20; Township 11 South, Range 5 West, in the Oak Creek drainage. At the head

of the creek the canyon sides are steep, grading into gentler slopes southward. Northern exposures are in the minority, with many long, gentle south slopes. Oak Creek flows generally south, resulting chiefly in east and west exposures. The soils of the McDonald Forest are of the Olympic clay and Olympic clay loam series of the Hill Group of residual soils originating from igneous basaltic rocks (Powers, Jones, and Ruzek, 1931).

VEGETATION OF THE AREA

Oregon white oak is the only oak of commercial importance indigenous to the Pacific Northwest. It is a medium-sized tree seldom reaching more than 50 to 75 feet in height and 2 to 3 feet in diameter. Poles of this species are usually short and crooked even when grown under forest conditions. It has a well developed lateral root system and a wide-spreading, round-topped crown, especially in solitary specimens. This tree occurs most abundantly in deep, rich loam in regions where the yearly rainfall does not exceed 30 inches and where humidity is very low during the summer months. Large seed crops are produced every few years but owing to the inability of germinating seeds to penetrate the heavy sods upon which they are disseminated, reproduction from seed is slow. Stump sprouts and root suckers are vigorous, and reproduction is obtained by this means (Harlow and Harrar, 1941).

Its ability to withstand the low summer humidity together with its habit of reproducing readily by root suckers may account substantially for the persistence of Oregon white oak on this area and also helps to explain its aggressiveness in invading grasslands when conditions for seed dissemination and germination are suitable. This species forms distinct fringes around grassland areas with individual trees and small clumps dispersed throughout. These fringes of oak are usually narrow and beyond them is the Douglas fir type with an intermingling of relict specimens of oak becoming decadent or already dead.

Ring growth studies of stumps of these relict specimens show that they grow at a slow rate throughout life. In the coniferous forest these large oaks persist until the forest canopy closes over them, whereupon they rapidly succumb to the intense competition. Pure stands are found particularly on hillsides in this area, seed dispersal apparently being effected when the acorns fall from the trees and roll downward. Possibly rodents are also instrumental in seed dispersal.

Douglas fir grows in a variety of soils, and on the McDonald Forest site conditions range from the poorest to the best for this species. In youth, Douglas fir forms extensive, pure, even-aged stands. Anchorage is provided by a well-developed, wide-spreading lateral root system. Seed is produced in abundance after the twenty-fifth year. Heavy seed crops are produced at intervals of two or three years. Crowns of this species are very inflammable and fire is its worst enemy (Harlow and Harrar, 1941).

On the area covered in this study there is a large number of old, open-grown trees of the "wolf tree" type which provide seed. These may not be expected to seed the surrounding areas effectively at greater distances than 300-400 yards (Isaac, 1930, 1943). It is from old trees of this type that growth ring studies have been made revealing the past fire history of the area. Because these trees are, in general, so widely scattered over the area, the effective range of seed dispersal of the individual trees does not overlap that of its neighbor and patchwise stands result. In many cases these patches or islands of Douglas fir timber are normally stocked stands producing good quality timber. Natural pruning is progressing satisfactorily. On the other hand, there are areas on which physical features have precluded the uniform germination and establishment of seedlings; therefore, poorly stocked stands are the result.

Bigleaf maple occurs singly or in small groves associated with the other timber species of this area. It is more abundant near the creek bottoms in the better quality soils. Long clear boles and narrow crowns are developed under forest conditions. When open grown the trunk breaks up into several ascending branches to form a globose crown. The root system is shallow and wide-spreading (Harlow and Harrar, 1941). This tree seems much more tolerant under forest conditions than oak.

Grand fir or lowland white fir, like bigleaf maple, is found principally on flood plains and gentle slopes on the area studied. As a rule it occurs singly but it is not uncommonly found in groups or small pure stands. Young trees are quite tolerant and have been found on this area forming dense thickets of sapling-sized trees. Older trees usually have long spire-shaped crowns and in maturity the crown becomes more dome-shaped. The root system is deep and spreading (Harlow and Harrar, 1941).

