PATTERN AND PROCESS IN FORESTS OF *SEQUOIA SEMPERVIRENS* (D.Don) Endl.

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Introduction

The patterns of vegetation species types and their structures and age classes that exist in the range of the redwood forest from Salmon creek in southern Monterey County, California, to Loeb park along the Chetco river in Curry County, Oregon, are the result of natural processes over eons of time linking the genetic potential of individual species to local site conditions determined by factors of climate, geology, topography, living organisms defined by their natural genetic potential including *Homo sapiens*, and the elapsed process time of each. Boundaries brought about by these factors in the vegetation and soil landscape may be as gradients, in relation to climate, or sharp with abrupt changes in geology and topography, or due to disturbances such as fire, landslide, sand dune movement, flood removal and deposition. Humans, have for thousands of years impressed an influence for example through use of fires. The arrival of Spanish Californians intensified human influences increasing with harvesting of redwoods during the past two hundred years evidenced by use as timbers in the Mission San Jose, and early timber export to the Sandwich Islands (Hawaii), ending the last century with what seemed to promise the complete destruction of these forests.

Despite this, John Muir (1897) writing about the condition of American forests and the coastal redwood forests in particular observed " . . . towering serene through the long centuries, preaching God's forestry fresh from heaven . . . here the forests reached their highest development" and observed "Timber is as necessary as bread, and no scheme of management failing to recognize and properly provide for this want can possibly be maintained." He also observed that redwood was remarkable in its ability to regenerate after disturbance through sprouting based upon the evidence of third growth coppice resulting from past events. During our present century redwood forests have through several cycles of timber harvest and management continued to meet necessary human needs from reconstruction of cities after the earthquake of 1906 to the present when most of us live in houses of wood instead of adobe, brush or bark , and many have hot tubs made of redwood instead of the bark slab sweat houses of earlier Californians.

Despite the material need for wood, we have also recognized the need to preserve outstanding redwood groves in an awareness, beginning during Civil War times, that these magnificent forests represent what we stand for as a country (Schama 1995). In addition to the gift of wonder which the size of these trees bring to our mind is the enrichment brought to us by the perspective of the brief interval of time our lives share in the long lives of these old trees, for as John Merriam (1930) wrote "the element of time pervades the forest with an influence more subtle than light, but that to the mind is not less real." Certainly, a society founded on lasting principles can also manage forests that include areas represented by a life cycle of several thousand years. Large areas of old-growth redwood forests have been set aside for their inherent qualities unaffected by human material needs facilitated by contributions of individuals to groups who purchase them such as the Save the Redwoods League and the Nature Conservancy and the saving of outstanding groves by private lumber companies toward such purchase or as outright gifts to state and county as in the case of Cheatham Grove along the Van Duzen River.

The present day patterns of vegetation types in the redwood region result from fundamental processes linking vegetation to soil and site modified by the goals of land use meeting the recognized needs of a free people. The resulting land mosaic in the context of Forman (1995) ranges from the undisturbed condition defined as an ideal of management for State and National Parks to the structured patterns of species types and age classes of redwood forests in a land pattern having a small proportion of yearly harvest areas and a large proportion of forest fallow areas meeting the ideal management goals for sustained production forests.

This paper will present data describing limits of survival of redwood and associated species that bring about their patterns of occurrence on the land in terms of the elements essential to life that link them to the site. These elements and water supplied by soil storage are the nuts and bolts linking vegetation to the various soils of the redwood region. Trees, being bound to the same soil for life, must obtain most of the elements essential for survival from that soil, and lack of or diminished availability for any one of them means death or retarded growth. Part of the process of species type selection is due to differences in the level at which redwood and its associated species require and obtain essential elements through the fit to availability from soil storage or current mineral weathering. Some sites have elemental inputs from external sources as flood sediment on alluvial flats, ocean sand deposition as at Ten Mile Beach or Crescent City, ocean aerosols with sodium, magnesium, sulfur and boron along the coast, or elements from sporadic volcanic ash fallout, and, additions by human use of fire or fertilization. As another species, our fit to the land requires

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rational forest management based on an understanding of these processes and patterns and the recognition of human needs for forest products as well the preservation of outstanding redwood groves and the continuation of the environmental protection offered by forests.

The information we will build on in this paper was learned from the soil-vegetation survey of most of the redwood region conducted cooperatively by the Pacific S.W. Forest & Range Experiment Station with the California Department of Forestry and University of California and research work we have carried out with analyses of foliage and soils of redwood forests in projects of the University of California Agricultural Experiment Station.

The Range Of Elemental Composition Of Redwood Soil And Vegetation

Soil and foliage data were organized to give ascending arrays of the range of values from elemental analyses fitted to three parameter cumulative probability functions developed by Weibull (1949), using a computer program from R.L. Bailey (Bailey & Dell 1973). Details are presented in papers by Zinke et al (1979,1986). The parameters and derived values for cumulative percentiles of the sample populations (n) are presented in Tables 1 and 2 for redwood region soils we have analyzed during the past 40 years. These parameters are: A, threshold or minimum value; B scale, a central tendency within the range of values; and C. a shape parameter ranging from reverse J distributions when C is 1 (as in most trace elements) to normal bell shaped distributions when C is 3. Table 3 contains similar parameters for foliage analyses from sample populations of redwood forest tree species.

Current year foliage elemental contents for redwood are presented as derived values for cumulative population percentiles arrayed in ascending order in Table 4. The soil and foliage tables are useful for probability rating of analytical values to ascertain their position within an expected range of values between low to high limits. Ultimately, as the forester knows the growing tree by its appearance and vigor is the best evidence of adequacy of fitness to the site, but when signs of distress appear, and when analytical values are available, their ratings within the distributions may offer clues to solutions to the problem or insight to patterns and processes in the forest.

Species differences show up in foliage elemental contents which reflect in the distribution parameters of Table 3. Figure 1 presents the values of current year foliage nitrogen, phosphorus, and calcium content in ascending order of cumulative fractions of foliage sample populations of species of the redwood forest region. Key points shown by these figures are:

- Red alder has nitrogen content that from the lowest to highest foliage amount is nearly double that for the other species, as has been long known.
- Western hemlock and grand fir foliage have higher ranges in nitrogen content than the other species.
- Redwood has a much higher affinity for phosphorus in
- the upper fifty percentile level of the sample population, where it becomes double that of most of its associates.
- Douglas-fir is second to redwood and higher than the other local species in its foliage concentrations of phosphorus.
- Foliage calcium content shows redwood region species grouping into three categories: definite accumulators such as redwood, grand fir, and Port Orford cedar; those with low potentials for accumulating calcium such as bishop pine Sitka spruce and shore pine; and species that are intermediate such as Douglas fir , red cedar, and red alder.
- These tendencies in the foliage sample populations are expressed by the scale factor B of the Weibull functions given in Table 3. For example from the B parameters in Table 3 for manganese it is apparent that the samples of *Lithocarpus* foliage have high manganese contents, while *Thuja and Chamaecyparis* have low amounts since these are near the 0.50 level in cumulative probability tables.

