Soils and Ecology of the Redwoods

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Good Evening, Ladies and Gentlemen. I'm certainly not a stranger to Humboldt County, having lived in some of the backwoods areas such as Thorn, Bridgeville, Harris, and other places while on the soil vegetation survey during the period from about 1947 to about 1953. During that time, we mapped the southern half of the County, and since then the survey was continued to complete the entire County and this year Del Norte County. The title of my talk tonight Soils and Ecology of the Redwoods will not be about the soils only, but also about some of the inter-relationships between the coast redwood and its environment.

If we look at the literature, we find that there is quite a bit of material available on the ecology of redwoods and also the soils aspects of this ecology. Some of this work began more than 100 years ago with the Whitney survey, which was a survey that the State of California sponsored for two years to inventory the land resources of California. In the report of that survey there is some very good information on the distribution of California vegetation and its relation to soil types. This information, much of which concerned this north coast country was recorded more than 100 years ago in the Whitney survey by eminent botanists such as Dr. Brewer.

Willis Linn Jepson, in his Silva of California, also recorded information on the redwood from observations while traveling through the countryside at the time of the turn of the century. Later we find the work of Professor Emanuel Fritz, and also that of Dr. E. P. Meinecke, working on the redwood groves along the Eel River Flats. Then, Professor Woodbridge Metcalf did his work on the growth of redwood, establishing study plots throughout the area. Recently there has been an upsurge in the interest in redwood ecology, particularly in relation to soils.

The State Division of Forestry, with help from Humboldt County, has been sponsoring a soil vegetation survey throughout the redwood region, and has now practically completed mapping this area, giving an inventory of plant communities and soil types as they occur on the landscape of the redwood region. This provides a comprehensive survey of the soil-vegetation relationships which exist here. Also the State Division of Beaches and Parks has been sponsoring a redwood ecology project by the Wildland Research Center of the University of California since the 1955 flood. This research has been conducted in the redwood stands along the Eel River, Bull Creek Flat, and in the Prairie Creek area.

A discussion of redwood ecology studies would be lacking without mentioning the contribution of private enterprise. For example, the Simpson Timber Company's work on redwood ecology; - soils analyses work done by Dr. Stoate, with cooperation from the Humboldt County Farm Advisors office - University of California, and from Dr. Rudy Becking and others at Humboldt State College, who have been working along with this project of Simpson Timber Co. Also, to mention some current workers, there is Dr. Peter Black at Humboldt State College who has been working with me on soil moisture studies related to the redwoods; and Dr. Mark Rhea, who is studying some soil aspects of redwood forests. Professor Dietrich Muelder and researcher Jack Hansen, of the University of California have been working on seed production and cone production in the redwoods and its adequacy to meet reforestation problems.

Some work is being carried out in distant places, also. For example, there are redwoods growing in a phytotron down at Cal Tech, in

Pasadena, (Dr. Henry Hellmers) which perhaps have a maximum growth rate. They have grown up to a millimeter an hour in these growth chambers at Cal Tech and Dr. Hellmers expects them to come out of the roof any day now. However, this millimeter an hour day and night is growth under the optimum conditions of a growth chamber with a particular temperature and daylight regime.

Well, to get into the subject I would like to present, I will review much of the material that these people have learned for us, plus work that I have been doing in association with others in the redwood ecology project of our Wildland Research Center. I would like to begin with slides showing the range of redwoods and the factors involved in it, followed by some idea of how we may assess other factors that are important in the range of redwood. Then I will follow this with the details of high quality stands on very good soil types here in the north coast range, and some of the variability we find in soils growing redwood.

Factors in the Range of Redwood

You all may know that the range of redwood extends from Salmon Creek in Monterey County north to the Chetko River in Oregon. Immediately the point comes to mind that the range is close to the ocean and the coastal fog belt. However, the fog belt extends south into Baja California and north almost to Portland. So there are other elements involved, although the range is encompassed by the fog belt. So perhaps we should concentrate on a concept of what is the range of the species in terms of its natural situation, and think of the species in its entire life cycle, including regeneration on the site.

For example, here is a redwood in the courtyard of the Santa Barbara City Hall; and last year I saw redwoods growing in Europe in Southern Italy. Some of the latter stands were of trees 3 feet in diameter and 100 feet high, growing very well, but the stands were not necessarily reproducing themselves in these areas. So we should think of the range in terms of the ability of the tree to regenerate on the site, which includes the plant community, soil, climate, and history, as well as the seed source and the genetic ability to withstand the local situation. So we should think of the local range of redwood in Humboldt County is seen in Figure 1. This map was made from the current soil vegetation maps of Humboldt County, by W. L. Colwell. It shows the presence of forests having at least 5% redwood crown cover designated to a 10 acre minimum. The individual soil-vegetation quadrangle maps which encompass the range of redwood in Humboldt County are indicated on the figure, numbered such as 11B1, 11B2, 11B3, etc. These may be purchased from the U.S. Forest Service at 630 Sansome Street, San Francisco at 45¢ each.

Redwoods and Forest

Looking at a range map such as this, one sees that not all of the fog belt includes redwood forests. In fact, here in Humboldt County in places where we get excessive fog drip we don't usually have redwood; but instead have Douglas-fir, as up on high mountain ranges such as Mt. Pierce or out on the Bear River Ridge. There have been measurements of this fog drip, and if you were to put a rain gage in these areas you could pick up about 60 inches of fog drip precipitation in that gage. Such measurements have been made south of San Francisco in similar situations under tanoak. In the middle of July, due to fog drip, one may find green grass adjacent to the trees from which the fog drip has precipitated, while in the open the grass is already dry.