The four species described above are the principal forest trees in this area. Other species of lesser importance in the forest are widely scattered or concentrated on flood plains, and in ravines and gorges, depending upon each species' individual requirements. Red alder is the main species on the flood plains with willow *(Salix spp.)* in association. Red-stemmed dogwood *(Cornus stolonifera)* and some Oregon ash *(Fraxinus oregona)* occur also on flood plains. Western yew *(Taxus brevifolia)* and flowering dogwood *(Cornus nuttallii)* inhabit the moister aspects and steep canyon sides. Scattered over the more exposed slopes and occuping similar sites are black haw *(Crataegus douglasii)*, Madrona *(Arbutus menziesii)*, the bitter cherry *(Prunus emarginata)*, and cascara *(Rhamnus purshiana)*.

The more predominant shrubby species of the area are thimble berry *(Rubus parviflorus)*, snow-berry *(Symphoricarpos albus)*, salal *(Gaultheria shallon)*, and poison oak *(Rhus diversiloba)*. A plant commonly invading the grasslands in advance of the tree growth is the common wild rose *(Rosa rubiginosa)*. This invasion ranges from a few clumps per acre to as high as an estimated 20 per cent of the area. Under the shade of the forest canopy swordferns *(Polystichum munitum)* are numerous. In the more open areas bracken fern *(Pteridium aguilinum)* often forms a dense ground cover. St. John's wort *(Hypericum perforatum)* is prevalent on some grassland areas and is very undesirable from the standpoint of forage value and its effect on the grassland vegetation.

EFFECTS OF LOGGING AND BURNING

As a result of logging and burning, forests on parts of the area have undergone retrogression. The young growth Douglas fir was heavily cut during 1915-1920, and although appearance of the remaining stumps indicate light burning, these patches now support an extremely dense cover of brushy species. Ostensibly this heavy ground cover precludes establishment of Douglas fir reproduction except by gradual encroachment from the edges of these brushlands. Such conditions, however, seem to represent the extreme condition.

Other tracts have been reforested extensively but from a forestry point-of-view they are not fully stocked with any one species or combination of species. The trees on these areas are therefore open-grown and limby. However, there are extensive areas adjoining these brushlands and open Douglas fir and oak forests that are heavily reforested. Fires of the past apparently have been largely ground fires, as is indicated by the heterogeneous nature of the forest on the area.

Pure stands of oak exist as invaders of grassland areas. The grassland has probably been maintained in the past by the annual burning by the Indians. Since the exclusion of fire by white man, Douglas fir is advancing beyond

the previous peripheries of the coniferous timber. This apparently is encouraged by the protection from summer desiccation afforded by the shade of the oaks. Abandoned farms are being invaded by Douglas fir and oak, especially the former, because of the adjacent uncut Douglas fir timber.

Grazing has been permitted, and the most obvious damage to the vegetation has been trampling along the fence rows. This, however, is not extensive enough to be of any economic consequence. Grazing has been light and browsing damage is barely noticeable. During a heavy snow in January 1943, sheep browsed Douglas fir seedlings that extended above the snow. No other green feed was available at the time. Where sheep have been concentrated for some time on an area, regardless of weather conditions, there are indications that they have browsed Douglas fir seedlings. Browsing on oak is not so noticeable nor so extensive.

Moles and ground squirrels are abundant and their mounds are numerous and widespread. Disturbance of the soil may afford suitable seed beds for germination of tree seedlings. On the other hand, the exposure of seeds on the mounds probably favor their destruction by seed-eating animals.

METHODS AND RESULTS

One hundred sample plots, 25 feet square, were taken, well distributed over the area. In order to maintain an unpredjudiced sample plot distribution, a box asimuth compass was used, and the plots established at 3-chain intervals except where no trees were present. In such cases, the distance between the plots was adjusted to fit the pattern of the forest stands. This was felt to be justified, because the study is concerned with the arboreal vegetation rather than the vegetation as a whole. Where a line followed a fence, plots were established one-half chain distance from the fence to avoid the influence of tree cutting when the fence was constructed, as well as the trampling and browsing by stock. All trees were measured at breast height, and those under 1 inch in diameter were counted as small trees or seedlings. Stumps were measured at stump height. Growth ring counts were made of both oak and Douglas fir and the diameters were also measured.