The percentile or decimal probability ranking of the sample population having a given analytical value can be used to assess the status of that foliage relative to the expected range for that species. Table 5 presents examples of percentile ranking of current year redwood foliage elemental values for the nine elements using parameters from Table 3. Some conclusions from the table and Figures 2 and 3 are:

- Foliage samples from high site quality have elemental compositions ranking high in expected range in comparison with those from lower quality sites where one or more elements may rank low.
- Salt burned redwood foliage is at the upper limit for sodium, and high for potassium, and often high for

TABLE 1: RANGE OF SURFACE SOIL PROPERTIES IN REDWOOD FORESTS ARRAYED BY CUMULATIVE PROBABILITY													
CUM. P	Bulk den.	pH	C	N	C/N	P watersol	Capacity	Ca	Mg	K	Na	Mn	Bas
%<=	m.tons/cu. m		%	%		ppm	milliequivalents/100 grams						%
1	0.29	3.9	0.350	0.026	9.5	0.004	10.28	0.56	0.17	0.03	0.02	0.02	
10	0.52	4.4	0.929	0.051	13.3	0.017	12.05	2.07	0.51	0.09	0.03	0.08	
20	0.63	4.6	1.496	0.074	15.9	0.045	13.70	3.44	0.88	0.14	0.05	0.15	
40	0.78	4.9	2.681	0.121	20.5	0.136	17.04	6.16	1.71	0.24	0.10	0.29	
50	0.84	5.0	3.361	0.147	22.9	0.208	18.91	7.66	2.20	0.29	0.13	0.37	
60	0.90	5.2	4.146	0.177	25.4	0.306	21.05	9.37	2.78	0.36	0.17	0.47	
80	1.04	5.5	6.387	0.260	31.8	0.671	27.04	14.10	4.50	0.53	0.31	0.75	
90	1.14	5.7	8.443	0.334	37.0	1.108	32.44	18.31	6.14	0.68	0.45	1.02	
99	1.36	6.3	14.578	0.551	50.8	2.929	48.18	30.43	11.21	1.13	0.96	1.82	
WEIBULL PROBABILITY DISTRIBUTION PARAMETERS													
A	0	3.564	0.2475	0.02079	8.16	0.00297	9.9297	0.2317	0.1158	0.0198	0.0198	0.006237	
B	0.9244	1.6617	4.1833	0.1666	18.07	0.3425	11.8874	9.7479	2.8828	0.3590	0.1669	0.5000	67
C	3.9659	3.1153	1.2403	1.3182	1.7778	0.7119	1.3067	1.3508	1.1329	1.3566	0.8813	1.1838	2
n	240	240	232	239	232	227	241	241	241	241	233	240	
Used parameters to derive rating table in spread sheet formula: =A+B*(-ln(1-p))^(1/C)													

TABLE 2: RANGE OF METER DEPTH STORAGE OF ELEMENTS IN REDWOOD SOILS								
CUM P	C	N	P watersol	CAPACITY	CA	MG	K	NA
%<=	kg/sq.m.	gm/sq.m.	mg/sq.m.	Exchangeable equivalents/sq.m.				
1	5.2	306.8	8	41.7	2.4	1.4	0.3	0.2
10	7.2	409.7	17	61.8	5.5	1.8	0.4	0.3
20	8.7	478.9	25	77.2	9.7	2.9	0.6	0.4
40	11.4	593.7	46	104.7	20.7	7.0	1.1	0.7
50	12.8	650.0	58	118.8	28	10.5	1.4	0.8
60	14.3	709.8	73	134.3	37.1	15.7	1.8	1.0
80	18.1	860.1	118	174.9	66.6	36.9	2.8	1.3
90	21.3	981.0	161	208.9	97.2	64.8	3.9	1.7
99	29.7	1288.9	300	300.2	203.8	195.9	7.4	2.6
WEIBULL PROBABILITY DISTRIBUTION PARAMETERS								.
A	4.4919	262.9888	7.7861	35.3737	2.0965	1.4075	0.2549	0.133
B	10.2679	467.3646	70.8178	104.3633	38.5198	16.4395	1.6354	0.8673
C	1.6996	1.9425	1.0777	1.6403	0.9224	0.6181	1.0361	1.4555
n	99	99	98	99	99	99	99	99
for spread sheets use = 1-EXP(-(((X-A)/B)^C)) to rate X values with appropriate parameters A,B,C.								

TABLE 3: PROBABILITY DISTRIBUTION PARAMETERS FOR ANALYTICAL VALUES FOR CURRENT YEAR FOLIAGE OF ASSOCIATED SPECIES AND FOR REDWOOD FIRST, SECOND, AND OLD FOLIAGE+TWIG.

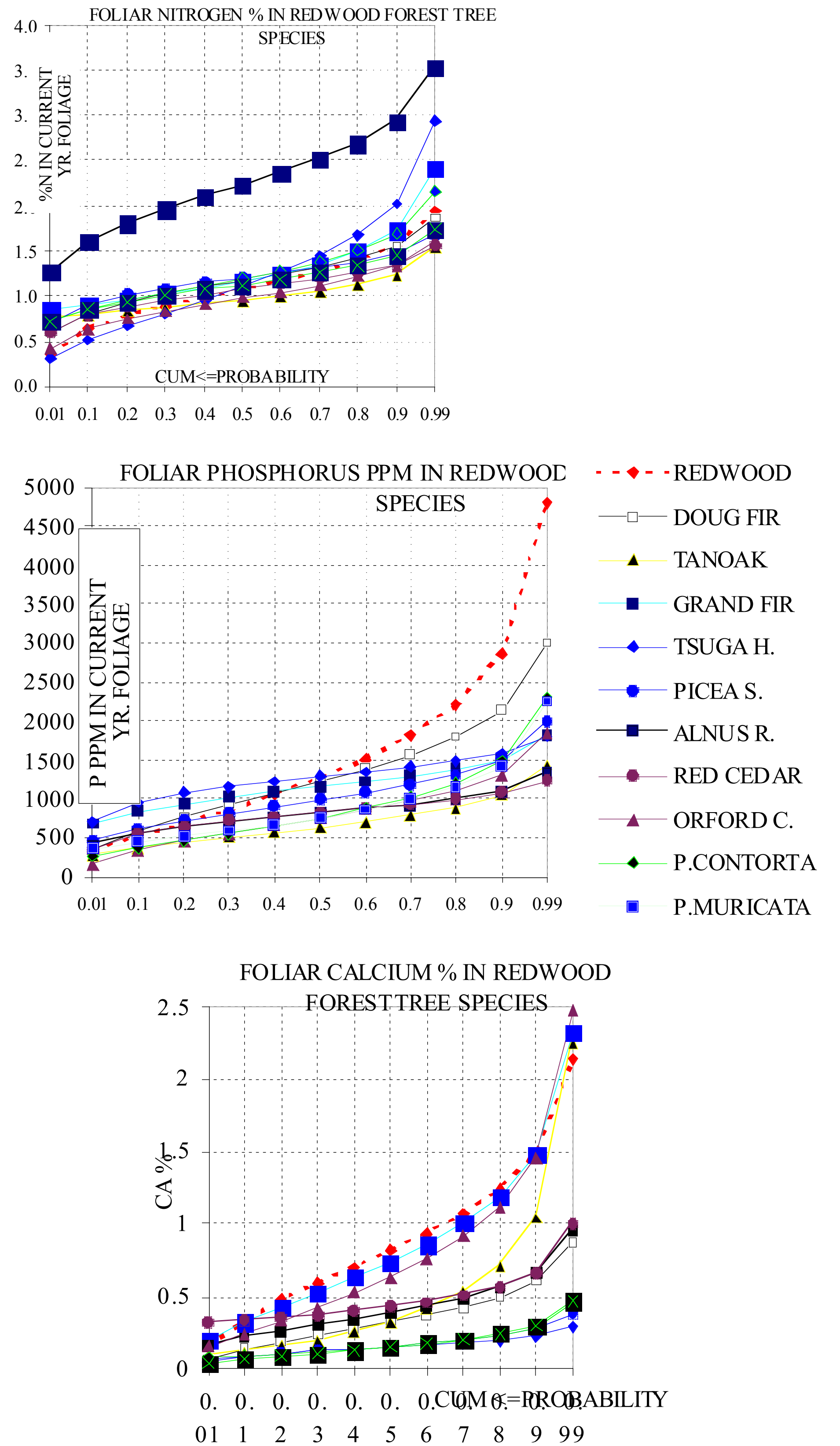
SPECIES	*ABIES GRANDIS*			*ALNUS RUBRA*			*CHAMAECYPARIS LAWSONIANA*			*LITHOCARPUS DENSIFLORUS*			*PICEA SITCHENSIS*		
PARAMETER	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
NITROGEN %	0.82665	0.45353	1.2246	1.0193	1.3976	2.5938	0.24651	0.82641	2.9875	0.73161	028042	1.4461	0.41045	0.86714	4.0201
PHOSPORUS ppm	582.91	665.27	2.4529	305.61	578.47	2.6785	97.515	793.31	1.9311	258.39	471.26	1.6682	400.95	709.7	1.8788
CALCIUM %	0.17424	0.73017	1.4131	0.13365	0.31309	1.5961	0.14167	0.66065	1.2075	0.09702	034697	0.83662	0.042768	0.14231	1.7479
MAGNESIUM %	0.07524	0.054586	1.0966	0.005346	0.11147	2.5027	0.042768	0.13111	1.23	0.02574	0.086762	0.77208	0.018711	0.027426	1.7174
POTASSIUM %	0.35343	0.2133	0.80667	0.18909	0.22772	0.80174	0.17107	0.35663	1.5232	0	047963	2.4947	0.17721	0.20039	1.2953
SODIUM %	0.00099	0.0065677	0.36439	0.00297	0.012843	0.69146	0.00099	0.0043227	0.46194	0.00099	0.0025108	0.68489	0.00099	0.0058164	037862
MANGANESE ppm	30.096	344.92	1.1718	49.896	210.68	1.27	32.076	166.63	1.215	133.65	499.48	1.1906	121.77	287.45	094934
IRON ppm	32.67	53.019	0.61443	30.69	205.81	0.71638	82.17	174.2	0.72865	14.85	114.1	0.878	8.91	39.514	088759
ZINC ppm	13.365	24.727	1391	9.9	29.921	0.84186	6.237	31.872	1.2417	7.92	7.2733	0.87113	10.89	16.969	1.1163
no. samples		17			24			26			21			41	

