Sampling a Lodgepole pine tree in the Ward Creek Basin near Lake Tahoe for nutrient element distribution. The tree was divided into samples of foliage, branches and trunk wood at different heights, and weighed and analyzed for total nutrient contents reported for the Lodgepole pine forest in the background.

The fertility of the forest

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The fertility of the forest, in contrast to other crops in agriculture, is stored not only in the soil, but also in the trees and in the litter of forest detritus on the soil surface. Efforts to utilize forests for additional products (for example, forest debris for fuel) will thus mean an increased removal of fertility. Predicting the magnitude of this loss requires an understanding of the fertility of the forest's various components. Studies of this type are being conducted by the authors in the California Cooperative Soil-Vegetation Survey, and in individual graduate student research projects at the University of California.

Soil in the forest serves as the source and storehouse for elemental nutrients trees need during growth. To evaluate the quantities of elements stored, sampling and analyses of more than 500 wildland soils were carried out in the Soil-Vegetation Survey. Each soil was sampled at intervals throughout its depth, and analyses of the chemical and physical properties were made at the Soil and Plant Nutrition department laboratories at Berkeley and Davis. These data have been used to calculate the total amount of nutrient elements stored in unit areas of forest soil. They have been arrayed by forest productivity site classes, 50 to 70 soils in each class.

Fertility storage in soils

The amounts of nitrogen, phosphorus, calcium, magnesium, and potassium stored in these forest soils were calculated, as well as the nonnutrient, carbon. They are averages within the site quality classes of Dunning with which the Soil-Vegetation Survey has classified most private forest land in California. Height of mature trees (300 years old) is used as an index; trees have been grouped as low, 100 to 125 feet; medium, 150 to 175 feet; high, 200 to 225 feet, and very high, 250 feet or more. Knowing these site productivity classes, the land owner can roughly assess fertility storage in the soil. Maintaining fertility storage in a form available to trees on the site without losing it through erosion or in water leaching the soil profile is a major problem in forest management.

Carbon, although not a nutrient element, represents the soil organic matter that is the basis of most soil fertility storage in forests. Carbon storage is lowest on sites of low productivity, ranging from 10 kilograms per square meter to a depth of one meter to 30 kg per square meter on the most productive sites. These data can be translated to pounds per acre by multiplying by 8920, or by 5 for approximating tons per acre. This large amount of carbon in the forest soil is a living reality including fungi, bacteria, small soil organisms, and the remnant organic compounds of past generations of forests. This decomposition returns the fertility of past generations to the present tree crop.

Total nitrogen storage in the forest soil, in relation to site productivity, parallels carbon content. On poor sites the average amount stored is 400 grams per square meter (X 8.92 = pounds per acre) and on the highest sites it is up to 1200 grams per square meter to a meter depth of soil. Not all of these large quantities of nitrogen are immediately available to current growth of forest trees because most is bound in the soil's living organisms that decompose soil organic matter.

Phosphorus frequently presents problems in California forest soils because it may be limited by forming insoluble compounds, or it may be lost through leaching if it is in too soluble a form. Furthermore, phosphorus contents may be low even in the best sites. This is probably for different reasons. At the poor sites it may be unavailable, while on the better sites, there may be depletion due to rapid uptake by the trees.

Calcium, magnesium, and potassium were measured as chemically equivalent weights per square meter of soil to a depth of one meter (eq/m²). To obtain gram weights they should be multiplied by the gram equivalent weights: 20 for calcium, 12 for magnesium, and 39 for potassium. Measurements showed that amounts of both calcium and potassium are highest in the intermediate productivity classes and lowest in the lowest and highest productivity classes. This is probably because of depletion by the tree growth in the more productive sites and a lack in the lower classes. Amounts of magnesium, on the other hand, are greatest in lower productivity classes, and decrease as productivity increases. These elements are stored in the forest soil on the soil's exchange capacity in a form available to the trees.

The exchange capacity of forest soils in California has been found to range from 40 to 300 equivalents of exchange capacity per square meter to a meter depth, with the average about 180 gram equivalents. These values are similar to those in commercial ion exchangers used for water softeners. This reactive capacity of the forest soil, spread over square miles of mountain watersheds, gives us the typical prime soft water quality yield of forested watersheds. The trees take up the mineral elements from this exchange storage during their growth. Following death and decomposition of the trees and other living organisms of the forest, the exchange capacity storage of the soil is recharged with the mineral elements, thus preventing loss to the forest in runoff water. As forest trees grow older, a larger proportion of a site's fertility is transferred to storage in stems, branches, and foliage.