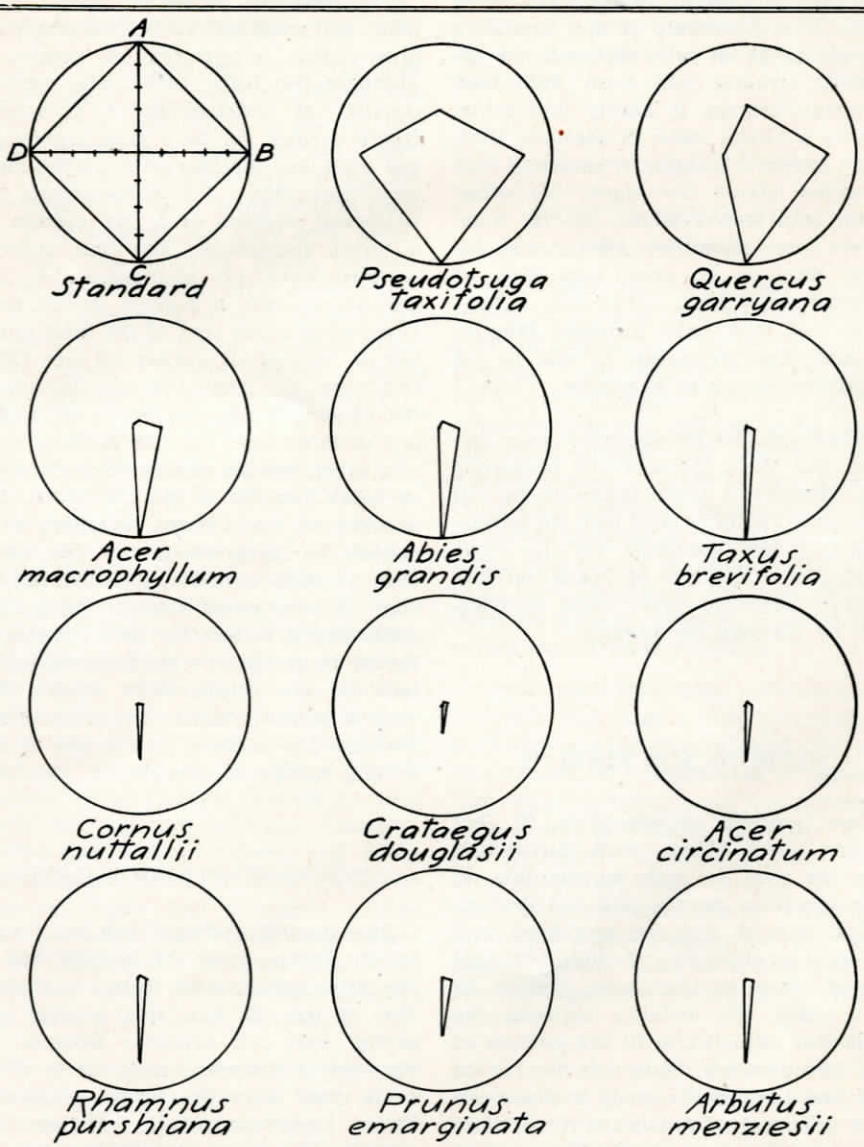
The data are presented both in tabular and graphical form. The graphical presentation is effected by means of phytographs (Lutz, 1930). The method consists of constructing a polygonal figure formed on four axes representing what are considered to be the most important criteria for characterizing the ecological position of a tree species in a forest association. The four criteria selected were: (1) abundance, i.e., the number of trees of a given species represented as a per cent of the total number of trees of all species 1.0 inch DBH and over; (2) frequency, i.e., the number of sample plots in which are found one or more trees 1.0 inch DBH or over of a given species expressed as per cent of total number of sample plots; (3) number of size classes in which each species is represented; and (4) basal area of each species expressed as per cent of total basal area of these four quantitative factors for each species in the same graph give an integrated picture of the relationships among the several measurements. The mass effect portrays the relative importance of the several species concerned.