SPECIES	*PINUS CONTORTA VAR. CON.*			*PINUS LAMBERTIANA*			*PINUS MURICATA*			*PINUS RADIATA*			*PSEUDOTSUGA MENZIESII*		
PARAMETER	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
NITROGEN %	0.66201	0.65166	1.8232	0.67092	0.58072	2.3656	0.63974	0.57036	2.3231	0.7725	063513	2.329	0.41788	0.85604	2.9246
PHOSPORUS ppm	254.83	664.15	1.3538	333.23	819.56	1.6583	355.51	541.9	1.2243	0	1297.7	4.402	248.69	1195.3	1.822
CALCIUM %	0.07227	0.10393	1.1564	0.047223	0.17247	1.4235	0.032967	0.15474	1.4799	0.11672	014817	1.685	0.051678	0.3318	1.6696
MAGNESIUM %	0.021285	0.091195	2.9138	0.04059	0.070913	1.1545	0.03564	0.09453	1.8319	0.05544	011671	2.222	0.03465	0.10885	1.4591
POTASSIUM %	0.13939	0.34273	1.8828	0.18018	0.34579	1.153	0.052272	0.39624	2.2915	0	059804	2.817	0.059994	0.59523	2.4458
SODIUM %	0.00198	0.021402	0.49215	0.00099	0.00041428	0.43529	0.00099	0.061016	0.79002	0.01188	0.047834	0.6376	0.00099	0.0019431	041499
MANGANESE ppm	71.28	126.6	0.82168	84.15	185.4	1.2488	29.403	200.44	1.3978	24.057	219.56	1.174	12.474	352.35	1.2252
IRON ppm	18.81	131.38	0.77454	15.147	73.422	1.183	13.86	120.74	0.81953	40.59	76.314	0.8869	22.77	196.78	1.1769
ZINC ppm	11.88	47.49	0.61044	7.128	21.142	1.8711	7.128	22.321	1.6217	11.088	28.364	2.327	3.96	24.139	1.0713
no. samples		26			42			86			38			160	

SPECIES	*THUJA PLICATA*			*TSUGA HETEROPHYLLA*			CURRENT YEAR			*SEQUOIA SEMPERVIRENS* 2 YR			3-4 YEAR (red twig bark)		
PARAMETER	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
NITROGEN %	0.36293	0.78782	3.6606	0.23998	1.0754	6.5363	0.1572	1.047	2.836	0	1.0685	3.4733	0.25661	0.49524	1.9475
PHOSPORUS ppm	0	898.55	4633	347.49	1021.6	3.9329	306.9	1298.3	1.2294	0	1114.4	1.7083	318.78	439	093148
CALCIUM %	0.3168	0.15511	1.0303	0.051678	0.11706	2.1166	0.069795	0.90712	1.8528	0.20196	078561	1.1714	0.24057	0.83019	1.4659
MAGNESIUM %	0.029304	0.043075	2.0369	0.038313	0.04813	2.3879	0.050787	0.1447	1.6369	0.01881	0.1944	0.93047	0.022275	0.13472	1.2518
POTASSIUM %	0.14058	0.25364	1.1212	0.13226	0.25169	3.7358	0.22968	0.48615	1.2454	0.050688	057135	1.6109	0.19998	0.28422	089426
SODIUM %	0.00099	0.0064015	0.65266	0.002376	0.039466	1.4697	0.00099	0.043423	0.69712	0.00198	0.073145	0.5435	0.00297	0.025182	0.5859
MANGANESE ppm	45.441	158.05	1.3801	240.57	307.07	1.3437	29.7	250.05	1.0953	7.92	249.68	1.3626	4.356	157.19	1.4326
IRON ppm	35.64	121.68	0.92879	34.65	33.591	1.0109	36.63	203.95	0.91896	55.44	209.42	0.82243	46.53	139.21	083812
ZINC ppm	1.584	16.321	1.3698	2.079	8.5444	3.7102	6.237	35.124	1.3992	8.91	29.03	0.88646	7.92	28.482	097647
no. samples		28			133		63 - 55 least for sodium				63 - 59			30 - 27	

A is threshold value, B is scale value, C is shape value in spread sheet equation: =1-EXP(-(((X-A)/B)^C))
where X is the analytical value to be ranked within the species range in cumulative p for that element.

FIGURE 1: RANGES OF FOLIAR NITROGEN, PHOSPHORUS AND CALCIUM IN REDWOOD FOREST TYPE SPECIES



- iron nitrogen and zinc and low or very low for calcium and sometimes for manganese.
- Albino foliage samples have a similar profile of such high and low elemental extremes.
- Redwood at extremes of geographic range will show some elemental imbalances, as very low iron at the southern limit.

The empirical data suggest the existence of sodium potassium metabolic interactions in redwood requiring high phosphorus and proteins (N) which are turned on in sites subject to high sodium. These suggest potassium sodium channel interactions. Similar patterns of element excess or deficiency appear in albino foliage, and may be related to errors in a similar metabolic function. A reflection of these properties is avoidance by redwood of very exposed coastal areas which are tolerated more by other species such as Douglas fir, Sitka spruce, shore pine, Monterey pine. During winters of intense westerly storms with high surf, redwood is salt burned a mile or more inland and residents have observed salt deposits in the evaporated rain on their windows (personal observation by Emory Eskola).

TABLE 4: RATING TABLE FOR REDWOOD CURRENT FOLIAGE

CUM. P	N	P	CA	MG	K	NA	MN	FE	ZN
%<=	%	ppm	%	%	%	%	ppm	ppm	ppm
1	0.364	315	0.145	0.06	0.242	0.001	33	35	8
10	0.631	516	0.338	0.087	0.309	0.003	62	53	13
20	0.774	703	0.473	0.109	0.375	0.006	93	77	18
40	0.984	1083	0.700	0.147	0.513	0.018	165	138	28
50	1.077	1296	0.814	0.166	0.591	0.027	208	178	33
60	1.173	1541	0.935	0.188	0.682	0.040	260	227	39
80	1.396	2226	1.243	0.244	0.942	0.087	416	381	56
90	1.562	2845	1.493	0.292	1.180	0.144	566	539	70
99	1.951	4803	2.138	0.419	1.887	0.389	1038	1111	111

Derived using parameters for current year redwood foliage in table 3.

