Soil and Nutrient Element Aspects of *Sequoiadendron Giganteum*[1]

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Abstract: A century ago, John Muir (1894) observed that the present range of bigtree is limited to ridgetops at middle elevations in the Sierra Nevada, apparently due to soil conditions related to glaciation. This paper will examine the relations between the trees and associated soils. The elemental content of a 1200-year-old 200-ton tree was examined and compared with the storage in litter and soil on the site. Twenty-two percent of total site nitrogen was in the tree, along with 27 percent of calcium and approximately 40 percent of magnesium and potassium, and 82 percent of on-site carbon. Remaining proportions were mainly in soil, with less than 10 percent of any element in leaf litter. A major influence of old *Sequoiadendron* on the soil is maintenance of a high base element status due to high contents in foliage and twigs returned in contrast to lower amounts in associated conifer species. Extremes of percentile arrays of foliar element analyses are used to identify sites with possible limitations for *Sequoiadendron*.

Several questions were raised by the topic of this paper. What are soil-related reasons for the present limited range of the species? What is the effect of long-lived trees on a soil? Soil factors may limit range or longevity of trees if essential elements become deficient or excessive on a site. This paper will present research data partially answering these questions. How the presence of a bigtree during more than a thousand years influences the soil and fertility elements, and how much is stored in the tree will be estimated by analyses of a tree which fell at U.C. Whitaker's Forest, Tulare County, California in 1965. These data will be compared with those obtained from soils influenced by old bigtrees at several groves from Giant Forest to Merced grove, and by comparison with soil properties typical of other sites in Sierra mixed-conifer forests. The question of limits to the range of giant sequoia will be examined in terms of the soil conditions existing at sites with extremes of analytical values for foliar elements.

Elemental Balance of an Old Tree and Its Soil

The growth of a single tree on a soil for millenial periods is evidence of a rapport between the elemental needs for tree growth and maintenance of chemical and physical soil conditions within the range of these needs. Thomas Edison noted (1926) the long life of sequoias indicates "that in that region there has been perfect balance between the redwood tree and all or nearly all surrounding conditions." Since the tree must remain on the soil in which it is rooted, an old *Sequoiadendron* must be in balance with the soil in this manner.

The balance of elements between tree and supporting soil was estimated through measurements on a fallen 1200-year-old tree which had a stem diameter of 26 feet (8 m) at the base, a crown diameter of 100 feet (30.5 m), and a height of 256 feet (78 m) including a pointed 10-foot dead top. During the early summer immediately after tree fall in 1965 the masses of foliage, twigs, small branches, cones, stem wood and bark, were measured and converted to mass of tree on an oven-dry basis. Samples of components were taken for analysis of elemental composition. Soil samples were obtained at uniform depth increments from pits at the base and at 15 feet (4.6 m) from the tree, and determination made of root contents and composition of major fertility elements, pH, bulk density, and stone content. Soil elemental storage and root contents were calculated to a meter depth over the area of the crown spread of the tree (731 m^2).

The mass of material which the tree accumulated over 1200 years represents elements obtained from the atmosphere and the soil during this period. Van Helmont reported in 1652 the growth of a willow tree in sandy soil amounted to 164 pounds while the soil lost 2 ounces of material (Russell 1950). Presumably the major proportion of the weight of the tree measured in this study was also derived from elements from the atmosphere.

Elements Derived from the Atmosphere

The mass of the fallen tree was assumed to be derived from the atmosphere in combining proportions represented by the photosynthetic equation (1), with both carbon dioxide and water obtained from the atmosphere, although the water was derived from seasonal soil moisture storage enroute from the atmosphere.

$$CO_2+H_2O=CH_2O+O_2 \qquad [1]$$

The dry mass of the 1200-year-old tree that fell at Whitaker's Forest was estimated by weighing various parts of the tree, and adding the product of the volume of stem wood and bark and density to obtain the data in *table 1.* This totaled 199 metric tons (X 0.98 = long tons; X 1.1 = short tons) for an initial estimate of CH_2O in equation 1. The combining weights of atmospheric compounds to form the

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tree and derived total weights in tons based on the estimated 199 tons are as follows:

$$\begin{array}{lcccccccc} \textit{grams:} & 44 & & 18 & & 30 & & 32 & \\ & CO_2 & + & H_2O & = & CH_2O & + & O_2 & [2] \\ \textit{tons:} & 292 & & 119 & & 199 & & 212 & \end{array}$$

These estimates do not include deciduous material such as foliage, and branches, or those respired during the 1200 years.