Moisture Requirement of Redwood

Redwoods certainly use water and all you have to do to demonstrate this is to place a plastic bag over a redwood branch, and you may have within an hour, enough water to drink. We find that redwood is closely tied to a moist environmental regime and perhaps some of its relation to fog is due to this sensitivity to moisture. Recent work by Dr. Richard Waring on the redwood ecology study referred to earlier,

indicated that if one were to express the moisture situation within which redwood grows by an annual moisture index (defined as the amount of soil moisture remaining in August as percent of the total storage capacity of the soil on a given site), then our best site would have a soil which was completely moist at that time. If the soil was bone dry, this would be one of our poorer sites.

There is a moisture gradient series in this annual moisture index from an index of 80 where the better redwood sites are, down to about 20 where the poorer ones are, and the redwood wouldn't extend below 20. Leaving the limit of the redwood forest you get out into a soil that has perhaps only 10% of its springtime moisture storage present in August, where you find canyon oak-chaparral as on Grasshopper Peak, or some of the poor Douglas-fir stands, or even into the grasslands soils up on Kneeland Ridge or some such place as that, which show a low moisture index of 20. So he found a range in terms of available soil moisture present at the end of the season, which could be used as an index of the moisture tolerance range of redwood. Thus anything which cuts down evapotranspiration water loss, for example, fog or even cool, humid, moist ocean air would be enough to perhaps aid the redwood in surviving on a given site, or at least to advance its survival there, since it would increase the-moisture index.

Of course, soil moisture is only one aspect of redwood distribution. If you take an aerial view and look east on Yager Creek you find that the redwood forest has a pretty sharp boundary on the eastern edge. Also, when you drive up the road to Bridgeville and get just beyond Grizzly Creek, there is a very sharp boundary to the redwood forest which breaks abruptly into grassland. Certainly this isn't necessarily where the fog stops every day. Similarly, when you drive east from Crescent City toward Gasquet. As soon as you enter the National Forest you find very few redwoods.

One reason might be that there is a soil change. There are geologic changes that are associated with the limits of the extension of redwood in many parts of its range. Some of the most notable cases are where serpentine intrusions occur. These usually limit the further extension of redwood. Therefore, if one goes down to Salmon Creek at the far southern end of the range of redwood, one finds that the rock type immediately south of these groves is a serpentine intrusion coming right down to the coast as if it was a wall stopping the advance of the species. Or, going east from Crescent City toward Gasquet, you will encounter serpentine and peridotite intrusions at the National Forest boundary, where redwood forest ends and there is Jeffrey pine and mixtures of various manzanitas with a few very poor redwood along alluvial flats.

A comparable situation occurs up Yager Creek where a different rock type appears, a metamorphic rock producing a rather gray colored soil which stops and is heavy in clay and high in magnesium and sodium. This produces the Yorkville soil series, a soil unfavorable to redwood. Thus, in many cases, limits of the redwood forest are determined by soil type differences perhaps related to the water relationships of the plant, or to problems of nutrition. In any case, there are some abrupt changes to the boundary of redwood which are not related to the fog.

If you go north from Strong's Station on the Van Duzern River and head north toward Iaqua Buttes, you see abrupt boundaries between the redwoods and the upper grasslands. The grasslands are on either the Kneeland soil series or the Yorkville soil series. Within the main redwood forest area there are numerous grass openings. There are many of these; for example, on Maple Creek there's a good grass opening right in the middle of a redwood forest; or Blanton Prairie up Yager Creek north of Carlotta is another example. There seem to be two situations involved there. One of them is that sometimes an outcrop of rock which is more calcium rich may occur and this gives rise to a different soil, for example, like one we call the Laughlin soil. Sometimes small areas of the

more alkaline Yorkville soil may give a prairie such as Luke Prairie near Bull Creek Flat.

Once grass is favored on a given site it tends to establish its own sod. It creates its own soil of grass-root remains and humus, which sometimes is unfavorable to invading species, either because of the microorganisms and that component associated with it, or because of a difference in quality of soil or the chemistry of soil. These are opinions that I am expressing at this point. It is observable that the plant community growing on a site is able to impress its influence on that soil to such an extent that it becomes unfavorable for the invasion of another plant community. In this case, the grassland may prevent redwood invasion. We find, though, that in places Douglas-fir is quite adept at invading these grasslands. We see this-step wise invasion into grasslands on the Bear River Ridge and on the ridge east of Punta Gorda.

Salt Burn

The other aspect of redwood range is the western distribution edge. You're certainly moving toward the fog as you go toward the coast line, and you will notice as in Figure I, that redwood isn't always found directly adjacent to the ocean. Many times quite a distance from the ocean, sometimes up to two or three miles. Remembering some extreme situations that occurred in the spring of 1960, when we had a storm with a strong west wind, and all up and down the coast, many redwoods turned brown and yellow on the westerly faces of their crowns. This happened all the way from the Chetko River clear down to ornamental plantings in Orange County, and everybody thought the redwoods were dying that year.

This was salt burn of the foliage that occurred due to a particular storm event and it resulted in many redwood canopies pruned off on the windward side, and we see many of our trees still showing the effects of that particular dieback. Redwood cannot always tolerate salt burn, and this seems to explain this coastal margin with its lack of redwood. Where it does extend close to the coast you see in areas where either it isn't strongly exposed to the wind or it has the protection of some sort of cover of other species more tolerant to this salt bearing wind. For example, Douglas-fir may provide this or sometimes further north Sitka spruce will. An example of this occurs on the sand dunes at Crescent City where going inland one traverses a wide area of bare dune and beach grass, then there is a pine area, and it isn't until you get about three or four miles inland that you reach the redwoods.

There is another feature of this inability of redwood to extend into certain situations. We have also some distinctive types of soils created under these salt spray conditions. We have quite a bit of salt spray fallout from the ocean and immediately inland for perhaps one or two miles onto the soils along the ocean terraces. This produces situations in which soils such as the Rohnerville series and the Cayucas series occur. These dark prairie soils are immediately adjacent to the coast. They are quite high in sodium and magnesium content, somewhat similar to the Yorkville soil over on the east side, but this time due to a different cause. Now it may be that some of this lack of ability for redwood to extend westerly is due to this soil situation, combined with the salt burn problem. However, other soils aspects may be involved. The soil pH tolerance of redwood ranges from an acid pH 5.0 to the alkaline pH 7.5, with an optimum pH of 6.5. Thus the boundaries of the range of redwood may also be related to pH limits. However, there's a chicken and an egg problem with all this - did the vegetation come there because of the soil, or did the vegetation create the soil which is there?