A few years ago, redwood foliage samples were collected from trees planted far outside their normal range at the approach to the Sacramento airport, and irrigated by local water. The foliage, poor in appearance, when analyzed had 1.058% N, 2288ppm P, .516% Ca,.306%Mg, .574%K,2.052%Na,21ppmMn, 258ppmFe,and 20ppm Zn. Using Table 4, the reader can quickly make an elemental profile ranking the foliage with visual interpolation. Actual ratings are: at 49% for nitrogen, 81% for phosphorus, 24% for calcium, 92% for magnesium, 48% for potassium, >100% for sodium, 0% for manganese, 66% iron, and 24% for Zinc. These data went beyond the distribution parameters for sodium, and below the threshold of 29ppm for manganese. They show a similar response to high sodium with the low manganese, and calcium, the high phosphorus rating, but not in the potassium and nitrogen amounts.

The foliage composition response to site will depend upon the soils, as well as the inherent metabolic properties translated from the genetic background of the species, subject to external inputs as the example of sodium as salt.

Limits to the range of a species such as redwood also occur in response to local soil conditions. Next we will examine some of these relations of foliage analyses as indicators of such soil conditions on upland areas.

TABLE 5: EXAMPLES OF REDWOOD FOLIAGE PROBABILITY RATINGS

LOCATION & CONDITION	N	P	CA	MG	K	NA	MN	FE	ZN
	Cumulative %<= from table 4								
	HIGH SITE (I)								
SITE I NR FLATIRON TREE BULL CR.	84	80	79	60	67	50	81	82	75
SITE I BULL CR. NEAR ALBEE CR.	86	83	76	56	70	48	80	87	87
	LOW SITE								
SITE III GRASSHOPPER RD.	17	21	79	16	26	72	71	52	73
	NORTH SOUTH LIMITS								
CHETCO RIVER LOEB PARK ORE.	75	79	30	58	74	7	48	36	60
SALMON CR. LOS PADRES N.F. CA.	65	67	42	90	71	59	62	8	53
	SALT BURN								
528 CA 72 ARCATA	56	64	3	55	88	96	43	80	91
528 CA 74 AIRPORT	95	72	5	67	90	99	21	98	60
528 CA 76 FREEWAY	94	83	27	69	93	99	53	88	87
528 CA 78 TURNOUT	75	61	31	71	61	97	69	98	86
528 CA 80 SAMPLES	81	56	34	71	64	97	21	99	98
	ALBINO FOLIAGE SPROUTS								
WOMENS FED GROVE HUM.ST.PK.	99	100	12	52	99	96	23	86	92
TERRACE CR.LOS PADRES N.F.	73	91	76	24	92	90	3	66	64
STRAWBERRY CR. U.C. BERK.	89	100	1	10	92	90	7	77	88
DITTO GREENISH YELLOW	61	99	1	10	69	100	15	63	92
	FASTIGIATE FOLIAGE SPROUTS								
528FCA 87 MUIR WOODS	28	45	56	67	13	20	58	30	38
528FCA 88 BY BOB FIRTH	21	48	45	56	33	28	25	26	30
	TREE TOP FOLIAGE CHANGE								
BIG TREE LIKE (BIGBASIN ST PK.)	26	42	66	61	13	11	96	26	60
NORMAL (same tree)	28	42	51	35	47	11	81	2	66

FIGURE 2:CUMULATIVE PROBABILITY RATINGS OF CURRENT REDWOOD FOLIAGE FROM SITE I & III AREAS

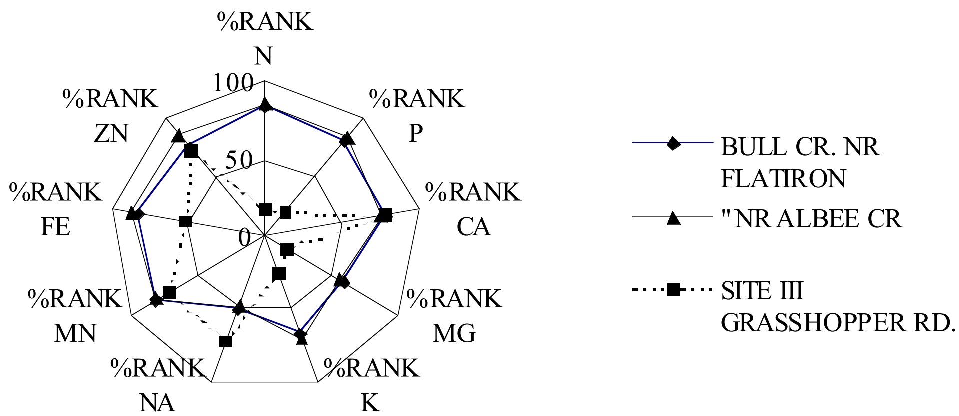
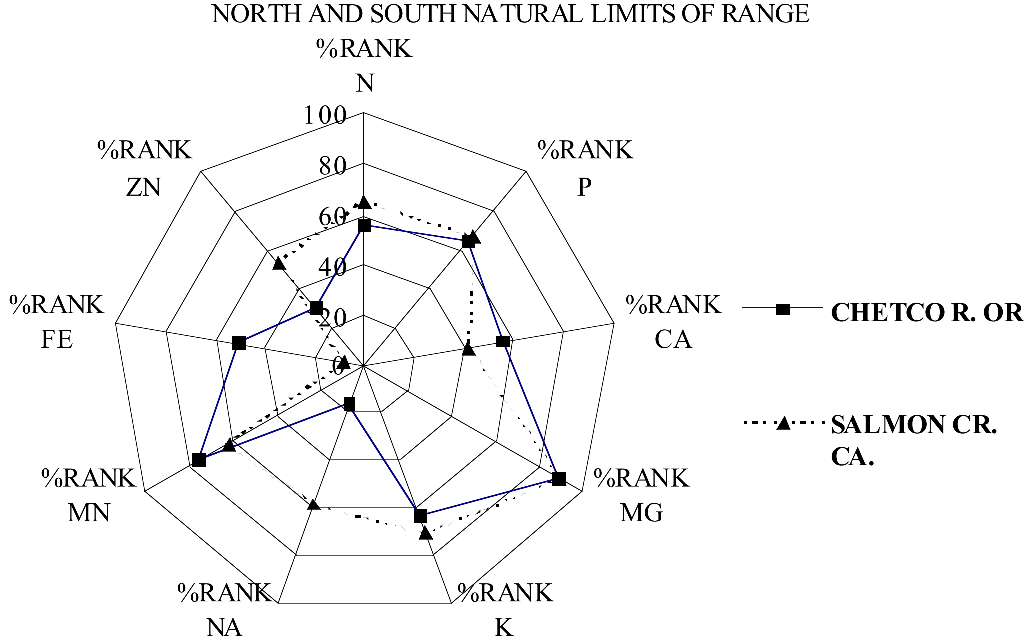
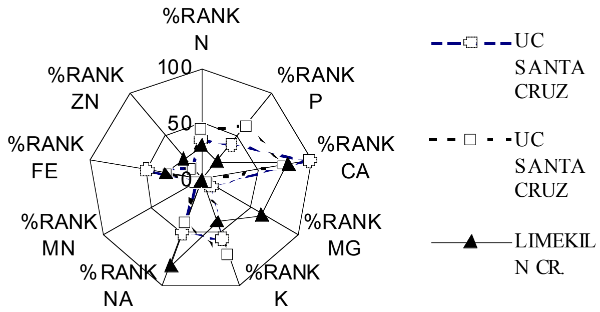


FIGURE 3:REDWOOD CURRENT FOLIAGE PROBABILITY RANKS AT NORTH AND SOUTH NATURAL LIMITS OF RANGE



Upland Areas

FIGURE 5:REDWOOD FOLIAR ELEMENT RANKING ON LIMESTONE SOILS



E 4A:REDWOOD FOLIAGE ELEMENT RANK ON
ES FROM A YOUNG (INCEPTISOL) AND AN OLD
(ULTISOL) SOIL.