The fallen Whitaker's tree is small compared to the bigtrees reported by Flint (1987) which range from 213 tons to more than 445 tons (stem volume X specific gravity of 0.3). Stagner (1952) reports trunk weights of 625 short tons for the General Sherman Tree, and 565 tons for the General Grant tree assuming a specific gravity of 0.4. Fry and White (1938) reported the wet field weight of the General Sherman tree at 2105 tons. By using the density of 0.3 (Cockrell and Stangenberger 1971), their volume of 42,650 cubic feet (1208 m^3) yields an estimated dry weight of 623 tons (trunk, 362; bark, 54; limbs, 37; roots, 142; and foliage, 28 metric tons). The weights of the constituent parts of the Whitaker's tree *(table 1)* show that 97 percent or 193 metric tons of the tree was slowly-cycling material (wood and bark), while 3 percent was the material frequently returned to the soil as foliage, twigs, and small branches. The foliage, branches, and cone materials were all collected and weighed with the help of a California Division of Forestry conservation camp crew.

Elements Derived from Soil

The elements derived from soil, although low in proportion to those from the atmosphere, are also elements essential to tree survival. Questions regarding the effects of the mono-culture of a single tree for many years on a soil relate to the continuing availability of these elements, or to the potential of undesirable depletions, excesses, or toxicities of elements. The elements considered in this study are nitrogen, phosphorus, calcium, magnesium, potassium, iron, manganese, and zinc, borrowed by the tree from available soil storage or from current mineral weathering. These elements are either utilized for a short time in tissues returned quickly to the soil, or stored for a long time in the structural elements of the tree. Eventually all are returned to the soil and rendered available to subsequent generations of trees on the site. The composition and weight in grams of the major essential elements in tree parts are shown in *tables 2* and *3.* The sum of the weights of all these elements in the tree was 1.064 metric tons. Since this is a small proportion of the total 199 tons (0.5 percent) it was not taken into account in the initial estimates of total combining weights in equation 2.

The analyses of mineral soil samples from two soil pits associated with the Whitaker's tree were used to calculate soil mineral storage of the fine-earth fraction (<2mm) under the crown projection area. The average composition of duff

***Table 1**-Weights of parts of a fallen Sequoiadendron at Univ. of California's Whitaker's Forest, Tulare County, California*

Component	Weight	
	Kilograms	Metric ton
Foliage		
200'-250'	83.8	
150'-200'	85.8	
100'-150'	34.0	
Total fol.	203.6	0.20
Branches		
200'-250'	145.2	
150'-200'	210.5	
100'-150'	96.2	
Total branch[1]	451.9	0.45
Bark-stem		
225'-250'	125	
175'-225'	470	
125'-175'	1190	
75'-125'	3840	
10'-75'	14100	
0'-10'	4140	
Total bark	23900	23.9
Wood-stem		
0-250'	168,993	169.0
Cones	382.2	
Seeds	7.9	
Cone resin	5.9	
Total cones	396	0.39
Roots		
0-25cm depth	2218	
25-50	767	
50-100	511	
100-150	1210	
150-200	438	
Total roots[1]	5130	5.1
Total tree[1]		199

[1] Excludes large branches >12" dia. but includes small branches and twigs. Roots to 15.25 m radius from tree; large roots > 1 " dia. excluded. Wood specific gravity was 0.3 for old growth as reported by Cockrell, and others (1971), and bark specific gravity measured on four samples with a mean of 0.26 and a S.D. of.0244 when oven dried. and a S.D. of.0244 on four samples oven dried for 36 hours. Total Tree is sum of parts not including large branches and roots.