Another example further south in the range of redwood is the coastal strip where redwood does not advance directly down to the ocean, for example, south of the Ano Nuevo Point in Santa Cruz County. Here the main redwood belt is inland and contains the Big Basin Redwoods State Park. The soils toward the ocean from this interior redwood belt are influenced by their position either over limestone out-

crops or position on coastal terraces subject to salt spray fallout and wind exposure. Despite the fact that all of this non-redwood area is within the fog belt. Another situation, as on the upper south fork of the Eel River where we find a very patchy occurrence of redwood on a few alluvial soil situations, or correlated with certain geological types across the countryside (see Figure I in 29C1).

Bill Colwell of the Forest Service Soil Vegetation Survey has observed that there is a younger sedimentary rock type that seems to favor the development of a fairly deep brown forest soil with a high potassium content; and the distribution of redwood in this area is usually coincidental with this geologic type or its alluvium. Therefore, we find that the distribution of soils may have some bearing on the distribution of redwoods.

Some Soils of the Redwood Region

Looking at the soil types that develop on a weathering sequence on a given rock type, we find that younger soils as they develop are practically gray in color and show evidence of the initial parent rock weathering. Here we have one of the dominant soils of the redwood region, the Hugo soil series. This soil series occupies about 80% of the area of the redwoods south of the Wildcat Hills and into northern Sonoma County - from central Humboldt to northern Sonoma County. And it's a soil that will be classified as a gray- brown podzolic soil, or sometimes named just a brown forest soil. It is the weathering of the clay and sand portion out of the sandstone parent-rock that gives the typically gray color to that soil. After a long time of weathering the soil begins to develop more of a yellow color, and then becoming reddish brown and finally red with old age. Thus the age of the soil and of the land surface can be roughly determined through this color sequence. These stages of development are identifiable as soil types on the soil maps.

During the initial weathering stages, the soil usually has a poor timber site quality. For example, when the bare rock is first being weathered, the poor site quality for redwood is apparent. But as the soil weathers gradually, and more and more kinds of Tertility materials are produced, it passes through a period of weathering toward maximum site quality with maximum availability of nutrients, other things being equal - rainfall, temperature, etc.

With further development the soil weathers to the Josephine soil series, or under cooler, humid conditions further west in the coast range, the Melbourne soil series with their deeply developed A horizons. These further developed soils have well developed B horizons on subsoil clay formation. Sometimes with slope creep, we get a Brigette Bardot profile, that is a soil with a double B horizon. Slope creep can produce one horizon superimposed on the other, with perhaps better site quality. Some very deep soil weathering takes place east of Fort Bragg where the Mendocin soil series forms areas of some of the best site quality for redwoods. The young growth redwood there is equivalent to that near Scotia. The soil will produce redwood trees 150 feet tall in 100 years.

However, when we get to the end product of a soil weathering sequence on a given rock type, we begin to get into red "worn out" soils. And the Sites soil series is an example of this. Of course, there are many things which go with this qualitative term "worn out." One of them is, for example, phosphorus fixation which takes place due to iron colloids present combined with the particular pH of the soil, and the inability of some plants to obtain phosphorus out of the soil at that pH. Here in the redwood region where we find this soil condition, redwoods give way to other species of plants, such as tanoak or chinquapin or some of the manzanitas. In the western part of Mendocin County, sugar pine show up on it, far outside of what we would normally think of as its normal range. In the redwood belt we often find sugar pine occurring on the Sites soil series. This soil represents very old weathering surfaces. The end point of weathering over a long period of time would be perhaps the stripping

of the soil and the renewal of the soil weathering cycle again on a given land surface.

If we look at a steep landscape, we may find that erosion is keeping pace with the weathering to the point where we always have a Hugo soil series stage at an equilibrium with the erosion rate. So we may find that the soil will not always go to the well developed end point; and thus the Hugo soil stage will be prevalent over much of the landscape. This is true of much of the Eel River drainage and the Van Duzen also.

There are many soil types that redwood just doesn't occur on. One of these is the Dubakella series, a soil developed on serpentine. You wouldn't think you would find Jeffrey pine west of the redwood belt, but here we find it west of Miranda. Serpentine outcrops occur at the head of Salmon Creek and on them we find Jeffrey pine. These continue into the Mattole River drainage near the head of Salmon Creek west of Miranda (Elk Ridge) with Jeffrey pine occurring west of the main redwood belt. These particular serpentine soils have subsoil pH of 7.5, although the top soil may have a pH of about 6. Another large area of this type is on Big Red Mountain down in northern Mendocino County near Cummings. It's almost all vegetated with Ponderosa pine, Jeffrey pine, sugar pine and manzanitas, with no redwood encroaching on it. Those of you who have traveled in the redwood region quite often are familiar with the soil type that forms the blue gray landslides formed by the Yorkville soil series. This was the soil that I mentioned earlier was high in sodium and magnesium. It is a clay soil with an expanding clay called montmorillonite. When it becomes wet, the clay platelets expand like an accordion due to infiltration with water. The combination of a slippery sodium magnesium coating on the clays (absorbed cations) with the expanding clay produces the glacier-like masses of blue clay soil. This is a soil that is very unfavorable to the occurrence of redwoods.

