whale oil annually. While the long term objective for jojoba would be to capture that market, this objective may be difficult to accomplish at first, for two reasons: (1) sperm whale oil sells for 28 cents per pound. Therefore, to enter that market, jojoba should sell for 10 cents per pound so as to make wax available at about 28 cents per pound. This appears to be impossible, if we wish to depend on the wild populations of jojoba for the seed. A price of 10 cents per pound is conceivable, however, from plantations of jojoba yielding 4,000 lbs per acre or more; (2) to produce 50,000,000 lbs of jojoba wax we must have at least 100,000,000 lbs of nuts.

Assuming a yield of 4,000 lbs per acre it would take 25,000 acres of jojoba to produce the quantity of nuts needed. Even if 25,000 acres of jojoba were planted today it would take 10 to 12 years before the potential production of 100,000,000 lbs of jojoba nuts would be realized.

While jojoba production at present cannot satisfy the large sperm whale oil market it can satisfy other specialty markets such as cosmetics, candles, floor waxes, specialty lubricants, etc. These markets are smaller but pay higher prices than 28 cents per pound for raw materials like jojoba wax.

Conclusions based on the information available today would indicate that: (1) jojoba wax has a good marketing potential; (2) large scale, profitable production of cultivated jojoba is possible; (3) jojoba nut production could be based on the wild stands for a few years, preferably with a government subsidy. Jojoba plantations should be established in the meantime so that jojoba production could eventually be based on these plantations. These three statements are valid now. If action is not taken now to go ahead with a large scale production project—initially based on the wild populations and eventually on cultivated jojoba—and if time is lost, two things may happen: (1) industries using sperm whale oil may reformulate their products or redesign their equipment so as to make the use of sperm whale oil unnecessary or essentially so; and (2) synthetic substitutes for sperm whale oil may be developed which will take the market hoped for away from jojoba.

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EUCALYPTUS

Fuel Dynamics, and Fire Hazard in the Oakland Hills

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This study reports the results of two years of fuel studies in blue gum eucalyptus stands. Fuel weights are related to stand densities, and the dynamics of fuel accumulation are investigated. Techniques for managing fuel loads in eucalyptus stands are discussed. Results of this study indicate that fuel buildup occurs very rapidly in unmanaged eucalyptus stands, and that to maintain low fuel levels, a fuel reduction program is essential. If prescribed fire is used, burning techniques that minimize air pollution must be used.

EUCALYPTUS HAS BEEN a scenic and aromatic addition to the California landscape for over a century. The rapid growth of early plantations caught the eye of timber speculators around 1900 and millions of eucalyptus seedlings, predominately blue gum (*Eucalyptus globulus*) were planted. They soon covered the crest of the Berkeley-Oakland Hills, and have created a serious fire hazard since that time at the urban-wildland interface. This study reports the results of two years of fuel studies in the Berkeley-Oakland Hills.

The stand basal area and existing fuel weights in Sibley Regional Park were measured in 1971. Fine fuels, segregated as undecomposed (litter) and partially to predominately decomposed (duff) fuels were measured by collecting randomly placed $0.1m^2$ quadrat samples into bags, and oven drying them. Heavy fuels were measured by the line-intersect technique.

More detailed methods were used the following year to investigate fine fuel dynamics. Litter trays were distributed to collect fine fuels, and each of ten $1 \cdot m^2$ frames was randomly placed in the Sibley study area. The trays were sampled for bark, capsule, branch and twig, and leaf fall every two weeks, from September, 1971 to March, 1973. Decomposition packets containing 25 to 50 gm of each fine fuel component replicated five times were placed in the field in October, 1972 and removed after six months.

The study was terminated soon after the massive freeze of December, 1972, because the eucalyptus tree crowns were severely damaged or killed and the area was cleared to reduce fire hazards.

TABLE 1. ACCESSION, DECOMPOSITION, AND HEAT OF COMBUSTION OF FUEL COMPONENTS IN EUCALYPTUS

	Yearly Accession		Decomposition		Heat of Combustion
	lbs/ac	g/m²	% 6 mos.	Adj. % 12 mos.	Kcal/gm
Leaves	2557	287	34.12	42.23	5.732
Bark	2660	291	13.56	16.79	4.616
Capsules	1813	203	14.94	18.49	5.052
Branch & twig	2580	289	9.50	11.76	4.591
Duff			11.43	14.15	5.454

Interior of a blue gum eucalyptus stand, showing the predominant large trees surrounded by saplings. Because of high ground fuel loads and their chemical inhibitory effect, other understory vegetation is sparse or absent.