Table 2-*Major element composition of parts of Whitaker Forest fallen Sequoiadendron tree*

Component[1]	N pct	P ppm	Ca pct	Mg pct	K pct	Mn ppm	Fe ppm	Zn ppm
Foliage								
200'-250'	.64	440	1.87	.07	.42	100	140	17
150'-200'	.92	729	1.70	.14	.42	99	142	19
100'-150'	.88	800	1.70	.17	.41	133	136	29
Branches								
200'-250'	.47	649	1.80	.14	.36	28	128	17
150'-200'	.45	460	1.74	.06	.33	25	133	15
100'-150'	.51	549	1.82	.10	.41	33	173	19
Bark								
225'-250'	.17	n.d.	.260	.033	.022	18	46	2
175'-225'	.14	70	.310	.034	.019	14	43	7
125'-175'	.14	20	.150	.016	.014	10	24	4
75'-125'	.14	20	.091	.016	.026	12	30	2
10'-75'	.21	70	.051	.011	.023	10	270	4
0-10'	.24	20	.076	.017	.027	20	151	2
Wood-stem								
Heartwood	.13	n.d.	.24	.02	.06	18	251	18
Sapwood	.08	n.d.	.43	.04	.06	18	15	2
Cones	.31	475	.51	.10	1.25	42	118	22
Seeds	1.50	5888	.57	.31	.44	11I	24	100
Resin	.30	440	.32	.16	n.d.	145	4784	161
Roots								
0-25cm	.71	n.d.	1.50	.10b	n.d.	160	208	31
25-50cm	.68	n.d.	1.05	.29	.14	343	522	45
50-100cm	.45	n.d.	1.00	.15	.21	136	437	131
100-150cm	.24	n.d.	.26	.13	.28	80	332	47
150-200cm	.30	n.d.	.81	.12	.28	114	336	105

[1] Excludes large branches and roots sampled at indicated levels. Heartwood analyses used in calculations of total tree storage, n.d. is not determined, and the 4784 for cone resin iron is okay.

layers associated with three old-growth giant Sequoias from a previous study (Zinke and Crocker 1962) was assummed to characterize the duff layers associated with the Whitaker's tree because litter was disturbed by tree fall.

The quantity of various elements in soil and leaf litter are shown in *table 4* and the distribution between tree and soil is shown in *table 5*. The distribution of elements on the site shows most of the mineral elements stored in soil and litter, but eighty percent of total site carbon stored in the tree. When compared to soil under other mature conifer trees, soils under old bigtrees have lower bulk densities, higher carbon and calcium contents, much higher base saturation of the soil exchange capacity due to calcium, a resultant higher soil pH, and higher nitrogen contents. Details are reported in an earlier study by Zinke and Crocker (1962).

The influences of old *Sequoiadendron* on soil are related to the composition of foliage and twigs recycled to soil. Foliar samples from a wide range of big tree sites, natural and artificial, were analyzed to evaluate the potential range of elemental content values.

Foliar Analyses as Indicators of Soil Limits

Sequoiadendron samples of current-, medium-, and old-age foliage were collected, analyzed for elemental composition, and the data arrayed in probability distributions as shown in *table 6*. The values in the table are useful to rank a foliage analysis by the equal or less than percentile in the array. In this process high or low extremes can be identified.

Table 3-*Total elemental weights in grams in fallen old-growth* Sequoiadendron *parts at Whitaker Forest.*

Component	N	P	Ca	Mg	K	Na	Mn	Fe	Zn
Live									
Foliage	1626	126	3609	235	849	99	21	28	4
Twigs, branches	2114	244	8037	432	1619	265	13	63	7
Cones	1321	231	2013	416	4813	38	18	73	10
Roots	27425	n.d.	52944	7293	7189	n.d.	833	1630	272
Total	32486	n.d.	66603	8376	14470	n.d.	885	1795	294
Dead									
Wood	215000		411000	38900	98000	43900	3040	42400	3040
Bark	47532		17427	3262	5645	4561	291	4605	81
Total	262532		428427	42162	103645	48461	3331	47005	3121
Tree	295018		495030	50538	118115	48863	4216	48800	3415

Cones include seeds. Tree sodium total exclusive of roots.