There is a broad belt where redwood does not occur between Garberville and Phillipsville, on the southeast side of Bear Butte, and in this area you find an outcrop of Yorkville soils crossing the highway cutting the redwood belt. These soils are out of the range of redwood in terms of soil pH; that is on the alkaline side. Well, there's another extreme soil out near the coast near Fort Bragg; the so-called podzol soil of the white plains. It's identifiable by a white surface horizon; the Noyo soil series. We found that as the soil pH dropped below 4, redwood begins to suffer. This soil has a pH ranging from 3.5 to about 4 right at the surface to about 3.5 in the subsoil, thus being outside the lower pH range of redwood. It is a typical podzol soil, a classical] type such as we see in the eastern United States. But here we have it on the coastal terraces near Fort Bragg.. And on these, redwood if it does occur, has very chlorotic-yellow foliage. We may find old trees only about 15 feet tall. They look like pyramids with a tremendous amount of taper - maybe 3 feet in diameter at the base, and only 16 feet high. They just don't grow well on these acid soils, and usually there is associated with them a pine forest such as Bishop pine with an understory of rhododendron and manzanitas.

Up on Starwein Ridge in northern Humboldt County, we have a very acid soil in an eroded area. Sometimes the question occurs, what happens t. the soil if you remove -the vegetation? In part, the soil is a result of the past vegetation history of the site. If you remove the vegetation, excessive leaching takes place under high rainfall here and an acid lithosol as on Starwein Ridge forms. A vegetation cover of Bear grass (Xerophyllum tenax), knobcone pine, chinquapin and manzanitas grows on this particular soil, and the redwood just stays off of it. What we found was that redwood did not tolerate some lithosols which had become very acid apparently through leaching of nutrients by rainfall.

Another condition which limits the range of redwood is the presence of some high organic matter soil. Perhaps we will be able to explain this in some of our current ecological work. We noticed that some soils which have a deep accumulation of organic matter in the surface; for example, the Cahto soil series, the Knee-

land soil series on Kneeland Prairie, or the Wilder soil series on the Bear River Ridge, are soils which redwood did not seem to tolerate. These are all acid prairie soil. Redwood was usually limited from encroaching of these particular soil areas, resulting in a grass opening, a fern prairie, or less frequently, a brush opening in the redwood forest. The interesting feature of the Kneeland series on Bear River Ridge was the possibility the soil had once been an eroded soil type on which a new formation of soil had taken place due to grass sod and root weathering forming a new soil over the rock layer. At least we find many times in the Kneeland soil series an interesting horizontal rock layer halfway down the soil profile. This Kneeland soil is an example of one of the soils that redwood normally does not invade. Rudy Becking has shown that it is possible to plant trees on these soils and get them established. But the question that remains is whether the trees can regenerate themselves on that soil and effectively occupy it.

The Usal soil series is an extremely dark acid soil that occurs near the coast. Examples of it can be found south of Ferndale on the Bear River Ridge near the summit entering the Bear River drainage. Other examples of the Usal soil are found at Usal Creek north of Fort Bragg. This is a soil that does not favor redwood, although we find some very low site quality redwood stands on it. There are usually stands of Douglas-fir with some hemlocks interspersed. Many times we noticed a plant succession where the climate or some change in environment had occurred favoring coniferous trees. Douglas-fir might be the first to invade the grassland soils, the very dark ones. Douglas-fir is generally the first tree to invade these grasslands.

Another typical grass soil, the Rohnerville series can be seen on the coastal bluffs, forming a broad grassland strip near the ocean.

Wind Exposure

Wind exposure is another factor that seems to restrict the range of redwood. The salt spray damage I mentioned can be seen on trees just north of Fort Bragg near the Ten Mile River. The whole west side of the trees turn brown due to the salt spray damage. This also occurs all summer long. If you even drive past Rio Dell and Scotia, as late summer approaches notice those trees on the left side of the bridge as you go east. Through the summer these trees generally begin to develop a bronze color as the summer develops and by early September sometimes the windward foliage of those trees is fairly well bronzed. It looks like this might be a response to the strong in-draft winds which occur up the Eel River drainage there. These winds from the coast, even when not foggy, have a high amount of aerosol content of salt material and there is a possibility of wind flagging or shaping of the foliage by killing by this incessant summer wind, possibly due to this material or to desiccation.

I'd like to indicate our findings from mapping these wind flaggings. For examples one can go up the Eel River canyon and map the azimuth of the wind direction Prom the wind flagging of the trees. As one moves from the ocean coast the azimuth wind is about N20W (near Table Bluff), and approaching the Eel River canyon it begins to deflect and arriving at Holmes and Shively, the wind is moving from N50W. At Dyerville Flat, the wind has deflected to N10W, following the canyon in that direction.

Another interesting thing is to go up on the ridge tops, like Bear River ridge, Mt. Pierce, and such, and you find other wind flagging deflections. If you measure and plot on a map this flagging, you will find that this upper wind has been deflected southwest into the Mattole drainage and over Kings Peak where we find that the wind flagging is offshore. It's a quite fascinating to be above the ocean on these ridges like Cooskie Ridge and find the trees wind flagged toward the ocean. In summary, the wind appears to come up the Eel River valley and then overflow the ridge tops over the Mattole and finally form an offshore wind over King's Peak. Perhaps we could call this the Kings Peak - Mattole eddy. This may have

some relevance to the absence of redwood in the lower Mattole. In this situation we many times have a drying air current flowing into the Mattole country in contrast to the moist air flowing up the canyons directly from the ocean in other areas.

One of the other aspects of wind in redwood ecology is the severe dieback of some of the crowns, such as at Weott. Some of it may be related to the intolerance of redwood to drying effects on the canopy or salt spray or whatever it is in the wind that flows up the Eel River drainage. It is particularly noticeable at the edge of clear cuts at Weott or at Pepperwood Flat where the edge of the stand receives a very strong onslaught of up-canyon wind. However, there are complications in evaluating top dieback.