INTERPRETATION OF DATA

Ring growth studies of oak and Douglas fir stumps show the growth rate of the latter species to be from 3 to 5 times that of oak. It has been pointed out earlier that oak precedes Douglas fir on most of the area, particularly those areas that were previously grassland. These facts account for the greater number of oaks 1.0 inch DBH and over. There is a wide difference in the basal area of the oak and Douglas fir; that of

the latter being about four times that of the oak (figure IV). This is further evidence of the more rapid growth by Douglas fir. However, about one-third of the basal area of Douglas fir represents stumps left from logging. On this area the Douglas fir was still of a comparatively small size when clear cut and had not yet completely crowded out the scattered old oaks. From this seed source oak reproduction has become established, particularly on the more exposed sites. This accounts for the abundance of small oaks on areas that were previously forested by Douglas fir. The frequency of oak and Douglas fir is nearly the same, the latter being found in six more sample plots than the oak (figure II). The reason for this is that some sample plots were taken on

Figure 1. Phytographs for the arboreal species in the McDonald forest.



OA, per cent of total abundance; OB, frequency; OC, per cent of four size classes represented; OD, per cent of total basal area.

north slopes where the oak has long been crowded out and also pure stands of older Douglas fir contained only widely scattered relict oaks.

Bigleaf maple trees are fewer in number but higher in frequency than lowland white fir, indicating that bigleaf maple is more uniformly distributed. The lower frequency of the lowland white fir is probably due to reproduction being more or less concentrated near seed sources. However, lowland white fir has gained a substantial foothold from the standpoint of abundance of trees 1.0 inch DBH and over (figure III). Except for a few suppressed trees of small size, lowland white firs are vigorous and competing strongly for their places in the forest canopy.

Figure III shows a significant relationship between the various species and the number that is represented in each size class. In general the forest growth is open enough to permit germination of Douglas fir seed. This is shown in the table by the large number of Douglas fir seedlings. These seedlings are more heavily concentrated on areas where an over-story of oak existed with a Douglas fir seed source in the immediate vicinity. This was particularly true on south slopes. A careful count on one sample plot with a southwest exposure revealed 94 Douglas fir trees under 1.0 inch DBH. On open areas having scattered single oaks or clumps, the Douglas fir reproduction is concentrated on the northeast side of the oaks. These clumps of reproduction are well defined with none or only an occasional seedling outside the areas covered by the shadow cast by the oak tree during the hottest part of the afternoon. This indicates that the partial shade cast by the oaks or other species prevents desiccation and is responsible for the establishment of Douglas fir seedlings. Where heavy brush or dense forest conditions are not encountered and an adequate seed source is present, small Douglas fir reproduction is

Figure II. Data from sample plots for trees 1.0 inch DBH and over.

Species	Abundance		Frequency	Size	Basal area in sq. ft.	
	No.	Per cent	Per Cent	Classes	BA	Per cent
Pseudotsuga taxifolia	378	40.2	76	4	242.7	72.7
Quercus garryana	420	44.5	71	4	62.6	18.7
Acer macrophyllum	40	4.3	20	4	17.0	5.1
Abies grandis	60	6.3	15	4	5.9	1.7
Cornus nuttallii	2	0.2	1	2	1.7	0.6
Crataegus	2	0.2	1	1	0.0	0.0
Acer circinatum	4	0.4	1	2	0.1	0.0
Taxus brevifolia	7	0.8	4	4	2.5	0.8
Rhamnus purshiana	7	0.8	3	3	0.0	0.0
Prunus emarginata	11	1.1	3	2	0.0	0.0
Sailx sp.	1	0.1	1	1	0.0	0.0
Arbutus menziesii	11	1.1	3	3	1.1	0.4
Totals 943		100.0			333.6	

Figure III. Number of trees in each size class.