The eucalyptus stands were quite dense, reflecting initial spacing of the early twentieth century plantations, excellent survival of the planted trees, and abundant reproduction since that time. Most of the trees were less than 5 inches in diameter at breast height (dbh) though the bulk of the basal area was accounted for by the larger trees (graph 1). The stand pattern on all 100 m^2 plots was an inverse-J shape, characteristic of an uneven-aged stand. However, there were very few trees in the 5- to 15-inch dbh categories; apparently competition from the larger trees restricted diameter growth of the understory.

Basal area

The stand basal area had a large effect on fuel weight, because basal area is an index of crown volume. The relation between basal area and fuel weight is presented in graph 2, and shows total fuel weights ranging from 45 to 100 tons per acre (10.3 to 22.5 kg/m^2). As basal area increases, most of the fuel weight increase occurs in the duff layer. The highest weights reported here are probably the upper limits for eucalyptus fuel weights, because over wide areas such high stand basal areas are uncommon in the Berkeley-Oakland Hills.

The accumulation of fuel depends on the balance between accession and decomposition rates. When yearly decomposition equals yearly accession, fuel does not accumulate. When decomposition is less than accession, fuel builds up to the level where the percentage of decomposition of the total mass equals the yearly addition. The yearly amount of litterfall is presented in table 1, along with the decomposition rate and the heat of combustion of each fine fuel component. From September, 1971, to September, 1972, 9550 lbs per acre (1.06 kg/m^2) fell, and the proportion by component is shown in the table. Over 50% of the total fell in the first two months during the fall of 1971, and the remaining 50% was evenly distributed over the next 10 months.

Decomposition

Decomposition of fuel over the six-month wet season resulted in losses of 10 to 40% of recognizable dry weight. Recognizable dry weight is defined as that proportion of the decomposition packet which retained its undecomposed character. That component which had decomposed to an unrecognizable state was assumed to be duff and was excluded from the final packet weight. Duff decomposition was measured as actual packet weight loss.

Analysis of variance showed that the various components decomposed at different rates. Orthogonal contrasts revealed leaf decomposition to be higher than the duff, and bark and capsule decomposition to be higher than the branch and twig component. Decomposition rates of the branch and twig component and duff did not differ significantly. Leaves have a high ratio of surface area to volume and tend to break up more easily than branch and twig fuels, or the compact duff layer.

Data from Western Australia in a similar Mediterranean climate, but for a different eucalyptus species, showed that 80% of decomposition occurred during the six-month rainy season. The figures in this study were adjusted to a 12-month basis using this figure so that they could be used in the construction of a fuel generator model.

Caloric content of fuel

Heats of combustion (on an ash-free basis) of the various components also differed significantly. Bark, capsule, and branch and twig fuels had lower caloric content than the duff, and the duff had a lower caloric content than the leaves. This latter result is contrary to the usual theory that high-energy compounds accumulate in the duff because they are resistant to decay. When corrected for ash content, duff should then have a higher caloric content than leaves. The results of this study indicate that, for eucalyptus, the theory does not hold. One reason may be that oils in the leaf (which have high heats of combustion) volatilize as the leaf sits on the ground, and the ash-free caloric content of the residual leaf is thus reduced. Another reason is that duff is comprised not only of leaf material but also of low energy constituents such as bark, capsules, and twigs, which lower the average energy content of the duff.

A computer program that models the accession and decomposition of eucalyptus fuel was developed from the data and was dubbed EUCFUEL. The basic algorithm of the model is that fresh litter components are decomposed at given rates each year into duff, which itself is decomposed at a given rate. At the end of each year in the model, the amount of fuel in each category—leaves, bark, capsules, branch and twig, and duff—is determined and summed to give total fuel weight. Accession rates, transfer rates of each category to duff, and loss rate of duff were taken from the eucalyptus plot data. As each year is incremented, yearly accession is added to the amount of bark, leaf, capsule, and branch and twig already present. The percentage of decomposition is then subtracted from these fuels and also from the duff component, and the decomposition from the other components is added to the duff component. Total fuel weight is then determined, the next year is incremented, and the program repeats itself. The program was run for 100 years, and the fuel accumulation is shown in graph 3.

Equilibrium

The equilibrium fuel level in the EUCFUEL model is not as high as some of the residual levels on the ground in the same area. It appeared that packet decomposition rates were slightly higher than actual field rates, perhaps due to the artificiality of introducing a packet to the forest floor. Nevertheless, the processes in the model and the fuel levels at various ages seem to apply to many areas in the Berkeley-Oakland Hills. A eucalyptus stand near Redwood Peak was sampled for fuel weight, but the stand history was unknown. Without a known undisturbed history, no comparison of actual age-fuel weight relations in the stand could be made. However, the proportion of each component could be compared with the predicted amounts for the same total fuel weight (table 2). A Chi-square analysis comparing the two distributions showed them to be dissimilar, primarily due to a much higher predicted capsule weight than actual. Some of the other components were quite closely predicted, suggesting perhaps that the year in which litter-fall was collected was a higher year for capsule production than normal.