An old time resident of Weott told me that there was a saw mill burner here for a long time in the corner of the town, and it may have been that which caused this dieback in the tops. Professor Fritz has offered another explanation that this top dieback occurs where redwood trees have been badly burned at their base and have suffered a loss of water conducting tissue.

The old redwood crowns and the possibility of plotting an azimuth of these flaggings can give you some idea of wind current flow -- but only at the time of year this takes place. I think it's mainly the in-draft summer breezes that cause this. However, it would require a study in itself to prove this. If you go into some of the old growth stands of the Pacific Lumber Company south of Freshwater, there are many trees subject to this same type of crown dieback.

Now, let's look again at some of the coastal strip and go north of Crescent City. We begin with the surf, of course, and then salt grass, and finally the first group of trees that we encounter are Abies grandis growing toward the seaward margin of the forest, forming a wind protection screen for the interior stands of beach pine (Pinus contorta), and Sitka spruce. Similarly, if we go down to Fort Bragg we have an open brush strip composed of lupine growing in this immediate seaward zone. In some places these dunes have blowouts such as in the area just north of Crescent City. It was noticeable in these that the species growing on these dunes, especially the Pine contorta, tend to acidify the soil almost immediately. From a fairly high pH of around 7.5 in open sand, it would begin to drop pH within about 30 years down to pH 4.5 under the individual pine trees growing on these sand dunes. We find Sitka spruce forests growing further inland on the same dune soil. It has developed for about 500 years when an A horizon of organic matter was added to that soil and a much better water holding capacity. Sitka spruce has the ability to tolerate this site better. And finally, after more soil development, were established redwoods such as in the former Marlarkey Forest where they were growing on fairly old sand dune. These are nearly reddish-brown in color with quite a degree of soil development.

Forest Harvest and Hydrology

Although we mentioned that redwoods may follow the availability of water, sometimes there's too much water. On the slopes, for example, above the Mad River just west of Korbel, you find soil slips where alder invades areas up the draws where there seems to be excessive water. And many times if an area is clear cut, it may result in temporary water logging of the site because every tree is acting like a drainage pump. About 18 to 20 inches of water per year is used by trees here in northwestern California. When you remove this drainage source it is possible to swamp the soil with an additional 18 to 20 inches of water. This in turn may result in an invasion of alders which naturally follow such a wet situation, or occasionally on log landings and other areas, Nebraska sedge will invade these sites. A period of drainage by these trees that can stand the new wet conditions will then occur. Finally the original forest will be re-established. In the Wildcat Hill area south of Ferndale is an example of Alnus rubra stands which have invaded cutover areas and many times open grass pasture, too.

In considering some of the dynamics of redwood forest composition, we can start with a virgin forest. You can have many generations of natural forests. When we clear cut and remove the redwood trees, a plant succession series follows. Redwood, of course, sprouts and provides coppice growth, and a partially stocked stand will often result about 5 years after logging.

Now if a fire happens to go through the area after logging, you may end up with a ceanothus brush (blue blossom) stage at this point. One of the best ways to germinate ceanothus seeds is to heat them strongly for a few minutes. Another way is to soak them in concentrated sulfuric acid) . However, within a few year the coppice forest begins to re-cloth its slopes, and 10 years later, the redwood coppice will be up to about 15 feet in height.

After another 10 years, if we go back on that same site we probably would find a fairly dense stand of young growth such as you are all familiar with, in the hills back of Scotia. In other words, there's a very quick recovery due to the sprouting ability of redwood on the site. But along with this, there are seed sources for Douglas-fir which allow a fairly good stocking of Douglas-fir along with the redwood on most of these sites . This process, however, can be interfered with by some particular aspect of soil dynamics involving the nitrogen cycle. I'd like to tie that in soon with some of the problems of redwood nutrition.

There is an example of good second growth forest on the Mendocin soil series near Fort Bragg. The fact that redwood coppice grows fast after harvesting is apparent in this area. Young redwoods have grown particularly well around the Indian Creek railroad grade west of Piercy. There were trees up to 12 and 18 inches in diameter growing through the railroad ties and around the abandoned track. The valley of the Eel River east of Scotia is good evidence of this regrowth potential of redwood. The stands coming down the slope there exhibit much scenic beauty.

Old Redwoods - The Superlative Trees

Old growth redwoods have problems, too. If you look at some of the old growth redwood groves on the Eel River in the vicinity of Stephens Grove . just north of Miranda, you can see these old superlative groves are associated with alluvial flats along the River. The life history of these groves is pretty closely tied in to these alluvial flats and soil produced on them. For example, in Bull Creek Flat, there is a stand of trees which is slightly more than 300 feet tall growing on a particularly good soil. Excavating in five foot steps in that particular soil, we reached a gravel layer at 30 feet depth which indicates probably an old stream bottom. This deep and fine soil sediment has been deposited over a long period of time. How long is an interesting question. Close examination of the soil formed on this flat revealed a series of old buried soil horizons. There are darker layers which occur through the profile. Since this hole was dug in about 1962, we have a top layer representing a silt deposition that took place in the 1955 flood. What is evident is that each of these soil depositions represents an old silt layer which was deposited during a flood. What we have here is a flood sediment deposition sequence associated with these old growth redwood forests. We find the superlative redwood groves on our river banks and benches. Our excavations revealed charcoal in every one of these various soil layers. We suspect there may be a fire-flood sequence associated with the old-growth groves. That's something to investigate. However, sometimes there was charcoal in the deposition layer and many times even a border of red soil around - these charcoal particles indicated that the fire might have been burning at the site, burning out roots in the soil.

Figure II is a schematic diagram of that soil profile I mentioned - on Bull Creek Flat. It shows 15 depositions layers of sediment that occurred in the life history of that particular soil. When we examined the trees in the flat we found one growing on this site, which fell

the next year due to the undercutting of the bank, giving us a good way to date that tree. The tree, as determined from growth ring counts, was about 958 years old. I think the tree started growing at the time the soil began forming over the gravel bed. What happened was that as each sediment layer deposited around the tree, it was noticeable that the tree accelerated its growth for a period. The tree responded to each new soil deposition, perhaps from renewed fertility or nutrient availability, or some change associated with the tree and the sediment took place.