Table 4-*Average weights of elements in leaf litter from three old giant* Sequoiadendron *trees as grams/sq.meter; and total weights as kilograms under crown spread (731 sq.meters) of Whitaker Forest fallen tree.*

Element	C	N	Ca	Mg	K	Mn	Fe	Zn
Mean								
Grams/m^2	5169	83	240	15	8	16	2	0.6
X Crown Spread Kg	3805	61	176	11.2	5.8	11.8	1.6	0.3

Average at three locations for sum of L and F layers multiplied by crown spread area of fallen tree to estimate amount at Whitaker fallen tree.

Table 5-*Elemental distribution between tree, litter, and soil at the site of the fallen Whitaker* Sequoiadendron[1]

Site component	Carbon	Nitrogen	Calcium	Magnesium	Potassium
Tree					
kilograms	79600	295	495	51	118
percent of total	80	22	27	37	40
Leaf Litter kilograms	3805	61	176	11.2	5.8
percent of total	3	5	9	8	2
Soil-1m kilograms	16045	957	1178	77	173
percent of total	16	73	64	55	58
Site Total kilograms	99,450	1313	1849	139.2	297
percent	100	100	100	100.0	100

[1] Weights are in kilograms in whole tree and under crown spread for litter, and soil 1 meter deep. Litter values from means of samples under similar trees. Litter had 47 percent carbon, tree assumed at 40 percent carbon as per CH_2O.

Table 6-*Cumulative probability distributions of elemental composition of* Sequoiadendron *foliage derived from samples obtained from 28 sampling sites throughout range of species.*[1] *Population percentiles of species with analytical values equal or less than those listed based upon Weibull cumulative probability distribution.*

Percentile = or<	N	P	Ca	Mg	K	Na	Mn	Fe	Zn
	Pct	*ppm*			*Pct*			*ppm*	
	Current year (scale + green twig)								
1	.580	482	.780	.110	.277	.001	49	30	9
10	.629	734	.919	.135	.403	.001	100	34	10
20	.677	862	1.000	.149	.466	.001	145	40	18
40	.777	1041	1.157	.170	.555	.001	233	53	25
50	.835	1120	1.230	.179	.594	.001	282	61	29
60	.901	1199	1.309	.189	.632	.001	337	71	34
80	1.089	1380	1.507	.211	.721	.002	487	103	48
90	1.261	1513	1.667	.228	.786	.003	620	135	60
99	1.774	1817	2.077	.268	.933	.014	1000	242	96
	2 to 3 years (scale +twig still green -medium age)								
1	.520	371	.775	.084	.230	.001	30	32	7
10	.550	542	.975	.103	.340	.001	49	38	11
20	.584	641	1.093	.118	.398	.001	69	45	14
40	.658	791	1.275	.144	.480	.001	110	60	21
50	.703	860	1.360	.158	.517	.001	133	69	25
60	.757	932	1.448	.172	.553	.001	160	81	30
80	.915	1103	1.660	.211	.639	.002	239	114	43
90	1.067	1233	1.824	.243	.702	.003	311	145	54
99	1.543	1546	2.220	.328	.847	.016	529	247	88
	5 years (scale brown + red twig, old age)								
1	.302	351	.772	.044	.254	.001	21	32	6
10	.327	383	.907	.052	.296	.001	28	36	8
20	.358	418	1.005	.061	.330	.001	36	41	10
40	.430	492	1.174	.081	.391	.001	55	53	14
50	.476	536	1.260	.093	.423	.001	65	61	17
60	.530	588	1.352	.108	.458	.001	79	70	20
80	.699	738	1.589	.153	.552	.002	116	100	30
90	.865	880	1.784	.196	.631	.003	152	130	40
99	1.408	1314	2.296	.332	.848	.019	265	229	70

[1] Used to rate a foliage analysis in the expected range for the species. For example a value of.628 percent Nitrogen for current foliar growth would indicate it is at the 10 percent or less level of the species range.