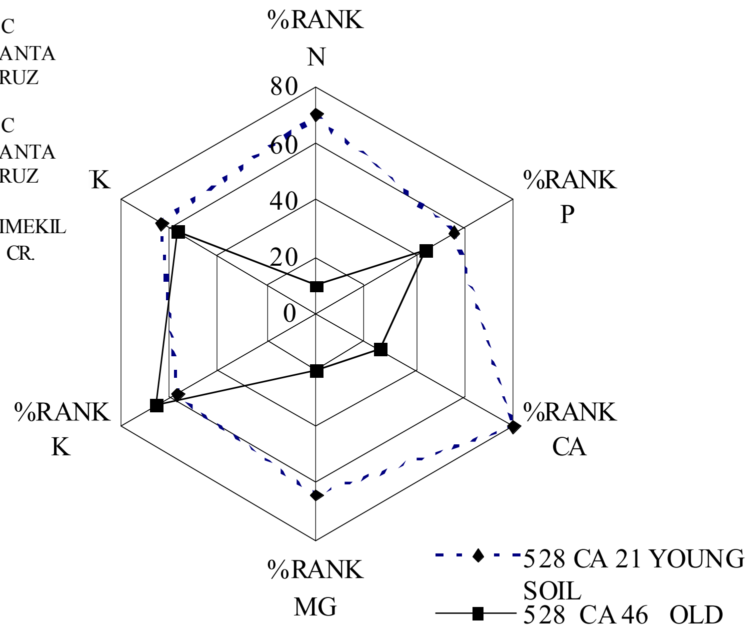
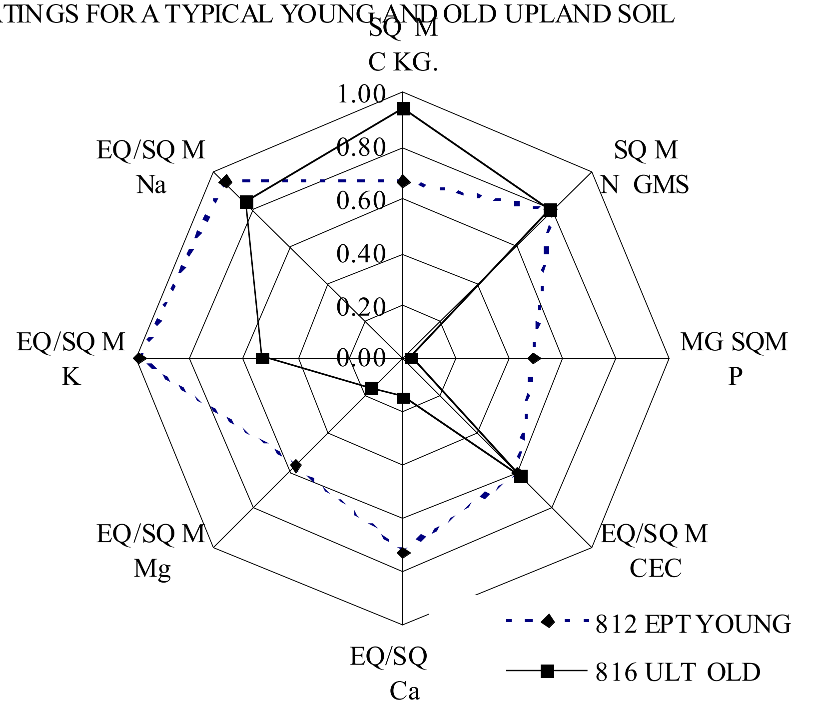


FIGURE 4B;METER DEPTH STORAGE PROBABILITY
RATINGS FOR A TYPICAL YOUNG AND OLD UPLAND SOIL



The major topographic categories that differentiate soil site conditions in the redwood region are those of the upland areas where soils generally age in development over time with little if any renewal, in contrast to valley alluvial areas where frequent renewal from floods and sediment deposition take place. On upland areas, soils on steeper slopes tend to remain immature in proportion to natural erosion rates (inceptisols and entisols), while on plateau tops and other flat surfaces with little erosion soils have developed over long periods of time into deep, red, fine textured, often strongly leached old soils (ultisols). The resulting pattern of soil types have related vegetation responses.. Figures 4A and 4B are radial profiles of cumulative probability for levels of soil storage of elements and analytical values of foliage samples from trees on such soils. The essential points are:

- The storage of elements in a young soil (inceptisol, soil 812 S.V. survey) generally rank high in content for major elements carbon, nitrogen, phosphorus, and the exchangeable basic elements calcium, magnesium, potassium and sodium, whereas in old soils (ultisol, soil 816 SV survey) the contents of available water soluble phosphorus, calcium and magnesium are at very low levels, and potassium is low.
- Ultisols may have high nitrogen levels, but even higher carbon levels render this nitrogen less available due to high C/N ratios.
- Redwood foliage samples from young soils show high levels of the elements nitrogen, phosphorus, calcium, magnesium; potassium, and sodium, with much lower nitrogen, calcium, and magnesium, and considerably lower phosphorus content in foliage samples from an ultisol.

The sharpest boundaries in the pattern of soil and vegetation types in the redwood region occur where geologic boundaries result in abrupt changes in soil parent rock. Examples are with the intrusions of serpentinite and peridotite that occur just interior of the redwood forest Curry County, Oregon, and in Del Norte County from Gasquet Mtn. and high divide southeast to Rattlesnake and Starwein Ridge, and on Elk Ridge at the head of Salmon Creek west of Miranda, on Red Mountain east of Leggett valley, and finally at the southernmost limit of redwood in Monterey County. These form abrupt boundaries blocking the present range of redwood where its foliage analyses are low in calcium and excessive in magnesium as is seen in Figure 3. The reverse is true where redwood occurs on limestone as on the campus of U.C. Santa Cruz as seen in Figure 5. Also, boundaries between hard graywacke sandstones of the Franciscan Formation, and the soft sediments of the Wildcat formation in the hills south of Ferndale result in Tonini soils (922 inceptisols) which favor conifer forests of Sitka spruce and grand fir lacking redwood. This is also an interaction with the strong onshore aerosol laden wind coming into these hills from the northwest, which

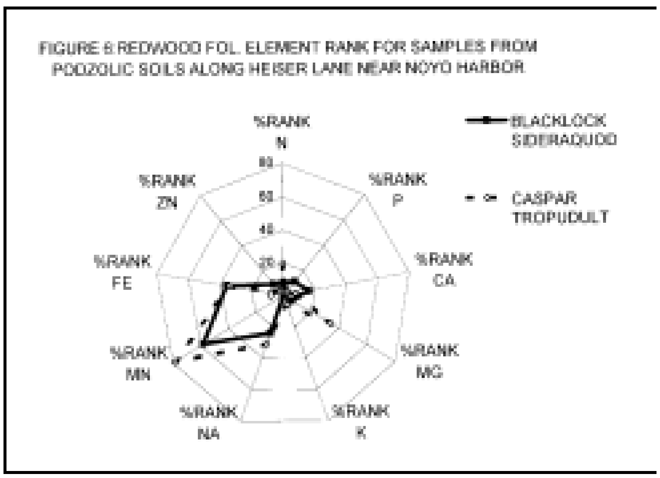


FIGURE 6 REDWOOD FOL. ELEMENT RANK FOR SAMPLES FROM PODZOLIC SOILS ALONG HEISER LANE NEAR NOYO HARBOR

eventually, evidenced by wind flagging, become off shore from the N.E. from Rainbow Ridge to the Cooskie ridges north of Kings Peak possibly leading to the redwood free areas in the Mattole and Bear River areas. Extremes of parent material effects on redwood foliage elemental composition are seen in Figures 5 and 6 showing radial plots of elemental ratings of current redwood foliage on a limestone area, and redwood foliage from the Blacklock soil southeast of Noyo Harbor (sv # 512 sideraquod).