In examining the cross section growth patterns during the age of the life of the tree, from 1 to nearly 1000 years, a series of growth accelerations were observed. In studying trees now in the Eel River Flat that were subject to deposition in the 1955 flood, these trees show subsequent to that, beginning about 1956 or 1957, an increase in growth rate, and that if we go back to the 1938 flood, we can find the increase in growth rate resulting from that also. That is where sedimentation had taken place. Similarly for 1916, 1961, and for earlier years there were growth responses probably due to flooding. And what this showed for the Bull Creek site was a frequency of occurrence of flooding from once every 30 to every 63 years with sediment deposition on the site, where this nearly 1000 year old tree had stood.

If we look at the soil and sample it in depth, we find that each of those various layers represented a past soil surface and has the properties of that past soil. For example, the bulk density (or weight per unit volume) of the recent layer is 1.3 and then it increases with depth, decreasing abruptly at successive buried layers. Each layer becoming less and less distinct as we go deeper into the soil. Other properties, likewise, such as total nitrogen content, do the same. Roots of the redwood trees likewise are more abundant in each of these buried surfaces. Perhaps without all of these sediment, other trees than the currently recognized tree on Redwood Creek might be the tallest in the world.

To check the tree age determination, assuming that the tree started as one of a seedling wave which normally occurs on new sediment on these alluvial flats, we felt that the age of this soil at the bottom layer must have been about 958 years, the age of the tree when it fell. Since there was charcoal in this layer also, we decided to have a radio carbon analysis performed on this old charcoal. It was 1000 years old, plus or minus 100 years, which agreed with our annual ring counts.

I'd like to mention what happens to these trees raising themselves up on these alluvial soil profiles. This was documented pretty well by Emanuel Fritz at Richardson Grove in his investigations there. As these soil layers pile up around a tree which starts as a young seedling in new alluvial soil, the tree begins to grow a new set of roots near the surface perhaps extending roots up from below where it had been growing them, and then it gets a boost in growth, and grows to a larger diameter on that new soil surface. Then a new sediment layer comes along, adding another 3 or 4 feet, and the tree again begins to grow outward in diameter on that new surface with a new root platform below it. So progressively the tree "jacks" itself up on the site, growing to a larger and larger diameter above the soil surface, but the smaller diameters remain below the soil surface. This can also be observed in the large fire scars in these old trees where you can walk down into the tree and into the lower smaller trunk column. This is also why the trees do not flare out at the butt on these areas of periodic sediment deposition. The redwood, therefore, has very little taper as it enters the soil in areas where sediment deposition due to flooding occurs.

Occasionally the tree falls, or perhaps burns out, and we have a pit developing down to a particular soil layer where that tree originated. These pits provide evidence of the past existence of a tree. Or there may be an old snag which might date back to a fire that laid charcoal on that particular soil surface. This happened at places on Bull Creek Flat.

Here is the beginning of one of these seedling waves on new sediment dating from the 1955 flood. The old stand perhaps represents the trees that came in on flood sediment at 1000 or more years ago. We can see such a wave of seedlings coming in at Stephens Grove, and naturally as we come to the light at the edge of the grove the trees will be growing much taller and faster. On the edge at about 100 years of age they will be 150 feet tall, but in the interior they are only 15 feet tall.

Looking at the front of Founder's Grove, you can see the seedling wave of 100 years age along the front of the grove with the older trees in the background. We don't have a good dating on the age structure on the older trees, but we can obtain one on the younger trees int. which we can get an increment borer.

We also noticed that if you have intensive recreational use in a redwood grove, the seedling wave may disappear. State Park personnel have put in a "people enclosure" in Stephens Grove. Around this enclosure you find no more seedlings left, but within the wire fence the seedlings survived. Here 1000 years from now you may find a few 1000 year old trees, but only when we give them special protection from people in this case. A problem in park management is how to regulate the use to maintain areas in a somewhat quasi-natural condition under the pressures of increasing use. That certainly challenges any forester in this management field.

In fact, finding out what is "natural" in any of our redwood groves is quite difficult. Many of you know the nice stand of oxalis that occurs in Hammand Grove up the Van Duzen River. It's probably one of the most beautiful groves in the redwood region as far as appearance of that understory. We have observed that not only did the redwoods react favorably to silting depositions, but so did the oxalis. After the flood with perhaps 3 feet of sediment over the oxalis, the oxalis immediately sends rhyzomes up to the surface from the buried stems and colonized the surface. The understory that you find in a redwood forest on the alluvial flats partly reflects the ability of the species to colonize sediment in this manner. So immediately following a flood, for one year the understory looks bare, there will just be a small amount of leaf litter. Then by the second year the dense cover of oxalis and fern begins to reappear. The age of the previous flooding on that site and sediment deposition can be evaluated by the structure of the ground flora.

There is another important aspect of flooding in redwood forests, that is the old growth groves on alluvial flats. Up to now, all of the flooding we have discussed was beneficial to the stands, apparently releasing them and increasing the growth and perhaps contributing to the great height growth that we have in redwood forests. But we noticed on Bull Creek Flat that some of the high crowns were fading out. We found there was a lot of organic matter, debris, and a different grade of sediment around these particular trees than we observed in other sites.

Ordinarily in digging soil profiles, we'd find a silt loam all the way down with very little change in soil texture. But here we had interfaces developing, and sometimes we found water perching on top of soil interfaces producing apparently a poor drainage problem. The interfaces resulted from an abrupt change in texture of materials. On top of the silt loam, we'd have a sand, and then we might have a gravel, and then another silt loam, and these in turn perched water layers of poor drainage within the soil. And leaf litter in a buried soil layer smelled putrid and had a blue-gray appearance, which was quite different than the more healthy look and odor we found in silt loam depositions. But to complicate the matter we dug into the bark and found that it was full of bark beetles. Was the tree weakened and then invaded by bark beetles? We felt that these trees with their crown dieback and dying foliage, was related to a different type of sediment deposition than had occurred in the other groves, plus the added problems of bark beetles. The sediment production from the watershed above seemed responsible.