Sites with such extremes in percentile range are shown in *table 7*. Where foliage showed low contents of nitrogen, phosphorus, magnesium, or iron; the soils were often sandy or stony. Where soils had high organic matter content from past occupancy by bigtrees with recycling interrupted by harvest (Indian Basin) foliar analyses were low in rank for nitrogen, phosphorus, potassium and zinc. Perhaps, following interruption of nutrient cycling by tree harvest these elements are temporarily tied up by the microbial population decomposing the stock of soil organic matter accumulated under the harvested forest. Areas influenced by human use often had foliage with excessive nitrogen, zinc, and sodium contents. High rankings of some elements occurred in foliage from trees on sandy or stony soils dominated by minerals containing these elements: for example, high magnesium and potassium were found in foliage on soil derived from granitic rocks with biotite mica. Soils at lower rainfall limits with high basic element content and resulting high pH tended to produce foliage with low ranking of elements rendered insoluble under these conditions such as zinc or phosphorus. The reverse occurred at high rainfalls, where resulting acid soils, wet and high in organic matter content, resulted in high percentile ranking of foliar manganese content.

Some examples of foliage that had extreme percentile values or showed deficiency symptoms are shown in *table 8.* Foliage sampled from bigtrees planted at low-rainfall areas outside the normal range (Wrightwood, San Bernardino County) displayed bronze-color foliage, and the contents of calcium, manganese, and zinc ranked very low in the probability distributions. A tree which was suppressed under white fir at Whitaker's forest had foliage that ranked very high in potassium, and very low in manganese. The soil in which this tree grew was a young sandy granitic soil (Corbett series). A nursery tree grown on an acid sandy soil with high water table showed excessive manganese and iron, very low calcium and a very reddish-brown foliage. Magnesium, phosphorus, and nitrogen were very high due to fertilization. Foliar analyses with percentile extremes indicate possible nutrient imbalances or deficiencies. These hypotheses, however, still need validating by controlled experiments.

There is a soil microbiological component to the nutritional rapport which bigtrees reach with soil. The symbiotic effects of mycorrhizae are very important in maintaining phosphorus uptake in the presence of high soil calcium and pH resulting from the bigtree influence on soil. These relations are dealt with in more detail (Molina 1992) in these Proceedings. High potassium and nitrogen content in wood and roots may make these tissues attractive targets for fungal pathogens in soil. Piirto deals with these soil problems in these Proceedings and in an earlier paper (1974).

The optimum range in soil properties for *Sequoiadendron* as for any species should be found at sites where foliar quantities of essential elements are not excessively high or low; and a rapid elemental cycling rate occurs. For *Sequoiadendron* this would be in a climate with moderately high precipitation and with a well drained soil well stocked with available essential elements.

Physiological factors may also affect foliar composition. *Sequoiadendron giganteum* var *pendula* (Carriere) M.L. Greene is an interesting weeping form of the bigtree that

Table 7-*Characteristics of sites on which* Sequoiadendron *foliage had low (< l0% values) or high (>90c% values) concentrations of major elements as listed in* table 6.

Low	Element	High
Immature stony sandy soils or cutover bigtree second growth. (Wawona, Indian Basin)	Nitrogen	Soils subject to septic tank or human influence (Crestline CA, Vancouver WA.)
Immature soils high in Calcium (McKinley, Indian Basin)	Phosphorus	Soils influenced by septic tanks and people (Crestline, Pack For. WA, Wawona)
Soils in mixed-conifer forest outside bigtree range acid sands (Vancouver, WA; Crestline)	Calcium	Cutover bigtree areas or understory of *Abies* or *Calocedrus* (Whitaker, Indian Basin, McKinley)
Stony sandy soils (Wawona)	Magnesium	Soils on granite with biotite mica or basalt (Chilao, Whitaker, Wawona)
Cutover bigtree soils and meadows (Indian Basin)	Potassium	Understory-mixed-conifer or young sandy soils on granite (Whitaker, Wawona)
Low rainfall sites outside natural range. Suppressed understory (Whitaker, Wrightwood CA)	Manganese	Sandy acid soils (Wawona, Grant Grove, Crestline)
Sandy Stony Soils (McKinley. Wawona)	Iron	Soils derived from basalt, or other soils at lower rainfalls (Vancouver, Pack For. WA, Crestline CA)
Soils in low rainfall or cutover bigtree areas (Wrightwood, Indian Basin)	Zinc	Soils having human inputs - Septic tanks etc. (Crestline, Chilao)