Since most commercial forest land is on these upland areas, it is of interest to see what effects timber harvest has on these fertility elements. In a study sponsored by Arcata Lumber Company, Louisiana Pacific Company, and Simpson Timber Company we evaluated the effects of clear cut harvesting old growth, and 64-year-old second-growth on a site which had been clearcut and burned seventy years previous in 1903. Multiple profiles were sampled in each condition on land of each company for old growth and adjacent clearcut old growth, with a follow up on 64-year-old second growth and clearcut second growth on L.P. land. Summary data for this sequence are presented in Table 6. These are means of eight profiles for each stage; where each profile was sampled in five uniform depth increments to four feet, and the elemental storage for each element calculated for a soil volume for a square meter to a meter depth. The soils were an ultisol on hard rock (Orick) for old growth and an ultisol on soft sedimentary rock (Mendocino) for second growth. The complete results were published Zinke (1983). The key points are:

- There was a decline in total soil storage of calcium and increases in total carbon, nitrogen, water soluble phosporus potassium sodium immediately following clear cutting of old growth.
- The overall effects of clear cutting old growth on soil nutrient storage seem to be eliminated during the long forest fallow period to merchantable second growth.
- Following clear cutting 64-year-old second growth there was an increase in soil storage of both carbon and nitrogen and a decrease in magnesium storage to a meter depth
- If only the surface half foot or less of the soil is considered, there is a large decline in all elements assessSed on a soil weight basis which is recovered during the subsequent forest fallow.
- Timber cropping is one of the few land uses that offer such a long fallow period for these upland soils.

The alluvial soils which give rise to the superlative groves for which the redwood region is famous are in contrast to the upland soils.

Soil And Vegetation Pattern And Process On Alluvial Areas

The major process distinguishing the soil of alluvial area

TABLE 6: METER DEPTH SOIL ELEMENTAL STORAGE & TIMBER HARVEST								
STAGE	C	N	P water s.	CEC	CA	MG	K	NA
OF CYCLE	kg/sq.m.	gm/sq.m.	mg/sq.m.	Exchangeable equivalents/sq.m.				
	ANALYTICAL DATA							
OLD GROWTH	10.2	585	67	64	14.9	2.8	0.6	0.8
" CLEAR CUT 1974	18.7	684	118	121	13.4	4.7	2.8	1.4
CUT 1903 '74 2ND GR..	10.9	518	45	149	33.8	47.3	1.2	1.2
" CLEAR CUT 1974	17.4	889	36	126	32.6	9.5	1.5	0.7
	Cumulative p<= from table 2							
OLD GROWTH	0.31	0.38	0.56	0.11	0.30	0.20	0.18	0.49
" CLEAR CUT 1974	0.82	0.56	0.80	0.51	0.28	0.31	0.79	0.82
CUT '03 2ND GR. '74	0.36	0.27	0.39	0.68	0.57	0.85	0.43	0.74
" CLEAR CUT 1974	0.77	0.83	0.31	0.55	0.55	0.48	0.53	0.42
Means of eight profiles for each stage.			Soils sampled in 5 uniform depth increments,					
two in top foot, and one foot increments to 48". Data calculated to a meter depth								
on a square meter areal volume. Soil for old growth (813) Orick ultisol, for second								
growth (915) ultisol on soft sedimentary deposits.				Table 2 parameters used.			used in ratings.	

redwood forests is the periodic flooding and deposition of new sediment and the buildup of sediment layers to 30 feet of soil depth or more.

The alluvial soil areas with their magnificent preserved redwood groves are a paradox. Despite their apparent timeless quality, these groves are frequently scenes of utter devastation after flooding and sediment deposition. The groves form canopies of mono-cultures with redwood—a species which tolerates and benefits from the intermittent flooding. These result in a forest with a world record biomass of 3,461 metric tons per hectare as measured in the excellent study by Fujimori (1977).

Floods may destroy or re-invigoration the forest with sediment having large quantities of essential fertility elements and presenting a seed bed for redwood regeneration which otherwise is inhibited by old growth (Florence, 1965). We have measured sediment deposits from maximums of 58" in 1964 at low points and grove borders to 5" or less at distances of 400' to 500' into groves. The old trees benefit from a growth increase due to this as shown by annual ring growth while the new generation of young trees becomes a wave of suppressed dwarfs under the canopy of 300' tall old-growth trees after the smaller 100-year floods. If the flood is the two-thousand-year biblical flood that removes most of the old growth, a new seedling regeneration wave on the open, initial sediment of a renewed soil deposition column becomes the even-age old-growth grove of the future, with a few tall remnant surviving giants towering overhead. The new sediment deposit itself is on river or creek gravels and begins the building of a new soil column with new deposits with each flood. In lower Bull Creek Flat we observed such a soil profile which since its initiation slightly more than a thousand years ago, based on a carbon 14 date, has had 15 flood sediment deposits to a depth of 29.5' (889 cm.), and trees with annual rings showing them to be in the thousand-year age class and heights of 300' or more.

During the period of our study, we have sampled flood sediment deposits from the December 1955 flood (in 1958), the flood of December 1963, and January 1974. Data from those sampled at Founder's Grove are presented in Table 7 for calculations of cubic meter storage of original sediment and that of a soil profile in Founder's grove. It is interesting to contrast these data those for the upland soils in Table 6. The data for sediment show that:

- Sediment freshly deposited has a bulk density that is higher than the usual surface redwood soil.
- The pH of sediment is much higher the usual forest soil of the redwood region.

TABLE 7. SOIL METER DEPTH ELEMENT STORAGE IN FOUNDER'S GROVE

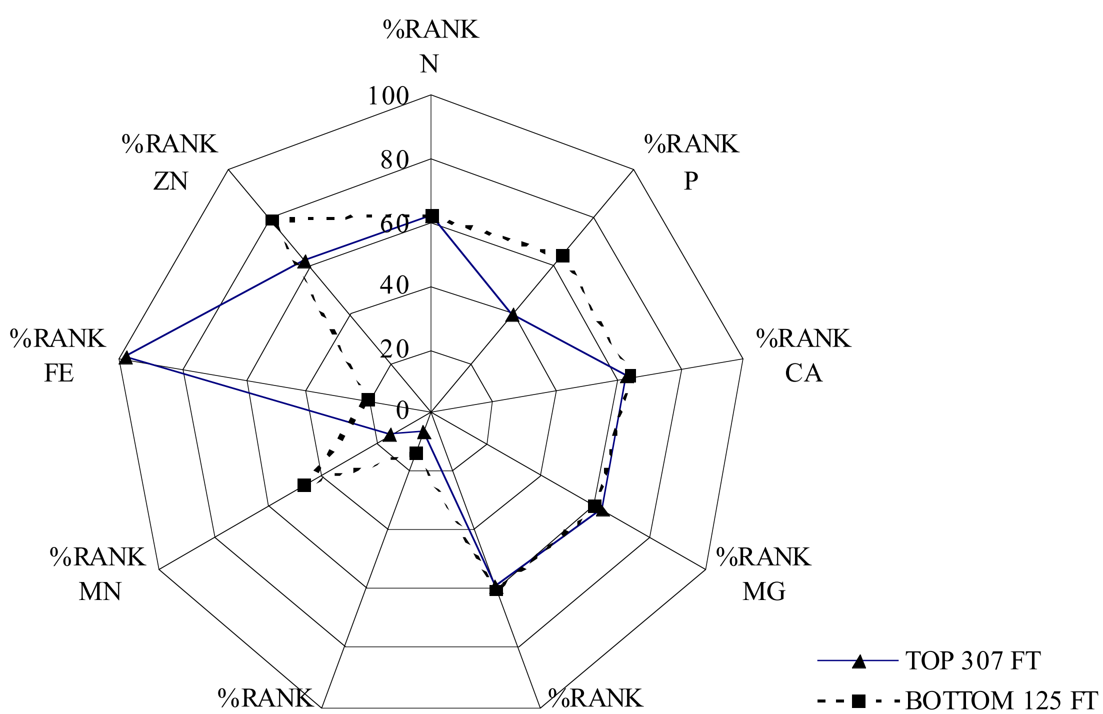
SEDIMENT & SOIL	C	N	P	C.E.C.	CA++	MG++	K+	NA+
	kg/cu.m.	g/cu.m.	mg/cu.m.	equivalents per cubic meter				
1974 new sediment	7.8	505.3	0.11	96.2	125.9	18.4	1.7	0.3
1955 sediment sampled '58	23	1140	0.36	159.6	110.4	35.7	6.6	11.1
Alluvial soil profile 108	22.7	1432.7	167	222.4	101.5	34.6	3.6	0.5
	C	N	P	C.E.C.	CA++	MG++	K+	NA+
	Cumulative p<= (from table 2)							
1974 new sediment	0.14	0.24	0.00	0.34	0.95	0.64	0.58	0.10
1955 sediment sampled '58	0.93	0.97	0.00	0.74	0.93	0.79	0.98	1.00
Alluvial soil profile 108	0.93	1.00	0.91	0.93	0.91	0.79	0.88	0.24