Storage in trees and litter

Our studies have been concerned with the quantities of fertility elements stored in trees and in litter on the forest floor, as well as in the forest's soil. To determine, for example, buildup of magnesium in trees and litter, at the expense of that stored in the soil, data were obtained by calculating the total content of magnesium in various parts of the forest. This was based upon known growth of red fir stands and on field sampling and laboratory analyses of forest trees, litter, and soil, as part of a thesis by Alan Stangenberger. Indicated depletion of soil magnesium could be recharged from soil mineral matter and ultimately recharge would occur in the natural course of forest processes through the death, fall, and decomposition of the trees. However, these data indicate that a complete harvesting of trees 160 years old would remove almost one-half of the site's magnesium fertility.

A 100-year-old lodgepole pine stand on the banks of Ward Creek in Tahoe Basin was investigated to determine the distribution of its fertility elements. Trees, leaf litter, and soil were sampled. The lodgepole pine sampled was studied according to foliage, branches, trunk wood, and bark at various height increments. Calculations were made from analyses and weights of these samples to determine total quantities of fertility elements.

Forty kilograms of carbon were found in a square meter of area, one-fourth of it in the trees. The nearly 1,000 grams of nitrogen in a square meter were mainly in soil and leaf litter; only a small proportion was in each tree, mostly in the foliage and branches. By 100 years of age this forest had redistributed the available phosphorus in the soil so that much was stored in leaf litter or in the tree. Phosphorus fertility lost can be easily replenished with fertilization.

An extreme among the forests we have studied is a redwood grove along Bull Creek in Humboldt County. The soil had been sampled in 1963 and the following year, a flood toppled a 1,000-year-old redwood tree growing 315 feet above this soil. The fallen tree was carefully measured, and samples of wood and bark were collected from top to bottom. Fertility storage quantities were calculated for each sample and equated to a unit area of the forest. Again, the tree contained a large proportion of the phosphorus on the site, and in the case of this old redwood 16 percent of the site nitrogen was in the tree. In the case of the mineral elements, 4 percent of the calcium and 6 percent of the magnesium were in the tree, along with a fairly large amount (13 percent) of potassium. The wood of coast redwood contains very little fertility, but because of their large size, these old trees contain a large proportion of the fertility of the forest.

Forest management implications

Large proportions of some fertility elements in the forest are contained in trees and in leaf litter. This is especially true of phosphorus and nitrogen, and less so of various other mineral elements. Larger amounts of fertility are stored at the tops of the tree trunks, in the branches, the twigs and the foliage; small amounts are in the main trunk. Demands for increased utilization of this forest material will greatly drain fertility from the forest in contrast with past harvests which were confined to the larger trunks and were thus more frugal of site fertility. Thus, with intensive timber harvesting, more attention must be paid to replenishing site fertility.

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TABLE 1. Nutrient Storage in a 100-Year-Old Lodgepole Pine Forest, Ward Creek Drainage, Lake Tahoe Basin (Weights as grams per square meter for C, N, and P; and equivalents per square meter* for Ca, Mg, and K. Soil calculations to 1-meter depth.)

Part of site	(C)	(N)	(P)	(Ca)	(Mg)	(K)
Foliage	555	25	1.2	0.20	0.08	0.04
Branches	734	11	0.7	0.19	0.10	0.03
Stem						
Wood	6,230	15	0.3	0.70	0.30	0.05
Bark	516	7	0.4	0.23	0.07	0.01
Roots	2,570	14	1.6	0.78	0.36	0.06
Tree Total	10,605	72	4.2	2.10	0.91	0.19
Litter	4,490	221	7.6	3.00	1.20	0.06
Soil (1 m depth)	25,590	636	0.1	60.00	16.00	5.00
Site Total	40,685	929	11.9	65.10	18.11	5.25

SOURCE: Paul J. Zinke, California Agricultural Experiment Station Project 1762.
*For conversion of gram equivalent weights, to grams, multiply by 39 for potassium, 12 for magnesium, and 20 for calcium.

TABLE 2. Nutrient Storage in a Redwood Forest on Bull Creek Flat, Humboldt County (Weights as grams per square meter for C, N and P; and equivalents per square meter* for Ca, Mg, and K. Soil calculations to 1-meter depth.)

Portion of site +	(C)	(N)	(P)	(Ca)	(Mg)	(K)
Foliage	1,234	10.4	1.09	0.5	0.1	0.1
Stem						
Wood	62,600	97.6	6.2	6.0	2.4	0.4
Bark	19,000	69.6	0.1	1.4	0.4	0.2
Total Tree (% site total)	82,192 (84)	177.6 (16)	7.4 (77)	7.9 (4)	2.9 (6)	0.7 (13)
Litter	1,660	19.8	1.8	1.9	0.8	0.1
Soil (to 1 m.)	14,361	907	0.3	176	42.6	4.4
Forest site Total	98,213	1104	9.5	185.8	46.3	5.2

SOURCE: Paul J. Zinke, California Agricultural Experiment Station Project 1762.
*For conversion of gram equivalent weights, to grams, multiply by 39 for potassium, 12 for magnesium, and 20 for calcium.
+ Exclusive of large branches and roots.