Table 8*-Some examples of foliage samples obtained from trees showing elemental extremes in foliage, and their percentile rankings.*

Location and foliage age[1]	Percent	ppm	-----------------Percent-------------			------------------Percent----------------		
	N	P	Ca	Mg	K	Mn	Fe	Zn
Wrightwood								
	-------------------analytical values----------------------							
Current	1.81	1087	.824	.147	.515	47	86	10
Medium	1.060	1073	.831	.130	.599	30	30	7
	-------------------Percent of species population equal or below--------------							
Current	79	46	3	18	30	1	71	1
Medium	90	77	2	29	71	1	75	1
Whitaker's								
	-----------------------analytical values----------------------							
Current	.802	1292	1.241	.177	.924	85	65	29
Medium	.646	994	1.466	.155	.804	44	68	19
	----------percent of species population equal or below----------							
Current	44	71	51	48	99	7	54	4 9
Medium	37	68	62	48	98	7	49	34
Indian Basin								
	----------------analytical values-----------------							
Current	.577	657	1.735	.209	.263	165	61	13
Medium	.558	553	1.613	.214	.230	56	66	10
	-------------percent of species population equal or below------------							
Current	1	6	93	78	1	25	50	8
Medium	12	11	76	81	1	13	46	8
Nursery tree								
	----------------analytical values---------------							
Current	1.34	2014	.57	.26	.48	509	96	44
Medium	1.10	2292	.85	.31	.46	768	164	57
Dead current	1.42	1337	.95	.21	.08	1881	272	82
	-------------percent of species population equal or below----------							
Current	91	>99	<1	99	23	82	76	7 5
Medium	91	>99	4	97	35	>99	93	8 8
Dead	93	>99	14	91	<1	>99	>99	97

[1] Wrightwood tree had bronze appearance: Whitaker's was suppressed in understory (not the fallen tree of this study); Indian basin second growth growing poorly; Nursery was 4-year-old purple-bronze tree with some dead foliage on acid poorly-drained sandy soil. Population percentile ratings by using *table 6*.

illustrates this. Foliar samples from a specimen of this variety were analysed and the results shown in *table 9*. The foliar calcium content is strikingly low. Since calcium adds to the rigidity of cell walls this may explain the drooping form of the tree which would probably not survive in the heavy snowfall of the present range of the species. Thus, an extreme in a foliar analysis may occur due to a genetic anomaly.

Comparison with other Mixed-Conifer Species

Arrays of foliar analyses for other mixed-conifer species associated with *Sequoiadendron* have been published by Zinke and Stangenberger (1979). Fifty-percentile values for other mixed-conifer species *Calocedrus decurrens, Abies concolor, Pinus ponderosa,* and *Sequoia sempervirens* are shown in comparison with *Sequoiadendron* in table 10.

The *Sequoiadendron* foliage is lower at the fifty percentile level in nitrogen, manganese, and iron than the foliage of any of the other species. Phosphorus and potassium contents are similar, magnesium contents slightly higher, and calcium contents of bigtree foliage much higher.

The differences in the soil composition under the influence of *Sequoiadendron* compared to other mixed-conifer species reflects these differences in foliage composition. During the lifetime of the 1200-year-old tree the foliage must

Table 9-*Foliar analyses of a pendulous bigtree* Sequoiadendron giganteum *(Lindl.) Buch. var* pendula *(Carriere) M.L. Greene rated by the cumulative probability values in* table 6.