- There is a high exchangeable calcium content in the sediments.
- Where sediment deposits are deep they result in a large accretion of calcium, magnesium , and potassium to the grove in terms of rank among all redwood soils.
- Organic carbon and nitrogen contents of sediment are usually low compared to redwood forest soils
- Available water soluble phosphorus is very low in the new sediment.
- Elemental storage in the top meter of new sediment and finally older redwood grove soil quickly reaches very high levels when rated alongside all redwood region soils as shown in samples three years after the 1955 flood.

These thousand-year-old trees resulting from past huge floods, and the even older remnant patriarch trees that survived, give us the opportunity of understanding long enduring processes.

TABLE 8:ELEMENTAL COMPOSITION AT VARIOUS HEIGHTS IN FALLEN ALLUVIAL FLAT TREES														
	RELATIVE	COMPONENT	N	P	CA	MG	K	NA	MN	FE	ZN	AL	S	CU
FEET	HEIGHT		%	ppm		%						ppm		
DYERVILLE GIANT-FOUNDERS GROVE fell 2/27/1991														
370	1	MATURE CONES	0.752	686	0.155	0.112	0.517	0.033	25	78	27	61	713	7.6
370	1	FEMALE FLOWERS	0.918	2938	0.206	0.079	0.932	0.001	29	46	35	28	1012	12.3
370	1	MALE FLOWERS	1.016	2996	0.512	0.136	0.934	0.012	30	116	40	77	1600	9.2
370	1	CUR YR FOL.	0.971	2925	0.618	0.341	0.653	0.034	125	106	58	68	1126	5.8
	1	%RANK	51	100	60	67	63	47	5	1	90			
365	0.98	CUR LINEAR LVS	1.025	3341	0.746	0.279	0.637	0.006	38	88	54	41	1371	4.8
		%RANK	54	100	61	66	62	3	0	0	85			
365	0.98	CUR YR SCALE LVS	0.912	2830	0.651	0.286	0.730	0.002	35	80	70	41	1744	12
		%RANK	48	100	60	66	63	0	0	0	97			
230	0.62	CURR YR. FOL.	0.797	2440	2.802	0.551	0.201	0.013	258	331	71	510	1412	3.4
		&RANK	41	100	71	71	0	11	53	99	98			
190	0.51	CURR YR. FOL.	0.942	4659	1.919	0.666	0.431	0.006	307	168	53	187	1486	2.8
		%RANK	50	100	68	72	59	3	75	16	84			
131	0.35	CURR YR. FOL.	1.047	4419	1.742	0.52	0.555	0.009	226	149	54	155	1485	5.4
		%RANK	56	100	67	70	61	6	38	9	85			
370	1	BARK	0.596	490	0.210	0.076	0.127	0.015	26	224	28	195	512	14.6
365	0.98	BARK	0.435	188	0.381	0.026	0.079	0.007	13	84	10	83	467	4.2
300	0.81	BARK	0.276	45	0.021	0.006	0.004	0.004	3	37	4	32	450	2.2
200	0.54	BARK	0.246	96	0.049	0.061	0.013	0.013	31	476	8	412	373	3.6
365	0.98	SAPWOOD	0.556	713	0.962	0.111	0.330	0.012	27	37	24	26	659	10.3
365	0.98	SAPWOOD	0.352	271	0.102	0.029	0.134	0.002	12	18	10	20	236	3.2
300	0.81	SAPWOOD	0.604	429	0.212	0.029	0.162	0.002	17	36	15	39	789	2.8
200	0.54	SAPWOOD	0.607	422	0.101	0.029	0.133	0.004	11	43	9	58	414	2.5
70	0.2	SAPWOOD	0.606	1746	0.295	0.067	0.528	0.036	14	25	17	14	1819	15.8
365	0.98	HEARTWOOD	0.239	74	0.068	0.014	0.004	0.001	8	19	2	10	187	2.9
300	0.81	HEARTWOOD	0.176	43	0.042	0.008	0.001	0.004	7	54	13	18	116	1.6
200	0.54	HEARTWOOD	0.130	21	0.049	0.01	0.001	0.001	9	50	3	30	105	0.7
-10	-0.03	ROTTEN HEARTWD	0.390	90	0.209	0.315	0.206	0.019	50	576	9	880	571	1.5
-10	-0.03	ROTTEN HEARTWD	0.386	84	0.165	0.266	0.171	0.017	50	603	10	752	552	1.8
-10	-0.03	ROTTEN HEARTWD	0.365	137	0.143	0.206	0.074	0.016	31	224	11	349	420	5.4
TREE # 102 LOWER BULL CREEK FLAT fell 12/1964														
307	0.98	FOL. ALL YRS	0.920	1080	1.020	0.150	0.370	0.012	144	336	40	323	862	3
		%RANK	62	40	63	62	59	7	15	98	62			
275	0.87	FOL. ALL YRS	0.850	893	0.870	0.072	0.400	0.024	88	160	30	180	811	4.8
		%RANK	61	21	62	58	60	22	3	10	37			
225	0.71	FOL. ALL YRS	0.800	1020	0.980	0.077	0.280	0.018	186	205	46	185	958	3
		%RANK	60	33	63	59	58	14	33	32	75			
175	0.56	FOL. ALL YRS	0.870	903	0.780	0.097	0.320	0.026	157	224	38	238	812	5.1
		%RANK	61	21	61	60	58	24	20	44	58			
125	0.4	FOL. ALL YRS	0.90	1271	1.120	0.094	0.380	0.018	214	183	48	275	1184	4.6
		%RANK	62	64	64	60	60	14	46	20	79			
Analytical values by Dr. J.L. Bertenshaw														