If an existing stand were cleared of fuel but the overstory trees were left, most of the fuel would be replaced in 30 years, with half of the equilibrium level being reached in 7 years and 95% of equilibrium being reached in 27 years. The implication of the model results for fuel management is that to maintain low fuel levels, a continuing short rotation fuel reduction program will be necessary.

The methods by which eucalyptus fuel reduction could be accomplished have not been intensively assessed from a biologic or economic standpoint. They include mechanical removal, thinning of the present stands, application of some kind of decomposition stimulator, and prescribed fire. The first two alternatives are being applied now in freeze-killed or damaged eucalyptus stands. Adequate dump facilities are lacking, however, so that a redistribution rather than a removal of fuel is occurring in some places. The third alternative, stimulation of decomposition, is a possibility, but the decomposition rates are already higher than for coniferous leaf litter, and further increases may be difficult to achieve.

Prescribed fire has been used in two forms: broadcast burning and pile burning. The latter technique has been used to consume debris from logged areas, but probably has less application to undisturbed areas. Broadcast fires have been used with success in undisturbed areas under reasonably moist (13–19% fuel moisture) weather conditions. Spring fires have reduced fuel loads up to 87–96% without damage to the overstory trees. This technique has been widely applied to eucalyptus forests in Australia to reduce fuel loads and prevent wildfires.

If prescribed fire is used for the purpose of reducing fuel loads in eucalyptus stands, the benefits must be weighed against costs such as air pollution. Since the eucalyptus groves are located within the San Francisco Metropolitan Area, burning techniques that minimize pollution must be used. Regulating the season of burning, the weather and fuel moisture at the time of ignition, the direction of the fire, and the acreage burned per day or week will be necessary. The applicability of fire will depend on the integration of the biological system with the social system.

The late 1972 freeze has resulted in a proposed fuel management program for the Berkeley-Oakland Hills. Management of eucalyptus groves is an integral part of such a program. The results of this study indicate that fuel buildup occurs very rapidly in unmanaged eucalyptus stands, and to maintain low fuel levels a fuel reduction program should be implemented.

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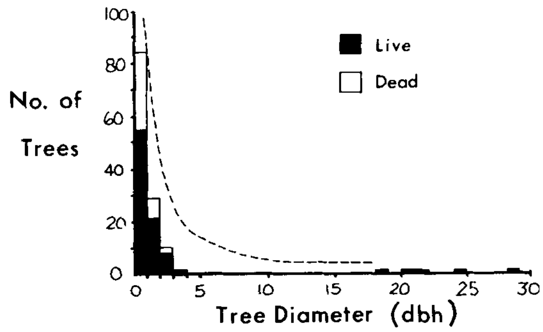
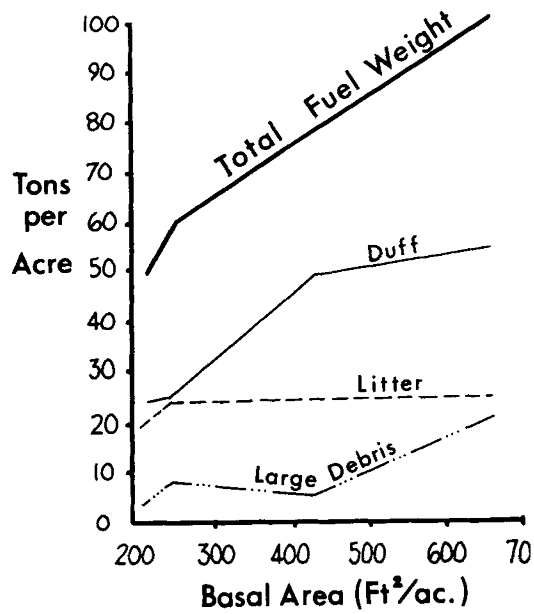
TABLE 2. ACTUAL DISTRIBUTION OF EUCALYPTUS FUEL LOAD COMPONENTS COMPARED TO THE DISTRIBUTION PREDICTED BY EUCFUEL

	Actual Amount lbs/acre	Predicted Amount lbs/acre
Leaves	3512	3447
Bark	10325	10345
Capsules	2330	6673
Br. & Twig	18353	12985
Duff	24195	25265
Total	58715	58715

GRAPH 1. TYPICAL STRUCTURE OF A EUCALYPTUS GLOBULUS STAND ON A 1000 FT² PLOT



GRAPH 2. RELATION OF TREE BASAL AREA TO FUEL WEIGHT



GRAPH 3. FUEL WEIGHT ACCUMULATION PREDICTED BY EUCFUEL