Foliage age	Percent N	ppm P	Percent Ca	Mg	K	ppm Mn	Fe	Zn
Current	1.388	2020	.887	.297	.955	77	204	36
Medium	1.270	1864	.914	.264	.844	49	212	33
Old	.629	1036	1.008	.118	.658	25	86	21
	--------------------percent of population equal or below -------------------------							
Current	92	>99	8	>99	>99	6	96	63
Medium	94	>99	7	92	99	10	96	65
Old	72	91	20	64	91	6	71	62

Sample courtesy J. Cranmer, Vagabond Lodge, Hood River, Oregon.

Table 10-*Values of 50 percent of foliage elemental concentrations in* Sequoiadendron *and associated mixed-conifer species with coast redwood for contrast.*[1]

Species, foliage year	N	P	Ca	Mg	K	Na	Mn	Fe	Zn
	percent	*ppm*	*--------------------percent-----------------------*				*--------- -ppm ----------*		
Sequoiadendron									
Current year	.835	1120	1.230	.179	.594	.001	282	61	29
2-3 yr	.703	860	1.360	.158	.517	.001	133	69	25
old	.476	536	1.260	.093	.423	.001	65	61	17
Calocedrus									
Current year	1.049	820	.677	.166	.370	.001	105	105	13
3 yr	.942	648	.711	.084	.307	.001	63	127	12
old	.767	478	.771	.066	.283	.001	40	123	12
Abies concolor									
Current year	1.086	987	.451	.092	.590	.001	412	73	27
3 yr	.891	522	.937	.088	.300	.001	466	96	26
5 yr	.798	452	1.097	.091	.254	.001	602	91	29
Pinus ponderosa									
Current year	1.147	1140	.127	.091	.541	.002	93	72	25
3 yr	.997	617	.335	.116	.361	.005	177	130	29
5 yr	.806	575	.368	.115	.304	.006	201	154	34
Sequoia sempervirens									
Current year	1.077	1270	.814	.166	.592	.027	209	173	33
2-3 yr	.962	899	.777	.150	.506	.039	199	190	28
old	.667	615	.887	.123	.389	.016	126	136	27

[1] These are values for the equal to or less than 50 percent level for comparison with other mixed conifer or related species. See *table 6* for complete probability distribution for elemental composition of Sequoiadendron foliage.

have been dropped, decomposed, and elements recycled repeatedly. The high calcium turnover in the falling foliage results in the high calcium content of soil surface layers.

Conclusions

The estimation of the weight and elemental composition of a recently fallen giant Sequoia tree indicates that only one ton of the total of nearly 200 tons of weight is derived from the soil. These are essential mineral elements, however, allowing survival of the tree. The long-lived tree, on this soil for more than a thousand years, has maintained a soil with high base status due mainly to high exchangeable calcium, a high pH, and a high organic matter content. This is a contrast to base-depleted acid soils developed under associated mature conifer trees.

Foliar analyses are offered as one way to determine the limits to the range of soil conditions tolerated by individuals of the species. Indications from the data are that the optimum soil for the survival of giant sequoia from seedling to mature tree is a soil with development not too weathered nor excessively young and stony; a soil that is well-drained of moisture; and a soil high in organic matter recharged with basic elements in bigtree litter.

The result is, as noted by John Muir (1894), the soils supporting the bigtrees are: "just where, at a certain period in the history of the Sierra, the glaciers were not, there the Sequoia is, and just where the glaciers were, there the Sequoia is not." At elevations above the Sequoia belt, as well as along the steep canyon sides below, the soils are too immature (sandy and stony). At lower elevations soils are too weathered of secondary minerals and heavy in clay to meet the demands of the trees or precipitation is too low to prevent accumulation of carbonates from the high calcium amounts cycled by the trees. Transects showing these types of soil development sequences with elevation have been shown by Zinke and Colwell (1965).

The groves, as a result, are located away from steep canyon sides with their stony colluvial soils. They are found on ridge tops or gentler slopes at elevations above the zone of mature and well-developed red and reddish-brown soils of lower elevations, but below the stony shallow soils of the glaciated upper elevations. Finally, as noted by Thomas Edison, the tree over its long life maintains a soil within its rooting zone that is in balance with its requirements, otherwise it could not survive!

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