Species	Under 1"	1.0"-3.0"	3.0"-10.0"	10.0" and over
Pseudotsuga taxifolia	598	94	154	130
Quercus garryana	85	181	220	19
Abies grandis	170	38	18	4
Acer macrophyllum	3	12	19	9
Cornus nuttalli			1	1
Crataegus douglasii		2		
Acer circinatum	8	3	1	
Taxus brevifolia	11	1	4	2
Rhamus purshiana	8	7		
Prunus emarginata		3	8	
Salix sp.	1	1		
Arbutus menziesii	6	4	6	

generally abundant. It is in the dense forest situations that lowland white fir is gaining a foothold.

While lowland white fir is not so well represented by abundance in the larger size classes, it does show a comparatively large number of small trees less than 1.0 inch DBH. This reproduction was found under dense forest conditions and this fact is indicative of the species' ability to reproduce under denser shade than Douglas fir. On this area, Douglas fir reproduction was not found under as low light intensities as lowland white fir.

Figure IV, showing the basal area of dead trees and stumps, is rather misleading for lowland white fir. Two large stumps were found on one plot which raised the proportion of dead trees or stumps to nearly one-half of the total basal area. This same consideration must be applied to the analysis of the data for Douglas fir for which both basal area and number of trees 10 inches DBH and over are high

Figure IV. Per cent of total basal area in square feet represented by stumps and dead trees.

	Total basal area	Basal area of stumps and dead trees	Per cent basal area of stumps and dead trees
Pseudotsuga taxifolia	242.7	85.8	35.7
Quercus garryana	62.6	8.7	13.9
Abies grandis	5.9	2.9	49.1
Acer macrophyllum	17.0	0.3	1.7

because of the large number of stumps on the area. Therefore, practically all of the basal area representing the dead trees of this species consists of stumps and is not a result of decimation by natural causes. On the other hand, 13.9 per cent of the total basal area of Oregon white oak represents dead trees with only one stump measured on the area. These oak trees have died from natural causes and especially heavy competition from the faster growing conifers. Most of these dead oaks were of the smaller size classes.

The greatest number of oaks is in the two size classes from 1.0 inch to 10.0 inches DBH indicating the slow growth of the species and the probable establishment of the oak stand following the 1915-20 logging. These size-classes are particularly prevalent on the areas that are represented in all four size classes are Douglas fir, Oregon white oak, bigleaf maple, lowland white fir, and western yew. The latter two species reproduce under dense shade if other conditions are suitable.

APPLICATION TO MANAGEMENT

Economically this area is producing neither forage nor timber to its greatest capacity. To bring the land into maximum timber production within a reasonable period of time would require extensive planting, the success of which would be doubtful, especially on the south and southwest exposures. It would seem practical to manage the existing stands of Dolglas fir for permanent timber production. Where this reproduction is entirely under the shade of the older oaks and has become well enough established, the oaks should be harvested.

Those areas best suited topographically to forage production, south slopes in particular, should have some range improvement work done on them. Rose bush eradication on this area would probably constitute a major expense item along with preparation of the soil and sowing the area to a good mixture of range plant species. At the same time the carrying capacity of the range would be greatly increased.

It is believed, however, that if the area is disturbed by only moderate grazing, it will eventually support a commercial stand of coniferous timber. On the other hand, if intensive range improvement is done, the normal succession toward tree growth may be halted for an indefinite period.

SUMMARY

One hundred sample plots were taken on the McDonald Forest in the Willamette Valley of western Oregon to determine the arboreal successional trend of a white oak-Douglas fir community. This area has been logged and burned over, resulting in some forest retrogression. The vegetation varies from grass and brush to oak and Douglas fir each in pure stands or with the two species in association. It was found that the greatest number of "seedlings and small trees" consists of Douglas fir, while the greatest proportion of trees 1.0 inch DBH and over is of white oak. The greatest concentration of lowland white fir seedlings and saplings was found to occur in the dense forest and near the original seed sources. Previously non-forested areas are being invaded by white oak, which is closely followed by Douglas fir. The absence of white oak and Douglas fir reproduction under the dense forest canopy and the abundance of lowland white fir under these same situations indicate a successional trend of white oak to Douglas fir followed possibly by a climax forest of lowland white fir, or a Douglas fir-lowland white fir association. This is further suggested by the presence of relict oaks in the dense Douglas fir stands.

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