Relationships Between Superlative Groves and Watersheds

If we look at the headwaters of the areas above some of the groves we can see why some people are clamoring for total watershed protection. Here is Franklin K. Lane Grove and here is the watershed immediately above the grove about 10 years ago. This is probably immediately after a timber harvest and might be in its worst state. Usually within a few years we begin to get a regrowth of vegetation like we've had up on Yager Creek, resprouting of many of the sprouting conifers and hardwoods, such as tanoak and redwood, and a reclothing of this slope. I expect about 7 years later that area probably recovered with a good vegetation cover. And one of the best things to do in treating such an area is to let it go back to vegetation without any further treatment. However, what complicates the issue still further is that when people see an area on which timber harvest has just occurred, they feel this is a good time to convert to some other use. And for better or worse, this is a policy question depending on the landowner's views. Sometimes conversion is a difficult task and it maintains the area in a more or less sediment yielding condition. Wildfires can also burn over areas periodically. If we do have burns on frequent occasions, we may find that these result in a changed sediment quality. Sometimes the change in quality of the sediment was detrimental to some of the lower-flat redwood trees.

It wasn't just due to the timber harvest; a checkered history of all kinds of events had happened. There was a timber harvest, following which if the area had been left along perhaps would have revegetated very rapidly. But then there were attempts at conversion to another type of cover. These were not continuous attempts to the extent that a good grass cover was established as sometimes this proves uneconomical on certain soil types. It is relatively difficult to convert certain soil types areas to grass compared to other soil type areas. This has been the experience in upper Bull Creek. Following all of this, a large fire burned over portions of this watershed. Besides this there was a tan bark harvest on some of the upper Cuneo Creek drainage. Some of the fires that occurred in this area in the old snags of tan bark resulted in a less well covered soil surface on the upper watershed. Washing and slipping has occurred. This terrain already had slip potential in it. For example, there were some natural slips in a heavily forested area and some of the gravel and rock flows came out of these slips and built up in the canyon. However, due to the checkered history of this landscape, there was accentuation of the sediment yield from the area due to the land treatment that had taken place. This is some of upper Cuneo Creek. Some evidence of the fact that this topography has been slipping for a long time can be observed from the curved tree stems that were formed. You can tell slip topography by that type of evidence on the landscape. You're dealing with something that's going to give you some problems. Look at this road across this area showing slip terrain. An experienced professional forester can identify things like this and stay away from it.

If we look at some of the upper headwater area below that slip zone now beginning to feed into the main channel, such as in Cuneo Creek, the main channel develops what we call a torrent. In Austria, Italy and much of Europe, one of the main problems in upland management is torrent control.

How to stabilize torrents by cutting down something at the point so it does not gravel the whole slope. Down lower we have these results, but some of this material came from natural erosion which was occurring even under dense forest cover. But not this in Cuneo Creek. This came from some of that slope country I just showed upstream.

This is before and after the flood in Bull Creek Flat, lower Cuneo Creek. The forest floor looked like this. In fact, there was a very good alder cover here above Maple Creek Lodge and near the bridge at Cuneo Creek. Past fires in the area were partly the cause of this particular

event. And here is the encroachment of sediment into upper Bull Creek Flat, which aroused so much concern in those who were managing these old growth redwoods.

Further down stream the deep undercutting of the bank in Bull Creek was conspicuous. Since Bull Creek Flat and forest had formed almost cataclysmically, it may end cataclysmically also, because the whole area is subject to floods as evidenced by the sediment records. So much of this undercutting may occur anyway as a natural process in a grove or alluvial flat such as this with ox bow formation in the stream channel. So one can't attribute all of the undercutting of the banks to any particular change in land use.

Probably one of the lessons we get out of our past sediment history on the Eel River is that regardless of what man does, there may be an event occur which is going to wipe everything out someday. And then a new grove of trees will start. But the main problem is not to accentuate conditions so it ends up wiping out -- say Scotia. In other words, we should try to manage our upland areas within the economic feasibility that we have so impressed on all of us, and not let it out of control, to the point that it may wipe us out at some time. Some of the control instituted later on Bull Creek Flat which were torn out were to. small to compete with rising sediment load which is coming down the channel from the upper headwaters and once you begin to establish a torrent it is very difficult to get it back into shape.

And then there are always other "side" problems which come about, such as the occupancy of the stream channel by perhaps one quarter of its volume replaced by a fill such as here, and then the deflection of the current to the adjacent groves and undercutting taking place on these alluvial flats. And in the undercutting opposite the freeway.

Now to some particular problems. This is an example of work done to ameliorate a condition by the timber industry. Simpson Company, when logging up Hunter Creek, met similar problems but they were able through a stream channel clearance program, which unfortunately was quite expensive, to clear quite a strip of their own channel. I think there was a cost of $30,000 a mile. It was pretty expensive. But the problem is from the industry viewpoint, regardless of what you do to an area after a timber harvest, to some people it's going to look terrible. And even after spending $30,000 on this, which makes a good stream out of it, some people still come along and call this a horror picture.

But the result is a fairly good stream channel condition there. This is the Hunter Creek channel after cleanup by Simpson. I don't think cleanup is always essential if there were adequate placement of roads and high lead settings such as by Simpson on their new logging areas on Starwein Ridge. They are making a very good adaptation of good practice to those upland areas in which high lead logging is used on the steep slopes and tractor logging on the gentler slopes. We also know that logged watersheds in the redwood region may recover soon to conditions where they resemble virgin forest areas in that the water they yield is clear and sediment free. For example, Nanning Creek north of Scotia, an area that was harvested of its original redwood stand is now a clear calm stream.