FIGURE 7: ELEMENTAL RANK OF FOLIAGE FROM TOP AND BOTTOM OF A LARGE TREE IN ROCKEFELLER GROVE



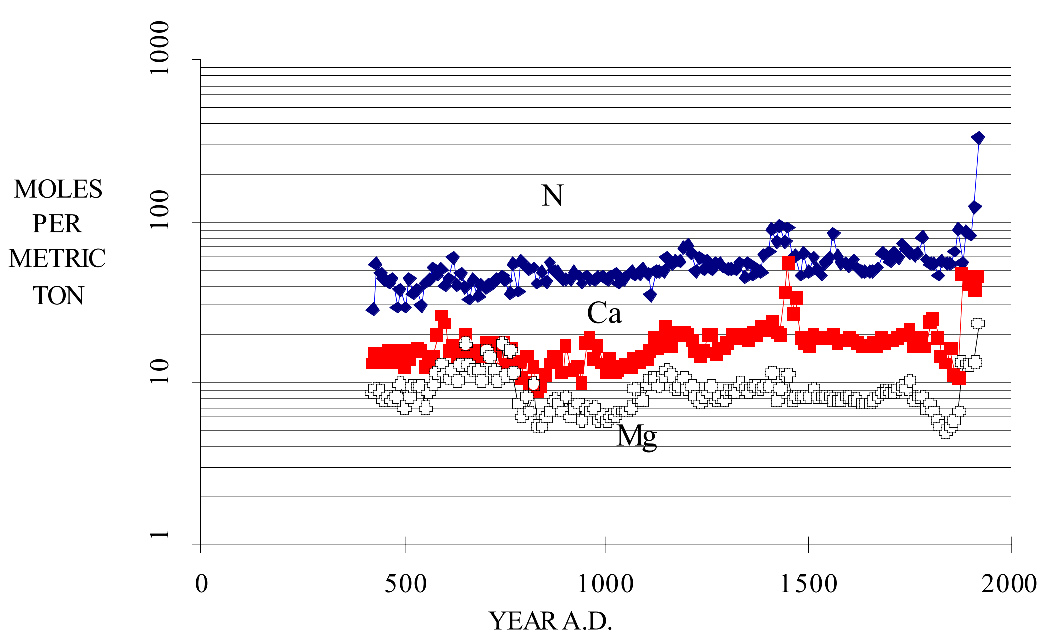
Pattern And Process In Trees Thousands Of Years Of Age

During the years of our studies, several large trees have fallen giving us the opportunity to sample foliage, bark, and wood from top to bottom of the trees offering an insight into the variation of elemental composition through the forest canopy. Data for such analyses on the Dyerville Giant which fell in Founder's Grove in February 27, 1991, and for a smaller tree (#102) which fell undercut by Bull Creek in Rockefeller Grove during the flood of December 1964 are presented in Table 8. Figure 7 shows a plot of cumulative probability percentiles for elements from top to bottom of the crown of the Bull Creek Flat tree. Most of the elements are uniformly high, at the 60% level of redwood foliage population samples except for manganese and iron. These elements show a reversal in relationship between top and bottom, with iron highest, and manganese lowest at the 307' top, and manganese high, and iron low at the lower edge of the crown at 125' up the tree. This suggests the tree is like a large redox column with high manganese relative to iron at the bottom keeping the iron mobile with height until reaching a level of low manganese where iron is retained. The taller residual giants such as the Dyerville giant extend to heights of more than 370' (or lengths as measured on the ground now) where even iron reaches a minimum at 365' along with minimal manganese. It is at these heights where in the presence of low foliage iron, we find a transition in foliage from that of a typical *Sequoia* to the scale-like leaves of a *Sequoiadendron* that appear able to survive in the presence of both minimal iron and manganese concentrations. This is seen in ratings at the bottom of Table 5 for similar foliage from tree tops sampled in Big Basin State Park.

Finally, we have the history of the site which the very old giant redwoods on the alluvial flats can give us regarding long-term processes associated with the land. A Haas Grove tree (near High Rock, a mile north of Founder's Grove) fell in 1932 and contains a cross section of wood from the past 1500 years. We split decade samples out of this section and analyzed them for thirteen elements: nitrogen, phosphorus, calcium, magnesium, potassium, sodium manganese, iron, aluminum, zinc, sulfur, copper, and boron, all essential elements (except aluminum) for life or sodium not considered essential for trees. Decades are close enough for annual ring times for redwoods as the presence of discontinuous rings has been long known (Fritz & Averell 1924) . Three periods of the data are presented in Table 9, and a selected set of elements are plotted in Figure 8 for the period of the section between 422 AD and 1932 AD. Some conclusions from these data are:

- A large change in trend in elemental contents occurred around the decade 920 A.D. which is about the date of the very large flood which gave rise to the 1000-year-old soil profiles and age class of old-growth trees on the Eel River and Bull Creek alluvial flats.
- During the century encompassing the period 1422 - 1522, there was a large increase in the wood contents of calcium, sodium, aluminum sulfur, and boron indicating a large external input event such as might occur by ash fall, excessive input from the river as could occur with an unusual flood or seismic induced erosion event.
- The sapwood period beginning in 1872 had a very large

FIGURE 8: NITROGEN, CALCIUM, AND MAGNESIUM IN WOOD OF THE HAAS GROVE CROSS SECTION BY DECADES



increase in almost all elements.

TABLE 9:PORTION OF THE HAAS GROVE TREE WOOD ELEMENTAL COMPOSITION (PPM) BY DECADE

YEAR	N	P	CA	MG	K	NA	MN	AL	FE	ZN	S	CU	B
FIRST ELEVEN DECADES													
422	400	10	530	210	24	71	5.6	24	31	3.2	79	3	5
432	750	9	600	220	24	66	5.6	19	32	2.5	57	1.9	23
442	660	12	550	210	23	54	5.5	24	26	2	69	1.5	12
452	610	13	540	190	31	64	3.3	14	23	2.3	66	1.9	17
462	570	10	630	200	25	71	5	27	30	4.8	69	2.3	31
472	610	13	520	190	24	62	4.4	22	26	2	77	3.2	30
482	410	11	540	200	36	53	4.4	21	21	7.2	66	2.1	22
492	530	12	630	240	24	53	7.8	24	23	7.2	70	2.6	13
502	410	10	500	170	13	30	4.4	11	15	3.1	59	1.3	11
512	610	18	550	200	10	66	5	19	18	4.1	79	1.7	18
1422-1522 AD													
1422	1040	14	820	190	10	16	9	6	18	0.8	90	1.3	5
1432	1300	10	780	220	7	19	8.8	7	16	1.7	109	2.5	6
1442	1040	12	1450	270	7	115	9.4	71	15	1	125	2.1	146
1452	1280	15	2140	270	15	504	8.2	201	16	1.3	138	2.7	544
1462	820	18	1070	190	7	146	8.2	75	40	2.2	98	2.9	148
1472	840	16	1350	200	8	240	10.5	115	81	5	84	7	340
1482	640	13	760	200	6	37	10	15	39	2	81	3	34
1492	890	16	690	200	7	48	9.4	11	31	2.7	94	2.9	29
1502	670	17	680	200	7	27	10.5	9	23	2.4	112	2.2	17
1512	820	10	800	220	10	28	10.5	12	16	2.5	91	2.4	14
1522	710	14	740	200	5	22	9.3	10	14	2.2	91	2	21
RECENT INCLUDING SAPWOOD													
1812	760	12	990	160	8	26	6.2	20	17	2.4	99	1.9	13
1822	650	22	760	140	10	30	6.9	19	16	3.6	110	1.9	23
1832	790	18	580	130	8	18	9.5	6	14	1.8	95	1.8	10
1842	770	23	520	120	15	33	8.8	9	13	3.8	114	2.5	9
1852	760	16	650	130	7	22	9.2	17	18	1.4	110	2.5	22
1862	910	18	450	140	13	13	16.9	20	24	1.3	115	2	7
1872	1240	32	430	160	18	32	20	105	103	4.6	155	3.6	8
1882	780	16	1890	330	15	131	24.6	24	55	6.5	208	3	19
1892	1190	14	1830	320	20	57	23.3	22	60	7.5	225	3.3	6
1902	1130	20	1600	310	24	108	21.3	18	48	8.8	212	2	5
1912	1730	27	1500	330	33	84	27.4	51	80	31.6	260	28.7	6
1922	4590	184	1790	560	221	261	82.3	955	113	44	1000	23.2	45

All analytical values expressed as ppm of oven dry wood. Samples are decade slices of the cross section. Year indicated is beginning of decade. Tree fell in 1932. Analyzed 1994 by Dr. J.L Bertenshaw. The complete section 422 to 1932 has been analyzed.
Sapwood begins 1882.

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