There are many good examples of timber harvest and logging carried out by the timber industry to achieve good watershed conditions. For example, on very steep slopes along Lawrence Creek the Pacific Lumber Company used a cable-logging system which lifts the logs off the slope, creating very little surface disturbance. The Union Lumber Company has beer rotating its cuts so that following an initial timber harvest disturbance the watershed is allowed to recover quickly under second growth forest cover to remain thus for fifty years or more under the protection of a dense cover of vigorous young trees. Cuts in this forest when carried out have been with very small tractors or with horses to create a minimum of watershed disturbance.

Soil Nutrients and Redwood

Let's get back to some of the problems of ecology of these trees and look at the advantage we took of this tree which fell under the soil profile we had dug at Bull Creek Flat. I don't think it was our soil profile that caused the tree to fall, at least I hope not. We have analyses on the soil and we know there is a certain amount of nitrogen, for example, in that total soil profile. Now all we have to do is cut up this trunk, which was about 300 feet high, and sample sawdust at intervals along the trunk and also sample the bark at intervals. Then we can run analyses for nitrogen and find out just how much nitrogen is tied up in a redwood tree and how much are we considering when we harvest a redwood tree or we wish to improve fertility - as Dr. Stoate was doing on some of the Simpson lands. We found about 159 pounds of nitrogen per tree in the foliage and the stem. Of this amount, about 97 pounds were in the wood and bark of the tree. We found that redwood itself had a very low nitrogen content compared to other forest trees having a range from a low in yellowish foliage of 0.5% nitrogen to a high of 1.3% in deep green foliage on good sites.

When we analyzed the soil we found that the soil underneath the redwood tree, down to a depth of 10 feet, the current depth of active rooting, had about 24,000 pounds per acre of nitrogen in it. In other words, in the total forest system (both soil and trees), there might be 27,000 pounds of nitrogen per acre in forests such as on Bull Creek Flat. About 10% of the nitrogen is in the redwood forest itself above ground, this is the amount that we might remove during the timber harvest. That means that floating in the soil is a large amount of fertility which apparently is tied up in microorganisms and organic matter in the process of decomposition. And therein lies another story. Why is there so much locked up and how is this related to the growth of the tree and the fertility .n the site?

Gene Hofsted of Arcata Redwood Company, had an area up Lost Man Creek in a group of old growth trees that were turning silvery-gray in color. Pathologist would say it was due to fungi, soils men said it was due to subsoil problems, and entomologist said it was insects. And so depending on the specialists, different answers were proposed. I have an answer, too, based on the soils, after examination of the situation. A graduate scholar working with us, Dr. Ross Florence from Australia, analyzed the soils from under the old redwood trees which were turning silvery-gray. He was concerned about this problem and wondered why it was occurring, and thought that one aspect of it might have been the tie-up of large amounts of nutrient material by micro-organisms in that soil underneath the trees. He found that if you were to add ammonium sulfate to a soil which he sampled from underneath that tree from forest that was turning silvery-gray, it went through the nitrification part of the nitrogen cycle very quickly to form a large build-up of nitrate nitrogen. There seemed to be an excess nitrate formation occurring and apparently the trees were suffering due to excess nitrate formation in this forest soil.

The Simpson Company had areas where some of the second growth was showing chlorotic areas in second growth redwood. This also seemed like a nitrogen problem. Florence analyzed the foliage and found the nitrogen content was down around 0.5 of 1% whereas redwood foliage in good condition is about 0.7 of 1%. He did find that rather than excess nitrate formation where the trees were grayish, as he found on Arcata Redwood Company land, all the nitrogen added as ammonium sulfate would just stay as ammonium with no nitrification. Apparently the trees weren't utilizing this nitrogen. This seemed to be related to microorganisms build-up associated with high organic matter input immediately after the timber harvest. He had two sides of a picture, excess of nitrogen as nitrate occurring under some of these very old groves and resulting in a nitrate poisoning and the other extreme point, a blocking of nitrification with ammonium build up, and possibly a blocked utilization by the tree resulting in a low nitrogen content in

the foliage. What seemed apparent was that a large part of the nitrogen cycle that was taking in the redwood forest soil was related to the amount of organic matter left and the soil micro-organisms, so depending upon how a redwood forest is affecting the nitrogen cycle in the soil of that forest, we may see some reflection in the health of the particular stand; with extremes of chlorotic foliage in young growth or silvery-gray foliage in the older, mature stands, at corresponding extremes of complete blockage of nitrification to excessive rates of nitrification.

Redwood Seed Production

One further point in regard to those seedling waves that I mentioned earlier. On those areas we measured a fall of about 8 million seeds on a single acre, based on numerous square foot quadrates in the forests along the South Fork of the Eel to a maximum of about 21 million seeds per acre per year in the Founder's Grove. Only 10 - 20% of these seeds are viable, so there's good seed production in many areas of redwoods. But a point that Dr. Muelder noticed in his investigation on seed and cone production in redwood was that, many times the seed production and cone production in redwood was related to a disturbance of some type.

Such a disturbance might be, for example, the sediment deposition or a disturbance due to flooding in these alluvial groves. Another would be due possible to land slippage around given trees, or in the case of harvesting timber, soil disturbance adjacent to trees would induce seed formation. But over about two-thirds of the redwood region he found no cone production. The center of this zone of no-cone production or low cone production was from the road out to Fort Bragg from Leggett Valley down to northern Sonoma County. Then proceeding north up into Humboldt County on the Eel River, he found good cone production, particularly along these alluvial flats, so there's an inter-relationship between cone production, tree nutrition, and disturbance of the underlying soil. These might be a reflection of some soil phenomena, such as soil micro-organisms found in the nitrogen cycle, or other nutrient cycles that are tied in closely with the soil ecology of redwoods.